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Proceedings of the Second International Conference on Alternative Aviation Fuels

November 6-8, 1997
Baylor University, Waco, Texas

March 1999

Final Report

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16. Abstract

Baylor University, in conjunction with the Federal Aviation Administration (FAA), U.S. Department of Energy, Texas State Technical College, and Environment Canada, presented the Second International Conference on Alternative Aviation Fuels to introduce members of the industry to the promise and applications of alternative fuels in aviation.

This publication contains 50 technical presentations presented at the Second International Conference on Alternative Aviation Fuels. Baylor University, in Waco, Texas, hosted the conference on November 6-8, 1997.

Topics covered in the papers and panel discussions included:

- Environmental impact of alternative aviation fuels
- Cost-effectiveness and characteristics of alternative fuels
- Alternative aviation fuel case studies
- Fuel suppliers' and manufactures' responses to alternative fuels
- Barriers to commercialization

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

On November 6, 1997, people from around the world gathered in Waco, Texas, at Baylor University for the "Second International Conference on Alternative Aviation Fuels." This conference was a follow-on of the successful "First International Conference on Alternative Aviation Fuels" held on November 2-4, 1995. Over 100 people were present to listen to researchers, representatives of industry, pilot organizations, and the U.S. government as they discussed the use of alternative fuels in the aviation industry. Many segments of aviation propulsion were discussed from low-horsepower reciprocating engines to turbine engines. However, the main topic of discussion was the need to find a replacement for 100-octane leaded aviation gasoline used in reciprocating engines.

The conference represented all points of view concerning the future of fuels in the aviation transportation industry. While on some points people agreed to disagree, there were a number of areas of wide agreement. First and foremost among these was the consensus that the days of leaded avgas are limited. Everyone agreed that either as a result of government regulation or as a result of unfavorable economics, in the near future, fuel producers are not going to be able or willing to continue to supply leaded avgas.

There was much discussion of the different advantages and disadvantages associated with the fuels offered as alternatives to leaded avgas. The renewable fuels advocates pointed out that renewable aviation fuels, such as ethanol and ethyl tertiary butyl ether (ETBE), have very good anti-knock characteristics, are much less prone to vapor lock, and have broad ranging economic and environmental benefits for society. Proponents of other fuels pointed out that these fuels have problems with range and the lack of existing infrastructure.

Representatives of Experimental Aircraft Association (EAA), Aircraft Owners and Pilots Association (AOPA) and Cessna pointed out the size of the aviation gasoline market is very small and therefore concluded that the future of aviation fuels should be tied to existing larger fuels markets. These people argued in favor of using autogas in aircraft or developing a fuel, such as 82UL, that has characteristics very close to existing unleaded motor gasoline. Opponents of this viewpoint noted the technical and economic difficulties of developing a high-octane aviation fuel derived from petroleum and the fact that the majority of avgas is used by aircraft that are unable to use a low octane fuel. They also pointed out that if the aviation community does not take advantage of the opportunities offered by the need to find an alternative to leaded avgas, then it will be passing up a unique chance to make flying more economically beneficial to the nation.

An airshow was held on the final day of the conference at the Texas State Technical College Airport where Baylor's Renewable Aviation Fuels Development Center conducts engine tests, aircraft modification, maintenance, and flight testing. Conference attendees were able to inspect Baylor's collection of alternative fueled aircraft and the aircraft of the Vanguard Squadron. The airshow was highlighted by the flight demonstrations of the Vanguard Squadron and Max Shauck in his Pitts S-2B.

The goals of the conference were to exchange information, encourage open debate between opposing viewpoints and, hopefully, stimulate new research and development of alternative aviation fuels. All of these goals were achieved.

BAYLOR
U N I V E R S I T Y

Dear Colleague:

Thank you for attending the "Second International Conference on Alternative Aviation Fuels" held in Waco, Texas, on November 6-8. Your participation made an important contribution to its success.

I hope that the conference was an informative and enjoyable experience for you and that you will find these proceedings to be useful.

A multiplicity of views were expressed by the international speakers on the various panels. This document contains the accumulated papers, speeches, and other presentation materials that were provided to us by the conference speakers. Wherever possible, when no materials were provided we tried to accurately summarize their remarks made during the conference.

Significant progress has been made since the first conference was held here two years ago, and much has been achieved during this conference. However, the need for these conferences will continue until the successful commercialization of alternative fuels in aviation is realized. Thank you for your good work on the behalf of aviation. I look forward to seeing you all at our next conference.

Sincerely,

Max Shauck

Max Shauck, Chairman
Baylor Department of Aviation Sciences

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AGENDA

Proceedings of the Second International Conference on Alternative Aviation Fuels
November 6-8, 1997
Baylor University
Waco, Texas

Comments from Senate Minority Leader	Senator Tom Daschle
Welcoming Remarks from the Mayor of Waco	Mike Morrison
Welcoming Remarks	Robert Sloan, President, Baylor University
Opening Remarks	Dr. Maxwell Shauck, Renewable Aviation Fuels Development Center, Baylor University
Welcoming Remarks	Dr. Herbert H. Reynolds, Chancellor, Baylor University
New Air Quality Standards and Global and Local Environmental Impacts of Aviation Fuels	Plinio Nastari, World Energy Council, (*Facilitator*) Jeremy L. Cornish, International Centre for Aviation and the Environment Bill Jordan, Texas Natural Resource Conservation Commission Randall Friedl, NASA Jet Propulsion Laboratory, California Institute of Technology Jim Davis, U.S. Environmental Protection Agency
Aviation Engine Emissions	Ray Valente, Tennessee Valley Authority (*Facilitator*)* Dave Stanley, Purdue University Brian Stage, U.S. Environmental Protection Agency Bob Shuter, Transport Canada Gus Ferrara, Gus Ferrara and Associates, Inc.
Paul MacCready's Remarkable Small Aircraft	Paul MacCready, AeroVironment, Inc.
Evening Address	William J. Wells, Delta-T Corporation
Current Research on Petroleum-Based Alternative Aviation Fuels and Engines	Ron Wilkinson, Teledyne Continental Motors (*Facilitator*) Gus Ferrara, Aircraft Owners and Pilots Association (AOPA) Cesar Gonzalez, Cessna Aircraft Company Kenneth Knopp, Federal Aviation Administration Joseph Valentine, Texaco Lars Hjelmberg, Hjelmco Oil Paul Pendleton, Federal Aviation Administration

* no written material

Current Research on Nonpetroleum-Based Alternative Aviation Fuels and Engines	Bill Holmberg, Sustainable New-Wealth Industries (*Facilitator*)* Chris Atkinson, West Virginia University Ted Aulich and Tim Gerlach Center, University of North Dakota Zoher Meratla, CDS Research, Ltd., Vancouver Ron Newberg, Canadian Aero Petroleum Marv Randall, Vangaurd Squadron Maxwell Shauck, Baylor University
Developments in the Production and Marketing of Alternative Fuels in North America	Bill Holmberg, Sustainable New-Wealth Industries (*Facilitator*)* William H. Cruickshank, Natural Resources Canada Todd Sneller, Nebraska Ethanol Board William J. Wells, Delta-T Corporation Russell Teall, NOPEC Corporation
Luncheon Presentation—The FAA's Aircraft Safety Research, Engineering & Development Programs	Bruce Fenton, Federal Aviation Administration
New Engine Technology	Brent Bailey, National Renewable Energy Laboratory (*Facilitator*)* Chris Atkinson, West Virginia University Leo Burkardt, NASA Lewis Research Center Ron Wilkinson, Teledyne Continental Motors
Future Fuels and Power Systems	Brent Bailey, National Renewable Energy Laboratory (*Facilitator*)* Paul MacCready, AeroVironment, Inc. Rudolf Voit-Nitschmann, Universität Stuttgart, Germany Benjamin Russ, Aurora Flight Sciences Corporation
The Clean Airports Program: Goals and Accomplishments	John Russell, U.S. Department of Energy (ret.) (*Facilitator*)* Gary Marchbanks, Oklahoma Gas & Electric Company Jeremy L. Cornish, International Centre for Aviation and the Environment Bill Holmberg, Sustainable New-Wealth Industries
International Alternative Aviation Fuel Experiences	Paul MacCready, AeroVironment, Inc. (*Facilitator*)* Jacques Callies, Aviation & Pilote Lars Hjelmberg, Hjelmco Oil Plinio Nastari, DATAGRO, Ltd. Rudolf Voit-Nitschmann, Universität Stuttgart, Germany Russ Robinson, Environment Canada Tony Marmont, Beacon Energy
Closing Remarks	Bob Harris, Nebraska Energy Office
Conference Registration Listing	
Conference Speaker Information	

* no written material

Statement of Senator Minority Leader to the Conferees of the Second International Conference on Alternative Aviation Fuels

The Honorable Tom Daschle
Senator of South Dakota

Thank you for inviting me to share my views with you on aviation and environmental issues. In doing so, I would like to offer my encouragement as you explore the feasibility of launching a more holistic "Clean Airports" program. As you may know, I am a pilot and have flown with Max Shauck. In fact, he instructed me in aerobatics—probably more to test my constitution than to improve my flying skills. You may also know that my wife Karin was director of the FAA and that I have been the longtime supporter of ethanol and other biofuels. Airplanes, airports, and aviation fuels are consequently big parts of my life. While I would not want to distract from your focus on ethanol, biodiesel, ETBE, and other alternative aviation fuels, I do believe it helpful to consider aviation more holistically. Airports could in fact be important centers of excellence as we advance technology to meet our transportation and economic development needs while insuring that airports become models of sound environmental stewardship.

There are several reasons why airports could play this role:

- Greenhouse gas emissions and other pollutants are international problems—aviation is the lead international industry in terms of communications, coordination, operations, safety, and advanced technology. Consequently, airports could have a major international impact in meeting global environmental challenges.

- Air travel is a major growth industry in most parts of the world—airport facilities and operations are constantly being expanded and upgraded with flexibility unique to airports. These expansions and upgrades routinely bring economic growth to local communities.

- Airports and aircraft are perceived to be "high-tech" industries capturing state-of-the art technologies—aviation and airport personnel are recognized and respected for their high qualifications.

- The public is comfortably and safely "captured" within the confines of airports, with ample opportunity to witness and learn about advances in benefits in energy and efficiency, renewable energy, and environmental protection.

- Because of rapid growth, airports will increasingly become "point sources" of pollution and greenhouse gases in cities striving to improve their environment. If airports and their operations are considered holistic systems, they can, through voluntary actions, serve as sound environmental examples for their community. Such voluntary operations will increase flexibility and efficiency while reducing costs in reaching international goals.

- While emissions from aircraft engines have been dramatically reduced in the past decade, the unprecedented growth in airline traffic has resulted in a net increase in air pollution from commercial aviation. As in the case of the automobile industry, the option of developing cleaner burning fuels becomes an increasingly attractive and potentially cost-effective method of meeting the environmental challenge facing the aviation industry. Baylor is to be commended for initiation of a program which synergistically tests cleaner burning turbine fuels while at the same time provides a three-dimensional picture of the level of pollution in Texas using an instrumented King-Air. Cooperation between the aviation industry and initiatives such as Baylor's are the models of development we in the public sector encourage as cost-effective, and, I believe, the results are much better than burdensome regulation.

Knowing the aviation industry, it is important to offer a note of caution. Pilots, airline owners and operations, aircraft and aircraft engine manufacturers, and those who regulate the industry are proud of their industry and their international successes. I do not believe they will respond well to what they perceive as over-regulation or public interference in what is their primary mission—moving increasing numbers of people and volumes of cargo rapidly, cost-effectively and, of paramount importance, safely.

I believe these folks will, however, respond to rational thinking, positive cooperation, and opportunities to further their mission while protecting the environment. We should welcome their inputs to the Clean Airports mission.

I wish you well at your conference and ask that you consider the factors I have listed as you prepare your draft strategic document on a holistic approach to "Clean Airports Operation". I look forward to reviewing your draft.

In closing I extend my thanks to Dr. Robert Sloan, President of Baylor university, for hosting this important conference and for the unique pioneering work Baylor has accomplished over the years in the development of renewable, clean-burning fuels and in advancing the cause of Clean Airports.

Welcoming Remarks From the Mayor of Waco

at *Ninfa's* Restaurant

Mayor Mike Morrison

I'll make this short, but I don't want to make it too short because I want you all to know how much we appreciate you coming to Waco. I was at the TSTC facility when it was dedicated as a clean airport facility—the first in the nation—this is something that is very important to Waco notwithstanding important nationally and internationally. I've had the chance to visit with several of you and just listening to conversations reminds me a little bit of how King John when he was presented with and had read through the Magna Carte responded, "My mind has never been so eloped by words." As I drift from conversation to conversation and listen to what is on your minds and the plans and dreams that you have, I am not quite bright enough to follow the path of recent technologies, but I am glad that you are and are here and that we have people like Max who is a really harsh spark plug if you will. I am glad to see that there are so many alternate uses for alcohol tonight and that there are some uses other than ethanol. Thank you for coming to Waco, and if you will let Max or Clay [Wilkins] know if there is anything you need while you are here, we will do our very best to make you feel welcome and that we appreciate not just your company, but also the reason for your company. We look forward to working with you in the future in the city of Waco and one of my tasks is, by the way, to work with and further your goals. So on behalf of the citizens of Waco, thank you very much. It is my honor and privilege to be with you here tonight.

After this speech, Clay Wilkins was presented with a retirement plaque expressing the appreciation of Baylor University and the Aviation Sciences Department for all of his contributions to the program and to the advancement of alternative aviation fuels.

Welcoming Address From the Baylor University President

Robert Sloan, President
Baylor University
Waco, Texas 76798-7413

Max, thank you very much. I have the easiest job here today. You all will be discussing hi-tech theoretical issues, marketplaces, government policies no doubt, and who knows what else. The easiest job today is the one I have which is to say welcome to Baylor University; we hope you find your accommodations here and our hosting of this event to be up to standards, and we hope to even excel those standards. Thank you for being here, thank you for what you do. We are excited about everything that Max and those that work with him do here and so I would only be expressing my ignorance on the subject if I tried to elaborate or even implied that I knew anything about the subject. But we are glad you are here, we are glad this conference is taking place on this campus, and Max, I hope that there are many more such conferences just like yours that we have the opportunity of hosting. Thank you for coming to Baylor.

Opening Address and Presentation of Plaque to Dr. Herbert Reynolds

Dr. Maxwell Shauck
Baylor University
Waco, Texas 76798-7413

Welcome to the Second International Conference on Alternative Aviation Fuels. I want to thank all of you for being here, particularly those who have come from other countries. During this conference, I am confident that although it may be small it will produce very solid results. We have leaders in Research and Development in alternate fuels, policy, environment, and powerplant development from the United States and many other countries.

Without fossil fuels and the petroleum industry, today's technology would not have been possible. Literally every aspect of our life—food, shelter, transportation—is dependent on them. However, today we are at a turning point: we can no longer afford to ignore ever increasing impact of fossil fuels. Last week, we attended a conference in Dallas at which we heard the CEO of British Petroleum, representatives from the insurance industries, and David Gardener from the EPA speak. They were all unanimous in recognizing the danger we face today in global warming. Aviation industry faces the same sort of challenges in dealing with the impact of aircraft emissions. We have representatives at this conference which may have different views and pose different solutions to the same problems. I know we can work together on this, rather than in opposition. That's not to say we won't disagree but let's assume that everyone's position is based on a professional attitude and a sense of responsibility. I hope this conference will help us work together on the challenges in general aviation. Please take advantage of the knowledge and the experience gathered here in the conversations and the sessions and have a productive conference.

At this time I would like to take the opportunity to recognize a man who has been very instrumental in the development of our program here at Baylor University as well as many others. Dr. Herbert H. Reynolds is the chancellor of Baylor University and has been a very strong support to this program ever since I arrived on campus in—I hate to tell you—1975. Dr. Reynolds was president of Baylor University, he was the 11th President, and the University really thrived under his presidency. He has been very good in allowing me and other people in the faculty, time to develop the research that is very important to us all. At this time I would like to ask Dr. Reynolds to say a few words and present him this plaque. The plaque reads, "Presented to Dr. Herbert H. Reynolds, chancellor of Baylor University. Thank you for your strong support for many years in the cause of Renewable Aviation Fuels on the part of the Aviation Sciences Department and the Renewable Aviation Fuels Development Center."

Welcoming Address and Acceptance of Plaque
Chancellor of Baylor University

Dr. Herbert H. Reynolds, Chancellor
Baylor University
Waco, Texas 76798-7413

Thank you very much Dr. Shauck. In reality I did not have an alternative. If you are around Dr. Shauck long enough, you know that it is better to agree with him than to take the time to avoid the sort of persuasion that he indeed is capable of. I appreciate your leadership and determination through the years. You were the right person to organize what we have been doing at Baylor to be a part of the larger effort. But thank you for many of your record-breaking kinds of activities. Also your good wife, Grazia, and all those others who have worked with you.

I am delighted to know that there are those of you from various parts of the United States as well as those from other countries. We are always glad to have folks come to Baylor University and be on our campus. We do look at things from a global perspective at Baylor, we have been doing this since our founding, we are the oldest, I would guess, the third or fourth oldest university west of the Mississippi. We have graduates from all fifty states and about 35 countries in the world. We are delighted that this conference is looking at this from a global perspective as well. Looking at the conference materials I was impressed by the fact that you are looking at the problem from a wide perspective, that you see airports as a major source of pollution and greenhouse gases. Airports, through voluntary action, serve as an environmental example for all of us. These voluntary operations increase our flexibility and efficiency by reducing the cost of reaching international goals for energy. Energy efficiency is obviously the foundation that will support the steady advent of renewable energy technology and clean airports. We wish to be showcased towards advanced technology. I am hopeful as I look at your conference agenda, that you will indeed be developing a concept paper where you have the power and capability to do this for our own model interest of minuscule variety. In this room you do have the ability to develop a concept paper that can set the stage for an expanded internationally oriented clean airports program. I know that in the weeks that follow I will be most interested in seeing this concept paper. Those involved will have to work hand in hand with Dr. Shauck and others to see what we can do at the national level to encourage some of our leadership particularly in congress to be of assistance in these matters.

I had a brief discussion with Mr. Holmberg before walking in here and we were talking about the necessity for getting the attention of the Congressional leaders and working with some of these folks from time to time on important issues and important opportunities doing all that we can in regards to the concept paper that might come out of your hands. So thank you for being here, thank you for what you are going to do during these days, and I look forward very much to reading such a concept paper, Dr. Shauck, that is produced by this group. Thank you very much.

New Air Quality Standards and Global and Local Environmental Impacts of Aviation Fuels

Plinio Nastari, World Energy Council (*Facilitator*)

Jeremy L. Cornish, International Centre for Aviation and the Environment
Bill Jordan, Texas Natural Resource Conservation Commission
Randall Friedl, NASA, Jet Propulsion Laboratory, California Institute of Technology
Jim Davis, U.S. Environmental Protection Agency

Second International Conference on
Alternative Aviation Fuels
November 6-8, 1997
Baylor University

New Air Quality Standards and Global and Local Environmental Impacts of Aviation Fuels

Plinio Nastari, Facilitator
World Energy Council, Brazil
San Paolo, Brazil

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In 1996, the world's production of ethanol (ethyl alcohol) for fuel and nonfuel purposes reached approximately 6.6 billion gallons, of which 3.8 billion gallons in Brazil, 1.52 billion gallons in the US, 0.34 in Eastern and Western Europe, 0.26 in Africa, 0.40 in Asia, 0.08 in Oceania, and 0.2 billion gallons in all other North, Central, and South American countries.

Of this total production, only a small fraction is subject to international trade, indicating that ethanol is being produced in most cases to satisfy local markets. The only traditional destination for ethanol is the Far East, importing some 0.09 billion gallons of industrial grade ethanol going into the beverage industry. And, since 1990, Brazil has also become a relevant importing market in 1997/98 of some 0.19 billion gallons of ethanol (not including methanol) as local ethanol and sugar producers have been importing it to sustain their sugar exports.

Even though, in particular for its fuel application, ethanol is produced in great part to supply local markets, the concepts behind its use are very much global. Environmental restrictions, the need to create or maintain domestic jobs and reduce foreign energy dependency, and the use of costly-to-dispose waste products are the most common reasons binding countries that have developed fuel ethanol markets.

As markets are created and expanded for fuel ethanol in various parts of the globe, in diverse applications, it is interesting to note that it has also increased the perception that renewable liquid fuels, as a class in itself, including biomass ethanol and vegetable oils, may not be a definite substitute for petroleum-based fuels, but only a temporary, suitable to some special cases, source of energy for the transition to new forms of energy in transportation.

The transition is happening at this very moment and may last for another 40 to 50 years. This may be a long time for one generation, but only a glimpse away in historic terms. Renewable liquid fuels may be suitable for various countries and applications for a few basic reasons. By the year 2015, the process of large-scale substitution of the lesser important uses for oil products will have initiated. Gasoline used in highway transportation is certainly one of the least noble applications and will be one of the first uses to be substituted by alternatives. However, it will take time and incredible amounts of capital to substitute transportation systems (vehicles) and to adapt fuel distribution systems (pumps, reservoirs, tanks, pipelines) in adaptation to dry sources of energy.

As the drive towards greater energy efficiency intensifies, increased value will be added to fuels that are simpler to control in conventional combustion engines and that are able to support higher compression ratios.

In the long run, there is little doubt that energy for transportation will be solar derived. Many envision the future as being linked only to photovoltaic conversion processes. However, biomass energy is solar energy, photochemically converted. Petroleum ultimately is also solar based, but what differentiates both is their cycle: millions of years, versus 6 to 12 months.

A second good reason for renewable fuels being suitable transition fuels is the fact that their production process creates or maintains jobs on a decentralized way. This fact is very important. as globalization is forcing capital-intensive techniques of production to become international standards and as emerging, developing, and lesser developed countries strive to generate enough savings to absorb the crowds entering the labor force every year. It is interesting to note that renewable fuel applications have also been adopted in industrialized countries as a strategy to maintain jobs and absorb increasing outputs generated by productivity increases in agriculture.

Third, renewable fuels are environmentally friendly, and the amount of scientific evidence supporting this point is large enough for it to be accepted without any question.

However, still today, a major obstacle has prevented ethanol use to increase: rarely, the positive externalities associated with its production and use are interned into its market price. Similarly, rarely have the negative externalities of oil products been reflected in its market price. The II United Nations Conference on Environment and Development (UNCED), also called RIO '92, brought the perspective for this to change. The signing of the Framework Convention on Climate Change (FCCC), during RIO '92, was a big step forward, and is a water divisor in the multilateral relation of countries, comparable to the Bretton Woods Treaty after World War II. The latter led to a whole set of rulings for the way in which countries should interact in the financial and trade areas. The FCCC certainly sets the basic ruling for their interaction in environmental terms.

The initial target determined by the FCCC was for Annex I countries (industrialized) to emit in year 2000 the same levels of green house gases (GHG) that they were producing in 1990. Since then, the Intergovernmental Panel on Climate Change (IPCC's) Second Assessment Report confirmed man-related causes for global warming coming basically from burning of fossil fuels. Currently, the discussion evolves around whether more stringent targets should be imposed, being the center issue of discussion for the World Climate Conference to be held in Kyoto, Japan, in December, 1997.

At this point, I wish to share with you the results of a very recent and valuable assessment produced by the World Energy Council, indicating the performance of various countries in terms of their GHG emissions, measured in gigatons (billion tons) per year.

First of all, the regional evaluation indicates that since 1990, some areas of the globe are fairing better than others, in terms of compliance to the established target.

Overall, in 1996 the world produced 6.4% more GHG, measured in CO_2 equivalent, than in 1990. North America increased its emissions by 8.2%, Latin America 13.2%, the 15 countries around the European Union are doing well at 0.8%, Central and Eastern Europe have reduced emissions by 31%, Middle Eastern countries increased by 41%, Africa by 19%, and Asia/Pacific countries 31%. Excluding the more advanced economies in Asia/Pacific, such as Japan, Australia, and New Zealand, the emission increase is 37%. The industrialized world, gathered around the OECD countries, increased GHG emissions from fossil fuels by 7.8%. Developing countries increased their emissions by 32%, while former soviet economies reduced it by 31%.

Looking at selected country cases, one can see that countries that until recently were champions in terms of the environmental quality of their energy matrices are finding difficulties to comply with the basic target. Norway increased its emissions by 14.5%, Denmark by 41%, and Sweden by 11.1%. Equally relevant, because of their large emission baseline, is the performance of the US (+8.4%) and Japan (+14.3%). On the opposite spectrum, one can find Switzerland (-1.2%), Germany (-7.8%), and the United Kingdom (-1.0%).

These findings, however, do not take into account the per capita emissions of each country. When one analyzes the percentage of CO_2 emissions and the proportion of the world population in each of these countries, the following data can be found:

- the US with 4.7% of the world's population is responsible for 25% of global CO_2, a factor of 5.3;

- Canada has a factor of 4.2, the EU-15 a factor of 2.26, the former soviet countries 2.04, Japan 2.54, Australia 4.33, China 0.63, India 0.22, Korea 2.75, and Brazil 0.81.

These figures are relevant to our discussion about the internalization of environmental positive externalities into the price of renewable liquid fuels, because as the world community enforces the targets defined in RIO, and some countries are proposing even tougher targets (Japan proposed that the target be revised to 5% below 1990 levels by year 2005), the incentive for trading carbon credits and entering into Joint Implementation programs and actions will grow.

The value of these credits can be very relevant. In 1996, the 3.8 billion gallons of ethanol produced in Brazil substituted the equivalent of 12.74 million tons of CO_2. The value of one ton of CO_2 has been estimated at between USD 10 and 100, which resulted in a benefit of USD 0.127 to 1.27 billion of USD 0.03 to 0.33 per gallon of ethanol.

These are the introductory remarks I wanted to make before we open this relevant panel on International Aspects of the Use of Renewable Fuels.

SECOND INTERNATIONAL CONFERENCE ON RENEWABLE FUELS FOR AVIATION

WACO, TEXAS

NOVEMBER 6-8, 1997

PLINIO NASTARI'S FIRST PRESENTATION

DATAGRO, BRASIL

WORLD ETHANOL MAP

USA
1,52
bi gal

Europe
0.34
bi gal

ASIA
0.40
bi gal

Africa
0.26
bi gal

Brazil
3.80
bi gal

Oceania
0.08
bi gal

DATAGRO, BRASIL

NEAR FUTURE: ETHANOL STILL A REGIONAL SOLUTION

- LOCAL MARKETS

- GLOBAL CONCEPTS (ENVIRONMENT, JOBS)

DATAGRO, BRASIL

RENEWABLE LIQUID FUELS

SUITABLE ENERGY FOR THE TRANSITION TO NEW FORMS OF ENERGY FOR TRANSPORTATION.

TRANSITION IS NOW.

SUITABLE BECAUSE:

- BY 2010/15, LARGE SCALE SUBSTITUTION OF OIL
- CREATES JOBS, DECENTRALIZED
- ENVIRONMENTALLY FRIENDLY

DATAGRO, BRASIL

MAJOR OBSTACLE

- RARELY, POSITIVE EXTERNALITIES ARE INTERNED INTO PRICES OF RENEWABLE FUELS.
- II UNCED (RIO'92): CLIMATE CONVENTION BROUGHT THE PERSPECTIVE OF THIS TO HAPPEN.

DATAGRO, BRASIL

FCCC: FRAMEWORK CONVENTION ON CLIMATE CHANGE

TARGET: ANNEX I COUNTRIES TO EMIT IN 2000 SAME LEVELS OF GHG OF 1990.

DATAGRO, BRASIL

CO_2 EMISSIONS FROM FOSSIL FUEL COMBUSTION (GIGATONS CARBON)

	1990	1996	% CHANGE
NORTH AMERICA	1.618	1.751	+8.2
LATIN AMERICA	0.287	0.325	+13.2
EU – 15	0.949	0.957	+0.8
CIS/C & E EUROPE	1.311	0.901	-31.0
MIDDLE EAST	0.177	0.249	+41.0
AFRICA	0.183	0.218	+19.0
ASIA/PACIFIC	1.529	2.004	+31.0
ASIA/PACIFIC (EXCL.JAPAN, AUSTRALIA, N. ZELAND)	1.126	1.546	+37.0
TOTAL OECD	3.035	3.273	+7.8
DCs	1.774	2.339	+32.0
CIS	1.311	0.901	-31.0
WORLD	6.120	6.513	+6.4

SOURCE: WEC

DATAGRO, BRASIL

SELECTED ANNEX I COUNTRIES CO_2 EMISSIONS - % CHANGE

	1990 – 1996
USA	+8.4
CANADA	+5.5
JAPAN	+14.3
AUSTRALIA	+9.5
N. ZELAND	+10.7
ICELAND	+25.0
NORWAY	+14.5
SWITZERLAND	-1.2
TURKEY	+16.0
DENMARK	+41.0
AUSTRIA	0
GERMANY	-7.8
PORTUGAL	+42.7
SWEDEN	+11.1
U.K.	-1.0

SOURCE: WEC

DATAGRO, BRASIL

SHARES OF GLOBAL CO_2 EMISSIONS AND POPULATION IN 1996 (%)

	% CO_2	% POPULATION
USA	25.0	4.7
CANADA	2.1	0.5
EU – 15	14.7	6.5
CIS	10.2	5.0
JAPAN	5.6	2.2
AUSTRALIA	1.3	0.3
CHINA	13.5	21.5
INDIA	3.6	16.3
KOREA	2.2	0.8
BRAZIL	2.1	2.6

DATAGRO, BRASIL

SOURCE: WEC

IMPACT OF ETHANOL IN BRAZIL

1996: 3.80 BILLION GALLONS OF ETHANOL SAVED 12.74 MILLION TONS OF CO_2 EQUIVALENT.

- VALUE OF 1 TON OF CO_2: USD 10 to 100
- SAVING IN 1996: USD 0.127 to 1.27 BILLION
- SAVINGS PER GALLON OF ETOH: USD 0.30 to 0.33 PER GALLON

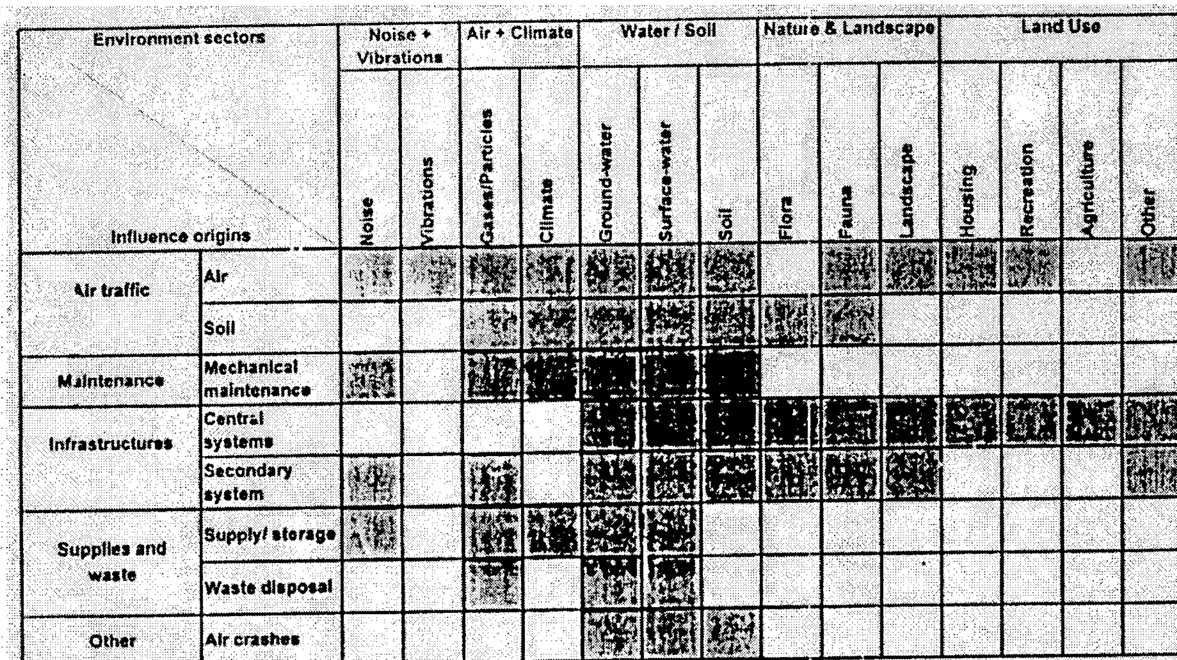
DATAGRO, BRASIL

Airports and the Environment

Jeremy L. Cornish
Executive Director
International Centre for Aviation and the Environment
Beaconsfield, PQ H9W 4B3
CANADA

PRESENTATION OVERVIEW

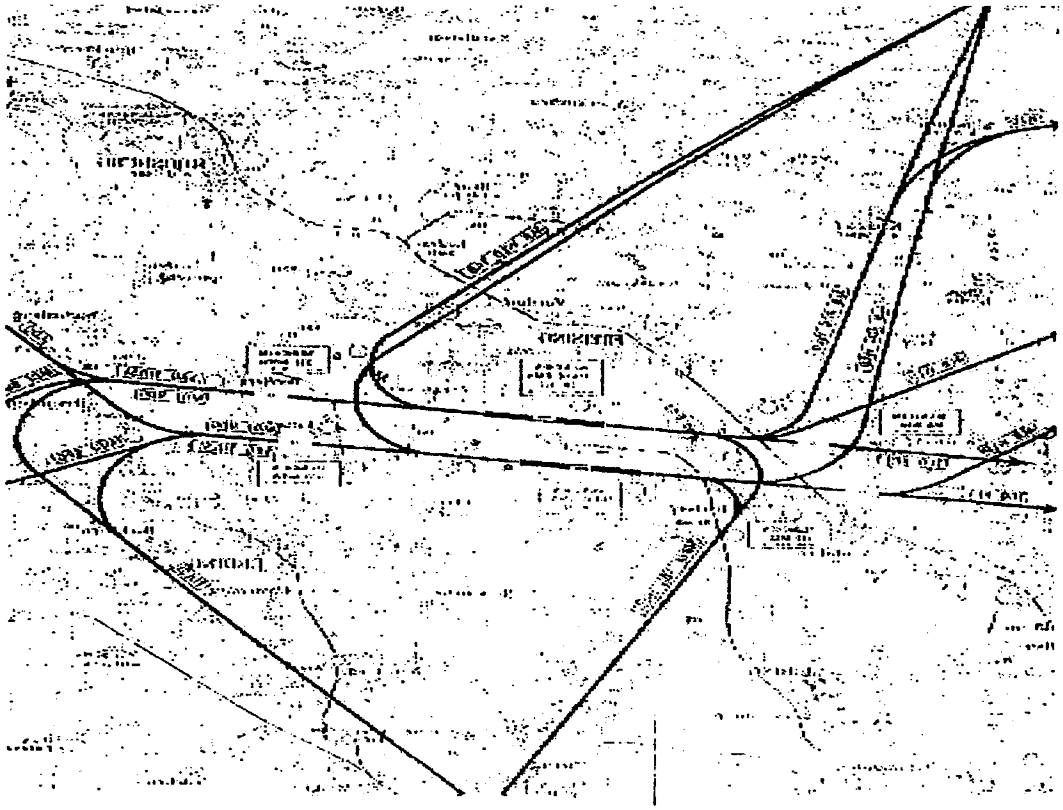
- Environment Matrix for Aviation
- Noise
- Air Pollution
- Water Pollution
- Hazardous Materials
- Solid Wastes
- Waste Management
- Conclusion

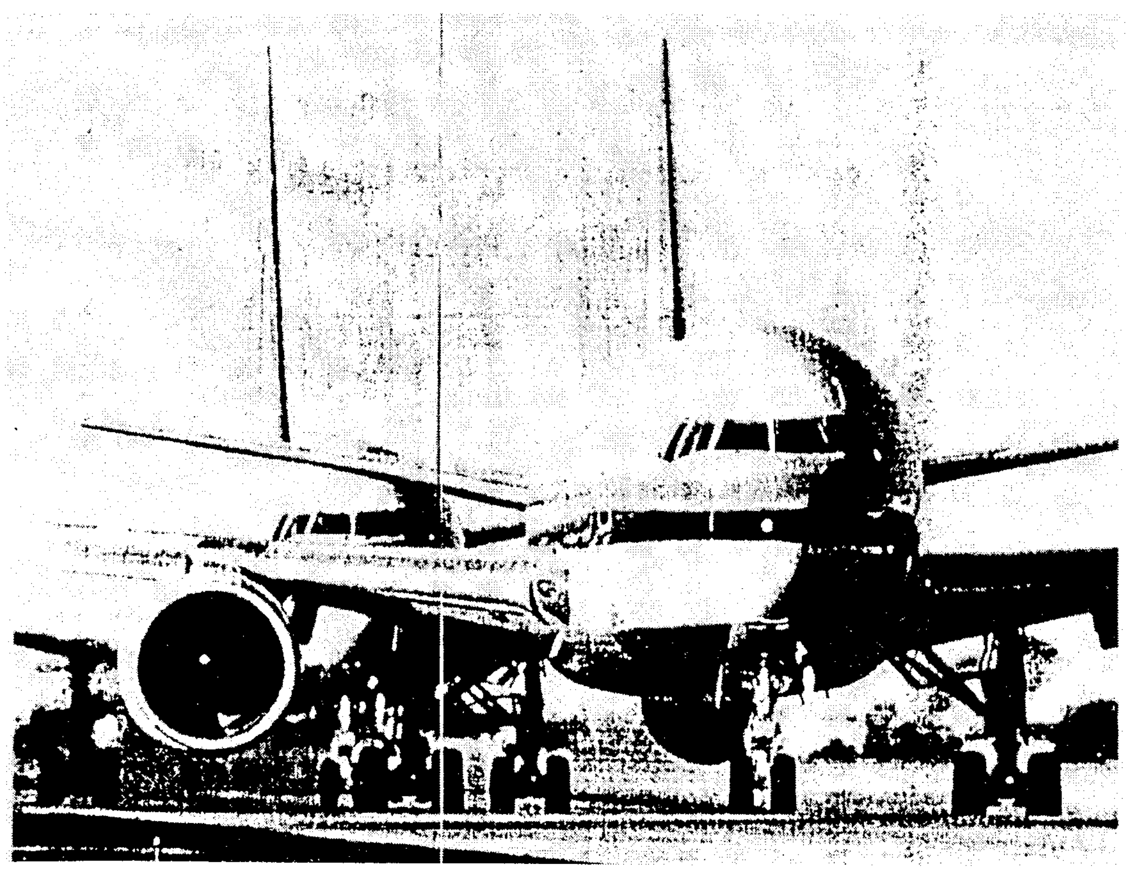


TERMS USED IN THE ENVIRONMENTAL RELEVANT MATRIX FOR AVIATION.

Air Traffic/Air: Normally refers to aircraft operation (engines)
Air Traffic/Ground: Refuelling,aircraft de-icing, operation of APUs.
Mechanical Maintenance: Maintenance of aircraft, test and static test procedures.
Primary Systems: Runways, security zones, taxiways and aprons
Secondary Systems: Parking areas, hangars, workshops, operational and administrative buildings, other areas.
Supplies/Storage: Heating, powerstand by units,ground vehicles for aircraft service, etc
Disposal: Waste, sewage, storage of hazardous substances, etc

Note - Some areas may be less significant than others.

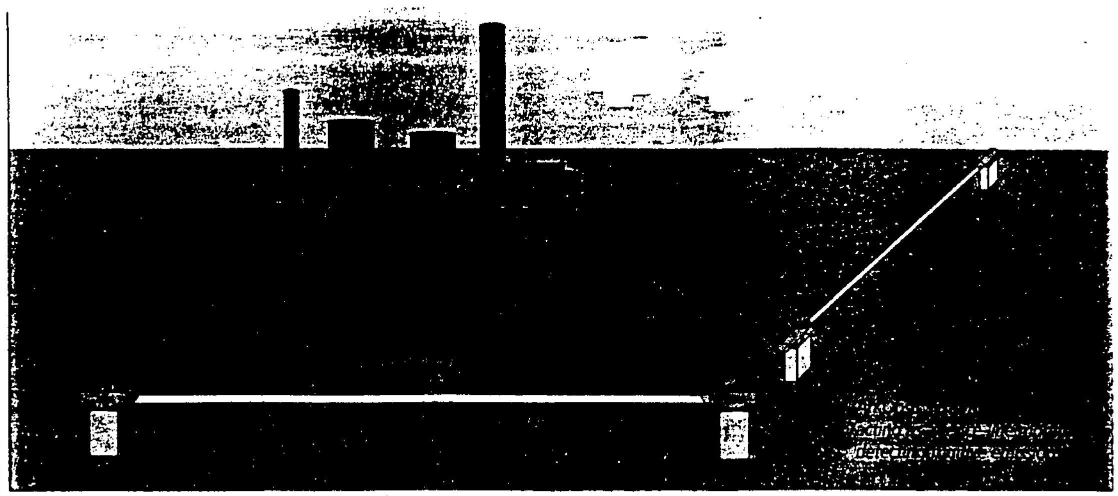




AIR POLLUTION
Impacts and Sources

- **Sources:**
  - Airway and airport congestion
  - Aircraft engine – due congestion on ground (45%)
  - APU's and ground support equipment (10%)
  - Ground access vehicles (45%)
  - Maintenance emissions (fuels. solvents. etc.)

Differential Optical Absorption Spectroscopy

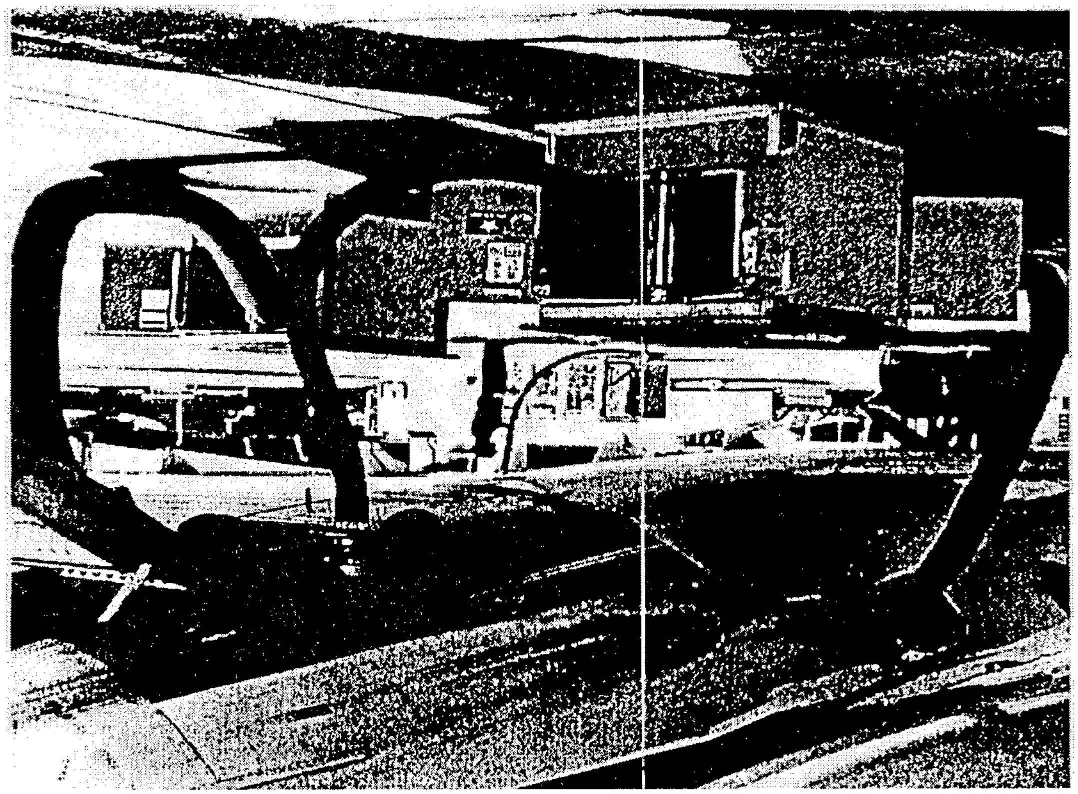


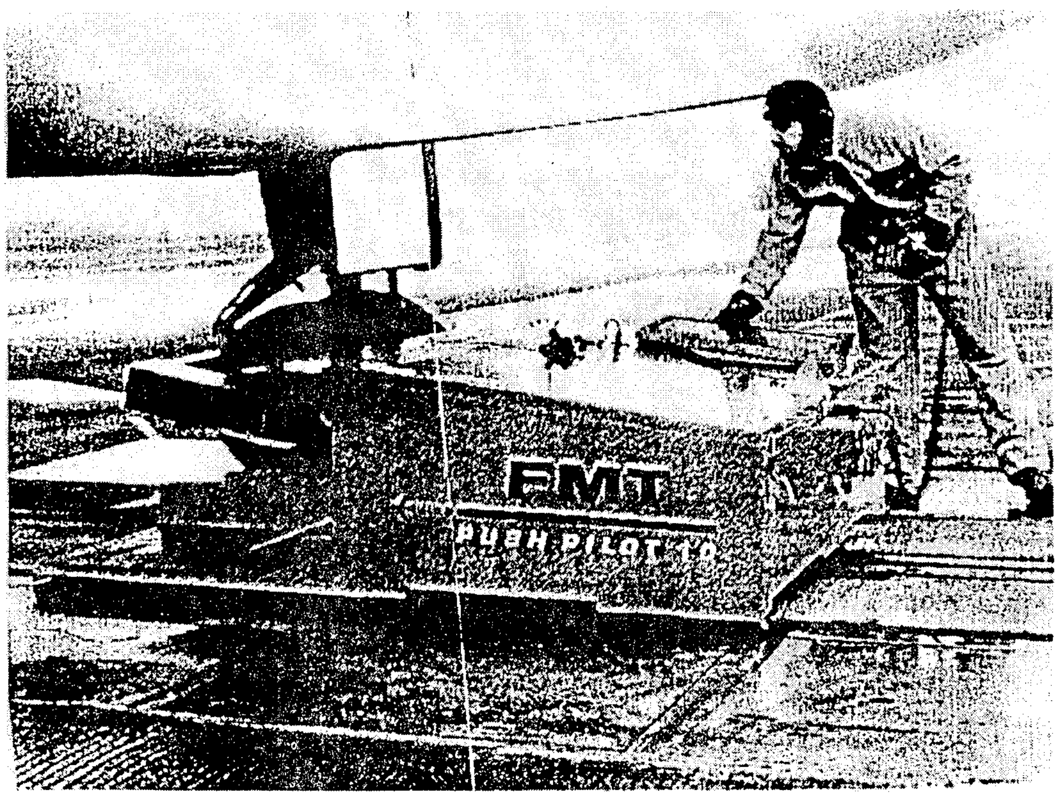
Performance Data (typical data which may vary significantly depending on application)

Compound	Max. measurement range (500 m path)[3]	Min. detectable quantities (monitoring path 500 m, measurement time 1 min.)	Zero drift (500 m path, max. per month)	Span drift (per month, better than)	Span drift (per year, better than)	Linearity error (of measurement range, better than)	Max. length of fibre optic cable (when measuring several compounds)[1]	Hardware requirement
NO_2	0-2000 µg/m³	1 µg/m³	±2 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
SO_2	0-5000 µg/m³	1 µg/m³	±2 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
O_3	0-1000 µg/m³	3 µg/m³	±6 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
NO[2]	0-2000 µg/m³	2 µg/m³	±4 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
NH_3[3]	0-500 µg/m³	2 µg/m³	±4 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
NO_3	0-500 µg/m³	0.1 µg/m³	±0.2 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
HNO_2	0-2000 µg/m³	1 µg/m³	±2 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
HF	0-2000 µg/m³	20 µg/m³	±40 µg/m³	±2%	±4%	±1%	10 m	AR 520
Hg	0-2000 ng/m³	20 ng/m³	±40 ng/m³	±2%	±4%	±1%	10 m	AR 500/520
H_2O	0-100 g/m³	0.2 g/m³	±0.4 g/m³	±2%	±4%	±1%	10 m	AR 500/520
Styrene	0-2000 µg/m³	5 µg/m³	±10 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
CS_2	0-2000 µg/m³	5 µg/m³	±10 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
Formaldehyde	0-2000 µg/m³	2 µg/m³	±4 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
Acetaldehyde	0-2000 µg/m³	2 µg/m³	±4 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
Phenol	0-2000 µg/m³	1 µg/m³	±2 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
Benzene	0-2000 µg/m³	3 µg/m³	±6 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
Toluene	0-2000 µg/m³	3 µg/m³	±6 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
p-, m-Xylene	0-2000 µg/m³	3 µg/m³	±6 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
o-Xylene	0-2000 µg/m³	10 µg/m³	±20 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
o-, m-, p- Cresol	0-2000 µg/m³	5 µg/m³	±10 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
C_6H_5Cl	0-2000 µg/m³	5 µg/m³	±10 µg/m³	±2%	±4%	±1%	10 m	AR 500/520
$C_6H_4Cl_2$	0-2000 µg/m³	5 µg/m³	±10 µg/m³	±2%	±4%	±1%	10 m	AR 500/520

[1] When monitoring individual compounds, fibre optic cables of extended lengths are available.
[2] Based on 200 m path. Recommended monitoring path length: 100 to 200 metres.
[3] Recommended monitoring path length: 300 to 800 metres.
• Besides the compounds above, the Opsis system monitors the following compounds: hydrogen cyanide (HCN), hydrogen bromide (HBr), hydrogen chloride (HCl), chlorine dioxide (ClO_2), chlorine (Cl_2), carbon dioxide (CO_2), phosgene ($COCl_2$), ethylbenzene ($C_6H_5C_2H_5$), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acrylonitrile ($CH_2=CHCN$), 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene and others.

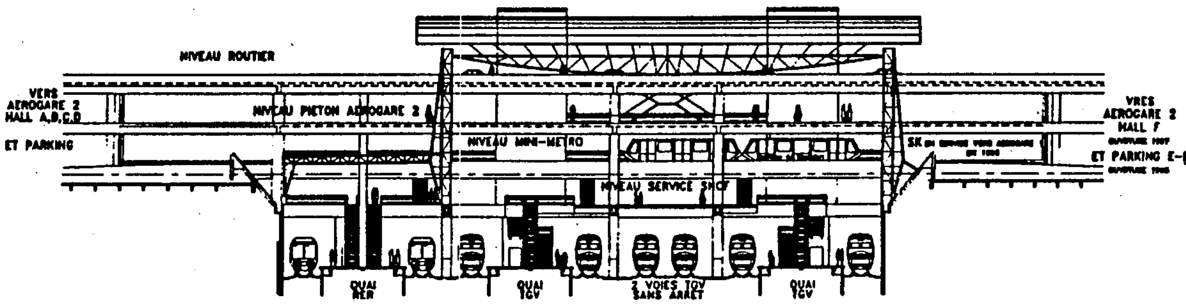
Please contact your Opsis supplier to discuss your particular system requirements, including the compounds you wish to monitor. Separate product sheets are available describing individual items of Opsis system hardware.
Specifications subject to change without notice




FMT
PUSH PILOT 10

* **GROUND TRANSPORTATION.**

LIGHT TRAIN SYSTEMS CONNECTING AIRPORTS WITH CITIES.
Switzerland, France, Germany, England

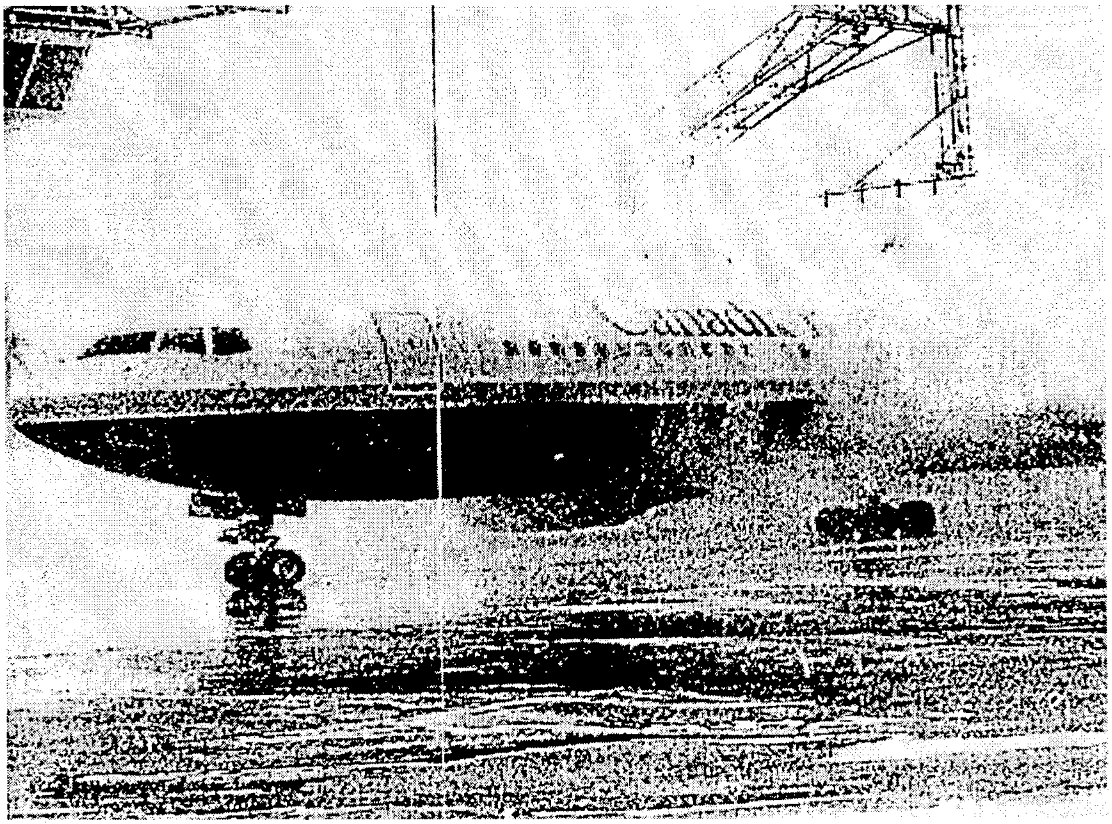


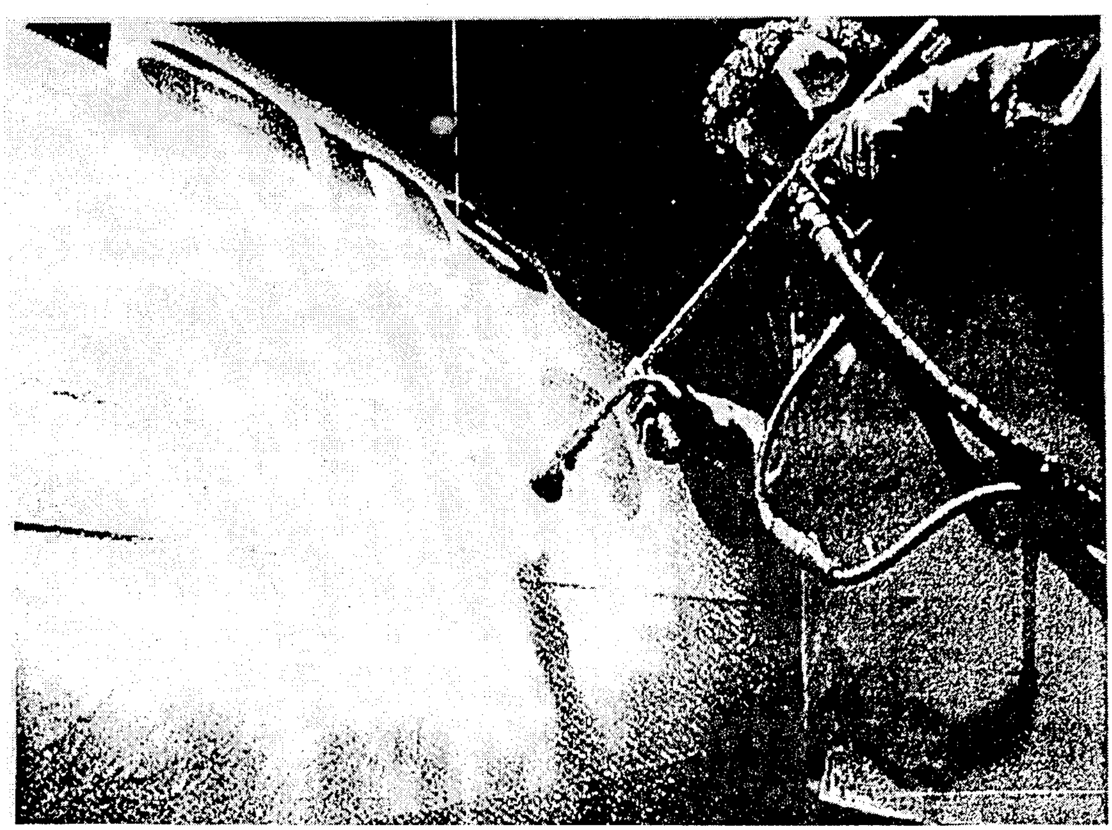
COUPE TRANSVERSALE

WATER POLLUTION
Impacts and Sources

- Discharges of substances into aquatic environment alters quality/nature of ecosystems with effects on human health or animal or plant life.

Pollution from paved areas	Chemical to melt snow or ice, residues from deicing, fuel spillage/leakage, aircraft toilets spillage, aircraft/ground vehicles washing
Pollution leading to groundwater & soil contamination	Leakage from piping systems, leakage in underground tanks, seepage from historical activities, fire training fluids, routine spills
Pollution due to wastewaters from facilities	Waste oils/chemicals, aircraft washing, food production in kitchens, wastewater from workshop and maintenance facilities.





HAZARDOUS MATERIALS
Example Waste Materials From Airport Operations

SOLVENTS	CHEMICALS AND METALS	OTHER MATERIALS
CFCs & halons	acids	hydraulic fluid
chlorinated solvents	sodium hypochlorite solution	corrosion inhibitor
acetone	caustic soda	dyes, additives, inks
odorless kerosene	sodium bisulphate	cleaning reagents
methylate spirit	lead, nickel, cadmium	paint strippers
petroleum distilate	chromic acid	adhesives & thinners
white spirit	cyanide	aircraft paint
paint solvents	plating strippers	paint strippers, thinners
alcohol	oxidizes	pesticides
ketone	blasting grit	herbicides
		disinfectants

SOLID WASTES
Example Waste Materials From Airport Operations

WASTE CLASSIFICICTION	EXAMPLES	COMPONENTS
administrative	Office & computer paper	wood
cargo	newsprint	cardboard
in-flight	food packaging	newsprint
maintenance	food wastes	mixed & fine paper
terminal	beverage containers	plastics
restaurant	film plastic & pallets	ferrous metals
other	cardboard packaging	non-ferrous
metals		
	galley wastes	food
	food concessions	glass
	metal parts	textiles
	custodial wastes	rubber
	hospital wastes	other

WASTE MANAGEMENT
Initiatives

- Environmental audits of airport operations.
- Strategies based on Reduce, Reuse, Recycle, Recover

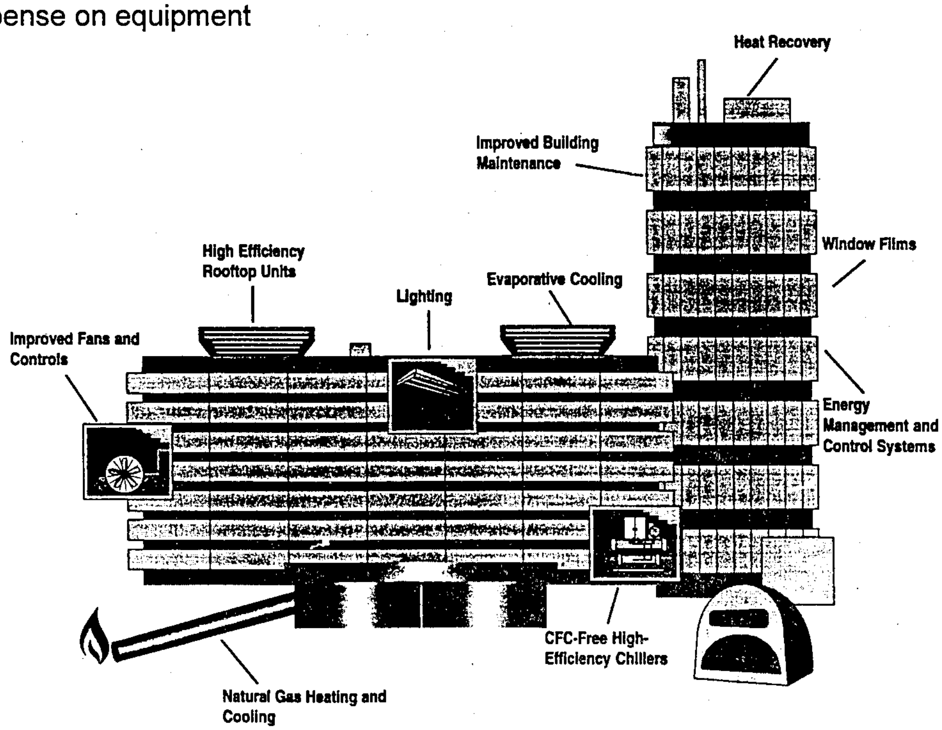
Heathrow (1993)	60% of waste from aircraft 80% diverted from landfills user fee for waste disposal
British Airways (1994)	20,000 t/yr 10,000,000 cans recycled save $250,000/month
AMR Corp (1993)	1,200 t/yr diverted (save $38,000/yr) recycled 500 t of aluminum reduced use of chemical

Technology Options

There are many technologies available to building owners interested in profitably achieving energy efficiencies in their buildings.

Maximizing savings requires:

- Skilled selection of technologies
- Staging implementation in the proper order to integrate systems and avoid wasted expense on equipment



New Air Quality Standards and Global and Local Environmental Impacts of Aviation Fuels

Bill Jordan
Mobile Sources Section
Texan Natural Resource Conservation Commission
Austin, Texas 78711

The state of Texas was able to claim volatile organic compound (VOC) emission reduction credit from Stage 3 aircraft controls. As you can see on the chart, there was about a half a ton of credit taken in Dallas/Fort Worth and almost one ton of credit taken in Houston/Galveston. Houston/Galveston was able to claim more credit because it was evaluated in 1999, whereas Dallas/Fort Worth was evaluated in 1996. Stage 3 aircraft controls started phase-in during 1994.

Stage 3 aircraft controls were mainly implemented to reduce noise and increase efficiency of turbine powered aircraft. As a side benefit, the VOC emissions improved and the state was able to claim credit for these reductions.

Emissions Inventory
Tons Per Day Volatile Organic Compounds (VOCs)

Texas State Implementation Plan	**Dallas/Fort Worth 1996 projected inventory**	**Houston/Galveston 1999 projected inventory**	**El Paso 1996 projected inventory**
Area Sources	162.62	196.68	23.30
Point Sources	70.64	516.95	9.32
On-Road Mobile	241.89	172.68	29.35
Off-Road Mobile	107.92	142.87	11.64
Total VOC Inventory	**583.07**	**1029.18**	**73.61**
Aircraft Inventory	5.40	2.43	0.29
Reduction counted due to Stage 3 engine controls	0.60	0.97	0.02

Global Environmental Impacts of Aviation Emissions

Randall Friedl
NASA, Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

Extended Abstract

Recently established links between the human-caused buildup in the atmosphere of chloroflurocarbons and carbon dioxide to stratospheric ozone depletion and global warming, respectively, have increased awareness of the potential for human activities to affect the atmosphere on a global scale. Substantial scientific interest has centered recently on the atmospheric impacts of future subsonic fleets and proposed supersonic fleets of aircraft. This interest has arisen from recognition of the rapid growth of aviation relative to other forms of transportation and from the fact that aviation represents a direct source of chemicals into the relatively "clean" upper troposphere and lower stratosphere. The emissions of interest include: water vapor, carbon dioxide, nitric oxide and nitrogen oxide (collectively referred to as NO_x), sulfur oxides, carbon monoxide, non-methane hydrocarbons, and soot. The impact of these emissions depends on the relative change they induce in the background atmosphere and on their role in atmospheric photochemical, dynamical, and radiative processes. Photochemical processing of these emissions can affect ozone and other important species. Climate change may result from changes in concentrations of radiatively important species (e.g., water, carbon dioxide, ozone, and particles). Formation of contrails and changes in clouds caused by aircraft emissions can also affect climate.

Aviation related atmospheric research is being conducted throughout the world. Two particularly large programs are sponsored by the European Commission and the United States. In the United States, the Atmospheric Effects of Aviation Project (AEAP) is managed and conducted by the National Aeronautics and Space Administration, in cooperation with the Federal Aviation Administration and in collaboration with other research Agencies, such as the National Oceanic and Atmospheric Administration (NOAA). Both the European and US programs have completed assessments of the impacts of subsonic aircraft on the atmosphere during 1997. Some of the highlights of those studies can be summarized as follows:

1. Present day aircraft contribute a significant fraction of the NO_x in the mid-latitude upper tropospheric region between 7 and 13 km and likely have increased ozone concentrations in that region by about 5%. Model calculations show that increases in ozone from growth in the subsonic fleet will be roughly proportional to the increased emissions of NO_x.

2. Current emissions of NO_x from aircraft, through induced changes in atmospheric ozone, are estimated to have an effect on climate that is comparable to that from aircraft carbon dioxide emissions. As carbon dioxide and NO_x emissions increase in the future, the climate response will increase as well.

3. Model sensitivity studies suggest that the climate impacts of aircraft-induced increases in cloud cover are potentially significant relative to those of other aircraft emissions. In some locations, high-altitude cloud cover has been observed to increase in conjunction with aircraft contrails. However, an accurate quantification of large-scale changes in cloud cover and corresponding radiative properties is not possible currently because of limited observational data and insufficient knowledge of the physical interactions between aircraft exhaust and clouds.

Substantial improvements in the fundamental understanding and model treatment of upper tropospheric gas and particle sources and chemistry and transport processes are required before more credible quantitative ozone and climate predictions can be made regarding the effects of aircraft emissions. Research efforts are continuing within the US and European programs and an international assessment is now being prepared under the auspices of the United Nations Environmental Programme (UNEP) and the World Meterological Organization (WMO). These efforts are particularly important in view of the renewed international effort to define realistic and binding limits on global emissions of greenhouse gases.

GLOBAL ENVIRONMENTAL IMPACTS OF AVIATION EMISSIONS

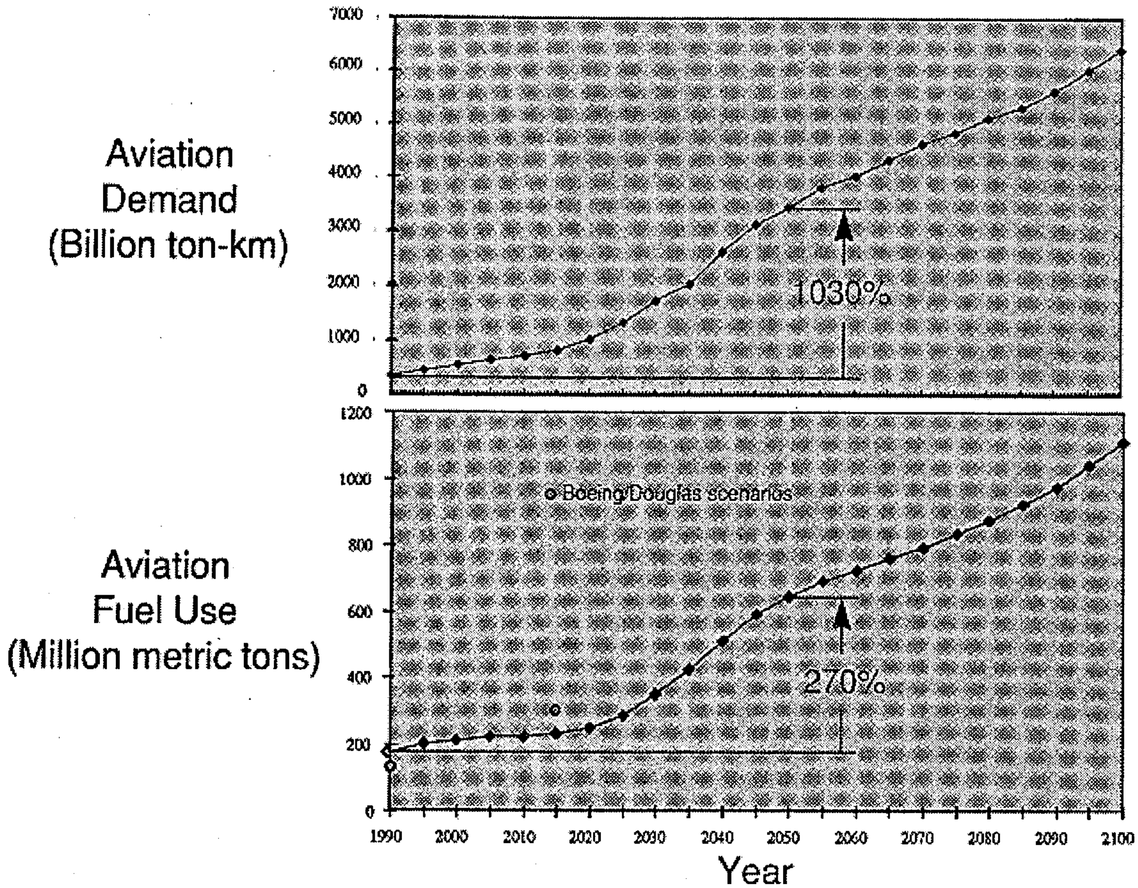
Randall R. Friedl
Jet Propulsion Laboratory

Aviation Global Environmental Concerns

- **International call for reduction of greenhouse gas emissions to near 1990 levels.**
- **Greenhouse emissions from transport result mainly from the use of fossil fuels; main greenhouse gas produced is CO_2.**
- **Transport sector responsible for about 25% of world primary energy use and 22% of CO_2 emissions from energy use.**
- **Air traffic uses roughly 13% of total transport energy but is growing at a faster rate (5%/year) than the other transport sectors.**

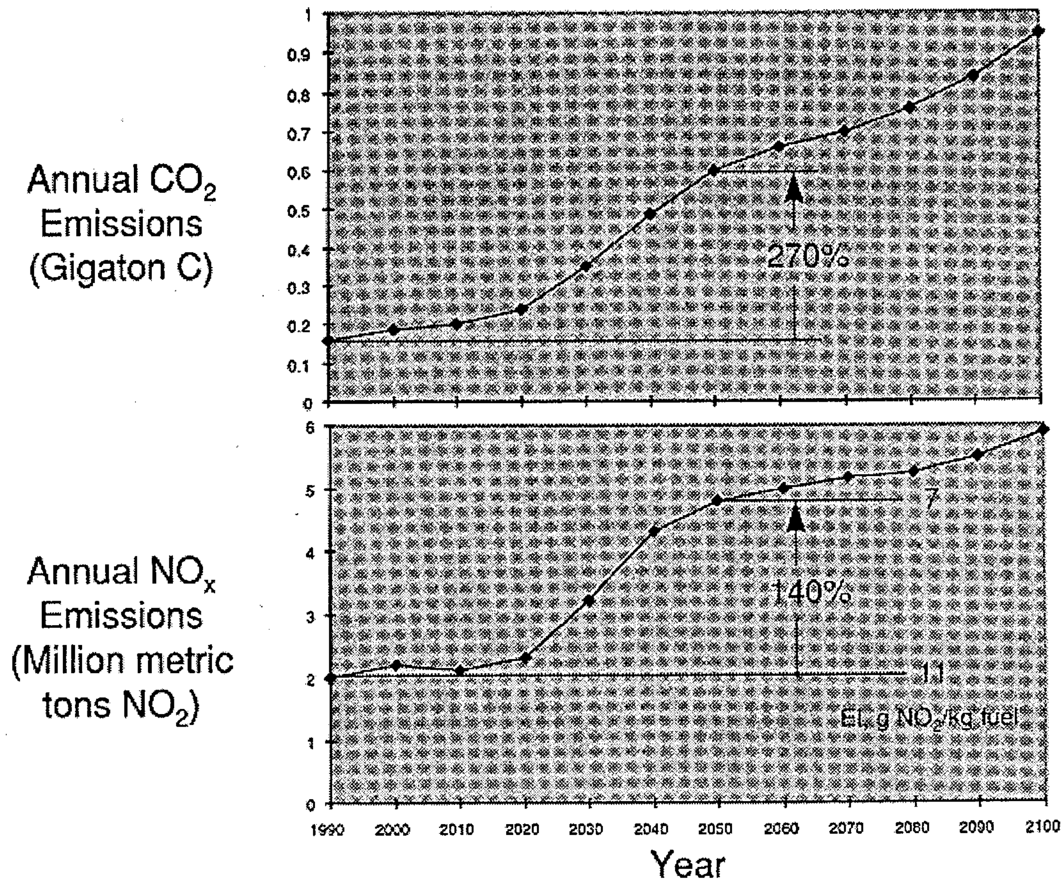
Projected Growth in Aviation Sector

from EDF study



Projected Growth in Aviation Emissions

from EDF study



Understanding Aircraft Effects

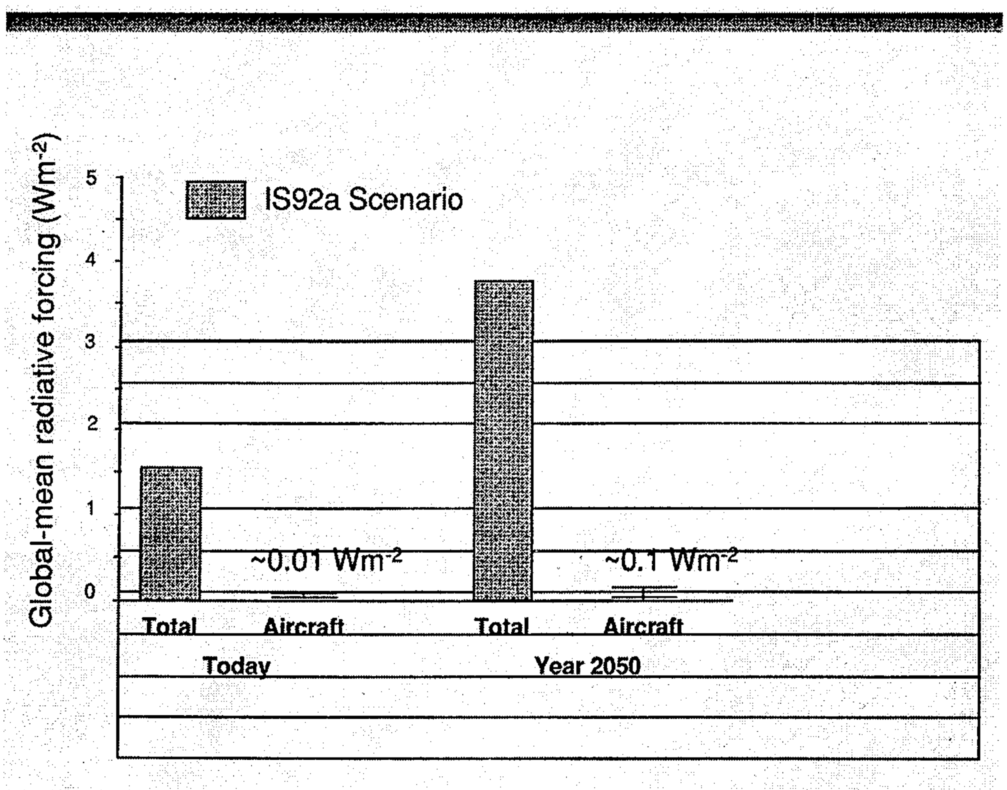
- **CO_2 emissions from aviation accumulate in atmosphere along with other CO_2 sources.**
- **NO_x emissions directly effect the levels of the potent greenhouse gas ozone.**
- **Water, sulfate, and soot emissions directly effect abundance of contrails.**
- **Water, sulfate, and soot emissions may indirectly promote the formation of high clouds.**

Summary of Assessment Results

Emittant	Radiative Forcing, Wm^{-2} Friedl et al., 1997	Brasseur et al., 1997
CO_2	0.007 +/- 0.005	0.03
NO_x	0.01 +/- 0.05	<0.05
H_2O (direct effect via contrails)	significant, sign uncertain	potentially significant
Soot and sulfur (dir. effect)	negligible	negligible
H_2O, soot, and sulfur (indirect effect on clouds)	potentially significant	potentially significant

Note: GISS GCM sensitivity = 1 deg C/Wm^{-2} for surface air

CO_2 and NO_x Climate Impacts in Perspective



SASS Goals and Objectives

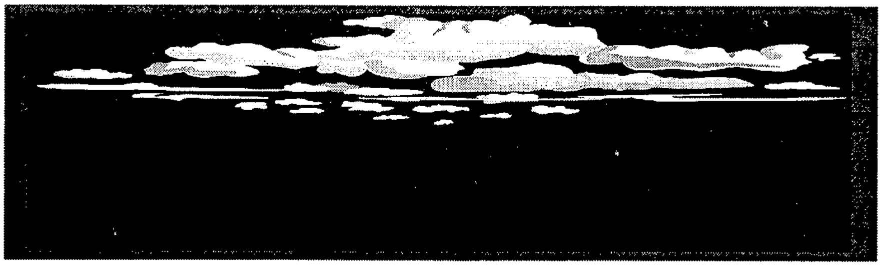
- **GOAL: Develop Scientific Basis for Assessments**
- **OBJECTIVE: Provide measure of the change in radiative forcing due to changes in O_3, CO_2, H_2O, and aerosols by aviation emissions - determine if aviation already having impact and provide assistance to international assessments of future change**

SASS Success Criteria

- **Quantitative measures of O_3, CO_2, H_2O, and aerosol changes due to aircraft, with quantified uncertainties**
- **Functional 2D and 3D models capable of performing credible assessment calculations**
- **Reduction of uncertainty in O_3 change prediction by factor of 5 relative to 1994 uncertainty estimate**

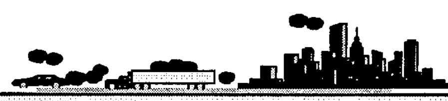
Implementation of EPA's New 8-Hour Ozone Standard

Jim Davis
U.S. Environmental Protection Agency
Dallas, Texas



IMPLEMENTATION OF EPA'S NEW 8-HOUR OZONE STANDARD

U. S. Environmental Protection Agency
Region 6



Background ... Ozone NAAQS Review

- **The Clean Air Act calls for national ambient air quality standards (NAAQS) for criteria pollutants.**
- **The Act requires EPA to review the scientific criteria at least once every five years with advice from the Clean Air Scientific Advisory Committee (CASAC)**
- **Proposal announced in the Federal Register 12/13/96**
- **EPA received 57,000 comments at public hearings, through letters, and via e-mail and telephone messages**
- **Final actions signed by EPA Administrator and published in the Federal Register on 7/18/97.**

Background ... Final Ozone NAAQS Rule

●First update in 20 years

●Old 1-hr NAAQS lacked adequate public health protection

●Changed averaging time to 8 hrs ... better associated with the health effects of exposure studies.

●Changed form ... "expected-exceedance" to concentration-based" ...

- ▼more directly relates to concentrations associated with health effects
- ▼avoids exceedances, regardless of size, from being counted equally for attainment test

●New 8-hour NAAQS will become effective 60 days after promulgation

●Existing 1-hr standard, for most purposes, will remain in effect until EPA determines area has attained

Ozone-Related Health Effects of Concern

●Moderate (approximately 15%) to large (over 20%) decreases in lung function (e.g., shortness of breath)

Respiratory symptoms such as those associated with chronic bronchitis (e.g., aggravated/prolonged coughing and chest pain)

Increased respiratory problems (e.g., aggravation of asthma) resulting in increased hospital admissions and emergency room visits

●Repeated exposures could result in chronic inflammation and irreversible structural changes in the lungs that can lead to premature aging of the lungs and illness such as bronchitis and emphysema

●Growing evidence suggests association with premature death.

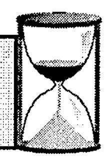
What about the new Ozone NAAQS?

EPA'S Revised Ozone Standard (NAAQS)

- **Phases out and replaces old 1-hr Primary with new 8-hour**
- **New 8-hour Primary NAAQS:**
  - ▼0.08 parts per million (ppm)
  - ▼"Concentration-based" form
  - ▼3-yr avg of annual 4th-highest daily max 8-hour concentration
- **Replaces old Secondary NAAQS with the new, 8-hr Primary**
- **Fate of old 0.12 ppm 1-hr NAAQS:**
  - ▼Not revoked in an area until EPA finds it has attained old NAAQS
  - ▼To revoke ... 3 consecutive yrs of AQ data meeting the 1-hr
  - ▼Retention is to ensure a smooth, legal, and practical transition

When will things happen?

General Timeframe for Ozone NA Actions



- **CAA provides up to 3 yrs for State governors to recommend and the EPA to designate NA areas according to their most recent air quality**
- **States will have up to 3 yrs from designation to develop and submit State Implementation Plans (SIPs) to provide for attainment of the new standard**
- **Thus, State areas would ...**
  - ▼Be designated NA for new 8-hour standard by 2000
  - ▼Nonattainment SIP submittals by 2003
- **Act allows up to 10 yrs plus two 1-yr extensions from date of designation to attain the revised NAAQS.**

EPA's Implementation Strategy for the new NAAQS is ...

Key Principles for Implementing the New Ozone Standard

- **New "transitional" classification for areas where regional measures will provide bulk of emission reductions needed for ozone improvement**
- **Avoid burdensome, new planning requirements and restrictions on economic growth for these transitional areas**
- **Focus efforts on regional utility emissions to reduce transport or local and regional measures.**

- Work from a regional plan developed by OTAG states
- Focus on major power plants ... cost-effective opportunities for reducing NO_x
- Focus on early, enforceable strategies in an attainment plan.

The Who's and How's of a "Transitional" Classification for Ozone?

INITIAL REQUIREMENT:

To qualify ... attainment of the old 1-hr NAAQS is key...

- **must be attaining the old 1-hr now**

or

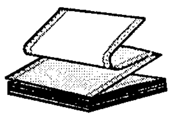
- **attain the old 1-hr prior to 2000 designation**

THEN ... NECESSARY ACTIONS:

- **If a "Regional Strategy" will provide for attainment and you adopt it....**
- **If a "Regional Strategy" plus additional measures will attain and you adopt both....**
- **If "Regional Strategy" will not affect the area, then local measures will provide for attainment , and you adopt them...**
- **You must submit an early SIP that provide for attainment prior 2000 attainment designation**

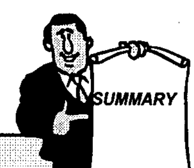
Advantages of a "Transitional" Classification for Ozone?

- Classified with other areas with similar air quality
- Recognizes areas early efforts to attain the 8-hour ozone standard
- Only minor revisions to new source review (NSR) and conformity in transition areas.



For more information...

- Download new standard and fact sheets from Clean Air Act Amendments bulletin board .... EPA's TTN ..... call (919) 541-5742
- Look under "Recently Signed Rules"
- For further information about how to access the board, call (919) 541-5384.
- Internet ... TTN can also be accessed through EPA's homepage http://ttnwww.rtpnc.epa.gov



What did they say?

New 0.08, 8-hr, 4th max average NAAQS

- Old 1-hr standard remains until attained
- Flexible Attainment Region Agreement continues under 1-hour standard
- "Transitional" classification available - certain advantages
- 3 yrs for designation, 3 yrs for SIPs, up to 10 yrs for attainment
- Regional NO_x control strategies may be important

AVIATION ENGINE EMISSIONS

RAY VALENTE, TENNESSEE VALLEY AUTHORITY (*FACILITATOR*)

DAVE STANLEY, PURDUE UNIVERSITY
BRIAN STAGE, U.S. ENVIRONMENTAL PROTECTION AGENCY
ROBERT J. SHUTER, TRANSPORT CANADA
GUS FERRARA, FERRARA AND ASSOCIATES
PAUL B. MACCREADY, AEROVIRONMENT, INC.

WITH EVENING REMARKS BY

WILLIAM J. WELLS, DELTA-T CORPORATION

SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
NOVEMBER 6-8, 1997
BAYLOR UNIVERSITY

Soydiesel and Jet-A Blended Fuels Project

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Professors David L. Stanley and Denver Lopp of Purdue University under grant from the Indiana Soybean Development Council are investigating the use of soydiesel as a blending agent with Jet-A fuels. The purpose of the project is to evaluate potential new uses for soybean products while exploring the impact of blended fuels on performance, engine and aircraft components, and exhaust emissions of a TPE-331-3U Garrett turboprop engine.

The first priority of testing was to determine the viability of the blended fuels, primarily with respect to engine operations. The parameters developed were based on the need for a resultant blend which still meets the specification requirements of ASTM D-1655 (Jet-A). Engine performance and fuel characterization was performed, and, based on the resulting characterization data, it was determined the blend level was restricted to a 2% soydiesel by volume.

As a consequence of the low level of blending permitted under Jet-A specifications, there is little incentive for the fuel manufacturers to utilize the soydiesel as a fuel extender. However, in view of the operational experience with soydiesel in mass transportation bus fleets which indicates a favorable impact on exhaust emissions, research of this type is warranted simply to explore the potential emissions impact of blended fuels. Finally, in the way of research rationale, soydiesel has fine lubricating qualities, a characteristic of significant importance for fuel controls and fuel pumps.

The project results to date are summarized below.

- The test operations conducted in 1996 were operationally successful with few parameter changes from standard Jet-A.

- Test operations conducted in 1997 were hampered due to soydiesel supply and quality control problems. During the course of test operations, an engine fire occurred. The cause of the fire and resultant damage to the engine are still under investigation.

- At constant power lever settings, fuel consumption generally increased with the 2% by volume soydiesel blend as compared to 100% Jet-A. The observed consumption was lower when the 20% by volume soydiesel blend was used.

- At constant power lever settings, horsepower generally dropped slightly with the addition of soydiesel. Extended operations at higher power setting should provide consistent data for both power output and fuel consumption.

- Emissions as tested with a Sun analyzer did not change significantly, but the equipment in use could only provide comparisons between fuels. For the second phase of testing, plans are underway to measure emissions with equipment designed for the volume of exhaust encountered with a turbine engine.

- Chemical testing of various blends indicated the maximum blending ratio which would meet current Jet-A specifications would be a 98/2% by volume blend of Jet-A with soydiesel. It was noted at this level the gum content did not meet specification, but it was felt this could be addressed with a slight modification of the soydiesel production process. Freeze point is also still an issue as yet unresolved.

Currently, investigation continues into the engine problems encountered during the course of testing. Most importantly, the test bed engine must be carefully evaluated for damage, and repairs then effected, as needed. In the meantime, work continues to develop the means for testing and evaluating turbine engine exhaust emissions. Once these problems are overcome, test operations will continue.

In an effort to provide a reliable supply of blending agent, NOPEC volunteered to supply biodiesel for future testing. The investigators would like to extend thanks to Russ Thiel, Kenlon Johannes, and Karl Rehberg, all of NOPEC. Their efforts, interest, and commitment to alternative fuels are greatly appreciated.

Reducing Alkyl Lead Emissions Under the Binational Toxics Strategy

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In keeping with the obligations of the Great Lakes Water Quality Agreement, Canada and the United States on April 7, 1997, signed the "Great Lakes Binational Toxics Strategy: Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes" (Strategy). This Strategy seeks percentage reductions in targeted persistent toxic substances so as to protect and ensure the health and integrity of the Great Lakes ecosystem.

The Strategy is a voluntary, cooperative effort, not a regulatory mandate. The U.S. Environmental Protection Agency and Environment Canada will work together with all stakeholders, including States, Tribes, Industry, Non-Governmental Organizations, and all others to develop solutions and implement actions.

Alkyl lead is one of the substances being targeted for reductions. The emissions inventory recently compiled for Section 112(c)6 of the Clean Air Act identifies distribution of aviation fuel as the source of nearly 80% of alkyl lead emissions. Please note that alkyl lead emissions occur during the distribution and refueling stages, but not during combustion. The U.S. EPA applauds the efforts of the CRC Development Group in their work to develop an unleaded aviation fuel and we look forward to working with you to developing solutions in order to reduce alkyl lead emissions.

Implementation of the Strategy will take place largely in workgroups organized around the various substances, including alkyl lead. The U.S. EPA has developed an initial draft of an alkyl lead workplan which will be revised and refined when the workgroup is fully formed with all interested stakeholders.

More information on the Binational Strategy, including an initial draft of the alkyl lead workplan, can be found on the Binational Toxics Strategy page on the Internet at http://www.epa.gov.bns

If you are interested in participating on the alkyl lead subgroup, please contact Mr. Ed Klappenbach of the U.S. EPA's Great Lakes National Program Office at 312-353-1378, klappenbach.edward@epamail.epa.gov.

Aviation Engine Emissions and The International Civil Aviation Organization Emissions Working Group

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CANADA

My presentation this afternoon will describe what the International Civil Aviation Organization (ICAO) is doing about controlling aircraft engine emissions. I was asked to do this because I am the Canadian member of the ICAO environmental committee and a member of the ICAO working group that addresses aircraft emissions problems. I am also the chairman of the emissions working group, but today I am only presenting a Canadian perspective on what is happening in ICAO; I am not speaking for ICAO.

(Slide 1. Outline)

I would first like to explain a little about ICAO and its role in environmental issues for those of you who are not familiar with this organization.

ICAO

ICAO is a UN agency which started with the signing of the Chicago convention on civil aviation in 1944. The signatories agreed on principles and arrangements to develop civil aviation in a safe and orderly manner. There are now about 186 signatories to the convention.

CAEP

The environmental issues in ICAO are handled by the Standing Committee on Aviation Environmental Protection (CAEP). This committee has 16 members, as well as observers from other countries, the European Union, the International Air Transport Association (IATA), the Airports Council International (ACI), the aerospace industry and environmental organizations. At a typical CAEP meeting there are usually more than 100 people.

CAEP is responsible for Annex 16 to the Chicago convention, usually referred to as ICAO Annex 16. This annex contains international standards and recommended practices for aviation. Volume one deals with Aircraft noise standards, and Volume 2 covers engine emissions standards. It is important to note that these are only recommended standards until they are adopted by countries, then they become regulations.

(Slide 2. CAEP)

CAEP has three working groups; one for aircraft noise, one for airport environmental issues, and one for engine emissions. Each working group includes delegates from 10-15 countries as well as advisors from industry. There is also an emissions planning group that was formed recently to address one specific emissions issue and a forecasting and economic analysis sub-group (FESG) which supports all of the working groups. Today I will talk about what is happening in the Emissions Working Group (Working Group 3) and in the Emissions Planning Group.

The problems being addressed by CAEP:

Aviation contributes to air pollution just like any other form of transportation that burns fossil fuels. The percentage of air pollution from aviation is small but air traffic is expected to double in the next 20 years. This is the main environmental problem from aviation and it will probably become worse once various agreements to limit CO_2 emissions come into effect. ICAO sets standards for the following pollutants from aircraft engines: soot, vented fuel, unburned hydrocarbons, carbon monoxide, and oxides of nitrogen (NO_x). In the case of the first two pollutants, standards apply to all gas turbine engines; for the other three, HC, CO and NO_x, the standards only apply to turbofan engines whose thrust is greater than 6,000 lbs. At this time, most of the efforts of CAEP are being directed towards reducing emissions of NO_x. This is based on concerns about NO_x being a precursor to ground level ozone, a radiative forcing gas in the troposphere and an ozone depleting substance in the stratosphere. I will deal with each of these problems separately.

At the most recent CAEP meeting, CAEP/3, there was a proposal for an increase in stringency for NO_x standard for aircraft engines. This proposal did not have the unanimous support of CAEP and was referred back to CAEP by the Council of ICAO. The Emissions Planning Group (EPG) was formed in June of this year and assigned the task of resolving this impasse. The EPG consists of a technical officer from ICAO secretariat and four CAEP members who were elected by their peers. The four CAEP members on the EPG are from The Kingdom of the Netherlands, the United Kingdom, the United States, and Canada. The EPG relies heavily on the CAEP emissions working group for technical information and the Forecasting and Economic analysis Sub-Group (FESG) for financial data. All recommendations for a change in the stringency of aircraft standards that are presented to CAEP are subjected to a cost benefit analysis so the FESG plays an important role in the decision making process. The emissions working group reviews the technical information and calculates the benefits, the FESG calculates (forecasts) the cost, and the EPG recommends action to CAEP based on this information.

Addressing the ground level ozone problem:

Studies prepared for CAEP/3 concluded that, despite the fact that aircraft emissions of NO_x were expected to double, they would still be small in comparison with land-side sources. We have been measuring the air quality in the vicinity of major Canadian airports and found that airports were less polluting than the surrounding areas. The only time the air pollution exceeded national air quality standards was when it was already above the standard when it reached the airport. This however was not considered to be justification for not taking action. Many CAEP members determined that this problem had to be addressed by increasing the stringency of the NO_x standard.

Radiative forcing:

Global climate continues to be a serious concern internationally and all sources of radiative forcing gasses, including those from aircraft need to be examined to determine if there is way of reducing their impact. Aircraft were targeted in the early discussions because they were considered to be the only direct source of NO_x in the upper atmosphere. Recent studies have shown that there are other sources. These include lightning, ground sources, and the stratosphere. The radiative forcing properties of NO_x are known to be greater that CO_2 so the emphasis has been placed on controlling NOx over CO_2. Recent information indicates that NO_x and CO_2 should be treated equally as far as radiative forcing is concerned because NO_x has a residency time of less than a month in the troposphere while CO_2 can last as long as 100 years. The EPG determined that the best course of action would be to pursue a solution that reduces the emissions of NO_x and CO_2 equally.

Stratospheric Ozone Depletion

Earlier research indicated that NO_x emissions from aircraft could decrease the ozone layer. The latest information indicated that this is true for super-sonic aircraft that operate higher in the stratosphere, but sub-sonic aircraft do not appear to deplete the ozone layer. One theory is that sub-sonic aircraft actually help the ozone layer because their NO_x emissions interfere with the CFCs that are known to reduce the ozone layer. Although concerns about stratospheric ozone depletion warranted an earlier increase in the NO_x standard using the precautionary principle, this was no longer the case.

What has ICAO done so far?

At the second meeting of CAEP, there was agreement to increase the stringency for NO_x by 20%. This was the precautionary measure that I mentioned earlier but it was also intended to address the concerns that many countries had with ground level ozone.

Several years ago ICAO adopted a resolution which set limits for an orderly retirement of older noisier jet aircraft. The phase-out of these Chapter 2 aircraft, referring to their ICAO noise standard, started in 1995 and will be complete in 2002. Not only will this measure improve noise levels in the vicinity of airports, it will also improve air quality because these older engines consume about 30% more fuel than the more modern aircraft.

It is important to note that aircraft engines are very efficient when compared to other engines. If they were not, airlines would end up carrying more fuel and fewer passengers and could not make a profit.

(Slide 3. Fleet Emissions)

(Slide 4. Fuel Consumption)

The technical dilemma:

Once again there is a proposal to reduce the NO_x emissions from aircraft engines for the reasons stated earlier. The problem is that in the design of aircraft gas turbine engines there is a direct relationship between the emissions of CO_2 and those of NO_x. To achieve better efficiency which is essential if airlines are going to make a profit, the engine manufacturer's have increased the temperature and pressure in the engine's combustors. This created an ideal environment for the production of NO_x. Unless there is also a change in technology to prevent NO_x levels from increasing, efforts to reduce fuel consumption tend to increase the amount of NO_x emitted per unit of fuel consumed. The problem is that today's technology is just about at the limit for the most modern engines. We are running out of technical solutions to this problem.

(Slide 5. NO_x vs. CO_2)

From an engine manufacturer's point of view, a new engine has to be designed to meet the regulation with plenty to spare because they prefer to develop new engines from existing ones. This is the most cost-effective approach for the manufacturers. Normally derived engines are more powerful because of increased pressure in the combustor but the NO_x levels usually go up. This is referred to as a throttle push. The manufacturers have to design the initial engine to be well below the NO_x limit to be able to derive additional engines.

(Slide 6. Throttle push)

The dilemma is that, if we are concerned about global climate change and want to reduce emissions of CO_2 from aviation, we need to have higher pressure ratios in the combustors. If we allow this, there will be higher emissions of NO_x, or conversely, if we regulate the emissions of NO_x too much we could end up with engines that are less efficient than they could be and their CO_2 emissions could increase. We are not completely sure of where this cross over takes place because of the proprietary nature of engine design information. I asked all the major engine manufacturers in the world to provide me with the information that we needed to determine this point, assuming today's technology. Their response was that I was assuming that we had not already crossed this line.

This complicated matters for the EPG because the proposal at CAEP/3 was for 16% reduction in the NO_x standard, and several countries still wanted a reduction of at least 16%. Some felt that because ICAO does not set standards for CO_2 but it does for NO_x, it should recommend a new NO_x standard.

The proposed solution:

The problem of ground level ozone resulting from aircraft engine exhaust was a sufficiently large concern to enough CAEP members to justify an increase in the NO_x stringency.

The global concerns about climate change indicated a need to reduce the emissions of both CO_2 and NO_x. The problem with reducing the NO_x standard, as discussed, is that it could lead to an increase in fuel consumption and therefore an increase in CO_2 emissions that could offset any benefits of the NO_x reduction. To avoid this problem, we proposed a very modest NO_x stringency increase that would address the ground level ozone problem without increasing our concerns about global climate change. Until there is a better way of making aircraft engines, i.e., a new technology that will break the NO_x vs. CO_2 impasse, there is no benefit in increasing the NO_x standard any further.

(Slide 7: NO_x proposal.)

This proposal represents a compromise between what many countries wanted to see for an increase in NO_x stringency and concerns that an increase that is too large could result in an increase of CO_2 emissions.

The EPG also suggested that ICAO rethink its procedure for emissions certification. The current system of measuring grams of pollutant per kilogram of fuel burned does not consider engine efficiency. For example, the old inefficient engines that powered the first jet aircraft have NO_x levels that would meet our latest standards. This is because these old engines had very low pressure ratios and therefore did not emit large quantities of NO_x per unit of fuel. However, they burned more fuel per passenger mile and the total NO_x emissions were higher than from today's engines. To avoid this type of problem, we proposed that future standards look at the pollution per passenger mile, or some other system which does consider the efficiency of the engine and of the aircraft itself.

Improved Operational Procedures:

At this time, the best way of reducing emissions is to reduce the amount of fuel that aircraft burn. Working Group 3 has been examining a number of ways of reducing fuel consumption through better operational measures. If we can reduce fuel consumption, we can reduce emissions of all pollutants. Many of these procedures are already in use by several airlines but are not universal. Some measures which we refer to as best industry practices include: (Slide 8. Best industry practices)

- single-engine taxi
- reduce speed at cruise
- better trimming
- not tankering fuel
- delay gear and flap extension
- flying at the optimum altitude for the aircraft

Some measures that are being considered by ICAO to improve air traffic control procedures include: (Slide 9. Operational measures)

- reduced separation
- improved communications
- flight management system (FMS) approaches
- point to point navigation

These are not new ideas; they have been discussed for several years because they will improve efficiency and save the airlines money in reduced fuel consumption. We are adding another reason for pursuing these measures, the potential to reduce pollution from aircraft and reduce aviation's contribution to global climate change. We hope that this provides the necessary incentive to proceed with these measures. A recent study indicates that fuel savings of up to 12% can be achieved by implementing all of these measures.

Alternate fuels:

I felt I should say something about what ICAO is doing regarding alternate fuels for jet aircraft since this is the main topic of this conference. Several years ago, some members of the emissions working group recognized the importance of exploring the option of alternate fuels. The leading option was to find a fuel that was derived from CO_2 in the air, or essentially oil from something that was grown or farmed. A number of vegetable oils were tested but none could come near the properties of kerosene so the idea was put aside for now. Efforts to use natural gas or hydrogen have also been shelved mainly because of the weight of the fuel tanks that would be required to ensure safety.

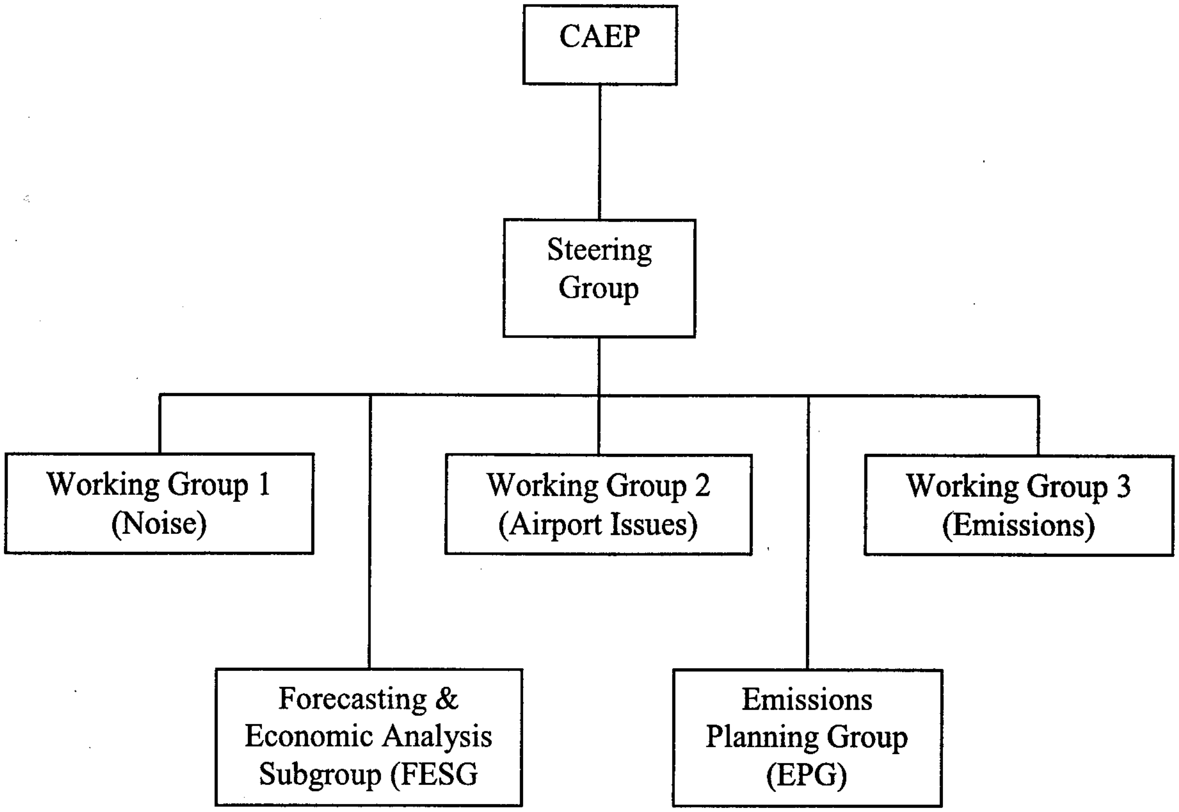
Future Action:

There are research programs sponsored by NASA to develop aircraft engines that reduce NO_x emissions by more than 50% and also have better fuel efficiency. The prospects are optimistic but until the designs are proven, the standards for aircraft engines will probably not change again because of concerns about emissions of CO_2. The major problem facing aviation and the environment is global climate change. The commitments to reduce CO_2 could have an impact on international aviation. The improvements in operational measures that we are exploring will probably meet the short term targets but the projected growth in aviation could cause problems which we will have to address very soon.

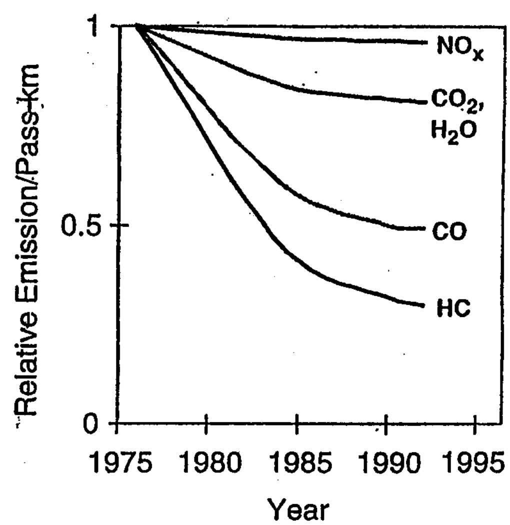
Slide 1. Outline

1. **ICAO Organization and brief history.**
2. **The ICAO emissions working group**
3. **Problems facing aviation and the environment**
4. **Main tasks of the working group**
5. **Recent progress**

Slide 2. CAEP



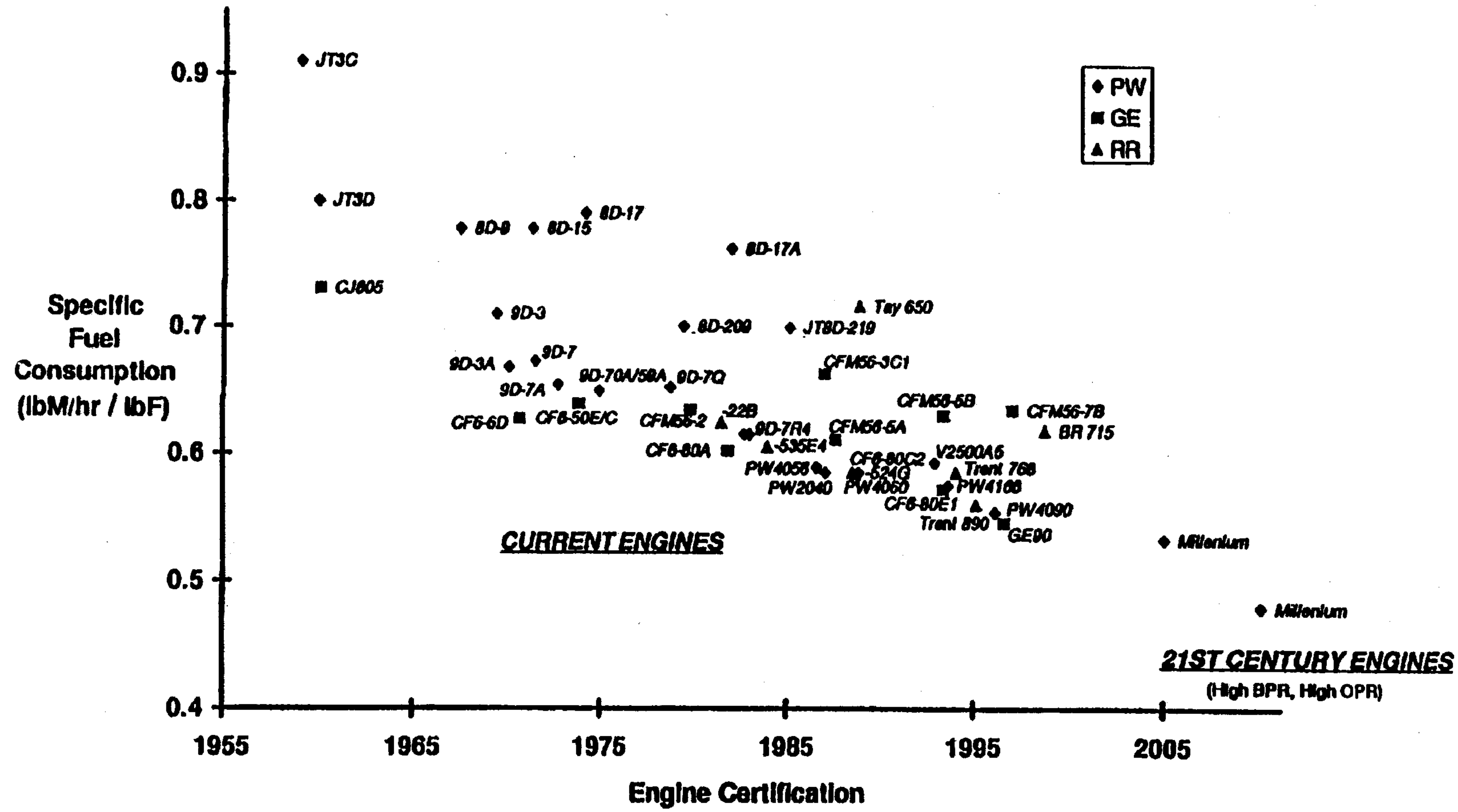
Slide 3. FLEET EMISSIONS



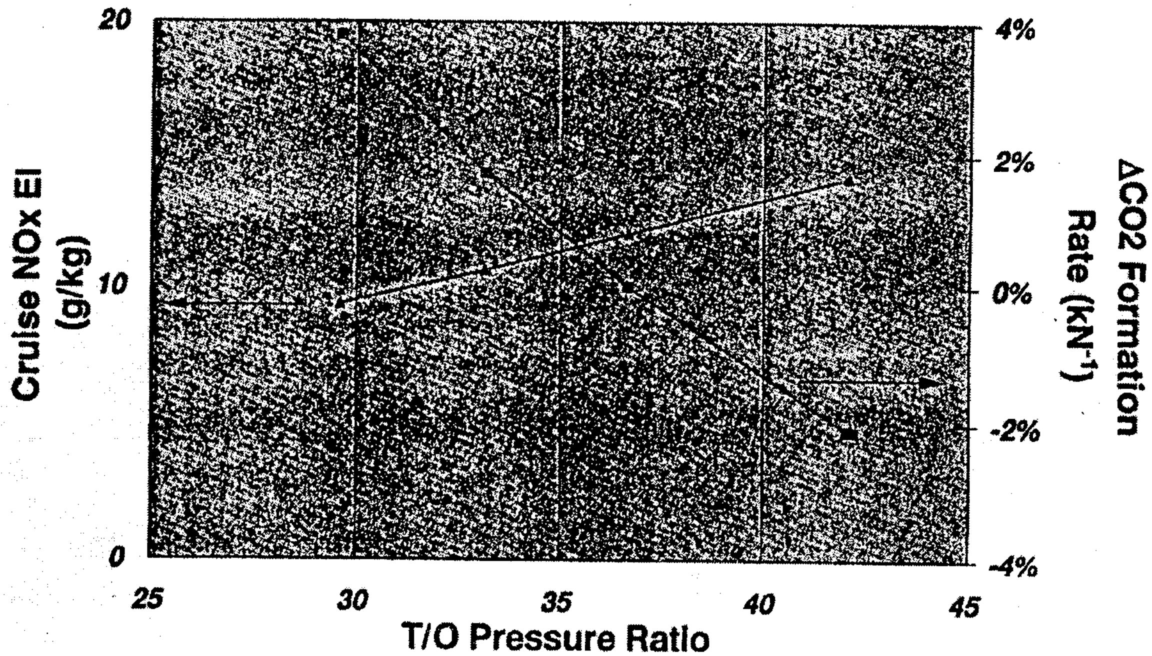
Source: Boeing 1996 Airline Environmental Symposium, September 4-6, 1996

Slide 4. ***FUEL CONSUMPTION PROGRESS***

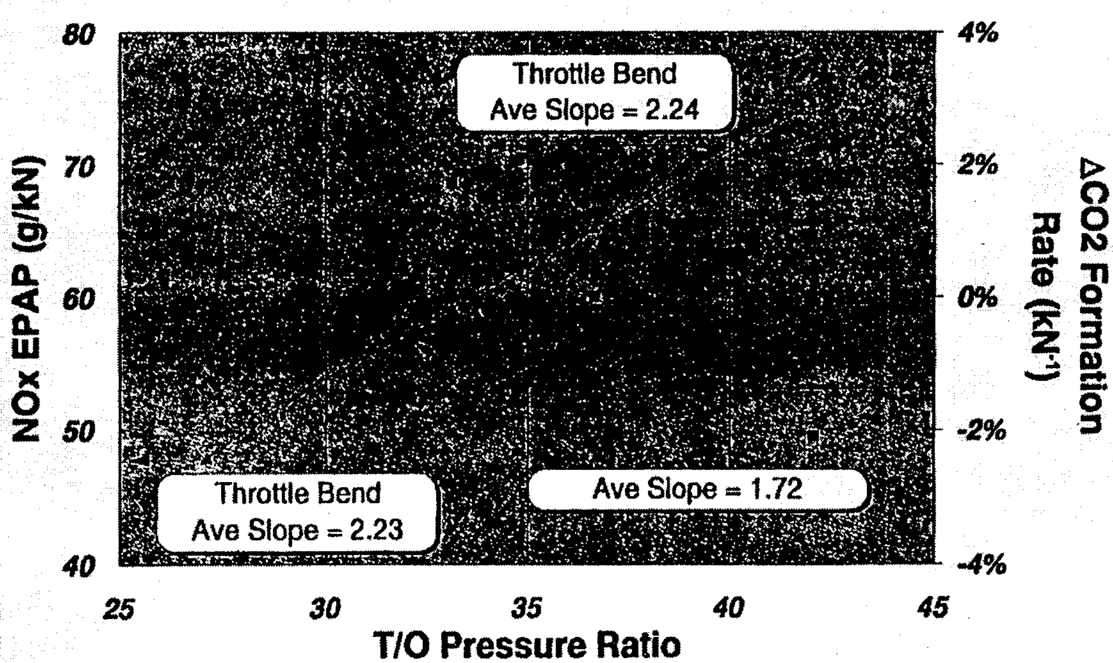
Further Reductions Theoretically Achievable



Slide 5. NO_x CO_2 Trade

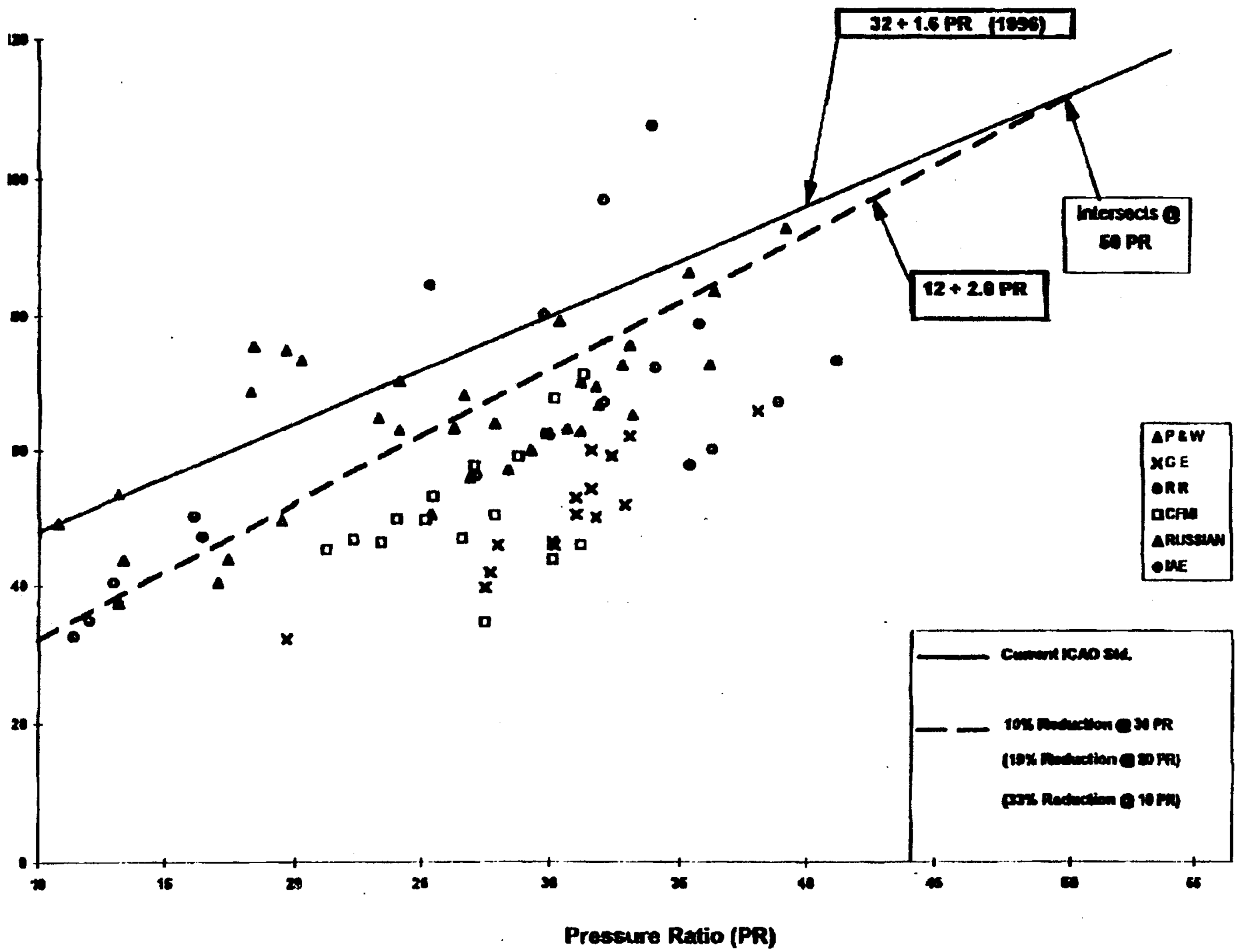


Slide 6. NO_x CO_2 Trade



OTTA-NOx3A.xls

Slide 7. CHARCTERISTIC NO_x OF ENGINES IN SERVICE IN THE 1950's



Slide 8. BEST INDUSTRY PRACTICES

- **single-engine taxi**
- **reduce speed at cruise**
- **better trimming**
- **not tankering fuel**
- **delay gear and flap extension**
- **flying at the optimum altitude for the aircraft**

Slide 9. IMPROVE AIR TRAFFIC CONTROL PROCEDURES

- **reduced separation**
- **improved communications**
- **flight management system (FMS) approaches**
- **point to point navigation**

A Comparison of Exhaust Emissions in Aircraft Piston Engines

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ABSTRACT

This paper compares the level of exhaust emissions from an aircraft piston engine when operated on neet gasolines and gasolines that contain ethers. The results presented were obtained with blends of gasoline and methyl-tertiary-butyl ether but they can be generalized for most oxygenated fuels. The paper also includes a discussion of concerns with evaporative emissions when using alcohol gasoline blends, and techniques for recovery (improved specific fuel consumption).

TEST METHODS

Engine Operations: The data[1] contained in this report was obtained using a Lycoming IO-320 engine. This is a normally aspirated piston engine with no emission controls and it is typical of general aviation practice. The fuel system was not modified from its original settings.

The test fuel consisted of an unleaded motor gasoline with a motor octane number of 89. This octane rating was sufficient to achieve knock free operation of this engine. The test fuel was blended with methyl-tertiary-butyl ether (MTBE) on a weight basis to achieve concentrations up to 30%, in 5% increments. The test sequence in Table 1 was repeated for each blend and multiple runs were made to minimize the effects of ambient conditions.

Data were collected at five power settings representing a typical flight profile. The power settings included taxi, takeoff, climb, cruise, and approach. At taxi, takeoff, climb, and approach power settings, the mixture control was initially left in the full rich position (this is typical of normal operations). After data were obtained at equivalent fuel flows using both fuels, the base fuel was selected and the fuel-to-air ratio was adjusted to achieve an equivalent fuel-to-air ratio. At the cruise setting, the power was set using the blended fuel and the mixture was leaned to peak exhaust gas temperature (EGT). After collecting emissions data, the base fuel was selected and data were collected at both the equivalent fuel flow and the equivalent fuel-to-air ratio settings.

The data were averaged without taking into consideration the relative amount of time one would normally expect to spend operating the aircraft at those power settings. As such, the exhaust emissions are higher than what one would normally obtain when conducting a time-weighted

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[1] This data was originally presented in *Ongoing Studies in Unleaded Aviation Gasoline*, David H. Atwood, Augusto Ferrara, and Kenneth J. Knopp, pp. 203 to 217, Proceedings of the 1994 AIAA/FAA Joint Symposium on General Aviation Systems, DOT/FAA/CT-94/63, May 24-25, 1994, Mississippi State University, Starkville, Mississippi.

average, since the majority of the flight cycle takes place in the cruise configuration where the fuel-to-air ratio is optimized for efficiency.

Table 1. Emission Profile

Power Setting	Test Fuel	Manifold Pressure (in Hg)	RPM	Mixture Setting
Taxi	Base	15	1200	Full Rich
	Blend	15	1200	Full Rich
	Base	15	1200	Equivalent Fuel-to-Air Ratio
Takeoff	Base	Full Throttle	2700	Full Rich
	Blend	Full Throttle	2700	Full Rich
	Base	Full Throttle	2700	Equivalent Fuel-to-Air Ratio
Climb	Base	25	2500	Full Rich
	Blend	25	2500	Full Rich
	Base	25	2500	Equivalent Fuel-to-Air Ratio
Cruise	Blend	23	2300	Lean to Peak EGT
	Base	23	2300	Equivalent Fuel Flow
	Base	23	2300	Equivalent Fuel-to-Air Ratio
Approach	Base	19	2000	Full Rich
	Blend	19	2000	Full Rich
	Base	19	2000	Equivalent Fuel-to-Air Ratio
Taxi in	Base	15	1200	Full Rich
	Blend	15	1200	Full Rich
	Base	15	1200	Equivalent Fuel-to-Air Ratio

In reviewing Table 1, bear in mind that the blends will have a lower energy density than the base fuel. When leaning to peak EGT, the leaning operation was first achieved on the blend so there would be no operations lean of peak EGT. The resulting mixture, when operating at equivalent fuel flows on the base fuel at the cruise power setting is roughly equivalent to operating at best power. A best power reading was not obtained with the blends.

Emissions Data: The following exhaust emissions were obtained using calibrated analyzers: total hydrocarbons (THC), carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and oxides of nitrogen (NO_x). Since the engine has no exhaust emission controls, the data will show substantially higher emission levels than are common for automobile engines.

RESULTS

The data are presented in two comparisons. Table 2 compares the exhaust emissions at equivalent fuel flows. This represents the anticipated level of emissions if no changes are made to the aircraft fuel system and the pilot uses the same technique. As expected, the THC and CO emissions decreased about 25% on average and the NO_x emissions increased about 40%. In addition, the power output increased 3%. The increase in power is a consequence of the leaner fuel-to-air ratios that result when the blends are used.

Table 2. Average Exhaust Emissions at Equivalent Fuel Flows

MTBE Concentration (% w/w)	Corrected Power (Hp)	Fuel Flow (lbm/hr)	THC (ppm)	CO (%)	NOx (ppm)
0 (Base)	71.6	45.2	692	8.99	259
5	72.7	45.0	622	8.80	235
10	71.9	45.5	689	8.50	284
15	73.0	45.6	612	8.71	236
20	72.5	44.9	557	7.29	465
25	73.2	44.9	588	7.72	374
30	73.6	44.1	499	6.71	363

Table 3 contains the results for when the engine is operated at equivalent fuel-to-air ratios. This data represent an attempt to show the difference one would expect if the fuel system is modified to compensate for the lower energy density of the blends.

Table 3. Average Exhaust Emissions at Equivalent Fuel-to-Air Ratios

MTBE Concentration (% w/w)	Corrected Power (Hp)	Fuel Flow (lbm/hr)	THC (ppm)	CO (%)	NOx (ppm)
0 (Base)	72.7	44.7	611	8.71	321
5	72.7	45.0	622	8.80	235
0 (Base)	71.2	45.2	719	8.78	286
10	71.9	45.5	689	8.50	284
0 (Base)	72.4	44.9	654	9.40	227
15	73.0	45.6	612	8.71	236
0 (Base)	72.0	44.1	622	7.96	430
20	72.5	44.9	557	7.29	464
0 (Base)	72.3	44.1	651	8.62	368
25	73.2	44.9	588	7.72	374
0 (Base)	72.3	43.1	595	7.88	374
30	73.8	44.1	499	6.71	363

The energy densities of the blends were based on calculated energy content using the values obtained from the literature for MTBE and the measured value for the base fuel. These calculations used a single point measurement for the energy content of the base fuel and this introduces errors. The resulting data may be biased by those errors. Table 3 is intended to show trends and not absolute values for the exhaust emissions.

Before reviewing the table, it is important to understand the concept of equivalent fuel-to-air ratio. The equivalent fuel-to-air ratio is represented by the equation:

$$\Phi = \frac{\text{Actual fuel/air ratio}}{\text{Stoichiometric fuel/air ratio}}$$

As the energy density of the fuel decreases, more fuel is required to achieve a stoichiometric fuel-to-air ratio. Hence, more fuel is required to keep Φ at the same value and the actual fuel-to-air ratio increases. In short, the higher the oxygenate concentration, the more fuel required to keep the same equivalent fuel-to-air ratio.

On the average, the THC emissions decreased about 8% and the CO decreased about 4% when operating on the blends at equivalent fuel-to-air ratios. This reduction is consistent with other data in the literature. The NO_x increased about 26%, which was greater than expected. A review of the data showed a large amount of scatter when attempting to lean the mixture to equivalent fuel-to-air ratios. This is especially true when looking at the NO_x data because small changes in the fuel-to-air ratio resulted in large changes in the NO_x emissions. The data at the 5% concentration was collected first and the operator's technique improved substantially during later tests. If the data are viewed without the 5% figures, the THC and CO both decreased about 9% and the NO_x increased about 3%. Once again these figures are based on the calculated energy density and are not absolute values.

The average power during these runs increases almost 2% when compared with the base fuel. This increase can be explained in part by the higher latent heat of vaporization of the oxygenated fuels and the need to burn more fuel when using the oxygenated fuels. Both have the effect of cooling the charge entering the combustion chamber, resulting in a higher effective compression ratio and greater power.

DISCUSSION

In addition to the exhaust emissions, there is strong concern about evaporative emissions. Unlike modern automobiles, the fuel tank in the aircraft is not a closed system. The aircraft tanks are vented to the atmosphere to prevent large pressure differentials as the aircraft climbs, which could cause structural damage. As a consequence, the fuel in the tank constantly evaporates as the aircraft sits on the ground. In this situation, the use of ethers constitutes a significant improvement over the use of alcohols, when blended with gasolines.

While the alcohols raise the Reid Vapor Pressure less than 1 psi, they result in much greater evaporative emissions. In addition, alcohols will tend to absorb water vapor and they can settle out of the fuel as the aircraft climbs to higher and colder altitudes. In contrast, the ethers reduce the RVP and they do not exacerbate the evaporative emissions.

During the testing, it was noted that the blended fuels have a flatter EGT curve and they could be used to obtain smooth operations at leaner fuel-to-air ratios than the base gasoline. The flatness of the EGT curve contributed to the difficulties experienced when leaning the mixture and it contributed to the data scatter.

The ability to operate at leaner fuel-to-air ratios can be exploited to compensate for the decreased energy density of the oxygenated blends. The engine can be operated at much leaner mixtures resulting in better specific fuel consumption though at lower power output. Increasing the manifold pressure can result in the same power output at slightly better fuel consumption rates. (Running at wide-open throttle is the most efficient mode for spark ignition, piston engines due to reduced pumping losses.) One cannot expect to achieve greater range at the same power output when using any oxygenated fuel, however. Likewise, reports of greater fuel efficiency at altitude are often the result of poor technique rather than real gains.

Aircraft piston engines typically use mixture enrichment to suppress engine knock (detonation) during takeoff and climb. As such, it is not reasonable to expect to use lean operations at these power settings without modifying the engine or changing operating conditions (for example, limiting manifold pressure). Also bear in mind that the takeoff and climb operations only represent a small portion of a typical flight profile, while cruise constitutes the bulk of the flight profile. These considerations will limit the amount of recovery one can expect to achieve while maintaining the same level of safety.

CONCLUSION

The use of ethers as blending agents with aviation gasoline will result in a small but significant reduction in hydrocarbon and carbon monoxide emissions. These emissions will be offset but an increase in NO_x emissions.

Remarkable Small Aircraft

Paul B. MacCready, Chairman
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Summary

Combining the lessons from bird and insect flight, the technological expertise of the model aircraft community, and the recent advances in GPS, microprocessors, sensors and servos, micro-engineering, and miniaturized video cameras permits tiny (under 50 gm) surveillance aircraft to exist at present. Smaller versions can be realistically contemplated.

Introductory Perspectives

Remote or autonomous control of aircraft is being accomplished with smaller and smaller devices that take advantage of advances in sensors, microprocessors, and controls. Consequently, aircraft that do not need to carry people or heavy loads of goods can now be tiny, with the smallness limited primarily by the propulsion power system and the dictates of the aerodynamics and mission requirements.

Because these small aircraft fall into the realm of natural fliers, there is renewed interest in learning from nature. Birds and flying insects have an evolutionary history of some 200 million years (also consider pterosaurs that coexisted with birds but became extinct 65 million years ago and bats that arrived just a few tens of millions of years ago). Obviously the rigors of achieving evolutionary success have adapted all these creatures to versatile and efficient flight. Birds were the main role models that stirred human's early ventures into flight. However, early in this century technology's capabilities in structural materials, fossil fuel power systems, and aerodynamic theory zoomed us quickly to our present magnificent aircraft. We no longer connected aviation to birds, except to worry about the danger of an aircraft jet engine being disabled by ingesting one.

Model aircraft enthusiasts, with their interest in bird-scale flight, often motivated by competition that emphasized vehicle efficiency, have greatly advanced associated technologies: airfoil characteristics at Reynolds Numbers below 50,000; tiny servos, gyros, and radio control systems; and power propulsion systems using batteries, CO_2, and gasoline or diesel fuels (plus glider launch by towing, elastic launches, or throwing). Add to the studies of natural flight and modelers' expertise the remarkable navigational capability now offered by GPS, and the rapidly-improving manufacturing capabilities of micro-engineering, and it becomes obvious that the time is ripe for tiny technological flying machines to emerge from their cocoons and be ready to perform missions of societal value.

But Also Consider

Before we get carried away with the concept of human technology beating nature, it is valuable to contemplate the Monarch butterfly. One subspecies navigates 3000 km from Toronto, Canada, to a particular grove of trees west of Mexico City. Its navigational prowess and goal-orientation is contained in a brain the size of the head of a pin, fashioned from the instructions of DNA. We have a way to go to match that, and if we succeed we have to start wondering if our technological developments may become our masters and/or survivors.

Figure 1 was prepared in 1996 to summarize how critical the present moment is in fashioning the future of life on earth. Having no insight about where we humans and natural creations are headed on this wonderful spaceship, I depicted a murky future of robotic and natural cockroaches – as a warning, not a prediction. The fact that many cockroaches can fly, and that we are trying to create technological equivalents, may put a higher priority on contemplating the message of figure 1.

Figure 2 emphasizes the figure 1 theme that this moment involves change unprecedented in civilization's history, and that humans now determine the future of life on earth (a responsibility we did not desire but which we have thrust upon ourselves). Three of the graphs show huge, human-caused growth/change; the fourth points out that the earth's size does not increase.

Figure 3 presents my personal overriding goal. The factors illuminated above make this goal hard to achieve, but emphasize that we simply must achieve it.

Although the natural fliers can teach us a lot about fundamentals of flight at small scale, there is no need to try to duplicate them exactly in order to fly. For example, for large aircraft, designers have found rotary motion of jet motors or propellers more practical than the reciprocating motion of wings. We travel on cars and bicycles, not mechanical 4-legged horses. Airliners do use flaps, controls, navigational sensors, and retractable landing gears as do birds.

Figure 4 shows the 5.5-m span flying replica "QN" pterodactyl that AeroVironment built to fly, for an IMAX film, like the original 11-m span creature that ruled the skies at the end of the Cretaceous period. Our temperamental, overweight adolescent crashed often (but never when the IMAX cameras were pointed at it). Fashioning the complicated sensors and autopilot and 13-muscle servo system so our model would fly like the real creature emphasized to us the elegant complexity of the active control nature's creatures (including humans) employ so effortlessly. Keeping this tailless creature flying was analogous to shooting an arrow with the feathered end forward. Most of nature's fliers, the insects as well as the vertebrates, operate with two wings, and the aerodynamic tail, if it exists, is only spread and activated during violent maneuvers. Active (and aeroelastic) control of the wings, in all twisting and bending modes, provides stability. It is unlikely that our tiny technological fliers will manipulate wings for propulsion. Stability, control, and propulsion will likely be more in line with conventional aircraft practice.

Examples

Figure 5 sets the stage with a summary of some of the more significant AV developments. One point it emphasizes is the connectedness of the technology of vehicles for land and air and their power systems that also relate to stationary energy devices. And overall there are environmental considerations.

Figure 6 starts at the large end of the size spectrum. This giant 30-m span, solar-powered Pathfinder is structurally so flexible that it can be considered analogous to a group of small aircraft flying close together. In concept it is like a group of geese in formation, each independent but having less induced drag because of combinations in effect representing a large span. Incidentally, it recently reached an altitude of 21800 m, higher than any propeller airplane had previously flown.

Figure 7, the AV Pointer hand-launched surveillance drone (2.75-m span, 3.0 kg for the version that incorporates GPS) probably has achieved more total flight hours than any other surveillance drones. Some of these planes have logged as many as 300 flights. Duration with rechargeable batteries for training is 20 minutes; with standard single-use lithium batteries for operational journeys, 60 minutes, while special high-power, single-use lithium batteries permitted 140 minutes.

Figure 8 shows a small, (46-cm span) aircraft, incorporating a video camera. The plane has a gross weight of 43 gms. In May 1997 it was flown successfully inside a small conference room, telemetering its vision to a projection video display.

Figure 9 is a larger (9l-cm span) vehicle that weighs only slightly more (59 gm). Flying as slowly as 8 km/hr it is even easier to operate in a confined space.

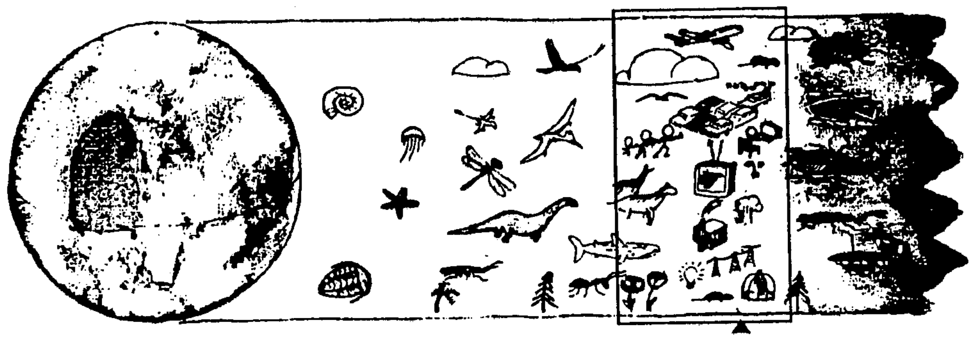
Figure 10 depicts a 15-cm-diameter flying wing. Such a vehicle weighing 42 gms, at this stage without video or GPS, recently flew 14 minutes at an average speed of 56 km/hr. Maximum speed was 69 km/hr. It employs a single-use lithium battery.

Figure 11 shows a complete field system for the tiny surveillance drone of Figure 7: carrying box, launcher, controller, and video integrated into the glasses. The vehicle can be seen in the box ready for elastic-assisted launch. The complete field system has been demonstrated (with a standard small video).

Figure 12. The next version will have all the electronics—GPS, video, sensors, servos, radio links, and power system integrated onto one circuit board. This transparent mockup shows the integration.

Figure 13. This 1-gm ornithopter follows as a conclusion to the presentation. It seems completely impractical, and yet, if I had not made a somewhat equivalent ornithopter in 1939 during a period of exploration of model aircraft, there would have been no Gossamer Condor in 1977 or the subsequent aircraft and ground vehicles shown on Figure 5.

Over billions of years
on a unique sphere
chance has painted a thin covering of life...
complex, improbable, wonderful, and fragile.

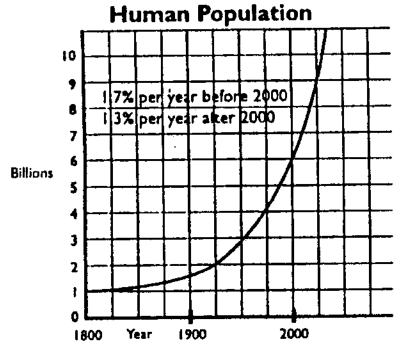


Suddenly we humans *(a recently arrived species no longer subject to the checks and balances inherent in nature).*
have grown in population, technology, and intelligence to
a position of terrible power:

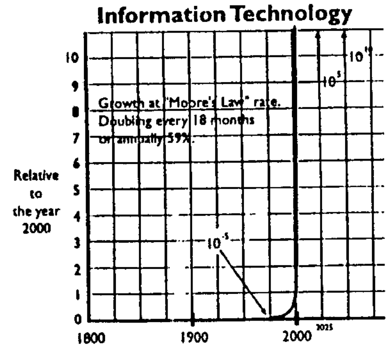
We now wield the paintbrush

Change

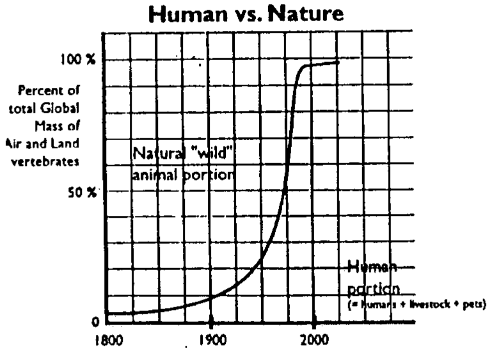
Human Population



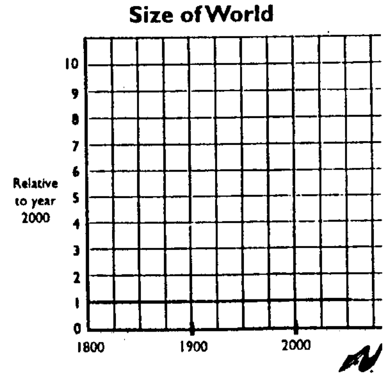
Information Technology



Human vs. Nature



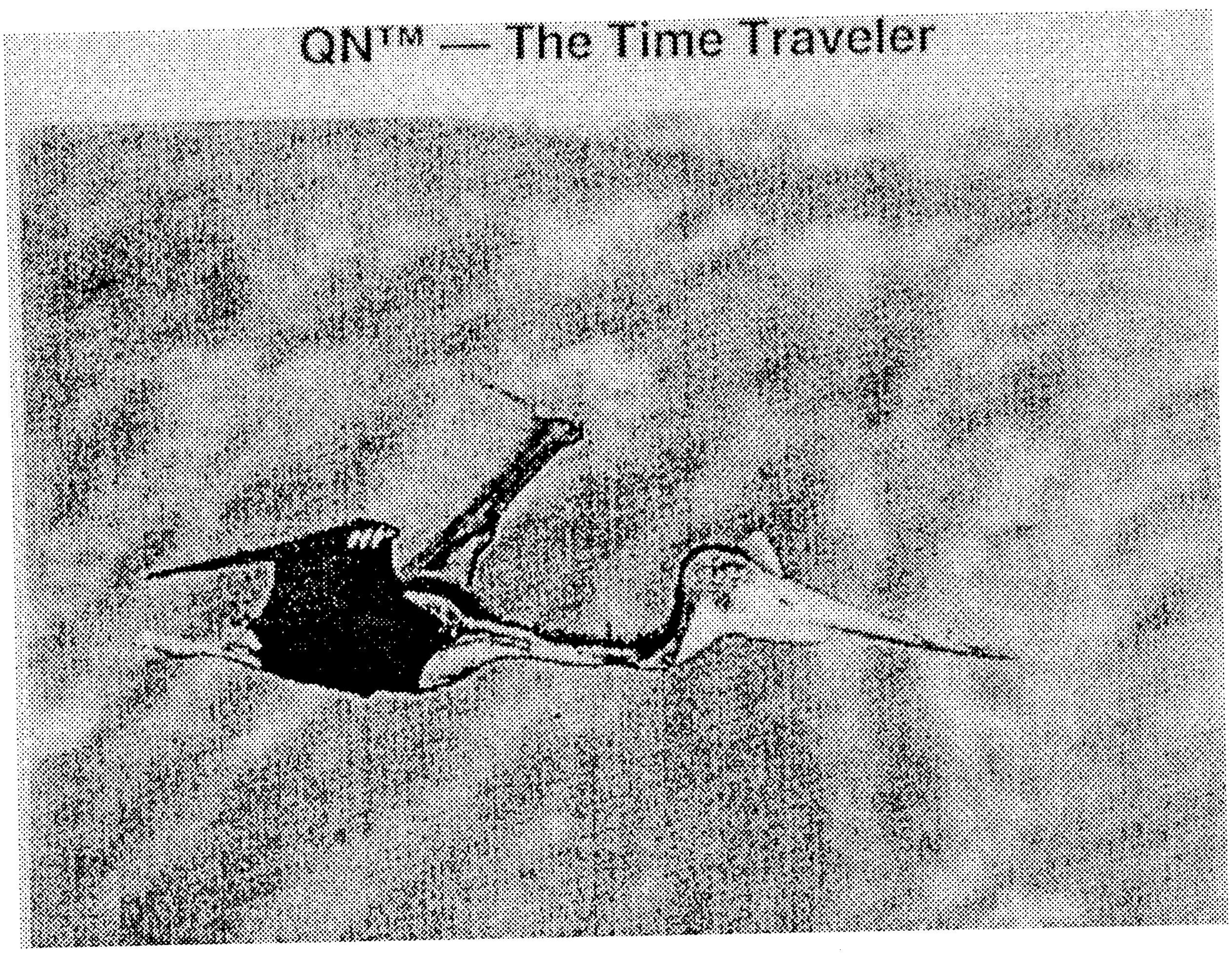
Size of World



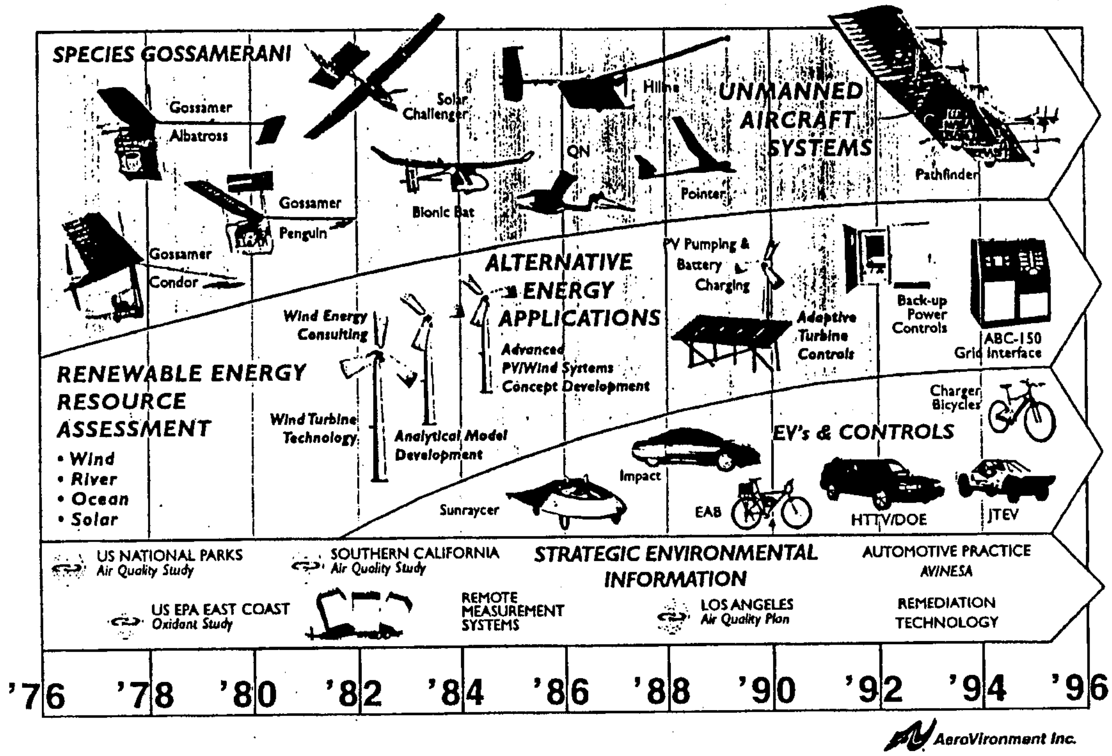
My Goal *(and perhaps yours)*

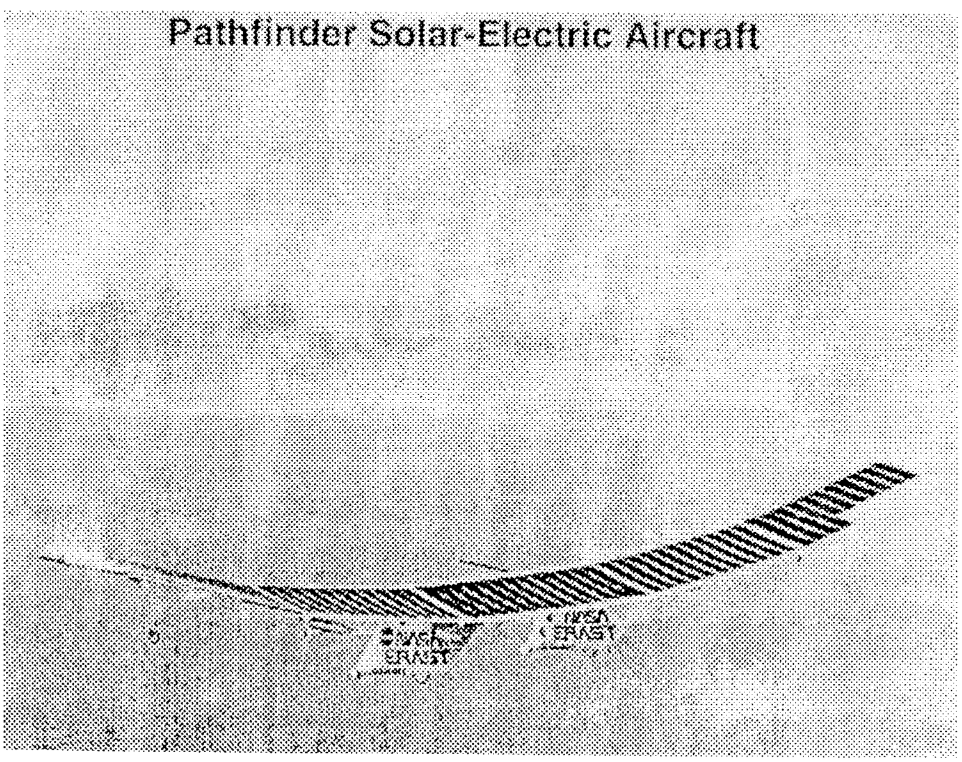
A desirable and sustainable world
when our children reach our present ages.

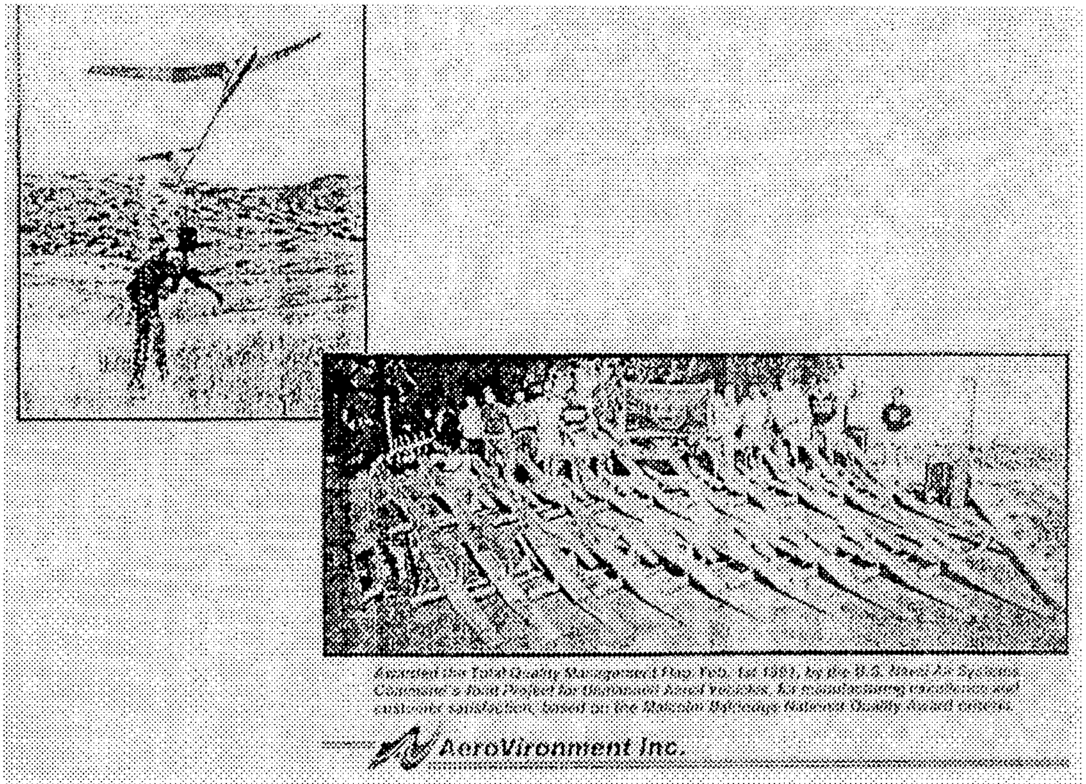
Paul MacCready



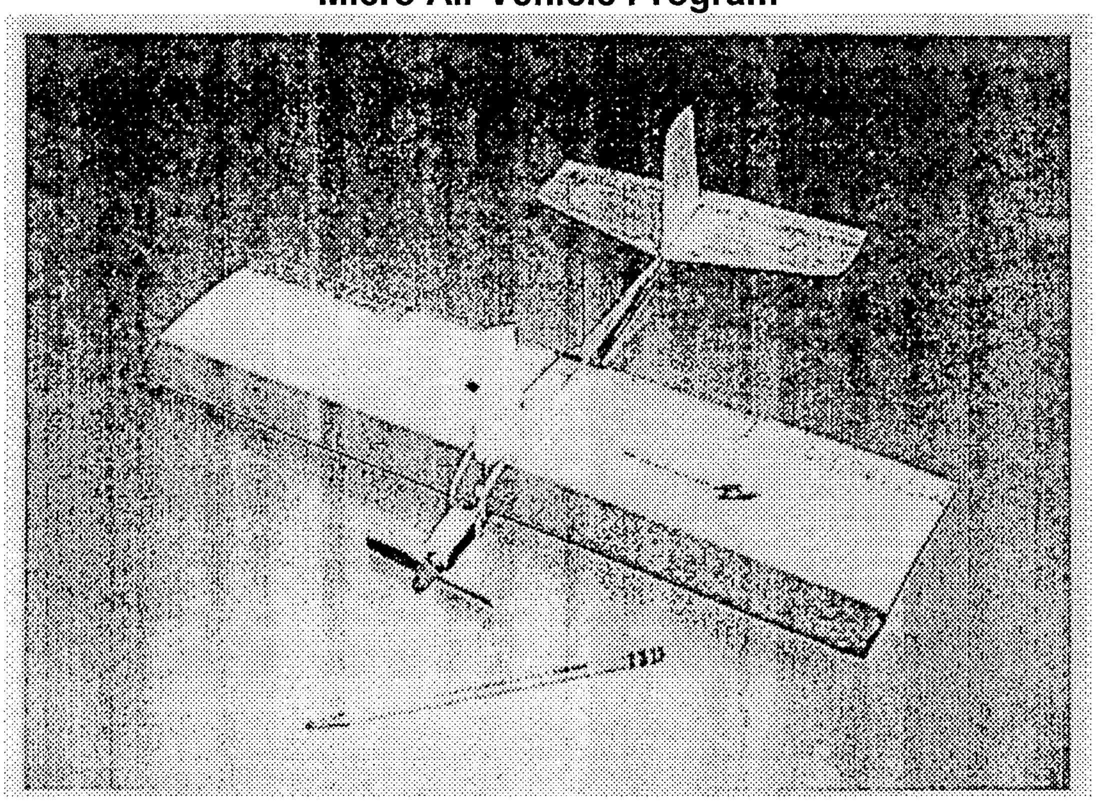
Clean Technology & System Innovation



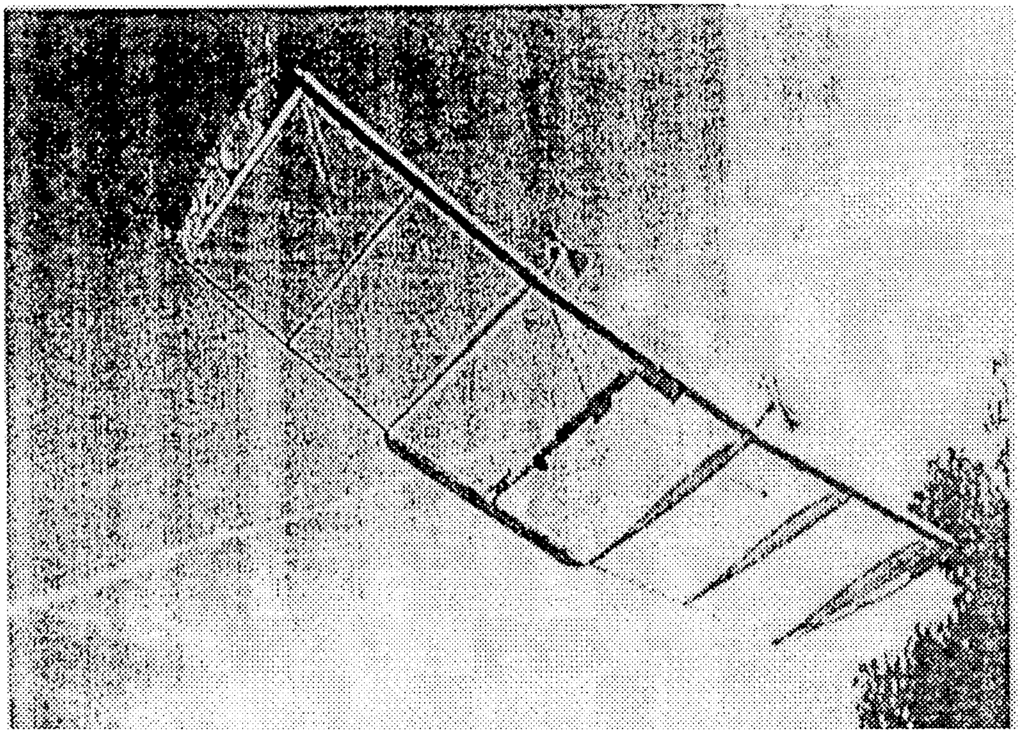




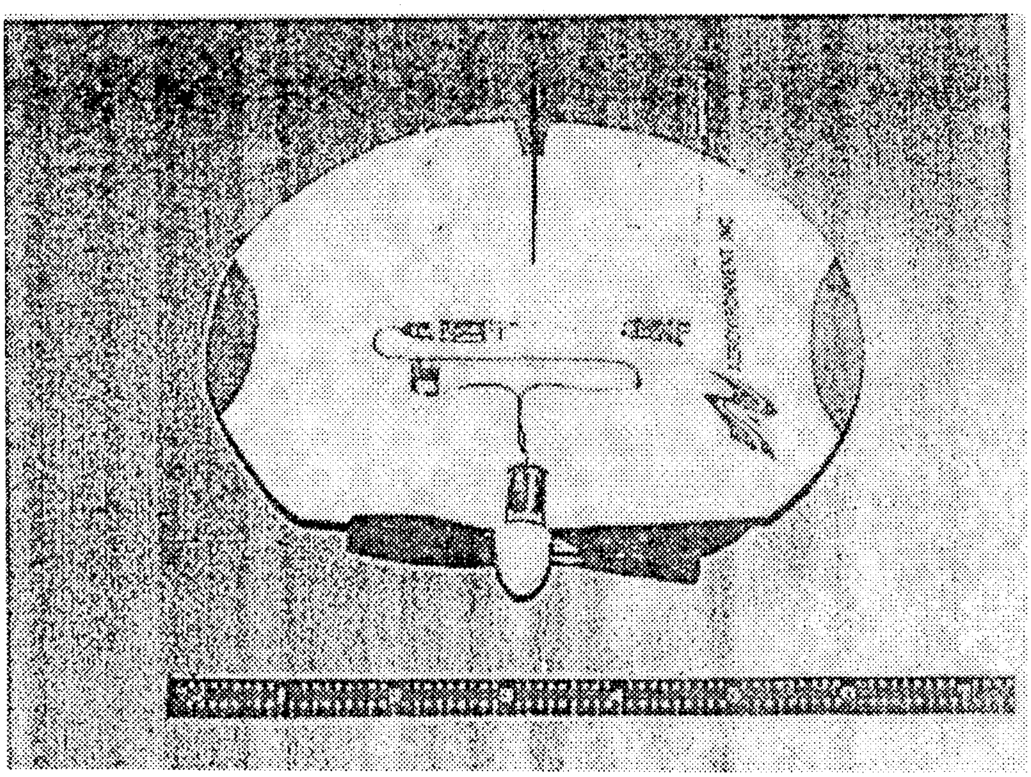
Micro Air Vehicle Program



Micro Air Vehicle Program

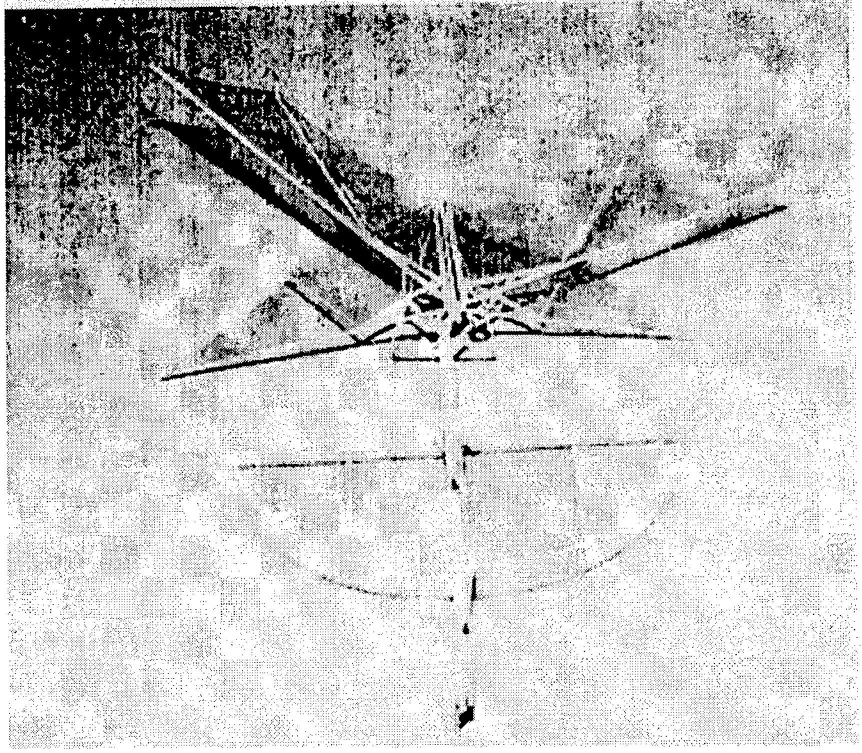


Micro Air Vehicle Program




Micro Air Vehicle Program

Micro Air Vehicle Program



Addendum: At the presentation, the 6 1/2-minute theme piece video "Doing More With Much Less" was shown. It puts into perspective various of the vehicles and concepts of the presentation, plus other vehicles, to illustrate that "impractical" vehicles can turn out to be valuable by pushing frontiers far beyond the expected and stimulating the development of societally valuable vehicles. As long as copies of the video last, they will be provided free to those requesting them. Contact Glynis Vatland at my office, phone: 626-357-9980, ext. 424; fax: 626-359-9628.

EVENING REMARKS, THURSDAY, NOVEMBER 6, 1997

William J. Wells, Vice President of Marketing
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Williamsburg, Virginia 23185

I would like to open with a quote from that noted philosopher, Kermit the Frog... "It's not easy being green."

It is especially hard when visiting my home state, Texas, the Western Mecca for fossil petroleum interests. Even harder to be green considering both my grandfathers moved to Goose Creek oil field and participated in the 1919 start-up of Humble Oil Refining, what is now the Exxon Baytown refinery, the world's single largest producer of gasoline. That is my heritage. It is now one that has served us well, fueled our industrial expansion into the mightiest nation on earth.

But the world moves on, and those who keenly observe this passage will do so to the benefit of themselves and their fellow humans. The transition from fossil to renewable energy, whether for aviation or ground transportation, is a good illustration. Predictably, those in the status quo willing to dig their heels in and do everything in their considerable power to forestall the inevitable. This happened last night on the ABC Evening News where Congressman Bill Archer was offered yet another platform to rail unopposed against what he honestly considers a failed ethanol program. Where does one begin to enumerate the benefits of this young program? Either in terms of net income to the U.S. Treasury, our foreign trade deficit, creation of new jobs to replace those lost to foreign oil and gasoline producers, cleaner air in RFG areas, proven greenhouse gas abatement - the list goes on and on - and I shall present hard numbers tomorrow morning. But consider this alone: we stand once again, on the brink of military action in the Persian Gulf. I think few would challenge the thesis that we find the action necessary primarily to protect our petroleum supply, now well over 50 percent of our needs. Senator Grassley recently informed Representative Archer that our activities in the Persian Gulf, not counting the war, was costing this nation $90 billion per year. The lowest estimate I have read is $35 billion per year.

There is a message here and it is not that some oil interests are wrong, it is that they have not heard the wake-up call. Actually, change is constant, as it must be, and there have been many wake-up calls: the Arab Oil Embargo, the Iranian Hostage Crisis, dwindling USA oil production and reserves, lead phase-down, catalytic converters, stratospheric ozone depletion, ground level ozone increases, dangerous levels of aromatics over California freeways, Clean Air Act amendments, gasoline reformulation, CAFE standards, the Persian Gulf conflict, the continuing Iraqi crisis, fuel contamination of California groundwater, and now the growing global awareness of increases of carbon dioxide levels in our atmosphere - which may lead to serious climatic consequences.

Some have heard these alarms and have told us so. British Petroleum and Royal Dutch Shell have stepped up and shown they understand the consequences of inaction regarding greenhouse gases, followed by less publicized statements from Mobil and Exxon. It is my fervent hope that the millennium will find a new spirit of cooperation between the fossil and renewable interests, but history predicts more storms on the horizon.

When I addressed this same conference two years ago, I suggested that each of you who cares about these important issues accept the mission of going out and communicating what you know to others, learning more yourself in the process. As you listen to the speakers at this excellent conference, I would like to ask that each of you think about your progress over the last two years and, more importantly, what your plans are for the important times ahead to make a difference. And believe me, each of you here can make a difference where you have passion and commitment in your beliefs. Thank you for your time and attention.

CURRENT RESEARCH ON PETROLEUM-BASED ALTERNATIVE AVIATION FUELS AND ENGINES

RON E. WILKINSON, TELEDYNE CONTINENTAL MOTORS (*FACILITATOR*)

GUS FERRARA, AIRCRAFT OWNERS AND PILOTS ASSOCIATION (AOPA)
CESAR GONZALEZ, CESSNA AIRCRAFT COMPANY
KENNETH KNOPP, FEDERAL AVIATION ADMINISTRATION
JOSEPH VALENTINE, TEXACO
LARS HJELMBERG, HJELMCO OIL
PAUL PENDLETON, FEDERAL AVIATION ADMINISTRATION

SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
NOVEMBER 6-8, 1997
BAYLOR UNIVERSITY

Petroleum-Based Alternative Aviation Fuels

Ron E. Wilkinson, Vice President for Engineering
Teledyne Continental Motors
PO Box 90 2000 Ninth Street
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Petroleum-Based Alternative Aviation Fuels

Second International Conference on Alternative Aviation Fuels

November 7, 1997

Panel Participants

• CRC Development Group	Ron Wilkinson
• AOPA	Gus Ferrara
• Cessna Aircraft Company	Cesar Gonzalez
• FAA	Ken Knopp
• Texaco	Joe Valentine
• Hjelmco Oil	Lars Hjelmberg

CRC Unleaded Avgas Development Group

Ron E. Wilkinson
Teledyne Continental Motors
Mobile, AL 36601

The unleaded AVGAS development Group is organized under the sponsorship of the Coordinating Research Council with the objective of conducting research and testing to facilitate development of the next generation aviation gasoline—an unleaded-high octane environmentally compatible cost-effective replacement for the current 100LL product. Complimenting the CRC Development Group is the CRC Aviation Engine Octane Rating Group which has the objective of determining the octane requirements of the current fleet.

Industry interest and participation in the Development Group has continued to grow since formation of the group. Active membership is currently at 37 with another 16 on the mailing list. Over 30 different organizations are presented including fuel producers, engine manufacturers, airframe manufacturers, component manufacturers, FAA, industry trade organizations, universities, consultants, and service organizations.

The CRC Development Group is currently focused on a research path which targets a test program involving motor octane (MON) screening of a 3D matrix of technically viable formulations. The current test plan provides for five separate laboratories to perform duplicate tests on 27 different formulations.

Octane requirements testing is continuing on representative engines with testing completed on several large bore engine models. Tests to date indicate octane requirements of 98 MON or greater depending on power setting and mixture. An industry standard procedure has been developed to support the octane requirements testing.

CRC UNLEADED AVGAS DEVELOPMENT GROUP

Second International Conference on Alternative Aviation Fuels

November 7, 1997

CRC Development Group

- Mission Statement
  - "organized under sponsorship of Coordinating Research Council"
  - "objective of conducting research and testing"
  - "facilitate development of next generation AVGAS"
  - "high-octane, unleaded, environmentally compatible, cost effective replacement"
  - "acts as a steering committee, providing oversight and direction"
  - "committed to an interactive collaborative process"
  - "ensuring availability of technical information for an aviation gasoline which meets requirements of both existing & future general aviation fleet"
  - "**Safety, reliable operation, & environmental awareness** are driving principles"

CRC Development Group Research Path

- Research currently focuses on MON screening of 3D matrix of technically viable formulations
  - Five separate labs to perform duplicate tests on 27 different formulations
  - Alkylate to be furnished by Company A
  - Oxygenate to be furnished by Company B
  - Metal additive to be furnished by Company C
  - Amine additive to be furnished by Company D
  - Samples (270) to be blended & furnished for test by Company D

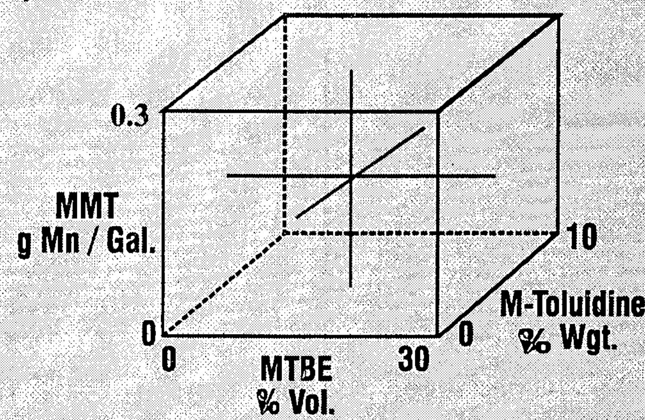
CRC Development Group Membership

- Over 30 different organizations, 53 individuals

  Airframe Manufacturers
  Engine Manufacturers
  Component Manufacturers
  Fuel Producers
  Universities
  Federal Aviation Administration
  Industry Trade Organizations
  AOPA, EAA, GAMA, NATA
  Service Companies
  Consultants

CRC Unleaded AVGAS Development Group
Cubic Test Matrix

Alkylate: Aviation



CRC Aviation Engine Octane Rating Group

- Complimentary to CRC Development Group
  - Membership common to both CRC groups
- Objective is to **determine the octane requirements of the fleet**
- Collaborative Effort
  - Engines furnished by the engine manufacturers
  - Test fuels provided by a fuel producer
  - Testing performed by the FAA Technical Center
- Accomplishments
  - Standard procedure developed
  - Representative engines rated

The Future for Aviation Fuels

Gus Ferrara
Aircraft Owners and Pilots Association, Inc.

The Future For Aviation Fuels

Gus Ferrara
Aircraft Owners & Pilots Association

Background

- 1990 Clean Air Act Amendments
  - First Evidence That Avgas Will Change
  - Removal of Lead
  - Possible Emissions Controls for Aircraft
  - Threat of Mandatory Reduction of Operations
- March 1991 AOPA Fuel Conference

Current Activity

- AOPA
  - Working with CRC to Develop an Unleaded Avgas
  - Working with CARB and EPA to Identify Safety as a Primary Concern
    - As Such, FAA has Precedence with Regard to Regulations
  - Supporting Funding for the FAA Research Program

Long Term Goals

- Safe Fuel
- Environmentally Sound
- Economically Viable Fuel
  - Cost of the Fuel
  - Certification Costs/Time Frame
  - Operating Costs/Engine Reliability
  - Can Be Used by the Entire Fleet
    - Distribution System

Cessna Future Fuels for General Aviation Support Program

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Wichita, KS 67277-7704

Cessna continues to collaborate with industry-wide efforts, while pursuing an independent fuels development support program.

Cessna continues to follow the guidelines developed during the ASTM future fuels for general aviation symposium held on 29 June 1988, in Baltimore, Maryland.

- Representatives from fuel producers, regulatory agencies, user organizations, and the general aviation industry participated in that event.

- During the symposium it was concluded that the short- and midterm future will remain heavily dependent on the continued availability of specialty high octane aviation gasolines.

- The long-term survival of the piston fleet will depend on the ability of the general aviation industry to adapt its piston products to use fuels available from large pools, such as motor gasolines and turbine fuels.

<u>Future General Aviation Fuels</u>

General aviation requires a relatively low volume but widespread fuels market.

⇨ Alternative low-volume specialty fuels of any type with limited sources and distribution networks will simply perpetuate the demonstrated vulnerable supply conditions of present aviation gasolines, e.g.,

  - 80/87 red
  - 100/130 green
  - 100LL blue

  Nevertheless, some short- and midterm specialty fuels may have to be developed for some existing engines.

⇨ For the long term, the general aviation fuels market will be better served by sharing other transportation fuels available worldwide in large pools.

Short- and Midterm Future General Aviation Fuels

High-Octane Unleaded Aviation Fuels.

- Cessna supports fuel producers research efforts to develop new technology unleaded high-octane fuels.
- While collaborating with industry-wide efforts, Cessna is also pursuing an independent program to insure the viability of almost half of the current worldwide piston fleet of aircraft bearing the Cessna logo.
- The initial phase of the program has been completed, with the development of an FAA approved, easy to use engine detonation indication system for on-board and laboratory applications.
- A device capable of precise blending of fuels for in-line control of octane ratings has also been developed.
- Future Cessna efforts will be oriented towards the establishment of engine and aircraft operational changes or modifications to adapt current piston products to unleaded fuels based on existing gasoline-ether blends technology.
- High-octane unleaded fuels, whether based on existing or new technologies, must provide the highest performance/cost ratio at current safety levels.
- Cessna considers ethyl tertiary butyl ether (ETBE) produced from ethanol as an indispensable constituent of future unleaded high-octane fuels.
- If the result is a specialty fuel, its long-term availability is questionable.

Long-Term Future General Aviation Fuels

Development of new piston products capable of using other transportation fuels available in large pools is the key to the long-term survival of this industry. Safety is the primary consideration in the development of new products.

- ⇨ Petroleum based fuels, and to a limited degree ethers, have a proven record of safety and reliability in aviation piston products.
- ⇨ Long-term storage stability, reliable cold weather and high-altitude restart characteristics, well established quality controls, and wide availability have contributed to the excellent safety record of petroleum based fuels.

Selection of future general aviation fuels must be based on conditions prevailing over the entire world, not just in the United States.

- ⇨ High mobility of general aviation airplanes must be complemented with worldwide readily available fuels.

High Specific Power Intermittent Combustion Engines.

- Turbine fuels of various types are available worldwide and thus represent a logical fuel of choice for high specific power aircraft piston engines.

- The success of aircraft turbine engines is due, in part, to their capacity to use a variety of turbine fuels with a wide range of characteristics.

- To accomplish this, the future multifuel piston engines must be insensitive to the octane or cetane characteristics of these turbine fuels.

- Multifuel piston engines are accessory intensive power plants not justifiable for low specific power applications.

- The multifuel combustion and compatible accessory technologies are available.

The 1991 annual book of standards reflected a revision to the ASTM D 1655 Aviation Turbine Fuels Specification that allowed, for the first time, the use of these fuels in other than turbine engines.

- The ASTM approval of the Cessna sponsored initiative to use turbine fuels in intermittent combustion engines was based on demonstrated technologies.

- The simple spark ignition engine with modest octane requirements remains as the logical choice for low specific power applications.

- Motor gasolines represent the largest pool of transportation fuels around the world, and a high percentage of these fuels have demonstrated their suitability on low specific power aircraft engine applications.

- The new grade 82 UL avgas initiative allows the tapping of the vast pool of unleaded motor gasolines at the refinery or at appropriate distribution system points. '

    - ⇨ Aliphatic ethers such as ETBE are allowed by the 82 UL specification, but alcohols and deposit control additives are excluded.

    - ⇨ Base unleaded motor gasolines must be subjected to complete screening qualification tests in conformance with grade 82 UL specification requirements.

- The 82 UL avgas initiative addresses the quality concerns of the industry and represents a cost-effective alternative for operators of future general aviation aircraft using low specific power piston engines.

<u>Environmental Considerations</u>

Significant progress has been attained in the reduction of propeller noise emissions and efforts continue in the reduction of exhaust noise.

Contemporary aircraft piston engines exhibit a limited potential for the adaptation of gaseous emissions control features.

- The grade 82 UL avgas initiative represents a significant first step in the development of lead-free aviation gasolines.

- Continuing efforts to develop unleaded high-octane aviation gasolines are a high priority general aviation industry commitment.

The design of advanced technology new piston engines must address important gaseous and noise emissions control requirements.

- Multifuel new high specific power engines capable of burning all types of aviation turbine fuels at modest compression ratios are considered by Cessna to offer optimum safety, fuel economy, and emissions control characteristics.

While addressing environmental concerns, we must put these issues in perspective.

- The total consumption of all types of gasolines in aviation is only 0.3% of the ground transportation consumption of motor gasolines.

- The general aviation industry is an active partner in the improvement and preservation of the environment but not at the expense of safety or the continued worldwide viability of the industry.

<u>Summary</u>

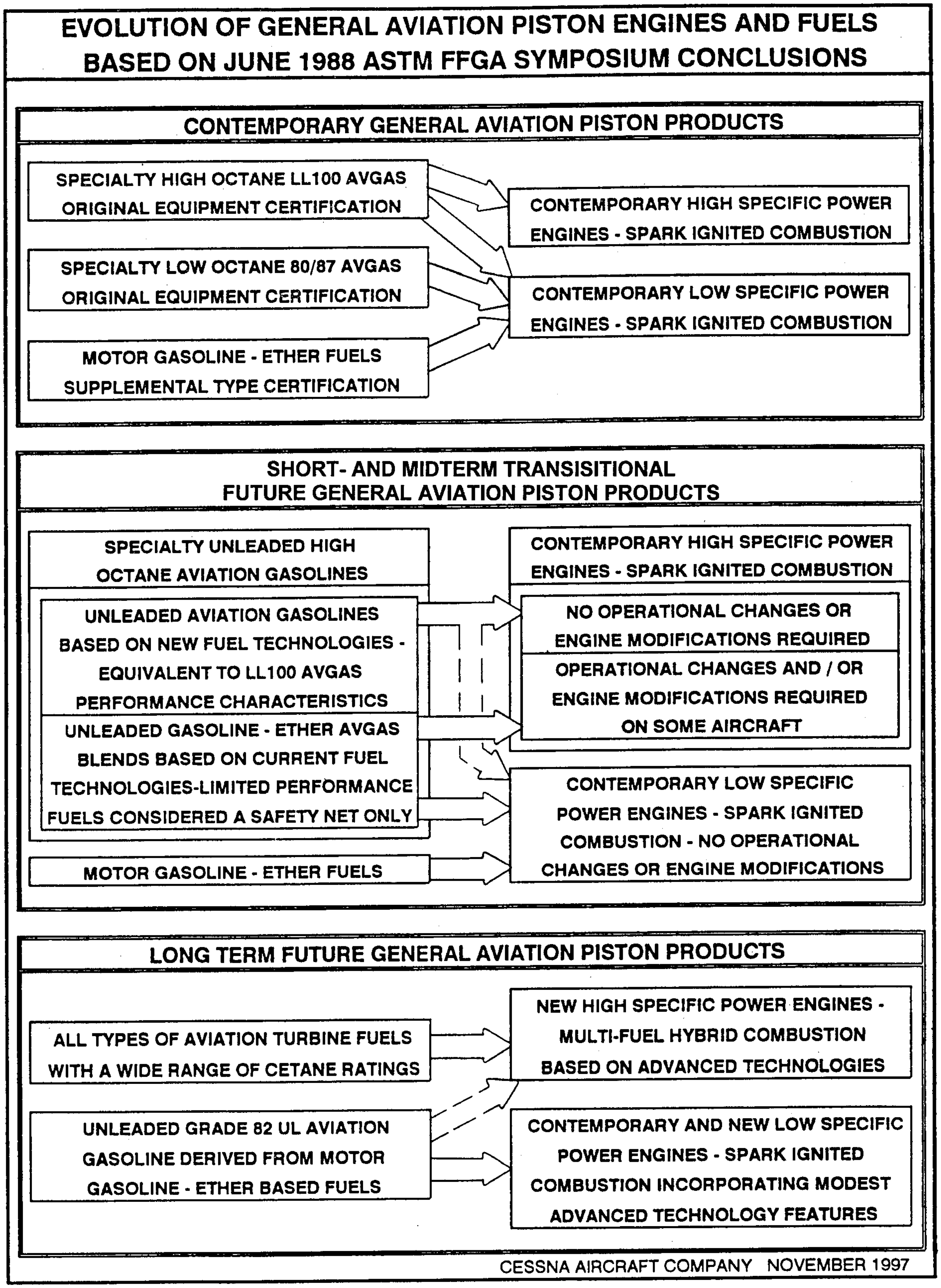
Insuring the continued viability of the present piston fleet is the first priority of the general aviation industry.

- The industry must support fuel producers research and validation efforts to develop affordable new technology unleaded high-octane fuels with operational characteristics similar to LL100 avgas.

- A safety net must be developed to provide means to adapt current piston airplanes to unleaded fuels based on existing gasoline-ethers technology.

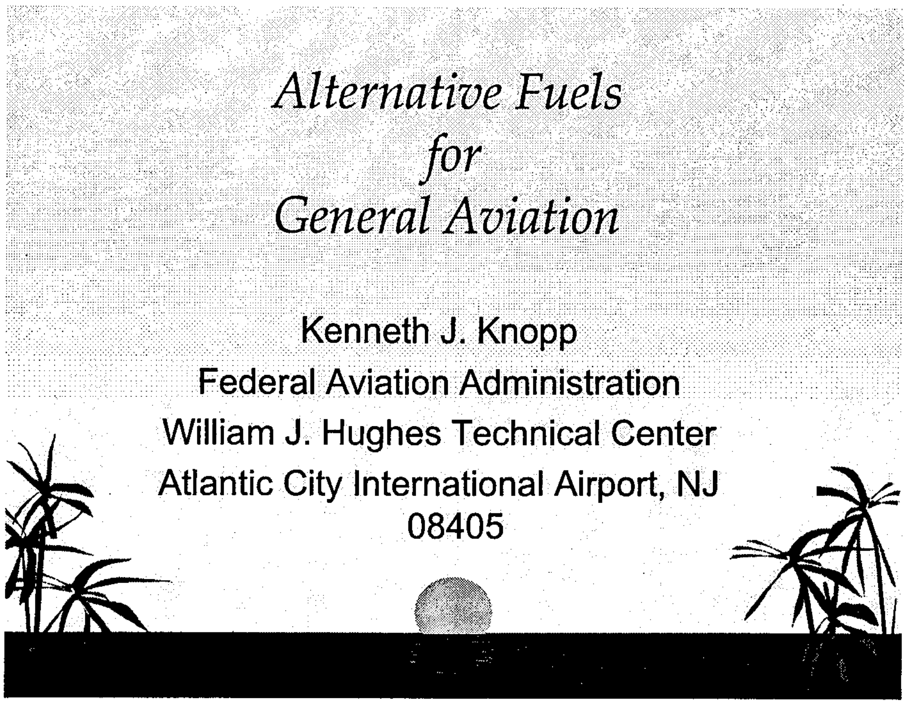
Committing our industry for a long-range future to a so called niche fuel market of specialty fuels will perpetuate the current general aviation dependence on vulnerable fuels of restricted availability.

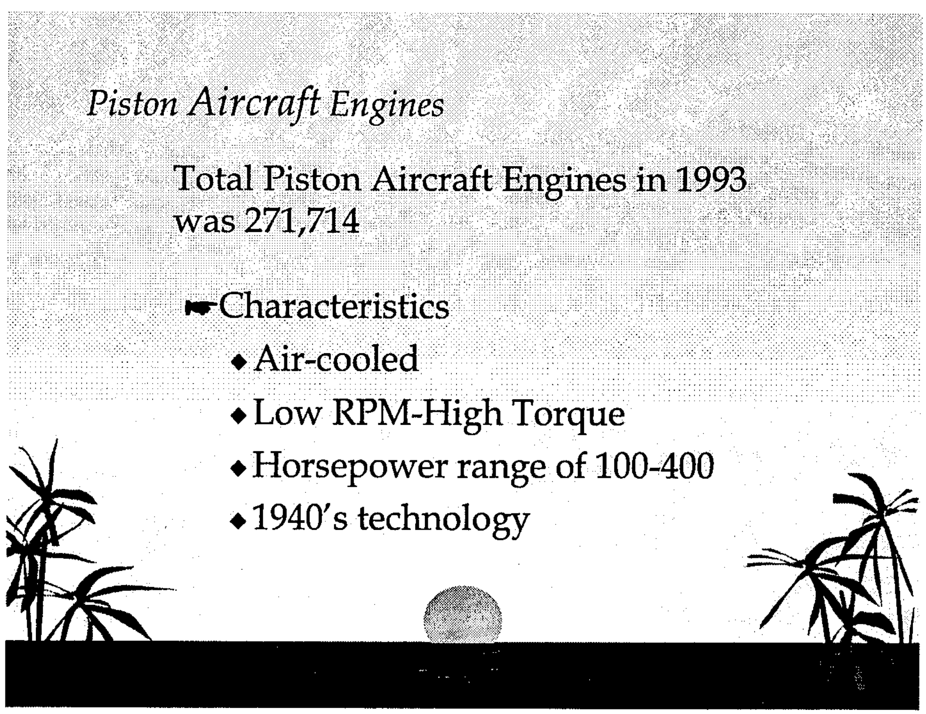
Concerns for the current piston fleet should not deter the development of advanced new piston products capable of using fuels available in large pools.


EVOLUTION OF GENERAL AVIATION PISTON ENGINES AND FUELS
BASED ON JUNE 1988 ASTM FFGA SYMPOSIUM CONCLUSIONS
CONTEMPORARY GENERAL AVIATION PISTON PRODUCTS
SPECIALTY HIGH OCTANE LL100 AVGAS ORIGINAL EQUIPMENT CERTIFICATION
SPECIALTY LOW OCTANE 80/87 AVGAS ORIGINAL EQUIPMENT CERTIFICATION
MOTOR GASOLINE - ETHER FUELS SUPPLEMENTAL TYPE CERTIFICATION
CONTEMPORARY HIGH SPECIFIC POWER ENGINES - SPARK IGNITED COMBUSTION
CONTEMPORARY LOW SPECIFIC POWER ENGINES - SPARK IGNITED COMBUSTION
SHORT- AND MIDTERM TRANSISITIONAL
FUTURE GENERAL AVIATION PISTON PRODUCTS
SPECIALTY UNLEADED HIGH OCTANE AVIATION GASOLINES
UNLEADED AVIATION GASOLINES BASED ON NEW FUEL TECHNOLOGIES - EQUIVALENT TO LL100 AVGAS PERFORMANCE CHARACTERISTICS
UNLEADED GASOLINE - ETHER AVGAS BLENDS BASED ON CURRENT FUEL TECHNOLOGIES-LIMITED PERFORMANCE FUELS CONSIDERED A SAFETY NET ONLY
MOTOR GASOLINE - ETHER FUELS
CONTEMPORARY HIGH SPECIFIC POWER ENGINES - SPARK IGNITED COMBUSTION
NO OPERATIONAL CHANGES OR ENGINE MODIFICATIONS REQUIRED
OPERATIONAL CHANGES AND / OR ENGINE MODIFICATIONS REQUIRED ON SOME AIRCRAFT
CONTEMPORARY LOW SPECIFIC POWER ENGINES - SPARK IGNITED COMBUSTION - NO OPERATIONAL CHANGES OR ENGINE MODIFICATIONS
LONG TERM FUTURE GENERAL AVIATION PISTON PRODUCTS
ALL TYPES OF AVIATION TURBINE FUELS WITH A WIDE RANGE OF CETANE RATINGS
UNLEADED GRADE 82 UL AVIATION GASOLINE DERIVED FROM MOTOR GASOLINE - ETHER BASED FUELS
NEW HIGH SPECIFIC POWER ENGINES - MULTI-FUEL HYBRID COMBUSTION BASED ON ADVANCED TECHNOLOGIES
CONTEMPORARY AND NEW LOW SPECIFIC POWER ENGINES - SPARK IGNITED COMBUSTION INCORPORATING MODEST ADVANCED TECHNOLOGY FEATURES
CESSNA AIRCRAFT COMPANY NOVEMBER 1997

Alternative Fuels for General Aviation

Kenneth Knopp
Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405





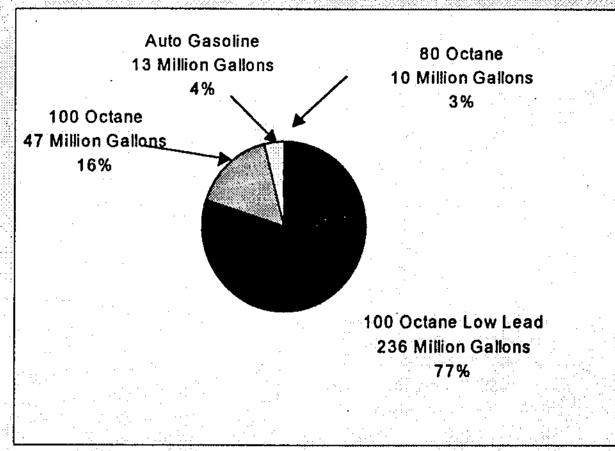
Aviation Gasoline (Avgas) History

- Pre-1920's
  - Straight-run unleaded motor gasoline, only end point and volatility control, no octane requirements
- 1923
  - First use of tetraethyllead (TEL)
- 1935
  - First 100-octane fuel
- 1942
  - First rich rating requirement of 130
  - 100/130 grade with 3-ml TEL/gallon allowed 30% increase in Rolls Royce Merlin engine over 80/87 octane grade

Aviation Gasoline (Avgas) History (cont.)

- 1944
  - First requirement for 115/145 grade for Wright R3350 engines in Boeing B29 aircraft
  - (same fuel as 100/130 but with 4.6-ml TEL/gallon)
- 1950
  - First requirement for 108/135 grade for commercial Pratt & Whitney R4360 engines in Boeing Stratocruisers
- 1970
  - First use of 100LL grade
  - Same octane performance as 100/130 but containing 2-ml TEL/gallon, thereby permitting use in low-compression engines designed for 80/87

1992 General Aviation Fuel Consumption (306 Million Gallons)



Reasons for a New General Aviation Fuel

- 1990 Clean Air Act
  - 1992—banned production of new engines requiring leaded fuels
  - 1996—banned sale of leaded fuels
- Montreal Protocol
  - 1998—bans bromide emissions
- Cost
  - Limited supply of tetraethyllead
  - Specialty fuel

Other Fuels for General Aviation Aircraft

- Ethanol
  Alcohol derived from anything containing starch or sugar

- 82UL Avgas
  Flight fuel that would be drawn from the motor gasoline supply

Ethanol

- Advantages
  1. Made in the USA
  2. Renewable fuel
  3. Good performance
  4. Proven aviation fuel
- Disadvantages
  1. Distribution system
  2. Poor starting characteristics
  3. 10% weight increase
  4. Range reduction
- Other considerations
  - Cost
  - Environmental impact

82UL Avgas

- Advantages
  1. Unleaded
  2. Proven aviation fuel
- Disadvantages
  1. Not usable by all aircraft
  2. Reduced range
- Other considerations
  - Cost
  - Distribution system
  - Environmental impact

FAA Commitment to High-Octane Unleaded Fuel

- Establishment of Future Fuel Program
- Facility Improvements
- Active Participation in American Society of Testing and Materials
- Establishment of Coordinating Research Council

Coordinating Research Council Members

- FAA
  - Technical Center
  - Engine and Propeller Directorate
  - Aircraft Certification Office
- Engine Manufacturers
  - Teledyne Continental Motors
  - Textron Lycoming
- Airframe Manufacturers
  - Cessna
  - New Piper
  - Raytheon
- Oil Companies
  - Air BP
  - Chevron
  - Exxon
  - Phillips
  - Shell
  - Texaco
- General Aviation Organizations
  - Aircraft Owners and Pilot Association (AOPA)
  - Experimental Aircraft Association (EAA)
  - General Aviation Manufactures Association

Future Fuels Concerns

Combustion quality (octane)
Volatility
Engine durability
Emissions
Material compatibility
Energy content
Distillation
Fuel cleanliness
Storage stability
Fuel system corrosion
Engine corrosion
Freeze point
Oil reaction
Water reaction
Conductivity
Dye reaction
Toxicity
Engine deposits
Additives
Availability
Transparent transition
Cost

Octane Rating

I. Background

- MON = Motor Octane Number
  - Heavy-Duty Cycles
- RON = Research Octane Number
  - Light-Duty Cycles
- Car Pump Octane Number = Antiknock Index
  - (MON+RON)/2
- 100LL = 100/130
  - 100 MON Aviation Lean Rating
  - 130 MON Rich Rating

Octane Rating (cont.)

II. Ground-Based - CRC Procedures

- Standard Reference Fuels
- Three High Power Points - TO, Max Cont, Cruise
- Engine Instrumented
  - Cylinder Head Temps, Exhaust Gas Temps,
  - Manifold Air Temp, Induction Air Temp,
  - Cyl Press, Fuel Flow Rate, Manifold Absolute Press,
  - RPM, Torque, Oil Press, Oil Temp
- Maximum Cylinder Head Temps - Cooling Air Pressure
- Maximum Oil Temp - Water Cooled

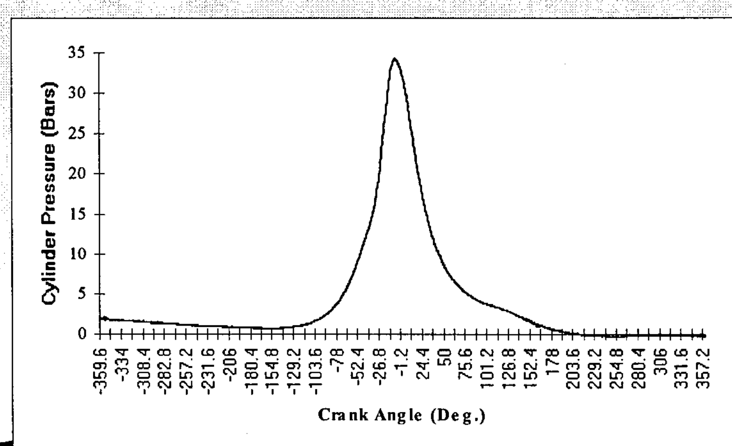
Octane Rating (cont.)

II. Ground Based (cont.)

- Pre (3) and Post (3) Baselines
  Washer Transducers
- Full-Rich Mixture MON/Lean-Configuration MON
  Lean to Peak EGT, Equivalent Energy Density
- Sea Level MON/Simulated Altitude MON
  Ind Air Press & Exh Back Press - Std. Pressure
  Ind Air Temp - Extreme Hot Day
  Ind Air Relative Humidity
- Cylinder Head Flush-Mounted Pressure Transducers
  Pressure Trace Digitized-Knock Number

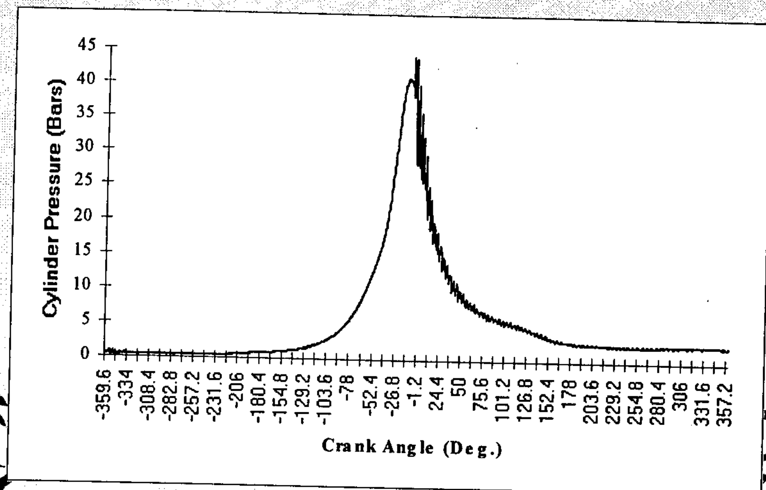
Octane Rating (cont.)

- Normal Combustion



Octane Rating (cont.)

Detonation



Octane Rating (cont.)

IIA. Ground-Based Results (CRC)

- Continental IO550d Engine
  98 Full-Rich MON
  100 Lean-Configuration MON

- Lycoming TIO540j2bd Engine
  Ready for Sea Level Octane Rating
  Altitude Octane Rating to be done at Lycoming

- After Octane Rating of Four "Worse Case" Engines
  Further Testing of Fuels Formulated to Meet MON

Emissions

- Emissions (Combustive and Evaporative)

    Various Power Settings

    Idle to Takeoff

    Various Fuel Blends

    Record Engine Temperatures and Pressures

    Record NO_x, CO, CO_2, THC, O_2

Power Baselines

Power Baselines

Power Map the Engine

Various Power Settings

Magneto Check Power to Takeoff Power

Vary RPM by 100

Vary MAP by 2 inches of Mercury (in Hg)

Volatility

- Volatility (Tendency to Form Vapor)

  Reid Vapor Pressure (RVP)

  Not Good For Oxygenated Fuels

  Vapor to Liquid Ratio (VLR)

  Vapor Lock Testing

  Various Power Settings - Cruise to TO

  Heat Fuel in 10°F Increments - 90°F to 120°F

  Record Engine Problems

Energy Density

- Energy Density

  Lower Energy Content

  Higher Fuel Flow Rate for Given Power

  Shorter Range

  Recovery Possible With Oxygenates

  Methyl Tertiary Butyl Ether (MTBE)

  Ethyl Tertiary Butyl Ether (ETBE)

  Leaner Configuration

Endurance

Endurance (Wear)

- Various Power Settings
- 150 Total Hours
- Maximum Operating Temperatures
  - Oil Temperature, Cylinder Head Temperature
- 25-Hour Inspection
  - Valve Seat Recession Measurement
  - Cylinder Compression Measurement
- 50-Hour Inspection
  - Oil Change
  - Oil Sample
  - Check Screens/Filters

Material Compatibility

☛ Material Compatibility

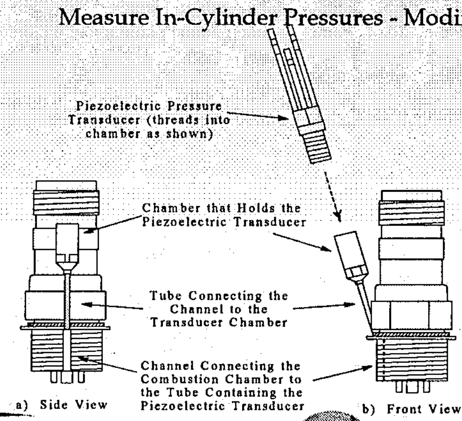
- Ethers and Elastomers
- Expose Various Elastomers to Different Formulations
  - Swell
  - Excessive Softness
  - Excessive Brittleness

Flight Testing

- Aercommander 680E Aircraft
- Use of Ethers
- Ground-Based Altitude Simulation
- Modified Vent/Fuel System
  - #1 Critical Engine - 100LL AVGAS Only
  - #2 R&D Engine
    - Unleaded Aviation Alkylate Containing 30% MTBE
    - 95.7 MON - Oxygenate
    - Overhauled
    - Unleaded Fuels Only

Flight Testing (cont.)

- #2 R&D Engine
  - 32-Channel, High-Speed Data Acquisition System
    - Measure Temperatures, Pressures, Fuel Flow Rates, RPM
    - Measure In-Cylinder Pressures - Modified Spark Plugs



Flight Testing (cont.)

- Endurance
  - 250 Total Hours
    - 2.5 Hours - Takeoff Power
    - 10 Hours - Max Continuous Power
    - 225 Hours - 65% Power
    - 12.5 Hours - Idle
  - 20-Hour Inspection
    - Valve Wear Recession/Cylinder Leak Down
  - 50-Hour Inspection
    - Check Screens
    - Oil Sample

Flight Testing (cont.)

- Engine Restarts
  - Shutdown #2 Engine at Various Altitudes
- Detonation Testing at Critical Altitude
  - Performed on Hot Day
  - CHT's, Oil T Near Maximum
  - Ind Air Temp Controlled to Extreme Hot Day at Altitude
    - Carburetor Heat
- Hot Fuel Testing - Volatility
  - Heat Fuel to 120°F within 90 Minutes
  - Maximum Operating Temperatures
  - Various Power Settings - Cruise to Takeoff

Flight Testing (cont.)

III. Flight Test Results

- 160 Hours to Date
- Engine Restarts - 4000 ft
- Endurance
  - No Appreciable Wear
  - Good Compression
- Lifter Failure - Stuck Valves?
  - Varnish in Guides

Other Considerations

- Standard Reference Fuel to Represent Oxygenates
- Rich Rating?
- Power Loss
  - Lower Energy Density/Recovery
  - May Need Timing Adjustments - Timing, Bore, Speed, etc.

Summary

- Currently Addressing MON Requirement
- Future
  - Address Candidate Fuels Meeting MON
    - Other Important Areas
      - Ground-Based Testing
      - In-Flight Testing

Alternative Fuels for General Aviation

Kenneth J. Knopp
Federal Aviation Administration
William J. Hughes Technical Center

Developing a High-Octane Unleaded Aviation Gasoline

Joseph N. Valentine, Research Engineer
Fuels and Lubricants Technology Department
Texaco Research & Development
Texaco Global Fuels
PO Box 509
Beacon, NY 12508

Background

The removal of tetraethyl lead (TEL) from U.S. automotive gasoline in 1996 caused concern within the general aviation (GA) community. Since the most widely used aviation gasoline, 100 low lead (LL) depends heavily upon TEL for its high antiknock quality, its demise in the automotive sector could cause severe shortages or cost increases in the aviation sector. In contrast, President Clinton signed the General Aviation Revitalization Act in 1994. This legislation essentially placed an 18-year statute of repose on aviation products and prompted Cessna Aircraft Co. to resume production of the Model 172, a previous mainstay of the GA industry. Texaco, a major worldwide supplier of aviation fuels, reaffirmed its commitment to GA by helping to form "GA Team 2000" as a founding member. The risk of mandated lead-free aviation gasoline provided Texaco with the incentive to begin development of a new high-octane unleaded aviation gasoline as a possible replacement for 100LL.

The octane boosting qualities of TEL are unparalleled and an unleaded replacement for 100LL would no doubt contain several high-octane components and possibly other additives as well. The existing 100LL consists of a relatively few components: aviation alkylate, light naphtha, toluene, and TEL. The future high-octane aviation gasoline may begin with "automotive" alkylate to which may be added oxygenates, aromatic amines, and other octane boosting additives such as manganese. The work performed at Texaco in Beacon, New York, explored combinations of the components and additives noted above. Conventional automotive octane enhancers are inadequate for use in high-performance aircraft engines because these engines operate at considerably higher power settings for longer periods of time than do their automotive counterparts. Also, detonation my not be heard from an aircraft engine operating at full power, and severe detonation in an aircraft could be catastrophic to an engine and fatal to the occupants.

Statistical Design and Engine Tests

The development of this alternative lead-free, high-octane aviation gasoline was the result of tests using a statistical experimental design known as "face centered central composite". This tool enabled the research team to obtain octane responses of the variables (composition) using three separate test methods or procedures and to illustrate these responses through models represented by first- and second-order equations and 3-dimensional plots. Input to the cubic matrices was based on standardized ASTM engine knock test methods as well as knock tests in a production aircraft engine on a dynamometer test stand. The ASTM standard tests to determine knock ratings of aviation gasolines were employed as a means to compare the attributes of the experimental fuels to the existing 100LL, and the production engine was used to verify the successes (or failures). Aviation gasolines are rated for antiknock quality using ASTM D 2700, Standard Test Method for Motor Octane Number (MON) of Spark-Ignition Engine Fuels (converted to Aviation Lean, but usually discussed in terms of MON), and ASTM D 909, Standard Test Method for Knock Characteristics of Aviation Gasolines by the Supercharge Method, reported in terms of performance number, or PN. Avgas is described using the convention 100/130 to indicate the lean and supercharge or rich ratings, respectively. Interestingly, D 2700 measures antiknock quality at maximum knock, while D 909 measures it at minimum knock. Because of this, the supercharge rating was considered a better predictor of the antiknock performance of a fuel under real world conditions than the motor rating, and although neither method predicted with great accuracy, data obtained from D 909 more closely aligned with results from the production engine.

Production Engine/Data Acquisition System

The production engine used in the project was a Lycoming IO-360, 200 bhp @ 2700 rpm, 8.7:1 compression ratio, requiring 100LL aviation gasoline. The engine was equipped so that cylinder head temperature, engine speed and load, and equivalence ratio could be selected while other parameters were recorded. The knock data acquisition system originated with one water cooled piezoelectric pressure transducer in each cylinder at strategic locations. Each transducer signal was routed through a charge mode amplifier, A/D data acquisition board, and onto a hard drive via LabView® software. Processing was accomplished on a Macintosh 8100/80 PowerPC and results were recorded on disks via magneto optical drive. Data was recorded at maximum engine speed (2700 rpm) and full power with the hottest cylinder at 500°F and an equivalence ratio of 1.11. Knock data were recorded at intervals of 200 or 400 cycles using an acquisition time of 3 milliseconds. The absolute value was integrated (to eliminate canceling pressure waves), and the signal was considered to be knock if the value exceeded "20" on an arbitrary scale. This threshold value was chosen based on earlier testing which showed that values at or below 20 were indistinguishable from other engine vibrations. It is interesting to note that each pressure transducer recorded 250,000 samples per second per channel, resulting in total knock data acquisition of 1,000,000 samples per second.

Equivalence ratio (Φ) is a term used to describe the ratio of the actual fuel/air ratio to the stoichiometric (chemically correct) fuel/air ratio:

$$\Phi = \frac{(F/A)\ \text{Actual}}{(F/A)\ \text{Stoichiometric}}$$

The stoichiometric fuel/air ratio was calculated based on fuel composition, and the actual fuel/air ratio was determined from the exhaust gases (using an oxygen sensor). This technique provided a convenient means of testing each experimental fuel at the same relative richness (I 1%) as the others, thus "normalizing" the data. Fuel flow was adjusted to maintain the desired equivalence ratio. (When $\Phi = 1$, the mixture is stoichiometric; when $\Phi > 1$, the mixture is rich; when $\Phi < 1$, the mixture is lean.)

Test Procedure

Previous testing indicated this particular engine had an octane requirement of about 103 MON (equivalent to 106 PN). Consequently, PRF[1] blends of 98, 102, 106, 110, and 114 PN were chosen to "bracket" the octane requirement of the engine and were used as a control group at the outset of a test session to verify data integrity. Knock tests were performed by first warming the engine on 100LL, then obtaining knock data for the 100LL followed by the five PRFs. Subsequent to this procedure, 10 experimental fuels were tested for knock intensity and number of knocking cycles. Each experimental fuel was tested at least twice (in random order), and the same fuel was never run twice consecutively. At the completion of the experimental test runs, the PRFs were again run and then the engine was shut down.

Results

Test results with fuels of various compositions are presented to illustrate the range of data obtained. Note that, as expected, MON was relatively insensitive to composition in predicting antiknock quality of the experimental fuels, and although the supercharge method was an improvement, its predictive qualities were questionable.

The results from motor octane, supercharge, and production engine tests were placed within the cubic configuration of the face centered central composite design using cube comers, face centers, and geometric center as data sites (actually, additional sites were added by dividing the axes into segments). Data from each method was analyzed using separate cubes for each method, and linear and quadratic equations were developed which described the knock response of the variables based on formulation. The axes of each cube represented (oxygenate, amine, and manganese concentrations) and each data point was the average of at least two determinations, the geometric center being the average of at least four determinations. Production engine data, which represented the knock intensity and number of knocking cycles corresponding to a specific fuel formulation (and the associated motor octane and supercharge ratings), were also analyzed. By combining the output from the equations of the three test matrices, a model was constructed which was used to predict antiknock quality of specific fuel formulations or to identify specific fuel formulations required to achieve a given antiknock quality. These equations, when plotted using 3-dimensional techniques, clearly illustrated synergistic and antagonistic effects among the variables. This unique feature of the predictive model was validated through additional selective testing.

Conclusions

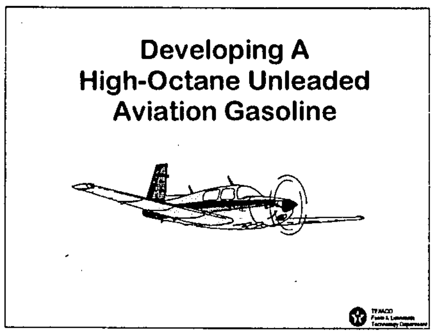
Motor octane and supercharge ratings by themselves were inadequate to define the antiknock quality of the experimental gasolines tested, and although supercharge was a better screening tool than motor octane, this work indicated the need to validate results using a production aircraft engine. Also, synergistic (as well as antagonistic) antiknock characteristics were identified by using the quadratic equations and 3-dimensional plots generated from the statistical experimental design. Equivalence ratio was a convenient and useful tool when experimenting with various

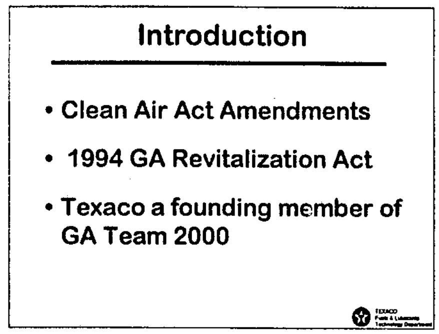
[1] PRF = Primary Reference Fuel. Volumetric mixtures of isooctane and n-heptane, or blends of isooctane and TEL which define the octane number scale.

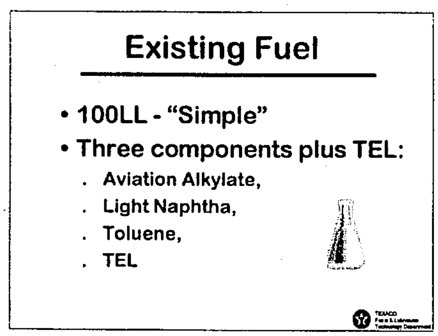
fuel blends in the production engine since it permitted testing with the same relative enrichment regardless of fuel composition.

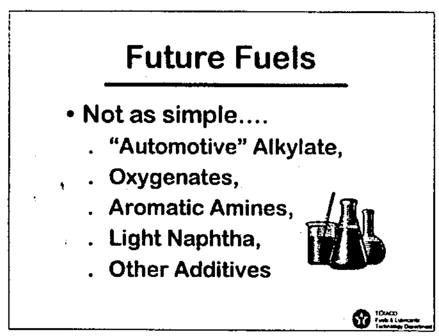
Future Testing

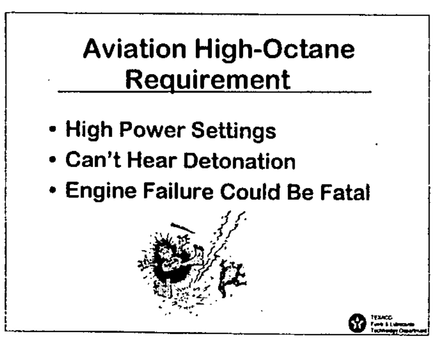
Candidate blends will be tested for their propensity to produce engine deposits and compared to results from 100LL in the production engine using simulated "flight school" or "touch and go" cycles. Also, emissions testing will be conducted to determine what advantages, if any, a new unleaded fuel may possess regarding engine-out pollutants, particularly carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NO_x), carbon dioxide (CO_2), and oxygen (O_2). When fuel system and materials compatibility performance have been satisfied, flight testing may be conducted.

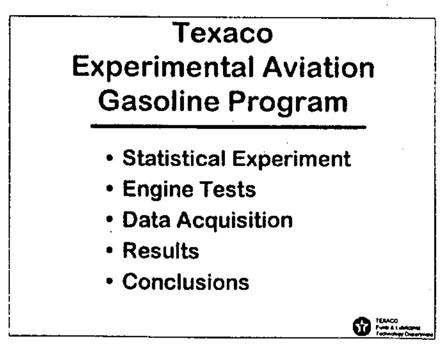










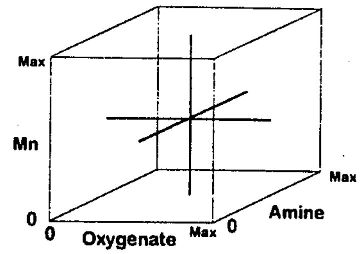


Experimental Fuels

- Wide Boiling Alkylate + ...
- MTBE, ETBE +
- Aromatic Amines +
- Manganese

TEXACO Fuels & Lubricants Technology Department

Statistical Design



Face-Centered Central Composite

TEXACO Fuels & Lubricants Technology Department

Engines

- Motor Octane (ASTM D 2700, MON)
- Supercharge (ASTM D 909, PN)
- Production IO-360 (KI, KC)

TEXACO Fuels & Lubricants Technology Department

Test Conditions (Aviation Lean)

- Motor Octane (D 2700)
  - Speed = 900 rpm
  - Intake Mixture = 300°F
  - Coolant = 212°F
  - R = 1.1 @ 90

TEXACO Fuels & Lubricants Technology Department

Test Conditions (Aviation Rich)

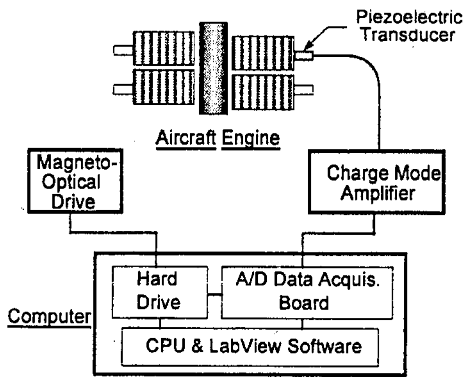
- Supercharge (D 909)
  - Speed = 1800 rpm
  - Intake Air = 225°F
  - Coolant = 375°F
  - R = 6.0 @ 94-150

TEXACO Fuels & Lubricants Technology Department

Test Conditions

- Lycoming IO-360 (non-ASTM)
  - Speed = 2700 rpm
  - Intake Air = 70°F
  - Cylinders = 500°F (hottest)
  - R = ?

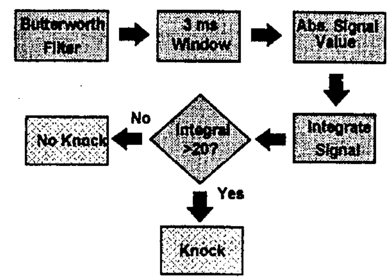
TEXACO Fuels & Lubricants Technology Department



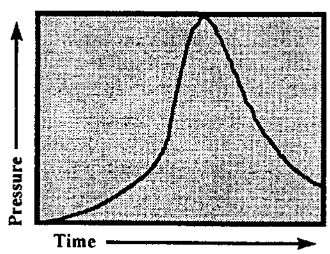
Hardware Setup

Knock Data Acquisition

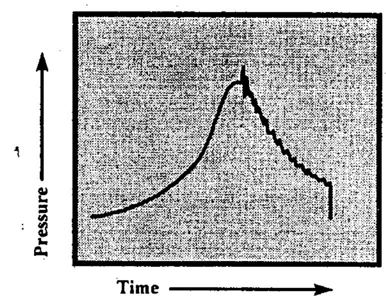
Software



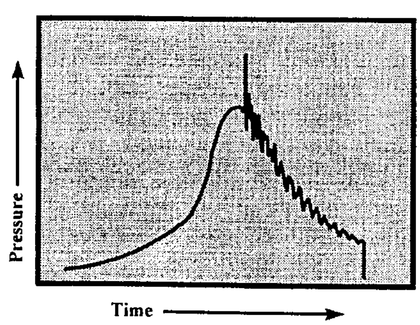
Normal Combustion



Incipient Knock



Heavy Knock



Equivalence Ratio (Φ)

$$\Phi = \frac{(F/A)_{\text{Actual}}}{(F/A)_{\text{Stoichiometric}}}$$

Φ = 1.0, mixture is stoichiometric
Φ > 1.0, mixture is rich
Φ < 1.0, mixture is lean

Φ = 1.11 for this program

Knock Test Results

	Fuel Composition				ASTM Methods		Production Engine	
Fuel	Hydrocarbon Vol%	Oxygenate Vol%	Amine Wt%	Mn g/gal	D 2700 MON	D 909 Supercharge	Knock Intensity	Knocking Cycles
100LL	100				N/A	134 6	0	0
PN-106	100				102 9	106	22	1
PN-110	100				103.3	110	0	0
1	80	20	6	0 1	98.5	142.2	0	0
2	75	25	3	0	96 9	138.2	0	0
3	70	30	0	0 1	96 4	132 1	0	0
4	75	25	6	0 05	99.6	144.8	23	3
5	80	20	6	0	97.4	137.6	36	16
6	80	20	0	0.1	95.3	116.8	38	57

ASTM D 910 vs. Three Experimental Fuels

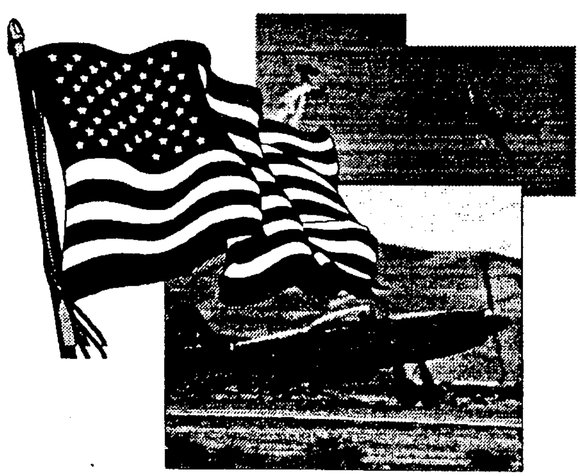
Requirement	D 910 100LL	Fuel A 20 vol% MTBE	Fuel B 25 vol% MTBE	Fuel C 30 vol% MTBE
Knock value min octane number, lean rating	100	97.5	96.9	98.0
Knock value, min rich rating				
Minimum Performance Number	130	140 2	136 2	143 8
Final boiling point, max F (C)	338 (170)	360	348	370
Net heat of combustion, min, Btu/lb	18720	18146	18830	18978
Vapor pressure				
min, psi (kPa)	5 5 (38)			
max, psi (kPa)	7 0 (49)	7.2	7.3	7.5
Potential gum (5-h aging gum), max mg/100mL	6	12.5	17.8	N/A
Freezing point max F	-72	-47	-43	-58

Conclusions

- Synergistic/Antagonistic Effects
- Prediction of Octane or Formulation
- Not All 98 MONs Are Equal
- Φ Useful to "Normalize" Fuels
- Production Engine Required to Validate Fuel Antiknock Quality

Future Testing

- Deposits
- Emissions
- Compatibility
- Flight Testing



The Unleaded Aviation Gasoline With Improved Environmental Qualities

Aviation Gasoline 91/96 Unleaded
(AVGAS 91/96 UL)

Lars Hjelmberg
Hjelmco Oil AB
Runskogsvagen 4B
S-192 48 Sollentuna
SWEDEN

Introduction

When we consider future fuels, we will certainly need to look at those substances that will be regulated in the future. Benzene, a substance approved today with a maximum content of 5%, be sure that it will be allowed to make up less than 1%. Normal-hexane, aromatics, sulfur, lead, and olefins will not be allowed in future fuels, and such a fuel will have to be one with a low vapor pressure. Some of you from the oil industry might say, "It is not possible to make a fuel like this if you want to make it from oil." That is true. It means that in the future we are looking for a fuel that will probably be semisynthetic, partially synthetic, or fully synthetic in its application. This is the only way to get the fuels that we need to meet the stricter requirements the authorities will be sure to create. Right now we have one foot on the oil side, and one foot on the synthetic side. I think those two will be thrown together for any future fuel.

To All International AVGAS Customers

Edition: V

Sollentuna 97-Oct-17

WHO CAN USE UNLEADED AVGAS 91/96 UL?

The use of unleaded AVGAS is approved by the major piston engine manufacturers Textron Lycoming and Teledyne Continental.

AVGAS 91/96 UL from Hjelmco Oil is an unleaded aviation gasoline with specific improved environmental qualities. A leaded version of this fuel was sold during the 1970s and called AVGAS 91/96.

Approximately 70% of all general aviation aircraft in the world today have engines from the aircraft engine manufacturers Textron Lycoming and Teledyne Continental, among others, which specify AVGAS 91/96 as an approved aviation gasoline.

In addition, the majority of the new aircraft engines manufactured today are certificated to use AVGAS 91/96.

These newly manufactured engines are found in brand new aircraft such as Piper PA28-181 (Archer), Piper PA28-161 (Warrior), and Cessna C 172 among others.

AVGAS 91/96 UL is suitable for aircraft engines certificated to use AVGAS 91/96, AVGAS 82 UL, AVGAS 80/87, and AVGAS 80.

WHAT IS THE DIFFERENCE BETWEEN AVGAS 91/96 UL AND AVGAS 100 LL?

AVGAS 91/96 UL is produced only from distillates which have been used by Hjelmco Oil in the production of an extra high-quality grade of AVGAS 100 LL for many years. AVGAS 91/96 UL is an extremely high-quality grade of AVGAS 100 LL without lead, dyes, and scavenger.

AVGAS 91/96 UL thus meets all the requirements of AVGAS 100 LL according to the US standard ASTM D-910, but with the following exceptions:

PARAMETERS	AVGAS 100 LL	AVGAS 91/96 UL
octane numbers rich mixture	min. 130 octane	min 96 octane
octane numbers lean mixture	min. 100 octane	min 91 octane
color	blue	transparent
scavenger	1.2 dibromoethane	not used or required
tetraethyllead	max 2-ml/Us gal	unleaded

WHAT ARE THE ENVIRONMENTAL QUALITIES OF AVGAS 91/96 UL?

AVGAS 91/96 UL is:

UNLEADED

Lead is a heavy metal which when inhaled is absorbed and stored in the human body. Lead can cause brain damage.

Gasoline without lead does not need to have any scavenger. For aviation gasoline, 1.2 dibromoethane is usually used. A substance which is carcinogenic and promotes the so-called greenhouse effect.

Unleaded fuels must according to Swedish regulations be transparent. The blue dye in the AVGAS 100 LL (1.4-dialkylamino-antraquinone) is said to cause skin irritation and allergic reactions. Thus the absence of lead is desirable for a number of reasons.

ALMOST FREE FROM BENZENE

AVGAS may, in Sweden, contain a maximum of 5% benzene, a toxic substance known to be carcinogenic. AVGAS that contains more than 0.1% benzene must, according to Swedish regulations, be labeled toxic and show a skull and crossbones.

AVGAS 91/96 UL contains less than 0.1% benzene and no carcinogenic 1.2 dibromoethane and is for that reason labeled harmful and shows a Saint Andrew's cross.
ALMOST FREE FROM SULPHUR

AVGAS may contain up to 0.05% sulphur. AVGAS 91/96 UL contains less than 0.001% sulphur. Sulphur is a substance connected with acid rain, human allergic reactions, and respiratory diseases.

ALMOST FREE FROM N-HEXANE AND METHYL-N-BUTYL KETONE AVGAS 91/96 UL contains less than 0.1% Normal-Hexane and is normally free of Methyl-n-butyl ketone. Both these substances affect the peripheral nervous system.

WHAT IS THE DIFFERENCE BETWEEN UNLEADED FUELS AND FUEL FREE FROM LEAD?

AVGAS 91/96 UL from Hjelmco Oil is free from lead when it leaves the refinery, but it can be contaminated with very small amounts of lead during the transport to the final end user. One reason for this is that we attempt to keep distribution costs down for a transport of AVGAS 91/96 UL. If the previous cargo has been AVGAS 100 LL we do not presently clean our trucks.

This means that from time to time the surface of the truck tanks, when completely dry, may contain very small amounts of lead as a residue from the AVGAS 100 LL. This lead may mix with the AVGAS 91/96 UL and be delivered to the end user.

Motor gasoline for cars which today is sold as unleaded is not necessarily free from lead. The current Swedish standard allows unleaded gasoline for cars to contain a maximum of 0.013 grams of lead per liter.

Thus we cannot currently warrant our AVGAS 91/96 UL as suitable for engines equipped with catalytic converters.

DOES THE AVGAS 91/96 UL CONTAIN ANY SUBSTANCES HARZARDOUS TO HEALTH?

The answer is yes. It is not possible to produce an aviation gasoline that does not contain something that is hazardous in some respect. AVGAS 91/96 UL does contain toluene as a distillate in order to obtain proper octane ratings with a rich mixture. The amount of toluene in AVGAS 91/96 UL is, however, about the same as in AVGAS 100 LL.

WHY IS AVGAS 91/96 UL NOT SAID TO BE ENVIRONMENTATLY FRIENDLY?

There is a growing tendency to call too many products environmentally friendly today. All combustion engines produce exhausts and residues that are harmful to the earth and the human race.

However, with AVGAS 9l/96 UL we have advanced as far as possible in offering an aviation gasoline with improved environmental qualities. While developing AVGAS 91/96 UL we have considered, in particular, pilots and mechanics who are frequently exposed to aviation gasoline vapor (i.e., Benzene, Normal-Hexane, and Methyl-n-butyl ketone). We have also concentrated on reducing pollution damaging to the earth in general (i.e., lead 1.2 dibromoethane and sulphur).

The specifications of the ASTM D-910 for aviation gasoline and the engine-type certificates issued by the US Federal Aviation Authority (Administration) (FAA) have set our limitations.

AVGAS 91/96 UL THE PUREST STANDARD AVIATION GASOLINE IN SWEDEN?

We who work for Hjelmco Oil claim that no standardized aviation gasoline in Sweden can compete with our AVGAS 91/96 UL when it comes to purity, handling, and environmental qualities.

In comparison with unleaded gasoline for cars (EUROSUPER 95), AVGAS 91/96 UL is 50 times purer. AVGAS 91/96 UL is the second generation of unleaded AVGAS from Hjelmco Oil. However, we are not satisfied.

We are developing an even better unleaded AVGAS - but this new fuel will not see the market for some time.

DOES HJELMCO OIL HAVE ANY MATERIAL SAFETY DATA SHEET FOR AVGAS 91/96 UL?

Yes. The material safety data sheet is enclosed at the end of this pamphlet. Regarding warning labels on the fuel pumps at airports, these will be provided by the fuel truck driver and posted by him upon delivery of your first batch of unleaded AVGAS 91/96 UL.

If you feel discouraged with the detailed information on the warning label of the AVGAS 91/96 UL, remember that this does not mean that AVGAS 91/96 UL is more dangerous than AVGAS 100 LL. The warning label of the AVGAS 91/96 UL fuel is made solely for Hjelmco Oil, and we have chosen to indicate its effects in more detail. A copy of the warning labels is enclosed at the end of this pamphlet.

WHY DOES HJELMCO OIL PROVIED AN AVGAS WITH IMPROVED, ENVIRONMENTAL QUALITIES FOR SMALL AIRCRAFT?

The current standard aviation gasoline is AVGAS 100 LL, but this fuel does not meet the current requirements for gasoline in Sweden and is today temporarily exempted from the ban of lead. Aviation gasoline in Sweden may contain a maximum of 0.8 grams/liter.

Since March 1, 1995, the production and import of leaded automotive gasoline is banned in Sweden. In the USA there is a proposal to ban lead in automotive gasoline from 1996.

We assume that the legislation in Sweden for aviation gasoline will follow the legislation for automotive gasoline as soon as this is practically possible.

<u>In Sweden there is currently a law stating that if there is a better product for the environment and/or human health on the market, everyone is obliged to use this better product.</u>

Hjelmco Oil pioneered the development of unleaded aviation gasoline in 1980 with an unleaded AVGAS 80. In 1981 this unleaded AVGAS was distributed nationwide. Compare this with the fact that- unleaded gasoline for cars first achieved nationwide Swedish distribution in 1987 i.e., six-years later.

The major customer for Hjelmco Oil and the unleaded AVGAS 80 during the 1980s was the Royal Swedish Airforce with their SAAB-SAFIR aircraft equipped with Textron Lycoming O-435 engines.

This aircraft is no longer used by the airforce and the consumption of unleaded AVGAS 80 has decreased considerably. It is not yet economically or technically feasible to produce an unleaded AVGAS 100 and at the same time meet the current aviation gasoline standard, the ASTM D-910.

For this reason, Hjelmco Oil began a project in 1988 to find a suitable alternative for the large majority of users that need an unleaded aviation gasoline. With assistance from the engine manufacturers Textron Lycoming and Teledyne Continental, we have found that the <u>majority</u> of general aviation aircraft engines have FAA certificates to use an aviation gasoline with octane ratings not exceeding 91 octane at lean mixture and 96 octane at rich mixture.

Contrary to an AVGAS with 100/130 octane, it is possible today to obtain the octane numbers 91/96 in an AVGAS without lead and still keep this unleaded AVGAS 91/96 within the ASTM D-910 standard for aviation gasoline.

<u>An aviation gasoline meeting the ASTM D-910 standard is approved for use without restrictions in Textron Lycoming and Teledyne Continental engines, among others.</u>

By providing AVGAS 91/96 UL, we can offer the aviation gasoline users a product that meets the standard for AVGAS and the requirements of the engine-type certificates issued by the US Federal Aviation Authority (Administration) (FAA).

<u>HOW CAN HJELMCO OIL BE SO SURE THAT AVGAS 91/96 UL WILL NOT CAUSE THE SAME ENGINE PROBLEMS AS AVGAS 100 LL DID WHEN IT WAS INTRODUCED IN THE LATE 1970's</u>

When AVGAS 100 LL was introduced, it was not long before aircraft engines certificated to use AVGAS 80 developed problems.

The main problem was that AVGAS 100 LL, with a tetraethyllead content approximately four times that of AVGAS 80/87, was used on engines certificated to use AVGAS 80/87.

Engines certificated to use AVGAS 80/87 have a low compression ratio. This often results in low combustion temperatures. With these low combustion temperatures, the scavenger in the fuel does not always act as intended, resulting in lead deposits in the engine. Sometimes deposits adhere to the engine valves, restricting their movement.

As a result of this, the engine could not aspirate properly, which can overheat the engine. In some cases the valves became lodged open and were damaged the next time the piston reached its highest point.

In other cases, the valves could not close properly resulting in the combustion flames passing through the valve and the valve seat. In that case, the valve head was damaged and could develop a mushroom-like appearance.

An unleaded gasoline will not cause such complications, however. This is because the source of the problems was lead.

HAVE THERE BEEN ANY FLIGHT TESTS CONDUCTED WITH AVGAS 91/96 UL?

Yes, in Stockholm in 1992, the Swedish Royal Institute of Technology, Department of Aeronautics tested the fuel on a 1988 Piper Warrior II equipped with a 160 horsepower Textron Lycoming O-320-D.

The flight tests were carried out using an advanced engine monitor system. One wing tank was filled with AVGAS 100 LL and the other wing tank with AVGAS 91/96 UL.

For various flight operations and during two seasons, temperature values have been recorded for cylinder heads (CHT), exhaust gases (EGT), simulated turbine inlet (TIT), engine oil, and fuel flow.

The measurements for CHT and EGT were taken 10 times every second for each cylinder.

The recordings were made with great accuracy and often within ± one-degree Celsius. The flights were performed first using one wing tank, and a short time later the other wing tank was used.

The advantage of this method is that the flight conditions for both fuels were the same.

The report from the Swedish Royal institute of Technology was written in English and concluded that the authors could not find any differences in engine performance using AVGAS 91/96 UL compared to AVGAS 100 LL.

The flight tests conducted by the Swedish Royal Institute of Technology were performed after consulting the engine manufacturer, Textron Lycoming.

The report (ISRN KTH/FPT/AR--63--SE) is available from Hjelmco Oil for a nominal fee.

WHY IS LEAD IN AIRCRAFT ENGINES NOT NEEDED TO LUBRICATE VALVES, ETC.?

In Sweden, Hjelmco Oil has produced and supplied unleaded AVGAS 80/87 between the years 1980-1992 for both military and civilian users.

Our experience with unleaded AVGAS is extensive and excellent. Aircraft engines are better off without lead because they run cleaner, have fewer technical problems, and lower maintenance costs.

Experience, although not statistically verified, indicates that an aircraft engine using an unleaded gasoline typically goes a longer period between major overhaul than do engines using a leaded gasoline.

There is a scientific report from the US FAA (DOT/FAA/CT-TN89/33) that compares valve wear on two Textron Lycoming engines, model IO-320-B, using AVGAS 100 LL and unleaded gasoline for cars.

(The above engines are certificated to use AVGAS 91/96.)

Each engine was run for 150 hours and every 16 hours of engine time the valve wear was measured and controlled.

The conclusion in the report is that no significant difference in valve wear could be found in these engines when using AVGAS 100 LL or unleaded gasoline for cars.

The above report can be obtained from the US FAA.

Worldwide there is significant use of automotive gasoline in aircraft. In the US there are said to be more than 40,000 aircraft flying on automotive gasoline.

In most of the states in the US, only unleaded automotive gasolines are available. The use of unleaded gasoline in aircraft engines in the Unites States is extensive. In smaller aircraft engines automotive gasoline sometimes is preferred to AVGAS 100 LL, because of the high amount of lead in AVGAS 100 LL.

In several parts of the world there are many years of experience using gasoline without lead in aircraft engines.

IS THERE ANY FLIGHT EXPERIENCE OF AVGAS 91/96 UL IN SWEDEN?

Yes, AVGAS 91/96 UL has been sold in Sweden at selected airports since April 1991 and nationwide since April 1993. The members of the aero-club at Stockholm Barkarby Airport have the most experience. Here at the Experimental Aircraft Association (EAA) Sweden headquarters, you will find a large variety of aircraft, home built as well as factory made.

There have not been any reported problems to Hjelmco Oil on AVGAS 91/96 UL for the four years and more that the fuel has been available.

During this time we have delivered fuel from 11 different batches. This has given us as a producer the opportunity to evaluate the small variations in the fuel which are always observed between different production dates.

HAS ANYONE HAD ANY PROBLEMS WHEN USING -AVGAS 91/96 UL?

Honestly - yes.

In very few cases, problems have been reported, and we have carefully analyzed them. In one case we also had the engine fully dismantled. In not a single case has the gasoline been found to be the reason for the engine problems.

ARE THERE ANY RESTRICTIONS FROM THE ENGINE MANUFACTURERS REGARDING USAGE OF UNLEADED AVIATION GASOLINE?

The answer is yes and no.

Teledyne Continental still recommends that a new or newly overhauled engine should be broken in with a leaded fuel. This is in order to reduce future valve/valve seat wear. Information from Teledyne Continental indicates that 4-5 engine hours on a leaded fuel is sufficient before a shift can be made to an unleaded fuel.

Regarding engines manufactured by Textron Lycoming there are no known restrictions and AVGAS 91/96 UL is listed among the approved fuels in their Service Instruction No. 1070 L dated January 20, 1995.

If you have any questions, or feel you want to know more, always consult the engine manufacturer.

DOES HJELMCO OIL RECOMMEND ANYTHING MORE WHEN USING AVGAS 91/96 UL?

The answer is yes. Because sometimes aircraft engines, without the knowledge of the customer, contain parts not produced by the engine manufacturer, we always recommend breaking in a new or overhauled engine with leaded AVGAS together with a dedicated break-in oil. When change takes place to normal additive oil (such as W8O, AD8O, 15W-50) the use of unleaded AVGAS 91/96 UL can be resumed.

The choice of engine oil will determine how your engine will perform in an unleaded environment. Unless the engine manufacturer/overhauler recommends something different, we recommend our customers use only the below listed engine oils together with AVGAS 91/96 UL.

ELF AD 80, AD 100, AD 120 all plus additive LW-16702
SHELL W 65, W 80, W 100, W 120 all plus additive LW-16702
SHELL 15W-50 with antifriction + anticorrosion additive

Do always use (not during engine break-in) Textron Lycoming LW-16702 oil additive together with AVGAS 91/96 UL. (The oil additive shall not be mixed with Shell 15W-50 which already contains this function.) See Lycoming service instruction SI No. 1409 A.

CAN ANYONE GIVE ME A GUARANTEE THAT MY AIRCRAFT ENGINE WILL RUN BETTER ON AVGAS 91/96 UL THAN ON AVGAS 100 LL?

Sorry, but the answer is no. However, by using AVGAS UL you may have created the conditions for your engine to run better.

A simple thing such as spots of lead on the plugs does negatively affect the combustion in your engine. You will not have these problems if you use an unleaded gasoline.

A large portion of the lead coming into the engine with the gasoline will end up in the engine oil. If the engine oil comes in contact with hot spots in the engine, the oil will carbonize more easily if lead is present. Deposits of carbon on valve stems affect/restrict the movements of the valve.

Getting rid of the lead in the engine will make your engine cleaner and the very low content of sulphur and lack of scavenger will reduce the conditions for corrosion.

The combination of AVGAS 91/96 UL and the semisynthetic aircraft engine oil SHELL 15W-50, which you can obtain from Hjelmco Oil is when it comes to keeping your engine clean, considered superior.

WHEN WILL HJELMCO OIL INTRODUCE AN UNLEADED AVGAS 100?

The American Society for Testing and Materials (ASTM) has a committee within the US working on an unleaded alternative to AVGAS 100 and the aircraft engines certificated to use this fuel. Hjelmco Oil is a producer member in this committee.

In parallel to this, Hjelmco Oil is in Sweden working on a completely new AVGAS using unique synthetic distillates. This new AVGAS may not require a recertification process for aircraft or engines. The environmental qualities of this new fuel will be even better than those of the unleaded AVGAS 91/96 UL.

WHAT SHALL I DO IF MY AIRCRAFT ENGINE PLATE SPECIFIES MINIMUM AVGAS 91/96 FUEL AND THE FAA APPROVED FLIGHT MANUAL TELLS ME AVGAS 100 LL

AVGAS 91/96 has not been produced since the early 1970s. If your aircraft engine plate specifies the minimum fuel AVGAS 91/96 and the FAA approved flight manual AVGAS 100 LL, this usually means that the aircraft manufacturer was not using AVGAS 91/96 when he certificated his aircraft. He was just using the fuel that was available to him at the time of certification

It is thus important from a legal point of view to compare what minimum fuel grade the FAA approved flight manual specifies and what the aircraft engine manufacturers operating manual specifies.

Hjelmco Oil is cooperating with the Swedish Civil Aviation Authority (CAA) in order to solve the cases where this discrepancy exists between the two manuals.

If you have any questions in this respect, we recommend you contact your local CAA or FAA branch.

It is also necessary to contact the aviation authorities if the labeling of the AVGAS grade on the aircraft tank does not correspond with the FAA approved flight manual (including revisions).

WHICH FUEL DOES THE AIRCRAFT ENGINE MANUFACTURER RECOMMEND FOR MY AIRCRAFT ENGINE?

At the end of this pamphlet we have listed the fuel specifications from Textron Lycoming and Teledyne Continental for each of their engine models.

The information regarding Textron Lycoming engines has been taken from their Service Instruction No 1070 L and the Teledyne Continental engines from their pamphlet "Continental Aircraft Engine Specifications" M5736X 02/85.

Each user of AVGAS should, regardless of the information from the aircraft engine manufacturer, always double check the engine identification plate against the FAA approved manual. Your aircraft might have been altered in such a way that the fuel requirements have changed.

There are aircraft engines manufactured by other than these companies already mentioned. Such manufacturers are Limbach, Rotax, etc. Always read your aircraft and engine manuals.

If your aircraft engine is approved for AVGAS 100 LL or unleaded automotive gasoline there should be no restrictions on the use of AVGAS 91/96 UL because the research octane number of the AVGAS 91/96 UL is close to 100. The research octane number is frequently used as an octane number for automotive gasolines.

If there are instances where the aircraft engine manufacturer require automotive gasoline with lead or AVGAS 100 LL we suggest a mixture of our AVGAS 91/96 UL and 10 - 20% of our AVGAS 100 LL, or our AVGAS 91/96 UL with a lead lubricating substitute.

Unfortunately you will lose some of the environmental qualities that are so unique to the AVGAS 91/96 UL if you mix it with AVGAS 100 LL.

If you use a lead lubricating substitute consisting of the alkali metals sodium and potassium, you have a special reason be careful.

Later if you use a leaded fuel the scavenger of that fuel will probably react with the above mentioned alkali metal and form inorganic salts. These salts are very corrosive to metals and thus your aircraft engine.

AVGAS 91/96 UL and AVGAS 100 LL produced by Hjelmco Oil are mixable because our components in AVGAS 91/96 UL are compatible with our AVGAS 100 LL components; the only difference being that they have a higher degree of purity.

<u>IS THE ENGINE WARRANTY ISSUED BY THE AIRCRAFT ENGINE MANUFACTURER VALID IF I USE AVGAS 91/96 UL?</u>

The use of unleaded AVGAS 7 is approved by Textron Lycoming and Teledyne Continental.

Therefore, there are no reasons for anyone to oppose warranty claims if AVGAS 91/96 UL is used as an aviation gasoline.

AVGAS 91/96 UL meets the standard ASTM D-910 for AVGAS 91/96, except that the fuel is undyed and the color is transparent. (Old AVGAS 91/96 was blue)

In Sweden there is a law specifying that unleaded gasolines shall be undyed and transparent.

<u>HOW DO I CHANGE FUEL IN MY AIRPORT FUEL TANK IF I WANT TO GO UNLEADED WITH AVGAS 91/96?</u>

If the change of fuel in the airport tank is an increase of the octane numbers for the fuel earlier delivered, i.e., you want to go from automotive gasoline or AVGAS 80/87 to AVGAS 91/96 UL, it is important that the product change is carried out in a controlled manner.

If the fuel you have today is AVGAS 100 LL and you want to change to AVGAS 91/96 UL with lower octane numbers, it will be sufficient to completely empty the AVGAS 100 LL tank (using the low-point draining facility) and then add AVGAS 91/96 UL. For a short period of time the AVGAS 91/96 UL fuel might be slightly contaminated with lead from the inner surfaces of the storage tank - but the lead will disappear after some period of time.

Hjelmco Oil has issued a service instruction dated May 14, 1993, (Exchange of aviation gasoline in airport tanks) which deals with the above issue. If you don't have this instruction available it can be ordered through our distribution service.

<u>WILL ANY OTHER AVIATION FUEL SUPPLIER PROVIDE AVGAS 91/96 UL IN SWEDEN?</u>

We are sorry - but we don't know. The total market in Sweden for AVGAS is limited. To set up a distribution system for a small product is very expensive.

Hjelmco Oil has the advantage in this case that our AVGAS 91/96 UL supercedes our AVGAS 80/87 UL and by doing so we can use the distribution system for AVGAS 80/87 UL and its storage tanks for this new product, without additional investment. By 1993, AVGAS 91/96 UL achieved nationwide distribution in Sweden and now more than 55 airports are served.

GENERAL AVIATION NEEDS YOUR ASSISTANCE!

Our effort to market our new fuel AVGAS 91/96 Unleaded is something that is good for the entire general aviation industry.

Local aero clubs, airports, and other types of aviation operations are carefully watched by people and organizations actively working for a better environment.

By providing AVGAS 91/96 UL to the aviation gasoline users, general aviation in Sweden is put in the forefront in respect of using fuels with improved environmental qualities.

AVGAS 91/96 UL more than meets most Swedish guidelines available today for automotive gasolines with enhanced environmental qualities to be available by the end of this century.

Help us to broadcast our message with the AVGAS 91/96 UL. Invite a newspaper reporter or your local TV station to your aero club or local airport. Call Hjelmco Oil beforehand and we will provide you with a set of information guidelines on how to achieve the best results. Don't hesitate to invite the reporter to fly a plane.

Telling your community that you are doing what you can in this field is a well allocated resource and will give your airport and general aviation a positive image.

Remember, unleaded aviation gasoline 91/96 from Hjelmco Oil has a 50 times lower concentration of certain environmental impurities than the maximum allowed today in unleaded, automotive gasoline. (Eurosuper 95 unleaded).

BATCH OF AUG 27 1993.

Sollentuna, Sept 6 1993.

CERTIFICATE OF QUALITY
AVGAS 91/96 UL (UNLEADED)

Appearance		B & C	ASTM D 4176
Octane number, Aviation Rating		93.1	ASTM D 910
Performance number, rich mixture		106.8	ASTM D 909
Octane number research		> 99.6	ASTM D 2699
Tetraethyllead (TEL-B)	gPb/1	< 0.001	ASTM D 3237
1.2 dibrdmoethane		none	
Color		undyed	Visual
Color		.....	IP-17A
Calorific Value, net	MJ/kg	43.65	ASTM D 1405
Aniline Gravity Product		8249	ASTM D 611
Density at 15 degrees C	kg/m3	7201.8	ASTM D 4052
Initial Boiling Point	degrees C	39	ASTM D 86
Evaporated 10 vol-% at	degrees C	67	
Evaporated 40 vol-% at	degrees C	101	
Evaporated 50 vol-% at	degrees C	105	
Evaporated 90 vol-% at	degrees C	111	
Final Boiling Point at	degrees C	135	
Sum of 10% + 50%, evaporated	degrees C	172	
Recovery	vol-%	98.2	
Residue	vol-%	1.4	
Loss	vol-%	0.4	
Evaporated at 75 degrees C	vol-%	not recorded	
Evaporated at 105 degrees C	vol-%	50	
Reid Vapor Pressure (RVP)	kPa	44,5	ASTM D 323
Freezing Point	degree C	<-75	ASTM D 2386
Total Sulphur	wt -%	0.0007	ASTM D 3120
Copper Corrosion, 2 hours at 100 degrees C		1	ASTM D 130
Existent Gum	mg/100 ml	< 0.5	ASTM D 381
Oxid. Stability, Potent Gum (16 h)	mg/100 ml	<0.5	ASTM D 873
Lead Precipitate	mg/100 ml	<0.5	ASTM D 873
Water reaction, Interface Rating		1	ASTM D 1094
Water reaction, Separation Rating		1	
Water reaction, Volume change	ml	0.5	
Total Acid Number (TAN)	mg KOH/g	.....	ASTM D 974
Dye	mg/l	none	
Antioxidant	mg/1	20	Shell Ionox
N-Hexane	mas-%	0.08	GC-method
Benzene	mas-%	0.04	GC-method
Methyl-n-butyl ketone	mg/kg	none	GC-MS

HJELMCO OIL AB

Date 1991-Mar-11

Material safety data sheet in accordance with section 17 of the Decision of the Council of State on the Classification, Warning Labelling and Material Safety Data ...sts of Dange... : Chemicals and section 19 of the Chemicals Degre...

1 Product information

1.1 Trade name	Aviation gasoline 91, unleaded (AVGAS 91/96 UL)
1.2 Product use	Fuel (use as aviation gasoline only)
1.3 Manufacturer/Importer Address, telephone, telex Telefax, Official Employer Idenfication Number (LY code)	Hjelmco Oil, Runskogsvägen 4 B, S 191-48 Sollentuna Sweden Tel. int+46-8-6269386, telex int+54-15737 Hjelmco S, Fax int+46-8-6269416.

2 Product classification

2.1 Danger symbol	Extremely flammable, harmful	2.2 Transport class	3 c1, 3 b) (VAK and ADR)
2.3 UN number	1203	2.4 Carcinogenic substances	
2.5 Warning labelling	$F+$, X_n: R: 12-20/21/22: S: 16-23-24-29-46		

3 Substances hazardous to health

3.1 Substances	3.2 Concentration	3.3 Dangerous property
Petroleum product	100 %	Extremely flammable, readily volatile liquid. Harmful when inhaled, in contact with skin and if swallowed. HTP (1987, 8h) = 770 mg/m^3
Contains aromatics, maximum 20 vol-%		HTP (1987, 15 min) = 1020 mg/m^3 (solvent naphtha, aromatics 20 %, boiling range min 110° C.)

4 Chemical and physical properties of the product

4.1 Boiling point	Range 30 - 170° C	4.2 Melting point	Freezing point max. -60° C.		
4.3 Vapour pressure	38 - 49 kPa (37,8° C)	4.4 Solubility in water	Insoluble		
4.5 Density	Approx. 715 kg/m3 (15° C)	4.6 Evaporation rate (butyl acetate=1)		4.7 pH	
4.8 Physical state, colour and odour	Clear liquid with an aromatic odour				

5 Fire and explosion data of the product

5.1 Flash point	Below - 50° C		
5.2 Flammable limits	1 - 8 vol-%	5.3 Auto-ignition temperature	Approx. 450° C.
5.4 Reactivity			

Date 1991-Mar-11

Trade name	Aviation gasoline 91, unleaded (AVGAS 91/96 UL)

6 Health hazard

6.1 Route of exposure	Inhalation of vapour. Skin contact.
6.2 Local effects (skin, eyes, mucous membranes)	Liquid irritates the eyes and skin. Vapour irritates the eyes and mucose membranes in the nose and throat.
6.3 Effects of overexposure Short-term exposure	Vapour irritates mucous membranes in the nose and throat and produces narcotic effects, headache and nausea
6.4 Effects of overexposure Long-term exposure	Prolonged over-exposure to vapour causes fatigue, headache and nervous disorders.

7 Special safety measures

7.1 Technical safety measures	USE AS AVIATION GASOLINE ONLY. Avoid skin contact and breathing of vapour. When necessary, wear protective gloves (e.g. nitrile rubber) and a respirator (organic vapour filter, type A). Must not be stored in unsuitable or unlabelled containers. Vapour is flammable. Danger of spark formation caused by static electricity must be eliminated by earthing. Keep sources of ignition away from open containers, smoking forbidden.
7.2 Special first-aid measures	When cleaning tanks, special instructions must be followed. <u>Splashes in the eyes</u>: Irrigate with plenty of water. <u>Ingestion</u>: Slurry of medical carbon (25-50 g) in water and medical attention. DO NOT INDUCE VOMITING due to risk of aspiration and chemical pneumonitis

8 Special instructions

8.1 Storage	
8.2 Corrosive properties	
8.3 Cleaning methods	Do not flush into sewer (explosion risk), to the ground or to water systems. Collect leaks if possible. Small amounts can be soaked up by absorbent material.
8.4 Hazards to the environment	Danger of ground water pollution.
8.5 Rendering the substance harmless	To be treated as hazardous waste according to authorities' advice.
8.6 Instructions for fire	DO NOT EXTINGUISH WITH WATER. Extinguishing agents CO_2, dry chemical foam.

For further information please contact	Signature
Hjelmco Oil Oil product information tel. int+46-8-297281	HJELMCO OIL pp. Lars Hjelmberg

☐ Further information enclosed

TEXTRON Lycoming
Reciprocating Engine Division/
Subsidiary of Textron Inc.
652 Oliver Street
Williamsport, PA 17701 USA

SERVICE INSTRUCTION

DATE: January 20, 1995

Service Instruction No. 1070L
(Supersedes Service Instruction No. 1070K)
Engineering Aspects are
FAA Approved

SUBJECT: Specified Fuels
MODELS AFFECTED: Textron Lycoming opposed series aircraft engines.
TIME OF COMPLIANCE: When refueling aircraft.

During the past several years significant changes have occurred in the grade designations and tetraethyl lead content of some of the commercial aviation fuels available on the world markets. These changes included the discontinuance of leaded commercial grades 91/96, and 115/145 fuels and the limited availability of 80/87 grade in US, as well as over seas countries. A low lead content fuel, currently designated "100LL" has been available. Also, a new unleaded, colorless AVGAS fuel, currently designated 91/96 UL has been introduced for use in a limited area of Europe. A summary of the current grades as well as the previous fuel designations are shown in the following chart.

FUEL GRADE COMPARISON CHART

Previous Commercial Fuel Grades (ASTM-D910)			Current Commercial Fuel Grades (ASTM-D910-75)			Current Military Fuel Grades (MIL-G-5572F)		
Grade	Color	Max. TEL ml/U.S. gal.	Grade	Color	Max. TEL ml/U.S. gal	Grade	Color	Max. TEL ml/U.S. gal
80/87	red	0.5	80	red	0.5	80/87	red	05
91/96	blue	2.0	91/96 UL	none	0			
			*IOOLL	blue	2.0			
100/130	green	3.0	100	green	**3.0	100/130	blue	2.00
115/145	purple	4.6	none	none	none	115/145	purple	4.6

* Grade 100LL fuel in some over seas countries is colored green and designated as "100L".
** Commercial fuel grade 100 and grade 100/130 having TEL content of up to 4ml/U.S. gallons are approved for use in all engines certificated for use with grade 100/130 fuel.

The importance of using the fuel specified for a specific model Textron Lycoming engine has always been stressed in Textron Lycoming service publications. However, if the specified fuel is not available, a higher grade-fuel may be used, subject in some instances to the restrictions described in the footnotes to the following table of specified fuels. The chart showing specified and alternate fuels that can be safely used in no instance permits use of fuels of lower grade than that which is specified. Also, it is not permissible in any instance to use automotive fuel in aircraft engines, regardless of its octane or advertised features because of the corrosive effect of its chlorine content and because of vapor lock that could result from its high vapor pressure. Any fuel used in Textron Lycoming engines must conform with Specifications ASTM-D910 or MIL-G-5572F.

NOTE

Isopropyl alcohol in amounts not to exceed 1% by volume may be added to the fuel to prevent ice formation in fuel lines and tanks. Although approved for use in Textron Lycoming engines, isopropyl alcohol should not be used in the aircraft fuel systems unless recommended by the aircraft manufacturer.

TABLE OF SPECIFIED FUELS

<table>
<tr><th rowspan="2">Engine Models</th><th colspan="2">SPECIFIED FUELS</th><th rowspan="2">Alternate Military and Commercial Grades</th></tr>
<tr><th>Certificated for Use With Grade</th><th>Commercial Grade Designation</th></tr>
<tr><td>O-235-C, E,-H; O-290-I O-435-A,-C</td><td>80</td><td rowspan="2">80</td><td rowspan="2">91/96 UL
or
①⑤100LL
or
⑤②③100
or
⑤④100/130
②③</td></tr>
<tr><td>O-290-D2; O-320-A,-C, -E; IO-320-A,-E; AEIO-320-E; 0-340-B; 0-360-B,-D-, GO-435-C2*; VO-435-A; GO-480-B,-D,-F; O-540-B; VO-540-A,-B</td><td>80/87</td></tr>
</table>

* -GO-435-C2 engines with Marvel-Schebler carburetor no. 10-3991 are certificated to use 91/96 fuel.

TABLE OF SPECIFIED FUELS (CONT.)

Engine Models	SPECIFIED FUELS		Alternate Military and Commercial Grades
	Certificated For Use With Grade	Commercial Grade Designation	
O-320-B,-D; IO-320-B,-D; LIO-320-B1A; AEIO-320-D; AIO-320-A,-B, -C; O-480-A; O-360-A,-C; IO-360-B, -E; AEIO-360-B,-H; VO-360-A,-B; IVO-360-A- HO-360-A,-B; HIO-360-B; O-435-A2; GO-435-C2*; O-540-A,-D,-E,-F,-G,-H; 10-540-Ci-D,-Ni-T; AEIO-540-D	91/96	100LL or 100	91/96 UL or ④100/130 or ④115/145
O-235-F,-G,-J,-K, -L; IO-320-C,-F; LIO-320-C1A; IO-360-A,-C, -D,-F; LIO-360-C; AEIO-360-A; AIO-360-A,-B; HIO-360-A,-C,-D,-E; TO-360-A,-C; LIO-360-A; TIO-360-A; VO-435-A,-B; TVO-435-A,-B,-C,-D,-E, -F.-G; GO-480-C,-G; IGO-480-A; GSO-480-A,-B; IGSO-480-A; 10-540-A,-B, -E,-G,-J,-K,-L,-M,-P,-R, -S,-U; HIO-540-A; TIO-540-A,-C,-E,-Fi-G,-H,-J, -N,-R,-S; LTIO-540-F,-J, -N,-R; TIO-54 I -A,-E; VO-540-C; IVO-540-A; TIVO-540-A; IGO-540-A,-B; IGSO-540-A,-B; TIGO-541-B,-C,-D,-E,-G; 10-720-A, -B,-C,-D	100/130	100LL or 100	④100/130 or ④115/145
O-320-H; O-360-E; LO-360-E; O-540-J,-L	100LL		

GO-435-C2 engines with Marvel-Schebler carburetor no. 10-3991 are certificated to use 91/96 fuel.

1. Grade 100LL or 100L in which the lead content is limited to 2 ml. of TEL per gallon are approved for continuous use in all Textron Lycoming engines listed herein. Inspection procedures described in the following footnotes are not required for engines using this fuel.

2. O-235-C, O-290-D, -D2 and O-435-A2, -K 1 (O-435-4) engines are built with solid stem exhaust valves. The use of fuels with higher lead content of more than 2 ml. of TEL per US. gallon must be limited to 25 % of the operating time. If used for longer periods of time the same 150 hour inspection requirement, described in the following note is applicable. O-235-C and O-290-D models can be converted to use sodium cooled exhaust valves. See latest edition of Service Instruction No. 1246 for procedure.

3. Early production O-320-A, -C, -E; GO-435; VO-435-A; and GO-480-B, -D, -F were built with solid stem exhaust valves and their use with fuels having lead content of more than 2 ml. of TEL per U.S. gallon is limited to 25 % of operating time. If specified fuel is not available and usage with high leaded fuel exceeds 25 % of the operating time, the valve stems should be inspected at 150 hour intervals for erosion, or "necking." This inspection is accomplished by removing the exhaust manifold and visually inspecting the valves through exhaust ports. To determine if an engine has solid stem exhaust valves, remove the rocker cover and look for valve rotor caps which are used with sodium cooled valves but not with solid stem valve in these particular engines.

4. Continuous use of military grade 100/1 30 or 1 15/145 fuel with 4.6 mililiters of TEL per U.S. gallon can result in increased lead deposits both in combustion chambers and spark plugs causing engine roughness and scored cylinder walls. It is recommended that the use of this fuel be limited wherever possible; however, when 115/145 fuel is used, periodic inspections of combustion chambers, valves and valve ports should be conducted more frequently and spark plugs rotated or cleaned whenever lead fouling is experienced.

5. See latest edition of Service Letter No. LI 85 for operating recommendations.

NOTE: Revision "L" adds new 91/96 unleaded AVGAS fuel for use in a limited area of Europe.

Aircraft engines manufactured by Teledyne Continental Certificated fuel qualities are found in the column, "Fuel Grade"

SPECIFICATIONS
CURRENT PRODUCTION ENGINES

MODEL	NO. OF CYL.	TAKEOFF POWER HP@RPM	METRO POWER HP@RPM	BORE & STROKE	DISP. CU/IN	ENGINE DIMENSIONS			WEIGHT DRY LBS. BASIC ENG.	PROP. DRIVE	FUEL GRADE	COMP RATIO
						LENGTH	WIDTH	HEIGHT				
O-200	4		100-2750	4.06 x 3.87	200	28.50	31.56	23.18	188	Direct	80/87	7.0:1
O-300-A* & C*	6		145-2700	4.06 x 3.87	300	39.75	31.50	23.25	270	Direct	80/87	7.0:1
O-300-D*	6		145-2700	4.06 x 3.87	300	36.00	31.50	27.00	272	Direct	80/87	7.0:1
IO-360-A*,C*,D*,G*,&H* †	6		210-2800	4.44 x 3.87	360	34.60	31.40	24.33	294	Direct	100/100LL	8.5:1
IO-360-J*,JB	6	210-2800	195-2600	4.44 x 3.87	360	34.60	31.40	24.33	294	Direct	100/100LL	8.5:1
IO-360-K*KB	6		195-2600	4.44 x 3.87	360	34.60	31.40	24.33	294	Direct	100/100LL	8.5:1
TSIO-360-A*	6		210-2800	4.44 x 3.87	360	35.84	33.03	23.75	300	Direct	100/100LL	7.5:1
TSIO-360-C*,CB	6		225-2800	4.44 x 3.87	360	35.84	33.03	23.75	300	Direct	100/100LL	7.5:1
TSIO-360-D,DB	6	225-2800	225-2800	4.44 3.87	360	34.60	31.40	24.33	278	Direct	100/100LL	7.5:1
L/TSIO-360-E*,EB	6		200-2575	4.44 x 3.87	360	*56.58	31.30	26.44	352*	Direct	100/100LL	7.5:1
TSIO-360-F*,FB	6		200-2575	4.44 x 3.87	360	*56.58	31.30	26.44	359*	Direct	100/100LL	7.5:1
TSIO-360-G*,GB,LB	6		210-2700	4.44 x 3.87	360	*33.57	33.88	31.90	354*	Direct	100/100LL	7.5:1
TSIO-360-H*,HB	6		210-2800	4.44 x 3.87	360	35.34	31.38	22.43	313	Direct	100/100LL	7.5:1
TSIO-360-K,KB	6	220-2800	220-2800	4.44 x 3.87	360	*56.58	31.30	26.44	359*	Direct	100/100LL	7.5:1
O-470-G*	6		240-2600	5 x 4	470	37.56	33.58	26.69	431	Direct	91/96	8.0:1
O-470-J*	6		225-2550	5 x 4	470	36.03	33.32	27.75	380	Direct	80/87	7.0:1
O-470-K* & L*	6		230-2600	5 x 4	470	36.03	33.56	27.75	404	Direct	80/87	7.0:1
O-470-M*	6		240-2600	5 x 4	470	43.31	33.56	19.62	409	Direct	91/96	8.0:1
O-470-R	6		230-2600	5 x 4	470	36.03	33.56	28.42	401	Direct	80/87	7.0:1
O-470-S	6		230-2600	5 x 4	470	36.03	33.56	28.42	412	Direct	100/100LL	7.0:1
O-470-U	6		230-2400	5 x 4	470	36.03	33.56	28.42	412	Direct	100/100LL	8.6:1
IO-470-C*	6		250-2600	5 x 4	470	37.93	33.58	26.81	431	Direct	91/96	8.0:1
IO-470-D* & E*	6		260-2625	5 x 4	470	43.31	33.56	19.75	426	Direct	100/100LL	8.6:1
IO-470-F*	6		260-2625	5 x 4	470	37.22	33.56	23.79	426	Direct	100/100LL	8.6:1
IO-470-H*	6		260-2625	5 x 4	470	38.14	33.58	26.81	431	Direct	100/100LL	8.6:1
IO-470-J* & K*	6		225-2600	5 x 4	470	38.14	33.39	26.81	401	Direct	80/87	7.0:1
IO-470-L	6		260-2625	5 x 4	470	43.17	33.56	19.75	430	Direct	100/100LL	8.6:1
IO-470-M*	6		260-2625	5 x 4	470	47.16	33.58	19.75	430	Direct	100/100LL	8.6:1
IO-470-N	6		260-2625	5 x 4	470	38.14	33.58	26.81	433	Direct	100/100LL	8.6:1
IO-470-S*	6		260-2625	5 x 4	470	41.41	33.56	19.75	426	Direct	100/100LL	8.6:1
IO-470-U*	6		260-2625	5 x 4	470	44.14	33.86	19.75	423	Direct	100/100LL	8.6:1
IO-470-V*,VO	6		260-2625	5 x 4	470	43.69	33.56	19.75	423	Direct	100/100LL	8.6:1
TSIO-470-B*,C* & D*	6		260-2600	5 x 4	470	39.52	33.56	20.25	423	Direct	100/100LL	7.5:1
IO-520-A* & J	6		285-2700	5.25 x 4	520	41.41	33.56	19.75	431	Direct	100/100LL	8.5:1
IO-520-B*,BA*,BB	6		285-2700	5.25 x 4	520	39.71	33.58	26.71	422	Direct	100/100LL	8.5:1
IO-520-C*,CB	6		285-2700	5.25 x 4	520	42.88	33.56	19.75	415	Direct	100/100LL	8.5:1
IO-520-D	6	300-2850	285-2700	5.25 x 4	520	37.36	35.46	23.79	430	Direct	100/100LL	8.5:1
IO-520-E	6	300-2850	285-2700	5.25 x 4	520	47.66	33.56	19.75	427	Direct	100/100LL	8.5:1
IO-520-F	6	300-2850	285-2700	5.25 x 4	520	41.41	35.91	19.75	430	Direct	100/100LL	8.5:1
IO-520-K	6	300-2850	285-2700	5.25 x 4	520	40.91	33.56	19.75	428	Direct	100/100LL	8.5:1
IO-520-L	6	300-2850	285-2700	5.25 x 4	520	40.91	33.56	23.25	431	Direct	100/100LL	8.5:1
IO-520-M*,MB	6		285-2700	5.25 x 4	520	46.80	33.56	20.41	413	Direct	100/100LL	8.5:1
IO-550-B	6	300-2700	300-2700	5.25 x 4.25	550	37.97	33.56	27.32	422	Direct	100/100LL	8.5:1
IO-550-C	6	300-2700	300-2700	5.25 x 4.25	550	43.31	33.56	19.78	433	Direct	100/100LL	8.5:1
TSIO-520-B*,BB	6		285-2700	5.25 x 4	520	39.75	33.56	20.32	423	Direct	100/100LL	7.5:1
TSIO-520-C & H	6		285-2700	5.25 x 4	520	40.91	33.56	20.04	433	Direct	100/100LL	7.5:1
TSIO-520-D*,DB	6		285-2700	5.25 x 4	520	43.25	33.58	22.34	423	Direct	100/100LL	7.5:1
TSIO-520-E*,EB	6		300-2700	5.25 x 4	520	39.75	33.56	20.32	421	Direct	100/100LL	7.5:1
TSIO-520-G	6	300-2700	285-2600	5.25 x 4	520	40.91	33.56	20.04	433	Direct	100/100LL	7.5:1
TSIO-520-J*,JB,N*,NB	6		310-2700	5.25 x 4	520	54.36	33.56	22.50	412	Direct	100/100LL	7.5:1
TSIO-520-K,KB	6		285-2700	5.25 x 4	520	54.36	33.56	20.32	412	Direct	100/100LL	7.5:1
TSIO-520-L*,LB	6		310-2700	5.25 x 4	520	50.62	33.56	20.02	514*	Direct	100/100LL	7.5:1
TSIO-520-M & P	6	310-2700	285-2600	5.25 x 4	520	40.91	33.56	20.04	436	Direct	100/100LL	7.5:1
TSIO-520-R	6	310-2700	285-2600	5.25 x 4	520	40.91	33.56	23.54	436	Direct	100/100LL	7.5:1
TSIO-520-T	6		310-2700	5.25 x 4	520	*38.20	33.56	32.26	426*	Direct	100/100LL	7.5:1
TSIO-520-U*,UB	6		300-2700	5.25 x 4	520	*44.73	33.56	28.86	536*	Direct	100/100LL	7.5:1
TSIO-520-V*,VB	6		325-2700	5.25 x 4	520	39.25	33.56	20.41	456	Direct	100/100LL	7.5:1
TSIO-520-W*,WB	6		325-2700	5.25 x 4	520	*50.62	33.56	20.02	539*	Direct	100/100LL	7.5:1
L/TSIO-520-AE	6	250-2400	250-2400	5.25 x 4	520	38.07	33.29	21.38	365	Direct	100/100LL	8.5:1
TSIO-520-AF	6	310-2600	285-2600	5.25 x 4	520	40.31	33.56	23.54	418	Direct	100/100LL	7.5:1
TSIO-520-BE	6	310-2600	310-2600	5.25 x 4	520	42.64	42.50	33.50	566*	Direct	100/100LL	7.5:1
TSIO-520-CE	6	325-2700	325-2700	5.25 x 4	520	41.00	34.00	25.00	527	Direct	100/100LL	7.5:1
GTSIO-520-C*	6		340-3200	5.25 x 4	520	42.56	34.04	23.10	481	Geared	100/100LL	7.5:1
GTSIO-520-D & H	6		375-3400	5.25 x 4	520	42.56	34.04	26.78	508	Geared	100/100LL	7.5:1
GTSIO-520-K	6		435-3400	5.25 x 4	520	*56.25	34.04	26.18	600*	Geared	100/100LL	7.5:1
GTSIO-520-L,N	6		375-3350	5.25 x 4	520	43.87	34.04	26.41	557	Geared	100/100LL	7.5:1
GTSIO-520-M	6		375-3350	5.25 x 4	520	43.87	34.04	26.80	507	Geared	100/100LL	7.5:1
Tiara 6-285*	6		285-4000	4.88 x 3.62	406	40.11	32.91	24.22	382	Geared	100/100LL	9.0:1

† Includes IO-360-AB,CB,DB,GB,HB   * Rebuilt Only   * Includes Turbo and exhaust system

LYCOMING WILLIAMSPORT -DIVISION
AVCO CORRORATION
WILLIAMSPORT, PENNSYLVANIA 17701

DATE: November 23, 1984

Service Instruction No. 1409A
(Supersedes Service Instruction No. 1409)
Engineering Aspects are
FAA Approved

SUBJECT: Avco Lycoming LW-16702 Oil Additive.
MODELS AFFECTED: All Avco Lycoming piston aircraft engines.
TIME OF COMPLIANCE: At initial oil fill and every oil change thereafter, or at every 50 hours, whichever occurs first.

Avco Lycoming has approved an oil additive LW-16702 that has an anti-scuffing agent. This characteristic serves to reduce wear. For engines already in service, the use of the additive may be started at the next oil change. Use oil additive, as shown in the following chart.

Use (one) 6 ounce can (LW-16702) per 6 - 8 quart sump.
Use (two) 6 ounce cans (LW-16702) per 12 - 15 quart sump.
Use (three) 6 ounce cans (LW-16702) per 17 - 19 quart sump.
Use (four) 6 ounce cans (LW-16702) 'per 23 quart sump.

This oil additive may be purchased from your Avco Lycoming distributor.

NOTE

"If it is determined that a FAA approved lubricating oil being used contains, in the proper amount, an oil additive equivalent to LW-16702, the provisions of this Service Instruction are being met."

NOTE: Revision "A" adds NOTE recognizing FAA-approved oils that contain an additive equivalent to

Avco Lycoming oil additive, LW-16702.
21530, 21530A - This number for Avco Lycoming reference only.

FUTURE FUELS

Unleaded bio-alkylate AVGAS

- low toxicity
- price competitive in Europe
- can meet ASTM D-910
- from renewable resources

FUTURE FUELS

Unleaded bio-alkylate AVGAS

- high-octane numbers, > 95
- no aromatics, < 1 weight %
- no sulphur, < 1 ppm
- no olefins

FUTURE FUELS

Bio-alkylate AVGAS

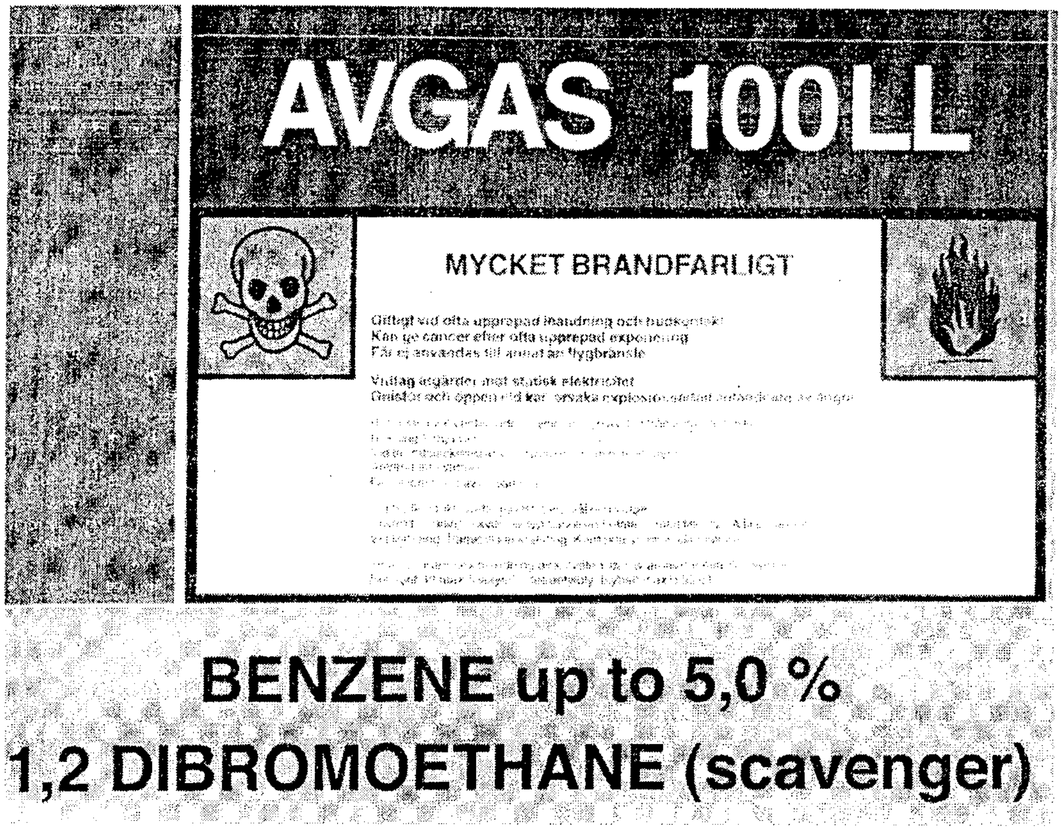
In nature carbon dioxide + water + sunlight	**Photosynthesis** → **Sugar** →	Enzymes Oil, Fat
Sugar and other bio-pulps	**Fischer-Tropsch synthesis** → **Imitates natural processes**	Fischer-Tropsch e.g., vegetable oil

FUTURE FUELS

Synthetic fuel components can be used to obtain nontoxic unleaded high-octane AVGAS

AVGAS 91/96 UL

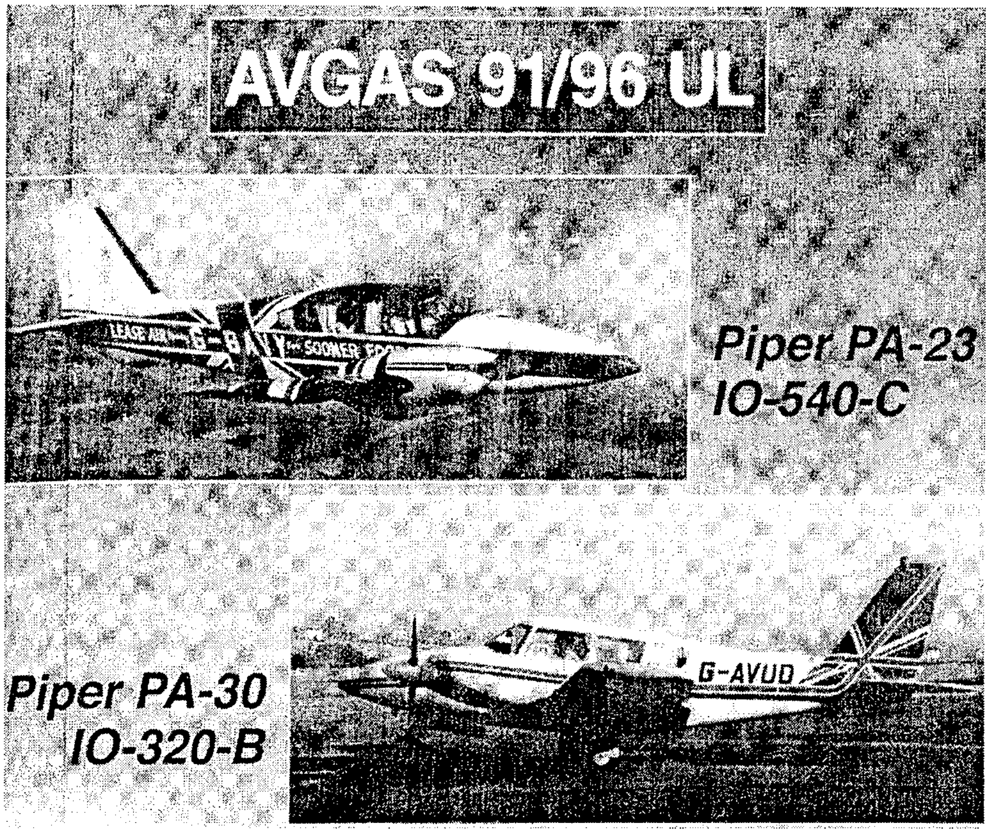
An unleaded aviation gasoline with a 50 times lower concentration of certain environmental impurities than the maximum allowed today in unleaded, automotive gasoline.

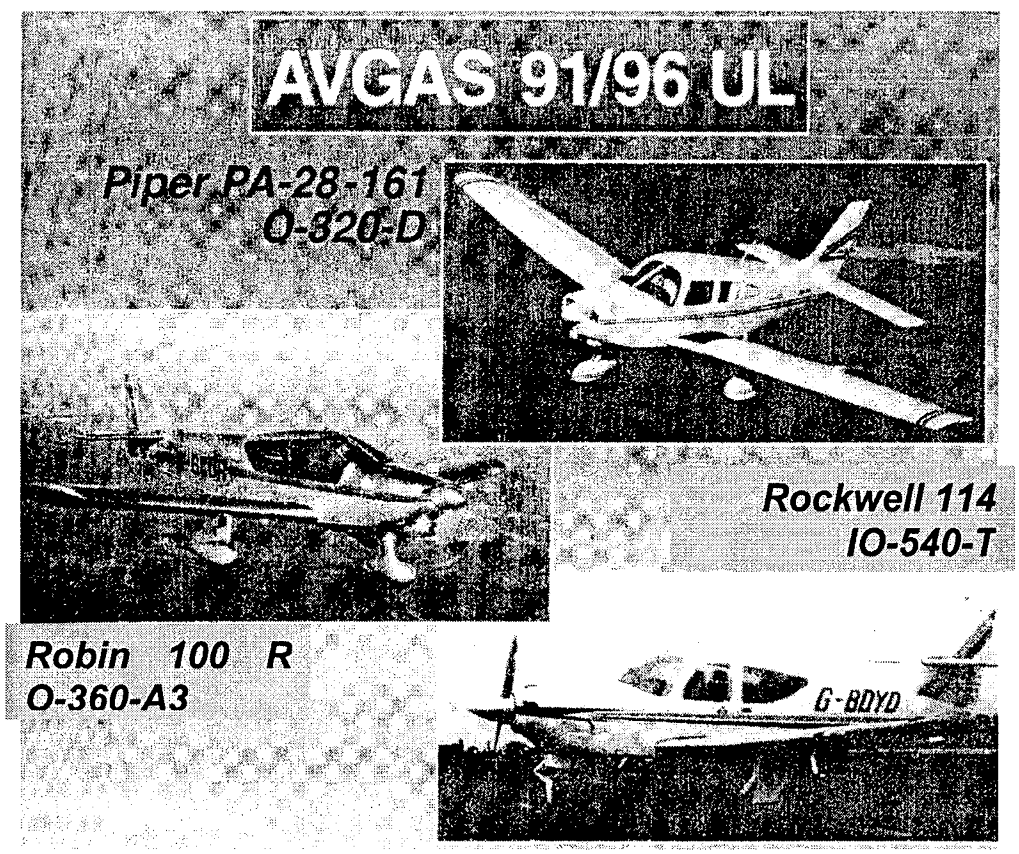

AVGAS 100LL
MYCKET BRANDFARLIGT
BENZENE up to 5,0 %
1,2 DIBROMOETHANE (scavenger)


AVGAS 91/96 UL
MYCKET BRANDFARLIGT
FARLIGT VID INANDNING
A FUEL FOR
≈ 70 % OF
THE GENERAL AVIATION FLEET

AVGAS 91/96 UL

Introduced spring 1991
Nationwide distribution spring 1993


AVGAS 91/96 UL
Piper PA-23
IO-540-C
Piper PA-30
IO-320-B
G-AVUD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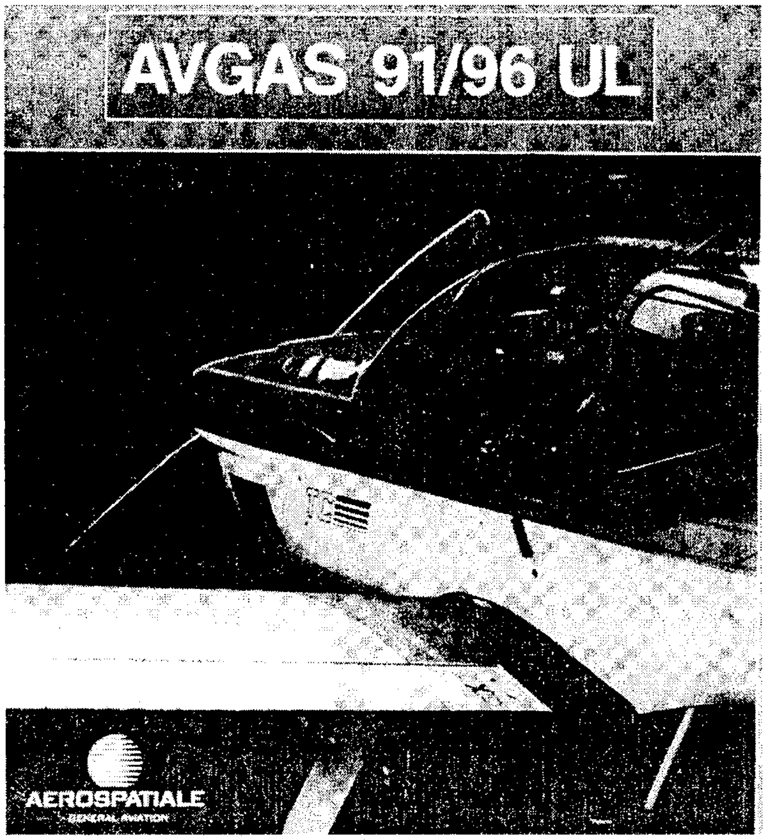

AVGAS 91/96 UL

ENVIRONMENTAL QUALITIES

• unleaded	brain damage
• no dyes	allergic reactions
• no scavenger	carcinogenic greenhouse effect
• almost no benzene (< 0.1%)	carcinogenic
• almost no n-hexane (<0.1%)	damage to nervous system
• almost no sulphur (<0.001%)	acid rain respiratory disease


AVGAS 91/96 UL
VI TÄNKER PÅ DIG
OCH DIN MILJÖ...
AVGAS 91/96 UL
DET OBLYADE FLYGBRÄNSLET MED
SPECIELLA MILJÖEGENSKAPER*
HJELMCO OIL AB
Runskogsvägen 4 B 191 48 SOLLENTUNA


AVGAS 91/96 UL
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SPECIELLA MILJÖEGENSKAPER*
HJELMCO OIL AB
Runskogsvägen 4 B 191 48 SOLLENTUNA

UNLEADED AVGAS FROM HJELMCO OIL

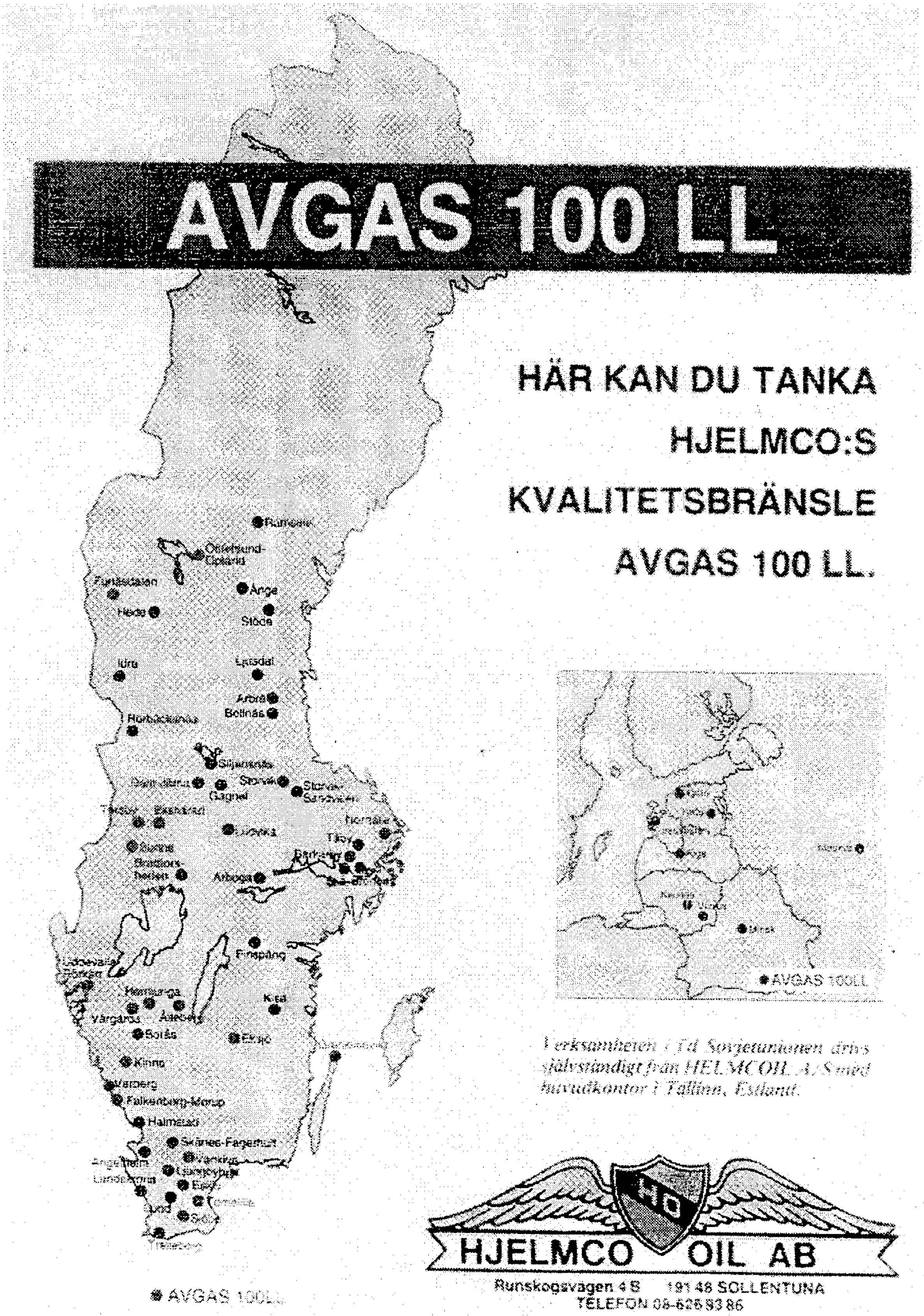
1st generation launched 1981	*80/87*
2nd generation launched 1991	*91/96*
3rd generation launched 199?	

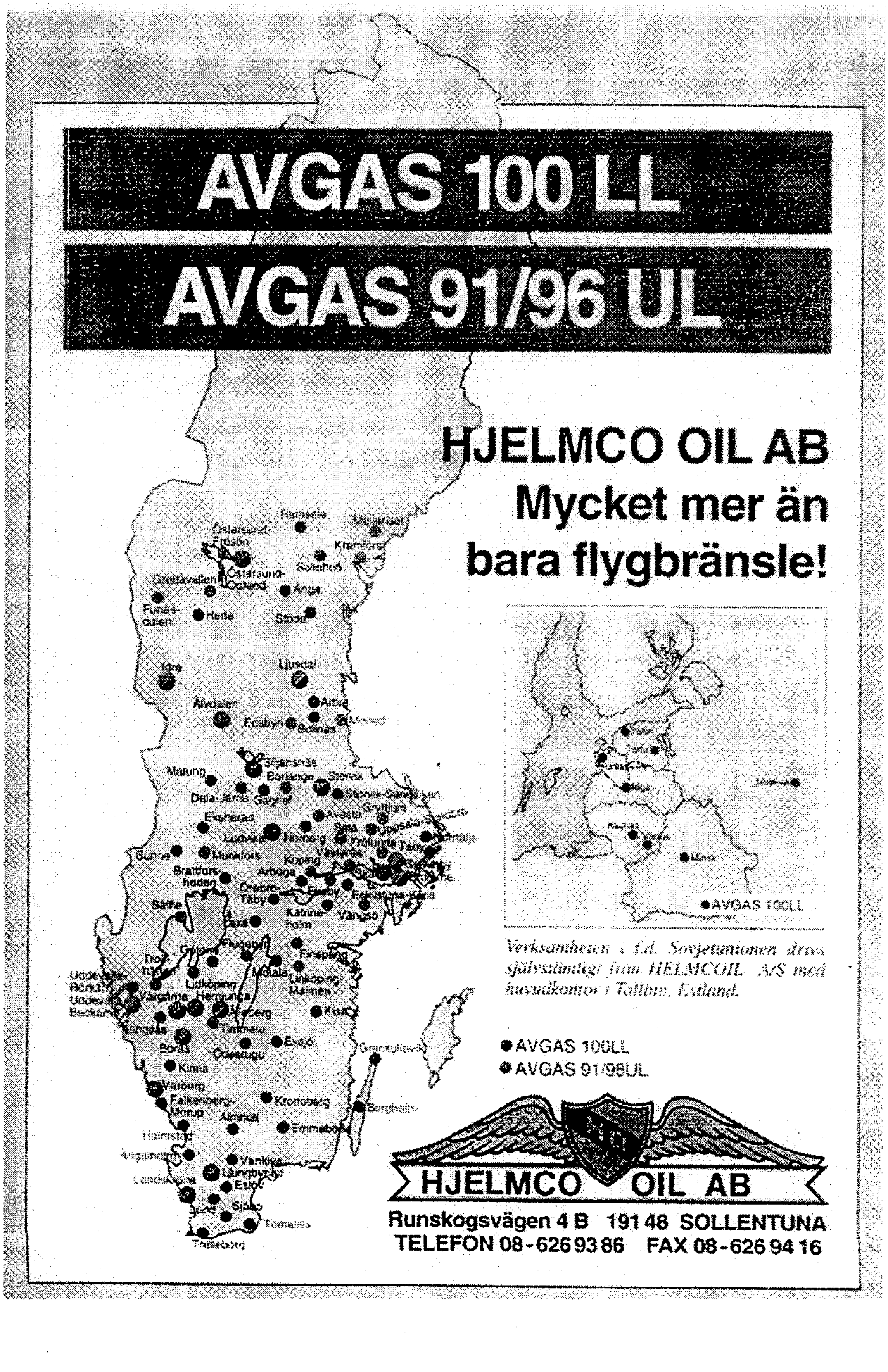
FUTURE FUELS

No **benzene**
n-hexane
aromatics
sulphur
lead
olefins

...Low **vapour pressure**


AVGAS 91/ 96 UL
HÄR KAN DU TANKA
FLYGBRÄNSLET MED
SPECIELLA MILJÖEGENSKAPER*
Hjelmco:s
AVGAS 91/96 UL
är rekommenderat av
Textron LYCOMING
(AVGAS 91/96 UL är det enda blyfria bränslet
som anvisas av Textron Lycoming. Se vidare i
serviceinstruktion nr 1070 L, daterad 95-01-20)
AVGAS 91/96UL
HJELMCO OIL AB
Runskogsvägen 4 B 191 48 SOLLENTUNA
TELEFON 08-626 93 86


AVGAS 100 LL
HÄR KAN DU TANKA
HJELMCO:S
KVALITETSBRÄNSLE
AVGAS 100 LL.
Verksamheten i f.d. Sovjetunionen drivs självständigt från HELMCOIL A/S med huvudkontor i Tallinn, Estland.
HJELMCO OIL AB
Runskogsvägen 4 B 191 48 SOLLENTUNA
TELEFON 08-626 93 86
AVGAS 100LL


AVGAS 100 LL
AVGAS 91/96 UL
HJELMCO OIL AB
Mycket mer än
bara flygbränsle!
●AVGAS 100LL
Verksamheten i f.d. Sovjetunionen drivs självständigt från HELMCOIL A/S med huvudkontor i Tallinn, Estland.
●AVGAS 100LL
●AVGAS 91/96UL
HJELMCO OIL AB
Runskogsvägen 4 B 191 48 SOLLENTUNA
TELEFON 08-626 93 86 FAX 08-626 94 16

Alternative Aviation Fuel Management

Paul Pendleton, Aircraft Propulsion Engineer
Aircraft Certification Division
Federal Aviation Administration
1801 Airport Road, Room 100
Wichita, KS 67209

I was the last speaker and as such

1. I presented an overview of where we have been during the 1930's with the advent of World War II in relation to leaded aviation gasoline.

2. I overviewed operations during the 1950s to 1970s with the advent of 100LL and where we are at today with recognition of all the significant points of the prior speakers comments during the Second International Conference on Alternative Aviation Fuels.

3. The primary points of my presentation are as follows:

Presentation

I got involved in alternative aviation fuels in the early 1980's when the Experimental Aviation Association and Petersen Aviation were working on obtaining FAA approval of automotive gasoline on U.S. civil type certified airplanes. We determined the primary obstacles to overcome were the reduced octane and raised vapor of automotive gasolines as compared to grade 100 and 100LL fuels currently available as well as grade 80 and 91/96 which may be produced with or without lead. We determined that there was going to be an adequate distribution system for unleaded gasoline for a long time in the future but that leaded gasolines would be expensive to produce and distribute in view of their low volume and number of refineries.

Recognizing that aviation gasoline's annual consumption is less than 0.5% of all domestic gasoline consumption and that this figure is less than the annual consumption of lawn mowers or a single day's consumption of automobile gasoline by US cars and trucks, we thought we should start working on a gasoline for aircraft based on fuel stocks intended for the automobile industry. As Ron [Wilkinson] and Ken [Knopp] here today have stated, the research on octane characterization of engines is an ongoing effort that we hope to have completed within the next 12 months. We are also confident that the airframe modifications that have been required on autogas approvals that have been issued by the FAA in the form of Supplemental Type Certificates (STCs) for vapor pressure will be able to be extended to the new fuel currently being considered by ASTA.

Some of the FAA issued STCs have included approvals for use of Anti-Detonation Injection (ADI) that have been proven very successful in dealing with the issue of low octane in engines originally rated on high-octane aviation gasolines. Aircraft that have been FAA STC approved are equipped with engines ranging in power from 50 to 1250 horsepower. These aircraft are approved with either 87 or 91 octane (RON + MON)/2 ratings both with and without ADI.

Yearly, approximately 25 million gallons of automotive gasoline are currently being used by the civil aircraft in the U.S. This compares with approximately 350 million gallons of avgas used by US civil aircraft annually. Most grade 80 gasoline blended for aircraft use in the last 15 years has been an unleaded product. This compares with all grade 91/96 unleaded aviation gasoline produced in Sweden for the last 10 years, which is still being produced today.

It should be noted that approximately 25% of all domestic (US) aircraft use approximately 75% of the aviation gasoline refined in this country. That means that these 25% need the high-octane and low vapor pressure aviation gasoline that we currently identify as 100LL or grade 100. Many of the reciprocating aircraft engines that the FAA has recently certified have been liquid cooled. These certificate holders have invested considerable financial resources which they are hopeful will be recoverable in the future years of general aviation. The Amine additives/blending agents mentioned by Joe Valentine will hopefully produce fuels for the octane requirements of all US aircraft engines previously and currently in production as well as future generation engines.

The engine analyzing equipment described by Cesar [Gonzalez] has produced very reliable results in assessing the detonation patterns of many engines and should play a significant part in the development of future fuels and engines for general aviation.

In summary, you have heard from several knowledgeable industry and government specialists about very positive efforts to bring general aviation in to the 21st century on a level comparable to the environmental constraints of all intermittent spark engines that we believe will be around for many years to come. I thank you for your consideration and continued support of these programs and welcome comments and any additional support we could consider.

CURRENT RESEARCH ON NONPETROLEUM-BASED ALTERNATIVE AVIATION FUELS AND ENGINES

BILL HOLMBERG, SUSTAINABLE NEW-WEALTH INDUSTRIES (*FACILITATOR*)

CHRIS ATKINSON, WEST VIRGINIA UNIVERSITY
TED AULICH AND TIM GERLACH, UNIVERSITY OF NORTH DAKOTA
ZOHER MERATLA, CDS RESEARCH, LTD.
RON NEWBERG, CANADIAN AERO PETROLEUM
MARV RANDALL, VANGUARD SQUADRON
MAXWELL SHAUCK, BAYLOR UNIVERSITY

SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
NOVEMBER 6-8, 1997
BAYLOR UNIVERSITY

The Development of an Optimized Flexible-Fuel Engine Controller for General Aviation Engines

Chris Atkinson
Department of Mechanical and Aerospace Engineering
West Virginia University
PO Box 6101
Morgantown, WV 26506

Synopsis

In the transition phase between the use of 100LL as aviation fuel and the full adoption of an alternative GA fuel, there will be a need for an intelligent engine controller that can allow general aviation (GA) engines to operate optimally on any mixture of avgas and, say, ethanol ranging from pure avgas to pure ethanol. Current aviation engine control technology is not capable of tolerating such a fuel composition variation, requiring the use of electronic engine control with sensor feedback on engine operating parameters to guarantee optimal operation at any possible fuel composition. This paper describes an optimized flexible fuel engine controller for GA engines currently under development that will allow these engines to operate on virtually any spark-ignitable fuel or fuel. The proposed flexible-fuel general aviation engine controller will allow the alternative fuel ethanol to be an attractive and viable replacement for 100LL avgas fuel, with potential benefits that include lower exhaust emissions—especially carbon monoxide and lead—higher thermal efficiency, reduced operating costs, and reduced dependency on foreign petroleum sources. Other potential benefits of the electronic control include more precise control of the engine with less pilot input required and additional fault-compensation and diagnostic capabilities for improved safety. This proposed controller will allow an engine to operate at a higher compression ratio for improved efficiency on high-octane fuel blends, with variable boost to allow the full realization of the engine's performance potential limited by the knock resistance of the particular blend in the tank. To accomplish this, the controller will have full authority fuel, ignition, throttle, turbocharger wastegate, and propeller pitch control. This will be a true single lever power control system, as the pilot need only to identify the flight mode and move the load demand lever; the controller automatically adjusts all control parameters to fulfill the load demand while optimizing for the goals of the flight mode.

Many concepts involved in the design of this controller have already been investigated and demonstrated at West Virginia University, including the use of in-cylinder combustion phasing to control ignition timing, the use of late ignition timing to control knock with a high compression ratio engine and a low octane fuel, turbocharger wastegate control, in-cylinder pressure knock detection, force washer in-cylinder pressure measurement, and the wide-range exhaust gas oxygen sensing for closed-loop fuel injection control. These proven concepts will be unified with throttle and propeller pitch control to yield a flexible-fuel single lever power controller.

Engine Controller Design Architecture allows:

1. True flexible fuel operation (from 100% avgas to 100% ethanol, for example),

2. Full authority fueling control (rich to stoichiometric to lean),

3. Full authority ignition timing control,

4. Wide-range turbocharger boost control through in-cylinder pressure monitoring and electronic wastegate control, and

5. Integration with Single-Lever Power Control (SLPC).

The use of cycle-by-cycle in-cylinder pressure measurement allows for variable turbocharger boost to be used, with maximum boost available to take advantage of the high equivalent octane rating of ethanol, while allowing for a derated equivalent compression ratio while operating on 100% 100LL avgas (to prevent detonation).

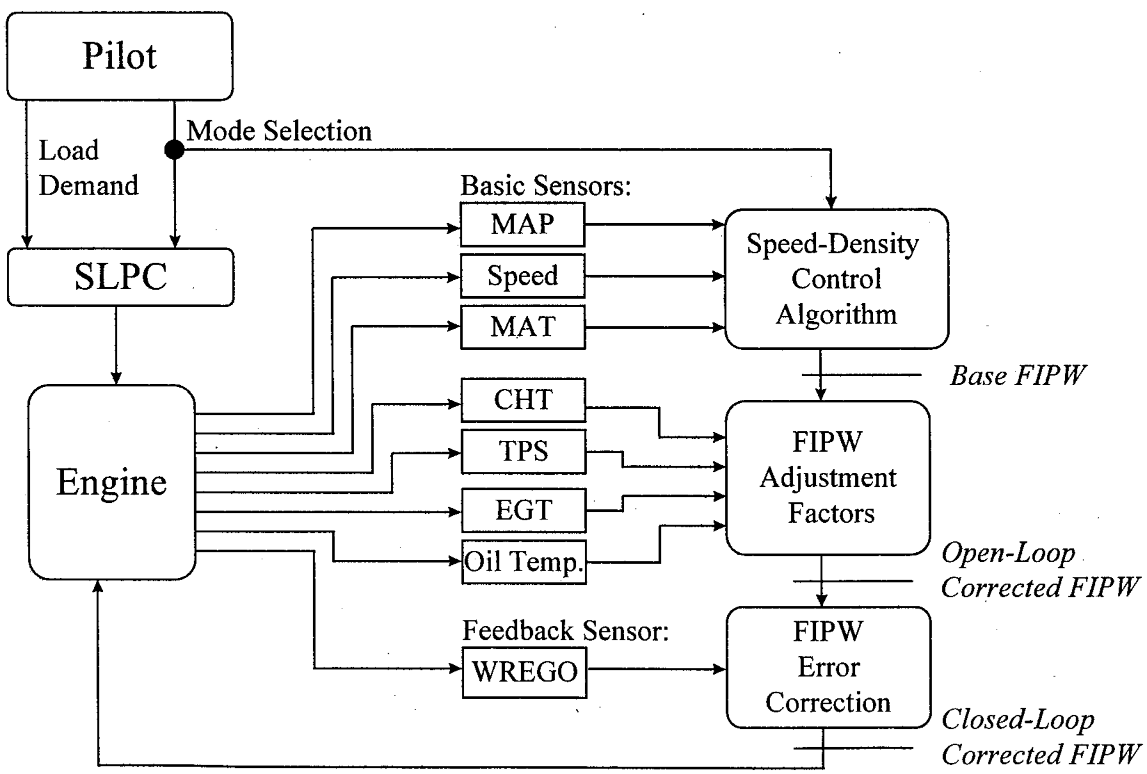


Figure 1. Fuel Injection Control Architecture

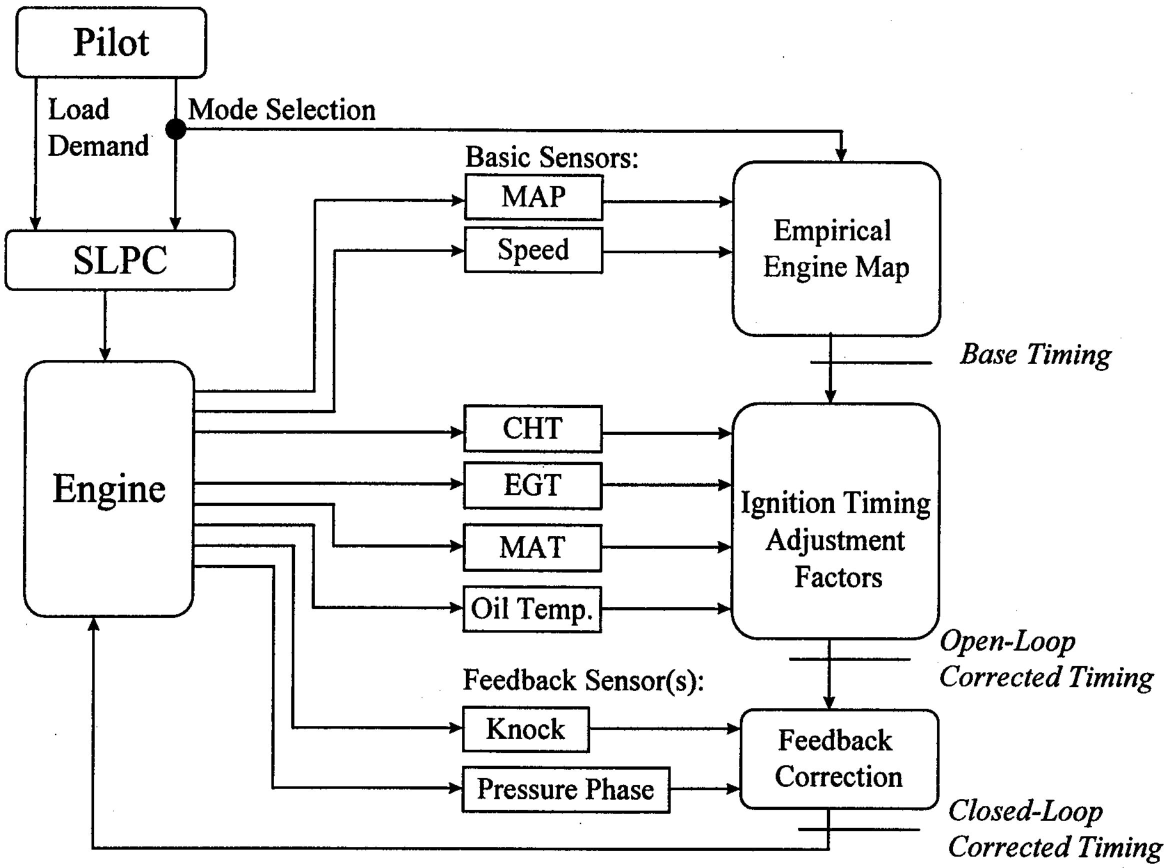


Figure 2. Ignition Timing Control Architecture

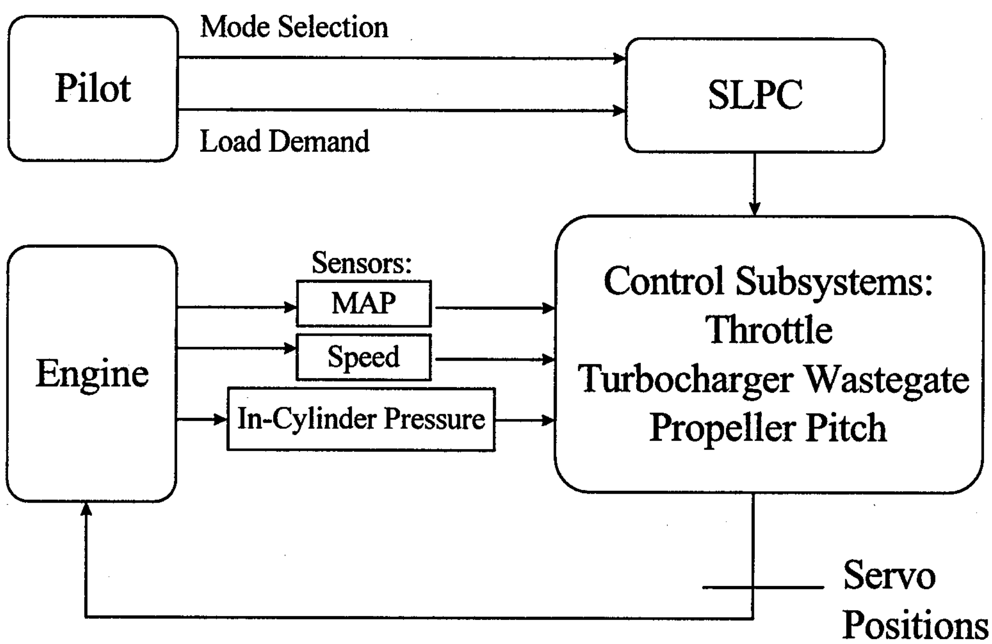


Figure 3. Single-Lever Power Control (SLPC) Control Architecture

Mode	Equivalence Ratio	Ignition Timing	Throttle Setting	Boost	Propeller Pitch
Cold Start	rich	retarded	part	none	low
Warm-Up	stoichiometric	advanced	part	none	low
Full Power	best power (slightly rich)	MBT (optimum)	WOT	knock or hardware limited	low
Cruise	minimum BFSC (lean)	MBT (optimum)	WOT or as required	as required	high
Flight Idle	stoichiometric	MBT (optimum)	part	none	low
Emergency Cooling	very rich	retarded	as required	as required	as required

Figure 4. Aircraft Engine Operating Modes

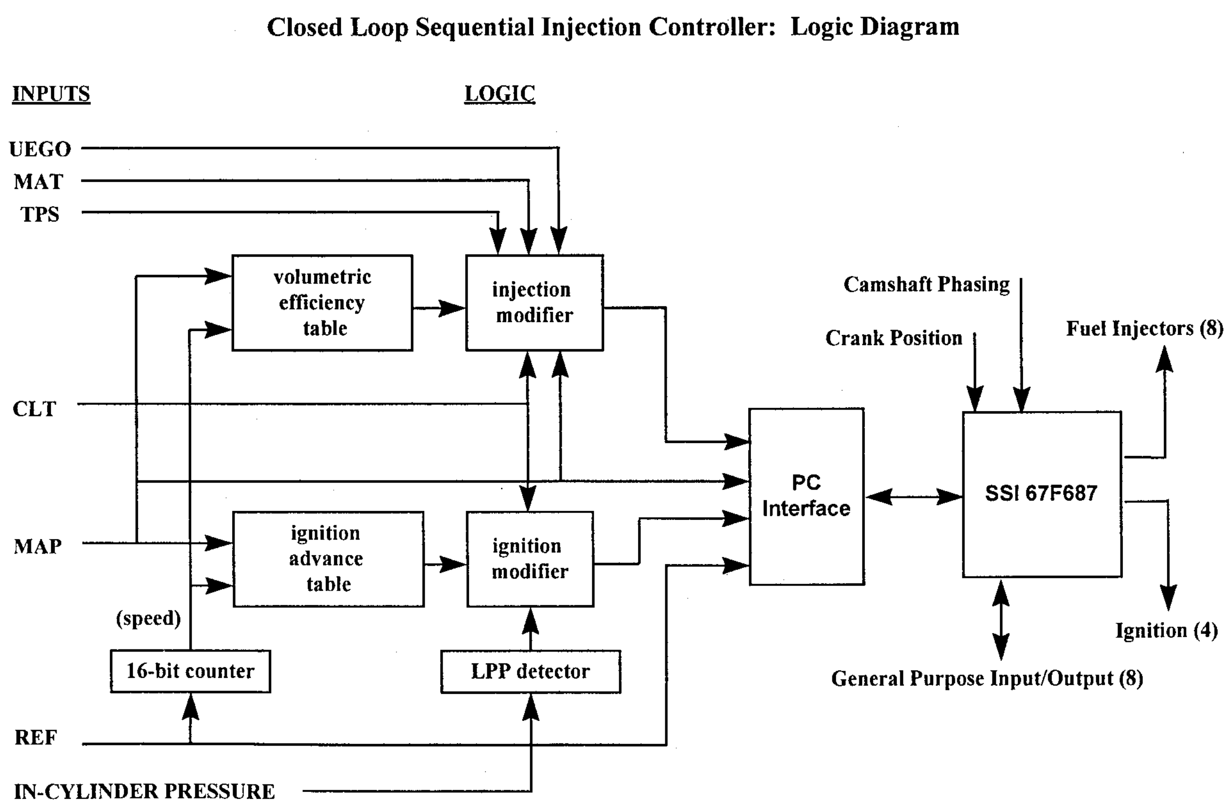


Figure 5. WVU PC-Based Development Engine Controller Architecture

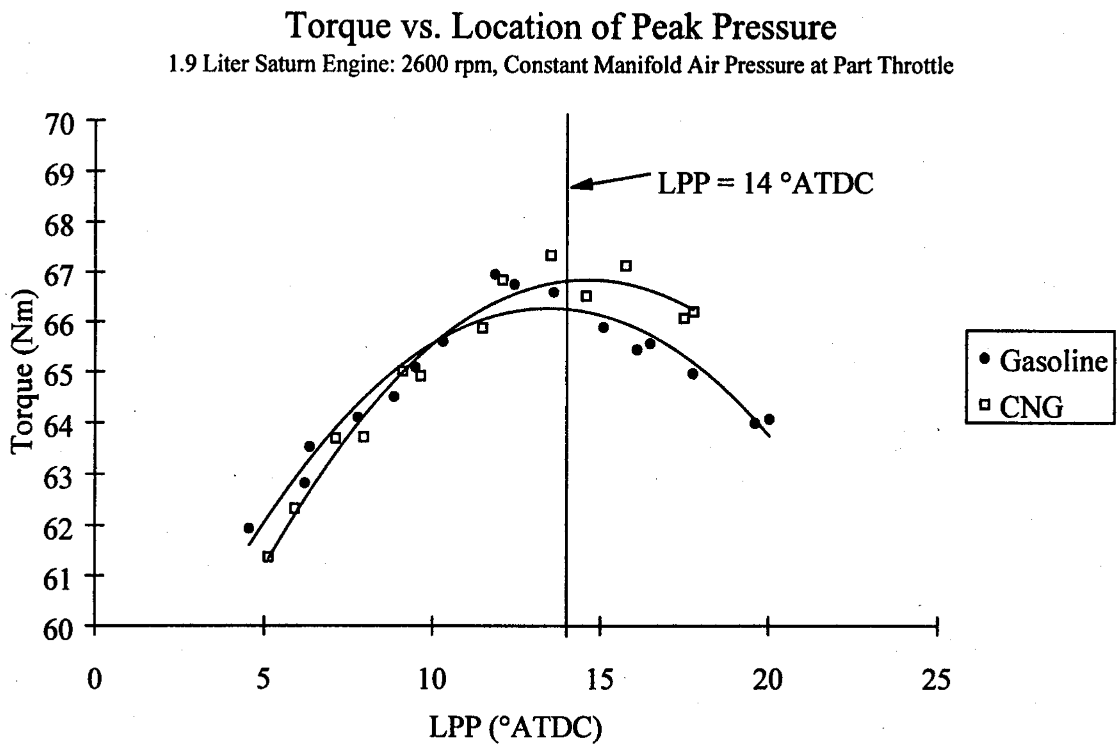


Figure 6. Basis for Ignition Timing Control Using In-Cylinder Pressure

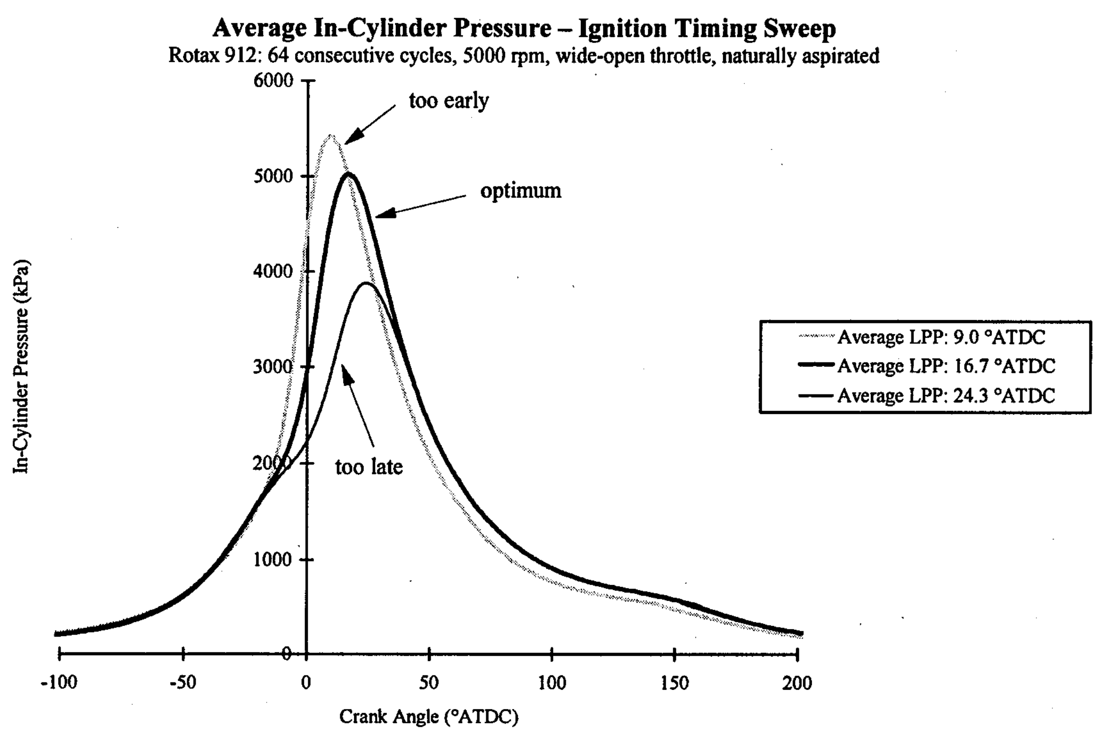


Figure 7. Effect of Combustion Phasing on the In-Cylinder Pressure

Development, Certification, and Commercialization of Aviation-Grade E85

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Energy & Environmental Research Center
PO Box 9018
Grand Forks, ND 58202-9018

Jim Behnken
Great Planes Fuel Development
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Brookings, SD 57006

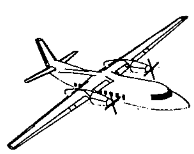
Unlike essentially all commercial automobile fuel sold in the United States today, commercial 100-octane aviation fuel for piston engine aircraft (avgas or 100LL) still contains lead, which is a human health hazard. Replacing avgas with an ethanol-based aviation fuel will improve the environment (since the high octane rating of ethanol eliminates the need for lead), maintain or increase performance, and reduce foreign oil dependency. Ethanol is also cheaper than avgas. Current ethanol and avgas prices are about $1.50 and $2.25 per gallon, respectively. An optimized blend of ethanol and a suitable high-octane petroleum-derived additive (to supply needed volatility and serve as a denaturant) will provide better engine performance and higher fuel efficiency than avgas by enabling the use of a higher engine compression ratio. The optimized ethanol blend also enables better engine starting at lower temperatures than achievable with 98% (denatured) ethanol, because of an increase in Reid vapor pressure from about 2.3 pounds per square inch (psi) for 98% ethanol to about 7 psi for a blend of 80% to 85% ethanol with an appropriate additive.

The University of North Dakota Energy & Environmental Research Center (EERC) is working with South Dakota State University at Brookings (SDSU), Lake Area Technical Institute at Watertown (LATI), Great Planes Fuel Development in Brookings (GPFD), the South Dakota Corn Utilization Council, and Texas Skyways, San Antonio, to commercialize an economically competitive ethanol-based avgas alternative. Fuel formulations prepared using ethanol from Heartland Grain Fuels (Aberdeen, South Dakota) and a medium volatility high-octane branched paraffin petroleum blendstock from a major U.S. oil company were evaluated in the lab at EERC. Following optimization of a fuel mixture comprising about 84% nondenatured ethanol, 15% petroleum blendstock, and 1% biodiesel (for lubrication and anticorrosion), U.S. Bureau of Alcohol, Tobacco, and Firearms approval of the selected petroleum blendstock as an ethanol denaturant was requested and granted. GPFD successfully applied for FAA approval to flight-test two engine–airframe combinations with AG–E85 and initiated on-ground engine testing and flight testing for FAA certification. As part of the certification process, EERC prepared a preliminary fuel specification for FAA review. Currently, GPFD is working with Texas Skyways to obtain FAA certification of three engine-airframe combinations for use with AG–E85.

In preliminary flight tests conducted with a Continental O-470-U/TS (that underwent minor carburetor modifications for use with AG–E85 but no engine modifications), AG–E85 and 100LL were shown to be essentially equal in performance, but the AG–E85 provided significantly higher fuel efficiency (see accompanying presentation). Fuel efficiency data acquired demonstrated that range is not simply a function of fuel energy content (about 88,200 and 120,000 Btu/gallon for AG–E85 and 100LL, respectively), but also a function of how the energy is used. Because of its higher latent heat of vaporization than 100LL (and possibly, other factors), ethanol combustion produces less waste heat, which means that a greater portion of its energy goes toward moving a plane than compared to 100LL. This may be the primary reason why the AG–E85 range reduction is only about 10% to 15% versus 100LL, instead of the 27% that would be predicted based strictly on the energy content difference between the two fuels. Actual fuel efficiency data for ethanol-based fuels versus petroleum fuels (with both aircraft and automobiles) need to be publicized, because in many cases, car companies and others provide mileage/fuel economy estimates based strictly on energy content and the assumption that all fuels will combust with the same efficiency as gasoline.

Flight tests are ongoing, and oil company commitment is being sought to produce and distribute AG–E85 or provide AG–E85 petroleum blendstock for blending and distribution by another entity. Current effort is focused on companies with midwest oil production capability to enable use of regionally produced ethanol. Because of increasing U.S. EPA pressure that has resulted in the prohibition of avgas in pipelines and the need for shipment by truck, major avgas producers are aware of the urgent need to develop unleaded avgas alternatives. This has resulted in less oil-company reluctance to discuss the use of ethanol as a major octane-supplying blendstock for aviation fuel than might be expected based on the history of integrating ethanol into the automobile gasoline pool.

Development, Certification, and Commercialization of Aviation Grade E85



Second International Conference on
Alternative Aviation Fuels
Waco, Texas — November 6-8, 1997

Project Team

Energy & Environmental Research Center, Grand Forks, North Dakota
South Dakota State University, Brookings, South Dakota
Lake Area Technical Institute, Watertown, South Dakota
Texas Skyways, San Antonio, Texas
South Dakota Corn Marketing Board
U.S. Department of Agriculture

Energy & Environmental Research Center

Motivation

EPA wants to ban 100LL, but permits its use while research is being conducted to find an alternative

$Pb(C_2H_5)_4$

Objective

Commercialization of a lead-free 100LL alternative that:

- *Meets or exceeds 100LL performance*
- *Is cheaper than 100LL*
- *Enables engine starting without auxiliary fuel*

Competition

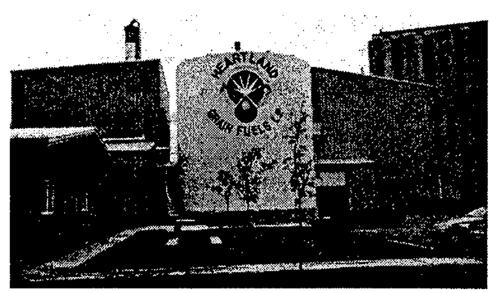
- *UL82: not enough octane, engine modifications*
- *Unleaded reformulated petroleum fuel: high price*
- *Auto E85: inconsistent quality, olefins & aromatics*
- *ETBE: more refining versus ethanol, environmental?*
- *Piston engines modified for turbine fuel: cost, time*
- *Aircraft diesel engines: cost, time*

Fuel Advantages

- *Competitive cost*
- *Increased engine performance, detonation resistance, reduced engine wear*
- *Current fuel production capability*
- *Lower emissions levels*
- *Easily adaptable to high-performance engines*
- *Supports ag and oil industries*

Commercialization Criteria

- *Price*
- *Performance*
  - *Power*
  - *Energy – range*
- *Availability – oil company stake*
- *Quality – fuel consistency*



Fuel Formulation

- *Survey refinery streams*
- *Assess oil company interest*
- *Laboratory volatility and octane testing*
- *Obtain flight test volume of selected product*

Fuel Components

- *Ethanol (undenatured)*
- *Appropriate petroleum refinery stream*
- *Corrosion inhibitor*
- *Lubricant*

Petroleum Additive/Denaturant

- *Appropriate volatility – finished fuel Rvp of 5.5 to 8.5*
- *High octane*
- *Minimal olefins, which cause gum, preignition, poor lean-mix antiknock*
- *Minimal aromatics, which cause poor lean-mix antiknock*
- *Good availability, quality/consistency, price*
- *Suitable as denaturant*

Lubricant

- *Use of soy methyl ester (biodiesel) initiated due to spark plug dryness, trace corrosion*
- *Octane testing to assess effect of adding biodiesel to spark ignition engine fuel*

100LL versus AG-E85 — Power

Continental O-470-U/TS with modified carburetion

- *AG–E85 achieves same horsepower as 100LL, but at 200 less rpms and 3 inches less manifold pressure*
- *With 100LL, cruise at 120 knots, 135 knots max versus 140 and 158 with AG-E85*
- *With AG–E85, climb rate increased by 35 to 40% versus 100LL*

100LL versus AG-E85 — Efficiency

- *With AG-E85 at 2500 feet in cruise, fuel flow 10% higher than book value for 100LL*
- *With AG-E85 at 8500 feet in cruise, fuel flow 5% higher than book value for 100LL*
- *Same exhaust gas temps and lower cylinder head temp with AG-E85 means less waste heat*
- *Thermodynamic efficiency of AG-E85 means ~30% more range than expected based on energy density*

Energy & Environmental Research Center

Project Status – FAA Certification Levels

- *Cessna 180, Continental O-470-U/TS Experimental for R&D, moving into Experimental to Show Compliance*
- *Cessna 182, Continental O-520-F/TS Experimental for R&D, burning AG–E85*
- *Cessna 172, Lycoming O-320/TS Paperwork for Experimental for R&D*
- *Cessna 182, Continental O-520-F/TS Run on 100LL for comparative data*

Project Status – Progress and Plans

- *Continental engines running smooth on AG–E85*
- *Successful starting at 48°F, will try lower as winter progresses*
- *Communicate results to:*
  - *Aircraft/engine manufacturers*
  - *Oil company*
  - *Pilots*

Acknowledgement

We thank the U.S. Department of Agriculture for supporting this work through the EERC National Alternative Fuels Laboratory

Energy & Environmental Research Center

USDA Award Number *97-38819-3993*

Additional Information

Please contact Ted Aulich at the EERC National Alternative Fuels Laboratory at (701) 777-2982 or Tim Gerlach at (701) 777-5144

Energy & Environmental Research Center

LNG Fueling of Aircraft

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CANADA

Background

The use of cryogenic fuels for aircraft, liquefied natural gas (LNG) and liquid hydrogen (LH_2) has been considered for the past two decades. LNG fueling has been demonstrated on surface vehicles since the mid 1960's. The most significant surface vehicle LNG fueling applications have, however, taken place over the past decade as a result of heightened environmental concerns.

LNG and LH_2 aircraft fueling have been demonstrated in the USA and Russia, although, none of the demonstrations culminated in an operational system. LNG was also a fueling option considered by NASA for the High-Speed Civil Transport aircraft project in 1986. [1]

The most significant research effort on LNG fueling has been undertaken in Russia because of projected shortages in the supply of kerosene and the ready availability of natural gas supply and infrastructure. Russia, a large country like Canada, depends heavily on air transportation for moving people and goods.

Most of the testing was carried out by Tupolev Aviation on a converted TU-155. [2] More recently, work is reported to focus on converting to LNG both passenger and cargo planes (TU-156 M2 and TU-154). [3] Tupolev has also demonstrated LH_2 fueling on the TU-155 experimental aircraft. [2]

In the last few years, the high levels of environmental emissions experienced at a number of airports and the potential threat of global warming have prompted the need to address mitigative solutions. From a global perspective, emissions from aircraft are still small. However, in addition to general pollution of the atmosphere, the projected growth in air traffic and location of major airport facilities within or close to urban centers exasperate urban pollution, particularly during the first half hour from takeoff start when jet fuel is consumed in the order of four times the fuel consumption at cruise altitude. Some airports, such as, Zurich and Geneva, are contemplating aircraft emission charges, while others expect strong opposition to future expansion due to increased emissions. Emission taxes, increasing the operating costs in the order of 6% to 8%, have been introduced in Sweden. A European Union proposal for a general energy tax is being debated. Some airlines surveyed have also indicated their commitment to purchasing and leasing only aircraft that meet the strictest international environmental requirements. [5]

Aircraft air pollution consists of the following: SO_x, NO_x, CO_2, CO, particulate, unburned hydrocarbons and vapor trails under certain conditions.

Alternate fuel options for aviation have been reviewed in reference 4. The main limitation of LPG has been attributed to the lack of availability. Alcohols, methanol, and ethanol were considered poor candidates because of their low energy content per unit weight and/or unit volume. Cryogenic fuels, LNG and LH_2, were identified as having the right attributes for replacing kerosene, notwithstanding the need for new handling means.

In terms of tackling carbon dioxide emissions, Germany's current focus on LH_2 fueling of aircraft represents the most important initiative. LH_2 fueling eliminates the release of CO_2, CO, particulate, and SO_x during combustion. The reduction of NO_x is being addressed through the design of the engine combustor. Some of the latter work is being carried out in Canada. This initiative is considered the first of its kind because of the following.

- It enjoys full political support.
- It is driven by an important aircraft OEM who is also a member of the Airbus group, the second largest civil aircraft manufacturer.
- It assembles major German industries, research institutions, and testing facilities covering all facets of LH_2 fueling.
- A tentative deployment schedule has been developed for the Dornier 328 and the Airbus A310 and A340. Local introduction of the three types of aircraft is planed respectively for 2005, 2010, and 2015.

Which Fuel: LNG or LH_2?

With a respective boiling temperature of -160°C and -253°C at atmospheric pressure, both LNG and LH_2 require special storage tanks in order to control the amount of boil-off gas produced by the heat leak into the fuel container. The effect of the heat leak depends on whether the fuel tank is operating or not.

Thus, for kerosene the prime concern is to keep the fuel and fuel line ancillaries warm to prevent freezing whilst cryofuels require keeping the heat out, using insulation. The ratio of the surface of a container to its volume is a direct measure of its efficiency in terms of the empty weight and heat leak, both of which are important design parameters for an aircraft. Therefore, for cryofuels, a small number of fuel tanks (preferably one or two) is generally required. The consequence of locating the fuel tank(s) inside or outside the fuselage, depending on the size of aircraft, leads to some loss of load relief contributed by the storage of kerosene in the wing of existing aircraft. However, based on work carried out to date, this is not identified as a drawback. Also, this element is only relevant during the initial ascent to cruising altitude

In demonstrating an alternate fuel on an aircraft, it is important to establish the objectives at the outset. A well developed demonstration project can provide technological innovation but it does not necessarily contribute to improving the environment in the near and sometimes medium term. However, within the framework of a practical deployment initiative, a demonstration project becomes a valuable tool. CDS current and projected activities in LNG and LH_2 fueling follow the latter approach. For a development program leading to a short-term introduction into commercial use, the following factors are considered significant.

1. The energy content per unit weight and/or unit volume of the alternate fuel must not be radically different from kerosene, otherwise the need to completely redesign the aircraft becomes the schedule driver. The associated costs can also discourage an early deployment. The comparative environmental benefits between the alternate fuel and kerosene need to be assessed on a mission basis: an alternate fuel may exhibit lower environmental emissions on a unit volume or unit weight basis, but if it takes substantially more fuel to complete a mission, these benefits may be eroded or lost. The same is true when comparing fuel costs.

2. The technology must be mature in order to produce sizable environmental dividends in the short term.

3. The fuel infrastructure must either exist or be easily deployed. Also, it must be sustainable for a long enough time frame.

4. The introduction of an alternate fuel must not adversely affect the purchase price of an aircraft or the operating costs if it is to gain acceptance by the airlines.

5. The environmental benefits must be evaluated on an objective and overall basis: in relative terms, there are no CO_2 and CO produced during the combustion of hydrogen. However, if hydrogen is produced by steam methane reforming (SMR), currently the most economical process, the following must be taken into consideration: the CO_2, CO, NO_x and unburned hydrocarbons produced not only by SMR, but also the extra energy required to liquefy hydrogen and the energy losses associated with storing and handling LH_2 in comparison to using LNG. Although not carried out, such an evaluation may well show that it is better to use LNG than LH_2 when the hydrogen production path is via SMR.

6. There must be a rational for targeting a specific size of aircraft so that any planned demonstration is designed to provide relevant data: environmental benefits, costs, weight benefits, volume penalty, refueling time, safety, system design, overall impact on aircraft, etc. An initial focus on a regional aircraft is not considered desirable because emissions from this size of aircraft are very small in comparison to those from a wide-body jet liner. The results obtained are not necessarily applicable to a large aircraft. For an alternate fuel providing a weight advantage in comparison to kerosene, small fuel tanks prevent capitalizing on this advantage, whilst the large fuel tank(s) required by a wide-body jet liner provide the opportunity to increase the range and/or the payload of the aircraft. Turbofan engines should be targeted in any demonstration because of their wide usage on large aircraft.

7 There is a need for a regulatory climate that is favorable to the introduction of alternate fuels. Because of its high technology, the aerospace industry has the capability to deploy practical alternate fuels.

The following table compares the properties of LNG and LH_2 to kerosene.

Properties	LH_2	LNG	Kerosene	Kerosene/ LNG	Kerosene/ LH_2
Density, kg/m^3	71	422.6	810	1.91	11.40
LHV, KJ/g	119.93	50.02	43.14	0.86	0.36
LHV, KJ/cm^3	8.46	21.14	34.94	1.65	4.13

The LH_2 Option

The above table shows that LH_2 has the best energy per unit weight, in addition to yielding the greatest environmental benefit. However, LH_2 has the lowest energy per unit volume which requires a fuel storage too bulky to be accommodated inside or outside the fuselage of a large existing aircraft. A fuel storage system using large containers integrated on the top of the fuselage was first introduced in the USA. The same concept is adopted for the A310 LH_2 fueling project in Germany. As stated above, a poor volumetric energy density requires a major redesign of the airframe.

Despite being perceived as the fuel of choice for the past 50 years, hydrogen remains the fuel of the future because of numerous challenges in producing it cleanly, efficiently, economically and in sufficient quantities for general use. In reviewing the criteria listed above for short-term commercial deployment, to provide a start on mitigating environmental emissions, the following can be noted:

(1) There is no hydrogen infrastructure. The importance of this factor has often been overlooked. As an illustration, extensive financial and technical resources were expanded in Canada and other countries for the development of the hydrogen fuel cell, considered one of the most important technological developments in recent years. Considerable technological progress has been achieved. In parallel with this development, the notion of the Zero Emission Vehicle (ZEV) has been successfully cultivated. Yet, the belated recognition that there is no hydrogen infrastructure has prompted an equally significant effort to develop fuel converters so that conventional fuels can be used with a fuel cell. ZEV, based on hydrogen fueling remains, therefore, just a notion.

On the international scene there have been two main initiatives. The Euro-Quebec project, a collaborative effort between the Province of Quebec, Canada, and the European Union, [6] and the WE-NET program in Japan. [7] Whilst both programs resulted in numerous studies and a few tests, no practical deployment of any size has yet taken place. On the Euro-Quebec project, the LH_2 transport options considered included 40-ft and 80-ft containers on which CDS participated as subcontractor for the detail design and testing program, a 15,000-m^3 barge system (5 spheres x 3,000 m^3) and a medium size LH_2 carrier ship. The WE-NET program assessed a wide range of LH_2 transport options varying from near/medium term using large aircraft [8,9] to long term targeting a 200,000-m^3 ship. [10] For the LH_2 transport by air option, CDS considered both LNG and LH_2 fueling of the aircraft.

(2) Although a number of technological areas have benefited from the space programs, there are still numerous areas that will require medium- to long-term development. The fuel pump is one example. The small-scale liquefaction capacity available at present requires multiple scale ups, achievable only in the long term, to be of significance.

(3) Cost parity with kerosene is projected to occur around the year 2035 unless a significant carbon tax is introduced earlier.

(4) The use of SMR to produce hydrogen at airports delays development work and scale-up capabilities on technologies needed by electrolysis plants and LH_2 international transport systems.

The LNG Option

Compared to kerosene, LNG offers a weight advantage of 16% based on equivalent energy. The volume penalty of 65%, of LNG compared to kerosene, can be accommodated inside or outside the fuselage, depending on the size of aircraft without design changes to the airframe.

The grade of LNG targeted contains 99.5% methane, produced in large scale by existing proven liquefaction technology. For this grade of fuel, the clean up of the feed natural gas and liquefaction of methane remove the following:

- carbon dioxide and water, which present the hazard of freeze up in the liquefaction plant
- odorant
- mercury and trace metals
- particulate matter
- heavy ends (ethane, propane, butane, and pentane) which produces the visible soot during combustion of natural gas

The combustion of vaporized LNG reduces CO_2 and NO_x emissions respectively by approximately 30% and 60%. It is also free of mercury, SO_x, and particulate. Contrails are produced at a lower rate than LH_2. Apart from the odorant which may be required, LNG has no additives. In order to alleviate CO_2 emissions from power plants, LNG and natural gas have seen considerable growth in the last few years, replacing conventional liquid and solid fuels. This growth is such that LNG is either readily available or can be rapidly deployed using the natural gas infrastructure in Asia, Australia, Africa, Middle East, East and West Europe, and North and South America.

In terms of deployment schedule, CDS believes that introducing LNG first yields significant environmental benefits in a short time whilst providing the transition period required for the deployment of other options, including LH_2. The experience with LNG fueling is considered useful for the eventual deployment of LH_2 fueling.

Again using the criteria tabled above for a short term deployment LNG has the following attributes:

(1) The volumetric energy density is close enough to kerosene to permit integration of the fuel tanks inside the fuselage without redesign of the airframe. It is envisaged that LNG fueling be introduced on new aircraft only.

(2) The LNG industry is thirty years old and is well developed. The yearly international LNG trade exceeds 100 million cubic meters. LNG transfer rates into and out of LNG carrier ship, in the order of 10,000 to 12,000 m^3/hr are performed daily. Technologies such as fuel tanks, conventional insulation and superinsulation, materials, spill management with or without ignition, gaseous and liquid leak detection valving, and pumps are either existing or easily adapted to aircraft.

The current generation of submerged pumps with integral condition monitoring gives approximately 8,000 to 10,000 operating hours. Areas that can easily be improved have been identified, [11] giving the opportunity to double this service life. Unlike kerosene fuel tanks, LNG fuel tanks "do not breath" in the course of normal operation. Redundant special seals have been developed for both instrumentation and electrical penetrations into the fuel tank.

Safety issues have been extensively addressed over the past thirty years, including vapor dispersion modeling, fire analysis, effects of a sudden tank depressurization, emergency response, etc. The tools required to predict the state conditions of the fuel under stationary and operating conditions have been developed. LNG can be jettisoned in the air, in a similar way to kerosene, without safety risks. The selection of the release nozzle in conjunction with the turbulence generated behind the aircraft provide good dilution and rapid dispersion. The main difference with kerosene is that at low altitude where water vapor is present, a vapor trail will momentarily appear because of freezing. The wide usage of turbofan engines on medium- and large-size aircraft lends itself to LNG fueling because there are already hundreds of gas turbines running either on natural gas or vaporized LNG. The use of LNG is expected to increase the engine life due to the absence of corrosive trace metals and gases

On the demonstrations carried out to date and the LH_2 development work planned in Germany, a vaporizer is needed so that the cryofuel is vaporized before being injected into the combustor. Whilst this is considered expedient for a demonstration project using dual fuel, CDS believes that a 100% cryofueled aircraft should not need a vaporizer because of the following: it adds weight and complexity to the fuel delivery system and requires an auxiliary on-board or ground support system to start the first engine. Preliminary contacts with the main turbofan engine manufacturers have indicated that the injection of LNG into the combustor is easily accommodated by a simple modification to the combustor.

(3) LNG fuel costs on the international trade are in the range of 3 to 4 US dollars per million Btu (equivalent to 8 gallons of kerosene). When sourced from peak shave plants in

Canada, the fuel cost is approximately $US 0.4/gal. Even when factoring the difference in volumetric energy density, LNG is competitive with kerosene.

Conclusion

A preliminary comparison of LNG versus LH_2 fueling of aircraft suggests that the small scale of LH_2 production and the lack of infrastructure are not favorable to the deployment of LH_2 fueling in the short to medium term. On the other hand, the maturity of the technology, the economics of the fuel, and the scale of the available international infrastructure suggest that LNG fueling is ready for commercial deployment. The latter is expected to provide the transition to the next generation of fuels.

Acknowledgement

The review of the front end design concepts and the valuable comments provided by Peter Roberts, Transport Canada, are gratefully appreciated.

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The LNG Option

- **Extensive international infrastructure**
- **Technology well developed**
- **Cheaper than kerosene**
- **Significant environmental benefits**
- **Favorable energy density**

The LNG Fueling Targeted: 99.5% Methane

- **30% reduction in CO_2 emissions**
- **SO_x and air toxics emissions eliminated**
- **60% NO_x emissions**
- **Negligible particulate**
- **Lower contrail formation than LH_2 at high altitude**

The LNG Fueling Components

- **Ground infrastructure**
- **Refueling system**
- **On-board fuel storage and delivery system**
- **Booster fuel pump/engine**

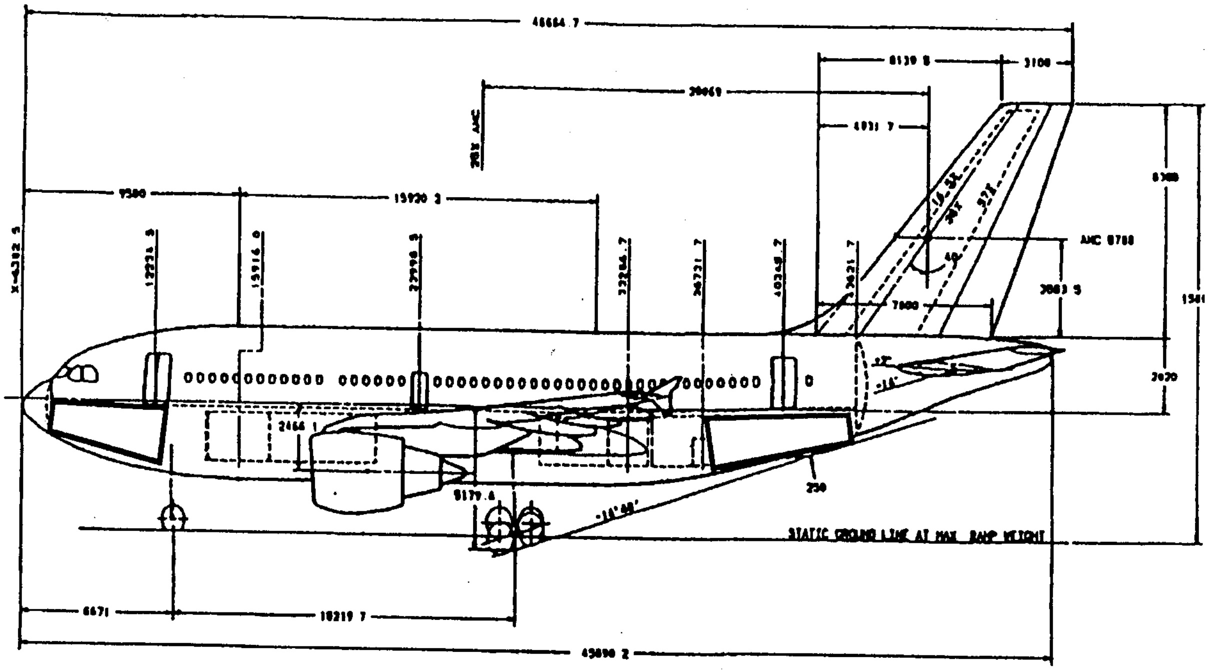
Comparative Properties

Properties	LH_2	LNG	Kerosene	Kerosene / LNG	Kerosene / LH_2
Density kg/m^3	71	422.6	810	1.91	11.40
LHV KJ/g	119.93	50.02	43.14	0.86	0.36
LHV KJ/cm^3	8.46	21.14	34.94	1.65	4.13

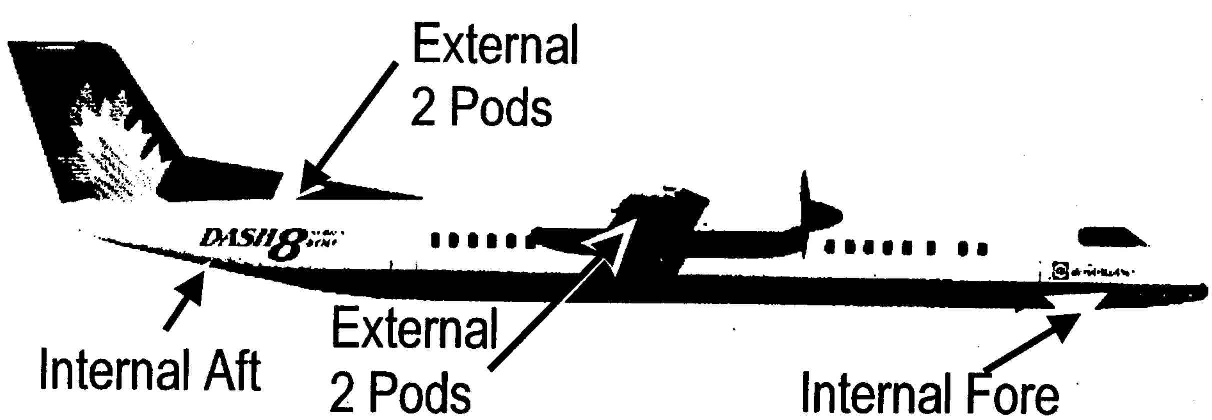
Target Aircraft Size

- **Wide-body preferred**
- **Regional aircraft considered for demo only**

LNG Fueling for Aircraft



LNG Fueling for Aircraft



Other Benefits

- Longer engine life
- Opportunity to provide engine cooling

Fuel Injection

- Direct LNG injection into combustor preferred
- Vaporizer version initially

Current Research on Nonpetroleum-Based Alternative Aviation Fuels and Engines

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Ladies and Gentlemen,

I attended the First Conference on Alternative Aviation Fuels to try to learn where the existing piston engine fleet was going with respect to future fuels. Although some very financially limited research was underway for a high-octane no lead fuel, there were no signs of eminent success. It seemed that the status quo was to be the rule of those days.

I met Max and Grazia at that Conference and became at least aware of *Alternative Fuels (i.e., Ethanol)*. We had several intense discussions on the benefits of Ethanol which carried over to the evening reception at Buzzard Billy's. Then I went home.

Three months later, I received a call from a gentleman at Environment Canada looking for information on the operation of a small Continental piston engine for emissions testing. We talked and now, as Canada's resident expert on alternative fuels, I was asked to submit a proposal to build and modify Canada's first and only Ethanol powered aircraft to gain knowledge on Northern operation. We were asked to proceed in April and expected (by then) to FLY by June 1 for demonstration at The Toronto Aviation Show.

Over those few weeks, we created multiple personalities. We disassembled and modified an aircraft we had at hand—a 1959 Cessna 150 with an 0200, 100 HP Continental engine. The name came from the fact that the aircraft was configured as a tri-cycle gear trainer OR a tail dragger for tundra and rough field operation OR a ski plane for winter operations OR a float plane for northern forays (Fishing Trips). We wanted to create both a test bed and an attractive display aircraft which would attract the attention the project deserved. The green and white paint scheme was, for me, synonymous with Ethanol.

The engine was slightly modified to increase compression by 30% and the carburetor re-jetted for an increased fuel flow. Fuel cells were increased from 20 gallons to 35 gallons. The instrument panel was updated to include fuel flow, fuel remaining, time to empty, 4-cylinder EGT, and 4-cylinder CHT. A digital MPG and oil temperature and pressure gauge completed the update. We created a fully instrument flying test bed with an estimated 120+ horsepower. I had watched Max demonstrate his Ethanol aircraft on a cold Texas day (50°F) and we know we had to overcome cold weather starting problems in a simple way. We installed a 3-litre primer tank and starts are now normal down to -20°F (we do preheat).

We first started the engine on July 12, 1996, and flew that day on 99%—200 proof Ethanol with 1% gasoline so we couldn't drink it. We flew to Oshkosh on July 31, 1997, fully approved for operations on both sides of the border. During the ensuing 18 months, we have accumulated over 130 hours of normal, trouble free flying—almost entirely on pine alcohol. This includes both hot and cold weather operations down to well below $0^{\circ}F$ on skis. We are now setting up to have the installation undergo full emissions testing for the regulated emissions.

All in all, it has been an interesting and informative project, the success of which came significantly from the work carried out by Max.

I still don't know what the future is for the piston engine fleet, but I do know that the status quo is no longer acceptable. Perhaps our project and its successful demonstration of an aviation use of Ethanol will assist in that direction.

Current Research on Nonpetroleum-Based Alternative Aviation Fuels and Engines

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I'm surrounded by this group of learned men, with their numerous degrees, and I feel just slightly out of place here. I don't bring any technical background to the discussion. However, I have been a pilot for 50 years, and I have flown the last 15 years with the Vanguard Squadron. The Vanguard is a group of pilots and builders from Sioux Falls, South Dakota and that area. As a group we have build six RV-3 aircraft, that is a single-seat, low-wing monoplane; we have three RV-6 two-place airplanes and there are currently three under construction. In 1992, 5 years ago, the South Dakota Corn Utilization Council sponsored Max to come up to our area with his Pitts and we were very impressed with the demonstrations that he put on in and around Sioux Falls. We picked his brain and discovered that he was very generous with the work that he had done up to then and the knowledge that his group had, so it occurred to us that since our aircraft were already corn yellow, and we were living in the corn belt, that we should switch our planes to ethanol.

So we went to the South Dakota Corn Utilization Council and asked for their sponsorship in helping us convert the six RV-3s. They have generously helped us in this plan and have been our sponsors for the last 5 years. To our surprise, it was not an expensive process in converting these airplanes. Probably the most expensive part was our fuel control unit by Bendix which we couldn't work on ourselves, but had to be sent in to have their mechanics put in one which was compatible with ethanol. Beyond that all we had to do was enlarge the orifice in our fuel injection nozzles about 10%, and we rinsed our tanks with aladyne, a one-time process. A couple of our planes that had wing tanks with aluminum fuel lines; we replaced those lines with Tecron-plus lines, and that was the extent of the conversion process. If a person started from day one to build an airplane to use ethanol as the six that are under construction, there would be no additional expense, other than maybe 5 dollars for the aladyne rinse, which is reusable. I would say that in about 2500 hours of cumulative flying time on the six aircraft over the last 5 years, we have had literally no fuel-related problems. Our airplanes have engines that are all Continental I0320s fuel injected. Some of them started at 7.5:1 compression ratios, but now we have converted most of them up to 10:1. The 10:1's run better, there is no question about it, they burn less fuel, they run stronger naturally, and we find at cruise, we were led to believe by Max that they would be burning more fuel, and they do. At a normal cruise setting, we are burning between 7% and 7.5% more fuel in a 10:1. It is slightly higher in a 7:1 and 8:1.

Most of our fuel has come from the Rone plant in Skyland, South Dakota. It is almost completely anhydrous, although I have been told getting ethanol that is completely anhydrous is almost impossible. Some of it has tested as high as 200.4 proof; we have run 190, E185; we have run all kinds of mixes. We even ran an airshow out in Bloomington, Illinois, on a fuel made from grass clippings. It ran well and it tasted pretty good too. We have been showing these airplanes off throughout the corn belt states for going on five seasons now, and I would guess that we have appeared at two to three hundred different places, airshows, farm fairs, agricultural festivals, anywhere there is a crowd. We have flown by homecoming parades, football games, and ethanol races at the local race track. And the response has been great. Probably our best response each year has been our five trips, one each year, to Oshkosh, primarily because of the size of the crowd there. Those of you who are familiar with that show know that somewhere around a million people attend that show during its week of operations. The first year that we went out there we saw a lot of blank stares. People didn't seem to know what we were about. Max had been up there, but it was a long way in the wilderness. Now there were six of us, the five of us and Max. And we answered a lot of questions, passed out a lot of literature, and enjoyed ourselves immensely. The second year, there were some of the same questions, but people were starting to catch on. Now after 5 years, most of the people that stop by to talk to us have heard about us, have seen us fly here and there, they know what is going on, and they are optimistic and enthusiastic. Those that don't stop by don't care. I would like to mention that I would like to see more support from the EAA for our push. I don't know why they don't support us much. I suspect that they just pay us lip service partially because they have put so much time and effort into the AutoGas modification and approval in airplanes and we are likely to pull that down. I might say this about AutoGas in our airplanes; in the early days when we were still 7.5:1, we experimented with AutoGas and didn't have much luck with it. Especially the AutoGas that contained 10% ethanol. That's dangerous mixing in an airplane when you take it to eight thousand feet, because we found a lot of vapor lock and that sort of problem. So we stopped using AutoGas in our airplanes long before we ever started using Ethanol.

We get this question a lot though, once you convert your airplane to ethanol, how can you fly cross-country, because you can't get ethanol everywhere you go. You can get it a lot of places, but not everywhere. That's a myth. We flew down yesterday, three of us, from Sioux Falls. Because of the wind we had to make two stops; normally we would only have made one. At the first stop, we came away with an approximate 50% mix AvGas and ethanol. All we had to do in that case is lean our mixture a little bit more, which we would have done anyway to adjust for changes in altitude and flight conditions. The second stop we made in Oklahoma City, where we came away with an approximately 80-20 avgas-ethanol mixture. A little more leaning; we were burning a little less fuel. The airplane performs about the same, but we think we were getting about a 50° lower cylinder head temperature on ethanol than on gas. As far as maintenance, when we do open an engine up, the plugs come cleaner than we are used to. We haven't had to do an engine overhaul since we converted to ethanol. We estimate that the life of these engines will be extended, and Max's figures will bear out that. He has lab tests to show what we have been proving. We assume that is because we are running cooler and cleaner. I can't speak about the emissions, but I would like to give one of our airplanes up to Ron's [Wilkinson] facility for testing. He has the equipment, and perhaps we can do that in the future. The problem is that it is quite a distance.

Let me talk about cold weather starting. You people in Waco don't know about cold weather. In South Dakota last winter we had chill factors of $-70^{\circ}F$ with actual temperatures of about 35 below and a wind chill to match. I won't talk about the wind chill factor as far as the engine is concerned, although they sure affect the pilot. But, if you take an engine and cool it to an ambient temperature of 35 below, and you start it on ethanol, you will agree with me that they will run on ethanol in cold weather. In our machine, we pulled a small tank off a weed-eater that holds about a pint, and hooked it up to our manual primer, fill it with AvGas once a month maybe, depending on how much we fly. A couple of squirts of that gets the engine running, and then the ethanol kicks in. But I've found that about plus 54°F, helps a little if we preheat selectively. We have little hairdryers that we keep in the cabin and use them to warm the cylinders for about 10 minutes before startup. Otherwise, we have found, they do pop for about 5 to 10 minutes as the ethanol starts up. I would be happy to answer any questions, but I think we are overtime already so I will hand it back to Bill.

Current Research on Nonpetroleum-Based Alternative Aviation Fuels and Engines

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We have been at this 17 years, and it is very satisfying. One thing that I think that was missing from the presentations in an earlier panel is what exactly would happen to the aviation industry if we go entirely over to ethanol or certain fuels that are not exactly the same mix as what we have now. I think we are missing what also could happen to the United States that happened in 1973. 1973 was the oil crisis that rocked the world. If you remember that, and you were involved in aviation, then you remember that Congress seriously considered cutting off all fuel to general aviation. Frankly, that scared the hell out of me. Aviation has been my life for as long as I can remember, and that's a long time. At that point in 1973, we were importing 30-33% of our oil from overseas. Today, we are importing over 53% of our oil. Now, it doesn't take a mathematician to figure out that we are at greater risk of having our fuel cut off. There are lots of other issues today, environmental among others, so I think that it really is time to be considering other fuels. I've been saying that for 17 years, so that is nothing new.

Enough has been said about ethanol that I am going to be repeating some of the things but I am going to be repeating it from the point of few of having gone through the certification of it. We were very concerned with publicity when we first started testing ethanol. We assumed that it was just like methanol, in fact I used a tougher lubricant for some time because I couldn't afford another engine or damage the one I had. We went to Southwest Research when we started working with a firm in Italy to help us with the certification from a financial standpoint and were able to afford doing certain tests. One of the tests we did were lubricity tests. It turned out from those tests, that ethanol has slightly better lubricity than aviation gasoline, which was a surprise to us. The results were foreknown when we did our endurance test for certification on the AE I0540, which was the first engine certified. When we do the certification, those of you who are not familiar with it, you take the engine apart and measure all the parts of the engine that you can and that will experience wear when you run the engine. Then you put it together again and run it through a series of impossible tests, take it apart at the end, and then remeasure all of those parts. Now this is done under an AER or FAA scrutiny. The wear test results showed very, very small wear. That would have been surprising had it not been for the earlier lubricity tests. From all that we know about fuel, there is no need for a lubricator. And the wear, that is another issue. Now we have talked to the FAA as a result of the first engine certification, and their estimate was that based on those test results was that we should look at increasing the time between overhauls on the engine since the wear was so minimal.

I would like to speak to something that was brought up on the previous panel, and that is the disabilities of the fuel. For those of you who know much about fuels, you know that ethanol is a much more stable fuel than gasoline because it is a single compound. I am not a chemist, but I have had a sort of crash course in the chemistry of fuels over the last 17 years. Ethanol, and it took me a long time to learn this so I'm going to show it off, is C_2H_5OH, right Bill? All of the combustion characteristics are single point, you couldn't ask for a better fuel to run an engine on. Obviously engines are designed to run on gasoline. But the characteristics are fairly close. The point being that if you have a fuel that is single point, you don't have to worry about designing and operating for example the people that run "two stoves" tell me that ethanol is much more attractive than gasoline although they are much more critical of two stoves.

Materials compatibility. There have been statements made that ethanol has serious materials compatibility problems. Well, the fact is that I think some of this misconception comes from people who have gotten methanol and ethanol confused. Ethanol does have some materials compatibility problems. There is no fuel that has zero material compatibility problems. Again, we went to Southwest research and had materials compatibility done; we knew that we found no elastomer problems. The one materials compatibility problem we had early on was the reaction of ethanol with aluminum which resulted in the formation of aluminum-oxide, and we discovered this the hard way. The aluminum oxide was a serious problem we found out we had to treat the tanks which were aluminum and that the aluminum fuels lines leaked in places. What has happened in the last ten years, the ethanol industry has started to be treated with an anti-oxidant, one of which is PCI-11 made by DuPont. They did that because they were putting aluminum caps on the storage tanks of their ethanol and they were experiencing the same problems. With the PCI-11 in the fuel, there is no longer any materials compatibility problem with aluminum.

Cold-start. I submit that I would rather have my engine be hard to start than I have my engine get wet when it gets hot. We are obviously talking about vapor lock. Aviation gasoline has very minimal problems with high read vapor pressure, but certainly AutoGas does. I think the problem is not carefully looked at. There are a lot of issues here. The range problem, Marv has alluded to the reduction in range that they have observed, while we can improve on that, I don't think we will ever get to 100% of the range that aviation gasoline has, I think we can live with the slight reduction in range that we are experiencing with the higher compression engines. Quite frankly, I see the future as falling into two camps, ethanol as a viable fuel, and the hydrocarbon section, particularly those engines that are going to be marginal with something. The results that we have during the certification testing, are likely to generate some discussion.

One of the tests that you have to do as part of the certification process is detonation testing. Our results in the case of certifying the IO-540 and the O-135 where we could not produce detonation under extreme conditions and the opinion of our first DER and also the project engineer was that the conditions we subjected the IO-540 to in particular were conditions that would cause 100LL to detonate. So we also talked to an engineer for Allison who builds Second World War Allison high-compression engines, and their results were the same: they did not find a detonation point for ethanol. I'm sure you can find one, but we have not yet been able to do so. So the detonation resistance of ethanol from all of our experience is excellence.

Power. We have experienced power increases in all of our engines using ethanol and that is using a calibrated dynamo. One result I can tell you was on engine components that occurred at our own test stand during the certification of the IO-540. That engine has a 9.75:1 compression ratio and it showed 125 HP on AvGas and 150 HP on ethanol. Now I am just reporting to you exactly what we found and again, that was on a calibrated dynamometer. That's a 20% increase in power. We typically have not seen that, but we have never seen a power increase of less than 5%. I think that's generally accepted. All the people that understand a lot about engines believe it is because the high latent heat of vaporization of ethanol essentially gives you a higher charge density in the cylinder so that's not a surprising result. Currently we at Baylor have tested ethanol, a 50-50 blend of methanol-ethanol blend. By the way, we haven't had a problem with the 50-50 blend of methanol and ethanol. I have flown it at various airshows around the country, and it has been a highly successful fuel. We did have a slightly higher problem with materials compatibility, but those guys did not have great success on flying 100% ethanol. In 1995, we did our first ETBE testing prior to flying the Paris airshow on ETBE. I really feel strongly that ETBE surpasses ethanol, at least in the transition period, simply because of the fact that ETBE has a better range than aviation gasoline. It has slightly less power than ethanol, and there is a subjective measurement that the airplane is more responsive on ETBE than on either aviation gasoline or ethanol; but that, again, is subjective. But I have been flying since 1955, and I have some feel for the responsiveness of the airplane on the fuel.

The certification process is something that always gets brushed off in discussions, and I am not going to say that it is not a problem. It is a bit of a problem, but first of all, we really did not take five years to certify the airplane. We took essentially a year of very concentrated work to certify the airplane. The problem on anyone of these projects is that we have a very small amount of money to do a very big job. We have had some support from a lot of bio groups and agricultural groups; we have had some support from the FAA Technical Center and the Department of Energy and the emissions programs of the state of Texas. That is probably the reason we haven't moved faster on the certification process. Do not believe, by any stretch of the imagination, that certification is an insurmountable obstacle. It is just something that has to be done.

I think we have run out of time, and I thank you for indulging me in a professor's prerogative to indulge in the sound of my own voice.

DEVELOPMENTS IN THE PRODUCTION AND MARKETING OF ALTERNATIVE FUELS IN NORTH AMERICA

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SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
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Developments in the Production and Marketing of Alternative Fuels in North America

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CANADA

Currently, essentially all the ethanol that is used as fuel in road vehicles and in general aviation is produced from corn. This is advantageous in that the technology used to produce the ethanol is centuries old, well understood, and can be implemented successfully at large scale. The unfortunate aspect is that the primary feedstock, corn, is expensive since it is also the source of a number of foods for human consumption. In addition, with current agricultural practices, it also requires significant fossil fuel inputs for its production and processing. These aspects of corn-based ethanol production have resulted in a significant effort over the last twenty years or more to develop technology that can utilize a much cheaper and more sustainable feedstock, namely cellulosic biomass.

Biomass feedstocks are composed of cellulose and may also contain hemicellulose and lignin. The cellulose and hemicellulose portion of these materials are biopolymers composed of sugar monomers that can be released via the chemical process of hydrolysis and then subsequently be fermented to ethanol. The residual lignin could be used as fuel to produce energy for use in processing or for sale. Consequently, biomass feedstocks are attractive for ethanol production since they:

1. retain the positive attributes of lowering CO and carcinogenic emissions seen with corn-based fuel ethanol,

2. are CO_2 neutral, and

3. mitigate the disposal of biomass wastes in the forest and agricultural industry.

The latter point with regard to biomass waste is particularly important since these are available at low cost and are available in abundant supply. As a case in point, Canada annually produces about 88.5 million oven dry tonnes of biomass waste, a large portion of which could be used for the production of fuel ethanol.

Notwithstanding the abundant supply of biomass feedstocks and their attractiveness as a source of fuel ethanol, there is as yet no commercially available technology which will enable their conversion to fuel ethanol at a cost that is competitive with gasoline. However, major advances in this area are being made and are subsequently summarized.

Pretreatment

Before the cellulosic and hemicellulosic components of biomass feedstocks can be converted to fermentable sugars, the native structure must be disrupted in order that subsequent chemical processing reactions can take place efficiently. Effective pretreatment process now exist for hardwood feedstocks, and work in Canada, the U.S., and Sweden is anticipated to result in equally efficient process for softwoods and agricultural wastes within the next one to two years.

Hydrolysis

The pretreatment process generally renders the hemicellulose into sugar monomers and low-molecular oligomers that are readily converted to monomeric form. However, pretreatment leaves the cellulosic fraction largely intact and it must be subjected to a directed hydrolysis in order to convert it to glucose, its monomeric sugar constituent. This is achieved by either acid or enzyme based processes, the development of which probably represents the most intense area of current R&D activity. The reason for this focus is that hydrolysis represents the most costly individual process step and thus solution of the "hydrolysis problem" will yield a major overall process cost reduction. Significant advances in both acid and enzyme based processes have been made in the last several years. These have been incorporated into integrated processes that will be implemented in demonstration plants planned for construction in both the U.S. and Canada.

Pentose Sugar Fermentation

The monomeric sugars derived from the hemicellulose fraction of certain biomass feedstocks, particularly hardwoods and agricultural residues, are comprised of sugars containing five carbon atoms and are not fermentable to ethanol using traditional brewer's yeast. Consequently, over the last five to ten years, there has been a major effort in a number of laboratories to use genetic engineering techniques to transform naturally occurring yeasts and bacteria to recombinant organisms capable of fermenting these pentose sugars. This effort has been successful and there are now strains of recombinant yeasts and bacteria that will efficiently convert pentose sugars to ethanol. Several of these are now being evaluated in pilot-scale fermenters and their viability at commercial scale is considered highly probable.

Value Added By-Products

As a commodity, ethanol is a low value product. This alone is unfortunate and is even more so when considered in the context of the cost of the technology required to utilize biomass feedstocks for its production. Notwithstanding the low cost of these materials, it will still be necessary to generate value added products from the biomass-to-ethanol process in order to establish its economic viability. In the early days, it was assumed that this would be derived from the use of the lignin component of biomass as a fuel to produce energy for the conversion process or for sale. Unfortunately, the reality of today's current low prices for electrical energy has significantly diminished the attractiveness of using lignin for this purpose. Consequently, several research groups are now focusing on employing lignin for the production of a range of chemicals to be sold in the food, pharmaceutical, and chemical processing industry. For these markets, prices of one to twenty or more dollars per kilogram are realistic, compared to forty cents per kilogram for fuel ethanol.

So, where does all this leave us with regard to likelihood that biomass will be a viable feedstock for the economical, unsubsidized production of fuel ethanol? The answer is—very close. There are three projects underway in the U.S. and one in Canada that are planning to construct demonstration plants which will use various biomass materials to produce ethanol. Successful demonstration of the technology in these plants will serve to pave the way for wide-scale introduction of this new technology into the fuel ethanol industry. It appears that the long sought after goal of ethanol at a cost competitive with gasoline is now within scoring range.

CANADIAN R&D ON ALTERNATIVE PRODUCTION TECHNOLOGY FOR FUEL ETHANOL

NATURAL RESOURCES CANADA - R&D ON FUEL ETHANOL

- Supported Under the Canadian Panel on Energy Research and Development Through the Biochemical Conversion Component of The Bioenergy Development Program
- Contracted Out to Canadian Industry on a Cost-Shared Basis
- Objective:

  The Production of Fuel Ethanol From Biomass at a Cost Competitive With Gasoline

- Rationale for Focus on Fuel Ethanol:
  - Lower CO and Carcinogenic Emissions From EtOH/Gasoline Blends
  - CO_2 Neutral
  - Mitigates Disposal of Biomass Wastes

BIOMASS AVAILABILITY IN CANADA
(Thousand ODT)

	Logging Residues (site + roadside)	Mill Wood Residues	Crop Residues	Urban Biomass	Primary Clarifier Sludge
Eastern Canada	2,355.6	236.7	82.4	1,184.5	195.2
Quebec	4,796.9	831.1	2,551.9	3,318.1	426.0
Ontario	3,171.6	752.6	8,024.4	5,516.2	301.7
Prairies	2,026.1	1,410.0	32,301.4	2,373.6	56.8
British Columbia	9,081.1	5,211.3	189.4	1,755.0	387.0
Total	21,431.3	8,441.7	43,149.5	14,147.4	1,366.7

Grand Total: 88,537 ODT

ETHANOL R&D – FINANCIAL SUPPORT
(Thousand CAN)

Fiscal Year	BDP Expenditure	Partner's Expenditure	Total
1994/95	949.2	1,637.7	2,586.9
1995/96	1,092.4	1,431.4	2,523.8
1996/97	1,378.4	1,316.1	2,694.5

ETHANOL R&D – RESEARCH FOCUS

- Softwood Pretreatment
- Feedstock Hydrolysis
- Xylose Fermentation
- Improved Ethanol Recovery
- Value Added By-Products

ETHANOL R&D – SOFTWOOD PRETREATMENT

- In Association With the University of British Columbia
- Abundant Softwood Residues in Canada
- Majority of Work to Date has Been on Hardwoods
- Objective:
  - Optimize Recovery of Fermentable Hemicellulose Sugars
  - Optimize Cellulose Hydrolysis
  - Refine Techno-Economic Modeling
- Results
  - 85% of Initial Hemicellulose Obtained as Monomeric Sugars
  - Optimum Conversion of Cellulose to Monomeric Glucose Requires Further Treatment

ETHANOL R&D – FEEDSTOCK HYDROLYSIS

- In Association With Iogen Corporation
- Objective:
  - Improved Cellulase Enzyme Production
  - Optimization of Cellulase Enzyme Hydrolysis
- Results
  - On-Line Protein Synthesis Monitor
  - Mutant with 50% Higher Protein Productivity
  - Recombinant DNA Technology has Yielded More Efficient Mixture of Trichoderma Cellulases
  - Improved Recovery and Reuse of Cellulase Enzymes

ETHANOL R&D – SOFTWOOD PRETREATMENT

- In Association With TEMBEC Inc.
- Objective:
  - Pilot Scale (2000 litre) Fermentation of Spent Sulphite Pulping Liquors Containing Hexose and Pentose Sugars
- Results
  - *Pichia Stipitis* Showed no Significant Improvement in Ethanol Yield Over Conventional *Saccharomycese* Strain
  - Utilization of a Recombinant Saccharomycese Strain Show Promise at Laboratory Scale and is Being Evaluated at Pilot Scale

ETHANOL R&D – SOFTWOOD PRETREATMENT

- In Association With Kemestrie Inc.
- Objective:
  - Production of Value Added By-Products From the Three Major Components of Biomass Feedstocks via Steam Explosion and Fractionation
  - Utilization of Forage Plants as Feedstocks
- Results
  - Cellulose Fibre Obtained has a DP > 600 Prior to Delignification, Falling to < 400 After Delignification
  - Conditions Can Be Modified to Produce Aplha Cellulose of DP > 700
  - The Cellulosic Fines Were Easily Hydrolyzed and Subsequent Fermentation of the Glucose Yielded Ethanol at a 90% Yield of Theoretical

CONCLUSION

Through Consultation, Cooperation and Cost Sharing With Industry and Academia, Natural Resources Canada Has Been Able to Optimize Its Use of Limited Financial Resources to Develop Viable Technology for the Conversion of Lignocellulosic Biomass Feedstocks to Fuel Ethanol

Comments for Panel 2: Outline Production and Marketing of Alternative Fuels

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I. An overview of alternative fuel production in the U.S.

II. Contribution to transportation fuel supply versus petroleum

III. Infrastructure challenges

IV. Marketing impediments

V. Potential markets for ethanol based fuels

VI. The role of public policy in production and marketing decisions

VII. Turning point: 2000-2007

Recent Advances in Renewable Ethanol Production

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Introduction

Many thanks to the sponsors of this event for inviting me here to speak and for the kind attention of the audience as I present my remarks. Thanks and gratitude are also due the sponsors for their foresight in organizing such a conference, only the second in the series. In the two short years since the inaugural session, much has happened to prove the wisdom of the direction this movement has taken us. As is true with much in life that is desirable, the path is not easy. It is appropriate that a prestigious institution of higher learning, Baylor University, has led the way in this effort to bring us cleaner burning, domestically derived, renewable aviation fuels. For this task must be firmly grounded in hard, unassailable science if it is to plow through the peril-laden fields of bureaucracy and special interests, both industrial and political. This task is as hard as they come.

And yet it is one that sorely needs attention. The issues involved in aviation fuels mirror those of ground transportation in many respects, and are unique in others. The subject is certainly relevant today from many perspectives, not the least of which is urban air quality as is being discussed here, and it applies to many classes of aviation. There are applications for turbofan systems such as large commercial passenger jets, as well as smaller turboprop aircraft, both of which burn petroleum distillates in a turbine. Then there are the conventional piston aircraft that still require 100-octane avgas, such as cropdusters and general aviation personal aircraft. We are pleased to see that some of these planes have finally received certification for alternative fuels and are able to make a contribution today.

Many of us in the industry believe that renewably derived ethanol, and its derivatives such as ETBE, are especially valuable in years to come. Before I describe the improvements that have occurred in the manufacture of fermentation ethanol, allow me to describe some of the reasons why it is needed.

Why Do It?

There are three basic reasons why it makes sense to pursue biologic ethanol and derivative ETBE as alternative fuels for aviation applications.

Environmental Reasons. Air quality around the world in major urban areas is poor, and emissions associated with airports make a significant contribution to the inventory of pollutants. This is not only a health risk but also a cause of major medical expense and lost productivity, contributing to decreased competitiveness. Beyond the photochemical soup that comprises the threatening smog, there is growing and, I believe, legitimate concern over possible adverse climate change caused by the so-called "greenhouse effect" attributed to the undeniable climb in atmospheric levels of carbon dioxide due solely to human combustion of fossil fuels. People are expressing their desires all over the world, and these threatening environmental conditions are not what we want.

Energy Security, Reasons. As everyone here knows, we are increasingly dependent on petroleum to fuel our appetites for transportation fuels and petrochemicals. Further, that petroleum is increasingly foreign and, more to the point, from areas of the world that are viewed as potentially "unfriendly" to our interests. To put it mildly. Even worse, imports of finished fuels, those that are already completely refined and ready for use, are also increasing, and these take away American refining jobs. Examples include finished gasoline from Venezuela and subsidized MTBE from Saudi Arabia. Dependence on these foreign-produced barrels of fuel puts this nation at risk, and our response in Kuwait over actions by Iraq are proof of our concern. When was the last time you saw military action in the cornfields of Iowa?

USA Economic Reasons. Creation of a new domestic fuels industry, such as the opportunity represented by renewable ethanol, will put people to work. You will find them designing and building ethanol plants, such as we do at Delta-T. You will find them running the plants, like these folks at the Chippewa Valley Ethanol Company in Benson, Minnesota. And you will find them among the vendors that supply the equipment and utilities and in the local banks, hotels, and restaurants.

Renewable Ethanol is Part of the Answer

Production of ethanol from renewable and sustainable resources is part of the answer. Look what a difference ethanol makes now. Even though ethanol comprises less than 1% of our gasoline pool, it is found in 12% of our gasoline, and most of that is hard at work cleaning up the most polluted areas. That same small percentage has the following beneficial effects:

- Nearly 200,000 additional jobs in 1997
- Net benefit to US treasury of $3.6 billion, counting the "subsidy"
- Trade balance improved by $2.0 billion, by-products exports/decline in fuel imports

This is not too shabby for a fuel comprising only about a percent of all gasoline used!

Ethanol Production Technology is Vastly Improved

The production of ethanol from fermentation routes has always suffered from a sort of poor technical perception. We are looked upon as a bunch of moonshiners, bootleggers, smugglers, bathtub gin makers, and, on the best of days, legitimate distillers. Actually, our profession has an excellent pedigree. There is strong evidence that humans discovered how to make alcoholic beverages from grain before learning how to bake bread. This makes us the world's first or second oldest profession, and I will leave you to ponder that one.

This long association with ethanol fermentation has made humans adept at the science involved, but highly deficient in the engineering and technology to execute this science. The last ten years has seen all of the important developments, a few of which will be discussed here. And the remarkable thing is that the improvements that matter have all served to lower the price of ethanol plants, not make them more costly.

Plants Cost Less and are Cheaper to Run

It was not so long ago that the full cost for an ethanol plant was over $4.00 per annual gallon; for example, about $80 million for a 20 million gallons per year (gpy) facility. And they rarely ran well, as evidenced by the Tennol plant in Jasper, Tennessee, that never ran successfully.

Contrast this with the modern, efficient, and reliable ethanol plant of today. Comparing apples to apples, our company offers a full turnkey installation of a drymill (whole grain) corn-to-ethanol plant for about $25 million for an annual capacity of 15 million gpy; for 40 million gpy, the figure drops to about $55 million. This is about $1.67/annual gallon and $1.38/annual gallon, respectively for proven technology with features that I will describe in a minute. Not only that, all the equipment is new of stainless steel composition and all the warranties still in place; as compared to the profusion of used equipment offerings of carbon steel construction with limited residual value and no manufacturers' warranty on critical items. We have come a long way, indeed, and ethanol plants rank right up there with petrochemical offerings in terms of quality of design, construction, and service.

Operating costs have also been greatly reduced, along with emissions. We estimate about 38,500 Btu per anhydrous gallon of fuel grade ethanol produced as our thermal energy usage. This is split about 60% to the boilers for process steam and 40% to the direct-fired natural gas distillers grains dryer. Electricity usage has been reduced to 1.0 kWh per gallon of anhydrous ethanol produced or less for all process and utility loads. The major reasons for this decrease in utility usage over historical values are three:

- High degree of process heat integration
- Use of molsieve instead of azeotropic distillation ethanol dehydration
- No direct steam injection, therefore no process effluent

New Features Lead to New Benefits

Table 1 in the attachments to this paper shows the design criteria, in approximate order of priority, that we use in our designs of ethanol plants. Table 2 goes on to examine the features and attendant benefits which those design criteria generate. I wish to speak of two of the most important ones here.

The first is the replacement of azeotropic distillation, which uses toxic and often carcinogenic chemicals, with molecular sieve dehydrators to dry the ethanol to fuel specification. Operating at about a third of the energy required by the distillation route, this innovation, which we reduced to significant commercial practice with a world-scale unit in Sicily in 1991, has become the industry norm. The second innovation is the complete absence of process liquid effluent, long held to be the Holy Grail of our industry. The Tennol plant, mentioned earlier, attempted this feat and failed miserably. We succeeded not because we just recycle all of the excess process condensate and still bottoms, but because we avoid completely its production through a novel liquefaction method that avoids steam injection and, therefore, omits the excess water. As a former general manager of an ethanol-producing company that had to deal with wastewater woes on a daily basis, I cannot begin to tell you how important this development is to our industry. Not only do you avoid the cost of building and operating a wastewater facility, you avoid potential fines from the EPA, real threats to shut down your plant, daily operating headaches, offensive odors in the community, and public airing of dirty laundry. I think this is the greatest boon ethanol technology has yet provided.

On the emissions issue, VOC and particulates have been greatly reduced through application of highly efficient scrubbers and baghouses to catch grain dust. On the greenhouse gas side, we benefit not only from the improved energy efficiency, but also from the replacement of coal-fired boilers with those that use natural gas. A study is in progress by Argonne Labs of the US DOE to quantify the greenhouse emission reductions attributed to modem com-to-ethanol plants, and I am certain that we will see that their benefit has been revealed to be larger than previously thought.

The Future

Starch from grains (corn, milo, barley) and tubers (potatoes, cassava/tapioca) along with natural sugars (cane, beet, and the molasses from these) form the basis of the fuel ethanol industry today, and these sources will be the low-cost source of ethanol from biomass for the next ten years or so. The use of lignocellulosic materials, however, is developing rapidly, and we should see the first plants soon.

These plants will operate on wood chips, agricultural waste, municipal solid waste (garbage) and similar materials. They hold two major areas of promise. First, once the "bugs" are worked out, they will produce ethanol at very low cost. Especially with waste materials that present a disposal cost today, cost of ethanol produced will rival that of gasoline. Second, because the lignin produced as a by-product can supply the power needed to run the facility, the greenhouse abatement potential is much greater compared to starch-based plants, even those that run on fossil natural gas.

Technology is the key to all of this. And companies like Delta-T are leading the way.
Thank you for your time and attention.

Table 1. Design for Optimum Blend of Following

- **Safety**
- **Acquisition Cost**
- **Operating Cost**
- **Maintainability**
- **Yield**
- **Emissions**
- **Longevity**

Table 2. Delta-T Drymill Corn-to-Ethanol Plant

Features	Benefits
No direct steam injected anywhere into the process flow	No liquid process effluent
Delta-T molsieve dehydrator UltraDryTI (100 ppmw) Completely integrated w/distillation	No chemicals (entrainers) Lower energy than azeotropic Finest molsieve in the world UltraDry™ feature allows inexpensive upgrade to industrial
Acidity reduction to 20-30 ppmw w/o caustic into rectifier	Dependable, low cost method for specification compliance in this normally troublesome area
Pre-concentration of whole stillage before centrifuge	Recovers valuable ethanol Reduces VOC out of dryer (DDGS)
Energy integration of DD&E; w/rectifier reflux	Low energy demand
Very low air (N_2) in CO_2 (<1%)	Easier, lower-cost purification
Single cooling station for fermenters	Saves money Reliability controlled w/sophisticated computer control
Predominant use of novel design P&F heat exchangers for mash	Lower cost

Table 2. Delta-T Drymill Corn-to-Ethanol Plant (continued)

Features	Benefits
Rotary, direct fired (natural gas) DDGS dryer	Lowest energy, brightest color indicating protein not Denatured
Consistently high-solids syrup (can always use the process condensate in front end)	Assures minimum energy usage on dryer Assures it will always be able to use ALL the syrup in the dryer
@ 40 MMGPY, 6 fermenters will be used	Expected yields of over 2.7 undenatured gal/bu
3-column distillation system- beer, rectifier, side stripper	Delta-T pioneered Least expensive to build Side stripper removes load off beer column
Vapor fuels draw off rectifier directly to molsieve	Only w/Delta-T Keeps finished fuel grade drier No cumbersome liquid draws No recycle of extra water w/extracted ethanol

Biodiesel as Part of Sustainable Energy, Emission Control, and Economic Development Policy

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I. What is Biodiesel?

Biodiesel is a renewable, biodegradable resource which can be effectively utilized as part of a sustainable energy policy for any region of the United States. Biodiesel has been designated as an alternative fuel by the U.S. Department of Energy[1] and is registered with the U.S. Environmental Protection Agency[2]. It is virtually nontoxic and has been listed by the U.S. Food and Drug Administration as a food processing agent for human consumption[3]. As a substitute for, or additive to, petroleum diesel it can reduce emissions of NOX, CO, hydrocarbons and particulates[4]. Standards for the composition of biodiesel are set by the National Biodiesel Board, a nonprofit corporation funded through the U.S. Department of Agriculture, and are consistent with proposed provisional standards established by ASTM[5].

Biodiesel is made from first-use and used vegetable oils and tallow. The first diesel engines developed by Dr. Rudolph Diesel were run on peanut oil. Biodiesel can be used in modern diesel engines without conversion which means that the existing infrastructure, including vehicles and fueling facilities, can be used with little or no modification[6]. In comparison to other alternative fuels, such as natural gas or electricity, the cost of implementing biodiesel is substantially less, especially when considering the cost of new vehicles, fueling facilities, and the retraining of support and maintenance personnel[7]. As an energy efficient solution to our current consumption habits, the National Renewable Energy Laboratory has estimated that on a life cycle basis, for every unit of energy used to produce biodiesel from first-use vegetable oil, four units of energy are created. Preliminary conclusions suggest that this ratio may be as high as one unit of energy input for ten units of energy created when used cooking oils are the primary feed stock[8].

European countries emphasize the use of biodiesel as part of their energy and environmental policies. In France all diesel fuel is composed of a 5% blend of biodiesel. In the United States, extensive testing of biodiesel in over 30,000,000 miles of use as a 20% blend with petroleum diesel, has shown biodiesel blends to be road worthy and environmentally friendly substitutes for pure petroleum diesel.

Feedstocks for biodiesel in the U.S. include over 22 billion pounds of first-use vegetable oils such as soy oil, peanut oil, canola oil, and others[9]. Perhaps the most significant source of vegetable oil for a regional sustainable energy policy is the use of used cooking oils from restaurants. It is estimated by the National Restaurant Association that there are over 376,571 restaurants in the United States[10] which produce an average of 150 gallons of waste oil per month from cooking operations. This yields nearly 3,000,000,000 gallons of waste oil feedstock per year. Currently the U.S. uses approximately 32 billion gallons of petroleum diesel per year[11]. With the combination of first-use and used vegetable oil and tallow, there are more than sufficient quantities of renewable and biodegradable oil feedstocks to make a 20% blend of biodiesel feasible for all U.S. diesel transportation uses, including mass transit, school buses, rail, and commercial trucking.

Use of biodiesel on a broad scale would reduce U.S. dependence on foreign energy sources. Policies to encourage the use and production of biodiesel should be developed and encouraged. These policies should include the creation of emission reduction credits for biodiesel use, industrial revenue bonds for biodiesel plant development, mandatory used-oil recycling requirements, favorable tax treatment, and other incentives for the use of biodiesel blends in public and private transport.

II. What is NOPEC?

NOPEC ("No OPEC") Corporation is a Lakeland, Florida based business which owns and operates the largest dedicated biodiesel production facility in the United States. Their 22,000,000 gallon per year plant is capable of handling multiple feed stocks, including first-use vegetable oils, used cooking oils, and tallow. Their unique process is protected by several pending national and international patent applications, and their facility is a world showcase for the latest environmental technology.

III. Biodiesel Plants as Part of Regional Economic Development

NOPEC's proprietary technology can be used to develop multi-feedstock biodiesel plants in almost any area of the world. In the U.S. these plants are ideally suited for "Brownfield Areas" and "Enterprise Zones." These biodiesel plants are low impact, clean, redevelopment projects that:

- create jobs,
- reduce pollution through the recycling of waste cooking oil,
- reduce the regions' balance of payment deficit for importing petroleum, and
- produce a product which is used to reduce air pollution.

A local biodiesel production facility can also help reduce the cost of using biodiesel in fleets by eliminating long-distance transportation costs. Plant construction usually runs about $1 to $2 per annual gallon of capacity, depending upon the local economic incentive packages available.

IV. Conclusion

In conclusion, biodiesel has the potential to reduce emissions wherever diesel is used, especially in medium- and heavy-duty vehicles, rail, marine use, and stationary generators and pumps. Biodiesel production is a clean process which utilizes recycled waste streams and provides opportunities for local economic development.

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12. “Alternatives to Traditional Transportation Fuels 1995,” page 30 and footnote 20 therein.

LUNCHEON PRESENTATION—THE FAA'S AIRCRAFT SAFETY RESEARCH, ENGINEERING, AND DEVELOPMENT PROGRAMS

BRUCE FENTON, FEDERAL AVIATION ADMINISTRATION

SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
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The FAA's Aircraft Safety Research, Engineering, and Development Programs

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Luncheon Presentation on 11/6/97

The fundamental mission of the FAA is to foster a safe and efficient air transportation system. One way the FAA assures a safe air transportation system is by taking the lead in developing technology, technical information, tools, standards, and practices to promote the safe operation of the civil aircraft fleet.

The FAA's program makes significant contributions to assure the safety, efficiency, and cost-effectiveness of the national aviation system. Today that system is under heavy pressure to keep up with rising traffic demand, needs for essential safety and security improvements, airspace user requirements for more flexible and efficient air traffic management operations, and demands for further mitigation of the environmental impacts of aircraft operations. To meet these challenges, the FAA employs a comprehensive research, engineering, and development (RE & D) program that assures all available resources remain customer focused and targeted on the highest-priority activities.

The economic health of the civil aircraft industry is closely linked to its safety record. For this system to remain viable, it needs to have the confidence of the flying public. That can be achieved only by the prevention of accidents and, when accidents do occur, the causes must be determined and any unsafe trends quickly corrected.

Aviation safety is measured by a variety of indicators that, when taken together, show a continuing pattern of improvement. However, one indicator – the aircraft accident fatality rate – has remained relatively constant over past 20 years, with approximately two deaths for every 10 million enplaned passengers. Consequently the total number of passenger fatalities has climbed steadily over the last two decades as airline travel has continued to grow. The FAA forecasts indicate that the number of aircraft operated by large US air carriers will increase from approximately 4,000 in 1990 to almost 5,350 in the year 2000. Commuter fleets are projected to grow from 1,000 to more than 2,200 during the same period. The result will be a jump in commercial operations at FAA-controlled airports from the 1990 level at 21.7 million to 28.7 million in the year 2000. Some growth projections over the next decade estimate up to 5% per year. Projecting the current accident fatality rate over the next 10 years would result in an increase of approximately 30% in total fatalities due to the growth on fleet size and enplaned passengers; clearly this is an unacceptable prospect. The goal of the FAA's Aircraft Safety Research (ASR) program is a 50% reduction in total fatalities in the next 10 years.

This goal translates to a 62% reduction from the fatality rates expected with present accident trends magnified by the aviation growth. There are two ways that research tasks contribute to the FAA goal. The first group of tasks is in place to identify and prevent factors from becoming causes for fatal accidents. These tasks include issues related to aging aircraft systems reliability and aircraft catastrophic failure prevention. The second group of research tasks is aimed at reducing the number of fatalities by increasing survivability of passengers on specific types of accidents. For US transport airlines between 1981-90, half of the fatalities were associated with accidents that were impact survivable. Therefore, these fatalities can be reduced by providing technology initiatives in fire safety and airplane crashworthiness in the issues that caused the fatalities in these accidents.

Since the FAA's RE & D activities are funded by the taxpayer, the thrust of the agency's ASR program is aimed at benefiting the flying public. The program is product oriented, with the emphasis on developing new or improved safety devices or procedures as well as providing data for providing safety rules, specifications, and advisory materials.

Research priority and direction can be established by many factors: in-service safety trends in accidents/incidents that culminate by major accidents such as the Aloha Airlines B737 in 1988 that drives aging aircraft issues and the Sioux City DC10 in 1989 that drives turbine rotor integrity issues. Environmental impact laws such as the 1990 Clean Air Act resulted in the need for developing a standard for unleaded aviation gasoline production.

To establish these needs, the Aircraft Certification Service established regional Directorates that perform technical policy management and program management for the aircraft certification programs. The responsibility is assigned with regard to the development and standardization of technical policy for a particular type certification category; the Engine & Propeller Directorate, in the New England Region, has oversight for turbine/piston engines, propellers, fuels, and lubrications, (FAR Part 33/35) the Small Airplane Directorate, in the Central Region, oversees small airplane issues (FAR Part 23); the Transport Airplane Directorate, in the Northwest Mountain Region, oversees transport issues (FAR Part 25); and the Rotorcraft Directorate, in the Southwest Region, oversees rotorcraft issues (FAR Part 27&29). The Flight Standards Service oversees issues regarding in-service operations regulations such as maintenance, repair, overhaul, inspection, and training. Research needs can be defined by any Directorate or Flight Standards office to support future rule making or certification.

FAA Aircraft Safety RE & D support of the rulemaking process has resulted in the following actions being put in to service:

- Floor proximity emergency exit lighting
- Halon 121 fire extinguishers
- Radiant heat-resistant evacuation slides
- Crash-resistant fuels systems
- Cargo and baggage compartment fire test criteria
- Upgraded occupant seat restraint requirement
- Upgraded tire and wheel performance
- Airborne low-altitude windshear equipment and training requirements
- More stringent fire test requirements for flight data and cockpit voice recorders.

The FAA promotes an open research partnership with industry, i.e., airlines, aircraft and engine manufacturers, and aircraft maintenance facilities which operate under the FAA standards. The FAA works collaboratively with other agencies such as NASA and the Department of Defense as well as aviation professionals, national laboratories, and academia. By reaching out to this cross section of the nation's academic community, private sector, and other agencies, the FAA gains access to both internal and external innovators, promoting the transfer of technology, personnel, information, intellectual property, facilities, methods, and expertise.

To facilitate these partnerships, the FAA has established committees whose membership is drawn from the aviation community. These committees provide technical guidance of research activities, and liaison with industry is conducted under the auspices of the subcommittee for Aviation Safety of the RE & D Advisory Committee.

The Aviation Rulemaking Advisory Committees (ARAC) provide advice and recommendation through the Associate Administrator for Regulation and Certification on the full range of the FAA's rulemaking activities. The membership of the ARAC is composed of representatives of the aviation industry. The ARAC provides the FAA with first hand information and insight from the affected segments of the industry on proposed and existing rules, advisory materials, and other standards. The CRC committee oversight of the development of an unleaded aviation gasoline's specification is another example of how these committees work.

These types of industry research partnerships and oversight committees early in the development of new technology (including technical in-kind investment contributions) will assure successful implementation of the regulatory outputs from the research activities.

Current/Active Aircraft Safety RE & D Initiatives for accident/incident prevention and/or mitigation:

- Advisory Circular (AC) Structural Integrity Goal

To prevent aircraft (transport, rotorcraft, commuter) structural failures by developing nondestructive inspection systems capable of early detection of material degradation (cracks, disbonds, corrosion) and methods to predict the onset of widespread fatigue damage. The FAA is updating/revising AC's to reflect methods used in maintenance, repair, and inspection. Also developing rules, AC's, and training material for advanced composite material structures.

- Mechanical & Electrical System Reliability and Integrity

Studying the potential impact of atmospheric hazards, both natural and man made, high-intensity radiated fields/lightning/portable electronic devices on advanced technology airplane systems including the complex software-based digital flight control/avionics.

- Flight Safety-Operational Hazards

The ground and in-flight icing hazard definition and detection and de-icing systems.

- Human Factors

Directed toward improved flight deck human engineering, identification, and mitigation of work environmental factors affecting flight crew, maintenance, inspection, personnel performance, and enhanced individual and team training.

- Fire Safety Missions

To develop near-term fire safety improvements to prevent uncontrollable in-flight fires and increase postcrash fire survivability and conduct long-range research to develop ultra fire-resistant cabin materials.

- Aircraft Crashworthiness Goal

To increase the occupant protection during an accident. The program evaluates ground and water impact requirements for rotorcraft, transport, and commuter aircraft. It is developing and validating the test procedures for certification standards and performance specifications.

- Propulsion System Safety

The main thrust of the propulsion system research is to support airworthiness assurance by enhancing the safe and reliable performance of turbine and general aviation piston engines, propeller systems, fuels and fuel transfer systems, and to minimize the hazards to the aircraft in case of a failure. The vulnerability and survivability of critical aircraft systems (required for continued safe flight/landing) that may be affected by the hazardous threat of single-point failures are a major consideration. Commercial A/C accidents caused by turbine engine failures have illustrated the need for improvements in component structural integrity, inspection tools, monitoring/diagnostics, rotor failure containment, and in-service performance reliability under adverse weather and foreign object ingestion conditions.

You have heard how the renewed interest in the environmental impact of unleaded aviation gasoline has created a major thrust to develop more environmentally safe aviation fuel. It is important for the FAA to play a major role in the development of this unleaded fuel replacement specification along with the CRC industry oversight team. The FAA's certification responsibility for assuring the airworthiness of piston engines to a fuel standard must result in reliable and safe operating life for all users.

- Turbine Engine Research

FAA service difficulty and accident/incident reporting show that there are an average of 15 uncontained turbine engine rotor failures per year in the US. When engine fragments penetrate or escape the engine casing, the FAA refers to the event as an uncontained failure. While the consequences of an uncontained failure includes immediate/total loss of engine power, the more serious problem is the potential secondary damage to the aircraft. Such damage can lead to fire, loss of control, hull loss, and occupant injury or death.

Aerospace Industry Association (AIA) data show that rotor disk/spacer fractures over the last 15 years are the number-one turbofan engine uncontained cause that result in the most severe secondary damage to the aircraft. Uncontained blades/other fragments are the fourth most common cause in this category. The DC10 accident at Sioux City, Iowa, in 1989 was a devastating uncontained disk failure. The primary failure mode of the Sioux City accident was a fatigue crack that originated from an undetected titanium alloy melt related defect. Approximately 40% of the uncontained rotor disk/spacer failures are caused by design and life prediction or quality control problems. Up to another 50% could have been prevented through enhanced and/or more aggressive nondestructive inspection. In response to these accidents trends and the Sioux City accident specifically, the NTSB and an FAA study team made recommendations related to improvements in Ti metallurgical quality (purity), NDI, and other rotor disk structural integrity design and lifting standards. The FAA/Industry collaborated through a number of consortium and working committees including the AIA Materials and Structure Committee, AIA Rotor Integrity Subcommittee, the Engine Titanium Consortium, the Jet Engine Ti Quality Committee, the ARAC, and the Power Plant Installation and Harmonization Working Group. These groups identified potential improvements in areas of manufacturing process control, manufacturing inspection, in-service inspection, design and life management tools, and uncontained failure hazards mitigation that require a new technical base provided by the FAA RE & D programs. Other improvements related to material tracking and inspection schemes have been identified that could be implemented without RE & D. The FAA turbine engine RE & D priority areas include engine structural integrity, advanced NDI and uncontained failure hazards mitigation.

Engine Rotor Structural Integrity

An industry (AIA)/FAA working group proposed an approach that will enhance the conventional design/life methods by developing a probabilistically based damage tolerant design code. The output of this research will lead to improved rotor material design and durability with risk assessment through a generic, public domain, standardized tool to be the basis for revised certification advisory material for engine rotor integrity.

Manufacturing Process for Rotating Component Materials

The objective of this research initiative is to develop and implement in a production environment an advanced manufacturing process that will produce premium quality rotor grade alloy materials that are significantly free of melt-related defects. The research will focus on a single step hearth melt approach. The goal is to provide a commercial standard that establishes manufacturing processes to produce rotor grade alloy materials that are superior to current processes by up to 2 orders of magnitude relative to the absence of melt related defects.

Engine Rotor Material Nondestructive Inspections;

This program has been conducting research to establish advanced industry standards that include reliable and cost-effective nondestructive methods or improvements to mature methods for detecting cracks, inclusions, and other anomalies in titanium alloys made for rotating engine parts. The activities are grouped in rotor billet production quality assurance, rotor in-service inspection, and inspection reliability assessment.

Turbine Engine Failure Hazards Mitigation:

While the other turbine engine research activities address the failure hazards from the standpoint of improving rotor system integrity, durability, and inspection risk management, the hazards mitigation research activity is based on the assumption that an uncontained rotor failure event can happen. The research goal is to provide the hazard threat characterization, analytical modeling tools, and technology to mitigate the threat to critical aircraft structures, systems, and occupants. The threat characterizations task will develop a debris database to correlate existing incident data so that debris and damage characteristics can be extracted and used in a vulnerability assessment analysis. Analytical modeling tools will be developed and validated to numerically simulate the containment and vulnerability of the aircraft to uncontained debris. These tools will be useful to both engine and airframe manufacturers to design a cost-effective engine debris containment system or aircraft structure hazard mitigation as appropriate compliance to certification requirements. Engine hazard mitigation technology will be done in two phases. Phase I will demonstrate the potential of advanced armor developments for improving current aircraft barrier technology and identify specific applications. Phase II will optimize the design of the containment and protective structures and verify their effectiveness by constructing and testing subscale models. The task will deliver detailed designs for improved rotor fragment barriers.

While this talk about the FAA's RE & D Program contained a level of detail difficult to retain, it was done to illustrate the diversity and technical sophistication of the Aircraft Safety Program. All programs are designed to provide deliverable outputs that are broadly applied to specific in-service safety issues with measurable safety improvement outcomes for the flying public.

NEW ENGINE TECHNOLOGY

BRENT BAILEY, NATIONAL RENEWABLE ENERGY LABORATORY (*FACILITATOR*)

CHRIS ATKINSON, WEST VIRGINIA UNIVERSITY
LEO BURKARDT, NASA LEWIS RESEARCH CENTER
RON WILKINSON, TELEDYNE CONTINENTAL MOTORS (NO PAPER GIVEN)

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A Real-Time Neural Network-Based Intelligent Performance and Emissions Prediction System for On-Board Diagnostics and Engine Control

Virtual Sensors

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Synopsis.

West Virginia University, in collaboration with NeuroDyne, Inc., has developed and is demonstrating a neural network-based engine performance, fuel efficiency, and emissions prediction system that is able to predict real-time engine power output, fuel consumption, and emissions using readily measured engine parameters. The system consists of a predictive engine model that is designed to run on a microprocessor in parallel with the engine in real time, taking input signals from the same sensors as the engine itself. The neural network (NN) model of the engine is able to make highly complex, nonlinear and multidimensional associations between selected input parameters and outputs in real time, to allow accurate predictions of engine performance (real-time torque output), engine emissions (unburned hydrocarbons, carbon monoxide, oxides of nitrogen, carbon dioxide, and particulate matter in diesel engines) and fuel consumption across the full range of engine operation. During limited dynamometer testing, the NN model learns in real time and on the fly the precise relationship between all designated inputs and outputs. Once operating in an aircraft, the model is able over time to update those relationships to allow for engine or component wear, subtle changes in fuel composition, or extreme combinations of operating or environmental variables. This virtual sensing system, which is equally well applicable to spark ignition or compression ignition engines, has been demonstrated in three automotive engine applications to date. This innovative system has immediate application in engine control, on-board diagnostics, and emissions measurement for both compression and spark-ignition ground vehicles and aircraft. Future potential applications include emissions monitoring and engine control for turboprop engines and gas turbines for propulsion and power.

New Technologies in Engine Control, Diagnostics and Modeling

- by
- Chris Atkinson, Sc.D.
- Dept. of Mechanical and Aerospace Engineering
- West Virginia University

FUTURE FUELS

Compression ignition:

- Fisher Tropsch synthetic distillates (zero S), perhaps from NG
- alcohols and oxygenates.

Spark ignition:

- Petroleum based (zero Pb)
- alcohols and oxygenates.

FUTURE ENGINES

Compression ignition engines:

- direct injection with rate shaping
- variable geometry turbocharging
- infinitely variable valve timing
- variable fuel properties

Spark ignition engines:

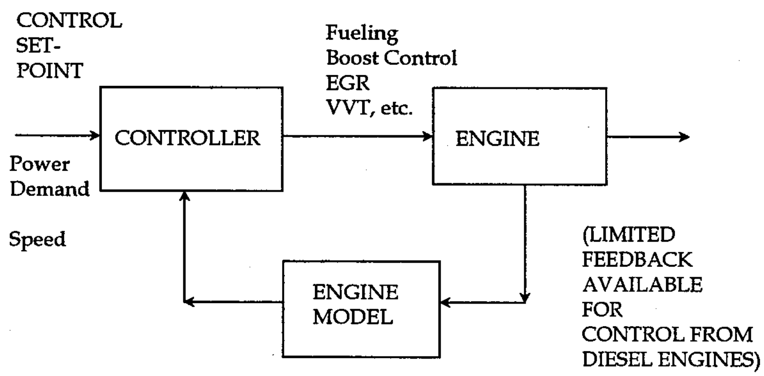
- variable fueling, boost, ignition
- variable valve timing, EGR

ENGINE CONTROL RESEARCH

Control System requirements:

- intelligent
- adaptive
- capable of learning
- real-time
- enhanced diagnostic capability
- predictive capability

MODEL-BASED CONTROL



MODEL-BASED CONTROL REQUIREMENTS

- Must be capable of fully transient, dynamic emissions prediction across the full range of possible engine performance,
- Must be capable of predicting instantaneous emissions, performance and fuel consumption under a wide range of environmental conditions, &
- Must provide control in real time with reasonable computational effort.

Disadvantages of Equation-Based Engine Models

These models must consider the full physics and chemistry of the

- air intake process (including turbocharging),
- injection process,
- combustion kinetics,
- heat transfer and thermodynamics, and
- engine mechanical dynamics.

AN ALTERNATIVE SOLUTION

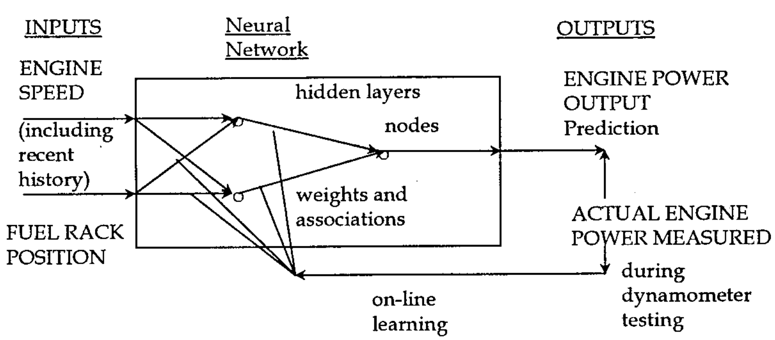
Develop an adaptive, intelligent engine model that learns from limited dynamometer-based training and can then go out into the field with excellent generalization capabilities. The model must allow the prediction of performance and emissions in real time for any transient engine operation.

→ NEURAL NETWORK-BASED INTELLIGENT ENGINE MODEL

ADVANTAGES OF NEURAL NETWORK PREDICTION

- Real-time emissions prediction
- On-line learning capability
- Highly nonlinear, multidimensional associations
- Excellent generalization
- Adaptive
- Excellent prediction capabilities

NEURAL NETWORKS



A Simplified Example: A NN model of a diesel engine, associating engine speed and fuel rack position to power produced, showing on-line learning or training achieved through comparing predicted output with actual measured value.

VIRTUAL SENSING ARCHITECTURE

- Partially recurrent neural network
- CI Engine Inputs (9 parameters)
  - Engine Speed
  - Manifold Boost Pressure
  - Manifold Air Temperature
  - Fuel Rail Pressure
  - Fuel Rail Temperature
  - Engine Coolant Temperature
  - Rack Position
  - Injection Timing or Lift
  - Exhaust Gas Temperature

CI Engine Predicted Outputs (7)

- Instantaneous torque/power output.
- Carbon monoxide (CO)
- Oxides of nitrogen (NO_x)
- Unburned hydrocarbons (HC)
- Particulate matter (PM)
- Smoke (opacity)
- Carbon dioxide (CO_2) [as a measure of fuel consumption]

Real time (20 Hz) prediction possible with Intel Pentium 100 MHz PC.

TRAINING *and* OPERATION

- 1) Limited duration dynamometer-based training to develop global weights or associations (engine on dynamometer with full emissions measurement)
- 2) Engine is sent out into the field in a vehicle (without the benefit of torque or emissions measurement), using the NN model to provide feedback.

POTENTIAL USES OF NEURAL NETWORK-BASED MODELS

- Engine Control - providing unmeasured or unmeasurable feedback parameters (e.g., NO_x and PM in diesel)
- Engine Diagnostics - emissions exceedances, sensor/system failure
- Engine Modeling - control system development and calibration

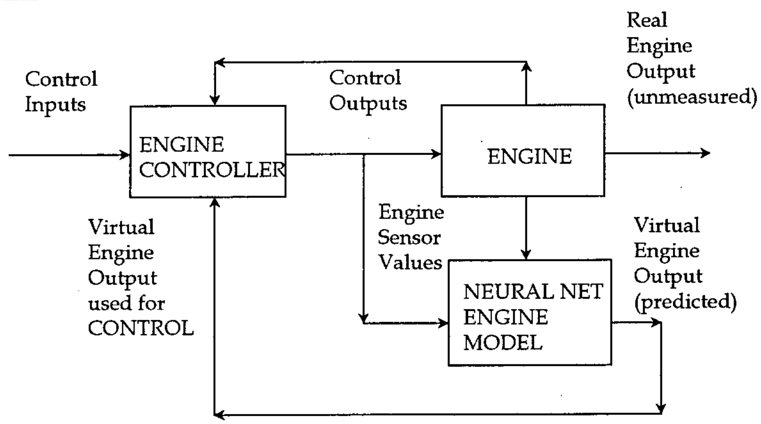
ENGINE CONTROL

- Allows for effectively "closed loop" control without any extra sensors. Enables VIRTUAL SENSING of
  - NO_x, CO, HC, or PM emissions
  - Allows an engine to be operated at the emissions/best power/best efficiency limit
- Simultaneous multidimensional control of fueling, boost, EGR, and valve timing.

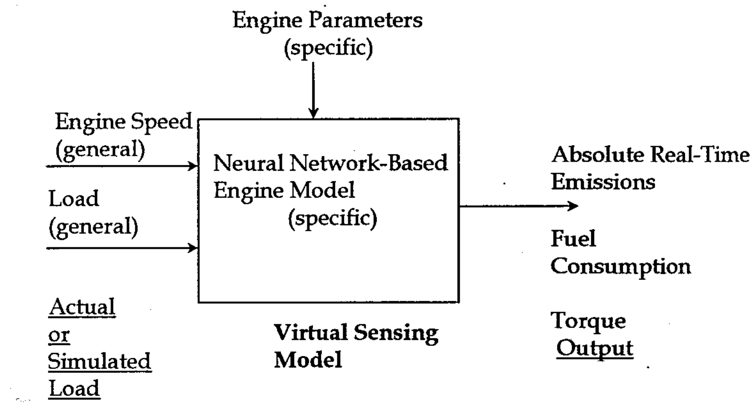
ENGINE DIAGNOSTICS

- Can provide real-time torque and fuel consumption with no extra sensors.
- Provides virtual sensor input for OBD, such as emissions exceedances.
- Competitive/voting nets using a subset of engine inputs can be used to determine sensor or system failure (for more obtuse failures).
- Provides a wealth of extra information with the same number of sensors.

NN-BASED ENGINE CONTROL



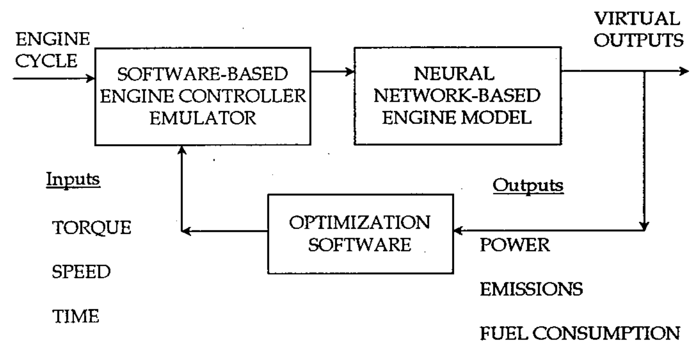
ENGINE MODELING



ENGINE MODELING

- Software-based virtual engine model for control system development, validation, and mapping.
- Can reduce time required for controller development.
- Can accurately model emissions on different engine cycles without requiring extra engine testing.
- Can be integrated with more complex modeling, such as KIVA.

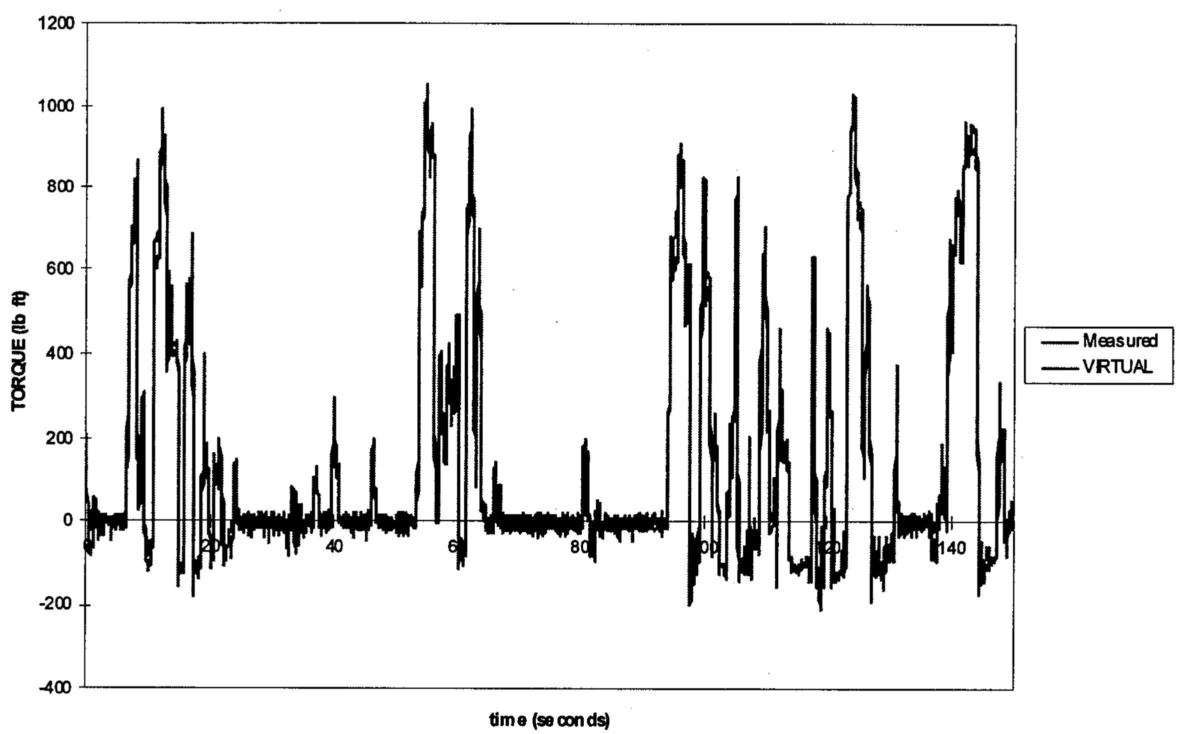
REDUCING ENGINE AND CONTROLLER DEVELOPMENT TIME



PROOF OF CONCEPT DEMONSTRATION - CI

Engine Test Parameters.	
Engine Type	10 liter, in-line 6 cylinder DI
Fuel	diesel (D2)
Compression Ratio	15:1
Turbocharger	150 kPa gauge max. boost
Fuel Injection System	mechanical cam driven
Maximum Power	300 hp (225 kW) at 2200 rpm
Data Rate	20 Hz
Net Training Requirement	30 minutes (approximately)
Engine Operating Conditions	hot, stabilized

Figure 1a. Measured vs. Predicted Engine Torque



CONCLUSIONS

Neural network-based engine models are potentially extremely useful in

- engine control,
- engine diagnostics, and
- engine modeling,

for low emissions, high fuel efficiency future generation GA engines using alternative fuels.

New Engine Technology

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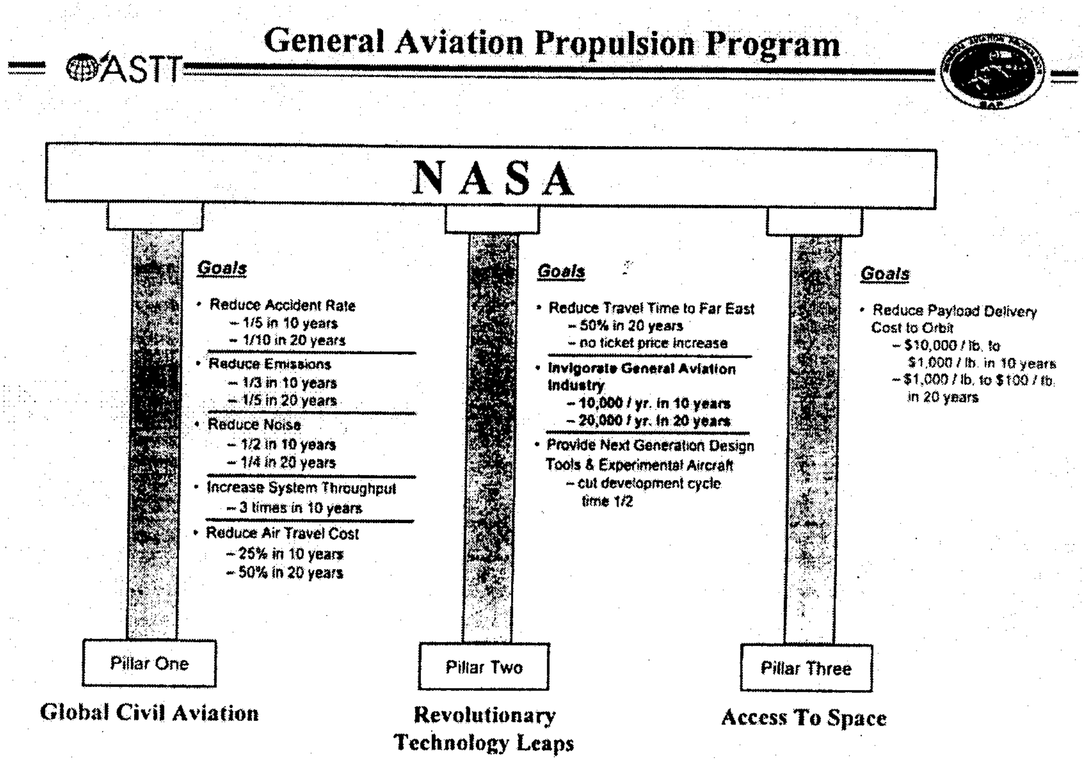
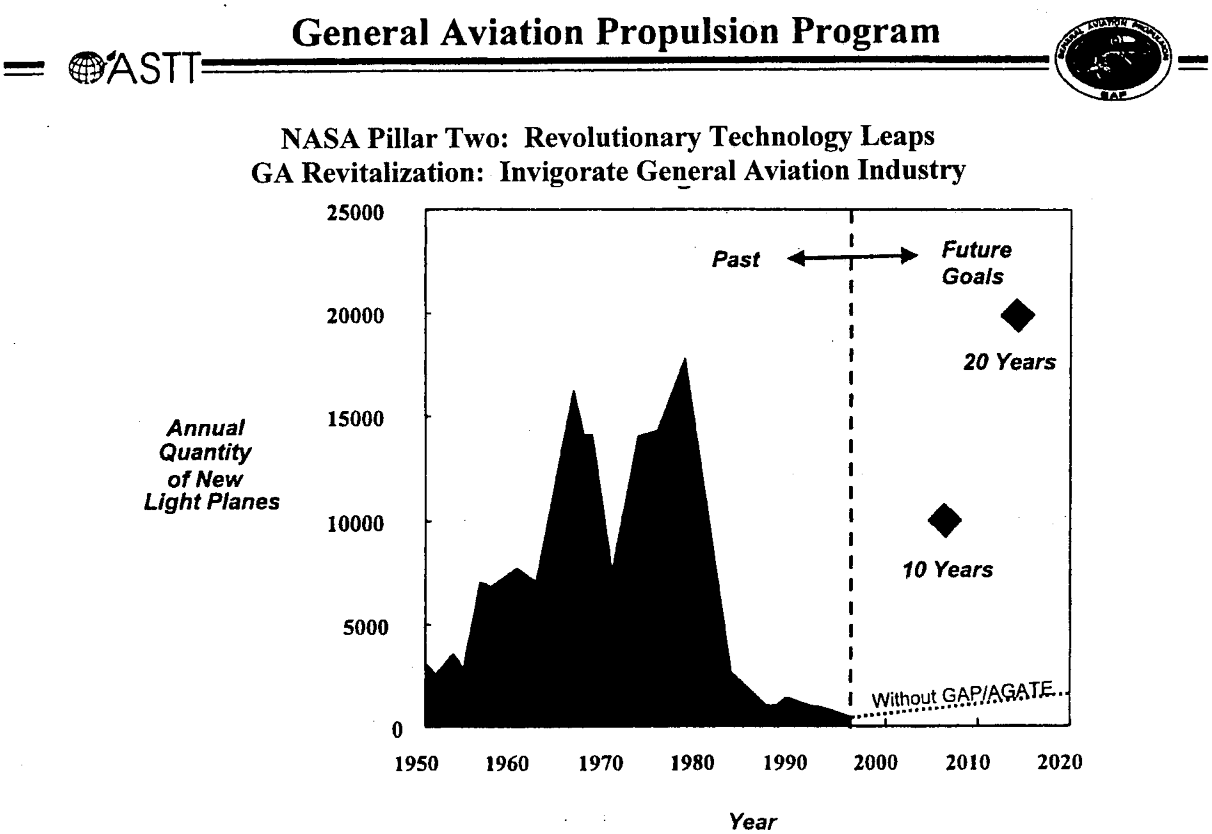
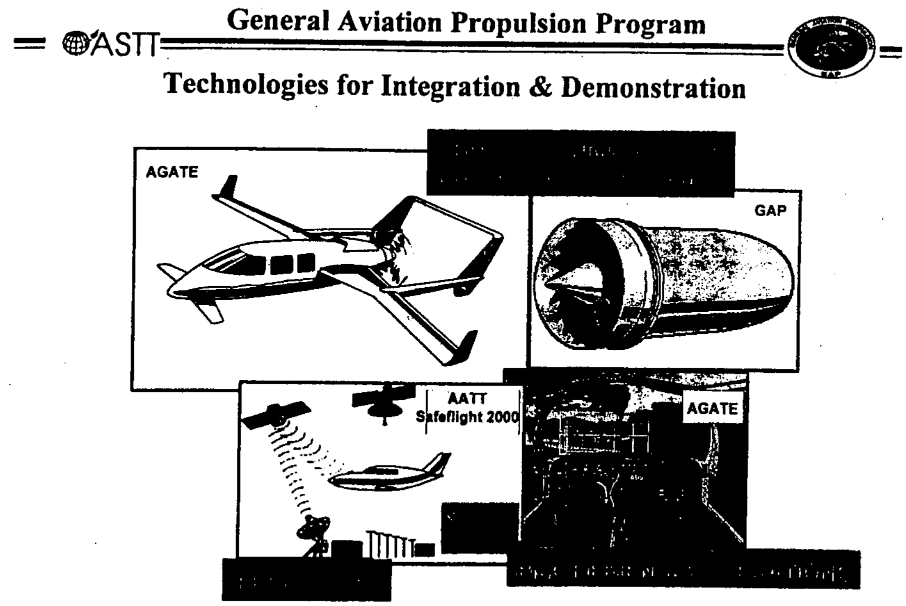
NASA's strategic direction is described by the "Three Pillars" and their goals as set forth by the NASA Administrator Daniel S. Goldin. NASA's Three Pillars are 1. Global Civil Aviation, 2. Revolutionary Technology Leaps, and 3. Access to Space. General aviation has fallen far behind in technology and affordability; therefore, NASA's current goal for general aviation technology development falls under Pillar Two, Revolutionary Technology Leaps. The enabling technology goal is to invigorate the general aviation industry, delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 20 years.



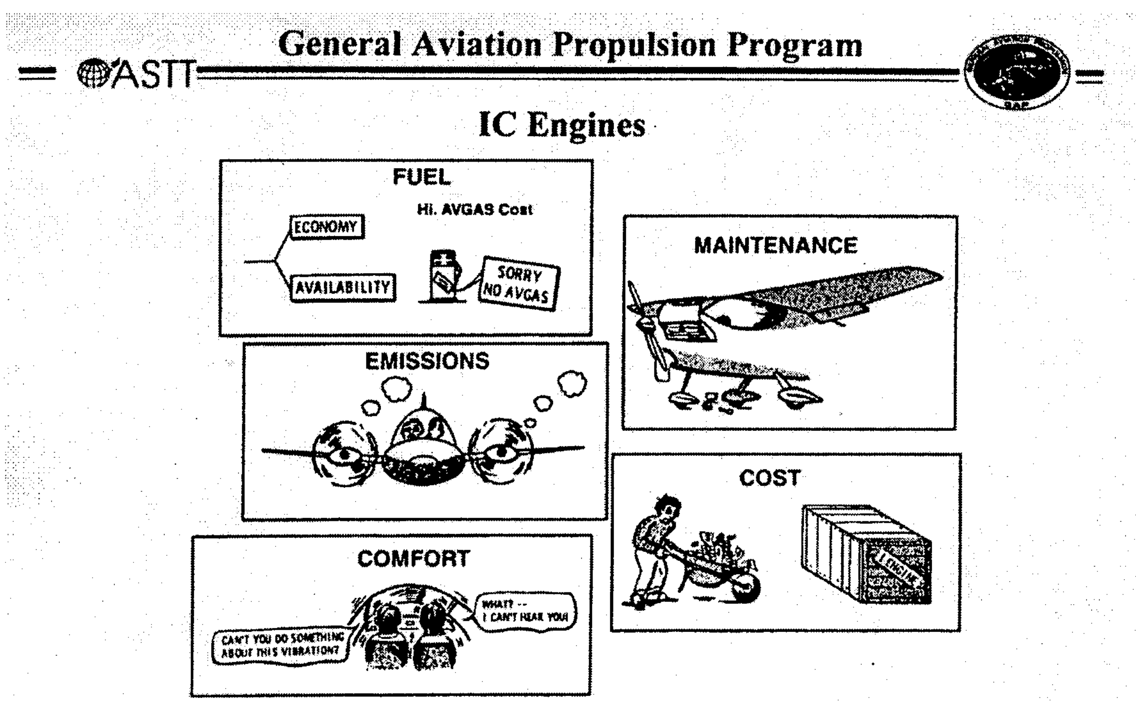
Putting NASA's goal in perspective, it means developing technologies that will once more enable general aviation manufacturers to produce aircraft that are attractive and affordable to the public. Though the goal production numbers may seem fantastic compared to today's production levels, they are really saying nothing more than we would like to get back to the production level which general aviation once enjoyed before the "big crash" of the 80s. Before 1980 the sales trend for general aviation aircraft generally followed the gross national product. With the average age of the current general aviation light-aircraft fleet being approximately 30 years and the basic technology level incorporated into those aircraft being much older than that, the market is ripe for rejuvenation.



NASA, the FAA, and the general aviation industry are all cooperating in trying to bring about the resurgence of general aviation. NASA has programs aimed at meeting the technology needs of the total general aviation market place and infrastructure. The two programs specifically aimed at general aviation are the Advanced General Aviation Technology Experiment (AGATE) program and the General Aviation Propulsion (GAP) program. AGATE is developing airframe and avionics technologies. GAP is concentrating on new engine development. Other NASA programs, while not specifically aimed at general aviation, have components which address the needs of general aviation. One such program is Advance Air Transportation Technology (AATT). This program is developing technologies for the air traffic control infrastructure which will increase safety, provide for greater numbers of aircraft, and allow more aircraft freedom in routing and flight paths. General aviation is an important part of this air traffic picture.

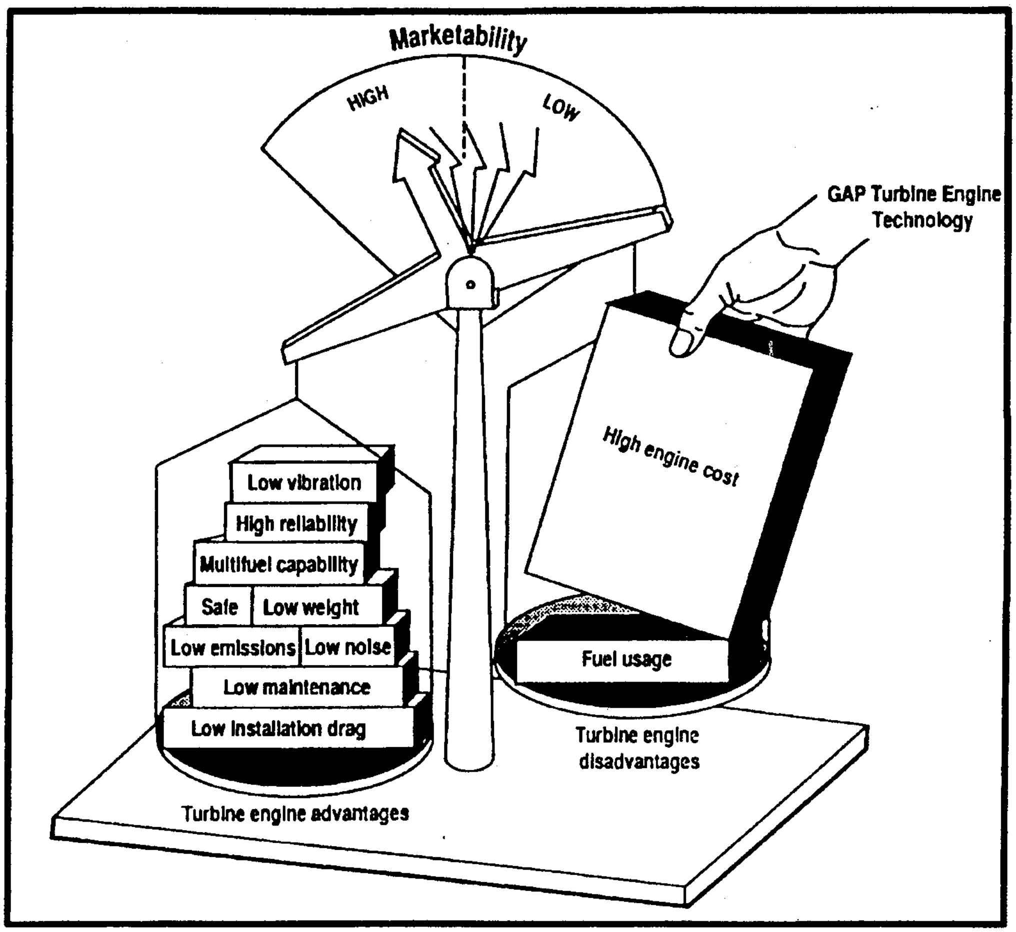


Why is there a need for new general aviation engine technology? Current piston aircraft engines are essentially 1940's designs. General aviation is the only industry still permitted to use leaded gasoline, this will not last forever. In Europe gasoline is very expensive compared to other fuels. Emissions are high, especially during periods of rich operation required to help cool the engine. The engines are noisy, produce a lot of vibration, and have archaic control systems. Acquisition and engine maintenance costs are very high. An aircraft piston engine is on the order of 20 times more expensive than an automobile engine.



Turbine engines would appear to be an excellent choice for future light general aviation aircraft power plants as they have proven to be for all other segments of aviation. One major factor has kept the turbine engine from significantly penetrating this market, affordability. Turbine engines are prohibitively expensive, about 2 to 4 times the cost of comparable performance piston engines.

Turbine Engines



The General Aviation Propulsion program was established to address the technology needs of the general aviation engine industry. The specific goal of GAP is to develop and flight demonstrate revolutionary propulsion systems for general aviation aircraft to support revitalization of the U.S. General Aviation Light-Aircraft Industry. This will be done in partnership with the FAA by developing technologies and processes that will result in low-cost, environmentally compliant, revolutionary propulsion systems for light general aviation aircraft. The major milestone of the program is to flight demonstrate fully manufacturable, certifiable propulsion systems in the year 2000 which meet or exceed the cost and operability requirements of the program.

General Aviation Propulsion Program:

Goal: Develop and flight demonstrate evolutionary propulsion systems for general aviation aircraft to support revitalization of the U.S. General Aviation Light-Aircraft Industry.

Objectives: Through a NASA/Industry/FAA Partnership

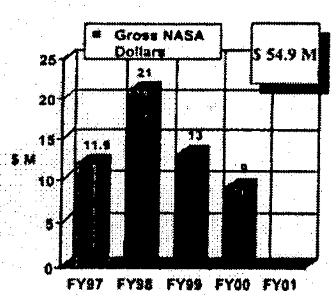
Develop technologies and processes that will result in low-cost environmentally compliant revolutionary propulsion systems for light general aviation aircraft.

Flight demonstrate proof-of-concept propulsion systems on appropriate test-bed aircraft.

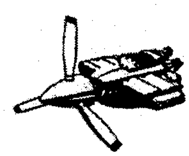
The GAP program is a four year program, begun in 1997, for which NASA has provided $55 million. Industry is making an equal investment in the program. GAP is divided into two Elements, the Intermittent Combustion (IC) Element and the Turbine Element. Each Element is implemented through a Cooperative Agreement with an industry led team. Each team will flight demonstrate its engine concept by the year 2000. The engine manufacturer on each team has committed to putting a new engine on the market, based on these engine concept demonstrators, within a couple of years after the completion of the GAP program.

ASTT General Aviation Propulsion Program

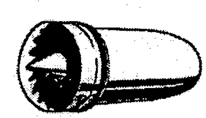
Goal: **Develop and flight-demonstrate revolutionary propulsion systems for general aviation aircraft to support revitalization of the U.S. General Aviation Light Aircraft Industry**



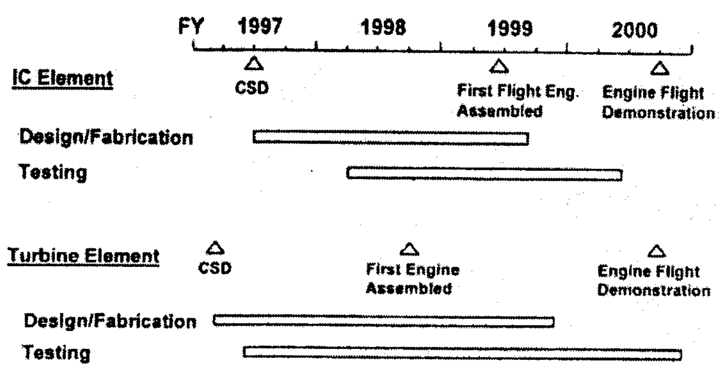
Equivalent Contributions From Industry Partners



CSD 283
Teledyne Continental Motors
IC Element



FJX-2
Williams International
Turbine Element



The design goals which have been set for each element are as follows:

IC Element

Reduce acquisition and maintenance costs by 50% compared to current engines. Avoid the use of leaded gasoline or any other environmentally dangerous fuel; use jet fuel if possible. Achieve propulsion related comfort and ease of use levels similar to those in the automotive world. Meet or exceed expected environmental regulations.

Turbine Element

The turbine engine already has the types of characteristics needed except for cost, so the major goal here is to reduce the acquisition and maintenance costs of small turbine engines by an order of magnitude while maintaining good performance levels. As with the IC Element the engine must meet or exceed expected environmental regulations.

General Aviation Propulsion Program

ASTT

Engine Performance Goals

	IC	Turbine
Cost Reduction	50%	90%
Fuel	JP	
Ergonomic	Similar to Automotive Comfort, Ease of Use	
Maintenance Cost Reduction	50%	90%
Specific Fuel Consumption Reduction	25%	
Environmental Compliance		
- Emissions		
-- gaseous emissions reduction	Meet expected standards for year 2000+	Meet expected standards for year 2000+
-- particulate visibility	Meet expected standards for year 2000+	Meet expected standards for year 2000+
- Noise	Meet expected standards for year 2000+	Meet expected standards for year 2000+

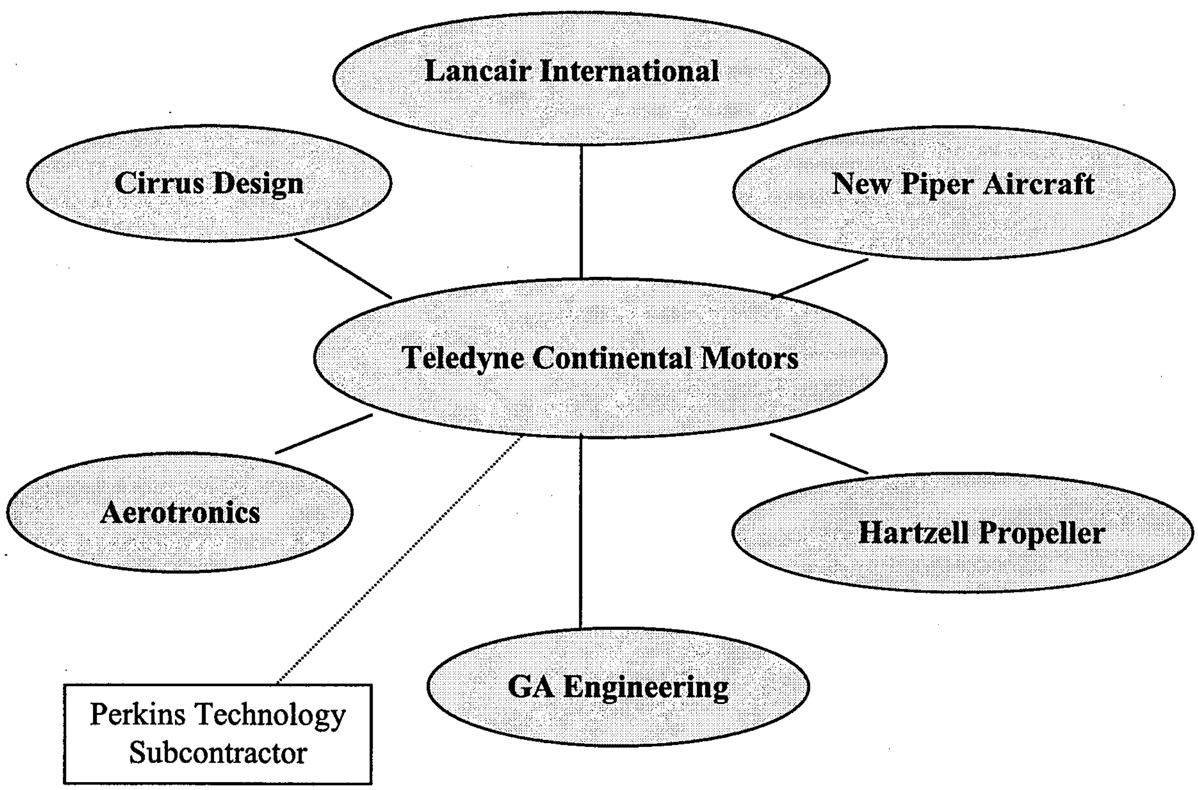
Future of GAP 10-15-97 ppt

IC Engine Element

The NASA industry partner for the IC Element is a team headed by Teledyne Continental Motors (TCM). The team consists of three airframers, Cirrus Design, Lancair International, and New Piper Aircraft, to insure that the new engine and propulsion **system** will fit the needs of the airframe companies for new products and to allow integrated engine/aircraft system design at the earliest stages of development. Aerotronics is developing engine controls and displays. Hartzell Propeller is developing quiet propeller designs. GS Engineering is consulting on engine design characteristics. Perkins Technology is subcontracted to TCM for detailed engine design and analysis.

ASTT General Aviation Propulsion Program

IC Contractor-Led Project Team



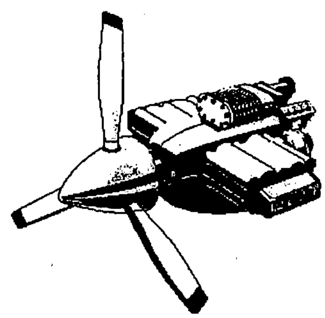
The engine being developed under the IC Element is a horizontally opposed, two stroke, compression ignition (diesel) engine which will run on jet fuel. Jet fuel is much more available worldwide than gasoline and is much cheaper than gasoline in some areas. The demonstrator engine will be a 4-cylinder 200 horsepower engine. It is designed to enable easy growth to 6- and 8-cylinder versions. It is a direct drive engine with a propeller shaft output speed of 2200 rpm. The reduction in output speed from the current 2700 rpm will facilitate a major reduction in propeller noise. One power lever will control the propulsion system including engine power and propeller pitch; there is no mixture control on a diesel engine. The engine will have a very low parts count and be designed for automated production methods to achieve a 50% reduction in cost.

General Aviation Propulsion Program

ASTT

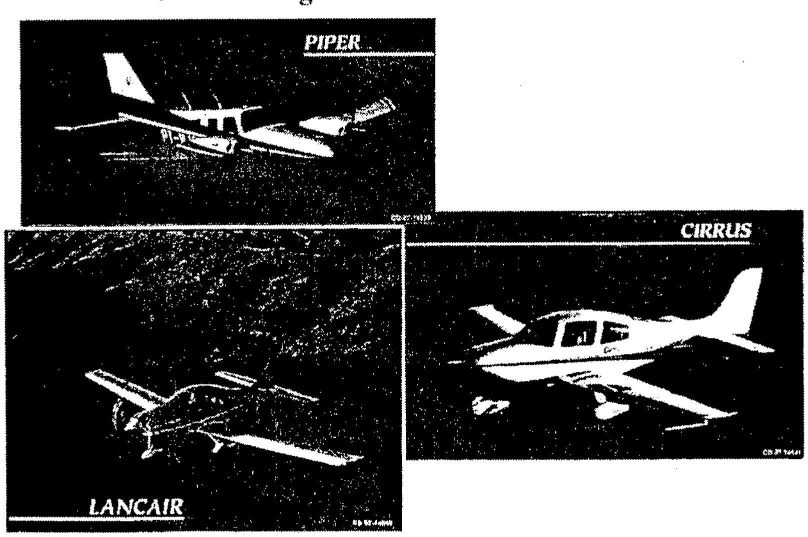
Teledyne Continental Motors CSD 283

- Compression Ignition Engine
- 2 Stroke, Direct Injection
- Liquid Cooled
- 200-bhp @ 2200-rpm
- Jet Fuel
- Single Lever Power Control
- Electronic Diagnostics and Display
- Low Noise, Vibration and Harshness
- Meets Expected Future Emissions Requirements
- 1/2 Cost Current Engines



The diesel engine will be flight demonstrated on three aircraft, the Cirrus SR20, the Lancair Columbia, and the Piper Seneca IV.

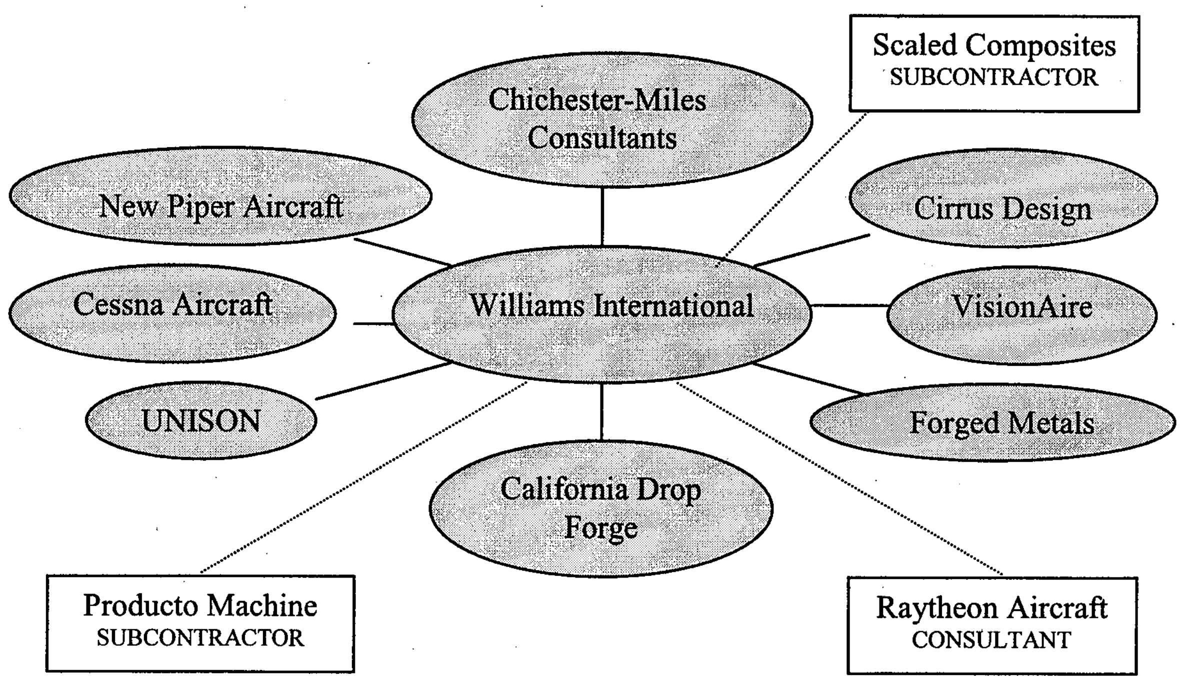
GAP IC Engine Demonstrator Aircraft



Turbine Engine Element

The NASA industry partner for the Turbine Element is a team headed by Williams International (WI). The team consists of five airframers, Cessna Aircraft, Chichester-Miles Consultants, Cirrus Design, New Piper Aircraft, and VisionAire, to insure that the new engine and propulsion system will fit the needs of the airframe companies for new products and to allow integrated system design at the earliest stages of development. Unison is developing the engine ignition system. California Drop Forge and Forged Metals are working on low cost forging techniques. Producto Machine is subcontracted to WI to develop very precise low-cost machining capabilities for small engine components. High precision is needed to maintain good performance capabilities in small engines. Scaled Composites is subcontracted to WI for final design, manufacture, and flight testing of the VJet II demonstrator aircraft. A totally new aircraft is needed to fully demonstrate the aircraft design and performance capabilities which this engine will enable. Raytheon Aircraft is participating on a consulting basis.

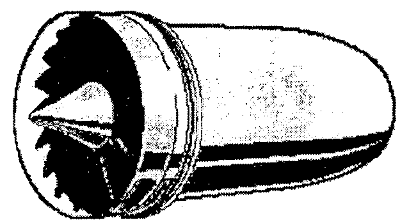
Turbine Contractor-Led Project Team



The FJX-2 turbine engine is a high-bypass turbofan with a "common core" design which will enable turboprop and turboshaft versions of the engine to be designed and produced. The engine design point is 700 lbs. sea level static thrust with a weight of less than 100 lbs., giving it an excellent thrust to weight ratio. At reasonable production levels the engine should be cost competitive with current piston engines. When the weight, performance, and installation advantages this engine provides are taken advantage of in an integrated aircraft design, the aircraft fuel burn for a given mission will be comparable to a piston engine powered airplane.

AGATE ASTT **General Aviation Propulsion Program**

WILLIAMS INTERNATIONAL FJX-2



- High-Bypass Ratio Turbofan
- 700-lb Thrust Class With Growth Capability
- 14 inch diameter by 41 inch Length
- Weighs Less Than 100 lbs
- Jet Fuel
- Cost Competitive With Comparable Power Piston Engines of Today
- Single-Lever Power Control
- "Takeoff to Landing" Fuel Burn Less Than Comparable Piston Engine Power Airplane
- Meets Future Exhaust Emissions and Noise Requirements
- Common Core Design For Turboprop and Turboshaft Version

The V-Jet II was conceptually designed by Dr. Sam Williams with final design and manufacture performed by Scaled Composites. The aircraft was specifically built to demonstrate the revolutionary type of general aviation light aircraft that the FJX-2 engine will enable. An old axiom is "new engines enable new aircraft" and that is certainly born out by the FJX-2 and the VJet II. A twin engine demonstrator aircraft was selected for safety purposes since this is a totally new engine being flown for the first time in a totally new aircraft. As seen in the chart the aircraft has excellent performance and weight characteristics. Although there is no intention to manufacture the aircraft, the V-Jet II was designed to be fully producible with low cost manufacturing techniques and viable as a certified production aircraft so that there would be no doubt as to the potential that the FJX-2 introduces into the general aviation light aircraft market. The aircraft was demonstrated for the first time at the Experimental Aircraft Association's Oshkosh '97 Fly-In Convention. The V-Jet 11 currently has FJX-1 interim engines installed which do not allow it to meet its full performance potential or fuel consumption goals, but do allow the aircraft to be checked throughout most of its flight envelope before the FJX-2 engine is ready.

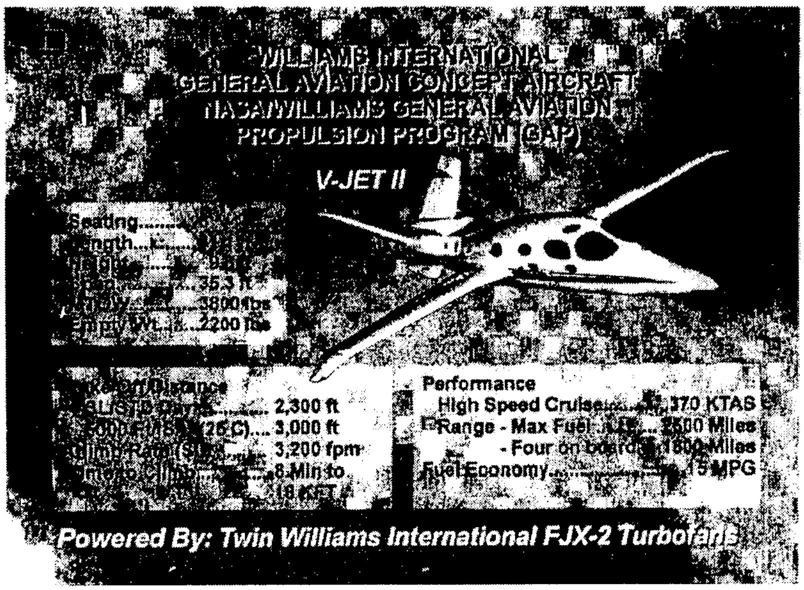
ASTT

V-Jet I Performance

What does the GAP program mean to the end general aviation customer? From a cost standpoint, it means aircraft which are much more affordable. When taken in conjunction with the technology goals of the AGATE program we can look forward to 4 place entry level diesel engine powered aircraft selling for less than $100,000 when moderate production levels are reached. That compares to approximately $150,000 for a current aircraft with much less performance and comfort. The outlook is even more dramatic for high-performance aircraft. An FJX-2 powered aircraft could sell for approximately $200,000 at reasonable production levels as compared to approximately $700,000 for such an aircraft today. The comfort level of the turbine aircraft will be far greater than today's noisy propeller powered aircraft in this performance class.

V-Jet II Performance

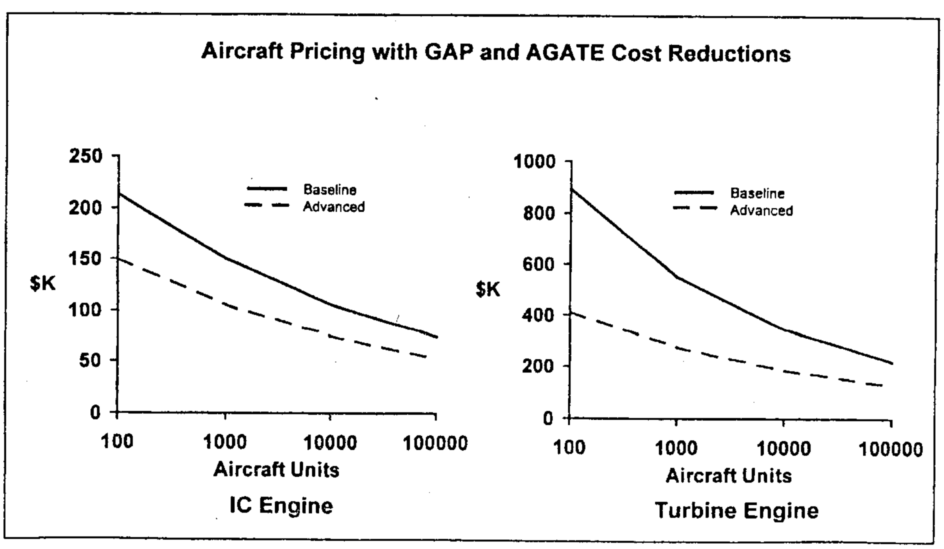
ASTT



The V-Jet I is a single engine version of the V-Jet II which would have seating for 4. There is no intention to build this aircraft, but a single-engine aircraft would have the potential for the lowest possible cost. The predicted performance characteristics of this aircraft will be validated through the measured flight performance of the V-Jet II.

General Aviation Propulsion Program

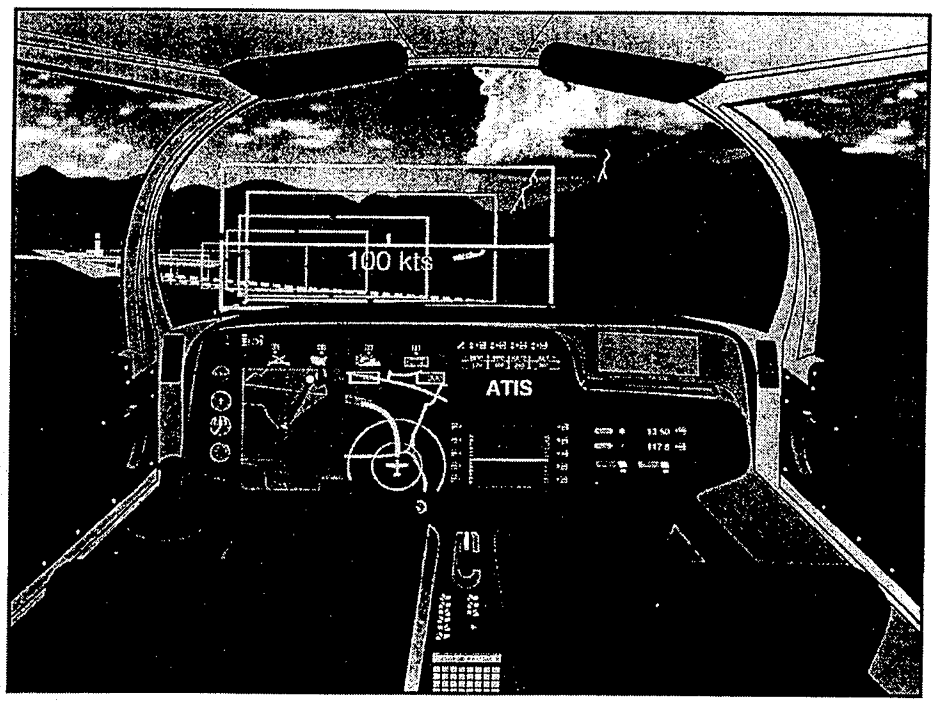
ASTT



Assumptions: Advanced Airframe/Avionics (AGATE) Cost Reduction of 24% of Baseline

While most changes in the aircraft cockpit user interface will result from the AGATE program, GAP will also make significant changes. There will be only one lever to control the propulsion system instead of as many as three now. The engine operational and health situation will be displayed on a dedicated integrated display and/or multifunctional display instead of on gages spread throughout the instrument panel. Information will be displayed in an easily understood format and only that information which is needed when it is needed will be displayed, so that the pilot work load associated with the engine will be vastly reduced.

AGATE CONCEPT COCKPIT



Coming soon, with the completion of the GAP and AGATE programs, are light general aviation aircraft that are fun and easy to fly. They will be affordable, comfortable, and allow general aviation to be a friendly neighbor. We will have the makings of a true personal transportation system.

Coming Soon to General Aviation

Fun & Easy
To Fly

Affordable
(Unheard of Performance/Price)

Clean
(Meet all Emissions Regs.)

PERSONAL TRANSPORTATION

Comfortable
(Very low NHV)

Quiet
(Friendly Neighbor)

Improved
Safety

FUTURE FUELS AND POWER SYSTEMS

BRENT BAILEY, NATIONAL RENEWABLE ENERGY LABORATORY (*FACILITATOR*)

PAUL MACCREADY, AEROVIRONMENT, INC.
RUDOLF VOIT-NITSCHMANN, UNIVERSITÄT STUTTGART, GERMANY
BENJAMIN RUSS AND JOHN LANGFORD, AURORA FLIGHT SCIENCES CORPORATION

SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
NOVEMBER 6-8, 1997
BAYLOR UNIVERSITY

Comments for Panel 2: Future Fuels and Power Systems

Dr. Paul B. MacCready, Chairman
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222 East Huntington Drive
Monrovia, CA 91016

Summary

Globally, major resources are being devoted to the exploration of alternative fuels and energy storage and conversion devices for autos; the programs were spurred by regulatory and market pressures for decreasing pollutant emissions and the consumption of oil. For aircraft, with even higher stakes on maximizing propulsion energy per kilogram of fuel and per dollar, these explorations for autos may prove beneficial. Consider the investigation of non-fossil fuels such as hydrogen and ethanol, improved efficiency of reciprocating engine and turbine technology with various fuels, and increased practicality of fuel cells. Examples are presented for special, non-piloted aircraft where electricity from batteries and solar power turns out to be surprisingly practical. As the economics of aviation fuels change, larger issues such as applying rational costs to all fuel sources and uses become increasingly important.

Overview of Energy for Natural and Technological Flight

Flight obviously offers survival advantages to creatures that would otherwise have to struggle over rough terrain and evade earthbound predators. Insects were the earliest true natural fliers, and the fact that now ¾ of the species fly gives evidence for the value of flight. Pterosaurs and birds followed into the air and more recently bats. All these vertebrate fliers feature two wings, adaptations of the forelimbs of their four-legged earthbound ancestors. See the author's preceding November 6 presentation on "Small Aircraft" for further details about natural fliers.

All the natural fliers derive their energy for flight from food – and thus from the stored energy of sunlight over the preceding days or weeks or years. Like humans, they tend to be hybrid with regard to their energy supply. (Humans use stored energy of glycogen for brief, high anaerobic power, and burn fat with atmospheric oxygen for continuous aerobic power). Some birds and pterosaurs discovered a new source of power for flight: the moving atmosphere (wherein movement is a consequence of heating of land, water, and air by sunlight). Slope currents and thermals mean that soaring birds need not sustain themselves with aerobic power; they need merely get into the air on brief anaerobic power, and then use nature's upcurrents. Natural fliers can store energy as the potential energy of weight x height. They can also convert kinetic energy to potential by spending speed to generate altitude. A few aquatic fliers (flying fish and flying squid) use the kinetic energy of speed as they exit the water to permit long glides. (Some flying fish also oscillate the bottom of the tail trailing in the water to provide propulsion to prolong flight.)

Sailplanes obviously have much in common with natural soarers. For modern ultralight sailplanes that can slow to 40 km/hr in thermals and the prehistoric giant natural soarers such as teratorn condor that have flight characteristics that are especially similar.

Our conventional airplanes burn fossil fuel with air to provide propulsive power. The high energy derived from liquid fuel (for gasoline in a reciprocating engine, typically about 4000 watt-hours/kg of fuel, equivalent to 0.41 lbs/HPhr) permits very long flights. Aircraft do not have hybrid power systems in the conventional sense, except to the extent that the engines are usually permitted brief periods of higher-than-continuous power for takeoff and initial climb. JATO (jet assisted takeoff), carrier catapult, sailplane tows, or brief use of an engine for takeoff are special cases.

Figure 1 illustrates that almost all energy that powers life on earth comes from sunlight, being used via different routes that have different time constants. In concept, all are renewable—if we are willing to wait millions of years for fossil fuel to be processed. All but fossil fuels can be truly renewable on a human time scale. The food and biomass categories consume CO_2 during growth and release it during energy generation for no net CO_2 (except for a time delay).

Figure 2 summarizes the sobering prediction that global consumption of fossil fuels will continue to rise, speeding the date when the convenient ones will be near exhaustion and hence be expensive.

Small aircraft, and a few special large ones (see author's preceding November 6 presentation), consume negligible amounts of global energy. Their value is in emphasizing that energy in the form of electricity can be attractive for some air vehicles. Electricity can be even more useful in cars, where weight of energy storage by battery is less significant. Figure 3 illustrates the high superiority of liquid fuel over batteries for any vehicle—except small ones when the convenience of battery power is more important than the energy content.

Figure 4 shows the relative amount of energy needed by different modes in the transportation sector. (Within the air mode, only about 1% relate to reciprocating engine use.) Aerodynamic efficiency of aircraft is rather high, as it must be for aircraft to fulfill their function effectively; aerodynamic efficiency for surface vehicles (by far the largest transportation energy consumer) is rather low because consumers do not highly value efficiency. (A glance at the shapes on the underside of your car will confirm the low priority on car aerodynamic efficiency.) It is obvious that globally there are far more "virtual" barrels of oil available from applying advanced aerodynamics to cars than to aircraft.

Energy for Airplanes

Jet fuel is the most used in aviation, powering the turbines employed by airliners, business jets, and military aircraft. Gasoline, especially "low lead 100", fuels the reciprocating engines of conventional small airplanes, although some can run on regular unleaded automobile gasoline. Diesel fuel, attractive from an energy per kilogram or per dollar standpoint, is rarely used for flight because of the high weight of reliable diesel engines.

A look toward the future when jet fuel and gasoline become less available and much more expensive (inevitable sometime because fossil fuel resources are finite) has pushed the search for substitutes. At present there are aggressive, well-funded programs exploring fuels for cars and trucks other than gasoline and diesel fuel. Most of these programs are strongly driven by local pollution from conventional motors: unburned hydrocarbons, carbon monoxide, oxides of nitrogen, particulates, plus sulfur and toxic materials. Some of the programs are driven by fuel efficiency—a subject of considerable importance for aircraft, but not for cars because car purchasers usually put fuel economy at a low priority compared to style and safety. Clean-burning hydrogen (with exhaust being only water when burned with oxygen, while some nitrogen compounds can result from burning with air) is very attractive from the emissions standpoint and also the energy per kilogram standpoint. It can be generated from many sources, including some natural ones that do not release CO_2. A wide distribution system does not exist, and storage on a vehicle (by pressure cylinders or in a hydride) is heavy and requires a large volume. Recent media releases suggest that the on-board reforming of gasoline or methanol is a practical way to generate hydrogen for cars. When or if this approach will be environmentally or commercially viable is not known, but as with many of the technology explorations for cars, there is large funding available that ups the likelihood of success. Perhaps developments for cars will provide breakthroughs for aircraft, but at present the chances for hydrogen-powered commercial aircraft do not seem high.

Incidentally, hydrogen can also provide static lift in blimps and dirigibles (although the safer helium is usually used). The only practical use for blimps has been advertising; flying billboards. For transport of people and goods, the drag associated with the giant volume required for the needed lift precludes efficient fast flights, and varying payloads dictate inconvenient alteration of static lift or reliance on some aerodynamic lift. Winged airplanes can do much better and by making fast trips can reduce capital cost per ton-mile.

Ethanol, ETBE (ethyl-tertiary-butyl-ether), or methanol can power surface vehicles as can CNG (compressed natural gas), liquefied natural gas, and propane and butane. All work; all are inconvenient at present compared to gasoline or diesel. Insulation technology can even make liquified natural gas feasible for aircraft. Ethanol has several attractive features. It can be made from waste material or special plants grown on marginal land, with the biomass converted into fuel by a cellulosic process, at a price perhaps competitive with future gasoline; it is high octane without lead; and its whole process from generation through consumption can be handled to produce only a tenth of the CO_2 per horsepower-hr released into the atmosphere by fossil fuel burning. A gasoline engine fueled by ethanol can achieve more power but deliver less mechanical energy per kg of fuel. ETBE likewise has less energy per kg available but may be able to deliver a bigger percentage and thus provide equal range for the airplane. At the recent Third Biomass Conference of the Americas held in Montreal, Prof. David Hall suggested that additional R&D will drive the real cost of ethanol from biomess down to under 80 cents US per gallon. However, the $950 billion/yr (Canadian) of subsidies worldwide for energy and agricultural industries tilt the present playing field unfavorably for the competitiveness of ethanol. If a level playing field (meaning all external costs considered) were to be created, biomass would "become a major modern energy provider (rather than capturing only niche markets)…."

Converting waste biomass to ethanol, deriving methanol or natural gas from coal or biomass, etc., are all being explored. A strong area of research is the use of electrical energy stored in batteries generated sometimes from solar cells or from fuel cells or from generators powered by turbines or reciprocating motors. In fact, more of the car-oriented research is being devoted to energy conversion and storage devices than to fuel alternatives. Flywheels, supercapacitors, high-power batteries, fuel cells, turbines, and ultraefficient reciprocating engines are being investigated and also various hybrid systems. If some sustainable energy system and fuel emerges for cars, its economics will be very attractive for aircraft but its weight may not be.

Electric Powered Vehicles at AeroVironment

Circumstances and planning have combined to give AeroVironment a significant role in electric powered vehicles and associated power electronics, electrical energy generation, storage, and use. The author's Nov. 6 presentation on "Small Aircraft" at the conference provides pertinent details. For surface transportation vehicles there have been the Sunraycer solar-powered car (with battery storage), the GM Impact battery-powered car, electric-assist bicycles ("hybrid vehicles that never run out of gas"; most recently the Charger), hybrid cars, a diesel electric hybrid military vehicle, fast charging systems, and battery packs with "brains" to increase usefulness and longevity, and battery pack test units for full-scale vehicle testing or simulation. We also explore and often test supercapacitors, flywheels, fuel cells, generators on turbines or reciprocating engines, optimized types of motors and control systems, and new battery types – and sometimes contribute to the developments of the technologies.

In aviation, our electric power interests have come to focus on the two ends of the vehicle size range. At the large end is the solar-powered 30-m Pathfinder and its larger descendants: one over 70-m span for flights perhaps reaching 100,000 ft and an intermediate size one with a regenerative fuel cell (that uses the wing spars as storage tanks for the pressurized storage of the oxygen and hydrogen gases) aimed at staying aloft for months. At the small end, our 3.5-kg, battery-powered Pointer surveillance drones serve as hand-launched "roving eyeglasses" whereby the operator can view remote objects and events in real time via video from the silent vantage point the vehicle provides. Smaller experimental vehicles are being flown battery powered, some with spans of more than 15 cm.

Electricity, usually with battery storage, is the preferred energy mode for low-power devices such as wristwatches, hand-held drills, quiet model airplanes, and golf carts. Fossil fuels, with some hundred-fold greater mechanical-energy-per-kilogram of energy storage than is obtainable from batteries, are the preferred mode for propelling big trucks and large aircraft. Someplace between these extremes is the dividing line for choosing between the convenience of electricity and the large energy availability from burning fossil fuels. This line has been edging upward as batteries have improved and vehicle efficiency increased (and, in the case of cars, the efficiency benefits of regenerative braking have become appreciated). The Pathfinder aircraft has moved the line up more than expected, because in the thin air high in the stratosphere the challenge of compressing and handling cooling to support combustion becomes formidable. Solar power may be small, at best in the range of 150-200 W/m^2 of projected area, but it doesn't require this air compression. For normal propeller aircraft electric power is not an option.

Final Comments

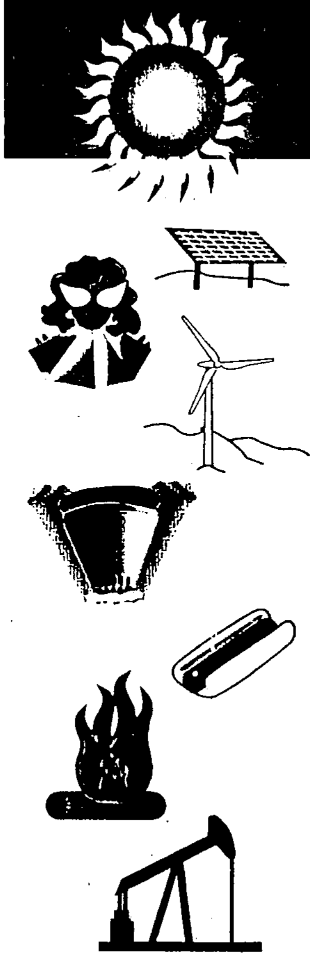
The best fuel is vehicle efficiency. A vehicle that travels on one-third the conventional energy uses only one third the fuel and emits only one third the pollution—and also makes feasible the use of less convenient (but more available or societally desirable) fuels because less energy is needed. High efficiency conversion of fuel to mechanical power is desirable. The high efficiency potential of fuel cells for generating the electricity is especially attractive. A sound route to efficiency and fuel conservation is have every passenger seat filled on both air and ground vehicles. Empty seats waste energy. For airliners, more runways and efficient traffic management can minimize the fuel-consuming time spent in holding patterns at crowded airports. Instant car rental can help fill cars and also let an individual vehicle be used a bigger percentage of the time. The best way to conserve fuel is to stay home and telecommute. There are many plans for surface travel by personal rapid transport vehicles that are operated to maintain speeds and avoid collisions (and need not be the "tanks" we all drive so as to be safe while mingling with all the other "tanks" on the road). Also, through automatic control, our private "personal rapid transit" vehicle safely takes us to within walking distance of our destination, and enroute we can relax or read or work and not have to have all attention focused on being a driver.

Hermann Scheer wrote a book "Solar Manifesto" (James & James Ltd., London, 1994) that points out the technological and economic feasibility of every country being energy independent, and less in need of huge military investments, by eventually relying completely on renewable energies. Although this visionary goal will achieve but little political support, there is value in putting it out for people to discuss. Aviation, car, and industrial energy all need to be considered in a system context. There are many more options for cars and industries to eliminate reliance on fossil fuels than for aircraft, and so the alternatives for surface application should initially receive the greatest attention. For aircraft, the substitution of telecommuting for business travel will continually grow. Clear identification of externalities is needed in determining the energy costs of various types of transportation so that rational decisions can be made about resource allocations to different uses.

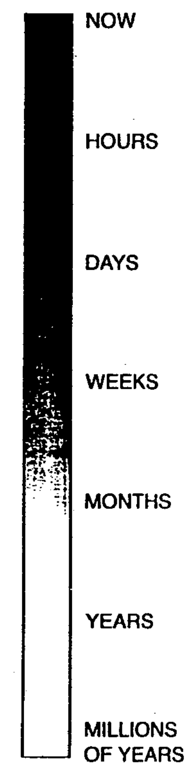
Technologies for powering vehicles will keep improving. The next decade or two will be the most exciting ever for transportation technologies. The outcome is not yet clear. If it were, we could all focus our attention on the winner (or the several winners for different applications). The stakes are high, for we are involved in the global environment and civilization's future as well as in global transportation.

SOLAR ENERGY SUPPLY

All the energy used on earth comes from sunlight*



• **Photovoltaic Solar Cells**	Turning sunlight into electrical energy at this moment
• **Solar Thermal Heating**	Warming us, our water, our homes, and our environment at present or over the last few hours.
• **Wind Power**	Using the wind associated with recent weather powered by the sun a few hours, days, or weeks ago.
• **Hydro Power**	Using the flow of rivers that were replenished by rain that resulted from heating the continents and oceans over the recent weeks or months.
• **Food for Muscles**	Over time periods from weeks to years, sunlight underlies the growth of our food (plants and animals) that serves as fuel for muscle power.
• **Burning Biomass**	Using the energy of sunlight stored in plants and trees over the last 10-100 years. Burn for heat; process for gaseous or liquid fuel such as ethanol (sometimes recycling biomass waste).
• **Burning Fossil Fuel**	Using the stored energy of sunlight that powered the growth of plants and animals millions of years ago.



All these energies are renewable, but on a human time scale we find it inconvenient to wait millions of years for fossil fuels to be regenerated. Hydro, wind, solar, and food are truly renewable on our human time scale. Burning wood (and other biomass) is renewable energy on our time scale - but only if we don't consume it too fast and run out.

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****Except for the small portion of nuclear, geothermal, and tidal energy.***

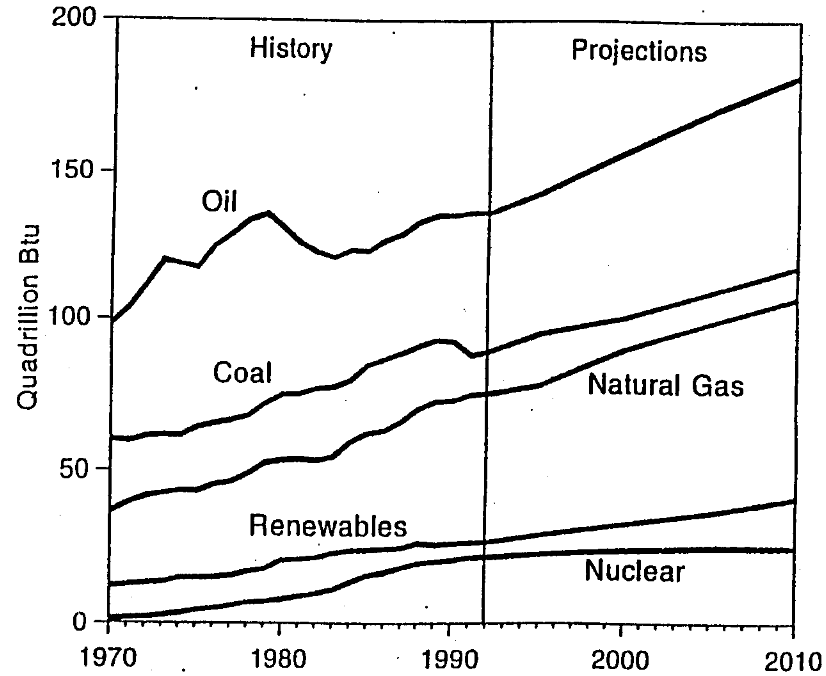

Figure 2. World Energy Consumption by Primary Energy Source, 1970-2010

HEIGHT TO WHICH FUEL SOURCE
COULD LIFT ITS OWN INITIAL WEIGHT

Gasoline	1000 Miles
Lead Acid Battery	10 Miles
Rubber Band	1/2 Mile

Figure 3. Useful Energy

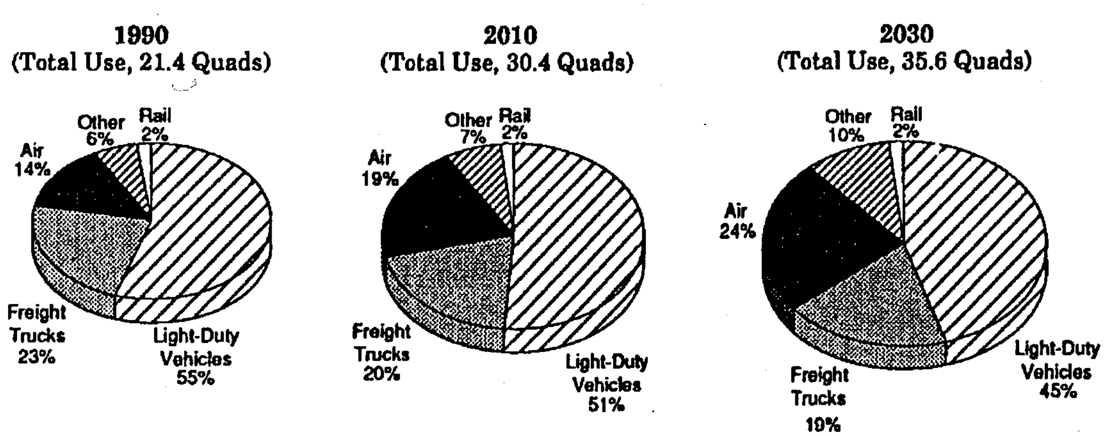

Figure 4. Oil Used in Transportation Sector (by Mode)

Future Fuels and Power Systems

Dr. Rudolf Voit-Nitschmann
Institute Fur Flugzeugbau
Universitat Stuttgart
Stuttgart, GERMANY

I would first like to thank Max and Grazia for inviting me to be a part of this conference. I am going to be discussing the solar-powered airplane from the University of Stuttgart (*named:* ICARÈ). I have to apologize for not having all of the slides in English; I hope you can follow me.

(Slide 1)
This is the solar-powered airplane of the faculty of the aerospace division of the University of Stuttgart and we built this airplane as part of a competition of the city of Ulm which is 100 kilometers south of Stuttgart. We were able to win this prize in July 1996, for the most or the best solar-powered airplane in the world.

(Slide 2)
First, I would like to tell you some of the rules of this competition: (*There follows a discussion of the points on the slide*).

(Slide 3)
(*Discussion of the points of the slide.*) It was very exciting to work on this project; I should say it was strongly supported by the students. It was exciting to see some students who are normally quiet taking responsibility and leadership of the project. I think we should do more student projects in our agency as we are teaching aerodynamics and structural engineering. I think the most important thing is to establish a goal that will force the students to put into application what they are being taught.

(Slide 4)
Next, I would like to show you an overview comparing some airplanes with very low power consumption as we go through some human-powered airplanes to the solar challenger which was the first solar-powered airplane and then Gunter Rochelt's Solair 1 and then the American Sunseeker and then the ICARE which is the largest solar airplane with a very large payload of 90 kg.

(Slide 5)
Because the aircraft needs about 500 watts of solar energy to fly, there are only certain times of day that there is enough solar radiation. On the 21st of July (the solid line), you can fly for about 9 hours. Even on March 21st and September 21st (dotted line) you can fly for about 2 hours. That means that you have to have excellent overall efficiency of the power chain, as you can see here. Thirteen percent of the maximum solar radiation on the wings is converted into power for the airplane.

(Slide 6)

Some components of the system. These are the batteries that store the power. They weigh about 25 kg.

(Slide 7)
Here you can see some work on the creation of the solar panels.

(Slide 8)
We used 2880 solar cells on our wing. We had five strings of solar panels on the inside part of the wing, one string on the outer part, and one string on the horizontal stabilator of the aircraft.

(Slide 9)
We constructed the aircraft of carbon-fiber deposits.

(Slide 10)
This is a cross-section of the wing. We used carbon-fiber spar heads and some carbon fiber uncut sandwiches to support the solar cells.

(Slide 11)
(*Review of data on the slide.*)

(Slide 12)
(*Review of data on the slide.*)

(Slide 13)
These are some drawings of the aircraft.

(Slide 14)
(*Review of data on the slide.*)

(Slide 15)
What will we do in the future? We would like to continue our research program at the German ministry for research and we have two visions. First, we would like to make a contribution to the attenuation of electric powered motorgliders in the future for recreational flight. The second is to make a contribution to high-flight platform to 60,000 feet electrically powered which can move somebody around Germany. Next year we would like to fly the glider more, perhaps take it on a flight of four to five hundred kilometers and try to improve the power system.

(Slide 16)
A photo of the glider taken during the competition.

(*Video footage of the glider*)

(*There were also some additional slides that were not referred to.*)

icaré

solarflugzeug der
universität stuttgart
fakultät luft- und raumfahrttechnik

Gewinner des Berblingerpreises der Stadt Ulm 1996
leistungsfähigstes Solarflugzeug weltweit

Summary of the Terms of Competition "Berblinger '96"

Task : Design of a manned, self-launching solar powered airplane

Minimum Requirements :

- solar powered cruise at 500 W/m² light intensity
- aerodynamically controlled
- maximum speed more than 120 km/h
- stall speed below 60 km/h
- glide ratio with engine off better than 1:20
- climb to 450 m after takeoff in 225 s
- energy storage only with batteries or similar systems
- equipped with an approved recovery system
- suitable for club-like operations
- transportable by trailer

Core Technologies to Fullfill the Terms of the Berblinger Competition

- configuration for minimum power requirements
- integration of fragile solar cells in a flexing wing structure
- integration of propulsion system with high efficiency
- extreme light structures with high reliability

Minimum Requirements for the Components :

- efficiency rate for engine better than 90% (takeoff and cruise)
- efficiency rate for the propeller better than 85%
- efficiency rate for the solar cells better than 17%
- structural weight of not much more than 160 kg

Aircraft	Gossamer Penguin	Solar Challenger	Solair I	Sunseeker	ICARÈ
Maiden Flight	1978	1980 (07.07.81) English Channel	1980	1991 ?	May 1996
Designer	Paul McCready	Paul McCready	Günter Rochelt	Eric Raymond	Aerospace Faculty Stuttgart
Wing Span	21,9 m	14.3 m	16,0 m	16,6	25 m
Wing Area		21.7 m²	15.04 m²	10 m²	25,7 m²
Empty Weight	31 kg	92 kg	120 kg	89 kg	284 kg
Payload	44 kg	48 kg	60 kg	74 kg	90 kg
Rate of Climb	0,1 m/s	1 m/s	0.5 m/s	0,25 m/s	2.0 m/s
Speed Range	< 40 km/h	28 - 64 km/h	34 - 90 km/h	45 - 140 km/h	44 - 120 km/h
Glide Ratio		15,7 (11.8m/s)		30	36 (16.5m/s)

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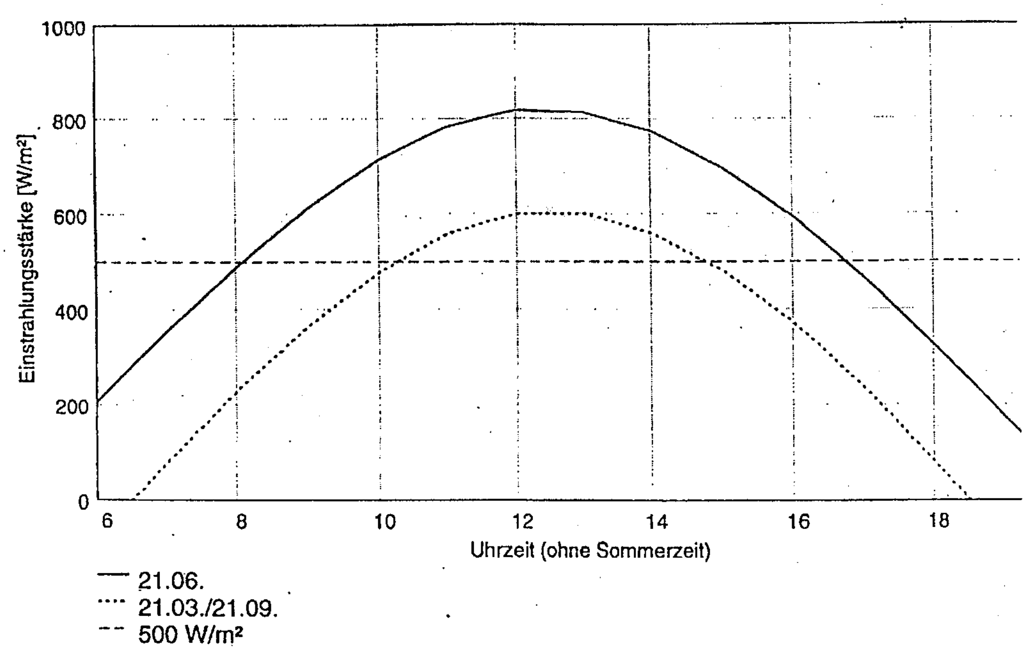

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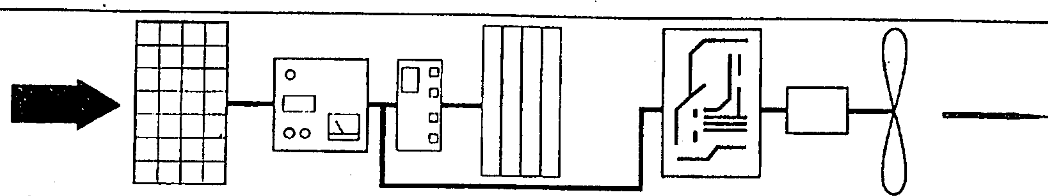
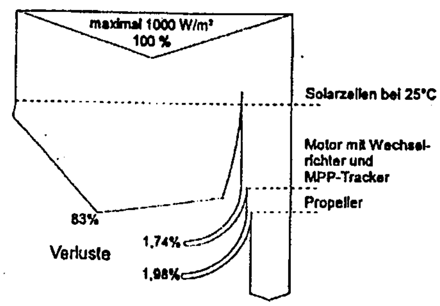
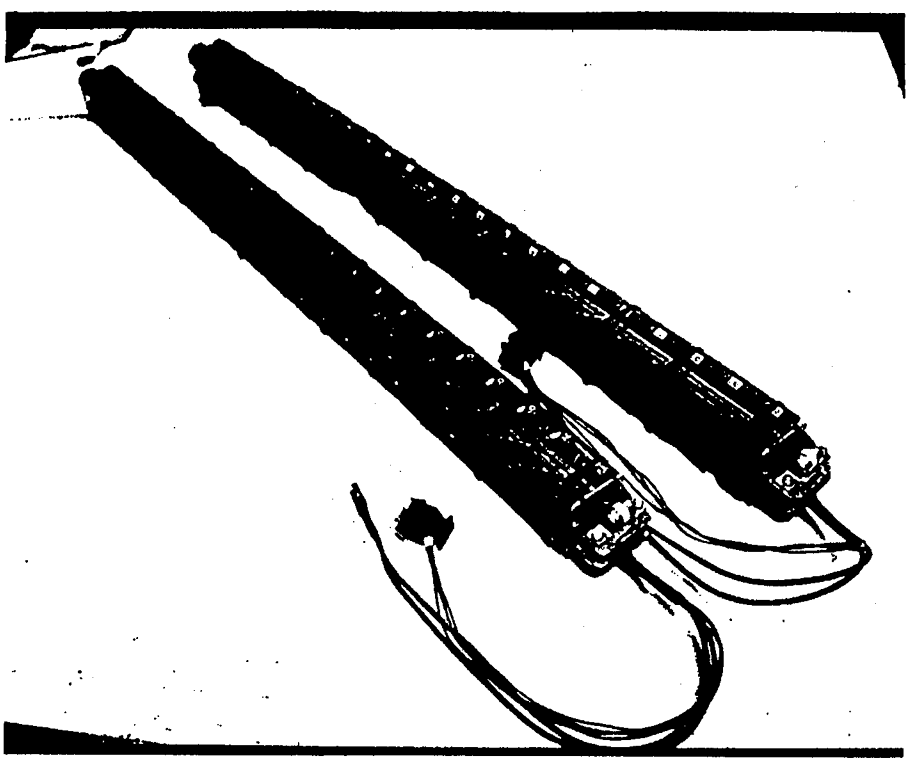


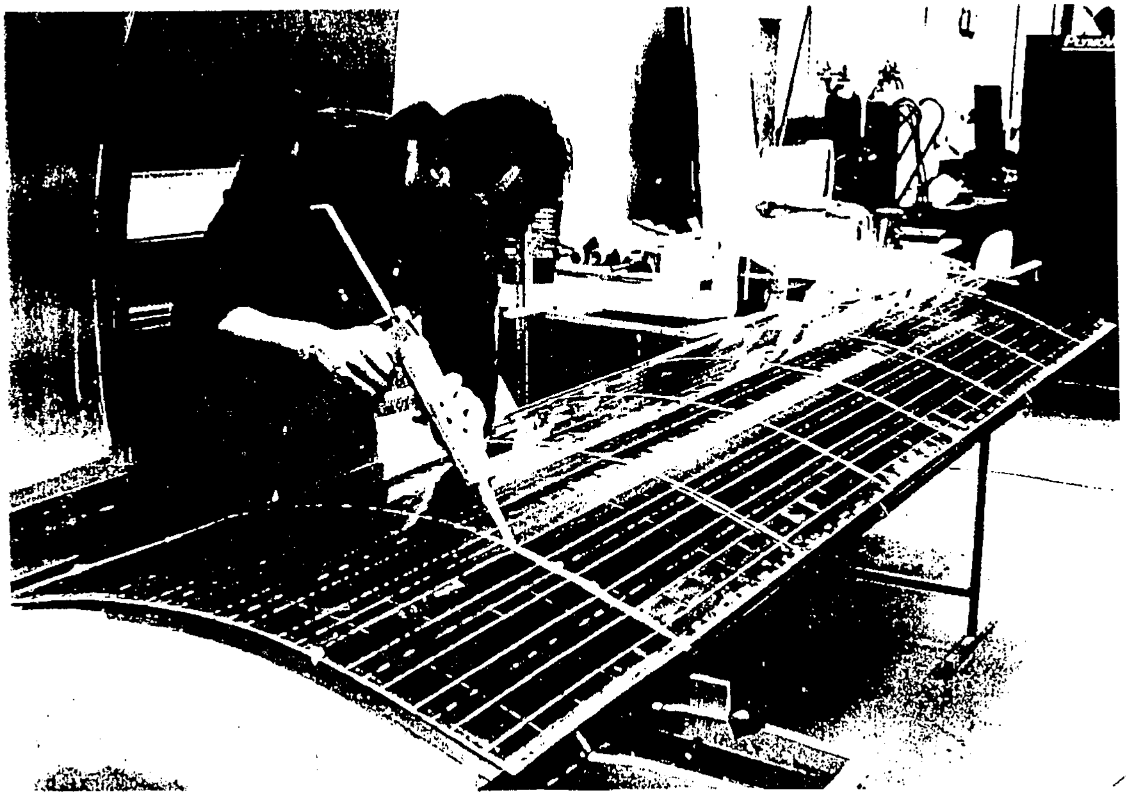
	Strahlungs-energie	Solar-generator (eingebettet)	Max. Power-Tracker	Batterie Manager	Batterie 4 x 96 Zellen	Leitungen	Wechsel-richter inkl. Steuerung	Elektro-motor	Propeller	Mechanische Energie (Vortrieb)
Wirkungsgrad:		17%	98%	99,5%		99,5%	98,5%	93%	87%	
Masse Icaré 2:		30kg	2,058kg	1,199kg	4 x 5,9 kg	1,5kg	6,08kg	11,7kg	1,48kg+1kg	

im Schwebeflug
(ohne Batterien):
21,6m² Solargenerator
55 kg Antrieb ohne Batterien
13,0 % Gesamtwirkungsgrad
bei 500 W/m² 1404 W Schubleistung



Aufteilung der Energieverluste





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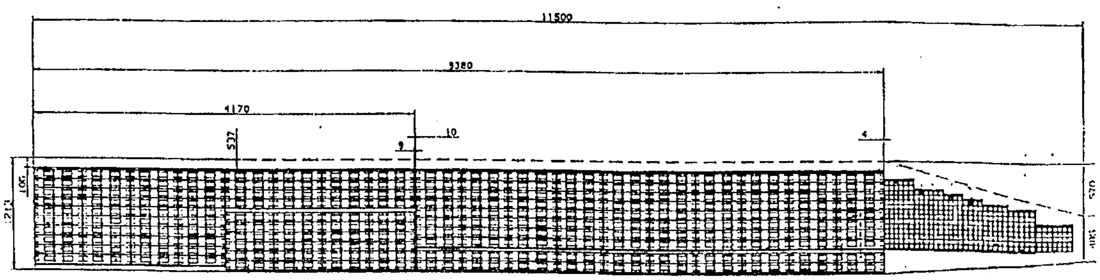
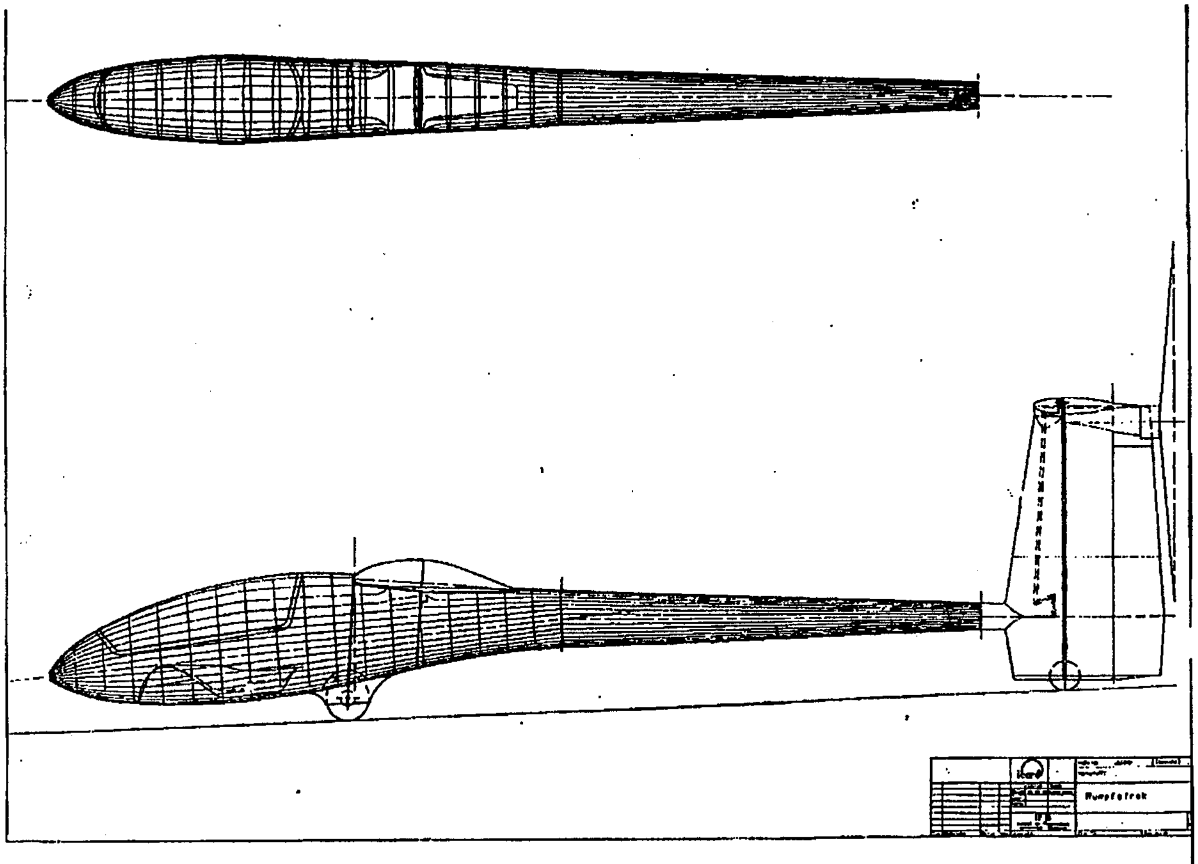


Solargenerator-Integration im Flügel (Oberfläche abgewickelt)

Flügel:	5 Stränge	á 360 Zellen	100mm x 100mm
	2 Stränge	á 360 Zellen	50mm x 50mm
Höhenleitwerk:	1 Strang	á 360 Zellen	100mm x 50mm

Gesamtgenerator-Ausgangsleistung bei 500 W/m² Einstrahlung: 1540 W

je Strang ca. 160V



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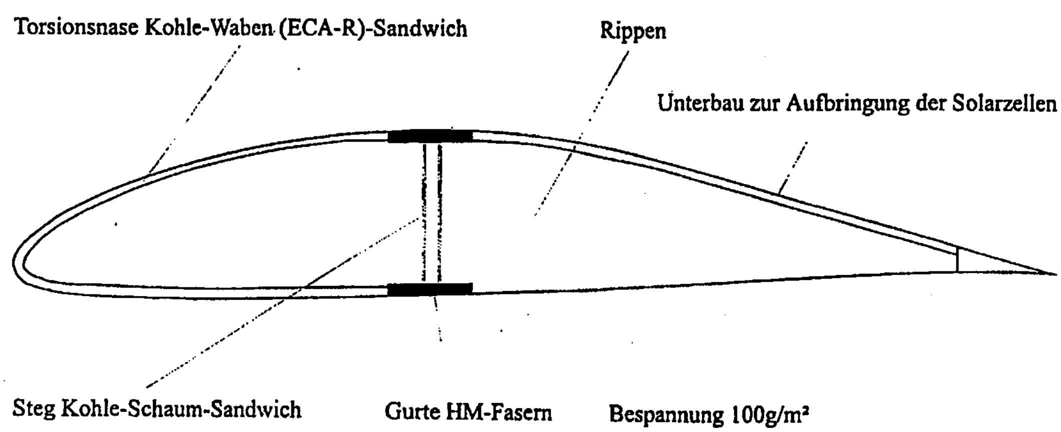
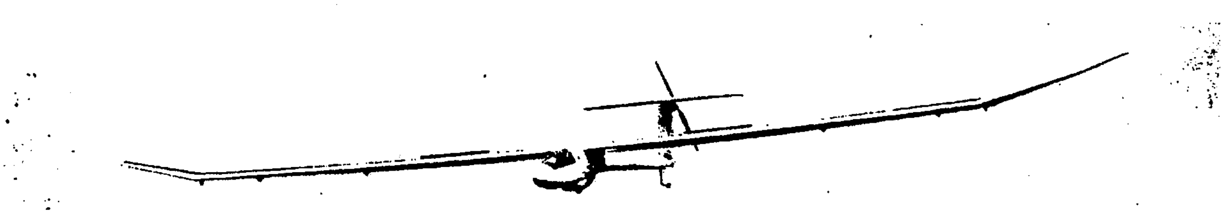
Strukturbauweise Tragflügel icaré 2



Masses

• structure	- wing	120 kg	
	- fuselage	34 kg	
	- elevator	7 kg	
	- vertical tail	7 kg	168 kg
• propulsion system	- solar cells	37 kg	
	- electronics	11 kg	
	- engine	12 kg	
	- batteries	24 kg	
	- propeller	3 kg	87 kg
• other systems	- controls, instruments, landing gear	18 kg	
	- recovery system	11 kg	29 kg
• pilot		max. 90 kg	90 kg
• maximum takeoff weight			374 kg

$m_{structure}/m_{TO}$=0.45



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BMBF Basic research programme „ High flying solar powered platform icaré 3"

first phase 97/98 objective: to provide basic technologies for the design of icaré3

- **flight testing of icaré2**
  - performance measurements, due to improve design tools for the conceptual design process of high flying solar powered platforms
  - operational lifetime testing of electronic propulsion system
  - component testing of autonomous flight control system

- **design of advanced electric propulsion system**
  - definition of advanced regenerative energy system
  - investigation of low temperature behavior

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Practical Flight Experiences

Performance

- initial rate of climb approx. 2m/s (batteries and solar cells)
- average rate of climb approx. 1.5m/s
- end of climb max. 360m
- best glide ratio approx. 1 : 36
- solar powered horizontal flight at approx. 2.1 kW input power ≅ approx. 590 W/m^2 light intensity

Influence of the Competition Requirements

- solar powered cruise causes too large of a wing area
- this in turn causes relative low L/D and low wing loading (low cruising speed)

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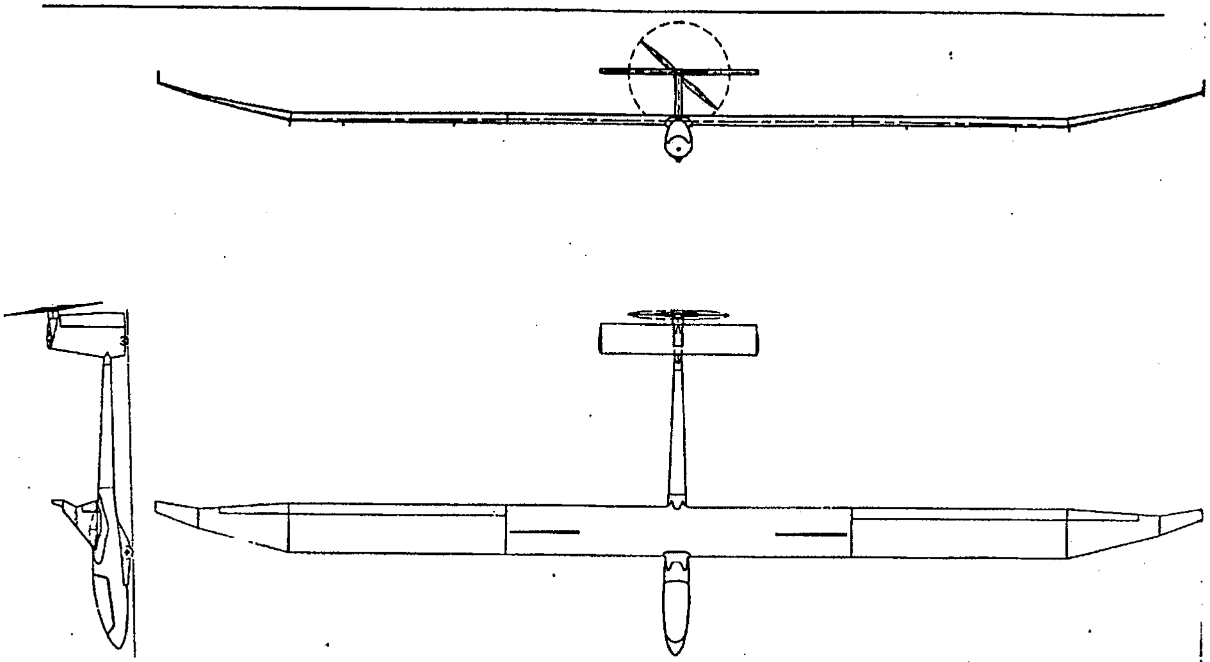

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Data and Performance

wing area	25,7 m²	
wing span	25 m	
area of solar cells	22 m²	
structure	168 kg	
propulsion (batteries, engine, electronics, propeller, solar cells)	79 kg	
payload (pilot weight)	90 kg	
maximum takeoff weight	374 kg	
minimum speed with maximum takeoff weight	12 m/s	43 km/h
maximum speed (v_{NE})	33 m/s	120 km/h
endurance without sunlight (batteries only)	40 min	
maximum range without sunlight (batteries only)	33,6 km	
best rate of climb	2.0 m/s	
required battery power for climb	12000 W	
minimum sink rate	0,40 m/s	
required solar-generator power for solar cruise	2100 W	
best glide ratio	36 bei	16.5 m/s

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Mit icaré 2 erhält eine Erkenntnis des deutschen Flugpioniers
Otto Lilienthal (1848-1896)
eine aktuelle Bestätigung, denn er formulierte einmal:

„Eine Flugmaschine zu erfinden bedeutet wenig,
sie zu bauen nicht viel,
sie zu fliegen alles."

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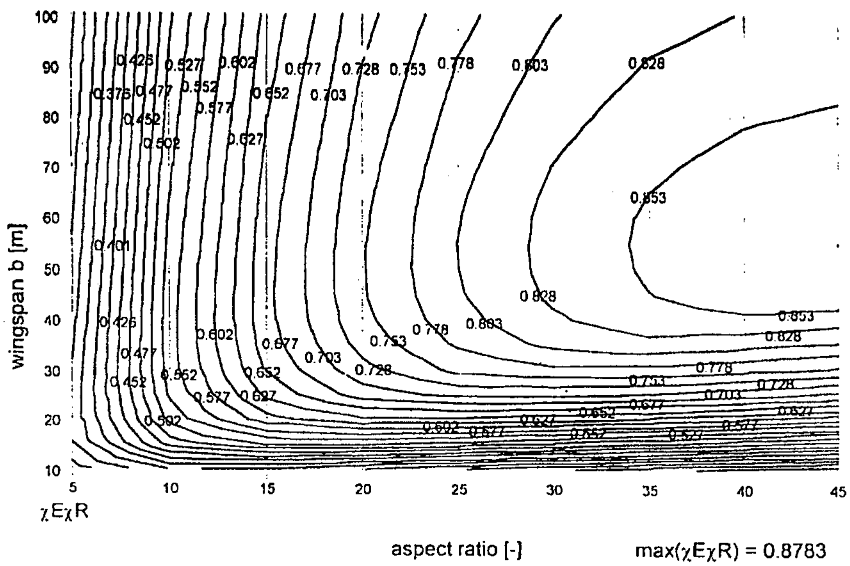
- **investigation of aeroelasticity of high flying wings with high aspect ratios**
- **aerodynamic research work due to high-altitude missions**
  - design of airfoils
  - basic aerodynamic data for conceptual design of icaré 3
- **conceptual design of icaré 3**
  - identification of missions and potentional customers
  - design of an appropriate configuration
  - conceptual design of systems
- **definition of flight control and flight management systems**

High-Altitude Platform



payload	50 kg
ult. load factor:	6 g
v_D:	135 km/h
Solar generator:	
cell efficiency:	22 %
mass:	800 g/m²
reg fuel cell eff.:	53 %
Engine efficiency:	93 %
Control efficiency:	98.5 %
power density:	700 W/kg
Prop. efficiency:	87 %
weight technology factors:	
structur:	0.35
engine & elec.:	0.5
energy storage:	0.5

Quotient of allowable and realizable wing loading for an unmanned high-altitude platform with improved propulsion and energy storage system and structure

Aurora's Family of High-Altitude Propulsion Systems

Benjamin Russ and John Langford
Aurora Flight Sciences Corporation
9950 Wakeman Drive
Manassas, VA 20110 U.S.A.

Introduction

Aurora Flight Sciences develops, produces, and operates a new generation of robotic aircraft; designs and fabricates aerospace structures involving composite materials; develops flight and propulsion controls; and develops and tests aircraft engine and turbocharger propulsion systems.

This presentation is a brief summary of Aurora's propulsion development work, outlining how Aurora's engine controls and propulsion technolgies contribute to the process of making alternative fuels and new piston engine concepts a reality for aviation.

Propulsion Systems for High-Altitude Aircraft

The high-altitude problem for propulsion systems is created by the thin air at high altitudes and an operating envelope which is much wider than for ground applications. Considerations such as specific power, fuel consumption, emissions, development costs, safety, and environmental issues are of principal concern. Very high altitudes are required for unmanned air vehicles (UAV) flying missions for atmospheric research, storm warning, and telecommunications applications. The requirement for long-endurance flights at subsonic speeds dictates the use of complex turbomachinery to compress the thin air, thus requiring sophisticated, leading-edge technology of hardware and control systems, especially when considering the performance issues mentioned above.

Various propulsion options have been investigated at Aurora. Several electric systems have been studied: the use of batteries, fuel cells, solar electric panels and microwave propulsion. With the relatively low power-to-weight ratios achieved by current electric propulsion technology however, these options are only applicable to platforms with payload weight capacities of only a few dozen kilograms of weight. Also, wind and sun conditions have to be favorable for solar-electric-propelled aircraft to be able to reach high altitudes where requirements exist to deploy payloads weighing between 50 kg and several hundred kilograms to altitudes above 60,000 ft for endurances exceeding 20 hours and thus requiring night operation. Technology employing regenerative solar propulsion systems, which produce hydrogen by electrolysis during the day for nocturnal consumption, is not yet developed enough to offer the required power-to-weight ratio for airborne missions and to be competitive to air-breathing propulsion systems in the near-term. Hydrazine- and hydrogen-fuelled engines have also been studied but due to the risks and hazards involved are not seen as viable or practical options.

The Arion I Recirculated-Exhaust-Gas Engine flies to 50,000 Feet

As a short-term, short-endurance solution and to demonstrate the high-altitude capability of modern robotic aircraft, Aurora pioneered the use of exhaust-gas-recirculating engines in an aircraft application. Oxygen carried on-board the aircraft in a cryogenic tank is used as the oxidizer. It is vaporized, then mixed with the diluent before the fuel mixture is added. As diluent or working gas for the cycle, the engine's own recirculated exhaust gas is used. After exiting the engine, the exhaust gas is cooled in a ram-air cooler to favorable intake temperatures and, after waste-gating overboard the mass amount equivalent to mass of fuel and oxidizer, the gas is plumbed back into the engine. The constituents contained in the exhaust gas that are fuels themselves add to the complexities involved in controlling this type of powerplant for aviation use. Tested first on a rotary gasoline engine on a dynamometer and in a single-piston engine using methane to study optimum mixture of fuel, oxygen, and diluent for optimized efficiency, the concept was brought to maturity with a modern, lightweight, flat-four 1.2-liter aviation engine running on gasoline. After one year of development and integration work, the recirculated engine, called the Arion I, was successfully flown in 22 flights up to 50,000-ft altitude onboard the Perseus A unmanned air vehicle (UAV).

The Arion II Triple-Turbocharged Piston Engine to 67,000-Feet Altitude

For longer endurance at altitude, the exhaust gas recirculating Arion I engine concept is not suitable due to the weight penalty of carrying the oxidizer for the combustion process. Concepts using turbomachinery in different types of cycles have been investigated, some with potential for applications for certain altitude and endurance profiles. A triple-turbocharged, dual-intercooled propulsion system, called Arion II, has been successfully developed in the last few years in Aurora's high-altitude engine test facilities and has propelled the twin-engine Theseus and the single-engine Perseus B UAVs to 20,000-ft altitude. The Arion II concept is based on the same 1.2-liter engine as the Arion I engine. The Arion II's power output is 63 kW (85 hp) at 67,000-ft altitude, using 100LL avgas. Extensive testing for endurance and reliability has been conducted in Aurora's altitude chambers, the unit is being integrated into the Perseus B UAV and will be flown to over 60,000 ft in 1998.

High-Altitude Engine Test Facilities

Essential for the development of high-altitude or any aviation propulsion system is the testing for the entire envelope of the system. Aurora has two high-altitude dynamometer test facilities in which 160-hp engines can be tested up to 90,000-ft altitude. The test chambers have the capabilities to provide intake air and cooling for extreme hot and cold temperatures according to military standard atmospheric conditions.

Aurora's FADEC (Full-Authority Digital Engine Control) for Aviation Engines

Aurora's propulsion systems are controlled by a FADEC unit (Full-Authority Digital Engine Control) featuring Single-Lever Power Control (SLPC). With the full-digital SLPC, which was developed at Aurora, the pilot commands desired power or thrust through a single digital input to the FADEC computer. The FADEC sets optimum propeller speed and engine settings at all times by respecting all limits and maintaining a healthy engine. It monitors and maintains turbocharger limits such as overboost, surge, turndown, and overspeeding conditions. With state-of-the-art engine control technology using high-fidelity feedback sensors, the advent of modern engine controls for general aviation engines has become technically and economically effective.

Single-Lever Power Control for General Aviation Engines

As a spin-off from the UAV engine development, Aurora developed a full-digital Single-Lever Power Control (SLPC) system embedded on a FADEC for general aviation engines and demonstrated the system during a flight test program on-board a Cessna O-2A. Up to 22% fuel savings in cruise conditions compared to the standard engine were measured, just by mixture feedback control alone. The SLPC-FADEC system also continuously looks for the optimum propeller and engine settings for any flight condition. Test pilots report large workload reduction, since a single-lever replaces the 3 levers used with the standard engine. Further improvements are: added safety and reliability due to the optimum propeller and engine conditions controlled by feedback control loops, increased engine life-time and TBO (Time Between Overhaul), reduced emissions, and inherent fault-tolerant control capabilities due to the SLPC-FADEC's continuous monitoring and searching for the optimum powerplant settings. The SLPC-FADEC is a milestone towards the glass cockpits of the future. The system can be retrofitted to existing engines and propellers or adapted to work with alternative fuels and on advanced engine concepts.

Summary and Conclusions

Aurora has a proven history of successfully developing and flying advanced aviation propulsion systems. Several advanced propulsion systems and potential aviation fuels, especially suited for high-altitude, long-endurance operation, have been investigated theoretically, by experiment and in flight. The technology of modern, high-efficiency aviation engines and control systems has been proven in unmanned air vehicles as well as in general aviation, which prepares us for the next generation of highly efficient, cost-effective aviation engines and the use of alternative fuels.

Aurora's Family of High-Altitude Propulsion Systems

Presented at:

The Second International Conference on Alternative Aviation Fuels

November 7, 1997

Ben Russ
John Langford

The High-Altitude Problem

- Lower Temperatures
  - » Engine must be capable of operating over a much wider range of temperatures
- Lower Pressure
  - » Amount of oxygen available for combustion is reduced
  - » Amount of air available for transferring heat away from the engine is reduced
- Low Costs Are First Order Driver

Considerations

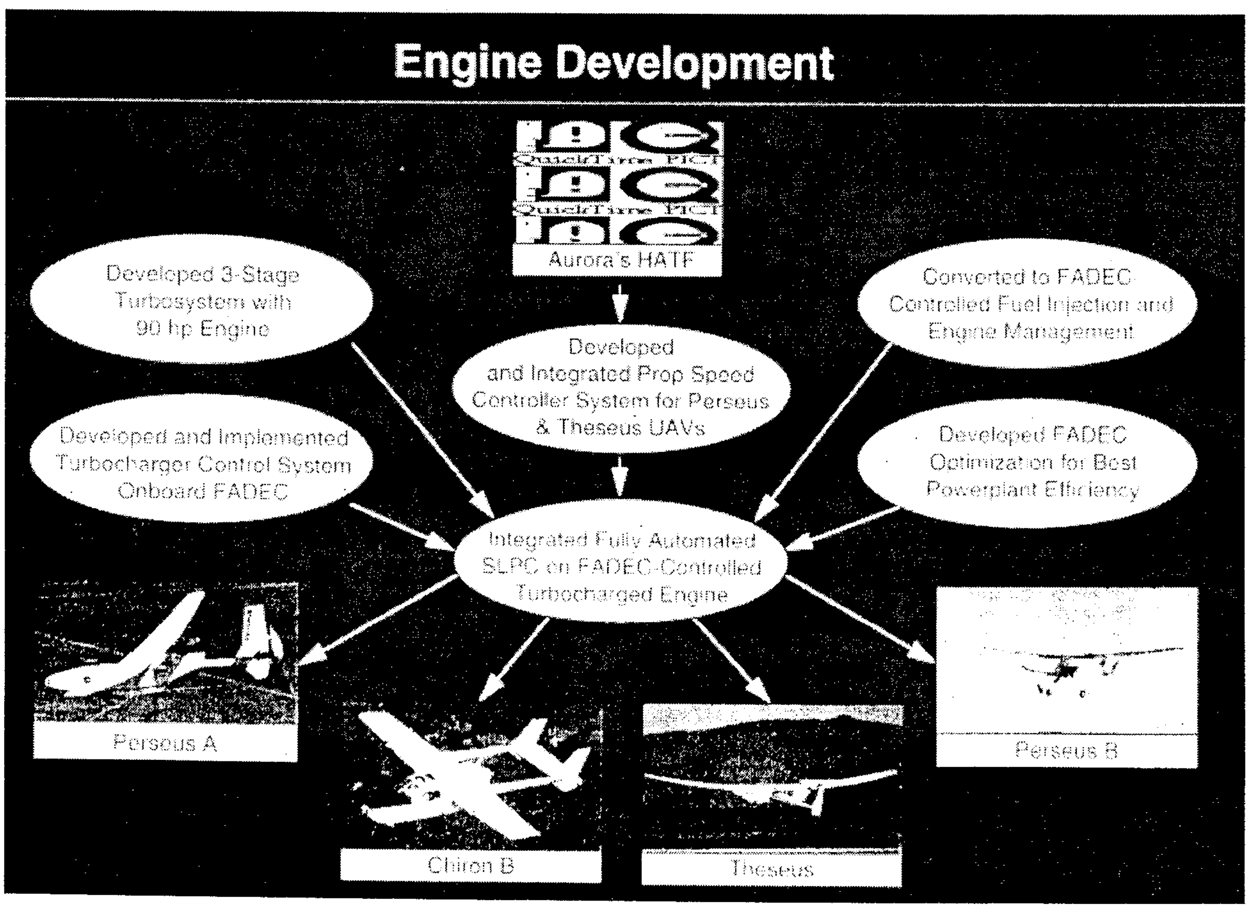
- **Specific power**
- **Specific fuel consumption**
- **Development cost**
- **Safety and environmental issues**
- **Subsonic speeds**

Various Propulsion Options Studied

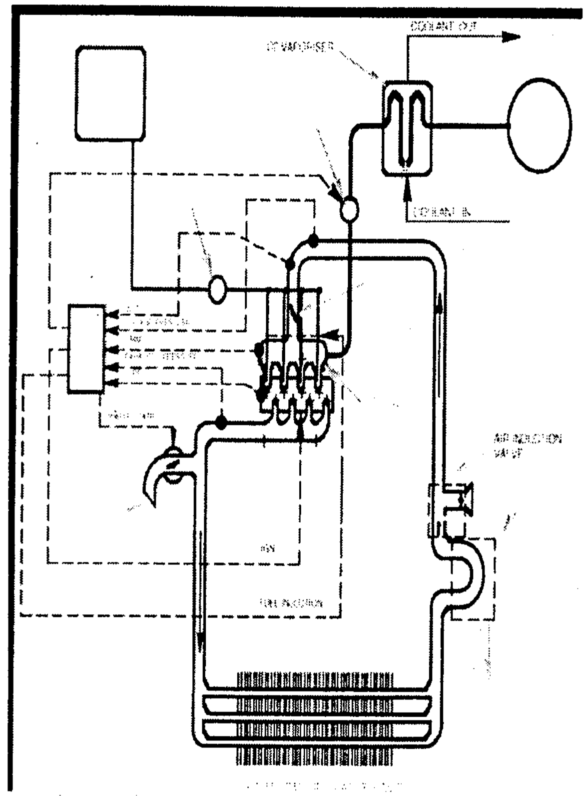
- **Electric**
  - » Battery
  - » Fuel cell, turbocharged/LOX
  - » Solar
  - » Microwave
- **Hydrazine engine**
- **Recirculating engine**
  - » Rotary gasoline, tested
  - » Hydrogen
  - » Methane, tested
  - » Piston gasoline, flown to 50,000 ft
- **Gas turbines**
  - » Turbo prop
  - » Jet
- **Turbocharged engines**
  - » Diesel
  - » Gasoline, 3-stage
    - – Flown to 20,000 ft
    - – Tested to 62,000 ft

Propulsion Options

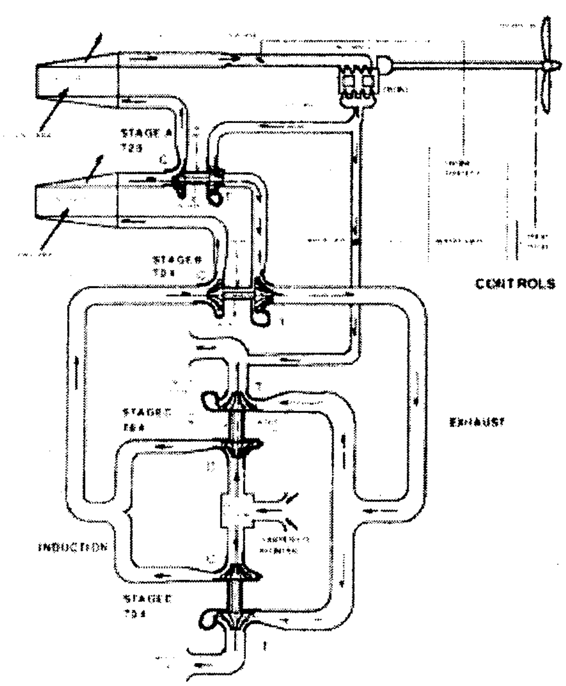
3-stage TC engine 155 kg 0.28 kg/kWh 220 kWh	Hydrazine engine 50 kg 3.6 kg/kWh 40 kWh	Battery/electric 60 kg 2.8 kg/kWh 57 kWh	
		Fuel cell/electric 125 kg 0.45 kg/kWh 136 kWh (280 kWh+)	
	Gasoline/O_2 engine 75 kg 1.3 kg/kWh 93 kWh	CH_4/O_2 engine 80 kg 1.2 kg/kWh 88 kWh (120 kWh+)	H_2/O_2 engine 80 kg 0.68 kg/kWh 134 kWh (230 kWh+)



Arion I Recirculating Cycle Engine

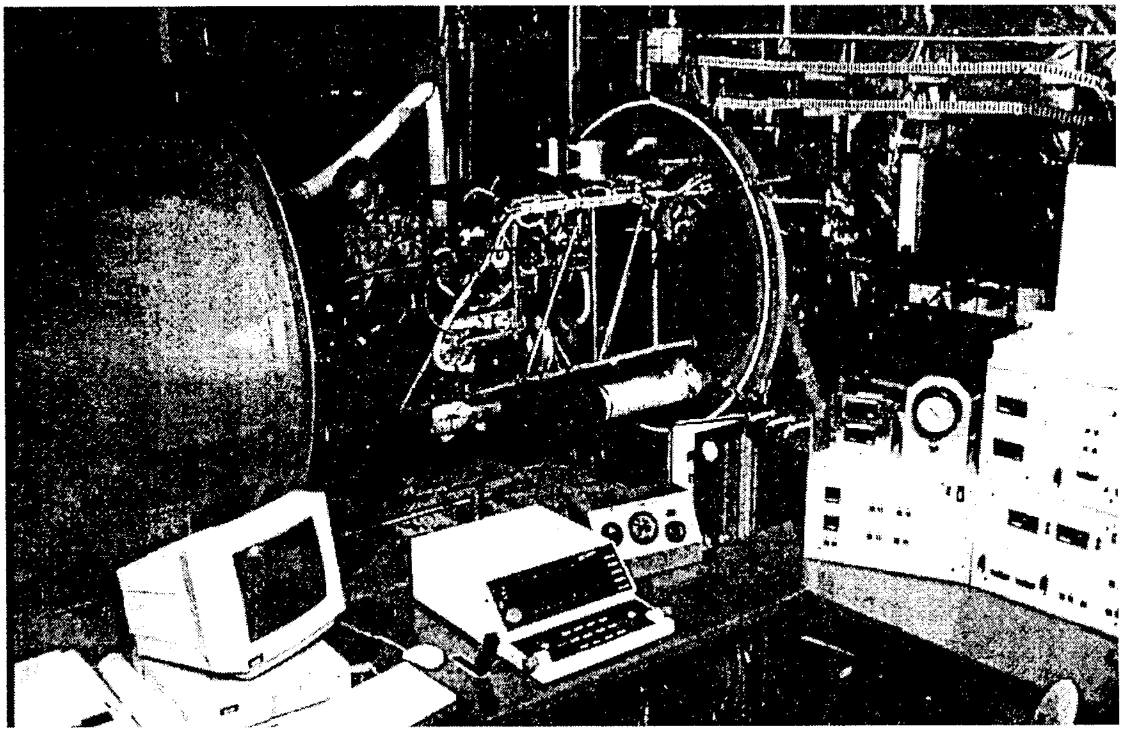


Arion IIB 3-Stage Turbochared Engine

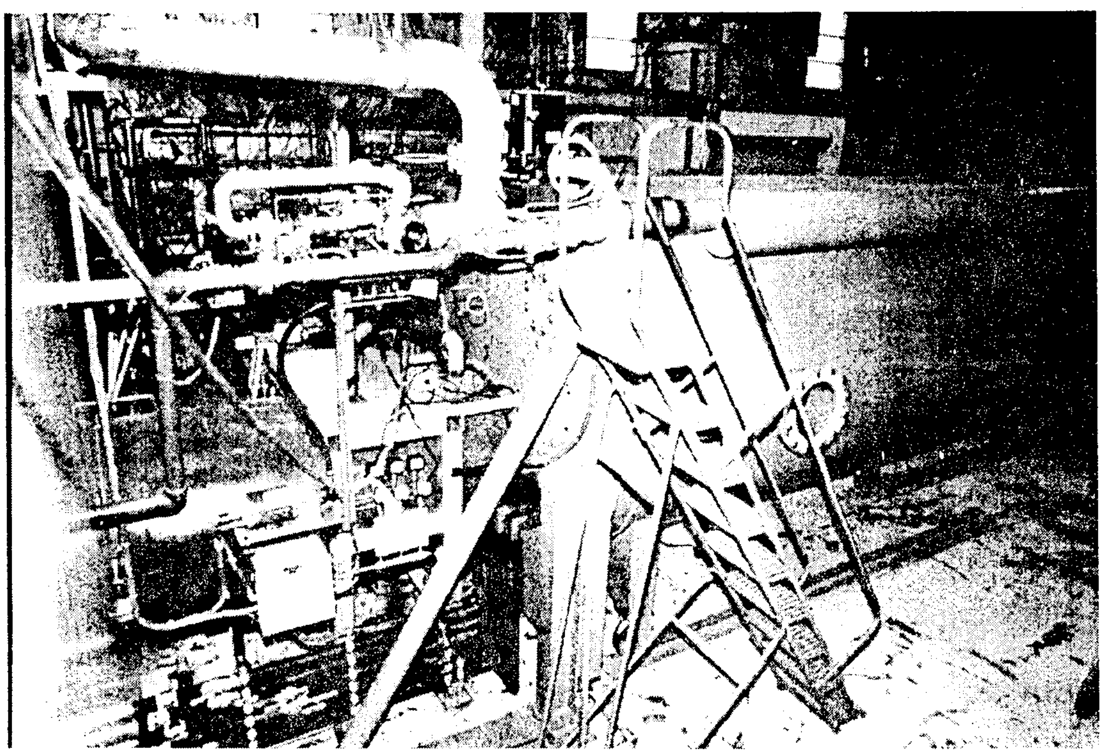


ARION II 20 km
3-STAGE URBOPOWERPLANT

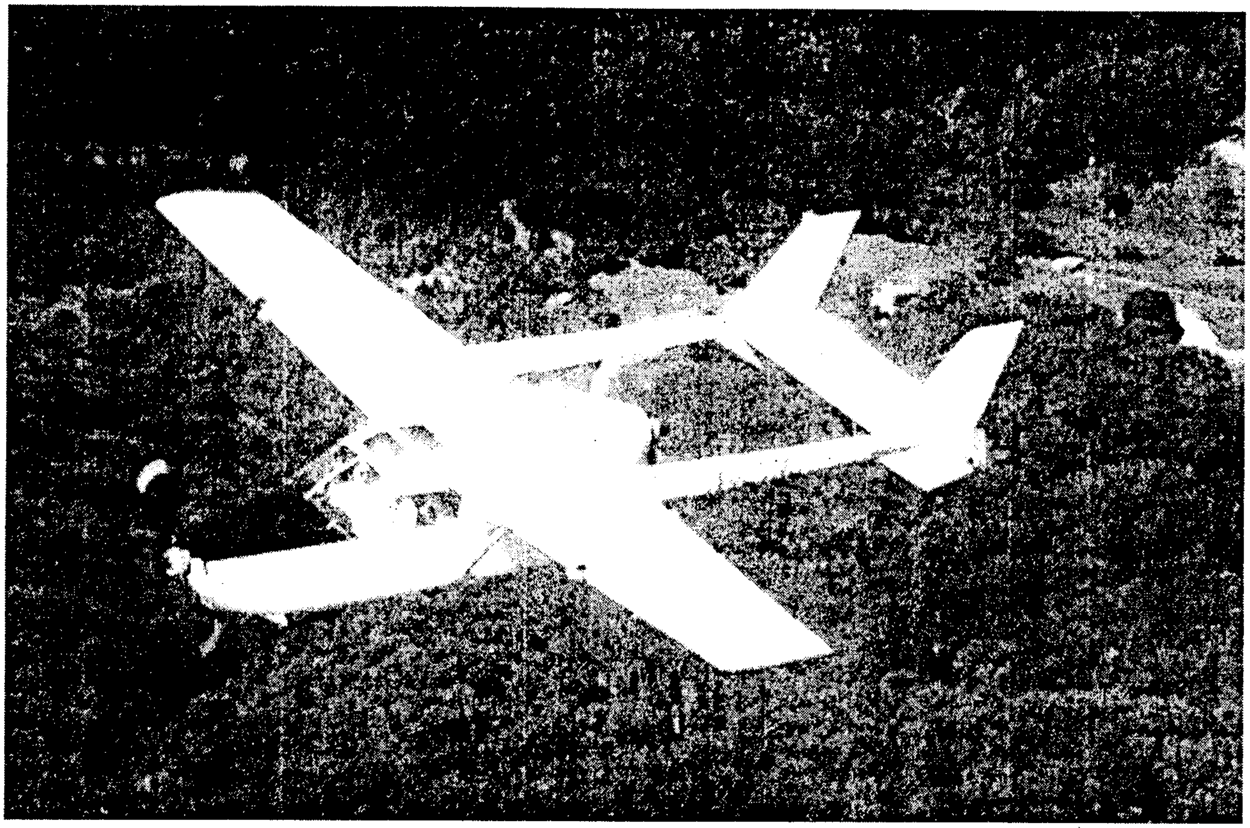
High-Altitude Test Facility (HATF)



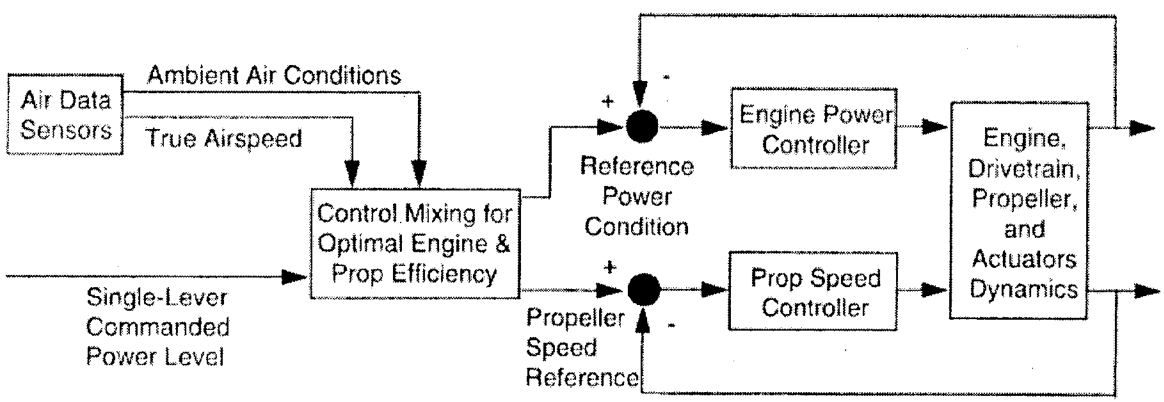
Ultrahigh-Altitude Test Facility



Single-Lever Power Control



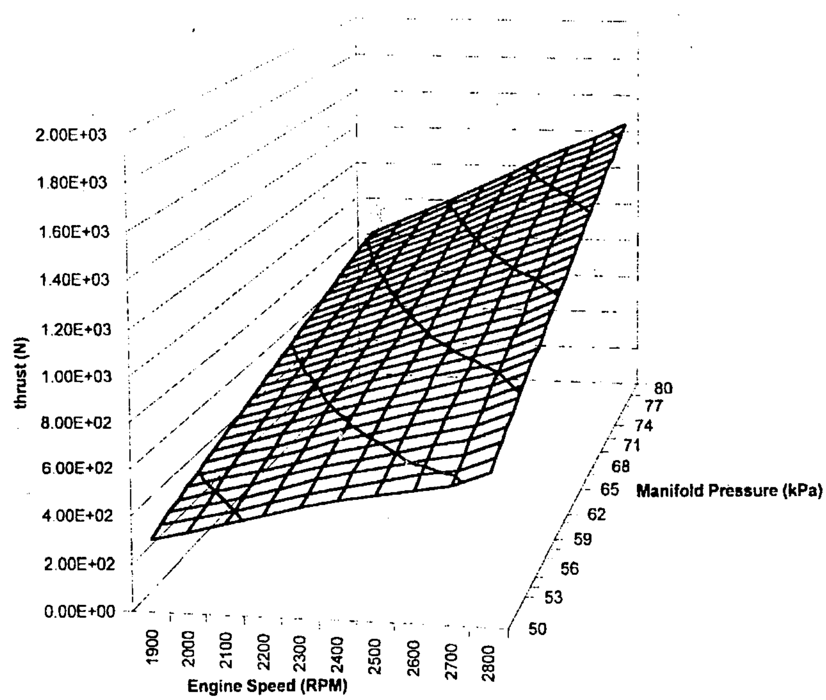
What is Single-Lever Power Control?



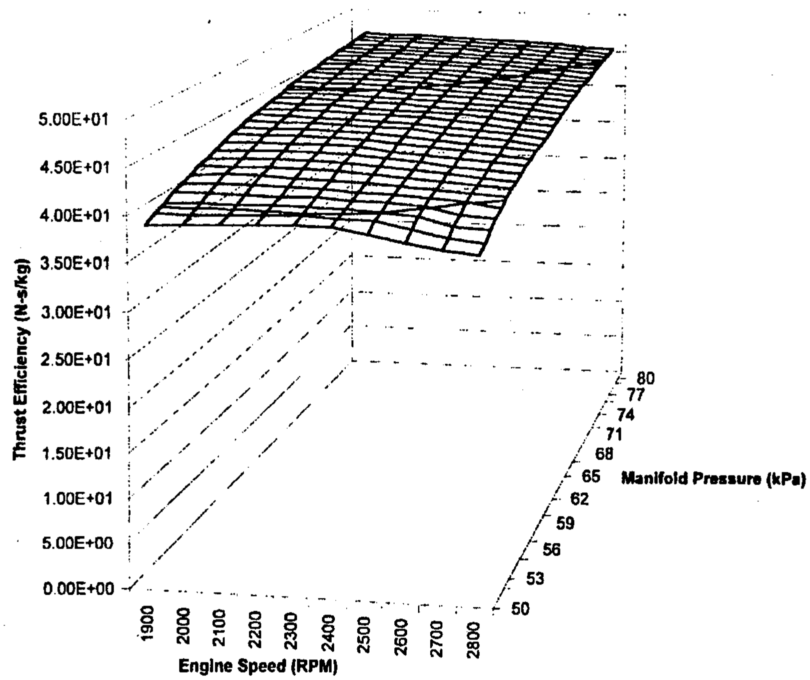
SLPC Benefits

- **Safety**
  - » Reduced pilot work and error
  - » Monitoring and fault-tolerant control capabilities
- **Reliability**
  - » Simplification of pilot-autopilot interface
  - » Increased time between overhauls
- **Performance**
  - » Efficiency optimization
    - Endurance improvement
    - Fuel savings
    - Emissions reduction
- **Integration**
  - » Simple add-on to full digital FADEC system
  - » Easy integration into future glass cockpits

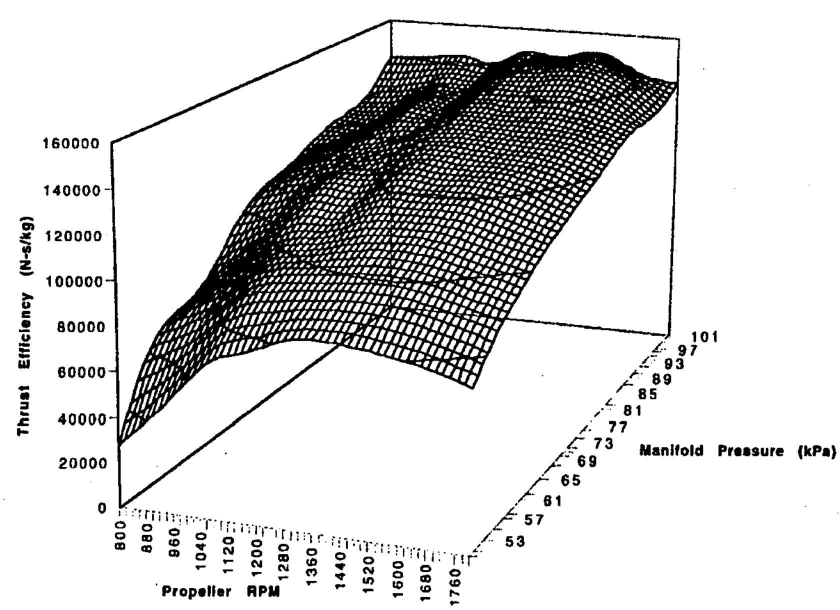
Thrust Contours for 0-2 (6,000 ft, 125 KIAS)



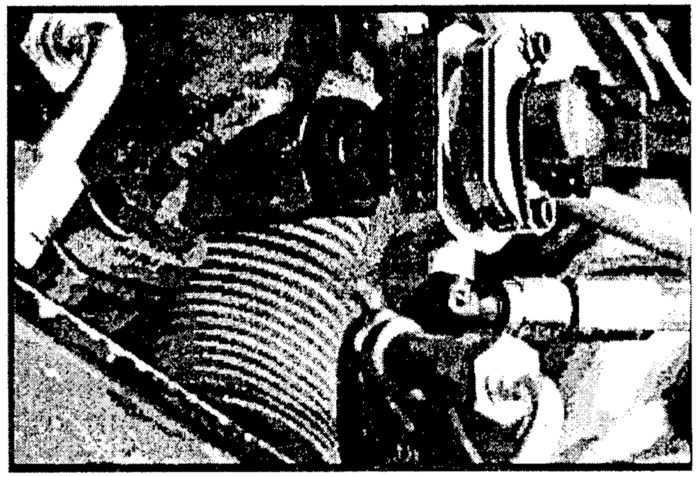
Thrust Efficiency Contours for 0-2 (6,000 ft, 125 KIAS)

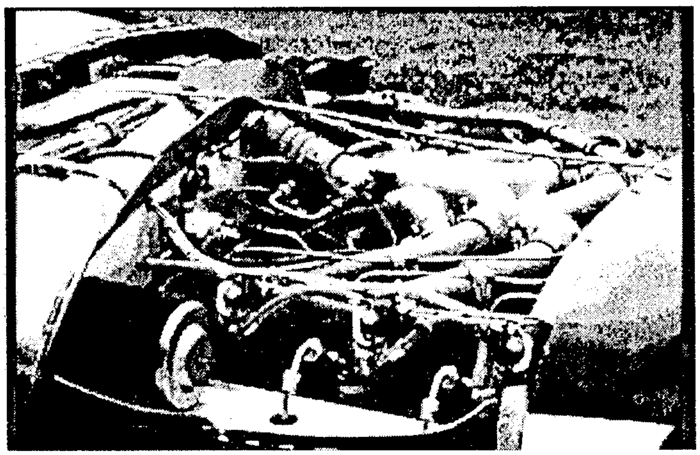


Thrust Efficiency Contours for Perseus B (46,000 ft, 70 KIAS)



SLPC Test Engine





Aurora's Interests

- Find additional people to join our Propulsion Group
- Continue development of powerplant
- Commercialize SLPC

Our facilities are available for rent

Contact:
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Manassas, VA 20110
703/369-3633
benjamin@hiflight.com

THE CLEAN AIRPORTS PROGRAM: GOALS AND ACCOMPLISHMENTS

JOHN RUSSELL, U.S. DEPARTMENT OF ENERGY (RET.) (*FACILITATOR*)

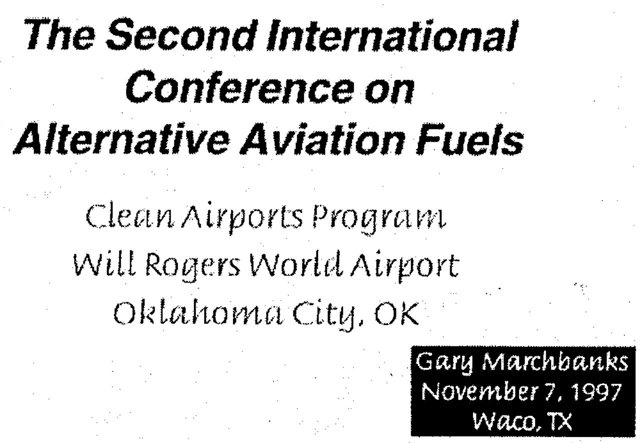
GARY MARCHBANKS, OKLAHOMA GAS & ELECTRIC SERVICES
JEREMY L. CORNISH, INTERNATIONAL CENTRE FOR AVIATION AND THE ENVIRONMENT
BILL HOLMBERG, SUSTAINABLE NEW-WEALTH INDUSTRIES

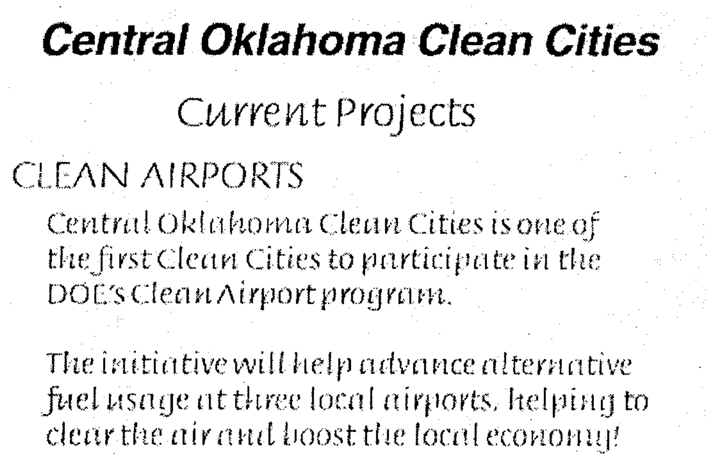
SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
NOVEMBER 6-8, 1997
BAYLOR UNIVERSITY

Clean Airports Certification Process

Gary Marchbanks
Oklahoma Gas & Electric Services
Oklahoma City, OK 73101-0321

(Slide 1) Central Oklahoma Clean Cities was chartered by the Department of Energy and *(Slide 2)* kicked off in May 1996. The coalition spent several months identifying areas that we could target to promote alternative fueled vehicles. It became apparent that a large concentration of vehicles was at our local airport, Will Rogers World Airport.





In October 1996, I attended the Clean Airports Program at Austin and met Max Shauk, the Clean Airports Administrator. We discussed the opportunity of certifying Will Rogers as a clean airport, the first commercial airport to consider designation.

The Clean Cities Coalition agreed we should pursue this project and we met with the airport director. Concurrent to this we had a project underway to make Southwest Airlines' two gates at Will Rogers be the first to have electric gates. I will discuss details of this project later.

(Slide 3) We had been working with Southwest for several months to make infrastructure changes to allow electric vehicles be used for ground support. Also, Whinery Off-Airport Parking had converted their entire fleet of off-airport buses to ONG. So the stage was set to focus on airport activities.

Clean Airports Certification Process

Meetings with airport officials

Partners

- *southwest airlines*
- *whinery off airport parking*
- *airlines*
- *cab companies*
- *FAA*

Write memorandum of understanding

We had meetings with stakeholders from airlines, FBO'S, city officials, and Clean City Coalition members to inform them of Clean Airports and determine what was to be in order to be designated.

Central Oklahoma Clean Cities

PROGRAMS GOALS

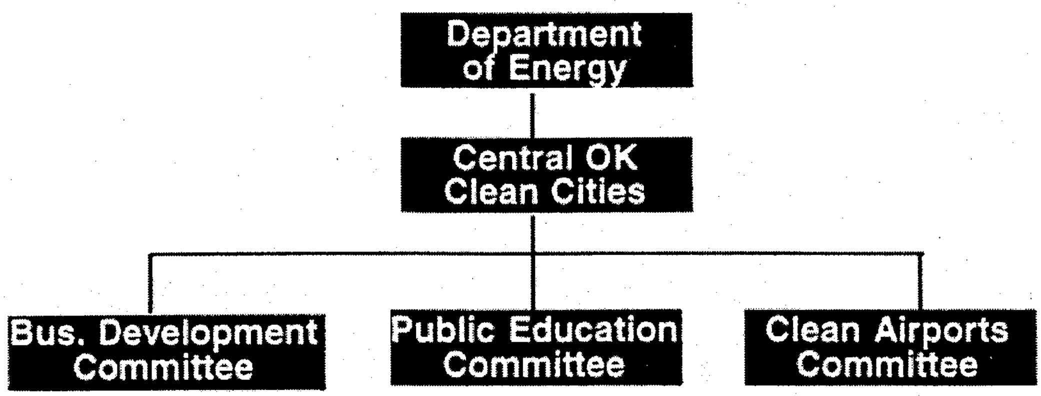
To help maintain Central Oklahoma's air quality, the clean cities remain involved in a variety of initiatives aimed at improving the region's air quality.

(Slide 4) Clean Cities formed a committee called the Clean Airport Committee to oversee the efforts. (Slide 5) The director of the airport and his staff chaired this committee with the members being airport officials, *(Slide 6)* airline representatives, cab companies, ground transportation, and freight haulers. A memo of understanding was written and submitted for approval.

"Let's Clear the Air"

Targets

- Alternative targets fuel vehicle
  - *– promotion and education*
- Clean air alert days
- Central Oklahoma air quality committee
- Central Oklahoma clean cities coalition
- Clean airports



Clean Airports Committee

Chairman - Director, Will Rogers, C.E. Page and Wiley Post Airports

Members
- *Whinery Parking*
- *Southwest*
- *Delta*
- *United*
- *Northwest*
- *American*
- *Airport Express*
- *Cab companies*

Members cont.
- *ONG*
- *OG&E*
- *Clean Cities Coord.*
- *Airport officials*
- *Fixed base operators*
- *State Alt. Fuels*
- *DRV Energy*

Certified July 16, 1997 - 1st Commercial Airport in the United States

Certification was July 16, 1997, at the monthly meeting of the Oklahoma City Airport Trust. A plaque was presented and is on display at the Will Rogers Airport executive offices.

(Slide 7) These areas were identified to focus on:

Aviation Fuels

Ground Transportation

Airside Transportation

Education

(Slide 8) 1. Aviation Fuel - As part of our agreement for designation we agreed to promote all alternative aviation fuels at Will Rogers, Wiley Post, and C. E. Page general aviation airports. We are planning meetings with the Oklahoma Pilots Association to promote ethanol use. The intention is to have a fueling facility in place at Wiley Post by mid-1999.

Aviation Fuel

Wiley Post Airport

CE Page Airport

(Slide 9) 2. Ground Transportation. - As I mentioned Whinery's Off-Airport has been successfully using CNG for 3 years. We have met and plan to again meet with the management of hotels, cab companies, and rental car fleets to encourage CNG use. Negotiations are currently underway to build a CNG station for airport and public use on the airport properties. The nearest CNG station is 6 miles away. We are working with the airport planning director to make arrangements to include electric charging receptacles in a newly planned airport-owned parking garage.

Ground Transportation

Present
- *Whinery off-airport parking*
- *Airport express*
- *UPS*

Future
- *freight companies*
- *cabs*
- *rental cars*
- *FAA*

Ground Transportation cont.

Infrastructure needs

- CNG station
- electric chargers

(Slide 10) 3. Airside Transportation - Southwest has completed their electric gate project by installing six chargers and they are using nine electric vehicles, including tugs and belt loaders. Plans are to test a pushback unit at Will Rogers.

Airside Transportation

Present

- Southwest Airlines

Proposed

- Delta
- American
- Will Rogers Airport Electric S-10's

Airside Transportation

Future

- United
- TWA
- Northwest
- Fed Transfer Center
- US Marshall
- FAA Monroney Center

The airlines also installed permanent 400-hz GPU's at each gate to utilize when appropriate.

(Slide 11) As typical at any airport infrastructure was a barrier in installation, but excellent cooperation from the City, Southwest, the utilities and electricians made this easier to overcome.

Southwest Airlines

Installed August 1997
- 9 - ground support equipment vehicles
- 2 - GPU's
- 6 - charging stations

Cheaper to operate
Dependable
Workers like - no emission

Special metering was installed to let Southwest and Will Rogers track hourly charging usage. Savings results were $80 for electric vs. $400 diesel, 2-day charges are typical and luggage has been protected by hauling fewer cars. TUG vehicles are smaller so indicator flags were installed to avoid accidents.

The airport is currently looking at using S-10s or Ford Rangers to replace gas engine vehicles. We have met with and are working to change Delta vehicles to electric. We also have talked to American and United. No commitment has been made from them. We have American, Delta, Continental, United, Northwest, Southwest, and TWA as our major carriers.

(Slide 12) 4. Education - We are working to build a permanent display in the airport lobby to explain Clean Airports and to showcase the commitment of the airport and its tenants.

Airport Terminal Education

Permanent display to recognize clean airport designation

Display alternative fuel vehicles in lobby

Tours to civic groups

A secondary need came out of our airport efforts and that was training needed to be performed for electric vehicle maintenance.

(Slide 13) The Mid-Del VoTech has set up an electric vehicle training, conversion, and safety program that will be available in January, 1999. This program will allow for state certification of technicians. This is one of the first in the nation to certify electric vehicle technicians. (Slide 14) Partners in this are FAA, Tinker Air Force Base, Southwest Airlines, DRV Energy, and OG&E Electric Services.

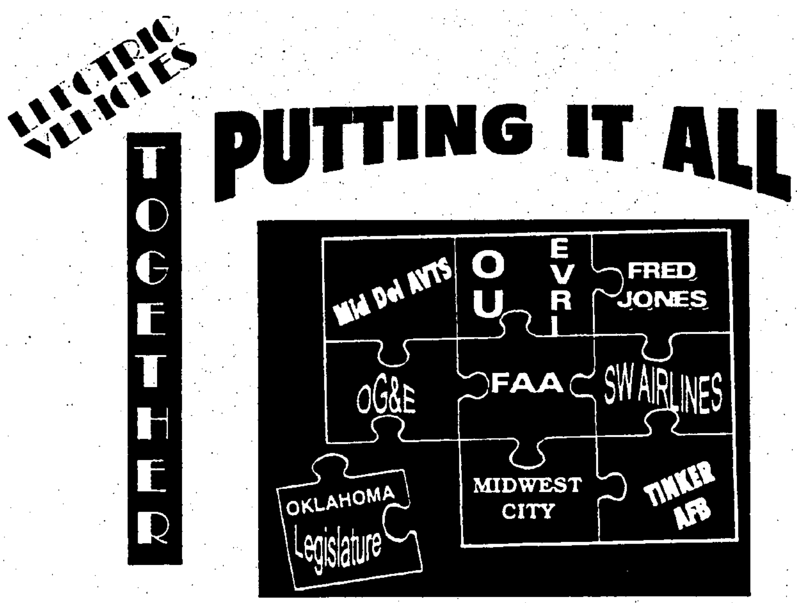
Electric Vehicle Training Center

Mid-Del VoTech
Midwest City, OK

Purpose

- *technician training*
- *conversion training*
- *safety training*
- *state certification*

We believe this effort has brought much visibility to alternative fuels and has opened new markets for us. Our legislators and governor have been supportive and both private and public loan funds are available for alternative fuel vehicles. UPS and the United States Postal Service operate large alternative fuel fleets in Oklahoma City, both have activity at the airport.



To see more fleets used it will take the following: *(Slide 15)*

Future Needs

Infrastructure

Maintenance support and training

Dependability and range

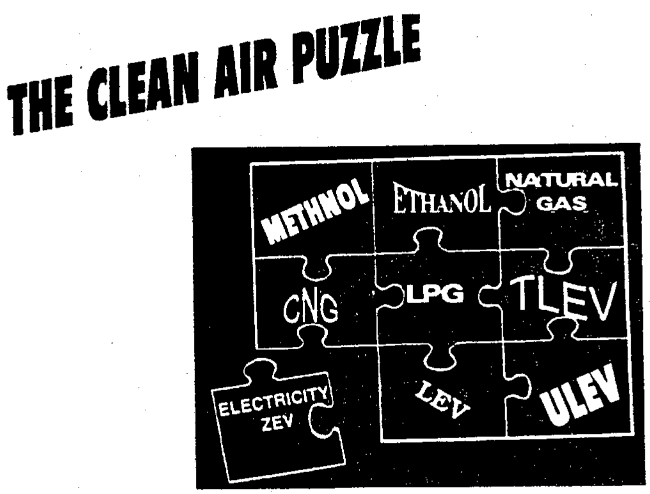
Economics

We are proud of our work, proud of the help from KW Grazia and Clean Airports and Dan Deaton of the Department of Energy.

(Slide 16) We took for more activity in the near future. Thank you and I will try to answer any questions. *(Slides from SW and airport facts)*

Summary and Conclusions

Much work has been done
Lack of airport infrastructure
Paybacks
Technology is now
First cost
No fuel that satisfies all needs



Conclusion—Sustainable Air Transport

Jeremy L. Cornish
International Centre for Aviation and the Environment
375 Beaconsfield Boulevard
Beaconsfield, PQ H9W 4B3
CANADA

- **Preservation of wildlife and ecosystems**
- **Social and economic concerns**
- **Preservation of cultural/archeological resources**
- **Air quality**
- **Water quality and hydrology**
- **Transportation noise**
- **Aesthetics and visual quality**
- **Hazardous materials transport**
- **Energy conservation**
- **Management of the environmental review process**
- **Operation and maintenance concerns**
- **Urban form**

International Centre
for Aviation and the Environment

Comments on the Clean Airports Program

Bill Holmberg
Sustainable New-Wealth Industries Inc. International
1925 N. Lynn Street, Suite 1000
Arlington, VA 22209

Thank you John. I had the opportunity to talk earlier with Max and John Russell about various aspects of the Clean Airports Program. I would like to build on the vision of people like Paul MacCready and other speakers here to make a recommendation that we consider making the U.S. Clean Airports Program into an international program. And also include a partnership in fossil fuels, renewable and other alternative fuels, not only for aircraft, but for other vehicles as well in terms of efficiency and the management of environment. Take a look at airports. The reason that we have them is that international business travellers can't take a bus or cab from Chicago to Tokyo, but you can take an airplane. The greenhouse gas issue has put the whole thing in a different perspective. Let's take a look at the history of the ethanol industry. We look at the ethanol industry as a frog trying to get from one end of the great pond to the other. First we have to leap onto the determination of the agricultural industry trying to find new markets for their crops. And that didn't take us too far. Then we had the first energy crisis and fuel shortages and we leaped to that pad. Then we sat for a while. Then we got into reformulated gasoline—oxygenates and we hopped onto that little pad. We had some problems, so we rocked back and forth on that little pad. Now, all that we have left is the greenhouse issue, and then maybe we can make it to the shore of full commercialization based on that.

Dear Conference Attendee,

Attached is testimony presented by Bill Holmberg to the U.S. Federal Aviation Administration. He testified verbally on 20 November 1997 and submitted a more complete report on 1 December.

His comments were well received and several attendees expressed support for the International Clean Airports Program. Bill worked cooperatively with Jeremy Cornish, Executive Director of the International Centre for Aviation and the Environment, and me in developing the written testimony.

At the Second International Conference on Alternative Aviation Fuels, Bill made a commitment to Dr. Reynolds, Chancellor of Baylor, and the attendees to develop a concept paper on the International Clean Airports Program (ICAP).

He would like to offer the attached material as this concept paper. Because of encouragement received, we are proceeding ahead with the ICAP. This includes:

- Development of a web site by the International Centre for Aviation and the Environment (ICAE) to serve the ICAP;

- Providing interested parties with a modified executive summary of ICAE's *The Greening of Aviation* that will serve as an additional dimension in defining ICAP;

- Exploring the feasibility of developing a comprehensive course of instruction on ICAP at Baylor University that can be made available to other educational institutions throughout the world; and

- Meeting with US and Canadian aviation and airport agencies, associations, and groups to explore measures designed to effectively advance ICAP.

We remain convinced that ICAP must proceed as a cooperative and voluntary effort. The information, ideas, and concepts presented to aviation industry must be "user friendly." We therefore welcome your comments, recommendations, and support.

Sincerely yours,

Max Shauck
Director

SUSTAINABLE NEW-WEALTH INDUSTRIES INC. INTERNATIONAL

SNI

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(703) 522.3392 Fax: 4193 energyusa@aol.com

James Littleton, AEE-120
FAA Office of Environment and Energy
Federal Aviation Administration
Washington, DC 20591

1 December 1997

Fax: 202.267.5594

Please accept this written material as an addendum to my brief presentation at the Federal Aviation Administration's, Office of Environment and Energy public hearing on 20 November 1997. The purpose of testimony is to solicit inputs from the FAA in launching the International Clean Airports Program and to recommend that Baylor University be designated by the FAA as one of the University Partners in the FAA's RE&D Advisory Subcommittee on Environment and Energy.

My name is Bill Holmberg, President of Sustainable New-Wealth Industries. We are advocates for energy efficiency and renewable energy with a focus on biofuels. This includes renewable and alternative fuels for ground vehicles and aircraft. I have been involved in these areas for twenty years in both government and private sectors.

Today, I also represent the Department of Aviation Sciences at Baylor University.

With the initial support of the Department of Energy, Baylor University launched the U.S. Clean Airports Program in mid-1996. Five communities now have Clean Airports; all small with the exception of Will Rogers Airport in Oklahoma City. Interest is rapidly mounting with international overtures.

The U.S. Clean Airports Program established the following goals:

- The airport will serve as home base for at least one alternative fuel aircraft or be used regularly by several alternative fuel aircraft;
- The airport will have refueling infrastructure for at least one type of alternative fuel aircraft;
- The airport will use alternative fuels in at least some of its ground vehicles (such as courtesy vans used by rental businesses or hotels, tractors used for pulling baggage carts, and emergency responses vehicles); and
- The airport will establish a public awareness campaign about alternative fuels (such as a display or an education program).

Under this concept, the Clean Airports Program established local partnerships between stakeholders, including fixed base operators, university aviation programs, and flying clubs, which are committed to operating aircraft on alternative fuels. These grass roots partnerships work to solve local transportation and air quality problems. Clean Airports partners work directly with local businesses and governments to shepherd them through the goal-setting, coalition-building, and commitments process necessary to establish the foundations for an alternative fuels airport.

Since these modest beginnings, the U.S. Clean Airports Program is now transitioning into the International Clean Airports Program. The international dimension expands the program beyond alternative fuels to include energy efficiency, all renewable and alternative forms of energy, and broad-based environmental programs including noise, water, land use, waste minimization and recovery, air pollution, and the stabilization of greenhouse gases.

This international dimension and expanded approach correctly positions the original focus on alternative aircraft fuels in the broader perspective of meeting the needs of a rapidly expanding aviation industry in a world demanding greater environmental protection and reduced use of fossil fuels.

The impetus for establishing the International Clean Airports Program was provided by the Clean Airports Summit in Denver, Colorado (10/17-19/97) and the Second International Conference on Alternative Aviation Fuels Conference at Baylor in Waco, Texas (11/6-8/97).

In Denver, the focus was primarily limited to use of alternative fuels in ground support vehicles, an expression of environmental concerns, and discussions on aircraft operations limiting fuel consumption. Alternative aviation fuels and broad-based environmental concerns were not primary agenda items.

The Waco conference addressed a broader range of issues including discussions and demonstrations of new flight concepts; solar, LNG, ethanol, ETBE, and biodiesel powered aircraft; piston and turbine fuels provided by new refinery processes using coal, natural gas, and biomass; a full range of creative concepts to advance and improve aviation and airport operations; and broad-ranging environmental concerns including greenhouse gas emissions and aircraft emissions as the major source of air pollution at airports.

As a result of these two conferences, it became clear that there was need for an effective and cooperative merger of corporate and government interests (safety, cost-effectiveness, speed of travel, convenience, and international acceptability) with the interests of the public for the same reasons. This merger, the ICAP, can investigate new concepts that may be before their time in the industry/government interface. There is the hope that historic conflicts between advancement and intrusion can be tempered with advanced aviation, engine, fuel, environmental, and communications technologies and—good will.

It was felt that the International Clean Airports Program (ICAP) could bridge these oft-times supportive and sometimes disparate interests. To do so, the ICAP must fully embrace cooperative and voluntary action. That is understood and accepted.

The opportunities for such cooperative and voluntary action include recognition that:

- Greenhouse gas emissions are international problems—aviation is the lead international industry in terms of communications, coordination, operations, safety, and advanced technology;

- Air travel is a major growth industry in most parts of the world—airport facilities and operations are constantly being expanded and upgraded with flexibility unique to airports;

- Airports and aircraft are perceived to be "high-tech" industries capturing state-of-the-art technologies—aviation and airport personnel are recognized and respected for their high qualifications;

- The public is comfortably and safely "captured" within the confines of airports, with ample opportunity to witness and learn about advances and benefits of energy efficiency and renewable energy;

- Because of rapid growth, airports and their nearby supporting infrastructure will increasingly become major "point sources" of pollution and greenhouse gases. If airports and their operations are considered holistic systems they can, through voluntary actions, serve as sound environmental examples for their communities. Such voluntary operations will increase flexibility and efficiency while reducing costs in reaching international goals.

Energy efficiency will be the foundation which will support the steady advent of renewable energy technologies at Clean Airports. District heating and cooling, advanced building technologies and commercial ground water heat pumps, along with a myriad of advanced energy efficiency technologies are examples of technology options. Renewable and less polluting alternative fuels, electric vehicles, and fuel cells can be phased into airport operations as economics and safety permit. Photovoltaics and solar thermal, with available incentives, are frequently cost-effective now. Steady improvements will soon obviate the need for incentives in all energy categories. "Green electrons" from renewable energy sources are already available in parts of the United States and the world.

As the United States and the world prepares for the next century, airports and aviation in general should serve as showcases of advanced technology and operations that use voluntary initiatives to cost-effectively meet environmental imperatives.

Therefor the **MISSION** of ICAP is to enhance the economic, environmental, and natural resource sustainability as well as the public image of the aviation industry in the full scope of its operations.

ICAP's priority tasks include:

- Limit its focus to cooperative and voluntary actions;

- Support existing environmental programs of international and domestic aviation industries, their associations, and supporting agencies;

- Advocate broad-spectrum environmental, energy efficiency, and renewable energy programs to include alternative ground transportation and aviation fuels, as well as the environmentally efficient use of fossil fuels;

- Strengthen the public perception that aviation is now and will be even more so in the future the high-tech industry that ensures safe, rapid, cost-effective, and environmentally sound travel;

- Promote the aviation industry as high-tech windows to a future where human needs and true sustainability are in harmony;

- Build on Baylor University's background in air pollution sampling and monitoring with aircraft using clean-burning alternative fuels. They have developed a program to specifically measure air quality impact of large airports using small, inexpensive, and alternatively fueled aircraft. Baylor has developed this prototype which will be flying missions early in the new year. They are now flying air monitoring missions for the State of Texas using a turbo prop King Air and periodically using one engine to test alternative jet fuels.

- Operate within a highly flexible organizational structure encouraging creativity without the limitations of liability and responsibility beyond those demanded by common sense.

- Work cooperatively with environmental and public interest groups showing interest in airport and airline operations. ICAP will strive to effectively convey concerns to the aviation industry in a cooperative manner.

The effectiveness of ICAP's organizational structure is greatly enhanced by advanced communications technology and its focus on cooperation, voluntary action, education, and technology transfer.

ICAP, rooted in the U.S. Clean Airports Program, is an open organization in its formative stages encompassing expertise from various international groups, including those focusing on environmental protection. ICAP will work with involved industries and organizations to develop concepts and plans designed to effectively mitigate the environmental impact of airport and aircraft operations. In doing so, ICAP hopes to preclude the need for more restrictive environmental legislation.

This, then, is a brief history and position of the U.S. Clean Airports Program; the rationale for expanding this concept to the International Clean Airports Program; the motivations for this expansion; and the guiding principals (Mission and Priority Tasks) for the ICAP.

Baylor University is the proper center for ICAP. They have 20 years experience in alternative aviation and ground transportation fuels; in air sampling from aircraft; in carrying the message for these two challenges to international audiences; and for building the educational foundation for these endeavors.

It is therefore recommended that the Department of Aviation Sciences at Baylor University and ICAP be supported in efforts to formalize the International Clean Airports Program. As an important step in this process, it is recommended that Baylor University be designated by the Federal Aviation Agency as one of the University Partners in the FAA's RE&D Advisory Subcommittee on Environment and Energy.

A more detailed operational plan for ICAP is being developed and will be made available to all interested parties on request. This plan is being jointly developed by a cooperative effort between Baylor University in Waco, Texas and the International Centre for Aviation and the Environment (ICAE) based in Canada. Their efforts will focus on liaison with interested parties including government offices, associations, and individuals developing a supportive education program at Baylor University and organizing a comprehensive information monitoring, storing, and exchange system at the ICAE. An outline of this system will be forthcoming.

For more information, please contact: biorefiner@aol.com. Comments are appreciated.

William C. Holmberg
President

INTERNATIONAL ALTERNATIVE AVIATION FUEL EXPERIENCES

PAUL MACCREADY, AEROVIRONMENT (*FACILITATOR*)

JACQUES CALLIES, AVIATION & PILOTE MAGAZINE
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TONY MARMONT, BEACON ENERGY, LTD.

CLOSING REMARKS BY BOB HARRIS, NEBRASKA ENERGY OFFICE

SECOND INTERNATIONAL CONFERENCE ON
ALTERNATIVE AVIATION FUELS
NOVEMBER 6-8, 1997
BAYLOR UNIVERSITY

International Alternative Aviation Fuels Experiences—FRANCE

Jacques Callies, Publisher
Aviation & Pilote Magazine
Aerodrome de Lognes-Emerainville
Lognes, 77185
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Short Biographical Introduction: IFR private pilot, aircraft owner, publisher of Aviation & Pilote magazine since 1975.

Every time we are in Texas, let's say at least once a year, I come and visit Grazia and Max Shauck. Of course, both talk about bio-fuels, what is new in the States, and so on. When Grazia asks me about Europe and France, what I do with my team to save the planet from air pollution, I answer: nothing... or not much. But, in my defense, I have the strong feeling that the world of American ecology is very lucky to have Grazia and Max Shauck as active members.

In the last ten years, my magazine and I have tried hard to interest flying people about air pollution and alternative fuels.

In 1988, we took the risk to fly a Cessna L-19 equipped with a GMA 140 TK diesel engine issued from a J8S Renault Diesel engine. At that time, this engine was mounted on the Renault 25 car. The engine had been prepared for aviation by a small team of technicians from SCOMA, an independent lab which had to work without the help and competency of Renault engineers. This test was supposed to lead to a complete range of engines from 150 to 700 horsepower. It failed for political, financial, and also technical reasons: personally, I heard of vibration problems which cracked first the engine mount and then when reinforced, the aluminum frame.

In 1993, we cosponsored Max flying with the Ethanol Pitts during the ten days of Paris-Le Bourget Airshow. It was obviously the opportunity for us to write about pollution and bio-fuels. With a very big interest shown by our journalist friends from French TV and radio, always looking for sensational aspects of information, but very little feedback from our pilot readers.

We tried again in 1995 with Max Shauck flying that time with ETBE. Mainly because it is always a real pleasure to exchange with the Shauck family. But we were already doubting the effective results on the French pilots' mentality. I mean: during the two years which had separated the Paris shows, no one in France had asked us for any information about biofuels - apart from one single aircraft owner whose intentions were not clear since he wanted to be in contact only with the Shauck's in the States, not with us.

In March '96, I flew to Waco with a contributor of my team, Michel Barry - he is an engineer and professional pilot - to test a Cessna 152 whose engine was certified to fly with ethanol. A very interesting experience, very positive for every one but, once more, we had no success; no one showed any interest in spite of the fact that, during the same period, new president Chirac wanted to help French farmers by announcing that there would be less taxes on biofuels, such as ethanol.

I even remembered we sold less copies that very month, certainly because of the cover showing an old Cessna 152 in spite of a exclusive tittle: "we flew bio." In fact, we got confirmation that French pilots prefer scoops on the new Piper models or the return of Cessna.

After the 95 Paris Airshow, Max Shauck had left behind almost one thousand liters of ETBE. As it was illegal to stock the fuel in our office, we joined Jacques Mangenot, a very dynamic person, airport manager of a secondary facility next to Paris, very much involved in aeroclubs activities. Mr. Mangenot had read our different articles on biofuels experiences, he also could legally stock the fuel, plus a team of friends able to conduct tests on engines, and was very enthusiastic about the idea to try a new fuel: so we gave him our barrels of ETBE.

I called him recently to know, about his experiences. His answer was "you know what, you forgot to give us Max Shauck's telephone number. How can we use your ETBE if we have no technical data?" No comment. But this lack of interest is significant since, fifteen years ago, the same people pioneered the use of GPS in France, with fantastic energy.

This year, Grazia and Max asked us if we could raise money for a third presentation in Paris. Personally, I was very involved in a different project and I found no time to help our American friends. Max did not come. But during this year's show, Philip de Segovia, our chief editor, was asked many times about Max Shauck absence, but no one talked about his fight, I should say our fight to promote better fuels.

The first time Grazia invited me on the phone for this conference, I answered "what for? I know nothing about French aviation experiments on alternative fuels."

When her assistant called me again and insisted, talking about French airport Roissy closed for one day because of air pollution which meant in her mind that we all had to do something quickly to save the world, I decided to come to tell you.

First: Roissy has not been closed at all. Just half the car traffic for a single day. A very unpopular measure served with a reinforced speed limit that very few drivers respected.

Second: may be the fact that no one sincerely cares in France about their own pollution is an important fact.

Third: may be the free point of view of an aviation publisher can be interesting for a community as yours.

Before flying to Waco, I called the office of Mrs. Voynet, the new minister of Environment, a very active person before the last elections in the world of ecology. The ministry people were charming but it was impossible to obtain within a month a clear official position on alternative fuels and aviation. We know a specialist Mr. Forrest answered our question, but his words were considered as dangerous from a political aspect since the press department of Mrs. Voynet preferred not to deliver his copy to us. And, obviously, the position of our green minister is not very comfortable. And we can imagine why.

How can France preserve its costly social system and meet the European economic criteria to enter the club of Euro money without reducing its budget and increasing its taxes?

Would it be realistic to develop a biofuel that costs twice the price of fossil fuel? If yes, how could it be sold at a competitive price without decreasing the percentage of fiscal taxes?

American drivers or flyers of France know taxes on fuels are heavy: it brings to the budget 25 billion dollars, approximately 10 percent of the state budget. Sincerely, I can't imagine our government deciding to loose money just for ecological reasons.

Anyway, I personally think our new minister is reserved towards biofuels. For environmental concerns. Indeed, Mrs. Voynet asked for a serious study on biofuels before setting new measures as her services pointed out that increasing biofuel production could cause an increase of pollution because of the increased use of pesticides to achieve a better production rate.

Finally, I met Jean-Pierre Leroudier from ADECA, the French association which promotes biofuels and, the same day, Luc Chatin, in charge of biofuels at the French petroleum company Elf. This company owns the first production unit for ETBE.

Both of them had not known of any aeronautical experience, apart from ours with Max Shauck and Baylor University and another one from Textron Lycoming. But, obviously, this last experience is the same one. An open talk of three hours was very interesting but most of the time "off the record." The opinion I forged and I think I may repeat without being refuted is quite simple.

1. ETBE production is not a technical problem, just a political one. If asked, Elf is able to provide as many liters of ETBE as necessary to make general Aviation fly but this will never happen, unless there is a European obligation to use this costly biofuel.

2. Max Shauck is not preaching in the desert with his biofuels because one day, under the pressure of the American government, lead will be illegal in general aviation in the States and, proceeding from this, in Europe.

3. We must not forget a fuel is used to make an engine run as well as possible and safely. Ecology comes after.

4. Diesel oil could be the solution for general aviation. Diesel oil, not jet fuel with additives because of degraded performances and excessive pollution of this combustion.

Ten years after my first experience of alternative fuel, Diesel is the fuel "a la mode" in France. The Renault-Socata diesel fueled engine, seems to be - when flying - the best compromise between the environmentally correct and the economically correct.

Our "green" minister, Mrs. Voynet, recently attempted to raise new taxes on the diesel fuel for cars, a decision motivated by its high degree of pollution. This attempt failed and the diesel car industry can expect continuous growth, as it represents already 50% of the French car fleet.

We have to admit French diesel engines have made significant progress. Today they are less noisy, more efficient and certainly more environmentally friendly than they use to be 10 years ago. For instance, sulfur rate in diesel oil has been reduced by a factor of 16. As the result of all this, the French diesel engine manufacturer Peugeot is exporting half its production.

In this context, it seems logical that the French government will support a diesel aero-engine. Mrs. Voynet had to rally behind the flag of the minister of Economics: she already accepted to be photographed in front of the new Renault-Socata engine.

However the fiscal position toward this new engine is not so clear. What makes this diesel aero-engine so attractive in France is not the absence of lead but, of course, the tax-exemption applied to kerosene which represented in 1997 almost 2 billion dollars tax exemption. Will the Tax services apply the same rate of tax to a new fuel suitable for aero-diesel operations? It is not sure.

I will conclude as a pilot and aircraft owner. To do business through France and Europe using our Piper twin, I burn every year roughly 8,000 gallons of AvGas. I don't feel guilty about that because my pollution gives work not only to my team but also to people from Piper, Textron, Bendix, maintenance shops, airports, and so on. If you were to ask me if I am sincerely supporting ecology and biofuels, I answer yes. But if you were to ask me if I am ready to pay the price for it, my answer is no.

Thank you for your attention.

International Alternative Aviation Fuel Experiences—SWEDEN

Lars Hjelmberg, President
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Runskogsvagen 4B
S-192 48 Sollentuna
SWEDEN

Thank you. I would like to take my part of the presentation to demonstrate the difficulties I have had in marketing. As you know, the 91/96 UL fuel is an approved fuel listed in the service instructions of major engine manufacturers like Continental and Lycoming. It is a legal fuel; you choose to take the left pump at the fuel service station instead of the right pump. Why is then, that after 7 years we only have 15% of the market? The price is the same as low lead—we make the same amount of profit on it as we do the 100LL. There is something else that is a problem with the pilot, the airplane mechanic, and the airplane owner. All three of these are some of the most conservative people in the world. Try to get a mechanic to change his mind. He will always say, "I have always been flying on 100LL, and I won't change my mind". The owner of the aircraft is not prepared to pay the price of the fuel even if it is the same price as 100LL. He wants to pay less for the environmentally sound gasoline because he considers it a risk to use such a fuel. Then you have a problem with the pilot. He is primarily concerned with the price of the gas. Even if you keep the prices the same, it is still a problem because the owner of the aircraft, if he believes there is a risk associated with the environmental fuel, will increase the rent of the aircraft, and the pilot won't rent it. In 1991 we started with five airports having the fuel. In 1993, we had 15 airports. Now we have 55 airports, but there are still 100 airports in Sweden that don't have it. We are offering every airport in Sweden a fuel tank and a steady supply of fuel if they won't it, but they don't take it. So, finally I would like to say that even if you have a certified fuel, you can prove it is better for the environment, better for the engine, and for everyone, it is a hell of a problem to sell it to the customer.

Plinio Nastari
DATAGRO, Ltd.
Rua Boa Vista, 133
San Paolo, SPP01014-030
BRAZIL

SECOND INTERNATIONAL CONFERENCE ON RENEWABLE FUELS FOR AVIATION

WACO, TEXAS

NOVEMBER 6-8, 1997

PLINIO NASTARI'S SECOND PRESENTATION

INSTITUTIONAL FRAME WORK CHANGES FOR ETHANOL IN BRAZIL

1975-1985

- **STRONG INTERVENTION MECHANISMS IN PLACE**
- **22% ANHYDROUS ETHANOL BLENDED IN ALL GASOLINE**
- **STRONG SALES OF E-100 VEHICLES**
- **PRODUCTION OF ETOH ROSE FROM 0.146 TO 3.12 BILLION GALLONS**
- **PRODUCTION OF SUGAR ROSE FROM 6.0 TO 7.8 MILLION TONS**
- **HIDRATED ETHANOL AND GASOHOL SOLD IN OVER 25,000 RETAILING STATIONS**

INSTITUTIONAL FRAME WORK CHANGES FOR ETHANOL IN BRAZIL

1985-1997

- INTERVENTION MECHANISMS GRADUALLY PHASED-OUT
- PRICES STILL CONTROLLED FOR GASOLINE AND ETHANOL
- 22% BLENDING MAINTAINED
- E-100 VEHICLE SALES DROPPED TO ZERO
- PRODUCTION OF ETOH ROSE FROM 3.12 TO 3.8 BILLION GALLONS. MOVE FROM HYDRATED TO ANHYDROUS
- PRODUCTION OF SUGAR ROSE FROM 7.8 TO 13.5 MILLION TONS

INSTITUTIONAL FRAME WORK CHANGES FOR ETHANOL IN BRAZIL

1997-ON TO THE FUTURE

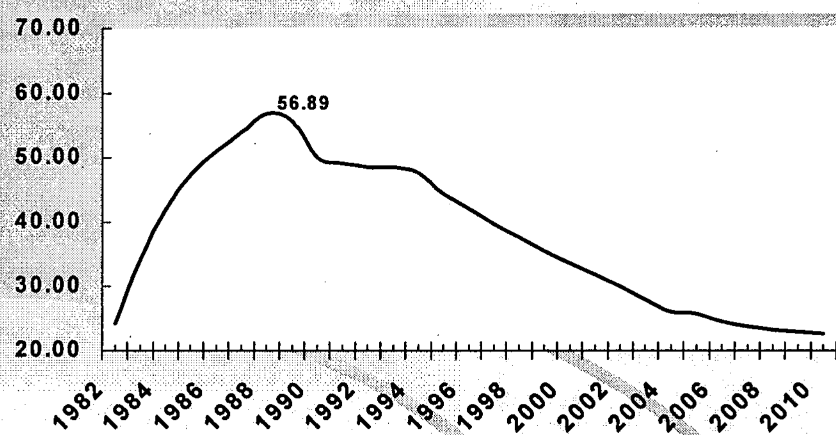
- END OF PRICE CONTROLS ON GASOLINE AND ETHANOL
- NEED TO CREATE A FISCAL MECHANISM TO PROTECT ETHANOL
- REDUCTION IN NUMBER OF PUMPS SELLING E-100
- NEED TO GUARANTEE NITCH MARKETS

ESTIMATED DEMAND FOR FUEL ETHANOL IN BRAZIL
(IN BILLION GALLONS)

	1997	2000	2005	2010
ANHYDROUS	1.33	1.68	2.40	3.20
HYDRATED	2.11	1.66	0.67	0.13
TOTAL FUEL	3.44	3.34	3.07	3.33
NON – FUEL	0.30	0.30	0.31	0.32
TOTAL	3.74	3.64	3.38	3.65

SOURCE: DATAGRO

SHARE OF ETHANOL IN TOTAL OTTO CYCLE FUEL DEMAND(%)



SOURCE: DATAGRO

CONSUMPTION OF GASOLINE
(BILLION GALLONS)

	1980	1990	1996
HIGHWAY	3.020	2.500	4.347
AVIATION	0.025	0.016	0.018
%	0.8%	0.6%.	0.4%

PRICES OF FUELS
BRAZIL - AVERAGE - AT PUMPS INCLUDING TAXES

	USD/GALLON
GASOLINE	
• AUTOMOTIVE	2.95
• AVIATION	3.97
HYDRATED ETHANOL	2.40
• PRODUCER OF NET TAXES	1.49

International Alternative Aviation Fuel Experiences—GERMANY

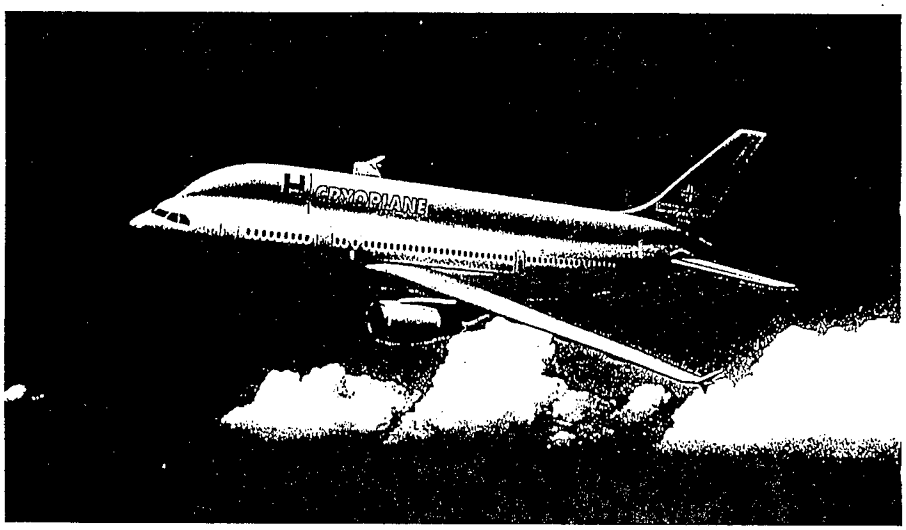
Rudolf Voit-Nitschmann
Institute Fur Flugzeugbau
Universitat Stuttgart
Stuttgart, GERMANY

Perhaps I have to expound on what the name ICARE means. The name of this plane was derived from the very famous Icarus of Greece. Unfortunately, I have to make a statement regarding alternative fuels that there are no major activities in Germany in terms of fuels for general aviation. We have had in Germany, a few years ago, very interesting aircraft engine projects, for example the Porsche engine, and this project was canceled in 1990 by the management due to financial problems. The engine had to be integrated in several French airplanes and in some new German airplanes—the Ouschmeyer R-90 and Cole TF-200—and those projects also had to be canceled after the canceling of the engine. And also the Sovel-diesel engine project that I think you know because he presents it at the Austrian airshow every year. But no engine is certified with this engine; I hope he will take this last step.

On the other hand we have a few activities, as you heard this afternoon, in electric powered flight. There is not only ICARE, there is also Pioneer in Germany in terms of solar-electric powered airplanes which Orbit created: Solar 1 airplane and also one airplane, Solarfuel, which he hasn't gotten up in the air up to this point, but I hope that he will do that next summer and then we will have two high-performance solar aircraft in Germany. The glider people are very interested in solar-powered activities because most of the modern gliders made in Germany are equipped with auxiliary engines and we have a lot of noise problems at our airfields in Germany. People are hoping to convert those engines to electric power in the future, perhaps, and I hope we can do a continuation to that objective.

In the field of large transport aircraft we have had a very interesting aircraft in the area of alternative aviation fuels; at the DASA center in Hamburg they are conducting research with the Russian Scientists into the Cryroplane. The goal was to convert an Airbus A310 to make it run on hydrogen. I think that is a very interesting project in Germany. They finished the paperwork in 1995 and I hope they will continue to produce a prototype on that. I know that there are existing plans to convert a Dornier 328 to hydrogen by DASA; Dornier now belongs to Fairchild but DASA will work together with them to make it run on hydrogen fuel. I think that's the most positive contribution from Germany to the field of alternative aviation fuels. I think that we can work together in that field to someday get progress in alternative aviation fuels, and I was very inspired during that meeting from the ideas that I have heard hear, and I am happy to bring these ideas back to the specialists in Germany. I hope that we can also do some activities in the general aviation field in the future.

CRYOPLANE
Deutsch-Russisches Gemeinschaftsprojekt
Flugzeug mit kryogenem Treibstoff

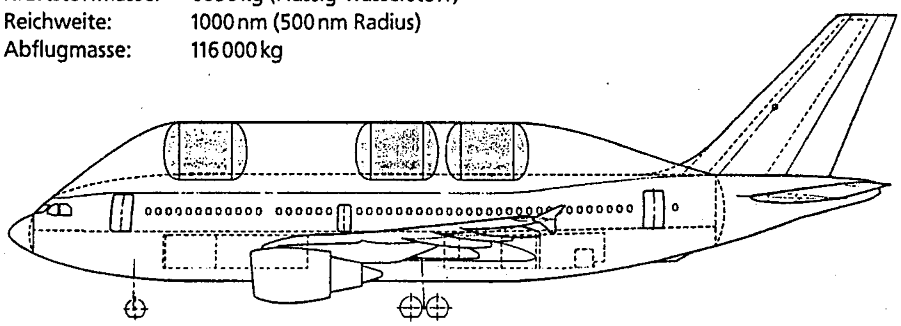


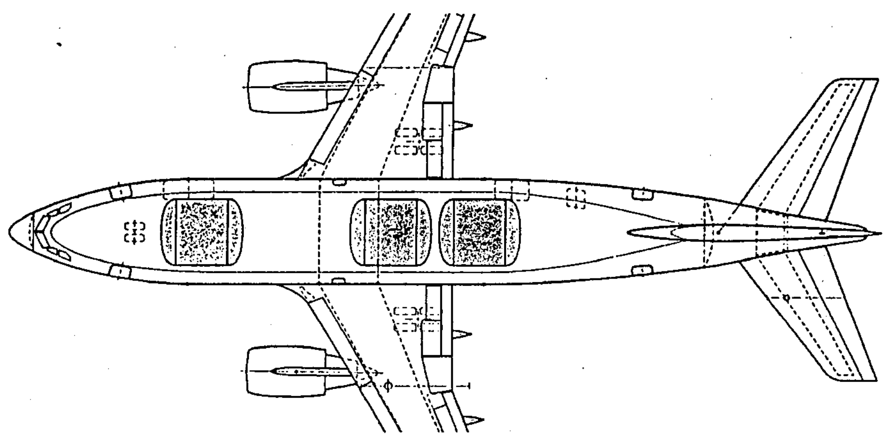
DEMONSTRATOR-FLUGZEUG

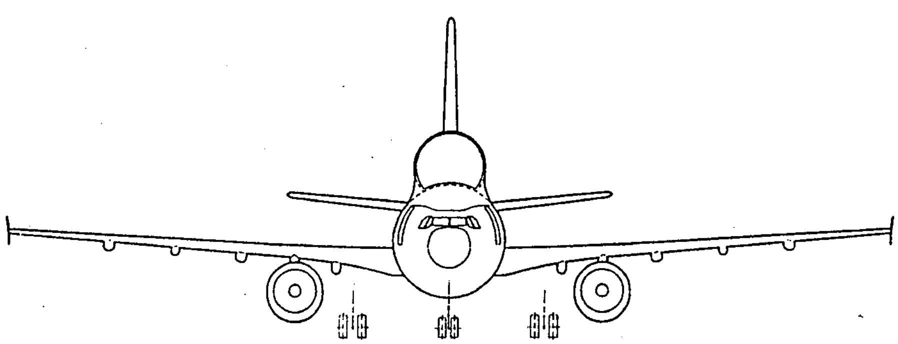
Entwicklung und Labortests von Komponenten sind notwendig, aber reichen nicht aus. Zunächst wird das Demonstrator-Flugzeug als **Flying Testbed** für Triebwerke und Kryo-System eingesetzt.
Im eigentlichen Demonstrator-Programm soll dann nachgewiesen werden, daß der Betrieb eines Kryo-Flugzeuges unter realistischen Einsatzbedingungen routinemäßig und mit hoher Zuverlässigkeit erfolgen kann. Dazu gehört z. B. die vollautomatische Betankung innerhalb gewohnter Abfertigungszeit.
Für das Demonstrator-Programm ist eine modifizierte A 310 vorgesehen, deren Triebwerk und Kryo-System (bis auf die Tanklänge) identisch mit dem späteren Serienflugzeug sind.
Die gegenwärtige Planung geht von einem Erstflug des Demonstrators etwa um das Jahr 2000 aus.

Wesentliche Daten:

Typ:	A 310 modifiziert
Triebwerke:	2 x P&W LH_2-Version 4000er Serie
Kapazität:	243 Sitze (All-Tourist-Bestuhlung)
Kraftstoffmasse:	6050 kg (Flüssig-Wasserstoff)
Reichweite:	1000 nm (500 nm Radius)
Abflugmasse:	116 000 kg







International Alternative Aviation Fuel Experiences—CANADA

Russ Robinson
Environment Canada
Hull, PQ
CANADA

Alternative transportation fuels (ATFs) have been used for many years in Canada. The National Energy Program (NEP) of 1980, which was developed to address the energy crisis of the late 1970's, then was the main driver for ATFs in Canada. The fundamental concept behind the NEP was the search for energy diversity and energy substitution, leading ultimately to energy self-sufficiency.

One of the first actions under the NEP was the introduction of a Propane Vehicle Grant Program under which a taxable grant of $400 was offered for any vehicle converted to propane. Between 1980 and 1985 approximately 67,000 vehicle conversions were funded under the Program.

The Propane Program was then complemented by a Natural Gas Vehicle Grant Program under which a $500 taxable grant was offered for any vehicle converted to natural gas. As there was no complementing refueling infrastructure for natural gas for vehicles (unlike propane which had more than 5,000 propane vehicle refueling stations in Canada) a grant program of up to $50,000 per station was offered to support the development of commercial (public) natural gas refueling stations. Later, a grant program was also developed to support home refueling of natural gas vehicles using the small refueling appliance. Approximately 35,000 to 40,000 vehicles were converted to natural gas as a result of these support initiatives.

The NEP also resulted in work on methanol and ethanol fuel vehicle applications. Research and development was undertaken for the use of methanol in large engines in urban buses and trucks and a number of demonstration or field trials were implemented in various Canadian cities. Alcohol fuels were also researched in light-duty vehicle applications through the flexible fuel vehicle technology which allows a vehicle to operate on gasoline or an alcohol or any mixture of the two fuels. Again field trials of vehicle technologies formed a part of the work.

Additionally, fundamental research was also carried out in the areas of electric vehicles, hydrogen, fuel cells, etc.

If we review the ATF market situation in Canada toady - in 1997 - for an optimist the market is stable. To a pessimist the market is stagnant or dying. The number of propane vehicles on the road is estimated at 85,000 and has remained at this level for a number of years. Currently, the actual number of natural gas powered vehicles in operation is approximately 15,000 to 20,000 and the annual conversion rate of approximately 3,000 to 3,500 vehicles per year has been constant for many years. The methanol fuelled large engine demonstration projects have all ended without continuation or expansion of the fuel use and the light-duty flexible fuel methanol and ethanol programs have not resulted in any significant use of these fuels.

The one bright spot in the use of ATFs in Canada has been the market success of the low-level ethanol gasoline blends. New ethanol plants are being built, and in one location nearing completion, specifically to supply the fuel market. More commercial retail outlets for the ethanol blended fuels are appearing every day and some of the major oil companies are entering the blends market.

The reason for presenting this information on the on-road use of alternative fuels in Canada is simply that any serious consideration of the use of alternative fuels in aviation should take into account the successes, and failures, of alternative fuels in other transportation modes. It is important to understand the true consumer perspective on fuels, fuel use, and fuel switching; what drives a change or what factors work directly against consumer change.

In the early 1980s there was a clearly defined "crisis" - the Energy Crisis and the public was genuinely concerned about the future. A future that was based upon predictions of only 5 to 10 years worth of conventional petroleum supplies. There was an urgent need to conserve what oil was left and to find substitutes quickly. In the 1990s the public's concern for future oil supplies had disappeared and to some extent had replaced by a concern for the environment. The energy situation now can be described as one in which we have so much conventional hydrocarbon energy that the burning of this hydrocarbon based fuel is the main environmental issue today, Global Warming.

In Canada today it can be suggested that the typical consumer view is that there is no crisis to be addressed - no crisis to drive change. Canada is still energy self-sufficient, national ambient air quality is actually improving (although pollution hot spots are still evident in major urban areas), fuel prices are stable or even falling, and the future looks good. So why change the status quo?

In the field of aviation there is even less reason for the average pilot to question any serious need for change. However, there are still two potential drivers for change within the aviation sector which cannot be dismissed.

The first is that aviation gasoline is the only remaining commercially available fuel containing lead antiknock additives. It is inevitable that action must someday be taken to remove the lead from this fuel. Current studies have indicated that it is difficult, if not impossible, to achieve adequate octane levels for aviation use with gasolines containing only hydrocarbon blends (i.e., without the use of heavy metal antiknock additives). Also, these studies have indicated a potential significant increase in the cost of any high-octane straight hydrocarbon replacement fuel.

The second issue on the horizon that could affect the fuels used in the aviation world relates to the international negotiations to address the threat of climate change. It has been suggested by many experts that serious actions will have to be taken if we are ever to achieve the goal of stabilization of carbon dioxide emissions. As in the days of the energy crisis when there were suggestions that fuel rationing might be used to address the energy issue, it could also be suggested that the strict control and possible restriction on fuel use might one day have to be considered in order to address the climate change issue. Certain recreational activities, such as sport aviation, are always easy targets for proposed restrictions in this area.

These two issues combined could result in a very positive outlook for the use of ethanol, a high-octane, bio renewable fuel, in both recreational and commercial aviation. I believe that it is important for people involved in the aviation field to keep a close watch on these two issues as they unfold, as they just may be the next clear drivers for change. These issues could push forward the necessity of fuel diversity in aviation and highlight the importance of this Conference and indeed the importance and foresight of Baylor University and Dr. Shauck in researching the use of alternative fuels in aviation.

Thank you.

International Alternative Aviation Fuel Experiences—UNITED KINGDOM
Alternatives to Jet A1 Aviation Fuel
Proposal for Research Collaboration

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UNITED KINGDOM

BACKGROUND

"Fifteen Percent Reduction From 1990 Levels By the Year 2010." This is the EU's target for greenhouse emissions and the main reason for the search for alternative energy sources.

With transport accounting for 27% of the EU's total energy use, alternative energy sources for road transport have long been documented and research established. One area not considered, however, is that of aviation fuels. This is an area of increasing concern as pollutants are emitted at a high level in the atmosphere where damage is greater than at ground level.

A recent EU report notes that the increase in emission forecasts are predicted to be the highest in the transport sector. The introduction of liquid biofuels therefore is thought to be an ideal way of reducing missions.

AIMS & OBJECTIVES

This project aims to outline the benefits of using liquid biofuels (i.e., methanol, biodiesel, ethanol) in place of Jet A1 fuel in aero engines to reduce the emission of greenhouse gases at altitude.

By consideration and assessment of the potential for liquid biofuels in aero engines, a real alternative to fossil fuels may be identified.

The objectives of the research will be sixfold:

- to undertake primary research into the use of liquid biofuels in aviation
- to assess the suitability of liquid biofuels for the gas turbine, noting the metallurgical and physical requirements of the engine
- to analyze the emission standards of liquid biofuels compared to that already documented for Jet A1. Initial feedback suggests that nitrous oxides would be reduced only

marginally, but that carbon dioxide emissions, which will exist in a closed-loop cycle, will be largely removed.

- to assess the practical implications of liquid biofuels production, in particular land allocation and the area required to sustain production

- the economies associated with the use of liquid biofuels. The effect of changes in EU policy, that is implementation of carbon taxes, should also be taken into account.

- to establish a standard for biofuels, taking into consideration the repeatability of the mix, fuel regulations, and availability of the raw materials

In particular, the research will undertake to develop the work of Beare Aviation Consulting, USA, which noted the following points of concern:

- viscosity of the blends
- density (specific gravity)
- total acid number (stability)

THE WAY FORWARD

The way forward for the project is to establish links with interested organizations with a view to submitting a proposal to the EU for funding. Due to the nature of the research, project partners are sought from research organizations, airline companies, and a farming cooperative that is able to supply the raw material for test. Initial reactions from Turbomeca in France, Rolls-Royce in the UK, and Loughborough University and Aston University in the UK have been positive, and all are keen to participate in the project.

Beacon Energy
Loughborough

Sunday, November 9,1997

FULL TEXT OF A PRESENTATION TO HAVE BEEN GIVEN BY PROFESSOR TONY MARMONT AT WACO TEXAS OF FRIDAY, NOVEMBER 7, 1997, BUT ACTUALLY PRESENTED IN SHORT FORM

BACKGROUND

Having spent 50 years in the manufacture of soft drinks where I created a vertically integrated production by high-tech robotic manufacturing lines in which we manufactured all our own raw materials, syrups, caps, bottles etc., this company acquired a 20% share of the UK market for soft drinks.

I then became involved in the production of our major raw material PET, a specialized polyester, to manufacture the bottles from. After this I sold this manufacturing facility to Shell Chemicals, a part of the Royal Dutch Shell Company, retiring from this operation in 1996. I also bought a wind turbine manufacturing company here in Texas which proved to be ahead of market demand (which is now just maturing). However I did construct and operate a 8-MW wind farm at Great Orton airfield at Carlisle UK; this has worked well and produced some 4.5 million kW per year (since opening in 1991). Also erected were other 300-kW machines throughout the world, including three operated by Texas Utilities here at Dallas Fort Worth Airport and another three at Amarillo operated by South West Public Services. I sold that company in 1995 and was able to concentrate my attention of the World Crisis of Global Warming through Greenhouse Gas Emissions (CHG).

EFFECT

My own home by this time was operating on Renewable Energy (RE) with two of our own manufactured 25-kW wind Turbines, 6 kW of Photovoltaic Panels (PV), 15 kW of CHP, a 14-kW heat pump, and our own water collection system from the roof (1/2 inch of rain yielding some 1000 Gallons). This is fed through sand filters and Reverse Osmosis plant to produce 100% pure water. In addition we run two electric cars, one a two door which is 5 years old running on lead acid batteries and a more recent one just 1 year old running on Nickel Metal Hydride batteries. My home is supported with a 200-kW lead acid storage battery set. We are now a net exporter to the grid selling come $7,000 worth of electricity annually, which represents 85% of the production, Beacon Energy offices are similarly operated.

I have been an instrument-rated pilot for some 40 years, flying multiengine turbo prop aircraft and also *multiengine* helicopters. I now run a twin Squirrel Eurocopter (A Star) from home.

Through this activity I first became aware of pollution problems in the 60s and 70s when I was able to see the build up of heavy red brown industrial haze emanating from major cities, which was only really visible when flying through it horizontally and also the color and quantity of snow on the Alps which I used to regularly fly over. So this is what prompted me to make my own home (and office) self supporting in major utilities.

Through my training, when I joined Shell, I noticed that the North Sea oil fields were in general down the banks of the prehistoric big river emanating from Hamburg and flowing into the Atlantic around the North of Scotland. This prompted the thought in me that since all the benefits we derive from oil are in the first place from Biomas then logically we should be able to extract all the chemicals, fuels, plastics, and the multitude of other things we have taken for granted in the 120-year existence of our oil using society.

Now I have instigated research into the production of PET from the Willow Tree (Salix Babylonica) and more recently from the green matter tops of presently wasted material of the potato plant and sugar beet. This was prompted by some work here in the USA at the University of Arizona of PET production from a dessert plant seed called "popweed" (Lesquerella Palmeri) which was polymerized (mixed) with Sebaic Acid produced from Castor Oil.

So I began the trail for producing Jet Al fuel Paraffin/Kerosene from Biomas, which is why I am here at your conference.

Coincidentally the president of my former employer SHELL, a Mr. Cor Hoerkstroetter, gave a policy speech in Amsterdam in April this year in which he forecast that by 2050, 50% of Shell's revenue would come from RE, and that by 2080, 80% would be derived from RE. To back this up, in May this year Shell made a major investment in the maturing market of PV's for electricity production. Also John Browne the Chairman of BP, announced a further major investment into the RE market. The mighty are moving!

Last month, the World Shipping Association met and announced that they were the cause of 5% of the world GHG. We know aviation is responsible for 3%, but at the worst place, at a high level in the atmosphere.

Unusually, there are now four unique MSC courses in RE at three Midland UK Universities. Leicester De Montfort with research into RE in the home and RE in domestic transportation; Loughborough University, in RE production and Energy Storage; Nottingham University, in RE in Architecture; and over the last three years some 100 graduates have gone out into industry to "seed corn" RE into the "corridors of power."

When I visited Moscow State Technical University in 1994 (they have some 250,000 students in 10 campuses around the city), I had the privilege to be given a guided tour of Star City, (MSTU does all the orbital and trajectory calculations for the Russian Space program). While there I met Cosmanought Commander Victor Anastafyev, who told me he was training for a Manned Mission to Mars to take place in 1998. MSTU was also doing the work for the indigenous food production for the 4-year journey. I wonder if that is still on target? But the thought of a 4-year journey made me think of the way they would have to manage their resources for food, water, and air and the way we don't manage our "Space Ship Earth" for these same things!

I now present some statistics for the UK Aviation Industry which were based on information from the General Aviation Manufacturers and Traders Association; these have not been cross checked as I only had a few days before coming to work on this presentation.

page 1 and 2 of Statistics

At MRETT, a sister organization (Midlands Renewable Energy Technology Transfer) they have started to work on partners for EU Community funding for a research program as follows:

Page 1 of "research program"

Significantly there has been a lead article in the Flight International Magazine prompting the Aviation Industry to "clean up it's act before they are forced to," and this was prompted by a 40% increase in landing charges at Zurich Airport based on the CRG emission characteristics of aircraft landing there.

Last week I was a guest at Turbomeca, at Bordes near Pau, South Western France, a pioneering gas turbine manufacturer. I was trying to obtain their support for the research program. Their stance was that they had already recognized the problem and had done some significant research into alternative fuels for aviation.

5 pages of Turbomeca data.

They did say that any research program from their point of view would start with land- and marine-based gas turbines, where safety was not a critical issue with regard to tests and regulatory issues. Since returning home to the UK from Waco they have now confirmed support for a biomas fuel program.

A recent committee on the problem of alternative fuel, that they were involved in, came up with the conclusion that "The Best Fuel was Fuel!" Unfortunately we cannot accept that as the pollution problem or the shortage of supply problem will hit us sooner!

I am hopeful for Turbomeca, Rolls Royce, EU funding, and University specialist departments support.

IF WE TRY TO FIX THE PROBLEM—WE MIGHT!—IF WE DON'T DO ANYTHING THEN THE PROBLEM WILL NOT SOLVE ITSELF—IT'S UP TO US!

U.K. Statistics: Source: General Aviation Manufacturers

C.A.A. Register 1996

fixed wing	under 2730 kg	7453
	2731 to 5700 kg	354
	5701 to 13610 kg	230
	over 13610 kg	636
Seaplanes		3
Amphibians		15
Motor Gliders		238
Helicopters		838
Gyrocopters		257
Microlights		3162
Gliders		8
Airships		
	Gas	8
	Hot Air	35
Balloons		
	Gas	3
	Hot Air	1648
Total (Add 100 not on UK Register)		15,159

COMMERCIAL FLIGHTS PER ANNUM, UK AIRSPACE = 1.8 MIL SOURCE: CAA 1997

UK Airports Air Transport Movements (Landing/Takeoff)
UK Operators

Scheduled	578,000
Nonscheduled	259,000
Total	838,000

UK Airlines Annual Kilometers Flown		541,000,000
Aircraft Hours Flown		
	Small Airlines	130,426
	Other	1,936,566

Increase 1993-1997 Estimated at 20%

TONNAGE OF UK AIRCRAFT

Airliners	550 @ 100,000 kg =	55,000 tonnes @ 5 tonnes per hour
Business Turbo	300 @ 10,000 kg =	3000 tonnes @ 600 liters per hour
Business Piston	400 @ 4000 kg =	1600 tonnes @ 100 liters per hour
Light Piston	7500 @ 1200 kg =	9000 tonnes @ 25 liters per hour
Helicopters	850 @ 1500 kg =	1275 tonnes @ 200 liters per hour
Total		69,875 tonnes

HOURS FLOWN BY UK AIRCRAFT

Airliners	1,800,000 hrs =	9,000,000 tonnes fuel per annum.
Business Turbo	200,000 hrs =	140,000 tonnes fuel per annum.
Business Piston	100,000 hrs =	10,000 tonnes fuel per annum.
Light Piston	750,000 hrs =	18,759 tonnes fuel per annum.
Helicopters	210,000 hrs =	42,000 tonnes fuel per annum.
Total	2,065,000 hrs =	**9,210,000 tonnes fuel**

AIRCRAFT FUEL CONSUMPTION PER AIRCRAFT TONNE PER FLYING HOUR

Large Airliners	B747 @ 370 Tonnes =	0.036 tonnes fuel/hour
	B767 @ 200 Tonnes =	0.025 tonnes fuel/hour
	B757 @ 104 Tonnes =	0.05 tonnes fuel/hour
	B737 @ 56 Tonnes =	0.046 tonnes fuel/hour
Business Turbo	@ 10 Tonnes =	0.014 tonnes fuel/hour
Business Piston	@ 4 Tonnes =	0.025 tonnes fuel/hour
Light Piston	@ 1.2 Tonnes =	0.021 tonnes fuel/hour
Helicopters	@ 1.5 Tonnes=	0.25 tonnes fuel/hour

Average all aircraft consume 0.03 tonnes per hour per tonne of aircraft

POLLUTION DUE TO HELICOPTERS

Service Aérothermodynamique **TURBOMECA**

- Aeronautics burns only 3 % of total world oil and produces only about 1 % of CO, HC and NOx emissions and about 2 % of anthropogenic CO_2 emissions.

- Emissions due to helicopters only are extremely low comparatively with other sources : for example,in France, 70 to 80 % of CO and NOx emissions are due to road transport and only 0.06 % of NOx and CO and 0.01 % of unburnt hydrocarbons are emitted by helicopters.

		Total Emissions	Road Transport	Foreign Trucks Transport Only	Helicopters
Tons of pollutants emitted per year in France	NOx	1507	1088	25	1
	CO	7338	6400	4	5
	HC			3	0.3

- Helicopters are not involved in high altitude pollution problem between upper troposphere and lower stratosphere but only in "ground" pollution as cars and trucks

POLLUTION LEVEL OF HELICOPTERS ENGINES

Service Aérothermodynamique **TURBOMECA**

- Combustion of modern turboshaft is very "clean" and produces extremely low level of HC and CO with a 70 % reduction during the last 20 years.
- SOx emission is only due to the sulphur content of the fuel, very low for kerosine (0.05 %).
- NOx level is comparable with car engine level and was only reduced by 10 % during the last 20 years because combustion improvements were balanced by thermodynamic cycle evolution.
- CO_2 level remains higher than car engine level but the thermodynamic cycle evolution during the last 20 years has already induced a 20 % reduction.

Example :

Mass of pollutant emitted by passenger between Brussels and Geneva

Pollutant (kg)	Car (1)	Car With Catalysed Exhaust (1)	Helicopter (2)
CO	6.5	1.2	0.5
HC	0.5	0.12	0.01
NOx	1.2	0.3	0.6
CO_2	105	105	300

(1) Car : from french Air Quality Agency

(2) EC 135 with Arrius engines

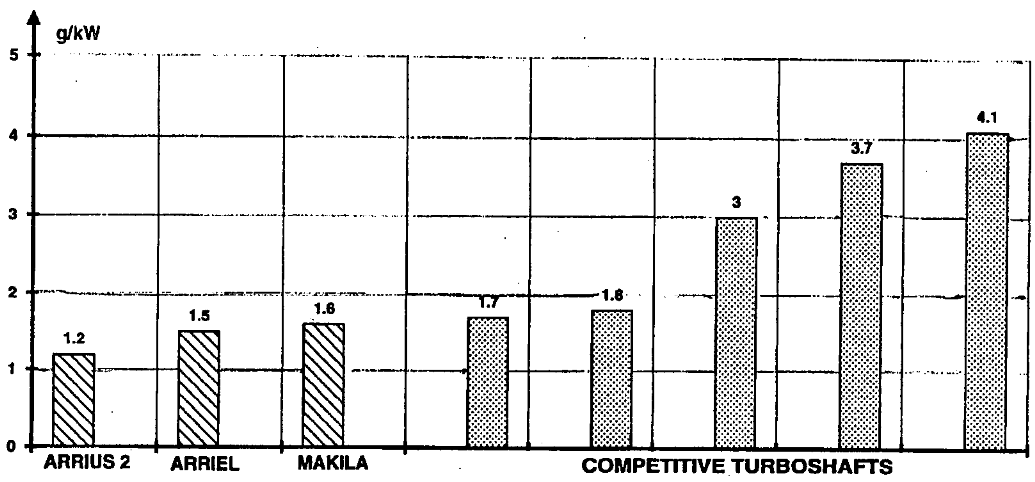
9/30/10/1997

POLLUTION LEVEL OF TURBOMECA TURBOSHAFTS

Service Aérothermodynamique **TURBOMECA**

Exhaust pollution has been a major concern of our engineers for 20 years and out new generation of engines has to-day the lowest level of pollution in the world.

Total pollution index (grams/kilowatt) during helicopter cycle : CO + HC + NOx



279/30/10/1997

LOW EMISSIONS RESEARCH PROGRAMS AT TM

Service Aérothermodynamique **TURBOMECA**

In spite of the very low impact of gas turbines on pollution at the present time, TM thinks they will have to reduce emissions (NOx and CO_2 essentially) to follow the general trend of more and more environmentally friendly engines.

So, TM is involved in several research programs with very ambitious objectives :

Turboshafts	CO_2 :	- 20 % in 2005 by reduction of specific consumption (different internal and cooperation programs)
	NOx :	- 50 % in 2005 by lean premixed prevaporised combustion (European program)
	SOx :	only dependent of international specifications on kerosine sulphur content
Industrial gas turbine	CO_2 :	- 20 % in 2000 by increase of pressure ratio or use of heat recuperator
	NOx :	- 70 % in 2000 by lean premixed prevaporised combustion
		- 85 % in 2010 by catalytic combustion (European program)
	fossil CO_2 and SOx :	- 100 % by use of biofuels

BIOFUELS

Service Aérothermodynamique TURBOMECA

- **Advantages** :
  - to save fossil fuels
  - to suppress emissions of "earth warming" CO_2
  - to reduce NOx and SOx emissions

- **Drawbacks** :
  - higher production cost (can be balanced by taxes relief)
  - physical and chemical properties not compatible with all current fuel specifications : heating value, viscosity, contaminants, ...

This last point implies very heavy qualification programs for aeronautic fuels, even for minor differences with the specifications (examples of additives certification in current jet fuels), and the associated research programs must have national or international size.

TM RESEARCH PROGRAMS ON BIOFUELS

Service Aérothermodynamique TURBOMECA

- **Alcohol** : important program realized 20 years ago on several industrial and aeronautical engines for Brazil (sugar cane ethanol)

  Main results : (only ground tests)
  - NOx reduced by 40 %
  - fuel consumption increased by 100 % (very low heating value)
  - insufficient lubricity for fuel pumps

- **Biogas** : TM is involved in a European research program on catalytic combustion of biogas for industrial gas turbines

- **Diester** : No program launched to-day but interest of several customers for industrial applications with our engines

MAIN PROPERTIES OF DIESTER FUEL

Service Aérothermodynamique **TURBOMECA**

	Jet Fuel	Diester	Conseauences	Solution
Heating value kJ/l	35 000	33 000	Small increase o fuel consumption (+ 6 %)	Adaptation of fuel control system (FCS)
Viscosity cst at 25 °C at - 30 °C Maxi acceptable	1.8 7 12	7 ?	Fuel atomisation quality drastically reduced	Adaptation of FCS flight and start enveloppes limited to t > - 5°
Cloud point °C	- 50	- 7	Fuel pumping problem filter clogging risk	
Flash point °C	43	185	Light-up difficulties	Increase of spark energy ? Flight enveloppe reduction
Flame temperature °K	2 400	probably higher	NOx increase Increase of combustor wall temperature	
Contaminants	0	Alkalys, Phosphore ?	Hot parts oxydation ?	Life reduction
Acid number Thermal stability		higher lower	pbs with FCS seals clogging risk of injectors	

+ a lot of other properties to be examined, following kerosene specification table

27V/10/10/1997

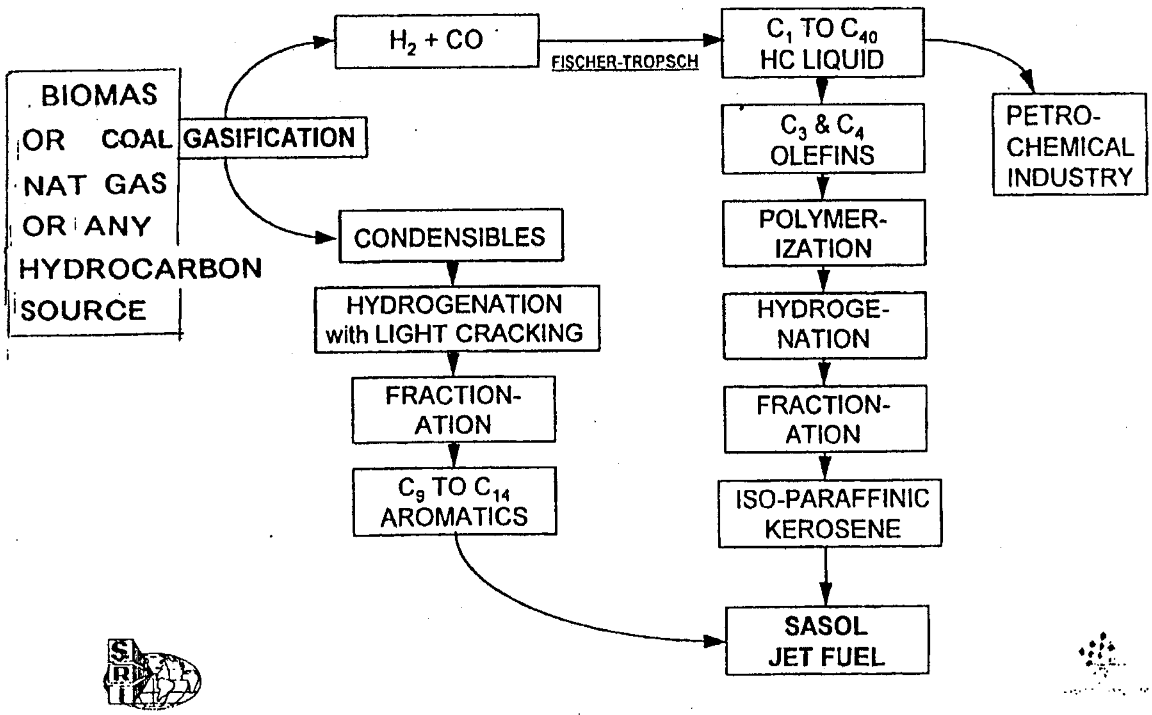
CONCLUSIONS ON ESTERS FUELS

Service Aérothermodynamique **TURBOMECA**

- No obvious alternatives at current fuel are imagined in the aeronautic world at the present time for different reasons, one of them being the very heavy and expensive certification program needed.
- Esters fuels specific properties would induce a drastic and probably unacceptable limitation of the helicopter flight envelope.
- Helicopters impact on pollution and greenhouse effect is so small that an helicopter cannot be considered as the right demonstrator of a biofuel program.

⇨
- TM prefers to develop new helicopter turboshaft with low emission combustors and reduced fuel consumption by keeping current kerosine fuel.
- TM proposes to test biofuels firstly on its industrial aeroderivative gas turbines and to demonstrate the emissions improvements and the consequences on other performances (start-up, life, ...) before imagining an eventual aeronautical use.

PRODUCTION SCHEME OF SASOL SYNTHETIC JET FUEL



CLOSING REMARKS

Bob Harris, Director
Nebraska Energy Office
1200 N. Street, 1st Floor, Suite 110
PO Box 95085
Lincoln, NE 68509-5085

Thank you Max. Over the years I have become a firm believer in alcohol. I used to drill for oil, but over the years have slowly become converted to ethanol. It is very appropriate that we are down here at Baylor University with Max and Grazia because when you are dealing with these types of renewable resources and you have closing remarks for an unbelievable conference like this it ought to be like a closing prayer; Max, to deal with renewables you have to have faith, but to deal with renewables in aviation that's superfaith! It takes somebody like you two to bind all the rest of us together to keep this concept rolling. And it does take a lot of work to get this thing rolling because we've heard the definition of a pioneer. A pioneer has a lot of holes in it from all the arrows; well were getting a lot of arrows shot into us, from verbally and emotionally and all the other ways they're coming at us. Two years ago if I would have said that there would be 500,000 vehicles, flex fuel E-85's, on the road when I did the wrap up remarks at the conference, people would have said I was crazy; I wouldn't have believed it myself. Ford and Chrysler, because of many different circumstances, came out this year and announced there would be 500,000 by the year 1999, and I think by the year 2001, General Motors will make another announcement, and we will have 1,000,000 flex-fuel vehicles on the line.

Now how does that come about? It is the way things work that I bring this up, because different things make up the aviation industry might make it turn to renewable fuels for aviation. Sport utility vehicles, who ever dreamed that the American public would go back to buying gas guzzlers? Well it couldn't meet the Kafay credits, the Kafay standards, the Big Three. So what they had to do was go out and start making Kafay credits, and it was an economic decision that was created by the EPAC, the energy policy act, to get these Kafay credits. So it was a bizarre turn of events that two years ago we would not have even thought about it. So now we have 500,000 to 1,000,000 vehicles on the line that will be out there by 2001, and the same thing will probably happen with aviation fuels because of environmental reasons. Our challenge now is to do the refueling sites. We've only 38 refueling sites. We met with the Big 3 to raise about 12-13 million of dollars to put in hundreds of refueling sites. Since we did have the chicken, now we have to come up with the egg—we have to come up with these refueling sites. Soon in California you are going to see the methanol stations out there are going to be converted to ethanol; the LA bus system that was methanol has been converted to ethanol. They got a hold of us on that situation. Another thing that you wouldn't have thought about are the tax credits that Bill [Holmberg] talked about was the archers' attack last February; the ways and means committee was going to attack ethanol and take away our tax credits. We had a lot of momentum going but for a few months there and it looked pretty scary. Well who would have believed that within 3 months the senate would have over 60% of the senators vote for a 7-year extension of the ethanol tax credits. Now we have a lot of work to do in the house, but it's unbelievable how far we've come. We even have it in the highway bill, and that is going to be able to get those 7 years. Now if these archers hadn't brought this up, we never would have got this going. The point is this happening, why are we getting this force behind us? The ethanol industry has started getting a lot of media attention and publicity. Max flying around the country in his plane, people are fascinated by that.

Now with all the different projects that are going on all over the country, a lot of these things that are going on are not just because of raw politics, but are because we are going around the country doing our things, and we have some strange bedfellows, i.e., Saddam Hussein. A lot of projects have failed, but we have learned a lot from them. The 60-day reserve costs about 200 million dollars a year to keep up, and now it is being reduced to a 40-day reserve. Why not establish a long-term solution for the strategic petroleum reserve? Why not work out credits for renewable and domestic reserves of petroleum and gas that would work out the long-term supply problem? This can be done, and I think some of these ideas will take hold down the trail. Some of our other strategies might have been too aggressive, but the good news about something like this is that it doesn't cost any money until it becomes a problem. On the international scene, I would like to challenge and add to what Bill Holmberg was talking about on an international coalition except that I want to expand it. An international Biofuels coalition; I have talked about this for a couple of years, and I think its time. I said biofuels not ethanol because there are already biofuels that need to be included like biodiesel and that it ought to be taken to the United Nations. The United Nations deals with some of the same stuff we are trying to do—job creation, economic development in the various countries—so I think we have an ally there. And I think the things that are going on in various countries—in European countries, South Korea, India, Brazil, Puerto Rico, and lots of other locations—have all started to promote biofuels. We need to pool together our resources and get together a comprehensive proposal, and together, with the appropriate government agencies, take the international biofuels federation to the United Nations.

Believe it or not, automobile manufacturers have been meeting for the last couple of years, and I think they are going to come up with a national automotive fuel, and they are also going to come up with a three-tier international fuel system. That will be announced next year and even some of the oil companies have agreed to look at it and take it seriously. There is a nationally reformulated gasoline that is going to happen down the trail in this country and that has to do possibly with international aviation fuel. There certainly will be changes in the aviation industry. It was a very wonderful conference; Max and Grazia deserve a round of applause.

SPEAKER INFORMATION

Second International Conference on Alternative Aviation Fuels
November 6-8, 1997
Baylor University, Waco, Texas

Chris Atkinson, ***Associate Professor, Department of Mechanical and Aerospace Engineering,*** **West Virginia University**. Dr. Atkinson's research interests include advanced engine control, emissions reduction, alternative fuel utilization, and hybrid electric vehicle development. He is co-developer of a neural network-based engine control and diagnostic and modeling technique known as virtual sensing, which offers an extremely robust, intelligent and adaptive alternative to equation-based model-based control. He has developed a high fuel efficiency, sub-ULEV emissions hybrid electric vehicle, and is currently working on a new linear alternator engine design.

In 1993, Dr. Atkinson received the Lewis F. Moody Award from the Fluids Engineering Division of the American Society of Mechanical Engineers (ASME) and in 1994 he received the Ralph K. Teetor Educational Award of the Society of Automotive Engineers.

He has been a member of the SAE Heavy Duty Engine Emissions Standards Committee and is currently a member of The American Society of Mechanical Engineers (ASME), the Society of Automotive Engineers (SAE), and the American Society of Engineering Education.

Dr. Atkinson holds the degree of B.Sc. in Chemical Engineering from the University of Natal, South Africa, M.S. in Mechanical Engineering for West Virginia University, and received the Doctor of Science degree (Sc.D.) from the Massachusetts Institute of Technology in 1991 in Mechanical Engineering.

Ted Aulich, ***Process Chemist Energy and Environmental Research Center,*** **University of North Dakota**. Mr. Aulich is a process chemist at the University of North Dakota Energy & Environmental Research Center (BERG) in Grand Forks, where he has worked for about 10 years. His work includes analysis of gasoline and ethanol-blended automobile fuels and evaporative emissions, development and optimization of gasification and pyrolysis-based technologies for conversion of coal and organic waste to fuels and chemical feedstocks, and characterization and environmental impact assessment of natural gas processing wastes.

For about the last 18 months, Mr. Aulich has been working with staff at South Dakota State University in Brookings and Lake Area Technical School in Watertown to develop, demonstrate, and commercialize an ethanol-based fuel for piston engine aircraft. His past and ongoing involvement in the ethanol industry includes research on volatility effects of ethanol addition to gasoline and comparison of ethanol-blended to other fuels on the basis of evaporative emission reactivity.

Mr. Aulich holds B.S. degrees in chemistry and biology from the University of North Dakota and the University of St. Thomas, St. Paul Minnesota, respectively. Prior to his employment at

BERG, he worked as a quality assurance director at H.B. Fuller Industrial Coatings, Vadnais Heights, Minnesota. He is not a pilot, but he likes a good window seat.

Brent K. Bailey, *Senior Program Engineer*, Department of Energy. Mr. Bailey is Senior Program Engineer at the National Renewable Energy Laboratory (NREL) working in the Alternative Fuels Utilization Program (AFUP) for the DOE. In his current assignment, he formulates project plans and oversees research contracts with the NREL for DOE. Mr. Bailey's technical career has focused on alternative fuel research. He spent two years working in the synthetic fuels industry at the University of Utah Research Institute in Salt Lake City, Utah, developing new processing techniques and managing pilot plant operations. He worked for ten years at Southwest Research Institute in San Antonio, Texas, on a variety of applied research projects in the alternative fuels area. Mr. Bailey has a broad background in alternative fuel processing, characterization, utilization, and emissions research with over 40 technical publications in the field. This experience has been used to generate forecasts of future transportation fuel quality for a variety of government and industry sponsors.

Mr. Bailey is a member of the Society of Automotive Engineers (SAE) and holds a Master of Science degree in Fuels Engineering from the University of Utah.

Leo Burkardt, Manager, *General Aviation Propulsion Program*, National Aeronautics and Space Administration. Mr. Burkardt has been employed with NASA for 30 years. Prior to his current position he has worked as an air-breathing propulsion systems analyst, a turbine engine test engineer, and a member of the large solid rocket motor technology team that fired the largest solid rocket in history (7.5 million lbs.thrust). He has authored/co-authored 12 technical papers. Mr. Burkardt holds a BSME from the University of Dayton.

Jacques Callies, *Owner*, Aviation & Pilot Magazine. Born in Toulon (France) on 12/02/51; his father Xavier was a former French Naval Officer and engineer—4 children in the family.

He discovered aviation in 1973, wrote his first story to Aviation & Pilote in 1975 (a ferry flight from USA to France in a Piper), joined the magazine staff the same year and became chairman of the publishing company in 1982. He cosponsored Max Shauck's demo flights at the Paris Airshow in 1993 and 1995.

He holds degrees in French Literature (DEUG, University of Paris XII) and Paris Chamber of Commerce Business School. He received his IFR qualification in 1988 and has logged over 2000 hours of flying time. He regularly flies the magazine's Piper Seneca II aircraft for business and smaller ones for pleasure. He is married to Catherine Le Goff, with two daughters aged 17 and 12. He likes skiing, fishing, sailing, flying, driving cars and bikes, smoking Havana cigars, drinking burgundy wines, etc.

Jeremy L. Cornish, International Centre for Aviation and the Environment. For over 35 years, Jeremy Cornish has worked in international civil aviation in managerial positions involved with passenger and cargo services, ramp operations planning, and operations control. As IATA Manager, Airport Handling Services, Mr. Cornish held for 10 years overall responsibility for airport handling activities and services worldwide, including its development and long-term planning. Additional areas of responsibility were Secretary of the IATA Operations Control Committee, the AACC/IATA Worldwide Ramp, Safety Campaign, and the IATA Live Animal Board. These activities included the ongoing development of several important international aviation industry publications. In this position, regular contact was required with senior management of airlines, airports, manufacturers, and civil aviation authorities.

As IATA Manager Facilitation, his direct responsibility encompassed passengers and cargo with the main objective to simplify procedures and formalities at airports, thereby improving airline and airport efficiency. This function demanded a high level of worldwide travel interfacing at senior government level, such as the International Civil Aviation Organization (ICAO), the World Customs Organization (NCO), the Council of Europe, Immigration Authorities, airport and airline officials.

Mr. Cornish recently spent a term as a visiting expert at Transport Canada's Transportation Development Centre on a comprehensive project to identify and assess environmental problems associated with the international aviation industry and develop an effective strategy to aid their solution, with the involvement of the international aviation community and providers of facilities and services, as well as, identifying areas of aviation environmental research and development of their priorities.

In March 1997 the International Center for Aviation and the Environment was founded as a non-profit corporation under the Federal Corporations Act. ICAE is an independent and neutral institution that coordinates and promotes research and development on global environmental issues and problems, and acts as a clearinghouse for the exchange of information between interested parties at national and international levels. As such, its main purpose is to create a synergetic relationship between governments, airports, airlines, providers of aviation products and services, as well as academia, on all matters pertaining to aviation and the environment.

William H. Cruickshank, *Manager Biochemical Conversion*, Bioenergy Development Program, Natural Resources Canada. Mr. Cruickshank received his B.Sc. in Honours Chemistry from the University of Waterloo in 1966 and his Ph.D. in Biochemistry in 1969 from the same institution. He has held many Post Doctoral Positions including those with Imperial Chemical Industries, National Research Council of Canada, and the Medical Research Council of Canada (Post-Doctoral Fellow).

From 1975-1981, Mr. Cruickshank was a Senior Scientist in the Blood Coagulation Research Laboratory with the Canadian Red Cross Blood Transfusion Service in Ottawa. He was the R&D Contract Manager with Public Works and Government Services, Canada from 1981 until he moved to his current position in 1992.

Jim Davis, U.S. Environmental Protection Agency Region VI. James is currently working as an Environmental Engineer in the Air Planning Section of the Environmental Protection Agency's (EPA) Region VI Office in Dallas. He has worked primarily in vehicle emission control programs for the past 12 years since graduating with a degree in Mechanical Engineering from the University of Wisconsin. For the past five years he has worked in overseeing State-implemented mobile source emission control programs including the vehicle inspection and maintenance programs and vehicle fuels programs. Prior to coming to the EPA Region VI Office, he worked in vehicle compliance programs in EPA's Office of Mobile Sources. He also serves as EPA's representative to the Dallas/Fort Worth Air Quality Advisory Committee.

Bruce Fenton, Program Manager, Propulsion and Fuels Safety Research, Engineering, and Development, Federal Aviation Administration. Mr. Fenton Holds a B.S. in Mechanical Engineering. He spent 12 years as a project engineer at the Naval Air Propulsion Center in Trenton, NJ, where he was responsible for turbine engine development, testing, and evaluation. He has spent 17 years as a project manager/program manager at the FAA William J. Hughes Technical Center at the Atlantic City International Airport, NJ, where he has been responsible for research, engineering, and development of

(1) antimisting additives for Jet A fuel
(2) turbine engine rotor system failure hazards mitigation
(3) turbine rotor integrity design methodologies.

Gus Ferrara, *President*, Gus Ferrara and Associates, Inc. Mr. Ferrara was previously Chairman of the local AIAA Chapter, Chairman of the CRC Committee on the Development of a High-Octane Unleaded Aviation Gasoline, and Chairman of AIAA General Aviation Systems Technical Committee. He flew the first aircraft operated on MTBE and worked with the Alternate Fuels Program which develops standards for the use of alternate fuels in aircraft. Mr. Ferrara has also been involved with the Aging Aircraft Program and the Unleaded AvGas Program. He received a Bachelor of Science in Mechanical Engineering from Drexel University. He currently owns a Cessna 172.

Randall Friedl, *Research Scientist*, Jet Propulsion Laboratory, National Aeronautics and Space Administration. Since coming to the Jet Propulsion Laboratory in 1984, Dr. Friedl has been conducting laboratory investigations of reactions relevant to ozone photochemistry in the Earth's atmosphere. He has developed an independent line of laboratory research that has resulted in over 25 peer-reviewed journal articles and one book chapter. For his earliest work on Antarctic ozone destruction, Dr. Friedl was awarded JPL's Allen Award for Excellence in 1990. He has also served two years as a JPL Group Supervisor, managing a group of staff scientists, postdoctoral workers, and an engineering assistant. In order to foster external research interactions, Dr. Friedl maintains memberships in the American Chemical Society, the American Geophysical Union, and Sigma Chi.

Recently, Dr. Friedl's work on atmospheric nitrogen compounds has had specific application to questions related to the atmospheric impacts of commercial aviation. As an extension of his focus on aircraft impacts, he spent the last two years at NASA Headquarters in Washington, DC, serving a Project Scientist on a NASA project designed to assess aviation's impacts. In addition he served as chairman/editor of the first NASA interim assessment of the effects of subsonic aircraft on the atmosphere. The assessment report represents a major milestone of NASA's Atmospheric Effects of Aviation Project (AEAP). For the aviation-related work, he was awarded a NASA Exceptional Service Medal in 1997.

Currently, Dr. Friedl is a Research Scientist at JPL and also the AEAP manager for laboratory studies.

Cesar Gonzalez, ***Senior Project Engineer of Advanced Design,*** **Cessna Aircraft**. Mr. Gonzalez has been employed by Cessna for 42 years, has been a member of SAE Committee AH-5 Aerospace Fuel, Oil, and Oxidizer Systems, and ASTM and CRC groups involved in current and future general aviation fuels. He has been active in the preparation of Industry Standards and Specifications for 27 years.

During the past seventeen years, he has been responsible for studies and related research activities on current general aviation piston powerplants and powerplants envisioned for development within the next twenty years.

Mr. Gonzalez received his B.S. and M.S. degrees in Mechanical Engineering from Wichita State University and has been an active pilot since 1950.

Robert A. Harris, ***Director,*** **Nebraska Energy Office**. Mr. Harris is responsible for administering state and federal energy programs and initiatives. He has been involved in many professional associations such as the National Association of State Energy Officials, Western Interstate Energy Board, Governors' Ethanol Coalition, National Ethanol Vehicle Coalition, Federal Fleet Conversion Task Force, and the U.S. Department of Energy - Core Stakeholders Committee. Prior to his current position, Mr. Harris served as President and Broker of Ag-Land Realty, Inc., a statewide firm specializing in farm and ranch sales and management with over 50 sales associates.

Mr. Harris earned a Bachelor of Arts Degree from the University of Nebraska and has been a licensed pilot since 1975.

Lars Hjelmberg, ***President,*** **Hjelmco Oil, Inc**. Mr. Hjelmberg founded Hjelmco Oil, Inc. in 1981. He is responsible for development and coordination of all Hjelmco Oil projects. In the past, Mr. Hjelmberg has been an advisor to the Civilian Aviation Board in Sweden. In addition, he is involved in the Aircraft Owners and Pilots Association and has invented computer software, unleaded aviation gasoline, and aviation refueling equipment. He received his MBA from the University of Umea (Sweden) in 1972.

Bill Holmberg, President, Sustainable New-Wealth Industries. Mr. Holmberg has been involved in biofuels since 1976 when he served as Operations Division Director, Office of Pesticide Programs, U.S. EPA. In 1978, he moved to the U.S. DOE and established the Office of Alcohol Fuels. He left the government in 1983 as a member of the Senior Executive Service and has remained involved in biofuels and sustainable agriculture.

Since 1983, he has worked in the private sector, promoting biofuels in a variety of ways, from assisting in the design of the component parts of an integrated ethanol/aquaculture/feedlot operation to lobbying on behalf of biofuels. He was a major contributor to the IRI study contracted by the National Soy Fuels Advisory Committee and worked with the Administration and Congress to include biodiesel in the Administration's Presidential Biofuels Initiative. Mr. Holmberg has also assisted in establishing the national Gasohol Commission, the Renewable Fuels Association, the Clean Fuels Development Coalition, Safer Air through Fuel Enhancement, Reformulation and Reforestation, and the American Biofuels Association.

Bill Jordan, ***Environmental Quality Specialist,*** **Texas Natural Resource Conservation Commission**. Bill Jordan works with the Air Quality Planning and Assessment Division in the Mobile Source Section of the TNRCC. He has been with the agency for 4 years.
Mr. Jordan has a B.A. and M.S. in Biology from University of Texas at Austin and University of Texas at Arlington, respectively.

Kenneth Knopp, ***Aerospace Engineer,*** **Federal Aviation Administration**. Mr. Knopp has been involved in research and development of different aviation fuels for the past five yeas. As an aerospace engineer, his responsibilities include arranging fuel tests, which entail procedures necessary to evaluate engine durability, emissions, and safety performance. These tests also are designed to evaluate propulsion and crashworthiness. His work has primarily focused on unleaded aviation fuels.

Mr. Knopp holds a B.S. degree in Aerospace Engineering from Wichita State University, KS. He is also a certified commercial pilot.

Denver Lopp, ***Professor,*** **Purdue University**. Professor Lopp teaches heavy transport curriculum, aircraft inspection, and aviation administration courses. Professor Lopp is also involved in aviation maintenance human factors initiatives. His background is in airline maintenance. Lopp has a B.S. in Industrial Supervision and an M.S. in Industrial Education.

Paul B. MacCready, ***Chairman,*** **AeroVironment, Inc**. Dr. MacCready, with an academic background in physics and aeronautics, has become a meteorologist, inventor, world champion glider pilot, and explorer of new horizons in conserving energy and the environment and in teaching thinking skills.

In 1977, his Gossamer Condor won the $95,000 award offered by British industrialist Henry Keener for the first sustained, controlled human-powered flight. Two years later, its successor, the Gossamer Albatross, won aviation's largest prize, the $213,000 Kremer Award for a human-powered flight from England to France. Subsequently, he has led teams at AeroVironment Inc. that have created many additional pioneering vehicles. In 1981, his DuPont-sponsored Solar Challenger carried a pilot 163 miles from Paris to England at 11,000 feet, powered solely by sunbeams.

Dr. MacCready founded AeroVironment Inc., a company providing air quality and hazardous waste services and consulting, development of alternative energy sources, design and manufacture of products for atmospheric monitoring, and creation of efficient vehicles for land, sea, and air. He is on the Board of Directors of two public companies, National Education Corporation and the MacNeal-Schwendler Company.

He received a Bachelor of Science in physics from Yale in 1947, a Master of Science in physics from Caltech in 1948, and a Ph.D. in aeronautics from Caltech in 1952.

Gary Marchbanks, ***Manager of Government Accounts,*** **OG+E Electric Services**. Mr. Marchbanks has been employed at OG+E for 24 years in various engineering and management positions. He received his bachelors degree in engineering from Oklahoma State University and is currently taking graduate courses at George Washington University. He is a member of IEEE, AEE, and is a member of the DOD-EEL partners. He is also active in Rotary, Leadership Oklahoma, and Vo-tech advisory board.

Tony Marmont, Beacon Energy, Ltd. With an interest in alternative energy sources which stems from the oil crisis of 1976, Anthony Marmont has gradually increased his involvement with renewable energy into a thriving concern which includes a number of ambitious projects. Within his Leicestershire home, the viability of many applications have been proved on a local scale. These include the generation of the Marmont's own electricity needs from photovoltaic panels and two 25-kW wind turbines, and sells excess electricity to the grid. The Marmonts are also owners of an electric car which is rechargeable from photovoltaics on the roof.

In 1992, Tony was awarded the title of visiting professor from De Montfort University. After this, he became involved in a number of university initiatives. This included the donation of funds to establish two centres, AMSET and CREST, for the advancement of research into renewable energy technologies. AMSET, the Anthony Marmont Sustainable Energy Technology Centre, was established at De Montfort University in 1993 to provide a stimulating environment for research and challenge the conventions of traditional energy production. CREST, the Centre for Renewable Energy Systems Technology, was also established in 1993 but based at Loughborough University. A number of experimental facilities and research programmes are currently running and the centre has been teaching a successful Masters course in Renewable Energy Systems Technology since 1994.

Beacon Energy is the company run by Tony and provides an advisory service to commercial and domestic users of renewable energy systems.

Zoher Meratla, P. Eng., *President,* CDS Research, Ltd. Dr. Meratla received his engineering degrees in England and started his career with flickers Engineering where he worked on the European fusion machine. For the past twenty years, he has headed the engineering of major LNG export facilities, peakshave plants, and development work for LNG equipment, including submerged cryogenic pumps. He has also had extensive experience on upgrading existing LNG process and storage facilities.

For the past ten years, he headed a specialist team for the design of a variety of cryofueling projects including LNG and LH_2 fueling for surface and air transportation, detail design and testing program for LH_2 surface transport modules, large-scale LH_2 transport by air, LH_2 production facilities, LNG peakshave and satellite projects, LNG spill vapor dispersion and fire analysis modeling, and software for computing the state conditions of a cryofuel under normal and abnormal operating conditions.

He is a member of the Aerospace Industry Association of Canada; the Canadian Standard GSA Z276 and NFPA 59A for LNG Production, Storage, and Handling; and is a specialist member of ISO Working Group 4 for the LH_2 fueling of aircraft.

Michael (Mike) Morrison, *Mayor,* City of Waco. Mike Morrison was sworn in as Mayor of the City of Waco on May 7, 1996. His term expires on May 2, 1998. Before being elected

Mayor he served two years as District III City Council member and more than 15 years in a variety of leadership positions in the community.

A graduate of Oklahoma State University Law School, Mayor Morrison joined Baylor University in 1977 and has served as William J. Boswell Chair of Law since 1990. He is a Fellow of the American and the Texas Bar Foundations and has been actively involved in voting rights matters and litigation since 1978. He served as chair of the Waco Charter Commission in 1986 and is current chair of the Community of Cities, a regional partnership of 25 area governments.

Plinio Nastari, Ph.D., ***Economist*****, DATAGRO, Ltd**. Plinio Nastari is a consultant for biomass resources, other than wood, for the World Energy Council. He is a professor of economics at the Getulio Vargas Foundation in Sao Paulo, Brazil. In addition, he is the lead author of Working Group III, Intergovernmental Panel on Climate Change (IPCC). Since 1986, he has been a member of the technical staff of the National Energy Commission of Brazil. In 1997 Mr. Nastari was the Administrative Director and an Elected Member of the Board: The Brazilian Association of Automotive Engineers (AEA), 1997. He is also the president of DATAGRO LTDA. PUBLICOES since 1989 and of PLINIO NASTARI CONSULTORIA E PARTICIPACOES, since 1994.

Mr. Nastari received his M.Sc. and Ph.D. in Agricultural Economics from Iowa State University in 1981 and 1983 respectively. He has been a member of Phi Kappa Phi and Gamma Sigma Delta since 1981.

Ron Newberg, ***President*****, Canadian Aero Engine and Accessories**. Mr. Newberg started Canadian Aero Engine and Accessories in 1987 to overhaul and repair private and commercial engines and accessories in Ontario Canada. It is a Transport Canada approved shop. He started Canadian Manufacturing in 1992 to manufacture various engine components and Canadian Aero Petroleum Products in 1990 to work with Transport Canada to approve the use of and supply unleaded fuels in Canada for private and commercial aviation uses. He developed and approved the ENVIRODYKE for above ground petroleum bases liquid storage. He also modified and certified several high-compression 0470 and 0520 Continental powered Cessnas to use unleaded fuels including 87 AKI on the 0520 without derating. Homebuilt and flew a Pitts Special, Volmer Sportsman, Thorpe T-18, and a Smith mini plane. Participated in the first Canadian Acrobatic competition. Modified a 1959 Cessna 150 for operational and emissions testing on 100% ethanol for Environment Canada with some 140 hours of operation to date including use at -20°F on skis in Canada.

Previously, he worked for Crown Life Insurance Company for 20 years setting up group insurance contracts for life, health, dental, and pension plans. He holds a private pilot's license, multi, land and sea, with 5000 hours since 1964.

Marv Randall, ***Team Leader*****, The Vanguard Squadron.** Mr. Randall began flying in 1947 and has been flying for 20 years. He flew fighters in the USAF, SD Air National Guard, has flown airshows in Decathlon, Pitts and RV3 for 20 years. Mr. Randall has logged more than 10,000 hours in over 100 types of planes, including nine seasons with the Red Baron Pizza

Squadron in 450 Stearmans. He helped convert the Vanguard Squadron to ethanol in 1993, using Max Shauck's work as an example. Mr. Randall has flown RV type aircraft more than 1000 hours.

Russ Robinson, ***International Centre for Aviation*****, Environment Canada.** Russ Robinson has a Bachelor of Science degree from Sir George Williams University in Montreal and has worked for the Government of Canada for more than 26 years. For the past 10 years his work has focused on all aspects of the use of alternative fuels in transportation; R&D, government policy, and support programs. Russ worked 5 years for the Department of Natural Resources investigating the energy implications of alternative fuels and is now with the Department of the Environment working on the environmental implications of ATFs.

Benjamin Russ, ***Engineer and Project Manager*****, Aurora Flight Sciences Corporation.** Benjamin Russ is Lead Engineer for Aurora's Propulsion Group and Project Manager for Single-Lever Power Control, engine tests, test facilities, and other projects. Ben is an aerospace engineer responsible for the high-altitude aircraft engines and propulsion systems as well as testing in support of Aurora's projects. Ben serves as project manager in various projects, including Single-Lever Power and Full-Authority Digital Engine Control (FADEC) for turbocharged UAV and general aviation engines.

Prior to joining Aurora in 1991, Ben worked for Motor Columbus Energie-und Umwelttechnik, analyzing and designing new generation coal power plants, industrial solar energy systems, and developing computer codes for thermophysical analyses (1988-1990) and at Mepro S.A. in Mexico City on computerized manufacturing of transmission and powerplant components for the automotive industry (1989-1991). He was also member of the small research team that built the German human-powered aircraft "Velair" which set a European record in 1989. As a student, he worked on the design of robots in the German Technology Research Institute for Robotics and Automation and at Dornier Aircraft Company on the design of aircraft structures for the Do228 and Do328 turboprops and for the Airbus A320. He holds a B.S. in Aerospace Engineering, (1986) and an M.S. in Aerospace Engineering (1991) from the Technical University of Stuttgart, Germany.

John A. Russell retired last year as Director, Alternative Fuels Utilization Division, U.S. Department of Energy. Mr. Russell has over 36 years of experience and Federal and commercial R&D. After a 30-year career with Southeast Research Instate in San Antonio, Mr. Russell retired in 1990 to accept his present position with DOE. His experience with alternative fuels fleet testing dates from early Department of Defense (DOD) evaluations of unleaded gasoline in 1971-76, DOE gasohol testing 1979-84, and most recently the ongoing DOE fleet demonstration under the Alternative Motor Fuels Act of 1988. In addition, he has participated as a test pilot in general aviation flight test programs on alternative fuels and serves as advisor to FAA on the subject. A 27-year member of the Society of Automotive Engineers, Mr. Russell is the author of numerous papers and technical manuals on alternative fuels, lubricants, and emissions.

In addition, Mr. Russell owns and flies an experimental aircraft which will be converted to ethanol in the near future.

Maxwell E. Shauck, Jr., Ph.D., ***Director of Aviation Sciences*****, Baylor University**. Dr. Shauck has been working with alternative aviation fuels since 1980 and has accumulated over 2500 hours of flying time on renewable aviation fuels. He has presented papers describing modification procedures, aircraft performance, and economics related to ethanol powered aircraft at international symposia in Canada, France, and Japan.

Among his other accomplishments, Dr. Shauck received the first Supplemental Type Certificate (STC) ever granted for a nonpetroleum fuel and has made a number of record flights in ethanol powered aircraft--resulting in five officially sanctioned National Aeronautic Association records. The most recent record attempt was the first transatlantic flight in an aircraft powered by alcohol fuel. For this flight he was awarded the Harmon Trophy—the most prestigious award in aviation—by the vice-president of the United States. A former navy jet pilot, Dr. Shauck has over 11,000 hours flying time and currently holds FAA Commercial, Instrument, Single and Multiengine, Flight Instructor, Aircraft and Instrument, and Glider Commercial ratings.

Robert J. Shuter, ***Senior Policy Advisor*****, Transport Canada International Aviation**. Mr. Shuter joined Transport Canada in 1988 as the Superintendent, Environmental Impact in the Air Navigation Technology Branch, where he was responsible for land-use planning, environmental studies, and aircraft noise and emissions problems. From 1994 until he accepted his current position in September 1997, Mr. Shuter worked in the Airworthiness Branch of Transport Canada where he was responsible for aircraft environmental standards, aviation environmental regulations, aircraft type certification problems, and providing technical support to airports with environmental problems.

He is also the Canadian member of the International Civil Aviation Organization Committee on Aviation Environmental Protection (CAEP), Chairman of the CAEP Emissions Working Group, and a member of the CAEP Emissions Planning Group.

Mr. Shuter completed a degree in civil engineering in 1971 at the Royal Military College of Canada specializing in environmental studies. After graduation, he served with the Canadian Armed Forces in Canada, England, Germany, and Egypt.

Robert Sloan, ***President*****, Baylor University.** As President and Chief Executive Officer of Baylor University, Dr. Sloan is responsible for the direction of the university toward meeting its present goals and those of the future. Dr. Sloan has served as President of the university since 1995, before which he was the Dean of the George W. Truett Theological Seminary, where he continues to play an active role as a Professor of Religion.

Dr. Sloan's educational and professional background is extensive in the fields of Biblical studies and Religion. After graduating from Baylor University with a B.A. in 1970, Dr. Sloan went on to graduate with honors from Princeton and the University of Basel with the M.Div. and D.Th., respectively. As well, through various professional organizations, Dr. Sloan continues to research and explore in a theological setting.

Todd C. Sneller, ***Administrator*****, State of Nebraska Ethanol Board**. Mr. Sneller began work in the Nebraska ethanol development program in 1976 with the Nebraska Gasohol Committee. He assisted the Nebraska Department of Economic Development as an industrial development consultant in 1978-79 before returning to the Nebraska Gasahol Committee as the agency's administrator in 1979. Since that time he has also served as technical advisor of the Nebraska Ethanol Authority and Development Board where he managed a $20 million equity fund.

Mr. Sneller currently serves as Administrator of the Nebraska Ethanol Board, a state agency located in Lincoln, NE. He has served on the board of the Renewable Fuels Association. He presently serves as chairman of the Clean Fuels Development Coalition and is an executive board member with the Clean Fuels Foundation. He also serves as a Nebraska representative to the 21 state Governor's Ethanol Coalition. He has served as an advisor to the Nebraska Department of Agriculture, Southeast Community College and the Nebraska Alternative Fuels Council. Mr. Sneller's work includes ethanol plant recruitment, legislative, and regulatory assistance to ethanol producers; marketing and policy program development; and public outreach activities. He has authored numerous articles for regional and national publications and is regular guest speaker at national fuel conferences.

Mr. Sneller received a Bachelor of Science degree from Nebraska Wesleyan University and is nearing completion of the Management Development Program at the University of Nebraska-Lincoln, College of Business Administration.

Brian Stage, *Environmental Scientist,* United States Environmental Protection Agency.
Mr. Stage is an Environmental Scientist with the U.S. EPA's Great Lakes National Program Office (GLNPO), the responsible office for writing and implementing the recently signed US/Canada Great Lakes Binational Taxies Strategy. Alkyl-lead is one of the substances being addressed in the Strategy. Mr. Stage is helping form a public-private group to develop a plan to address alkyl-lead by supporting and encouraging stakeholder efforts to reduce alkyl-lead releases. In addition to working on the Binational Taxies Strategy, Mr. Stage has also worked on Great Lakes contaminated sediments issues.

Mr. Stage has a B.S. in Biological Sciences from Purdue University and an M.En. in Environmental Science from Miami University.

Dave Stanley, *Professor,* Purdue University. Prof. Stanley currently teaches powerplant curriculum, specifically powerplant system and propulsion courses at Purdue University. He is involved in test cell development which has as its objective the establishment of a research test cell capable of measuring power output and exhaust emissions for aircraft engines. Prof. Stanley hold a B.S. in Aviation Technology, B.A. in Math and English Education, and an MS in Industrial Technology.

Russell Teall, *Director of Legislative Affairs,* NOPEC. Mr. Teall is graduate of University of California Berkeley Law School and has held positions with the California Attorney General's Office, the U.S. Congress, and with a private firm as a litigation attorney. He currently lives on an island in the Florida Keys and enjoys boating and scuba diving with his wife and two children. Formerly the president of the National Boat Owners Association, he has directed various international tourism and environment projects.

Mr. Teall is now the Director of Legislative Affairs for NOPEC Corporation, the largest producer of biodiesel in the United States. He has been involved with NOPEC during the development and implementation of alternative fuel projects. He was also with the United States Post Office and the State of Iowa and local school districts. Prior to joining NOPEC, Mr. Teall provided marine marketing research for the National Biodiesel Board and Board of Directors.

As NOPEC's Director of Legislative Affairs, Mr. Teall has developed a multicompliance strategy which helps regulated fleets meet multiple federal requirements in a cost-effective program utilizing biodiesel.

Ralph Valente, *Project Engineer*, Tennessee Valley Authority. Mr. Valente is principal investigator for studies of ozone formation and transport and other atmosphere related projects. He has extensive engineering, scientific, and project management experience in current air quality issue areas. In the past he has worked for the U.S. EPA and Washington State University. He received his M.S. in Engineering from Washington State University and his B.S. in Meteorology from the State University of New York in 1978.

Joseph Valentine, *Senior Research Engineer,* Texaco, Inc. Mr. Valentine has worked for 16 years with Texaco, 10 of them in fuels research. He is currently the project coordinator for Texaco's High-Octane Unleaded Aviation Gasoline effort. This project involves the development of alternative fuels to replace high-octane leaded piston engine gasoline in the future. In 1997, he authored an SAE paper describing the methods and criteria used by the Texaco team to formulate promising experimental blends using a statistical design approach.
He is a member of ASME, SAE, CRTC, and First Vice Chair of Subcommittee D02.01 on Combustion Characteristics, ASTM. He received a BSME from the State University of New York at Buffalo.

He also holds a private pilot certificate and owns a Cessna 150.

Rudolf Voit-Nitschmann, Institut Für Flugzeubau, Universität Stuttgart. Prof. Dipl.-Ing. Rudolf Voit-Nitschmann studied aerospace and aeronautical sciences at the University of Stuttgart.

In the spring of 1980 he took over responsibility for the development of the light aircraft of type SC 01 SPEED CANARD at Gyroflug GmbH (FFT) where he became technical director in 1984. He was responsible for the development of the serial version of the SPEED CANARD and together with his small R&D team, he achieved the first Luftfahrt-Bundesamt (German civil aviation authority) and FAA (Federal Aviation Administration, US) certification of a composite aircraft in a canard configuration according to FAR 23. During his technical directorship a surveillance version of the SPEED CANARD was developed as was the EUROTRAINER 2000, a four-seater trainer aircraft.

In January 1994 he was appointed Professor of Aircraft Design at the University of Stuttgart. From the very beginning of his appointment he was given responsibility for the icaré 2 solar aircraft project of the aerospace and aeronautical faculty. Under his direction, the small icaré team won the 1996 Berblinger Prize awarded by the City of Ulm. His sphere of activities covers research and teaching in the fields of aircraft design, construction, and lightweight composite construction. He acts as an expert for the Steinbeis-Stiftung as well as for the Ministry of Science and Research.

In 1995 he established the Steinbeis Transfer Centre for Aerodynamic, Aircraft Design and Lightweight Construction. The STZ-AFL is also commissioned by the DAeC (German Aero-Club) to carry out type testing on microlight aircraft. As director of this centre, he offers his vast expertise to various companies.

William J. Wells, ***Director of Sales*****, Delta-T Corporation**. Dr. Wells is knowledgeable proponent of ethanol and its benefits. Prior to his current position, he has served in many capacities including: president and CEO of American Eagle Fuels, several positions at Celanese Chemical, director of Alternative and Reformulated Fuels at Alternative Fuel Technologies, president and director of marketing at Murex, Inc./Indechem Marketing, and general manager of Heartland Grain Fuels.

Dr. Wells holds a Ph.D. in Chemistry for the University of Texas and a Bachelor of Science in Chemistry from Lamar State College of Technology.

Ron E. Wilkinson, ***Director Advanced Programs*****, Teledyne Continental Motors**. Mr. Wilkinson is currently responsible for business development and program management activities associated with application of TCM aircraft engines to the worldwide general aviation market. He has been responsible for seven patents relating to aircraft engine technology and author of two publications: "Design and Development of Voyager 200/300 Liquid Cooled Aircraft Engine," and "Liquid Cooled Turbocharged Propulsion System for HALE Application." Before coming to Teledyne Motors in 1972, Mr. Wilkinson worked for Pratt & Whitney Aircraft's R&D Center as Senior Design Engineer. He earned a B.S. in Aerospace Engineering from Auburn University in 1968.

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