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The Potential Role of Technological Modifications and Alternative Fuels in Alleviating Air Force Energy Problems

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Examines short- and long-term measures to reduce the consumption of petroleum jet fuels by the Air Force. Engine retrofits and aerodynamic modifications to existing aircraft can save significant quantities of jet fuel; however, savings in fuel expenditures are not enough to offset high initial costs of engine retrofits. If accomplished early in an aircraft's life cycle, relatively lower costs of modest aerodynamic modifications may be recoverable through savings in fuel expenditures. Synthetic JP fuels derived from oil shale or coal appear to be the most attractive future alternatives to petroleum jet fuels. If the foreign oil cartel maintains its price-setting effectiveness and a synthetic fuels industry develops in the United States, development of an Air Force capability to interchangeably use fuels derived from crude oil, oil shale, or coal could be economically attractive and enhance the Air Force's position in the jet fuel marketplace. (Author)

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PREFACE

The fast-changing world energy situation could significantly influence the nature of future international conflicts and the effectiveness with which the United States Air Force could execute its missions. The "energy issue" has assumed a prominent position in both short- and long-term Air Force planning. Uncertainties in the future availability and economics of crude-oil-based jet fuels pose a particular challenge to the Air Force, the largest DoD consumer of jet fuel. To meet this challenge, the Air Force will be obliged to undertake measures to conserve jet fuel in the short term and to develop a future capability for using jet fuels derived from alternatives to crude oil.

In response to a joint request by the former Vice Chief of Staff (General R. H. Ellis), the Project RAND Air Force Advisory Group, and the former Air Force Chief Scientist (Dr. Michael Yarymovych) in his capacity as chairman of the Air Force Energy R&D Steering Group, a research effort was mounted at Rand for the purpose of identifying R&D activities that might provide (1) a short-term reduction in the Air Force's consumption of crude-oil-based jet fuels and (2) a long-term noncrude-oil-based fuel option for future aircraft development programs.

This report assesses the cost recovery potential and energy efficiency of selected technological modifications (engine retrofits and aerodynamic changes) to existing aircraft in the Air Force fleet to reduce present fuel consumption. For the long term, an assessment is made of (1) domestic energy resource alternatives to crude oil that might be suitable for the production of jet fuels, (2) the most desirable fuel forms derivable from those resources, and (3) the technological prospects and benefits of developing the capability to produce these fuels for use in Air Force engines.

This report and a companion report* that examines the military

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*William T. Mikolowsky and Larry W. Noggle, *An Evaluation of Very Large Airplanes and Alternative Fuels*, The Rand Corporation, R-1889-AF, December 1976.

utility of large airplanes using alternative fuels constitute a unified treatment of Rand's energy research activities for the Air Force. This report should be useful to the Air Force Aero-Propulsion Laboratory, the Air Force Systems Command, and such Air Staff offices as DCS/Research and Development, particularly AF/RDQPN, which served as the Office of Primary Responsibility for this research. The work was performed under the Project RAND project entitled *Technology Applications Research.*

J. P. Weyant, a contributor to this report, is a consultant to The Rand Corporation.

SUMMARY

Crude oil has been the only fuel source for aircraft propulsion to date because it has been in abundant supply, has been relatively inexpensive, and has very attractive physical properties. However, over the next 50 years, the present geopolitical imbalance of crude-oil resources will be exacerbated by the continued depletion of oil reserves. As these supplies diminish, prices will escalate and availability will become less certain both at home and abroad. As a consequence, the Air Force will need to consider ways to reduce its consumption of crude-oil-based jet fuels in existing and in new equipment and might possibly have to develop propulsion systems capable of operating on jet fuels derived from energy resource alternatives to crude oil.

Since the Air Force is already working vigorously to modify peacetime operations to conserve energy in the short term, as well as examining the long-term prospects for new fuel-conservative aircraft designs, this report's primary focus is on two technological options that have received less attention thus far and that could reduce consumption of crude-oil-based jet fuels. Within this framework, the overall objective of this report is to identify and assess the possible benefits of R&D programs that might provide (1) a short-term reduction in Air Force jet fuel consumption through selected aerodynamic and propulsion modifications to the existing fleet and (2) a long-term noncrude-oil-based fuel option that could be exercised in future aircraft development programs.

A PERSPECTIVE

The world supply of recoverable fossil energy resources is limited and not uniformly distributed. In the case of crude oil, nearly three-quarters of the measured and indicated reserves are in the Middle East, North Africa, the Soviet Union, and Eastern Europe. United States production of crude oil has been declining in recent years and at the present time over 40 percent of the crude oil that we consume is imported. Even with full development of oil from the Alaskan north slope and the

outer continental shelf, and the use of enhanced recovery techniques, the Energy Research and Development Administration (ERDA) indicates that, at best, U.S. domestic crude-oil production might remain at today's levels between now and the end of the century. Nevertheless, domestic demands for liquid fuels are expected to increase significantly, even with aggressive conservation efforts. A continuation of the present trend of closing the gap between supply and demand by importing increasing quantities of crude oil might potentially threaten the policy independence, national security, and economic health of this nation. As a consumer of energy, a developer of technology, and a protector of the national interest, there are several short- and long-term options open to the Air Force that could reduce its future consumption of crude-oil-based jet fuels.

SHORT-TERM TECHNOLOGICAL MODIFICATIONS TO REDUCE JET FUEL CONSUMPTION

We have examined the cost and energy consequences of selected propulsion and aerodynamic modifications that might reduce the fuel consumption of the Air Force fleet. The cost recovery potential is measured in an energy context by comparing the savings in jet fuel expenditures with the cost of performing the modification. Energy efficiency is measured by comparing the savings in jet fuel energy with the energy required for manufacturing and installing fuel-conservation devices.

Analysis of the engine retrofitting option for the four leading jet fuel consumers of the Air Force fleet, the C-141, B-52, F-4, and KC-135, indicates that

1. Such an option could save considerable energy compared to the energy required to manufacture and install new engines, and
2. Even if jet fuel prices were to triple in constant dollar terms between now and the end of the century, savings in jet fuel expenditures would not be adequate to offset engine retrofit costs.

Most Air Force airplanes have engines developed in the late 1950s and early 1960s. Retrofit of newer, more efficient engines could result in a 20 to 30 percent reduction in fuel consumption, which would more than offset the energy required to manufacture and install the engines. However, the reductions in expenditures for jet fuel would not be sufficient to recover the costs of the retrofit because of three major factors: (1) the high procurement costs for the new engines; (2) the low level of peacetime flying hours for military aircraft; and (3) the advanced age of the average aircraft by the time the retrofit program was completed (average fleet ages would be about 15 years or more).

These facts lead us to conclude that any proposal attempting to justify the cost effectiveness of the engine retrofitting option will have to consider not only reduced expenditures for jet fuel but also the possible operational advantages offered by enhancements in capability (e.g., greater range) or reductions in fleet size at equal capability.

We have also investigated the utility of modest aerodynamic changes that have been proposed for some transport-class Air Force aircraft--the C-141 and the C-130--to reduce drag and hence reduce fuel consumption. Analysis of this option indicates that

1. Aerodynamic modifications can save modest amounts of energy, even after considering the energy required to effect the modifications, and
2. If made early in the life cycle of an aircraft, savings in jet fuel expenditures can offset the costs of modest aerodynamic modifications.

Adding drag-reducing wing fillets to an unstretched C-141A and removing its vortex generators could reduce fuel consumption by as much as 8 percent. Our analysis indicates that such a modification could save more energy than that required for the modification.

In the late 1960s, such a modification was estimated to cost about $120,000 per aircraft (1974 dollars). At this price, savings in jet fuel expenditures would clearly offset the cost of the modification. If costs were to rise to $250,000 to $400,000 per aircraft (1974 dollars) to accomplish the modification, there is some doubt as to whether savings in fuel expenditures could offset modification costs before the fleet reached the end of its useful life. Nevertheless, further exploration of the cost of an aerodynamic modification and a determination of the additional years the C-141A is to be kept in service seem desirable.

Modifications to the afterbody of the C-130 have also been proposed, to reduce aerodynamic drag an estimated 3 to 9 percent, depending on the extensiveness of the modifications. Such modifications would result in net savings in energy, but it is unlikely that costs could be recovered through savings in jet fuel expenditures because of the advanced age of most of the C-130 fleet.

The Air Force is currently testing the drag reduction potential of winglets using the KC-135 as a test bed. The cost and energy effectiveness of this modification will have to be assessed after the test program is concluded.

Prospects for reducing energy use by modifying aerodynamic characteristics and offsetting the modification costs through savings in jet fuel expenditures do not appear to be particularly attractive for aircraft currently in the fleet (with the possible exception of a C-141 modification). Nevertheless, the relatively lower cost of aerodynamic modifications compared to engine retrofits and the potential 5 to 10 percent reductions in fuel consumption lead us to conclude that the option may be viable for future aircraft if modifications are accomplished early enough in the aircraft life cycle to allow cost recovery.

FUEL ALTERNATIVES

Assessment of Alternatives

The recent three year time period during which large increases in jet fuel prices have occurred stands in stark contrast to the 25 to 50 year time period spanning basic research through operational usage that is typical of the development and implementation of new propulsion concepts. The Air Force, therefore, must be acutely attuned today to the possibility that in the future it may have to resort to an alternative fuel that may require either the modification of existing engine hardware or even the introduction of a new generation of aircraft engines. Our initial research on alternative fuels sought to identify the most promising energy resource alternatives to crude oil that could be used for the production of new jet fuels and to determine the most attractive fuel forms.

Analysis of the alternative fuels option indicates that

1. Domestically abundant oil shale and coal are the most promising energy resource alternatives to crude oil that could be used for the production of future military jet fuels into the next century, and
2. A synthetic jet fuel, or synthetic JP, similar to conventional hydrocarbon jet fuels in use today, is the most attractive military fuel form derivable from U.S. oil shale or coal resources, given the energy conversion technology that is expected to be available in the future.

An analysis of the cost and energy efficiency of the production and distribution of jet fuels from coal revealed that a synthetic JP fuel would require lower energy expenditures and would result in a less costly fuel product than the other two major alternatives--the cryogenic fuels liquid hydrogen and liquid methane. Synthetic JP also has the advantage of being far more similar to jet fuels in use today than the two cryogenic alternatives, which should ease transitional problems for military users and promote its assimilation into a domestic fuels market now dominated by crude-oil-based fuels.

A related mission analysis of large transport-class airplanes (with gross weights of 1 to 2 million pounds) fueled by synthetic JP, liquid hydrogen, liquid methane, or nuclear propulsion has indicated that for a broad class of present and future mission applications, a synthetic-JP-fueled aircraft enjoys a significant advantage in terms of cost and energy effectiveness.* Nuclear propulsion begins to look attractive only for station-keeping missions that require large station radii (greater than 4000 n mi) and extremely long loiter times on

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*William T. Mikolowsky and Larry W. Noggle, *An Evaluation of Very Large Airplanes and Alternative Fuels*, The Rand Corporation, R-1889-AF, December 1976.

station (e.g., hundreds of hours). At present, no missions requiring such a capability are apparent. Analysis suggests that liquid-hydrogen-fueled military aircraft would become attractive only if there were dramatic reductions in the energy requirements and costs for liquefying gaseous hydrogen. Projections of possible advances in hydrogen liquefaction technology by liquid hydrogen manufacturers indicate that such dramatic improvements are not likely to be forthcoming.

Despite the attractive features of synthetic JP, there are definite resource, capacity, environmental, government policy, and international factors that could tend to limit its availability in the future. Nonetheless, our research results suggest that there is a strong likelihood that a coal and oil-shale synthetic fuels industry could develop in the United States between 1990 and 2025, and that the switch from crude-oil-based jet fuels to coal- or oil-shale-based fuels in this time period would be dictated by comparative economics rather than by a total lack of availability of crude oil.

Implications for Synthetic Jet Fuel R&D

The latter stages of our research on alternative fuels focused on: (1) the identification of R&D needed to develop the synthetic jet fuel option; (2) the delineation of conditions under which it may become necessary to change to fuel and/or engine technologies that are not totally dependent on crude oil as an energy source; and (3) an assessment of the possible benefits to the Air Force resulting from the development of a synthetic jet fuel propulsion capability.

Our findings indicate that

1. Significant R&D is needed to develop the synthetic jet fuel option for the future, at least part of which will probably have to be conducted by the Air Force to assure a suitable fuel product for military use. An aggressive program of basic research should probably begin now,* considering the 25 to 50

*A limited amount of Air Force research in this general area is already being conducted by the Air Force Aero-Propulsion Laboratory and one of its contractors, the Exxon Research and Engineering Company.

year life cycle of propulsion technology, and considering the foreboding projections on the availability of domestic crude oil in the future.

2. The R&D should focus on developing a full understanding of the physical, chemical, and economic influences of synthetic jet fuels on refinery operations and on military jet engines.
3. Any characterization of possible economic benefit to the Air Force from possession of a multifuel capability is subject to great uncertainty, because of the influence that the foreign oil cartel may be able to exert on the energy conservation and supply options that are developed domestically in the future. If the foreign oil cartel's price-setting effectiveness does not diminish in the future, the 1980 present value benefit* to the Air Force between 1995 and 2020 of being able to procure the cheapest jet fuel alternative could amount to roughly $1 billion (1974 dollars). Conversely, if the cartel's price-setting effectiveness does diminish, which could delay the introduction of synthetic fuels in the United States, any economic benefit from possession of a multifuel capability would be so delayed that the 1980 present value benefit would be negligible.

The R&D activities outlined above should reveal the proper technology balance between emphasis on energy conversion (e.g., the refinery) and on energy use (e.g., the military jet engine). Success in these R&D activities alone, however, will not assure that the synthetic jet fuel option can be exercised in the future, since the R&D policies adopted by ERDA and by the private sector will in large part determine the future availability of technologies for producing synthetic crude oils suitable for refining to jet fuels. Furthermore, even if the technologies are developed, their possible commercialization will be heavily influenced by world oil prices, and particularly by the price-setting effectiveness of the foreign oil cartel.

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*The present value economic benefit is referenced to 1980 because that is when the major R&D expenditures would likely have to commence.

Since the economic benefit to the Air Force from possessing a multifuel capability is so sensitive to future trends in world oil prices, three alternative scenarios on the price of imported crude oil were considered in the benefit assessment. If the price of imported oil were to rise to $19.50 per barrel (1974 dollars) by the year 2000, the 1980 present value benefit of the multifuel capability between 1995 and 2020 could amount to roughly $1.9 billion (1974 dollars). The $1 billion benefit previously cited is assumed to result if the price of oil rises to $15 per barrel (1974 dollars) by the year 2000. If, however, the foreign oil cartel were to lose its price-setting effectiveness, resulting in an assumed year 2000 price of $9 per barrel (1974 dollars), any economic benefit stemming from a multifuel capability could be delayed, and hence, be negligible in 1980 present value terms, since the direct economic stimulus for the development of a synthetic fuels industry would be delayed. However, in this circumstance, the United States could find itself in the undesirable situation of having to import 90 percent of its crude oil by 2020, with all the attendant national security and economic problems.

If the foreign oil cartel continues strong, and if a synthetic fuels industry is developed in the United States, a policy of relying solely on crude oil for jet fuel needs could place the Air Force in, at best, an awkward marketplace negotiating posture by the turn of the century. Furthermore, by the time other energy users begin shifting to coal and shale oil, crude oil in the low extraction cost category will have been depleted.

CONCLUSIONS

Analysis of short-term and long-term Air Force options for reducing consumption of crude-oil-based jet fuel has indicated that an aerodynamic modification for the C-141 may still be an attractive fuel-conserving modification, depending on the additional number of years the C-141 force is to be kept in service and the cost of the aerodynamic modification. Some additional exploration of both these questions appears warranted. Technological modification of other aircraft in the present Air Force inventory does not seem to be warranted in view of the cost and the limited potential returns that are in large part driven by the low annual utilization rate for military aircraft and the advanced age of the fleet. It seems that the only major way that technology can potentially contribute to reductions in Air Force consumption of crude-oil-based jet fuels in a cost-effective manner is through force modernization, by the introduction of aircraft with improved fuel consumption characteristics, or by development of a synthetic jet fuel propulsion capability. The research in this report has focused on the latter option.

If an aggressive synthetic fuels commercialization program is not instituted prior to the end of the present century, the United States could be importing nearly all of the crude oil that it consumes by the year 2020. With an aggressive synthetic fuels commercialization program, the Air Force may be able to realize a significant cost avoidance in terms of reduced fuel costs, if it is in a position to use a jet fuel that is derived from a coal- or oil-shale-based replacement for crude oil. However, to be in a position to use such a synthetically derived jet fuel, the Air Force may have to initiate a more substantial R&D program before the end of this decade in order to develop the basic fuel and engine technology that could then be used in military jet engines that are designed in the late 1980s and early 1990s. An investment in this R&D should be considered as a hedge against uncertainties in the economics and availability of crude-oil-based jet fuels in the future.

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