NASA TM - 81793

3 1176 00140 1505

NASA Technical Memorandum 81793

NASA-TM-81793 19800011777

THE ROLE OF TECHNOLOGY AS AIR TRANSPORTATION FACES THE FUEL SITUATION

CORNELIUS DRIVER

MARCH 1980

LIBRARY COPY

APR 8 1979

LANGLEY RESEARCH CENTER
LIBRARY, NASA
HAMPTON, VIRGINIA

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

THE ROLE OF TECHNOLOGY AS AIR TRANSPORTATION FACES THE FUEL SITUATION

by Cornelius Driver
NASA Langley Research Center
Hampton, Virginia

INTRODUCTION

The National Aeronautics and Space Administration is specifically charged in the Space Act of 1958 with fostering United States aeronautical research in support of the aircraft industry and the Armed Services. At the Langley Research Center we have responsibility for lead roles in conducting disciplinary research for the four vehicle classes of subsonic long haul, supersonic, military, and general aviation. In the Aeronautical Systems Division, we conceptually apply various research discipline outputs to specific airplane configurations in order to identify profitable discipline research areas. The perspective provided in this paper is, therefore, that of systems integrators whose task is to identify the application and payoff of various research disciplines.

For this presentation, the discussion is limited to the subsonic commercial transport type aircraft and the approach will be to provide a brief perspective of the fuel situation as it exists, the progress that has already been made in fuel reduction, near-term prospects for further reduction, and long-term prospects for even further reductions, all primarily from the technology point of view.

PRESENT SITUATION

We should start with the understanding that we are dealing with the largest, most complex, and most successful air transportation system in the world today (fig. 1). It touches every city of significant size in our country and enables us to reach any other area in less than one day of travel time. At the present time there are about 3000 airplanes in the system (ref. 1). The number of intercity passengers by trip distance is shown in figure 2 (ref. 2). On trips over 200 or 300 miles, an overwhelming number of passengers travel by air. This passenger preference has developed because of speed and comfort - and at least until the present - decreasing ticket prices (fig. 3).

N80-20260 #

Now - how much fuel does this system use, and how does it compare with the total energy budget (fig. 4 (from ref. 3))? The amount of energy used by airplanes is about 70 percent of the amount we use to heat our residential hot water (ref. 4). Within the air segment alone, how much is used and how is it changing? Are we making any progress (fig. 5)? The data (ref. 5) indicates that the absolute amount of fuel used by the airlines has been almost constant since 1972. During that same period, it has been possible to increase the number of passenger miles by 70 billion without an increase in fuel burned due to efforts in increasing load factor larger aircraft, more efficient control of flight profiles, traffic optimization, and a myriad of other small actions. For the period shown, a 50 percent increase in fuel efficiency has already been achieved (fig. 6 (from ref. 5)).

Our interest in this paper is toward the present and future use of aircraft fuel (fig. 7 (from ref. 6)) and how this use might be affected by technology. The price of domestic jet fuel since 1972 is shown in figure 8 (refs. 7-9) and dramatically illustrates the change in fuel price since 1972 and, even more dramatically, the changes during the past year. Obviously, it is very difficult for the airline industry to track costs accurately in such a changing situation. It must be understood the airlines have to deal with total costs, not just fuel cost. Dramatic changes are occurring in other areas too - for example: the basic wage inflation is shown in figure 9 (ref. 5); the change in aircraft cost per seat in figure 10 (ref. 5), and the engine maintenance cost in figure 11 (ref. 5). The cost of developing a new engine is shown in figure 12 (ref. 5). Keep in mind that a new aircraft incorporating a number of advanced technologies involves a number of complex interacting factors - with one thing in common - the aircraft almost always costs more. The fact that 90 percent of the airplanes flying in the free world are produced in the United States is evidence that the manufacturers have been meeting the challenge successfully. The importance of aircraft sales to our balance of payments is shown in figure 13 (ref. 10) - our most important <u>net</u> export is aircraft and the related technologies.

NEAR-TERM ACTIONS UNDERWAY BY THE MANUFACTURERS AND AIRLINES

The present models of airplanes in service generally have a design margin available to further improve payload capability as higher thrust engines are offered by the engine manufacturers. All three major United States manufacturers have derivative aircraft in production with further modifications planned to more precisely match the airplane to the individual airline requirement. Some of the derivative concepts presently in service are shown in figure 14 (ref. 11). Two specific new proposals - a stretched DC-10, and a derivative Lockheed 1011 are shown in figures 15 and 16. The benefit of the increased carrying capability on passenger seats per gallon is dramatic, as shown for the Boeing 747 in figure 17 (ref. 5).

At present, several new aircraft are being proposed to the airlines for introduction into service in the early 1980's. One of these aircraft is shown in figure 18. These new airplanes will incorporate many advancements over their predecessors - better engines, better aerodynamics, better structures, better avionics, and so on. The new wing technology being applied to these new airplanes is shown in figure 19 (ref. 12). Supercritical aerodynamics and increased wing aspect ratio or wing span reduce drag nearly 10 percent. Compared to today's 727 aircraft, more than a 30 percent improvement in fuel consumption will be achieved (fig. 20, ref. 12).

LONGER RANGE RESEARCH EFFORTS

Advanced technology elements for application to airplanes designed in the late 1980's and early 1990's are encompassed in the NASA program called Aircraft Energy Efficiency or ACEE. The program elements and their timing are shown in figure 21. These items will be applied to aircraft design as rapidly as it makes technical and economic sense to do so. I will briefly review some of the more important elements in each of these areas.

First, engine programs (ref. 13). The propulsion efforts in ACEE (fig. 22) are managed by the Lewis Research Center in Cleveland, Ohio. An aggressive component improvement program for existing engines is being pursued. One example of these improvements is active clearance control between the rotating parts and the engine case. Keeping these clearances at a minimum results in a small increase in engine efficiency. Application of the latest engine discipline research to an actual engine is being pursued in the E^3 program in which a complete Energy Efficient Engine will be demonstrated by both Pratt and Whitney and General Electric. Many of the features of this engine are already being incorporated in the advanced engines being offered to the manufacturers and the airlines.

Recent advances in propeller design have reawakened interest in the fuel-efficient turboprop propulsion system. These 8 to 10 blade propeller designs have more than four times the disk loading of the propellers used in the 1960's on the Lockheed Electra and they remain efficient at speeds approaching those of current turbofan transports. Here, too, an aggressive program to determine the payoff of technology is being pursued. Airframe propulsion integration, noise, and gear boxes all need to be addressed before successful reapplication of this advanced technology to high speed airplanes. The fuel saving resulting from this progress is shown in figure 23 (ref. 13).

Turn now to the advanced aerodynamics (fig. 24) for the ACEE program (ref. 14). Here we are studying advanced supercritical airfoil sections applied to wings with increased aspect ratio. Present aircraft, like the 727, have wing aspect ratios of about 7; future aircraft will have aspect ratios above 10. These changes, while seemingly small, introduce severe problems in aircraft balance, landing gear storage, high lift systems and propulsion integration. All of these problems must be solved concurrently to achieve the fuel and gross weight reductions potentially obtainable by the application of advanced wing technology.

An important part of the future improvements are in the active control programs (fig 25). These programs include active maneuver and gust load alleviation to reduce wing weight, as well as relaxed static stability with reduced horizontal tail size to reduce drag. Again, aggressive programs are underway both in-house and under contract with the major airframe contractors to understand and apply this technology as rapidly as possible.

In the structures and materials area (ref. 14), the ACEE program is aimed primarily at the application of composites to provide a major reduction in aircraft weight as well as an increase in stiffness. A typical example is the use of graphite fiber embedded in a resin matrix. The fibers can be placed in various orientations to optimize strength and stiffness and there is a potential reduction in fabrication cost because of the reduction in the number of parts. Major emphasis is being placed on design, application, service life, failure modes, and fabrication cost to provide the manufacturer with the confidence to build these parts and to guarantee them to the airlines. Efforts are underway in both secondary structures (fig. 26) and primary structures (fig. 27).

When all of the technologies being pursued by the ACEE program are ready for application by airplane designers in the late 1980's, a large further reduction in fuel consumption will be achieved. The goal is a 50 percent reduction as shown in figure 28 (ref. 5). The time of application of this advanced technology will be determined by overall economic considerations which include multibillion dollar expenditures in manufacter's development costs and airline start-up costs.

FUTURE FUELS FOR AIRCRAFT

The generally accepted scenario of figure 29 (ref. 15), wherein historical and projected consumption of oil by the United States exceeds domestic production capability, presents a variety of questions regarding the availability and character of future aviation fuels. In the near-term, consideration must be given to the production of jet fuel from the remaining domestic and imported crude oil, and to the production of synthetic jet fuel (synjet) from the large U.S. resources of coal and oil shale. In the far term, consideration must also be given the use of liquid methane (produced from coal), and liquid hydrogen (produced from coal or nonfossil energy sources). Although the production of such fuels is generally beyond NASA's charter, the technologies associated with the use of such fuels in the air transportation system are being addressed by NASA.

Historically, the average barrel of oil (both domestic and foreign) has been decreasing in available middle-range distillates and in hydrogen content. Coal-derived synthetic crude oil will likely have similar deficiencies. It may be necessary to establish the best compromise between engine hardware and energy cost. An example of the results of NASA's fuel-related technology program is seen in the lower right hand corner of figure 29. Experimental combustors (ref. 16) that have been evaluated exhibit a relative insensitivity of maximum liner temperatures (an important factor in combustor life) to the hydrogen content of the fuel.

Preliminary results from a NASA-sponsored study being conducted by Boeing are encouraging in that blends of naturally occurring and synthetic crude oil feedstocks, projected to be available until near the turn of the century, appear to be refinable to present specifications for commercial jet fuel.

Cryogenic fuels such as liquid hydrogen and liquid methane have received considerable attention by NASA. Studies (ref. 17) have determined that, from the standpoint of aircraft performance, cryogenically fueled configurations result in about a 10 percent reduction in fuel consumption or aircraft gross weight. These low density fuels can best be contained within fuselage tanks, both fore and aft of the passenger compartment (fig. 30). Problems such as long-life cryogenic tanks and fuel-feed systems appear to have viable solutions. Airport requirements for liquid hydrogen have also been assessed and found to be tractable. The major issues are the relative hazards (both on the ground and in the air) and fuel cost. The issue of relative hazards is receiving NASA attention with an assessment of the ground handling and crash safety of liquid hydrogen and liquid methane as compared to that for aviation kerosene.

Regarding the cost of alternate fuels, the results of both industry and NASA-sponsored studies are summarized in figure 31 (ref. 17). This bar graph shows estimates of the price of liquid hydrogen, liquid methane, synjet produced from coal, and synjet produced from oil shale. Fuel price is expressed in dollars per gigajoule, and aviation kerosene at 75 cents per gallon is shown as a reference point. Each bar represents a particular fuel production process. The reader is referred to reference 17 for process identification and details. The prices shown include the price elements associated with coal and oil shale conversion processes, 1000 mile pipeline transmission, liquefaction of the hydrogen and methane, upgrading and refining of the synthetic crude oil as required for production of synjet, and fuel storage, distribution and fueling facilities at the airport. The price estimates are based on 1980 dollars ($16 per ton coal and 3 cents per kilowatt hour electrical power) and include profit as calculated by a 15 percent discounted cash flow financial accounting method. Liquid hydrogen is seen to be the most expensive alternate fuel, costing about 40 percent more than liquid methane, and twice as much as synjet produced from either coal or oil shale.

SUMMARY

Since the beginning of the fuel price increase in 1973, the manufacturers and the airlines have made dramatic improvements in their fleet fuel efficiency. They are now generating 70 billion additional passenger miles with the same amount of fuel used in the early 1970's - a 50 percent increase in fuel efficiency per passenger mile.

Both derivative aircraft and new aircraft will be introduced in the early 1980's that will further improve fuel efficiency by about 30 percent.

Aggressive research programs are underway in a joint effort by government and industry to develop and prove the technology that will provide a further 50 percent improvement in the fuel efficiency of airplanes designed in the late 1980's and early 1990's.

Initial consideration of alternate fuels indicate that the synjet fuels may be compatible with existing engines and systems. Studies of the use of cryogenic fuels such as liquid methane and liquid hydrogen indicate that airplanes using these fuels could be about 10 percent more efficient than comparable technology airplanes. More work is required on cryogenic fuels to understand how to make them available at the airport, to understand the safety implications, and to reduce their cost.

REFERENCES

1. Aerospace Facts and Figures 1979/80. Aerospace Industries Association of America, Inc., Washington, DC 20036.

2. Miller, M. P.; and Mays, R. A.: Transportation and the U.S. Petroleum Resource: An Aviation Perspective. Journal of Energy, Vol. 2, No. 5, Sept.-Oct. 1978, pp 259-268.

3. Withington, H. W.: Commercial Air Transportation Developments in the Next Three Decades. Boeing Commercial Airplane Company, D6-46309, November 1977.

4. Anon: Exploring Energy Choices: Ford Foundation Energy Policy Project. 1776 Massachusetts Ave., N.W., Washington, DC, 20036, 1974, Library of Congress Catalog Card Number 74-77757.

5. Hopps, R. H.; and Hopkins, J. P.: Commercial Transports in the 1980's: The Role of Economics in Differentiating Expectations and Possibilities. Presented at AIAA-RAS Energy and Aerospace Workshop, London, December 5-7, 1978.

6. Povinelli, F. P.; Klineberg, J. M; and Kramer, J. J.: Improving Aircraft Energy Efficiency. Astronautics & Aeronautics, February 1976, Vol. 14, No. 2, pp 18-31.

7. Anon: U.S. Airline Fuel Consumption and the U.S. Energy Spectrum. Prepared by Energy Analysis and Forecast Management Group, Boeing Commercial Airplane Company, Rept. D6-42870, Feb. 1976.

8. Monthly Energy Review. DOE/EIA-0035/9(79) NTISUB/E/127-009, September 1979.

9. Ott, J.: Fuel Costs Pave Way for Fare Boost. Aviation Week and Space Technology, September 10, 1979, pp 32.

10. Bureau of Census (U.S. Exports Schedule B, Commodity and Country), Report FT-410, FT-135, FT-990.

11. Steiner, J. E.: Commercial Airplanes for the 1980's. International Aviation Conference, Lloyd's of London Press, New York, NY, May 24, 1979.

12. Anon: Airplanes for the Eighties. Boeing Commercial Airplane Company, N 8447 July 1979.

13. Nored, D. L.; Dugan, F. J., Jr.; Saunders, N. T.; and Ziemianski, J. A.: Aircraft Energy Efficiency (ACEE) Status Report. Aeropropulsion 1979 Conference, May 15-16, 1979, NASA CP-2092.

14. Leonard, R. W.: Airframes and Aerodynamics. Astonautics & Aeronautics, Vol 16, No. 7/8, July-August 1978, pp 38-46.

15. Bower, R. E.: Future Directions in Aeronautical Research and Technology. Presented at the AIAA Aircraft Design Conference, Dayton, Ohio, December 14-15, 1978.

16. Longwell, J. P, and Grobman, J.: Alternative Aircraft Fuels. Presented at International Society of Mechanical Engineers, London, April 9-13, 1978, NASA TM-73836.

17. Witcofski, R. D. Comparison of Alternate Fuels for Aircraft. NASA TM 80155, 1979.

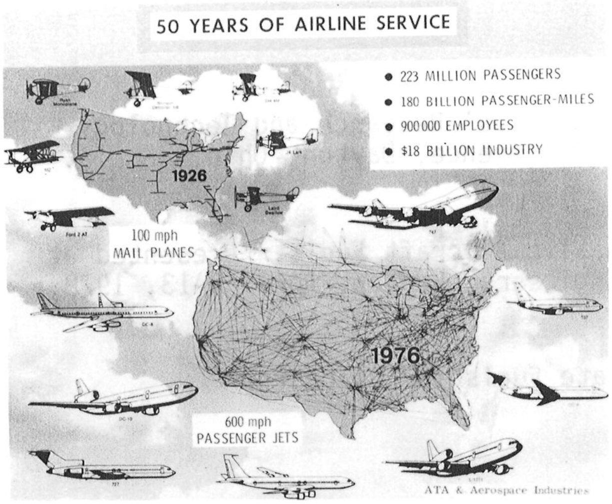


Figure 1.

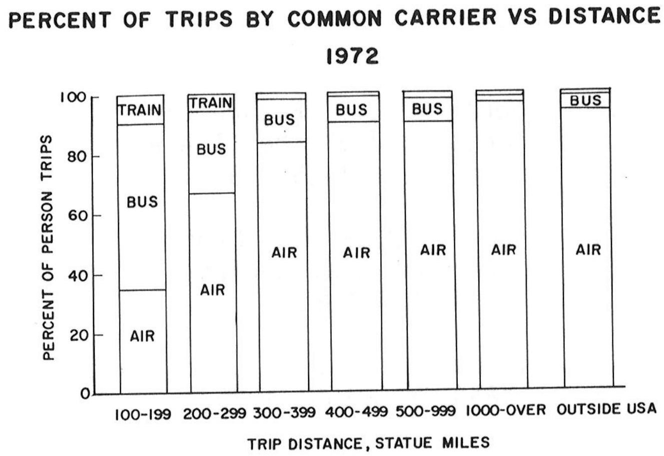


Figure 2.

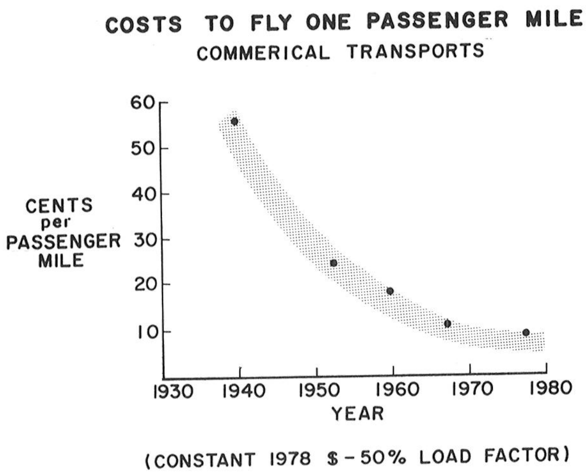


Figure 3.

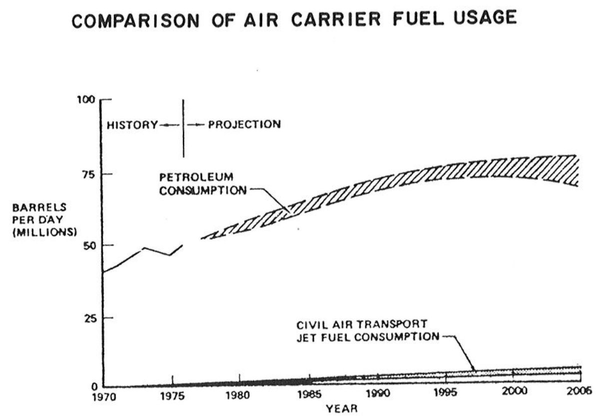


Figure 4.

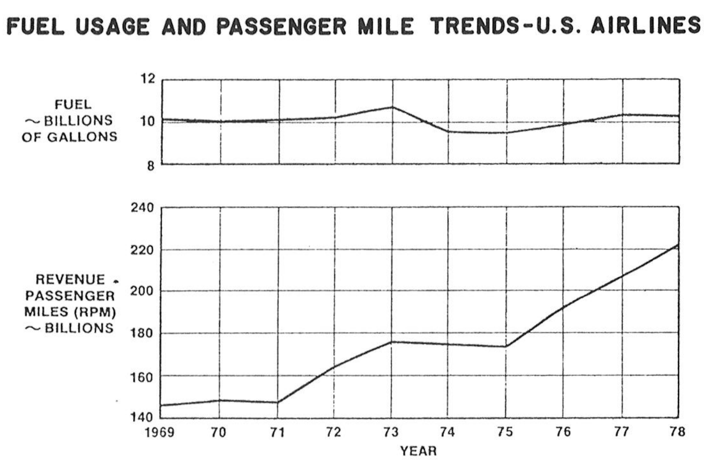


Figure 5.

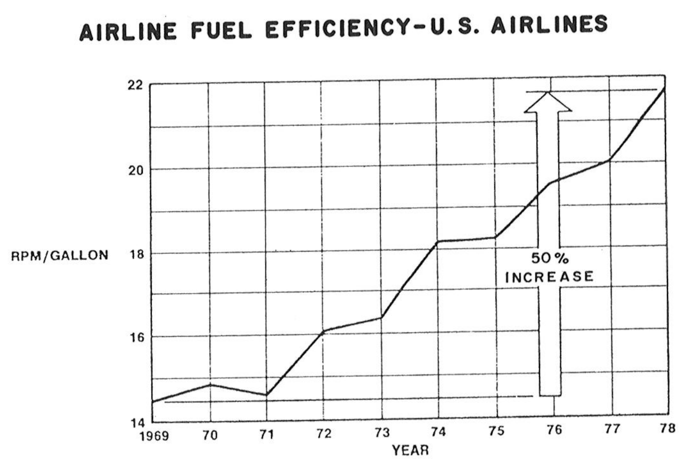


Figure 6.

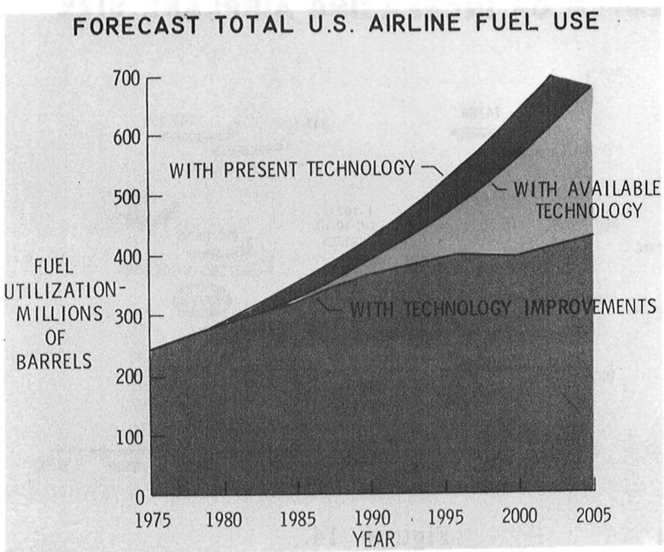


Figure 7.

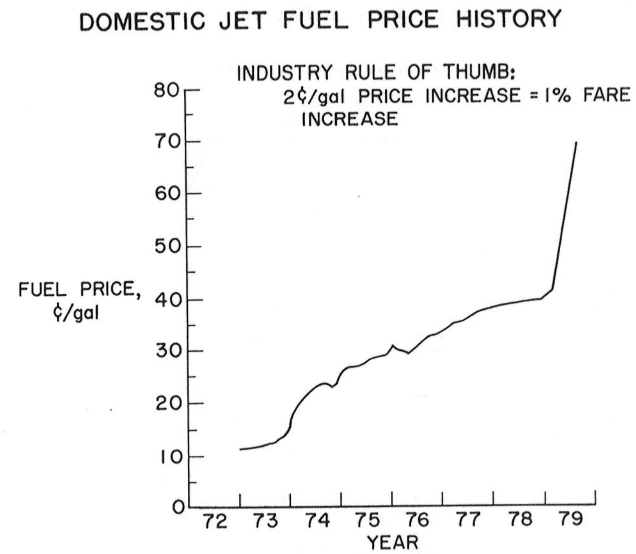


Figure 8.

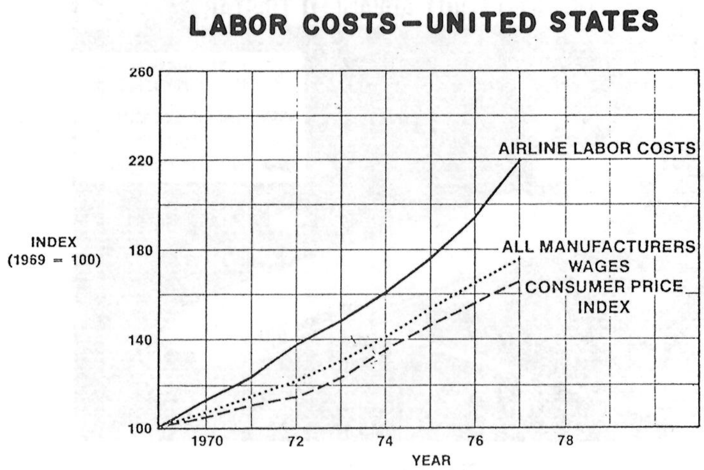


Figure 9.

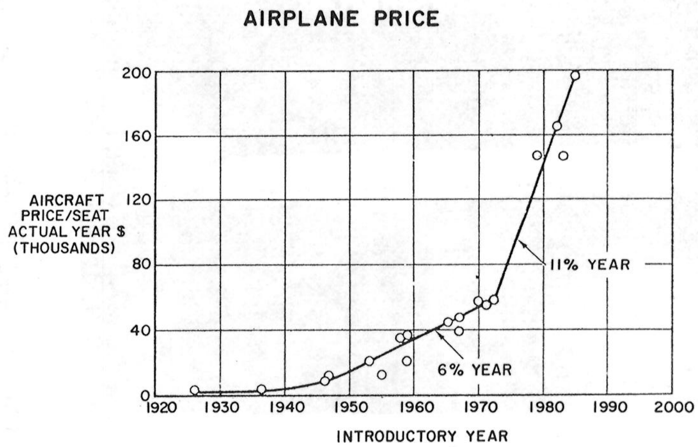


Figure 10.

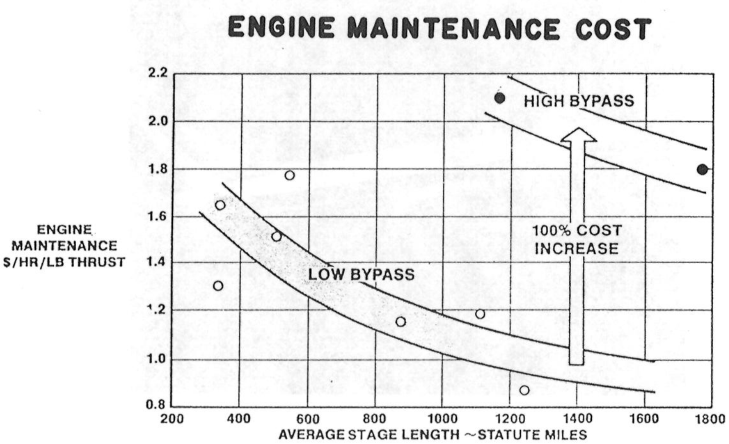


Figure 11.

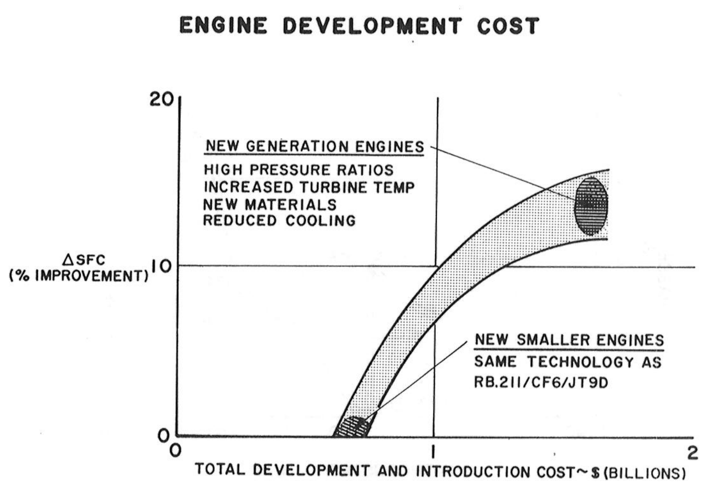


Figure 12.

EFFECT OF AIRCRAFT SALES ON BALANCE OF TRADE

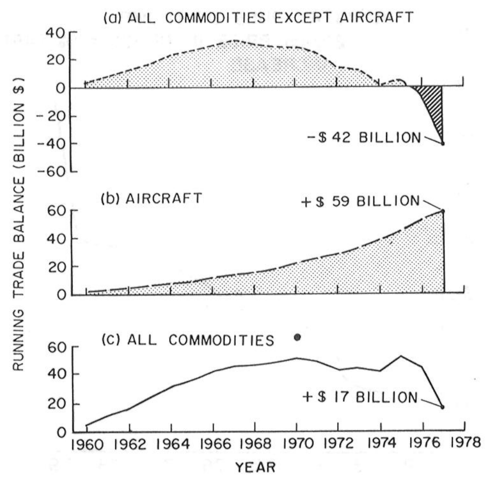


Figure 13.

EXAMPLE OF INCREASING AIRPLANE SIZE

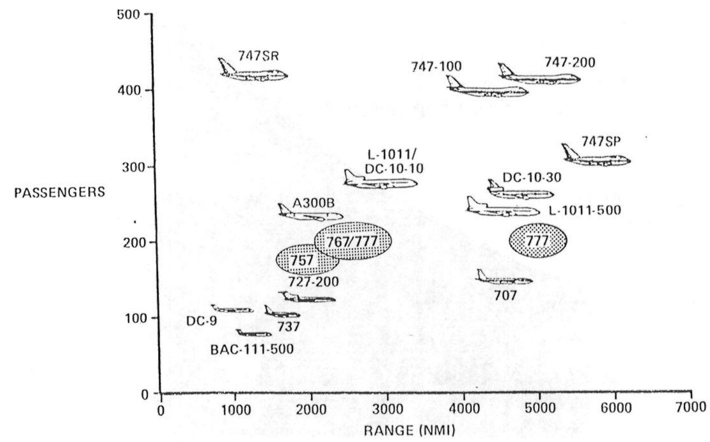


Figure 14.

Figure 15.

Figure 16.

HISTORY OF FUEL EFFICIENCY

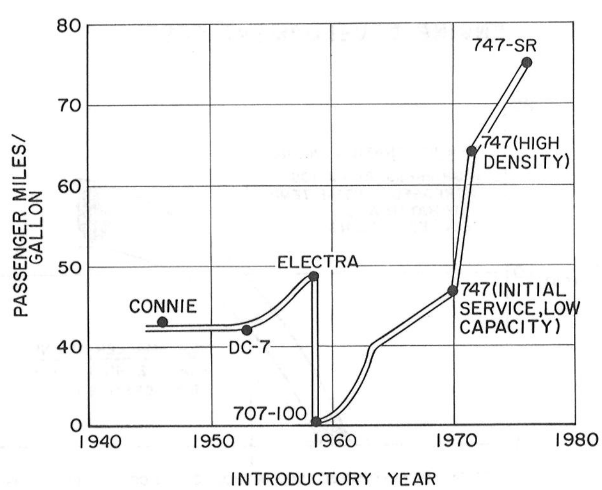


Figure 17.

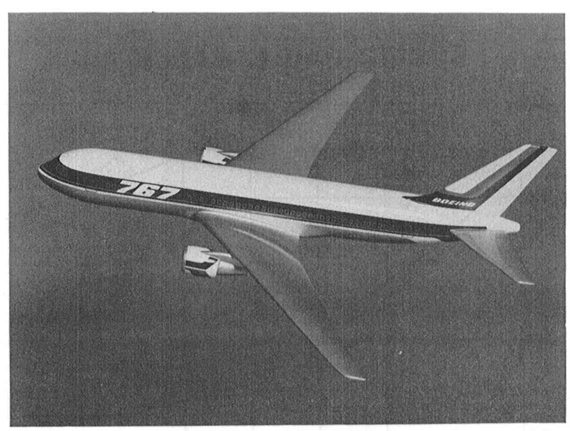


Figure 18.

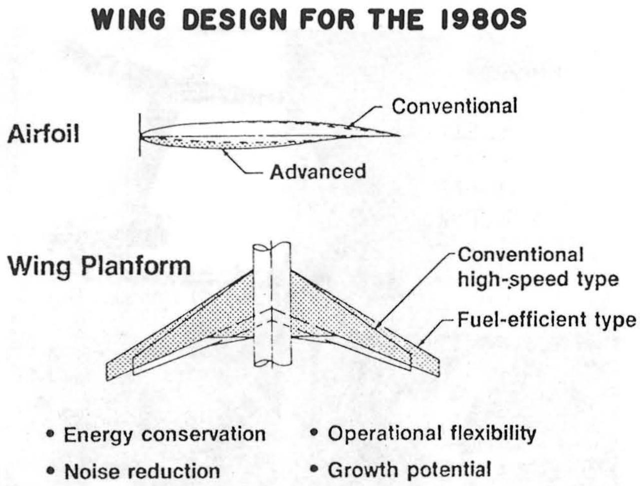


Figure 19.

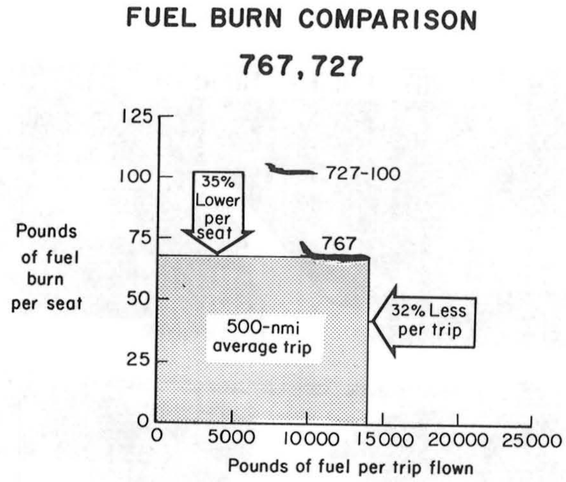


Figure 20.

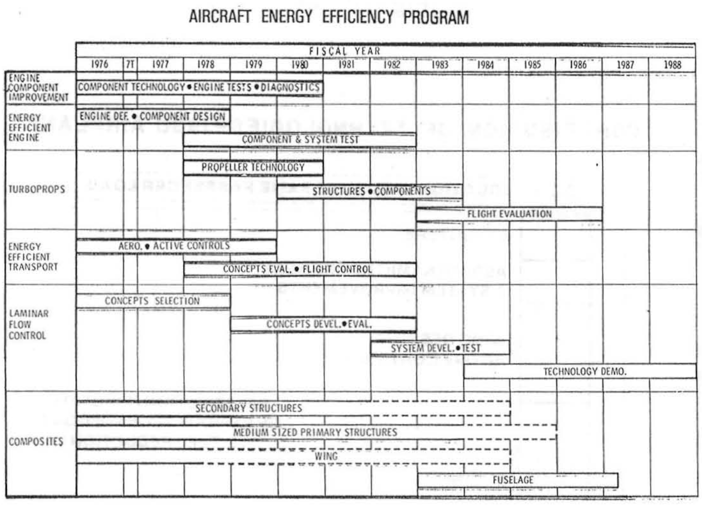


Figure 21.

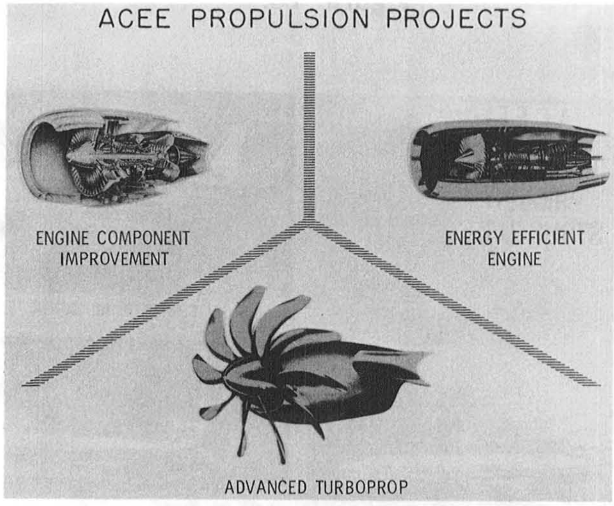


Figure 22.

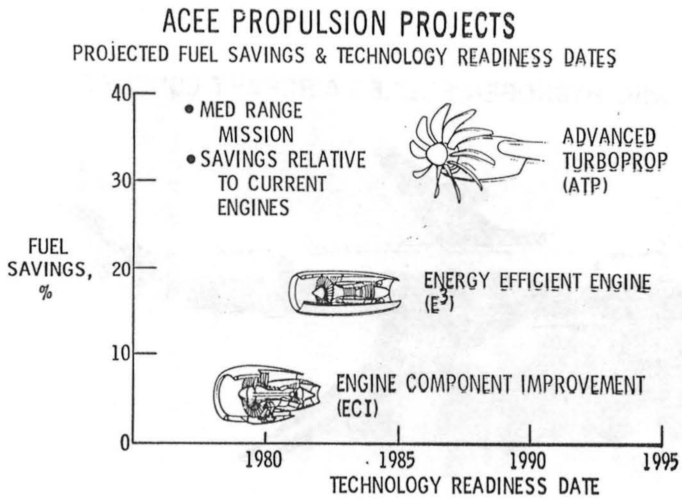


Figure 23.

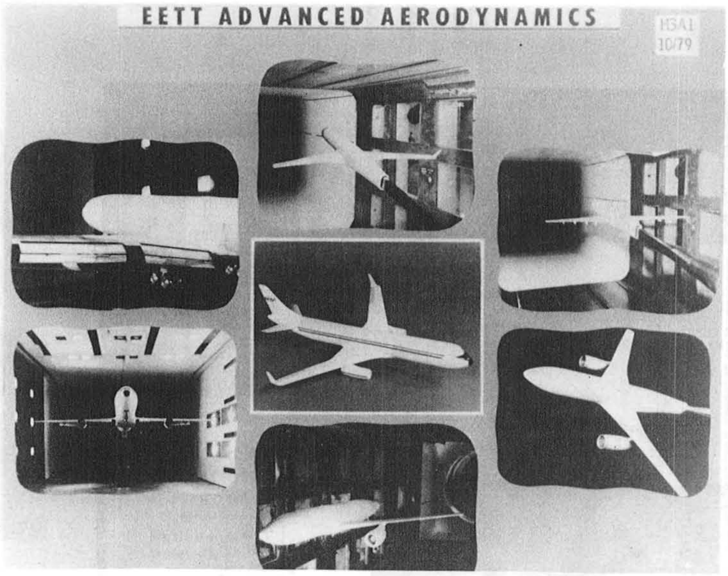


Figure 24.

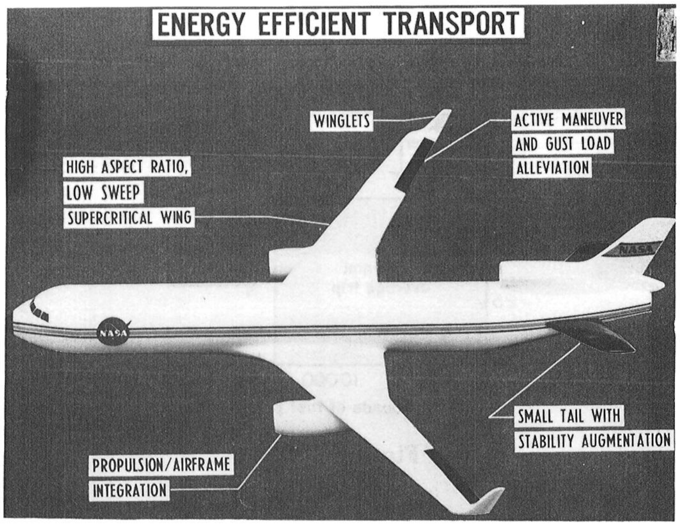


Figure 25.

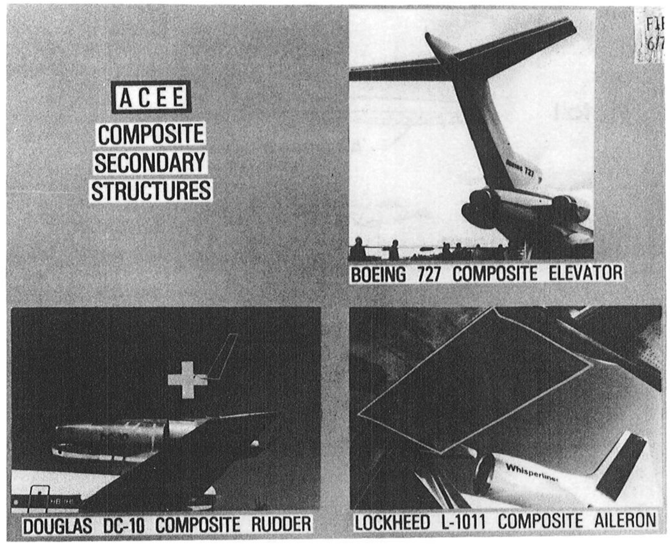


Figure 26.

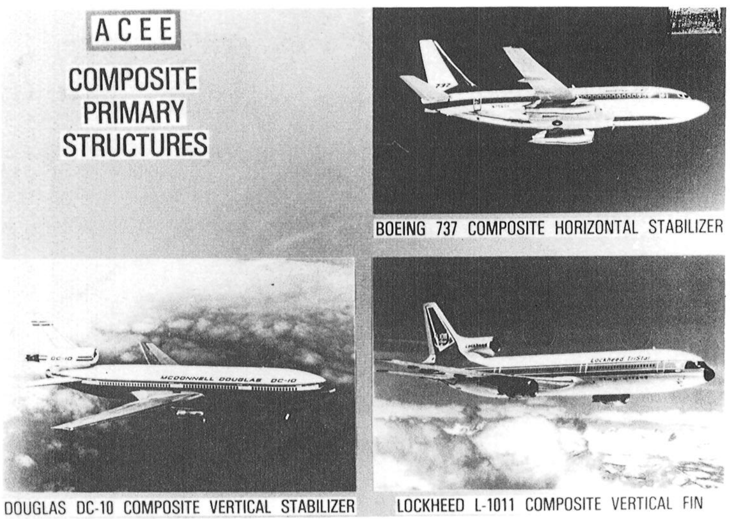


Figure 27.

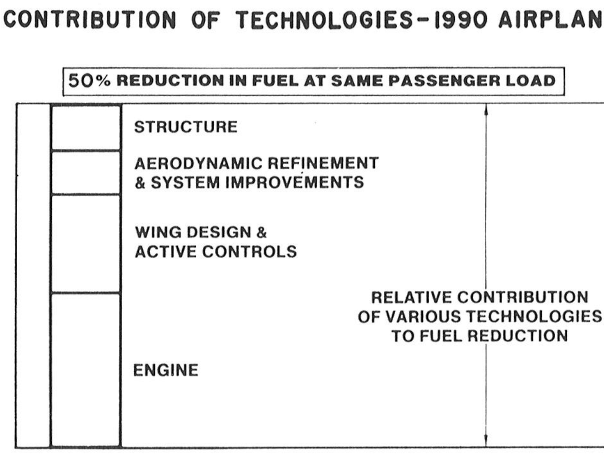


Figure 28.

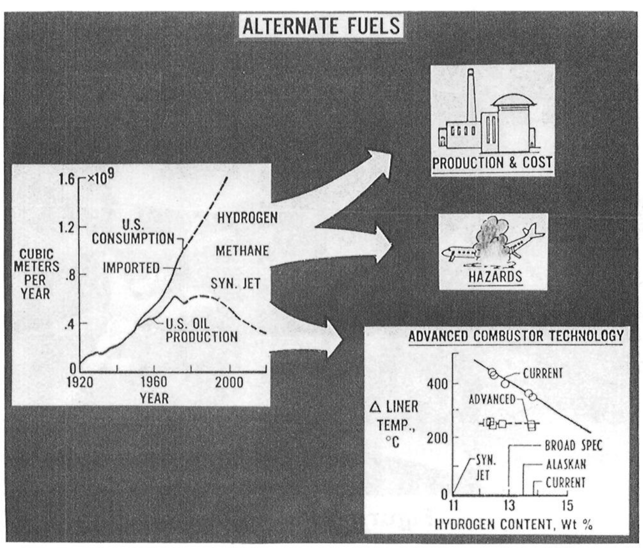


Figure 29.

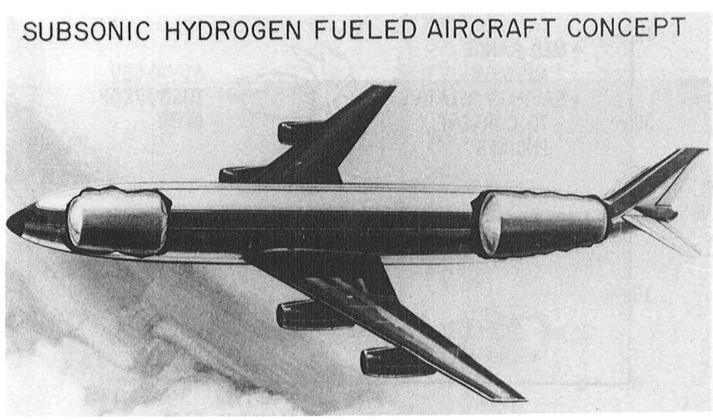
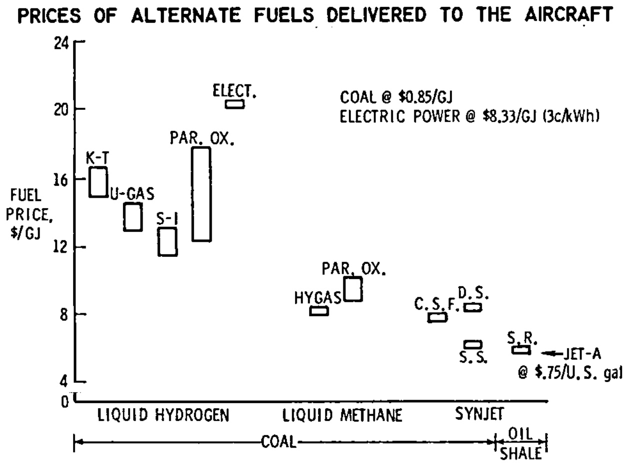


Figure 30.



PRICES OF ALTERNATE FUELS DELIVERED TO THE AIRCRAFT
FUEL PRICE, $/GJ
24
20
16
12
8
4
0
ELECT.
COAL @ $0.85/GJ
ELECTRIC POWER @ $8.33/GJ (3c/kWh)
PAR. OX.
K-T
U-GAS
S-I
PAR. OX.
HYGAS
C.S.F.
D.S.
S.S.
S.R.
JET-A @ $.75/U.S. gal
LIQUID HYDROGEN
LIQUID METHANE
SYNJET
COAL
OIL SHALE

Figure 31.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-81793		

4. Title and Subtitle	5. Report Date
THE ROLE OF TECHNOLOGY AS AIR TRANSPORTATION FACES THE FUEL SITUATION	March 1980
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Cornelius Driver	
9. Performing Organization Name and Address	10. Work Unit No.
NASA Langley Research Center Hampton, Virginia 23665	530-04-13-01
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics & Space Administration Washington, DC 20546	Technical Memorandum
	14. Army Project No.

15. Supplementary Notes

Paper presented at Upper Midwest Council, Minneapolis, Minnesota, Nov. 1, 1979.

16. Abstract

A brief perspective of the air transportation situation are discussed including intercity air traffic, airline fuel consumption, fuel price effects on ticket price, and projected traffic and fuel useage between now and the year 2000. Actions taken by the airlines to reduce fuel consumption are reviewed, as well as efforts currently underway to improve fuel consumption, including derivative and new aircraft. Longer-range technology payoffs resulting from NASA research programs are briefly reviewed, as well as results of existing studies on the use of alternate fuels. Substantial fuel savings have already been achieved and significant further improvements can be expected.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Subsonic Commercial Transport Aircraft Intercity Air Traffic Airline Fuel Consumption Fuel Price Effects Fuel Useage	UNCLASSIFIED - UNLIMITED Subject Category 05

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED	13	$4.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161

DO NOT REMOVE SLIP FROM MATERIAL

Delete your name from this slip when returning material to the library.

NAME	DATE	MS
M. Szyskowski	6/2	406

NASA Langley (Rev. Dec. 1991) RIAD N-75