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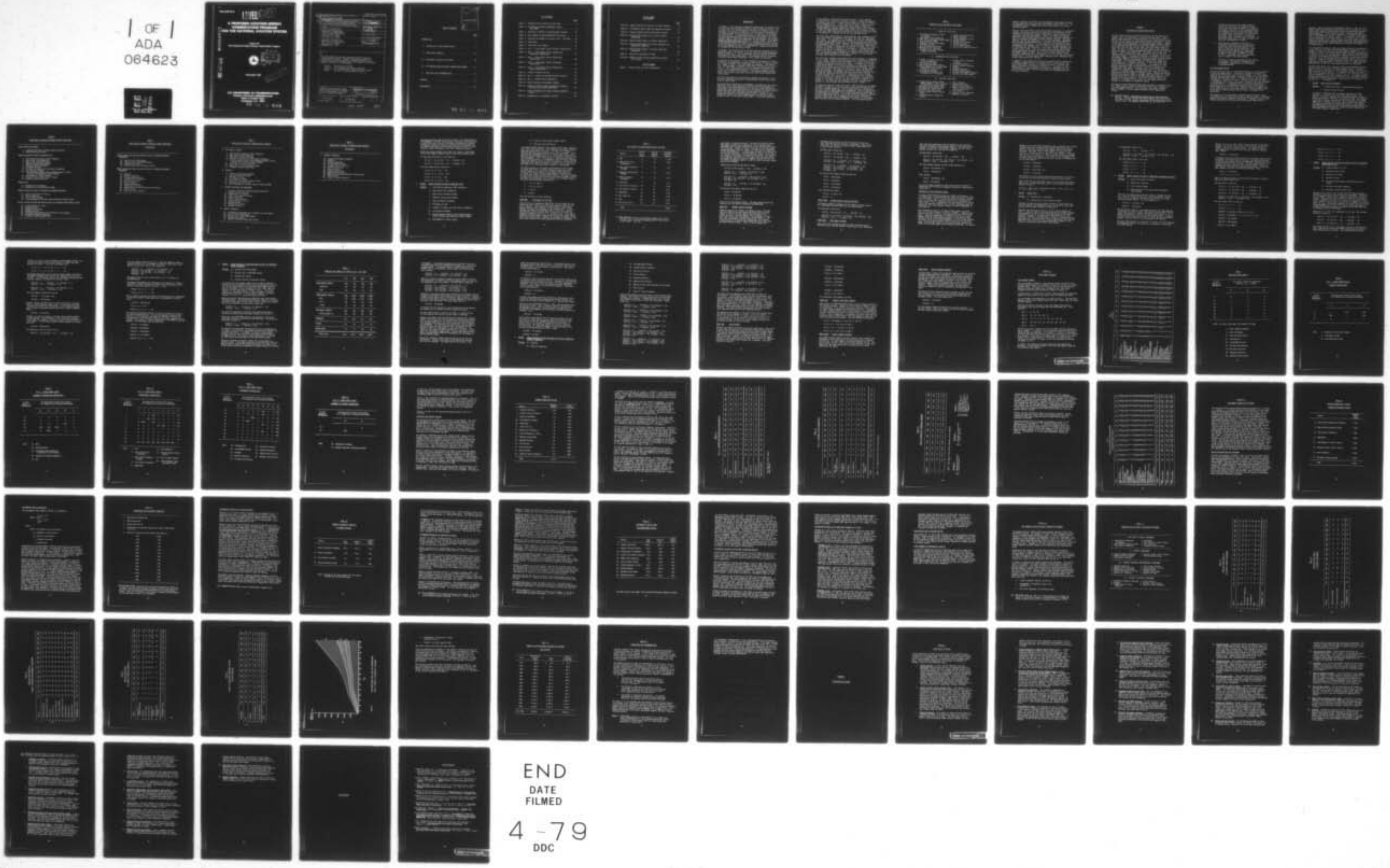

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A PROPOSED AVIATION ENERGY CONSERVATION PROGRAM FOR THE NATIONAL AVIATION SYSTEM

Volume III

The Proposed Aviation Energy Conservation Program

November 1978

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
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16. Abstract

This study presents an overview of potential options for improving aviation energy efficiency. Included in the proposed program are alternatives that could be pursued by the Federal Government as well as options that could be adopted by the various segments of the aviation industry. The report is in four volumes:

Volume I - The Short Run, 1977-1978
Volume II - The Intermediate and Long Run, 1979-1990
Volume III- The Proposed Aviation Energy Conservation Program
Summary - Overview of preceding technical volumes.

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Aviation Energy Conservation Program; Revenue Ton-Miles Per Gallon (RTM/G); Policy Evaluation Model, Cross-Impact Analysis; Cost/Benefit Analysis

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INTRODUCTION

In Volume I, a six step policy generation methodology was introduced and utilized to analyze options to improve aviation energy efficiency. The six steps are: (1) Clarification of the Goal, (2) Progress in Fuel Conservation, (3) Analysis of Conditions, (4) Projection of Developments, (5) Identification of Policy Options, and (6) Synthesis and Evaluation of Policy Options. The underlying motives for the analysis are many, including the national policy goal of energy conservation, the airline economic usage of high-priced petroleum, and the mandates of the Energy Policy and Conservation Act of 1975 (P.L. 94-163) (EPCA). While the latter served to focus this study, via the mandated 10 percent increase in energy conservation, the analysis was extended beyond the 10 percent goal of the EPCA and results in a comprehensive, proposed program which is designed for maximum energy savings.

In Volume I, the Clarification of the Goal analysis concluded that the appropriate goal to guide this study and future FAA energy conservation planning should be to: maximize Revenue Ton Miles per Gallon (RTM/G) consistent with other agency goals. The proposed Aviation Energy Conservation Program (AECP) developed in this volume has that goal.

As reported in the Progress in Fuel Conservation discussion of Volume I, substantial improvement has occurred in RTM/G since 1972 after a period of six years in which little improvement was detected. From 1966 to 1971, RTM/G averaged 1.73 annually with minor fluctuations from year to year. In 1972, RTM/G climbed to 1.90 and reached an estimated 2.32 in 1976. This improvement represents a 34 percent increase in efficiency over the 1966 to 1971 measure. The proposed program developed herein would preserve the gains to date and raise future energy efficiency values.

The third step, Analysis of Conditions, defined the technical, socio-political, economic, regulatory, and operational factors which significantly impact RTM/G.

The fourth step, Projection of Developments, concluded that the factors identified in the third step were such that further improvements in RTM/G would not be forthcoming unless an aviation energy conservation program were instituted specifically for the purpose of achieving energy conservation gains above the gains already realized since 1972. Of course, the technical, socio-political, economic, regulatory, and operational factors will differ depending upon the specific scenario assumed to exist for the next several years. To test the sensitivity of the analysis, three scenarios were put forth: a most probable ("surprise-free") scenario, a potential scenario in which the emphasis on energy conservation is reduced, and an uncertain scenario in which a new oil embargo occurs. It was found that at least in the short run, the most probable scenario would show little change in RTM/G, the reduced emphasis on energy conservation scenario would show a decline in RTM/G, and the embargo scenario would show a mild increase in RTM/G. At any rate, RTM/G could not be expected to rise much in the near future in the absence of a program such as the one developed herein.

The fifth step, Identification of Policy Options, was conducted for the short (1977-1978), intermediate (1979-1981), and long run (1982-1990) time frames. The selection of the breakdown as to short, intermediate, and long run was somewhat arbitrary, reflecting time periods within which primarily operational, airport capacity, and technological options could be implemented, respectively. The short run options were identified in Chapter V of Volume I, intermediate run options in Chapter I of Volume II, and long run options in Chapter III of Volume II. The identification process consisted of a description of the impact of each option upon RTM/G if the option were implemented in isolation from all other options. Thus, the impact estimates are maximums. Chapter II of this volume evaluates the nonadditivity of the options.

The sixth step, Synthesis and Evaluation of Policy Options, is completed in this volume. Although a detailed evaluation of options was conducted in prior volumes within stated time frames, this volume describes the synthesis and evaluation across time frames. In Chapter VI of Volume I, a detailed evaluation of the short run options was undertaken and the timing of the impacts over the 1977-1978 period was estimated. Options which significantly conflicted with FAA safety, noise, or emissions goals were deleted. For example, the short run option "Decrease IFR Spacing" was judged to compromise safety and was deleted from the list of potential options for the Aviation Energy Conservation Program, leaving seventeen short run options as candidates for such a program. A similar analysis was conducted for the intermediate run options in Chapter II of Volume II and for the long run options in Chapter IV of Volume II. The result was the seventeen short run, fourteen intermediate run, and thirteen long run options listed in Table 1.

The forty-four options listed (forty-two if RNAV and WVAS are not double counted) are inputs to an aviation energy conservation program and do not form a program themselves. The six step process has successfully served as a policy option generation methodology. Now, the options must be synthesized and integrated into an optimal program for maximizing aviation energy conservation. Two further steps are needed to translate the forty-two options into a proposed Aviation Energy Conservation Program. These steps are not independent and consist of Cross-Impact Matrix Analysis and Cost-Benefit Analysis. The Cross-Impact Matrix

TABLE 1

POTENTIAL POLICY OPTIONS BY TIME FRAME

I. SHORT RUN (1977-1978)

- Fuel Advisory Departure (FAD) Procedures
- Wake Vortex Class Sequencing
- Wake Vortex Avoidance Systems (WVAS)
- Area Navigation (RNAV)
- Temporary Construction Runways
- GA Runways at Hubs
- Snow-Ice Removal Equipment
- Maximum Use of Simulators
- Increase Load Factor Through Capacity Restraint
- Reseat Existing Aircraft
- Reduce Tankering
- Climb Procedures in TCA's
- Optimum Descent
- Optimum Cruise Speed
- Optimum Altitude
- Taxi on Fewer Engines
- Load to Aft Center of Gravity

II. INTERMEDIATE RUN (1979-1981)

- Terminal, En Route, and Flow Control Automation
- Area Navigation (RNAV)
- Wake Vortex Avoidance Systems
- Ground Movement of Aircraft Under Alternative Power Sources
- Fog Dispersal Systems
- Performance Measurements and Evaluation for Jet Engines
- Retrofit With JT10D/CFM56 Engines
- Derivative Aircraft
- Lighter-Than-Air Vehicles
- Winglets
- Wingtip Extensions
- Aft Body Modifications
- On-Board Performance Computers
- Retrofit with JT8D Engines

III. LONG RUN (1982-1990)

- Discrete Address Beacon System (DABS)/Automatic Traffic Advisory and Resolution System (ATARS)
- Microwave Landing Systems (MLS)
- Post-UG3RD Air Traffic Control
- STOL-Ports and STOL-Strips
- Airport Surface Traffic Control (ASTC)
- Digital Electronic Propulsion Control
- Active Controls
- Composite Materials
- Supercritical Airfoils
- Replace Aircraft With New Near Term Aircraft
- STOL Aircraft
- Large Air Cargo Transports
- Advanced Jet Engines

Analysis quantifies the effects of each potential option upon all others and then quantifies the joint impact upon RTM/G of each option set. The Cost-Benefit Analysis compares the cost of each option to its (cross-impacted) benefits.

The use of the two criteria raises two potential approaches to a proposed program. One approach would be to select the (cross-impacted) option combination with the most favorable cost benefit ratio consistent with achieving a specified improvement in RTM/G. For example, the option combination with the most favorable cost benefit ratio that achieves at least a 10 percent improvement in RTM/G could be selected. The other approach, and the one used herein, is to select the option combination with the most favorable RTM/G impact consistent with achieving a specified cost-benefit ratio. The cost-benefit ratio constraint could be interpreted as an aggregate ratio for the entire options package or as an individual one for each option. The latter, stricter interpretation is used in this study. Thus, the process used to select the aviation energy conservation program is to select the options combination with the highest impact on RTM/G, then to verify if every option in that particular combination has a cost-benefit ratio of less than one (benefits exceed costs). As stated above, these steps may not be independent and several iterations may be required.

In Chapter I, the options are structured by organizational grouping and by method of impact and the cross-impact matrix is constructed. The Cross-Impact Matrix Analysis is conducted in Chapter II and the Cost-Benefit constraint is evaluated in Chapter III. In Chapter IV, the proposed Aviation Energy Conservation Program is generated and a forecast of RTM/G is made. Finally, conclusions and recommendations are provided in Chapter V.

CHAPTER I

SETTING UP THE CROSS-IMPACT MATRIX

The fuel impact of each of the forty-two policy options identified in Volumes I and II was evaluated in isolation from the others. These impact values are useful in providing inputs for decision analysis, but they are not sufficient for selecting the optimal combination of options to serve as the proposed Aviation Energy Conservation Program. Indeed, if the options were independent, the proposed program would be composed of all forty-two options with the result that RTM/G would be 48.34 per cent higher than the 1976 value by 1985, and 65.84 percent higher by 1990! The fact is, however, that the option impacts cannot be added to obtain the impact of a program composed of some or all of the individual options. Options impact each other. The effect might be that the impact of two or more options taken together is less than the sum of the individual impacts. This would be the case, for example, of the short run options, Temporary Construction Runways and General Aviation Runways. Each enhances RTM/G in the same way, by raising airport capacity to reduce delay. The individual impacts by 1978 are 0.30 percent and 1.07 percent and 1.37 percent, inclusive. On the other hand, some options enhance each other's effectiveness. For example, the intermediate run options, RNAV and On-Board Performance Computers, have maximum individual impacts on RTM/G by 1981 of 2.00 percent and 1.50 percent, respectively. The RNAV impact value of 2.00 percent, however, is a maximum value and depends critically upon the aircraft's being able to strictly adhere to the RNAV routes. Without the on-board computer, the impact of RNAV in isolation would more likely be 1.6 percent as the full utilization of the RNAV route system would not be feasible with present avionics. The actual individual impacts are, therefore, 1.6 percent and 1.5 percent, but the impact of the two together is 3.5 percent, a synergistic result.

The impacts of the forty-two options upon each other is evaluated in the next chapter using a technique called Cross-Impact Matrix Analysis or just Cross-Impact Analysis. The technique is discussed in greater detail elsewhere [1] but the general approach can be summarized as follows:

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[1] Joseph P. Martino, Technological Forecasting for Decisionmaking, New York: American Elseviar Publishing Company, 1972, pp. 271-281, and James R. Bright, A Brief Introduction to Technology Forecasting, Austin, Texas: The Pemaquid Press, 1972, pp. 11-1 to 11-17.

1. A matrix of pair-wise cross impact values is constructed indicating the percentage change in and/or time phase delay of option i on option j. For example, the effect of the "On-Board Performance Computer" option on the option "RNAV" could be represented by "+25 percent," indicating that the former raises the value of the second by 25 percent (from 1.6 percent to 2.0 percent). No time phase effect exists (it does not speed up or delay the implementation of RNAV).

2. Every possible combination of options is processed by applying the cross-impact matrix to the base case (individual option value) matrix using every option combination. Note that for forty-two options, this would mean evaluating about 4,398 billion combinations of options (the number of subsets is given by 2^{42}). Fortunately, there are some shortcuts, discussed in the next chapter.

3. The set(s) of options producing the best results is selected. The concepts of dominance and intertemporal comparability are incorporated as discussed below.

The Cross-Impact Matrix

The most difficult task in a Cross-Impact Analysis is the construction of the cross-impact matrix. The matrix is composed of 1,764 cells (being 42 by 42) with each cell having two numbers. The first number indicates the percentage impact of option i on option j and the second indicates the time phase shift. For example, the i-j cell may have "-20 percent, +5 years" as an entry. This would mean that if option i is implemented, then option j will begin five years later than indicated in the base matrix. An important rule in constructing the matrix is that only earlier or contemporaneous options affect later options. Nonoccurrence of an earlier option i means that the cross-impacts of i on all other options is zero in the analysis. Finally, diagonal cells of the matrix, indicating the effect of option i on option i, are meaningless.

The analysis will be conducted by evaluating options from all three time frames with respect to their method of impact on RTM/G. The method analysis of Volume I, Chapter VI and Volume II, Chapters II and IV, are used to partition the forty-two options into seven method sets for analysis. These partitions are presented in Table 2. After the intra-method impacts are determined, each option will be evaluated for cross-impacts with respect to other options within the appropriate organization grouping (Air Traffic Control, Airports, Operating Procedures, Engine Technology, and Aircraft Technology). The organizational groupings of the options are given in Table 3. Then possible cross-impacts will be determined for all other options. For example, Fuel Advisory Departure Procedures will first be analyzed under the method grouping of Reduce Gallons per Hour by Reducing Delay, then under the organizational grouping of Air Traffic Control Options, and finally, with respect to all other options.

For presentational purposes, the cross-impact values will be denoted by r(i,j) and t(i,j) for the level and time impacts, respectively. For example, r(1,29) would be the percentage impact of option 1 on option 29. A value of r(1,29) = +10 percent would indicate that the implementation of option 1 would raise the base matrix value of option 29 by 10 percent. A value of -10 percent would indicate a reduction in the base values for option 29. Also, t(5,8) would be the time phase impact of option 5 on option 8. A value of +2 would mean that option 8 will begin two years later than in the base matrix. Similarly, t(5,8) = -2 means that the implementation of option 5 would speed up option 8 by two years.

The base value matrix will, with one or two slight exceptions detailed below, consist of the values listed in Volumes I and II. The base matrix is a 42 by 14 matrix, for the 42 options and the 14 years (1977-1990 inclusive) of the analysis. The base matrix values for option i in year k will be denoted by b(i,k), k = 77,78,....,90. The b(i,k) value will be cumulative, as it was in Volumes I and II. For example, option 2 "Reseat Existing Aircraft," has a base value of 0.2 percent in 1977 and 0.4 percent in 1978 and thereafter. Thus, b(2,77) = .2, b(2,78) = .4, b(2,79) = .4, ..., b(2,90) = .4.

1. METHOD: RAISE SEATS PER AIRCRAFT

OPTIONS: 1. Increase Load Factor Through Capacity Restraint

2. Reseat Existing Aircraft

In Volume I, these two short run options were noted as being additive; i.e., there is no cross-impact between them. The analysis in Volume I combined their cumulative effects on RTM/G as being 0.55 percent in 1977 and 1.10 percent in 1978. The supporting analysis, however, implied that the distribution of the RTM/G impact was 0.7 percent for option 1 and 0.4 percent for option 2 (increase of 0.6 percent in average load factor). Both options were implemented by the airlines in the early seventies; hence, the remaining impacts upon RTM/G are limited to the 0.7 percent and 0.4 percent impacts, respectively.

TABLE 2

PARTITION OF OPTIONS BY METHOD OF IMPACT UPON RTM/G

RAISE SEATS PER AIRCRAFT

1. Increase Load Factor Through Capacity Restraint
2. Reseat Existing Aircraft

REDUCE GALLONS PER HOUR BY REDUCING DELAY

3. Fuel Advisory Departure (FAD) Procedures
4. Wake Vortex Class Sequencing
5. Wake Vortex Avoidance Systems
6. Temporary Construction Runways
7. Snow-Ice Removal Equipment
8. GA Runways at Hubs
9. Terminal, En Route, and Flow Control Automation
10. Fog Dispersal Systems
11. Discrete Address Beacon System (DABS)/Automatic Traffic Advisory and Resolution System (ATARS)
12. Post-UG3RD Air Traffic Control
13. Airport Surface Traffic Control (ASTC)
14. STOL-Ports and STOL-Strips

REDUCE MILES

15. Maximum Use of Simulators
16. Expand Use of Area Navigation (RNAV)

REDUCE GALLONS PER HOUR BY IMPROVING AIR/GROUND OPERATIONS

17. Load to Aft Center of Gravity
18. Reduce Tankering
19. Taxi on Fewer Engines
20. Ground Movement of Aircraft Under Alternative Power Sources

REDUCE GALLONS PER HOUR AND HOURS PER MILE BY IMPROVING OPERATIONAL SYSTEMS

21. Climb Procedures in TCA's
22. Optimum Descent
23. Optimum Cruise Speed
24. Optimum Altitude
25. Performance Measurement and Evaluation for Jet Engines
26. On-Board Performance Computers
27. Microwave Landing Systems (MLS)

TABLE 2

PARTITION OF OPTIONS BY METHOD OF IMPACT UPON RTM/G

(Continued)

REDUCE GALLONS PER HOUR AND HOURS PER MILE BY IMPROVING ENGINE TECHNOLOGY

28. Retrofit With JT8D Engines
29. Retrofit With JT10D/CFM56 Engines
30. Advanced Jet Engines
31. Digital Electronic Propulsion Control

REDUCE GALLONS PER HOUR AND HOURS PER MILE BY IMPROVING AIRCRAFT TECHNOLOGY

32. Winglets
33. Wingtip Extensions
34. Aft Body Modifications
35. Lighter-Than-Air Vehicles
36. Derivative Aircraft
37. Active Controls
38. Composite Materials
39. Supercritical Airfoils
40. Replace Aircraft With New Near Term Aircraft
41. STOL Aircraft
42. Large Air Cargo Transports

TABLE 3

PARTITION OF OPTIONS BY ORGANIZATIONAL GROUPING

A. AIR TRAFFIC CONTROL

3. Fuel Advisory Departure (FAD) Procedures
4. Wake Vortex Class Sequencing
5. Wake Vortex Avoidance Systems
9. Terminal, En Route, and Flow Control Automation
11. Discrete Address Beacon System (DABS)/Automatic Traffic Advisory and Resolution System (ATARS)
12. Post-UG3RD Air Traffic Control
16. Expand Use of Area Navigation (RNAV)
27. Microwave Landing System (MLS)

B. AIRPORTS

6. Temporary Construction Runways
7. Snow-Ice Removal Equipment
8. GA Runways at Hubs
10. Fog Dispersal Systems
13. Airport Surface Traffic Control (ASTC)
14. STOL-Ports and STOL-Strips
20. Ground Movement of Aircraft Under Alternative Power

C. AIRCRAFT OPERATORS AND MANAGEMENT

1. Increase Load Factor Through Capacity Restraint
2. Reseat Existing Aircraft
15. Maximum Use of Simulators
17. Load to Aft Center of Gravity
18. Reduce Tankering
19. Taxi on Fewer Engines
21. Climb Procedures in TCA's
22. Optimum Descent
23. Optimum Cruise Speed
24. Optimum Altitude

D. ENGINE TECHNOLOGY

25. Performance Measurement and Evaluation for Jet Engines
28. Retrofit With JT8D Engines
29. Retrofit With JT10D/CFM56 Engines
30. Advanced Jet Engines
31. Digital Electronic Propulsion Control

TABLE 3

PARTITION OF OPTIONS BY ORGANIZATIONAL GROUPING

(Continued)

E. AIRCRAFT TECHNOLOGY

26. On-Board Performance Computers
32. Winglets
33. Wingtip Extensions
34. Aft Body Modifications
35. Lighter-Than-Air Vehicles
36. Derivative Aircraft
37. Active Controls
38. Composite Materials
39. Supercritical Airfoils
40. Replace Aircraft With New Near Term Aircraft
41. STOL Aircraft
42. Large Air Cargo Transports

Both options appear under Section C of Table 3, Aircraft Operators and Management. Neither option affects Simulators, Optimum Descent, or any of the other options listed under the operational heading. Furthermore, there is no reason to believe that either option has any significant effect on the options from the Air Traffic Control, Airports, Engine Technology, or Aircraft Technology headings.

These two options present a pure case, as it were, in that there are no cross-impacts between either of them and any other option.

For the base value matrix, the values are:

$b(1,77) = .35,\ b(1,78) = .70\ \ldots,\ b(1,90) = .70$

$b(2,77) = .20,\ b(2,78) = .40\ \ldots,\ b(2,90) = .40$

The cross-impact matrix values are:

$r(1,j) = 0,\ j = 2,3,\ldots\ldots,42$

$r(2,j) = 0,\ j = 1,3,4,\ldots\ldots,42$

$t(1,k) = 0,\ k = 2,3,\ldots\ldots,42$

$t(2,k) = 0,\ k = 1,3,4,\ldots,42$

2. METHOD: REDUCE GALLONS PER HOUR BY REDUCING DELAY

OPTIONS:

3. Fuel Advisory Departure (FAD) Procedures
4. Wake Vortex Class Sequencing
5. Wake Vortex Avoidance Systems
6. Temporary Construction Runways
7. Snow-Ice Removal Equipment
8. GA Runways at Hubs
9. Terminal, En Route, and Flow Control Automation
10. Fog Dispersal Systems
11. Discrete Address Beacon System (DABS)/Automatic Traffic Advisory and Resolution System (ATARS)
12. Post-UG3RD Air Traffic Control

13. Airport Surface Traffic Control (ASTC)

14. STOL-Ports and STOL-Strips

This impact method grouping is the largest of the seven, representing 12 of 42 policy options. Some important facts about aviation delay were established in Volume I. In Table 13 of Volume I, total CY-1975 delay was estimated at 30.3 million minutes. Using the B727 fuel consumption rate of 19.1 gallons per minute, estimated 1975 delay-related fuel burn is 7.4 percent of the 1975 total fuel consumption. The critical point for analytical purposes is that all twelve options, if implemented, could not have a combined impact upon RTM/G in excess of about 7.4 percent. In Table 4, the individual fuel impacts estimated in Volumes I and II are listed. The total of the individual option impacts is 6.40 percent.

The twelve options can be further partitioned into four groups: (1) those that affect or control acceptance rates for a given airport capacity, (2) those that increase airport capacity, (3) those that affect airport runway weather conditions, and (4) those that attack the wake vortex problem. The fourth category of wake vortex options could logically have been included in any of the three prior groupings, but is broken out for further analysis. The delay-reducing options groupings are:

1. 3, 9, 11, and 12
2. 6, 8, 13, and 14
3. 7 and 10
4. 4 and 5

They are discussed in those groupings.

GROUP ONE: ACCEPTANCE RATE OPTIONS

FAD, Flow Control Automation, DABS/ATARS, and Post-UG3RD ATC each affect the rate at which aircraft can be accepted, given an airport's capacity. FAD transfers airborne delay to ground delay without affecting ATC procedures in the terminal area. In fact, FAD does not change the acceptance rate at airports; it merely redistributes actual aircraft rates to be more in line with the effective acceptance rates for a 1.7 percent saving. Flow Control Automation permits tighter metering and spacing and reduces separations by up to 20 percent. However, as explained in Volume II, the wake vortex options also reduce separations and are, therefore,

TABLE 4

FUEL IMPACTS OF DELAY-REDUCING POLICY OPTIONS

Option	Year of First Impact	Year of Maximum Impact	Maximum Individual Impact
3. FAD	77	78	1.70%
4. Wake Vortex Class Sequencing	77	78	0.40
5. Wake Vortex Avoidance Systems	77	81	1.00
6. Temporary Construction Runways	77	78	0.30
7. Snow-Ice Removal Equipment	77	78	0.13
8. GA Runways	77	78	1.07
9. Flow Control Automation	79	81	0.60*
10. Fog Dispersal Systems	79	81	0.10
11. DABS/ATARS	82	86	0.20*
12. Post-UG3RD ATC	88	90	0.30*
13. ASTC	82	90	0.30
14. STOL-Ports/Strips	82	85	0.30
TOTAL			6.40%

---

*Some nonadditivity has already been accounted for in this estimate; thus, the maximum individual option impact would be even higher. See text.

substitutes (.9 percent overlap). The gross Flow Control Automation impact includes the .9 percent in its 2.5 percent total. DABS/ATARS permits reduced separations as well and net fuel impact of 0.2 percent. However, at least .1 percent of the Flow Control Automation impacts could be viewed as a substitute for DABS/ATARS, so that DABS/ATARS has a .3 percent gross savings in the absence of Flow Control Automation. The Post-UG3RD ATC system has its impact via strategic flow control and metering and spacing. The impact of this option was estimated as 0.30 percent above the other options. Post-UG3RD ATC could in isolation, however, account for half the Flow Control Automation impact, so that its gross individual impact would be 0.60 percent.

Summarizing, we have as base matrix values:

b(3,77) = 0.85, b(3,78) = 1.70,..., b(3,90) = 1.70

b(9,77) = 0, ..., b(9,79) = .50, b(9,80) = 2.08,
b(9,81) = 2.5, ..., b(9,90) = 2.5

b(11,77) = 0, ..., b(11,82) = .02, b(11,83) = .09,
b(11,84) = .21, b(11,85) = .29, b(11,86) = .30, ...,
b(11,90) = .30

b(12,77) = 0, ..., b(12,88) = .10, b(12,89) = .50,
b(12,90) = .60

The nonzero cross-impacts among the four are:

r(3,9) = -36 percent

r(9,11) = -33 percent

r(9,12) = -50 percent

There are no time phasing effects. The wake vortex options also interact with Flow Control Automation and DABS/ATARS.

GROUP TWO: AIRPORT CAPACITY OPTIONS

Temporary Construction Runways, GA Runways at Hubs, and STOL-Ports and STOL-Strips each require the construction of short runways to service aircraft smaller than the typical air carrier aircraft. The fuel impacts of 0.30 percent, 1.07 percent, and 0.30 percent, respectively, are not additive. The first two are essentially perfect substitutes, while either of the two short run options would substitute for perhaps half the STOL-Port/Strip impact. Also, if the GA runways are provided, there would be no need for specific STOL-Strips until 1985 when the STOL aircraft is available. ASTC, on the other hand, is additive and merely reduces ground delay for a given airport capacity.

The base matrix values are:

b(6,77) = .15, b(6,78) = .30, ..., b(6,90) = .30

b(8,77) = .54, b(8,78) = 1.07, ..., b(8,90) = 1.07

b(13,77) = 0, ..., b(13,82) = .01, b(13,83) = .05,
b(13,84) = .09, b(13,85) = .10, ..., b(13,90) = .10

b(14,77) = 0, ..., b(14,82) = .01, b(14,83) = .02,
b(14,84) = .05, b(14,85) = .11, b(14,86) = .18,
b(14,87) = .24, b(14,88) = .28, b(14,89) = .29,
b(14,90) = .30

The nonzero cross-impacts among the four are:

r(8,6) = -100 percent

r(6,8) = -28 percent

r(6,14) = -50 percent

r(8,14) = -50 percent

with time phasing effects

t(6,14) = +3 years, and

t(8,14) = +3

GROUP THREE: AIRPORT WEATHER CONDITION OPTIONS

The Snow-Ice Removal Equipment and Fog Dispersal Systems options are independent from each other and all other options.

The base matrix values are:

b(7,77) = .06, b(7,78) = .13, ..., b(7,90) = .13

b(10,77) = 0, b(10,78) = 0, b(10,79) = .02, b(10,80) = .08,
b(10,81) = .10, ..., b(10,90) = .10

GROUP FOUR: WAKE VORTEX OPTIONS

Wake Vortex Class Sequencing and Wake Vortex Avoidance Systems obviously attack the same problem. Specifically, the 0.40 percent gain from class sequencing could be expected to be included in the gain from WVAS giving a maximum impact for both wake vortex options of 1 percent. Additionally, however, the wake vortex options interact with Flow Control Automation.

The base matrix values are:

b(4,77) = .20, b(4,78) = .40, ..., b(4,90) = .40

b(5,77) = .10, b(5,78) = .20, b(5,79) = .36, b(5,80) = .85
b(5,81) = 1.00, ..., b(5,90) = 1.00

The cross-impacts between the wake vortex options are:

r(4,5) = -40 percent, and

r(5,4) = -100 percent

Also, we have

r(4,9) = -20 percent, and

r(5,9) = -40 percent

to give the impact between the wake vortex option reduction in separations and Flow Control Automation reduction in separations, respectively.

SYNTHESIS OF DELAY-REDUCING OPTIONS

The twelve delay-reducing options are clearly interrelated. It is assumed that all interrelationships among the options have been fully evaluated. That is, groups one and four have been related and it is assumed that groups two and three are independent of other groups. This is reasonable since the capacity of an airport limits, but does not interact with, aircraft acceptance rates or procedures, and airport weather options are quite independent of other options.

With reference to Table 3, the above options appear in either Part A, Air Traffic Control, or Part B, Airports. Indeed, of the eight ATC options of Table 3, only RNAV and MLS are not included above. These are independent of separations and are not cross-impacted with the delay-reducing options. Of the seven airport options of Table 3, only Ground Movement of Aircraft Under Alternative Power and Airport Surface Traffic Control are not included above. These do not interact with group two above; however, the former has a decided impact upon the group one options. The Ground

Movement of Aircraft Under Alternative Power, hereafter Tow Aircraft, option reduces fuel consumed during ground holding delay and in taxiing. Both FAD and Flow Control address both air and ground delay and, therefore, part of their impact is shared with Tow Aircraft. The same is true of the wake vortex options. Forty percent of each prior impact is viewed as ground related delay common with the tow aircraft options. The effect of fuel consumption due to ground delay being removed by the prior options is accounted for by the cross-impacts:

r(3,20) = -20 percent,

r(4,20) = -5 percent,

r(5,20) = -10 percent, and

r(9,20) = -20 percent

The effect of aircraft towing upon the above options is discussed in the later section containing the discussion of that option.

None of the above options impact upon aircraft operator and management options, engine technology options, nor aircraft technology options in Table 3.

All r(i,j) impacts not listed above are zero. Also, t(i,j) = 0, i = 3,4,...,14, j = 1, ..., 42.

3. METHOD: REDUCE MILES

OPTIONS: 15. Maximum Use of Simulators

16. Expand Use of Area Navigation (RNAV)

Simulator use does not affect RNAV, nor does it impact either the aircraft operator and management options of Table 3 or any of the options from the other sections of that table.

RNAV does not impact any of the Air Traffic Control options of Table 3. However, RNAV is affected by option 26, On-Board Performance Computers, of the Aircraft Technology section of the table. Without the computer, the maximum gain from RNAV could not be achieved. Instead, an ultimate gain of about 1.6 percent would be more realistic. The base matrix value is adjusted for this and the beneficial impact from the on-board performance computer is discussed in the analysis pertaining to that option.

The base matrix values are:

b(15,77) = .10, ..., b(15,90) = .10

b(16,77) = 0, b(16,78) = .20, b(16,79) = .80, b(16,80) = 1.45,
b(16,81) = 1.60, ..., b(16,90) = 1.60

The cross-impact matrix values are:

r(15,j) = 0, j = 1, ..., 42

r(16,j) = 0, j = 1, ..., 42

t(15,k) = 0, k = 1, ..., 42

t(16,k) = 0, k = 1, ..., 42

4. METHOD: REDUCE GALLONS PER HOUR BY IMPROVING AIR/GROUND OPERATIONS

OPTIONS:
17. Load to Aft Center of Gravity
18. Reduce Fuel Tankering
19. Taxi on Fewer Engines
20. Ground Movement of Aircraft Under Alternative Power Sources

The only cross-impact among the four options is between the last two. They are complete substitutes in that option 20 is essentially taxi on no engines and part of the gain from 20 is that which was gained from 19. The cross-impacts are:

r(19,20) = -5 percent, and

r(20,19) = -100 percent

Notice that the rules for cross-impact analysis have been modified in that option 20 begins later than option 19 (only earlier options affect later options). However, the tow aircraft option is, in a sense, an extension of the Taxi on Fewer Engines option. Certainly, the gains from 19 would be nullified if option 20 were instituted; however, the gains from 19 can be acquired in the interim.

The first three options are from Part C of Table 3, Aircraft Operator and Management Options, and option 20 is from Part B of the table on airport options.

Options 17-19 do not affect other Aircraft Operator and Management options, nor do they affect options from the other sections of Table 3. Option 20 is another matter. The towing of aircraft would make Airport Surface Traffic Control, option 13, meaningless. Hence,

$r(20,13) = -100$ percent

Furthermore, option 20 could prevent all of the gains from increased acceptance rates (delay-reducing options) from being realized due to the fact that towing aircraft consumes more time than having the aircraft move under their own power. Without further study, it is impossible to exactly quantify the repressing effect that towing aircraft would have upon the reduced spacing options. Thirty percent, however, would be a conservative estimate. Hence,

$r(20,j) = -30$ percent,

$j = 3, 4, 5, 6, 9, 11, 12$

Again, the peculiar nature of option 20 has resulted in relaxing the prior option effect rule.

The base matrix values are:

$b(17,77) = .10,\ b(17,78) = .20,\ \ldots,\ b(17,90) = .20$

$b(18,77) = .15,\ b(18,78) = .30,\ \ldots,\ b(18,90) = .30$

$b(19,77) = .10,\ b(19,78) = .20,\ \ldots,\ b(19,90) = .20$

$b(20,77) = 0,\ b(20,78) = 0,\ b(20,79) = .62,\ b(20,80) = 3.03,$
$b(20,81) = 3.70,\ \ldots,\ b(20,90) = 3.70$

The cross-impact matrix values are:

$r(17,j) = 0,\ j = 1, \ldots, 42$

$r(18,j) = 0,\ j = 1, \ldots, 42$

$r(19,20) = -5$ percent, $r(19,j) = 0,\ j = 20$

$r(20,j) = -30$ percent, $j = 3, 4, 5, 6, 9, 11, 12$

$r(20,13) = -100$ percent

$r(20,19) = -100$ percent

$r(20,j) = 0$ all other j

t(17,j) = 0, j = 1, ..., 42

t(18,j) = 0, j = 1, ..., 42

t(19,j) = 0, j = 1, ..., 42

t(20,j) = 0, j = 1, ..., 42

5. IMPACT: REDUCE GALLONS PER HOUR AND HOURS PER MILE BY IMPROVING OPERATIONAL SYSTEMS

OPTIONS:
21. Climb Procedures in TCA's
22. Optimum Descent Profile
23. Optimum Cruise Speed
24. Optimum Altitude
25. Performance Measurement and Evaluation for Jet Engines
26. On-Board Performance Computers
27. Microwave Landing Systems (MLS)

Options 21, 23, and 24 refer to more fuel-efficient operation of existing aircraft within the existing ATC environment. Options 22 and 27 together comprise what is generally referred to as optimal descent. Option 22 by itself achieves an impact of 0.6 percent; whereas, combined with option 27 it achieves an impact of 2.6 percent. Options 25 and 26 deal with the use of computers in aviation. Option 25 uses a ground-based computer to evaluate the fuel consumption performance of aircraft and to detect engine deterioration. On-Board Performance Computers are used to assist the flight crew in optimizing aircraft performance.

Options 21, 23, and 24 are independent of the other four and have base matrix values of:

b(21,77) = .08, b(21,78) = .16, ..., b(21,90) = .16

b(23,77) = .35, b(23,78) = .70, ..., b(23,90) = .70

b(24,77) = .32, b(24,78) = .65, ..., b(24,90) = .65

These three options do not cross-impact with any of the remaining four, although the on-board performance computer would make the three options easier to achieve. The three options are under

Section C of Table 3, Aircraft Operator and Management options and do not affect other options under Section C or under the other sections of Table 3. Thus, the cross-impacts are:

r(i,j) = 0; i = 21, 23, 24; j = 1, ..., 42

t(i,j) = 0; i = 21, 23, 24; j = 1, ..., 42

Performance Measurement and Evaluation Program (PMEP) and On-Board Performance Computers both improve fuel utilization by existing aircraft. The Performance Computer can completely perform the PMEP function; whereas, the reverse is not true. Thus,

b(25,77) = 0, ..., b(25,79) = .12, b(25,80) = .57,
b(25,81) = .70, ..., b(25,90) = .70

b(26,77) = 0, ..., b(26,79) = .25, b(26,80) = 1.23,
b(26,81) = 1.50, ..., b(26,90) = 1.50

The cross-impacts between the two are:

r(25,26) = - 47 percent, and

r(26,25) = -100 percent

However, whereas the PMEP does not affect either MLS or Optimum Descent, the Performance Computer does. By providing the flight crew with real-time flight information, the Performance Computer would improve the Optimum Descent results by at least 10 percent. Hence,

r(26,22) = +10 percent

Finally, as stated in Volume II, the MLS option greatly enhances Optimum Descent. The enhancement in that volume was separately listed under MLS, however, the effect is more accurately shown as a cross-impact. The MLS option enhances Optimum Descent by a factor of 4, or

r(27,22) = +400 percent

The base matrix value for option 22 is:

b(22,77) = .30, b(22,78) = .60, ..., b(22,90) = .60

The cross-impact raises this to 2.4. Given the composite impact of options 22 and 27 of 2.6 estimated in Volume II, this gives a base matrix value for MLS, net of cross-impacts of:

b(27,77) = 0, ..., b(27,82) = .01, b(27,83) = .01,
b(27,84) = .03, b(27,85) = .07, b(27,86) = .13,
b(27,87) = .16, b(27,88) = .19, b(27,89) = .19,
b(27,90) = .20

The impact of MLS is not as much direct, as it is indirect via Optimum Descent.

Performance Measurement and Evaluation for Jet Engines is listed in Section D of Table 3 and does not affect the other options of that section or any other options of Table 3. Thus,

r(25,j) = 0, j = 1, ..., 42

t(25,j) = 0, j = 1, ..., 42

MLS is listed in Section A of Table 3 (ATC options) and is independent of the other options listed there and in the remainder of Table 3. Thus,

r(27,22) = +400 percent

r(27,j) = 0, j = 22

t(27,j) = 0, j = 1, ..., 42

The On-Board Performance Computer is listed in Section E of Table 3, Aircraft Technology options. It could be expected to enhance both option 37, Active Controls, and option 40, New Near Term Aircraft. The magnitude of the enhancement might well be small, however, and is ignored in the analysis. The main enhancement is for RNAV and Optimum Descent. The cross-impact matrix values are:

r(26,16) = +25 percent

r(26,22) = +10 percent

r(26,25) = -100 percent

r(26,j) = 0, all other j

t(26,j) = 0, j = 1, ..., 42

6. METHOD: REDUCE GALLONS PER HOUR AND HOURS PER MILE BY IMPROVING ENGINE TECHNOLOGY

OPTIONS: 28. Retrofit With JT8D Engines

29. Retrofit With JT10D/CFM56 Engines

30. Advanced Jet Engines

31. Digital Electronic Propulsion Control

To evaluate the cross-impacts among the four engine technology options and the succeeding eleven aircraft technology options, the air carrier fleets used in the individual option impact analysis must be considered. Table 5 presents the 1975, 1980, 1985, and 1990 air carrier fleets used in Volumes I and II. This fleet forecast is a baseline forecast in that it assumes no retrofit/modification, derivative, or new aircraft programs. The fleet forecast is for all U.S. trunk and regional carriers.

Option 28 involves retrofitting the B707/DC-8 fleet with refanned JT8D-209 engines. The 1980 baseline B707/DC-8 fleet of 515 aircraft was used for the analysis and a total retrofit program was assumed. Given that assumption, the base matrix values are:

b(28,77) = 0, ..., b(28,79) = .58, b(28,80) = 1.16,
b(28,81) = 1.75, ..., b(28,90) = 1.75

The retrofit program was assumed to delay 4ENB replacements by extending the depreciation/retirement schedule by five years.

Option 29, the JT10D/CFM56 retrofit, was assumed to include all Two-Engine Turbojets and B727W from the 1980 fleet. The resulting base matrix values are:

b(29,77) = 0, ..., b(29,79) = 1.66, b(29,80) = 3.32,
b(29,81) = 4.96, ..., b(29,90) = 4.96

The depreciation/retirement schedules would also be lengthened by five years. The effects of the change in depreciation schedule can be quite significant. For example, in Table 5 the two-engine turbojet fleet declines from 720 to 497 between 1980 and 1985 in the baseline case. The retrofit option would result in the 1980 and 1985 fleets being the same for the retrofitted aircraft.

Option 30, Advanced Jet Engines, should also be evaluated as a retrofit option. The engines would not be available until 1985 and would be used to replace 1975 technology engines (the 1960's technology engines would have disappeared, by engine retrofit or aircraft

TABLE 5

BASELINE (NO CHANGE) AIR CARRIER FLEET, 1975-1990

	1975	1980	1985	1990
FOUR-ENGINE TURBOJET	632	615	541	467
B707/DC-8	528	515	367	220
B747	104	100	174	247
THREE-ENGINE TURBOJET	923	1,234	1,622	2,009
B727	747	1,024	1,131	1,238
DC-10	108	125	272	420
L-1011	68	85	219	351
TWO-ENGINE TURBOJET	523	720	497	274
B737/DC-9/BAC-111	523	720	497	274
TURBOPROP	266	263	261	259
PISTON	118	60	40	25
ROTARY-WING	10	15	20	20
TOTAL FLEET	2,472	2,907	2,981	3,054

replacement). The advanced engines would, therefore, have only a 10 percent specified fuel consumption advantage over current technology engines. A 20 percent retrofit, aimed primarily at the B747/DC-10/L-1011 wide-bodies, would produce the following base matrix values:

b(30,77) = 0, ..., b(30,86) = .12, b(30,87) = .57,
b(30,88) = 1.41, b(30,89) = 1.88, b(30,90) = 2.00

Option 31, Digital Electronic Propulsion Control (DEPC), involves the replacement of current technology hydromechanical controls with microcomputers built into engines. The base matrix values are:

b(31,77) = 0, ..., b(31,82) = .06, b(31,83) = .13,
b(31,84) = .33, b(31,85) = .73, b(31,86) = 1.27,
b(31,87) = 1.60, b(31,88) = 1.87, b(31,87) = 1.60,
b(31,88) = 1.87, b(31,89) = 1.94, b(31,90) = 2.00

Options 28, 29, and 30 involve the retrofitting of different aircraft categories (B707/DC-8, B737/DC-9/B727, and B747/DC-10/L-1011, respectively); hence, there are no cross-impacts among the three. Options 30 and 31 do cross-impact, however, since the advanced jet engines would have DEPC built into them. The cross-impact value is

r(31,30) = -20 percent

to account for the 2 percent of the 10 percent gain with advanced jet engines due to digital electronic propulsion control.

The only other option in Section D of Table 3 is option 25 and no cross-impacts with the four options above is expected.

However, the engine retrofit/modification programs would strongly impact the Derivative Aircraft and New Near Term Aircraft options. The five year extension in life given to each aircraft which had been reengined would mean that the aircraft would not be subject to replacement. The derivative aircraft option involved replacement of 25 percent of the B737/DC-9 fleet, 40 percent of the B707/DC-8 fleet, and replacement of new order B747/DC-10. The impacts of the three derivative options are .38 percent, 3.43 percent, and .66 percent, respectively. The new near term aircraft option assumed complete B707/DC-8 replacement and replacement of half of the B727 fleet.

Option 28, therefore, affects both the derivative and new near term options. Seventy-five percent of the derivative aircraft gain would be impacted. The impact would involve both a time phase and a percentage impact effect. The combined effects would be approximately a two year delay for the aircraft other than the B707/DC-8 and a five year delay for the B707/DC-8. The effects can be approximated by:

r(28,36) = -50 percent

t(28,36) = +3

The effect of option 28 on the new near term aircraft would be due to the effect upon the B707/DC-8 fleet. Essentially, the B707/DC-8 replacement would be delayed five years with other replacements not affected. From Table 5, this would mean that when replacement finally occurred, fewer aircraft would be replaced. The effects can be approximated by:

r(28,40) = -40 percent

t(28,40) = +3

No other cross-impacts would be significant, although the initiation of an engine retrofit program might increase slightly the probability of other retrofit options (e.g., supercritical wings).

Option 29, the JT10D/CFM56 retrofit, affects the two-engine turbojet and B727 fleets. Thus, it impacts upon both the derivative and new near term aircraft options by totally substituting for the B737/DC-9 replacement, but to otherwise leaving the option unaffected. Thus,

r(29,36) = -10 percent

and all other cross-impacts and all time phase impacts are zero. The effect of option 29 upon the new near term aircraft option would be due to the B727 commonality between the options. The effect would be to eliminate 25 percent of the gain from the new near term. The time phase effect would not be as drastic as was the case for option 28; however, a two-year delay in the new near term program would be likely. Hence,

r(29,40) = -25 percent

t(29,40) = +2 years

7. METHOD: REDUCE GALLONS PER HOUR AND HOURS PER MILE BY IMPROVING AIRCRAFT TECHNOLOGY

OPTIONS: 32. Winglets

33. Wing Tip Extensions

34. Aft Body Modifications

35. Lighter-Than-Air Vehicles

36. Derivative Aircraft

37. Active Controls

38. Composite Materials

39. Supercritical Airfoils

40. Replace Aircraft With New Near Term Aircraft

41. STOL Aircraft

42. Large Air Cargo Transports

These eleven options provide the bulk of the potential energy savings. The solution to energy conservation is essentially technological in nature. To appreciate this fact, one need only peruse the base matrix values for the options. These values are:

b(32,77) = 0, ..., b(32,79) = 1.27, b(32,80) = 2.15,
b(32,81) = 3.00, ..., b(32,90) = 3.00

b(33,77) = 0, ..., b(33,79) = 1.27, b(33,80) = 2.15,
b(33,81) = 3.00, ..., b(33,90) = 3.00

b(34,77) = 0, ..., b(34,79) = 2.10, b(34,80) = 3.56,
b(34,81) = 4.98, ..., b(34,90) = 4.98

b(35,77) = 0, ..., b(35,79) = .10, b(35,80) = .47,
b(35,81) = .57, ..., b(35,90) = .57

b(36,77) = 0, ..., b(36,79) = .79, b(36,80) = 3.71,
b(36,81) = 4.47, ..., b(36,90) = 4.47

b(37,77) = 0, ..., b(37,82) = .04, b(37,83) = .08,
b(37,84) = .20, b(37,85) = .44, b(37,86) = .76,
b(37,87) = .96, b(37,88) = 1.12, b(37,86) = 1.16,
b(37,90) = 3.30

b(38,77) = 0, ..., b(38,82) = .11, b(38,83) = .22,
b(38,84) = .55, b(38,85) = 1.21, b(38,86) = 2.09,
b(38,87) = 2.64, b(38,88) = 3.08, b(38,89) = 3.19,
b(38,90) = 3.30

b(39,77) = 0, ..., b(39,82) = .10, b(39,83) = .20,
b(39,84) = .50, b(39,85) = 1.10, b(39,86) = 1.90,
b(39,87) = 2.40, b(39,88) = 2.80, b(39,89) = 2.90,
b(39,90) = 3.00

b(40,77) = 0, ..., b(40,82) = .38, b(40,83) = .75,
b(40,84) = 1.90, b(40,85) = 4.18, b(40,86) = 7.22,
b(40,87) = 9.12, b(40,88) = 10.64, b(40,89) = 11.02,
b(40,90) = 11.40

b(41,77) = 0, ..., b(41,85) = .01, b(41,86) = .03,
b(41,87) = .10, b(41,88) = .17, b(41,89) = .19,
b(41,90) = .20

b(42,77) = 0, ..., b(42,86) = .02, b(42,87) = .09,
b(42,88) = .21, b(42,89) = .28, b(42,90) = .30

The eleven options together have a 1990 additive impact of 35.42 percent. Unfortunately, there are many cross-impacts among the options. Before analyzing these impacts, however, the cross-impacts outside the impact method grouping will be analyzed. In Section E of Table 3, On-Board Performance Computers, is the only option not listed above. No cross-impact is expected. Furthermore, the cross-impacts with ATC, Airport, Aircraft Operator and Management, and Engine Technology options have been analyzed in previous sections. The engine retrofit options were seen to be the ones cross-impacting with the aircraft technology options.

The remaining cross-impacts involve only the eleven options above. The options can be grouped as follows: (1) 32, 33, and 39, (2) 34, 37, and 38, (3) 35, 41, and 42, and (4) 36 and 40. The first grouping is for wing retrofits, the second for aircraft structural changes, the third for special purpose aircraft, and the fourth for new air carrier aircraft.

GROUP ONE: WING RETROFIT

Winglets and wingtip extensions are perfect substitutes. They could be done along with option 34, but would not affect the base matrix value for the aft body/drag reduction retrofit/modification program. A 100 percent winglet/wingtip extension program was assumed. The supercritical airfoil retrofit program was assumed to cover 30 percent of the fleet. However, the new near term aircraft has supercritical airfoils which account for about 30 percent of its improved efficiency and winglets which account for 10 percent. The cross-impacts are given by r(32,33) = -100 percent

r(32,40) = -10 percent

r(32,j) = 0 all other j

r(33,32) = -100 percent

r(33,40) = -10 percent

r(33,j) = 0 all other j

r(39,40) = -30 percent

r(39,j) = 0 all other j

All time phase cross-impacts are zero.

GROUP TWO: AIRCRAFT STRUCTURAL CHANGES

Both options 34, Aft Body Modifications, and 38, Composite Materials, are retrofit programs. Option 37, Active Controls, however, cannot be retrofitted. It is assumed that active controls will be treated as a modification program for in-production aircraft. Consequently, it forms a separate option with no cross-impacts. Thirty percent of the gain from options 36 and 40, derivative and new aircraft respectively, is due to composites. Furthermore, the gains from these two aircraft structural mod programs could be expected to delay new aircraft deliveries by three years. The cross-impacts are given by:

r(i,j) = -30 percent, i = 34, 38; j = 36, 40

r(i,j) = 0, i = 34, 38; all other j

t(i,j) = +3, i = 34, 38; j = 36, 40

t(i,j) = 0, i = 34, 38; all other j

GROUP THREE: SPECIAL PURPOSE AIRCRAFT

The Lighter-Than-Air Vehicle and the Large Air Cargo Transport are separated in time (seven years) and each affects only 10 percent of the fleet. No cross-impacts are expected between the two. The STOL aircraft, as well as the two air cargo vehicles, do not cross-impact with any other option due to the specificity of their application and impact.

GROUP FOUR: NEW AIR CARRIER AIRCRAFT

The derivative aircraft and the new near term aircraft are primarily oriented towards B707/DC-8 replacement. Derivatives for partial B737/DC-9 replacement are also part of the derivative package and the new near term aircraft would replace part of the B727 fleet. Nevertheless, the cross-impacts are strong. Realistically, only one or the other option would be pursued. At this stage of the analysis, however, such an assumption cannot be built into the analysis. Should both programs be pursued, the cost/benefit analysis of Chapter IV would be required to eliminate one or the other.

Derivative aircraft purchases would be expected to delay new near term purchases by at least four years and would reduce the new near term impact by 30 percent by foreclosing the B707/DC-8 replacement market. The cross-impacts are:

$r(36,40) = -30$ percent

$t(36,40) = +4$

All cross-impacts among the options have now been estimated. In the next chapter, these cross-impacts are used to select an optimal Aviation Energy Conservation Program.

CHAPTER II

CROSS-IMPACT ANALYSIS

Cross-Impact Summary

The cross-impacts estimated in the previous chapter can now be incorporated into the analysis to produce an option set or option sets which maximize RTM/G. These sets will serve as inputs to the cost-benefit analysis of the next chapter and, ultimately, will lead to the proposed Aviation Energy Conservation Program of Chapter IV.

The base matrix is summarized in Table 6, which provides the cumulative impact for each option for each year of the 1977-1990 study period.

The cross-impact time phase matrix is given in Table 7. The time phase impacts are few as most impacts affect the level, rather than the timing, of other options.

There are 28 options involved in the cross-impact level analysis. Fortunately, they can be divided into five disjointed sets. These sets are:

Set 1: 6 - 8 - 14

Set 2: 16 - 22 - 25 - 26 - 27

Set 3: 3 - 4 - 5 - 9 - 11 - 12 - 13 - 19 - 20

Set 4: 28 - 29 - 32 - 33 - 34 - 36 - 38 - 39 - 40

Set 5: 30 - 31

Tables 8-12 provide a summary of the cross-impact values according to the set numbers. In Table 8, the cross-impacts among the short airport runway options are summarized. For example, if option 6 is selected, the table indicates that the base matrix value of option 14 will decline by 50 percent. Using 1990 as an example year, this would give a total impact from all three options of 1.22 percent (.30 percent from 6, 72 percent of the base 1.07 impact for 8, and 50 percent of the base .30 impact for 14).

In Table 9, the landing and navigation options cross-impacts are presented. Of particular interest is the fact that these include the only positive cross-impacts.

TABLE 6

BASE MATRIX

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1. Capacity Restraint	.35	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
2. Reseat Existing Aircraft	.20	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
3. FAD	.85	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
4. Wake Vortex Class Sequencing	.20	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
5. Wake Vortex Avoidance Systems	.10	.20	.36	.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6. Short Temporary Runways	.15	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
7. Snow-Ice Equipment	.06	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
8. Short GA Runways	.54	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
9. Flow Control Automation	0	0	.50	2.08	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
10. Fog Dispersal Systems	0	0	.02	.08	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
11. DABS/ATARS	0	0	0	0	0	.02	.09	.21	.29	.30	.30	.30	.30	.30
12. Post-UG3RD ATC	0	0	0	0	0	0	0	0	0	0	0	.10	.50	.60
13. Airport Surface Traffic Control	0	0	0	0	0	.01	.05	.09	.10	.10	.10	.10	.10	.10
14. STOL-Ports/Strips	0	0	0	0	0	.01	.02	.05	.11	.18	.24	.28	.29	.30
15. Simulators	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
16. RNAV	0	.20	.80	1.45	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
17. Load to Aft CG	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
18. Reduce Fuel Tankering	.15	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
19. Taxi on Fewer Engines	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
20. Tow Aircraft	0	0	.62	3.03	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70	3.70
21. Climb Procedures in TCA's	.08	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
22. Optimum Descent	.30	.60	.60	.60	.60	.60	.60	.60	.60	.60	.60	.60	.60	.60
23. Optimum Cruise Speed	.35	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
24. Optimum Altitude	.32	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65
25. Perf. Measurement & Evaluation	0	0	.12	.57	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
26. On-Board Performance Computers	0	0	.25	1.23	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
27. MLS	0	0	0	0	0	.01	.01	.03	.07	.13	.16	.19	.19	.20
28. JT8D Retrofit	0	0	.58	1.16	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
29. JT10D/CFM56 Retrofit	0	0	1.66	3.32	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
30. Advanced Jet Engines	0	0	0	0	0	0	0	0	0	.12	.57	1.41	1.88	2.00
31. Digital Electronic Prop. Control	0	0	0	0	0	.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00
32. Winglets	0	0	1.27	2.15	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
33. Wingtip Extensions	0	0	1.27	2.15	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
34. Aft Body Modifications	0	0	2.10	3.56	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98	4.98
35. LTA Cargo Vehicles	0	0	.10	.47	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
36. Derivative Aircraft	0	0	.79	3.71	4.47	4.47	4.47	4.47	4.47	4.47	4.47	4.47	4.47	4.47
37. Active Controls	0	0	0	0	0	.04	.08	.20	.44	.76	.96	1.12	1.16	1.20
38. Composite Materials	0	0	0	0	0	.11	.22	.55	1.21	2.09	2.64	3.08	3.19	3.30
39. Supercritical Airfoils	0	0	0	0	0	.10	.20	.50	1.10	1.90	2.40	2.80	2.90	3.00
40. New Near Term Aircraft	0	0	0	0	0	.38	.75	1.90	4.18	7.22	9.12	10.64	11.06	11.40
41. STOL Aircraft	0	0	0	0	0	0	0	0	.01	.03	.10	.17	.19	.20
42. Large Air Cargo Transports	0	0	0	0	0	0	0	0	0	.02	.09	.21	.28	.30

TABLE 7

TIME PHASE CROSS-IMPACTS

If this option is implemented	This option changes its beginning date by________(years).		
	14	36	40
6	+3	0	0
8	+3	0	0
28	0	+3	+3
29	0	0	+2
34	0	+3	+3
36	0	0	+4
38	0	+3	+3

NOTE: All other time phase cross-impacts are zero.

6. Short Temporary Runways
8. Short GA Runways
14. STOL-Ports/STOL-Strips
28. JT8D Retrofit
29. JT10D/CFM56 Retrofit
34. Aft Body Modifications
36. Derivative Aircraft
38. Composite Materials
40. New Near Term Aircraft

TABLE 8

SET 1 -- CROSS-IMPACT VALUES
(AIRPORT INTERACTIONS)

If this option is implemented	The base matrix value of this option will change by the indicated percentage		
	6	8	14
6	--	-28%	-50%
8	-100%	--	-50%
14	0	0	--

NOTE:
6. Temporary Construction Runways
8. GA Runways at Hubs
14. STOL-Ports/STOL-Strips

TABLE 9

SET 2 -- CROSS-IMPACT VALUES

(LANDING AND NAVIGATION INTERACTIONS)

If this option is implemented	The base matrix value of this option will change by the indicated percentage				
	16	22	25	26	27
16	--	0	0	0	0
22	0	--	0	0	0
25	0	0	--	-47%	0
26	+25%	+10%	-100%	--	0
27	0	+400%	0	0	--

NOTE:
16. RNAV
22. Optimum Descent
25. Performance Measurement and Evaluation for Jet Engines
26. On-Board Performance Computers
27. MLS

TABLE 10

SET 3 -- CROSS-IMPACT VALUES

(OPERATIONAL INTERACTIONS)

If this option is implemented	The base matrix value of this option will change by the indicated percentage								
	3	4	5	9	11	12	13	19	20
3	--	0	0	-36%	0	0	0	0	-20%
4	0	--	-40%	-20%	0	0	0	0	-5%
5	0	-100%	--	-40%	0	0	0	0	-10%
9	0	0	0	--	-33%	-50%	0	0	-20%
11	0	0	0	0	--	0	0	0	0
12	0	0	0	0	0	--	0	0	0
13	0	0	0	0	0	0	--	0	0
19	0	0	0	0	0	0	0	--	-5%
20	-30%	-30%	-30%	-30%	-30%	-30%	-100%	-100%	--

NOTE:

3. FAD
4. Wake Vortex Class Sequencing
5. Wake Vortex Avoidance Systems
9. Flow Control Automation
11. DABS/ATARS
12. Post-UG3RD ATC
13. Airport Surface Traffic Control
19. Taxi on Fewer Engines
20. Ground Movement Under Alternative Power

TABLE 11

SET 4 -- CROSS-IMPACT VALUES

(TECHNOLOGY INTERACTIONS)

If this option is implemented	The base matrix value of this option will change by the indicated percentage								
	28	29	32	33	34	36	38	39	40
28	--	0	0	0	0	-50%	0	0	-40%
29	0	--	0	0	0	-10%	0	0	0
32	0	0	--	-100%	0	0	0	0	-10%
33	0	0	-100%	--	0	0	0	0	-10%
34	0	0	0	0	--	-30%	0	0	-30%
36	0	0	0	0	0	--	0	0	-30%
38	0	0	0	0	0	-30%	--	0	-30%
39	0	0	0	0	0	0	0	--	-30%
40	0	0	0	0	0	0	0	0	--

NOTE:

28. JT8D Retrofit
29. JT10D/CFM56 Retrofit
32. Winglets
33. Wingtip Extensions
34. Aft Body Modifications
36. Derivative Aircraft
38. Composite Materials
39. Supercritical Airfoils
40. New Near Term Aircraft

TABLE 12

SET 5 -- CROSS-IMPACT VALUES

(ADVANCED JET ENGINE INTERACTIONS)

If this option is implemented	The base matrix value of this option will change by the indicated percentage	
	30	31
30	-	0
31	-20%	-

NOTE:
30. Advanced Jet Engines
31. Digital Electronic Propulsion Control

In Table 10, the most complex set of cross-impacts, those pertaining to operations in controlled airspace, are provided. The Wake Vortex Avoidance System option dominates Wake Vortex Class Sequencing and all options conflict with the towing aircraft option.

Table 11, the interaction of technology options is displayed. These are the large impact options, as noted previously, and it will probably be some optimal combination of these options that contributes the most to increasing RTM/G in the long run. Options 32 and 33 are perfect substitutes and hereafter option 32, Winglets, is arbitrarily selected over option 33, Wing Tip Extensions. Thus, option 33 is hereafter deleted.

Finally, in Table 12, the interaction between options 30 and 31 is evaluated.

Selecting the Optimal Program

As only 28 of the 42 options were involved in cross-impacts, the remaining independent options will be part of any optimal program. The 14 options which are independent of all others are given in Table 13 and account for a 5.71 percent increase in RTM/G. Furthermore, the 1978 (short run) gain is only 3.34 percent and the 1981 (intermediate run) gain is 4.01 percent. Nevertheless, those 14 options will definitely be in the final program of this chapter and are, appropriately, referred to as the foundation options.

By building a foundation set and then adding optimal subsets from disjointed option sets, methodological efficiencies are available. For example, without this approach, selecting just 14 optimal options (the foundation set) would require checking all combinations of 42 options taken 14 at a time (slightly over 1.355 billion possibilities). Fortunately, this is only the case when everything truly is related to everything else. With disjointed sets, the sum of the optimal combination of each subset is the optimal combination for the set.

The Set 1 options are now optimized and added to the foundation subset. There are only eight combinations of the three options. An examination of Table 8 reveals that option 14 decreases neither of the other two. This leaves three possibilities: include 6, include 8, or include both. As it turns out, options 6 and 8 are perfect substitutes. Yet, including both diminishes option 14 further. The optimal combination, therefore, is options 8 and 14, which together raise RTM/G by 1.07 percent by 1978, 1.07 percent in 1985, and 1.22 percent in 1990.

The set 2 options shown in Table 9 include options 16 and 22 which do not reduce others. Thus, RNAV and Optimum Descent are included. Option 27 provides only a positive cross-impact, so it too is included. The question

TABLE 13

PROGRAM FOUNDATION OPTIONS

	Option	Maximum Impact	Year Achieved
1.	Capacity Restraint	0.70%	1978
2.	Reseat Existing Aircraft	.40	1978
7.	Snow-Ice Equipment	.13	1978
10.	Fog Dispersal Systems	.10	1981
15.	Simulators	.10	1977
17.	Load to Aft CG	.20	1978
18.	Reduce Fuel Tankering	.30	1978
21.	Climb Procedures in TCA's	.16	1978
23.	Optimum Cruise Speed	.70	1978
24.	Optimum Altitude	.65	1978
35.	LTA Vehicles	.57	1981
37.	Active Controls	1.20	1990
41.	STOL Aircraft	.20	1990
42.	Large Air Cargo Transports	.30	1990
	TOTAL	5.71%	

is whether to include 25, 26, or both. In Table 14, all three cases are given. Clearly, the optimal combination of Set 2, Landing and Navigation Options, is 16 RNAV, 22 Optimum Descent, 27 MLS, and 26 On-Board Performance Computer. Option 25 Performance Measurement and Evaluation Program, is dropped.

The Table 14 results clearly show the concept of dominance. An option set is said to dominate another option set if its goal measure exceeds the other in every time period. In the case of Table 14, the three options plus 25 dominate the 3 alone; all five options dominate the 3 plus 25, but the 3 plus 26 dominate all five. If a time series exceeds another in some time periods, but not in others, then policy option selection depends upon the rate of time discount. Obviously, dominating policy option subsets make option selection trivial.

The Set 2 options add 6.34 percent to RTM/G by 1990, which, when added to the 5.71 percent from the foundation options and 1.22 percent from the Set 1 options, gives a cumulative 1990 impact of 13.27 percent. The 1978 cumulative impact of the foundation, Set 1, and Set 2 options is 5.21 percent and the 1981 cumulative impact is 8.57 percent.

The Set 3 options are by far the most complexly interrelated. Options 11, 12, and 13 do not affect other options, so they form the core of the Set 3 optimal options. Option 5 dominates option 4 of the wake vortex options. The remaining options cross-impact other options and the optimal selection is not easily derived. There are numerous possible combinations and each must be evaluated because the results may be counter-intuitive. The optimal combination of the Set 3 options is 3, 5, 9, 11, 12, 13, and 19. This combination reduces the Flow Control Automation to 34 percent, reduces DABS/ATARS to 67 percent, and reduces Post-UG3RD ATC to 50 percent of their base matrix values, respectively. The forecast of the optimal Set 3 option combination is given in Table 15.

The 1978 cumulative impact of the 28 options selected so far is now 7.31 percent. The impact for 1981 is 13.12 percent and the impact for 1990 is 18.32 percent. While these improvements are certainly noteworthy, the technology options from the remaining sets will produce an equally impressive improvement in RTM/G.

The Set 4 options are the technology options. As stated previously, option 33 has been deleted and option 32, Winglets, selected since the options are substitutes. These options interact in a very complex manner involving time phase lags (see Table 7) as well as level impacts (see Table 11). Essentially, the options partition into four groups: (1) engine retrofits (28 and 29), (2) structural changes (32, 34, 38, and 39), (3) derivative aircraft (36), and (4) new near term aircraft (40). This subdivision is based upon the cross-impacts of Table 11. Three programs shown in Table 16 are produced by the analysis. Program A

TABLE 14

SET 2 -- LANDING AND NAVIGATION OPTION ANALYSIS

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
16. RNAV	0	.20	.80	1.45	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
22. Optimum Descent*	.30	.60	.60	.60	.60	.69	.72	.87	1.23	1.77	2.04	2.31	2.36	2.40
27. MLS	0	0	0	0	0	.01	.01	.03	.07	.13	.16	.19	.19	.20
Subtotal	.30	.80	1.40	2.05	2.20	2.30	2.33	2.50	2.90	3.50	3.80	4.10	4.15	4.20
Total With 25	.30	.80	1.52	2.62	2.90	3.00	3.02	3.20	3.60	4.20	4.50	4.80	4.85	4.90
Total With 26	.30	.80	1.91	3.70	4.16	4.27	4.30	4.49	4.92	5.58	5.90	6.23	6.29	6.34
TOTAL WITH BOTH**	.30	.80	1.61	2.92	3.24	3.34	3.37	3.55	3.97	4.60	4.91	5.23	5.28	5.33

*Includes MLS Cross-Impact
**See Table 9

TABLE 15

SET 3 -- OPTIMAL OPTION COMBINATION

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
3. FAD	.85	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
5. Wake Vortex Avoidance System	10	.20	.36	.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9. Flow Control Automation	0	0	.33	1.37	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
11. DABS/ATARS	0	0	0	0	0	.01	.03	.07	.10	.10	.10	.10	.10	.10
12. Post-UG3RD ATC	0	0	0	0	0	0	0	0	0	0	0	.05	.25	.30
13. ASTC	0	0	0	0	0	.01	.05	.09	.10	.10	.10	.10	.10	.10
19. Taxi on Fewer Engines	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
TOTAL	1.05	2.10	2.59	4.82	4.55	4.57	4.63	4.71	4.75	4.75	4.75	4.80	5.00	5.00

NOTE: All impacts are net, after cross-impacts.

TABLE 16

THREE ALTERNATIVE TECHNOLOGY PROGRAMS

Program	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
A	1.81	5.43	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87
B	.93	1.57	2.19	2.57	2.94	4.09	6.37	9.41	11.31	12.83	13.25	13.59
C	5.61	10.19	14.69	14.89	15.11	15.74	17.00	18.68	19.73	20.57	20.78	20.99

NOTE: Only one of the three programs can be adopted.

Program A

36. Derivative Aircraft
32. Winglet Retrofit

Program B

40. New Near Term Aircraft
32. Winglet Retrofit

Program C

28. JT8D Retrofit
29. JT10D/CFM56 Retrofit
32. Winglet Retrofit
34. Aft Body Modification
38. Composite Retrofit
39. Supercritical Airfoil Retrofit

includes derivative aircraft and winglet retrofit of the remaining fleet. Program B includes the new near term aircraft and winglet retrofit of the remaining fleet. Note that neither of Programs A or B dominates the other. Program B is higher through 1985, but Program A dramatically exceeds Program B thereafter. Program C is basically a retrofit/modification program over the existing fleet (70 percent engine retrofit, 100 percent winglets and aft body modification). Although Program C dominates both A and B, the cost of the retro/mod program elements indicates that a final decision on program choice should be deferred until the cost-benefit analysis section.

Finally, the Set 5 options of Table 12 are easily evaluated. Better results are obtained if both options are introduced than if either is introduced alone, even though the option 30 base matrix impact is reduced by 20 percent.

The three possible overall programs are presented in Table 17 (all impacts net of cross-impacts). All foundation options plus the selected options from sets 1, 2, 3, and 5 are presented first, then each of the three option groups within Set 4 is added individually. The cost-benefit analysis of the next chapter will be used to select among the three programs as well as to evaluate other options from Table 17. Nevertheless, it is clear that substantial savings are available.

TABLE 17

POTENTIAL AVIATION ENERGY CONSERVATION PROGRAMS

WITH CUMULATIVE IMPACT UPON RTM/G

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1. Capacity Restraint	.35	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
2. Reseat Existing Aircraft	.20	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
3. FAD	.85	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
4. Wake Vortex Avoidance Systems	.10	.20	.36	.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7. Snow-Ice Equipment	.06	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
8. Short GA Runways	.54	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
9. Flow Control Automation	0	0	.33	1.37	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
10. Fog Dispersal Systems	0	0	.02	.08	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
11. DABS/ATARS	0	0	0	0	0	.01	.03	.07	.10	.10	.10	.10	.10	.10
12. Post-UG3RD ATC	0	0	0	0	0	0	0	0	0	0	0	.05	.25	.30
13. Airport Surface Traffic Control	0	0	0	0	0	.01	.05	.09	.10	.10	.10	.10	.10	.10
14. STOL-Ports/Strips	0	0	0	0	0	0	.01	.03	.06	.09	.12	.14	.15	.15
15. Simulators	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
16. RNAV	0	.20	.80	1.45	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
17. Load to Aft CG	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
18. Reduce Fuel Tankering	.15	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
19. Taxi on Fewer Engines	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
21. Climb Procedures in TCA's	.08	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
22. Optimum Descent	.30	.60	.60	.60	.60	.69	.72	.87	1.23	1.77	2.04	2.31	2.36	2.40
23. Optimum Cruise Speed	.35	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
24. Optimum Altitude	.32	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65
26. On-Board Performance Computers	0	0	.51	1.65	1.94	1.97	1.97	1.99	2.02	2.08	2.10	2.13	2.14	2.14
27. MLS	0	0	0	0	0	.01	.01	.03	.07	.13	.16	.19	.19	.20
30. Advanced Jet Engines	0	0	0	0	0	0	0	0	.10	.46	1.13	1.50	1.55	1.60
32. Digital Electronic Prop. Control	0	0	0	0	0	.06	.13	.33	.73	1.27	1.60	1.87	1.94	2.00
36. LTA Cargo Vehicles	0	0	.10	.47	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
37. Active Controls	0	0	0	0	0	.04	.08	.20	.44	.76	.96	1.12	1.16	1.20
41. STOL Aircraft	0	0	0	0	0	0	0	0	.01	.03	.10	.17	.19	.20
42. Large Air Cargo Transports	0	0	0	0	0	0	0	0	0	.02	.09	.21	.28	.30
SUBTOTAL	3.60	7.31	9.03	12.78	13.77	14.02	14.23	14.84	16.09	18.04	19.73	20.12	21.64	21.92
Program A	0	0	1.81	5.43	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87
TOTAL WITH PROGRAM A	3.60	7.31	10.84	18.21	20.64	20.89	21.10	21.71	22.96	24.91	26.60	26.99	28.51	28.79
Program B	0	0	.93	1.57	2.19	2.57	2.94	4.09	6.37	9.41	11.31	12.83	13.25	13.59
TOTAL WITH PROGRAM B	3.60	7.31	9.96	14.35	15.96	16.59	17.17	18.93	22.46	27.45	31.04	32.95	34.89	35.51
Program C	0	0	5.61	10.19	14.69	14.90	15.11	15.74	17.00	18.68	19.73	20.57	20.78	20.99
TOTAL WITH PROGRAM C	3.60	7.31	14.64	22.97	28.46	28.92	29.34	30.58	33.09	36.72	39.46	40.69	42.42	42.91

CHAPTER III

COST/BENEFIT ANALYSIS OF OPTIONS

The 29 basic options and the three alternative programs (A - 2 options, B - 2 options, C - 6 options) produce three potential Aviation Energy Conservation Programs containing either 31 or 35 options. Thus, only seven or eleven options from the total of 42 given in Table 6 were eliminated by cross-impact analysis. The only requirement used in Chapter II for inclusion of an option was that the addition of the option produce a net increase in RTM/G. The inclusion process was occasionally counter-intuitive. For example, option 20, Ground Movement of Aircraft Under Alternative Power, produces an individual option impact of 3.70 percent, a relatively large fuel impact. However, inclusion of option 20 had such strong cross-impacts upon other options that the other options were reduced by more than 3.70 percent. As a result, option 20 was excluded. On the other hand, many of the options retained had fuel impacts producing increases in RTM/G as small as 0.10 percent. While such options produce a net increase in RTM/G (however marginal), they may well produce total benefits worth less than their costs. Any option included should have a cost/benefit ratio less than one. This chapter calculates the cost/benefit ratio for each of the options from Table 17 and retains only those with favorable cost/benefit ratios. Any excluded options may change the cross-impact values. Thus, if one or more options are excluded, options may change the cross-impact values and the analysis of the previous chapter must be repeated. An option excluded previously may then be selected. Options meeting both the cost/benefit requirement and having a favorable net impact upon RTM/G will then be part of the proposed Aviation Energy Conservation Program.

Options Retained But Not Evaluated

Several of the options included in Table 17 will be instituted regardless of any consideration of their fuel impact. Specifically, the FAA Upgraded Third Generation Air Traffic Control options will be adopted. Also, implementation of flow control options, like option 3, FAD, have already begun. The eight options included without cost/benefit analysis in the final proposed Aviation Energy Conservation Program of the next chapter are listed in Table 18. The options excluded from the analysis correspond to Part A of Table 3, the Air Traffic Control options (except ASTC). The remaining options are all subject to cost/benefit analysis and the partitions of Table 3 are followed. Hence, the cost/benefit ratios are calculated for the Airports, Aircraft Operators and Management, and Engine Technology groupings.

TABLE 18
OPTIONS AUTOMATICALLY PASSED THROUGH COST/BENEFIT SCREEN

Option	Maximum RTM/G Impact
3. Fuel Advisory Departure Procedures	1.70%
5. Wake Vortex Avoidance Systems	1.00%
9. Flow Control Automation	1.65%
11. DABS/ATARS	0.10%
12. Post-UG3RD Air Traffic Control	0.30%
13. Airport Surface Traffic Control	0.10%
16. Area Navigation	1.60%
27. Microwave Landing Systems	0.20%
TOTAL	6.65%

Cost/Benefit Ratio Assumptions

The Cost/Benefit Ratio (CBR) of option i is defined as

$$\mathrm{CBR}(i) = \frac{\sum_{n-1}^{t} C_n(1+r)^{-n}}{\sum_{n=1}^{t} B_n(1+r)^{-n}}$$

where

CBR(i) = Cost/benefit ratio of option i

B_n = Benefits in time period n

C_n = Costs in time period n

r = Discount rate used

t = Time horizon

Examination of the above equation indicates that there are two important analytical decisions to be made: the selection of the discount rate and the selection of the time horizon. A 10 percent discount rate is commonly used by Federal agencies and is adopted herein. The time horizon is much more difficult to determine. For this analysis, a 1990 horizon is adopted. This may discriminate against some of the long run options (e.g., STOL Aircraft), but these could be reevaluated in the future.

Benefit estimation is another area of controversy. Option 7, Snow-Ice Removal Equipment, for example, provides safety benefits in addition to its energy conservation benefits. The hardline approach of evaluating only energy conservation benefits is adopted since this study is oriented towards energy conservation. Finally, benefit estimation will be accomplished by using gallons derived from Revenue Ton Mile forecasts from FAA Aviation Forecasts Fiscal Years 1977-1988, September 1976, and the FY-1976 adjusted RTM/G value of 2.25. For example, 1980 forecasted domestic Revenue Passenger Miles of 181.8 billion would mean 18,180 million RTMs. Adding the forecasted domestic cargo RTMs of 5,144 million produces a total of 23,324 million RTMs. Using the adjusted 1976 level of RTM/G of 2.25, this implies the need for 10,336 million gallons of fuel (the same FAA document forecasts air carrier domestic fuel consumption for 1980 at 9,097 million gallons, thereby assuming an increase in RTM/G to 2.56 by 1980). An option raising RTM/G by one percent would save 103,660 gallons of fuel. To calculate the value of the fuel, the current dollar values in Table 19 were used. Assuming a constant price of fuel does not change the conclusions. The 1980 value is 37.8¢ per gallon, so an option raising RTM/G by one percent would have a benefit in 1980 of $39,183 million.

TABLE 19

ASSUMPTIONS FOR COST/BENEFIT ANALYSIS

1. Ten percent discount rate
2. 1990 time horizon
3. Energy benfits only
4. Gallons derived from FAA forecasts and "base" RTM/G value of 2.25
5. Fuel price forecast (current dollars per gallon)*

1977	$.308
1978	.330
1979	.353
1980	.378
1981	.404
1982	.432
1983	.462
1984	.495
1985	.529
1986	.567
1987	.606
1988	.649
1989	.694
1990	.743

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*For purposes of this analysis, fuel prices were forecast (as shown) to include a 7 percent annual compound increase. Recent prices have risen more than that forecast which would mean benefits are conservatively biased. Even if no inflation in fuel prices is assumed, the conclusions of the cost/benefit analysis are unchanged.

Cost/Benefit Analysis of Airport Options

Options 7, 8, 10, and 14 must be evaluated on a cost/benefit basis. As stated earlier, option 13, Airport Surface Traffic Control, is automatically a part of the proposed Aviation Energy Conservation Program since it is a part of the FAA's UG3RD Air Traffic Control plans. Options 8 and 14 affect airport capacity (see p. 15) and options 7 and 10 affect airport weather conditions (p. 16).

Options 8 and 14 are Short GA Runways at Hubs and STOL-Ports and STOL-Strips, respectively. Option 8 has a 1977-1990 benefit of $478.2 million and option 14 has a 1977-1990 benefit of $27.8 million. In Alternatives For Increasing Airport and ATC System Capacity, [2] it was suggested that 15 hubs would benefit from option 8. Taking 6,000 feet as the average runway length and using $1 million per mile for construction costs (as in Alternative), the option 8 gross cost is $17.0 million. Allocating the costs equally between 1977 and 1978, the 1977 equivalent total cost is $16.6 million. The cost/benefit ratio for option 8 is, therefore, equal to .035 and the option is easily retained. Option 14 assumed STOL strips at the top 20 hubs. Again, using one 6,000 foot strip at each hub and a 1977 price of $1 million per mile for construction costs, a total cost figure can be derived. However, benefits were estimated in current dollar terms, so costs must be also. A 5 percent inflation rate for construction costs was used. The strips were assumed to be constructed proportionally with the benefit allocation of Table 6. The 1977 equivalent total cost for option 14 is $15.0 million; hence, the cost/benefit ratio for option 14 is .540 and it is retained. The construction cost of $1 million per mile may be somewhat conservative, but the results would not change unless a much higher cost figure was used.

Up to this point, options 8 and 14 have been retained, but both options are excluded in the final recommendation. Although several hubs would benefit from short, GA runways, implementation is severely constrained by the unavailability of land around most major hub airports. Furthermore, STOL-ports/strips are feasible only if STOL activity increases; however, the STOL aircraft option is deleted later for cost-benefit reasons. In the event that STOL activity increases despite the fact that it is not part of the program proposed herein, option 14 would be feasible.

The weather conditions options, 7 Snow-Ice Removal Equipment, and 10 Fog Dispersal Systems, produce 1977-1990 benefits of $57.9 million and $37.8 million, respectively. Using 15 Snow-Ice Removal Units at ten airports (mostly in the Great Lake Region) and Fog Dispersal Systems at ten airports (various) would cost roughly $18 million and $15 million, respectively, using values

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[2] Federal Aviation Administration, Mimeographed, November 1975.

TABLE 20

SUMMARY COST/BENEFIT ANALYSIS
OF AIRPORT OPTIONS

Option	Costs (M)	Benefits (M)	Cost/ Benefit Ratio
7. Snow-Ice Removal Equipment	$17.6	$ 57.9	.304
8. Short GA Runways*	16.6	478.2	.035
10. Fog Dispersal Systems	13.1	37.8	.347
14. STOL-Ports/STOL-Strips*	15.0	27.8	.540

*Note: Deleted in the final program for the reasons discussed on the preceding page.

of $1.2 million and $1.5 million per unit. The 1977 value of these costs are $17.6 million and $13.1 million, respectively. Consequently, the cost/benefit ratios for option 7 is .304 and for option 11 is .347 and both are retained.

A summary of the cost/benefit analysis of the airport options is provided in Table 20. It should be noted that the above analysis does not include energy costs for processing materials or construction, nor are maintenance costs evaluated. In addition, fog dispersal systems could require large amounts of energy to operate. Therefore, costs are understated to that extent, however, these options would require a substantial increase in costs to outweigh the benefits which is unlikely. The options are, therefore, included in the final program.

Cost/Benefit Analysis of Operational Options

Section C of Table 3 includes options 1, 2, 15, 17, 18, 19, 21, 22, 23, and 24. All are short run options and, with the exception of option 21, Climb Procedures in TCA's, all have been at least partially instituted by the air carriers. This fact alone suggests that the cost/benefit ratios for each must be favorable.

Benefit calculation is straightforward and is shown in Table 21. It is the estimation of costs which is most difficult. Each is discussed in turn.

Option 1, Load Factor Increase Through Capacity Restraint, results in two types of costs: increases in Direct Operating Costs and costs of fleet changes. Year 1975 DOC for the domestic scheduled airlines was $.529 per RTM (Flying Operations, Maintenance, Passenger Service, and Aircraft and Traffic Service Costs of $9,022 million for 17,067 million RTMs). 3/ A 0.01 percent addition to DOC would add roughly $.006 to DOC per RTM. During the 1977-1990 period, this would result in a present value cost of $130.2 million. Fleet change costs are assumed zero and incurred in the pre-1977 period.

Option 2, Reseat Existing Aircraft, is presumed finished by 1978. Estimated renovation costs for all carriers in 1976 is $70 million. This amount is assumed in both 1977 and 1978 for a discounted cost of $136.8 million (allowing for 5 percent inflation). This figure is probably quite high and actual costs might be as low as half this figure.

Option 15 is Maximum Use of Simulators. Three wide-body and five smaller aircraft simulators would more than cover the maximum need for simulators and would cost between $8-15 million. Simulator leasing or time-sharing could reduce this figure further. For this analysis, the maximum of $15 million is used.

3/ "U.S. Scheduled Airline Operating Revenues and Expenses - Year 1975," *Aviation Week and Space Technology*, 104 (June 7, 1976), pp. 36-37.

Option 17, Load to Aft Center of Gravity, would require minor operational changes. A total cost of $10 million would likely be rather high.

Option 18, Reduce Fuel Tankering, would incur a cost due to foregone arbitrage profits to the airlines. Due to the fact that 6 percent of the added fuel will be burned, tankering only makes sense when the fuel price between stations is greater than 6 percent and even then tankering occurs in one direction only. If one percent of all gallons carried are due to tankering, in all probability an overstatement, then the 1977-1990 cost would be $36.8 million, assuming an 8 percent gain on all tankered fuel. The cost per year would rise from $2.1 million in 1977 to $3.2 million in 1990 ($10.9 million not discounted) due to increases in total gallonage (hence, flying) and a rising price per gallon for fuel. The problem with the institution of this option, however, is due to what is known as "The Tragedy of the Commons." The benefits do not totally accrue to the parties enduring the costs, so that the actual cost/benefit ratio may be unfavorable. This is discussed further at the end of this chapter.

Option 19, Taxi on Fewer Engines, has a minimal cost. Five million dollars for adopting this option would probably be an overstatement.

Option 21, Climb Procedures in TCA's, would require ATC operating and equipment costs. Exact figures are difficult to estimate, but $25 million should comfortably serve as an upper bound on the costs. Of course, there might be environmental or safety costs which have not been evaluated.

Option 22, Optimum Descent, would require ATC improvements and aircraft operating procedural enhancements. The incredibly large benefit of $659.7 million shown in Table 21 will exceed by far any likely costs. Some of the costs of MLS and the On-Board Performance Computer should be allocated to this option. Discounted costs of $100 million would still be high, however.

Option 23, Optimum Cruise Speed, causes a cost due to extended flight time. Flying operations costs for all domestic RTMs for 1975 were $4,047 million, 4/ or $.237 per RTM. A one percent increase in this value would only raise 1977-1990 costs by $58.3 million. The expected increase due to extended flight time would be 1.2 percent (.82 M to .81 M) for a cost of $70.00.

Option 24, Optimum Altitude, would require ATC and operational costs of no more than $25 million. Indeed, the actual costs could essentially be close to zero.

The above costs have all been included in Table 21. Every option has a favorable cost/benefit ratio, even though the costs of several of the options are knowingly overstated. Fortunately, the analysis requires only that the

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4/ "U.S. Scheduled Airline Operating Revenues and Expenses - Year 1975," Aviation Week and Space Technology, 104 (June 7, 1976), pp. 36-37.

TABLE 21

COST/BENEFIT RATIOS (CBR)

FOR OPERATIONAL OPTIONS

	Option	Costs (M)	Benefits (M)	Cost/ Benefit Ratio
1.	Capacity Restraint	$130.2	$312.7	.417
2.	Reseat Existing Aircraft	136.8	178.7	.766
15.	Maximum Use of Simulators	15.0	46.0	.326
17.	Load to Aft Center of Gravity	10.0	89.4	.112
18.	Reduce Fuel Tankering	36.8	134.0	.275
19.	Taxi on Fewer Engines	5.0	89.4	.056
21.	Climb Procedures in TCA's	25.0	71.5	.350
22.	Optimum Descent	100.0	659.7*	.152
23.	Optimum Cruise Speed	70.0	312.7	.224
24.	Optimum Altitude	25.0	290.4	.086

*Includes strong cross-impact from On-Board Performance Computer and MLS.

the first impact is not until 1985. The benefits from options 31 are evaluated as being $368.2 million. The costs for option 30 would include R&D and production costs to the manufacturers or the costs to the air carriers. The latter is used. The advanced jet engine retrofit would be applied to 20 percent of the 1990 fleet, or 611 aircraft. The costs would likely be $5 million per aircraft (the JT10D/CFM56 retrofit analyzed below is $4.5M per aircraft). By using a 5 percent inflation rate and a retrofit schedule consistent with the fuel impact time frame of Table 17, the 1977-1990 cost is $1,953.0 million. The retrofit program is not economic during the time frame of the analysis. Extension of the time horizon to 1995 adds $341.8 million in benefits to give a cumulative value of $581.1 million, still an uneconomic result. As a result, the Advanced Jet Engines Retrofit option is dropped. Option 31 is assumed to be introduced in 1982 and utilized by the entire fleet by 1990. From Table 5, which gives the fleet size, and Table 17, which gives the time framed impact, this results in a 1977-1990 cost of $503.6 million, assuming an average unit cost of $250,000 (1977) and 5 percent inflation. The costs exceed the benefits, so option 31 is dropped. Thus, both of these engine technology options have proven uneconomical for the time frame of this analysis.

Cost/Benefit Analysis of Aircraft Technology Options

The only aircraft technology options not a part of either Program A, B, or C are: option 35, LTA Freighter, option 37, Active Controls, option 41, STOL-Aircraft, and option 42, Large Air Cargo Transport. The 1977-1990 benefits are $215.6 million, $221.0 million, $26.5 million, and $34.7 million, respectively.

Option 35 assumed a 5 percent replacement of the all-cargo fleet with LTAs. This would mean about two aircraft in 1980, three by 1985, and four by 1990. The NASA LTA feasibility study has studied a 75-ton payload heavy-lift airship in conjunction with the Goodyear Aerospace Corporation. The price per vehicle would be around $30 million, assuming that the military purchased enough airships to make production feasible. This would produce, at 5 percent inflation, a cost of $93.1 million and a cost/benefit ratio of .432.

Option 37 required that 30 percent of the 1990 fleet be equipped with active controls and that these changes be the result of a modification, not a retrofit program. This would mean that 916 aircraft in the 1990 fleet would have active controls. The costs would be at least $0.5 million per aircraft, producing a 1977-1990 cost of $302.2 million and an unfavorable CBR of 1.367. Extension of benefits through 1995 adds $256.3 million in benefits and lowers the CBR to .633. The long-range benefits from active control technology are so great that the option is retained.

Option 41 assumed the existence of a STOL fleet of at least twenty aircraft. At $10 million each, the 1977-1990 costs would be $123.1, producing a CBR of 4.645. Extension of benefits through 1995 only adds $42.7 million in benefits and only lowers the CBR to 1.779. This option is deleted.

Option 42 involved a 10 percent replacement of all-cargo tonnage capacity involving only one aircraft by 1986, one in 1988, and one more in 1990. These large air cargo transports would cost at least $40 million each. The 1977-1990 cost for this option would be $72.2 million for a CBR of 2.079. Extension of benefits through 1995 lowers the CBR to .731, however, so the option is retained.

Cost/Benefit Analysis of Technology Programs A, B, and C

Programs A, B, and C were evaluated in Table 16. Using the values there, the benefits from the three are $2,837.0 million, $3,262.7 million, and $6,686.0 million, respectively. The apparent dominance in benefits of Program C is due to the fact that Program C is applied to the entire fleet; whereas, Program A replaces 13.5 percent of the fleet and Program B replaces 27.5 percent of the fleet. Adjusting for total fleet replacement, both A and B would yield benefits several times greater than those of Program C. The costs for each program are now evaluated.

PROGRAM A COSTS - Program A involves replacement of 25 percent of the B737/DC-9 fleet with DC-9Ds, 40 percent of the B707/DC-8 fleet with DC-10Ds; and all new purchase, viz: B747 and DC-10s with the L-1011L. United Technologies Research Center's RECAT document R76-912036-16 (NASA CR-137877, June 1976), Douglas Aircraft Company's RECAT Study (RR6-GEN-21540, April 1976), and other RECAT studies are used to evaluate the options. The DC-9D price of $9.6 million, the DC-10D price of $20.3 million, and the L-1011L price of $25 million (1977) were used and adjusted thereafter by a 5 percent inflation rate. The discounted costs of Program A are $5,270.9 million, producing a cost/benefit ratio of 1.858. Extending benefits through 1995 adds $1,595.7 million in benefits, and lowers the CBR to 1.189.

PROGRAM B COSTS - Program B involves the purchase of 839 new near term aircraft by 1990, replacing the B707/DC-8 fleet and half the B727 fleet. The 1977-1990 costs are $7,504.0 million, producing a CBR of 2.300. Extension through 1995, however, adds benefits of $3,087.5 million, dropping the CBR to 1.182, about the same as the Program A value. Some of the Program A derivatives, however, would be aged by 1990, being introduced by 1981; whereas, the new near term fleet would have an average age of about 4.5 years in 1990. This later introduction of the new near term biases the results in that all of the costs and few of the benefits are captured in the 1977-1990 time frame. Extending the horizon to the year 2000 gives a CBR of .930 for Program A and of 0.724 for Program B. The dominance of Program B over Program A is apparent in the longer term.

PROGRAM C COSTS - The Program C costs arises from a massive retrofit program ending in 1981 and covering 2,907 aircraft. Based upon the RECAT study, options 28 and 29 would average about $4.5 million per aircraft (R76-912036-16, p. 84), option 32 would cost about $.20 million per aircraft, option 34 would cost $2.5 million per aircraft, option 38 would cost $1.5 million per aircraft, and option 39 would cost $2.0 million per aircraft. Thus each aircraft retrofit would cost $10.7 million. This is tantamount to practically rebuilding the airplane and an examination of the Program C options reveals that that would, indeed, be the case. The 1977-1990 costs would be a staggering $26,307.7 and the cost/benefit ratio would be 3.935 through 1990, 2.464 through 1995, and 1.689 through the year 2000. Program C is rejected and Program B selected over Program A.

Reevaluation Due to Deleted Options

Only options 30, 31, and 41 were rejected due to the cost/benefit analysis. Option 31 impacts option 30 only and option 41 is independent of all other options. Thus, no reevaluation is necessary. The increase in RTM/G will be 14.35 percent by 1980, 21.62 percent by 1985, and 31.71 percent by 1990 as a result of the proposed Aviation Energy Conservation Program presented in the next chapter.

Final Comment on Cost/Benefit Analysis

It should be emphasized that few of the costs used in this chapter are definitive. Rather, most represent upper bounds on the cost figures. Similarly, the benefit figures are for fuel conservation only and ignore the other policy variables often evaluated. For example, the RECAT study also evaluated benefits due to noise, emissions, trip time, congestion reduction, etc. The options were selected primarily on the basis of their RTM/G impact, rather than their cost/benefit ratios. The only requirement from a CBR standpoint was that the CBR be less than one; the amount by which each is less than one was immaterial.

CHAPTER IV

THE PROPOSED AVIATION ENERGY CONSERVATION PROGRAM

The proposed Aviation Energy Conservation Program consists of 28 of the original 42 options. The program is divided into four subprograms according to the organizational grouping of Table 3: FAA Air Traffic Control, Airports, Aircraft Operators and Management, and Aircraft Technology. The components of these programs are summarized in Table 22. Note that none of the five engine technology options listed in Table 3 are a part of the program. Of the five, Digital Electronic Propulsion Control can be expected to actually occur. However, it will be instituted for emissions, noise, safety, comfort, and fuel reasons and not based upon fuel consideration alone.

Forecasts of the impact of each subprogram on RTM/G are provided in Tables 23-26 and a summary forecast is given in Table 27 and Figure 1. The improvement in RTM/G is seen to be substantial, rising by 14.35 percent in 1980, 21.62 percent in 1985, and 31.71 percent in 1990. The corresponding values of RTM/G for the three years would be 2.57, 2.74, and 2.96, respectively, versus the 1976 adjusted value of 2.25. 5/

In Volume I, three aviation energy scenarios were presented. The baseline forecast corresponds to the Most Probable ("Surprise-Free") scenario of Table 6 of Volume I. The other two scenarios, the Potential Scenario of Reduced Emphasis on Energy Conservation and the Uncertain Scenario of a New OPEC Embargo, Tables 7 and 8, respectively, were found to reduce RTM/G and mildly stimulate it. Numerous factors could influence these forecasts. The analysis in Chapter III of Volume I listed technical, socio-political, economic, regulatory, and operational factors influencing RTM/G. Some events not taken into account in the forecasts which would definitely alter the results are:

- A major economic recession in the U.S.
- Development of alternative fuels (e.g., synthetics).
- Political commitment to alternative modes.

5/ The actual value for 1976 is 2.32 which adjusts to 2.25 when the effect of load factor increases (a program option) is removed to create a baseline value (this is discussed in Volume I, p. 59).

TABLE 22

PROPOSED AVIATION ENERGY CONSERVATION PROGRAM

I. AIR TRAFFIC CONTROL SUBPROGRAM

- Fuel Advisory Departure Procedures
- Wake Vortex Avoidance Systems
- Flow Control Automation
- DABS/ATARS
- Post-UG3RD Air Traffic Control
- Area Navigation
- Microwave Landing Systems

II. AIRPORTS SUBPROGRAM

- Snow-Ice Removal Equipment
- General Aviation Runways
- Fog Dispersal Systems
- Airport Surface Traffic Control
- STOL-Ports/STOL-Strips

III. AIRCRAFT OPERATORS AND MANAGEMENT SUBPROGRAM

- Capacity Restraint
- Reseat Existing Aircraft
- Maximum Use of Simulators
- Load to Aft Center of Gravity
- Reduce Fuel Tankering
- Taxi on Fewer Engines
- Climb Procedures in TCA's
- Optimum Descent
- Optimum Cruise Speed
- Optimum Altitude

IV. AIRCRAFT TECHNOLOGY SUBPROGRAM

- On-Board Performance Computers
- Winglets
- Lighter-Than-Air Cargo Vehicles
- Active Controls
- New Near Term Aircraft
- Large Air Cargo Transports

TABLE 23

BASELINE RTM/G IMPACT OF
AIR TRAFFIC CONTROL SUBPROGRAM

	Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
3.	FAD	.85	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
5.	WVAS	.10	.20	.36	.85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
9.	Flow Control Automation	0	0	.33	1.37	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
11.	DABS/ATARS	0	0	0	0	0	.01	.03	.07	.10	.10	.10	.10	.10	.10
12.	Post-UG3RD ATC	0	0	0	0	0	0	0	0	0	0	0	.05	.25	.30
16.	RNAV	0	.20	.80	1.45	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
27.	MLS	0	0	0	0	0	.01	.01	.03	.07	.13	.16	.19	.19	.20
	SUBPROGRAM I TOTAL	.95	2.10	3.19	5.37	5.95	5.97	5.99	6.05	6.12	6.17	6.21	6.29	6.49	6.55

TABLE 24

BASELINE RTM/G IMPACT
OF AIRPORTS SUBPROGRAM

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
7. Snow-Ice Equipment	.06	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13	.13
10. Fog Dispersal Systems	0	0	.02	.08	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
13. ASTC	0	0	0	0	0	.01	.05	.09	.10	.10	.10	.10	.10	.10
SUBPROGRAM II TOTAL	.06	.13	.15	.21	.23	.23	.28	.32	.33	.33	.33	.33	.33	.33

TABLE 25

BASELINE RTM/G IMPACT OF

AIRCRAFT OPERATORS AND MANAGEMENT SUBPROGRAM

	Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1.	Capacity Restraint	.35	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
2.	Reseat Existing Aircraft	.20	40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
15.	Simulators	.10	10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
17.	Load to Aft CG	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
18.	Reduce Fuel Tankering	.15	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
19.	Taxi on Fewer Engines	.10	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20	.20
21.	Climb Procedures in TCA's	.08	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16	.16
22.	Optimum Descent	.30	.60	.60	.60	.60	.69	.72	.87	1.23	1.77	2.04	2.31	2.36	2.40
23.	Optimum Cruise	.35	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
24.	Optimum Altitude	.32	.65	.56	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65
	SUBPROGRAM III TOTAL	2.05	4.01	4.01	4.01	4.01	4.10	4.13	4.28	4.64	5.18	5.45	5.72	5.77	5.81

TABLE 26

BASELINE RTM/G IMPACT OF AIRCRAFT TECHNOLOGY SUBPROGRAM

Option	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
27. On-Board Performance Computers	0	0	.51	1.65	1.94	1.97	1.97	1.99	2.02	2.08	2.10	2.13	2.14	2.14
32. Winglets	0	0	.93	1.57	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19	2.19
35. LTA Air Cargo	0	0	.10	.47	.57	.57	.57	.57	.57	.57	.57	.57	.57	.57
37. Active Controls	0	0	0	0	0	.04	.08	.20	.44	.76	.96	1.12	1.16	1.20
40. New Near Term Aircraft	0	0	0	0	0	0	.38	.75	1.90	4.18	7.22	9.12	10.64	11.40
42. Large Air Cargo Transports	0	0	0	0	0	0	0	0	0	.02	.09	.21	.28	.30
SUBPROGRAM IV TOTAL	0	0	1.54	3.69	4.70	5.15	5.56	6.85	9.40	12.84	15.03	16.86	17.40	17.80

TABLE 27

CUMULATIVE PERCENTAGE IMPROVEMENT IN RTM/G

(BASELINE SCENARIO)

Subprogram	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
I. ATC	.95	2.10	3.19	5.37	5.95	5.97	5.99	6.05	6.12	6.17	6.21	6.29	6.49	6.55
II. Airports	.06	.13	.15	.21	.23	.23	.28	.32	.33	.33	.33	.33	.33	.33
III. Aircraft Operators	2.05	4.01	4.01	4.01	4.10	4.10	4.13	4.28	4.64	5.18	5.45	5.72	5.77	5.81
IV. Aircraft Technology	0	0	1.54	3.69	4.70	5.15	5.56	6.85	9.40	12.84	15.03	16.86	17.40	17.80
TOTAL	3.06	6.24	8.89	13.28	14.89	15.45	15.96	17.50	20.49	24.52	27.02	29.20	29.99	30.49

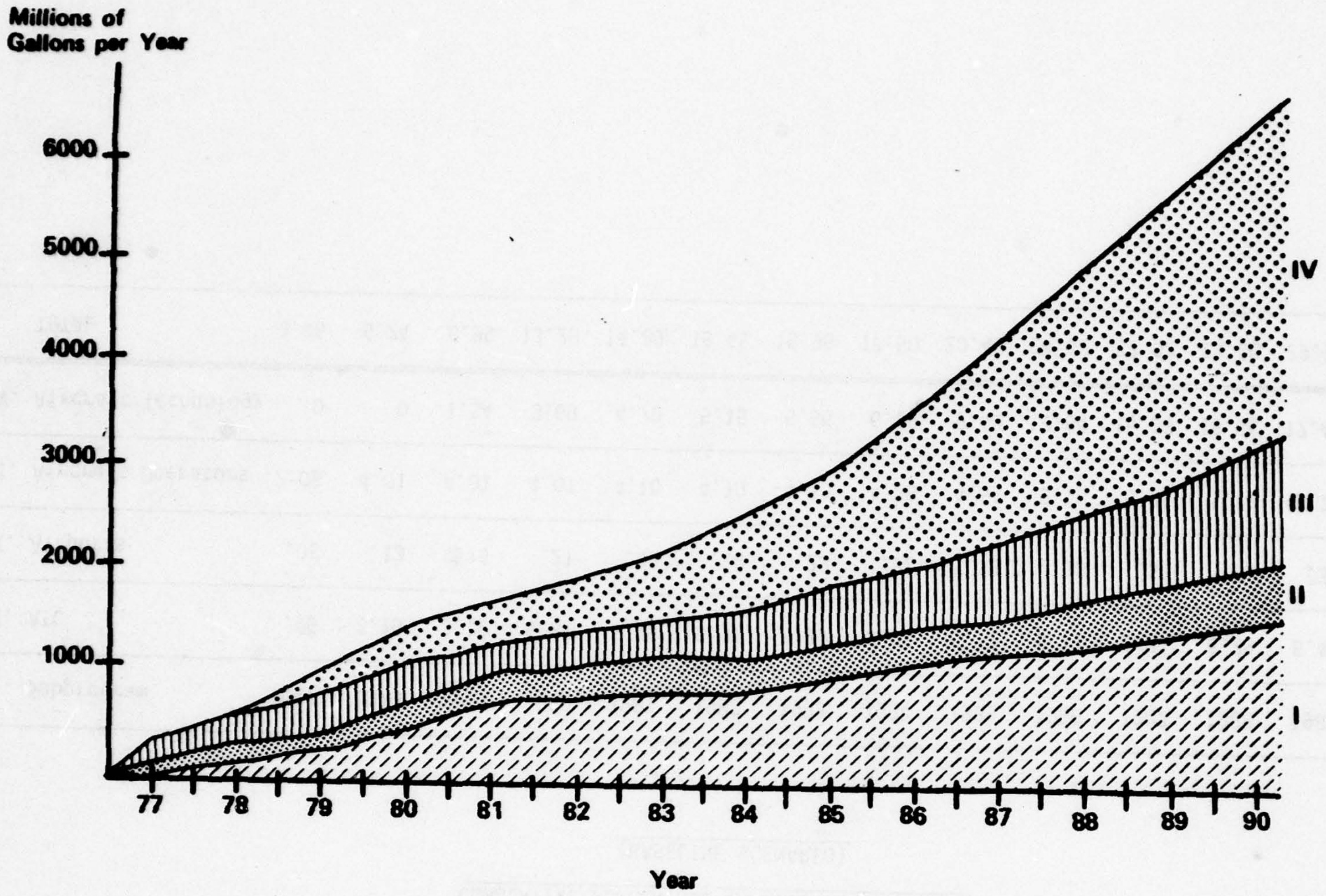

FIGURE 1

GALLONS SAVED PER YEAR BY SUBPROGRAM

I-ATC, II-Airport, III-Operations, IV-Aircraft

- Development of commercially viable propfan aircraft.
- Change in attitude towards travel.

Many other events could also have been included.

Using the methodology of Chapter III, the number of gallons saved and the value of the fuel can be estimated. The results are presented in Table 28. The program would save 37 billion gallons between 1977-1990 over what would have been used with no changes (i.e., RTM/G remained 2.25). The savings would be $21.6 billion in current dollars (the price of fuel is assumed to rise 7 percent annually). Discounting at 10 percent, a higher than average inflation rate for the period, still produces a savings of $8.9 billion.

The analysis has been restricted to benefits from fuel consumption. However, the New Near Term Aircraft, the UG3RD ATC components, and the other options of the proposed program would also produce beneficial effects on safety, emissions, noise, passenger time and comfort, as well as employment in the aircraft manufacturing industry.

TABLE 28

PROPOSED AVIATION ENERGY CONSERVATION PROGRAM

FUEL SAVINGS

Year	Millions of Gallons Saved	Value (M)	Value Discounted at 10% (M)
1977	268.8	$ 82.8	$ 82.8
1978	560.9	185.1	168.3
1979	852.6	301.0	248.7
1980	1,382.2	522.5	392.5
1981	1,693.0	684.0	467.2
1982	1,820.7	786.5	488.4
1983	1,968.1	909.3	513.2
1984	2,276.4	1,126.8	578.2
1985	2,851.0	1,508.2	703.6
1986	3,599.2	2,040.8	865.5
1987	4,214.6	2,554.0	984.7
1988	4,816.3	3,125.8	1,095.6
1989	5,163.9	3,583.8	1,141.9
1990	5,616.8	4,173.3	1,208.8
1977-1990	37,084.5	$21,583.9	$8,939.4

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Previous volumes of this report generated 42 unique options designed to increase efficiency in aviation, as measured by Revenue Ton Miles Per Gallon (RTM/G) of fuel consumed. In this volume, the techniques of cross-impact analysis and cost/benefit analysis were used as screens for purposes of arriving at a final Aviation Energy Conservation Program. The final program includes the 26 options listed in Table 22 described more fully in the Appendix.

The proposed program includes the implementation of facilities, such as the FAA's Upgraded Third Generation Air Traffic Control system, for which in some cases no specific implementation decisions have been made. In addition, although the short run program was not fully implemented during 1977 as assumed by the analysis, implementation of many of the options is already underway. Several conclusions can be drawn under the assumption that the proposed Aviation Energy Conservation Program is implemented in its entirety:

1. The program produces highly significant savings in aviation fuel, averaging 2.6 billion gallons each year over the 1977-1980 period (equal to 32 percent of total 1976 usage).*

2. The program is long-range and optimal in nature. The maximum savings for the entire period is achieved, rather than increasing short run fuel conservation while engendering long run difficulties.

3. The program is realizable and feasible. All options comprising the program are based on known technologies and none of the options conflict with other FAA goals.

Of course, it is not presumed that the proposed Aviation Energy Conservation Program is the single best solution to the obvious need for energy conservation within the National Aviation System. Any alternative proposals, however, should be subjected to the rigorous analysis used herein. Cross-impact analysis is crucial to the development of a systematic solution because the problem is difficult, the options complex, and their interrelationships obscure.

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*Note: Total energy savings for the Nation will be slightly less because implementation of the proposed program may require an increase in other energy costs for construction and operation of some options.

The fundamental recommendation is that the program should be initiated as soon as possible by those having prime responsibility. The program proposed by this study is based on the best estimates available at the time. Further program development and analysis will refine the conclusions, but would be unlikely to alter them significantly. The primary remaining analysis would consider the problems of program implementation. The implementation of the proposed Aviation Energy Conservation Program would produce important benefits for the aviation community and achieve a major step toward the President's goal of energy conservation.

APPENDIX

DEFINITION OF OPTIONS

APPENDIX

DEFINITION OF OPTIONS

A brief description of each of the 26 policy options comprising the proposed Aviation Energy Conservation Program, as previously presented in Table 22, is provided below. The 16 policy options listed in Table 1 which did not become a part of the proposed AECP are presented thereafter. More detailed information on the options is available in Volumes I and II of the supporting study.

1. Active Controls - In most current commercial aircraft, mechanical and electronic devices, in combination with the aerodynamic control surfaces, augment inherent stability and control characteristics. Active controls for aircraft would involve the coordination of aerodynamic surfaces and advanced flight computers and electrohydraulic systems to increase the inherent stability of the aircraft. By relaxing static stability, controlling maneuver load, actively suppressing flutter, and alleviating gust loads, active controls result in reduced structural weight and improved aerodynamic performance. The reduction in weight results in fewer gallons of fuel being burned and a proportional increase in RTM/G.

2. Airport Surface Traffic Control (ASTC) - This option is an analog ground surveillance radar system which provides accurate information to controllers on aircraft location. Currently, controllers determine aircraft location visually, when weather permits; by pilot position reports via voice radio, when the controllers are unable to see; or by using the current Airport Surveillance Detection Equipment (ASDE) which is installed at high density airports. Current systems severely limit the capacity of ground control and constrain the rate at which aircraft can be handled for the airport. ASTC will be an improvement over the current ASDE and will effectively raise ground control capacity. This should reduce overall delay, resulting in fewer gallons of fuel being wasted due to delay, and a higher value for RTM/G.

3. Capacity Restraint - This option is simply the substitution of a smaller aircraft for the existing aircraft on a route (e.g., substituting a B727 for a B707). The load factor will be higher, assuming passenger demand remains constant, for the

smaller aircraft, but, more importantly, the smaller aircraft will burn less fuel. By carrying the same passenger load on a route and using less fuel, this practice results in an increase in RTM/G.

4. Climb Procedures in Terminal Control Areas (TCA's) - Federal Aviation Regulation (FAR) 91.70(a) states that " . . . no person may operate an aircraft below 10,000 feet MSL at an indicated airspeed of more than 250 knots (288 mph)." Unfortunately, many aircraft have optimal climb rates which are greater than 250 knots, so that FAR 91.70(a) causes these aircraft to burn more fuel than necessary while under 10,000 feet. For example, the optimal climb speed for a B727-200 is 320 knots. By revising FAR 91.70(a) to permit higher speed climb rates, fewer gallons will be consumed, thereby raising RTM/G. Safety considerations and noise abatement procedures may limit full use of optimal climb rates.

5. Discrete Address Beacon System (DABS)/Automatic Traffic Advisory and Resolution System (ATARS) - DABS is a cooperative surveillance system with an integral data link capability which is capable of supporting ATARS. Both of these items are components of the UG3RD Air Traffic Control system, and they enhance the air traffic controller's capabilities by providing for discrete air-ground communication and improved efficiency in applying separation standards. The increased system capacity should lead to less aircraft delay, fewer gallons of fuel being burned, and an increase in RTM/G.

6. Flow Control Automation - This includes a comprehensive package of options including ARTS III enhancements to improve terminal area metering and spacing, en route enhancement to support area navigation techniques, and provide en route metering and advanced (circa 1990) metering and spacing. By reducing spacing between aircraft, the effective capacity of airports will rise, decreasing delay. The reduction in delay will result in fewer gallons being wasted, thereby raising RTM/G.

7. Fog Dispersal Systems - The existence of fogs at airports reduces pilot's visibility needed for visual ground reference in the approach, touchdown, and rollout zones of the airport runway. As a result, the airport requires Instrument Flight Rules (IFR) which have the result of lowering effective airport capacity from its Visual Flight Rules (VFR) level. A fog dispersal system would prevent fogs from reducing airport capacity, thereby decreasing aircraft delay (hence, gallons burned).

8. Fuel Advisory Departure (FAD) Procedures - FAD is an airport-specific flow control system which transfers airborne delay to ground delay by altering actual aircraft departure times consistent with acceptance rates at the destination airport. Since an aircraft burns far less fuel while on the ground or at the gate, a given amount of a system delay results in much less fuel being wasted when the FAD procedures are used.

9. Large Air Cargo Transports - Considerable economies in cargo handling can be obtained by using high capacity air cargo transports (freighters). The largest air cargo transport currently available is the B747F with a cargo capacity of 127.5 tons. An advanced technology cargo transport carrying up to 180 tons would have a higher RTM/G value because of its greater capacity as well as its design (supercritical wings, new engines, etc.).

10. Lighter-Than-Air (LTA) Cargo Vehicles - Since LTA's do not use fuel for lift, but only for propulsion, they can carry a given cargo load using less fuel than a conventional air cargo transport. This results in increased efficiency and higher RTM/G.

11. Load to Aft Center of Gravity (CG) - By allocating cargo and passenger weight so that the aircraft center of gravity is at the aft limit specified as safe for aerodynamic stability, aircraft drag is reduced. This drag reduction results in less fuel being burned and, thereby, increases RTM/G.

12. Microwave Landing Systems (MLS) - MLS is a component of the UG3RD Air Traffic Control System and provides improved measurement guidance during the descent of the aircraft. This permits descent and approach profiles to be used which are optimal with respect to fuel consumption.

13. New Near Term (NNT) Aircraft - The NNT aircraft is a 1980 aircraft employing JT10D/CFM56 engines, winglets, supercritical airfoils, active controls, and composite materials. It is 38 percent more fuel efficient than conventional aircraft and will raise the overall RTM/G when used to replace obsolete, fuel-inefficient aircraft.

14. On-Board Performance Computers - A computer, on-board the aircraft, optimizes fuel utilization by permitting fuel conservative descent profiles, by monitoring aircraft health, and by performing other functions which result in the most efficient performance of the aircraft with respect to fuel usage.

15. Optimum Descent - Conventional descent procedures for aircraft involve a step-down approach; that is, the aircraft drops to a lower altitude, flies at that altitude for a while, then drops to an even lower altitude, etc. This procedure is not optimal with respect to fuel consumption. The idle-thrust descent and/or NASA landing approach procedure are optimal descent profiles in that they minimize fuel usage during the aircraft descent phase. Safety-related problems will have to be resolved before full implementation can proceed.

16. Optimum Altitude - Fuel consumption by an aircraft depends on several factors, one of which is the altitude at which the aircraft flies. Given aircraft cruise speed and weight, there is an optimum altitude for minimum fuel consumption for the aircraft. Currently, aircraft are flying, on the average, at altitudes below the optimum altitude. By increasing the average altitude of an aircraft, its fuel consumption will decline.

17. Optimum Cruise Speed - Cruise speed also affects the rate of fuel consumption for an aircraft. Currently, aircraft speeds are above the optimal speed for minimum fuel consumption. By slowing down to the optimum cruise speed, each aircraft will reduce its fuel consumption.

18. Post-UG3RD Air Traffic Control - The UG3RD Air Traffic Control System will probably be replaced with a new system in the 1990's. This new, post-UG3RD system has not been completely defined, but is expected to use advanced automated systems, such as the Global Positioning System (GPS). GPS uses satellites to provide high-accuracy navigation information to aircraft. Improvements in operational procedures resulting from the installation of the post-UG3RD ATC system are expected to have a beneficial effect on fuel consumption.

19. Reduce Fuel Tankering - Because of differing prices and availability of fuel at various airports, aircraft operators tend to carry more fuel than that needed for a particular flight. This practice is called "tankering" and is fuel-inefficient because more fuel is burned in flight due to the added weight of the tankered fuel. Fuel reservation systems and education campaigns to illustrate the economics of tankering could greatly reduce this practice. Reduced fuel tankering would result in less fuel burned on a particular flight, thereby raising RTM/G.

20. Reseat Existing Aircraft - By increasing the number of seats in existing air carrier aircraft, the potential passenger load is thereby raised. Reducing first class seats and providing

smaller seats in coach have been the general approaches. The increase in RTMs resulting from the reseating of aircraft exceeds the increase in the number of gallons consumed, as long as load factors do not decline.

21. Area Navigation (RNAV) - RNAV provides flexibility for airspace users and air traffic control for maximizing utilization of the airspace. This capability allows reduction in actual distance flown as opposed to the conventional circuitous navigation along airways and decreases congestion in the airspace with attendant fuel savings.

22. Simulators - Air carriers and general aviation are now using simulator training for flight crews in lieu of actual training flights. By maximizing the use of aircraft simulators, the fuel normally expended in actual flying for training purposes can be reduced.

23. Snow-Ice Removal Equipment - The time required to open runways after a snowfall is highly variable, depending in large measure upon the intensity of the snowfall and the availability of snow-ice removal equipment. Increasing the availability of such equipment, as a proposed amendment to the Airport and Airway Development Act of 1970 would do, would assist in the reduction of aircraft delay due to snow and ice problems.

24. Taxi on Fewer Engines - Aircraft operating on the ground do not need to use all of the engines on the aircraft. Considerable fuel can be saved by shut-down of one or more engines for taxiing. This option is currently employed by all users to some extent, but it could be increased for additional fuel savings.

25. Wake Vortex Avoidance Systems (WVAS) - The WVAS is a ground-based system for predicting or detecting the existence of wake vortices. The controller can relay wake turbulence warnings to the pilot so that evasive actions can be taken. The WVAS permits reduced separation standards, leading to a reduction in delay.

26. Winglets - Winglets are vertical airfoils added to the tips of each aircraft wing to reduce drag-due-to-lift and to help disperse the wingtip vortex. The primary benefit is the higher lift/drag ratio which reduces fuel consumption required for aircraft lift at a given gross takeoff weight. Dispersal of the wingtip vortex helps somewhat in reducing the wake vortex problem.

The following 16 policy options are those from Table 1 (p. 3) which were eliminated from the proposed program as given in Table 22 (p. 62).

1. Advanced Jet Engines - A retrofit program beginning in the mid-1980's which replaces conventional jet engines with an advanced turbofan characterized by an 8 percent reduction in specific fuel consumption versus the JT10D/CFM56.

2. Aft Body Modifications - Modifications to the engine aft body using improved materials and a general drag reduction program (control surface rigging items, surface irregularity items, etc.). The modifications would be performed on the existing air carrier fleet on a retrofit basis.

3. Alternate Ground Movement of Aircraft - The use of towing methods for moving aircraft from the gate to the runway prior to takeoff and the return leg upon landing. Powered landing gear, cable tow, and articulated tractors are just three possible alternate power sources for the ground movement of aircraft.

4. Composite Materials Retrofit - The retrofitting of select aircraft structures (e.g., fairings, secondary body structures) in order to reduce aircraft weight. The lighter weight aircraft would then use less fuel.

5. Derivative Aircraft - Replacement of portions of the existing fleet with derivatives of the DC-9, DC-10, and L-1011. The derivative aircraft would employ new engines, winglets, composites, and other state-of-the-art technologies. The DC-9 derivative would replace 25 percent of the B737/DC-9 fleet, the DC-10 derivative would replace 40 percent of the B707/DC-8 fleet, and the L-1011 derivative would replace future DC-10 and B-747 orders.

6. Digital Electronic Propulsion Control (DEPC) Systems - A prime reliable microcomputer capable of meeting the control requirements of turbine engines will do away with the need for the relatively less efficient hydromechanical control systems in use today. The DEPC system would monitor fuel flow in a real-time environment and reduce fuel consumption.

7. General Aviation (GA) Runways - This option involves the construction of short runways at large hub airports to service the GA population. When air carrier and GA aircraft are involved in mixed operations on the same runways, separation standards are higher than would be the case for air carrier operations alone. Large, heavy aircraft used primarily by air carriers create wake vortices which require greater

separation standards to ensure that following aircraft will not encounter wake turbulence. By providing runways specifically for smaller GA aircraft, overall airport capacity is higher and the acceptance rate on the air carrier runways rises due to reduced separations. Thus, delay with its accompanying negative impact on fuel burn, is reduced. This option is limited due to the unavailability of land around major hub airports.

8. JT8D Retrofit - The reengining of all four engine narrow-body aircraft with the refanned JT8D-209/-217 engines would improve significantly the fuel efficiency of those aircraft. For most DC-8's and B707's, 10 percent less fuel would be used to carry the same loads.

9. JT10D/CFM56 Retrofit - The reengining of all B727's and B737's/ DC-9's with the current technology JT10D/CFM56 engines would result in 8 to 10 percent less fuel being consumed to carry the same aircraft loads.

10. Performance Measurement and Evaluation Program (PMEP) - The PMEP is a computerized system to monitor the fuel performance of each aircraft. The replacement of deteriorated engine parts and the overhaul of jet engines would be revised in light of the PMEP results. By maintaining engine performance at acceptable levels, fuel usage by inefficient engines will be avoided.

11. STOL Aircraft - The short takeoff and landing (STOL) aircraft could serve select commuter markets and reduce airport congestion by replacing several, smaller commuter aircraft.

12. STOL-Ports/Strips - Short takeoff and landing (STOL) aircraft require sufficiently different controller operational procedures, and separate STOL operations from those of the air carriers are preferable. The construction of STOL dedicated airports or of STOL-strips at existing airports will both expand airport capacity and reduce air carrier separation standards.

13. Supercritical Airfoil Retrofit - The supercritical airfoil produces a higher lift coefficient for a given wing weight or produces the same lift with a lighter wing. In both cases, fuel consumption is reduced.

14. Temporary Construction Runways - Short, temporary parallel runways could be used during airport construction and reconstruction to reduce the effect of runway closures on aviation

system capacity and delay. By installing a short runway parallel to the runway being resurfaced or constructed, the capacity loss can be reduced to the extent small aircraft can use the additional short runway.

15. Wake Vortex Class Sequencing - Wake turbulence is wingtip generated vortices. Large heavy aircraft create more turbulence and air traffic control spaces aircraft during takeoff and departure based on wake turbulence potential and the size aircraft next in the queue. By proper sequencing of aircraft in the queue, wake turbulence spacing can be diminished.

16. Wingtip Extensions - Wingtip extensions are three to four foot segments added to the end of each wingtip to raise the lift/drag ratio and disperse the wingtip vortex.

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