FUEL/ENGINE/AIRFRAME TRADEOFF STUDY - PHASE I

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INTRODUCTION

The Douglas Aircraft Company received a contract from the Air Force to study the effects of broadening the specifications for JP-4 and JP-8 fuel on the performance and cost of all USAF aircraft presently using JP-4 as well as those expected to be introduced into the force structure by 1983. Phase I of this study was to determine analytically the effects of these specification changes on minimizing fuel cost and maximizing the fuel availability/flexibility without degrading performance, safety, and survivability/vulnerability.

The maximum variations to the property specifications to be considered were as shown in table I. Union Oil Company was chosen to study the property variation effects on fuels, Pratt & Whitney Aircraft Group studied the effects on engines, and McDonnell Douglas studied the effects on the airframe.

HIGHLIGHTS OF FUEL SUPPLY STUDY

Union Oil Company obtained twenty-four foreign and nine domestic crude assays which contained sufficient data to correlate freeze point and smoke point with initial boiling point and final boiling point. This data was examined to determine the effects on fuel availability, fuel costs, and hydrogen content (an important factor in engine life), when varying the fuel properties to the maximum amount shown in table I.

When comparing the change from theoretical yields of present specifications to proposed specifications, yields would increase as shown in table II. This large increase in JP-8 is due wholly to the extension of boiling limits in a narrow cut product that are made possible by an extension of the freeze point limits. Reasonable quantitative effects of fuel specification variations on military fuel prices could not be determined because of extreme market instability.

Seven selected crudes were analyzed for changes in hydrogen content which would result from the changes in specifications. Based on a similar weighting system as used for volume effects, the change in hydrogen content is predicted to be 0.3% lower (0.17 wt % H).

HIGHLIGHTS OF ENGINE STUDY

The overall objective of the engine manufacturer effort in Phase I was to assess the impact of broadened-specification fuels on the performance and durability of gas turbine engines used in USAF aircraft. The various engine-related parameters addressed in this phase of the program included ignition characteristics, combustion efficiency, emissions, thermal loads, burner exit temperature distribution, erosion, and coking of the fuel system. The sensitivity of these parameters was discussed with regard to the proposed relaxations of current JP-4 and JP-8 fuel specifications shown in table I.

A fuel characterization study was performed to determine the effects of the proposed changes in JP-4 and JP-8 fuel specifications on fuel hydrogen content. Through the use of interproperty correlations, a change from current JP-4 and JP-8 fuel values of final boiling point and smoke point to the proposed specification limits is predicted to decrease current fuel values of hydrogen content by 0.25 (% by weight).

Thermal analyses were performed on combustor liner and turbine airfoil temperatures in two USAF engines: the J57-59W and the F100-PW-100. Increases in turbine airfoil temperatures were found to be negligible for both engines (figs. 1 and 2).

The Phase I effort concluded that there would be a small increase in maintenance costs due to a small decrease in combustor life. The study showed that the proposed relaxed specifications would have a negligible effect on visible smoke emissions. The broadened-property JP-4 and JP-8 fuels are expected to have no impact on engine performance, with the exception of ignition capability, relative to current JP-4 and JP-8 fuels. The higher viscosity and lower volatility of the broadened-property fuels may have an adverse effect on ignition capabilities when fuel and/or air temperatures are relatively low (cold-day ground starts and altitude ignition). The extent of this effect depends on both operating conditions and the particular engine employed and cannot be predicted because of a lack of pertinent data. However, the incremental effect of the broadened-property fuels on ignition capabilities relative to current JP-4 and JP-8 fuels is expected to be less than the incremental effect associated with the use of JP-5 relative to JP-4 fuel.

HIGHLIGHTS OF AIRFRAME STUDY

The main objective of the airframe manufacturer effort in Phase I was to determine the effect of broadened-specification fuels on aircraft fuel system performance. It was beyond the scope of this program to study all the airplanes in the Air Force inventory. "High fuel user" airplanes (fig. 3) were selected for this study. Together these aircraft consume 75% or more of the fuel used by the USAF.

The fuel systems and fuel management methods of each airplane were studied to evaluate the effect on the system performance of operating with tank fuel temperatures near the freeze point. The recovery temperature was used as a means of predicting minimum inflight fuel temperatures and the relationship with maximum allowable freeze points. It is recognized that the use of MIL-STD-210B and the aircraft recovery temperatures is a fairly conservative approach; however, a less conservative approach could not be justified with the limited amount of data that is available on this subject.

Using the selected approach, with some consideration of flight conditions (figs. 4 and 5), it was determined that all the airplanes in the study could obtain tank fuel temperatures below the present maximum allowable freeze point of both JP-4 and JP-8. It was therefore concluded that the maximum allowable freeze point of JP-4 or JP-8 cannot be increased without degrading system performance and safety as critical conditions are approached.

CONCLUSIONS

Major conclusions from the fuel/engine/airframe tradeoff study were as follows:

1. An increased freeze point is questionable because of a data base problem.
2. There was no impact on engine performance, turbine durability, and coking.
3. There was a small maintenance cost increase as a result of a small combustor life decrease.
4. Using JP-4 as standard fuel will avoid the use of high-demand middle-distillate fuels and give producers flexibility.
5. Extensive use of JP-8 in the United States will increase middle-distillate demand and cause a slight increase in engine hot-section maintenance.
6. There is need for an accepted single flight model.
7. Present aircraft operations and systems are freeze-point sensitive.

RECOMMENDATIONS

Recommendations for USAF action and further study are as follows:

1. An experimental study of the effect of fuel properties on engines should be made, including carbon formation, deposition, and erosion; fuel thermal stability and coking in actual systems; and afterburner performance and durability.
2. An improved durability combustor liner design and development program (new design and retrofit) should be conducted.
3. The actual freeze point (not specification maximum) should be used for dispatch evaluations.
4. Aircraft systems and procedures for operations near the actual freezing point should be reviewed.
5. Tests should be conducted with special blend fuel at broadened-property limits.
6. Future aircraft studies should include airplane and systems design-cost trade-offs for higher freeze-point tolerance.

TABLE I

PROPOSED SPECIFICATION CHANGES

	JP-4	JP-8
FREEZE POINT, °F (°C)		
PRESENT SPECIFICATION, MAXIMUM	−72 (−58)	−58 (−50)
PROPOSED VARIATION	+14 (8)	+18 (10)
PROPOSED SPECIFICATION, MAXIMUM	−58 (−50)	−40 (−40)
FINAL BOILING POINT, °F (°C)		
PRESENT SPECIFICATION, MAXIMUM	518 (270)	572 (300)
PROPOSED VARIATION	+25 (14)	+25 (14)
PROPOSED SPECIFICATION, MAXIMUM	543 (284)	597 (314)
SMOKE POINT, mm		
PRESENT SPECIFICATION, MINIMUM		20[a]
PROPOSED VARIATION		−2
PROPOSED SPECIFICATION, MINIMUM		18

a. MAXIMUM 3.0 VOLUME PERCENT NAPHTHALENES

TABLE II

EFFECT OF SPECIFICATION CHANGE ON YIELD

FUEL TYPE	PERCENTAGE INCREASE
JP-4	8.5-9.0
JP-8	41-62

FIGURE 1

J57 LINER TEMPERATURE PARAMETER AT CRUISE CONDITION COMPARED WITH THE BLAZOWSKI CORRELATION

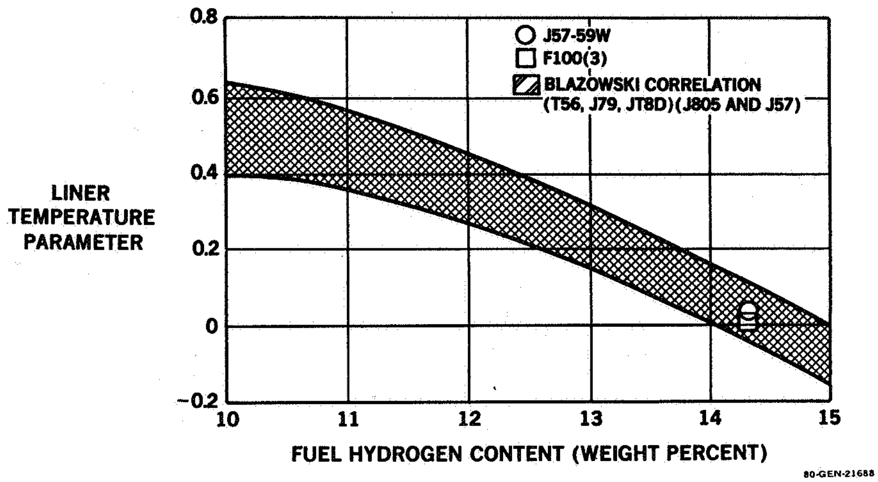
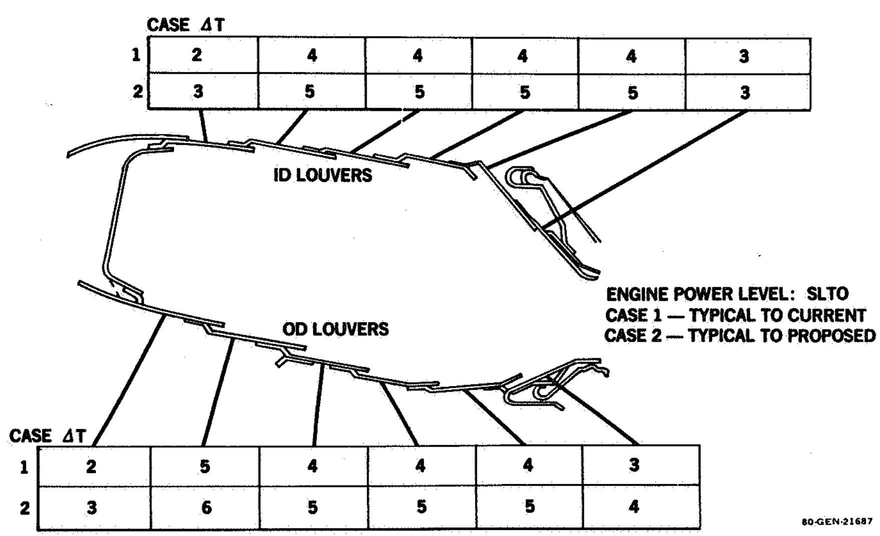


FIGURE 2

EFFECT OF FUEL SPECIFICATION RELAXATIONS ON INCREASE IN AVERAGE COMBUSTOR LINER TEMPERATURES



ID louvers:

CASE	ΔT					
1	2	4	4	4	4	3
2	3	5	5	5	5	3

OD louvers:

CASE	ΔT					
1	2	5	4	4	4	3
2	3	6	5	5	5	4

FIGURE 3

PROJECTED FUEL USE

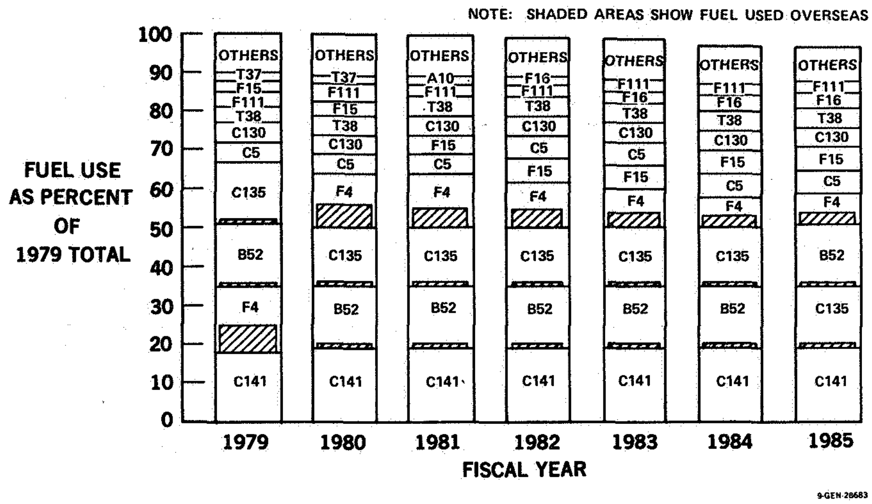


FIGURE 4

C-130 ADIABATIC WALL TEMPERATURE

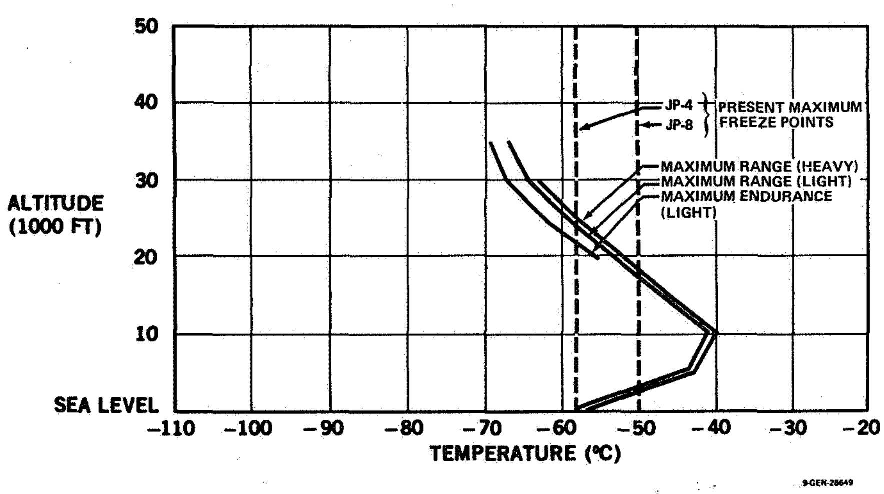


FIGURE 5

ALLOWABLE FREEZE POINT INCREASE (°C)

NOTES:
1. OUTSIDE AIR TEMPERATURES FROM MIL-STD-210B, ONE DAY PER YEAR RISK MINIMUM TEMPERATURES
2. BASED ON ADIABATIC WALL TEMPERATURES

	KC-10A	C-9	B-52	C-130	C-135	C-141	C-5	F-4	F-15
JP-8									
MAXIMUM RANGE — HEAVY	0.5	−3.0	−5.0	−13.0	−4.0	−5.0	−3.5	4.5	1.5
MAXIMUM RANGE — LIGHT	−3.5	−6.5	−11.5	−16.5	−8.5	−9.5	−8.5	−0.5	−4.0
MAXIMUM ENDURANCE — LIGHT	−10.5	−14.5	−14.0	−19.5	−13.5	−18.5	−15.0	−7.5	−10.0
JP-4									
MAXIMUM RANGE — HEAVY	8.5	5.0	3.0	−5.0	4.0	3.0	4.5	12.5	9.5
MAXIMUM RANGE — LIGHT	4.5	1.5	−3.5	−8.5	−0.5	−1.5	−0.5	7.5	4.0
MAXIMUM ENDURANCE — LIGHT	−2.5	−6.5	−6.0	−11.5	−5.5	−10.5	−7.0	0.5	−2.0

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