CP 495

EVALUATION OF A NEW FUEL WITH HIGHER ENERGY DENSITY

by

P.E.Desmier, Operational Research and Analysis Establishment
R.R.Hastings, Directorate of Research and Development Air

Department of National Defence
M Gen George Pearkes Building
101 Colonel By Drive
Ottawa, Ontario K1A OK2
Canada

SUMMARY

In order to increase the range and endurance of fighters operating in the far northern regions of Canada, and to extend maritime surveillance capability with existing aircraft assets, the Department of National Defence of Canada has pursued the development of an aviation fuel with a high energy density. The fuel selection criteria included: an energy increase of at least 10% by volume over current NATO F40/JP-4; acceptable performance and durability impact on aircraft systems; and large scale availability at reasonable cost.

This paper provides a description of the analysis which was used to determine the potential benefits to be derived from the use of a high energy density fuel. Mission analyses include discussions which cover fighter - CF-18, maritime surveillance - CP-140 Aurora, and tankers - CC-137, and KC-130, aircraft. The paper then discusses the fuel characteristics which were perceived to have a potential impact on aircraft or engine military performance. The results of engine component rig tests are then briefly discussed to demonstrate how critical fuel blend factors were evaluated to ensure that an optimal energy/performance blend was determined. Finally a description is provided on testing objectives for the subsequent full scale engine performance and durability testing as well as an outline of the final flight certification program for the High Density Fuel (HDF).

The test results to date have been most encouraging. There appears to be considerable potential for the introduction of HDF to military service.

NOMENCLATURE

AAR	=	Air-to-Air Refuelling
C	=	Celsius
C/L	=	Centerline station
CF	=	Canadian Forces
CON	=	Configuration
cSt	=	Centistokes
DND	=	Department of National Defence Canada
F	=	Fahrenheit
FUS	=	Fuselage weapon station
HDF	=	High Density Fuel
I/B	=	Wing In-Board pylon station
IFR	=	Instrument Flight Rules
L	=	Litre
MJ	=	Mega-Joules
NM	=	Nautical Miles
O/B	=	Wing Outboard pylon station
TOS	=	Time On Station
W/T	=	Wing Tip station

INTRODUCTION

The Department of National Defence (DND) in Canada was approached by a petroleum firm in 1986 with a proposal for a high energy density fuel which was, for the most part, similar to existing aviation fuels and which could have an operationally significant beneficial impact. The proposal provided that the fuel could be produced in significant quantities, at approximately constant energy costs, and that while some of the fuel characteristics were questionable in light of previous design considerations; further evaluation would be prudent.

It was decided to evaluate the potential for fuel development by:

(1) Determining whether or not a real operational need exists for the extension of the range and/or endurance of any Canadian Forces aircraft fleets. While this may seem a rather obvious point, aircraft mission requirements, as they are currently defined had to be evaluated against existing fleet capabilities to determine if any deficiencies exist and whether those deficiencies could be mitigated through the use of HDF.

(2) The evaluation of the operational benefits of using HDF in aircraft which were identified as potential targets of opportunity for the extension of operational capability would then be carried out. A relative assessment of aircraft range and endurance capabilities on current and the HDF fuel was completed and that assessment is the primary discussion area for this paper.

(4) Once the operational need had been identified, and the potential for satisfaction of that need through the use of HDF verified, a review would be conducted of the critical fuel factors impacting on energy content, performance, military acceptability, and aircraft and engine durability.

(5) Component rig testing would then be conducted to identify the fuel blend factors which offered potential for energy density improvements and the effects that those blend factors would have on the performance and durability of airborne systems.

(6) The component rig testing would identify the preferable architecture of the fuel, and then full scale engine sea level static, altitude chamber, and flight testing would be used to verify the performance improvements, durability acceptability, and certify the fuel for military use.

OPERATIONAL NEEDS

For any particular mission profile and aircraft configuration, the maximum operating range and time-on-station (TOS) of certain Canadian Forces aircraft are limited by the volume rather than the weight of fuel that the aircraft can carry. This factor is most significant for maritime surveillance operations as current aircraft are heavily tasked to cover the coastlines of Canada. Since the primary combustion process in the gas turbine engine involves burning a given weight of fuel in a given weight of air, it stands to reason that HDF would have a positive operational impact on the ability of maritime surveillance aircraft limited by fuel volume to fulfill more strenuous missions.

Other operational factors need also be considered. The CF 18 aircraft is required to operate extensively in the far northern regions of Canada. Missions are extended by virtue of the territory which must be covered. The consequences of depletion of fuel are catastrophic due to the extreme weather conditions encountered and distance from relief centers. The ability to carry an additional 10% of energy could have significant operational and flight safety benefits for the CF 18 aircraft.

Closely tied to the fighter operations in the previously mentioned, and in many other operational theaters is the conduct of Air-to-Air (AAR) refuelling. Canada has an extensive AAR refuelling mission requirement, and once again, the carriage of fuel having a higher energy content was determined to be beneficial. Tanker range and endurance would assumedly benefit as would the amount of energy which could be transfered to the supported fighter aircraft. Potentially more aircraft could be refuelled with a fixed energy load, or conversely a fixed number of aircraft could be refuelled with a greater amount of energy.

OPERATIONAL IMPACT ASSESSMENT

The operational impact of an aviation turbine fuel with 10% more volumetric energy content relative to NATO F40 was examined for four different Canadian Forces aircraft: the CF-18A, the CP-140 (Aurora), the KC-130 (Hercules) and the CC-137 (Boeing 707). Various mission profiles and weapon/aircraft configurations were simulated for each aircraft in all phases of flight. Expended fuel was accounted for at the end of each phase such that the aircraft would land with its minimum IFR (Instrument Flight Rules) reserves. In this manner, operating range and TOS may be varied independently so as to determine the operational impact due to the increase in energy content realized by a higher density fuel.

For each aircraft, a mission profile is examined which requires it to operate at a certain range from its home base. After a long-range cruise it may either dash to the target and unload its stores (CF-18A), loiter-on-station in an ASW (Anti-Submarine Warfare) role (CP-140), or loiter-on-station and provide air-to-air refueling to fighter aircraft (KC-130 and CC-137).

Regardless of the operational requirements, each simulation determines the fuel expended at the conclusion of each phase of flight. The phases are:

(1) Start/Taxi/Take-Off

(2) Climb to cruising altitude

(3) Cruise to operating area

(4) Fulfill mission requirements

(5) Cruise to home base

(6) Descend to home

(7) Approach and landing

All data such as specific range, fuel flow, TAS(True Airspeed) etc. were modelled as polynomials in the appropriate parameter, i.e., aircraft gross weight or time. By varying the cruise range and loiter time and landing with minimum IFR reserves, each simulation provided a straightforward determination of the operational benefit of HDF on fuel volume limited aircraft.

CF 18A

Three mission profiles were considered for the CF-18A. They are LLLL, LLLH, and HLLH (L=Low, H=High). Figure 1 illustrates the three profiles used in the analysis. For each profile, there were seven combinations of aircraft configurations and weapons (MK-82 SE Bombs, BL755 Bombs, LAU-5003A/A Rocket Launcher with 10 lb RX warhead and nose cones). Tables 1-3 detail the different configurations and store data used in the analysis.

CON	AIRCRAFT STATION								
	LEFT					RIGHT			
	W/T	O/B	I/B	FUS	C/L	FUS	I/B	O/B	W/T
1	AIM-9 (1)	Weapon (2)	Weapons (2)	Clean	330 gal Tank	Clean	Weapons (2)	Weapons (2)	AIM-9 (1)
2	AIM-9 (1)	Weapons (2)	330 gal Tank	Clean	Weapons (2)	Clean	330 gal Tank	Weapons (2)	AIM-9 (1)
3	AIM-9 (1)	Weapons (2)	330 gal Tank	Clean	330 gal Tank	Clean	330 gal Tank	Weapons (2)	AIM-9 (1)

CON = configuration
() = number of stores

TABLE 1. AIRCRAFT CONFIGURATIONS

Store	Weight per Store (lbs)	Drag Index
MK-82 SE	565	6.0
BL 755	610	16.8
LAU-5003	530	8.0
330 gal Tank	230	10.5/14.5
Pylon	130/273	3.0/7.5
VER	175	9.0

N1/N2 = CENTERLINE/WING

TABLE 2. STORES DATA

Number of Tanks	NATO F40 Fuel (lbs) (includes internal)
1	11910
2	13960
3	16010
Total Internal	9860

TABLE 3. USABLE FUEL

The CF-18A Aircraft Operating Instructions (AOI) were used to calculate the range and fuel expended under each profile and configuration. For each dash distance (A or B), a radius of action was determined such that the aircraft landed with 2000+/- 25 lbs of fuel. Each simulation was run with F40 and HDF (1.10x F40). Table 4 shows the percent increase in the radius of action as a result of using a higher density aviation turbine fuel.

The results shown in Table 4 indicate significant operational improvement when using HDF. The percent increase in the radius of action varies from a low of 13% (in itself significant) to a high of 26%. Even though the difference in the radii of action due to the two fuels increases as the configurations change from 1 to 3, the percent difference decreases. After weapons release, the aircraft is much heavier for configuration 3 than for configuration 1. It may cruise further from home but it will also expend fuel at a faster rate.

Under the profile LLLH and configuration 1, Table 4 shows that the operational requirements are not met using either F40 or HDF when armed with BL755 bombs and dashing 100NM. However with LAU-5003 rocket launchers under the same conditions, the requirements are met with HDF but not with F40. This situation also occurs under profile HLLH with BL755's and configuration 1.

CF-18 A RADIUS OF ACTION (NM)

		LLLL						LLLH						HLLH					
		A			B			A			B			A			B		
Weapons	CON	F40	HDF	%	F40	HDF	%	F40	HDF	%	F40	HDF	%	F40	HDF	%	F40	HDF	%
MK-82	1	191	219	15	176	205	16	225	263	17	n/a	235	--	305	359	18	242	304	26
	2	237	269	14	224	257	15	288	332	15	263	310	18	395	454	15	348	418	20
	3	289	326	13	278	316	14	360	410	14	339	394	16	493	558	13	458	536	17
BL 755	1	173	199	15	155	181	17	196	230	17	n/a	n/a	--	255	309	19	n/a	239	--
	3	274	309	13	261	297	14	334	381	14	312	363	16	457	520	14	414	448	18
LAU-5003	1	189	216	14	173	202	17	220	258	17	n/a	229	--	295	347	18	231	291	26
	3	285	321	13	273	311	14	349	402	15	331	385	16	485	550	13	447	525	17

% = Denotes percentage improvement over F40

CON = Configuration

TABLE 4. CF-18 PERCENT INCREASE IN RADIUS OF ACTION DUE TO HDF USAGE

CP 140 - AURORA

Figure 2 illustrates the two mission profiles considered for the CP-140 aircraft. For each profile, there are two aircraft configurations (labelled A and B). The AOI for the CP-140 was used to determine fuel flow, cruise range and TAS under any gross weight of the aircraft for each profile and configuration. In each simulation, the aircraft cruised to an operating area and, under power of three engines, loitered on station for a definite period before returning home and landing with 5000+/- 25 lbs of fuel. Figures 3 and 4 illustrate the operational advantage when using a higher density aviation turbine fuel in the CP-140 aircraft.

Since the aircraft returns with its minimum IFR reserves, the results in Figures 3 and 4 represent the maximum allowable TOS for any particular cruise range and the maximum cruise range for a particular TOS. Tables 5a and 5b show the percent increase in TOS and cruise range generated by HDF. The percent increase in TOS (Table 5a) varies from a low of 9% for the shorter cruise range (longer TOS) to a high of 48% for the longer cruise range (shorter TOS). The average increase in the TOS, regardless of the cruise range is approximately 1 hour. Table 5b shows that the percent increase in cruise range varies from 11% for a shorter TOS (longer cruise range) to a high of 30% for a longer TOS (shorter cruise range). The average increase in cruise range, regardless of the TOS, is approximately 180 nm.

Cruise Range (nm)	Congig./ Profile	Time-On-Station (hours)		
		F40	HDF	%
500	A/1	9.4	10.2	9
	A/2	8.9	9.9	11
	B/1	8.9	9.7	9
	B/2	8.6	9.6	12
1000	A/1	6.8	7.8	15
	A/2	6.2	7.2	16
	B/1	6.2	7.2	16
	B/2	5.7	6.8	19
1500	A/1	3.8	5.0	32
	A/2	3.0	4.3	43
	B/1	3.1	4.3	39
	B/2	2.5	3.7	48

TABLE 5a.

Time-on Station (hours)	Config./ Profile	Cruise Range (nm)		
		F40	HDF	%
2	A/1	1752	1940	11
	A/2	1646	1832	11
	B/1	1645	1821	11
	B/2	1564	1739	11
4	A/1	1464	1655	13
	A/2	1351	1540	14
	B/1	1362	1540	13
	B/2	1274	1452	14
6	A/1	1139	1328	17
	A/2	1026	1217	19
	B/1	1038	1214	17
	B/2	955	1137	19
8	A/1	775	960	24
	A/2	673	863	28
	B/1	673	845	26
	B/2	609	793	30

(% denotes percent improvement)

TABLE 5b.

TABLE 5. CP 140 PERCENT INCREASE IN CRUISE RANGE AND TIME-ON-STATION

KC-130 - HERCULES

Figure 5 illustrates the mission profile for the typical KC-130 mission. All calculations on the KC-130 tanker were based on the variant configuration consisting of external fuel tanks and refuelling pods installed. This configuration resulted in a drag index of +18. The AOI for the CC-130 was used to determine distance, fuel flow, TAS etc. at all points in the profile.

In terms of fuel capacity, there are stress factors to be considered when distributing fuel in the KC/CC-130. For instance the wing tanks are weight (not volume) limited and structural damage may occur if their capacity to hold 62920 pounds is exceeded. However the KC-130 tanker configuration has an additional 3600 gallon tank (23400 pounds of F40) in the cargo compartment which is volume (not weight limited) and could be used to carry HDF.

In its role as a tanker, the KC-130 would cruise to a rendezvous point, loiter for a period of time, meet the CF-18's and refuel each fighter before returning home to land with 6500 +/- 25lbs of fuel. Figures 6a-6f show the results of refueling up to 6 CF-18A's with 10,000 lbs of fuel each. Figures 7a and 7b show the results of refueling 1 and 3 CF-18A's with 15,000 lbs each. Plots for 2 or 4 aircraft (refueled with 15,000 lbs each) are not included since they are approximately equivalent to refueling 3 and 6 aircraft respectively with 10,000 lbs each.

In aerial refueling, the KC-130 has the advantage of providing tanker support to CF-18 aircraft on northern patrol. With this capability, the fighters could extend their time on partrol and, thus, provide 24 hours coverage with fewer missions and fewer aircraft. Clearly, the economic implications are substantial.

Figures 6 and 7 show the operational impact of utilizing HDF in a typical KC 130 tanker mission. Use of the fuel increases KC 130 cruise range by 50-60 nm or loiter time by 30-40 minutes. Although these benefits are marginal, a substantial operational improvement can be achieved in the energy off-loaded to the CF-18 aircraft as shown in Table 4.

CC-137 (BOEING 707)

Figure 5 also illustrates the mission profile for the CC-137 tanker. The AOI for the CF-137 was used to determine distance, fuel flow, TAS etc. at all points in the profile. The tanker configuration also accounted for an additional 5% in fuel expenditures in each phase.

As for the KC-130, the CC-137 would cruise to a rendezvous point, loiter for a period of time, meet the CF-18's and refuel each aircraft before returning home to land with 16000+/- 25 lbs of fuel. Figures 8a-8f show the results of refueling up to 6 CF-18A with 10,000 lbs of fuel each. Figures 9a and 9b show the results of refueling 3 CF-18A with 15,000 lbs each.

Similar to the KC-130, the CC-137 has the capability of providing tanker support to fighter aircraft. Figures 8 and 9 show the justification for using HDF instead of F40 in aerial refueling. As an example, Figure 8d shows the results of refueling 4 CF-18A with 10,000 lbs of fuel each. If F40 was used, with a cruise range of 1000nm, the CC-137 could loiter for 5.2 hours, refuel all aircraft and return home with 16,000 lbs of fuel. If HDF was used, the time to loiter could be extended to 8.9 hours (+71%). On the other hand, if the loiter time was fixed at 2 hours, the tanker could cruise for an additional 200nm with HDF and still refuel all 4 CF-18A's.

The results of the operational impact assessment show substantial gains in operational performance using HDF instead of F40.

For the CF-18A, a higher density fuel not only extends the operating range but in certain cases fulfils mission requirements which would only be marginally, if at all possible if F40 had been used. In the case of the CP-140, the results also indicate significant operational improvement. The CP-140 can add 1 hour to fulfilling its maritime surveillance role or extend its operating range 200 NM beyond its normal limits. For the KC-130 and CC-137, each tanker could refuel more aircraft, cruise for longer distances and/or loiter on station for a longer period of time. Furthermore, the refueled fighters are able to patrol over longer distances and for longer times using HDF, thereby decreasing the number of missions and aircraft needed to patrol, and increasing the patrol area.

FUEL PERFORMANCE CRITERIA

It is now viable to develop a high energy density fuel while retaining acceptable performance characteristics, and minimal negative operational and durability effects. F40 is termed a wide cut fuel as it is distilled over a wide boiling range. Its' properties approach the ideal from the operational perspective. F40 has a low freeze point, low viscosity, low flash point, high volatility, and burns efficiently and cleanly. Typically F40 performs well throughout all flight regimes, and due to its' relatively low viscosity and high volatility, demonstrates good low temperature startability. By way of comparison F45 (JP5), is distilled over a very narrow boiling range and is blended to be a fuel which can be safely stored. Unfortunately, the very properties which make it a safe fuel, result in its performance being poorer than F40 in terms of both startability and efficiency. These two fuel provide what can be considered the bounds used to determine the acceptability limits and operational goals for HDF. HDF performance should ideally approach that of F40, but will not have characteristics which are less acceptable than those of F45. A brief discussion on fuel characteristics is provided in order to provide a fundamental understanding of the considerations which identified the testing required to determine the HDF specification, and verify its operational acceptability.

The first and foremost quality to be discussed is that of heat of combustion. Within very narrow bounds, the heat of combustion, which is a direct expression of energy content, is constant for hydrocarbon fuels on a mass basis at approximately 43.5 MJ/KG (18500 BTU/LBM). Thus to achieve a higher energy density on a volumetric basis, the specific gravity of the fuel must be increased. The means of increasing the specific gravity of a hydrocarbon fuel is to increase the aromatic content of the fuel. The inclusion of a high percentage of aromatics requires access to the appropriate crude stocks and unfortunately also carries some performance penalties. Increasing the volumetric energy content can potentially cause a number of engine operational problems. Control systems which do not provide for mass flow metering of the fuel can produce excessive acceleration rates, overtemperature conditions, or overspeeding, which can in turn, cause durability or internal aerodynamics problems.

Aromatics are the heavy hydrocarbons in a fuel blend and therefore are required to increase to produce a more dense fuel with increased energy. Aromatics when burning, produce a more luminous flame which enhances heat transfer to the combustor walls. This increased heat transfer results in higher skin temperatures and hence shortened component lives. Increased aromatics also results in a somewhat decreased combustion efficiency which manifests itself most significantly in the production of undesireable emissions, most notably smoke. Thus in achieving a higher energy density fuel, hot section durability can be lessened, and increased smoke can be expected. The increased smoke emissions are operationally significant for the fighter missions, and will have increasing importance in maritime surveillance as subsurface-to-air weapons become more heavily utilized.

The vapour pressure which a fuel blend exhibits will be high if there is a large percentage of volatile components. High volatility is desirable for good low temperature start capabilities; however that same characteristic can give rise to safety problems and other problems such as fuel delivery pump vapour lock. The HDF goals were aimed primarily at performance as the safety issues associated with shipboard fuel storage are of minor concern to the CF. As such, the HDF vapour pressure was targeted at the F40 level.

The flash point concerns mirror those of vapour pressure, and once again it was determined to attempt to obtain good low temperature start characteristics by maintaining a relatively low flash point.

Freeze point, cloud point, and viscosity are characteristics which are interrelated and can be discussed together. The freeze point and cloud point are essentially the same and describe when wax begins to crystallize in the fuel. The formation of wax is significant in that the wax can clog filters or fine orifices causing fuel metering problems. Typically freeze point and viscosity vary proportionally, a high freeze point indicating a high viscosity at low temperatures. Viscosity is recognized as a critical parameter in terms of fuel nozzle spray patterns and atomization which in turn affect cold startability and flame stability. As stated previously, the HDF cold start characteristics were considered to be of importance in assessing that fuels acceptability due to both cold weather operational and altitude relight considerations.

The final fuel characteristics to be discussed are the chemical contaminants. Tar sands derivatives contain higher levels of such contaminants as mercapton sulfur which attacks elastomers in fuel system and engine control components. The goals of the HDF blend would have to be to minimize the trace element contaminants and also to assess the effects of the actual contaminant levels during component testing.

TEST PROGRAM

The specification of HDF characteristics, and verification of the fuels operational acceptance was to be carried out in five phases as described below.

An initial test program was used to identify the critical blend factors for HDF to assess whether the operational goals were possible at the increased density level. This testing was conducted at Universite Laval (Ref 5.) and utilized a scaled research combustor at two constant temperature, constant pressure conditions. The combustor employed a pressure jet atomizer and had twelve thermocouples installed at four planar locations on the combustor wall. Table 6 provides a comparison of the critical characteristics of the five sample HDF blends, as well as for the as-tested F40.

Property	HDF A	HDF B	HDF C	HDF D	HDF E	F40
Specific Gravity	.846	.863	.841	.849	.851	.754
Hydrogen Content (mass)	.133	.129	.136	.133	.132	.145
Viscosity @ 293K (cSt)	2.88	3.13	2.78	3.16	2.96	.756
Net Calorific Value (MJ/L)	36.9	37.3	36.9	36.9	37.1	32.8

TABLE 6. - PROPERTIES OF TEST FUELS

This test program confirmed the expected fuel performance characteristics. All HDF blends burned slightly less efficiently, and produced more pollutants and visible emissions than the F40. Some increase in wall temperatures in the primary combustion zone of the combustor was observed for all HDF blends; however, in general the effects were not considered significant. Once past the primary zone, there were only negligible wall temperature differences. In fact, this initial test phase indicated that although further testing would be necessary to quantitatively assess visible emissions; there was no obvious impediment to the further testing of the HDF. For the most part all HDF blends performed equally well.

The second phase of testing was conducted in a combustor rig at the Gas Dynamics Lab of the National Research Council of Canada (Ref 6.). As opposed to the phase 1 atmospheric pressure testing, the combustion conditions in phase 2, approached the normal operating temperatures and pressures of the T56 series of engines used in the CP140 (P-3), and CC130 aircraft. For this test program F40 and Jet A-1 (NATO F35 and similar to F34) were used for comparative purposes. The HDF blends tested were the same as in the Laval tests. The significant conclusions for this test program were that:

a. Emission species for all test and reference fuels were similar in nature and concentration levels;

b. No significant increases in wall temperatures were noted for any of the test or reference fuels;

c. The smoke levels for the all HDF blends showed little variance, and were slightly greater than for F35 and F40, but not unacceptably high; and

d. Exhaust gas temperatures were higher for the HDF fuel blends than for F40, which may be significant in terms of IR signature.

The final conclusion of the Ref 6. report was that the HDF fuel performed similarily to the reference fuels, and that there appeared to be no reason for concern about conducting full scale engine testing.

The third phase of testing was conducted at Pratt and Whitney Canada in conjunction with advance igniter testing (Ref 8.). This phase of testing was intended primarily to verify the cold start characteristics of the HDF type blend. The same five HDF blends were tested along with F40 and F35 reference fuels in a PW300 full annulus test rig. The test rig employs 22 air blast nozzles and two hybrid pressure atomizing/airblast nozzles. Combustor pressure drop was varied from two to five inches of water, and the inlet temperatures varied down to -29C (-20F). The low pressure drops and temperature represent a severe test condition, particularly for air blast nozzles which depend on relatively high velocities to assure adequate atomization.

Once again the test results were most favourable for the HDF blends. The HDF blends started down to the lowest temperatures at the minimal pressure drops which represent the most severe relight conditions. The HDF blends performed as well as the F40 reference fuel and exceeded the F35 start characteristics. The high viscosities of the HDF blends were anticipated to cause a worsening of the fuels cold start capabilities but that was not borne out in the test observations. These test results challenge some previous concepts of fuel performance.

At the time of writing, the previous three test phases had been completed. The remaining two test sequences are intended to identify fuel acceptability using full scale engine tests, and finally, flight test. Full scale engine testing will be conducted on the T56 engine and the F404 engine used in the CF 18. The flight testing will most likely be carried out using a CF 18 aircraft. Engine full scale testing will have the following objectives:

a. To verify acceptable engine performance using HDF fuels, this will be achieved by conducting back-to-back power hooks on certified laboratory quality test stands, using F40 and HDF;

b. To verify that no accelerated hot section duress occurs by the conduct of limited scope Accelerated Mission Testing (AMT) (150 hours for the T56, 50 hours for the F404);

c. To quantify both visible emissions and pollutants produced by the use of HDF; and

d. To conduct cold soak atmospheric starts.

REFERENCES

1. Aircraft Operating Instructions CF18A/CF 18B HORNET (U), C-12-188-NFM/MB-001, 31 December, 1987 (U).

2. Aircraft Operating Instructions CF 140 AURORA (U), C-12-140-000/MB-001, 27 June, 1986 (U).

3. Performance Data for Lockheed Hercules (U), C-12-130-J00/MB-002, 20 June 1985 (U).

4. Aircraft Operating Instructions CC 137 Flight Test Procedures (U), C-12-137-000/MB-Z04, 19 December, 1986 (U).

5. Kretschmer D., LaViolette M., " Comparison of Five High Density Fuels", Universite Laval Report No. 183, January 1989

6. Campbell I., Test Report of Department of National Defence Strategic Military Fuels, National Research Council Report CTR-GD-017, February 1990

7. McCaldon K., Critchley I., Sampath P., "Plasma Jet Ignition Research Final Report", September 1989, Pratt and Whitney Canada Proprietary.

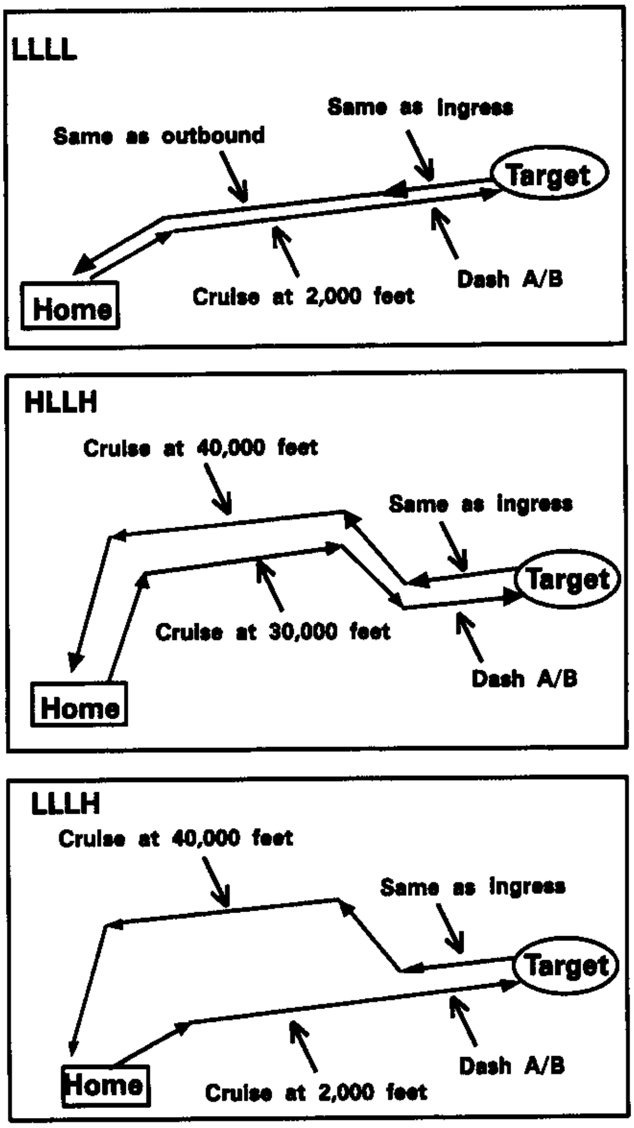

Fig.1 CF-18A Mission Profiles

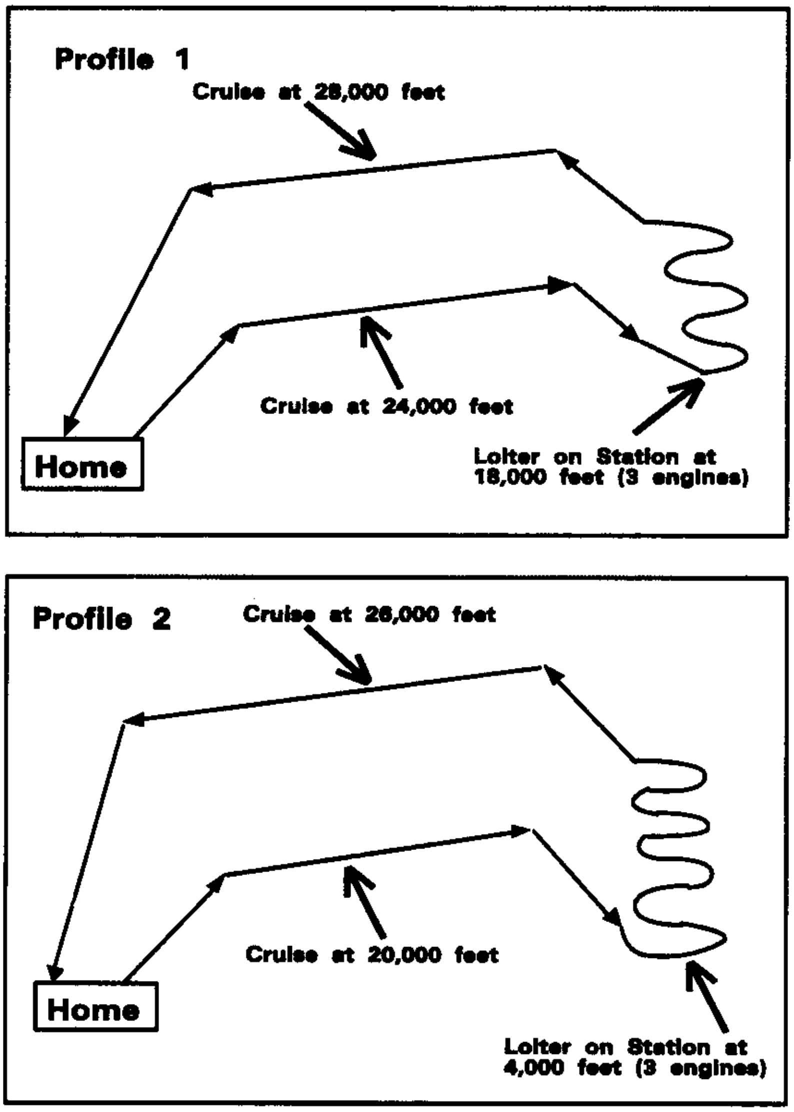

Fig.2 CP-140 Mission Profiles

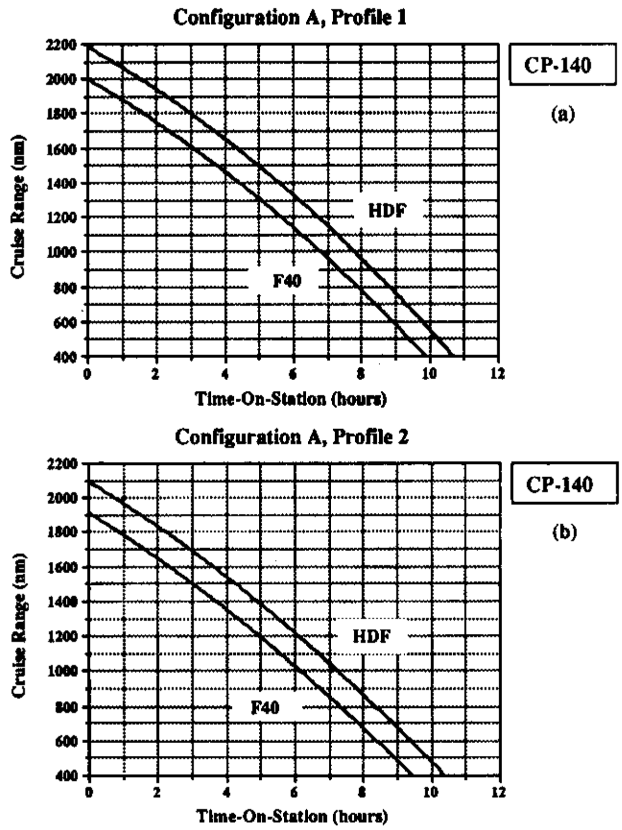

Fig. 3(a,b) Improvements in Cruise Range and Time-On-Station by using a High Density Fuel (Configuration A)

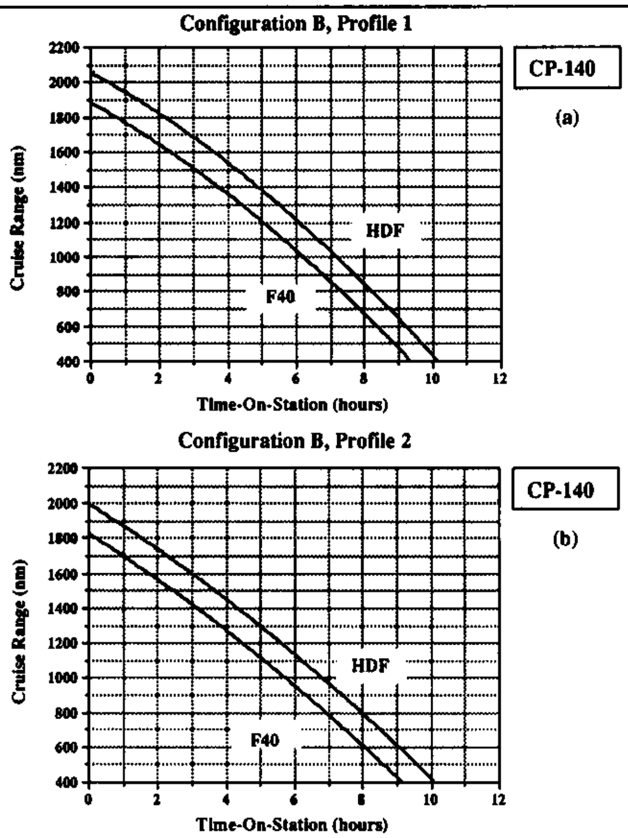

Fig. 4(a,b) Improvements in Cruise Range and Time-On-Station by using a High Density Fuel (Configuration B)

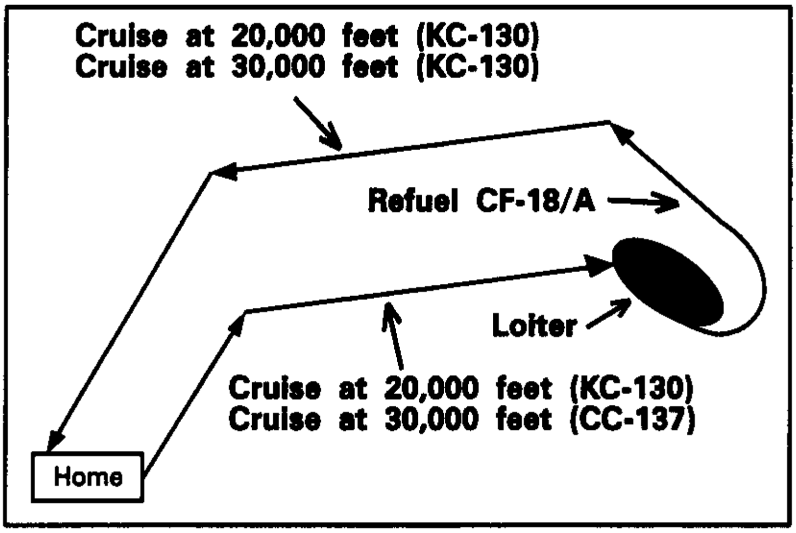

Fig.5 KC-130 and CC-137 Tanker Mission Profile

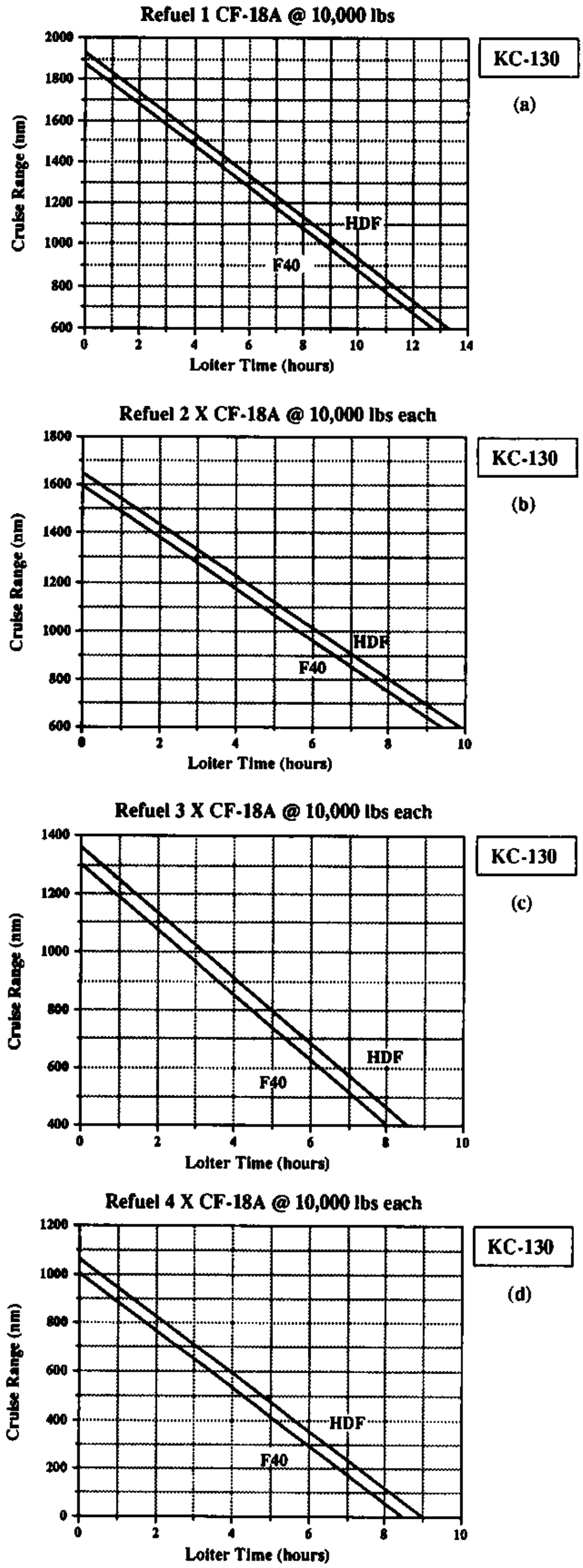

Fig. 6(a-d) Improvements in Cruise Range and Loiter Time in aerial refueling by KC-130 aircraft

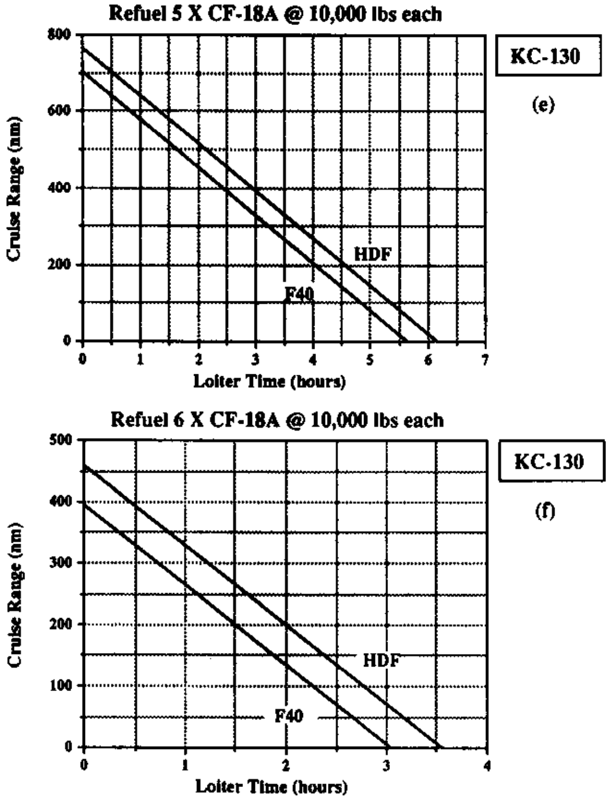

Fig. 6(e,f) Improvements in Cruise Range and Loiter Time in aerial refueling by KC-130 aircraft

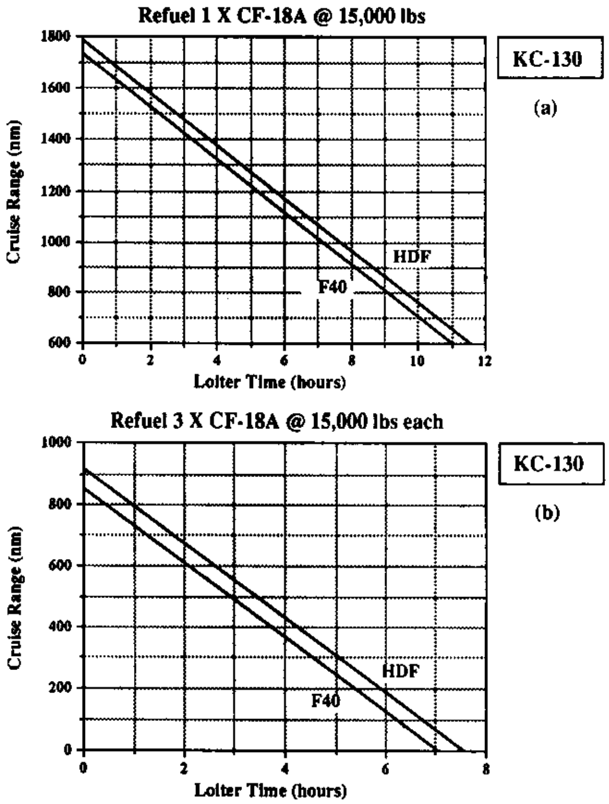

Fig. 7(a,b) Improvements in Cruise Range and Loiter Time in aerial refueling by KC-130 aircraft

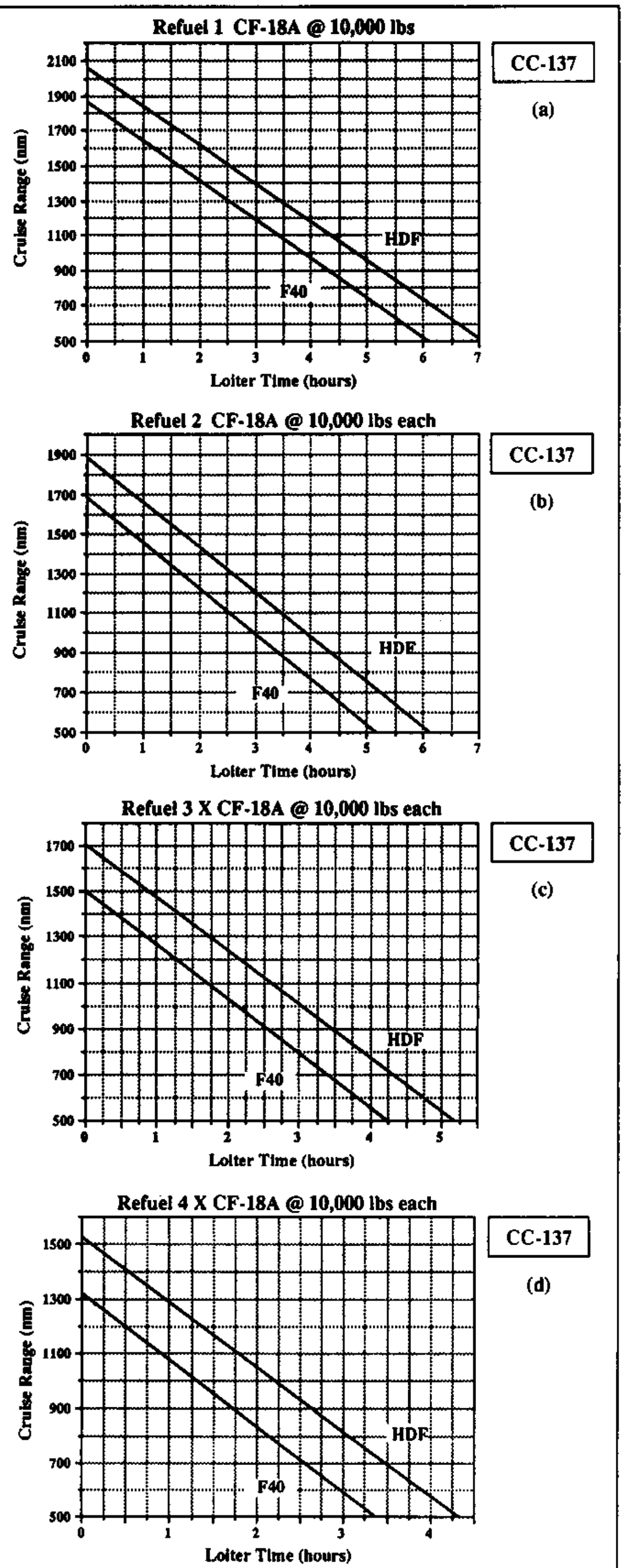

Fig. 8(a-d) Improvements in Cruise Range and Loiter Time in aerial refueling by CC-137 aircraft

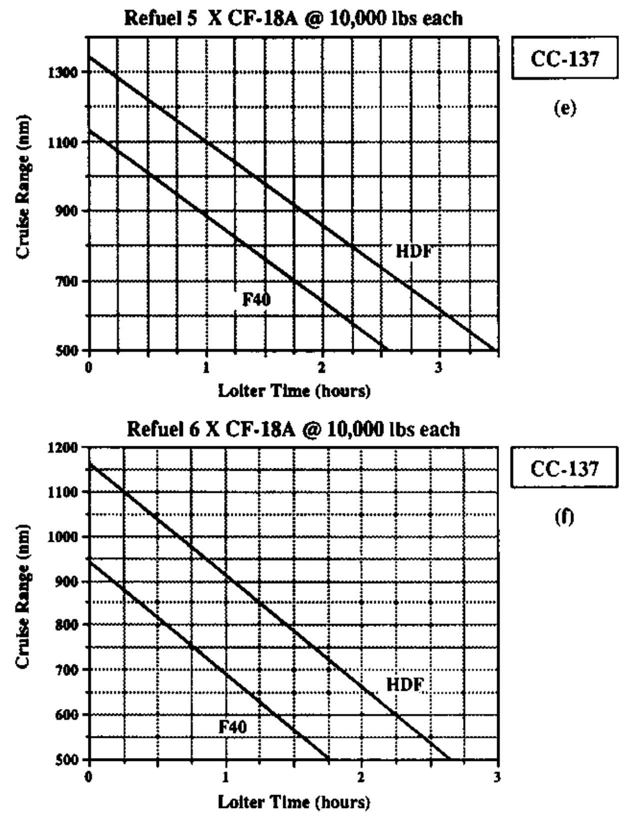

Fig. 8(e,f) Improvements in Cruise Range and Loiter Time in aerial refueling by CC-137 aircraft

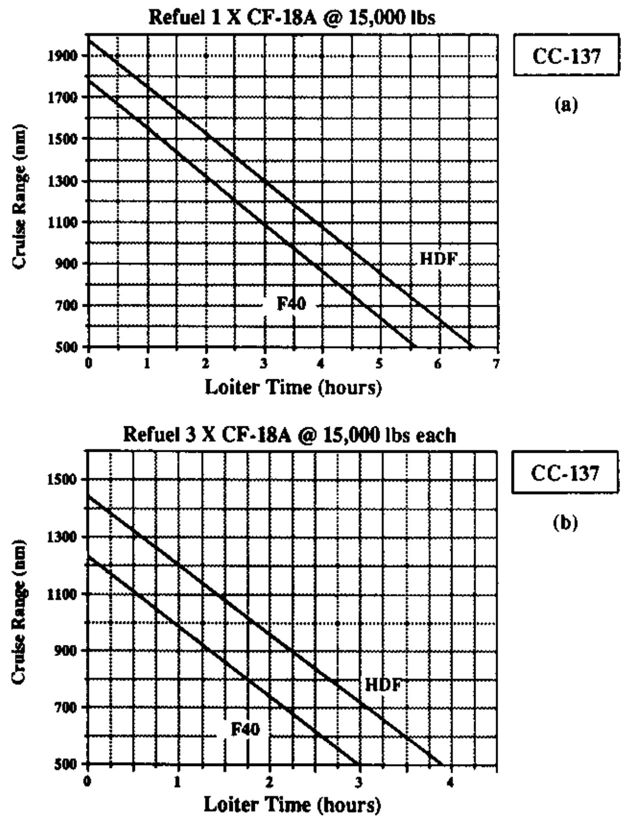

Fig. 9(a,b) Improvements in Cruise Range and Loiter Time in aerial refueling by CC-137 aircraft