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**ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT**
7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

**AGARD REPORT 801**

# Impact Study on the Use of JET A Fuel in Military Aircraft during Operations in Europe

(Etude de l'impact de l'utilisation du carburant JET A par les avions militaires lors des opérations en Europe)

By

**Graham Batchelor (UK)**
**Cliff Moses (US)**
**Ron Fletcher (UK)**



**NORTH ATLANTIC TREATY ORGANIZATION**



Published January 1997

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North Atlantic Treaty Organization
*Organisation du Traité de l'Atlantique Nord*

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# Impact Study on the Use of JET A Fuel in Military Aircraft during Operations in Europe

## (AGARD R-801)

# Executive Summary


NATO fuel F-34 is derived from the European civil airline fuel JET A1 by the addition of a mix of additives which addresses specific operational problems. In the USA, the standard civil aviation fuel is JET A which differs in practice from Jet A1 in several factors but mainly in its Freeze Point for which the specification level is set at –40°C, some 7°C higher than that of JET A1. Surprisingly, despite the fact that JET A is produced in high quantities and is used on occasions in American military aircraft, it has found no place in NATO catalogues. For many years the question has arisen as to whether or not it should have a role in fuel logistics planning — if only for use in emergency scenarios. This study has taken a first look at the position and has attempted both to identify the relevant differences in these two fuels and, more importantly, to begin to address the question of what, if any, are the operational limitations that would occur from the use of JET A as a base fuel in the European military environment.

A careful study of both the variations in the Specification of the two fuels and also the variations that actually exist in purchased fuels, concludes that Freeze Point difference is the main factor to be considered. It shows that whereas the Specification limits for JET A1 and JET A vary from –47°C to –40°C respectively, purchased fuels of the type vary from –50°C to –44°C; such values are compared against the cold temperature extreme of Central Europe of –31°C with the lowest recorded value of –42°C. It is also noted that although the Specified maximum viscosity limits are the same for both fuels, in delivery the JET A value is a little higher. Taken together these factors suggest that the fuel changes have the potential to produce the following operational problems:

- fuel flow supply limitations from external fuel tanks and/or wing tip tanks during flight at low speed operations;
- fuel freeze/engine supply problems following long aircraft soak times, either when positioned in the extreme Northern part of Europe or on the very rare occasions when Central European temperatures drop to around the lowest recorded value of –42°C;
- start-up problems following extensive cold-soak of the aircraft/fuel system.

The second part of the study involved interviews both in Europe and in the US with military aircraft operators, designers and fuel suppliers. Some prejudice against the JET A fuel was expressed within Europe although no direct experience was available to assist the study. In contrast, on the basis of the experience gained by the US in the use of both fuels, clear statements of support were collected which covered the full range of operations. It was learned that concern with limitations which can arise in flight have been overcome by the specification of minimum flight speeds over altitude given within the official Technical Orders for each aircraft type.

The conclusion of the study is that the US civil aviation fuel JET A may be used as a base fuel for a F-34 substitute in current NATO military aircraft operations in Europe providing:

1. the same precautions are followed as those employed in using the European civil aviation fuel JET A1 (e.g. use of additive package);

2. where not in existence today, appropriate Technical Orders be prepared for each aircraft type to address the fuel factors identified.

More generally, the feeling gained from the study is that acceptance of JET A would offer sufficient logistical prizes to justify the associated operational limitations.

# Etude de l'impact de l'utilisation du carburant JET A par les avions militaires lors des opérations en Europe

## (AGARD R-801)

# Synthèse


Le carburant OTAN F-34 est dérivé du carburant utilisé par les compagnies aériennes européennes, le JET A1, par l'ajout d'un mélange d'additifs qui permet de résoudre certains problèmes opérationnels spécifiques. Le carburant standard de l'aviation civile aux Etats-Unis, le JET A, a des caractéristiques différentes du JET A1, notamment son point de congélation, pour lequel la spécification est de –40°C, c'est-à-dire à 7°C au-dessus de celui du JET A1. Etonnamment, malgré le fait que le JET A soit produit en grande quantité et qu'il soit utilisé parfois dans les avions militaires américains, il n'a pas trouvé sa place dans les catalogues de l'OTAN.

Depuis de nombreuses années la question posée est de savoir si le JET A avait un rôle à jouer dans la planification de la logistique des carburants — même si ce n'était seulement que pour des scénarios ayant un caractère d'urgence. Cette étude présente une première analyse de la situation, qui a pour objectif d'identifier les principales différences entre ces deux carburants et, chose plus importante, d'aborder la question des limitations opérationnelles éventuelles qui résulteraient de l'utilisation du JET A comme carburant de base dans l'environnement militaire européen.

L'examen détaillé des différences qui existent entre les spécifications de ces deux carburants et les différences réellement constatées entre eux, tels que livrés à la pompe, montre que la différence de point de congélation est le principal facteur à prendre en considération. Tandis que les limites annoncées dans les spécifications du JET A1 et du JET A varient entre –47°C et –40°C respectivement, les carburants tels que livrés varient entre –50°C et –44°C; de telles valeurs sont à comparer à la limite inférieure de température pour l'Europe centrale, de –31°C et à la limite inférieure record, de –42°C. Il est à noter également que, bien que les limites maximales de viscosité spécifiées soient les mêmes pour les deux carburants, la valeur limite pour le produit JET A livré est légèrement supérieure à celle du JET A1. Pris ensemble, ces deux facteurs indiquent que ces fluctuations dans les caractéristiques des carburants peuvent en principe conduire aux problèmes opérationnels suivants :

- limitation du débit d'alimentation en carburant à partir des réservoirs de carburant extérieurs et/ou des réservoirs d'aile lors du vol à basse vitesse;
- gel du carburant/problèmes d'alimentation moteur suite à de longues périodes d'immobilisation au sol, soit dans l'extrême nord de l'Europe, soit dans les très rares occasions où les températures en Europe centrale chutent à des valeurs voisines de la limite inférieure record, de –42°C;
- problèmes de démarrage suite à l'exposition prolongée de l'aéronef/circuit carburant, au froid.

La deuxième partie de l'étude est composée d'entrevues avec les concepteurs, les fournisseurs de carburant et les exploitants d'avions militaires en Europe et aux Etats-Unis. Certains préjugés concernant le carburant JET A ont été exprimés en Europe, bien qu'aucune expérience réelle ne fut avancée comme contribution à l'étude. En revanche, sur la base de l'expérience acquise par les Etats-Unis avec les deux carburants, des déclarations d'adhésion très marquées ont été enregistrées, couvrant toute la gamme des opérations — tactiques, stratégiques et de pont aérien. Il en est ressorti que les inquiétudes concernant les limitations susceptibles de se produire en vol avaient été dissipées par la spécification de vitesses minimales au-dessus de certaines altitudes préconisées dans les instructions techniques propres à chaque type d'aéronef.

L'étude conclut que le carburant de l'aviation civile américaine, JET A, peut être utilisé comme carburant de base en remplacement du F-34 pour les opérations aériennes actuelles de l'OTAN en Europe, sous réserve :

- de prendre les mêmes précautions qui sont prises pour le carburant de l'aviation civile européenne JET A1 (par exemple l'utilisation du mélange d'additifs);
- d'établir des instructions techniques pour chaque type d'aéronef, pour chaque cas où de tels documents n'existeraient pas aujourd'hui, afin de répondre aux facteurs carburant identifiés.

Plus généralement, l'impression donnée par l'étude est que l'acceptation du JET A offrirait suffisamment d'avantages pour justifier les limitations opérationnelles associées.

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**Interior Ballistics of Guns**
AGARD CP 392, January 1986

**Advanced Instrumentation for Aero Engine Components**
AGARD CP 399, November 1986

**Engine Response to Distorted Inflow Conditions**
AGARD CP 400, March 1987

**Transonic and Supersonic Phenomena in Turbomachines**
AGARD CP 401, March 1987

**Advanced Technology for Aero Engine Components**
AGARD CP 421, September 1987

**Combustion and Fuels in Gas Turbine Engines**
AGARD CP 422, June 1988

**Engine Condition Monitoring — Technology and Experience**
AGARD CP 448, October 1988

**Application of Advanced Material for Turbomachinery and Rocket Propulsion**
AGARD CP 449, March 1989

**Combustion Instabilities in Liquid-Fuelled Propulsion Systems**
AGARD CP 450, April 1989

**Aircraft Fire Safety**
AGARD CP 467, October 1989

**Unsteady Aerodynamic Phenomena in Turbomachines**
AGARD CP 468, February 1990

**Secondary Flows in Turbomachines**
AGARD CP 469, February 1990

**Hypersonic Combined Cycle Propulsion**
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**Fuels and Combustion Technology for Advanced Aircraft Engines**
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**Technology Requirements for Small Gas Turbines**
AGARD CP 537, March 1994

**Erosion, Corrosion and Foreign Object Damage Effects in Gas Turbines**
AGARD CP 558, February 1995

**Environmental Aspects of Rocket and Gun Propulsion**
AGARD CP 559, February 1995

**Loss Mechanisms and Unsteady Flows in Turbomachines**
AGARD CP 571, January 1996

**Advanced Aero-Engine Concepts and Controls**
AGARD CP 572, June 1996

**Service Life of Solid Propellant Systems**
AGARD CP 586, May 1996

**ADVISORY REPORTS (AR)**

**Producibility and Cost Studies of Aviation Kerosines** *(Results of Working Group 16)*
AGARD AR 227, June 1985

**Performance of Rocket Motors with Metallized Propellants** *(Results of Working Group 17)*
AGARD AR 230, September 1986

**Recommended Practices for Measurement of Gas Path Pressures and Temperatures for Performance Assessment of Aircraft Turbine Engines and Components** *(Results of Working Group 19)*
AGARD AR 245, June 1990

**The Uniform Engine Test Programme** *(Results of Working Group 15)*
AGARD AR 248, February 1990

**Test Cases for Computation of Internal Flows in Aero Engine Components** *(Results of Working Group 18)*
AGARD AR 275, July 1990

**Test Cases for Engine Life Assessment Technology** *(Results of Working Group 20)*
AGARD AR 308, September 1992

**Terminology and Assessment Methods of Solid Propellant Rocket Exhaust Signatures** *(Results of Working Group 21)*
AGARD AR 287, February 1993

**Guide to the Measurement of the Transient Performance of Aircraft Turbine Engines and Components** *(Results of Working Group 23)*
AGARD AR 320, March 1994

**Experimental and Analytical Methods for the Determination of Connected — Pipe Ramjet and Ducted Rocket Internal Performance** *(Results of Working Group 22)*
AGARD AR 323, July 1994

**Recommended Practices for the Assessment of the Effects of Atmospheric Water Ingestion on the Performance and Operability of Gas Turbine Engines** *(Results of Working Group 24)*
AGARD AR 332, September 1995

**LECTURE SERIES (LS)**

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AGARD LS 150, April 1987
AGARD LS 150 (Revised), April 1988

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AGARD AG 328, August 1993

**REPORTS (R)**

**Application of Modified Loss and Deviation Correlations to Transonic Axial Compressors**
AGARD R 745, November 1987

**Rotorcraft Drivetrain Life Safety and Reliability**
AGARD R 775, June 1990

**The Single Fuel Concept and Operation Desert Shield/Storm**
AGARD R 810, January 1997 (NATO Unclassified)

# Summary

The study comprised two parts. The first consisted of a 'paper' study of the differences in specifications and actual supply properties of the two kerosene fuels JET A1 and JET A, and the identification of potential operations limitations that could arise within the European military arena if the latter fuel were to replace JET A1 as the base fuel in the NATO F-34 fuel specification. The second part comprised a series of interviews with the military users and the suppliers of the equipments and fuels to learn whether or not their views/experiences matched those obtained in the first part of the study.

From such a study it is concluded that US civil aviation fuel JET A can be used to replace European civil aviation fuel JET A1 providing:

a) the same precautions are followed as are employed today with JET A1, particularly those with respect to the use of additives;

b) appropriate Technical Orders are prepared for each aircraft type.

The preparation of such Orders is not thought to be too burdensome a task as the fuel property variations are not large. Further, it is to be noted that such Orders are in place already for most US aircraft that fly within Europe (eg. F15, F16) and they are not considered necessary for the lower altitude flying aircraft of type A10 and F111.

## PREAMBLE

The paper focuses on the fuel Jet A as it differs from Jet A1 (Nato F-35). It assumes that were Jet A to be used by Nato in Europe, then all the mandatory military additives would be added to it before use in battle. Such additives include Corrosion Inhibitor (CI), Fuel Systems Icing Inhibitor (FSII) and Static Dissipator (SDA), which convert NATO F-35 into NATO F-34 fuel (US designation JP-8).

## 1. INTRODUCTION

In recent years, fuels usage policy for Nato Europe has evolved via Working Group 4(WG4) of the Nato Pipeline Committee (AC/112). The seminal outcome has been the decision to adopt (convert to) F-34 as the primary fuel for land-based military aircraft in Europe; that F-34 to be based on the civil Jet A1 (Nato F-35) commercially available in the Theatre. Once taken, that decision inspired, as a longer term goal, a Single Fuel Concept (SFC) aiming to make F-34 the sole fuel for all military land and air operations in Europe. By 1990 the air aspect of the policy had taken effect with such jet fuel being supplied through the major Nato Pipeline Systems.

Jet A1 of the quality in point is the civil aviation norm in Europe and throughout the whole of the "Free/Western" world outside North America. Emphasis on Europe as the focus for initial SFC planning owes much to the fact that Jet A1 is a minority fuel within North America. In USA the standard civil aviation fuel is Jet A which simple fact alone dictates that, in global terms, Jet A consumption probably exceeds that of Jet A1. Add the further fact that upto recent times numbers of commercial aircraft engaged in conventional air reinforcement of Europe (ex USA) might themselves have been fuelled with Jet A, and it becomes a matter for surprise that the fuel found no place in Nato catalogues. Clearly Jet A has a de facto place in Nato operational planning. A question therefore arises as to whether it should not also have one in fuel logistics planning - albeit for emergency scenarios only.

For the proper weighing of that question, a clear picture of Jet A is needed - not least with regard to possible consequences of its sometime use as a base fuel for Nato military aircraft in Europe. This study aims to provide such a picture and, specifically, to answer the question "What, if any, are the operational limitations that would occur from the use of Jet A as a base fuel in the European military environment?"

At present Jet A is manufactured and used only in North America - where it is the primary commercial jet fuel, and where Jet A1 is very much a secondary product. In Europe, where today Jet A is neither produced nor consumed, Jet A1 is the main stream commercial jet fuel.

Within the compass of a single specification describing both grades (ASTM D.1655 being the definitive example), Jet A and Jet A1 differ only in their Freezing Points: -40°C and -47°C respectively. However, for what can be deemed "regional" factors, Jet A1 is to some extent differently defined by (say) the USA specification ASTM D.1655 and (say) the UK specification DERD 2494. The latter, although embodying requirements special to the needs of certain UK hardware, is very close to being a norm for Jet A1 production in the world outside North America. Certainly DERD 2494 typifies commercial Jet A1 in Europe - and that, as Nato F-35, forms the basis for the F-34 on which the SFC is centered.

## 2. FACTORS OF IMPORTANCE

*The points discussed under this sub-heading apply to kerosene-type turbine fuels in general, not just to Jet A.*

### 2.1 FREEZING POINT

#### 2.1.1 Definition

Freezing Point is an often misunderstood parameter of fuel quality. Actually, it is a misnomer. A normal petroleum fuel is composed of many thousands of hydrocarbon compounds, and as such does not exhibit an overall change from the liquid state to the solid state in the manner of a pure substance. Instead, as the fuel temperature falls, there comes a point at which initial components crystallize. With a continuing fall in temperature, the crystallization process progresses, resulting first in the formation of a slurry of wax crystals in the fuel and eventually an immobile structure comprised of a stable wax material from which all recoverable liquid has been removed. In actuality, the Freezing Point of a jet fuel is determined by rewarming this waxy material. The temperature at which the last crystal of the slurry disappears is defined as the Freezing Point.

The F-34 fuel specification requires that the Freezing Point be less than -47°C. In comparison, the Freeze Point for Jet A may be as high as -40°C. It should be noted that these are the maximum values. In 1991, the average Freeze Point for 39 Jet A samples was -44°C; the lowest Freeze Point was -59°C, and only two samples were at the spec limit of -40°C. This average value has been consistant for the last 15 years. Similarly for F-34, from 100 samples of F-34 in Europe in 1987, the average Freeze Point was -50°C with a minimum of -60°C and a maximum of -47°C.

As an aside, a degree of expertise is needed to fully distinguish between the onset of hydrocarbon crystallization and haze due to prior freezing out of water. Although fuel and water are considered immiscible, absolute immiscibility does not exist in nature. At normal ground ambient atmospheric conditions, water will be dissolved in a kerosene fuel at an equilibrium concentration of perhaps 30 ppm. This dissolved water begins to come out of solution, as ice, as the fuel temperature falls below 0°C; the process becomes largely complete by –30°C, i.e., well above the Freezing Point of any jet fuel. A fuel system icing inhibitor (FSII, see section 2.3.1) is used to control this problem. FSII has no impact on Freezing Point.

#### 2.1.2 Aircraft Factors

As the fuel temperature drops below the Freezing Point of the fuel, a slurry of wax crystals will begin to form in the fuel tank. In isolated parts of the tank, wax structures will begin to form and, in extreme cases, eventually grow to fill the tank. Thus two problems can occur: those that can arise as a consequence of the formation of two-phase flow and those as a result of fuel holdup. Current military aircraft are not designed to handle two-phase flow in any form and its presence will lead to filter plugging and engine starvation. Fuel holdup will reduce the fuel available and so prevent the pilot from completing the mission.

Water also accrues in aircraft systems as a result of breathing and temperature cycling in tank ullage space. Although some modern aircraft systems are designed to scavenge and dispose of limited quantities of water, water as ice can cause filter blockage at entry to engine .

The problem of filter plugging by wax or ice crystals does not occur in civilian aircraft as they make full use of heaters on the fuel filters. These are widely omitted from military aircraft designs in the interests of weight saving aimed at overall performance enhancement. Consequently FSII (Fuel Systems Icing Inhibitor) is required in all military jet fuels.

Much attention is paid to the fuel cooling problem during the design of military aircraft and attempts are made to minimise those conditions which produce maximum cooling rates; that is by the avoidance of the use of exposed and/or thin section fuel tanks. Inevitably, however, a compromise has to be reached and such geometrics do exist in practice especially around the wing tanks of fighter aircraft which are particularly vulnerable when cooling factors are at their greatest such as when flight takes place at relatively slow air speeds (eg during air refuelling exercises). The commonly accepted design criterion is that fuel shall be delivered to the engine fuel system at a temperature not less than 3°C above its Freezing Point. In practice this means that pilot action of some sort will be triggered by an indicated fuel temperature of –37°C in the case of Jet A and -44oC for Jet A1.

### 2.1.3 Ground Ambient Weather Factors

According to STANAG No. 2831, Western Europe is classified as having a 'mild cold' climate with cold temperature extremes of -6 to -19°C; the lowest temperature recorded is -24°C. Similarly, Central Europe has an 'intermediate cold' climate with cold temperature extremes of -21 to -31°C; the lowest temperature recorded is -42°C. Thus it is only in Central Europe, and then very rarely, that ambient temperatures become potentially of significance to the question raised in this study. For, although in theory, the extreme level of -42oC could prove limiting for the (-40oC) JetA fuel, in practice it is not to be expected that freezing would occur at any significant level due to the long 'soak' times required for fuel to fall fully to ambient levels as will be shown later.

### 2.1.4 Altitude Factors

In flight, the temperature which the aircraft skin experiences depends upon the ambient air temperature and the mach number of the aircraft - for a fixed air temperature, the slower the speed, the lower is the skin temperature. The effect is readily quantifiable:

$$TAT = OAT\,(1+0.2kM^2)$$

where: **TAT** = the effective air temperature experienced at the skin of an aircraft (or Total Air Temperature)

**OAT** = the Outside (or Static) Ambient Air Temperature

**k . .** is a design configuration dependent Wing Recovery Factor, never unity but typically 0.9

Altitude effects are dominant as, upto the range experienced by most aircraft, an increase in altitude decreases the outside air temperature by approximately 6.5oC per kilometre in height to a value of around -60oC.

Figure 1 (overpage)illustrates the effect for selected flight Mach numbers. It will be noted that for speeds greater than Mach 1.0, fuel atmospheric cooling ceases to be a factor unless the ambient air temperature falls well below -60oC, for at such speeds the skin termperature will exceed even the higher freeze point. At slower speeds the absence of useful kinetic heating can be an operational limitation; this will be specifically addressed for F15 and F16 aircraft in Section 3.2.2.

The other key factor affecting fuel temperature onboard an aircraft is the mission time. To illustrate, Figure 2 presents predicted fuel temperatures for a Boeing 747-200 mission. With an ambient temperature of -40°C, it is seen that the fuel temperature does not reach this temperature for about seven hours, regardless of the initial fuel temperature. The rate of cooling is obviously aircraft dependant, and the characteristics of individual NATO military aircraft are not readily available. However, comfort can be taken in noting that NATO missions in Europe are rarely more than two hours in duration. For such short time periods, perhaps the only part of the aircraft to consider is its external wing tanks which can on occasions be sufficiently cooled to cause fuel holdup during transfer to main tanks; this will be addressed in Section 3.2.2.

### 2.1.5 Conclusion

A base fuel substitution of Jet A1 to Jet A brings with it a change in freeze point from -47oC to -40oC. Such values are the specification limits, however, and are rarely observed in purchased fuels. It is more usual for the actual freeze points to be -50oC and -44oC respectively. Against these values are to be compared the cold temperature extreme of Central Europe of -31oC with a lowest recorded value of -42oC, and the possible altitude cooling effects (Figures 1 and 2) that occur over the short flying times (less than 2 hours) typical in European operations. Also to be considered are the design factors of individual aircraft as they related to fuel cooling and, especially, external fuel tank cooling.

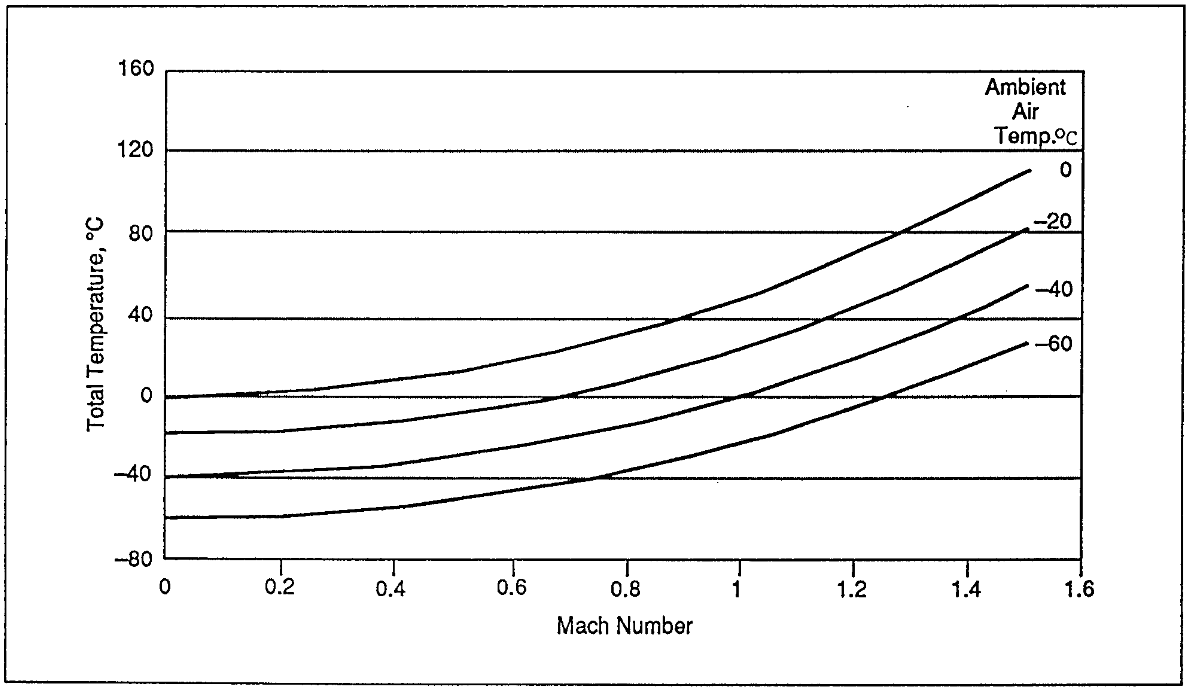


*FIGURE 1 EFFECT OF MACH NO. UPON TOTAL TEMPERATURE OVER A RANGE OF AMBIENT AIR TEMPERATURES*

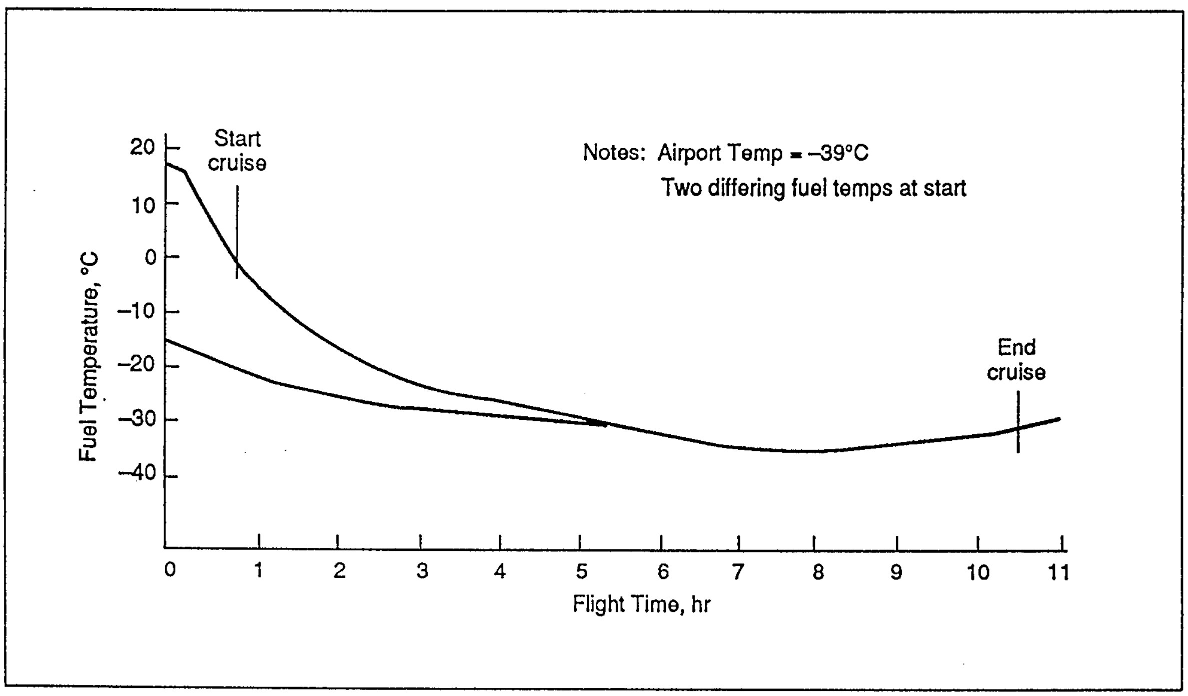


*FIGURE 2 TYPICAL FUEL TEMPERATURE CHANGE DURING 747 AIRCRAFT FLIGHT MISSION*

From the above sections it would appear that operational difficulties related to fuel freeze point are unlikely to be experienced except under the following scenarios:

1. in-flight operations at low speed, at relatively high altitude and for significant time periods

2. ground operations at bases well to the north of the European Central zone where ambient temperatures are lowest

3. the coming together in other zones of ground operations with a specific supply of Jet A fuel at the freeze point limit of -40oC for long time periods and during the lowest ambient temperatures ever recorded.

## 2.2. VISCOSITY

### 2.2.1 Definition

The viscosity of a fluid is a measure of its internal resistance to motion, and it varies considerably with temperature. Lowering the fuel temperature increases the viscosity. Most fuel specifications specify maximum viscosity limits at a low specified temperature to assure adequate pumping and flow capabilities as well as good fuel atomization in the combustion system to enable ease of starting.

The viscosity limit for Jet A fuel is the same as that for Jet A-1: quantified as 8.0 centistokes (cSt) at -20°C. In reality the average viscosity of Jet A delivered in USA is 5.5 cSt (at -20°C) and it is to be expected that any Jet A fuel produced in Europe would exhibit the same average viscosity at delivery. In comparison European Jet A1 has a lower average value of 3.8 cSt at delivery. Such a variation between the two fuels is not considered significant in terms of pumpability but its potential for influencing engine behaviour is discussed below.

### 2.2.2 Engine Factors

The importance of fuel viscosity relates to engine ignition. There are two fuel factors which affect the ignition characteristics of aircraft gas turbines; volatility and atomization. However, when comparing Jet A and Jet A1, (or even F-34), since all have the same limits of volatility, at low temperatures each has a negligible level of vapor pressure. It follows that, for kerosene fuels, engine ignition limits are effectively related only to fuel atomization.

Viscosity is the fuel property that most affects fuel atomization, especially for the well established Pressure-Swirl atomizers. More advanced systems such as the Air Blast atomizer are less sensitive to viscosity but, because air flow is low at ignition, such designs often incorporate Pressure-Swirl as a primary stage. Fuel surface tension and density are also of significance; however, these two properties are relatively constant among similar fuels and also they do not vary with temperature as much as viscosity does. Of most concern to ignition-system design performance is the requirement that an engine shall be capable of starting on a fuel of 12 cSt viscosity. Typically, Jet A will reach this viscosity at a higher temperature than Jet A1, so in theory if viscosity were the limiting factor in aircraft starting it would mean that the use of Jet A could compromise the cold-temperature starting limit. In practice, however, it is considered most unlikely that viscosity will control as cold-day starting is usually limited by other factors, such as battery strength or stiffness of lubricants in the engine/gearbox.

For relight at altitude, this difference in viscosity is even less important because the fuel will have been heated by other engine systems and the engine itself will still be hot despite a flame-out.

In summary, no significant degradation in ignition characteristics resulting in the fuel change is anticipated since the viscosity of all Jet A fuels will meet the viscosity requirement of F-34 derived from the Jet A1 base fuel.

## 2.3 ADDITIVES

### 2.3.1 Purpose

Additives are used in aviation fuels to address specific problems. In some cases the additives are mandatory, in other cases they are optional. Only officially (NATO) approved additives can be used, and to the quantities defined.

Three fuel additives are required by the F-34 fuel specification that are not a part of either the base Jet A1 fuel specification or the alternative Jet A.

- a fuel system icing inhibitor (FSII),
- a corrosion inhibitor (CI), and
- a conductivity additive

These additives can be added in the theatre, but it is preferable to add them at the refinery for uniformity and control. The standard additives used in F-34 are compatible with Jet A thus no problem would occur with its substitution for Jet A1, and in addition there are no additives used in Jet A that are not approved for use in F-34.

The purpose of the FSII is to prevent the growth of ice crystals from minute concentrations of water coming out of solution at low temperatures and from water condensing in fuel-tank ullage. As discussed earlier, such crystal can build up on fuel filters and block the flow, starving the engine. These additives have also been found to be effective against microbiological growth. Di-ethylene glycol monomethyl ether is the composition of FSII required for F-34, and is permissible for use in Jet A.

The corrosion inhibitor serves two purposes. The intended purpose is that of preventing corrosion in piplenes and storage tanks. Fortuitously, these additives also provide lubricity to fuels. This latter effect is especially important for fuels which have been severely hydrotreated during refining to improve stability, remove sulfur, and/or reduce aromatics. The exact composition of these materials is proprietary, but they are controlled by Specification Mil-I-25017.

The conductivity additive is most important in the military systems because it helps to reduce the buildup of static electrical charge during the fueling of aircraft. In the past the discharge of such a buildup has started fuel fires with the subsequent destruction of aircraft and loss of life.

### 2.3.2 Aircraft Factors

While the presence of the three additives is required by the F-34 fuel specification, the 'Technical Orders' for individual aircraft allow for the use of alternative fuels, and sometimes emergency fuels, which may not contain these additives. In such cases, specific requirements and/or limitations for operations, inspections, and maintenance are also provided. For example, operation of F15 and F16 aircraft on fuels without a corrosion injibitor may be restricted to 10 consecutive hours, while operation without FSII can be limited to one flight. Also, operations with fuels without FSII, call for particular care to be taken to assure that sump drainage procedures are strictly complied with to minimise possible water contamination of the fuel.

## 2.4 SUMMARY

Of the three factors considered above, freeze point, viscosity and additives, only freeze point is considered to have the potential for making a significant impact upon operational conditions. There is no reason why additives cannot be added to Jet A any more readily than to Jet A1, the only point to consider is whether such action takes place at the refinery or in the field. In the case of viscosity, there is no variation in specifications but in practice Jet A fuel delivered to the user tends to have a slightly higher viscosity which, in theory, could lead on rare occasions to some compromise in the cold-temperature starting limit. In addition even for the freeze-point variation between the two fuels, there are a very limited set of operations scenarios in which the base fuel change could be significant (see Section 2.15).

# 3. USE OF JET A FUEL IN MILITARY AIRCRAFT

The conclusions in the summary above have been reached primarily based upon information available in the open literature. What follows is a report of a limited series of meetings held with military aircraft operators, designers and fuel suppliers on their views/experiences of the possible consequence of a change in base fuel.

## 3.1 EUROPEAN AIRCRAFT

Discussions were held with representatives of seven large organisations from the military and civil sectors; these covered two fuel suppliers, two aircraft manufacturers, one engine maker and two users. Their emphases of concern naturally differed, for example the supply side exhibited no enthusiasm for the continuous use of Jet A in Europe - or indeed anywhere else outside USA - primarily because supply logistics militate against a two-grade scenario. The spread of long range wide-bodied twin engined passenger aircraft has hardened airlines against proliferation of Jet A in lieu of Jet A1 - an opinion trend evident also in USA. That being so, the issue of Jet A in Europe is now farther removed from the practical realm than was at one time the case but that is not to say it might surface again in the future.

Many of the concerns felt by European equipment manufacturers are associated with a perception of Jet A as being inherently different from Jet A1 as defined by the Systems Check List (JSCL)*. If it is accepted that the Jet A will be produced in Europe (the physical transfer of Jet A per se from North America to Europe must be an unlikely event in other than an emergency scenario) then such "quality" objections to the Grade largely disappear.

As far as Freezing Point itself is concerned, it is sometimes difficult to draw a line between concerns expressed by equipment manufacturers on their own accounts and those expressed on behalf of their clients. Although the latter are, in the main, well able to look after themselves, some smaller operators do look to hardware suppliers for guidance in fuel usage matters. Even on the military side, those nations who do not maintain in-house and in-depth petroleum technology capability tend to pay a lot of attention to manufacturers' views. Such views can be much influenced by precisely what has or has not been contracted for (or certified). Nonetheless, once due cautionary comment has been made, the bottom line usually is that Freezing Point is an operational concern for the end user.

It is interesting to note that, whilst the conversion to F34 from F40 was much delayed due to potential helicopter cold-start problems, one major supplier does clear its helicopters for as many fuel types as possible - covering a range wider than that represented by the Jet A/JetA1 specifications.

The concluding statement that can be made following these meetings is that although concerns were expressed about the substitution of Jet A for Jet A1 (F-34), no objections were received and no potential difficulties were identified other than those presented in section 2.

## 3.2 UNITED STATES AIRCRAFT

### 3.2.1 General

U.S. Air Force combat aircraft of concern in the European Theater are as follow:

- Combat: F15, F16, F111, A10, B52
- Airlift/Tanker: C5, C130, C141, KC135, KC10

It is to be noted that today the use of Jet A fuel is allowed as an "alternate fuel" in the Technical Orders (T.O.) of all of the above aircraft; alternate fuels are defined as follows:

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* More fully . . AFQRJOS (Aviation Fuel Quality Requirements for Jointly Operated Systems)

> A fuel authorized for continuous use. The operating limits, thrust outputs, and thrust transients shall not be adversely affected. The applicable aircraft flight manual shall define limitations, if any, of a significant nature on aircraft performance parameters such as range, altitude, loiter time, or rate of climb, and engine performance parameters such as specific fuel consumption or starting and stopping time. The use of an alternate fuel may result in a change of maintenance or overhaul costs. External adjustments may be necessary or desirable for use of an alternate fuel. (T.O. 42B1-1-14, Technical Manual: Fuels for U.S. Aircraft, 31 August 1989)

U.S. aircraft are qualified to start and operate on fuels with viscosities of 12 cSt or less. As mentioned earlier, although Jet A and Jet A1(F34) have the same specification limits on maximum viscosity, in reality the average viscosity of Jet A is somewhat higher. Since viscosity increases with decreasing temperature, this means that starting and operational limits on an average Jet A will not be as cold as those for an average Jet A1 based F34 fuel. For altitude relight, this viscosity difference will be negligible since the fuel delivered to the engine is heated by the engine oil cooler.

### 3.2.2 Experience

The Air Mobililty Command (AMC) operates routinely in and out of commercial airports and often flies on Jet A fuel; no particular problems have been encountered. With regard to the higher freeze point, only long-haul flights at high altitude would be of concern. C130 aircraft operating within Europe do not fly at high altitudes nor for extended periods due to the relatively short distances involved. Also, long haul flights at high altitude are rare for C5 and C141 aircraft returning to the United States from Europe; when necessary to avoid low ambient-air temperatures, altitudes and routing can be changed without significant problems.

With respect to condition monitoring, some older aircraft have no means of measuring fuel temperature. Standard practice is to avoid ambient temperatures less than the freeze point of the fuel. However, Combat missions originating in Europe are of short duration, normally only a few hours, not long enough therefore to cool the fuel to problem temperatures even on cold days.

Fighter and attack aircraft are routinely stationed in Europe. The A10 and F111 aircraft do not fly over 25,000 ft altitude and so are not subjected to sufficiently low temperatures to cause concern. The F15 and F16 aircraft do fly at high altitudes, and precautions on the use of Jet A are included in the Technical Orders for these aircraft due to concerns about fuel transfer from external wing tanks during sustained subsonic flight at high altitudes. The following compares F-16 flight conditions under which caution is given that fuel may not transfer after flights of more than 5 minutes:

| Conditions for Restricted Fuel Transfer from External Fuel Tanks on F16 Aircraft Due to Low Temperature | | |
|---|---|---|
| Altitude, ft | F34 Fuel | Jet A Fuel |
| 25,000 - 30,000 | <275 knots | <300 knots |
| 30,000 - 40,000 | <0.72 mach | <0.83 mach |

In other words, at altitudes above 25,000 ft, F16 aircraft are cautioned to maintain a somewhat higher airspeed when operating on Jet A. However, for the F15 aircraft, the conditions of restricted fuel transfer are considered to be the same for both fuels:

| Conditions for Restricted Fuel Transfer from External Fuel Tanks on F15 Aircraft Due to Low Temperature | |
|---|---|
| Altitude, ft | Jet A and F34 fuel |
| >25,000 | <200 knots |
| >40,000 | <250 knots |

Responses to inquiries to Headquarters USAFE indicate that based on mild winter temperatures in Europe (-10°F), no real operational problems are envisioned for F-15 and F-16 aircraft providing the procedures of the Technical Orders are followed.

To summarize the experience and feelings of the US Air Force, there would appear to be little significant impact with the use of Jet A in Europe on an emergency basis providing the procedures of the Technical Orders for the individual aircraft are followed.

## 4.0 DISCUSSION AND SUMMARY

The study comprised two parts. The first consisted of a paper study of the differences in Specifications and actual supply properties of the two kerosene 'base' fuels Jet A1 and Jet A, and the potential operational limitations that could arise if the latter fuel were to be employed within the European military arena. The second part comprised a series of interviews with the military users and the suppliers of the equipments and fuels to learn whether or not their views/experiences matched those obtained in the first part of the study. Each are summarised below:

With respect to fuel properties, the specification for the US civilian aviation jet fuel Jet A differs from the NATO F-34 (based upon Jet A1) fuel specification only in the required additive package and minimum freeze point. If the F-34 additive package is included in the Jet A, then the only difference is that F-34 fuel specification requires a freeze point no higher than -47°C, whereas the freeze point of Jet A can be as high as -40°C. In practice, however, the fuels supplied tend to exhibit average freeze points at the somewhat better levels of -50°C and -44°C respectively, In addition although the specified maximum viscosity limits are the same for both fuels, in actuality, the viscosity of the average Jet A delivered in the US is found to be a little higher than the average F-34 and Jet A-1 delivered in Europe. Taken together these factors suggest that the fuel change could produce the following potential problems

- fuel flow supply problems from external fuel tanks and/or wing tanks during flight at low speed operations

- fuel freeze/engine supply problems following long aircraft soak times either when positioned in the extreme Northern part of Europe or on the very rare occasions when Central European temperatures drop to (the lowest recorded value of) -42°C.

- start-up problems could occur at somewhat higher temperatures following extensive cold-soak of the aircraft/fuel system.

In making such statements, emphasis is placed upon the use of the word potential in the introductory statement as in all three statements difficulties would only occur during the extremes of conditions stated.

The second part of the study involved interviews both in Europe and in the US. Some prejudice against the Jet A fuel was expressed within Europe and although no direct experience was available to assist the study there were no objections raised. In contrast, due to the need by the US forces to operate their aircraft on both fuels, clear statements were able to be collected which were of interest to the full range of operations from tactical through strategic to airlift. From the meetings it was learned that limitations which arise in flight from the two differing freeze points of the fuels have been overcome by a clear definition of minimum speed at altitude given within the official Technical Orders for each aircraft type.

In general, US experience supported in full the factors raised in the 'paper' study and, it would appear, had addressed the main factors within the Technical Orders process for all operating conditions considered normal for Europe. For the abnormal, e.g. where fuel was to be employed on an exceptionally cold day, consideration might be given to providing users the means to measure the actual fuel properties so as to allow them to determine the margin of safety available relative to its specification value.

## 5.0 CONCLUSIONS

It is concluded that the US civil aviation fuel, Jet A, may be used continuously as a base fuel for a F34 substitute in current NATO military aircraft operations in Europe providing;

1. the same precautions are followed as those employed in using the European civil aviation fuel Jet A-1 (e.g. injections of additive).

2. where not in existence today, appropriate Technical Orders are prepared for each aircraft type to meet the normal limits of temperatures found within Europe

and it is noted that the effects on aircraft operations that can occur in extreme conditions of low temperature could be mitigated against by the measurement of the actual freeze point of the fuel employed, and the defining of appropriate limits in operation in the Technical Orders.

Finally, the authors would wish to thank all those personnel on both side of the Atlantic who have contributed towards this study.

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**14. Abstract**

The differences in specifications and actual supply properties of kerosene fuels JET A1 and JET A are studied. Potential operation limitations within the European military arena are outlined in the case that JET A was to replace JET A1 as the base fuel in the NATO F-34 fuel specification. Interviews with the military users and the suppliers of the equipment and fuels are reported on.

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