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PROPULSION AND POWER RAPID RESPONSE RESEARCH AND DEVELOPMENT (R&D) SUPPORT

Task Order 0011: JP-8+100 Development History and Maintenance Benefits

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14. ABSTRACT

JP-8+100 was introduced into the field in 1994. Since that time, JP-8+100 has received limited acceptance due to a lack of solid engineering information and scientific fact regarding use and limitations of the additive Spec-Aid® 8Q462. As a result, no official Air Force position has ever been established regarding the additive's use or non-use. In 2006, Senior Leader for Propulsion, Ted Fecke convened and tasked an IPT to formulate and recommend a supportable Air Force position regarding the use of JP-8+100 in Air Force Weapons Systems. In fulfillment of that tasking, the IPT has collected all relevant available technical and scientific information about JP-8+100 and has formulated a supportable position based on these facts.

In conclusion, this report documents field data and maintenance experience supporting the use of JP-8+100 additive technology in all Air Force Weapon Systems using JP-8.

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JP-8+100, Spec-Aid® 8Q462, thermal stability, thermal management, additive

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TABLE OF CONTENTS

Section **Page**

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This report documents the development history of the +100 thermal stability additive for use in kerosene-based fuel such as JP-8, provides the maintenance benefits from using JP-8+100 in several US Air Force weapons systems to include trainer, fighter, helicopter and C-130H transport aircraft and discusses the concerns generated by “urban legends” that have been technically or administratively resolved. Because of consistent maintenance benefits from using Spec-Aid® 8Q462, ASC/EN endorses the use of JP-8+100 in weapons systems that would benefit from its use.

In the 1993/94 time period, the US Air Force replaced the gasoline-like JP-4 with JP-8 which had been used since the early 1950’s in aviation turbine engines. JP-8 is a low volatility, kerosene-based fuel with a higher flash point and is much safer from a fuel handling perspective and improved survivability if an aircraft was exposed to an ignition source. Soon after conversion, aircraft powered by legacy fighter, trainer, transport and helicopter engines that were designed to use JP-4 began to have coking problems. F-15 and F-16 Units began experiencing increased fuel-related anomalies that included augmentor blowouts and no-lights. The anomalies were above and beyond those caused by weak fan and core modules, convergent exhaust nozzle failures and other control malfunctions. Coking also increased on fuel spray nozzles in trainer, transport and helicopter engines causing fuel streaking that accelerated turbine vane distress and early engine removals. As a result, unscheduled engine maintenance workload increased significantly and became a major concern to the MAJCOMs.

The requirement for increased thermal stability has grown since high performance military aircraft depend on more heat sink in the fuel to cool aircraft subsystems, engine oil and electronic components. Therefore, increased thermal stability has become a very important property of aviation fuels for turbine engines. AFRL recognized this requirement for future systems and initiated a program in the late 1980’s to develop an additive to improve the thermal stability of JP-8. Qualification of an additive was finally achieved that increases the thermal stability of JP-8 by approximately 100 °F and thus is known as “+100” or plus one-hundred. A rigorous protocol evaluated over 300 candidate additives for materials compatibility with all Air Force weapon systems and a wide variety of JP-8 fuels available worldwide. Testing included bench and rig tests of additized fuel, storage and pumping as well as engine accelerated mission testing and field service evaluations in several operational aircraft.

Additives have been used in fuels for military jet engines for decades and have become extremely important to the safety and reliability of turbine engines. JP-8 is essentially Jet A used by commercial aviation but with the addition of a “military additive package”. The additive package contains three additives: 1) a Fuel System Icing Inhibitor (FSII) to prevent free water in the fuel from freezing, 2) a Corrosion Inhibitor / Lubricity Improver (CI/LI) that reduces corrosion and enhances lubricity to prevent fuel pump failure, and 3) a Static Dissipater Additive (SDA) that improves fuel electrical conductivity thereby mitigating fire hazards caused by any delayed static discharges during ground fuel handling. These additives are transparent to the User in most cases except that the Conductivity Units of delivered fuel is closely monitored. While effective in increasing safety and engine reliability, the “military additive package” does not contain any ingredients that are tailored to reduce fuel coking. To fulfill this need, the +100 additive contains a detergent / dispersant, an antioxidant and a metal deactivator. These ingredients not only reduce the formation of insoluble particulates in the fuel, but also help prevent them from adhering to hot metal surfaces. The +100 additive compliments the “military additive package" by improving the thermal stability of kerosene-based fuels such as JP-8, thus effectively increasing the net cooling capacity of the fuel while reducing fouling and coke deposits. The +100 additive works equally well in other kerosene-base fuels such as Jet A and Jet A-1 used in commercial aviation.

While some Units have reported little to no improvement from using the +100 additive, most operational Units agree that use of the additive has helped to significantly reduce coking and augmentor anomalies. The actual benefits of the +100 technology has been found to be dependent upon several factors including engine condition, engine design features, local maintenance procedures and practices, engine hot time, augmentor usage and percent utilization of the +100 additive. In some cases, JP-8 fuels have been found to deposit residues on hot metal surfaces where bulk fuel temperatures are as low as 200 °F to 250 °F. Therefore, continued use of JP-8+100 is encouraged to minimize the gradual increase in coking deposits in hot section parts and augmentor fuel systems that will occur over a 6 to 12 month period and lead to increased engine anomalies and unscheduled removals. This concern was validated for certain legacy fighter and trainer engines when additive use was discontinued in 2005 for 12-13 months to resolve filter coalescer issues. Although discontinuing additive use for up to six months has not created any major problems thus far, providing aircraft return to using the additive upon return to the home station, doing away with the +100 additive completely will definitely have long term affects that may take two to three years for recovery to prior levels of engine reliability when JP-8+100 was used.

During the initial service evaluations of JP-8+100 and then the rapid expansion programs, a few "urban legends" emerged due to the fuel handling precautions and restrictions that were initially imposed. For the most part, these precautions and restrictions have been either reduced or rescinded in the current edition of T.O. 42B-1-1 "Quality Control of Fuels and Lubricants" based on rigorous laboratory tests, field service evaluations and over five years of operational use. Issues and findings associated with the "urban legends" and their resolution have been addressed and technical data included in this report.

However, in late 2009, the Defense Energy Support Center (DESC) began advocating a return to the 1:100 blend back to bulk ratio even though it has been verified through exhaustive testing and field experience that fuel quality and filter coalescer performance are not degraded using the current T.O. recommended 1:1 blend back ratio. As a result, HQ AFPET issued a Fuels Technical Letter (FTL-09-05 dated 29 December 2009) mandating a return to the 1:100 dilution ratio for all JP-8+100 fuel returned to DESC capitalized fuel assets but subsequently amended the blend back ratio to 1:10 on 2 April 2010. If a 1:10 blend cannot be met, a waiver must be requested by the Unit through the respective MAJCOM and AFPET to DESC for specific disposition instructions. Discussions continue regarding the maintenance and operational impact of this change.

Theodore G. Fecke

Theodore G. Fecke
Senior Leader for Propulsion
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PREFACE

This document has been prepared for public release and provides all relevant technical data and engine maintenance information supporting the use of JP-8+100 in selected Air Force weapons systems that have been shown to benefit from its use based on a document authorized for release to DOD Components only. This report discusses the development of the +100 thermal stability additive and the system engineering processes that were successfully completed to transition and evaluate the benefits of JP-8+100 in field service. The obstacles encountered after the Initial Service Evaluations of JP-8+100 and during Rapid Expansion Program to achieve widespread use provide an interesting perspective of conditions at different operational Units during peacetime and periods of regional conflicts that became an important part of the development history and provided valuable lessons learned. Some of the issues included the early perception by implementation planners that filter coalescer cartridges would be disarmed if in contact with JP-8+100, an overly cautious 1:100 dilution ratio if JP-8+100 was returned to operating storage, fuel handling precautions and fuel transfer restrictions that made aircraft defuels difficult at small units with only three R-11 fuel trucks to provide two grades of fuel and lastly, the general lack of endorsement by high authority. Primarily, anything that represents a cost benefit may impact outyear maintenance budgets needed to purchase new parts to improve engine build standards. There were also concerns that any trace of the +100 additive in fuel issued from operating storage to transient aircraft of other services would contaminate their fuel systems if an aircraft defuel was required at the home station. The fuel handling precautions and restrictions were resolved or rescinded through exhaustive testing and field evaluations but the 1:1 dilution ratio used for more than 5 years was changed administratively to 1:10 in April 2010. This change will likely have the effect of precluding small Units with fuel handling issues and limited storage volume from using JP-8+100 and thus accruing any maintenance benefits.

Unfortunately, the public release document has experienced unavoidable delays in preparation due in part to its complexity, breadth of coverage and the unforeseen changes to fuel handling guidance in April 2010. Nonetheless a comprehensive document with far reaching impact has been completed. The main body of the report summarizes the development history and benefits by aircraft and engine type while technical papers and the analyses of the maintenance data for several engine types are documented in Appendices. The report also discusses JP-8+100 use and benefits in US Army and civilian helicopters, provides a Navy view on “Aviation Fuel Stability Challenges in a Marine Environment” and the FAA Advisory Circular 20-24B, “Qualification of Fuels, Lubricants and Additives for use in Certified Aircraft Engines.” The most recent addition to the development history is presented in the Appendix P, “Turbine Fuel Management Issues.”

The contributions of the three authors of this document will be briefly discussed although the important contributions of many others will be covered in the Acknowledgements Section:

Mr. Robert W. Morris, Jr., Fuels and Energy Branch of the Air Force Research Laboratory’s Aerospace Energy, Power, and Thermal Management Division at Wright-Patterson AFB, OH (AFRL/RZPF), provided fuels, thermal stability additive and borescope photography expertise, was the lead Fuels Laboratory participant on the JP-8+100 IPT for preparation of the original DOD Components only document, chief proponent of this document and editing manager for both documents, sponsor of contracted work, the primary interface with the DESC and AFPET, principle investigator and author of Helicopter Experience using JP-8+100, and a continuing source of encouragement in spite of his overwhelming workload in the office and travel dealing with complex technical and fuels management issues.

Mr. Charles E. Bentz was the principal investigator of JP-8+100 maintenance benefits in F-15 and F-16 fighter and C-130H transport engines since 1998 though analyses of removal data from the USAF CEMS database covering the time period from January 1993 thru December 2006. Analysis methodologies were developed using Management and Fault Coded removal subsets to evaluate maintenance trends due to Scheduled and Unscheduled Maintenance that included Opportunistic Maintenance performed during removals for engine anomalies due to coking, gas path deterioration and mechanical failures after conversion to JP-8 and then to JP-8+100. The maintenance benefits from improved engine reliability due to more new parts and higher engine build standards were also addressed. One or more site visits were made to thirteen operational Units to update, coordinate and validate the findings of the maintenance analyses with engine shop supervision and establish the benefits from evolving local maintenance procedures and best practices. Also, the filter coalescer experience in fuel systems and fuel handling issues faced by Units were also analyzed and reported. Mr. Bentz was a participant in the JP-8+100 IPT and collaborated with Mr. Morris and Mr. Stonecipher in the preparation of the DOD Components only report and this public release document along with other contributors. Continuing support to AFRL/RZPF since 1998 has been provided as an Independent Contractor through Universal Technology Corporation (UTC), 1270 North Fairfield Road, Dayton, Ohio 45432-2600 under prior contracts and the current Prime Contract FA8650-08-D-2806, Task Order 0011.

Mr. Joseph F. Stonecipher, as a member of the JP-8+100 IPT from GE Water and Process Technologies, led the GE Betz team that collected and analyzed base level maintenance data for the J-69 and J-85 engines that power the T-37 and T-38 pilot trainer aircraft and also analyzed maintenance and removal data from the USAF CEMS data base utilizing the methodologies developed by Mr. Bentz. The increase in engine anomalies due to coking after the +100 additive was turned off and return to JP-8 use in May 2005 along with pictures showing the accelerated coking on J-85 fuel spray nozzles has provided vivid examples of the benefits of using JP-8+100 in this legacy engine that was designed to use JP-4. The support of the JP-8+100 IPT also included the analysis and charting of the CEMS removal data for all the engine types powering F-15 and F-16 fighters and the C-130H transport aircraft using several Fault Code subsets for engine anomalies to show the impact of turning the +100 additive off for 13 months. Three appendices have been devoted to the excellent analytical contributions of Mr. Stonecipher.

Based on the maintenance data presented in this report, use of JP-8+100 along with evolving maintenance procedures and best practices has provided reductions in coking in trainer, fighter, helicopter and C-130H transport engines that has reduced or helped to avoid Unscheduled maintenance, reduced control component removals and contributed to improved reliability and time on wing for legacy engines in the USAF inventory. However, much work remains to make JP-8+100 transparent and widely used in all weapons systems that will benefit from its use.

ACKNOWLEDGEMENTS

This report documents the current state of knowledge regarding the additive technology known as JP-8+100 (or +100 for short). It represents an exhaustive treatise on everything we know about the additive, how it impacts aircraft systems, what it is, and what it is not.

Prior to acknowledging those who contributed to the preparation of this document, the authors would be severely remiss if we did not acknowledge the fact that JP-8+100 is a reality today mainly because of the foresight and superb leadership of Mr. William ('Bill') E. Harrison III, formerly the Branch Chief of the Fuels and Energy Branch, AFRL/RZPF. Initially, Bill helped author early reports documenting the upward trend in heat sink requirements of aviation fuel for advanced military aircraft which in turn led to the realization within the fuels research community that a solution to the overall fuel thermal stability problem was required after conversion to JP-8 – and required soon. Acting on that realization and using his position as Branch Chief, Bill worked tirelessly to obtain programmatic and financial support for the developmental research programs that would eventually culminate in the qualification of what we now call 'JP-8+100'. After successful completion of the planned engine component tests at engine manufacturers using JP-8+100, an abbreviated engine Accelerated Mission Test and flight tests in an F-16, Bill successfully obtained high level support in the Air Force and Air National Guard for field demonstrations in several different weapons systems at various locations that eventually proved that use of a thermal stability additive in JP-8 not only reduced fuel coking but resulted in reduced engine anomalies and maintenance for engines powering legacy pilot training, fighter, helicopter and C-130H transport aircraft in service today. The end result of Bill's foresight and leadership is that Air Force Units using JP-8+100 (and some of our NATO allies) are now experiencing fewer engine anomalies due to fuel coking problems resulting in improved mission readiness and maintenance cost benefits.

This kind of document could not have been prepared through the efforts of a single person. So, even though I am listed on the cover as the primary author, I am uncomfortable with that title because of the truly Herculean efforts put forth by the other authors listed on the cover. So in an effort to give credit to those truly deserving, this 'author' would like to humbly express his gratitude to the following individuals:

First, to Mr. Charles E. (Chuck) Bentz an Independent Contractor through Universal Technology Corporation. It was Chuck who spent literally hundreds of hours pouring through mind-numbing document after mind-numbing document, extracting and organizing what we know about JP-8+100 use in Air Force engines. With his background in turbine engine development and maintenance, he has brought a unique perspective to this effort - leading us to an understanding of how turbine engines are maintained, how the +100 additive has impacted these engines, and the demonstrated maintenance benefits that can be achieved by using the additive. I don't think there is anyone who could have brought such a broad-scope perspective to this effort and yet be able to understand and explain all the intricate details about the interactions between the additive on various engines in the USAF inventory and the concurrent directed and Unit-level voluntary maintenance program enhancements. Being able to reason out the interactions and their impacts on overall maintenance avoidance took special talent and a dedication. Thanks, Chuck, for making this report truly a one-of-a-kind legacy document.

Secondly, I would like to express my sincere gratitude to Mr. Joe Stonecipher of GE Water and Process Technologies (GE Betz), the manufacturer of the +100 additive, Spec-Aid® 8Q462.

While many might suppose that Joe had commercial motivation to work on this report (which is true), I know that Joe has spent hundreds of hours going through reams of engine removal data in an honest effort to understand the impact of the additive on maintenance operations and costs. I also can attest that, while there were many opportunities to ‘cherry pick’ the data to present findings in a more favorable light to GE Betz, Joe resisted that temptation. As a result, the trend data, especially Section 3 and Appendices L, M, N and O, is what it is and speaks for itself. Joe maintained the integrity of this report by letting the data tell the story. Thanks Joe to you and your support team.

Thirdly, I would like to express my thanks to Mr. Chris Barber of the US Army at Redstone Arsenal, Huntsville, AL for providing data and documentation about the US Army implementation and use of JP-8+100 at Ft. Rucker in Dothan, Alabama.

Thanks also goes to Doug Mearns and Sherry Williams of the Navy for their input along the way and for providing us with a clear, concise understanding of the Navy position regarding use of the +100 additive in Navy systems. The combined effort from the authors on the Air Force side, Mr. Barber on the Army side and Ms. Williams and Mr. Mearns of the Navy has resulted in a document that the authors believe truly reflects a tri-service perspective of JP-8+100 fuel.

I would also like to thank the following: Mr. James Young for his help in understanding various filtration issues and for his paper on the JP-8+100 filtration assessment at SwRI® and the resulting field demonstration at Laughlin AFB; Mr. Mel Regoli, HQ AFPET/PTP and Mr. Paul Twehues, HQ AFPET/PTOT for help in understanding filtration and for help in addressing the common questions regarding JP-8+100; Mr. Gary Besse of SwRI® for helping us understand the rigorous filtration testing conducted at SwRI® that led to the Laughlin implementation that helped rescind and modify the initial JP-8+100 fuel handling restrictions and precautions.

All of the authors and co-authors would also like to express our thanks to all the individuals at the various Units and Commands who supported this program over the last decade and a half. Special thanks to Mr. Paul Shows, Propulsion General Forman at the 56th FW, Luke AFB, AZ for helping the authors understand engine maintenance procedures in general and specifically, the impact of the +100 additive technology on engine maintenance avoidance.

Finally, I would like to express thanks to Mr. Ted Fecke, Senior Leader for Propulsion whose initiative and encouragement made this report possible. For many years, this author has recognized the need for a document of this nature and now, thanks to Mr. Fecke, it is a reality.

As a final 'Author's Note', it should be noted for the reader that during the time period when this report was being written, the Fuels Branch of the Air Force Research Laboratory changed office symbols from AFRL/PRTG to AFRL/RZPF. To lessen the confusion to the reader, the old office symbol has been changed to RZPF in the body of this document.

Thanks to all who directly and indirectly participated in the preparation of this document. The expertise of many was needed to complete this work and I believe it is a document with far-reaching ramifications. Thank you!

Robert W. Morris, Jr., AFRL/RZPF

EXECUTIVE SUMMARY

This document provides a comprehensive review of JP-8+100 use covering more than 15 years of field service evaluations in T-37 and T-38 trainer aircraft, F-15 and F-16 fighters, C-130H transports and several helicopter aircraft. The primary focus will be to show overwhelming evidence that use of JP-8+100 in conjunction with improved engine build standards, thorough baking and cleaning programs, timely removal of coke from fuel spray nozzles and use of evolving maintenance procedures and best practices has reduced engine and control removals for legacy and more modern turbine engines in the USAF inventory.

The +100 additive was developed and fielded by the USAF to reduce coking problems in legacy turbine engines designed to use JP-4 and also provide additional heat sink for advanced weapons systems. The additional surfactants in JP-8+100 were the main reasons for the fuel handling precautions and restrictions that ultimately limited the widespread use of the +100 additive at small fighter and C-130H transport Units. Since CI and FSII had initially exhibited some effects on filter coalescer performance, early perceptions developed among the planners that the +100 additive would disarm filter coalescers and a 1:100 return to bulk ratio was mandated which was later rescinded to a 1:1 dilution ratio. Although the initial perceptions were accurate for many of the candidate +100 additives that **did not** pass the rigorous screening and compatibility testing conducted by AFRL/RZPF, the Spec-Aid® 8Q462 thermal stability additive is a strong dispersant of solids in JP-8 and has no serious detrimental effect on water coalescence in filter cartridges affecting the service life and overall performance of filter separators to remove solids and water.

The fuel handling procedures, precautions and return to bulk restrictions that were established for use of the +100 additive in JP-8 gained considerable notoriety among fuels handlers at small Units due to the increased work required to perform defuels and fuel transfers. Their frustration overshadowed any initial benefits that engine shop analysts were able to determine after the conversion to JP-8+100. Fortunately, the precautions and restrictions have been rescinded or modified by T.O. 42B-1-1, Quality Control of Fuels and Lubricants, and most fuel handling issues have become non-issues.

In spite of the mandated fuel handling precautions and problems with aircraft defuels and fuel transfers at small Units, maintenance analyses at several Units showed that JP-8+100 has steadily reduced augmentor anomalies in the legacy F100 engines and F110 engines, helped reduce hot section distress in turboprop and helicopter engines due to fuel spray nozzle coking and has become a part of several evolving maintenance procedures and best practices developed by Units that have helped reduce augmentor no light and blowouts that caused unscheduled engine and fuel control removals.

The synergies of improved engine reliability, use of digital electronic engine control and engine monitoring technologies coupled with using JP-8+100 have also helped to avoid maintenance. After the +100 additive was turned off for one year when the condition of fighter engines had been improved and sustainable, engine anomalies increased immediately proving that JP-8+100 helps to avoid maintenance problems due to coking. Approximately 18 to 30 months were required after the additive was turned on again for the rate of engine anomalies to return to near the former level.

Valuable lessons have been learned from the logistic problems the Users faced during the conversion to and use of JP-8+100. Anything that provides an operational benefit should not place increased burdens on support personnel in Aircraft Maintenance and the Fuels Flight. An

alternate approach to increase fuel issue flexibility and enhance defuel capability would be to inject the +100 additive using an injector mounted on the refueler truck. This concept has been successfully demonstrated by the US Army at Fort Rucker in Dothan, Alabama at the helicopter 'School House' where an infra-structure for injecting a thermal stability additive and managing the use of JP-8+100 has been evaluated.

In spite of the issues and myths that have surrounded JP-8+100, the use of the +100 additive continues to grow. Based on the maintenance benefits demonstrated by the USAF, the Canadian Forces converted directly from JP-4 to JP-8+100. The Royal Danish Air Force continues to use the +100 additive in country while a pilot training unit of the German Air Force will start using JP-8+100 in their Tornado fighters at an Air Force training base in the CONUS. The RAF in the UK had conducted a 12-month evaluation of JP-8+100 in a squadron of Tornado fighters and determined positive maintenance trends which became the basis for the German Air Force pilot training unit to start using the +100 additive. However, the RAF has yet to make a decision to use the +100 additive. The Pakistan Air Force is using the +100 additive while other countries operating US military aircraft are considering its use. Currently, the Pacific Air Force (PACAF) has converted Elmendorf AFB in Alaska to JP-8+100 and is considering other Units which may encourage other foreign military to start using JP-8+100 at other locations.

Since future high performance engines may require the use of thermal stability additives to increase aircraft thermal management margins, wisdom may prevail in obtaining the necessary endorsements and approvals allowing use of JP-8+100 fuel in all aircraft in the USAF inventory. The cost of the additive should not be an issue since its cost is already included in the price of JP-8 fuel set by DESC each year. For inter-operability, the barriers faced by the Army and Navy in using the +100 additive should be re-examined and remedies implemented.

Since **all US engine manufacturers have approved the use of Spec-Aid® 8Q462 in Jet A for commercial aircraft engines and in JP-8 for military fighter, transport and helicopter aircraft**, handling and use of JP-8+100 fuel can become transparent and seamless. One approach for consideration might be "there are no non-program aircraft in the USAF, only Units that choose not to use JP-8+100 fuel". But total transparency can only be achieved if an aircraft from a 'non-program' Unit can refuel with JP-8+100 at a 'program' Unit without any reservations or restrictions.

This technical document also discusses some of the common myths and misconceptions that became 'urban legends' among Users and Non-Users of JP-8+100. By and large, these 'urban legends' have become non-issues or are now known to be without merit based on scientific and engineering data and field experience gained during the last decade. Although conversion to JP-8+100 gained initial support and moved at a fast pace to initiate early field evaluations and the rapid expansion programs, valuable lessons were learned from the early field introduction programs when the fuel handlers objected to the fuel handling restrictions and precautions and some Users doubted that use of JP-8+100 provided any benefits. Unfortunately, some engines were in poor condition but improving making it difficult to sort out any benefits from using the +100 additive while several years would be required before it was proven that the surfactants and detergents in the +100 additive did not defeat the ability of filter coalescers to remove dirt and water from JP-8 fuel. The fuel handling precautions and restrictions alone had so burdened the fuel handlers at ANG fighter and C-130H Units that these Units turned the additive off in order to support quick response missions after 9/11 and during the conflict in Iraq. However, the RCM Program has improved engine reliability that is sustainable. Units have now attained higher utilization of the +100 additive since fuel handling restrictions and precautions have been rescinded or modified. Therefore, several lessons learned are provided to smooth the introduction and use of new thermal stability additives that will become available in the future:

- High level endorsement needed to insure support for use of a thermal stability additive.
- Engines designed to use JP-4 need a thermal stability additive in JP-8 to reduce impact of coking.
- JP-8+100 use will not solve the anomaly problems of augmented turbofan engines in poor condition although the hot section parts will run cleaner.
- JP-8+100 is one of several maintenance procedures and best practices that provided benefits.
- Units with high utilization of JP-8+100 benefited most.
- Turning the additive off for extended periods will increase engine anomalies due to coking and take 18 to 30 months for recovery to near former levels of unscheduled engine and control component removals after returning to additive use.
- Use of a thermal stability additive will help reduce fuel spray nozzle coking and hot section distress in turboprop and turbo shaft engines operated at high temperatures for extended periods.
- Making the use of thermal stability additives transparent and free of any handling restrictions or precautions is imperative.
- Injecting a thermal stability additive at the skin of the aircraft at small Units allows flexibility for defuels and fuel transfers with limited refueler assets.
- Conduct timely testing of filter coalescers to ensure they are not adversely impacted by new thermal stability additives.

The maintenance benefits from use of JP-8+100 were ultimately demonstrated beyond any doubt when the +100 additive was turned off for 12 to 13 months starting in June 2005. Returning to use of straight JP-8 caused an increase in engine anomalies for engines powering F-15, F-16 fighters, C-130H transport, T-37 and T-38 fighter trainers and military helicopters that were originally designed to use JP-4. The accelerated coking that occurred over 3 to 6 months caused an increase in no lights and blowouts during augmentor transients, fouling of fuel control components, increased carbon deposition on fuel spray nozzles that caused hot section distress and more reparable demands from Depot and an overall decrease in the mean time before removal of the engines to fix the problems. After the +100 additive was turned on again, it would take 18 to 30 months for the reliability of the engines most affected to return to the former levels that had been attained for each engine type when the +100 was in use. More detail of the maintenance benefits from use of JP-8+100 for each engine type can be found in Section 9.4 Conclusions of this report.

New guidance in Dec 2009 mandated a **1:100** blend back ratio of JP-8+100 to DESC capitalized JP-8 assets thus rescinding the **1:1** blend back ratio approved in Jul 2006. However, the blend back ratio was then re-revised to **1:10** on 2 Apr 2010. Although the return of fuel to operating storage is rare or not required at pilot training, fighter and C-130H aircraft Units, apprehensions exist that a finite trace of the +100 additive in the fuel in operating storage issued to a transient aircraft will disarm filter separators at other DOD facilities if a defuel was required. It is clear that these fears are unsubstantiated based on current field experience.

Unwavering support is needed for use of JP-8+100 at Units that will benefit from its use in order to decrease the maintenance workload from engine anomalies and hot section distress caused by coking from kerosene-based fuels. A thorough review of years of operational experience and demonstrated performance for current technology API/IP filter separator vessels should allay any concerns and encourage a commitment to again use a 1:1 dilution ratio if return of JP-8+100 to bulk storage is necessary for operational reasons.

REPORT SYNOPSIS

A thorough study of a report of this magnitude and depth would be a monumental task for any reader. This document contains a review and explanation of the important engine management and fuels maintenance issues along with historical maintenance information as well as analyses of engine and control component removal data. Insights into the significant events that impacted decisions and policies regarding the use of JP-8+100 are also presented. For the reader's benefit, the authors are providing a top level synopsis of the major topics contained in various sections of this report. The reader is encouraged as a minimum to review the Executive Summary before passing any judgment (pro or con) on the benefits and use of JP-8+100.

JP-8 Conversion: In the 1980s, the Office of the Secretary of Defense (OSD) made the decision to replace JP-4 with JP-8 in order to reduce fuel costs and to improve flight safety due to aircraft fire hazards. Several years passed before conversion from JP-4 to JP-8 was completed in the CONUS. After the conversion began in 1993, turbine engines designed to use JP-4 as the primary fuel - such as the legacy F100 engines powering F-15 and F-16 fighters - began to experience abrupt increases in augmentor no light and blowout problems due to coking in the augmentor spray rings. Legacy turbofan engines in B-52H bombers experienced cold starting and high altitude relight problems due to the poorer fuel atomization of JP-8. Turboprop engines in transports and turbo shaft engines in helicopters experienced accelerated coking on the face of the fuel spray nozzles that caused fuel streaking and premature engine removals due to hot section distress. J69 and J85 engines in T-37 and T38 trainer aircraft were very sensitive to coking from using JP-8 that increased the contracted workload and spare parts demand for these engines. The impact of coking on the flying program and maintenance workload of the operational and training Units soon gained priority status and the MAJCOMs approached the Engine Development Community at WPAFB, OH for solutions. Fortunately, AFRL and the fuels research community as a whole understood the need for higher thermal stability in JP-8 and had been aggressively working this issue. By the time the MAJCOMs approached the R&D community about the coking issue with JP-8, an additive was already available and ready for field transition.

Service Evaluations: Initial service evaluations of JP-8+100 were launched in F-16A/B fighters at Kingsley Field, Klamath Falls, OR and the C-130H transport aircraft at Louisville, KY. Reductions in hot section coking and maintenance workload were immediately noted. These demonstrations provided the basis to launch the Rapid Expansion Program at other Units. The removal data recorded in the Comprehensive Engine Management System (CEMS) database showed that augmentor anomalies and control removals in legacy fighter and trainer engines had been reduced while fewer fuel spray nozzles from transport engines had failed the spray pattern check after several cleanings. Engine and control component removals began to decline over a 1 to 3 year period after conversion to JP-8+100 while reductions for more advanced models of the fighter engines accrued over 3 to 5 years as new engine parts and modules with improved build standards were installed to achieve the inherent performance and reliability of the engines. Since use of Spec-Aid® 8Q462 was voluntary during the initial service evaluations and the Rapid Expansion Program, each Unit had to initiate requests for additive injection equipment to be installed on their fuel fill stands in order to issue JP-8+100 to the R-11 refueler trucks.

Fuel Handling Issues: Although Kingsley and Louisville did not report any problems with the JP-8+100 fuel handling precautions for defuels and fuel transfers, soon after the Rapid Expansion Program began, fuel handlers at other Air National Guard Units became disturbed.

When JP-8 was used, two refuelers were topped-off with JP-8 and the third refueler was usually empty and used for defuels and fuel transfers. However, the JP-8+100 Implementation Plan had directed that two of the three assigned refuelers be marked JP-8+100 and used only to issue JP-8+100 while the third refueler was used to issue JP-8 to 'non-program' or transient aircraft. Thus, an empty refueler was no longer available for defuels or fuel transfers unless the fuel in the JP-8 fuel truck was returned to bulk storage which then required advanced planning and extra work. If JP-8+100 was defueled from an aircraft, it had to be transferred to another +100 aircraft or returned to the same aircraft since return to bulk storage was limited to around 1000 gallons at the recommended 1:100 dilution ratio (JP-8 to JP-8+100). Since conversion to JP-8+100 was voluntary, the Fuels Flight also questioned why they were assigned extra work if there was no directive or endorsement from higher authority. These complaints dominated the discussions with leadership, aircraft maintenance and the fuel handlers at most Units. Without an empty refueler, other aircraft on station to transfer fuel or sufficient return to bulk capacity, untimely defuels and fuel transfers at C-130H Units were considered unworkable. ANG units operating from commercial airports had to exercise some creativity to defuel and dispose of purchased Jet A that had been injected with the "Air Force Additive Package" and the +100 additive when assigned aircraft were deployed.

Fuel Driven Maintenance Issues: After conversion to JP-8 and then to JP-8+100, the engine shops found themselves consumed with a host of new problems such as fixing augmentor anomalies due to coking, changing control components and performing a thorough baking and cleaning of all F100 augmentor spray rings and feed tubes to remove coke in addition to restoring engines to higher build standards as engine modules and new spare parts became available from Depot. At C-130 units, a modified cleaning procedure was being used to remove coke from the face of T56 fuel spray nozzles during the yearly isochronal inspection of the aircraft and a two minute idle before engine shutdown was directed to reduce coking on the face of fuel spray nozzles to help reduce fuel streaking and hot section distress.

With JP-8+100 use in its infancy, no simple analytical tools were available for engine analysts to sort out any maintenance benefits from using the +100 additive, however, **most Units were hoping for significant reductions in unscheduled engine removals due to coking in a short time**. Without clear direction from higher authority to use the +100 additive and no immediate evidence that JP-8+100 was helping reduce engine anomalies, the increase in fuel handler workload was considered more pain without gain and elevated the debate and often forced a local decision to not use the +100 additive. After 9/11occured, fighter and transport units turned the +100 additive off in order to support rapid response missions and minimize preparation for extended deployment.

Endorsement Issues: The engine maintenance environment became more stable as engine build standards continued to improve and unscheduled engine and control removals continued to show consistent reductions. At this point it became easier to show engine maintenance benefits from using JP-8+100 in fighter, trainer, transport and helicopter engines; however, there existed a general lack of interest in the Logistic Program Offices at the MAJCOMs and Air Staff to endorse the use of the +100 additive. Informing senior leadership and decision makers of the +100 additive benefits and gaining their support can be challenging. Anything that is perceived to provide a maintenance cost savings represents a potential threat to outyear budgets that are needed to buy new engine parts, improve engine build standards and achieve the inherent reliability of the engine type. The constant advocacy and defense of outyear planning budgets is understandable since aircraft maintenance budgets had been under-funded since the early 1980's and continue under constant review at the MAJCOM level - competing with other programs internal and external to the USAF and the Department of Defense (DOD).

Improved Build Standards and Maintenance Practices: The poor condition of some legacy F100 and F110 engines during the initial service evaluations resulted in more unscheduled engine removals than when engines are in good condition. Starting in early 1997, the F100 Reliability Centered Maintenance (RCM) Program and the F110-100B Mod Program provided new modules and engine spare parts that significantly improved engine build standards and reliability. In 2006, the F110 Service Life Extension Program (SLEP) was initiated to increase the gas path life limited components from 3000 to 4000 cycles. At some Units, use of the +100 additive had become a part of several maintenance procedures and best practices that had steadily reduced unscheduled engine removals due to coking to very low levels after the RCM Program was implemented.

Additive Turned Off Demonstrated JP-8+100 Benefits: In 2005, a significant event occurred that puts in perspective the value of using the +100 additive. AFPET directed that the +100 additive be turned off to resolve some filtration issues related to media migration in M100 filter monitors installed in refueler trucks. These filter monitors are considered the 'last chance' to capture any water that might make it through regular filter separator vessels in the fuel distribution system in an event where these elements were disarmed by JP-8+100. The JP-8+100 fuel was never implicated as a contributing factor in the media migration issue but with filter monitors now being removed as a precaution, AFPET directed +100 use be temporarily suspended until the media migration issue was resolved – eliminating even the possibility of water making it through filter coalescers and onto aircraft. **But turning the +100 additive off for 12 to 13 months, as occurred during 2005 and 2006, resulted in a 6% increase in augmentor anomalies at one Unit and 10 to 15% at other Units demonstrating that +100 additive use had helped to maintain the inherent reliability of the F100 engine** achieved through a fully-supported and well-managed RCM Program. Of importance is that 18 to 30 months after the +100 additive was turned on again, the engine anomaly and control removal rates due to coking returned to near the unscheduled removal rates that had been attained before the additive was turned off.

Maintenance Synergies: F100 and F110 fighter engines were experiencing increased time on wing at most JP-8+100 locations from improved build standards and new spare parts. When the +100 additive was turned off in the May/Jun 2005 time period, Augmentor Blowouts and No-lights increased in F-15 and F-16 fighters forcing engine removals, control changes and the baking and cleaning of the augmentor spray rings in F100 engines. Coking also increased on the fuel spray nozzles of legacy J85, T56 and several helicopter engines causing increased turbine distress. J69 engines experienced increased flameouts and control removals. As a result of these occurrences, most Units were eager to resume use of JP-8+100 to reduce engine anomalies and maintenance workload.

Small reductions in augmentor anomalies can be achieved through maintenance-only activities such as frequent baking and cleaning of the augmentor spray rings and cleaning the fuel spray nozzles but these are not fully sustainable without continuous use of a thermal stability additive to mitigate the fouling and coking that is driven primarily by the lower thermal stability of the JP-8 fuel used. Use of the +100 additive is considered a vital component of other important maintenance and support practices to include the baking and cleaning intervals of spray rings and fuel spray nozzles, local maintenance procedures and best practices, continued improvement of the engine build standards and the per cent utilization of the +100 additive at the home station. If one or more of these components falls behind or is dropped, an increase in unscheduled engine removal rate will result in 3 - 6 months and take 2 to 3 years for recovery.

Return to JP-8: Since engine maintenance environments can be very dynamic, engine shop analysts may not have time or expertise to review available engine removal data to determine any benefits from using JP-8+100. Also, preparing local reliability metrics may not require in-depth investigations if the flying program is going well. As a result, the fuel handling arguments against the use of the +100 additive often prevailed. After the announced closing of the Depot at San Antonio Air Logistics Command (SA-ALC), the implementing office lost funding to continue technical support of the Rapid Expansion Program. Decision making then fell to individual Units. As a result, the ANG C-130H Units decided to turn off the +100 additive as other ANG F-16 Units did after 9/11 to provide quick response to assigned missions or rapid deployment. Fortunately, the training Units within Air Educational and Training Command (AETC) continued to use the +100 additive in T-37, T-38 and F-16 aircraft since defuels and fuel transfers were rarely an issue as small quantities of fuel could be easily removed from an aircraft and transferred to another aircraft on the flight line.

Fuel Handling Restrictions and Precautions Rationale: In 1994, the implementing organization made the decision to require a 1:100 blend back to bulk ratio for JP-8+100 based on precedence for blending other products such as diesel fuel, automotive gasoline, mixed turbine fuels into JP-4 bulk storage (see **Appendix P**). This decision was made without the benefit of testing or a field evaluation. There was concern that the additives used in JP-8 (CI/LI, SDA and FSII) are surface active agents (surfactants) and had shown some negative impact on the ability of filter coalescer elements to separate water from the fuel. Therefore, the assumption was made that Spec-Aid® 8Q462, with known surfactant properties, coupled with the surfactants already present in JP-8, could potentially defeat the ability of receipt filter coalescer elements to remove dirt and water in the fuel. The above assumptions would later be proven false during a multi-phased test program conducted at SwRI®, San Antonio, TX where rigorous tests were conducted to determine the effects of aviation fuel additives on filtration performance.

Precautions and Restrictions Rescinded: The SwRI® program, which evaluated the performance of API/IP 3rd and 5th Edition filter coalescer elements for use with JP-8+100, was a turning point in the overall +100 program. It was funded by DOD, Ministry of Defense (MOD in the United Kingdom - UK) and industry participants. The test program determined that the Spec-Aid® 8Q462 thermal stability additive (+100) did not affect the filtration performance for either water or solids any more than standard JP-8 therefore JP-8+100 should not require dilution for JP-8+100 returned to bulk storage. These conclusions were verified at Laughlin AFB in a field test completed in 2006. As a result of the SwRI® test program and the validation of those results at Laughlin, Tech Manual T.O. 42B-1-1, Quality Control of Fuels and Lubricants, Change 3 dated 31 July 2006 was issued removing handling precautions for JP-8+100 and approved return of JP-8+100 fuel to bulk storage without dilution (1:1). From August 2006 through December 2009, JP-8+100 use was free of any handling precautions and restrictions. However, a Fuel Technical Letter (FTL) was issued 29 December 2009 changing the blend back dilution ratio to 1:100. Then on 2 April 2010, another FTL was issued amending the return to bulk dilution ratio to 1:10. More discussion can be found in the Executive Summary, Conclusions and Recommendation sections of **Appendix P, Turbine Fuel Management Issues**.

Urban Legends: The problems each Unit faced with the JP-8+100 fuel handling procedures, precautions and restrictions soon became “urban legends” within the fuels and maintenance communities. Initially, there were complaints regarding fumes and skin contact issues after the conversion to JP-8 and then again with JP-8+100. One Unit reported that burning JP-8+100 in a space heater resulted in foul smells. Other complaints were received simply stating that the additive “stinks!" Air Force toxicology experts performed analyses and determined that JP-8 is more of a human health hazard than JP-4[a]. But the experts also determined that the presence of the +100 additive did not increase the basic toxicological problems associated with conventional JP-8. Due to the decreased volatility of JP-8, diligent and continued use of personal protective equipment when handling JP-8 is the most effective way of guarding against extensive JP-8 exposure. Should contamination occur, washing with soap and water is effective in removing JP-8 from the skin.

Development Process Disconnect: Most fuels handling problems that were reported by small Units were valid considering the mandate to provide two grades of fuel using the three assigned R-11 fuel trucks. Some of the issues were directly related to increased workload for unplanned defuels and reverting an aircraft to non-program status for quick response deployment. It is generally agreed that an early test program to establish the impact of the +100 additive in combination with the ‘Air Force additive package’ on the performance of filter coalescer elements would have shown that the surfactants in JP-8+100 would not defeat the ability of the API/IP 1581 3rd Edition filter coalescer elements to remove dirt and water. If such test data had been available, the implementation plan would probably not have mandated the overly cautious fuel handling procedures, precautions and restrictions and would have made JP-8+100 use more transparent with broader acceptance.

In retrospect, the disconnect in conducting timely filtration element tests, whether omitted by the urgency to transition the +100 additive technology to field use or from lack of funding, caused considerable disruption for the continued use and widespread acceptance of JP-8+100. The forgoing discussions emphasize the need to establish an Office Primary Responsibility (OPR) within the USAF responsible for filtration development and compatibility testing as new fuel additives become available for field service.

Technology Advances: Another benefit that has occurred for high performance fighter engines is the use of full authority digital engine controls with control modes that provide self trimming and engine monitoring. The self trimming feature adjusts the engine geometry to maintain acceptable stability margins and desired engine performance as the gas path hardware degrades in service. This helps to minimize engine stalls and augmentor no lights and blowouts. The more advanced engine diagnostic systems provide vital information for the engine mechanics to identify control malfunctions and reduce the unmerited removal of control components that are functioning properly thereby reducing the demand for control reparables from Depot. Although engine diagnostic information can be used to stay on top of engine anomalies, this information can also help to avoid engine maintenance by providing data to make informed decisions.

Concluding Remarks: After reading this report, there should be little doubt that the use of the Spec-Aid® 8Q462 thermal stability additive in JP-8 along with best maintenance practices and procedures has reduced the impact of coking in the engines that power legacy fighter, C-130H

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[a] *National Library of Medicine: www.ncbi.nlm.nih.gov : 223-312, A Review of Neurotoxicity Risk of Selected Hydrocarbon Fuels, July 2001*

transport, helicopter and pilot training aircraft in the Air Force inventory. As documented in **Appendix P**, a decade and a half of using JP-8+100 has not uncovered any filtration issues as speculated or feared nor has any fuel from operating bulk storage with any trace of +100 additive surfactants been inadvertently issued to non-program aircraft. Five years of field experience at two large operational Units confirms that JP-8 issued to fill stands as well as the JP-8+100 fuel issued from the R-11 fuel trucks to aircraft are consistently clean and below the Test Limits for solids and water. The additional surfactants in the +100 additive injected in JP-8 at the fill stand have not impacted the ability of the API/IP 1581 5th Edition M100 filter separators to maintain low levels of solids and water during their three-year service interval even after 3.2 million gallons of JP-8+100 has been issued from each of the R-11 fuel trucks.

Although the initial perceptions were accurate for many of the candidate +100 additives that **did not** pass the rigorous screening and compatibility testing conducted by AFRL/RZPF, the Spec-Aid® 8Q462 thermal stability additive is a strong dispersant of solids in JP-8 and has no serious detrimental effect on water coalescence in filter cartridges affecting the service life and overall performance of filter separators to remove solids and water. The rigorous filter coalescer tests at SwRI®, while admittedly not in strict adherence to the API/IP 1581 5th Edition filter separator qualification protocol, none the less **proved** for typical real-world operational scenarios that **"there was no fundamental difference in average filtration performance between JP-8 and JP-8+100 @ 256"**mg/l and that **"JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage"**. However, the filtration testing of JP-8 concluded that **CI and FSII have detrimental effects on water removal performance** while **the +100 additive does not affect the filtration performance for either water or solids.**

Mandating a return to a 1:100 dilution ratio for JP-8+100 in late December 2009 without any technical basis or defendable supporting data tacitly disregarded the body of scientific data and field experience that proved that the surfactants in JP-8+100 do not disarm current technology filter coalescers qualified to the API/IP 1581 Specification 5th Edition M100 filter separators. Units had been using a **1:1** dilution ratio without any issues since 31 July 2006 as recommended by Change 3 to T.O. 42B-1-1. Two other concerns may have influenced this administrative decision: 1) the apprehension that any JP-8+100 returned to bulk storage will infect fuel systems at other installations if transient aircraft refuel at a +100 'program' Unit and require a defuel or fuel transfer at a 'non-program' installation, and 2) that administrative posturing or leveraging is occurring in the fuels support infrastructure that unfortunately will directly impact the maintenance workload for Air Force aircraft and engines due to coking from use of JP-8.

Amending the RTB dilution ratio to 1:10 on 2 April 2010 may offer some relief but small Units prefer a 1:1 dilution ratio without any handling restrictions to make use of JP-8+100 transparent if for operational reasons some fuel must be returned to bulk storage. However, many smaller fighter and C-130H transport Units may not return to using JP-8+100 because of the extra workload for the fuel handlers in performing defuels and fuel transfers to bulk storage at the mandated 1:10 dilution ratio with only three assigned R-11 fuel trucks.

Since the return of JP-8+100 to operating storage is rare or not needed at Units with high ops tempo flying and no filter separator technical issues have occurred or exist with the API/IP 1581 Specification 5th Edition M100 class filter separator cartridges installed in fuel systems at Air Force installations, any infrastructure support issues should be openly discussed and objectively resolved. Collaborative and cooperative endeavors should be initiated with other military services to resolve any perceived fuel handling issues at Air Force installations that are not covered in T.O. 42B-1-1, providing they can be defined, to help allay any concerns that may impact the receipt of JP-8 at Air Force Units capable of issuing either JP-8 or JP-8+100 to transient aircraft and during joint service training exercises.

Unfortunately, overly restrictive fuel handling policies will impact mission readiness forcing Units to **not** use JP-8+100. This will inevitably result in maintenance cost implications for current and future maintenance budgets of the MAJCOMs. MAJCOMs should not be saddled with increased financial burdens for sake of a fuels handling event that is feared but has never been experienced or can be handled more effectively by timely problem solving.

1.0 INTRODUCTION

The initial service evaluation of JP-8+100 began in November 1994 at the 173rd Fighter Wing (FW), Oregon Air National Guard (ANG) located at Kingsley Field, Klamath Falls, Oregon. Rather than convert every aircraft to JP-8+100 initially, the decision was made to convert the aircraft after the scheduled shop visit for a Phase Inspection. As a result, the single engine F-16 fighter aircraft at Kingsley Field were gradually converted to JP-8+100 over a span of 9 months.

After aircraft had logged 50 or more flight hours on the +100 additive, the flight line mechanics reported they could pick out with 100% accuracy those aircraft that had been using JP-8+100 even for a short period of time just by looking up the tail pipe at the coloration and cleanliness of the last stage turbine, the augmentor spray rings and the flame holders of the F100-PW-200 engines. PW is the abbreviation for the engine manufacturer, Pratt and Whitney Aircraft.

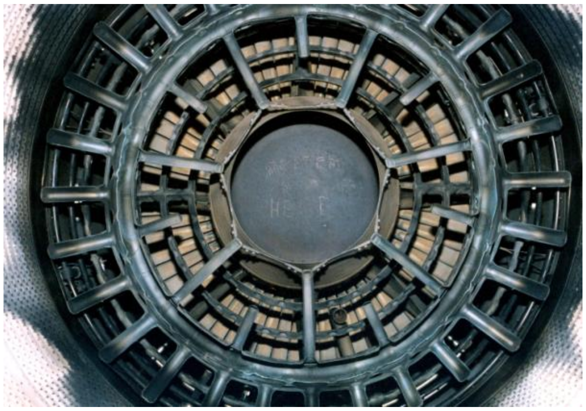

Figure 1. F100-PW-200 Engine Showing Turbine and Augmentor After 200+ Hours on JP-8

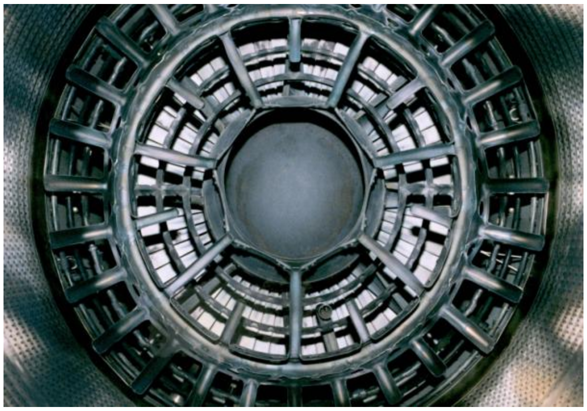

Figure 2. F100-PW-200 Engine Showing Turbine and Augmentor After 56 Hours on JP-8+100

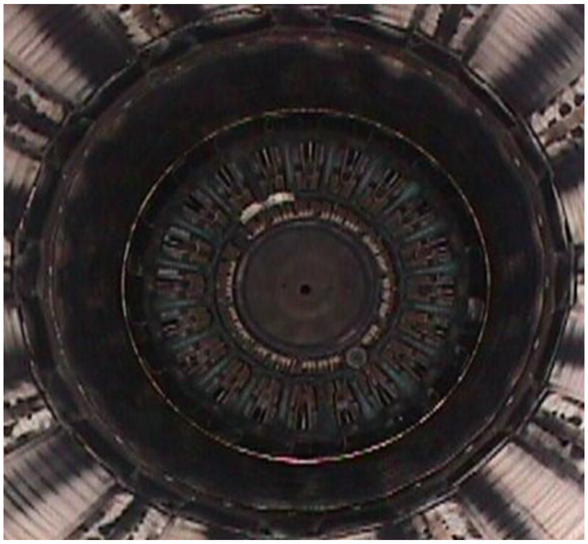

Figure 3. F110-GE-100 Engine Showing Turbine and Afterburner on JP-8

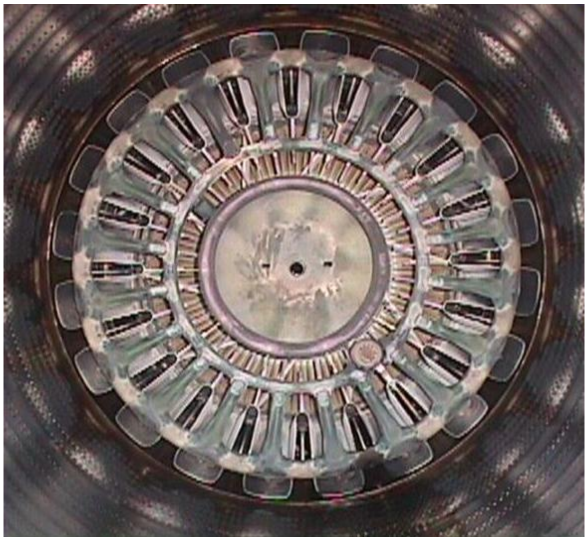

Figure 4. F110-GE-100 Engine Showing Turbine and Afterburner on JP-8+100

For over a decade, **Figures 1** and **2** have been used in many publications and presentations to show vivid examples of a 'dirty engine' using JP-8 versus a 'clean engine' that had been using JP-8+100. To a seasoned engine maintainer, an immediate benefit of a clean engine is the ability to quickly accomplish a visual inspection of the hot section parts such as the fuel nozzles, turbine vanes and blades, and the after burner and exhaust system components. Any finite cracks and/or worn parts are no longer covered by carbon and coke deposits and thus easily detected during the scheduled inspection. **Figures 3** and **4** show similar pictures of the afterburner section for General Electric (GE) F110 engines.

For over a decade, these pictures were used to show the immediate benefits of using JP-8+100 since more time was needed to accumulate and analyze engine maintenance data from a larger population of different engine types and from within engine families in order to determine any reductions in unscheduled engine and control component removals due to coking. Avoiding unscheduled maintenance allows better use of resources to perform the scheduled engine maintenance program. It has only been in the last few years that sufficient engine removal data under more stable maintenance conditions have become available to determine, with measured clarity, what JP-8+100 has been doing for the Air Force fleet of engines. Now, visual images of cleaner turbines, augmentors and afterburners are no longer the only evidence demonstrating the benefits of the +100 additive especially when a significant event occurs like in May/June 2005 when the +100 additive was turned off for 12 to 13 months to resolve some filter coalescer issues that resulted in increased engine anomalies.

This report is a distillation of a more detailed non-public release report prepared in 2008 and provides a technical discussion of the +100 thermal stability additive and presents what has been learned from 1994 through 2009 about the maintenance impact of JP-8 use on engine and control removals and the maintenance benefits that have been demonstrated for those Units using JP-8+100. Also, information is provided concerning the implementation of the +100 additive technology, references to how additized JP-8, Jet A or Jet A-1 fuels can now be handled based on the most current issue of Technical Manual T.O. 42B-1-1, Quality Control of Fuels and Lubricants, and lessons learned, resolved and unresolved issues gathered from over a decade's worth of field experience at several operational units with different aircraft, engine types and assigned missions.

The development and service evaluation of the +100 additive was conducted by the Fuels Branch of the Air Force Research Laboratory (AFRL/RZPF) at WPAFB, OH in close cooperation with GE Betz. The additive essentially increases the thermal stability margin of a kerosene-based fuels used in current and advanced USAF engines that was lost during the conversion from JP-4 to JP-8. While use of JP-8 improved fuel handling safety and reduced the hazards of aircraft fires from ignition sources, it accelerated engine coking and increased the unscheduled maintenance workload to fix engine anomalies and thus an additive was needed to reduce the formation of residues and coke on the fuel-wetted engine parts exposed to high temperatures. A secondary benefit of JP-8+100 is the reduction of visible exhaust emissions.

Great care has been taken to simplify a significant amount of complex engine maintenance data and field experience that were obtained before and after the conversion to JP-8 and then to JP-8+100 which hopefully will provide ample data for the reader to assess the maintenance benefits from using the +100 additive. Due to the complimentary interactions between the scheduled and unscheduled maintenance programs at operational units, the dynamics of the engine maintenance environment during periods when engines were in poor condition and restoring of engine build standards, the influence of local maintenance procedures and best practices and the per cent use of the +100 additive, no attempt was made to provide financial information such as specific cost benefits, avoidance of maintenance costs or Return on Investment (ROI) associated with using JP-8+100 although some of the elements of typical cost estimating models impacting cost avoidances will be briefly discussed. Maintenance activity is driven by several variables unique to each organizational unit and engine type making it difficult - if not impossible - to isolate one particular contributor preferentially over another as having more or less of an impact on overall maintenance avoidance and readiness primarily because of synergism. However, upper management, aircraft maintenance and fuel handlers can use this document to learn more detailed information applicable to engine types of interest that will allow an independent assessment of additive use, its impact on avoiding unscheduled engine maintenance and associated repair costs.

Decision makers should keep in mind the top level findings of this report -- **JP-8+100 helps to avoid unscheduled engine maintenance due to coking, increases aircraft readiness and engine time on wing**.

2.0 ORIGIN AND DEVELOPMENT HISTORY OF JP-8+100

2.1 Background

The formal process used to develop new weapons systems, make hardware changes to improve reliability and safety is very structured and complex requiring both fiscal and management support plus continued advocacy and cooperation from the highest levels down to the Users of the end item, the maintainers and their support organizations. The direction from OSD in the 1980's to change the fuel type used in USAF weapons systems to reduce safety hazards and to reduce support costs seemed to be a change that would enjoy broad support from the Users. Changing fuel from a highly volatile fuel like JP-4 that Air Force engines had been designed to use for over 40 years to JP-8, a low volatility fuel would appear to be a responsible and logical step to reduce aircraft fire hazards due to ignition sources and to improve fuel handling safety. Several years before the conversion to JP-8 occurred, the Fuels Branch at AFRL/RZPF at WPAFB, OH had anticipated that some engines in the inventory would have coking problems. The approach selected was to develop, qualify and field a thermal stability additive for use in JP-8 that would raise the temperature at which varnishes and coke would start to form on hot metal surfaces of fuel wetted engine parts. The goal was an increase in the thermal stability margin of JP-8 by 100 °F and this goal was achieved. After conversion to JP-8, the extent of the coking problems and the resulting increase in unscheduled engine removals became a real burden to engine maintainers who were at that time in the process of restoring the build standards of engines. The immediate action taken to the deal with the engine coking problems was to issue direction to bake and clean the affected parts more frequently to reduce the impact of accelerated coking. A longer term approach was to develop hardware changes to reduce the coking problems in the affected engine components that were feasible and affordable. Although fighter, transport and helicopter Units were eager to use JP-8+100, overly cautious fuel handling procedures and restrictions had been established making it more difficult for the fuel handlers to perform defuels and fuel transfers with the assigned R-11 fuel trucks. Also, several events occurred such as 9/11 and the Iraq war requiring deployment and rapid response to assigned missions that forced Units to stop using JP-8+100. Therefore, the field evaluations at different Units did not go smoothly due in part to fuel handling procedures established in the implementation plans to provide two grades of fuel (both JP-8 and JP-8+100), the return to bulk restriction of 1:100 blend back ratio and the initial perception that the additional surfactants contained in the detergent/dispersants of the +100 additive would defeat the 3rd Edition filter coalescer elements. After exhaustive filtration tests were conducted, it was later proven that JP-8+100 has no greater impact on a filter coalescer element than straight JP-8 (see **Section 2.10.3, SwRI® Executive Summary**). Units that continue to use JP-8+100 recognize that the +100 additive has become a part of other evolving maintenance procedures and best practices that have helped reduce engine anomalies and unscheduled maintenance due to coking. This section highlights some of the challenges and obstacles that were overcome and the progress made to gain acceptance by the Users and the recent endorsement of ASC/EN for use of the +100 additive in USAF weapons systems that will benefit from its use.

2.1.1 Fuel Thermal Stability Challenges

The onboard fuel in military and commercial aircraft supplies the energy for operation of the engine(s), powers the aircraft subsystems and provides the thrust that sustains powered flight.

Before entering the combustion chamber, the onboard fuel passes through heat exchangers that cool the aircraft subsystems, including the avionics, environmental control and electrical systems, generators, hydraulics, gear boxes, and engine components to include the engine oil and the electronic control components. During aircraft descent, the engine fuel flow is decreased but the aircraft subsystems are hot and continue to transfer heat to the fuel causing fuel temperatures in some of the fuel-wetted components to exceed the 325 °F thermal stability limit of kerosene based fuels like JP-8, Jet A and Jet A-1. After augmentor shutdown when the residual fuel is being removed from the augmentor spray rings and feed tubes, the hot metal surfaces can easily exceed the thermal stability limit of JP-8 and causes surface deposits to form that turn to coke after several augmentor lights.

2.1.2 Insoluble's and Coking

As fuel temperatures approach 140 °C (284 °F), autoxidation products begin to form as surface deposits and bulk fuel insoluble's.[1] At lower temperatures, these carbonaceous deposits manifest themselves as varnish-like or gum-like deposits that can adversely affect the operation of precision engine control components that rely on tight clearances and smooth operation to function properly. At higher temperatures, deposits form on hot metal surfaces taking on the appearance of coal, being hard, black and brittle, and commonly referred to as 'coke'. Coke deposits can cause significant degradation in augmentor performance, fouling of augmentor fuel controls and are the cause of fuel-related engine anomalies and engine removals. To make matters worse, the hard coal-like deposits are firmly attached to metal surfaces and are difficult to remove. For expediency, the engine is removed from the aircraft in order to clean and/or replace the engine components that malfunctioned. The control components may be returned to the Depot for an exchange or partially disassembled and cleaned in the engine shop to remove visible gums and coke slurry in the metering valves. Also, the augmentor fuel spray rings and feed tubes are removed as needed and subjected to labor intensive baking and cleaning procedures. Some coke deposits cannot be fully removed and some spray rings are declared unserviceable and returned to Depot for an exchange. Coke-related maintenance is so prevalent that entire maintenance lines have been setup at the engine depot for the removal of the coke deposits or contractors have been qualified to perform some of the refurbishment tasks.

2.1.3 Aviation Turbine Fuels

The fuel specification for JP-4 was developed by the Propulsion Laboratory at WPAFB, OH in the early 1950's to provide a jet engine fuel with good ignition and burning characteristics across the flight envelope and satisfy the design requirements of more advanced military engines and aircraft. Because of its low flash point, low freeze point and low viscosity, JP-4 was uniquely suited for jet engines except for the safety hazards posed by its high volatility. For the next 40 years, engine combustion systems would be designed and developed around the fuel properties of JP-4 which had a limiting bulk temperature of 325 ºF. If operated above this limit, the fuel would deposit increased amounts of varnishes and coke on high temperature fuel-wetted parts. To allow occasional use of JP-5, the Navy adopted fuel, and other kerosene based fuels available at foreign operating locations, fuel density adjustments were provided on legacy engine fuel controls. The scheduled maintenance intervals to remove coke deposits in the fuel-wetted components were established during engine development and refined during the service life of each new weapons system.

During the Vietnam War, the Air Force became acutely aware of aircraft vulnerability to fires and explosions brought on by battle damage. To provide a safer fuel, the Air Force developed a specification for a kerosene-based fuel that would meet the requirements for current and future jet engines but would be less vulnerable to fires and explosions thereby offering improved combat survivability. The Air Force began conversion to this new fuel, JP-8, as the standard aviation turbine fuel in 1990 with conversion being completed in 1996. For informational purposes, **Table 1** provides the comparison of the NATO, US Military and Civil fuel designations for aviation turbine fuels with some comments and footnotes provided for clarification.

Table 1. Overview of Nomenclature and Characteristics of Typical Aviation Turbine Fuels

Fuel Designation[1]			**Comments**
NATO	**US**	**Civil**	
F-34	JP-8[2]	Jet-A-1 & Jet A[3]	Straight cut kerosene
F-37	JP-8+100	● GE Betz Spec-Aid® 8Q462 ● AeroShell Performance Additive (APA) 101 ● Turboline FS100C	Components are all approved by engine OEMs and include dispersant/detergent base, antioxidants and metal deactivator. There is only one qualified additive, GE Betz (formerly BetzDearborn) Spec-Aid® 8Q462, also marketed as Aeroshell APA 101 and Turboline FS100C
F-40	JP-4	Jet B	Wide cut, approx. 70% kerosene, 30% gasoline/naphtha
F-44	JP-5[4]	none	Straight cut kerosene

Notes:

1. The civil fuels are the same base fuel as their military counterpart, but the military fuel contains three further additives: a static dissipating additive (SDA), fuel system icing inhibitor (FSII), and corrosion inhibitor/lubricity improver (CI/LI).

2. JP-8+100 is JP-8 with the Spec-Aid® 8Q462 additive

3. Jet A has a higher freezing temperature than Jet A-1 and is only produced in the US (-40 °C vs. -47 °C respectively).

4. F-44 may be considered identical to F-34, with the exception of the flash point (60 °C and 38 °C respectively). The flash point for F-44 is higher due to the safety requirements necessary in the marine environment.

Note: Updated from Table 1-1, "F-37 (F-34+100) Implementation, Master Implementation Plan", Air Staff, Department of National Defense, Ottawa Ontario, Canada, Version 1.0, 27 August 2002.

2.1.4 JP-8 Conversion Experience

After conversion to JP-8, some legacy fighter, turbo-prop and turbo-shaft engines experienced significant increases in unscheduled maintenance due to coking problems. Engines in service had been designed and developed to use JP-4; a "naphtha" based fuel roughly equivalent to a blend of gasoline and kerosene but were now using a straight kerosene-based fuel (JP-8) that has a lower thermal stability than JP-4. As a result, varnishes and coke deposits formed more rapidly in fuel-wetted components exposed to high temperatures. After conversion to JP-8, the coke and varnish deposits began to cause numerous control malfunctions and augmentor anomalies. As a result of the accelerated coking, engine maintainers were forced to re-evaluate shop maintenance procedures and cleaning intervals, forcing costly and labor intensive maintenance procedures. Extreme measures were taken over a short period of time to bake and clean all spray rings and feed tubes in legacy F100 engines and replace any affected engine hardware.

As a result of the accelerated coke buildup in various engine models in fighter, transport and helicopter aircraft, engine maintainers began to diligently search for new courses of action to minimize the impact of accelerated coking since the maintenance procedures and intervals recommended in Tech Data proved inadequate in preventing engine anomalies due to coking. In some cases, extreme measures had to be taken. For example, some units had already begun decreasing the baking and cleaning interval from the required 1200 engine flight hours (EFH) to around 600 hours while other units began baking and cleaning the augmentor fuel spray rings every time an augmentor was removed and entered the engine shop for maintenance which occurred in the range from 150 to 400 EFH. Based on fouling, the Augmentor Fuel Control (AFC) was removed and the exit ports cleaned to eliminate any malfunctions in the metering valves. Engine fuel spray nozzles in C-130H transports, several helicopter engines, and trainer aircraft engines such as the J85 and fuel slingers in the J69 were inspected and cleaned more frequently to reduce coking on the spray nozzle tips that would cause hot streaks and reduce turbine vane life. Operational Units were eager to try anything that would reduce engine anomalies and thereby decrease maintenance workloads caused by coking

2.1.5 Increased Aircraft Cooling

During the late 1970's and on into the 1980's, aircraft engine and airframe designers continued to develop engines and aircraft with improved performance capability to meet advanced mission requirements. Each new aircraft required substantially greater cooling from the onboard fuel. **Figure 5** shows the increases in heat loads for the aircraft hydraulic systems, the environmental control system (ECS), the electrical system including the avionic systems and the engine(s) for current F-16C/D and F-15E fighters and an Advanced Aircraft compared to the F-4 fighter. For example, the Advanced Aircraft has approximately a 2.4 increase in required cooling compared to the F-15E noting that the heat loads for the aircraft hydraulics, ECS and engines have increased significantly. Although advanced weapons systems were requiring a significant increase in cooling capacity from the onboard fuel, less cooling capacity is available because of reduced aircraft fuel loads and improved engine fuel economy [referred to as reduced Specific Fuel Consumption (SFC)]. As a result, aircraft fuel systems used a complex architecture of routing and recirculation in order to provide the increased cooling capacity required. At higher flight speeds, aerodynamic heating increases aircraft skin temperatures and aircraft heat loads minimizing opportunities for heat rejection.

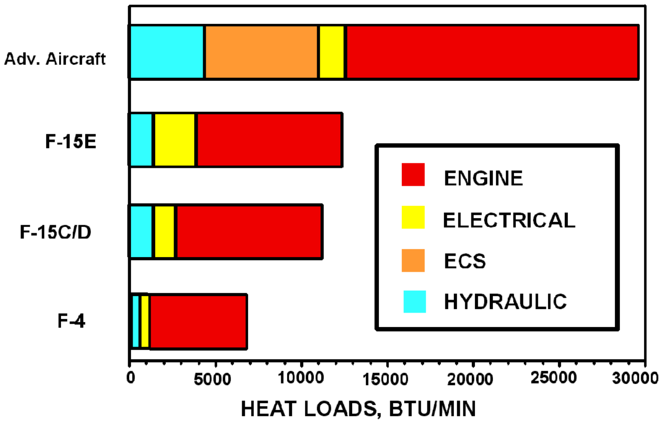

Figure 5. Weapon System Heat Loads

2.1.6 JP-8 Thermal Stability Requirements

Aircraft and engine designers realized that additional cooling capacity could be extracted from JP-8 fuel if fuel temperatures were allowed to rise above 325 °F, the limiting bulk temperature established for hydrocarbon fuels used in conventional aircraft engines. However, designers also realized that as fuel operating temperatures were increased, the formation of coke in fuel systems and fuel-wetted hot engine components would also increase. Experience has shown that a rise in temperature as small as 25 °F could significantly impact the operation of an aircraft. Therefore, if cooling capacity was to be increased by allowing fuel temperatures to rise, a way had to be found to improve the thermal stability of the fuel so that elevated temperatures could be sustained without increased coking. From this need, a goal was established to develop a high-thermal stability JP-8 to support sustained bulk fuel temperatures as high as 425 °F without experiencing coking beyond that which would typically be experienced by conventional JP-8 at 325 °F. Increasing the thermal stability margin by 100 °F would provide an increase in the cooling capacity or heat sink of the onboard fuel by up to 50%.

2.1.7 Additive Development

In response to the challenge of developing a high-heat sink JP-8, the Fuels Branch of the Air Force Research Laboratory (AFRL/RZPF) began in the 1980's to explore ways of imparting a 100 °F increase in thermal stability margin for JP-8[2]. The approach taken was based on the use of additives. The Fuels Branch leveraged its knowledge of aviation turbine fuel additives and thermal stability combined with the experience of automotive fuel additive manufacturers to develop an additive for JP-8 that would eventually become designated as JP-8+100. The '+100' designation comes from the 100 °F thermal stability margin imparted to JP-8 by the additive. Other research projects were later initiated to develop additive packages to achieve up to 900 ºF increase in the fuel thermal stability limit. Specialty fuels such as JP-TS and JP-7 offered an alternate, more costly path for jet fuel development, but these options presented significant problems with regard to specialty processing, increased procurement costs and increased logistic support requirements so they were dismissed as viable options for consideration. Therefore, research was directed to develop a cost effective additive package that could be mixed with JP-8 fuel close to the point of refueling an aircraft.

During the course of the test and evaluation program for this new additive technology, over 350 candidate additives and additive combinations were evaluated. Screening tests were conducted on the following additive classes: antioxidants, detergents, dispersants and metal deactivators. Screening was accomplished using three different tests: the Isothermal Corrosion Oxidation Test, the Quartz Crystal Microbalance and the Hot Liquid Process Simulator. Additives that performed acceptably[b] in these laboratory-scale tests were then evaluated in five aircraft/engine fuel system component simulators: the Phoenix Rig, Extended Duration Thermal Stability Test (EDTST), the Near Isothermal Fuel Stability Test (NIFTR), the Augmentor Simulator and the Advanced Reduced Scale Fuels System Simulator (ARSFSS).

Detergent and dispersant additives proved most effective in reducing coke deposition by chemically binding to polar organic compounds in the fuel and preventing their adherence to surfaces, thereby reducing formation of surface deposits. Antioxidants, especially in the presence of detergents and dispersants, further reduced deposition, by inhibiting reactions with

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[b] *See "Materials Compatibility Testing", Section 2.3*

oxygen dissolved in the fuel. Additionally, metal deactivators also enhanced the thermal stability of fuels by chelating or 'deactivating' trace metals such as copper.

Several additive packages submitted by manufacturers showed promise of meeting the desired +100 °F goal but only one additive was eventually accepted by the fall of 1994. This additive, developed and manufactured by BetzDearborn (now known as GE Betz after acquisition by GE Water and Process Technologies) received the designation Spec-Aid® 8Q405. In the field, this proprietary additive was combined with an antioxidant and a metal deactivator into a single cocktail blend and evaluated during early field demonstrations at ANG Units at Kingsley Field, Klamath Falls, OR and Louisville, KY. During the first cold weather season at Kingsley Field, the antioxidant used in the additive formulation sometimes separated out and collected at the bottom of the additive bulk storage tank. Therefore, a new formulation was developed by replacing the antioxidant with another widely used antioxidant and the new cocktail mix (8Q405 plus a new antioxidant and existing metal deactivator) was designated Spec-Aid® 8Q462 in September 1996. This is the additive used in JP-8+100. Spec-Aid® 8Q462 was eventually also marketed in the commercial aviation sector as Turboline® FS100/FS100C[c] and in Europe as AeroShell Performance Additive 101® (APA101).

During the extensive test program that led to the eventual establishment of Spec-Aid® 8Q462 as the JP-8 additive, mixtures of up to four times the recommended concentration for JP-8+100 were evaluated with no adverse material degradation. The evaluation and qualification testing continues for additive packages from other suppliers in order to provide additional qualified sources for +100 thermal stability additives and to take advantage of new technologies that may provide improved performance.

2.1.8 Initial Fuel Handling Precautions

The Air Force moved quickly to make JP-8+100 available for service evaluations at several active and ANG Units operating fighter and transport aircraft and helicopters. Being a different fuel grade than JP-8, fuel handling procedures were established to maintain the quality of JP-8 fuel issued from the existing bulk storage facilities at each operating unit that proved to be overly cautious making it difficult to issues two grades of fuel at small units' assigned three R-11 fuel trucks. For completeness, the rationale for establishing the initial handling precautions and blend back restrictions for aircraft using JP-8+100 are discussed but have been rescinded by T.O. 42B-1-1 as discussed in other sections of this report. The concerns that the detergent/dispersants and surfactants in Spec-Aid® 8Q462 might reduce or defeat the ability of existing receipt filter coalescers to remove water from fuel led the San Antonio Air Logistics Command fuels organization responsible for the implementation of the JP-8+100 field evaluations (SA-ALC/SF) to establish strict fuel handling procedures for JP-8+100. For example, a blend back-to-bulk ratio of 1:100 (1 part additized fuel blended back into a minimum of 100 parts of straight JP-8 fuel) was established as a standard operating procedure for handling JP-8+100 until research and experience could define a more suitable blend back ratio. Also, it was directed that existing filter coalescers had to be changed if any JP-8+100 came in contact with the elements. This relatively high blend back ratio, along with the fact that not all Air Force assets were approved to use JP-8+100 and the Navy and Army steadfastly refused to approve use of JP-8+100 in their aircraft even during co-mingled military activities, ultimately made it

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[c] *Turboline FS100 is a specialty version of Spec-Aid® 8Q462 for the commercial market and prepared for blending at 512 mg/L. FS100C is the concentrated version of FS100 and is the direct equivalent to Spec-Aid® 8Q462 with a treat rate of 256 mg/L.*

impractical for most Units to continue using JP-8+100. Units also sought guidance from SA-ALC/SF regarding relocating JP-8+100 program aircraft to non-program locations via equipment transfers or training exercises. In these cases, the receiving Units were concerned about the potential impact of aircraft defuels of JP-8+100 would have on their JP-8 fuel handling systems. To alleviate this concern, a conservative protocol to refuel an aircraft scheduled for transfer or a mission was established. Two consecutive refuels with straight JP-8 (where each refuel was a minimum of 75% of the aircraft's fuel load capacity) was required before the aircraft would be considered a non-program aircraft. Most Users did not have extra refuelers and bulk storage capacity available on short notice to off load large quantities of fuel in the event of an aircraft abort nor did they typically have the flexibility to schedule two flights using "straight 8" to remove an aircraft from +100 status. Thus, limited defuel and fuel transfer capability without an empty fuel truck coupled with manpower and scheduling issues became the prime detractors that eventually forced many Units to stop using JP-8+100 especially after 9/11.

Fortunately, several fighter Units stayed the course and continued to use JP-8+100 although some Units stopped using the additive for brief periods during deployments and support of assigned missions on short notice, especially those in response to the 9/11 terrorist attacks in New York City and Washington D.C. C-130H transport units had tried JP-8+100 for a short time but found that aircraft defuels, ground handling and return to bulk storage issues were too difficult to manage with available fuel handling assets because of the large quantities of fuel involved.[d] Continued support of operations in Iraq and Homeland Security missions after 9/11 also made it difficult to continue using JP-8+100 regardless of aircraft type.

2.1.9 Continued AFRL/RZPF Support

Although the fuel handling precautions and some events discouraged the continued use of JP-8+100, AFRL/RZPF steadfastly assisted all Units with technical support and ongoing maintenance benefits analyses. The detailed benefits analyses for several operational Units assigned F-15, F-16, various helicopters types and C-130H transport aircraft consistently showed that JP-8+100, in conjunction with improved maintenance procedures implemented by the engine shop (such as more frequent baking and cleaning of augmentor spray rings, the cleaning of control components and fuel spray nozzles), provided a steady reduction in engine anomalies and control malfunctions.

From the late 1990's through the early 2000's, the JP-8+100 additive technology continued to be of interest to maintainers but the use of the additive was more often surrounded with more urban legends and myths than scientific fact. In 2006, interest in using JP-8+100 regained some momentum after the +100 additive had been turned off for one year to resolve filter coalescer issues and Units had experienced a surge in coke-related engine anomalies that increased unscheduled engine removals. Yet, myths and urban legends continued to stifle use of the +100 additive in the field.

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[d] *A typical C-130 fuel load is 9,250 gallons compared to about 3,500 to 4,500 gallons for an F-15 and 2,300 gallons for an F-16*

2.1.10 Rigorous Filter Coalescer Testing

During 2005 and 2006, rigorous laboratory experiments were funded by several interested parties[15] that evaluated the impact of Spec-Aid® 8Q462 on filter coalescer elements. These experiments were performed at Southwest Research Institute (SwRI®) using a test rig that could stress filters and coalescers at real-world scale. The results of these experiments indicated for the first time that the 1:100 blend back ratio may have been far more stringent than was actually required. These tests, along with the analysis of filters from actual field service with JP-8+100, concluded that JP-8+100 has no more adverse effect on filter coalescers than standard JP-8. While there are some that argue the validity of the SwRI® experiments, this important finding prompted AFPET to publish new guidance in T.O. 42B-1-1, Change 3, 31 July 2006 allowing unrestricted use of Spec-Aid® 8Q462 by rescinding or modifying all the special fuel handling requirements and precautions that were established when JP-8+100 was initially released for field evaluation. Also, a blend back ratio of 1:1 was recommended for JP-8+100 returned to bulk. (See **Appendix K**)

2.2 Thermal Stability: The Science and Chemistry of Coking

2.2.1 Chemistry of Thermal Stability

Aviation fuel for turbine engines and diesel fuels readily form carbonaceous deposits known as ‘coke’, ‘varnishes’ and ‘gums’ when subjected to elevated temperatures. **Figure 6** shows typical coke deposits on a fuel spray nozzle and the dome region of the annular combustor in a J85 engine. The coke deposits are formed by the high radiation temperatures in the combustor dome that plates out the very fine and continuous mist of fuel from the fuel/air mixing performed by the fuel spray nozzles that wets the hot metal surfaces during engine operation and during engine shutdown. With significant coking on the face of a fuel spray nozzle and on the pintel as noted in **Figure 6**, fuel streaking will occur in the spray pattern from the coke deposits as shown in **Figure 7** causing accelerated oxidation and erosion of the turbine inlet vanes at the exit of the combustor. An example of the erosion and cracking of a vane trailing edge is shown in **Figure 8.** The negative impact of vane distress is possible and collateral damage to the turbine blades can occur requiring a shop visit for major repairs to the hot section and other sections of the engine based on inspection limits.

Figure 6. Coking Around Primary Fuel Nozzle, J85 Engine

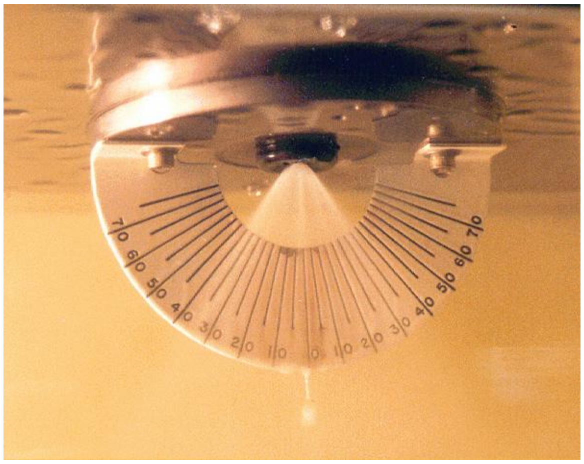

Figure 7. Spray Pattern Streaking From Coke Deposits on Nozzle Tip

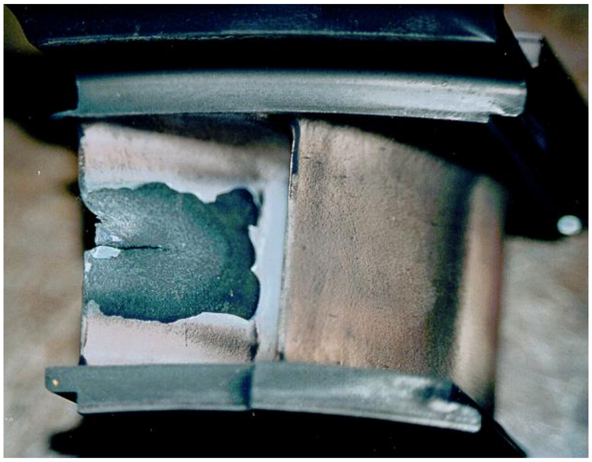

Figure 8. Turbine Vane Damage Resulting From Streaking Fuel Nozzles

The chemistry of the formation of deposits in fuel is very complex. Only in the last decade or so have scientists begun to more fully understand the fundamental chemistry of deposition. What is known is that the formation of these deposits involves the formation of 'free-radical' chemical species (a result of heating fuel) and then those free radicals react with the oxygen dissolved in fuel (between 40 and 80 ppm at room temperature) to form hydro peroxides[3,4]. These precursors undergo additional reactions with fuel components, including dissolved metals. The chemistry and physics of fuel deposit formation can be summarized in six key points[5]:

1. The initial process is a reaction between oxygen dissolved in the fuel and the fuel itself
2. The chemistry pathway mainly involves free-radicals

3. The formation of deposits is dependent upon temperature, fuel flow, dissolved metals and dissolved oxygen
4. The deposits form in both fuel liquid and vapor phases and these occur simultaneously. This simultaneous occurrence enhances deposit formation in both phases – they are synergistic
5. Metals can have a significant impact on deposition
6. The amount of dissolved oxygen is important. Removal of this oxygen typically reduces significantly the amount of deposit formed

Probably the most effective means of suppressing gum, varnish and coke formation is to somehow interrupt or inhibit the chemistries involved in thermal oxidative deposition. This can be accomplished through the removal of dissolved oxygen (deoxygenation) or through interrupting or suppressing some other feature of the chemistry. It is this latter methodology that thermal stability improving additives typically employ to improve fuel thermal stability. The current +100 additive is an example of this latter approach. Spec-Aid® 8Q462 consists of an antioxidant, a metal deactivator and a detergent/dispersant. These additives work synergistically to inhibit the formation of deposits, neutralize deposits that do form, and impart a cleaning action to the fuel. Specifically, the antioxidant inhibits the reaction between free-radicals and dissolved oxygen. A metal deactivator is used to chelate (deactivate) metal ions (to combine a metal ion with a chemical compound to form a ring) in the fuel, thereby preventing them from reacting with other deposit-forming fuel components. The dispersant component has the function of encapsulating gum, varnish and coke particles that form in the bulk fuel thereby neutralizing them and then inhibiting them from migrating to surfaces and forming deposits. The detergent imparts a cleaning action to the fuel, assisting in the removal of deposits that do eventually find their way to a surface in spite of the action of the dispersants.

No two JP-8s, no two Jet As are alike. Even a single refinery operating on a single feedstock with a fixed process will produce slightly different products on any given day. That is why the specifications governing fuels like Jet A and JP-8 are very broad in nature. Since fuels can and do vary, it is important that any additive used to enhance thermal stability (or any other fuel characteristic or property for that matter) is able to perform its function in a wide range of fuels with consistent results.

2.2.2 Fuel Thermal Stability Impact on Fuel Systems

The thermal stability limit of liquid hydrocarbon fuels was initially established in the 1960's. At that time, it was generally known that the limiting bulk temperature of any liquid hydrocarbon fuel was 163 ºC (325 ºF). This was based primarily on experience with "straight run" distillate fuels without any additional processing. Thus, this temperature was established as the upper limit for bulk fuel temperatures in aircraft and engine fuel systems. These design limits were used for all military and commercial jet aircraft produced through the late 80's when JP-4 was the primary fuel used in USAF aircraft. As aircraft systems have advanced, the 325 °F limit has made thermal management for advanced systems a significant challenge since advanced aircraft subsystems have higher heat rejection requirements and high performance engines operate at higher temperatures.

The fuel specifications of JP-4 (NATO code F-40), the standard fuel for the Air Force, were defined circa 1951 in MIL-J-5624E. JP-4 has been the primary fuel for USAF jet engines from

1951 through 1994 when the USAF made the conversion to JP-8 as the primary fuel procured to MIL-DTL-83133F. Being a mixture of aliphatic and aromatic hydrocarbons, JP-4 is a flammable transparent liquid with clear or straw color, with a combination gasoline/kerosene-like smell. Due to its high volatility and composition, JP-4 tended to be more thermally stable in aviation fuel systems than JP-8 – producing fewer deposits compared to JP-8 under most conditions.

Maintenance procedures and intervals set in place during the early years were based upon the typical deposition tendencies of JP-4 fuel. However, when the Air Force made JP-8 the primary aviation turbine fuel, the established maintenance procedures and service intervals proved to be inadequate. It has been shown that **fuel oxidative reactions for JP-8 start as low as 93 ºC (200 ºF) causing varnishes and coke to form** on fuel spray nozzle tips and internal passages, the internal surfaces of augmentor spray rings, spray bars, feed tubes, and the fuel dump probes. The metering valves in the augmentor fuel control are now inspected and cleaned to remove any slurry of gums and coke. It has been found that a rapid increase of deposits and liberation of coke particles can occur in the augmentor spray rings over a short period of time after an engine using JP-8+100 has been returned to using JP-8 causing a marked increase in engine anomalies. Events such as augmentor no lights and blow outs will cause a marked increase in unscheduled maintenance activity to return engines to a serviceable condition - especially when the performance of the gas path components of engines is degraded. Several engine control components would be changed on some legacy fighter engines resulting in multiple maintenance actions being required to clear the engine for service and considerable fuel burned in the test cell.

In addition to being a major driver in fuel-related engine maintenance, the presence of carbon deposits in the engine hot section can often obscure finite cracks and other defects approaching inspection limits during borescope inspections. **Engine maintenance personnel have commented that the hot sections of engines using JP-8+100 are much easier to borescope** with less positioning needed to find surface defects. When defects such as a crack or oxidation/erosion are hidden by carbon deposits, additional time is required to position the borescope to carefully examine the extent of the distress from different angles in order to make a decision of the appropriate action to be taken. Timely detection may avoid costly repairs and potential flight safety issues.

2.3 Materials Compatibility Testing

In order to assure compatibility between the +100 additive and materials used in aircraft systems, some 220 materials were identified for evaluation. The materials selected can be categorized as: adhesives, bladders, coatings, sealants composites, fuel filters, gaskets and O-rings, hoses, locking devices, lock wire, potting compounds, electrical wire and insulation, joining metallic's (both welding and brazing) and explosion suppression foams. Materials from these categories, beginning with those most likely to have compatibility problems, were subjected to nearly 300 prolonged, high temperature tests with JP-8 fuel and JP-8+100[6]. Following exposure, the physical and chemical properties of the materials and additized fuels were determined. The properties tested include: hardness, elongation, weight loss, cohesion, volume swell, tape adhesion, pitting, resistivity, laminar shear, peel strength, tensile strength, torque, compression set, LAP sheer, graphite, color change, hydro peroxides, acid number, gums, conductivity and phenols.

Testing and evaluation of these materials was accomplished at both normal and 4-times (4X) normal dosage rates for JP-8+100 during a 28-day thermal aging cycle at temperatures that were representative of those temperatures to which the material would be exposed during normal application (160 °F and 200 °F). During the testing, the test fuel was changed out every 7 days thereby simulating renewing of the fuel during normal operation. The testing and evaluation concentrated on the degradation of physical properties as well as evaluation of test fuel samples for any materials (particularly metallic) that might have leached into the fuel during the testing.

2.3.1 Conclusions

Researchers concluded that Spec-Aid® 8Q462 was "judged acceptable primarily based on its comparison to the JP-8 (control) fuel."

2.4 Engine Ground Testing

After successful completion of the materials compatibility testing of Spec-Aid® 8Q462 in fuels from 28 different military locations worldwide, AFRL contracted with Pratt & Whitney Aircraft (P&WA) and General Electric Aircraft Engines (GEAE) to evaluate JP-8+100 in production fuel spray nozzles installed in burner rigs. After completion of component rig testing, engine tests were arranged under the joint service Component Improvement Program (CIP) to use JP-8+100 in ground test engines. An F100-PW-220 engine was initially operated for 50 hours using JP-8+100 and achieved 224 Total Accumulated Cycles (TAC) without an incident during the short test period. Another test in an F100-PW-200 engine, the original engine delivered in the F-16 A/B fighter, successfully completed a full 4,000 TAC's which is the upper service limit for certain engine modules before mandatory removal and scheduled maintenance. JP-8+100 was also tested in the F100-PW-229 and in fuel nozzles for the F119, the engine development for the F-22 Advanced Tactical Fighter. In each case, use of the +100 additive removed the light carbon deposits from the hot section parts allowing the engine to run under more clean conditions.

In May 1994, the first informal "dirty engine" Accelerated Mission Test (AMT) was conducted using JP-8+100 in an F100-PW-200 engine at the 149th FW, Kelly AFB, TX. The AMT was successfully completed without any performance issues from using JP-8+100. The engine mechanics observed no visible smoke during engine testing and were amazed that the augmentor liner, flame holders, tail cone, spray bars and Low Pressure Turbine (LPT) were very clean compared to carbon deposits on these same parts using straight JP-8. With the completion of all laboratory test protocol required for release of a new additive and the successful completion of ground testing, the +100 additive was ready for flight testing.

2.5 Field Service Evaluations

2.5.1 F-16 Flight Test at Edwards AFB

Prior to launching operational evaluations at several Air National Guard (ANG) and Active Air Force Units, the JP-8+100 additive was tested in a limited propulsion evaluation by the 412th TW, Air Force Flight Test Center at Edwards AFB, California from September 26th through September 29th 1994 in an F-16C powered by a F100-PW-220E engine[7]. The objective was to demonstrate, over a limited flight envelope, that JP-8+100 did not adversely impact flight operations. The test consisted of 3 flights totaling 4.4 flight hours. All 28 spool down and Jet Fuel Starter (JFS) assisted air starts were successful. Augmentor light-off performance during throttle transients was very good when compared to -220 flight test results using JP-8. In general, the -220E engine exhibited satisfactory functional operability in both primary and secondary control modes. The secondary control mode is the backup mode in case of a malfunction in the Digital Electronic Engine Control (DEEC).

2.5.2 F-16 Flight Test Conclusion

The Technical Letter Report signed by 416th FTS/CC stated "It was demonstrated that over the limited flight envelope tested, the test fuel did not adversely impact flight operations".

This flight demonstration cleared the fuel for initial service evaluations at several Units that were eager to start using JP-8+100 to help reduce coking in the augmentor spray rings that was causing engine anomalies, increased troubleshooting and unscheduled maintenance. Several Unit commanders expressed a sincere desire to try JP-8+100 in an attempt to find relief from the abrupt increase in engine anomalies caused by coking after conversion to JP-8 that had reduced aircraft readiness and increased the maintenance workload.

Following the successful F-16 flight test at Edwards AFB, the Fuels Branch at AFRL (AFRL/RZPF, formerly POSF and PRTG) held meetings with System Program Offices (SPOs) at the Aeronautical Systems Division at WPAFB OH, with MAJCOMs, the National Guard Bureau in Washington DC, and HQ AFMC to review the status and readiness of the +100 additive for early transition through field service evaluations. Following these meetings, the Director of the Air National Guard, Major General Sheppard, approved ANG participation in field service evaluations of the +100 additive.

2.5.3 Early Service Evaluations

In November 1994, the initial field service evaluation of JP-8+100 was launched at Kingsley Field in Klamath Falls, OR under an informal agreement between the National Guard Bureau, Kingsley Field and AFRL/PRTG. The assigned mission at Kingsley Field was to train ANG pilots in the single engine F-16A/B fighter that was powered by the F100-PW-200 engine. From 1994 through 1997, several other ANG, active Air Force and Training Units began service evaluations in F-15, F-16, A-10, C-130H, T-37, T-38 and helicopter aircraft to include:

Otis ANGB, MA
Portland ANG, OR
Burlington, VT
Springfield ANG, OH
Louisville ANG, KY
Nashville ANG, TN
Westfield ANGB, MA
Fargo ANG, ND
Kirtland AFB, NM
Sheppard AFB, TX
Langley AFB, VA
Lakenheath RAFB, UK
Luke AFB, AZ

During the service evaluations, deployed aircraft used the available JP-8 fuel at the operating location but resumed using JP-8+100 upon return to the home station.

2.6 Electrical Conductivity and Charging Tendency of JP-8+100

Aviation turbine fuel, flowing through pumps and in pipes can generate significant electrostatic charges which, due to the poor electrical conductivity of fuel, can result in discharges.[8] Normally for fluids which are reasonably conductive, these charges bleed off very rapidly and pose no threat to aircraft systems. Aviation fuels, however, have a relaxation period of seconds to minutes. If a fuel becomes highly enough charged, spark and corona discharges can produce enough energy to ignite fuel/air mixtures in fuel tanks if the ratio is right. Hence, the electrical conductivity of fuel becomes a serious safety issue in fuel handling. In the mid-1970's eight USAF aircraft experienced fuel tank fires during refueling. Static discharge was determined to be the cause of each of these incidents. To reduce the hazard of fire from electrical discharge, the Air Force uses a special additive in fuel to improve its electrical conductivity. This additive is Stadis 450 and manufactured by Octel. In the past, Shell manufactured ASA-3 that was also used to improve electrical conductivity but production of this additive was discontinued in 1994.

In addition to improving the thermal stability of JP-8, it has been observed in laboratory tests and from field experience that the presence of the +100 additive in the fuel can increase its conductivity. MIL-DTL-83133F calls for fuel conductivity to be "between 150 and 450 pS/m (picosiemens per meter) for F-34, the NATO code for JP-8, and between 50 and 450 pS/m for F-35, the NATO code for Jet A-1, at ambient temperature of 29.4 °C (85 °F), whichever is lower, unless directed by the procuring activity. For JP-8+100 referenced in MIL-DTL-83133F, the conductivity limit must be between 150 and 700 pS/m at ambient temperature of 29.4 °C (85 °F), whichever is lower, unless otherwise directed by the procuring activity."

In laboratory testing, backed up by field experience, it has been found that the presence of the +100 additive, at the normal concentration usage of 256 mg/L, can increase the conductivity of most fuels by approximately 100 pS/m.[9] In typical JP-8 fuels with low conductivity, the use of the +100 additive alone did not increase the native conductivity of the fuel above 150 pS/m so the presence of the additive did not eliminate the need for Stadis 450.

When evaluated in various fuel filter media, studies found that the +100 additive does not produce high electrostatic charging on filter media typically in use today for JP-8.

2.7 Fuel Gauging Studies

Fuel gauging systems on aircraft are typically one of three types - Ultrasonic, DC Capacitance or AC Capacitance. Fuel electrical conductivity is one of the fuel characteristics that can affect the accuracy of these systems. Since the JP-8+100 additive is known to affect fuel conductivity, studies were initiated with a major fuel gauging system manufacture to evaluate the impact of the +100 additive on these systems.

The studies found that for current aircraft (B-1B, B-2, RC-135, F-15, F-16, F-18 and F-22), "there will be negligible error using JP-8+100 on a properly calibrated fuel gauging system." [10]

2.8 Fuel Pump Tests

Initial field demonstrations of JP-8+100 were conducted on F100 series engines. Over the course of the field evaluations, a significant amount of engine time was accumulated on the additive. During the course of the field demonstrations, two main fuel pumps from this engine series were made available to AFRL for the purpose of evaluating the effect, if any, of the +100 additive on the fuel pumps.

While the details regarding the origin and service history of these pumps have been obscured or lost over time, there were at least two reports that document the condition of two F100 Model 70800-02 Main Engine Fuel Pumps (serial number B0465 and B1449). The teardown inspections were performed by Argo-Tech Corporation in May 1996 and August 1997 and were documented in Argo-Tech reports EN-6283 and EN-6404.[11,12] Pump serial number B0465 was documented to have 5,139 flight service hours with 4,363 hours using JP-8+100. Pump serial number B1449 was documented to have a total of 1063.5 flight service hours of which 398 hours were on JP-8+100 fuel.

Both reports document that the pumps were received in normal condition. The reports also document the following:

- Pump flow performance was within Acceptance Test Procedure (ATP) limits but slightly less than observed during the original calibration prior to shipment.
- Shaft cranking torque and bolt torques were normal
- Impeller shims, key and volute housing showed no fretting wear. All parts were in normal condition and showed no significant wear.

Both reports concluded that "On the basis of the observed condition of the hardware and recorded performance, the pump would be expected to operate for an additional 500 to 1000 hours in the same environment without significant degradation of performance or component wear." These reports essentially concluded that there was no impact on the fuel pumps from the use of JP-8+100.

Teardown inspections were also conducted of the fuel pumps from an F110-GE-100 engine: the fuel boost pump, main fuel pump and the augmentor fuel pump. The total engine hours on the pumps was 791 hours with 67% of the time using JP-8+100. The inspection procedure noted no deterioration in pump performance and observed that all internal components were in excellent condition with no degradation of the elastomer seals. The vendor recommended reassembly and return of the pumps to service. The engine manufacturer concluded that JP-8+100 fuel is acceptable to use in the fuel pumps on the F110 engine.

2.9 Teardown Inspections of Engine and Augmentor Fuel Controls

2.9.1 Unified Fuel Control – F100-PW-100 Engine

A Unified Fuel Control (UFC) was obtained from Kingsley Field during the JP-8+100 field demonstration for a teardown inspection at the manufacturer's facility. The UFC is back to back control with shared computational functions that provides for main engine geometry and fuel control and fuel flow to the augmentor. The UFC was delivered to Allied Signal (formerly Bendix) in South Bend, Indiana where a team of engineers and technicians disassembled and inspected all the internal parts of the hydro-mechanical control. While no formal report was ever compiled on the findings of this teardown inspection, the consensus of the team was that the UFC was in excellent condition, perhaps in slightly cleaner condition than would be normal for a control of that vintage and that there were no apparent adverse effects from the control having used JP-8+100.

2.9.2 Main Engine Control and Augmentor Fuel Control – F110-GE-129 Engine

The controls from an engine with 791 hours operation were inspected at the vendors. Approximately 67% of the engine hours were using JP-8+100. The controls were bench tested, torn down and inspected to determine both the functional and physical condition. Both controls were subject to and "as received" repeat of the standard production Acceptance Test Procedure (ATP), and the test data compared to test data prior to engine test. This comparison revealed some small changes in measured parameters between pre- and post-test ATP data; however, all were within the "new parts limits." The Main Engine Control (MEC) and the Augmentor Fuel Control (AFC) were then disassembled and examined for any indications of distress or anomalies that would be attributable to exposure to and operation with JP-8+100 fuel. The disassembled piece parts and the seals and O-rings did not show any indication of distress, wear or signs of impending failure and the general condition was 'much cleaner than expected' for the hours of operation reported. Each vendor recommended that the controls be returned to service after normal replacement of the elastomer seals and O-rings and reassembly.

2.10 Providing Fuel Quality

From the earliest days of powered flight, the availability of clean, dry fuel for aircraft use has been extremely important to achieve the desired engine performance across the flight envelope free of any flight safety issues. In the early days when the bulk of the fuel used for flight was delivered in metal cans, simple filtration mechanisms (such as chamois leather) had been used to assure the cleanest, driest possible fuel.[13] As aircraft technologies progressed, the need for clean dry fuel became even more important. Current fuel filtration processes and equipment are now governed by tightly controlled and regulated specifications such as API/IP 1581.[14]

2.10.1 Fuel Handling Restrictions/Precautions

Filter coalescer performance, the ability to remove all particles and water, is greatly affected by the presence of surfactants in fuels. Many additives currently used in aviation fuels exhibit some degree of surfactancy. Additional surfactancy is present in JP-8+100 because one of the components of the +100 additive is a proprietary detergent/dispersant. Planners were convinced the existing coalescer-type filtration would quickly become disarmed after coming into contact with the additive and subsequently dirt and/or water would pass through to receiver aircraft.[16] Therefore, the decision was made to install water absorbing filters in the fuel trucks. In addition, the implementation plan instructed the fuel handlers not to allow JP-8+100 fuel to come in contact with any filter coalescer elements such as the receipt elements in bulk storage. If contact did occur, all the filter coalescer elements were to be changed. Further, a 1:100 blend back to bulk ratio policy (1 part JP-8+100 blended into a minimum of 100 parts of spec grade JP-8) was adopted because the experience base of fuel managers had shown that virtually any type of aviation fuel could be blended into JP-8 at a 1:100 ratio without impacting the bulk fuel properties. However, the above fuel handling restriction and precautions quickly became problematic for the Fuels Flight and often resulted in the Unit choosing not to use JP-8+100.

Unfortunately, these restrictions and precautions were based on long standing concerns rather than scientific investigations that could be used to determine if filter coalescer elements would be defeated due to slightly higher concentrations of surfactants in JP-8+100. For unknown reasons, filter coalescer tests were not attempted before or after the initial service evaluations began in 1994, however, the fuel handling problems that occurred at most Units during aircraft defuels and fuel transfers back to bulk storage ultimately inhibited widespread acceptance and use of the +100 additive. Thus, a cooperative program discussed below was launched in 2004 to conduct rigorous filter coalescer tests to compare JP-8 and JP-8+100 filtration results. Then a three- month field trial was completed by mid 2006 that verified the conclusions and recommendations of the filter coalescer test program.

The fuel handling procedures directed in the implementation plan soon gained notoriety at all operational Units, especially at C-130H Units. With only three R-11 fuel trucks assigned to small Units, it was directed that two fuel trucks would issue JP-8+100 and one issue straight JP-8. Prior to JP-8+100 conversion, two refuelers would issue JP-8 and the remaining fuel truck was usually empty and available to defuel an aircraft. Based on the flying program, small Units will schedule fuel deliveries from the refinery so that one tank is topped off and allowed to settle before use and the other tank used to service aircraft. If an abort occurred when most assigned aircraft were deployed, the fuel handlers faced a real challenge to ready another aircraft to support the mission if the available aircraft was filled with a ramp load of around 5000 gallons of JP-8+100. Unfortunately, less than 1000 gallons could be returned to bulk storage (which was never attempted), around 200 to 500 gallons could be transferred to a bowser and then another 1000 - 1500 gallons transferred to the fuel tanks servicing the engine test cell but usually no additional storage capacity was available to download the remaining JP-8+100.

Although several defuels or fuel transfers are accomplished each month, the unscheduled defuels would cause the most problems. Some scheduled maintenance like the yearly Isochronal Inspection (ISO) for C-130H aircraft requires removal of all fuel from the fuel tanks. The one month shop entry for an ISO is planned while a mission abort would create a real panic to launch another aircraft when the minimum refuel load of 5000 gallons of JP-8+100 issued to the aircraft to withstand local wind conditions had to be removed and another aircraft serviced with JP-8. On the other hand, the small quantity of fuel in a fighter after a mission could be easily transferred to another program aircraft while defueling 5,000 to 9,000 gallons of JP-8+100 from a C-130H presented a major problem. Once defueled, the fuels manager would be faced with what to do with the surfactant laden fuel since most bulk storage receipt plumbing did not have a bypass around the receipt filter coalescers and the fuel handlers were instructed not to let any JP-8+100 contact the receipt filters thus making return to bulk not doable. In retrospect, it was most unfortunate that the implementation plan adopted a worst-case scenario that made defuels of large aircraft almost impossible to perform.

2.10.2 Filter Coalescer Test Program Launched

Shortly after the Rapid Expansion Program began in 1996, the Users at small Units began asking questions about the high blend back to bulk ratio for JP-8+100 – wondering if a lower ratio could be used to ease the strain of defuels, fuel transfers and return to bulk storage using the three assigned R-11 trucks. Simply, an additional fuel truck was needed but none were available. Since no filtration or water separation studies had been performed prior to releasing JP-8+100 for field use, no data existed which could be used to establish an acceptable blend back to bulk ratio. So, a collaborative, jointly funded program was initiated in 2004 at Southwest Research

Institute® (SwRI®) to: a) determine an operationally acceptable blend back to bulk ratio, b) to evaluate the individual and synergistic effects between typical aviation fuel additives and the JP-8+100 additive, and c) to determine if there were any effects on filter coalescer elements from switching back and forth between JP-8 and JP-8+100.[15] A testing protocol was adopted that was based on API/IP 1581 3rd and 5th Edition testing specifications but was more focused on evaluating the surfactancy impact of the additives in JP-8+100 on filter coalescer performance compared to JP-8 with lesser emphasis on filter coalescer qualification testing.

2.10.3 Fuel Handling Restrictions Precautions Rescinded or Modified

The overall conclusion of this work was that **"there is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 @256"** (Editor: JP-8+100 additized at 256 mg/l dosage rate). Any portion of the test matrix where the JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol. However, both JP-8 and JP-8+100 performed differently than Jet A as the Jet A tests passed the protocol using the agreed upon failure criteria". Based on the testing results, it was concluded that "**JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage.**" However, the filtration testing of JP-8 concluded that **CI and FSII have detrimental effects on water removal performance** while **the +100 additive does not affect the filtration performance for either water or solids.**

This work represents a significant milestone to make the +100 technology transparent and usable at all units, large and small, program and non-program. To place special emphasis on this work, SwRI® has granted permission to reprint the Executive Summary from that report in this Section.

Upon presentation of this data and the conclusions within the general fuels community, there was some controversy because the protocol used for the test program did not strictly adhere to API/IP 1581 3rd or 5th Edition protocols. However, in the months following the release of this data, the Air Force Petroleum Office (AFPET) at Wright-Patterson Air Force Base initiated a field trial at Laughlin Air Force Base.[16] The results of the field trial is published in a technical paper entitled "JP-8+100 and Filtration" and provided in **Appendix A** of this report. The objective of the field trial was to verify through field testing the conclusions of the SwRI® report by documenting the impact of JP-8+100 on real-world filter coalescer systems in USAF R-11 refueling vehicles. In March 2006, the first aircraft was serviced at Laughlin AFB with JP-8+100. As normal operations at Laughlin continued using JP-8+100, AFPET and the fuels managers at Laughlin closely monitored the R-11 refuelers for signs of filtration issues. Once a month the filtration vessel on one of the refuelers was opened and the filter elements were replaced and the used elements sent to the manufacturer for analysis to determine if there had been any impact on the filters performance from using JP-8+100. The evaluation ended in May 2006. Based on the data collected and the filter tests performed, AFPET changed their technical guidance for fuel handling precautions in T.O. 42B-1-1, "Quality Control of Fuels and Lubricants", Change 3, 31 July 2006 and advised all units they could treat JP-8+100 just as they would JP-8 with respect to blend back to bulk and rescinded the 1:100 ratio requirement.

Aviation Fuel Filtration
Cooperative R&D Program
SwRI® Project 08-10844

February 2006

Executive Summary

Public Release of Executive Summary granted to AFRL/PRTG, WPAFB OH by Gary B. Besse (SwRI®) on April 4, 2007

A multi-phased program was organized to investigate the effects of aviation fuel additives on filtration performance. The main emphasis of the program was to determine if the GE 8Q462 thermal stability additive (designated as +100) is detrimental to filtration performance. The five phases of the program included:

Phase I: Using a Design of Experiment (DOE), determine the required dilution ratio of JP-8 to JP-8+100 to have the mixture filtration perform the same as JP-8.

Phase II: Using a DOE, determine the effects of the individual aviation fuel additives and combination of additives on filtration performance.

Phase III: Determine the filtration effects when switching between JP-8 and JP-8+100 using a different filtration system and corrosion inhibitor.

Phase IV: Determine if salt-water contamination has different filtration performance than de-ionized water.

Phase V: Determine if Department of Defense (DOD) filter separators will pass MIL-PRF-52308J (API/IP 1581 5th Edition M).

The conclusions for each phase of the program are provided below:

Based on the statistical analysis utilizing the failure criteria agreed upon by the program members (water by Aqua-Glo greater that 10 ppm free water and solids by gravimetric membrane greater than 0.5 mg/l), the following conclusions can be made for **Phase I:**

- For 3rd Edition elements, the average maximum water by Aqua-Glo for JP-8 (34.25 ppm) is significantly greater than the average at JP-8+100@256 (6.50) during the 100 ppm water challenge.
- There is no statistical difference in the average maximum Aqua-Glo between JP-8 and JP-8+100@256 (256 mg/l of +100 additive) for the 5th Edition elements at the 100 ppm water challenge or the 0.5% water challenge.
- There is no statistical difference in the average maximum Aqua-Glo between JP-8 and JP-8+100@256 for the 3rd Edition elements at the 0.5% water challenge. All tests resulted in values > 10 ppm.
- For both the 3rd and 5th Edition elements, there is no significant difference in the average maximum effluent solids between JP-8 and JP-8+100@256.
- For both the 3rd and 5th Edition elements, there is no significant difference in the average maximum differential pressure between JP-8 and JP-8+100@256 at either the 100 ppm or 0.5% water challenge.

- For the 3rd Edition elements, the average maximum conductivity (k) for JP-8 is significantly less than the average JP-8+100@256 during the 100 ppm and 0.5% water challenge and the particulate removal stage.
- For the 5th Edition elements, there is no statistical difference in the average maximum k between JP-8 and JP-8+100@256 during the 100 ppm and 0.5% water challenge and the particulate removal stage.

The only significant difference between the fuels for the maximum adjusted water content by Karl Fischer (KF) was found in the 3rd Edition elements at the 0.5% water challenge. The average for the JP-8 was greater than the average for JP-8+100@256.

Thus the overall conclusion is that there is no fundamental difference in the average filtration performance between JP-8 and JP-8+100@256. Any portion of the test matrix where the JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol.

However, both JP-8 and JP-8+100 performed differently than Jet A as the Jet A tests passed the protocol using the agreed upon failure criteria.

Based on these results, it is concluded that JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage.

Based upon the statistical results and resulting regression models, the **Phase II** conclusions are:

- The corrosion inhibitor (CI) has detrimental effects on water removal performance at the 0.5% water challenge. Increases in CI resulted in increases in maximum Aqua-Glo, maximum adjusted KF and maximum differential pressure. All five tests that passed the Aqua-Glo limits contained no CI. CI also had detrimental effects on filtration performance with respect to maximum differential pressure at the solids test phase.
- The fuel system icing inhibitor (FSII) has detrimental effects on water removal performance at the 100 ppm water challenge. Increases in FSII resulted in increases in maximum Aqua-Glo, maximum adjusted KF, and maximum differential pressure. All four test failures by Aqua-Glo limits contained FSII at 2000 ppm. FSII was not a significant factor in any of the response surface models for the solids test phase.
- The GE 8Q462 thermal stability additive (+100) does not affect the filtration performance for either water or solids. During the 100 ppm water challenge, increases in +100 resulted in decreases in the maximum Aqua-glo. All of the four test failures at 100 ppm contained no +100 additive. At the 0.5% water challenge, +100 was not a significant factor. Among the five tests that were under the Aqua-Glo limit (i.e. passes), two had no +100 and the other three contained the +100 additive.
- Increases in the static dissipater additive (STADIS 450) increased the maximum conductivity at the 100 ppm and 0.5% water challenge stages in addition to the solids test stage.

From the limited test data for **Phase III**, the Nalco 5403 corrosion inhibitor appears to have some performance benefits when evaluating filtration life over the use of DC14A. The differential pressure was constant during the switching between JP-8 and JP-8+100 and was lower than the test using DC14A as the corrosion inhibitor. This same trend was found when comparing the Velcon and Facet coalescer/separators. However, it is not known if that is a function of the additive, the elements, or a combination of both.

The Aqua-Glo effluent data when using Nalco 5403 corrosion inhibitor appears to show less free water downstream during the switching tests. The Nalco 5403 data is consistent when used with either the Velcon or Facet elements. With either corrosion inhibitor, the API/IP 1581 5th Edition elements appear to remove water at the 100 ppm challenge level better than the API/IP 1581 3rd Edition elements.

Phase IV utilized salt water as the water test contaminant using Jet A, JP-8, and JP-8+100 as the test fuels. Compared to the results from Phase 1, the salt water removal efficiencies were the same or better than those when de-ionized water was utilized as the water contaminant.

The scope of work for **Phase V** was to validate the claim that filter manufacturers can produce a DOD configured element that can meet the performance specified in MIL-F-52308J (API/IP 1581 5th Edition M). During the 80 gpm evaluations, one manufacturer passed MIL-F-52308J requirements utilizing the "improved" separator. During the 350 gpm evaluations, two evaluations passed the MIL-F-52308J requirements, one with bayonet separators, the other with the MSN 4330-01-511-8316 separators.

Therefore, it has been validated that current filter manufacturers can meet the performance specifications outlined in MIL-F-52308J with modifications to the existing filtration designs.

2.11 ASC/EN Technical Bulletin Endorses Use of JP-8+100

The ASC/EN Technical Bulletin, EN-AB-08-002 dated 12 August 08, endorses the use of JP-8+100. The summary and recommendations of this bulletin follows while a complete copy is provided in **APPENDIX O** of this document.

Summary:

Because of the consistent documented cost savings associated with the Spec-Aid® 8Q462 +100 additive, the simplified handling policy, and resolution of all past concerns with use of +100 additive, ASC/EN endorses the use of the JP-8+100 additive on weapons systems that would benefit from its use.

Recommendation:

1. System Program Managers (SPM), Directors of Engineering (DOE) and Chief Engineers (CE) are encouraged to review the existing technical information regarding the +100 additive and determine if a cost savings could be realized with its use.
2. Determine if any additional verification, flight test, or field service evaluation is required to approve use of +100 on your weapons system.
3. Identify additizing equipment required to implement usage and coordinate with the Air Force Petroleum Office.
4. Update technical data to authorize use of the +100 additive.

3.0 FIGHTER, TRAINER AND TRANSPORT EXPERIENCE USING JP-8+100

3.1 Introduction

This section discusses the operational and maintenance environments of turbofan and turbojet engines that power fighter and trainer aircraft and the turboprop engines that powered C-130H transport aircraft during the conversion to JP-8 and then to JP-8+100 with emphasis on maintenance activity that helped reduce the impact of coking. The analyses considered the unique design and hardware features of each engine type, the impact of performance condition and the maintenance practices that evolved to deal with accelerated coking from using JP-8 and after the conversion to JP-8+100. Turbo shaft engines powering several military and civilian helicopters will be discussed in Section 4 that follows. The field experience will show that most military engines have directly benefited from the synergies of evolving maintenance procedures, best practices and use of JP-8+100.

3.1.1 Background

During the late 1980's and early 1990's, DOD maintenance budgets available to the Major Commands (MAJCOMs) began to fall short of the needs to support the assigned flying programs. The circumstances that evolved deserve explanation in order to better understand the problems facing the engine maintenance shops of the active and ANG fighter Units.

Before conversion to JP-8 in the 1993/94 time period, the performance condition of several military engines had become a major concern to the MAJCOMs. The Scheduled Maintenance Program had been directly impacted from fewer new parts and the increased use of used parts that were within inspection limits and refurbished parts. As a result, the engine build standards had steadily declined reducing the average time-on-wing forcing more unscheduled maintenance to fix engine anomalies and to perform additional engine trims. Unfortunately, the legacy F100 engines configured with hydro-mechanical Unified Fuel Control (UFC) and the Electronic Supervisory Control became more susceptible to engine and augmentor anomalies due to the degraded performance of the fan and high pressure core modules and scheduling limitations. On the other hand, ANG and Special Forces Units had taken delivery of new C-130H transport aircraft starting in CY92 but soon learned that use of max power should be limited to take off and emergency conditions only to avoid accelerated distress of the engine hot section parts from higher Combustor Exit Temperatures (CET). The hardware configuration and performance condition of most turbo shaft engines in helicopters and turbo jet engines in pilot training aircraft were stable but conversion to JP-8 greatly increased coke deposits on the fuel spray nozzles and in the combustor domes requiring more frequent cleaning to avoid hot section distress from fuel nozzle streaking. Coking also increased on fuel spray nozzles and fuel systems of J85 engine afterburners that power T-38 trainers that increased unscheduled engine removals and maintenance workload at the Engine Regional Repair Center (ERRC).

Although a thermal stability additive had been developed by the Fuel Laboratory at AFRL/RZPF in anticipation of the conversion to JP-8, it would take several years to gain acceptance for the benefits from using JP-8+100. Some of the delays were attributed to completing rigorous filter coalescer testing that confirmed in early 2006 that the additional surfactants in JP-8+100 did not defeat the filter coalescer elements. Completion of a three month field service evaluation of the filter coalescers helped to rescind the initial fuel handling restrictions and precautions that made aircraft defuels, fuel transfers and return to bulk difficult if not impossible to perform at C-130H Units with only three assigned R-11 fuel trucks.

There were high expectations among Unit commanders and engine shop managers that JP-8+100 would quickly eliminate all coking problems in the F100 augmentor spray rings and the fuel nozzles in T56 and several helicopter engines. Some fighter Units were quick to observe positive reductions in engine anomalies and coking after one year of using the +100 additive while other Units did not find any notable changes. The T56 engine mechanics found that fuel nozzles were cleaner during the Home Station Check (HSC) and much easier to clean during the yearly isochronal (ISO) inspections of the aircraft with fewer fuel nozzles being replaced due to streaking after repeated cleaning. The engine mechanics for helicopter and J85 engines noted that the carbon deposits on the face of the fuel spray nozzles was more porous and easier to remove and the area around the spray tips was free of carbon. However, the fuel handling restrictions and precautions that were initially imposed for JP-8+100 seriously impacted the workload of the Fuels Flight at the smaller fighter and C-130H transport Units. Limited refueler assets to perform defuels, fuel transfers and Return to Bulk Storage were the other key issues that did not have immediate solutions until rigorous filtration tests determined that the additional surfactants in JP-8+100 did not harm or defeat the filter coalescers in the fuel trucks or the bulk storage receipt system.

3.1.2 Engine Types and Models Analyzed

Listed below are the aircraft and engines types that were analyzed to determine the impact of coking after conversion was made to JP-8 and then to JP-8+100:

- T37 Trainer Aircraft powered by two J69-T-25 turbojet engines
- T38 Trainer Aircraft powered by two J85-GE-5 augmented turbojet engines
- F15A/B, C/D & E fighter aircraft powered by F100 -100/ -220/ -229 augmented turbofan engines
- F16A/B & C/D fighter aircraft powered by F100 -220/ -229 augmented turbofan engines
- F16C/D fighter aircraft powered by F110-GE-100/ -129 augmented turbofan engines
- C130H transport aircraft powered by four T56-A-15 turboprop engines
- UH-1N, TH-53A, MH-53J & HH-60G helicopters powered by T400, T64 and T700 engines

In the discussions that follow, it is important to recall that the legacy engines were originally designed to use JP-4, a naphtha based fuel but were cleared to use JP-8, a kerosene based fuel. Although maintenance evaluations were conducted for the -200 engines in the F-16A/B, the engine type is no longer in service. The -200 engine was derived from the -100 engine and has a Backup Fuel Control (BUC) for use in the single engine F-16 fighter aircraft. In addition to the maintenance trend data, photos of J85 fuel spray nozzles show the dramatic difference in the type of coke deposited on the face of the spray nozzles using JP-8 and JP-8+100.

Before embarking on the more arduous task of explaining the engine configuration changes, the dynamics of the maintenance environment, the impact of evolving maintenance procedures, the maintenance analysis methodology and all the variables considered in the maintenance benefits analyses, a summary of the Maintenance Impact from using JP-8+100 is provided for each engine type. It is worthy to note that **all the CEMS engine maintenance data that has been analyzed confirms that using the +100 additive helps to improve engine time in service by**

delaying the onset of coking that eventually causes engine anomalies and hot section distress. Conversely, turning off the +100 additive for extended periods allows coking and fouling to accelerate causing increased engine anomalies forcing engine and control removals and increased Unscheduled Maintenance to fix the problems.

3.2 Engine Maintenance Impact

The conversion to JP-8 caused many changes in maintenance procedures and inspection intervals to deal with accelerated coking problems. The following order has been chosen to provide a brief summary of the maintenance impact from improved engine build standards, full authority digital engine control capabilities and the synergies of evolving maintenance procedures, best practices and use of JP-8+100:

- F100 engine family
- F110 engine family
- J85 and J69 trainer engines
- T56 turbo prop transport engine

The turbo shaft engines for helicopter aircraft will be discussed in Section 4 'HELICOPTER EXPERIENCE USING JP-8+100'.

To better understand the complexities of sorting out the benefits from using the +100 additive, more detail is provided in Section 3.3 to explain the engine maintenance environments for each engine family to show the impact of the filter separator issues, engine control type, improving engine build standards, the evolving maintenance procedures and best practices and the intermittent use of JP-8+100 that extended the time required to almost ten years in order to determine the maintenance benefits from using the +100 additive.

3.2.1 F100 Fighter Engine Family

The F100-PW-100, -220/E and the -229 engines.

3.2.1.1 Maintenance Impact on F100-PW-100, -220/E Fighter Engines

When the +100 additive was turned off in the Jun 05 time period for 12 to 13 months, augmentor anomalies increased 20 to 50% for -100 engines with a corresponding increase of 96% in UFC removals to fix the problems due to increased coking. For the -220/E engines, augmentor anomalies increased around 11% for the total fleet of engines, 4% for the F-16C/D fighters and 43% for the F-15C/D fighters. The UER Rate for the F-16s increased around 20% and 60% for the F-15s. The MFC removals for the -220/E fleet increased around 14% and 10% for the AFC. When JP-8+100 use at one Unit decreased from 100% to less than 50% utilization in 2003, the UER Rate increased by 74% during the following year and an additional 24% increase in 2005 when the +100 additive was turned off in Jun 05 providing a clear indication of engine sensitivity to the percent utilization of JP-8+100 in the -220/E engines.

Table 2 shows the steady decline of engine anomalies at a large Unit assigned F-16C/D fighters from CY97 through CY04 that was attributed to the synergies of improved engine condition and reliability, the baking and cleaning procedures and the continuous use of JP-8+100. After 5 months of not using the +100 additive starting in Aug 05, engine anomalies increase from 8 events to 18 events by Dec 05 and then reduced by 3 events to 15 when the additive was turned on again in mid Aug 06. During the 5 months in 2005, 11 of the 18 engine anomalies or 61% were attributed to a combination of augmentor no-lights and control system malfunctions. During 7 ½ months in 2006, 11 of the 15 of the engine anomalies or 73% were attributed to the same reasons. Considering the large number of assigned engines at this Unit and nothing else had changed, it was concluded by engine management that the abrupt increase in engine anomalies was due to accelerated coking from using straight JP-8. Later in Section 3.6, **Table 6** will show that the engine anomalies continued to decrease during CY07 and CY08. It is worthy of emphasis that the full authority digital control system, self trimming and engine monitoring on the -220/E engine have helped to reduce unmerited engine and control removals as indicated by the lower removal metrics compared to the legacy -100 engines.

Table 2. Engine Anomalies at a Large Fighter Unit (1997-2006)

F100-PW-220/E Engines									
CY97	**CY98**	**CY99**	**CY00**	**CY01**	**CY02**	**CY03**	**CY04**	**CY05**	**CY06**
34	35	29	32	20	18	13	8	18	15
Note: Additive turned off 1 Aug 05 through 16 Aug 06. When additive was turned off, anomalies increased.									

The unscheduled removal trends for F-15 and F-16 aircraft show that use of JP-8+100 has helped to avoid engine and augmentor anomalies for both -100 and -220/E engines based on the increased occurrence of augmentor anomalies and the increased number control removals when the +100 additive was turned off. With increased use, the JP-8+100 can be counted on to the help reduce engine coking and improve the mean time before unscheduled engine removals.

3.2.1.2 Maintenance Impact on F100-PW-229 Fighter Engines

The dynamic maintenance environment for -229 engines presented many challenges to determine any benefits from using JP-8+100. A sustained period of improved engine reliability from 18 to 24 months was lacking to establish stable maintenance conditions in order to sort out any benefits from using the +100 additive in -229 engines. When the +100 additive was turned off in 2003 to support the surge of large aircraft using this location as a refueling stop, the UER Rate started to increase in 2004 but decreased again when more new parts were provided to improve engine durability. It could be argued that the MFCs that were removed from 2000 through 2003 when JP-8+100 utilization was around 50% had contributed to the significant reduction in 2004 and that after using JP-8 for six months in 2005, the MFC Removal Rate had increased by 97% but without additional information it is difficult to understand the 76% decrease in MFC removals during six month in 2006. Although the reported MFC and AFC removals had reduced the engine anomalies, other maintenance issues were involved in the control removals that may be understood through further investigation of the CEMS removal data. The engine mechanics did report that use of the +100 additive has provided cleaner combustor and turbine parts and reduced the carbon and coke deposits in the augmentor making the scheduled borescope inspections easier, allowing more direct viewing of any distressed areas with greater resolution. Also, the +100 additive has helped reduce the formation of varnishes and coke from fuel exposed to hot metal surfaces that can plug orifices and cause sticky servo valves since varnishes and coke will start to form when fuel contacts hot metal surfaces above 200 °F. Therefore, a cleaner burning fuel with higher thermal stability can help avoid maintenance by reducing unscheduled engine and control component removals.

3.2.2 Maintenance Impact on F110-GE-100 & -129 Engines

In spite of only brief periods of stable maintenance conditions, the data indicates that use of JP-8+100 helps the MEC and AFC on the F110-GE-100 and -129 engines to function more precisely since varnishes and coke can form when fuel contacts hot metal surfaces around 200 °F. Fouling in the MEC and AFC components can cause sticky valves that affect control performance. As the utilization of JP-8+100 decreased, there was a corresponding increase in MEC and AFC removals. The +100 additive also helps fuel to burn cleaner in the engine. Cleaner gas path hardware is easier to borescope while clean fuel control components help to reduce unscheduled engine and control component removals. As a result, requests for Depot reparables decrease allowing more time to perform the Schedule Maintenance Program for each engine model.

3.2.3 Maintenance Impact on J69-T-25 and J85-GE-5 Trainer Engines

The legacy J69 and J85 engines are very sensitive to coking from using JP-8 since these small gas turbine engines were developed to use JP-4 as the primary fuel. The engines were initially designed as small turbojet engines for missile and drone applications but later used as the engines for the T-37 and T-38 trainer aircraft. The J69 engine remained a straight turbojet while an afterburner was added to the J85 engine. Soon after conversion to JP-8, the combustion system for each engine showed accelerated build-up of carbon that caused an increase in engine anomalies plus the engine hot section parts were more difficult to clean. In addition, the hot metal surfaces in the J69 engine heated the fuel beyond its thermal stability limit and discolored the fuel filters, which are now changed more frequently. After the conversion to JP-8+100, AETC found that the impact of coking in the J69 and the augmented J85 engines was more manageable but not free from coking problems. Use of JP-8+100 has provided consistent reductions in unscheduled maintenance and parts demand for J69 and J85 engines but are best shown when the +100 additive was turned-off for 13 ½ months starting in May 05. During this time period, the engine flameout rate increased 3.9X after the +100 additive was turned off, the engine NRTS increased from 0.75/mo to 3.01/mo and the MFC Removal Rate increased by 60%. Prior to 2005, the removal rate for the MFC increased by 42% in 2003 and 22% during 2004 from sticking valve problems. After conversion to JP-8+100, the parts demand rate for J85 engine fuel nozzle tips decreased by 55.3% and a 73 to 75% reduction was noted for fuel nozzles and the main and pilot spray bars in the afterburner. When the +100 additive was turned off, the engine UER Rate increased by 110%, the MFC Removal Rate increased by 152%, the AFC Removal Rate increased by 57% and augmentor related unscheduled removals increased by 72%. There is little doubt that use of the +100 additive has provided a significant reduction in the maintenance workload, reduction in parts demand and helped to increase the reliability and time on wing of the legacy J69-T-25 and J85-GE-5 trainer engines.

3.2.4 Maintenance Impact on T56-A-15 Turbo-Shaft Engines

A Unit that trains pilots for terrain following missions that used JP-8+100 18% of the time experienced a UER Rate of 3.73 but achieved a UER Rate of 0.91 when JP-8+100 use increased to 82% of the time for a 76% reduction in UER Rate. When the +100 additive was turned off Air Force wide circa May/June 2005 to resolve fuel filtration and surfactant issues, the fuel spray nozzle dropouts increased from 1 per ship set to 4 per ship set during the annual ISO, a 13%

increase, after 12 to 13 months of using JP-8. After return to using JP-8+100, fuel nozzles failing the spray pattern check reduced to around 1 per ship set during the annual ISO for the aircraft. Frequent use of intermittent max CET at 1077 °C and continuous 1050 °C CET had a marked impact on coking of the fuel spray nozzles but use of JP-8+100 helped reduce the dropouts operating at the higher combustion temperatures. The data also indicates there is merit for Units that operate at or below 1010 °C CET to use JP-8+100 to reduce fuel nozzle coking and hot section distress. The maintenance data confirms that use of JP-8+100 helps reduce fuel nozzle coking and accelerated hot section distress for Units that consistently operate T56 engines at higher CET power settings.

3.3 Dynamic Maintenance Environment

As the active forces were taking delivery of the new -220 and equivalent -220E engines for both the F-15 and F-16 aircraft, ANG Units were receiving the older -100 and -200 engines that were in poor condition. Large operational Units assigned the -100 engines were positioned to stay on top of engine deterioration by performing more frequent engine trims and through Opportunistic Maintenance that changed engine modules approaching cyclic life limits to be ready for periods of extended deployment. Because of the poor condition of some -100 and -200 engines, the conversion to JP-8 only magnified the maintenance problems due to coking and increased the unscheduled maintenance workload. Coking in the augmentor spray rings and the fouling of control system components exposed to high temperatures increased the occurrence of engine anomalies related to augmentor no-lights, blowouts and afterburner induced stalls.

With increased tempo in maintenance activity at many active and ANG Units due to a forced baking and cleaning program of all spray rings, the conversion to JP-8+100 added one more variable to an already dynamic maintenance environment. Initial benefits analyses at several Units showed remarkable reductions in control component removals and engine anomalies after conversion to the +100 additive but part of the reductions were due to more frequent engine trims, local maintenance procedures, the spray ring baking program, replacing the "tired fan modules" on legacy F100 engines and more recently installing fan, high pressure core and turbine modules built to higher standards under the RCM program.

3.3.1 Impact of Engine Condition

It was found that engine condition and evolving maintenance practices can have a profound impact on engine anomalies making it more difficult to sort out benefits from using JP-8+100. For instance, legacy -200 engines in poor condition without the benefit of frequent engine trims were more susceptible to an augmentor anomaly in a student pilot training environment where throttle transients into augmentor are not always coordinated with aircraft attitude and flight envelope restrictions. As the Units improved the condition of the legacy -100 and -200 engines, performed more frequent trims and reduced the baking and cleaning intervals of the augmentor spray rings, the unscheduled engine removals for augmentor anomalies began to decline. Further reductions in unscheduled engine removals were possible in the newer -220, -220/E and the -229 engines configured with full authority digital engine controls that provided self trimming and engine monitoring and diagnostics, from improved module build standards and module alignment guided by the RCM Program and the evolving local maintenance procedures, best practices and continued use of JP-8+100.

On the other hand, the turbo shaft engines that power C-130H and helicopter aircraft enjoyed relatively stable hardware configurations over the years due to improvements in hot section materials and cooling designs that were introduced to improve engine reliability and durability but these engines were more susceptible to fuel nozzle coking when operated at higher power settings in performing assigned training missions.

3.3.2 F100 Fighter Engine Designations

The F-15A/B fighter is powered by two F100-PW-100 engines while the newer F-15C/D aircraft converted to the -220/E engines that provided improved thrust configured with a full authority digital engine control system that provides self-trimming and an engine monitoring and diagnostic capability. The F-15E is powered by F100-PW-229 engines with an even higher performance for increased range. The single engine F-16A/B is fitted with either the F100-PW-200 or -220/E engines while the F-16C/D is powered by either the F100-PW-220/E and -229 engines or the F110-GE-100 or -129 engines. Some F-16's were converted to -229 engines in the early 2000 time frame to provide improved performance.

For clarification, the -220/E designation refers to two engine types, either the -220 or the -220E engine. The -220E is the -220 Equivalent engine derived from -100 or -200 engine hardware converted to a -220 configuration by changing all the externals and control systems to include engine module upgrades and a new chem-milled augmentor outer case. The new digital control system for the -220E has a separate hydro-mechanical MFC and AFC rather than a combined UFC and provides full authority control of all engine variables along with continuous self-trim and full-time engine monitoring and diagnostics.

Each engine type incorporates advances in structural design and materials technology, improvements in internal aerodynamics, heat transfer, combustion, and control system hardware/software while only the newer engine series incorporate engine monitoring with diagnostics. The technology incorporated in each new engine type provided incremental to marked improvements in fighter engine performance and aircraft operability but presented new maintenance challenges due to hot section durability issues. New design features such as full authority engine control systems, continuous self-trim capabilities and built-in engine diagnostics in the digital electronic control system provided further reductions in engine anomalies and improved fault isolation. The advances in engine performance were attained by higher cycle pressure ratio and turbine inlet temperatures but compounded the maintenance problems after conversion to JP-8 due to coking for engines designed to use JP-4 as the primary fuel.

3.4 Engine Maintenance Management

The performance of modern high performance gas turbine engines degrade in service due to oxidation and erosion of the gas path hardware. Fouling, mechanical wear, cyclic fatigue and breakage of engine components affect the integrity and operation of the engine and must be restored to achieve the inherent reliability of the engine type. Light and heavy overhauls are performed by regional repair centers and the engine Depot while the day-to-day maintenance of engines assigned to a Unit is performed by engine mechanics on the flight line and in the engine shop.

Engine maintenance is conducted under two programs, Scheduled and Unscheduled. The primary goal of the Scheduled Maintenance Program is to maximize engine service life before whole engines and modules, control components and engine accessories must be returned to the

Depot or regional maintenance center for refurbishment. Unscheduled Maintenance detracts from the Scheduled Maintenance Program but is a necessary part to fix problems and return engines to service. Any time an engine module is removed, inspections are performed that may identify parts out of inspection limits that must be replaced. As the build standards of engines are improved and remain in trim, augmentor anomalies will decline but accelerated coking in the spray rings and fouling in the augmentor control will continue to cause engine anomalies.

3.4.1 Unscheduled Maintenance

How MAL Codes (HMC) sometimes referred to as Fault Codes are used to report causes for removal and fall in general categories that an engine component is damaged or broken, did not pass inspection limits, is leaking or had malfunctioned causing an engine anomaly. The Fault Code removals represent the Unscheduled Maintenance workload. The engine tech data provides guidance and suggestions for the engine mechanics to fix a problem and return an engine to service. In the legacy engines, troubleshooting during a trim run was the only course of action to identify whether gas path hardware and/or control components was causing the anomaly and to determine the most effective course of action. After an engine module and/or one or more control components have been replaced, a successful engine trim run or acceptance run must be achieved for the engine to be declared serviceable. On the newer engines with full authority digital engine controls with built-in engine monitoring and diagnostics, fault codes will identify most problems requiring maintenance. There were some exceptions for performing trims on the legacy engines that are outlined in tech data for the engine type whereas the newer engines with digital controls have built-in self-trim during flight that is also used to perform the engine acceptance run after a shop visit.

3.4.2 Scheduled Maintenance

For most engines, the majority of work is performed under the Scheduled Maintenance Program at intervals set by the Tech Order (T.O.) for the engine type and accomplished when the Total Accumulated Cycles (TAC) or aircraft Flight Hours (FH) are reached. Over flying these limits is by exception only requiring approval. Unscheduled Maintenance is required when an engine will not start; has a fuel or oil leak, a component malfunctions, breaks or is damaged, an engine anomaly occurs or oxidation/erosion is beyond inspections limits. Although a certain amount of unscheduled work is budgeted and planned for, it must be fit into the Scheduled Maintenance workload in order to maintain adequate spare engines to support the flying program. However, increased engine anomalies and safety of flight issues will always rearrange shop priorities.

The Management Code removals start at HMC 799 and are considered as No Defect Scheduled Engine Removals to include HMC 875, Removed for Reuse (Cannibalization or Cann Action). A Cann Action may be accomplished to fill a shortfall in Base level spares; no available Reparables from Depot or to conduct engine troubleshooting but are based entirely on a management decision whereas a removal under a fault code is considered an unscheduled removal event. Cann Actions are generally used to sustain the flying program of the Unit and to balance the remaining service life of other modules or components on a mid-life engine. Other management decision maintenance actions include No Defect Scheduled Maintenance, perform Special/Scheduled Inspections, remove components with Expired Max Cycles/Sorties and perform Opportunistic Maintenance. If a spare module and/or control component is not available from Depot due to parts shortages, the Unit may have to wait for a spare. Creative management is then used to draw upon available assets in the engine shop to assemble a serviceable spare engine.

3.4.3 Comprehensive Engine Management System

Tracking the maintenance performed under the Scheduled and Unscheduled Maintenance Programs is documented in the CEMS data base. A similar system, the Comprehensive Aircraft Maintenance System (CAMS), tracks aircraft maintenance activity and is essential to insure all maintenance is performed before clearing an aircraft for service. Other tracking systems are used by some Units that interchange maintenance data with existing logistic databases but will not be discussed in this report.

The CEMS was designed and developed to provide configuration and logistics management of Air Force engines by tracking the serialized hardware installed in each name plate engine and the accumulated cycles and Flight Hours. CEMS provides alerts for engine components that are approaching accumulated cycle or FH limits so that the maintainers can take appropriate action directed by the T.O. Also, the actuarial data is analyzed by Item Managers to determine if parts should be procured based on consumption or repair cycle issues, locate critical installed parts and track the configuration status of all name plate engines. How Malfunction Codes (HMC) are used to document the reason an engine was removed from an aircraft and the reasons for removal of engine modules, control components and life limited components from an engine. The removal of an engine, a module or control components can be a scheduled event or due to an unscheduled event if something in the engine failed or malfunctioned.

The HMCs in the range from 006 to 780 cover the Fault Removals while the HMCs from 793 through 881 are used to document the reasons for removal of serialized components by Management Decision under the Scheduled Maintenance Program. **Depending on engine condition and other factors, the unscheduled engine removals can range from 15 to 35% of the total causes for engine removals**. As unscheduled engine removals increase, the Schedule Maintenance Program may suffer as the engine shop spends more time fixing engine malfunctions. The conversion to JP-8 created these types of problems for the engine shops increasing their workload to support the flying program.

Figure 9 shows two simplified categories under the Fault and Management Coded removals. Under the Fault and Management Decision categories are sub-groups of HMCs that are used to sort through the CEMS database to determine the number of engine and control component removals that are associated with Gas Path Deterioration and Operational Anomalies and removals for T.O. Directed and Opportunistic Maintenance. The number of removal events for each sub-group can be trended over several calendar years to establish engine condition and to capture the removal events that were impacted by fuel type and coking. The two categories under Management Coded removals, T.O. Directed and Opportunistic Maintenance, can be used to determine the impact of the Scheduled Maintenance Program on engine condition over a period of time. **Tables 3**, **4** and **5** list the specific HMC in each sub-group that can be used to sort the CEMS database to determine the trends for Operational Anomalies, Gas Path Deterioration, T.O. Directed and Opportunistic Maintenance for an engine type. A brief description for each HMC is provided in each Table. Based on feedback from C130H Units, six additional HMCs (111, 151, 690, 780, 900 and 972) were added to the gas path deterioration sub-group for T56-A-15 engine maintenance analyses.

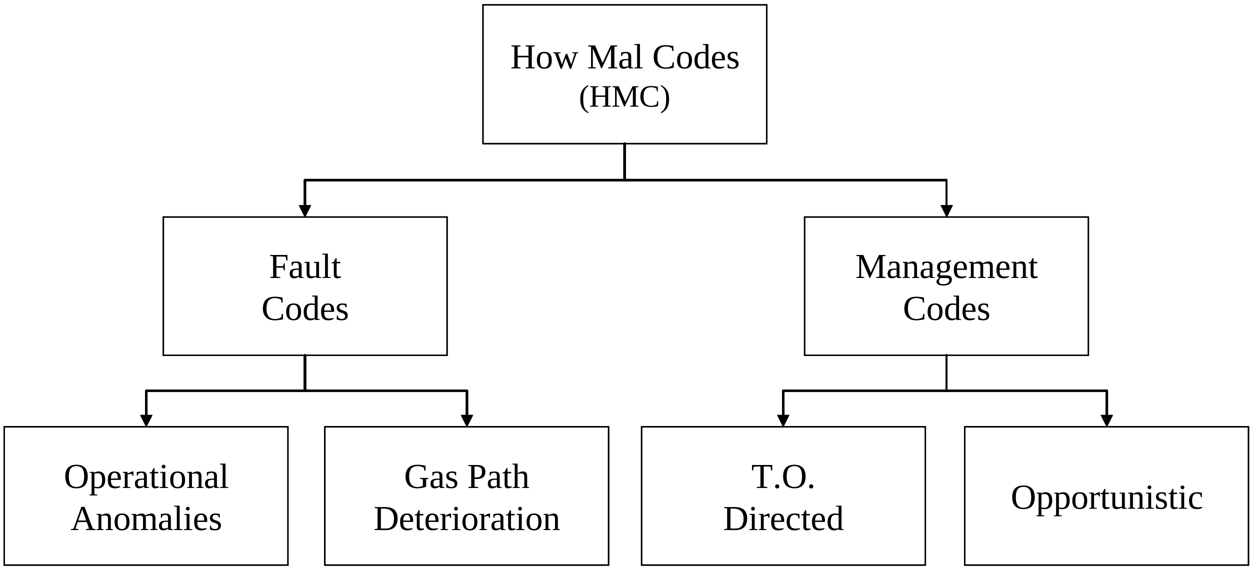

Figure 9. HMC Fault and Management Sub-Groups

Table 3. Operational Anomalies

69	Flameout
156	Afterburner or Augmentor Problem Repair
193	Excessive Stalls
205	Start Or Off Idle Stagnation
207	Augmentor Induced Stagnation
208	Augmentor Nozzle Mechanism Deterioration
223	Control System Component Malfunction
230	Dirty Contaminated Or Saturated By Foreign Material
231	Augmentor Blowout
232	Augmentor No Light
233	Augmentor Rumble
242	Failed To Operate-Specific Reason Unknown
315	Surges-Fluctuates
513	Compressor Stalls (Afterburner)

Table 4. Opportunistic Maintenance

799	No Defect
800	No Defect - Part Removed - Reinstalled To Facilitate Other Maintenance
804	No Defect - Removed For Scheduled Maintenance, Modification or Assessment
812	No Defect - Defect Caused By Associated Equipment Malfunction
875	Removed For Reuse (Cannibalization)
876	Non-T.O. Directed Removal
880	Opportunistic Maintenance Removal of Tracked Parts

Table 5. HMC Subset for Gas Path Deterioration

141	Compressor Case Failure or Excessive Air Leakage
146	Combustion Damage
147	Combustion Case Burn or Hot Spot
150	Thrown, Damaged or Failed Buckets
152	Turbine Nozzle Failure
153	Turbine Damage Due To Material Failure
175	Adverse EGT-TIT Trend
176	Adverse RPM Trend
182	Performance Trend Indicates Compressor Section Deterioration Or Damage
183	Performance Trend Indicates Combustion Section Deterioration Or Damage
184	Performance Trend Indicates Turbine Section Deterioration Or Damage
185	Performance Trend Indicates Accessory Section Deterioration Or Damage
186	Removed For Further Test Cell Diagnostic Check
187	Borescope Indicates Compressor Section Deterioration
188	Borescope Indicates Combustor Section Deterioration
189	Borescope Indicates Turbine Section Deterioration
190	Cracked
191	High EGT
192	Overtemperature
195	Exceeding Quality Check Temperature Limit
226	Engine Start Time Beyond Limits
277	Fuel Nozzle-Oil Line Coking
279	Spray Pattern Defective
334	Temperature Limits Exceeded
525	Pressure Incorrect/Fluctuates
537	Low Power Or Thrust
561	Unable To Adjust To Limits

Single engine fighters will have a higher percentage of removals for Scheduled Maintenance compared to twin engine fighters to stay on top of TCTO compliances. Either flight line or engine shop supervision will select the HMC for an engine removal and then collaborate with CAMS and CEMS data analysts to insure accurate reporting of the cause for an engine and/or component removal. However, the HMCs used to track engine module and control component removals in the engine maintenance shop are selected by shop supervision. With modern engine monitoring capabilities and fault isolation algorithms installed in the engine control system, the engine shop has a more informed basis for analyzing engine anomalies, selecting an appropriate HMC for malfunctions and reasons for the component removal to fix a problem. It is worth mentioning that the Army and Navy have an engine management system similar to the Air Force CEMS that uses the same fault and management decision codes and reasons for removal to document scheduled and unscheduled removal of serialized engine and control components and to track life limited parts and components.

It is important to note that some of the engine types investigated during the early evaluation of JP-8+100 did not have the benefit of full authority digital electronic controls and built-in engine monitoring and diagnostics which forced the engine mechanics to troubleshoot the engine anomalies in the test cell or through limited engine troubleshooting performed in the aircraft. On the older fighter engines, some fault trees in tech data were more informational forcing engine management to make decisions on what corrective action should be taken to fix an engine anomaly. Typical control malfunction removals for the legacy F100 engines included dirty or faulty engine and augmentor fuel control (the UFC), a faulty Convergent Exhaust Nozzle Control (CENC) or fouled Tt2.5 temperature and N2 (RPM) sensors. After conversion to JP-8, the UFC on -100 and -200 engines and the augmentor spray rings were frequently removed to fix engine anomalies but some Units soon learned that a degraded fan or core module was a candidate for removal and would cause another engine anomaly after 50 to 100 FH due to additional performance deterioration and needed another engine trim.

Sorting out the cause of an engine malfunction was sometimes all consuming for ANG Units that had received "tired engines" from the active forces or other ANG Units. Refurbishing engines with marginal performing modules from available spare assets through a Cann action or a refurbished module from Depot could also be a challenge since maintenance budgets had been underfunded for several years. Therefore, the Scheduled Maintenance activity along with the Unscheduled Engine and Control Removals had to be carefully analyzed to determine any benefits from using JP-8+100.

As the maintenance data will show, the synergies of improved engine build standards, the full authority digital engine control systems, built-in self trim, engine monitoring and diagnostics, local spray ring baking and cleaning procedures and the use of JP-8+100 had helped to reduce unscheduled engine removals and also helped reduce the fuel burned to perform engine trims and acceptance runs. Without the synergies of improved engine build standards, timely spray ring baking and cleaning programs and the evolving local maintenance procedures and best practices, unscheduled engine removals will experience marginal improvement due to engine anomalies caused by coking and not achieve the inherent reliability of the engine hardware.

3.4.4 Single Engine Fighter Maintenance Challenges

The maintenance of a single engine fighter is more labor intensive than a twin-engine fighter because of the checkout and testing procedures to insure safety of flight and perform TCTO upgrades. After the reassignment of aircraft from the active forces to ANG Units and between ANG Units during the late 1980's and early 1990's, the receiving Units usually faced intense periods of training and familiarization to effectively operate and maintain the newly assigned aircraft and engines. ANG Units reported that it was customary to handoff troublesome engines to another Unit to bear the burden of identifying and replacing the tired or timed-out modules and control components that had been causing unscheduled engine removals. Unfortunately, long lead times and limited maintenance budgets had created untimely delays to obtain the needed Reparables from Depot to restore the troublesome engines. As a result, the engine shops became very creative in supporting the flying program and dealing with augmentor anomalies until Fan and Core modules were available to improve the build standards of the assigned engines. Some engines received more troubleshooting and trim runs to fix problems that resulted in one or more control component changes and additional trim runs to determine if the problem was fixed. Several years were usually required to improve the reliability of the assigned engines and to stabilize the Scheduled and Unscheduled Maintenance activity. As the reliability levels of the engines improved, unscheduled engine and control component removals due to anomalies began to decrease and the average engine time-on-wing increased.

The increased number of trim runs required for troubleshooting augmentor anomalies in the legacy F100 engines coupled with the special hardware inspections and the coke removal procedures had created extra workload for the engine shops at each Unit. Local maintenance procedures were also evolving to deal with the coking problems. Engine anomalies increased due in part to coking deposits in the augmentor spray rings of the legacy F100 -100 and -200 engines but also due to insufficient fan suppression margin during augmentor light off from erosion of the blade tip seals that had degraded fan and compressor performance.

3.4.5 Augmentor Coking Problems

Until the late 1980's, coking was not considered a significant problem when JP-4 was used. However, after conversion to JP-8 (circa 1993/94), an Advisory instructed Units to bake and clean the F100 spray rings on an "as needed" basis that would later include baking and cleaning of the external feed tubes and the Augmentor Signature Elimination Probe (ASEP) located in the exhaust duct. The conversion to JP-8 fuel accelerated the coking in the augmentor spray rings that formed on top of any coke deposited by JP-4. Units became acutely aware of fuel coking in the F100 augmentor spray rings, especially in Segment III (Seg III). They also noted a coke slurry would accumulate in the Seg III fuel outlet port of the UFC on -100/-200 engines and the same port of the AFC on -220/-220E engines.

Pressurizing the spray rings during quick-fill changes the cross section of the augmentor spray rings from an oval shape to a more round cross section. This opens the flow area around the tips of the pintels and releases fuel to the augmentor. Upon shutdown, the area around each pintel tip closes as the cross section of the spray ring returns to an oval shape. The flexing of the oval shaped spray ring during quick fill would fracture the hard coke on the inner walls that would be liberated to form a coke slurry with the fuel that would move back and forth in the spray ring during each augmentor cycle but eventually settle in the feed tubes and the exit ports of the augmentor fuel control. Since some of the coke particles are too large to pass through the pintel orifices in the spray rings and the venturi orifice in the ASEP, the coke slurry would continue to accumulate in the ASEP housing requiring baking and cleaning of the Probe and all upstream components. The ASEP, which also houses the Pt6 probe, has a venturi mounted on the end of the probe that is located in the hot exhaust stream to provide a continuous negative pressure during engine operation. **Figure 10** shows the ASEP housing with the venturi on the left and pitot holes for Pt6 measurement to the right on the leading edge. Note the coke particles that are attached to the inner tube on the right that is in the hot gas stream shown in **Figure 11** and the coke that has fallen off when the tube was removed from the housing. The suction of the venturi attempts to drain all the fuel and coke slurry from the spray rings, feed tubes, manifold and sleeve valves in the augmentor control side of the UFC or AFC but a slurry still accumulates in the augmentor fuel discharge ports and in the ASEP housing and must be cleaned by disassembly. As the spray rings continue to release coke deposits, especially Seg III, the slurry that accumulates in the augmentor fuel system will at some point obstruct flow and contribute to an augmentor no-light or blowout.

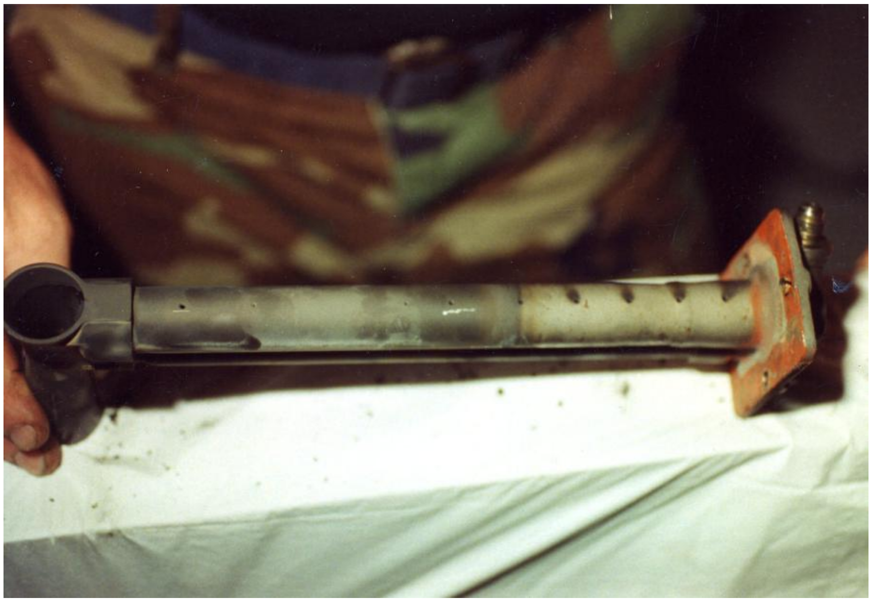

Figure 10. Augmentor Signature Elimination Probe (ASEP)

Figure 11. Coke on ASEP Inner Tube

Due to the location of the Seg III feed tube, residual fuel remains in the spray ring after augmentor shutdown between the 4 and 8 o'clock position to "boil off" since the need for ram air pressure in the spray ring had not been anticipated to remove the residual fuel after augmentor shut down. Hydrocarbon varnishes will start to form at temperatures as low as 200 °F and create baked deposits of hard coke on the inner walls of the spray ring after several augmentor lights. When the highly volatile JP-4 was used, the naphtha compounds in the residual fuel would vaporize quickly but some coke would form from the kerosene-based products in the fuel as service hours increased. JP-4 is approximately 60 to 70% naphtha based compounds which vaporize quickly at high temperatures while the remaining 30 to 40% of the fuel are kerosene-based hydrocarbon distillates. Using JP-8, the rate of coke build up was accelerated causing partial blockage of the pintel nozzles in the spray rings that would cause a no-light or blowout. Although the low volatility of JP-8 makes it ideal to reduce aircraft fire hazards, the 100% kerosene-based JP-8 does not vaporize quickly and therefore remains longer in the spray rings and feed tubes where it boils off forming layer upon layer of varnishes after each augmentor cycle. These multiple layers ultimately become hard coke.

3.4.6 Self-Cleaning Spray Rings

In the late 1990's, a CIP task was initiated in response to the spray ring coking problems. To purge the residual fuel after augmentor shutdown, a small hole was added on the Seg II and Seg IV spray rings to provide ram air pressure from the exhaust stream to force the fuel out of the spray rings after augmentor shutdown. During augmentor operation, the small hole functions as a spray nozzle. The "self-cleaning" Seg II and IV spray rings were made available circa 2002 and are replacing spray rings NRTS (Not Reparable This Station) to the Depot. A self-cleaning Seg III spray ring was planned for manufacturing release in 2008 but requested funding has been delayed beyond 2009. To accommodate the design change, the fuel feed line for the Seg III spray ring will be changed to bottom dead center where the Seg II feed tube port is located on the augmentor duct to provide more rapid draining of Seg III and the Seg II feed tube will enter through the original Seg III port in the augmentor duct.

3.4.7 Baking and Cleaning Program Established

In the early 1990s prior to JP-8 conversion, some Units began using local vendors to bake and clean the augmentor spray rings and feed tubes. They also removed any coke from the augmentor fuel exit ports of the UFC while some Units disassembled the shut-off valves in the exit ports of the AFC to remove coke particles behind the valves. Large diameter ceramic kilns, like those used by potters, were procured with support racks that could be used to bake one set of augmentor spray rings or a set of feed tubes. Care was needed to center the Seg V spray ring to avoid heat distress from the heater coils that lined the inside diameter of the kiln and to insure the bake time started when the inside temperature reached equilibrium. Large industrial ovens with temperature controllers were procured in the late 1990's and early 2000 to increase through put and more precisely control bake temperatures for more consistent bake cycles and coke removal. **Figure 12** shows the interior of an industrial oven used by a large fighter Unit. The tubing connected to each spray ring supplies low pressure air to oxidize coke attached to the interior wall of each augmentor spray ring. **Section 5.1** will discuss the benefits of a SPRAY RING FLOW BENCH in flow checking F100-220/E spray rings after a baking and cleaning cycle.

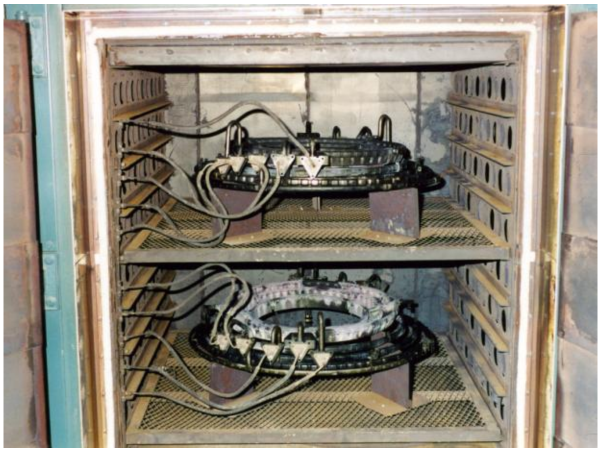

Figure 12. Augmentor Spray Ring Baking Oven

By 1998, a 1200 FH limit was established for baking and cleaning the spray rings and feed tubes to coincide with the augmentor module time change. In June 22, 1998, TCTO 2J-F100-908 directed that all engine spray rings, feed tubes and the ASEP would be baked over a one year period and subsequently at intervals not to exceed 1200 FHs. Some Units accomplished this directive over a six month period to baseline all assigned engines. They also elected to bake the spray rings, feed tubes and ASEP on convenience when augmentors were removed while engines were in the engine shop for maintenance. The baking intervals ranged from 250 to over 600 FHs. However, ANG and Active Air Force Units continued searching for new maintenance procedures to better manage augmentor coking problems that had increased unscheduled engine removals and maintenance workload.

3.4.8 F100 Engine Control and Monitoring System Improvements

Before discussing the data analysis methodology, it is important to understand the basic features and differences between the engine control and monitoring systems on the legacy F100-100/-200 engines and later series -220/-220E and -229 engines.

The control system for the legacy -100 and -200 engines used a complex hydro-mechanical control Unit called the Unified Fuel Control (UFC) which was essentially a back to back Main Fuel Control and Augmentor Fuel Control with shared sensors and mechanical servos to schedule engine variables that included a separate supervisory control to trim the exhaust nozzle area. This unit was called the Electronic Engine Control or EEC. The basic -200 engine design was improved and released as the -220 series engine. The -220E engine or “Equivalent” -220 engine was built using upgraded -100 and -200 engine modules configured with the same control and accessory configuration as the -220 engines. The -220/-220E control mode was converted to a full authority digital engine control with built-in engine monitoring and diagnostics, better known as the Digital Electronic Engine Control (DEEC). The DEEC regulates and monitors the operation of the engine and the control system components which includes an MFC and AFC. The DEEC also performs self-trims of the engine geometry in flight and in the test cell. The self-trimming capability of the DEEC helps to stay on top of normal gas path deterioration while the early engines fitted with UFC and the EEC required more frequent engine trims to adjust for gas path deterioration and seasonal temperature changes to avoid engine anomalies.

During the -100 and -200 engine trims, the position of the Compressor Inlet Variable Guide Vane (CIVV) and Rear Compressor Variable Guide Vane (RCVV) were checked and adjusted and the "E Click" changed on the EEC to reset the engine within the trim band or trim window. Higher "E-Click" engines ran at higher turbine inlet temperatures to produce the required Engine Pressure Ratio (EPR). These engines were more likely to experience trim problems and anomalies due to the normal deterioration of the gas path hardware in the hot and cold sections of the engines.

The control mode for the -220/E engines was changed from a scheduling controller using slow response sensors to an airflow control mode that provides closed loop regulation of all engine variables using sophisticated control algorithms with lead/lag compensation, more accurate, fast response sensors and position feedback. The DEEC provides more control functions, including improved inlet/engine airflow matching, precise engine transient regulation and re-cycling the augmentor light-off sequence to achieve successful transients up to max power. The DEEC will automatically recycle the augmentor up to three times to achieve a successful light if a no-light is detected by the Light-Off Detector (LOD). Also, the DEEC and the Engine Diagnostic Unit (EDU) will detect and record a host of engine and control system faults including augmentor no-light or blowout conditions. The monitoring capability also records pre- and post-event history of an anomaly that is later downloaded by the Comprehensive Engine Diagnostic Set (CEDS) after each flight for analysis in the Comprehensive Engine Trending and Diagnostic System (CETADS). Further analyses of an engine anomaly would be required by engine shop specialists to establish the most responsible course of maintenance action to fix any problems that have been detected.

The engine monitoring functions integrated into the DEEC and EDU on the -220/-220/E engines provides diagnostic information to help select How Mal Codes (HMC) that best describe engine malfunctions. In contrast, the early vintage hydro-mechanical engine controls for the -100 and the -200 engines were unable to provide any monitoring information. The Engine Health Recorder (EHR) recorded parameters to include: engine operating hours, whole and partial RPM cycles, Low Cycle Fatigue (LCF), N1 Sensor failure, Hot Starts and two over-temperature conditions. As a result, engine anomalies were investigated in the test cell using the Automated Ground Engine Test System (AGETS). The AGETS had its limitations but was an improvement over the ground test equipment originally fielded for the -100 engine. The AGETS was noted for long engine test runs that consumed a lot of fuel (1200 to 2500 gallons). In most cases, the engine mechanics would rely heavily on their experience using tech data to pursue a course of action to fix an engine anomaly. Unfortunately, the EEC was a prime candidate for removal due to ease of removal whereas the UFC required several hours to remove and replace. As coking problems increased after conversion to JP-8, it was not unusual for engine mechanics to change one or more engine control components on a -100/-200 engine, run back to back trims and still have an augmentor problem. In some cases, reparable UFCs were "leakers" and had to be replaced with another UFC. Other control components such as the CENC, AFPC, the N2 and Tt2.5 Sensors would be changed to fix an augmentor anomaly. The CEMS analysts would routinely query the CEMS database to determine if available UFC reparables had been removed for an engine anomaly at another Unit. Based on past experience with Product Quality Deficiency Report (PQDR) exchanges and settlement, engine shop managers would avoid a UFC with prior removal history for an engine anomaly.

While engine trims were performed to adjust for gas path degradation and troubleshoot engine anomalies, other trims were required after removal of timed-out engine modules (Fan, Core and LPT) or removal of a control component suspected of causing an augmentor anomaly. If recently baked spray rings were installed, the engine mechanics would surmise that the problem may be due to a weak fan or core module. Whereas, the DEEC and EDU would keep a -220/E engine in trim and help diagnose the type of engine anomaly that occurred. The diagnostic codes from the -220/E engines would provide a basis to make an informed decision for a control change rather than replacing the UFC on the -100/-200 engine hoping that an engine anomaly would be fixed. These examples are typical of the challenges that engine mechanics faced and the benefits of the advanced engine diagnostic technology that helped in making informed maintenance decisions.

The synergies of advanced controls and diagnostic system technology, evolving maintenance procedures that included more frequent baking and cleaning of the augmentor spray rings and the use of the +100 additive helped reduce the unscheduled maintenance workload. The self-trimming feature in the DEEC reduces engine ground run time and fuel burned plus the engine trim is updated in flight resulting in fewer engine anomalies as engine modules deteriorate. The turbine inlet temperature is continuously up-trimmed to maintain engine airflow and EPR to provide desired thrust performance throughout the flight envelope.

3.4.9 Fighter Engine Maintenance Policy Changed

A major change in engine maintenance policy occurred in 1997 that improved the reliability of fighter engines. The maintenance policy for F100 engines was changed from On Condition Maintenance (OCM) to Reliability Centered Maintenance (RCM). Every engine shop visit is now used as an opportunity to align engine modules to achieve the inherent reliability of the available F100 engine hardware. The RCM Program also provided new and improved parts to build engines and engine modules to higher standards that helped to improve engine performance and operability. A similar program was launched in 1998 for F110 fighter engines under the F110-100B Mod Program. Despite the dynamic maintenance environment that existed at many Units, the launch of the RCM Program began to restore engine performance, operability and improve reliability that created a more stable maintenance environment. With improved engine build standards, engine reliability started to improve and approach quasi steady state conditions. As the build standards of F100 engines began to improve starting in 1997, it became easier to evaluate the individual contributions of several evolving maintenance procedures and best practices that were implemented to deal with the coking issues from using JP-8 and any benefits from intermittent to full time use of the +100 additive.

3.5 Maintenance Analysis Methodology

The maintenance benefits methodology that was developed to analyze the impact of the Scheduled and Unscheduled Maintenance Programs before and after the conversion to JP-8 and then use of JP-8+100 also evolved over several years and needs explanation to understand the maintenance benefits derived from using the +100 additive.

3.5.1 Background

From 1998 through 2004, AFRL/PRTG (now RZPF) supported several maintenance benefits studies of active and ANG Units to determine the maintenance impact from using the +100 additive. These studies determined through analyses of the CEMS removal data from several fighter Units that additional time would be required for the condition of the engines to improve, become stable and sustainable. This became a reality after the launch of the RCM Program but would require additional time before the engines in service achieved desired levels of MTBR that were sustainable. It was also concluded that a thorough evaluation of the +100 additive could be accomplished at that time. Fortunately, the RCM Program has made this happen. At some fighter Units, stable maintenance conditions were achieved in 12 to 24 months after launch of the RCM Program when unscheduled engine removals due to anomalies had reached new and sustainable levels of engine and control component removals. At other Units, stable conditions were yet to be attained due to some recurring engine durability issues.

At some Units, experienced engine managers reported that evolving engine shop procedures and best practices along with the use of the +100 additive had reduced engine anomalies while engine managers at other Units commented they did not see any immediate benefits from using JP-8+100. Later it was determined that engine type and performance condition had a profound impact upon the comments offered. These observations became a clear indication of the challenges ahead to develop an approach that would take into consideration all the variables of the operational and engine maintenance environment at each fighter Unit compared to Units operating transport and helicopter aircraft.

3.5.2 Analysis Methodology

The methodology that evolved initially analyzed the engine anomalies and removal data entered in the CEMS database. Recognizing that understanding the engine maintenance environment at each Unit presented both unique and similar challenges, the methodology needed to evaluate every aspect of the engine maintenance performed over several years using data archived in the CEMS database and locally documented engine maintenance performed by each engine shop. Since several F100 engine models were studied, the methodology considered all variables that could affect engine anomalies to include: 1) the condition of the assigned engines during the analysis period, 2) the Scheduled Maintenance performed, 3) the baking and cleaning program for augmentor spray rings and feed tubes, 4) the type of engine control system and engine monitoring and diagnostic capability, 5) control software changes that would impact engine anomalies, 6) the operational and training environments for each Unit, 7) the reliability benefits from improved engine modules available under the RCM Program, 8) the date of conversion to JP-8 and then to JP-8+100 and 9) the per cent utilization of the +100 additive. The analyses also considered the synergies of engine shop procedures and best practices that were evolving to cope with increased coking on T56 fuel spray nozzles, in the -100 and -220/E augmentor spray rings, fouling of augmentor fuel controls, the extra trim runs to troubleshoot -100 engine problems and the acceptance runs to declare -220/E engines serviceable.

One or more site visits were made to each Unit to better understand the maintenance performed, the rationale for selecting certain removal and fault codes for input to the CEMS database, review analyses of the engine maintenance trends with engine shop managers using data archived in the CEMS database over several years for both Scheduled and Unscheduled removal events and to obtain comments from engine shop managers what they had concluded was driving the engine and control component removals.

3.5.3 Scheduled and Unscheduled Engine Maintenance Activity

Figures 13 and 14 illustrate the engine maintenance activity at a large fighter unit over a nine year period operating F-16C/D fighters powered by the F100-PW-220/E augmented turbofan engine. The majority of the shop workload shown in **Figure 13** is performed under Scheduled Maintenance (Management Decision Removals). In **Figure 13**, note that the percentage of engine removals to perform Special or Scheduled Inspections of the hot section parts was quite high from CY93 through CY98 ranging from 25 to 61% of the Scheduled Removals and represents a major workload for the Engine Shop. On the other hand, frequent engine inspections provided unique opportunities to expose marginal components that can be replaced to improve the engine reliability.

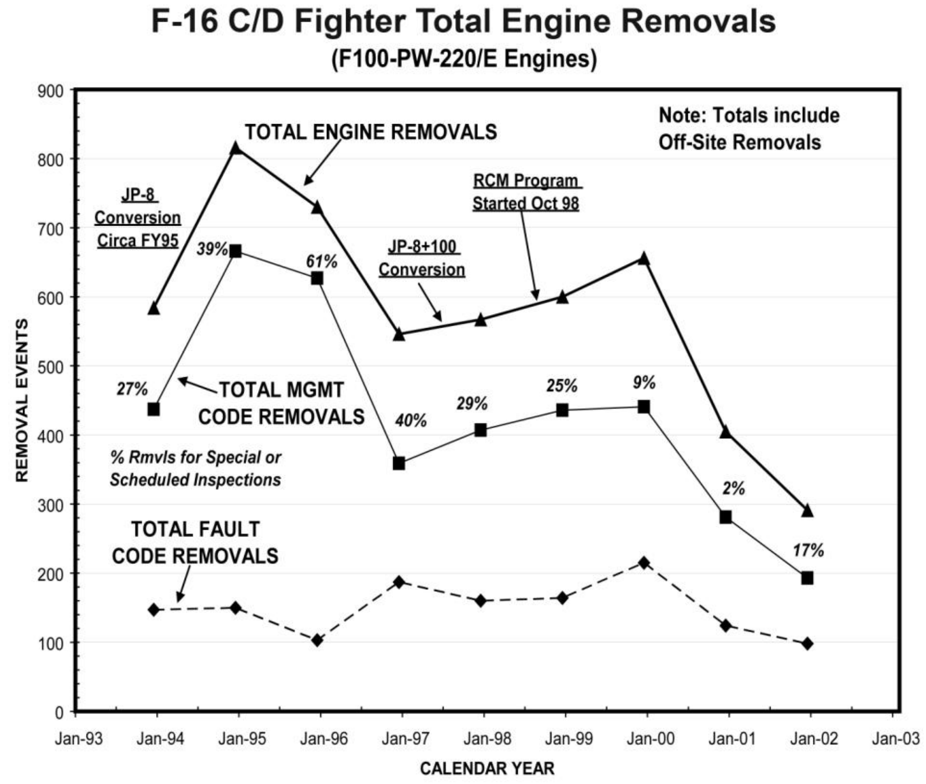

Figure 13. F-16 C/D Fighter Total Engine Removals

During late CY98 and early CY99, the Unit had received 39 whole engines built to higher standards and also began to re-align engine modules as recommended by the RCM Program to improve the reliability and service interval of engines. By CY00, both the Scheduled and Unscheduled removals started to decline due to the synergies of several activities such as DEEC logic updates, HPT and LPT tip curl inspections and fixes, conversion to the chem-milled augmentor duct, baking the spray rings, cleaning the AFC outlet ports and continued use of the +100 additive. The affects of these maintenance activities coupled with increased engine acceptance runs that occurred shortly after conversion to the +100 additive made the engine maintenance environment far from stable. Because engine reliability was still improving, more service time would be required before the benefits of the engine maintenance activity could settle in and establish a new plateau for the reliability of the assigned engines.

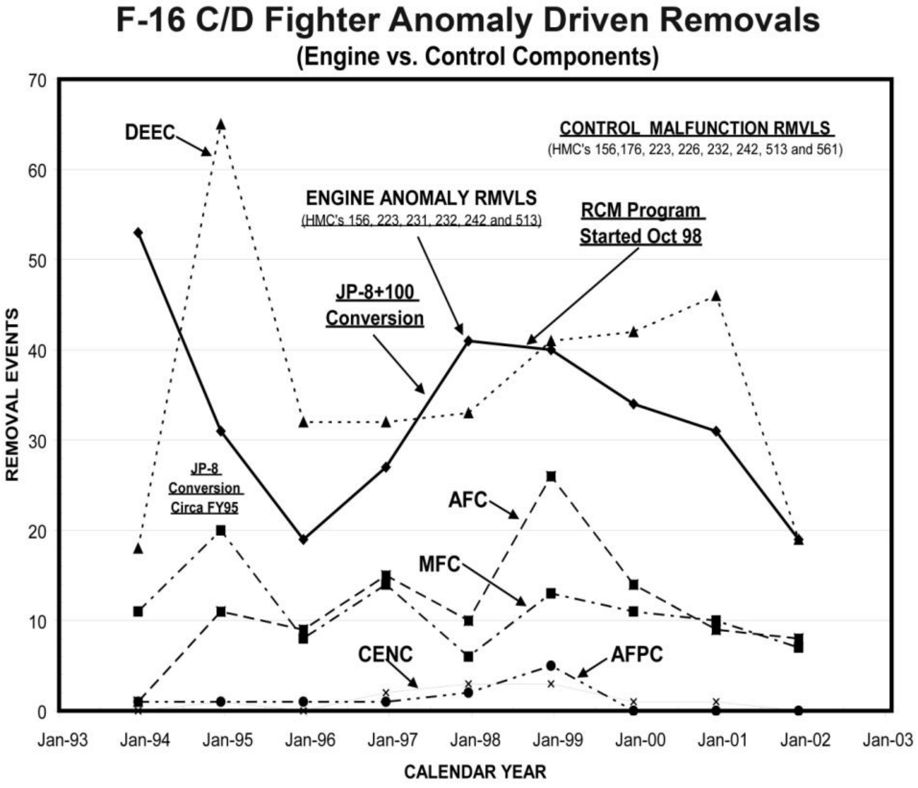

Figure 14. F-16 C/D Fighter Anomaly Driven Removals

Figure 14 shows the engine and control component removals caused by engine anomalies. The Fault Codes used for the engine anomaly and control malfunction trends are as follows: HMC 156 is for Augmentor Problems, HMC 223 is for a Control System Malfunction, HMCs 231 & 232 for an Augmentor Blowout or No-Light, HMC 242 is for Failed to Operate, Specific Reason Unknown, HMC 513 for Compressor Stalls (Afterburner) and HMC 561 is for Unable to Adjust to Limits. Although the removals for Engine Anomalies had been driven by all the referenced HMCs previous to CY96, from CY97 through CY01, Augmentor Blowout and No-Light, Compressor Stalls (Afterburner) and Excessive Stalls were more prevalent causes for removals, however, engine anomaly removals experienced a 53% reduction from Aug 98 through Dec 01. The DEEC removals for malfunctions remained high from CY94 through CY97 due to reliability and control logic issues while DEEC logic upgrades were installed during CY95 and CY98 to avoid anomalies related to excessive stalls and afterburner stall problems. However, DEEC removals continued to increase due to reported Control System Malfunctions and Failed to Operate, Specific Reason Unknown from CY98 through CY00 with no apparent correlation with the conversion to JP-8+100. Removals for Augmentor No-Light were also highly irregular starting in CY 98.

It can be noted that CENC removals for augmentor anomalies were very low from CY93-01 while the MFC, AFC and the AFPC removals reached a peak during CY98 and then gradually decreased from CY99-01. The MFC removals reduced from 13 to 7 events, AFC removals reduced from 26 to 8 events and the AFPC removals reduced from 5 to no events. During this time period, the anomaly related MFC removals ranged from 37 to 54% of the total unscheduled MFC removals. The total unscheduled AFC removals were high due to the cleaning of all fuel outlet ports starting with 7 in CY98, 15 in CY99, 53 in CY00 and 85 in CY01. **Figure 15** shows the coke slurry that has accumulated in the Seg III fuel outlet port of an AFC from a -220/E engine. The inner parts of the regulator valve shown in **Figure 16** have been removed from the Seg III valve regulator port shown in **Figure 17** for cleaning. Note the coke particles and gums on the valve parts and in the side port of the Seg III housing that can affect valve operation. The cleaning and reassembly is accomplished without removing the fuel manifold housing.

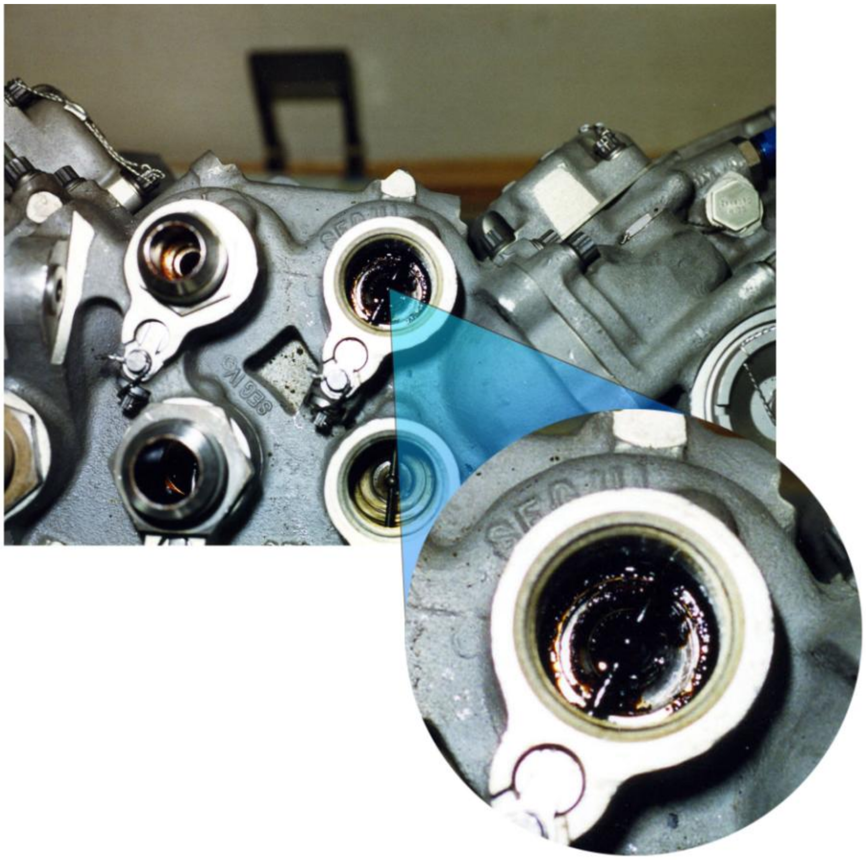

Figure 15. Coke in AFC SEG III Fuel Outlet Port

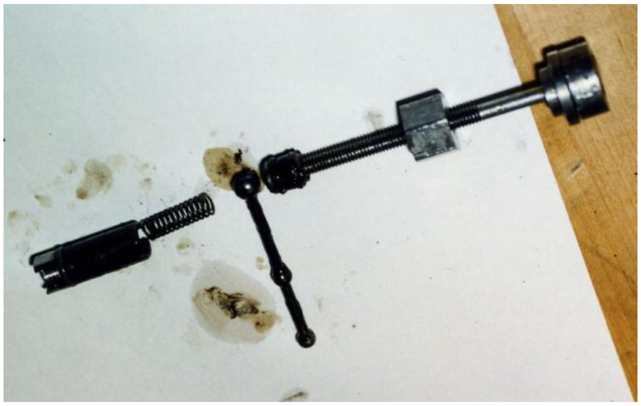

Figure 16. SEG III Valve Regulator Parts

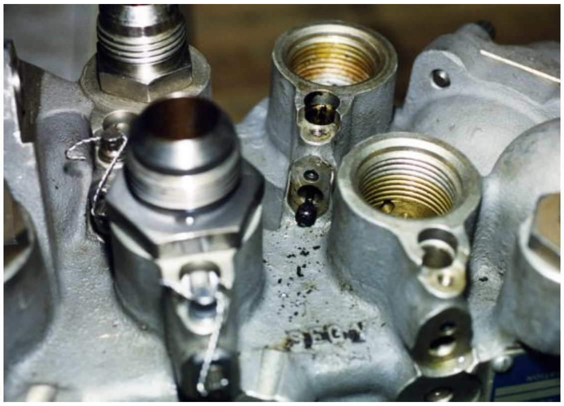

Figure 17. SEG III Valve Regulator Port

By removing the AFC cleaning events, the anomaly related AFC removals ranged from 39 to 70% of the adjusted unscheduled AFC removals. During CY98, 40% of the AFPC removals were reported as anomaly related but none were involved from CY99 through CY01. This sudden drop may have been associated with the 5 AFPC removals for Scheduled Maintenance in CY98. The majority of DEEC removals from CY99 to CY01 were related to Internal Malfunctions or Failed to Operate, Specific Reason Unknown although Augmentor No-Light indications could be traced to fouling in the fuel outlet ports of the AFC. CENC and AFPC removals also reduced but were driven by management decision removals for Expired Max Cycles and Opportunistic Maintenance.

Although the maintenance environment at this Unit had been very dynamic for several years, seasoned leadership had guided steady progress in reducing Unscheduled Engine Removals through a well-managed Scheduled Maintenance Program and evolving maintenances procedures and practices that helped reduce augmentor anomalies. Based on the maintenance data analyzed, it became evident that an additional 18 to 24 months of service time would be required for the reliability of the assigned engines to reach a sustainable level after the engine build standards of all assigned engines had been improved under the RCM Program. Also, engine and operational conditions needed to be reasonably stable so that any change in the maintenance and support variables could be used to identify the most likely cause for an increase or decrease in the engine anomalies and unscheduled engine removals.

3.6 Ultimate Proof of JP-8+100 Benefits

Table 6 shows Engine Anomaly Trends for F-15 and F-16 fighters at two locations. The Engine Anomaly Trends for the F-16 fighters is an extension of the Engine Anomaly Trends shown in **Table 2** and **Figure 14** of this section. It is noteworthy that the engine reliability had been steadily improving from improved module build standards. After returning to using straight JP-8 starting in 1 Aug 05, the Engine Anomalies for the F-16s at this Unit had increased from 8 in CY04 to 16 in CY05 and then to 21 in CY06, a period of 13 months. Recovery to near the former level did not occur until CY08, approximately 18 to 24 months after the +100 additive was turned on again. For the twin engine F-15 fighters at another operating location, a stable level of Engine Anomalies had been reached by CY01 and continued until the +100 additive was turned off in Aug 05 at which time the Engine Anomalies increased from 10 in CY05 to 25 in CY06 and have recovered to the near the former level after 30 months of using JP-8+100. Another consideration for the extended recovery period is that the F-15 fighter Unit deploys part of their aircraft for brief periods and uses the available JP-8 spec fuel at the operating locations while the F-16 Unit has very high utilization of JP-8+100.

Table 6. Engine Anomaly Trends (2002 – 2008)

F100-PW-220/E Engines							
Fighter	CY02	CY03	CY04	CY05	CY06	CY07	CY08
F-15	4	6	7	10	25	14	11
F-16	19	13	8	16	21	12	6
Note: When the +100 additive was turned off 1 Aug 05 through 16 Aug 06, the engine anomalies increased due to coking and then reduced to within the former level.							

The dramatic increase in the Engine Anomalies after the +100 additive was turned off for 13 ½ months clearly shows that using JP-8+100 helps to reduce the impact of coking in the -220/E engines that power F-15 and F-16 fighters. Recovery to the former level of engine anomalies will vary depending on the flying hours the engines are off the additive and the per cent utilization of the +100 additive for the assigned engines after returning to JP-8+100 use.

While the +100 additive has helped reduce the maintenance workload by increasing average time on wing or MTBR, it does not prevent coking in the augmentor spray rings and feed tubes exposed to high gas temperatures. Quick removal of the residual fuel after augmentor shut down is essential to help reduce coking in the spray rings and the accumulation of the coke slurry in the outlet ports of the Augmentor Fuel Control (AFC) and Fuel Dump Probe (ASEP) in the core exhaust stream.

3.7 Impact of Scheduled and Unscheduled Engine Maintenance

The following sections provide a summary of the condition and the dynamic maintenance environment that existed for F100, F110, J85, J69 and T56 engines during the conversion to JP-8 and then to use of JP-8-100 that impacted the evaluation and analyses of benefits from using the +100 additive. Use of the +100 additive is considered but one of several maintenance and support procedures and best practices that have helped to reduce the impact of coking after conversion to a kerosene based fuel.

3.7.1 F100-PW-100 & -220/E Fighter Engines Maintenance Assessment

The analyses of engine removal data from Jan 97 through Sep 06 became very complex because of the dynamic maintenance environment and the varied utilization of JP-8+100 at operational and ANG Units, although the pilot training Units in AETC and the ANG were the most consistent users of JP-8+100. Aircraft were off the additive while deployed and starting in 1997, an aggressive RCM Program was in progress to improve the engine build standards to achieve the inherent reliability of the fighter engines. Engine maintainers were also accomplishing two separate blade row changes in the LPT of the -220/E engines during 2003-04 and 2004-05 that were accomplished in one year by Units assigned F-16 fighters and over a three to four year time compliance for Units assigned F-15 fighters. Therefore, variables such as engine condition, frequency of spray ring baking and cleaning, local maintenance practices and Opportunistic Maintenance performed when an engine was in the shop for maintenance and the per cent use of JP-8+100 collectively caused different unscheduled removal trends for different F100 engine models. For instance, the legacy -100 engines fitted with the hydro-mechanical UFC and EEC exhibited greater sensitivity to coking resulting in more engine anomalies than did the newer -220/E engines that had been converted to a full authority digital control system with self-trimming and engine monitoring and with separate MFC and AFC components. When the +100 additive was turned off in May/Jun 05 to resolve the media filtration and filter coalescer issues, the engine anomalies for all the -100 and -220/E engines increased indicating that use of the +100 additive had reduced the rate of coking in the augmentor spray rings and the fouling of the outlet ports of the AFC on the -220/E engines and the UFC on the -100 engines. After the additive was turned on approximately one year later, the engine anomalies experienced a steady decline over the following twelve to twenty-four months to approximately the former level before the additive was turned off.

Engine maintainers have been very creative in applying preventative maintenance procedures that helped to improve engine reliability and time on wing. For instance, the replacement of LPT blades during the 2003 to 2005 time period permitted more Opportunistic Maintenance on augmentor modules and baking and cleaning of the spray rings that helped reduce unscheduled engine removals. Reduced flying hours also reduced the number of anomaly events but the UER Rate actually increased which forced careful review of which metrics, actual number of events or unscheduled engine Removal Rate should be used to understand any benefits from using JP-8+100.

3.7.1.1 Maintenance Impact Due to Coking (-100 and -220/E Engines)

When the +100 additive was turned off in the Jun 05 time period for 12 to 13 months, augmentor anomalies increased 20 to 50% for -100 engines with a corresponding increase of 96% in UFC removals to fix the problems due to increased coking. For the -220/E engines, augmentor anomalies increased around 11% for the total fleet of engines, 4% for the F-16C/D fighters and 43% for the F-15C/D fighters. The UER Rate for the F-16s increased around 20% and 60% for the F-15s. The MFC removals for the -220/E fleet increased around 14% and 10% for the AFC. When JP-8+100 use at one Unit decreased from 100% to less than 50% utilization in 2003, the UER Rate increased by 74% during the following year and an additional 24% increase in 2005 when the +100 additive was turned off in Jun 05 providing a clear indication of engine sensitivity to the percent utilization of JP-8+100 in the -220/E engines.

Additional discussions and analyses of the maintenance trends for the -100, -220/E and -229 engines through Sep 06 can be found in **Appendix M**. However, it is cautioned that the accuracy of these observations is dependent on the HMCs used by each Unit to report the unscheduled engine and control removal events and subject to interpretation during the maintenance data analyses. It is worth noting that the full authority digital control system on the -220/E engine that provides self trimming and engine monitoring has helped reduce unmerited engine and control removals as indicated by lower engine and control component removals compared to legacy -100 engines.

The unscheduled removal trends for F-15 and F-16 aircraft show that JP-8+100 has helped to reduce engine and augmentor anomalies for both -100 and -220/E engines based on the increased number of augmentor anomalies and number of control removals when the +100 additive was turned off, and can be counted on in the future to the help avoid engine maintenance.

3.7.2 F100-PW-229 Fighter Engine Maintenance Assessment

Gas path refurbishment and control software changes contributed to brief periods of improved engine reliability and reduced unscheduled removals but the periods of stable maintenance activity were too brief to sort out the impact of coking on augmentor operation and the causes of unscheduled removal of AFC and MFC components during periods when JP-8 or JP-8+100 was used. When new engine parts and module realignment procedures were implemented under the RCM Program in 1998, the Unit also started using JP-8+100. Although the UER Rate showed a steady decline over several months as did unscheduled MFC and AFC removals, it was impossible to sort out any benefits from using the +100 additive since the Opportunistic Maintenance tasks had significantly improved engine reliability. When the +100 additive was turned off in 2003 to support the surge of large aircraft using this location as a refueling stop, the UER Rate started to increase in 2004 but started to decrease again when more new parts were provided to improve engine durability. Also, the fuel spray bars in the -229 augmentor and the redesigned augmentor fuel system manifold compared to the -220/E and legacy -100 engines have significantly reduced coking problems in -229 engines. During the period of analysis, the synergies of the RCM Program, control software changes, local maintenance procedures and use of JP-8+100 all contributed to brief periods of reduced UER Rate. Based on the -100 and the -220/E experience, a sustained period of improved engine reliability from 18 to 24 months will be needed to achieve stable maintenance conditions in order to sort out any benefits from using the +100 additive in -229 engines. Also, the impact of coking on the -229 augmentor fuel system that uses spray bars may be slightly smaller than the -220/E and legacy -100 engines that use spray rings.

3.7.2.1 Maintenance Impact Due to Coking (-229 Engines)

The dynamic maintenance environment for -229 engines presented many challenges to determine any benefits from using JP-8+100. A sustained period of improved engine reliability from 18 to 24 months was lacking to establish stable maintenance conditions in order to sort out any benefits from using the +100 additive in -229 engines. When the +100 additive was turned off in 2003 to support the surge of large aircraft using this location as a refueling stop, the UER Rate started to increase in 2004 but decreased again when more new parts were provided to improve engine durability. The engine mechanics did report that use of the +100 additive has provided cleaner combustor and turbine parts and reduced the carbon and coke deposits in the augmentor making the scheduled borescope inspections easier and allowing more direct viewing of any distressed areas with greater resolution. Also, the +100 additive has helped reduce the formation of varnishes and coke from fuel exposed to hot metal surfaces that can plug orifices and can cause sticky servo valves since varnishes and coke will start to form when fuel contacts hot metal surfaces around 200 °F. Therefore, a cleaner burning fuel with higher thermal stability can help avoid maintenance by reducing unscheduled engine and control component removals.

3.7.3 F110-GE-100 & -129 Fighter Engines Maintenance Assessment

The analysis of maintenance activity for the GE fighter engines also presented real challenges to determine any maintenance benefits from using JP-8+100. Engine removals to solve potential fuel coking issues were sometimes offset by increased unscheduled engine removals to correct mechanical faults and turbine deterioration issues. Periods of stable maintenance activity were brief for both the -100 and -129 engines limiting useful data to sort out the impact of coking on engine and afterburner operation that may have caused the unscheduled removal of MEC and AFC components during periods when JP-8 or JP-8+100 was used.

In 1998, the Air Force initiated the F110-100B Mod Program that provided new parts to improve the durability of the Combustor and Low Pressure Turbine. In addition, the control system was changed to a digital electronic engine control. The -100B Mod Program was ongoing through 2004, however, a Service Life Extension Program (SLEP) was initiated in 2003 to increase the service life of life limited hot section parts from 3000 to 4000 cycles. The new engine parts improved engine durability and provided a steady reduction in unscheduled engine removals and the UER Rate starting in 1998 that can be noted in the trend data for both -100 and -129 engines but the installation of the new parts in both the -100 and -129 engines made it more difficult to sort out any benefits from using JP-8+100. When the +100 additive was turned off for 12 ½ months starting in Jun 05, unscheduled removal rates for the MEC and AFC increased but in some cases decreased, however, the overall number of control removals was quite small for the F110 engine fleet.

It is important to note that the installation of more durable hot section parts has contributed to periods of improved engine reliability and reduced unscheduled removals but the removal data also indicates that increased control removals during this same time period had contributed to reduced engine and afterburner anomalies by purging what appears to be weak controls resulting in a decline in afterburner no-lights. After three to four years of control removals for engine and afterburner anomalies, there would be an abrupt decrease in MEC removals for one year after which the engine anomalies and control removals would start to increase. When HMC 242 (Failed to Operate-Specific Reason Unknown) is used more frequently to report both MEC and AFC removals, fouling must be occurring in the MEC especially when JP-8 use increased, or conversely, JP-8+100 use decreased. Another reason offered is the flight line mechanics are handing off the problem to the engine shop to diagnose and fix. However, MEC removals were found to be low in number and that gas path deterioration was not determined an issue in causing the afterburner anomalies. It was noted that some MEC removals were performed to fix an engine anomaly while other MEC removals were performed to fix afterburner anomalies but not necessarily on the same engine. However, MEC removals were complimentary in that benefits accrued to all components that depend on the MEC for metering, speed sensing and regulation functions. It was also noted that the number of AFC removals for the entire fleet was very small and that insufficient removal events occurred to determine the impact of fouling on AFC removals. Additional discussions and analyses of the maintenance trends for the -100 and -129 engines through Sep 06 can be found in **Appendix N**.

3.7.3.1 Maintenance Impact Due to Coking (-100 and -129 Engines)

In spite of the brief periods of stable maintenance conditions, the data indicates that use of JP-8 +100 did help the MEC and AFC on the F110 engines to function more precisely since varnishes and coke will start to form when fuel contacts hot metal surfaces around 200 °F. Fouling in the MEC and AFC components can cause sticky valves that affect control performance. As the utilization of JP-8+100 decreased, there was a corresponding increase in MEC and AFC removals. The +100 additive also helps fuel to burn cleaner in the engine. Cleaner gas path hardware is easier to borescope while clean fuel control components help to reduce unscheduled engine and control component removals. As a result, requests for Depot reparables decrease allowing more time to perform the Schedule Maintenance Program for each engine model.

3.7.4 J85-GE-5 and J69-T-25 Trainer Engines Maintenance Assessment

The legacy J85 and J69 engines are very sensitive to coking when using JP-8 since these small gas turbine engines were developed to use JP-4 as the primary fuel. The engines were initially designed as small turbojet engines for missile and drone applications but later used as the engines for the T-38 and T-37 trainer aircraft. The J69 engine remained a straight turbojet while an afterburner was added to the J85 engine. More detail of J85 and J69 Maintenance Trends from use of JP-8 and JP-8+100 can be found in **Appendix L**.

Soon after conversion to JP-8, the fuel spray nozzles and dome of the annular combustors of the J85 engines showed accelerated build-up of carbon that caused an increase in engine anomalies plus the combustor and afterburner fuel system parts were more difficult to clean. For the J69, a fuel slinger system in the engine shaft injects the fuel into the annular combustor as the shaft rotates, however, it could not be determined if the fuel control or the fuel slinger system were causing the 3.9X increase in engine flameout rate after the +100 additive was turned off for 13 ½ months. Also, the hot metal surfaces in the J69 engine heated the fuel beyond its thermal stability limit and discolored the fuel filters, which are now changed more frequently. After the conversion to JP-8+100, AETC found that the impact of coking in the J69 and the augmented J85 engines was more manageable but not free from coking problems. Another issue developed with media (water-absorbing) filters that replaced the filter coalescer elements that were thought to be defeated by the additional surfactants in JP-8+100. Later that assumption was proven false based on rigorous filtration testing conducted at SwRI® in San Antonio TX. After using water absorbing filters in refueler trucks for several years, it was found that the filter media was migrating to the aircraft and engine filters causing fuel starvation and several flameouts. It is noteworthy that the analyses of CEMS removal data for the J69 engine showed increases in MFC removals 3 to 4 years prior to discovering the media migration problems. At that time, it was thought the sticking fuel control valve problems was an isolated MFC problem rather than related to the media in the water-absorbing filters.

3.7.4.1 Maintenance Impact Due to Coking (J69 and J85 Engines)

Using JP-8+100 in the J69 and J85 engines has provided consistent reductions in unscheduled maintenance and parts demand but are best shown when the +100 additive was turned-off for 13 ½ months starting in May 05. During this time period, the engine flameout rate for J69 engines increased 3.9X after the +100 additive was turned off, the engine NRTS increased from 0.75/mo to 3.01/mo and the MFC Removal Rate increased by 60%. Prior to 2005, the removal rate for the MFC increased by 42% in 2003 and 22% during 2004 from sticking valve problems. After conversion to JP-8+100, the parts demand rate for J85 engine fuel nozzle tips decreased by 55.3% and a 73 to 75% reduction was noted for fuel nozzles and the main and pilot spray bars in the afterburner. When the +100 additive was turned off and JP-8 used, the engine UER Rate increased by 110%, the MFC Removal Rate increased by 152%, the AFC Removal Rate increased by 57% and augmentor unscheduled removals increased by 72%.

There is little doubt that use of the +100 additive has provided a significant reduction in the maintenance workload, reduction in parts demand and helped to increase the reliability and time on wing of the legacy J69-T-25 and J85-GE-5 trainer engines.

3.7.5 T56-A-15 Turbo Prop Engines Maintenance Assessment

After conversion to JP-8 in the 1994, T56 engines began to experience increased hot section distress due to fuel spray nozzle streaking caused by coking on the spray tip. Borescope inspections had showed accelerated material oxidation and erosion and cracks on the combustor exit vanes and linear cracks in the walls of several combustor cans requiring immediate replacement. Three procedures were implemented to correct the hot section problems: 1) remove and clean the fuel spray nozzles during the annual ISO (Isochronal Inspection) of the aircraft that occurs around 400 FH and check the spray pattern for streaking, 2) perform a two-minute idle before engine shutdown, and 3) issue a pilot advisory to limit max power use to takeoff and emergency conditions only. Units with aggressive low level missions operating more than 1,000 FH per year were advised to perform hot section borescope inspections during the Home Station Check (HSC) that occurs six months after the annual ISO although some Units decided to remove and clean all fuel nozzles and perform a spray pattern check. The two-minute idle prior to engine shutdown allows the fuel nozzles to cool and reduce formation of residues and coke on the nozzle tips from unburned fuel in the dome of each burner can although the fuel nozzle cleaning procedure implemented in 1994 had not reduced the number of fuel nozzles that failed the spray pattern check. Overnight soaking in a fluid to remove carbon and cleaning with felt material did not remove the hard coke deposits on some spray tips forcing replacement with reworked or new fuel nozzles from Depot. As a result, the OEM recommended changing to a nylon brush to clean the fuel nozzle tips instead of using a felt material.

After conversion to JP-8+100 in May 1995, one unit reported that fuel nozzles failing the spray pattern check had dropped from a high of 30 during 1994 to 0 - 2 nozzles each year after 1997. After using JP-8+100 less than one year, the engine mechanics at C-130H Units commented that the hard coke deposits that usually form on the face of fuel spray nozzles were more porous and easier to remove during the scheduled cleaning.

Eight C-130H Units were contacted 30 months after all C-130H units had turned the +100 additive off circa March 2001. Units that had fuel nozzle dropouts of 1 to 2 fuel nozzles fail the spray pattern check while using JP-8+100 continued to have 1 to 2 fuel nozzle dropouts per aircraft ISO after one year of using JP-8. Other Units that had around 3 fuel nozzle dropouts per year using the +100 additive had the same number of dropouts after one year of using straight JP-8. When the flying hours increased by 2 to 3X between scheduled aircraft ISO's, the fuel nozzle dropouts almost doubled depending upon the fuel nozzle dropout rate at each Unit. The engine mechanics could not confirm if the engines were being operated at higher CET (combustor exit temperature) but the local outside air temperatures at the operating locations were 20 to 30 degrees higher than in the CONUS. The engine shop chiefs agreed that increased time intervals between cleaning would allow more coke deposits on the face of the fuel nozzles making cleaning with the nylon brush more difficult but they could not explain why fuel nozzle dropouts were not significantly higher.

A Unit that trains pilots for terrain following missions had used JP-8+100 18% of the time and experienced a UER Rate of 3.73 but achieved a UER Rate of 0.91 when JP-8+100 use increased to 82% of the time for a 76% reduction in UER Rate. However, it was learned that the OEM had released new combustor exit vanes during the evaluation period with improved cooling that may have contributed to some of the UER Rate reduction during the time when JP-8+100 was used but the number of turbine modules turned in for refurbishment was small and the User had no way of knowing if the new vanes were installed by the regional overhaul center.

When the +100 additive was turned off Air Force wide circa May/June 2005 to resolve media filtration and filter coalescer issues, **the fuel spray nozzle dropouts at the Unit training pilots for terrain following missions had increased during the 12 to 13 month time period that JP-8 was used from 1 per ship set to 4 per ship set during the annual ISO, a 13% increase**. There are 24 fuel nozzles per ship set, four engines per aircraft with 6 fuel nozzles per engine. **After return to using JP-8+100, fuel nozzles failing the spray pattern check reduced to around 1 per ship set during the annual ISO for the aircraft**.

Operating at 1050 °C max continuous CET and 1077 °C max intermittent for 5 minutes to perform terrain following and steep ascent conditions is unique to the pilot training syllabus at this Unit and exposes the face of the fuel spray nozzles to higher combustion temperatures and accelerated coking. These observations suggest that frequent use of intermittent max CET at 1077 °C and continuous 1050 °C CET has a marked impact on coking of the fuel spray nozzles but **use of JP-8+100 has helped reduce the dropouts operating at the higher combustion temperatures**. The data also indicates there is merit for Units that operate at or below 1010 °C CET to use JP-8+100 to reduce fuel nozzle coking and hot section distress.

Further analyses are needed to determine if the new Pin Fin turbine vanes and first stage blades released early in 2003 with improved internal cooling will improve hot section durability. Also, a Mod 2 fuel nozzle tip was released in Jan 2007 that was designed to reduce coking on the fuel nozzle tips and streaking in the spray pattern. However, incorporation of the Mod 2 fuel nozzle tip will occur as fuel nozzles are returned to Depot for refurbishment or available in new fuel spray nozzles from the OEM. However, the fuel spray nozzles will have the same part number and be interchangeable with the current BOM fuel spray nozzles which will make it more difficult to establish when the entire T56 engine fleet has been fitted with the new Mod 2 fuel nozzle tip.

3.7.5.1 Maintenance Impact Due to Coking (T56-A-15 Engines)

A Unit that trains pilots for terrain following missions that used JP-8+100 18% of the time experienced a UER Rate of 3.73 but achieved a UER Rate of 0.91 when JP-8+100 use increased to 82% of the time for a 76% reduction in UER Rate. When the +100 additive was turned off Air Force wide circa May/June 2005 to resolve fuel filtration and filter coalescer issues, the fuel spray nozzle dropouts increased from 1 per ship set to 4 per ship set during the annual ISO, a 13% increase, after 12 to 13 months of using JP-8. Frequent use of intermittent max CET at 1077 °C and continuous 1050 °C CET had a marked impact on coking of the fuel spray nozzles but use of JP-8+100 helped reduce the dropouts operating at the higher combustion temperatures. The data also indicates there is merit for Units that operate at or below 1010 °C CET to use JP-8+100 to reduce fuel nozzle coking and hot section distress. After return to using JP-8+100, fuel nozzles failing the spray pattern check reduced to around 1 per ship set during the annual ISO for the aircraft. The maintenance data confirms that use of JP-8+100 helps reduce fuel nozzle coking and accelerated hot section distress for Units that consistently operate T56 engines at higher CET power settings.

4.0 HELICOPTER EXPERIENCE USING JP-8+100

This section discusses service evaluations of JP-8+100 at two military units that train helicopter pilots and a civilian law enforcement unit that uses Jet A +100. The larger military unit is the 'School House' for all military helicopter pilots while the other unit provides advanced training for special missions. The 'School House' program evaluated a truck mounted additive injection system and the economic benefits from using the +100 additive in aviation training over a 15 month period while the other military unit provided opportunities to periodically borescope the coking on hot section parts over a 24 month period after conversion to JP-8+100 plus system operational reliability metrics used to track Mission Capable Rates and Air and Ground Aborts. Although one of the civilian law enforcement units was unable to continue using the +100 additive due to a leaking additive injector that was never fixed during the six month evaluation program, the other unit realized immediate benefits from using the +100 additive and has continued its use.

4.1 'School House' Evaluation Program

At the time of the evaluation, there were around 600 helicopters representing all models operated by the military services. The helicopter names and engine types include: 1) TH-67 Creek trainer helicopter powered by the Rolls Royce C250-28B engine, 2) OH-58 Kiowa Warrior reconnaissance helicopter powered by the RR C250-30 engine, 3) UH-60 Blackhawk utility helicopter powered by the T700-GE-700 twin pack engines, 4) AH-64 Apache attack helicopter powered by T700-GE-701/C twin pack engines and 5) the CH-47 Chinook cargo helicopter powered by two T55-712 Lycoming engines. The total hours flown each year at the 'School House' is more flight hours than at any other military unit thus providing a good sample of engine maintenance and reliability data for analysis. In addition, the aircraft are not deployed and have a high operational tempo. The annual fuel usage for the assigned helicopter aircraft is approximately 12 million gallons which is dispensed by a fleet of 32 commercial fuel trucks operated by a contractor covering 5 main airfields, 3 with POL storage and truck fillstands, two airfields with no fillstands, 17 stage airfields and one hot refuel and rearm forward area (FARP). One field uses a hydrant system to dispense approximately 2% of the 12 million gallons and was not converted to issue JP-8+100. In addition, there are approximately 2 million gallons of Jet A with FSII annually purchased locally to refuel helicopters at surrounding civil airports through into-plane contracts. Thus, it was estimated that the assigned aircraft would be using JP-8+100 more than 80% of the total flying hours providing acceptable levels of confidence in the data generated.

4.1.1 'School House' Program Focus

The primary focus of the program at the 'School House' was to evaluate a truck mounted additive injection system that issues JP-8+100 fuel at the 'skin of the aircraft'. A secondary goal was to assess any economic benefits. The design goal was to selectively additize JP-8 on the fuel truck enabling the same truck to issue either JP-8+100 or JP-8 to program and non-program aircraft in a logistically friendly manner. Transient aircraft, ground vehicles and equipment were not included in the evaluation and were not issued additized fuel. Also, there was a need to selectively additize depending on the type of aircraft being serviced because any impact on training could not be tolerated. As a result, it was determined that "additizing at the skin" shown in **Figure 18** was a good choice if there was a need to control whether an aircraft received the +100 additive or not. (ATTC - Acronym for Aviation Technical Test Center)

Figure 18. Refueling of ATTC Apache Helicopter

4.1.2 Fluid Drive Injection System

Because the USAF had experienced good performance and reliability with the Hammonds fluid drive injectors on fill stands and pipelines, the same type of fluid drive injector were selected for installation on the fuel trucks (**Figure 19**). Since the fluid drive units are purely mechanical, no safety hazards were possible in an explosive environment. The fluid drive injectors were considered low risk since several thousand units were in service on fuel trucks at commercial airports. Therefore, no first article evaluation or testing was performed to expose the truck mounted additive injection system to typical field conditions at the 'School House'. In hindsight, first article testing would have exposed several problems that were not anticipated with the truck mounted fluid drive injectors.

Figure 19. Truck Mounted Hammond Injector

The additive tanks were intended to be installed on the driver side of the truck, the same side as the truck equipment box. On most trucks, the additive tanks were installed on the front of the equipment box which allowed the driver to see the additive tank level and refill the tank on the same side as the truck diesel tank (**Figure 20**). The valve controlling the output of the fluid drive injector to the additive tank (OFF Position) or to the truck fuel stream (ON Position) was located in the equipment box of the truck with a vinyl label to remind the drivers to turn "+100 OFF WHEN CIRCULATING" shown in **Figures 21**. Since this hardware installation was not possible on all trucks due to space limitations of the larger equipment box on dual reel fuel trucks, the additive tank was mounted on the passenger-side frame of those trucks. However, arrangements to gain access and fix the additive injection systems on all 32 fuel trucks that were in service at the various airfields became very complex.

Figure 20. Refilling On-Truck Additive Tank

Figure 21. Additive On/Off Valve

Figure 22 shows the injector and the additive reservoir tank mounted on a typical refueler truck. The on-truck additive storage tank and calibration system as designed and installed had several shortcomings and did not function properly. Of immediate concern was spillage of additive from the calibration bottle. Since fuel trucks often operate on unimproved roads to reach the stage airfields rather than smooth airport ramps, poor road conditions contributed to some of the difficulties encountered. Although the tank system was redesigned to correct the performance deficiencies, it was concluded that mechanical fluid drive injectors were better suited for a stationary flow application rather than truck mounted operating on unimproved roads. Also, the injector motors that were selected and installed on the trucks were too large for the desired additive fuel flow rate at the minimum flow rate setting. Calibrating the fluid drive injectors required recirculation fuel and need of an operator to run the truck. Because the injector is a diaphragm pump with inlet and outlet check valves, a device was built that allowed the measurement of additive quantity injected at the operating pressure of the truck; however, accuracy within 10% was the system limit. There was no way to determine if the injector was actually pumping without calibrating it. However, a pressure gauge on the injector outlet could have been used to observe the pulsing output from the diaphragm pump.

Figure 22. Additive Reservoir Tank and Injector

4.1.3 Computer Controlled Injection System

As a result of the shortcomings of the fluid drive injectors, a design study selected a 12 volt DC powered, computer controlled injector system available from the Economy Controls Corporation. The injectors are controlled by an ON/OFF switch in the truck equipment box and are triggered by a Fluid Controls pulsed signal (10 pulses per gallon of fuel) in the meter register. Accuracy of the Economy Controls model 12ETS injection pump was within 1%. There were 10 pulses per cc of additive providing a near constant additive stream and the pump output was accurate over a wide range of pump outlet pressures up to 150 PSIG. The current draw when pumping was 7 amps and negligible at idle conditions. These pumps were mounted on the additive tanks which then could be mounted remotely. The only intrusion into the truck plumbing was an injection port which was located downstream of the filter vessel and any recirculation point. This technology allowed the design of an injection system on 2 trucks that could not be fitted with the Hammonds fluid drive injectors as shown in **Figure 23** and **24.**

Figure 23. Truck Mounted Economy Controls Injector

Figure 24. Truck Mounted Economy Controls Injector

Figure 25. Bulk Storage of Neat Additive

The bulk neat +100 additive is stored in a tank (**Figure 25**) at each airfield with a fuel fill stand. The additive storage tanks are conveniently located where the fuel trucks refill with diesel. For convenience, an electric pump is used to refill the additive tank on each truck. Also, the truck mounted additive tanks were sized to require refilling every 6th load of JP-8 fuel. The +100 additive is injected at the rate of 1 gallon additive per 4000 gallons of jet fuel that is 32 oz of additive to 1000 gallons of JP-8. To eliminate any spillage, a 6 gallon tank was mounted on the 3000 gallon fuel trucks to provide 5 gallons of the +100 additive. The bulk additive tanks were sized at 350 gallon capacity to require resupply every 2 months that keeps the neat +100 additive “fresh”.

4.1.4 Defuels and Filtration Issues

Even though the +100 additive is injected downstream of the filter vessels on the trucks, there is the possibility that additized fuel in an aircraft will be returned to the truck fuel tank since the fuel contractor at the 'School House' uses the same trucks to refuel and defuel. The trucks at Ft. Rucker use a 3 stage vessel for filtration. The first element is a coalescer, then a separator and lastly a monitor. The coalescers are 4" x 20" and monitors are 2" x 20". The Facet 2" x 20" monitors were retained in the 3rd stage. As M100 rated coalescers became available from Velcon, these elements were installed in the first stage. Using monitors in the first stage is not a best practice simply because they were not designed for that purpose. One remaining concern was that the filter vessel delta-P was not corrected for truck flow rate versus filter vessel rated capacity, possibly giving a false sense of goodness when the delta-P reading is low from low fuel flow rate. There exists a remote possibility that the coalescers may be disarmed and the increase in monitor backpressure may not be detected. Coalescer elements can be disarmed by contamination from small quantities of chemicals as discovered during testing at Velcon. However, the +100 additive does not contain any disarming chemicals or compounds.

Figure 26. "Goo" Found in Filter Element Vessel

Some interesting anomalies were noted over the course of using monitors in both the 1st and 3rd stages. Metal shavings were found in the first stage filters since the fuel pumps on trucks can shed metal debris. Some of the debris is so fine that it will pass through the filters and show as a grey matter on Millipore pads and still be within weight limits. One of the most interesting observations was a monitor that had shut off flow while passing wet fuel just as it was designed to do. After remaining in the test rig over the weekend in the saturated condition, it was found to be filled with "goo" on Monday as shown in the bottles in **Figure 26**. A similar thing happened to a monitor in a refueler truck that had been exposed to wet fuel. The filter vessel delta-P reading reached the 15 psid (differential pressure) limit forcing the truck into maintenance but was not worked on for a few days. After removing the elements, "goo" was found in the first stage elements. It would appear that after a monitor element shuts down from excess water exposure, the reaction of Super Absorbent Polymer (SAP) can relax over time and produce what may have been called "apple jelly" in the past. Although, there was concern that un-reacted SAP from monitor elements was washing downstream and possibly clogging aircraft and engine fuel screens, no impending bypass indications were ever noted by the engine maintainers at the 'School House' but the USAF did have three in-flight incidents from engine filter screens blockage by reacted SAP from ground monitors. As a precaution, sample screens from all models of aircraft and engines at the 'School House' were removed from the fleet and sent to AFPET at Wright Patterson AFB for investigation. Also, fuels lab specialists at Naval Air Systems Command (NAVAIR) were helpful in evaluating used filter elements. Some traces of SAP were chemically detected but no material was ever found and no issues have been reported by the aircraft maintainers. Facet monitor elements continue to be used in the 3rd stage of the fuel trucks.

4.1.5 Potential Overdosing of JP-8

Because mechanical or electrical injection systems are designed to additize at a fixed ratio, any blend back of JP-8+100 into the refueler tank will increase the concentration of the additive in fuel being issued. Accounting for blend back of additized fuel from the aircraft back into neat JP-8 in the fuel truck tank was not considered a pressing issue but should be addressed by more advanced systems that have sensors and computational capability to keep track of the additization rate in the fuel truck after a fuel transfer or defuel back to the fuel truck. The fluid drive injectors were sometimes found to be overdosing the fuel when the calibrations were checked although the +100 additive was tested up to 4x the standard concentration for materials compatibility by the AFRL Fuels Laboratory but not for engine operation. However, no issues of any detrimental effects were reported from overdosing the fuel from inaccurate additive injection even when a truck was found to be at 2x desired injection ratio. Due to the limited quantities of fuel in helicopters after a training flight and high operational tempo at the 'School House', defuels and fuel transfer were never considered a problem.

4.1.6 Maintenance Benefits

Despite the intermittent use of Jet A in helicopters issued at commercial airports, use of the +100 additive in JP-8 has reduced carbon deposits and engine removals for low power. While it is believed that optimum benefits can be achieved with more accurate injection and continuous use of the +100 additive, maintenance avoidance and reductions in maintenance costs have been demonstrated for the large fleet of helicopters at the 'School House'.

4.1.7 O & S Cost Reductions

The U.S. Army converted to the "Single Fuel on the Battlefield" doctrine beginning in 1990 and changed to JP-8 as the primary fuel for all Army systems in 1992. After conversion to JP-8, the legacy turbo-shaft engines that power rotary-wing aircraft began to experience increased fuel nozzle coking that caused streaking in the spray pattern and accelerated hot section distress. The increased carbon deposits in the dome region of the engine combustors also affected combustion performance and engine power that prevented engines from operating normally. As engine Mean Time before Removal (MTBR) reduced, the maintenance workload increased to diagnose engine problems and replace fuel-wetted components to restore engines to service in order to support the operational tempo at the 'School House'. Thus, a study was conducted using an established cost model that compared the accrued elements of cost during the baseline period while using JP-8 and Jet A to the same cost elements during a period when the +100 additive was injected into these fuels in order to estimate any reductions in Operational and Support (O & S) Costs.

4.1.7.1 Analysis Methodology

For purpose of the analyses, 35 fuel-wetted parts were selected from the engines that power the UH-60, AH-64, CH-47 and OH-58 to establish any change in demand after using the +100 additive. An additional 5 fuel-wetted parts were added for the TH-67. The cost model included Non-Recurring Engineering (NRE) costs for the redesign and replacement of coalescer filters, a fuel additive storage tank and mixing capability, the qualification cost of the +100 additive in the C250 series engines, and replacement of the storage tank coalescers and tank truck filter coalescer elements that are recommended for use with the Spec-Aid® 8Q462 additive.

The baseline for the initial Economic Analysis (EA) covered the period from FY2000 through FY2002 but another year of parts demand was added one year later when the EA was updated in order to provide a more current baseline for the 22 parts from the legacy fleet and 4 parts from the TH-67. The number of parts for the legacy fleet was reduced since no demand was experienced for some engine parts during the JP-8+100 utilization period. Data for JP-8+100 use period covered 15 months beginning in March 2004. The following fail codes were used for 'scored' unscheduled removals that were entered into The Army Maintenance Management System-Aviation (TAMMS-A) data base: 069 (Flame Out), 070 (Broken), 117 (Deteriorated), 180 (Clogged), 230 (Dirty), 314 (Slow Acceleration), 317 (Hot Start), 374 (Internal Failure), 381 (Leaking), 481 (Over Heats), 537 (Low Power or Torque) and 900 (Burned, includes charred). The maintenance man-hours associated with the unscheduled removal events for each part number were also applied. However, the follow-on EA was based upon engine parts demands recorded in the Operating & Support Management Information System (OSMIS) database from FY2000 through FY2003. Seven databases were used to establish the engine parts demand from March 2004 through August 2005 when JP-8+100 was used.

4.1.7.2 Estimated Savings

Based on the lower engine parts demand recorded in the OSMIS database after conversion to JP-8+100, reductions in average cost per flight hour for fuel-wetted parts from the baseline period (FY 2000 through 2003) compared to FY 2004 when the +100 additive was used provided the following O & S cost benefits: a 32% reduction for the UH-60, 88% reduction for the OH-58, 36% reduction for CH-47 and a 43% reduction for the AH-64. The total estimated cost savings for FY 2004 was $6,425,998.

It is important to note that the magnitude of the savings per flight hour for the UH-60 was influenced both by JP8+100 use and fuel spray nozzle maintenance procedures using the Bauer Flow Stand. Also, the magnitude of the average cost reductions for the T-55 turbo-shaft engines in the CH-47 helicopter was influenced by two factors: 1) a 44% reduction in the refurbishment costs for the Lycoming T-55 Gas Turbine Engine Power Unit and 2) a 37% reduction in engine replacement demand per year for the baseline period while using JP-8 compared to the period when JP-8+100 was used. For the UH-60, the magnitude of the average cost reductions was influenced by: 1) a 45% reduction in the refurbishment costs for the GE T700 turbo-shaft engine and 2) a 25% reduction in the average engine demand per year during the baseline year compared to the 15-month period when JP-8+100 was used. The refurbishment cost reductions could be attributed to a combination of factors to include: 1) a change in engine build standards, 2) work scope and 3) negotiated refurbishment costs. Based on the Economic Analyses, a break-even occurred in 1 year with a 36.07 Savings-to-Investment Ratio (SIR). It is cautioned that the estimated savings are only applicable to the turbo-shaft engines utilized in the operational and maintenance environment at the 'School House'. Engine condition and the state-of-the-art of the fuel spray nozzles and combustor design will impact the benefits to be derived from using JP-8+100. The analysis methodology is considered basically sound and applicable to determine the maintenance benefits from using JP-8+100.

4.2 USAF Helicopter Operational Evaluation Program

A cooperative program was arranged with the Air Force Special Operations Command (AFSOC) at the 58th Special Operations Wing, Kirtland AFB NM to evaluate the effects of using JP-8+100 in UH-1N, TH-53A, MH-53J and HH-60G rotary-wing aircraft. The primary mission of the 58th SOW is to train student pilots using the UH-1N helicopter powered by the T400 'Twin Pack' engine, the TH-53A and the MH-53J helicopters powered by two T64 engines and the HH-60G helicopter that uses two T700 engines. The helicopters remain on-station most of the time although the Unit is called upon to participate in search and rescue missions.

All engine maintenance was performed on Base in a "Queen Bee" engine shop that also overhauls helicopter engines from other Units. Since JP-8+100 had never been used in the helicopters assigned to Kirtland, ground qualification testing was conducted for each engine model before the service evaluation began. The engine testing was performed to uncover any compatibility and performance issues that would delay approval from higher authority to conduct the operational evaluation program.

To prepare for the service evaluation, an additive injector shown in **Figure 28** was installed on one fill stand and calibrated and four R-11 refueling trucks were assigned. However, a delay was encountered when it was found that the existing fuel filter separator vessel shown in **Figure 27** was very old and no longer functioning optimally. SA-ALC/SF recommended that a new filter separator vessel be installed in the fuel farm and demonstrated operational before starting the evaluation program. Approval was granted in April 1997 to start the evaluation program on all helicopter aircraft assigned to the 58th Special Operations Wing.

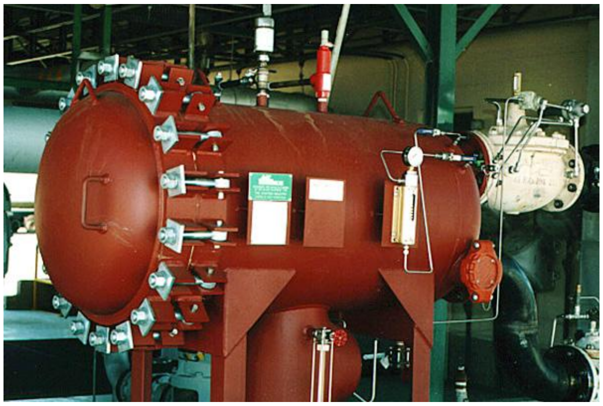

Figure 27. New Filter Separator Vessel

Figure 28. Model 800-IL Additive Injector

A 24-month test program was planned to allow adequate time to accumulate at least 400 flight hours on the helicopters selected for tracking. All helicopters assigned to the 58th Special Operations Wing were converted to JP-8+100. Seven to nine engines from each helicopter type were selected for tracking although not all finished the program due to scheduled and unscheduled maintenance. The items that were tracked included periodic borescope inspections of the engine hot section while installed in the aircraft, an assessment of the system level operational reliability metrics and a review of the engine maintenance records at the "Queen Bee" maintenance shop. The dome regions of several modified heater combustor cans on NH-53J and TH-53A helicopters were also borescoped to determine any changes in coking after conversion to JP-8+100.

The hot sections of all engines were borescoped before starting the service evaluation to establish a baseline and then during the evaluation program to determine any changes in coking from using the additive. The first inspection was conducted after 50 FHs and then the inspection intervals were extended to 100 FH intervals for the remainder of the program providing no deterioration was discovered in the combustor or turbine. The pilots were also requested to perform periodic Single Point Power Checks on the engines to detect any loss in power while using JP-8+100.

Upon completion of the service evaluation, an assessment was made of the operational reliability trends for each helicopter type, any changes in engine maintenance activity and a comparison of the coking in the combustor dome and on the fuel nozzles observed during several inspection intervals to determine any changes from using JP-8+100.

4.2.1 Operational Metrics Assessment

Three operational metrics were tracked to determine any changes in system level reliability that might be attributable to using JP-8+100: 1) the Mission Capability Rate, 2) the Air Abort Rate and 3) the Ground Abort Rate. All three metrics provide management with a measure of the Units effectiveness to support the flying program. However, the metrics provided only system level reliability indicators and did not show the impact of malfunctions for either the engines or the airframe subsystems.

The Mission Capability Rate is the ratio of serviceable aircraft to the assigned aircraft and is a top level management indicator of aircraft readiness to perform missions. An aircraft is declared serviceable when all scheduled and unscheduled maintenance for the airframe and engine(s) have been performed and all items on the flight clearance checklist have been approved. The number of aircraft in service is also affected by the Not Mission Capable due to Maintenance (NMCM) or Supply (NMCS) or both for either the airframe or the engines. There are also several variables in the maintenance tracking system that affect the rolling average of the Mission Capability Rate limiting its use for determining any changes after conversion to JP-8+100.

The Air Abort and Ground Abort metrics provide a measure of system reliability for the helicopters in service but specific Work Unit Codes must be analyzed to establish if the discrepancies or malfunctions were caused by airframe subsystems, the engines or were non-fuel related. However, other data management records must be researched manually to obtain the required information. Since the use of JP-8+100 primarily benefits the engine hot section and the functioning of the fuel control system, an inordinate number of aborts caused by the airframe subsystems could offset any reduction in aborts derived from using the +100 additive in the engines. To obtain specific information from either the Air or Ground Abort metrics, it would be necessary to establish the engine fuel related aborts in order to evaluate the change after conversion from JP-8 to JP-8+100.

For example, Mission Capability Rate for all three helicopters improved after conversion to JP-8+100 as shown in **Table 7** whereas the Air and Ground Abort Rates for the UH-1N and HH60G abruptly increased during the first year of using JP-8+100 and then showed a 1 to 7.7% decrease during the second year of use as shown **Tables 8** and **9**. The baseline for each of the helicopter systems was a one year period prior to the start of the two-year operational evaluation program. The TH-53A and MH-53J helicopters also experienced a steady increase in the Mission Capability Rate after conversion to JP-8+100 as shown in **Table 10** but the Air Abort Rate continued to increase during the two year evaluation program. Data trends for the Ground Abort Rate of TH-53A and MH-53J helicopters were not tracked.

Table 7. Mission Capable Rate – UH-1N, TH-53A, MH-53J & HH60G Helicopters

Airframe/Engine	**Baseline** (May 96 – Apr 97)	**Year 1** (May 97 – Apr 98)	**Year 2** (May 98 – Apr 99)
UH-1N/T400	64%	65.50%	69.20%
TH-53A & MH-53J/ T64	65.60%	78.20%	82%
HH60G/T700	50.40%	63%	78.20%

Table 8. Air Abort Rates – UH-1N & HH60G Helicopters

Airframe/Engine	**Baseline** (May 96 – Apr 97)	**Year 1** (May 97 – Apr 98)	**Year 2** (May 98 – Apr 99)
UH-1N/T400	23.2 Events/1000 FH	101 % increase	7.5 % decrease
HH60G/T700	13.4 Events/1000 FH	54.5 % increase	1 % decrease

Table 9. Ground Abort Rates - UH-1N & HH60G Helicopters

Airframe/Engine	**Baseline** (May 96 – Apr 97)	**Year 1** (May 97 – Apr 98)	**Year 2** (May 98 – Apr 99)
UH-1N/T400	9.2 Events/1000 FH	55.4 % increase	7.7 % decrease
HH60G/T700	10.9 Events/1000 FH	36.8 % increase	5 % decrease

Table 10. Mission Capable and Air Abort Rates – TH-53 & MH-53J Helicopters

58th Special Operations Wing, Kirtland AFB NM			
Metric	**Baseline** (May 96 – Apr 97)	**Year 1** (May 97 – Apr 98)	**Year 2** (May 98 – Apr 99)
Mission Capability Rate	65.60%	78.20%	82%
Air Abort Rate	6.8 Events/1000 FH	38.8 % increase	27.3 % increase

Unless the malfunctions for the airframe and engine can be segregated, use of the global Mission Capability Rate and the Air and Ground Abort metrics cannot provide sufficient detail to determine if the engines directly benefited from using JP-8+100. Based on several intervals of borescope inspections of the engine combustors and fuel spray nozzles for each engine type, the hot sections of engines using JP-8+100 were running cleaner than engines using JP-8.

4.2.2 Engine Hot Section Observations

The borescope images showing the carbon and coking deposits in the hot sections of T64, T400 and T700 engines provided some interesting observations and the most conclusive evidence that some benefits had been derived from using JP-8+100. Since all helicopters at Kirtland AFB had been converted to JP-8+100, borescope images were obtained from these same engine types at Hurlburt AFB, FL using JP-8 in order to compare the coke accumulation at similar flight hours. **At 500 FH, the engines at Hurlburt had more carbon and coke deposits in the hot section than engines using JP-8+100 at Kirtland. The combustor dome and liner as well as the turbine and tail pipe on all the engines at Kirtland were running cleaner using JP-8+100**. More specific examples are provided for each engine and helicopter type in the discussions that follow.

4.2.3 T64-GE-100 Engines Used in MH-53J and TH-53A Helicopters

A small reduction in carbon and coke deposits was observed in the combustor dome region and along the outer sidewalls extending to the combustor exit vanes after conversion to JP-8+100 shown in **Figures 29** and **30** and **Figures 31** and **32,** respectively. However, the carbon deposits on the nozzle cups shown in **Figures 33** and **34** made it difficult to distinguish any difference in buildup after 815 FH. Although the coke deposits on the face of the fuel spray nozzles were minimal after 103 EOT, at 815 FH carbon buildup was significant but the deposits were more porous and powdery in appearance and flaked off the nozzle face easily, often leaving behind a bare metal surface completely free of coke and carbon. Note in **Figure 35** that the edge of the diffuser cone on the fuel nozzle has a hard coke flake growing at 61 FH with more growth and porous carbon attached at 815 FH shown in **Figure 36.** Also note that the first stage vanes shown in **Figure 38** have considerable buildup of silica on the pressure surface and on the end wall leading edge after 815 FH when compared to the vanes shown in **Figure 37** at 61 FH.

Figure 29. T64 Combustor Dome, EOT: 103 FH; +100 Time: 61 FH

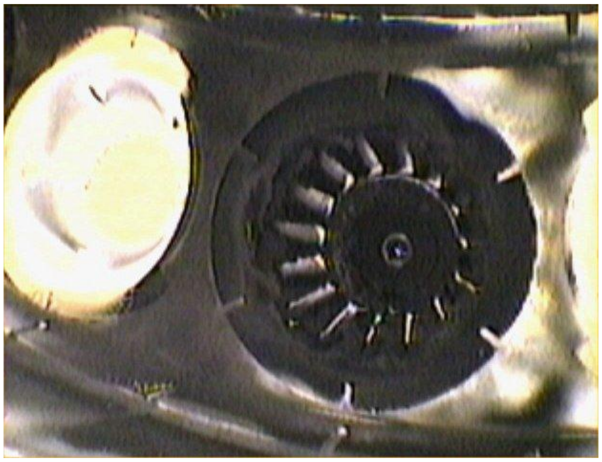

Figure 30. T64 Combustor Dome, EOT: 857 FH; +100 Time: 815 FH

Figure 31. T64 Combustor Wall, EOT: 103 FH; +100 Time: 61 FH

Figure 32. T64 Combustor Wall, EOT: 857 FH; +100 Time: 815 FH

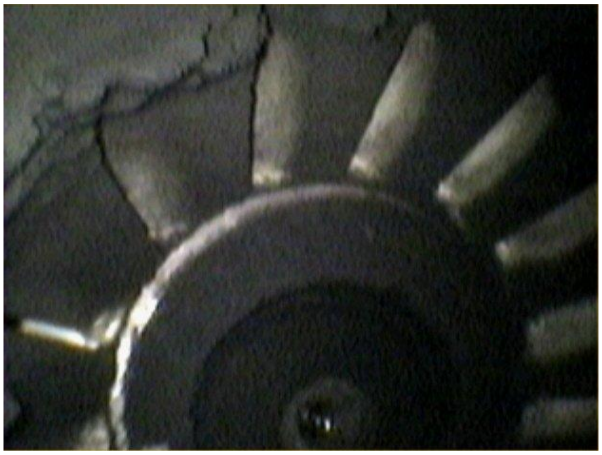

Figure 33. T64 Combustor Nozzle Cup, EOT: 103 FH; +100 Time: 61 FH

Figure 34. T64 Combustor Nozzle Cup, EOT: 857 FH; +100 Time: 815 FH

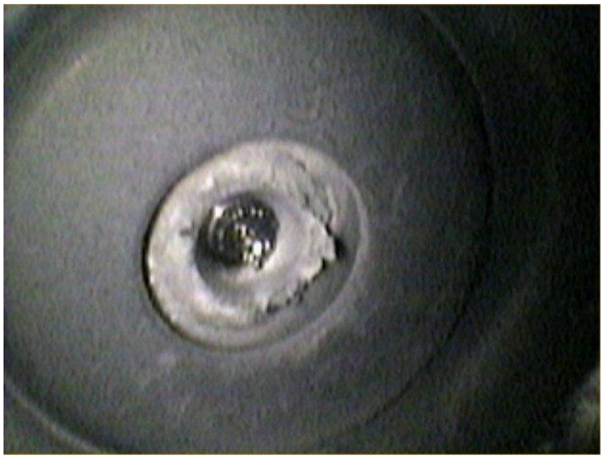

Figure 35. T64 Combustor Nozzle, EOT: 103 FH; +100 Time: 61 FH

Figure 36. T64 Combustor Nozzle, EOT: 857 FH; +100 Time 815 FH

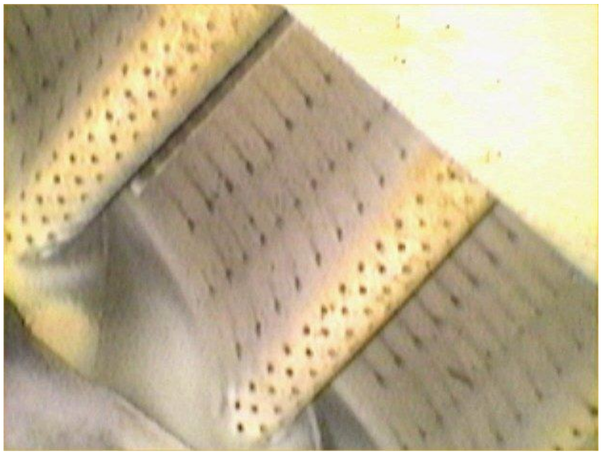

Figure 37. T64 Vane, EOT: 103 FH; +100 Time: 61 FH

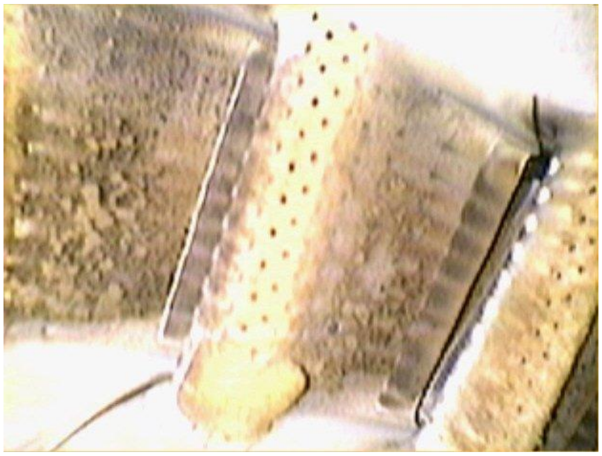

Figure 38. T64 Vane, EOT: 857 FH; +100 Time: 815 FH

It is worthy to note that the T64 engine was designed to use either JP-4 or JP-5. JP-4 is more volatile and highly flammable compared to JP-5, which has a minimum flash point of 140 ºF to reduce vulnerability to fires and explosions when exposed to an ignition source. JP-8 is similar to JP-5 but has a lower flash point of 100 ºF, lower density and viscosity. Since droplet size is dominated by the viscosity characteristics of a fuel for a given atomizer (fuel spray nozzle), higher viscosity fuels like JP-5 and JP-8 affect the fuel/air mixing in the combustor dome region leading to more unburned hydrocarbons in the exhaust. With lower volatility and thermal stability, JP-8 like JP-5 will form carbon deposits and coke crystals more readily on hot fuel-wetted surfaces.

After using the +100 additive for 100 FH, the last stage of the power turbine and engine tailpipe of the T64 engines were running cleaner and retained this level of cleanliness for the duration of the service evaluation program. Flight personnel also noted that the exterior surfaces of the H-53 aircraft were not covered with a fine carbon film after conversion to JP-8+100 and the antenna wire that runs along the right side of the aircraft no longer had a significant buildup of carbon up to 1/16th inch thick. Once the aircraft had been washed and began using JP-8+100, the carbon deposits on the antenna wire were greatly reduced as well as soot deposits on the airframe surface.

4.2.3.1 T64 Component Removal Trends

The Due in for Maintenance (DIFM) records for engines from the 58th Special Operation Wing were investigated at the "Queen Bee" engine maintenance facility at Kirtland to determine any changes in component removals before and after conversion to JP-8+100. The component removal data during the evaluation program were subsequently normalized to events per 1000 FH for comparison with removals during the baseline period. The data included both malfunction and management decision component removals. **Most notable was an 84% reduction in the Fuel Spray Nozzle Removal Rate after conversion to JP-8+100 and a 25% reduction in the Fuel Control Removal Rate**. The removal rate for the 1st and 2nd stage turbine vanes experienced reductions of 58% and 15%, but the causes for removal may be more related to distress from reduced vane cooling effectiveness on the 1st stage turbine vanes due to silica deposits on the leading edge and pressure surfaces plus removals for expired cycles than caused by fuel properties. However, the reductions in Spray Nozzle and Fuel Control removals indicate that use of JP-8+100 had provided positive benefits for the maintenance environment at the 58th SOW, Kirtland AFB.

4.2.3.2 TH-53A and MH-53J Cabin Heaters

AFSOC had expressed an interest in using JP-8+100 to reduce coking deposits in cabin heaters that had caused fires. The cabin heater is located forward of the rotor head and transmission on top of the crew cabin and burns onboard fuel in a combustor can with a single fuel spray nozzle. The heaters provide crew comfort during colder operating conditions when the cargo compartment doors are open. It was reported that the significant buildup of coke deposits in combustor cans had caused fires in several cabin heaters that posed serious safety issues for the crew and aircraft. Prior to the 1997 heating season, all the combustor cans in the cabin heaters had been replaced with a modified can. The OEM added an extra drain port in the combustor can to improve fuel drainage after shutdown of the heater.

Borescope inspections were performed on four heater combustors before the operational evaluation started and at the end of the first heating season. The flight crews were also asked to estimate heater use during each flight and enter the time on the aircraft forms which were tallied periodically. After 100 to 200 hours of operation using JP-8+100, the combustor cans remained relatively free of carbon and coke deposits with only small deposits in remote sections of the combustor. Borescope images for the baseline condition and after 179 hours of operation were compared. In all cases, the fuel nozzle and combustor remained clean in each heater with the exception of a light shiny varnish on the nozzle tips that did not affect the operation of the combustor. (See **Figures 39** through **42**)

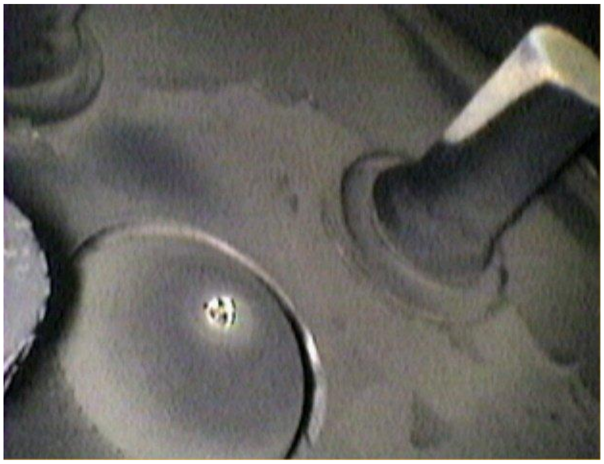

Figure 39. MH-53 Heater Combustor Dome, +100 Time: 0 Hrs

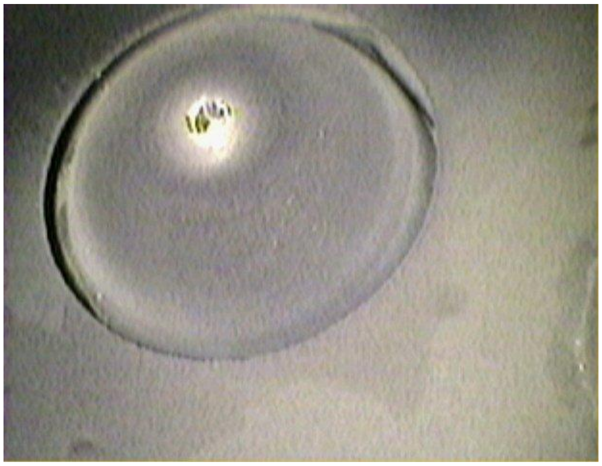

Figure 40. MH-53 Heater Combustor Fuel Nozzle, +100 Time: 0 Hrs

Figure 41. MH-53 Heater Combustor Dome, +100 Time: 179 Hrs

Figure 42. MH-53 Heater Combustor Nozzle, +100 Time: 179 Hrs

While it was impossible to determine the individual contributions of either the combustor can modification or the use of JP-8+100, the synergies of these changes has eliminated detrimental coking in the cabin heater combustor cans. If these benefits continue in the future and flight safety goals are achieved, it can then be concluded that a viable solution to the cabin heater fire problem has been achieved.

4.2.4 T400-CP-400 Engines Used in the UH-1N Helicopter

The combustion system and fuel nozzles of the T400 engine are identical to later versions of the PT6 engine. The PT6 was developed to use commercial grade Jet A fuel that has a higher density, viscosity and freeze point than JP-8. Density adjustments were provided on the fuel control to use JP-4, JP-5 or JP-8. The conversion from JP-4 to JP-8 did not cause any major maintenance issues for T400 engines except for a significant increase in carbon and coke deposits on the fuel spray nozzle face, the shrouds covering the fuel nozzles and on the outer wall of the reverse flow annular combustion system. Each fuel spray nozzle is mounted on the engine high pressure case and extends through the outer wall of the combustor liner a short distance from the dome region and is covered with a shroud for shielding. The baseline photos of engines using JP-8 at Hurlburt show the extent of coking deposits on a fuel nozzle shroud at 109 EOT since the last engine overhaul and at 1,215 EOT (See **Figures 43** through **50**). The combustor dome and outer liner walls are covered with carbon and coke deposits while small coke crystals can be seen around the fuel spray nozzle tip and on the shroud. The magnitude of the deposits has not affected combustor performance or hot section life. The liner of the reverse flow combustor apparently has adequate dilution flow to shape the temperature profile entering the exit vanes to minimize any temperature peaks that may occur from fuel spray nozzle streaking due to coking.

Figure 43. T400 Engine Combustor Dome, Hours Since Overhaul: 109

Figure 44. T400 Engine Combustor Wall, Hours Since Overhaul: 109

Figure 45. T400 Engine Fuel Nozzle Shroud, Hours Since Overhaul: 109

Figure 46. T400 Engine Fuel Nozzle, Hours Since Overhaul: 109

Figure 47. T400 Engine Combustor Dome, Hours Since Overhaul: 1215

Figure 48. T400 Engine Combustor Wall, Hours Since Overhaul: 1215

Figure 49. T400 Engine Fuel Nozzle Shroud, Hours Since Overhaul: 1215

Figure 50. T400 Engine Fuel Nozzle, Hours Since Overhaul: 1215

In contrast, the borescope images of a high time engine at Kirtland were baselined at 1543 EOT shown in **Figures 51** through **54** and then after using JP-8+100 for 414 FH (**Figures 55** through **58**) shows a substantially cleaner combustor dome and fuel nozzle face although some carbon streaking can be noted on the outer liner wall of the combustor and some fine coke crystals on the fuel nozzle shroud. **Figure 56** shows a burn through in the combustor liner that was reported to the engine mechanics. The burn through was the only distress noted during the service evaluation. However, additional service time will be required to assess the reductions in maintenance workload from using JP-8 in T400 engines.

Figure 51. T400 Combustor Dome,
Hrs Since O/H: 1543; Time on +100: 0 Hrs

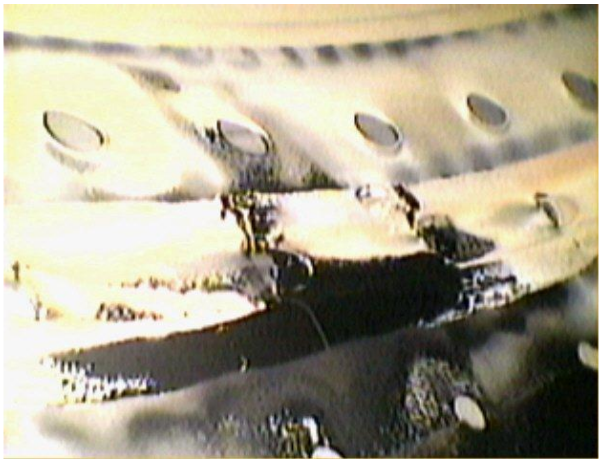

Figure 52. T400 Combustor Wall,
Hrs Since O/H: 1543; Time on +100: 0 Hrs

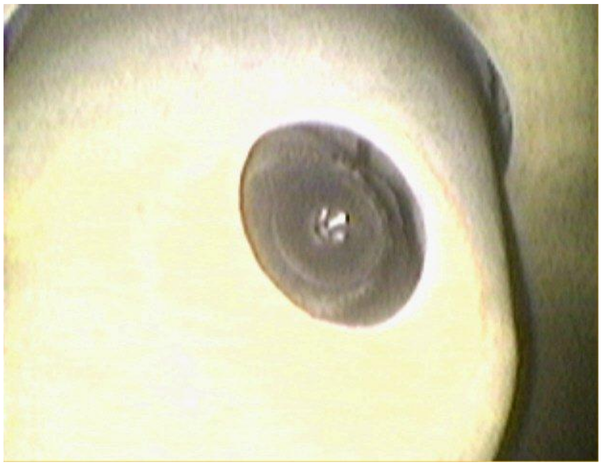

Figure 53. T400 Combustor Nozzle,
Hrs Since O/H: 1543; Time on +100: 0 Hrs

Figure 54. T400 Combustor Nozzle Shroud,
Hrs Since O/H: 1543; Time on +100: 0 Hrs

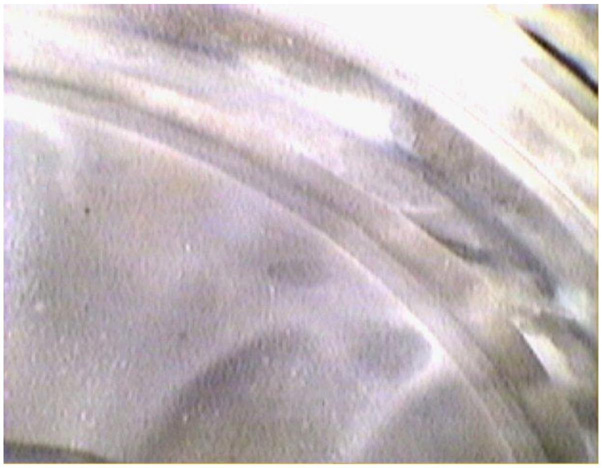

Figure 55. T400 Combustor Dome, Hrs Since O/H: 1957; Time on +100: 414 Hrs

Figure 56. T400 Combustor Wall, Hrs Since O/H: 1957; Time on +100: 414 Hrs

Figure 57. T400 Combustor Nozzle, Hrs Since O/H: 1957; Time on +100: 414 Hrs

Figure 58. T400 Combustor Nozzle Shroud, Hrs Since O/H: 1957; Time on +100: 414 Hrs

4.2.4.1 T400 Component Removal Trends

An exhaustive search was made of the DIFM records in the “Queen Bee” engine shop for T400 engines assigned to the 58th Special Operations Wing that had been refurbished. Several engine components to include the fuel pump, manual and auto fuel control, combustor liners and the injectors were investigated to establish the causes for removal. In some cases, the removals were documented but not the malfunction. Although a lot of component removal data were reviewed for T400 engines that entered the overhaul cycle, it was concluded that the removal data at best were either conservative or possibly incomplete and should not be used to assess any maintenance changes from conversion to JP-8+100.

4.2.5 T700-GE-701C Engines in HH-60G Helicopters

The T700 engine is an advanced technology turbo-shaft engine with an annular combustor using swirl cups and vaporizing fuel nozzles in the combustor dome to atomize the fuel. The improved fuel/air mixing in the T700 combustor provides much cleaner burning than the combustor design in T64 engines. After the conversion to JP-8+100, the heat shields in the combustor dome became cleaner compared to engines using JP-8. Engines that were selected for tracking had been in service from 1327 to 2153 EOT (**Figures 59** through **63** and **Figures 69** through **73**). The baseline images for some of the low time engines had light carbon deposits on the vanes in the swirl cups and small coke crystals on the vaporizing fuel nozzles as shown in **Figures 62** and **72**. Patches of carbon were also observed on the vaporizing fuel nozzles and on the flared surface of the swirl cups. After using JP-8+100 for approximately 400 FH, the vaporizing fuel nozzles and the swirl cups appeared to be running cleaner on the lower time engines shown in **Figure 67**. On the higher time engine shown in **Figure 77**, a small increase in coke deposits were noted on the swirl cup vanes and a fringe of small coke crystals had developed on the outer diameter of the vaporizing fuel nozzles. The small patches of carbon on the flared exit of the swirl cup had also increased in size in the direction of flow but had no impact on the operation as the combustor walls and exit vanes and turbine blades were very clean and free of carbon. The T700 Engine Primer Nozzles shown in **Figures 63, 68** and **73** were relatively clean in the baseline engines and showed no increase in carbon deposits after using JP-8+100. After using the +100 additive for 395 hours, the combustor dome shown in **Figure 64** appeared to have fewer carbon deposits compared to the baseline image shown in **Figure 59**. However, the higher time combustor dome shown in **Figure 74** appears to have accumulated more carbon deposits compared to the baseline combustor dome shown in **Figure 69** after using JP-8+100 for 344 hours. The slag deposits and surface erosion on the vanes shown in **Figures 61, 66, 71** and **76** are more related to the operational environment than the fuel used. However, one or more clean engines from overhaul would have provided valuable information to determine if JP-8+100 will reduce the buildup of carbon deposits on hot section parts, especially on clean nozzle swirl cups and vaporizing fuel nozzles.

Figure 59. T700 Engine Combustor Dome, EOT: 1327; +100 Time: 0 Hrs.

Figure 60. T700 Engine Combustor Wall, EOT: 1327; +100 Time: 0 Hrs.

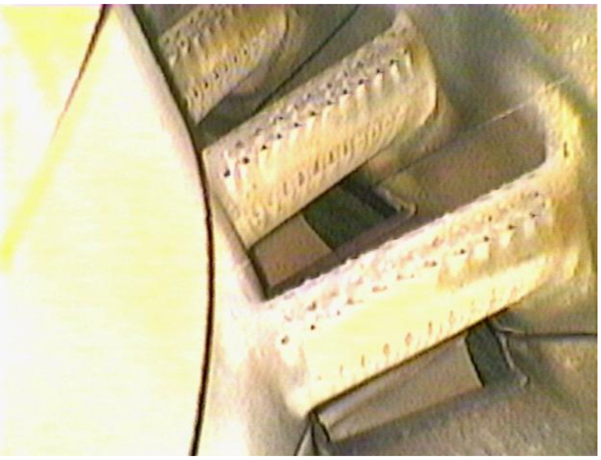

Figure 61. T700 Engine Vanes, EOT: 1327; +100 Time: 0 Hrs.

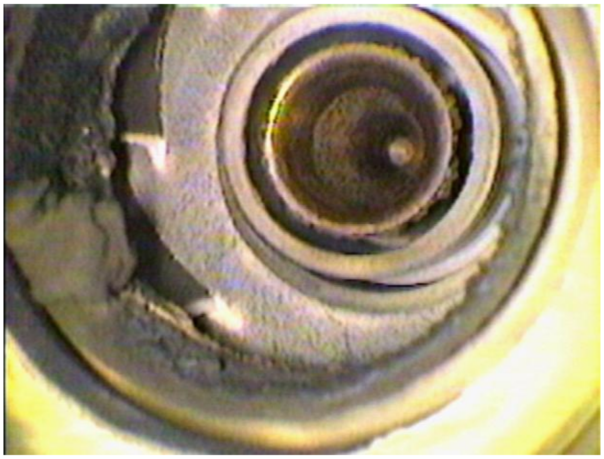

Figure 62. T700 Engine Fuel Nozzle, EOT: 1327; +100 Time: 0 Hrs.

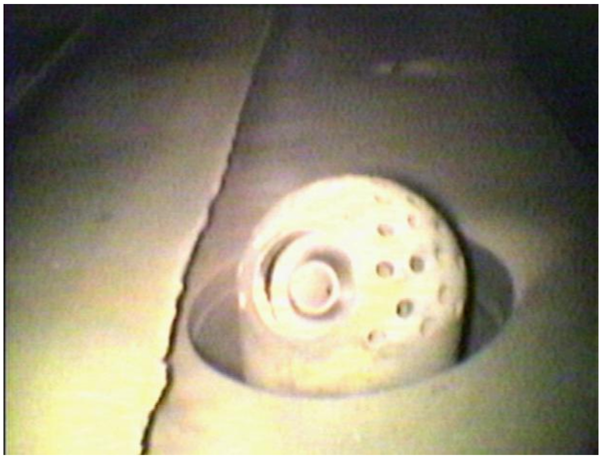

Figure 63. T700 Engine Primer Nozzle, EOT: 1327; +100 Time: 0 Hrs.

Figure 64. T700 Engine Combustor Dome, EOT: 1722; +100 Time: 395 Hrs.

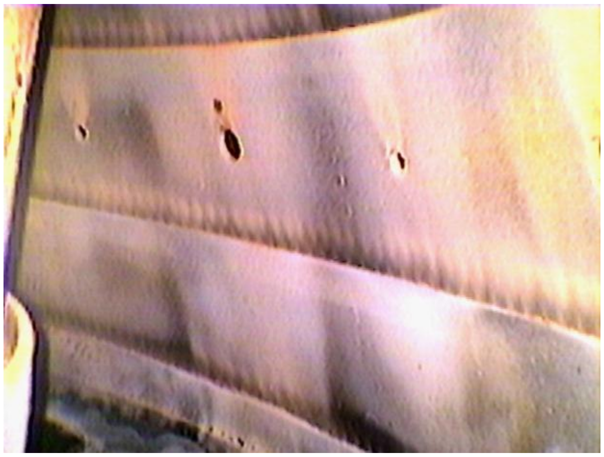

Figure 65. T700 Engine Combustor Wall,
EOT: 1722; +100 Time: 395 Hrs.

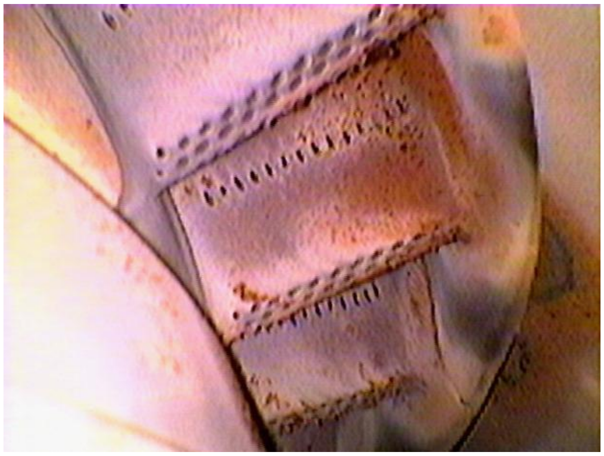

Figure 66. T700 Engine Vanes,
EOT: 1722; +100 Time: 395 Hrs.

Figure 67. T700 Engine Fuel Nozzle,
EOT: 1722; +100 Time: 395 Hrs.

Figure 68. T700 Engine Primer Nozzle,
EOT: 1722; +100 Time: 395 Hrs.

Figure 69. T700 Engine Combustor Dome, EOT: 2153; +100 Time: 0 Hrs.

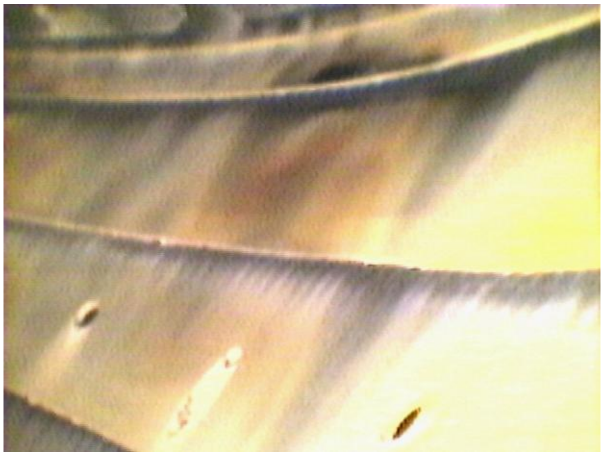

Figure 70. T700 Engine Combustor Wall, EOT: 2153; +100 Time: 0 Hrs.

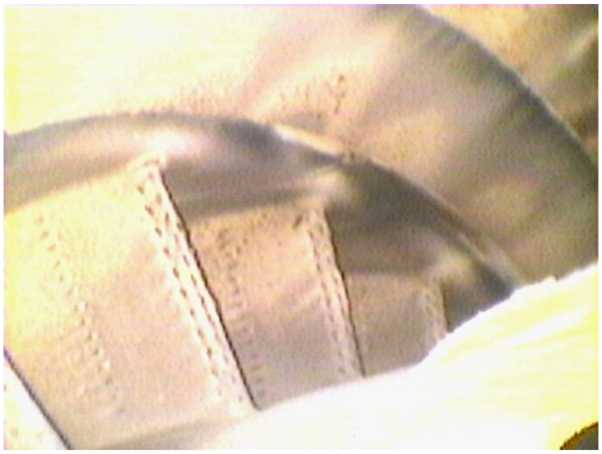

Figure 71. T700 Engine Vanes, EOT: 2153; +100 Time: 0 Hrs.

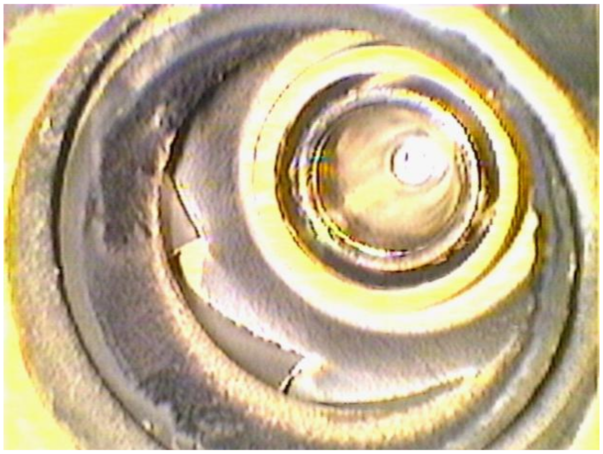

Figure 72. T700 Engine Combustor Fuel Nozzle, EOT: 2153; +100 Time: 0 Hrs.

Figure 73. T700 Engine Primer Nozzle,
EOT: 2153; +100 Time: 0 Hrs.

Figure 74. T700 Engine Combustor Dome,
EOT: 2495; +100 Time: 344 Hrs.

Figure 75. T700 Engine Combustor Wall,
EOT: 2495; +100 Time: 344 Hrs.

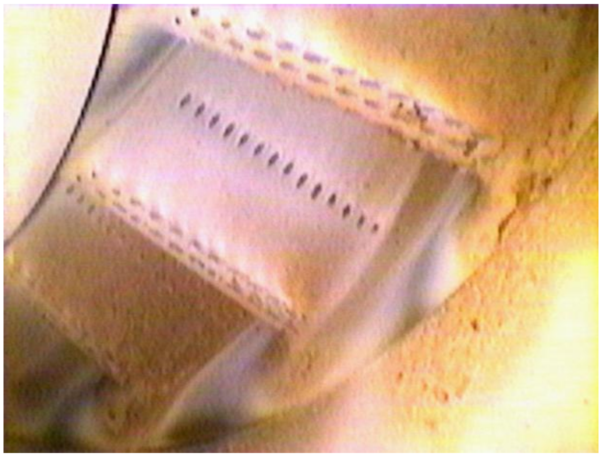

Figure 76. T700 Engine Vanes,
EOT: 2495; +100 Time: 344 Hrs.

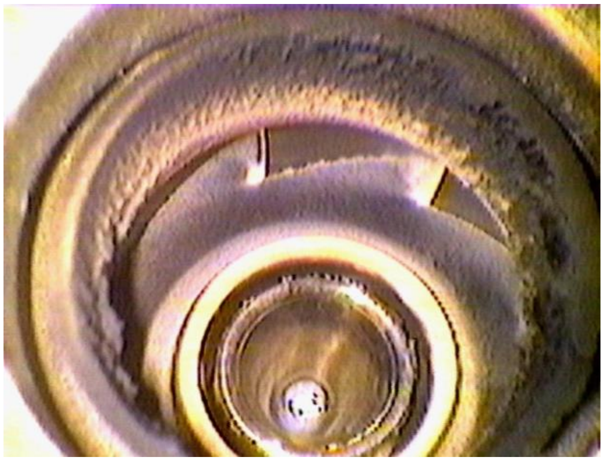

Figure 77. T700 Engine Fuel Nozzle, EOT: 2495; +100 Time: 344 Hrs.

The borescope images suggest that using JP-8+100 in clean combustor hardware direct from overhaul will reduce the buildup of carbon and coke deposits **whereas the +100 additive is unable to remove hard carbon and coke deposits in higher time combustion systems once the coke deposits are well established, however, the growth of new deposits is at a reduced rate.**

4.2.5.1 T700 Component Removal Trends

A comprehensive review of engine maintenance records was conducted to determine the number of fuel component removals during the baseline period from May 1996 through Apr 1997 and during the operational evaluation from May 1997 through Apr 1999. **Table 11** shows the removals that occurred.

Table 11. T700 Fuel Component Removals

Engine Component	Removals during Baseline	Removals during Evaluation
Hydro-mechanical Fuel Control	18	0
Fuel Pump	3	0
Vaporizing Fuel Nozzles	0	0
Primer Fuel Nozzles	6	2

It is noteworthy that no Vaporizing Fuel Nozzles were changed prior to and during the operational evaluation. This is primarily due to a combustion system design that is inherently clean burning. The Hydro-mechanical Fuel Control removals were high during the baseline period due to an identified manufacturing deficiency that needed to be corrected. However, it could not be determined from the data records if malfunctions or scheduled maintenance were responsible for some of the fuel control removals. The Primer Fuel Nozzle removals decreased from 6 in one year to 2 removals over a two year period. The aircraft mounted fuel pump removals showed a marked reduction but it could not be determined if the removals were for a malfunction or a management decision removal. Regardless of the specific reasons for the Fuel

Component Removals, the engine maintenance workload due to fuel related issues decreased during the operational evaluation of JP-8+100.

4.2.6 Conclusions

The use of JP-8+100 in the helicopters assigned to the 58th SOW, the UH-1N, TH-53A and MH-53J and the HH-60G, has helped reduce the formation of carbon deposits and coke in the combustion systems of T64, T400 and T700 engines compared to using JP-8. There was a noticeable difference in carbon and coke deposits on the fuel nozzles and combustors in T64, T400 and T700 engines after using JP-8+100. The engine mechanics commented that the carbon deposits on fuel spray nozzles were more porous and easier to remove. With less carbon in the combustion gases, the engine hot section parts and the aircraft surfaces are running cleaner. **The unscheduled engine maintenance workload has been reduced and fewer control components are being removed due to fuel related issues. Although the combustors in these engines are operating much cleaner from using JP-8+100, the detergents and dispersants in the +100 additive are unable to remove established hard carbon deposits and coke on the fuel nozzles in high time engines but growth is at a reduced rate.** Advances in combustion technology in recent years have also helped in addition to improved fuel spray nozzle atomization and fuel/air mixing in the combustor dome to better accommodate the higher viscosity and lower aromatic properties of kerosene based fuels such as JP-5, JP-8 and Jet A. However, use of the +100 additive promotes cleaner burning and reduces carbon deposits in the engine and on the aircraft skin that has reduced maintenance workload.

4.3 Tampa PD Aviation Unit Helicopter Evaluation of Jet A+100

A joint program was established between the Air Force, Tampa Police Department Aviation Unit and Hillsborough County Florida Sheriff's Office in December 1997 to evaluate the use of Spec-Aid® 8Q462 in Jet A commercial fuel. The type aircraft used by the Tampa Police Department (PD) include two Hughes OH-6 helicopters and one Bell Model 500E helicopter. The Hillsborough County Sheriff's Office (HCSO) uses a Bell OH-58 Jet Ranger. **Figures 78** and **79** show the helicopters used by the Tampa PD and the HCSO. Each aircraft is powered by one T63-A-720 turbo-shaft engine shown in **Figure 80** manufactured by the Allison Engine Company. The commercial designation of this engine is the M250 C20B.

The Tampa PD Aviation Unit and Marine Squad initially contacted AFRL/RZPF in September 1997 regarding the possible use of the +100 additive in helicopter engines to reduce the impact of coking from using Jet A fuel. Prior to this time, the only use of the additive in rotary wing aircraft had been at Kirtland AFB in UH-1, HH-60 and MH-53 helicopter aircraft. Since the Tampa PD and the HCSO support one another and sometimes refuel at each Unit, the HCSO also expressed an interest in participating in the service evaluation. However, use of the +100 additive by the HCSO was sporadic since their additive injector developed a leaking problem shortly after installation that was never fixed during the 6 month evaluation program. For this reason, any observations and data from HCSO were not reported because of inconsistent use of the +100 additive.

Figure 78. OH-6 and Model 500E Aircraft, Tampa Police Department

Figure 79. Bell Jet Ranger, Hillsborough County Sheriff's Office

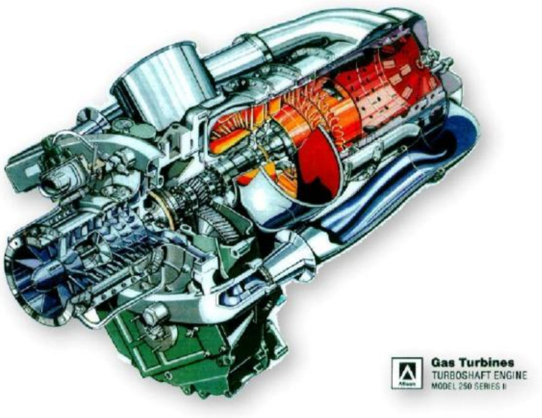

Figure 80. Allison T63-A-720 Engine

4.3.1 Two-Phased Test Program

In December 1997, AFRL/RZPF prepared a two-phased test program in collaboration with the Allison Engine Company, the Tampa PD and HCSO that included a baseline phase (Phase I) and additive evaluation (Phase II). Engine metrics were selected for tracking that included extensive use of borescope and video image recording equipment from AFRL/RZPF. During the two-month baseline phase, all engine hot sections were borescoped to document the extent of carbon deposits and then archived for future comparisons. The borescope inspections also verified that the engines operated by the Tampa PD and HCSO were in good mechanical condition. During the six month service evaluation, periodic borescope inspections were performed along with personal discussions with the engine mechanics to determine any changes in maintenance procedures after use of the +100 additive began. The T63 engine has a two stage compression system that is mounted on the gear box. A small multi-stage axial flow compressor supercharges the inlet airflow to the centrifugal compressor that further increases the pressure. The compressor discharge air is ducted to the rear of the engine where the air enters a single combustor can, fuel is injected and the fuel/air mixture burns providing hot gas to drive the turbine that in turn drives the compression system and the gear box. The gear box provides power to the rotor transmission.

4.3.2 Baseline Borescope Observations

Significant coke and soot deposits were observed in the dome of each combustor, especially around the igniter as well as on the face of the fuel spray nozzle. **Figures 81** through **84** show typical coke deposits in the combustor dome, chunks of attached carbon, coking on the face of the fuel spray nozzle and coke crystals on the lip of the primary shroud. **Figures 85** through **88** show the carbon deposits on the wall of the combustor, the dome, combustor exit vanes and the igniter area although the carbon deposits were considered typical for this engine type. As the coke crystals grow in size and carbon deposits increase around the secondary shroud, it is possible that the fuel spray pattern will begin to streak fuel causing localized distress on the combustor exit vanes.

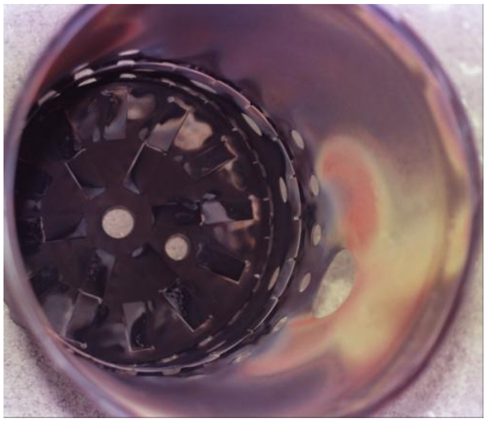

Figure 81. Coke Deposition in Combustor Dome, 250 C20B Engine

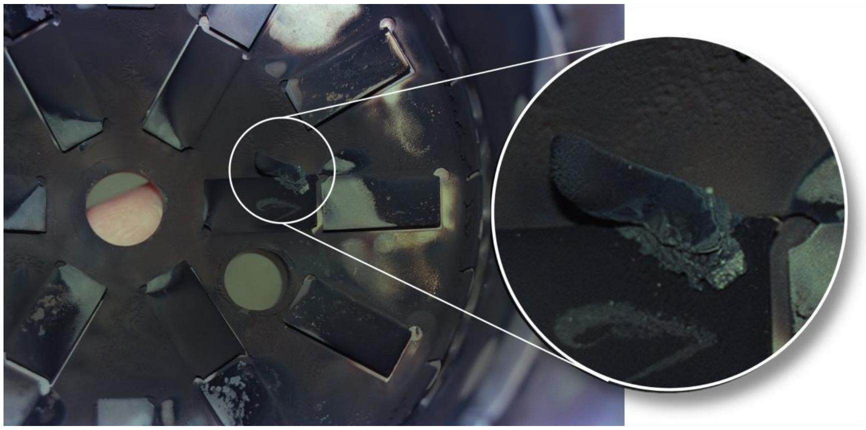

Figure 82. Enlarged View of Coke Deposition

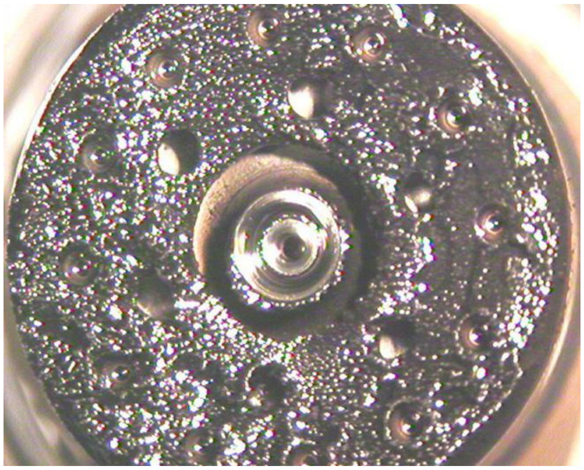

Figure 83. Typical Coke Deposition on Fuel Nozzle Face

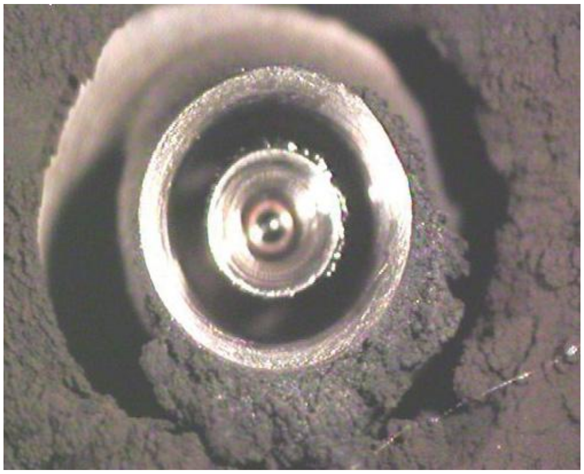

Figure 84. Coke Deposits Around Primary Fuel Nozzle

Figure 85. Combustor Wall Baseline

Figure 86. Combustor Dome Baseline

Figure 87. Baseline Condition of Exit Vanes

Figure 88. Baseline Condition of Ignitor

Due to the maintenance workload at each Unit, only two engines were tracked. Before the two month baseline program began, the fuel spray nozzles were replaced with new or clean rebuilt nozzles. By mid-March 1998, the baseline period was completed and the engines were inspected again and borescope video images taken for comparison. The following month, the six month additive evaluation program began and was completed in September 1998. New or clean refurbished fuel spray nozzles were installed when the evaluation program began in order to evaluate the extent of coke buildup while using the +100 additive.

4.3.3 Evaluation Phase

During Phase II, borescope inspections were performed before the compressor wash (cleaning procedure) to document the coke buildup in the combustor dome and on the fuel spray nozzle and to determine if any maintenance had been performed. Several intermediate inspections were performed, one in July, mid-August and the final inspections were completed in September. During the July inspection, a “grease-like” deposit was observed on the face of the fuel spray nozzle around the primary nozzle shown in **Figure 89.** As a precaution, all engines were taken off the additive for two weeks and clean nozzles installed to continue flying. After some investigation, it was concluded that the “grease-like” material found around the primary nozzle were normal for the older T63 engines in service but not on the newer Model 500E aircraft and were not caused by the +100 additive since the deposits were present when Jet A only was used. **Figure 90** shows finite coke crystals on the lip of the secondary shroud that can cause streaking in the spray cone if the size increases and deflects or bends localized fuel flow in the spray cone.

After completion of the evaluation program, the two Tampa PD helicopters had accumulated 240 and 340 FH. It was reported that the Tampa PD continues to use the additive to reduce maintenance costs due to coking. Prior to use of the +100 additive, it was not uncommon for the engine mechanics to clean the fuel spray nozzle when removed to accomplish the weekly compressor wash. The soap solution used to clean the small axial flow compressor is effective in removing salt and any fouling to restore engine performance but the solution would not remove coke deposits on the interior surface of the combustor. Typically, a 10 to 20 hour interval between fuel nozzle cleanings was considered a normal maintenance procedure. After conversion to Jet A+100, the **maintenance personnel found that the fuel spray nozzle cleaning interval could be extended from 50 to 75 FH early in the evaluation program and by the end of the program to 200 FH**. The maintenance personnel also commented that the "grease-like" deposits were no longer present on the fuel spray nozzles on the older engines after conversion to the +100 additive.

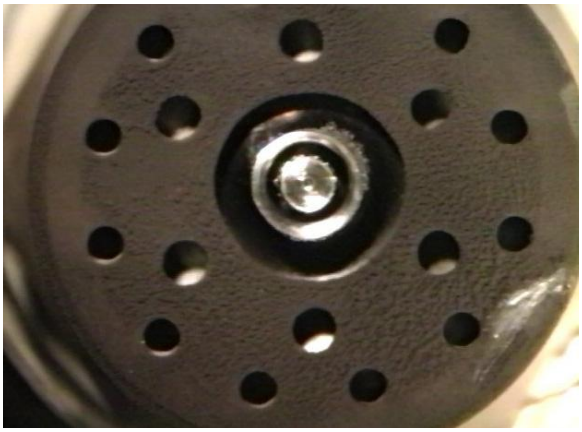

Figure 89. Carbon Deposition on Nozzle Face After Using Jet A+100

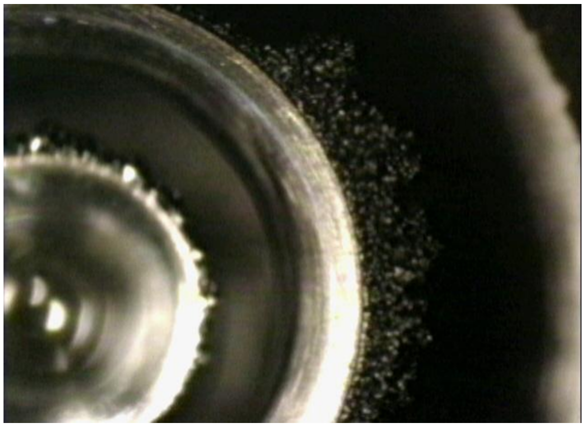

Figure 90. Enlarged View of Nozzle Coking

4.3.4 Finite Surface Cracks Evaluated

During the service evaluation, maintenance personnel detected some finite cracks on the combustor exit vanes of one engine and requested assistance from AFRL/RZPF. The detergents in the +100 additive are noted for cleaning the combustor exit vanes and downstream hot section parts making it easier to borescope bare metal surfaces that are free from coke and soot. Borescope images verified that the cracks were beyond inspection limits and potentially a safety issue. The engine was removed and sent to overhaul to avoid any liberated material from causing collateral damage to the turbine. Prior to using the additive, the vane surfaces and leading edges would become black making it difficult to detect any cracks and the extent of oxidation and erosion from any angle using normal resolution borescope equipment. Thus, use of the additive was credited with preventing a potential incident caused by a turbine failure.

4.3.5 Summary

Use of the +100 additive in the single engine Hughes OH-6 and Bell Model 500E law enforcement helicopters operated by the Tampa PD showed significant reductions in coking and sooting in the combustor of the T63-A-720 engines. After logging over 900 FH during the 9 month evaluation program, nearly **a ten-fold increase in the cleaning interval was demonstrated for the fuel spray nozzles**. When the Unit used Jet A, the fuel nozzle was typically cleaned every 10 to 20 FH during the scheduled water wash of the engine compression system when the fuel nozzle was removed to inject a water and soap solution at the compressor inlet while motoring the engine. After using the +100 additive for 4-5 months, the engine mechanics determined that the cleaning interval for the fuel nozzle could be extended from 75 FH to over 200 FH before it was necessary to remove the coke deposits on the fuel nozzle tip. Periodic power checks conducted by the pilots indicated that engine torque remained at normal levels throughout the service evaluation when Jet A+100 was being used and there was no power losses during the time the additive was used. Although cleaning a single fuel spray nozzle requires less than one man-hour, more time can now be devoted to other maintenance and inspection tasks performed during the weekly water wash.

5.0 BEST PRACTICES, PROCEDURES AND LESSONS LEARNED

Background

Many challenges were faced during the initial service evaluations and rapid expansion programs for JP-8+100. The Users assumed additional workload to use the +100 additive as well as comply with the initial fuel handling precautions and restrictions that were mandated to protect the quality of fuel issued from the fuel trucks since there was concern that the detergents and dispersants in Spec-Aid® 8Q462 added to the Air Force additive package (FSII, SDA and CI/LI) might defeat the ability of the filter separators to remove water and particle contaminants. By mid 2006, the fuel handling precautions and restrictions had been rescinded or modified based on exhaustive filtration tests at SwRI® and a subsequent three month filtration test program at Laughlin AFB designed to evaluate the conclusions and recommendations of the SwRI® investigations. Based on these accomplishments, Change 3 dated 31 July 2006 of T.O. 42B-1-1, Quality Control of Fuels and Lubricants, stated no dilution was required for JP-8+100 return to bulk storage (also see **Appendix K**). Although Sections 3 and 4 provide examples of maintenance avoidance from using JP-8+100 in legacy and more modern fighter, transport and helicopter engines, it is worthy to note that hot section parts are running cleaner, easier to inspect and the exhaust plume is barely visible according to the engine mechanics. Use of JP-8+100 has become a part of several maintenances procedures and best practices that have evolved in the engine shops that have reduced the impact of coking that occurred after conversion to JP-8. With exception to the spray ring flow check procedure that follows, many of the maintenance procedures to reduce the impact of coking were implemented over a short time period starting in 1996 for removing coke from spray rings and augmentor fuel controls of F100 engines and the fuel spray nozzles of T-56 engines. These procedures and cleaning intervals are continually being refined as experience is gained from operational experience. Also, several lessons learned will be briefly stated that were determined during the conversion to JP-8+100 in order to smooth the introduction and use of new thermal stability additives that will become available in the future.

5.1 Spray Ring Flow Check Procedure

5.1.1 Spray Ring Flow Bench

To better manage coke removal from F100-220/E augmentor spray rings, the engine shop at a large fighter Unit added the flow bench shown in **Figure 91** to their inhouse maintenance procedures in 2004 to insure that baked and cleaned augmentor spray rings meet flow requirements before installation in the augmentor module. Over 250 spray ring sets were tested over a two-year period providing accurate test data for each of the five spray rings in the categories of: 1) Passed, 2) Failed Low and High, 3) NRTS and 4) Saved after a second bake cycle. NRTS is Not Reparable This Station. Each spray ring was checked for acceptable flow within established high and low limits at several pressure levels that are the same flow limits measured during the pressure check performed by the Augmentor Fuel System Analysis System during an engine acceptance run. Because of controlled test procedures, the operator of the flow bench can perform a more thorough flow check of each spray ring than the pressure checks performed during an engine acceptance run. A pressure fault detected during an engine acceptance run would require the engine to be returned to the shop to remove the augmentor, replace any faulty spray rings and re-install the augmentor to perform another engine acceptance run. A low flow spray ring can cause an augmentor no light or blowout during the acceptance run or shortly after the engine has been returned to service depending upon augmentor use that would force the engine back into the shop for removal of the augmentor. High flow spray rings are stretched and returned to Depot for repair.

Figure 91. Augmentor Spray Ring Flow Bench Showing Spray Ring Mounted

Table 12. Augmentor Spray Ring Flow Testing

F100-PW-220/E Engines (2 Yrs data to Nov 2006)							
Segment	Cost	Total Tested	Passed	Failed Low	Failed High	NRTS	Saved
1	$6,969	245	93%	4.9%	2.0%	6.9%	2.4%
2	$6,606	259	75.1	22.8	1.5	24.3	9.3
3	$10,175	295	28.1	30.2	41.7	71.8	7.7
4	$33,519	236	86	6.4	0	6.4	6.3
5	$10,676	257	89.9	3.9	6.2	10.1	2.3
		1292					
		> 250 sets tested	Serviceable	Rebake	Stretched	Return to Depot	After baking

Note: Testing disparity due to dropouts from initial inspections for cracks, bracket distress and heat shield condition.

		Spray Ring Failure Costs: Coking and Stretched					
Segment	Cost	No. Failed Low	Reparable $	% of Total Cost	No. Failed High	Reparable $	% of Total Cost
1	$6,969	12	83,628	4.2	5	34,845	2.3
2	$6,606	59	389,754	19.6	4	26,424	1.8
3	$10,175	89	905,575	45.5	123	1,251,525	84.4
4	$33,519	15	502,785	25.3	0	0	0
5	$10,676	10	106,760	5.4	16	170,816	11.5
			1,988,502	100		1,483,610	100

Individual Reparable Costs: **$23.67/FH** (57.3% Failed due to Coking) **$17.66/FH** (42.7% Stretched)

Total NRTS Cost/FH **$41.33/FH** (2 yr average at 42,000 FH/Yr)

Table 12 shows two-years of flow bench test data for the 5 spray rings used in the -220/E engines. As noted, Seg III can be a primary source of augmentor anomalies for Units that do not have access to a flow bench since kiln ovens are not effective in providing uniform heat transfer to remove all the coke from each spray ring during the bake cycle especially if the coke deposits are well established. The shaded area in **Table 12** shows that 28.1% of Seg III spray rings passed the flow check while 30.2% failed the low flow check and 41.7% failed the high flow check. It is noted that 7.7% of the 28.1% were Saved after a second bake and cleaning cycle. Low flow is caused by coke deposits on the inner walls of the spray ring around the pintle orifices while high flow indicates the spray ring has stretched. By flow checking the spray rings, low flow spray rings can be recycled through the bake and cleaning process while failed spray rings for high flow are returned to the Depot for repair or disposal along with the low flow spray rings that cannot be cleaned after a second bake cycle.

It is noted that Seg II has the second highest dropout rate of 22.8% for Failed Low flow after being recycled through the bake and cleaning process while only 1.5% failed the high flow check. Seg II had 9.3% of the spray rings Saved after a second bake cycle, the highest in that category. Therefore it is important to consider the percent of spray rings that were saved after a second bake cycle.

Units that only bake the spray rings once run the chance that the per cent that passed will be reduced by the per cent that were saved after a second bake. For example, it is reasoned that the percentage of the Seg II and Seg III spray rings that passed without a second bake cycle would be 65.8% and 20.4% respectively. Another scenario for consideration would be the per cent of Low and High Flow spray rings that were installed that caused a failed engine acceptance run or caused an engine to have an augmentor anomaly shortly after return to service. In this case 71.8% of the Seg III and 24.3% of the Seg II spray rings that were NRTS could contribute to an augmentor anomaly during the acceptance run or later in service.

By flow checking, engine augmentors can be fitted with a set of spray rings that are fully functional thus eliminating five additional variables that can defeat a successful engine acceptance run. If some coke remains in the Seg III spray ring after the bake and clean cycle and a flow bench was not available to check the flow characteristics, the potential exists for up to 30% of the -220/E acceptance runs may detect an out-of-limit low flow during the pressure check or experience a no light or blowout in the aircraft at a future date. In either case the sunk cost to perform an acceptance run has been wasted and must be repeated after the suspected spray rings have been replaced in the engine shop.

5.1.2 Flow Bench Maintenance Benefits

The Total NRTS Costs for spray rings shown in the lower half of **Table 12** is $41.33/FH based on the number that failed the Low Flow and High Flow checks using the FY07 Depot exchange cost for each spray ring. The highest single replacement cost for the spray rings flow checked over 2 years was $1.252M for the Seg III spray ring that Failed High (stretched) and second highest replacement cost was $906K for Seg III spray rings that Failed Low (coking). Considering all spray ring replacement costs, 57.3% of the total cost or $23.67/FH was for Failed Low due to coking and 42.7% or $17.66/FH was for Stretched conditions. Using a simplified cost estimating model, failure of the spray rings due to coking is a little over 1.43% of the total engine Materials Supply Division (MSD) and the General Supply Division (GSD) costs per aircraft flight hour.

Using the 2007 cost of JP-8 at $2.30/gallon, a -220/E engine acceptance run costs around $4,669 that includes the labor, fuel burned and the MSD and GSD costs/flight hour. The average fuel burned is around 525 gallons per test cell run that accounts for 37.1% of the estimated cost of the acceptance run with 35.3% chargeable to engine MSD and GSD costs and the remaining 27.6% for touch labor. During two years of use, the flow bench has rejected around 72% of the Seg III spray rings tested. The cost avoidance from failed engine acceptance runs has paid for the flow bench installation in one year. Avoiding the consumption of 35,000 to 40,000 gallons of fuel each year for engine ground testing would allow more sorties to be launched at no additional cost and less wear on engines during an acceptance run.

As worldwide fuel prices continue to increase, use of JP-8+100 in F100 series engines known to have coking problems in the augmentor spray rings will help to avoid engine maintenance costs. Fighter Units that have frequent augmentor no light and blowout problems during engine acceptance runs or shortly after an engine is returned to service may find an early return on investment after installing a spray ring flow bench. Spray rings, especially the Seg III, can be fully checked and, if necessary, enter another bake and cleaning cycle to remove coking that is causing the low flow. Otherwise, the Seg III spray ring can be returned to the Depot for a new or repaired spray ring. Based on the number of -100/-220/E engines assigned to a Unit, a one to three year return on investment is possible to purchase and install a spray ring flow bench that includes the cost to satisfy all the environmental mandates. The -229 engine uses fuel spray tubes in the augmentor that have thus far not caused augmentor anomalies due to coking and would not benefit from a flow bench designed for the legacy F100 engines fitted with spray rings.

5.1.3 SEG II/III Self-Cleaning Design Mod

A Seg II/III spray ring design modification has been developed under the Joint Service Component Improvement Program (CIP) with a planned date for manufacturing release in FY08 but has been delayed due to funding constraints. This Mod is intended to more quickly remove the residual fuel in SEG III after augmentor shutdown thereby helping to reduce the coking between the 4 and 8 o'clock position in the spray rings. The SEG II and SEG IV spray rings have already been modified and released to the field circa 2004. A small hole in each spray ring that faces upstream provides ram air pressure to force the residual fuel from the spray ring after augmentor shutdown. Plumbing changes are required for the fuel supply line of the Seg III spray ring to enter from bottom dead center through the Seg II mounting port in the augmentor case. The Seg II spray ring supply line will then be routed through the Seg III mounting port in the augmentor case. The design change will reduce augmentor no lights and blowouts due to coking and reduce the current NRTS of 72% for the Seg III spray ring partially due to heavy internal coking. This design change would also allow better alignment of the Seg III spray ring with the other 4 spray rings in -220/E augmentor and help increase the average time-on-wing. A side benefit might be future use in the legacy -100 engines if economically viable. The potential exists for fewer engine troubleshooting runs and UFC changes to fix an augmentor anomaly.

5.1.4 Spray Ring Maintenance Best Practices

For Units unable to justify the installation of a spray ring flow bench but continue to experience augmentor no lights and blowouts from unknown causes, it is suggested that the Seg III spray ring, which has a 72% dropout due to coking and stretching, be replaced while the other spray rings are baked and cleaned when the augmentor module has been removed for suspected coking problems. Augmentor anomalies have been reduced when the spray rings are baked and cleaned and the Seg III spray ring replaced by convenience before or during a phase check of the aircraft around 600 FH. This replacement practice better aligns the spray rings and reduces the likelihood that accelerated coking in the Seg III spray ring would force several baking and cleaning cycles of all spray rings before reaching the 1200 FH recommended service interval.

5.2 Ground Support Equipment Benefits

It was reported that JP-8+100 reduced fuel system fouling/coking and maintenance in ground equipment. In tests of the A/M32A-60B ("Dash 60") start carts at the 152nd RECCE Group (ANG), Reno NV, JP-8+100 fuel nozzle fouling was significantly reduced as well as combustor damage and burn-throughs. Savings of $1,500 per start cart were estimated.

5.3 JP-8+100 Use

5.3.1 Additization Rates

Spec-Aid® 8Q462, the additive used in JP-8+100, is a combination of an antioxidant, a metal deactivator and a proprietary detergent/dispersant. There is some difference in opinion whether the correct additization rate is 256 parts per million by volume (ppmv) or 256 mg/liter as both of these have been used somewhat interchangeably. The published density for Spec-Aid® 8Q462 is 7.5 pounds mass (lbm) per gallon. This equates to a specific gravity of 0.898 or 898 g/liter. Additization at 256 mg/liter is equivalent to 285 ppmv. Additization at 256 ppmv is equivalent to 230 mg/liter. In most laboratory evaluations of +100, additization is typically 256 mg/liter. In the field, however, additization is usually calculated on a volume basis and is set at 256 ppmv. Based on the thermal stability performance curves shown in **Figure 92**, it makes little difference whether injection is at 256 mg/l or 256 ppmv, since there is no impact on the thermal stability enhancement performance. However, injecting additive at 256 mg/liter results in approximately 10% more additive being consumed than if injection is at 256 ppmv.

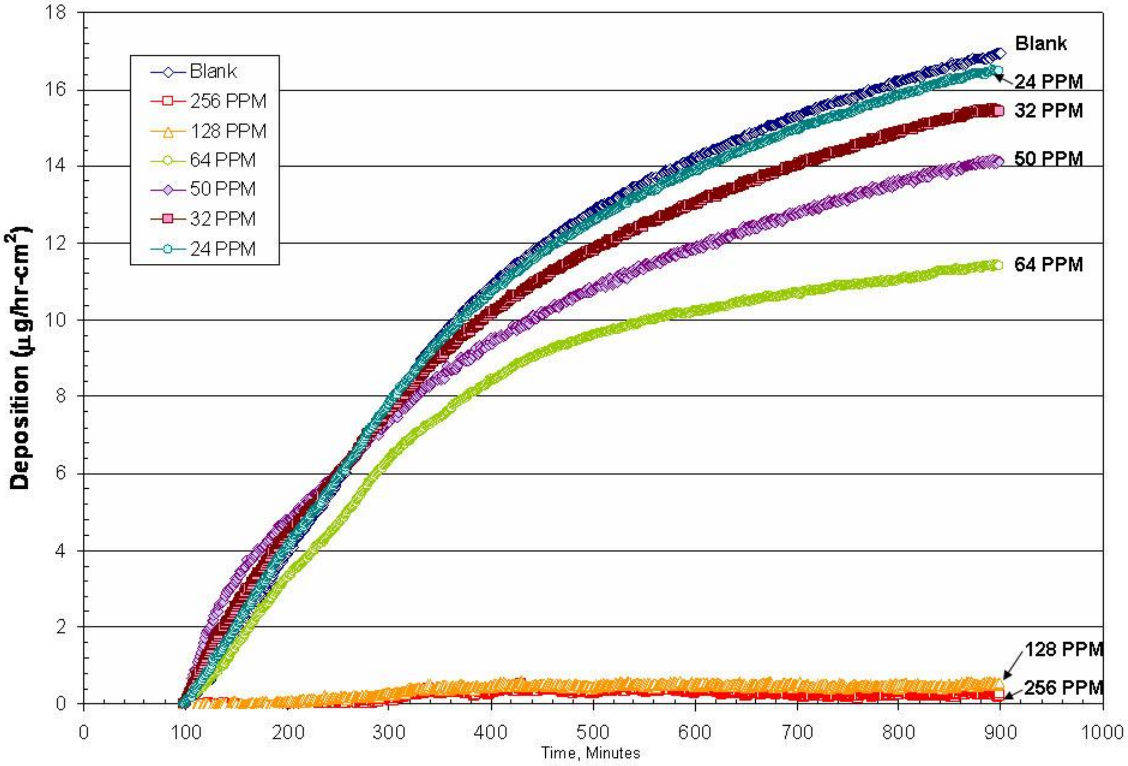

Figure 92. Effect of Additive Dosage Rates on Fuel Thermal Stability Rating

During the development of JP-8+100, many tests were conducted using concentrations of additive up to 4 times the normal dosage rates. Most of the materials compatibility testing was done at these dosage rates. Therefore, while it is most desirable to maintain additive dosage rates at the approved 256 mg/l, there is no harm in temporary over-dosages up to 1,024 mg/l. In isolated cases, the additive injector on the fill stand has malfunctioned resulting in over-dosages beyond 4X. No negative impact has been noted on systems exposed to these high dosage rates, however, the User is encouraged to calibrate injectors often so that additization rates are always at optimum levels.

A minimum effective dosage rate has never been officially determined although some data obtained during the early part of the testing and qualification of the +100 additive suggests that thermal stability improving effectiveness is significantly reduced below 128 mg/l as shown in **Figure 92**.

5.3.2 Impact of +100 Additive on Fuel Conductivity

The addition of Spec-Aid® 8Q462 to fuel may increase fuel conductivity by 70-150 pS/m (pico-Siemens per meter) and as much as 300 pS/m at extreme temperatures. As shown in Table 4.2 of T.O. 42B-1-1, the Receipt and Use conductivity for JP-8 should be in the range from 50 to 700 CU while the specification range for Use is from 150 to 450. In case the base stock fuels are running high in conductivity, the User should monitor additized and base stock fuel conductivity to make sure it does exceed recommended use limits.

In some cases, the addition of Static Dissipater Additive (SDA) may need to be reduced in delivered fuel to allow for the 70-150 pS/m increase after the +100 additive is injected. On the other hand, studies have shown that the presence of the +100 alone (without the SDA) is not enough to raise base stock JP-8 conductivity to specification limits. Therefore, it is still necessary to use SDA in JP-8.

5.3.3 Materials Compatibility

The Spec-Aid® 8Q462 additive has been evaluated for compatibility with over 200 materials used in aircraft systems. The materials studied were selected by materials experts from both the Air Force and the major aircraft and engine manufacturers. Only those materials that were of suspected concern were tested. The study concluded that JP-8+100 was "judged acceptable primarily based on its comparison to JP-8 the control fuel."

In the 15+ years that the additive has been in use, there have never been any confirmed reports of material compatibility issues from using JP-8+100. There have, however, been reported materials compatibility issues with other JP-8 additives, such as the Fuel System Icing Inhibitor (FSII).

5.3.4 Injection Approaches for Spec-Aid® 8Q462

5.3.4.1 In-Line Injection at the Fill Stand

As mentioned Section 5.3.1 above, the recommended dosage rate for Spec-Aid® 8Q462 in JP-8 is either 256 mg/l or 256 ppmv depending on whether injecting the additive for laboratory studies or use in the field. Field injection can be accomplished using in-line, fuel-stand-mounted injectors (commonly a Hammonds 800 Series) shown in **Figures 93** and **94**. These injectors operate based on hydraulics and do not require electrical power to function. As fuel flows through the in-line injector, an internal device meters and injects the additive into the fuel. The turbulence produced by the fuel in the downstream plumbing as it flows to the refueler truck is sufficient to accomplish complete blending of the additive into the fuel before reaching the refueler truck.

Figure 93. Hammonds In-Line Additive Injector

Figure 94. Additive In-Line Injector, Additive Feed and Fuel Line Connections

Figure 95. 500 Gallon (US) Bulk Additive Storage Tank

Figure 96. 2000 Gallon (US) Bulk Additive Storage Tank

The additive is usually stored in a bulk storage tank and plumbed directly to the inlet port of the additive injector. **Figures 95** and **96** show two bulk storage tanks, a 500 US gallon capacity vertical tank and a larger 2000 US gallon tank. Shut off valves placed strategically in the additive supply line from the tank allows the User to turn the additive feed on or off. The installation details for these tanks are determined by the environmental, safety and health regulations and policies at the using location. Typically, some sort of secondary containment is provided in case there is a tank leak or rupture.

Even though in-line, fill stand-mounted injectors have proven to be reliable; they still must be calibrated frequently to assure proper additization rate. A long term check of additization rate can be accomplished by monitoring the amount of fuel issued from the fill stand over a specific time period compared to the amount of additive replenished in the additive bulk storage tank. While less accurate than other calibration methods, this method does provide a ‘sanity check’ for the additive dosage rate.

6.0 US NAVY FUEL STABILITY CHALLENGES

The US Navy maintains strict control of aviation fuel specifications because some naval aircraft operate from both land based and carrier environments. The technical paper entitled "Fuel Stability Challenges in a Marine Environment: A US Navy View" delivered at the IASH 2000, 7th International Conference on Stability and Handling of Liquid Fuels, Sherry A. Williams, et al, Graz, Austria, September 24-29, 2000 provides an excellent review of the challenges in providing high quality aviation fuel. This paper provides a USN perspective of worldwide fuel handling, use of JP-5 and commercial fuels, land and shipboard fuel storage and handling problems, and the use of additives in defining fuel stability requirements for ship and aircraft fuel operating in a marine environment. This paper also discusses the entire scenario of fuel handling problems and stability issues facing the USN for shipboard and aviation use to include fuel additives and thermal stability improvers such as the +100 additive. Because the scope of the Navy paper is considered of vital interest to military and commercial users of aviation fuel, the technical paper has been included in **Appendix B** of this report to better understand the breadth of fuel requirements for US Navy shipboard, aviation and non-aviation systems.

The primary concerns that the US Navy identified for use of the +100 additive are:

1. Inhibits dirt and water removal from the fuel prior to aircraft loading by disarming the shipboard filter coalescers and decreases the performance of shipboard centrifugal purifiers
2. Has the potential to dislodge accumulated sediment from storage distribution systems, blocking delivery systems and/or contaminating aircraft or ship propulsion systems
3. Has not been cleared for use in shipboard propulsion and power generation systems which often use aviation fuel as an alternative to their primary fuel, F-76
4. Does not have a field test kit which can accurately detect concentrations in the fuel down to 25 ppm, which is necessary to facilitate real time flight deck defueling decisions

As a result, the US Navy is not planning on implementing or conducting further evaluation of the USAF approved Spec-Aid® 8Q462 +100 thermal stability additive. Therefore, the US Navy requests that the USAF or any Allied Military organization contemplating expanded use of the GE Betz additive not issue any fuel containing the +100 additive to any Navy aircraft.

Paper Abstract

> *"Ship and aircraft propulsion fuels face unique stability challenges in the 21st century. Increasing hardware requirements, changing refinery practices, and stringent environmental mandates all contribute to these challenges. Unfortunately, the United States Navy (USN) is not immune to these issues. Having worldwide commitments to supply both ship and aircraft support, the USN is faced with difficult decisions regarding how to best address these stability issues in both ship and aviation fuels without compromising operational capability. What may be acceptable solutions for commercial ships, commercial aircraft, or land-based military aircraft may be unacceptable due to the USN operating environment. From long-term storage requirements to the utilization of commercial distillate marine fuels to the shipboard impact of the +100 aviation fuel thermal stability improvers, the USN is constantly addressing stability problems and their potential solutions. The intent of this paper is to*

provide an overview using current issues of the USN philosophy, approach and rationale to address the fuel stability challenges of the 21st century".

Discussions

Due to the unique operating requirements of the USN, the need for stable fuel is absolute. Operations routinely require worldwide movement of ships, aircraft and non-aviation equipment. This requirement means that ship and aircraft fuel are lifted from many parts of the world and the USN mixes both military specification and commercial fuels from many sources in shipboard storage tanks. Aircraft propulsion fuel stability is another concern in the Navy's shipboard environment. All aircraft capable ships must be able to receive, store and issue JP-5 aviation fuel. In addition to this fuel being used in aircraft aboard ship, JP-5 is an alternate fuel for ship propulsion, ship's auxiliary equipment and Marine landing vehicle use. JP-5 is the only aircraft fuel that is approved for use in the Navy's marine environment. All shipboard fuel, both ship propulsion and aircraft propulsion, must meet a minimum 60 °C (140 °F) flashpoint. Therefore, JP-8, JP-4 and commercial aviation fuels (all with lower that 60 °C flashpoint requirements) are not authorized for use in aircraft carriers and are not authorized for storage onboard ship.

One of the biggest stability problems for aviation fuels in the marine environment is the use of additives, including the +100 thermal stability improver additive. Additives that may pose no problems for shore-based users can cause many unforeseen problems in the shipboard environment. Therefore, the USN has investigated the possible shipboard effects of the +100 additive for use in JP-5.

To determine the possible economic benefit of using the +100 additive and since future aircraft may require the additive, the USN has investigated the effects of the +100 additive in the shipboard environment and determined preliminary costs for making shipboard systems compatible with the additive. The most significant detrimental impacts of the +100 additive on the shipboard fuel distribution system circa 2000 are: 1) use of additized fuel in non-aircraft systems, 2) disarms current DOD filter coalescer elements used in aviation fuel filtration systems, 3) decreases the ability of centrifugal purifiers to effectively separate water and sediment from fuel, 4) cleans interior surfaces of fuel tanks and piping which will cause an increase in the sediment during initial shipboard implementation, and 5) can cause false low readings on the shipboard Free Water Detector and/or the Aqua-Glo free water detector.

The biggest impact for the USN is the use of +100 additized fuel in non-aircraft systems. JP-5 is not only used for aircraft propulsion but also an alternate ship propulsion fuel where JP-5 is commingled with F-76 in water-compensated storage tanks. JP-5 is also used in support/ auxiliary equipment on-board ship and is used in US Marine Corps landing forces vehicles. These non-aircraft uses perpetuate the problems that must be taken into account when evaluating the impact of the additive in the shipboard environment.

The USN recently completed a study on the costs of implementing the use of the +100 additive in the shipboard environment. Preliminary estimates show that if the current technological roadblocks could be overcome, it would cost a minimum of $20M/carrier to retrofit each to be +100 compatible. USN cost benefit studies have determined that the maintenance cost savings to carrier aircraft would not justify the costs of shipboard implementation, thus the USN is not planning shipboard implementation of the +100 additive at this time.

Finally, the USN will continue to support the development and evaluation of new equipment, fuels and additives by working with weapon system designers to ensure environmental and fuel requirements are considered in the design of new systems prior to implementation. This partnership will ensure compatibility between hardware and fuel prior to implementation. While not all the developments that may benefit commercial activities can be utilized, the USN will continue to challenge the industry to come up with shipboard-friendly alternatives.

7.0 FAA QUALIFICATION OF ADDITIVES FOR AIRCRAFT USE

The FAA has formal procedures for approving the qualification of fuels, lubricants and additives in certificated aircraft engines. A copy of this published document can be found in **Appendix C** of the report entitled "Qualification of Fuels, Lubricants and Additives for Aircraft Engines", Advisory Circular (AC) No. 20-24B, dtd 12/20/85. The purpose of this section is to provide general comments and a synopsis of AC 20-24B to outline the guidance on methods of compliance to obtain approval for a new additive but in no way superseded the procedures and requirements described in the most current release of AC 20-24B.

General Comments: The FAA's requirements for approval focus on safety, not performance enhancement. Therefore, FAA requirements related to fuel additives are intended only to prove that the product does not harm the engine, and are not intended to validate performance improvements. The applicant is required to control the formulation and manufacture of the additive. So, the applicant cannot seek approval for a product that is purchased off the shelf unless an agreement is obtained from the additive manufacturer, however, the designer / manufacturer of an additive may seek approval for a product. The FAA does not approve the fuel additive per se, but rather approve specific engines to operate with the fuel additive. This complicates the approval process since the FAA is not structured to provide "blanket" approval for all turbine engines.

Approval Options: The most practical approach for approval of a new additive is to work with the engine manufacturer and have their internal engineering organizations evaluate the additive. If acceptable, the engine manufacturer can then approve it internally and publish service information allowing use of the additive. However, if engine manufacturers have no interest, then the applicant would have to approach the FAA as an independent 3rd party and apply for a Supplemental Type Certificate (STC) for specified engine models. The application would be made to the geographically assigned Aircraft Certification Office (ACO).

Relative to fuel, oil or additives, the STC procedures may be considered "cumbersome", because approval must be obtained for each engine model separately, and then for each airplane for which those engines will be installed. The additive has to be shown to meet both the engine regulations (CAR 13 or FAR 33) and the airplane regulations (CAR 3 or FAR 23). FAA AC 20-24B provides guidance on compliance methods to obtain these approvals. The Advisory Circular specifies a 150 hour endurance test (or a 500 hour flight test) and materials compatibility analyses.

The following material is an abbreviated version of AC 20-24B referenced above:

Background: In certificating an engine, the Administrator has responsibility under Federal Aviation Regulations (FARs), Part 33, for establishing the limitations for the engine operation on the basis of the operating conditions demonstrated during the block tests. Such operating limitations include those items relating to power, speeds, temperatures, pressures, fuels and lubricants which are found to be necessary for safe operation of the engine. The limitations on fuels and lubricants include the additives that may be blended with fuels and lubricants. The suitability and durability of all materials used in the engine are established on the basis of experience or test, and all materials used in the engine must conform to approved specifications.

Discussion: Fuels and lubricants found to perform satisfactorily during the type certification program of an engine are approved as part of the Type Certificate (TC) and are listed on the pertinent Type Certificate Data Sheet (TCDS). Issuance of the TC constitutes approval of the fuel and lubricant specifications provided by the engine manufacturers. It is FAA policy that fuels and lubricants produced by companies other than those used in the type certification program may be used in a certificated engine provided the products meet the fuel(s) or lubricant(s) specification(s) for that engine. Fuels or lubricants that are not in conformance with the TC holder's approved specification listed on the TCDS, or a specification approved under a Supplemental Type Certificate (STC) are not eligible for use in a certificated engine. These non-conforming fuels or lubricants must satisfy the certification requirements outlined in Paragraph 5 of AC 20-24B, PROCEDURE, in order to be approved. In addition, all synthetic lubricants are considered "new material" and must be individually approved. Additives to be used as a supplement to an approved fuel or lubricant also are considered to be a "new material" because their addition can significantly alter the physical and chemical properties of the fuel or lubricant. These additives must be approved on an individual basis. In all cases, separate approval is required for each engine model or model series. Further, such materials are not eligible to be used in a certificated aircraft until the compatibility of these materials has been established with aircraft components with which they come in contact.

Procedure: The producer of a product requiring an STC or an amendment to an existing TC may apply to the Aircraft Certification Office (ACO) in the geographical area in which the applicant is located. The geographic ACO will administer the program; however, the ultimate approval and issuance of the engine STC, or an amendment to an existing TC, is the responsibility of the Engine and Propeller Certification Directorate located in the New England Region. Such STCs or amended TCs, may be approved for the fuels, lubricants and additives for use in designated engine(s) upon receipt of suitable data demonstrating compliance with the applicable portions of the FAR Part 33. The data should be obtained during an FAA approved and witnessed test program and should include: a) Preliminary Data, b) Test Description, c) Final Data, d) Identification and e) Concentration. More detail is provided in each of these sections in AC 20-24B.

a. Preliminary Data: The applicant should submit a report to substantiate that the fuels, lubricants or additive combinations have undergone sufficient test and development to show that, under the conditions in which they will be used in the aircraft, they are compatible with the applicable engine and aircraft materials.

b. Test: A description of the test program and equipment that the applicant proposes to use in demonstrating the airworthiness of the material to be approved shall be submitted for approval. In accordance with FAR 33.53 and 33.91, Engine Component Test, a test should be performed with the objective of showing that the subject material will not cause deterioration or any other unsatisfactory condition on or in any of the non-metallic engine parts.

c. Final Data: At the completion of the aircraft engine tests, a report should be submitted that describes, at minimum, the engine, test conditions, chronological history of test conditions, analyses of fuel samples, depositions or other harmful effects due to deterioration, excessive seal swelling, shrinkage, hardness or unsatisfactory condition on or in any engine parts. Please refer to AC 20-24B for more detail requirements.

d. Indentification: The material tested must be covered by a specification that is written in sufficient detail to provide, at minimum, the physical properties and limits by which uniform quality and composition can be maintained. If the material is to be used in a blend with another material, instructions for blending should be provided which include safety precautions.

e. Concentration: The materials tested should be approved for use in the concentrations "up to the maximum" at which they were qualified by test.

The above procedures are not considered unreasonable, as fuel or additives may have adverse effects on different engine models and airplane types due to differences in fuel wetted materials or engine performance demands. For example, it cannot be "assumed" that because an additive works in an automobile engine or one model series of turbine engine that it will have no harmful effect on another turbine engine or airplane type. Further clarifications can be obtained from the FAA Point of Contact.

FAA Point of Contact:

Mark Rumizen
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Three documents, located in **Appendix D**, **Appendix E** and **Appendix F**, are examples of service information from GE Aircraft Engines, Pratt & Whitney, and Turbomeca that provide minimum specifications and/or approvals for aviation fuels and additives for use in aviation gas turbine engines manufactured and supported by these engine companies. Document titles are as follows:

GE Aircraft Engines, Specification No. D50TF2, Issue No. S15 dtd Feb 9, 2005. Reference Table II – Fuel Additives, page 8, in the row for Thermal Stability (**Appendix D**).

United Technologies – Pratt & Whitney, Turbojet Engine Service Bulletin No. 2016, Revision No. 28 dtd January 27, 2006. Engine Fuel and Control – Fuel Additives – Requirements for, and Approval of. Reference Part III: Approved Additives in Section C. (2) Thermal Stability Additives on page 9 (**Appendix E**).

Turbomeca - Service Letter No. 2258/04/Arriel1/76. Subject: Arriel 1 - All Varients; Use of '+100' additive to fuel and Turbomeca - Service Letter No. 2259/04/Arriel2/17 - 2nd Issue, Subject: Arriel2 - All Variants, Use of '+100' additive to fuel (**Appendix F**).

8.0 RESOLVED AND UNRESOLVED ISSUES IN HANDLING JP-8+100

Introduction: During the JP-8+100 field service evaluations and the rapid expansion program that followed, several fuel handling issues were identified. Aircraft defuels and the mandated fuel handling precautions soon became insurmountable barriers to widespread acceptance and use of the +100 additive - especially at small Units. For expediency, the Air Force decided to inject the additive at the fill stand. In retrospect, injecting the additive on the refueler trucks may have provided more flexibility to provide two grades of fuel and support untimely defuels with limited refueler assets - again, especially at smaller Units. The cautious 1:100 blend back ratio severely limited returning more than 1,000 gallons of JP-8+100 to bulk storage. Units with legacy fighter engines benefited immediately after conversion to JP-8+100 while other Units with more modern engines noted that benefits accrued over 1 to 3 years. At some fighter Units, additive use soon became an important part of several maintenance procedures that helped reduce engine anomalies and unscheduled engine removals. JP-8 use in turbo shaft and legacy fighter engines accelerated fuel nozzle coking that would cause hot section distress and reduce engine time on wing. However, readiness for rapid deployment forced many Units standing alert to turn the +100 additive off. A summary of the JP-8+100 transition issues and the fuel handling challenges faced by Units are provided below followed by an explanation of the resolved and unresolved issues. Recommendations are provided to make use of the +100 additive as seamless and transparent as possible.

JP-8+100 Technology Transition Issues:

- Use was voluntary. Units wanted solution to fuel coking and hot section distress.
- No initial interest in JP-8+100 at Fighter Engine Depots. MAJCOMs encouraged service evaluations.
- Handling procedures and management responsibilities mandated to assure highest quality fuels.
- Handling precautions established to prevent disarming API 1581 3rd Edition filter coalescers.

Units Faced Many New Challenges:

- Handling responsibilities increased to provide dual fuel capability, service large transient aircraft.
- Small Units directed to dedicate two refuelers to issue JP-8+100 and one refueler to issue JP-8.
- Major handling and logistic problems to defuel C-130H transports with 3 full R-11 fuel trucks.
- Defuels and fuel transfers - usually untimely - were complicated without empty refueler and RTB capacity.
- Without bypass of 3rd Edition filter coalescer vessel in receiving line, RTB considered impossible.
- JP-8+100 RTB limited to around 1,000 gallons with 1:100 blend back ratio. RTB would require filter changes.
- 1-2 month advanced planning required to return aircraft to JP-8 status before deployment.
- POL must insure JP-8+100 not issued to unauthorized or non-program aircraft.
- OPR support ended during rapid expansion program due to SA-ALC closing. Decisions left to +100 Users.

Other Fuel Handlers concerns:

- Additive injection varies with fuel flow rate. No way to insure concentration of +100 additive.
- Additive will increase conductivity of JP-8+100 above use limit if JP-8 receipt CU is too high.
- Hard plumbing and quick disconnect fittings needed to reduce additive spillage and body contact.

- Health concerns – JP-8 is an irritant to skin inside protective gloves, shoes and clothes.
    - Spec-Aid® 8Q462 additive feared to increase toxicological problems associated with JP-8.
    - Elevated anxiety for JP-8+100 use. More health and safety precautions than JP-8.
- The Spec-Aid® 8Q462 additive stinks. Difficult to remove small spots on clothes and pavement.

Post 9/11 and Iraq War Issues:

- Many AF and ANG Units turned the additive off to remain on alert status for rapid deployment.
- Some Units continued to use the additive. Stopped during surge to refuel large aircraft with JP-8.
- Without additive, augmentor anomalies increased due to coking in legacy fighters in 3-6 months.
- Return to JP-8 decreased average time on wing and increased engine maintenance workload.

Background: Rising fuel costs and flight safety issues were major consideration in the conversion from JP-4 to JP-8. The OSD decision to execute this conversion forced the use of JP-8 which has a higher propensity to form coke due to a lower volatility than JP-4 resulting in an increase in the formation of varnishes and coke in fuel-wetted engine components exposed to high temperatures. After conversion to JP-8 in 1993/1994, the legacy F100 engines powering F-15 and F-16 fighters began to experience an abrupt increase in augmentor anomalies due to coking. These engines were developed to use JP-4 which is highly volatile, evaporates rapidly leaving very few residues on hot metal surfaces. Increased coking was also observed on the fuel spray nozzles that caused fuel streaking and reduced hot section life of turbo-prop engines powering C-130H transport aircraft, turbo-shaft engines in helicopters and legacy trainer engines. The impact of coking on the flying program and maintenance workload of the operational Units soon gained priority status and the MAJCOMs approached the Engine Development Community at WPAFB, OH for solutions. It was timely that the Fuels Branch in the Propulsion Directorate (AFRL/RZPF) had completed the qualification of an additive in 1994 that increased the thermal stability of JP-8 by 100 ºF. Although the +100 additive was targeted for initial use in the F-22 Advanced Tactical Fighter to increase fuel heat sink capacity and reduce the formation of varnish and coke deposits, it was considered available as a mature technology for legacy aircraft.

A two-phased program was planned to evaluate JP-8+100 use in operational service. Phase I, launched in 1994-1995, provided initial service evaluations in F-16A/B fighter and C-130H transport aircraft. Phase II provided for rapid expansion to other F-15, F-16, C-130H transport and helicopter Units that volunteered to use the JP-8+100 fuel. The benefits demonstrated during the initial field service evaluations motivated many operational Units to expeditiously field the +100 technology - irrespective of the logistical burden imposed by the special handling requirements associated with aircraft defuels. Overly cautious fuel handling precautions were initially established to preclude defeating the water separation capability of the API 1581 3rd Edition filter coalescer elements in the fuel storage receiving vessels if exposed to JP-8+100. The Return to Bulk (RTB) storage was also limited to a blend back of 1:100 (1 gallon JP-8+100 to 100 gallons JP-8). Implementation Plans were developed for each aircraft type and were fully coordinated with the MAJCOMs and System Program Managers. Field training was also provided.

For the next fifteen years starting in 1994, the Units that used JP-8+100 noted steady reductions in augmentor no lights and blowouts and reduced coking on fuel spray nozzles. It is worthy to note that the legacy fighter engines assigned to some ANG Units were in relatively poor condition when the initial field service evaluations began in 1994. However, by 1997 the conditions of these engines were improving as more spare parts became available from Depot. The F100 RCM and F110B Mod Programs provided improved module build standards and engine reliability. Although C-130H and helicopter engines were in typically better condition than the fighter engines, the Units operating these systems often reported that the fuel spray nozzles exhibited less coking and streaking in the spray pattern after conversion to JP-8+100 and were easier to clean. This resulted in reductions in hot section distress. However, the fuel handling precautions that the implementing organization had imposed initially so impacted the ability of small Units to stand alert after 9/11 and during Iraqi Freedom that the +100 additive was turned off in all but a few locations. Currently, more Units are returning to additive use.

Just prior to the introduction of the +100 additive, the Air Force had completed approval and implementation of a Static Dissipator Additive (SDA) for use in JP-8. While SDA did not disarm 3rd Edition filter coalescers, its surfactant characteristics did reduce the 3rd Edition filter coalescer compatibility with JP-8. Based on this prior experience, there was concern that introducing the +100 additive (as yet another additive with surfactant characteristics) would overwhelm and perhaps defeat 3rd Edition filter coalescers currently in use. As a result, fuel handling restrictions and an overly cautious blend back ratio to bulk storage (1:100) were mandated to assure fuel quality and minimize the possibility of these filter coalescers being defeated and ineffective in removing finite particles and water. The fuel handling restrictions greatly reduced the ability of the Fuels Flight at small Units to perform defuels, fuel transfers and provide two grades of fuel. However, the qualification of a new filter coalescer element to replace the API 1581 3rd Edition element was approved in July 2002 - eight years after the initial service evaluations began. Unfortunately, the API/IP 5th Edition M100 element designed for use with JP-8+100 was qualified too late to modify or rescind any of the fuel handling precautions and restrictions that had burdened operational Units.

Another significant event occurred in late 2005 when a jointly funded program to investigate the effects of fuel additives on filtration performance at SwRI® concluded that **“there is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 at 256 mg/l dosage rate. Any portion of the test matrix where the JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol”.** Based on these rigorous filtration tests, SwRI® concluded that “JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage”. Simply stated, **JP-8+100 can be returned to bulk at a 1:1 ratio**. More technical detail can be found in Section 2.10.3 - “Fuel Handling Restrictions/ Precautions Rescinded or Modified” and in **Appendix P**, “Turbine Fuel Management Issues”.

Based on the results of the SwRI® filtration testing and subsequent implementation of the recommendations of the successful study at Laughlin AFB discussed above and Reference #16 in Section 10, the fuel handling precautions were modified or rescinded by Change 3 of T.O. 42B-1-1, dated 31 Jul 2006 (see **Appendix K**). The conclusions of the SwRI® study coupled with the results of the field trials at Laughlin justified the updates to T.O. 42B-1-1 and removed any barriers for fighter, C-130H and helicopter Units to start using the +100 additive again without the burdens of handling precautions and RTB restrictions. However, small fighter and transport Units assigned only three R-11 refuelers still would face additional workload when performing defuels and fuel transfers to provide two grades of fuel, JP-8 and JP-8+100.

Section 8.1 that follows provides more detailed discussions of the issues that resulted from the fuel handling precautions and RTB restrictions that were mandated in the Implementation Plan to assure clean fuel was issued to aircraft at Units that volunteered to use JP-8+100 during the initial service evaluations and the rapid expansion program. The extreme precautions were mandated to NOT issue JP-8+100 to "non-program aircraft" and avoid any contact of additized fuel with the 3rd Edition filter coalescer elements for fear that the elements at non-program Units would be defeated of water separation and particle filtration if a defuel or return to bulk storage were accomplished. Ten issues are discussed, to include the following:

8.1.1 Handling Procedures and Additive Injection Approaches to Assure Fuel Quality
8.1.2 Providing Two Grades of Fuel Burdened Smaller Units
8.1.3 The Spec-Aid® 8Q462 Additive Increases Conductivity of JP-8+100
8.1.4 Concern for JP-8 Health Issues that May be Affected by Spec-Aid® 8Q462 Additive
8.1.5 The +100 Additive Stinks and Difficult to Remove from Clothing and Pavement
8.1.6 Aircraft Defuels Created Major Handling Problems
8.1.7 Impact of Delayed Filter Coalescer Development
8.1.8 Coordination and Management Responsibilities Increased after Conversion
8.1.9 No Scientific Basis for 1:100 Blend Back Ratio
8.1.10 Loss of Funding and Depot Closing Ended Support by SA-ALC/SF

Each of the above issues are unique but are related to fuel handling precautions and restrictions mandated in the implementation plans for each Unit to include: 1) providing two grades of fuel at each operating Unit, 2) the overly cautious fuel handling procedures for issuing JP-8+100 and performing defuels and fuel transfers and 3) returning additized fuel to bulk storage at 1:100 dilution rate. Therefore, some of the background information used in discussing each issue may be repetitious but are provided to explain the problems Units faced in issuing and handling both JP-8 and JP-8+100. Following the discussion of each fuel handling issue is a brief summary of the issues that have been resolved and recommended action for the unresolved issues.

8.1 JP-8+100 Fuel Handling Issues – Resolved and Unresolved

8.1.1 Handling Procedures and Additive Injection Approaches to Assure Fuel Quality

Discussion: All fuel managed at USAF and ANG locations passes through at least two filter separator vessels before issue to the fill stands. A final filtration occurs when fuel is issued to the aircraft through a filter separator on the refueler truck itself. For the field service evaluations, refueler trucks were marked "JP-8+100", segregated from the remaining JP-8 trucks on the POL parking ramp and given a re-colored green/yellow clipboard with markings "Do not use for servicing transient aircraft". Since JP-8+100 was treated as a separate grade of JP-8, Aircraft Maintenance and Fuels Flight personnel on the flight line were instructed to check refueler truck markings to ensure that JP-8+100 was not issued to non-program aircraft. They were also required to ensure that the aircraft AFTO 781F recorded that JP-8+100 was used to refuel the aircraft.

For expediency, the Air Force decided to inject the +100 additive at the fill stand converting JP-8 from bulk storage into JP-8+100 as close as possible to the refueler truck. The time and cost to perform engineering studies, obtain Depot approval and perform the modifications to inject the +100 additive on the refueler trucks was considered prohibitive.

At larger Units, fuel deliveries are managed by the Maintenance Operations Control (MOC). Orders for fuel type and quantity are communicated to the Resource Control Center (RCC) for inbound aircraft and the Fuels Flight delivers the fuel. After landing, transient aircraft request fuel from the RCC. To avoid any errors in the fuel grade issued at the aircraft, precautions and procedures were developed that required teamwork between the fuel truck operators and flight line maintenance supervisor assigned to each aircraft.

Resolved Issues: Change 3 to T.O. 42B-1-1, dated 31 July 2006, rescinded or modified the fuel handling precautions based on the conclusions of the SwRI® study and verified at Laughlin AFB (see **Appendix K**). "There is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 at 256 mg/l dosage rate and JP-8+100 fuel can be returned to bulk storage at a 1:1 blend back ratio". The API/IP 1581 5th Edition M100 filter coalescer elements designed for use with JP-8+100 have been installed in the receiving and issuing filter coalescer vessels and the refueler trucks.

Unresolved Issues: "Should the +100 additive be injected at the fill stand or on the refueler trucks"? Fuel managers at large fighter Units prefer injecting the additive at the fill stand to avoid any human errors and for ease of management, whereas, the smaller Units would have greater flexibility if the +100 additive was injected using a truck-mounted injector system on each refueler truck while fuel is being issued at the "skin of the aircraft". This would allow smaller Units with three R-11 fuel trucks to return JP-8 to bulk storage and defuel JP-8+100 from fighter and transport aircraft. This approach would also allow the fuel handlers at C-130H Units to off load up to 6,000 gallons of JP-8+100 per fuel truck. In the event of an emergency defuel, Units with larger transport aircraft like the C-5 and the C-17 could use several fuel trucks to offload fuel.

Recommendations: Conduct an engineering design study to determine the cost and operational benefits of injecting the +100 additive on the fuel trucks at the "skin of the aircraft" in order to provide a basis for making an informed decision to meet the operational requirements of small fighter, transport and helicopters Units.

8.1.2 Providing Two Grades of Fuel Burdened Small Units

Discussion: After conversion to JP-8+100, Units were still required to issue JP-8 to non-program aircraft and to return locally assigned aircraft to a 'JP-8 status' before deploying to non-program locations. Small Units were typically assigned three R-11 fuel trucks while some Units had one or more R-9 fuel trucks that were being phased-out. To provide dual-fuel capability, one refueler truck remained on JP-8 status and two refueler trucks were dedicated to issue JP-8+100 only. Fuel trucks are usually topped-off after refueling a large aircraft to be ready to service other inbound aircraft. Thus, an unscheduled defuel of JP-8+100 would require JP-8 fuel returned to bulk storage and a defuel and transfer of JP-8+100 to another aircraft if available or returned to the same aircraft. However, the JP-8 dedicated truck was not available to refuel inbound aircraft with JP-8. Creative management was required by the MOC, the RCC and the Fuels Flight to accomplish fuel transfers, ready a backup aircraft for launch, defuel the aircraft that aborted and transfer JP-8+100 to another aircraft, to Aerospace Ground Equipment (AGE) storage or the engine test cell.

While supporting Iraqi Freedom missions, C-130H Units would frequently have all the assigned aircraft deployed with exception to one or more aircraft on station undergoing the annual isochronal inspections. This significantly reduced fuel transfer capability to other aircraft for defuels. Although the Implementation Plans for the +100 additive mandated specific management responsibilities and handling procedures, each Unit was responsible for establishing lines of communication to maintain strict control of fuel type issued to assigned aircraft and non-program aircraft. As a result, planning and scheduling functions increased as did the dialogue between Flight Operations, the MOC and the RCC. The Fuels Flight had to remain flexible to issue two grades of fuels, support the documentation, be prepared for untimely defuels and accomplish fuel transfers with limited mobile storage capacity for JP-8+100 defuels using the two dedicated R-11 fuel trucks.

Resolved Issues: After 9/11 and support of Iraqi Freedom missions, the smaller fighter and C-130H Units solved fuel handling problems by turning the +100 additive off. This action solved local refueling and aircraft readiness issues since the 5th Edition M100 filter coalescer element was not qualified until July 2002 and RTB at 1:1 blend back ratio was not approved until mid 2006 by Change 3 of T.O. 42B-1-1, dated 31 July 2006 (see **Appendix K**).

Unresolved Issues: The ability to perform aircraft defuels and a fuel transfer at small Units was impacted after conversion to JP-8+100. All fuel trucks were topped-off with no empty fuel truck available to defuel an aircraft requiring extra work to create mobile capacity to offload fuel.

Recommendations: Determine an approach for small Units assigned three R-11 fuel trucks to perform aircraft defuels, fuel transfers and return JP-8+100 to bulk storage. Approaches considered should make the use of JP-8+100 transparent and seamless even though two grades of fuel are provided during high tempo exercises.

8.1.3 The Spec-Aid® 8Q462 Additive Increases Conductivity of JP-8+100

Discussion: Several Units that participated in the initial service evaluation of JP-8+100 provided excellent comparative data to evaluate the impact of the +100 additive on fuel conductivity since these Units handled both JP-8 and JP-8+100. The conductivity of JP-8 was measured upon receipt while the conductivity of JP-8 and JP-8+100 in the fuel trucks was measured weekly. Kingsley Field provided Conductivity Unit (CU) measurements over an 18+ month period starting in January 1995 that ranged from a low of 63 to a high of 1,419 upon receipt of JP-8 with an average of 362. The lowest weekly refueler reading for JP-8 was 139 and a high of 688 with an average of 368 compared to a low for JP-8+100 of 170, a high of 667 and an average of 335. JP-8 refueler conductivity test results exceeded the procurement specification limit twice during the analysis period but not the use limit while the JP-8+100 refueler conductivity exceeded the procurement spec limit three times but not the use limit. The procurement spec limit for JP-8 was 600 CU and the use limit 700 CU.

The wide variations that were observed in the conductivity of JP-8 at time of delivery were most likely a result of the Static Dissipater Additive injected at the terminal truck loading racks. Conductivity data for JP-8 from Kingsley Field showed a near linear increase of around 200 CU from a low of 40 ºF to a high of 87 ºF. One fighter Unit reported exceeding the use limits on several occasions during colder temperatures and worked with Quality Assurance and the fuel supplier to reduce the CU of the delivered fuel.

Resolved Issues: Tests conducted during the early 1980s found that the newer high frequency DC design gauging systems used in F-15 and F-16 fighters are unaffected by fuel conductivity levels up to 5,000 CUs. Since the Spec-Aid® 8Q462 thermal stability additive can raise the conductivity level by 150 CUs at ambient temperatures and as much as 300 CU at higher temperatures, it was recommended (circa 1996) that the maximum allowable conductivity level for JP-8 delivered to JP-8+100 locations be reduced to 450 CU at the point of SDA injection and a maximum limit of 550 CU upon receipt at base level. It was reasoned that a maximum procurement spec limit of 450 CUs and a receipt limit of 550 CUs would allow for conductivity to increase during shipping and from seasonal temperature variations to not exceed the maximum use limit.

Unresolved Issues: None

Recommendations: Follow directions published in the most current release of T.O. 42B-1-1.

8.1.4 JP-8 Health Concerns That May be Affected by Spec-Aid® 8Q462 Additive

Discussion: Immediately after conversion to JP-8 on the West Coast in 1993, Reno NV ANG maintenance technicians filed medical complaints regarding fumes and skin contact issues. Air Force toxicology experts performed analyses and determined that JP-8 is more of a health hazard than JP-4.[22] Tests performed on JP-8+100 did not increase the basic toxicological problems associated with JP-8. Air Force health and safety experts agree that maintenance technicians should be diligent and continue to use personnel protective equipment (PPE) when handling JP-8 and take immediate action to reduce irritation if fuel contacts skin tissue especially inside protective gloves, shoes and clothes. Should contact occur, washing with soap and water is effective in removing JP-8 from the skin. For all maintenance and fuel handling operations, JP-8+100 can be handled as safely as JP-8 as long as the same health and safety precautions are followed.

As with any hydrocarbon fuel, JP-8 can host various "bugs and microbes" in the fuel/water interface layer in aircraft fuel tanks and bulk storage. Studies are continuing to evaluate any effects the "bugs and microbes" may have on human health and safety when handling JP-8 and JP-8+100 as fuel biological contamination continues to be a worldwide Air Force problem. Many operators of large military aircraft had experienced a problem know as "Apple Jelly". In this case, "Apple Jelly" was referred to as a mixture of Fuel System Icing Inhibitor (FSII), water and other various contaminants that appeared in aircraft fuel tanks. Later, it was discovered at Units using JP-8 that a very thick gelatinous, jelly-like substance was being found when refueler units were "sumped" or the media filters were changed. These contaminants may also include bugs and microbes that live in this material, feeding on the fuel molecules. However, no "Apple Jelly" has been found in the aircraft fuel systems of Units using JP-8+100.

Resolved Issues: The dispersants in the Spec-Aid® 8Q462 additive keep any solids and water particles in suspension while the detergent in the additive helps reduce varnishes and coke from adhering to metal surfaces. There has been no effects of "bugs and microbes" on human health or safety and no "Apple Jelly" has been found in the aircraft fuel systems of Units using JP-8+100.

Unresolved Issues: None

Recommendations: Follow directions published in the most current release of T.O. 42B-1-1.

8.1.5 The +100 Additive Stinks - Difficult to Remove From Clothing and Pavement

Discussion: Two noteworthy comments were received from Fuels Flight personnel. It was reported that JP-8+100 had been inadvertently used in a space heater. Although the odor was tolerable, the heat derived from using the additized JP-8 did not compensate for the foul smell! Other fuel handlers commented that small spots of the Betz additive on clothing and pavement stink and are difficult to remove. There were also concerns that frequent exposure to Spec-Aid® 8Q462 additive and to JP-8+100 over 20 years would cause health hazards.

The Material Safety Data Sheet (MSDS) states that if handled improperly, the Spec-Aid® 8Q462 additive could be a moderate health hazard. If spilled, the additive poses many of the same health hazards as JP-8 and the same handling precautions apply. The additive is a blend of antioxidants, detergent/dispersants, metal deactivators and solvents. It is not carcinogenic and poses no special hazards; however, it is a severe irritant to the eyes and can cause moderate skin irritation. The color of the additive is amber to brown, has a strong odor, can be easily detected by its smell and breathing any vapors should be avoided. The additive has a flash point of 165 ºF that is higher than JP-8 with a minimum flash point of 100 ºF.

Splash proof chemical goggles or other eye protection, protective clothing and nitrile petroleum gloves should be used in situations where the additive may be splashed, sprayed or spilled. Adequate ventilation should be maintained and a spill treated as an oil spill using non-flammable absorbent material to contain and absorb the additive. Once the absorbent material has been removed and placed in a container for disposal, sand or grit should be spread across the pavement to preclude slipping and falling. Small amounts of the additive spilled around the additive storage tank and the fill stand plumbing can be removed using absorbing materials and appropriate precautions used such as nitrile gloves and washing with soap and water. After cleaning, the contaminated area can be pressure-washed to remove any visible spots and smell.

Resolved Issues: Space heaters using JP-8+100 should be properly vented outside the work area. If clothing and safety apparel are contaminated, remove promptly. Clothing should be laundered with soap and water until the smell and any spots have been removed. Specific procedures are also provided in the MSDS for disposal of large quantities of the additive and all handling precautions. It is emphasized that the additive and JP-8+100 pose no greater health hazards than JP-8.

Unresolved Issues: None

Recommendations: Follow directions published in the most current release of T.O. 42B-1-1.

8.1.6 Aircraft Defuels Created Major Handling Problems

Discussion: Aircraft defuels are untimely except when an aircraft is scheduled for a phase check or the yearly isochronal inspection. Units located at commercial airports have experienced major problems with defuels since Jet A was purchased from a contract fuel supplier and fuel transfers were limited to aircraft on the ramp because Jet A that had been additized with the standard Air Force additive package cannot be returned to commercial bulk storage. Large fighter and pilot training Units usually did not experience logistic problems with defueling and fuel transfers because aircraft are readily available to receive fuel transfers. The number of refuelers assigned to a Unit depends on the size of the Wing and tempo of the flying program. An Air Force Wing can range in size from 60 to over 160 fighter aircraft, whereas the smaller ANG Units operating F-15, F-16 and C-130H aircraft are assigned 12 to 15 aircraft with typically only three assigned

R-11 fuel trucks - each with a 6,000 gallon capacity. To maintain dual-fuel capability at the smaller ANG Units, one R-11 refueler was used to issue only JP-8 while the other two refuelers were dedicated for “JP-8+100 Use Only”. Prior to providing two grades of fuel, two fuel trucks were filled with JP-8 and the third fuel truck used for defuels and fuel transfers.

The Concept of Operations (CONOPS) in the Implementation Plan was to use the dedicated JP-8+100 fuel trucks for an occasional defuel and fuel transfers. In principle, defuels and fuel transfers can be easily handled at large Units assigned F-15 and F-16 fighters, T-37 and T-38 trainers and helicopters. After a sortie, the aircraft returns with minimum fuel reserves that can be easily downloaded to a JP-8+100 dedicated fuel truck and then transferred to another program aircraft, returned to the same aircraft, to AGE, or delivered to the engine test cell fuel storage tanks. However, defueling a C-130H aircraft with 5,000 to 9,000 gallons of fuel created a significantly more complex challenge especially on short notice.

After landing, C-130H aircraft are typically refueled to a minimum ramp load of 28,000 pounds of fuel (around 4,100 gallons). This fuel load helps to stabilize the aircraft in case of adverse weather conditions. After issuing fuel, the fuel truck returns to the fill stand and is topped-off with JP-8+100 or JP-8 - making it ready to service other inbound aircraft. The C-130H ramp fuel load can exceed 5,000 gallons while a full load of fuel is around 9,100 gallons. The minimum fuel load in most cases is adequate for local training missions making all serviceable aircraft on the ramp ready for a planned training sortie. The frequency of defuels is around 3 per month. With fewer aircraft on station, storage and off-load capacity for large quantities of fuel could become a major challenge since all the aircraft on station are filled to the minimum ramp load.

After 9/11 and during Iraqi Freedom operations, the ANG C-130H Units supported materials transport missions worldwide leaving fewer aircraft on the home station for fuel transfers. In case of an aborted mission due to an aircraft or engine problem, reducing aircraft gross weight for tire changes or landing gear repair, removing all fuel for fuel tank repairs or shop entry for the annual isochronal inspection of the aircraft could result in the quantity of fuel to be removed from an aircraft ranging from 4,100 to 9,100 gallons.

After much deliberation, the Fuels Flight at C-130H Units did not consider returning JP-8+100 to bulk storage as a viable option due the quantities of fuel involved and fear of disarming the 3rd Edition filter coalescers in the fuel receiving vessel. If in contact with JP-8+100, the implementation plan directed the filter coalescers be replaced. The Fuels Flight had to coordinate with the MOC and RCC to find aircraft that could receive additional fuel since bulk storage could only handle up to 1,000 gallons of JP-8+100 at a 1:100 RTB ratio and the available storage for transfer to AGE is less that 220 gallons or the engine test cell may be less than 1500 gallons. The C-130H operators also explored getting a fourth refueler to augment defuel and fuel transfer capability but there was no encouragement. A large bowser capable of off-loading 3,000 to 5,000 gallons of fuel was needed. Unfortunately an R-11 refueler truck can provide the same capability but at considerably higher cost. The bowsers that were assigned had limited storage capacity of 220 gallons each and provided no relief.

Off-site defuels also created logistic problems since the Unit operating the aircraft retained responsibility for defuels. If a fighter or trainer aircraft required maintenance at a non-program Unit and the Unit did not have capacity in their bowser to receive fuel, the Unit responsible for the aircraft was instructed to mount a tank on a flatbed truck and go defuel the aircraft. Whether this scenario ever occurred could not be confirmed but several defuels from trainer aircraft were accomplished and fuel transferred to a bowser without any problems. However, every precaution was taken by C-130H Units to avoid off-station defuels because of the large quantity of fuel involved and the cost burden of recovering or paying for a controlled disposal of the additized fuel. In planning for a mission to a non-program location, it was not unusual to start using JP-8 two-months in advance in order to fly two missions with at least 75% of fuel load using JP-8 as instructed in T.O. 42B-1-1, but later recinded. If a Unit had been assigned a high priority mission, a backup aircraft was also returned to a non-program status two months in advance in case the primary aircraft had to abort the mission.

Large fighter pilot training Units adjusted to the fuel management responsibilities and handling precautions mandated in the Implementation Plan for JP-8+100, but these same procedures were more burdensome for small fighter units with limited capacity to defuel aircraft. Although injecting the +100 additive on the fuel truck would provide more flexibility to perform defuels at small Units, large fighter Units concluded that aircraft fueling and defuels are easier managed if the +100 additive is injected at the fill stand reducing the chance of issuing JP-8+100 to a non-program aircraft. The larger fighter Units are assigned 20 to 25 fuel trucks whereas the small fighter and C-130H transport Units are assigned only three R-11 fuel trucks.

Although the CONOPS acknowledged there would be “logistic burdens induced by the special handling requirements associated with aircraft defuels”, the seasoned personnel in Aircraft Maintenance and the Fuels Flight would have to bear the burdens of a Plan that was not suited for defueling large quantities of JP-8+100, dealing with an overly cautious blend back ratio and the pressing need for a fourth refueler to return JP-8+100 at a 1:100 dilution ratio to bulk storage was not considered by fuel handlers as a viable option.

Before the conversion to JP-8+100, defuels, fuel transfers and returning JP-8 to bulk storage at C-130H Units were considered routine procedures that were easily accomplished and transparent. However, handling precautions established for JP-8+100 caused significant procedural changes that were implemented to avoid disarming the 3rd Edition filter coalescer elements in the receiving vessels. The continued alert status to support Iraqi Freedom missions provided a good reason for C-130H operators to stop using JP-8+100.

Resolved Issues: Change 3 to T.O. 42B-1-1, dated 31 July 2006, adopted the SwRI® study conclusion that JP-8+100 fuel can be returned to bulk storage at a 1:1 blend back ratio. Also, the API/IP 1581 5th Edition M100 filter coalescer cartridges qualified for use with JP-8+100 have been installed in the receiving and issuing filter separator vessels and refueler trucks allowing JP-8+100 to be returned to bulk storage.

Unresolved Issues: Even though all fuel handling restrictions have been rescinded by T.O. 42B-1-1, some Units have not forgotten the extreme precautions and procedures the fuel handlers were directed to follow in order to protect fuel quality when JP-8+100 was introduced. As engine maintenance avoidance becomes more widely accepted at small fighter and C-130H transport Units, the engine maintenance benefits will hopefully have greater influence in achieving widespread use of JP-8+100.

Recommendations: Inform the Users of the maintenance avoidance that can accrue from using the +100 additive and follow directions published in the most current release of T.O. 42B-1-1. Also, conduct an engineering study that considers injecting the +100 additive on the fuel trucks using truck-mounted injectors to provide greater flexibility and capacity to defuel JP-8+100 from large transport aircraft such as a C-130H.

8.1.7 Impact of Delayed Filter Coalescer Development

Discussion: Based on experience that the military package additives (SDA, CI/LI and FSII) had introduced significant surfactancy characteristics to JP-8, the assumption was made that the addition of Spec-Aid® 8Q462 would disarm 3rd Edition filter coalescer elements. Based on this assumption, the decision was made to avoid exposing 3rd Edition filter elements to JP-8+100 without the benefit of any testing to validate the assumption.

This assumption was later proven incorrect in 2005 by the SwRI® test program that determined the impact of additives on filtration performance for 3rd and 5th Edition elements. However, the development of a filter coalescer element designed for use in fuel systems issuing JP-8+100 took longer to qualify than anticipated and was not available until mid 2002 - 7+ years after the initial service evaluations began at Kingsley Field and 5 years after the rapid expansion program started at Units assigned F-15, F-16 and C-130H aircraft. The test protocol for the 4th Edition filter coalescer element used Petronate L during the qualification process that created problems for the filter manufacturers. The Petronate L was simply too harsh and caused a lot of problems so a new protocol was needed. As a result, valuable time was lost in developing a new test protocol for the API/IP 1581 5th Edition filter coalescer element.

Water absorption media filters used extensively in commercial fuel systems dispensing Jet A were then selected to replace the 3rd Edition filter coalescer elements in all R-11 fueler trucks that issued JP-8+100. For commonality, the AF directed that all 3rd Edition filter coalescer elements be replaced with media filters at Units using neat JP-8. For Jet A to be used in Air Force engine, FSII, CI/LI and SDA must be added. Since Jet A does not contain any of the Air Force additives, filter manufacturers had cautioned that FSII, a surfactant, might affect media filters.

Later, the Units using JP-8 reported that a thick gelatinous, jelly-like substance was found when changing the media elements and refueler trucks were "sumped". The substance was commonly referred to as "Apple Jelly"; however, the problems with Apple Jelly had occurred only at locations NOT using JP-8+100. After evaluating all the facts, in CY02 the Air Force directed all Units issuing JP-8 to convert back to coalescing-type filtration.[16] Following the conversion back to coalescing filters in 2002, the problems with Apple Jelly basically disappeared.

Three years passed following the problems with Apple Jelly with few problems related to JP-8+100. Then, in the summer of 2005, three T-37 aircraft at Sheppard AFB, TX experienced single engine flame-outs while in flight. Attempts to restart the engines failed in all cases but all three aircraft landed safely on the remaining engine. Large amounts of Super Absorbent Polymer (SAP) were found trapped in the aircraft engine filters and fuel controls blocking fuel flow to one engine until fuel starvation occurred. Further investigation identified SAP in aircraft filters taken from several other AF Bases within the CONUS. In order to insure flight safety, the AF directed the removal of water-absorbing filter monitors from all refueling equipment at Air Force installations. Filter monitors were replaced with either API/IP 1581, 5th Edition, M100 Class filtration, API 3rd Edition qualified filtration or DOD filter elements tested using the API/IP, 5th Edition, M Class test criteria. New R-11 fuel trucks were being delivered with the 5th Edition M100 filter coalescer elements.

Following this decision, the Air Force JP-8+100 program was reduced to one single location (Moody AFB, GA) that had refueling equipment with API/IP 1581, 5th Edition, M100 filter coalescer elements. All other AF units were directed to turn off the +100 additive. During the ensuing 12 ½ months when the +100 additive was not in use, F-16 fighter aircraft powered by F100-PW-220/E engines at a large pilot training Wing experienced a 6% increase in augmentor anomalies due to coking. Other Units experienced increased engine anomalies due to coking during the 12 ½ months the +100 additive was not in use. The UERs, augmentor anomalies, MFC and AFC removals increased for both F-15 and F-16 aircraft and created more unscheduled workload that could not be ignored.

After the Sheppard AFB flameout problems, a cooperative program was arranged with support from the USAF, DESC, US Army AMCOM, GE Infrastructure, ChevronTexaco, QinetiQ, ConocoPhillips and the UK MOD/DLO with work performed at the Southwest Research Institute (SwRI®) in San Antonio TX to investigate the effects of aviation fuel additives on filtration performance. The main emphasis of the program was to determine if the Spec-Aid® 8Q462 thermal stability additive was detrimental to filtration performance. A test protocol was adopted based on API 1581 3rd Edition and API/IP 1581 5th Edition testing specifications but was more geared to evaluating surfactancy of AF fuel additives and less geared toward filter coalescer qualification. The overall conclusion of the rigorous testing was that "there is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 @ 256 mg/l dosage rate. Any portion of the test matrix where the JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol ". Based on these results, it was concluded that "JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage".[15]

Following the completion of the SwRI® study, the Air Force Petroleum Office (AFPET/AFOT) at WPAFB initiated a field trial at Laughlin AFB[16] with the expressed intent of testing the conclusions of the SwRI® report and documenting the impact of JP-8+100 on real-world existing filter coalescer elements in USAF R-11 fuel trucks. The 3 month evaluation was completed in May 2006. Based on the data collected and the filter tests performed, AFPET changed the technical guidance for fuel handling precautions in T.O. 42B-1-1, "Quality Control of Fuels and Lubricants", Change 3, 31 July 2006 and instructed Units to treat JP-8+100 just as they would JP-8 with respect to handling precautions and blend back to bulk and rescinded the 1:100 ratio requirement. Return of JP-8+100 to JP-8 would require no dilution when returned to bulk storage (see **Appendix K**).

Had thorough testing of the 3rd Edition filter coalescer element been conducted prior to or during the initial service evaluations and the subsequent rapid expansion program and had the 5th Edition M100 been available, Units may not have been burdened with fuel handling precautions and RTB restrictions. The use of the +100 additive would have been more transparent to the Fuels Flight. Consequentially, a more positive attitude resulting from fewer mandated precautions would have prevailed and possible no 'urban legends". However, the field trial at Laughlin AFB was needed to confirm the conclusions of the SwRI® study. This eventually was the key in rescinding the 1:100 blend back to bulk ratio as directed by SA-ALC/SF circa 1994 and entered in Table 3-2 of T.O. 42B-1-1 prior to Change 3 dated 31 July 2006.

Accurate information of 3rd Edition filter coalescer performance using JP-8+100 would have also improved inter-operability and reduced the advanced planning and coordination required to convert an aircraft to a non +100 status prior to deployment. Continuous use of JP-8+100 would have helped reduce augmentor and fuel nozzle coking over a longer period of time.

Resolved Issues: The rigorous filtration investigations conducted at SwRI® concluded that "there is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 at 256 mg/l dosage rate. Any portion of the test matrix where the JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol". Based on the test results, it was concluded that "JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage". Thus, JP-8+100 can be returned to bulk at a 1:1 ratio and no fuel handling restrictions or precautions exists based on 22 June 2006 Memorandum for HQ AETC/A4MF (see **Appendix K**).

Unresolved Issues: The delay in qualifying of a new filter coalescer element for use with JP-8+100 indicates a broken development process in three areas:

1) Filtration elements should be qualified and ready for field use when a new thermal stability additive is transitioned to service.

   Discussion: Sufficient lead time is necessary to conduct research, development and qualification testing of advanced filtration systems. These are equally as important as the development of a new additive. Use of JP-8+100 rapidly expanded to fighter, C-130H and helicopter Units starting in 1997 but a compatible filter coalescer element was not qualified to meet the API/IP 1581 5th Edition M100 specifications until mid 2002. In 1994, the implementing organization mandated several fuel handling precautions and restrictions prior to the initial service evaluations that were not based on science and were not rescinded until after the SwRI® filter test program was completed, circa 2005-06. Unfortunately, SA-ALC/SF, the implementing organization for the JP-8+100 service evaluation programs, essentially began to shutdown after the rapid expansion program was launched. Reorganization within the Fuels Community and lack of continued funding during the closing of the Depot at Kelly AFB TX left many support tasks in the field and management functions requiring Air Staff action without leadership and resolution that hindered the smooth transition and acceptance of the +100 additive technology.

2) Firm requirements definition and qualification specifications are needed before filter manufacturers will conduct independent development to qualify a new proprietary filter or validate that an existing filter passes an approved test protocol for a new additive.

   Discussion: A baseline Filter Test Protocol must be established and a small quantity of a new additive provided for filter manufacturers to begin filter coalescer development which can require 1-2 years to complete the qualification process. Filter manufacturers currently work with additive suppliers to evaluate candidate thermal stability additives in approved filter coalescers. A key indicator of timing to start a new filter development is the progress of materials compatibility testing of a new thermal additive performed by AFRL/RZPF.

3) Establish an OPR within the USAF to manage and coordinate the development and qualification of filter coalescer elements for competitor +100 offerings and future thermal stability additives.

Discussion: A robust filter development was underway in the early 1990's for the +100 additive but was dropped when there was a push to develop a drop-in API filter. Also, filter development fell on hard times when the debate over test protocols, the mix of API versus DOD vessels and other issues created insurmountable barriers to overcome plus the logistic community showed no interest in endorsing the use of JP-8+100. Participation of the API/IP organizations is needed to harmonize the design requirements, performance specifications and qualification protocol for military class filter coalescer elements compatible with current and advanced thermal stability additives. Timely support of these activities is essential.

Since competitive issues and proprietary data are involved, coordination with AFRL/RZPF in the Fuels Laboratory at WPAFB OH will be necessary to determine the development status of competitive and advanced thermal stability additives. AFRL/RZPF expertise will also be needed to help solve fuel handling problems and service related issues identified by the Users.

Recommendations: 1) Establish a baseline Filter Test Protocol for filter manufacturers to begin filter coalescer development work for new thermal stability additives and insure that a small quantity of each new additive is available to support the 1-2 year development and qualification process, 2) Based on lessons learned, utilize the API/IP organizations to harmonize the design requirements, performance specifications and qualification protocol for military class filter coalescer elements compatible with current and advanced thermal stability additives, 3) AFPET/AFOT is a likely candidate to manage filter coalescer development by coordinating requirements and timing of new filtration developments with AFRL/RZPF, and 4) AFPET/AFOT request Fuels Laboratory support to take charge of filtration development for thermal stability additives.

8.1.8 Coordination / Mgmt Responsibilities Increased After +100 Conversion

Discussion: In addition to the fuel handling precautions and RTB restrictions, mandatory coordination and management responsibilities were established in the Implementation Plan intended to strictly control the issue of JP-8+100. These additional tasks were considered extreme measures by the Maintenance Organization and Fuels Flight compared to management responsibilities for JP-8. The C-130H Units were instructed to track the fuel type onboard each aircraft in addition to the fuel quantity on-board after each flight. In planning for scheduled support missions involving deployment to a non-program location, C-130H aircraft were required to fly two consecutive missions after refueling with at least 75% of the fuel load using JP-8. An abort would cause major fuel transfer problems to ready another aircraft for the planned support mission. Some C-130H Units would have a backup aircraft on non-program status in case reliability issues forced the primary aircraft to abort. With few aircraft on station during the Iraqi conflict to perform fuel transfers, Units had no choice but to return to using JP-8 only.

The interpretation of the fuel handling restrictions in the Implementation Plan was not always uniform between fighter and transport Units causing great apprehension among Fuel Handlers and Aircraft Maintenance supervision at small Units. Some Units considered RTB not doable since they did not have bypass plumbing around the receipt filter coalescers. Planning and scheduling functions increased as did the dialogue between Flight Operations and the MOC. The Fuels Flight had to remain flexible to issue two grades of fuels, prepare the documentation, be ready for untimely defuels and accomplish fuel transfers with limited mobile storage capacity since two R-11 refuelers were dedicated to issue JP-8+100 with the other filled with JP-8.

F-15 and F-16 aircraft were scheduled to fly a least one mission with JP-8 before deploying to a non-program location, however, some Units interpreted the instructions to fly two missions after refueling with at least 75% of the fuel load with JP-8 before the aircraft was declared off the +100 additive.

Transient air crews flying non-program aircraft scheduled for a refueling stop at a "+100 Base" might be notified upon arrival that there would be delays in issuing JP-8 due to high OPS tempo in servicing assigned aircraft. The pilot of a non-program transient aircraft might be offered JP-8+100, but someone in Aircraft Maintenance was required to brief the pilot, annotate the AFTO 781F that JP-8+100 had been issued to a non-program aircraft and notify the home station that JP-8+100 had been used to refuel one of their aircraft. Some pilots welcomed JP-8+100 while others were apprehensive since their Unit had not volunteered to participate in the rapid expansion program. After 9/11 and heightened alert status in support of Iraqi Freedom missions, Units had sufficient reasons to turn off the +100 additive.

It was unfortunate that the drawdown in DOD manpower, closure of the Depot at Kelly AFB, TX and loss of funding for the Directorate of Aerospace Fuels (SA-ALC/SF) came at a critical time during the rapid expansion of JP-8+100. Problem solving was left to the Units and many turned the additive off when they were unable or unwilling to handle the logistics of aircraft defuels and the additional responsibilities of managing the use of JP-8+100 and support alert status. Some Units felt abandoned but adjusted to the added responsibilities in order to continue benefiting from reduced coking and maintenance workload. Other Units chose the easy way out by turning the additive off to reduce the fuel handlers workload and major frustration with the defuel problems. After the ANG C-130H Units decided to turn the +100 additive off, some Units felt there was no further use for the injection equipment at the fill stands and recommended removal. However, a letter was circulated informing Units that no decision had been made to remove the injection equipment.

Resolved Issues: Coordination and management procedures have evolved between the MOC, RCC and the Fuels Flight at large fighter Units to effectively manage the use of JP-8+100. The directions published in T.O. 42B-1-1 have rescinded all fuel handling precautions and restrictions established by the Implementation Plans making use of JP-8+100 transparent.

Unresolved Issues: Units objected to additional workload for defuels and fuel transfers, handling precautions and RTB restrictions since use of the +100 additive was voluntary. Even though all fuel handling restrictions have been rescinded by T.O. 42B-1-1, some Units have not forgotten the precautions and procedures the fuel handlers were directed to follow in order to protect fuel quality when JP-8+100 was introduced.

Recommendations: Although JP-8+100 use is voluntary, Units should be more open to learn of the maintenance benefits that have been demonstrated by other Units since all the fuel handling precautions and restrictions have been rescinded by T.O. 42B-1-1. For example, high power takeoff and intermittent high power when using JP-8 in turboprop engines can accelerate fouling of the fuel spray nozzles and decrease the service life of the engine hot section due to oxidation and erosion. Augmentor spray rings and feed tubes in legacy F100 engines are more susceptible to coking and augmentor anomalies using straight JP-8.

8.1.9 No Scientific Basis for 1:100 Blend Back Ratio

Discussion: An overly cautious blend back ratio was directed in the Implementation Plans for the initial service evaluations of JP-8+100. The rationale for this decision was based on the concern within the fuels community that the additional surface active agents in the Spec-Aid® 8Q462 additive in combination with the surfactants already in JP-8 would defeat the capability of the 3rd Edition filter coalescers to remove dirt particles and water. Just prior to the introduction of the +100 additive, the Air Force had completed approval and implementation of a Static Dissipator Additive (SDA) for use in JP-8. While SDA did not disarm 3rd Edition filter coalescers, its surfactant characteristics did reduce the 3rd Edition filter coalescer compatibility with JP-8. As a result, there was concern that introducing the +100 additive (another additive with surfactant characteristics) would overwhelm and perhaps defeat 3rd Edition filter coalescers currently in use. Thus, fuel handling precautions and a blend back ratio to bulk storage of 1:100 were mandated to assure fuel quality and minimize the possibility that filter coalescer performance would be compromised in removing any solids and water.

The dilution ratio of 1:100 (1 gallon JP-8+100 to 100 gallons JP-8) was arbitrarily set based Table 3-2 "Turbine Fuel Blending Table" in T.O. 42B-1-1 circa 1993 for blending JP-4 with JP-8, however, this table has since been deleted from the T.O. The blending ratios recommended in Table 3-2 varied from 1:1 to 1:10 and included turbine fuels such as Jet A, Jet A-1, JP-5, JP-7, JPTS, JP-10 etc. Most notable by its absence is JP-4 that was recommended at a blend ratio of 1:100 in JP-8! Other reasons for the high dilution ratio considered: 1) every precaution to minimize the concentration of the +100 additive in bulk storage so that additive injection at the fill stand would achieve but not exceed the 256 mg/l dosage rate in JP-8 and 2) the 1:100 dilution rate would minimize any chance that the +100 concentration would impact JP-8 in bulk storage that would be issued to non-program aircraft.

However, Units did not return any JP-8+100 to bulk storage based on their individual interpretation of T.O. 42B-1-1 and warnings that the 3rd Edition filter coalescer elements in the receipt line would be defeated after contact with JP-8+100 and needed to be changed. Since Unit supply carried only one set of replacement filters which were scheduled for change every three years or when the pressure drop across the filtration vessel exceeded limits defined in the Fuels Quality Tech Order, there were labor and replacement costs that the Units did not want to bear.

Since no testing or experience base was referenced, it can be assumed that the implementing organization selected the most extreme blend ratio of 1:100 for dilution of JP-8+100 back to bulk storage to lessen any chance that additive concentration in JP-8 bulk storage could reach a level that would defeat the 3rd Edition filter separator elements as fuel was issued from bulk storage. Unfortunately, the fuel handling precautions and restrictions were made without regard to the difficulties fuel handlers would experience in providing two grades of fuel with limited mobile capacity for aircraft defuels, fuel transfers and return to bulk storage.

Resolved Issues: The SwRI® report provided scientific data to rescind the 1:100 blend back to bulk ratio as stated in the Det 3, WR-ALC/AFT (AFPET) letter dated June 22, 2006, SUBJECT: JP-8+100 Program. A copy of this letter is provided in **Appendix K.**

Based on the statistical analysis utilizing the failure criteria agreed upon by the participants of the cooperative program, the following conclusions were made by SwRI®:

1) There is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 @ 256 mg/l.
2) JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage.

Unresolved Issues: Small C-130H Units that purchase Jet A from a contract supplier and inject both the AF additive package and the +100 additive need additional capacity to defuel the 'equivalent' JP-8+100 when fuel transfers are not possible to other aircraft rather than dispose of the fuel. An alternate would be to turn the additive off until more aircraft are on home station.

Recommendations: Develop approaches that provide flexibility for Units using Jet A to use the +100 additive and perform planned defuels and fuel transfers and unscheduled events without hardships in order to accrue the benefits of reduced coking and fouling of hot section parts that decreases hot section life.

8.1.10 Loss of Funding and Depot Closing Ended Support by SA-ALC/SF

Discussion: The loss of funding for the Implementing Office (SA-ALC/SF) and subsequent drawdown of fuels specialists created a real void in leadership and technical support for the transition of JP-8+100, especially for the fuel handlers at small Units. The fuel handling precautions and restrictions created major barriers in performing defuels, fuel transfers and return to bulk at small units with only three assigned R-11 fuel trucks with two filled with JP-8+100 as directed and one with JP-8. Immediate short term workarounds were needed for the fuel handling problems as well as a solution to the filter coalescer issues but no office was assigned responsibility to work the issues even though the problems were communicated within the major commands and the engine development community. As a result, three to five years of dedicated support was lacking after the Implementing Office began closing shop after the closing of the Depot at Kelly AFB was announced. The Implementing Office initially managed the IPT, arranged for the installation of injection equipment on the fill stand(s) at each Unit, developed training material and provided instructions but then support was stopped. Basically, the Users were left to make their own decisions in a program that was voluntary from the start.

A sustainment plan for JP-8+100 use was needed but fell on hard times during the drawdown plus work was needed to expedite the qualification of the 5th Edition M100 filter coalescer element. During the initial service evaluations, rigorous filtration tests should have been conducted to verify the impact of the surfactants in JP-8+100 on 3rd Edition filter coalescer elements and to establish a responsible blend back ratio of JP-8+100 to JP-8 in bulk storage rather than mandating an overly cautious RTB ratio that would affect fuel handling at all installations. In hindsight, early solution of these technical issues would have reduced or eliminated the fuel handling problems and allowed a more relaxed environment to objectively evaluate the maintenance benefits from reduced coking provided by the +100 additive.

On the maintenance side, the engine shops were dealing with engine anomalies that increased unscheduled workload, restoring engine build standards as new modules and engine parts became available while performing new cleaning procedures that were being released to deal with accelerated coking from using JP-8. During this dynamic maintenance environment, engine analysts were too busy tracking life limited parts and modules to analyze the benefits of reduced coking on maintenance workload to counteract the overtures of the more vocal fuel handlers whose workload had significantly increased due to the mandated fuel handling precautions and RTB restrictions for JP-8+100 and wanted the additive turned-off.

By mid 2006, most of the major fuel handling issues had been modified or rescinded but several years had lapsed during which the Users of JP-8+100 felt abandoned and unprepared to sort out the maintenance benefits from using the +100 additive.

Since use of the +100 additive was voluntary, the ANG Units decided to turn-off the +100 additive in order to be on alert status, support rapid response missions and participate in extended deployment. Only the fighter training Units in AETC and the ANG continued to use JP-8+100 since they did not deploy and enjoyed the maintenance benefits from using JP-8+100 due to reduced coking. It is worth noting that these Units were developing maintenance procedures and best practices in conjunction with using JP-8+100 that helped reduce engine anomalies and unscheduled engine removals due to coking. AFRL/RZPF, the champion of the +100 development, remained committed and continued to provide technical support to Units requesting help and continued the support of maintenance benefits analyses at several F-15 and F-16 fighter, C-130H transport and helicopter Units. However, the additive manufacturer was caught in the crossfire between seasoned Chiefs in Aircraft Maintenance, Engine Shop and Fuels Flight Managers with no one to stand in the gap.

Resolved Issues: AFPET prepared a major revision of T.O. 42B-1-1 Change 3 dated 31 July 2006 to include technical guidance contained in the MEMORANDUM FOR HQ AETC/A4MF, dated June 22, 2006, SUBJECT: JP-8+100 Program, w/ copies to: HQ ACC/A4LF, HQ PACAF/A4RP, HQ USAFE/A4RMF, HQ AFSOC/A4RMF, HQ ANG/A4RMF and AFRES/LGSWF (see **Appendix K**).

For quick reference, paragraph 4 of this letter is included that summarizes the changes to existing guidance:

"Therefore, based on the results of the SwRI® report and the 90-day field evaluation at Laughlin, we [Det 3, WR-ALC/AFT (AFPET)], endorse the use of +100 at any location using existing filtration qualified to the API 1581, 3rd and 5th Edition or DOD filtration qualified using the API 1581, 5th Edition M or M100 class filters. For those locations going back on +100, please use the following information pending a formal change to existing technical guidance on JP-8+100:

a. Maintain adequate JP-8 stocks for issue to contract carriers, commercial aircraft, or foreign military or commercial aircraft. Do not issue JP-8+100 to non +100 aircraft.

b. Use one-time defuels to the maximum extent possible and issue defueled +100 product to the next aircraft requiring fuel.

c. Return JP-8+100 to bulk storage only as a last resort. If a return to bulk (RTB) is absolutely necessary, no dilution is necessary.

d. When converting refueling units, drain and remark accordingly. Do not change filters.

e. Aircraft will be considered off +100 after one refuel with at least 75% of the aircraft fuel capacity using non +100 fuel.

f. Bases utilizing the +100 additive will treat the additized fuel as a separate fuel grade.

g. Increase water content testing to daily for R-11 refueling units equipped with filter elements that were not qualified with +100 until confidence has been gained that the elements are performing satisfactorily.

[Authors note: Follow directions in the most current release of T.O. 42B-1-1.]

Unresolved Issues: Loss of Implementing Office due to organizational drawdown and Depot closing at Kelly AFB created a management and support void forcing Users to make independent decisions.

Recommendations: Establish an OPR within the USAF AFPA HQ AFPET/AFTH to manage and support:

1) Development and qualification of filter coalescer elements for current and new thermal stability additives.
2) Issue a requirements document requesting the Fuels Branch, AFRL/RZPF, in the Propulsion Directorate to manage new filtration development, and
3) Field evaluations of competitor +100 additive offerings and advanced thermal stability additives.

As discussed in 8.1.7 Item 3), coordination with the Fuels Laboratory, AFRL/RZPF, is important to determine the development status of competitor and advanced thermal stability additives and to help solve fuel handling problems and service related issues identified by the Users.

9.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

9.1 Brief Additive Development Summary

In the 1980 time frame, the OSD made the decision to replace JP-4, a highly flammable fuel, with JP-8, a low volatility kerosene-based fuel, to improve flight safety due to aircraft fire hazards and to reduce fuel costs. The conversion to JP-8 became final in the CONUS circa 1993/94 even though kerosene-based fuel was being used in USAFE before the conversion. The Navy had converted to JP-5, a kerosene-based fuel with a higher flash point than JP-8, before the Vietnam War to reduce aircraft fire hazards and fuel handling on aircraft carriers.

The Fuels Laboratory (AFRL/RZPF) had anticipated that coking problems would develop in engines designed to use JP-4 after conversion to JP-8 and began research in the late 1980's to increase the thermal stability of JP-8 by 100 °F hence the term +100 additive was born. A far more reaching goal of the research was to increase the thermal stability of kerosene-based fuels for advanced engines operating at higher turbine inlet temperatures. The low volatility JP-8 fuel does not readily evaporate like JP-4 when in contact with hot metal surfaces and 'boils off' at a reduced rate forming varnishes that turn into carbon deposits and hard coke after repeated high temperature cycles. Laboratory tests have shown that varnishes will begin to form when wall surface temperatures are between 200 to 250 °F.

Shortly after conversion to JP-8, the legacy F100 engines powering F-15 and F-16 fighters began to experience an abrupt increase in engine anomalies due to coking in the augmentor spray rings while the legacy turbofan engines in B-52H bombers experienced cold starting and high altitude relight issues due to fuel atomization problems. Turbo-prop, turbo-shaft engines in helicopters and legacy trainer engines experienced accelerated coking on the fuel spray nozzles that caused fuel streaking and hot section distress. Unfortunately, the decision makers did not anticipate the magnitude of the JP-8 coking problems experienced in engines designed to use JP-4 that would significantly increase unscheduled engine removals and maintenance workload. However, design changes have been developed for several engine types under the Joint Service Engine Component Improvement Program (CIP) and incorporated to fix some of the coking problems while other approved design changes are waiting funding for manufacturing release.

The impact of coking on the flying program and maintenance workload of the operational Units soon gained priority status and the MAJCOMs approached the Engine Development Community at WPAFB, OH for solutions. It was timely that the Fuels Branch in the Propulsion Directorate (AFRL/RZPF) had completed the qualification of an affordable additive in 1994 that increased the thermal stability of JP-8 by 100 ºF. Although the +100 additive was targeted for initial use in the F-22 Advanced Tactical Fighter under development during the late 1980's and 1990's to increase fuel cooling capacity and reduce potential coking issues, it was considered a mature technology and ready for transition to field service after successfully completing all materials compatibility tests, ground engine testing and a flight test at Edwards AFB. Currently, JP-8+100 is an alternate fuel for the F-22 Raptor and a primary fuel for the F-35 Joint Strike Fighter under development to provide increased cooling for avionics systems and engine components that depend on the onboard fuel for cooling.

The initial service evaluations in F-16 fighters and C-130H transports demonstrated reductions in coking that were complimented by accelerated baking and cleaning programs for the F100 augmentor spray rings and new cleaning procedures for T56 fuel spray nozzles. The success of the initial service evaluation programs led to rapid expansion programs for fighters, transport and helicopter aircraft assigned to Operational, AETC and ANG Units. However, there had been some issues with the additives used in the standard military additive package - specifically CI/LI and SDA - used in JP-8. Since CI/LI and SDA and the +100 additive are surfactants, there was concern that the combined surfactancy effect of these additives in the fuel could exacerbate problems identified for the established level of CI/LI and SDA in JP-8 and result in defeating the 3rd Edition filter coalescer elements thereby allowing water and dirt to enter bulk storage and aircraft fuel tanks. Unfortunately, filtration tests using JP-8+100 were not performed prior to the initiation of the service evaluations to determine if the levels of surfactancy would defeat the filter coalescer elements. As an interim measure, fuel handling restrictions and precautions were established by the implementing organization plus blend back to bulk ratios to assure fuel quality that severely impacted fuel handling, defuels and return to bulk and impacted the evaluation of maintenance benefits from using JP-8+100 at fighter, C-130H transport and helicopter Units. However, the fuel handling restrictions did not impact the pilot training Units due to the high tempo training activity, ease of defuels and fuel transfers and operation at one location. In spite of fuel handling issues, many Units benefited from reduced unscheduled engine removals due to coking but the fuel handling restrictions and precautions impacted the ability of some Units to perform aircraft defuels and fuel transfers, stand alert and deploy on short notice.

From rigorous filtration testing completed in 2005, it was determined that JP-8+100 does not defeat the 3rd Edition filter coalescer elements. As a result, all the fuel handling precautions and Return to Bulk restrictions originally established for the initial service evaluations starting in late 1994 and the rapid expansion program that began in late 1997 have been modified or rescinded in T.O. 42B-1-1, Change 3 dated 31 July 2006 and clarified by more current release of this document. Units can now use JP-8+100 free from fuel handling precautions and restrictions that were originally established. Since all US engine manufacturers have approved the use of thermal stability additives in Service Bulletins and Aviation Fuel Specs, the one issue remaining to improve inter-operability is to obtain concurrence that there are “No non-program engines or airframes, only Units that decide not to use JP-8+100”.

9.2 Poor Timing Debated

The conversion to JP-8+100 that closely followed the switch from JP-4 to JP-8 has been considered by some as poor timing, however, some fighter Units greatly benefited from reduced coking. At the time of conversion, the legacy F100 engines assigned to ANG Units were in poor condition but improving as more new parts became available and engine build standards improved but made it difficult to sort out benefits from using JP-8+100. Some Units struggled with the fuel handling restrictions and precautions in performing aircraft defuels and fuel transfers with limited refueler assets and thought the 1:100 return to bulk restriction was too burdensome that limited the ability of fuel handlers at small units to issue fuel. Other Units commented that use of JP-8+100 required extra work because of the fuel handling restrictions and that higher authority had not directed the use of the additive so “Why should they be forced to do extra work”. Also, the additional management tasks to provide two grades of fuel increased the workload at small Units with only three R-11 refueler trucks making short notice aircraft defuels and fuel transfers very difficult to perform. The mandated 1:100 blend back ratio coupled with limited bulk storage capacity at the smaller Units also limited the blend back of fuel to less than 1000 gallons of JP-8+100 which was never attempted since the receiving filters were directed to be changed if exposed to JP-8+100.

Since use of JP-8+100 was voluntary and Units believed no relief was in sight for the fuel handling precautions after the 5 year delay in qualifying the API/IP 1581 5th Edition M100 filter coalescer element and conditions only worsened after 9/11 when support missions for Operation Iraqi Freedom increased and more aircraft were deployed, most Unit elected to turn the +100 additive off. Concern was also expressed that the conversion process was adversely impacted by the loss of the implementing organizations support to find solutions for pressing logistic issues uncovered by the Users during the rapid expansion of JP-8+100 at Units operating F-15, F-16, C-130H and rotary-winged aircraft. Lacking an endorsement from higher authority and since use of JP-8+100 was considered voluntary; Units commanders from ANG fighter and transport Units recommended that the +100 additive be turned off that occurred approximately 18 months after the Rapid Expansion Program began circa 1997/8.

9.3 Endorsement Issues

As engine conditions improved and engine anomalies were on the decline, it became easier to show some benefits from using JP-8+100, however, there existed a general lack of interest by the Logistic Program Offices at the MAJCOMs and Air Staff to endorse the use of JP-8+100. Unfortunately, informing senior leadership and decision makers of the +100 additive benefits can be a challenging experience. Anything that is perceived to provide a cost avoidance represents a potential threat to outyear maintenance budgets that are needed to buy new engine parts, improve engine build standards and achieve the inherent reliability of the engine type. This is understandable since aircraft maintenance budgets are under constant review and have been under funded in the past for sake of other programs internal and external to the USAF and DOD.

For example, the F100 RCM Program and the F110-100B Mod Program have provided significant improvements in engine build standards and reliability starting in early 1997. Another program, the F110 SLEP, was initiated in 2006 to increase life limited components from 3000 to 4000 cycles. The poor condition of some legacy F100 engines during the initial service evaluations resulted in larger maintenance cost avoidance estimates than when engines are in good condition at large training Units where use of the +100 additive has become a part of several maintenance procedures and best practices that have steadily reduced the unscheduled engine removals due to coking since the RCM Program was implemented. But turn the +100 additive off for 12 ½ months as occurred in 2005 and 2006, the augmentor anomalies increased by 6%. Therefore, use of the +100 additive helps maintain the inherent reliability of the F100 engine achieved through a well-supported and well-managed RCM Program. Small reductions in augmentor anomalies are achievable through more rigorous local maintenance procedures but are also affected by the inherent thermal stability of the delivered fuels, the frequency of augmentor use and improved build engine standards. The synergies of procuring adequate new spare parts to achieve and maintain high engine build standards, the use of evolving local maintenance procedures and best practices along with the use of JP-8+100 needs to be emphasized to improve engine time on wing.

9.4 Conclusions

In spite of the mandated fuel handling precautions and problems with aircraft defuels and fuel transfers at small Units, maintenance analyses at several Units showed that JP-8+100 has steadily reduced augmentor anomalies in the legacy F100 engines and F110 engines, helped reduce hot section distress in turbo-prop, helicopter and trainer engines due to fuel spray nozzle coking and became a part of several maintenance procedures developed by Units that helped reduce augmentor no lights and blowouts that caused unscheduled engine and fuel control removals.
It is noteworthy that the benefits of the +100 additive became easier to quantify as the engine reliability improved from improved build standards for engine modules.

Maintenance Impact on F-15 and F-16 Fighter Engines: The ultimate proof for the benefits of using JP-8+100 occurred during a three year time period after return to using straight JP-8 starting in 1 August 2005. The engine anomalies at a large F-16 Unit increased from 8 in CY04 to 16 in CY05 and then to 21 in CY06, a period of 13 months, after the +100 additive was turned off. Recovery to near the former level did not occur until CY08, approximately 18 to 24 months after the additive was turned on again. For the twin engine F-15 fighters at another operating location, a stable level of engine anomalies had been reached by CY01 and continued until the +100 additive was turned off in August 2005 at which time the engine anomalies increased from 10 in CY05 to 25 in CY06 and recovered to near the former level approximately 24 months after the return to using JP-8+100. **The dramatic increase in the Engine Anomalies after the +100 additive was turned off for 13 ½ months clearly shows that using JP-8+100 helps to reduce the impact of coking in the -220/E engines that power F-15 and F-16 fighters**. Recovery to the former level of engine anomalies will vary depending on the amount of flying hours the engines are off the additive and the per cent utilization of the +100 additive for the assigned engines after returning to using JP-8+100. **But turning the +100 additive off for 12 to 13 months, as occurred during 2005 and 2006, resulted in a 6% increase in augmentor anomalies at one Unit and 10 to 15% at other Units demonstrating that +100 additive use had helped to maintain the inherent reliability of the F100 engine** achieved through a fully-supported and well-managed RCM Program. Of importance is that 18 to 30 months after the +100 additive was turned on again did the engine anomaly and control removal rates due to coking return to near the unscheduled removal rates that had been attained before the additive was turned off.

While the +100 additive has helped reduce the maintenance workload by increasing average time on wing or MTBR, it does not prevent coking in the augmentor spray rings and feed tubes exposed to high gas temperatures. Quick removal of the residual fuel after augmentor shut down is essential to help reduce coking in the spray rings and the accumulation of the coke slurry in the outlet ports of the Augmentor Fuel Control (AFC) and Fuel Dump Probe (ASEP) in the core exhaust stream.

Maintenance Impact on T-37 and T-38 Trainer Engines: Continued use of JP-8+100 in the J69 and J85 engines has provided consistent reductions in unscheduled maintenance and parts demand but the benefits are best shown when the +100 additive was turned-off from 12 to 13 months starting in May 2005. During this time period, **the engine flameout rate increased 3.9X after the +100 additive was turned off, the engine NRTS increased from 0.75/mo to 3.01/mo and the MFC Removal Rate increased by 60%**. Prior to 2005, the removal rate for the MFC increased by 42% in 2003 and 22% during 2004 from sticking valves in the MFC. **After conversion to JP-8+100, the parts demand rate for J85 engine fuel nozzle tips decreased by 55.3% and a 73 to 75% reduction was noted for fuel nozzles and the main and pilot spray bars in the afterburner.** When the +100 additive was turned off and neat JP-8 used, the engine UER Rate increased by 110%, the MFC Removal Rate increased by 152%, the AFC Removal Rate increased by 57% and augmentor unscheduled removals increased by 72%. There is little doubt that use of the +100 additive has provided a significant reduction in the maintenance workload, reduction in parts demand and helped to increase the reliability and time on wing of the legacy J69-T-25 and J85-GE-5 trainer engines.

Maintenance Impact on C-130H Transport Engines: A Unit that trains pilots for terrain following missions that used JP-8 18% of the time experienced a UER Rate of 3.73 but achieved a UER Rate of 0.91 when use of JP-8+100 increased to 82% of the time for a 76% reduction in UER Rate. When the +100 additive was turned off Air Force wide circa May/June 2005 for 12 to 13 months to resolve fuel filtration and filter coalescer issues, the fuel spray nozzle dropouts increased from 1 per ship set to 4 per ship set (24 fuel nozzles per ship set) during the annual ISO, a 13% increase. After return to JP-8+100, fuel nozzles failing the spray pattern check reduced to around 1 per ship set during the annual ISO for the aircraft. Also, frequent use of intermittent max CET at 1077 °C and continuous 1050 °C CET in the T56-A-15 turbo prop engines had a marked impact on coking of the fuel spray nozzles but use of JP-8+100 helped reduce the dropouts from operating at the higher combustion temperatures. The data also indicates there is merit for Units to use JP-8+100 that operate at or below 1010 °C CET to reduce fuel nozzle coking and hot section distress. However, the maintenance data confirms that use of JP-8+100 helps reduce fuel nozzle coking and accelerated hot section distress for Units that consistently operate T56 engines at higher CET power settings.

Maintenance Impact on UH-1N, TH-53A and MH-53J and the HH-60G Helicopters: The use of JP-8+100 in the helicopters has helped reduce the formation of carbon deposits and coke in the combustion systems of T64, T400 and T700 engines compared to using JP-8. The engine mechanics commented that the carbon deposits on fuel spray nozzles were more porous and easier to remove. With less carbon in the combustion gases, the engine hot section parts and the aircraft surfaces are running cleaner. **The unscheduled engine maintenance workload has been reduced and fewer control components are being removed due to fuel related issues.** Although the combustion systems in these engines are operating much cleaner from using JP-8+100, the detergents and dispersants in the +100 additive are unable to remove established hard carbon deposits and coke on the fuel nozzles in high time engines but growth is at a reduced rate.

Maintenance Impact on the Hughes OH-6 and Bell 500E Law Enforcement Helicopters: Use of Jet A +100 in the single engine helicopters operated by the Tampa PD showed significant reductions in coking and sooting in the combustor of the T63-A-720 engines. After logging over 900 FH during the 9 month evaluation program, nearly **a ten-fold increase in the cleaning interval was demonstrated for the fuel spray nozzles**. When the Unit used Jet A, the fuel nozzle was typically cleaned every 10 to 20 FH during the scheduled water wash of the engine compression system when the fuel nozzle was removed to inject a water and soap solution at the compressor inlet while motoring the engine. After using the +100 additive for 4-5 months, the engine mechanics determined that the cleaning interval for the fuel nozzle could be extended from 75 FH to over 200 FH before it was necessary to remove the coke deposits on the fuel nozzle tip. Periodic power checks conducted by the pilots indicated that engine torque remained at normal levels throughout the service evaluation when Jet A+100 was being used and there was no power losses during the time the additive was used. Although cleaning a single fuel spray nozzle requires less than one man-hour, more time can be devoted to other maintenance and inspection tasks performed during the water wash. Additive use continues.

Another benefit that has occurred for high performance fighter engines is the use of full authority digital engine controls with control modes that provide self-trimming and engine monitoring. The self-trimming feature adjusts the engine geometry to maintain acceptable stability margins as the performance of the gas path hardware degrades in service helping to minimize engine stalls and augmentor no lights and blowouts. The engine diagnostic system provides additional information for engine maintainers to identify control malfunctions and reduce unmerited removal of control components. As a result, these improved engine diagnostics have reduced unscheduled maintenance workload and the demand for control reparables from Depot.

However, anything that provides an operational benefit should not place insurmountable burdens on personnel in Aircraft Maintenance and the Fuels Flight. Valuable lessons have been learned from the logistic problems reported by the Users during JP-8+100 conversion and changes have been made to eliminate these burdens. Fortunately, an infra-structure for injecting thermal stability additives and managing the issue of JP-8+100 has been set-up and evaluated. Since future high performance engines will require thermal stability additives, wisdom may prevail to make the necessary changes that will allow use of JP-8+100 in all aircraft in the USAF inventory. For inter-operability, the barriers faced by the Army and Navy in using the +100 additive should be re-examined and remedies implemented.

The steady decline in crude oil quality worldwide cannot be ignored. The refining costs of JP-8 have increased to upgrade the hydro-carbon molecules and remove sulfur from poorer grade crude oil feed stocks. Current weapon systems in service, advanced systems entering the inventory and those in development will need thermal stability additives to increase the temperature at which varnishes and coke begin to form on hot metal surfaces in fuel-wetted components. The only alternatives will be to use specialty fuels refined for high temperature applications costing 2 to 3 times that of JP-8 using a thermal stability additive. Inter-operability will be sacrificed using specialty fuels and the handling problems will be more demanding than using a kerosene-based fuel like JP-8 with an additive.

9.5 Recommendations

Since all US engine manufacturers have approved use of the +100 additive in Jet A and JP-8 in their engine offerings for fighter, transport and helicopter aircraft and commercial aircraft, every effort should be made to make use and handling of JP-8+100 fuel transparent and seamless. There should be no “non-program” engines or aircraft in the inventory, only Units that chose not to use JP-8+100. Since there are no handling restrictions or precautions, filtration or RTB issues, complete transparency can only be achieved if an aircraft from a “non-program” Unit can easily refuel with JP-8+100 at a “program” Unit without any apprehension or caveats.

This technical document has presented some of the common myths and misconceptions that have become “urban legends” among Users and non-Users of JP-8+100 most of which are without merit and non-issues. Since all the fuel handling precautions and RTB restrictions have been modified or rescinded, Units can now use JP-8+100 without any reservations. Future releases of T.O. 42B-1-1 should be reviewed for any changes of JP-8+100 use and handling.

Thus, the lessons learned and unresolved fuel handling issues identified during the initial service evaluations and the rapid expansion programs at F-15, F-16, C-130H, pilot training and helicopter Units have provided an agenda for change to make the use of JP-8+100 transparent to all Users.

9.6 Agenda for Change

The following +100 additive issues deserve attention:

- Make +100 use transparent. No "non-program aircraft", only Units that choose not to use the additive.
- Obtain MAJCOM endorsement for JP-8+100 use. Higher authority will follow.
- Eliminate any problems associated with aircraft defuels and returning JP-8+100 to bulk.
- Consider additive injection at "skin of the aircraft" to provide dual fuel capability and defuel flexibility.
- Minimize preparation of "program" transport and fighter aircraft for quick reaction deployment.
- Simplify management procedures to schedule and perform aircraft refueling and defueling.
- Establish an USAF OPR to manage and coordinate the timely development of filtration elements for future thermal stability additives.

9.7 Concluding Remarks

The maintenance issues the Users faced during the conversion to JP-8 and then to JP-8+100 have been covered in this report plus the lessons learned and issues that have been resolved. The initial engine maintenance analyses for Kingsley and Louisville identified the additive benefits and fuel handling issues but after the Rapid Expansion began the Implementing Office was no longer available to develop solutions to reduce the workload of the Fuels Flight at small fighter and C-130H Units to perform defuels and fuel transfers with limited refueler assets. However, the fuel handlers and engine shops at the AETC and ANG pilot training Units were able to effectively use the +100 additive to reduce engine and control component removals as did other ANG Units operating legacy F100 fighter engines. When the +100 additive was turned off for 12 to 13 month starting in mid 2005, it was again shown that use of JP-8 increases the engine anomalies and maintenance workload. After the +100 additive was turned on again, the engine anomalies started to decrease after approximately 6 to 12 months but 18 to 30 months was required for engine anomalies to return to near the former levels before the additive was turned off. Small fighter and C-130H Units benefited from additive use when most of the aircraft were on the home station but defuels and fuel transfers became difficult to perform when only one or two C-130H aircraft were on station. Before support activity for Iraqi Freedom reached full tempo, all fighter and C-130H Units had turned the +100 additive off with exception to the pilot training Units in AETC and the ANG. Since 2006, operational Units have started to return to JP-8+100 use to avoid maintenance workload. Starting in early 2009, interest in using the +100 additive continues to grow as several operational Units have begun using JP-8+100 again while several other Units are preparing to use the +100 additive in the near future.

10.0 REFERENCES

1. Striebich, R. C.; Rubey, W. A. Prepr. Pap, - Am. Chem. Soc., Div. Pet. Chem, 1994, Pages 39, and 47-50.

2. Heneghan, S. P.; Zabarnick, S. and Ballal, D. R., "JP-8+100: The Development of High Thermal Stability Jet Fuel", AIAA 96-0403, 34th Aerospace Sciences Meeting and Exhibit; January 15-18, 1996.

3. Heneghan, S. P.; Zabarnick, S., "Oxidation of Jet Fuels and the Formation of Deposits", Fuel, 1994, Vol. 73 No. 1

4. Hazlett, R. N., "Free Radical Reactions Related To Fuel Research", (Ed. W. Pryor) Frontiers of Free Radical Chemistry, Academic Press, Inc., 1980, Pg 195.

5. Heneghan, S. P.; Zabarnick, S. and Ballal, D. R., "JP-8+100: The Development of High Thermal Stability Jet Fuel", AIAA 96-0403, 34th Aerospace Sciences Meeting and Exhibit; January 15-18, 1996.

6. "Fuel and Fuel System Materials Compatibility Test Program for a JP-8+100 Fuel Additive", Kalt, D., Vangsness, M., Saliba, S., et.al., AFRL-PR-WP-TR-2000-2015, January 2001.

7. "Propulsion Evaluation of JP-8+100 Fuel in the F100-PW-220E Engine Installed in an F-16 Aircraft", AFFTC-TLR-94-76, June 1995; C.J. Chan and Major D.G. Carey, AFFTC, Edwards AFB CA.

8. "Service Test of Two Fuel Conductivity Additives", Martel, C.R., Technical Report AFWAL-TR-80-2051, 1980.

9. "Conductivity and Charging Tendency of JP-8+100 Jet Fuel", Leonard, J.T. and Hardy, D.R., IASH 2000, the 7th International Conference on Stability and Handling of Liquid Fuels, September 2000.

10. "JP-8+100 Fuel Study Covering the Parameters: Temperature, Density, Dielectric Constant, Velocity of Sound and Electrical Conductivity and the Effects of JP-8+100 Fuel on Fuel Gauging System Performance", Kline, B. R., Technical Report WL-TR-95-2158, Aero Propulsion and Power Directorate, Wright Laboratory, Air Force Materiel Command, September 1995.

11. "F100 Pump Model 708000-02 S/N B0465 Pump Received from Wright-Patterson AFB", Bates, J. A., Argo-Tech Corporation, Report EN-6283, May 6, 1996.

12. "F100 Pump Model 708000-03 S/N B1449 Pump Received from Wright-Patterson AFB", Bates, J. A., Argo-Tech Corporation, Report EN-6404, August 7, 1997. [Editor: The cover page of this report references pump model 708000-03 while the body of the document reports the pump model to be 708000-02.]

13. "Aviation Fuel Handling: Specifications Controlling the Performance of Filter Units Used In A Jet Fuel Distribution System", Rugen, P. D., Paper for IASH 2000, The 7th International Conference on Stability and Handling of Liquid Fuels, September 2000.

14. "Specifications and Qualification Procedures for Aviation Jet Fuel Filter/Separators – API/IP Specification 1581, Fifth Edition", American Petroleum Institute/The Institute of Petroleum Document 1581, July 2002.

15. “Southwest Research Institute® Aviation Fuel Filtration Cooperative R&D Program – Final Report”, Besse, G. B., Buckingham, J. P., Hughes, V., SwRI® Project No. 08-10844, February 2006. (Industrial Proprietary)

16. “JP-8+100 and Filtration”, Young, J. E., AFTH 06-001, Southwest Research 8th International Fuels Conference, January 2007.

17. “Evaluation of the Effects of JP-8+100 on the Operation and Maintenance of Rotary- Wing Aircraft, Part I – TH-53A/MH-53J Helicopters”, 1999; AFRL-PR-WP-TR-1999-2076, R. W. Morris Jr., AFRL/PRTG, W-PAFB OH.

18. “Evaluation of the Effects of JP-8+100 on the Operation and Maintenance of Rotary-Wing Aircraft, Part III: UN-1N Helicopter”, February 2001; AFRL-PR-WP-TR-2006-2007, R. W. Morris Jr., AFRL/PRTG, W-PAFB OH.

19. “Evaluation of the Effects of JP-8+100 on the Operation and Maintenance of Rotary-Wing Aircraft, Part II: HH-60 G Helicopter”, February 2001; AFRL-PR-WP-TR-2006-2028, R. W. Morris Jr., AFRL/PRTG, W-PAFB OH.

20. “Demonstration and Evaluation of a Fuel Thermal Stability Improving Additive in Commercial Jet A for Non-Military Applications”, +100 Bibliography Doc ID 642, R.W. Morris, Jr. and G. Buchhalter, AFRL/PRTG, W-PAFB OH.

21. “Application of Reliability-Centered Maintenance for USAF Gas Turbine Engines”, 14 Feb 03; PCOE BP 99-4, Rev A, Dennis J. Cassette, ASC/LPE, et al, W-PAFB OH.

22. National Library of Medicine: www.ncbi.nim.nih.gov; 223-312, "A Review of Neurotoxicity Risk of Selected Hydrocarbon Fuels", July 2001.

23. “JP-8+100: Current Knowledge and Best Practices”, AFRL-RZ-WP-TR-2008-2126, April 2008, AFRL/RZTG, WPAFB, OH; Robert W. Morris, Jr., Charles E. Bentz, Joseph F. Stonecipher, Christopher Barber, James Young and Edwin Wells.

[Authors note: AFRL/RZTG has been changed to AFRL/RZPF]

APPENDIX A

JP-8+100 and Filtration

James E. Young, USAF

Presented at
Southwest Research 8th International Filtration Conference
(reprinted by permission)

AFTH 06-0001

JP-8+100 and Filtration

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ABSTRACT

During the planning stage of the JP-8+100 program, the United States Air Force was concerned with the surfactancy nature of the Betz Dearborn 8Q462 additive and the impact it would have on filtration. Planners were convinced the existing coalescer-type filtration would quickly become disarmed after coming into contact with the additive and subsequently dirt/water would pass through to receiver aircraft. No actual testing was performed by the Air Force to validate this perception. Instead the decision was made to use water -absorbing filtration vice coalescing-type filters and the JP-8+100 filtration issue was thought to be solved. Thirteen years after this decision, the Air Force has now determined that JP-8+100 was perhaps not as bad on coalescer-type filtration as first thought and that the use of water absorbing filters was not a good idea.

INTRODUCTION

From the very beginning, those of us involved with the USAF JP-8+100 program felt the decision to use water absorbing filtration was the right thing to do. We were convinced the +100 additive was a “super surfactant” and would immediately disarm conventional coalescers on contact. In our view, this “new” filter technology would make the JP-8+100 implementation very simple... change the filters in the refueling vehicles that would service the aircraft and add the +100 additive as the fuel was going into the refueling unit cargo tank. This process would protect the coalescing filters in our fixed fueling systems and simplify the entire process. To go one step further, we took an added precaution in the technical guidance by warning our operators to NOT defuel or return fuel to our bulk storage systems and expose the coalescing filters to the +100 additive. We thought our plan was sound and believed we wouldn’t encounter any great problems with filters if everyone followed our guidance. Unfortunately, we were wrong.

The purpose of this paper is to outline the events that have occurred to date with the Air Force JP-8+100 program. It is not intended to question filter qualification requirements or any other filtration requirement.

JP-8+100 AND FILTRATION

APPLE JELLY

Standardization is one thing we strive for in the military. If everyone uses the same type equipment we can reduce many of the headaches faced by logisticians every day. A classic example of this is the water-absorbing filters we were using for the JP-8+100 program. At a given base using +100, we had refueling vehicles equipped with water-absorbing filters (those issuing +100) and we also had units with coalescing filters (issuing JP-8). Once we saw how easy it would be to have a standard filter (water-absorbing-type), we quickly moved forward with what seemed to be a brilliant idea and installed the water-absorbing filters in all our R-11 units.

The first sign of a problem began at those locations only issuing JP-8. We began to receive information about a very thick gelatinous, jelly-like substance being found when we “sumped” our refueling units or changed filter elements. Initially, this situation occurred mostly in the fall of the year and usually at the same locations. The photos below clearly depict the extent of the problem we were encountering with what was then commonly referred to as “Apple Jelly.”

Figure 1-1 Elements Removed From Equipment at Tinker AFB OK

APPLE JELLY SOLVED

As we continued to work through the Apple Jelly phenomenon, it became clear that the Air Force was the only Service with the problem. Likewise, we determined the problems began after we converted all our refueling units to water-absorbing filters. We also saw that the problems were mostly occurring at locations where we were NOT issuing JP-8+100. After putting everything together, it became rather evident that if we removed the water-absorbing filters and went back to coalescers, our problems would perhaps end. Therefore, after evaluating the facts, the Air Force directed (CY 2002) all units issuing only JP-8 to convert back to coalescing-type filtration. Following the conversion back to coalescing filters in 2002 our problems with Apple Jelly basically disappeared.

SHEPPARD AFB FLAMEOUTS

Following the problems with Apple Jelly, we had three years with few JP-8+100 related problems. Granted, some locations went off the program because of perceived/actual logistics difficulties and no documented aircraft maintenance benefits. However, we had between 50 – 66 percent of those originally converted still using the additive. Then, in the summer of 2005, three T-37 aircraft at Sheppard AFB, Texas experienced a single engine flame-out while in flight. Attempts to air-restart the aircraft failed in all cases. All three landed safely on the remaining engine and a lengthy investigation ensued. Large amounts of carboxymethylcellulose/potassium super absorbent polymer were found trapped in the aircraft engine filters and fuel control hardware blocking the flow of fuel to the one engine until fuel starvation occurred. Further investigation efforts resulted in the identification of the same super absorbent polymers in aircraft filters taken from several other bases within the continental United States. In order to ensure safety of flight, the Air Force directed the removal of water-absorbing filter monitors from the equipment used to refuel at all Air Force activities. Filter monitors were replaced with either API/IP 1581, 5th edition, M100 Class filtration, API 3rd edition qualified filtration or DoD filter elements tested using the API/IP 1581, 5th edition, M Class test criteria. Following this decision, the Air Force JP-8+100 program was reduced to one single location (Moody AFB GA) that had refueling equipment outfitted with API/IP 1581, 5th edition, M100 filters.

SOUTHWEST RESEARCH INSTITUTE COOPERATIVE

After the Sheppard AFB aircraft flameout problems, the USAF, Defense Energy Support Center, US Army AMCOM, GE Infrastructure, ChevronTexaco, ExxonMobil, QinetiQ, ConocoPhillips, and the UK MOD/DLO formed a cooperative with the Southwest Research Institute in San Antonio, Texas. A multi-phased program was organized to investigate the effects of aviation fuel additives on filtration performance. The main emphasis of the program was to determine if the GE 8Q462 thermal stability additive was detrimental to filtration performance. There were five phases of the program. For the purposes of this paper the only two that were applicable are:

- Using a Design of Experiment (DOE), determine the required dilution ratio of JP-8 to JP-8+100 to have the mixture filtration perform the same as JP-8.
- Using a DOE, determine the effects of the individual aviation fuel additive and combination of additives on filtration performance

Based on the statistical analysis utilizing the failure criteria agreed upon by the program members (water by Aqua-glo greater than 10 ppm free water and solids by gravimetric membrane greater than 0.5 mg/L, the following conclusions were made:

- For 3rd edition elements, the average maximum water by Aqua-glo for JP-8 (34.25 ppm) is significantly greater than the average at JP-8+100 @256 ppm (6.50) during the 100 ppm challenge.
- There is no statistical difference in the average maximum Aqua-glo @ 256 ppm for the 5th edition elements at the 100 ppm water challenge or the 0.5% water challenge.
- There is no statistical difference in the average maximum Aqua-glo between JP-8 and JP-8+100 @ 256 ppm for the 3rd edition elements at the 0.5% water challenge. All tested resulted in values > 10 ppm.
- For both the 3rd and 5th edition elements, there is no significant difference in the average maximum effluent solids between JP-8 and JP-8+100 @ 256 ppm.
- For both the 3rd and 5th edition elements, there is no significant difference in the average maximum differential pressure between JP-8 and JP-8+100 @ 256 ppm at either the 100 ppm or 0.5% water challenge.
- For the 3rd edition elements, the average maximum conductivity for JP-8 is significantly less than the average at JP-8+100 @ 256 ppm during the 100 ppm and 0.5% water challenge and the particulate removal stage.
- For the 5th edition elements, there is no statistical difference in the average maximum conductivity between JP-8 and JP-8+100 @ 256 ppm during the 100 ppm and 0.5% water challenge and the particulate removal stage.
- The only significant difference between the fuels for the maximum adjusted water content by Karl Fischer was found in the 3rd edition elements at the 0.5% water challenge. The average for the JP-8 was greater than the average for JP-8+100 @ 256 ppm.

The overall conclusion of the cooperative final report was that there is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 @ 256 ppm. Any portion of the test matrix where the JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol. However, both JP-8 and JP-8+100 performed differently than Jet-A as the Jet-A tests passed the protocol using the agreed upon failure criteria. Based on these results, it was concluded that JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage. Another conclusion was that the GE 8Q462 thermal stability additive does not affect the filtration performance for either water or solids.

JP-8+100 FILTRATION FIELD EVALUATION PROGRAM

The use of JP-8+100 fuel was temporarily suspended at most Air Force locations following the three aircraft incidents at Sheppard AFB. Media migration from the refueling unit filters (water absorption monitors) was identified as a contributing factor to the aircraft flameout conditions, but was not related to or caused by the use of JP-8+100 fuel.

Previous to a year-long study by Southwest Research Institute, the filter elements installed in Air Force refueling units were considered incompatible with JP-8+100. The Air Force JP-8+100 technical order guidance consistently stated the +100 additive was a surfactant that would disarm all coalescing-type filter elements. However, based on the conclusions and recommendations made by the Southwest Research Institute study, which indicated JP-8+100 fuel is no different than JP-8 on filtration systems from an operational perspective, we determined additional field-testing was necessary to make key decisions associated with JP-8+100 fuel and future handling guidance. The objective of the field evaluation was to verify the results of the Southwest Research Institute work and document the impact of JP-8+100 fuel on existing coalescing filtration systems contained in the USAF R-11 refueling vehicles.

After obtaining approval from the applicable agencies, Lauglin AFB TX was selected to perform the initial field evaluation. Laughlin's minimal transient aircraft workload, favorable weather conditions and OPS tempo made it an ideal location where the evaluation could be conducted and controlled with no expected impact to flying operations. The Laughlin refueling fleet consisted of ten Oshkosh, five (96 – 98) Kovatch and one (05) Kovatch R-11 refueling vehicles. The required actions for the test were:

- Install new JP-8+100 compatible filters in eight of the assigned R-11 Oshkosh refueling units. The filter elements were manufactured by Velcon Filters, Colorado Springs, CO. Part numbers for the items were: I-440A4 for the coalescers and SI-542 for the separators.

- Retain two of the R-11 Oshkosh refueling units and all five of the R-11 Kovatch units (96 – 98) with the existing filter coalescer and separator cartridges. The two Oshkosh units were equipped with DoD filters tested using API/IP 1581, 5th edition, M Class coalsescer and separators, and the five Kovatch units contained API 1581, 3rd edition qualified coalescers and separators. The 05 Kovatch contained API/IP 1581, 5th Edition, M100 qualified filtration system and could thus be used to issue either JP-8 or JP-8+100 fuel.

- In summary, there were 16 refuelers at Laughlin, 10 converted to the JP-8+100 approved elements, two remained for servicing JP-8 to transient aircraft, and four (2 Kovatch with API 3rd edition filtration and 2 Oshkosh with DoD filters tested to the API/IP 5th edition, M class) would service JP-8+100 through existing coalescer elements and be used as the basis for the test.

The plan was for the Laughlin evaluation to last at least thirty days, but not to exceed three months. The evaluation would start once the first aircraft received JP-8+100 fuel and would end when there was data indicating the existing filters in the Oshkosh and Kovatch R-11 units were compatible with the JP-8+100 fuel or if there was similar data indicating the Southwest Research Institute conclusions were flawed.

On March 1, 2006, the first aircraft was serviced at Laughlin AFB, TX with JP-8+100 fuel and the filter evaluation began. For the next three months all assigned Laughlin AFB aircraft used +100 and as required the applicable reports and filter tests were conducted. The following requirements were established for the evaluation.

- Increase the sampling frequency for water and particulates from every seven days to every day for the refueling units equipped with the existing filter coalescer and separator cartridges.

- Perform multiple one-time defuels with the R-11 refueling units to preclude returning JP-8+100 product back to bulk storage tanks.

- Every 30 days, open the filter vessel on one refueling unit (equipped with the existing filter coalescers), remove/replace one of the coalescer elements and ship the removed element to a designated filtration original equipment manufacturer for quality testing. Continue this process for three months or until the determination can be made that the elements are or are not compatible with JP-8+100.

- Maintain a running history of the amount of JP-8+100 each R-11 refueling unit issues to aircraft and defuels from aircraft.

- Document any anomalies (excessive water/PC downstream of a refueling unit filter separator, high differential pressure readings, filter changes, etc.) and corrective action taken during the evaluation period.

- Only issue JP-8+100 to program aircraft. Document aircraft forms accordingly.

- Provide status reports bi-weekly outlining quantity of fuel issued for the R-11 units equipped with existing coalescer and separator cartridges, refueling unit differential pressure readings, quantity of water drained from each R-11 filter separator, problem areas, and any other item that may be of interest.

At the end of May 2006, the evaluation ended. The tables and laboratory reports at the end of this paper outline the results. Based on the data collected and the filter tests performed, we felt the Laughlin evaluation provided the information we needed to continue with the JP-8+100 program and NOT go to the extra effort and expense of installing filter elements that had been qualified with JP-8+100. Therefore, we changed our technical guidance and advised our bases they could return to JP-8+100 and use the existing filters installed in their refueling equipment. We have been operating in this manner since July 2006 and have not encountered any problems with filtration.

CONCLUSION

Based on the conclusions of the Southwest Research Institute *Aviation Fuel Filtration Cooperative R&D Program* and the Laughlin AFB 90-day Filter Field Evaluation, the USAF has began issuing JP-8+100 at a number of locations. At some of these locations the refueling units are equipped with coalescing-type filtration qualified according to the API/IP 1581, 5th edition, M100 requirements. However, at a number of the other locations we are using filters that were not qualified per the API/IP 1581, 5th edition. The elements at these locations have been installed since July 2006 and are performing satisfactorily.

REFERENCES

1. Bessee, Buckingham, Hughes, “Southwest Research Institute Aviation Fuel Filtration Cooperative R&D Program”, Final Report, SwRI Project No. 08-10844

APPENDIX B

Fuel Stability Challenges in a Marine Environment: A US Navy View

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FUEL STABILITY CHALLENGES IN A MARINE ENVIRONMENT: A US NAVY VIEW

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ABSTRACT

Ship and aircraft propulsion fuels face unique stability challenges in the 21st century. Increasing hardware requirements, changing refinery practices, and stringent environmental mandates all contribute to these challenges. Unfortunately, the United States Navy (USN) is not immune to these issues. Having worldwide commitments to supply both ship and aircraft support, the USN is faced with difficult decisions regarding how to best address these stability issues in both ship and aviation fuels without compromising operational capability. What may be acceptable solutions for commercial ships, commercial aircraft, or land-based military aircraft may be unacceptable due to the USN operating environment. From long-term storage requirements; to the utilization of commercial distillate marine fuels; to the shipboard impact of the "+100" aviation fuel thermal stability improvers, the USN is constantly addressing stability problems and their potential solutions. The intent of this paper is to provide an overview, using current issues, of the USN philosophy, approach, and rationale to address the fuel stability challenges of the 21st century.

KEYWORDS: Aircraft, Military, Shipboard, Stability, U.S. Navy

INTRODUCTION

Due to the unique operating requirements of the USN, the need for stable fuel is absolute. Operations routinely require worldwide movement of ships. This requirement means that ship propulsion fuel is lifted from many parts of the world and the USN mixes both military specification and commercial fuels from many sources in shipboard storage tanks. The USN will generally store fuel for longer time periods than a commercial user. The United States maintains stocks of fuel in prepositioned stocks. The fuel is stored in locations of diverse climatic conditions for extended periods of time. Although the stocks are routinely rotated and replenished, that rotation time is significantly longer than the normal storage time for a typical commercial user. Another unique factor is the aviation fuel handling systems found on board

USN ships. The handling system consists of copper-nickel piping. This piping may lead to copper contamination in the aviation fuel, resulting in thermal stability failures. While facing these types of stability challenges, the USN places stringent controls on acceptable additives and does not allow aftermarket additives.

This paper will describe how the use of commercial fuels, the availability of stability tests, increasing environmental mandates, and the use of additives all play a role in defining the Navy's fuel stability requirements for both ship and air propulsion fuel in the marine environment, and how the Navy attempts to meet these challenges.

SHIP PROPULSION FUEL

Over the past 27 years, the USN has refined their ship propulsion fuel requirements. Where residual fuels such as Navy Special Fuel Oil (approximately 180 cSt) were once used, a high quality middle distillate fuel is now required for the ever-increasing number of marinized gas turbine engines used in the fleet. The current United States specification for Naval distillate fuel is MIL-F-16884 Revision J, which meets the requirements for NATO F-76[1]. This fuel is qualified for use aboard all USN ships as well as NATO allied ships specifying NATO F-76 fuel. NATO F-44 (the Navy's JP-5 aviation fuel) and NATO F-75 (low pour point F-76) are acceptable alternatives for ship propulsion when F-76 is not available. When F-76, F-75 and F-44 are all not available, commercial distillate fuel that meets the requirements of the USN's commercial Marine Gas Oil Purchase Description (MGO PD) can be lifted, but it must be burned within 6 weeks of receipt. In rare situations, the Navy lifts commercial fuel that does not meet the requirements of the MGO PD. In those situations, the fuel will typically meet the requirements of ASTM D 975 (*Standard Specification for Diesel Fuel Oils*)[2], D 396 (*Standard Specification for Fuel Oils*)[3] or D 2880 (*Standard Specification for Gas Turbine Fuel Oils*)[4]. The USN's MGO PD is slightly more stringent than these typical commercial fuel specifications. Table 1 illustrates the major differences between ASTM grade commercial fuels, USN MGO PD, and USN F-76 specification requirements.

No current commercial fuel specification requires testing for storage stability or demulsification, two very important tests required by the USN. Storage stability is of great importance due to long fuel storage times. Fuels slowly oxidize during storage in the presence of air, forming undesirable oxidation products such as sticky gums, residues or particulates. These products can inhibit the performance of engines and cause failures in fuel handling equipment such as filter-coalescers. A storage stability test to predict how long a fuel will remain stable during storage is an absolute requirement for the USN. Demulsification is another important test requirement since most USN ships use automatic water-compensating systems on fuel tanks to store ship propulsion fuel. Another area of concern is flash point since the USN requires a minimum flash point of 60°C and some commercial fuel specifications allow a lower minimum flash point. Cloud point limits for commercial fuel tend to vary by location or are not required at all. A ship may lift fuel with a cloud point that is acceptable for the climate where the fuel lift occurs. However, that ship may then be called into a colder operating location, where the higher cloud point fuel may cause filter-plugging problems. The USN's worldwide operations require a lower cloud point than most commercial users need. The Navy's MGO PD specifies a cloud point of –1.1°C (for F-76, the cloud point requirement is –1° C), although suppliers in the warmer climates usually have a difficult time meeting this requirement. Sulfur, density and carbon residue requirements are very similar between the commercial and military specifications. For carbon residue, although the commercial specifications allow a higher maximum amount, the USN has found that most commercial fuel meets the military specification limit. The three ASTM fuel specifications (D 975, D 396 and D 2880) do not set any limits on the addition of additives. Since many fuel additives are known to have surface-active characteristics, they have the potential to stabilize fuel/water emulsions and thus cause a problem when using water-compensated fuel tanks. In an earlier survey conducted by the Navy, commercial refiners reported using a wide variety of additives on an "occasional" or "frequent" basis[5]. These additives were said to have one or more of the following functions: antioxidant, dehazing agent, dispersant, rust inhibitor, antistatic agent, metal deactivator, pour point depressant, flow improver, cetane improver and ignition improver. Today, there are just as many, if not more, additives available commercially. The USN's MGO PD also does not place any limits on the use of additives, since this Purchase Description is meant to be in line with commercial standards as much as possible. The extensive use of additives in commercial marine fuels is one more reason why the USN tries to minimize its use of commercial fuels.

The use and availability of storage stability tests is another current challenge for the USN. As mentioned above, commercial fuels are not tested for storage stability. The USN's military specification for F-76 requires a storage stability test, either ASTM D 5304 (*Standard*

Test Method for Assessing Distillate Fuel Storage Stability by Oxygen Overpressure)[6] or a modified ASTM D 2274 (*Standard Test Method for Oxidation Stability of Distillate Fuel Oil – Accelerated Method*)[7]. ASTM D 5304 is a stability test developed by the United States Naval Research Laboratory[8]. Filtered fuel is placed in a pressure reactor and pressurized with oxygen to 800 kPa. The pressure reactor is then placed in a forced air oven at 90°C for 16 hours. After aging and cooling, the total amount of fuel insoluble products is determined gravimetrically. If the amount of insoluble products does not exceed 1.5 mg/100mL, then the fuel will remain stable for a period of at least 24 months. If a supplier decides to use ASTM D 2274, then this test must be conducted for 40 hours, instead of the ASTM-required 16 hours. At 40 hours, the result is more comparable to the ASTM D 5304 results. The current NATO STANAG for F-76 only requires that ASTM D 2274 be run for 16 hours. The Navy has found that running this test for only 16 hours may falsely pass unstable fuels. There have been numerous occasions where fuel had been procured based upon the ASTM D 2274 16-hour test and became unstable within a few months. Some of this fuel made it onboard USN ships, where it caused excessive filter coalescer change-outs. Other incidents involved large quantities (several million barrels) of fuel in storage that required filtering and the addition of a stability additive before the fuel could be issued to ships. These problems have resulted in millions of dollars being spent over the years to clean up the fuel. This data suggest the need for a stricter storage stability test requirement within the NATO STANAG for F-76. At the last NATO conference, the USN requested the consideration of adding ASTM D 5304 and/or extending the test time for ASTM D 2274 to 40 hours. ASTM D 5304 may not be suitable for the commercial industry since it requires specialized equipment and takes 16 hours to run. Therefore, the USN is also in the beginning stages of developing a new test method to determine storage stability of middle distillate fuel that involves the quantification of the chemical composition of the fuel. This test, if successful, will be easier and more suitable for both military and commercial fuel user needs.

Today, commercial fuel lifts account for approximately 4-5% of the Navy’s total ship propulsion fuel lifts each year. In order to define the quality of the commercial fuels in terms of the USN F-76 specification, the Navy periodically conducts a worldwide survey of commercial fuels. A fuel sample is taken from the shore tank of the supplier for testing to MIL-F-16884 specification requirements. Surveys were conducted in 1983, 1986, and 1996[9,10,11]. Testing varied for each of these surveys in comparison to the USN F-76 specification revision in use during that time period. Additional tests were also added as part of the R&D program for revising USN fuel specifications. For this paper, the stability properties will be examined. See Table 2 for a comparison of the stability test results over the different surveys.

The storage stability test method used for each of these fuel surveys was the test method specified in the USN F-76 specification during that time period. During the 1980's, the USN was using the 16-hour ASTM D 2274 test. Table 2 shows that the majority of commercial marine distillate fuel samples passed this test. In 1996, the samples were tested to the more stringent ASTM D 5304. Again, most of the commercial fuels passed this test. This data suggest that most commercial fuel is actually storage stable. The biggest stability problem the USN faces when lifting commercial fuels is that the fuel is not tested for stability. When a USN ship is lifting commercial fuel, there is no way to tell if it will fail or has already failed for storage stability, since commercial fuel isn't tested for stability. Therefore, strict use requirements are placed upon the ship to segregate and burn commercial fuel within six weeks of the lift. The Navy is currently trying to ballot, within ASTM, a new grade of commercial distillate fuel that will require a storage stability test. This new fuel grade would not only benefit the USN by allowing the utilization of more commercial specification versus military specification fuels; it would also be useful for emergency standby generators in hospitals, the locomotive industry, United States Coast Guard vessels, etc. This greater usage would hopefully increase availability and lower costs.

The USN has partnered with the Defense Energy Support Center (DESC), the fuel procurement agency for the United States Department of Defense, and with the United States Coast Guard, on an in-line fuel-sampling program. Whenever a participating USN ship lifts commercial fuel, they collect a continuous drip sample and send the sample to a commercial laboratory for analysis. These samples are analyzed and the results compared to the MGO PD requirements, which are contractually enforceable on the supplier. A few, additional F-76 tests are analyzed for R&D purposes. This is a pilot program, still in the evaluation stages. Over the past year, the USN has collected 27 samples. This data is preliminary and conclusions cannot be made before many more samples are collected globally over a several year time period.

In the United States and abroad, increasing environmental regulations are forcing changes in all types of fuel, both commercial and military. For ship propulsion fuel, the biggest change expected in the near future is a lowering of the sulfur content to a maximum of 15 ppm.

Currently, the F-76 specification allows 1% sulfur; the fuel lifted worldwide over the past 10 years has been in the 0.3 to 0.7 wt. % sulfur range (barrel-weighted averages)[12]. The biggest concern the Navy has with a lower sulfur limit is the possibility of lubricity problems. Currently, there is no lubricity additive or test requirement in the United States or NATO F-76 specifications. Although newer engines and fuel handling systems are designed for lower sulfur fuels, many Navy ships have older technology (up to 30 years old) that was designed for and tested on higher sulfur fuels. With the lower sulfur levels, these engines will have to withstand a larger sulfur range of 15 ppm up to 10,000 ppm, depending on the geographic location of the fuel lift. The effects of low sulfur and lower lubricity on this older technology equipment are currently under study. In terms of stability, the USN does not expect to encounter additional problems with the lower sulfur requirements. If anything, a fuel having lower sulfur content should be more storage stable.

Current Navy policy restricts the use of additives in all types of fuel. Within the Navy's F-76 specification, the following additives are allowed to be added by the refiner: Stabilizer additive (conforming to DoD-A-24682), Metal Deactivator (N, N-disalicyclidene-1,2 propanediamine), and Ignition Improver (as listed in specification). These additives may only be added by the refiner, not at the shipboard level and are allowed but not required. No aftermarket additives are allowed. This strict control on additization is necessary, considering the large amount of aftermarket additives that are available worldwide and the possibility of incompatibility problems between additives.

In terms of thermal stability, the USN does not require thermal stability testing for F-76. The need to address thermal stability within the USN's F-76 specification is currently under study.

Aircraft propulsion fuel stability is another concern in the Navy's shipboard environment. All aircraft capable ships store JP-5 aviation fuel. In addition to this fuel being used in aircraft aboard ship, JP-5 is an alternate fuel for ship propulsion when F-76 is not available and in cold weather operations since F-75 is not always available.

AIRCRAFT PROPULSION FUEL

The stability of aircraft propulsion fuel in the marine environment is of great concern to the Navy. USN ships must be able to receive, store and issue JP-5 (MIL-DTL-5624)[13] for ship-based aircraft, and also use it for ship propulsion, ship's auxiliary equipment, and Marine landing vehicle use.

JP-5 is the only aircraft fuel that is approved for use in the Navy's marine environment. All shipboard fuel, both ship propulsion and air propulsion, must meet a minimum 60°C (140°F) flashpoint. Therefore, JP-8, JP-4 and commercial aviation fuels (all with lower than 60°C flashpoint requirements) are not authorized for use in aircraft onboard carriers and are not authorized for storage onboard ship.

The USN specification for JP-5 (MIL-DTL-5624) requires thermal stability testing according to ASTM D 3241, *Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)*[14]. The JFTOT test results must meet the following requirements at 260°C: change in pressure drop of 25-max and tube deposit code of < 3. The aircraft fuel handling system on board ship can have a great affect on the thermal stability of JP-5. USN ships' aviation fuel handling systems contain copper-nickel piping. While copper-nickel has proven for decades to be an acceptable cost-effective material for this application, it can have a significant detrimental impact on the fuel delivered to the aircraft, since it leads to an increase in the copper concentration of jet fuel. This copper contamination lowers the thermal stability of the fuel, as tested by the JFTOT. Surveys of fuel samples taken from USN aircraft carriers show copper concentrations varying from 40 ppb up to approximately 1300 ppb, averaging around 250 ppb[15]. Copper concentration > 50 ppb can cause a fuel to fail the JFTOT specification requirements in MIL-DTL-5624. The operational impact of the copper is dependent on both the fuel's bulk temperature and its residence time at temperature. The higher the fuel's temperature and the longer its residence time at elevated temperature, the greater its impact on increasing carbon deposition. The USN has not yet incurred any significant maintenance penalty or increased deposition due to copper contamination. This is attributed to the relatively low bulk fuel temperatures and minimal fuel recirculation rates of its aircraft. However, as new aircraft continue to place additional heat load requirements on the fuel, increasing both bulk fuel temperatures and fuel recirculation rates, the risk for additional coking due to copper contamination increases. When a ship offloads JP-5, JFTOT testing is conducted before that fuel can be placed back into United States aviation fuel stocks. If the fuel fails JFTOT due to copper contamination, then the fuel must be blended to lower the copper concentration or the fuel is downgraded. The Navy is in the process of developing a filter that can remove the copper from fuel[16]. Having the ability to remove the copper and thus improve the thermal stability will result in significantly reducing potential impact of carbon formation in advanced USN aircraft and in reducing the cost and logistics penalty due to the fuel being downgraded.

Aviation fuel, just like other hydrocarbon fuels, is susceptible to autoxidation during long-term storage. The reaction products that are of primary concern are hydroperoxides, which have been found to be detrimental to the elastomers in aircraft fuel systems. The potential for the fuel to form peroxides during storage is quite high due to the increased amount of severe hydroprocessing used in refineries today. Naturally occurring inhibitors are removed during this process, thus increasing the fuel's ability to peroxidize during storage[17]. In addition, severe cracking reactions create branched chain compounds, which have proven to be extremely susceptible to oxidation. Since 1976, the USN has required the addition of phenolic type antioxidants into aviation fuel to inhibit hydrocarbons from reacting with dissolved oxygen during storage[18]. The antioxidant is added at a concentration between 17.2 ppm and 24 ppm at the refinery prior to exposure to air. Since the antioxidant may be depleted during storage, the USN has developed a test to determine the peroxidation potential of fuels stored in prepositioned stocks. The test is not an ASTM method. A sample of jet fuel is aged by pressurizing to 50 psi air at 100°C. The concentration of hydroperoxides, existent gum and antioxidant is then determined at 24 hr intervals for the duration of the test. This test simulates the storage of a jet fuel for approximately nine months for every 24 hours of testing. At the end of the test, the fuel is considered storage stable for approximately nine months for every 24 hours of testing if the hydroperoxide concentration does not exceed 8 ppm. Since the USN JP-5 specification mandates the use of an approved antioxidant, this test for determining hydroperoxidation potential is not a procurement requirement, but only a long-term storage test requirement.

The USN expects the increasing environmental mandates, such as lower sulfur limits, to extend to aviation fuel, as well as to ship propulsion fuel, as discussed above. However, lowering the sulfur limit is not expected to produce any type of problem for JP-5. The USN specification requires a corrosion inhibitor additive. This additive doubles as a lubricity improver and should counteract any lubricity problems associated with the lowering of the sulfur content of aviation fuel, with respect to aviation uses. The use of lower sulfur JP-5 for ship propulsion or auxiliary equipment needs further review. As with marine distillate fuel, the USN does not anticipate any stability concerns to surface from lowering sulfur limits. Synthetic jet fuel has also been proposed for use by the US military as way to increase availability and provide a more environmentally friendly product. Unfortunately, all current specification requirements were based on conventional petroleum-derived products. Since the synthetic products may have different issues and requirements, their potential impacts on USN unique operations and requirements have to be studied.

One of the biggest stability problems for aviation fuels in the marine environment is the use of additives, including the "+100" thermal stability improver additive. Additives that may pose no problems for shore-based users can cause many unforeseen problems in the shipboard environment. Over the past 5 years, the USN has investigated the possible shipboard effects of the +100 additive for use in JP-5. The United States Air Force (USAF) has implemented this additive at all Fighter and Trainer bases worldwide and selected Air National Guard C-130 bases. The additive is a combination of antioxidant, metal deactivator, and proprietary dispersant/detergent. It increases the heat sink of the fuel by 100°F and has shown the capability to reduce fuel-related carbon deposition and its associated maintenance costs in certain in-service aircraft. To determine the possible economic benefit of using this additive, and also since future aircraft may require the additive, the USN has investigated the effects of +100 in the shipboard environment and determined preliminary costs for making shipboard systems compatible with the additive. The most significant detrimental impacts of the additive on the shipboard fuel distribution system are: use of additized fuel in non-aircraft systems, disarms current DoD filter coalescer elements used in aviation fuel filtration systems, decreases the ability of centrifugal purifiers to effectively separate water and sediment from the fuel, cleans fuel tank and piping interior surfaces which will cause an increase in the sediment during initial shipboard implementation, and can cause false low readings on the shipboard Free Water Detector and/or the Aqua-Glo free water detector. The biggest impact for the USN is the use of +100 additized fuel in non-aircraft systems. JP-5 is not only used for aircraft propulsion. It is also an alternate ship propulsion fuel, where JP-5 is commingled with F-76 in water-compensated storage tanks. JP-5 is also used in support/auxiliary equipment on-board ship and is used for United States Marine Corps landing forces vehicles. These non-aircraft uses perpetuate the problems that must be taken into account when evaluating the impact of the additive in the shipboard environment. The USN recently completed a study on the costs of implementation of the +100 additive in the shipboard environment. Preliminary estimates show that if the current technological roadblocks could be overcome it would cost a minimum of $20 M/carrier to retrofit each to be +100 compatible[19]. USN cost benefit studies have determined that the maintenance cost savings to carrier aircraft would not justify the shipboard implementation costs, thus the USN is not planning shipboard implementation of +100 at this time.

CONCLUSIONS

Worldwide operations, specialized fuel handling systems and more complex weapon systems create unique fuel stability challenges for the USN. Increased reliance on commercial products as well as more stringent environmental regulations just add to the challenge at hand. These challenges often require different and/or more stringent solutions than what may be acceptable for commercial ships, commercial aircraft or land-based military aircraft. The USN will meet the stability challenges of the new millennium through a multi-disciplined approach. The USN will continue to review and improve its specifications and operating requirements, looking for ways to update and enhance existing tests while removing those that no longer provide useful information. In addition, the USN will continue to work with the industry to investigate ways to reduce cost and increase availability by striving to develop and implement commercial specifications that meet both USN and commercial requirements whenever possible. The USN will also continue to work with weapon system designers to ensure environmental and fuel requirements are considered in the design of new systems prior to implementation. This partnership will ensure compatibility between hardware and fuel prior to implementation.

Finally, the USN will continue to support the development and evaluation of new equipment, fuels and additives. While not all the developments that may benefit commercial activities can be utilized, the USN will continue to challenge the industry to come up with shipboard-friendly alternatives.

Table 1: Subset Comparison of Specification Requirements for Commercial and Military Ship Propulsion Fuels.

Requirement	**ASTM D 975 Grade No. 2-D**	**ASTM D 396 Grade No. 2**	**ASTM D 2880 Grade No. 2-GT**	**USN MGO PD**	**USN F-76 (MIL-F-1884J)**
Storage Stability, max, mg/100mL	No requirement	No requirement	No requirement	No requirement	1.5
Demulsification, Max, minutes	No requirement	No requirement	No requirement	No requirement	10
Flash Point, °C min	52	38	38	60	60
Cloud Point, °C max	-43 to +20	No requirement	No requirement	-1.1	-1.0
Sulfur, max, % wt.	0.5	0.5	No requirement	1.0	1.0
Density, max, kg.m^3	No requirement	876	876	876	876
Carbon Residue on 10% bottoms, max %wt.	0.35	0.35	0.35	0.35	0.20
Additives	No limit	No limit	No limit	No limit	Specific additives allowed

Table 2: Comparison of Storage Stability Test Results for Commercial Distillate Marine Fuel.

Year of Survey	**Test Method**	**# of Samples**	**# Samples Passing**
1983	ASTM D 2274 (16 hr)	19	15
1986	ASTM D 2274 (16 hr)	28	26
1996	ASTM D 5304	42	36

Keywords: aircraft, military, shipboard, stability, US Navy

REFERENCES

1. MIL-F-16884J, US Military Specification for Naval Distillate, F-76.
2. ASTM D 975-98b, "Standard Specification for Diesel Fuel Oils," *2000 Book of ASTM Standards, Vol. 05.01.*
3. ASTM D 396-98, "Standard Specification for Fuel Oils," *2000 Book of ASTM Standards, Vol. 05.01.*
4. ASTM D 2880-98, "Standard Specification for Gas Turbine Fuel Oils," *2000 Book of ASTM Standards, Vol. 05.02.*
5. Boyle J.F., Layne R.P., McGee T., and White E.W., "Navy Needs and Experience with Distillate Fuel Stability and Cleanliness", *American Society for Testing and Materials, Special Technical Publication 751*, (1982) 60-75.
6. ASTM D 5304-94, "Standard Test Method for Assessing Distillate Fuel Storage Stability by Oxygen Overpressure," *2000 Book of ASTM Standards, Vol. 05.03.*
7. ASTM D 2274-94, "Standard Test Method for Oxidation Stability of Distillate Fuel Oil (Accelerated Method)," *2000 Book of ASTM Standards, Vol. 05.01.*
8. Turner L.M., Martin C.J., Beal E.J., and Hardy D.R., "Use of ASTM D5304 in Assessing Unstable Diesel Fuel", *5th International Conference on Stability and Handling of Liquid Fuels*, (1994).
9. Modetz H., Burnett M., Talbot A., Giannini R., Strucko R., and Hardy D., "Navy Shipboard Fuels Flexibility Program – Survey and Characterization of Commercial Marine Fuels," Navy Report DTNSRDC-PASD-CR-16-84, (1984).
10. Woodward P.W. and Shay J.Y., "USN Mobility Fuels: Worldwide Survey and Analysis of Both Commercial and Navy Fuels," NIPER Report 428, (1989).
11. Giannini R., Lynn N., and Strucko R., "Worldwide Survey of Commercial Marine Distillate Fuel," Navy Report, (2000).
12. USN F-76 Database, (1990-2000).
13. MIL-DTL-5624T, US Military Specification for Turbine Fuel, Aviation, Grades JP-5 and JP-4.
14. ASTM D 3241-98, "Standard Test Method for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)," *2000 Book of ASTM Standards, Vol. 05.02.*
15. Kamin R.A., Internal Navy Correspondence, August 2000.
16. Morris, R.E. and Chang E. L., "Development Of A Filter To Selectively Remove Copper From Jet Fuels Using A Polyamine Chelant Immobilized On Silica Gel," Accepted for publication in *Petroleum Science and Technology*, 18 March 2000.
17. Turner L.M., Kamin R.A., Nowack C.J., and Speck G.E., "Effect of Peroxide Content on the Thermal Stability of Hydrocracked Aviation Fuel", *3rd International Conference on Stability and Handling of Liquid Fuels,* (1988).
18. Pande S.G., Black B.H., and Hardy D.R., "Development of a Test Method for the Determination of the Hydroperoxide Potential and Antioxidant Effectiveness in Jet Fuels During Long Term Storage", *Coordinating Research Council Project No. CA-43-98, Report No. 614*, (1988) 1-19.
19. Naval Air Systems Command and Naval Sea Systems Command Integrated Product Team, "+100 Aviation Fuel Additive Preliminary Shipboard Implementation Study", *Navy Report*, (1998).

APPENDIX C

Qualification of Fuels, Lubricants and Additives for Use in Certified Aircraft Engines

FAA Advisory Circular 20-24B, 12/20/85

U.S. Department
of Transportation
Federal Aviation Administration

Advisory Circular

Subject: QUALIFICATION OF FUELS, LUBRICANTS AND ADDITIVES FOR AIRCRAFT ENGINES

Date: 12/20/85
Initiated by: ANF-110

AC No: 20-24B
Change:

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1. PURPOSE. This advisory circular (AC) describes procedures which may be used for approving the qualification of fuels, lubricants and additives for use in certificated aircraft engines.

2. CANCELLATION. AC No. 20-24A, effective April 14, 1967, is cancelled.

3. BACKGROUND. In certificating an engine, the Administrator has responsibility under Federal Aviation Regulations (FARs), Part 33, for establishing the limitations for the engine operation on the basis of the operating conditions demonstrated during the block tests. Such operating limitations include those items relating to power, speeds, temperatures, pressures, fuels, and lubricants which are found to be necessary for safe operation of the engine. The limitations on fuels and lubricants include the additives that may be blended with the fuels or lubricants. The suitability and durability of all materials used in the engine are established on the basis of experience or tests, and all materials used in the engine must conform to approved specifications. Experience and test data should be on engine models which are, at minimum, similar in configuration, materials, operating characteristics, and power category to those of the engine in which these materials are intended for use.

4. DISCUSSION. Fuels and lubricants found to perform satisfactorily during the type certification program of an engine are approved as part of the Type Certificate (TC) and are listed on the pertinent Type Certificate Data Sheet (TCDS). Issuance of the TC constitutes approval of the fuel and lubricant specifications provided by the engine manufacturers. It is Federal Aviation Administration (FAA) policy that fuels and lubricants produced by companies other than those used in the type certification program may be used in a certificated engine provided the products meet the fuel(s) or lubricant(s) specification(s) for that engine. Fuels or lubricants that are not in conformance with the TC holder's approved specification listed on the TCDS, or a specification approved under a Supplemental Type Certificate (STC) are not eligible for use in a certificated engine. These non-conforming fuels or lubricants must satisfy the certification requirements outlined in Paragraph 5 of this AC, PROCEDURE, in order to be approved. In addition, all synthetic lubricants are considered "new material" and must be individually approved. Additives to be used as a supplement to an approved fuel or lubricant also are considered to be a "new material" because their addition can significantly alter the physical and chemical properties of the fuel or lubricant These additives must be

approved on an individual basis. In all cases, separate approval is required for each engine model or model series. In order to extend an approval from one model series on to another entire class of engines (i.e., all Lycoming non-supercharged direct drive engines up to 720 cubic inch displacement), it must be substantiated that the engine tested represents the most severe operating conditions of all the engines for which approval is requested. For reciprocating engines, factors which should be considered include piston speeds, maximum BMEP, maximum cylinder and barrel temperature limits, turbocharger lubrication design, piston ring configurations, and gaskets, rings, and seals used in the engine and propeller oil system. Further, such materials are not eligible to be used in a certificated aircraft until the compatibility of these materials has been established with aircraft components (including propellers, where applicable) with which they come in contact.

5. PROCEDURE. The producer of a product requiring an STC or an amendment to an existing TC, as described in Paragraph 4 above, may apply to the Aircraft Certification Office (ACO) in the geographical area in which the applicant is located. The geographic ACO will administer the program; however, the ultimate approval and issuance of the engine STC, or an amendment to an existing TC, is the responsiblity of the Engine and Propeller Certification Directorate located in the New England Region. Such STCs or amended TCs, may be approved for the fuels, lubricants, and additives for use in designated engine(s) upon receipt of suitable data demonstrating compliance with the applicable portions of FAR Part 33. The data should be obtained during an FAA approved and witnessed test program and should include the following:

a. Preliminary Data - Prior to FAA authorization for test, the applicant should submit a report to substantiate that the fuels, lubricants, or additive combinations have undergone sufficient test and development to show that, under the conditions in which they will be used in the aircraft, they are compatible with the applicable engine and aircraft materials. The data should include compatibility with fuels, lubricants, and additives that are approved for the engine, propellers (where applicable), and aircraft. For fuel additives, the additive must be soluble in the fuel at all anticipated temperatures; the blending procedures must be feasible; the additive must be shown not to congeal at cold temperatures, thereby clogging fuel lines and filters; the additive must be compatible with other approved fuel additives (i.e., anti-icing additives); and the additive should not change fuel octane number.

b. Test - A description of the test program and equipment that the applicant proposes to use in demonstrating the airworthiness of the material to be approved shall be submitted for approval. The engine(s) which are selected must be subjected to the pretest inspection, FAR 33.42 and 33.82; the calibration tests, FAR 33.45 and 33.85; the endurance test, FAR 33.49 and 33.87; the operation test, FAR 33.51 and 33.89 and the teardown inspection, FAR 33.55 and 33.93. It is conceivable that the requirements of the operation test, FAR 33.51 and 33.89, can be satisfied concurrently with or as an addendum to the endurance test, FAR 33.49 and 33.87. The applicant is requested to submit for FAA approval, the specific engine test procedure for each of the engines which will be subjected to the 150-hour endurance test. This test procedure should provide all the specific information required to perform the test (i.e., test location, engine model to be tested, specific test hardware and instrumentation to be used, engine minimum and maximum operating parameters, the engine lubricant to be used, the lubricant change interval, a list of all information to be recorded during the test including changes to oil properties, the intervals at which this data is to be recorded, etc.) In addition, in accordance with FAR 33.53 and 33.91, engine component test, a test should be performed with the objective of showing that the subject material will not cause deterioration or any other unsatisfactory condition on or in any of the non-metallic engine oil-wetted parts used in any of the engines in which the additive is used. A 500-hour controlled flight test, under the test conditions listed below, may be considered as an equivalent for the endurance portion of the requirements of FAR 33.49 and 33.87, when followed by a complete teardown inspection:

Takeoff power or thrust	5 hours minimum
Max. continuous power or thrust	20 hours minimum
Cruise power or thrust	450 hours minimum
Idle	25 hours minimum

c. Final Data - At the completion of the aircraft engine tests, a report should be submitted which includes, at minimum, the following:

(1) A description of the engine in which the material was tested.

(2) A chronological history of test conditions and engine performance, including r.p.m., power or thrust levels achieved during the test, fuel and oil consumption, oil changes, parts replacement, and other pertinent test results.

(3) An analysis of lubricating oil samples taken before and after the test, and before each oil change. These analvzes are required for both fuel and oil substantiation testing.

(4) An analysis of the fuel used during the test. For fuel substantiation testing, these analyzes must demonstrate minimum or "worst case" properties.

(5) Evidence that abnormal wear, deposits metal attack, or other harmful effects did not occur as a result of the material under test.

(6) Evidence to establish that deterioration, excessive seal swelling, shrinkage, hardness, or unsatisfactory condition on or in any of the non-metallic engine oil-wetted parts did not occur as the result of the material under test.

d. Identification - The material tested must be covered by a specification that is written in sufficient detail to provide, at minimum, the physical properties and limits by which uniform quality and composition can be maintained. If the material is to be used in a blend with another material, instructions for blending should be provided which include safety precautions.

e. Concentration - The materials tested should be approved for use only in the concentrations "up to the maximum" at which they were qualified by test.

Robert E Whittington

Robert E. Whittington
Director, New England Region

APPENDIX D

GE Aircraft Engines Fuel Specification D50TF2

Issue Number S15

Dated: February 9, 2005

GE Aircraft Engines

Specification No. D50TF2
Issue No. S15
Date February 9, 2005
Page 1 of 10
CAGE Code 07482

General Electric Company
Cincinnati, OH 45215

Supersedes D50TF2-S14

SPECIFICATION

AVIATION TURBINE FUELS

1. SCOPE

*1.1 Scope. This specification establishes the minimum requirements for aviation gas turbine fuels for use in GE Aircraft Engines (GEAE). The requirements of this specification are generally compatible with all commonly used commercial and military gas turbine fuel specifications, such as ASTM D 1655, Aviation Turbine Fuels and ASTM D 6615, Jet B Wide Cut Aviation Turbine Fuel, throughout the world.

*1.1.1 Classification. This specification contains the following class(es). Unless otherwise specified, the requirements herein apply to all classes.

CLASS A:	Aviation Kerosine	(Jet A)
CLASS B:	Wide-cut Distillate	(Jet B, with additives, JP-4)
CLASS C:	Low-freeze Kerosine	(Jet A-1, with additives, JP-8)
CLASS D:	High-flash Kerosine	(JP-5)
CLASS E:	Low-flash Kerosine	(Gost 10227 Grade RT)

1.2 Definitions. For purposes of this specification, the following definitions shall apply:

Barrel - A barrel is defined as 42 U.S. gallons (0.159 m^3).

PREPARED NW Betcher	REVIEWED	APPROVED ☒ EVENDALE
APPROVED MF Grandey	DISTRIBUTION 10A	☒ LYNN

*1.3 Regulated Materials. The requirements of P2TF1, CL-A, shall be complied with. The material(s) shown below were referenced in this specification and P2TF1, CL-A, as of the date of this specification issue. The list below does not include all materials, which are referenced in sub-tier documents.

(a) Copper and Compounds
(b) Diethylene glycol monomethyl ether

2. APPLICABLE DOCUMENTS

*2.1 Issues Of Documents. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue shall apply.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

ASTM D 56	Flash Point by Tag Closed Tester
ASTM D 86	Distillation of Petroleum Products
ASTM D 130	Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test
ASTM D 323	Vapor Pressure of Petroleum Products (Reid Method)
ASTM D 381	Existent Gum in Fuels by Jet Evaporation
ASTM D 445	Kinematic Viscosity of Transparent and Opaque Liquids (And the Calculation of Dynamic Viscosity)
ASTM D 1094	Water Reaction of Aviation Fuels
ASTM D 1266	Sulfur in Petroleum Products (Lamp Method)
ASTM D 1298	Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D 1319	Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
ASTM D 1322	Smoke Point of Aviation Turbine Fuels
ASTM D 1552	Sulfur in Petroleum Products (High-Temperature Method)
ASTM D 1840	Naphthalene Hydrocarbons in Aviation Turbine Fuels by Ultraviolet Spectrophotometry
ASTM D 2386	Freezing Point of Aviation Fuels
ASTM D 2622	Sulfur in Petroleum Products X-Ray Spectrometry

ASTM D 3227	Mercaptan Sulfur in Gasoline, Kerosine, Aviation Turbine, and Distillate Fuels (Potentiometric Method)
ASTM D 3241	Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)
ASTM D 3242	Acidity in Aviation Turbine Fuel
ASTM D 3338	Estimation of Heat of Combustion of Aviation Fuels
ASTM D 3828	Flash Point by Setaflash Closed Tester
ASTM D 3948	Water Separation Characteristics of Aviation Turbine Fuels by Portable Separometer
ASTM D 4052	Density and Relative Density of Liquids by Digital Density Meter
ASTM D 4057	Manual Sampling of Petroleum and Petroleum Products
ASTM D 4294	Sulfur in Petroleum and Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectrometry
ASTM D 4306	Aviation Fuel Sample Containers for Tests Affected by Trace Contamination
ASTM D 4529	Estimation of Net Heat of Combustion of Aviation Fuels
ASTM D 4809	Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Intermediate Precision Method)
ASTM D 4952	Qualitative Analysis for Active Sulfur Species in Fuels and Solvents (Doctor Test)
ASTM D 5191	Vapor Pressure of Petroleum Products (mini method)
ASTM D 5453	Determination of Total Sulfur in Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence
ASTM D 5972	Freeze Point of Aviation Fuels (Automatic Phase Transition Method)

GE AIRCRAFT ENGINES SPECIFICATIONS

P2TF1	Regulated Materials

3. REQUIREMENTS

3.1 Composition. The fuel shall consist of hydrocarbon compounds only except for specific additives as specified in this document. It shall contain no visible free water, sediment, or suspended matter.

3.2 Chemical And Physical Requirements. The chemical and physical requirements for the finished fuel shall conform to Table I.

3.3 Certificate Of Analysis. Each shipment of fuel shall be accompanied by a certificate of analysis showing conformance to all requirements of this GEAE specification, class and issue number.

*TABLE I

Aviation Turbine Fuels (NOTE 1)

PROPERTY	CLASSES A and C	CLASS B	CLASS D	CLASS E	ASTM TEST METHOD
Total Acid Number, mg. of KOH/g, Max.	0.10	______	0.10	0.10	D 3242
Aromatics, Vol. %, Max.	25	25	25	25	D 1319
Total Sulfur, Wt. %, Max.	0.30	0.40	0.40	0.30	D 1266, D1552, D 2622, D 4294 or D 5453
Mercaptan Sulfar, Wt. %, Max. (NOTE 2)	0.003	0.005	0.003	0.005	D 3227
Distillation Temperature, °F (C°)					
10% Recovered, Temp., Max.	401 (205)	TBR	401 (205)	347 (175)	D 86
20% Recovered, Temp., Min.	______	194 (90)	______	______	
20% Recovered, Temp., Max.	______	293 (145)	TBR	______	
50% Recovered, Temp., Min.	______	230 (110)	______	______	
50% Recovered, Temp., Max.	TBR	374 (190)	TBR	TBR	
90% Recovered, Temp., Max.	TBR	473 (245)	TBR	TBR	
98% Recovered, Temp., Min.	______	______	______	536 (280)	
End Point, Temp., Max.	572 (300)	______	572 (300)	______	
Distillation Residue, %, Max.	1.5	1.5	1.5	1.5	
Distillation Loss, %, Max.	1.5	1.5	1.5	1.5	
Flash Point, °F (°C), Min.	100 (38)	______	140 (60)	82 (28)	D 56 or D 3828
Specific Gravity at 60°F (15.6°C), Minimum (°API, Max.)	0.775 (51)	0.751 (57)	0.788 (48)	0.775 (51)	D 1298 or D 4052
Specific Gravity at 60°F (15.6°C), Maximum (°API, Min.)	0.840 (37)	0.802 (45)	0.845 (36)	0.840 (37)	D 1298 or D 4052
Reid Vapor Pressure, psi (kPa), Max.	______	3.0 (21)	______	______	D 323 or D 5191

TBR denotes To Be Reported

*TABLE I (continued)

Aviation Turbine Fuels (NOTE 1)

PROPERTY	CLASSES A and C	CLASS B	CLASS D	CLASS E	ASTM TEST METHOD
Freezing Point, °F (°C), Max.	CLASS A -40 (-40) CLASS C -53 (-47)	-58 (-50)	-51 (-46)	-58 (-50)	D 2386 or D 5972
Viscosity at -4°F (-20°C) cSt, Max.	8.0	______	8.5	8.0	D 445
Net Heat of Combustion, Btu/lb, Min. (Mj/kg), Min.	18,400 (42.8)	18,400 (42.8)	18,400 (42.6)	18,400 (42.8)	D 4529, D 4809 or D 3338
Combustion Properties One of the following requirements shall be met:					
(1) Smoke Point, Min., or	25	25	25	25	D 1322
(2) Smoke Point, Min., and	18	18	18	18	D 1322
Naphthalenes, Vol. % Max.	3.0	3.0	3.0	3.0	D 1840
Copper Corrosion, Max.	No. 1	No. 1	No. 1	No. 1	D 130
Thermal Stability					D 3241 (NOTE 3)
Filter Pressure Drop, mm Hg, Max.	25	25	25	25	
Visual Tube Rating	<3	<3	<3	<3	
Existent Gum, mg/100 ml, Max.	7	7	7	7	D 381
Water Reaction: Interface Rating, Max.	lb	lb	lb	lb	D 1094 or D 3948 (NOTE 4)
Additives (NOTE 5 and 6)	Table II	Table II	Table II	Table II	

NOTE 1: The requirements herein are absolute and are not subject to correction for precision of the test methods. If multiple determinations are made, average results shall be used.

NOTE 2: The mercaptan sulfur determination may be waived if the fuel is considered "sweet" by the Doctor test as described in ASTM D 4952.

*NOTE 3: ASTM D 3241 test (JFTOT) shall be conducted for 2.5 hours at a control temperature of 500°F (260°C). Tube deposits shall always be reported by the visual method. If the deposit includes peacock (rainbow) colors, rate these as code "P". Fuels that produce peacock colors fail to meet thermal stability requirements.

*NOTE 4: D 3948 is applicable at point of manufacture. The microseparometer rating (without electrical conductivity additive) must have a minimum value of 85. The microseparometer rating (with electrical conductivity additive) must have a minimum value of 70.

*NOTE 5: The additives listed in Table II may be blended, separately or in combination, into any of the fuels to the extent shown. The recommended additives, because of their organic nature and relatively low level of concentration, cannot be detected by routine analytical procedures.

*NOTE 6: The specific additives used, and their concentrations, shall be declared by the fuel Supplier.

*TABLE II - Fuel Additives

Additive Type	Maximum Concentration	Description
Anti-oxidants, lbm/1000 barrels (g/m^3)	8.4 (24.0)	-- 2,6-ditertiary-butyl phenol. -- 2,6-ditertiary-butyl-4-methyl phenol. -- 2,4-dimethyl-6-tertiary-butyl phenol. -- 75% min. 2,6-ditertiary-butyl phenol, plus 25% max. Mixed tertiary and tri-tertiary-butyl phenols; Ethyl 733 & AO-37. -- 55% min. 2,4-dimethyl-6-tertiary-butyl phenol, plus 15% min. 2,6-ditertiary-butyl-4-methyl phenol; remainder as monomethyl and dimethyl tertiary-butyl phenols; Topanol AN. -- 72% min. 2,4-dimethyl-6-tertiary-butyl phenol, 28% max. monomethyl and dimethyl-tertiary-butyl phenols; AO-31.
Metal Deactivators, lbm/1000 barrels (g/m^3)	2.0 (5.7)	N,N'-Disalicylidene-1, 2 Propanediamine N,N'-Disalicylidene-1, 2 Cyclohexanediamine
Corrosion Inhibitor, Lbm/1000 BBL (g/m^3)	8.0 (23.0)	Apollo PRI-19
	8.0 (23.0)	Octel DCI-4A
	8.0 (23.0)	Octel DCI-6A
	16.0 (46.0)	HITEC E-515
	8.0 (23.0)	HITEC E-580
	8.0 (23.0)	NALCO 5403
	8.0 (23.0)	NALCO 5405
	16.0 (46.0)	TOLAD 245
Anti-Static Additives, g/m^3	3.0	STADIS 450 (Initial Dosage)
	5.0	STADIS 450 (Total Dosage)
Thermal Stability mg/l	256	BetzDearborn Spec.Aid 8Q462
	256	AeroShell Additive 101
	256	Turboline FS100C
	559	Turboline FS100
Microbicide, Ppm by Wt.	270	BIOBOR JF
	100	KATHON FP 1.5
Anti-Icing, % by Vol.	CL-A,B,C is 0.15 CL-D is 0.20	Diethylene glycol monomethyl ether (Di-EGME)
Leak Detection, mg/kg (NOTE 1)	1.0	Tracer A (LDTA-A®)

NOTE 1: The EPA Requested, airport fuel delivery system leak detection additive(s) listed may be permitted in the fuel in the concentrations listed. These additives are not for fuel performance improvement or in remediation of a fuel contamination problem. Reason for permitting the additive is listed with the material.

D50TF2-S15

REVISION HISTORY

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-S2	DCID 32173	07-26-66
-S3	DCID 32616	02-01-68
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-S4	CID 73111	03-06-72
-S5	CID 73557	12-26-74
-S6	CID 73915	11-18-77
-S7	CID 74408	07-29-82
-S8	CID 75151	10-22-86
-S9	CID 076210	05-18-89
-S10	CID 077149	08-21-91
-S11	CID 077685	04-30-93
-S12	CID 077832	02-22-94
-S13	CID 078938	11-11-99
-S14	CID 079146	05-29-01
-S15	CID 079516	02-09-05

* Denotes latest change

APPENDIX E

United Technologies, Pratt & Whitney Service Bulletin No. 2016, Rev. 28

Dated: January 27, 2006

UNITED
TECHNOLOGIES
PRATT&WHITNEY

SERVICE BULLETIN

FAA APPROVED
TAF–12A–0

No. 2016

ENGINE FUEL AND CONTROL - FUEL AND ADDITIVES - REQUIREMENTS FOR, AND APPROVAL OF

1. Planning Information

A. Effectivity

Model	Application
JT3C, JT3D, JT4A, JT8D, JT9D, JT12A/JFTD12A, PW2000, PW4000, PW6000, F117-PW-100	All engines.

Issue Sequence

JT3C	73-17
JT4A	73-12
JT3D	73-14
JT8D	73-1
JT9D	73-1
JT12A/JFTD12A	73-3
PW2000	73-1
PW4000	73-1
PW6000	73-1
F117-PW-100	73-1

B. Reason

To assure the use of satisfactory engine fuels and additives in the listed gas turbine flight engines.

C. Description

Listing of acceptable fuels, minimum requirements, and approved additives for use in the listed gas turbine flight engines.

D. Compliance

Compliance with this Service Bulletin is specified by the FAA Engine Type Certificate for the model application of this Service Bulletin.

E. Manpower

Not applicable.

F. Weight Data

None.

Distribution Code

2590

G. References

(1) American Society for Testing and Materials (ASTM) test methods ASTM D 1655, Standard Specification for Aviation Turbine Fuels.

(2) Performance Specification MIL-PRF-25017, Corrosion Inhibitor/Lubricity Improver, Fuel Soluble.

(3) Russia State Standard Committee GHOST 10227.

(4) Peoples Republic of China (PRC) National Technology Supervisory Bureau, No. 3 Jet Fuel, GB 6537.

(5) Service Bulletin No. PWF117 73-1; Engine Fuel And Control - Fuel And Additives - Requirements For, And Approval Of. Issue Sequence 73-1, PWF117 Series.

2. Accomplishment Instructions

For F117-PW-100 engine model fuel requirements, see Reference 1, Service Bulletin No. PWF117 73-1. For all other models, the following applies.

Part I: Minimum Property Requirements.

A. The following list of fuel properties provides an envelope of minimum requirements that are acceptable for use in Pratt & Whitney engines covered by this bulletin. Because these fuel properties address engine requirements only, this bulletin is neither intended nor suitable for direct use as a purchase specification for procurement of fuel by operators of the listed Pratt & Whitney engines. Rather, it is intended to allow operators to include minimum approved fuel requirements for Pratt & Whitney engines in conjunction with other functional requirements when formulating their own jet fuel specification. Further, it is to provide assistance in judging the acceptability of jet fuels manufactured to other specifications that exist throughout the world.

B. Technical Requirements: Tests shall be performed, insofar as practicable, per the latest issue of the listed ASTM test methods.

C. Quality:

(1) Fuel shall consist solely of hydrocarbon compounds except as otherwise specified herein. It shall be visibly free from water, sediment, and suspended matter, and shall be suitable for use in aircraft turbine engines.

(2) The odor of the fuel shall not be nauseating or irritating. No substances of known dangerous toxicity under usual conditions of handling and use shall be present.

(3) Fuel containing dissolved metals is not fit for purpose.

D. Properties:

Table 1 - Fuel Minimum Property Requirements

Properties	Units	Limits		ASTM
		Min	Max	Test Method
Acidity, Total	mg KOH/g		0.10	D 3242
Gravity @ 15° C (60° F)	°API	37	57	D 287
Density @ 15° C (60° F)	kg/L	0.775	0.840	D 1298, D 4052
Distillation Temperature				
10% Recovered	°C (°F)		205°C (401°F)	D 86
50% Recovered	°C (°F)		232°C (450°F)	
90% Recovered	°C (°F)		To Be Reported	
Final Boiling Point	°C (°F)		300°C (572°F)	
Loss	%		1.5	
Residue	%		1.5	
Total Sulfur	weight %		0.30	D 1266, D 1552 D 2622, D 4294 D 5453
Mercaptan Sulfur	weight %		0.005	D 3227
(Only one of the two tests listed must be performed)				OR
	None	Negative	Negative	D 4952 (Doctor Test)
Net Heat of Combustion	MJ/kg (BTU/lb)	42.8 (18,400)		D 4529, D 4809 D 3338
Freezing Point	° C (° F)		-40° C (-40° F) (Note 1)	D 2386, D 5972
Reid Vapor Pressure	kPa (psi)		21 (3) (Note 2)	D 323
Aromatics	Volume %		25	D 1319

Properties	Units	Limits		ASTM Test Method
		Min	Max	
Combustion Properties (One of the following requirements must be met)				
(1) Smoke Point OR (2) Smoke Point and Naphthalenes	mm mm Vol. %	25 18	 3	D 1322 OR D 1322, D 1840
Copper Strip Corrosion, 2 Hrs @ 100° C (212°F)	None		No. 1	D 130
Viscosity @ -20.0°C (-4.0°F)	cSt		8.5	D 445
Existent Gum	mg/100mL		7	D 381
Thermal Stability				
Filter Differential Pressure Visual Tube Rating	mm Hg None		25 <3	D 3241
Note 1 - The requirements for this property shall be determined by the user and shall appear on all purchase orders for the selected fuel. The fuel freezing point shall be no higher than the limit shown in the table. The freezing point shall be at least -3° C (27° F) below the minimum engine fuel inlet temperature as measured by ASTM D 5972.				
Note 2 - For PW4164, PW4168, PW4168A, PW4074, PW4074D, PW4077, PW4077D, PW4084D, PW4090, PW4090D, PW4090-3, PW4098, PW6124 and PW6122-1D application, Reid Vapor Pressure must be less than 14 kPa (2.0 psi). See Part II, Paragraph D.				

Part II: Fuels Conforming to Minimum Property Requirements.

NOTE: PRATT & WHITNEY CANNOT GUARANTEE THAT ANY PARTICULAR BATCH OF FUEL CONFORMS TO THE SPECIFICATION TO WHICH IT WAS SOLD. IT IS THE OPERATOR'S RESPONSIBILITY TO ENSURE THAT EACH SHIPMENT OF FUEL CONFORMS TO THE MINIMUM REQUIREMENTS OF THIS SERVICE BULLETIN. A CERTIFICATE OF ANALYSIS CONFIRMING COMPLIANCE TO ALL REQUIREMENTS SHOWN IN PART I SHALL ACCOMPANY EACH SHIPMENT OF FUEL.

A. The fuels listed in the following table comply with the minimum requirements for approved fuels (Part I), for use in the listed Pratt & Whitney gas turbine flight engines, provided freezing point, as measured by ASTM D2386, is equal to or below the minimum engine fuel inlet temperature.

Table 2 - Fuel Specifications Conforming to Minimum Property Requirements for Use in P&W Commercial Engines

FUEL TYPE	GRADE DESIGNATION	SPECIFICATION	REVISION	ISSUING AGENCY
Kerosene	Jet A/A-1	D1655	Latest	ASTM
Wide-Cut	Jet B (see Paragraph D.)	D6615	Latest	ASTM
Kerosene	JP-8/JP-8+100 NATO F-34/F-37	Mil-DTL-83133	Latest	U.S. Military
Kerosene	JP-5/NATO F-44	Mil-DTL-5624	Latest	U.S. Military
Wide-Cut	JP-4/NATO F-40 (see Paragraph D.)	Mil-DTL-5624	Latest	U.S. Military
Kerosene	Russian RT	GOST 10227	86	Russia State Standard Committee
Kerosene	Peoples' Republic of China No. 3 Jet Fuel	GB 6537	94	PRC National Technology Supervisory Bureau

NOTE: This table only addresses the specifications for jet fuel without additives. Refer to Part III for a complete list of additives approved for use in engine fuel.

B. An acceptable fuel or any mixture of acceptable fuels may be used. However, changing to a fuel with a substantially different heating value or gravity may require maintenance in the form of engine fuel control (trimmer) adjustment.

C. Extensive operation on low lubricity fuel can result in accelerated engine fuel pump wear. Rapid fuel pump wear should be considered an indication of low lubricity fuel and dictate a change in the fuel or addition of a lubricity improver. See Part III, Paragraph B.(1).

D. Wide-cut fuels such as JP-4 and JET B, which are characterized by a Reid Vapor Pressure in the range of 2.0 - 3.0 psi at 38°C (100°F) or a Flash Point less than 28°C (82°F), are not acceptable for use in PW4164, PW4168, PW4168A, PW4074, PW4074D, PW4077, PW4077D, PW4084D, PW4090, PW4090D, PW4090-3, PW4098, PW6124 and PW6122-1D engine models.

F. Grade TS-1 fuel is the main commercial aviation turbine fuel in Russia. Commonwealth of Independent States (CIS) fuels conforming to specification GOST 10227-86, Type TS-1 kerosene, are acceptable for transient operation. Transient operation is defined as 50% or less of total operating time. Grade TS-1 is in compliance with Table 1 Minimum Property Requirements except for the test method for Thermal Stability (TS). Grade TS-1 is tested for thermal stability by GOST Test Method 11802, a static test method, which measures insoluble gums in the fuel. The TS-1 specification limit using this test method does not meet Pratt & Whitney fuel thermal oxidative stability requirements. The minimum properties in Table 1 require a dynamic or fuel flowing test for the measurement of thermal stability. In consequence, the engine operator can use TS-1 on a continuous basis if the following step(s) are taken:

(1) Test a fuel sample obtained from the airport storage tanks prior to initiation of service. Test to be used should be ASTM D 3241. Alternately, test method GOST 17751 can be used but if the results of this test exceed the specification requirement for GOST 10227, Grade RT fuel, then the fuel must be retested using ASTM D 3241 test method.

(2) Operator shall test TS-1 fuel obtained from the aircraft fuel tank quarterly for fuel thermal oxidative stability according to the ASTM D 3241 test method.

(3) At each engine shop visit of engines above 10,000 hours since previous shop visit, perform a flow check of all fuel nozzles. Refer to the applicable CMM.

Part III: Approved Additives.

NOTE: These fuel additives were approved on the basis of information and samples of material furnished by the manufacturer or marketer of the additive. Pratt & Whitney analysis of this information and results of tests on product samples indicated no significant adverse effect on engine materials when used within the stated concentrations. Approval of each additive applies only to the formulation submitted for testing. A modification since the date of approval makes an additive unacceptable until tests of the modified product show to Pratt & Whitney satisfaction that there is no adverse effect on engine materials or operation.

A. Antioxidants may be added to jet fuels after manufacture to prevent the formation of gums and peroxides during storage. Antioxidants are required in some fuels, most notably those that contain blending stocks that have been hydrogen treated. In other fuels, the addition of antioxidant is at the option of the supplier. The following antioxidant formulations are approved at concentrations not to exceed 24 mg of active ingredient per liter of fuel:

(1) 2,6-ditertiary-butylphenol

(2) 2,6-ditertiary-butyl-4-methylphenol (sometimes referred to as BHT)

(3) 2,4-dimethyl-6-tertiary-butylphenol

(4) 75% minimum 2,6-ditertiary-butylphenol and
25% maximum tertiary-butylphenols and tritertiary-butylphenols

(5) 55% minimum 2,4-dimethyl-6-tertiary-butylphenol and
15% minimum 2,6-ditertiary-butyl-4-methylphenol and
30% maximum mixed methyl and dimethyl tertiary-butylphenols

(6) 72% minimum 2,4-dimethyl-6-tertiary-butylphenol and
28% maximum tertiary-butyl methylphenols and tertiary-butyl dimethylphenols

B. Corrosion Inhibitor/Lubricity Improver: The lubricating properties of jet fuels are important in preventing wear or seizure of rubbing surfaces such as engine controls, servo valves, pump bearings, and gear and piston-type pumps. The lubricating properties of fuels can be improved by adding an approved corrosion inhibitor/lubricity improver. Corrosion Inhibitor/Lubricity Improvers approved for use are those shown on the Qualified Products List QPL 25017 of products qualified under Performance Specification MIL-PRF-25017, Inhibitor, Corrosion/Lubricity Improver, Fuel Soluble.

C. Thermal Stability Additive:

(1) The following thermal stability additive is approved for use in engine fuel, at the option of the refiner, to ensure adequate high temperature stability at time of use.

Octel Jet Fuel Additive Number 5 (JFA-5)	11 mg/L, maximum

(2) The following additive has been shown to improve jet fuel thermal stability, and in some applications to significantly reduce fuel nozzle coking and improve hot section cleanliness. This additive package consists of an antioxidant, a metal deactivator, and a dispersant. It is approved for use in any of the following available product forms. The products are identical, except that Turboline FS100 is diluted:

AeroShell Performance Additive 101	256 - 300 mg/L
or	
BetzDearborn Spec Aid 8Q462	256 - 300 mg/L
or	
Turboline FS100	533 - 625 mg/L
or	
Turboline FS100-Concentrate	256 - 300 mg/L

D. Metal Deactivator: Some trace metals, most notably copper, can act as catalysts to promote the auto-oxidation process in fuels. This process leads to the formation of deposits, gum, and coke within fuel systems. Metal Deactivator additives bind to metal atoms and metal surfaces to mitigate catalytic oxidation. Metal deactivator additives can be added to fuels containing copper to restore thermal oxidative stability. The following metal deactivator formula is approved:

(a)	N, N^1 - propane-diamine disalicylidene - 1,2	5.7 mg/L, maximum.

E. Fuel System Icing Inhibitor: Fuel System Icing Inhibitors (FSII) have been found to be highly effective in preventing ice from forming due to free and dissolved water in jet fuel. FSII acts as an antifreeze. FSII combines with free water to form an azeotropic mixture with a lower freeze point. In addition, FSII is a biostat that controls and regulates microorganism growth at the fuel/water interface. The following FSII additive is approved:

(1)	Diethylene Glycol Monomethyl Ether (DiEGME), conforming to Mil-DTL-85470	0.15% Vol. Max.
(2)	Russian Additive "I" (Ethylene Glycol Monoethyl Ether)	0.15% Vol. Max.
(3)	Russian Additive "I-M" (50/50 blend of "I" with methyl alcohol)	0.15% Vol. Max.

F. Static Dissipator: The ability of a fuel to dissipate electrical charge that has been generated during pumping and filtering operations is controlled by its electrical conductivity. Some fuels such as JP-4 and JP-8 require that static dissipator be added for safety considerations. If required, static dissipator additive may be added to fuels in sufficient concentration to increase electrical conductivity to a range of 150 to 600 picosiemens per meter (pS/m) at the point of injection. The point of injection of the additive shall be determined by agreement between the purchasing authority and the supplier. The following electrical conductivity additive is approved:

(1)	Octel America Stadis 450	3.0 Parts Per Million by Weight Max
(2)	Russian Additive "Sigbol"	3.0 Parts Per Million by Weight Max

Part IV. Other Additives.

A. The following additives do not provide specific benefit to engine operation, and are not recommended for continuous use. However, these additives are used for various reasons relative to handling or storing jet fuel in ground or airframe systems. The following additives are approved for flight use in all P&W engines included in this service bulletin, subject to limitations stated below.

(1) Biocide Additive: fuel tank maintenance practices as specified by the airframe manufacturer, are of prime importance in controlling microbial growth. However, many other factors such as climate, aircraft design, route structure and utilization also effect microbial growth, so occasional use of a biocide may be required.

Biocide additive may be used on a limited basis, defined as intermittent or noncontinuous use in a single application to sterilize aircraft fuel systems suspected, or found to be contaminated by microbial organisms. For those operators where the need for biocide use is indicated, Pratt & Whitney recommends, as a guide, a dosage interval of once a month. This interval can then be adjusted, as an operators own experience dictates.

Engines operated in private and corporate aircraft where utilization rates are relatively low, may use the additive continuously at one-half the concentration level indicated below.

NOTE: Fuel system filters can become contaminated following use of a biocide additive if the dosage interval is too long, and too much microbiological contamination has been allowed to accumulate. To avoid this, Pratt & Whitney recommends using a dosage interval that is short enough to prevent significant accumulation of microbial organisms. If significant contamination is suspected, operators should draw and test a sample of fuel to ensure it is free of suspended matter.

Biobor JF	270 Parts per Million by Weight Max
Kathon FP 1.5	100 Parts per Million by Weight Max

(2) Leak Check Additive - Ground Fuel Systems: Occasional use of a leak check additive may be required by local airport and/or environmental authorities. The leak check additive listed below may be used when it has been added to the fuel for the express purpose of detecting leaks in airport fuel distribution systems.

Tracer A - 1 part per million maximum

B. The following additives are not approved for flight use. However, these additives are used to benefit test cell operations or aircraft systems, and are approved for non-flight use, subject to limitations stated below.

(1) Antismoke Additive: The following additives may be used only in post overhaul test cell operation of engines for maximum of five hours duration. They are not approved for flight use.

(a)	Hitec 3000	0.10% Volume Max
(b)	Nuchem TA-104	0.10% Volume Max
(c)	Apollo DGT-2	0.10% Volume Max

(2) Leak Check Additive - Aircraft Fuel Systems: Leak check fluids are periodically used to check the aircraft fuel system for leaks. The following additives are approved to be used for this purpose with the understanding that after checking the fuel system for leaks, and prior to running the engine, the fuel system is to be drained of the leak check fluid and refueled with fresh, clean fuel.

NOTE: Pratt & Whitney approves engine consumption of residual levels of these additives after the aircraft fuel system has been drained and refueled with fresh clean fuel, as specified below. Please consult airframe manufacturer for specific recommendations relative to checking airframe fuel systems.

(a) The following dyes are approved with maximum concentration shown:

1	Mil-D-81298, Type II Yellow Dye	1 mg/L, maximum
2	Mil-D-81298, Type III Green Dye	1 mg/L, maximum

(b) The following lubricating/preservation oils are approved without limitation:

1 Mil-PRF-6081, Grade 1005

2 Mil-PRF-6081, Grade 1010 (PMC 9852)

3 Shell Pella Oil 61906

4 Witco Golden Bear

(c) The following calibration fluid is approved without limitation:

1 Mil-PRF-7024, Type II

(d) The following purging/preservation fluid is approved without limitation:

1 Mil-PRF-38299

Part V: Emergency Fuels.

A. Operation of Pratt & Whitney gas turbine engines on fuels that do not comply with the minimum requirements for approved fuels (Part I) is not recommended. However, other fuels may be considered acceptable for limited use on an emergency basis with certain restrictions and precautions. Generally, the problems most commonly associated with the use of fuels that do not conform to jet fuel specifications are as follows:

(1) Harmful effects of additives containing lead and phosphorus on hot section alloys.

(2) Relatively poor lubricating properties of gasoline fuels with respect to premature wear of pumps and servos.

(3) High vapor pressure of gasoline fuels result in the potential for fuel boiling and pump cavitation, as well as the need for precautionary procedures during fueling and defueling.

(4) Heavier fuels, such as lamp, diesel, and heating oils have higher viscosities and freezing points that could make them unsuitable for use under cold weather conditions or in sustained high altitude operation.

B. Operation of specific Pratt & Whitney gas turbine engines on certain fuels, as specified below, is prohibited, and cannot be approved even for limited use on an emergency basis.

NOTE: Non-inclusion of a specific fuel in this paragraph shall not be interpreted to imply that the fuel is acceptable for emergency use. Please refer to Paragraph C.

(1) The low pressure air blast fuel injection systems of the PW2000, PW4000, and PW6000 engines are particularly sensitive to fuel vaporization. Operation of these engines on highly volatile fuels, including gasoline, either individually, as a mixture, or blended with an otherwise acceptable fuel is prohibited even for limited use in emergency situations.

(2) Use of wide-cut fuels such as JP-4 and JET B, which are characterized by a Reid Vapor Pressure in the range of 2.0 - 3.0 psi at 38°C(100°F) or a Flash Point less than 28°C (82°F) in PW4164, PW4168, PW4168A, PW4074, PW4074D, PW4077, PW4077D, PW4084D, PW4090, PW4090D, PW4090-3, PW4098, PW6124 and PW6122-1D engine models is prohibited even for limited use in emergency situations.

C. Because of the wide variance in physical and chemical properties, dilution rates, and circumstances under which a non-specification fuel might be considered for emergency use, Pratt & Whitney should be consulted for guidance on a case-by-case basis.

D. Recommended Limits for Emergency (See Note 1) Usage of Aviation Turbine Fuel Contaminated with Red Dye.

(1) Pratt & Whitney is willing to accept, for "emergency" use only, Aviation Turbine fuel containing a maximum of 0.14 pound per 1,000 barrels (0.41 milligrams per liter) of C.I Solvent Red 164 (or 2.5 % of the full EPA-IRS mandated dye concentration specified for off-road high sulfur diesel fuel) subject to the following restrictions and/or actions.

(a) Service Criteria:

1 That the concentration of dye in the fuel be measured "in situ" and in at least three widely separated locations along the airport distribution system, using PetroSpec Analyzer Model JT-100S (See Note 2). Values of concentration to be reported out which then defines the "emergency", And, that these measurements be verified by a laboratory analysis of the fuel sample in (b) 2, below.

2 That the number of emergency fuel uplifts be limited to three without restrictions for Category I aircraft as defined below (See Note 5).

3 That the fourth emergency fuel uplift for Category I aircraft be followed immediately (within 48 hours) by contact with the engine manufacturer for maintenance action, which might include immediate removal and inspection of critical fuel system components. Aircraft can remain in service, but no further emergency uplifts of dyed fuel are allowed.

(b) Reporting Requirements:

1 That the airline report each emergency fuel uplift action to the engine manufacturer on the same date that it occurs. Report detail to include types of aircraft, numbers of aircraft, tail numbers, engine serial numbers and number of uplifts to each aircraft during duration of Emergency.

2 That the airline(s) secure samples (See Note 3) of the dyed fuel in sufficient quantity, and have performed on that fuel the characteristic tests defined by ASTM D1655, Standard Specification for Aviation Turbine Fuels, for Thermal Stability (Test Method D 3241, 260 C Breakpoint limit), Distillation (D 86), Existent Gum (D 381), Freeze Point (D 2386) and have the laboratory verify the concentration of dye in the fuel. Results (See Note 4) to be reported to the engine manufacturers within 72 hours.

3 That a full analysis of the fuel sample to all the characteristics of ASTM D1655 be completed and results sent to the engine manufacturer within two weeks.

Note 1. An unexpected and unforeseen situation that requires urgent and prompt action, the situation being where dye contaminated fuel has gotten into that part of the airport distribution system where it can not be segregated or isolated for remediation without halting airport operations.

Note 2. A meter reading of 0.28 milligrams per liter. Scale on this instrument is calibrated to solid red dye standard. To obtain liquid red dye equivalent value, multiply the meter reading by 1.446 (1.446 X 0.28 = 0.41 milligrams per liter). The PetroSpec JT100S is manufactured at Varlen Instruments Inc., Bellwood, Illinois.

Note 3. If the fuel system contaminated serves several airlines, only one sample for analysis need be drawn, from the point in the fuel system which has the highest level of dye contamination.

Note 4. Information for data bank entry to establish overall sensitivity of U.S. produced fuels to the dye (and diesel fuel). Long range goal is possible relaxation of requirement.

Note 5. Category I Aircraft:
Large Wide Body - B747, DC10, MD11, B777, A330, A340
Medium Wide Body - A300, A310, B767, DC10, L1011
Medium Narrow Body - B707, B757, DC8, A318, A319, A320, A321, MD90
Small - BAE 146, B737, B727, DC9, BAC111, MD80's, Fokker 70/100

3. Material Information

None.

P&W Reference No.
BM/DB/AS/TJR/WM/RAA/LJF/BW/GZ/JDH/TAR/JDH/CMS/RDG
09-02557, 294176, 295474, 09-03480, 304909,
94KC221B, 09-03357, 09-04298, 09-05413,
89FA033, 94MC014, 97MC009, 97KCC90, 94KC221B,
98MC018, 97MC009A, 98MC048, 98MC049
99MA038, 00MC020, 00MC021, 00MC022, 01MC331, 01MC331A,
06JC001, B

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SERVICE BULLETIN REVISION NOTICE

SB No. 2016
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SUBJECT: Turbojet Engine Service Bulletin No. 2016 Revision No. 28 dated January 27, 2006.

SERVICE BULLETIN TITLE

ENGINE FUEL AND CONTROL - FUEL AND ADDITIVES - REQUIREMENTS FOR, AND APPROVAL OF

MODEL APPLICATION

JT3C, JT3D, JT4A, JT8D, JT9D, JT12A/JFTD12A, PW2000, PW4000, PW6000, F117-PW-100

BULLETIN ISSUE SEQUENCE

JT3C	73-17
JT4A	73-12
JT3D	73-14
JT8D	73-1
JT9D	73-1
JT12A/JFTD12A	73-3
PW2000 Series	73-1
PW4000	73-1
PW6000	73-1
F117	73-1

THIS IS A COMPLETE REISSUE - The subject attached Bulletin No. 2016 constitutes the complete instruction. The contents are in accordance with the following list of effective pages.

A copy of this Revision Notice and any future revision notices must be filed as a permanent record with your copy of the subject bulletin.

PAGE	REVISION No.	DATE
1 thru 18	28	January 27/06

REASON FOR REVISION:

Replace test methods no longer supported by the American Society for Testing and Materials (ASTM).

Offer density as an alternative to API gravity requirements.

Describe Controlled Service Use (CSU) for Russian TS-1 fuel.

Distribution Code
2590

Printed in United States of America

Replace a list of randomly selected approved corrosion inhibitor/lubricity improvers with a statement referring to QPL 25017 per Mil-PRF-25017.

Removes a red dye leak check additive that is no longer approved for use.

Revise the measure of temperature units to list degrees Celsius followed by degrees Fahrenheit.

Add a statement that warns that fuel containing dissolved metals is not fit for purpose. Dissolved metals degrade thermal stability and may attack turbine materials.

Update the References section.

Add a statement that for the F117-PW-100 engine model, operators must refer to Service Bulletin No. PWF117 73-1 for fuel requirements.

<u>EFFECT ON PRIOR COMPLIANCE</u>:

None

APPENDIX F

Turbomeca Service Letters 2258/04Arriel1/76 and 2259/040Arriel2/17

Dated: February 11, 2004

Turbomeca
groupe snecma

SERVICE LETTER

OPERATOR SUPPORT
40220 Tarnos – France
Tel. (33) (0) 5 59 74 40 00
Telex 570 042
Fax (33) (0) 5 59 64 74 98

Technical Support Department
Fax (33) (0) 5 59 74 45 34

SM/FD/MP

Service Letter No. 2258/04/ARRIEL1/76

Subject : ARRIEL 1 – All variants
Use of '+100' additive to fuel

Bordes, February 11, 2004

Dear Sir, Madam,

We previously notified you of the determining factors resulting in manifold labyrinths and/or fuel injection wheel coking on Arriel 1 engines.

This occurrence results in increased difficulties during start, permeability decrease, rundown time decrease, gas generator noises and possible seizing of the gas generator.

This occurrence can be reduced by using an additive that enhances fuel thermal stability. The well-known additive, '+100', NATO symbol S-1749, has been approved by Turbomeca.

The '+100' approved additive can be used with JP8 and Jet A1 and mixed with other fuel additives. It is manufactured in the United States by Betz Dearborn where it is known as SPEC AID 8Q462 or Turboline FS100 or Turboline FS 100C and in Europe by Shell Aviation under the name AeroShell Performance Additive (APA 101).

Product	Concentration	
	Minimum (mg/l)	Maximum (mg/l)
SPEC AID 8Q462	256	300
Turboline FS 100 (dilute)	533	625
Turboline FS 100C (concentrate)	256	300

This additive and its conditions of use will soon be incorporated into the applicable Maintenance Manuals.

CAUTION: This additive may adversely effect the coalescing filters that are designed to ensure water/fuel separation during refuelling.

Please contact your fuel suppliers and your aircraft manufacturer for any additional information.

For experience feedback, please also contact your nearest Turbomeca representative to get him informed of the additive use, once you have reached 1,000 operating hours with the '+100' additive.

Please contact us for any additional information or assistance.

S. MAILLE
Technical Support Department

Turbomeca
groupe snecma

SERVICE LETTER

OPERATOR SUPPORT
40220 Tarnos – France
Tel. (33) (0) 5 59 74 40 00
Telex 570 042
Fax (33) (0) 5 59 64 74 98

Technical Support Department
Fax (33) (0) 5 59 74 45 34

SM/FD/MP

Service Letter No. 2259/04/ARRIEL2/17 – 2nd issue

Subject : ARRIEL 2 – All variants Use of '+100' additive to fuel

Bordes, February 11, 2004

Dear Sir, Madam,

We previously notified you of the determining factors resulting in manifold labyrinths and/or fuel injection wheel coking on Arriel 2 engines.

This occurrence results in increased difficulties during start, permeability decrease, rundown time decrease, gas generator noises and possible seizing of the gas generator.

This occurrence can be reduced by using an additive that enhances fuel thermal stability. The well-known additive, '+100', NATO symbol S-1749, has been approved by Turbomeca.

The '+100' approved additive can be used with JP8 and Jet A1 and mixed with other fuel additives. It is manufactured in the United States by Betz Dearborn where it is known as SPEC AID 8Q462 or Turboline FS100 or Turboline FS 100C and in Europe by Shell Aviation under the name AeroShell Performance Additive (APA 101).

Product	Concentration	
	Minimum (mg/l)	Maximum (mg/l)
SPEC AID 8Q462	256	300
Turboline FS 100 (dilute)	533	625
Turboline FS 100C (concentrate)	256	300

This additive and its conditions of use will soon be incorporated into the applicable Maintenance Manuals.

CAUTION: This additive may adversely effect the coalescing filters that are designed to ensure water/fuel separation during refuelling.

Please contact your fuel suppliers and your aircraft manufacturer for any additional information.

For experience feedback, please also contact your nearest Turbomeca representative to get him informed of the additive use, once you have reached 1,000 operating hours with the '+100' additive.

Please contact us for any additional information or assistance.

Maille

S. MAILLE
Technical Support Department

APPENDIX G

Material Safety Data Sheet – SPEC-AID® 8Q462

Dated: May 5, 2006

GE Water and Process Technologies

GE
Water & Process Technologies

Material Safety Data Sheet

Issue Date: 05-MAY-2006
Supercedes: 05-MAY-2006

SPEC-AID 8Q462

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1 Identification of Product and Company

Identification of substance or preparation
SPEC-AID 8Q462

Product Application Area
Distillate fuel stabilizer.

Company/Undertaking Identification
GE Betz, Inc.
4636 Somerton Road
Trevose, PA 19053
T 215 355-3300, F 215 953 5524

Emergency Telephone
(800) 877-1940

Prepared by Product Stewardship Group: 215 355-3300

2 Composition / Information On Ingredients

Information for specific product ingredients as required by the U.S. OSHA HAZARD COMMUNICATION STANDARD is listed. Refer to additional sections of this MSDS for our assessment of the potential hazards of this formulation.

HAZARDOUS INGREDIENTS:

Cas#	Chemical Name	Range (w/w%)
91-20-3	NAPHTHALENE Irritant; absorbed by skin; sensitizer; possible human carcinogen (IARC=2B; NTP=anticipated); toxic to liver, kidney, and blood; causes nasal tumors in rats	5-10
100-41-4	ETHYLBENZENE Flammable liquid; Irritant (eyes, skin, and respiratory); possible human carcinogen (IARC=2B; NTP=anticipated);potential nervous system toxin	0.1-1.0
64742-94-5	SOLVENT NAPHTHA, PETROLEUM, HEAVY AROMATIC Combustible liquid; irritant (eyes)	40-70
64742-65-0	PETROLEUM DISTILLATES,SOLVENT DEWAXED HEAVY PARAFFINIC Nuisance oil mist	15-40
128-37-0	BHT (BUTYLATED HYDROXYTOLUENE) Irritant (eyes)	7-13

3 Hazards Identification

```
*********************************************************************************
                                        EMERGENCY OVERVIEW

  WARNING

        May cause moderate irritation to the skin. May cause dermatitis.
        Severe irritant to the eyes. Vapors, gases, mists or aerosols may
        cause irritation to the upper respiratory tract. Prolonged exposure
        may cause dizziness and headache.

        DOT hazard: Combustible liquid
        Odor: Strong; Appearance: Amber To Brown, Liquid

        Fire fighters should wear positive pressure self-contained breathing
        apparatus(full face-piece type). Proper fire-extinguishing media:
        dry chemical, carbon dioxide or foam--Avoid water if possible.
*********************************************************************************
```

POTENTIAL HEALTH EFFECTS

ACUTE SKIN EFFECTS:
Primary route of exposure; May cause moderate irritation to the skin. May cause dermatitis.

ACUTE EYE EFFECTS:
Severe irritant to the eyes.

ACUTE RESPIRATORY EFFECTS:
Primary route of exposure;Vapors, gases, mists or aerosols may cause irritation to the upper respiratory tract. Prolonged exposure may cause dizziness and headache.

INGESTION EFFECTS:
May cause abdominal pain, nausea, vomiting, dizziness, lethargy and blurring of vision. Cardiac failure and pulmonary edema may develop. Large doses cause severe kidney damage. May be fatal. Aspiration may cause lung injury or death.

TARGET ORGANS:
Prolonged or repeated exposures may cause CNS depression and/or defatting-type dermatitis.

MEDICAL CONDITIONS AGGRAVATED:
Not known.

SYMPTOMS OF EXPOSURE:
Excessive dermal exposure causes defatting and drying of skin. Excessive inhalation of vapors causes dizziness, headache and nausea.

4 First Aid Measures

SKIN CONTACT:
Wash thoroughly with soap and water. Remove contaminated clothing. Thoroughly wash clothing before reuse. Get medical attention if irritation develops or persists.

EYE CONTACT:
Remove contact lenses. Hold eyelids apart. Immediately flush eyes with plenty of low-pressure water for at least 15 minutes. Get

immediate medical attention.

INHALATION:

Remove to fresh air. If breathing is difficult, give oxygen. If breathing has stopped, give artificial respiration. Get immediate medical attention.

INGESTION:

Do not feed anything by mouth to an unconscious or convulsive victim. Do not induce vomiting. Immediately contact physician. Dilute contents of stomach using 3-4 glasses milk or water.

NOTES TO PHYSICIANS:

This product contains a hydrocarbon solvent. Aspiration into the lungs will result in chemical pneumonia and may be fatal.

5 Fire Fighting Measures

FIRE FIGHTING INSTRUCTIONS:

Fire fighters should wear positive pressure self-contained breathing apparatus (full face-piece type).

EXTINGUISHING MEDIA:

dry chemical, carbon dioxide or foam--Avoid water if possible.

HAZARDOUS DECOMPOSITION PRODUCTS:

elemental oxides

FLASH POINT:

165F   74C P-M(CC)

MISCELLANEOUS:

Combustible liquid
NA 1993;Emergency Response Guide #128

6 Accidental Release Measures

PROTECTION AND SPILL CONTAINMENT:

Ventilate area. Use specified protective equipment. Contain and absorb on absorbent material. Place in waste disposal container. Remove ignition sources. Flush area with water. Spread sand/grit.

DISPOSAL INSTRUCTIONS:

Water contaminated with this product may be sent to a sanitary sewer treatment facility,in accordance with any local agreement,a permitted waste treatment facility or discharged under a permit. Product as is - Incinerate or land dispose in an approved landfill.

7 Handling & Storage

HANDLING:

Combustible. Do not use around sparks or flames. Bond containers during filling or discharge when performed at temperatures at or above the product flash point.

STORAGE:

Keep containers closed when not in use. Store in cool ventilated location. Store away from oxidizers.

8 Exposure Controls / Personal Protection

CHEMICAL NAME	EXPOSURE LIMITS
NAPHTHALENE	
PEL (OSHA):	10 PPM
TLV (ACGIH):	10 PPM

ETHYLBENZENE
PEL (OSHA): 100 PPM(125PPM-STEL)
TLV (ACGIH): 100 PPM(125PPM-STEL)

SOLVENT NAPHTHA, PETROLEUM, HEAVY AROMATIC
PEL (OSHA): NOT DETERMINED
TLV (ACGIH): NOT DETERMINED
MISC: Note- manufacturer's recommended exposure limit: 100 ppm.

PETROLEUM DISTILLATES,SOLVENT DEWAXED HEAVY PARAFFINIC
PEL (OSHA): 5 MG/M3(MIST)
TLV (ACGIH): 5 MG/M3(MIST)

BHT (BUTYLATED HYDROXYTOLUENE)
PEL (OSHA): 10 MG/M3
TLV (ACGIH): 2 MG/M3

8) EXPOSURE CONTROLS/PERSONAL PROTECTION (continued)

ENGINEERING CONTROLS:

Adequate ventilation to maintain air contaminants below exposure limits.

PERSONAL PROTECTIVE EQUIPMENT:

Use protective equipment in accordance with 29CFR 1910 Subpart I

RESPIRATORY PROTECTION:

A RESPIRATORY PROTECTION PROGRAM THAT MEETS OSHA'S 29 CFR 1910.134 AND ANSI Z88.2 REQUIREMENTS MUST BE FOLLOWED WHENEVER WORKPLACE CONDITIONS WARRANT A RESPIRATOR'S USE.
USE AIR PURIFYING RESPIRATORS WITHIN USE LIMITATIONS ASSOCIATED WITH THE EQUIPMENT OR ELSE USE SUPPLIED AIR-RESPIRATORS.
If air-purifying respirator use is appropriate, use a respirator with organic vapor cartridges and dust/mist prefilters.

SKIN PROTECTION:

neoprene gloves-- Wash off after each use. Replace as necessary.

EYE PROTECTION:

splash proof chemical goggles

9 Physical & Chemical Properties

Density	7.5 lbs/ga	Vapor Pressure (mmHG)	< 5.0
Freeze Point (F)	-45	Vapor Density (air=1)	> 1.00
Freeze Point (C)	-43		
Viscosity(cps 70F,21C)	18	% Solubility (water)	< 0.0

Odor		Strong	
Appearance		Amber To Brown	
Physical State		Liquid	
Flash Point	P-M(CC)	165F	73C
pH 5% Extract (approx.)		6.0	
Evaporation Rate (Ether=1)		< 1.00	
Percent VOC:		63.0	

NA = not applicable ND = not determined

10 Stability & Reactivity

STABILITY:
Stable under normal storage conditions.
HAZARDOUS POLYMERIZATION:
Will not occur.
INCOMPATIBILITIES:
May react with strong oxidizers.
DECOMPOSITION PRODUCTS:
elemental oxides
INTERNAL PUMPOUT/CLEANOUT CATEGORIES:
"B"

11 Toxicological Information

Oral LD50 RAT:	>2,000 mg/kg
NOTE - Estimated value	
Dermal LD50 RABBIT:	>2,000 mg/kg
NOTE - Estimated value	

12 Ecological Information

AQUATIC TOXICOLOGY
Daphnia magna 48 Hour Static Acute Bioassay
LC50= 28.3; 0% Mortality= 6.3 mg/L
Fathead Minnow 96 Hour Static Acute Bioassay
LC50= 7.7; No Effect Level= 6.3 mg/L

BIODEGRADATION
No Data Available.

13 Disposal Considerations

If this undiluted product is discarded as a waste, the US RCRA hazardous waste identification number is :
Not applicable.

Please be advised; however, that state and local requirements for waste disposal may be more restrictive or otherwise different from federal regulations. Consult state and local regulations regarding the proper disposal of this material.

14 Transport Information

DOT HAZARD:	Combustible liquid
PROPER SHIPPING NAME:	COMBUSTIBLE LIQUID, N.O.S.(AROMATIC SOLVENT) NA 1993, PG III
DOT EMERGENCY RESPONSE GUIDE #:	128

Note: Some containers may be DOT exempt, please check BOL for exact container classification

15 Regulatory Information

TSCA:
All components of this product are listed in the TSCA inventory.
CERCLA AND/OR SARA REPORTABLE QUANTITY (RQ):
198 gallons due to NAPHTHALENE;2,704 gallons due to XYLENE;
Treat as oil spill
SARA SECTION 312 HAZARD CLASS:
Immediate(acute);Delayed(Chronic);Fire

SARA SECTION 313 CHEMICALS:

CAS#	CHEMICAL NAME	RANGE
91-20-3	NAPHTHALENE	6.0-10.0%
100-41-4	ETHYLBENZENE	0.1-1.0%
1330-20-7	XYLENE	0.1-1.0%

CALIFORNIA REGULATORY INFORMATION

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT (PROPOSITION 65):

This product contains one or more ingredients known to the state of California to cause cancer and reproductive toxicity.

MICHIGAN REGULATORY INFORMATION

CAS#	CHEMICAL NAME
91-20-3	NAPHTHALENE
1330-20-7	XYLENE

16 Other Information

NFPA/HMIS		CODE TRANSLATION
Health	2	Moderate Hazard
Fire	2	Moderate Hazard
Reactivity	0	Minimal Hazard
Special	NONE	No special Hazard
(1) Protective Equipment	B	Goggles,Gloves

(1) refer to section 8 of MSDS for additional protective equipment recommendations.

CHANGE LOG

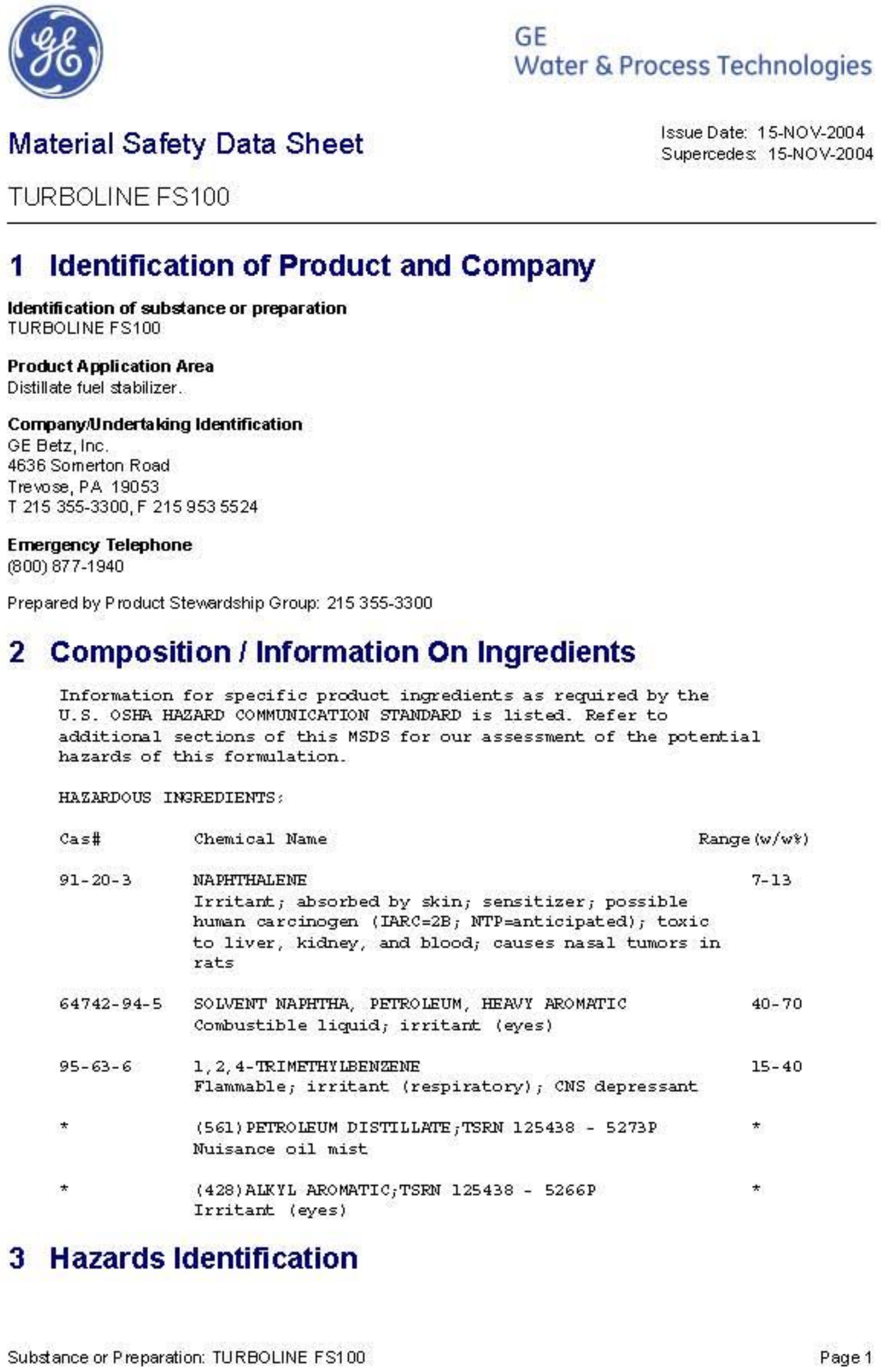
	EFFECTIVE DATE	REVISIONS TO SECTION:	SUPERCEDES
MSDS status:	15-SEP-1999		** NEW **
	17-MAY-2001	8	15-SEP-1999
	17-AUG-2001	2	17-MAY-2001
	07-JAN-2003	2,4,8,15	17-AUG-2001
	01-APR-2004	15	07-JAN-2003
	15-NOV-2004	15	01-APR-2004
	21-MAR-2006	2	15-NOV-2004
	05-MAY-2006	2	21-MAR-2006

APPENDIX H

Material Safety Data Sheet – Turboline® FS100

Dated: November 15, 2004

GE Water and Process Technologies



GE
Water & Process Technologies

Material Safety Data Sheet

Issue Date: 15-NOV-2004
Supercedes: 15-NOV-2004

TURBOLINE FS100

---

1 Identification of Product and Company

Identification of substance or preparation
TURBOLINE FS100

Product Application Area
Distillate fuel stabilizer.

Company/Undertaking Identification
GE Betz, Inc.
4636 Somerton Road
Trevose, PA 19053
T 215 355-3300, F 215 953 5524

Emergency Telephone
(800) 877-1940

Prepared by Product Stewardship Group: 215 355-3300

2 Composition / Information On Ingredients

Information for specific product ingredients as required by the U.S. OSHA HAZARD COMMUNICATION STANDARD is listed. Refer to additional sections of this MSDS for our assessment of the potential hazards of this formulation.

HAZARDOUS INGREDIENTS:

Cas#	Chemical Name	Range (w/w%)
91-20-3	NAPHTHALENE Irritant; absorbed by skin; sensitizer; possible human carcinogen (IARC=2B; NTP=anticipated); toxic to liver, kidney, and blood; causes nasal tumors in rats	7-13
64742-94-5	SOLVENT NAPHTHA, PETROLEUM, HEAVY AROMATIC Combustible liquid; irritant (eyes)	40-70
95-63-6	1,2,4-TRIMETHYLBENZENE Flammable; irritant (respiratory); CNS depressant	15-40
*	(561)PETROLEUM DISTILLATE;TSRN 125438 - 5273P Nuisance oil mist	*
*	(428)ALKYL AROMATIC;TSRN 125438 - 5266P Irritant (eyes)	*

3 Hazards Identification

****

EMERGENCY OVERVIEW

WARNING

May cause moderate irritation to the skin. May cause dermatitis. Severe irritant to the eyes. Vapors, gases, mists or aerosols may cause irritation to the upper respiratory tract. Prolonged exposure may cause dizziness and headache.

DOT hazard: Combustible liquid
Odor: Slight Hydrocarbon; Appearance: Brown-Black, Liquid

Fire fighters should wear positive pressure self-contained breathing apparatus(full face-piece type). Proper fire-extinguishing media: dry chemical, carbon dioxide or foam--Avoid water if possible.

****

POTENTIAL HEALTH EFFECTS

ACUTE SKIN EFFECTS:
Primary route of exposure; May cause moderate irritation to the skin. May cause dermatitis.

ACUTE EYE EFFECTS:
Severe irritant to the eyes.

ACUTE RESPIRATORY EFFECTS:
Primary route of exposure;Vapors, gases, mists or aerosols may cause irritation to the upper respiratory tract. Prolonged exposure may cause dizziness and headache.

INGESTION EFFECTS:
May cause abdominal pain, nausea, vomiting, dizziness, lethargy and blurring of vision. Cardiac failure and pulmonary edema may develop. Large doses cause severe kidney damage. May be fatal. Aspiration may cause lung injury or death.

TARGET ORGANS:
Prolonged or repeated exposures may cause CNS depression and/or defatting-type dermatitis.

MEDICAL CONDITIONS AGGRAVATED:
Not known.

SYMPTOMS OF EXPOSURE:
Excessive dermal exposure causes defatting and drying of skin. Excessive inhalation of vapors causes dizziness, headache and nausea.

4 First Aid Measures

SKIN CONTACT:
Wash thoroughly with soap and water. Remove contaminated clothing. Thoroughly wash clothing before reuse. Get medical attention if irritation develops or persists.

EYE CONTACT:
Remove contact lenses. Hold eyelids apart. Immediately flush eyes with plenty of low-pressure water for at least 15 minutes. Get immediate medical attention.

INHALATION:

Remove to fresh air. If breathing is difficult, give oxygen. If breathing has stopped, give artificial respiration. Get immediate medical attention.

INGESTION:

Do not feed anything by mouth to an unconscious or convulsive victim. Do not induce vomiting. Immediately contact physician. Dilute contents of stomach using 3-4 glasses milk or water.

NOTES TO PHYSICIANS:

No special instructions

5 Fire Fighting Measures

FIRE FIGHTING INSTRUCTIONS:

Fire fighters should wear positive pressure self-contained breathing apparatus (full face-piece type).

EXTINGUISHING MEDIA:

dry chemical, carbon dioxide or foam--Avoid water if possible.

HAZARDOUS DECOMPOSITION PRODUCTS:

elemental oxides

FLASH POINT:

150F 66C P-M(CC)

MISCELLANEOUS:

Combustible liquid
NA 1993;Emergency Response Guide #128

6 Accidental Release Measures

PROTECTION AND SPILL CONTAINMENT:

Ventilate area. Use specified protective equipment. Contain and absorb on absorbent material. Place in waste disposal container. Remove ignition sources. Flush area with water. Spread sand/grit.

DISPOSAL INSTRUCTIONS:

Water contaminated with this product may be sent to a sanitary sewer treatment facility,in accordance with any local agreement,a permitted waste treatment facility or discharged under a permit. Product as is - Incinerate or land dispose in an approved landfill.

7 Handling & Storage

HANDLING:

Combustible. Do not use around sparks or flames. Bond containers during filling or discharge when performed at temperatures at or above the product flash point.

STORAGE:

Keep containers closed when not in use. Store in cool ventilated location. Store away from oxidizers.

8 Exposure Controls / Personal Protection

EXPOSURE LIMITS

CHEMICAL NAME

NAPHTHALENE
PEL (OSHA): 10 PPM
TLV (ACGIH): 10 PPM

SOLVENT NAPHTHA, PETROLEUM, HEAVY AROMATIC
PEL (OSHA): NOT DETERMINED
TLV (ACGIH): NOT DETERMINED

MISC: Note- manufacturer's recommended exposure limit: 100 ppm.

1,2,4-TRIMETHYLBENZENE
PEL (OSHA): NOT DETERMINED
TLV (ACGIH): 25 PPM(TRIMETHYLBENZENE MIXED ISOMERS)

(561)PETROLEUM DISTILLATE;TSRN 125438 - 5273P
PEL (OSHA): 5 MG/M3(MIST)
TLV (ACGIH): 5 MG/M3(MIST)

(428)ALKYL AROMATIC;TSRN 125438 - 5266P
PEL (OSHA): 10 MG/M3
TLV (ACGIH): 2 MG/M3

8) EXPOSURE CONTROLS/PERSONAL PROTECTION (continued)

ENGINEERING CONTROLS:

Adequate ventilation to maintain air contaminants below exposure limits.

PERSONAL PROTECTIVE EQUIPMENT:

Use protective equipment in accordance with 29CFR 1910 Subpart I

RESPIRATORY PROTECTION:

A RESPIRATORY PROTECTION PROGRAM THAT MEETS OSHA'S 29 CFR 1910.134 AND ANSI Z88.2 REQUIREMENTS MUST BE FOLLOWED WHENEVER WORKPLACE CONDITIONS WARRANT A RESPIRATOR'S USE. USE AIR PURIFYING RESPIRATORS WITHIN USE LIMITATIONS ASSOCIATED WITH THE EQUIPMENT OR ELSE USE SUPPLIED AIR-RESPIRATORS. If air-purifying respirator use is appropriate, use a respirator with organic vapor cartridges and dust/mist prefilters.

SKIN PROTECTION:

neoprene gloves-- Wash off after each use. Replace as necessary.

EYE PROTECTION:

splash proof chemical goggles

9 Physical & Chemical Properties

Density	7.4 lbs/ga	Vapor Pressure (mmHG)	< 5.0
Freeze Point (F)	< -30	Vapor Density (air=1)	> 1.00
Freeze Point (C)	< -34		
Viscosity(cps 70F,21C)	11	% Solubility (water)	< 0.0

Odor		Slight Hydrocarbon
Appearance		Brown-Black
Physical State		Liquid
Flash Point	P-M(CC)	150F 65C
pH 5% Extract (approx.)		7.0
Evaporation Rate (Ether=1)		< 1.00
Percent VOC:		83.0

NA = not applicable ND = not determined

10 Stability & Reactivity

STABILITY:
Stable under normal storage conditions.
HAZARDOUS POLYMERIZATION:
Will not occur.
INCOMPATIBILITIES:
May react with strong oxidizers.
DECOMPOSITION PRODUCTS:
elemental oxides
INTERNAL PUMPOUT/CLEANOUT CATEGORIES:
"B"

11 Toxicological Information

Oral LD50 RAT:	>2,000 mg/kg
NOTE - Estimated value	
Dermal LD50 RABBIT:	>2,000 mg/kg
NOTE - Estimated value	

12 Ecological Information

AQUATIC TOXICOLOGY
No Data Available.

BIODEGRADATION
No Data Available.

13 Disposal Considerations

If this undiluted product is discarded as a waste, the US RCRA hazardous waste identification number is :
Not applicable.

Please be advised; however, that state and local requirements for waste disposal may be more restrictive or otherwise different from federal regulations. Consult state and local regulations regarding the proper disposal of this material.

14 Transport Information

DOT HAZARD:	Combustible liquid
PROPER SHIPPING NAME:	COMBUSTIBLE LIQUID, N.O.S.(NAPHTHALENE) NA 1993, PG III, RQ
DOT EMERGENCY RESPONSE GUIDE #:	128

Note: Some containers may be DOT exempt, please check BOL for exact container classification

15 Regulatory Information

TSCA:
All components of this product are listed in the TSCA inventory.
CERCLA AND/OR SARA REPORTABLE QUANTITY (RQ):
148 gallons due to NAPHTHALENE; Treat as oil spill
SARA SECTION 312 HAZARD CLASS:
Immediate(acute);Delayed(Chronic);Fire
SARA SECTION 313 CHEMICALS:

CAS#	CHEMICAL NAME	RANGE
91-20-3	NAPHTHALENE	6.0-10.0%
95-63-6	1,2,4-TRIMETHYLBENZENE	21.0-30.0%
1330-20-7	XYLENE	0.1-1.0%

CALIFORNIA REGULATORY INFORMATION

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT (PROPOSITION 65):

This product contains one or more ingredients known to the state of California to cause cancer and reproductive toxicity.

MICHIGAN REGULATORY INFORMATION

CAS#	CHEMICAL NAME
91-20-3	NAPHTHALENE
1330-20-7	XYLENE

16 Other Information

NFPA/HMIS		CODE TRANSLATION
Health	2	Moderate Hazard
Fire	2	Moderate Hazard
Reactivity	0	Minimal Hazard
Special	NONE	No special Hazard
(1) Protective Equipment	B	Goggles,Gloves

(1) refer to section 8 of MSDS for additional protective equipment recommendations.

CHANGE LOG

	EFFECTIVE DATE	REVISIONS TO SECTION:	SUPERCEDES
	---------	---------------------	----------
MSDS status:	08-APR-1999		** NEW **
	12-APR-1999		08-APR-1999
	02-SEP-1999	3,4,5,8,11,14,15;EDIT:	12-APR-1999
	19-APR-2000	4,15	02-SEP-1999
	03-JAN-2001	2,8	19-APR-2000
	17-MAY-2001	8	03-JAN-2001
	17-AUG-2001	2	17-MAY-2001
	01-APR-2004	15	17-AUG-2001
	15-NOV-2004	15	01-APR-2004

APPENDIX I

Material Safety Data Sheet – Turboline® FS100C

Dated: May 5, 2006

GE Water and Process Technologies

GE
Water & Process Technologies

Material Safety Data Sheet

Issue Date: 05-MAY-2006
Supercedes: 05-MAY-2006

TURBOLINE FS100 (CONC)

---

1 Identification of Product and Company

Identification of substance or preparation
TURBOLINE FS100 (CONC)

Product Application Area
Distillate fuel stabilizer.

Company/Undertaking Identification
GE Betz, Inc.
4636 Somerton Road
Trevose, PA 19053
T 215 355-3300, F 215 953 5524

Emergency Telephone
(800) 877-1940

Prepared by Product Stewardship Group: 215 355-3300

2 Composition / Information On Ingredients

Information for specific product ingredients as required by the U.S. OSHA HAZARD COMMUNICATION STANDARD is listed. Refer to additional sections of this MSDS for our assessment of the potential hazards of this formulation.

HAZARDOUS INGREDIENTS:

Cas#	Chemical Name	Range (w/w%)
91-20-3	NAPHTHALENE Irritant; absorbed by skin; sensitizer; possible human carcinogen (IARC=2B; NTP=anticipated); toxic to liver, kidney, and blood; causes nasal tumors in rats	5-10
100-41-4	ETHYLBENZENE Flammable liquid; Irritant (eyes, skin, and respiratory); possible human carcinogen (IARC=2B; NTP=anticipated);potential nervous system toxin	0.1-1.0
64742-94-5	SOLVENT NAPHTHA, PETROLEUM, HEAVY AROMATIC Combustible liquid; irritant (eyes)	40-70
*	(561)PETROLEUM DISTILLATE;TSRN 125438 - 5273P Nuisance oil mist	*
*	(428)ALKYL AROMATIC;TSRN 125438 - 5266P Irritant (eyes)	*

3 Hazards Identification

****

EMERGENCY OVERVIEW

WARNING

May cause moderate irritation to the skin. May cause dermatitis. Severe irritant to the eyes. Vapors, gases, mists or aerosols may cause irritation to the upper respiratory tract. Prolonged exposure may cause dizziness and headache.

DOT hazard: Combustible liquid
Odor: Strong; Appearance: Amber To Brown, Liquid

Fire fighters should wear positive pressure self-contained breathing apparatus(full face-piece type). Proper fire-extinguishing media: dry chemical, carbon dioxide or foam--Avoid water if possible.

****

POTENTIAL HEALTH EFFECTS

ACUTE SKIN EFFECTS:
Primary route of exposure; May cause moderate irritation to the skin. May cause dermatitis.

ACUTE EYE EFFECTS:
Severe irritant to the eyes.

ACUTE RESPIRATORY EFFECTS:
Primary route of exposure;Vapors, gases, mists or aerosols may cause irritation to the upper respiratory tract. Prolonged exposure may cause dizziness and headache.

INGESTION EFFECTS:
May cause abdominal pain, nausea, vomiting, dizziness, lethargy and blurring of vision. Cardiac failure and pulmonary edema may develop. Large doses cause severe kidney damage. May be fatal. Aspiration may cause lung injury or death.

TARGET ORGANS:
Prolonged or repeated exposures may cause CNS depression and/or defatting-type dermatitis.

MEDICAL CONDITIONS AGGRAVATED:
Not known.

SYMPTOMS OF EXPOSURE:
Excessive dermal exposure causes defatting and drying of skin. Excessive inhalation of vapors causes dizziness, headache and nausea.

4 First Aid Measures

SKIN CONTACT:
Wash thoroughly with soap and water. Remove contaminated clothing. Thoroughly wash clothing before reuse. Get medical attention if irritation develops or persists.

EYE CONTACT:
Remove contact lenses. Hold eyelids apart. Immediately flush eyes with plenty of low-pressure water for at least 15 minutes. Get

immediate medical attention.

INHALATION:

Remove to fresh air. If breathing is difficult, give oxygen. If breathing has stopped, give artificial respiration. Get immediate medical attention.

INGESTION:

Do not feed anything by mouth to an unconscious or convulsive victim. Do not induce vomiting. Immediately contact physician. Dilute contents of stomach using 3-4 glasses milk or water.

NOTES TO PHYSICIANS:

This product contains a hydrocarbon solvent. Aspiration into the lungs will result in chemical pneumonia and may be fatal.

5 Fire Fighting Measures

FIRE FIGHTING INSTRUCTIONS:

Fire fighters should wear positive pressure self-contained breathing apparatus (full face-piece type).

EXTINGUISHING MEDIA:

dry chemical, carbon dioxide or foam--Avoid water if possible.

HAZARDOUS DECOMPOSITION PRODUCTS:

elemental oxides

FLASH POINT:

165F 74C P-M(CC)

MISCELLANEOUS:

Combustible liquid
NA 1993;Emergency Response Guide #128

6 Accidental Release Measures

PROTECTION AND SPILL CONTAINMENT:

Ventilate area. Use specified protective equipment. Contain and absorb on absorbent material. Place in waste disposal container. Remove ignition sources. Flush area with water. Spread sand/grit.

DISPOSAL INSTRUCTIONS:

Water contaminated with this product may be sent to a sanitary sewer treatment facility,in accordance with any local agreement,a permitted waste treatment facility or discharged under a permit. Product as is - Incinerate or land dispose in an approved landfill.

7 Handling & Storage

HANDLING:

Combustible. Do not use around sparks or flames. Bond containers during filling or discharge when performed at temperatures at or above the product flash point.

STORAGE:

Keep containers closed when not in use. Store in cool ventilated location. Store away from oxidizers.

8 Exposure Controls / Personal Protection

EXPOSURE LIMITS

CHEMICAL NAME

NAPHTHALENE
PEL (OSHA): 10 PPM
TLV (ACGIH): 10 PPM

ETHYLBENZENE
PEL (OSHA): 100 PPM(125PPM-STEL)
TLV (ACGIH): 100 PPM(125PPM-STEL)

SOLVENT NAPHTHA, PETROLEUM, HEAVY AROMATIC
PEL (OSHA): NOT DETERMINED
TLV (ACGIH): NOT DETERMINED
MISC: Note- manufacturer's recommended exposure limit: 100 ppm.

(561)PETROLEUM DISTILLATE;TSRN 125438 - 5273P
PEL (OSHA): 5 MG/M3(MIST)
TLV (ACGIH): 5 MG/M3(MIST)

(428)ALKYL AROMATIC;TSRN 125438 - 5266P
PEL (OSHA): 10 MG/M3
TLV (ACGIH): 2 MG/M3

8) EXPOSURE CONTROLS/PERSONAL PROTECTION (continued)

ENGINEERING CONTROLS:
Adequate ventilation to maintain air contaminants below exposure limits.

PERSONAL PROTECTIVE EQUIPMENT:
Use protective equipment in accordance with 29CFR 1910 Subpart I

RESPIRATORY PROTECTION:
A RESPIRATORY PROTECTION PROGRAM THAT MEETS OSHA'S 29 CFR 1910.134 AND ANSI Z88.2 REQUIREMENTS MUST BE FOLLOWED WHENEVER WORKPLACE CONDITIONS WARRANT A RESPIRATOR'S USE.
USE AIR PURIFYING RESPIRATORS WITHIN USE LIMITATIONS ASSOCIATED WITH THE EQUIPMENT OR ELSE USE SUPPLIED AIR-RESPIRATORS.
If air-purifying respirator use is appropriate, use a respirator with organic vapor cartridges and dust/mist prefilters.

SKIN PROTECTION:
neoprene gloves-- Wash off after each use. Replace as necessary.

EYE PROTECTION:
splash proof chemical goggles

9 Physical & Chemical Properties

Density	7.5 lbs/ga	Vapor Pressure (mmHG)	< 5.0
Freeze Point (F)	-45	Vapor Density (air=1)	> 1.00
Freeze Point (C)	-43		
Viscosity(cps 70F,21C)	18	% Solubility (water)	< 0.0

Odor		Strong
Appearance		Amber To Brown
Physical State		Liquid
Flash Point	P-M(CC)	165F 73C
pH 5% Extract (approx.)		6.0
Evaporation Rate (Ether=1)		< 1.00
Percent VOC:		63.0

NA = not applicable **ND = not determined**

10 Stability & Reactivity

STABILITY:
Stable under normal storage conditions.
HAZARDOUS POLYMERIZATION:
Will not occur.
INCOMPATIBILITIES:
May react with strong oxidizers.
DECOMPOSITION PRODUCTS:
elemental oxides
INTERNAL PUMPOUT/CLEANOUT CATEGORIES:
"B"

11 Toxicological Information

Oral LD50 RAT: >2,000 mg/kg
NOTE - Estimated value
Dermal LD50 RABBIT: >2,000 mg/kg
NOTE - Estimated value

12 Ecological Information

AQUATIC TOXICOLOGY
Daphnia magna 48 Hour Static Acute Bioassay
LC50= 28.3; 0% Mortality= 6.3 mg/L
Fathead Minnow 96 Hour Static Acute Bioassay
LC50= 7.7; No Effect Level= 6.3 mg/L

BIODEGRADATION
No Data Available.

13 Disposal Considerations

If this undiluted product is discarded as a waste, the US RCRA hazardous waste identification number is :
Not applicable.

Please be advised; however, that state and local requirements for waste disposal may be more restrictive or otherwise different from federal regulations. Consult state and local regulations regarding the proper disposal of this material.

14 Transport Information

DOT HAZARD: Combustible liquid
PROPER SHIPPING NAME: COMBUSTIBLE LIQUID, N.O.S.(AROMATIC SOLVENT)
NA 1993, PG III
DOT EMERGENCY RESPONSE GUIDE #: 128
Note: Some containers may be DOT exempt, please check BOL for exact container classification

15 Regulatory Information

TSCA:
All components of this product are listed in the TSCA inventory.
CERCLA AND/OR SARA REPORTABLE QUANTITY (RQ):
198 gallons due to NAPHTHALENE;2,704 gallons due to XYLENE;
Treat as oil spill
SARA SECTION 312 HAZARD CLASS:
Immediate(acute);Delayed(Chronic);Fire

SARA SECTION 313 CHEMICALS:

CAS#	CHEMICAL NAME	RANGE
91-20-3	NAPHTHALENE	6.0-10.0%
100-41-4	ETHYLBENZENE	0.1-1.0%
1330-20-7	XYLENE	0.1-1.0%

CALIFORNIA REGULATORY INFORMATION

CALIFORNIA SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT (PROPOSITION 65):

This product contains one or more ingredients known to the state of California to cause cancer and reproductive toxicity.

MICHIGAN REGULATORY INFORMATION

CAS#	CHEMICAL NAME
91-20-3	NAPHTHALENE
1330-20-7	XYLENE

16 Other Information

NFPA/HMIS		**CODE TRANSLATION**
Health	2	Moderate Hazard
Fire	2	Moderate Hazard
Reactivity	0	Minimal Hazard
Special	NONE	No special Hazard
(1) Protective Equipment	B	Goggles,Gloves

(1) refer to section 8 of MSDS for additional protective equipment recommendations.

CHANGE LOG

	EFFECTIVE DATE	REVISIONS TO SECTION:	SUPERCEDES
MSDS status:	09-SEP-1999		** NEW **
	17-MAY-2001	8	09-SEP-1999
	17-AUG-2001	2	17-MAY-2001
	07-JAN-2003	2,4,8,15	17-AUG-2001
	01-APR-2004	15	07-JAN-2003
	15-NOV-2004	15	01-APR-2004
	05-MAY-2006	2	15-NOV-2004

APPENDIX J

Material Safety Data Sheet – AeroShell Performance Additive 101

Dated: June 19, 1998

Shell Aviation Ltd.

Shell Aviation

Safety Data Sheet

Issued: June 19, 1998

SDS No. Sn11m074

*Aero*Shell Performance Additive 101

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1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND COMPANY

Product name: *Aero*Shell Performance Additive 101

Product code: 001A9641

Product type: Fuel additive

Supplier: Shell Aviation Ltd.

Address: Shell-Mex House, Strand
London WC2R 0ZA, UK

Contact numbers:

Telephone: +44 (0)20 7546 2770
Telex: -
Fax: +44 (0)20 7564 6640

Emergency telephone number:

24 hour +44 (0)151 350 4595

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2. COMPOSITION/INFORMATION ON INGREDIENTS

Preparation description: A mixture of polymeric materials and antioxidant in highly refined mineral oil and hydrocarbon solvents

Dangerous components/constituents:

Component name	**CAS number**	**Content range**	**EC hazard**	**R phrases**
Distillates (petroleum), solvent-dewaxed heavy paraffinic	64742-65-0	10 - 30%(m/m)	*	
Solvent naphtha (petroleum), heavy aromatic	64742-94-5	50 - 80 %(m/m)	Xn Xi	R65 R37/38
1,2,4-Trimethylbenzene	95-63-6	1 - 5	Xn	R10,R20 R36/37/38
Butylated hydroxytoluene	128-37-0	5 - 10%m/m		

* DMSO extract by IP346 less than 3%m/m

3. HAZARDS IDENTIFICATION

Human health hazards: Harmful: may cause lung damage if swallowed. Aspiration into the lungs may cause chemical pneumonitis which can be fatal. Mildly irritating to the skin. Prolonged/repeated contact may cause defatting of the skin which can lead to dermatitis. Prolonged exposure to vapour/mist concentrations above the recommended occupational exposure standard may cause: dizziness, weakness, fatigue, headache, nausea, irritation of the respiratory tract, vomiting, diarrhoea, asphyxiation, unconsciousness and even death. Vapour and liquid may cause eye irritation.

Safety hazards: Not classified as flammable, but will burn.

Environmental hazards: Not readily biodegradable. Has the potential to bioaccumulate. Expected to be slightly toxic to aquatic organisms. Large volumes may penetrate soil and could contaminate groundwater.

4. FIRST AID MEASURES

Symptoms and effects: Prolonged exposure to vapour/mist concentrations above the recommended occupational exposure standard may cause: headache, dizziness, nausea, irritation of the eyes, upper respiratory tract, mouth and digestive tract, asphyxiation, unconsciousness and even death. Splashes into the eye may cause irritation and conjunctivitis. If ingested can lead to irritation of the mouth, irritation of the throat, irritation of the digestive tract, vomiting, convulsions and coma. Aspiration into the lungs may occur directly or following ingestion. This can cause chemical pneumonitis which may be fatal.

First Aid - Inhalation: Remove to fresh air. If breathing but unconscious, place in the recovery position. If breathing has stopped, apply artificial respiration. If heartbeat absent give external cardiac compression. Monitor breathing and pulse. OBTAIN MEDICAL ATTENTION IMMEDIATELY.

First Aid - Skin: Wash skin with water using soap if available. Contaminated clothing must be removed as soon as possible. It must be laundered before reuse.

First Aid - Eye: Flush eye with water. If persistent irritation occurs, obtain medical attention.

First Aid - Ingestion: DO NOT DELAY. Do not induce vomiting. Protect the airway if vomiting begins. Give nothing by mouth. If breathing but unconscious, place in the recovery position. If breathing has stopped, apply artificial respiration. OBTAIN MEDICAL ATTENTION IMMEDIATELY.

Advice to physicians:	Treat symptomatically. Diagnosis of ingestion of this product is by the characteristic odour on the victim's breath and from the history of events. In cases of ingestion, consider gastric lavage. Gastric lavage must only be undertaken after cuffed endotracheal intubation in view of the risk of aspiration. In cases of chemical pneumonitis, antibiotic and corticosteroid therapy should be considered. Administration of medicinal liquid paraffin may reduce absorption from the digestive tract.

5. FIRE FIGHTING MEASURES

Specific hazards:	Combustion products may include: carbon monoxide, oxides of nitrogen, oxides of sulphur, oxides of phosphorus, unidentified organic and inorganic compounds.
Extinguishing media:	Foam and dry chemical powder. Carbon dioxide, sand or earth may be used for small fires only.
Unsuitable extinguishing media:	Water in a jet. Use of Halon extinguishers should be avoided for environmental reasons.
Protective equipment:	Proper protective equipment including breathing apparatus must be worn when approaching a fire in a confined space.
Other information:	Keep adjacent containers cool by spraying with water.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions:	Vapour can travel along the ground for considerable distances. Remove all possible sources of ignition in the surrounding area and evacuate all personnel. Do not breath vapour, mists, aerosols. Ventilate contaminated area thoroughly. Avoid contact with skin, eyes and clothing. Take off immediately all contaminated clothing.
Personal protection:	Wear: impervious overalls, PVC or nitrile rubber gloves; safety shoes or boots - chemical resistant, monogoggles.
Environmental precautions:	Prevent from entering into drains, ditches or rivers. Use appropriate containment to avoid environmental contamination. Inform local authorities if this cannot be prevented.
Clean-up methods - small spillage:	Absorb or contain liquid with sand, earth or spill control material. Shovel into a suitable, clearly marked container for subsequent safe disposal in accordance with local regulations.
Clean-up methods - large spillage:	Prevent from spreading by making a barrier with sand, earth or other containment material. Reclaim liquid directly or in an absorbent. Dispose of as for small spills.
Other information:	Observe all relevant local regulations. Spilled product must not be re-used as an aviation fuel additive. See Section 13 for information on disposal.

7. HANDLING AND STORAGE

Handling:	When using do not eat, drink or smoke. Only use in well-ventilated areas. When handling product in drums or totes, safety footwear should be worn and proper handling equipment should be used. Prevent spillages.
Handling temperature:	Ambient.

Storage:	Keep only in original container. Keep in a cool, dry, well-ventilated place. Keep away from sources of heat or ignition. Keep in a bunded area.
Storage temperature:	Ambient.
Product transfer:	Electrostatic charges may be generated during pumping. Ensure electrical continuity by bonding all equipment.
Other information:	Never siphon by mouth.

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8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Occupational exposure standards: In the absence of occupational exposure standards for this product, it is recommended that the following are adopted:

Component name	Limit type	Value	Unit	Other information
Distillates (petroleum), solvent-dewaxed heavy paraffinic	TWA	5	mg/m^3	Ref: ACGIH
Trimethylbenzene	TWA	25	ppm	Ref: ACGIH
Butylated hydroxytoluene	TWA	10	mg/m^3	Ref: ACGIH

Note: ACGIH - 'Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices', American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1996 edition.

Hygiene measures:	Wash hands before eating, drinking, smoking and using the toilet.
Respiratory protection:	Not normally required. If risk of inhalation wear half mask respirator with organic vapour cartridge and built-in particulate filter NPF 20 (gas only).
Hand protection:	PVC or nitrile rubber gloves.
Eye protection:	Wear chemical monogoggles if splashes are likely to occur or in high pressure applications.
Body protection:	Wear overalls to minimise contamination of personal clothing. Launder overalls and undergarments regularly. Safety shoes or boots - chemical resistant. If splashes are likely to occur wear a PVC apron. Minimise all forms of skin contact.

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9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Liquid at ambient temperature
Colour:	Clear light amber liquid
Odour:	Strong
Vapour pressure:	Data not available
Density:	910 kg/m^3 at 15°C
Kinematic viscosity:	4.28 mm^2/s at 40°C
Vapour density (air=1):	>1

Flash point:	68°C (PMCC)
Flammability limit - lower:	Data not available
Flammability limit - upper:	Data not available
Auto-ignition temperature:	Data not available
Oxidising properties	
Evaporation rate (ether=1)	>1
Solubility in water:	<0.01%
n-octanol/water partition coefficient:	Data not available

10. STABILITY/REACTIVITY

Stability:	Stable.
Conditions to avoid:	Heat, flames and sparks.
Materials to avoid:	Strong oxidizing agents.
Hazardous decomposition products:	Hazardous decomposition products are not expected to form during normal storage.

11. TOXICOLOGICAL INFORMATION

Basis for assessment:	Toxicological data have not been determined specifically for this product. Information given is based on a knowledge of the components and the toxicology of similar products.
Acute toxicity - oral:	LD_{50} > 2000 mg/kg (estimated value)
Acute toxicity - dermal:	LD_{50} > 2000 mg/kg (estimated value)
Eye irritation:	Expected to be slightly irritant.
Skin irritation:	Irritant.
Respiratory irritation:	Data not available from animal studies.
Skin sensitization:	Not expected to be a skin sensitizer
(Sub) chronic toxicity:	This product has not been evaluated in long-term chronic exposure tests. Repeated skin exposure expected to cause moderate to severe irritation. Repeated inhalation of mists expected to cause irritation of the respiratory tract.
Carcinogenicity:	This product has not been evaluated in long-term chronic exposure tests. Dermal application to mice expected to cause tumours. Carcinogenic response may be a consequence of repeat, local contact and the exposure conditions.

Human effects: Prolonged/repeated contact may cause defatting of the skin which can lead to dermatitis. Under conditions of poor personal hygiene, excessive exposure may lead to irritation, oil acne and folliculitis and development of warty growths which may subsequently become malignant. See Section 4 for information regarding acute effects to humans.

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12. ECOLOGICAL INFORMATION

Basis for assessment: Ecotoxicological data have not been determined specifically for this product. Information given is based on a knowledge of the components and the ecotoxicology of similar products.

Mobility: Liquid under most environmental conditions. Emulsifies in water. Product remaining on soil surface will partly evaporate, but a significant proportion will remain after one day. If the product enters soil, one or more constituents will be mobile and may contaminate groundwater.

Persistence/degradability:

COD:	2510 mg0$_2$/g
TOC:	835 mgC/g
Closed bottle test:	35% degradation after 28 days

Ecotoxicity: Estimated to be moderately toxic

Other information: This product is a preparation. The EC has not yet defined criteria for classifying products as dangerous for the environment.

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13. DISPOSAL CONSIDERATIONS

Precautions: See Section 8.

Waste disposal: Waste arising from a spillage should be disposed of in accordance with prevailing regulations, preferably to a recognised collector or contractor. The competence of the contractor should be established beforehand. Do not dispose into the environment, in drains or in water courses.

Product disposal: As for waste disposal.

Container disposal: All containers should be emptied and returned to the supplier.

Local legislation:

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14. TRANSPORT INFORMATION

Not dangerous for conveyance under UN, IMO, ADR/RID and IATA/ICAO codes.

15. REGULATORY INFORMATION

EC Label name:	Contains: solvent naphtha (petroleum), heavy aromatic
EC Classification:	Harmful
EC Symbols:	Xn
EC Risk Phrases:	R65 Harmful: may cause lung damage if swallowed R37/38 Irritating to respiratory system and skin
EC Safety Phrases:	S26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice. S28 After contact with skin, wash immediately with plenty of soap and water S36/37/39 Wear suitable protective clothing, gloves and eye/face protection S43 In case of fire use foam/dry powder/CO_2 - Never use water
EINECS (EC):	All components listed.
MITI (Japan):	Not established.
TSCA (USA):	All components listed.
AICS (Australia):	All components listed.
DSL (Canada):	All components listed.
National legislation:	
Other information:	

16. OTHER INFORMATION

Uses and restrictions:	Use only as an aviation turbine fuel additive package. Consult 'The *Aero*Shell Book', published by Shell Aviation Limited, for further details and examples, including specification approvals. This product must be used, handled and applied in accordance with the requirements of the equipment manufacturer's manuals, bulletins and other documentation.
Technical contact point:	Shell Aviation Ltd. OIAM/37
Technical contact number:	
Telephone:	+44 (0)20 7546 2429
Telex:	-
Fax:	+44 (0)20 7546 6640
SDS history:	Edition number: 1 First issued: June 19, 1998
Revisions highlighted:	

SDS distribution:	This document contains important information to ensure the safe storage, handling and use of this product. The information in this document should be brought to the attention of the person in your organisation responsible for advising on safety matters.
Other information:	

This information is based on our current knowledge and is intended to describe the product for the purposes of health, safety and environmental requirements only. It should not be construed as guaranteeing any specific property of the product.

APPENDIX K

Memorandum for HQ AETC/A4FM

Dated: June 22, 2006

DEPARTMENT OF THE AIR FORCE
AIR FORCE PETROLEUM OFFICE
DET 3, HQ WARNER ROBINS AIR LOGISTICS CENTER (AFMC)
WRIGHT-PATTERSON AFB OH 45433

JUN 22 2006

MEMORANDUM FOR HQ AETC/A4RMF

FROM: Det 3, WR-ALC/AFT (AFPET)

SUBJECT: JP-8+100 Program

1. The investigation of three aircraft incidents at Sheppard AFB TX during June 2005 determined media (carboxy methyl cellulose) to be migrating from the water-absorbing filter elements in the R-11 refueling units. After the media were identified, a corporate decision was made in July 2005 to retrofit all Air Force refueling equipment with coalescing-type filtration. The change in filtration caused many locations to stop issuing JP-8+100 because few bases had what was then considered to be the required +100-qualified filtration.

2. Subsequent to the aircraft incidents at Sheppard, Southwest Research Institute (SwRI) in San Antonio TX performed an in-depth study funded by the Air Force, Defense Energy Support Center, General Electric (GE) Betz, U.S. Army, Chevron/Texaco, ExxonMobil, Conoco/Phillips, QinetiQ, and the UK Ministry of Defense. The purpose of the study was:

a. Using a Design of Experiment (DOE), determine the required dilution ratio of JP-8 to JP-8+100 to have the mixture filtration perform the same as JP-8.
b. Using a DOE, determine the effects of the individual aviation fuel additives and combination of additives on filtration performance.
c. Determine the filtration effects when switching from JP-8 and JP-8+100 using a different filtration system and corrosion inhibitor.

Based on the statistical analysis utilizing the failure criteria agreed upon by the program members, the following conclusions were made by SwRI:

a. There is no fundamental difference in the average filtration performance between JP-8 and JP-8+100 @ 256 ppm.
b. JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage.

3. Following the report from SwRI, the AFPET asked HQ AETC if they would host a field evaluation at Laughlin AFB TX to validate the SwRI report. After considerable dialog and coordination/approval, an evaluation began at Laughlin AFB on 1 March 2006. The Laughlin refueling fleet consisted of 10 Oshkosh, five Kovatch (96-98) and one Kovatch (05) R-11 refueling vehicles. For the evaluation, eight of the Oshkosh units were equipped with JP-8+100 compatible filters and the remaining units retained the existing filter elements. Four randomly selected test R-11 units (89L-1032, 89L-1034, 98L-0037 and 98L-0038) were identified for daily water and particulate testing downstream of the final filtration. Units 89L-1032 and 1034 were equipped with DoD elements qualified using the API/IP 1581, 5th Edition, M Class test

criteria, and 98L-0037 and 98L-0038 were equipped with API 1581, 3rd Edition filter elements. Biweekly status reports were provided to HQ AETC and the AFPET/AFTH. On 1 June 2006, the evaluation ended with a total of 1,938,930 gallons of JP-8+100 issued from the four test units. During the test, there was not a single failure from any of the units for particulates or water. The end result of the short field evaluation at Laughlin basically supported everything outlined in the SwRI report.

4. Therefore, based on the results of the SwRI report and the 90-day field evaluation at Laughlin, we endorse the use of +100 at any location using existing filtration qualified to the API 1581, 3rd and 5th Edition or DoD filtration qualified using the API 1581, 5th Edition M or M100 class filters. For those locations going back on +100, please use the following information pending a formal change to existing technical guidance on JP-8+100:

a. Maintain adequate JP-8 stocks for issue to contract carriers, commercial aircraft, or foreign military or commercial aircraft. Do not issue JP-8+100 to non +100 aircraft.
b. Use one-time defuels to the maximum extent possible and issue defueled +100 product to the next aircraft requiring fuel.
c. Return JP-8+100 to bulk storage only as a last resort. If a return to bulk (RTB) is absolutely necessary, no dilution is necessary.
d. When converting refueling units, drain and remark accordingly. Do not change filters.
e. Aircraft will be considered off +100 after one refuel with at least 75% of the aircraft fuel capacity using non +100 fuel.
f. Bases utilizing the +100 additive will treat the additized fuel as a separate fuel grade.
g. Increase water content testing to daily for R-11 refueling units equipped with filter elements that were not qualified with +100 until confidence has been gained that the elements are performing satisfactorily.

5. Please contact Mr. Jim Young at DSN 785-4311 for additional information or to answer any questions.

FRANCIS J. RECHNER, Colonel, USAF
Commander

cc:
HQ ACC/A4LF
HQ PACAF/A4RP
HQ USAFE/A4RMF
HQ AFSOC/A4RMF
HQ ANG/A4RMF
HQ AFRES/LGSWF

APPENDIX L

J85 and J69 Maintenance Trends

J85 and J69 Maintenance Trends

1.0 Background

The legacy J85 and J69 engines are very sensitive to JP-8 since these small gas turbine engines were developed to use JP-4 as the primary fuel. The engines were initially designed as small turbojet engines for missile and drone applications but later modified to power the twin engine T-37 and T-38 trainer aircraft. The J69 engine remained a straight turbojet while an afterburner was added to the J85 engine. Soon after conversion to JP-8, the combustion system for each engine showed accelerated build-up of carbon that caused an increase in engine anomalies plus the engine hot section and fuel system parts were more difficult to clean. In addition, the hot metal surfaces in the J69 engine heated the fuel beyond its thermal stability limit and discolored the fuel filters which are now changed more frequently. After JP-8+100 conversion, the training wings of the Air Education and Training Command (AETC) found that coking in the J69 and the J85 engines was more manageable but not free from coking problems. Based on data made available by the Units visited, several examples are used to show the maintenance impact of JP-8 use versus using JP-8+100. The first example compares the carbon related causes for engine removals at two different Units operating the same aircraft during periods when JP-8 and JP-8+100 was used, the second example compares the air and ground aborts when the +100 additive was turned off for 13 months while the third example analyzes the unscheduled engine and control component removals due to fuel related anomalies during JP-8 and JP-8+100 use that were documented in the Comprehensive Engine Maintenance System (CEMS) database.

2.0 J-85 Carbon Related Removals

Maintenance personnel at Laughlin AFB commented that the two top drivers for engine removals from T-38 training aircraft were afterburner anomalies and engine no starts/hot starts. Laughlin has used JP-8+100 continuously since 1997 except for a 13 month period starting in May 2005 when the +100 additive was turned off by the fuels community to resolve some media filtration and filter coalescer issues. Thus, a more detailed review of the available engine records focused on the frequency of carbon-related events that had caused engine removals covering the time period from Jan 01 through August 2005. From May 2005 through August 2005, Laughlin reverted to using JP-8 which accelerated coking in J-85 engines and diluted the maintenance benefits of continuous use of the +100 additive but could not be easily sorted out during the records review. For purposes of comparison, another Unit was selected that used JP-8 in T-38 aircraft for more advanced pilot training. For the purposes of the analyses, a carbon-related event was counted as the root cause for an engine removal when maintenance personnel replaced: 1) a main fuel nozzle due to streaking in the spray pattern, 2) for coking of the afterburner main spray ring bar, or 3) the T.O. troubleshooting tree directed removal of the pilot spray ring bar. **Figures L-1** and **L-2** shows the top reasons for engine removal events and the root causes at Laughlin.

Figure L-1 shows the UER Rate at Laughlin where the top two drivers were afterburner anomalies and engine no starts/hot starts. During the site visit, maintenance personnel commented that the causes of the engine removal events were more often related to other malfunctions than fuel coking as noted on the right side of **Figure L-1**. The carbon related causes ranks 11th in relation to the top ten causes at a 0.07/1000 FH rate for engine removals which supports observations made by maintenance personnel that carbon or coke related engine removal events were rare while using JP-8+100 compared to other causes for engine removals.

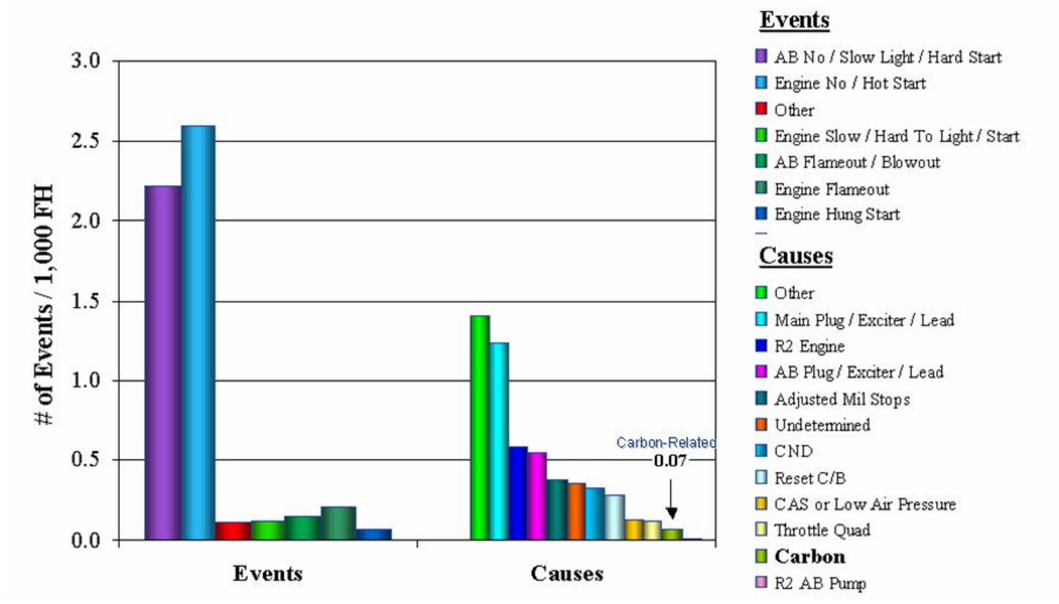


Figure L-1. Laughlin UER & Root Cause Rates During JP-8+100 Use Jan 01-Aug 05 Time Period

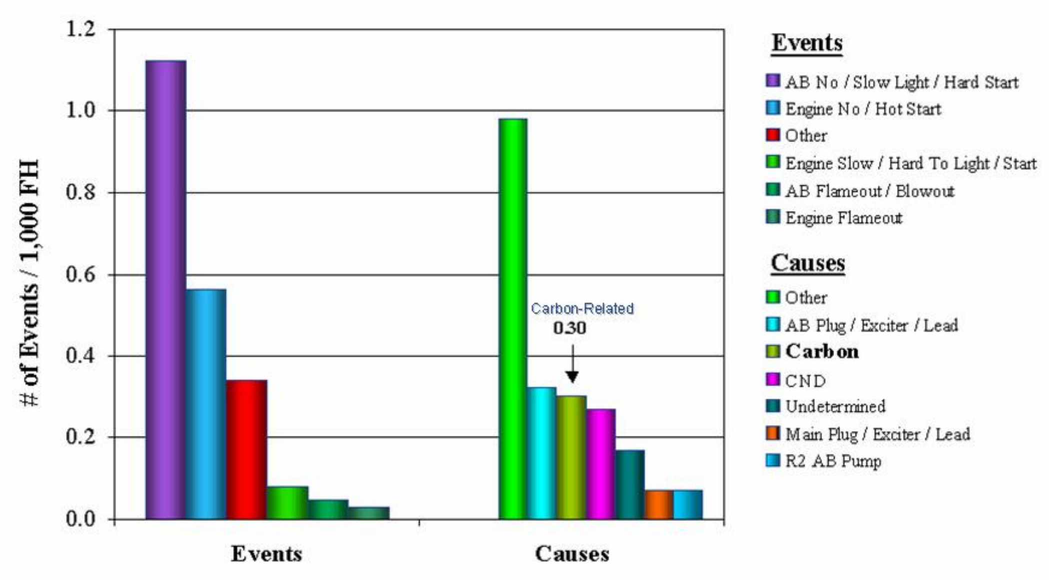


Figure L-2. Laughlin UER & Root Cause Rates During JP-8 Use

For comparison, **Figure L-2** shows the engine removal events and the root causes at another training Unit that has used JP-8 continuously. Although the top drivers for unscheduled engine removals at Laughlin and this unit were afterburner anomalies and engine no starts/hot starts, the Unit using JP-8 experienced a 0.30/1000 FH engine removal rate for carbon related causes compared to the 0.07/1000 FH engine removal rate at Laughlin where JP-8+100 has been used continuously since 1997 with exception to the last 4 months of the data analysis period when the +100 additive was turn off in Jun 05 for 13 month and turned on again in Jul 06. As noted, the use of JP-8 in J-85 engines has resulted in a 4X higher incident rate for carbon related causes for engine removals compared to Laughlin that has used JP-8+100 continuously since 1997. At Laughlin, 2.1% of the removal events were carbon related whereas 25.8% of the removals events were carbon related at the Unit that uses JP-8.

Figure L-3. Laughlin J85 Fuel Spray Nozzle After 1,350 FH

Figure L-4. Comparison Unit J85 Fuel Spray Nozzle After 200 FH

In addition to the engine removal data, pictures were taken of the J85 fuel spray nozzles at both Units. **Figure L-4** shows typical coking on the face of a J85 fuel spray nozzle after using JP-8 for approximately 200 FH since replacement. Note the accelerated build-up of carbon on the nozzle face, particularly around the spray tip in the center where fuel is atomized and then compare the carbon build-up on the fuel spray nozzle from Laughlin shown in **Figure L-3** that had used JP-8+100 for approximately 1,350 FH. The accelerated build-up of hard coke greatly increases the chances for "fuel streaking" in the spray cone and distortion of the temperature profile entering the turbine vanes that could cause localized hot section distress. It is noteworthy that after approximately 1,350 FH of using JP-8+100 at Laughlin, coking is absent around the spray tip on the J85 fuel spray nozzle compared to significant coke buildup around the spray tip at the other Unit after using JP-8 approximately 200 FH.

There are three notable differences in the carbon deposits on the face of J85 fuel spray nozzles using JP-8+100 compared to JP-8 that deserves explanation:

- JP-8+100 use does not eliminate carbon but hard coke deposits are minimized
- The area surrounding the fuel nozzle tip remained free of carbon while using JP-8+100
- Carbon deposits from using JP-8+100 are easier to remove due to different morphology

Close examination of the J85 fuel spray nozzles that used JP-8+100 or JP-8 reveals subtle differences in the amount and physical appearance of the carbon deposits on the nozzle face.

JP-8 use creates a very hard and tenacious layer of carbon deposits on the face of the J85 fuel spray nozzles as shown in **Figure L-4** that are difficult to remove. Similar coke deposits accumulate on the face of T56 fuel spray nozzles using JP-8 that are sometimes difficult to remove with a nylon brush during the yearly isochronal inspection of the C-130H aircraft that occurs at approximately 400 FH . In contrast, the carbon deposits on the J85 fuel spray nozzles that use JP-8+100 were much softer, powdery and very easy to remove. **Figures L-5** and **L-6** show magnified images to highlight these differences. Note in **Figure L-5** that some of the carbon has already flaked off during handling of the nozzle. The difference in carbon deposits not only impacts ongoing base level maintenance workload but also refurbishment processes managed by the Depot and the procurement of spare parts. The fuel spray nozzles are cleaned and flow checked organically at the ERRC or by qualified subcontractors to determine if the part can Return To Service (RTS) or must be replaced with a new or refurbished fuel spray nozzle. Details of the impact on RTS and Not Reparable This Station (NRTS) rates for the various J-85 parts will be discussed later in this Appendix.

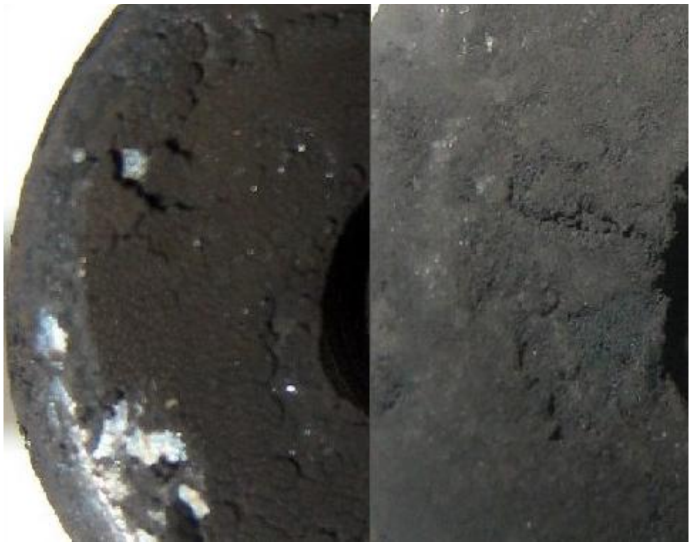


Figure L-5. Magnified Carbon Deposits From JP-8+100 Use

Figure L-6. Magnified Carbon Deposits From JP-8 Use

2.1 Air and Ground Abort Engine Removals

Troubleshooting trees in Tech Data are used to guide flight line and engine shop mechanics in making responsible maintenance decisions based on input from pilot squawks, symptoms observed through inspections or an installed or ground test run of an engine. Based on the maintenance concept for the engine and the tasks that can be performed on station by the assigned military or contracted maintenance personnel, the engine may be removed and fixed locally or forwarded to an Engine Regional Repair Center (ERRC) for further investigation and needed refurbishment to fix the problem. Several reasons can be selected to document an unscheduled engine removal to include something broke, gas path deterioration, a component did not function properly (a malfunction), the engine would not start, or an augmentor no light or blowout occurred in flight. These type events and others that force an engine or component removal are tracked by entering the appropriate malfunction codes in the CEMS database for that serialized engine name plate.

Unlike the training wing at Laughlin AFB where removal events were documented and root causes determined, the maintenance approach of the training wing at Sheppard AFB only permitted the events that were part of the retained tasks to be documented. Although two-level maintenance is performed at Sheppard, any maintenance tasks beyond the established retained tasks are performed by the ERRC at Laughlin AFB, TX. Sheppard operates the T-37 and T-38 aircraft to train pilots for fighter aircraft in the USAF and NATO countries and also conducts the Introductory Fighter Fundamentals Program.

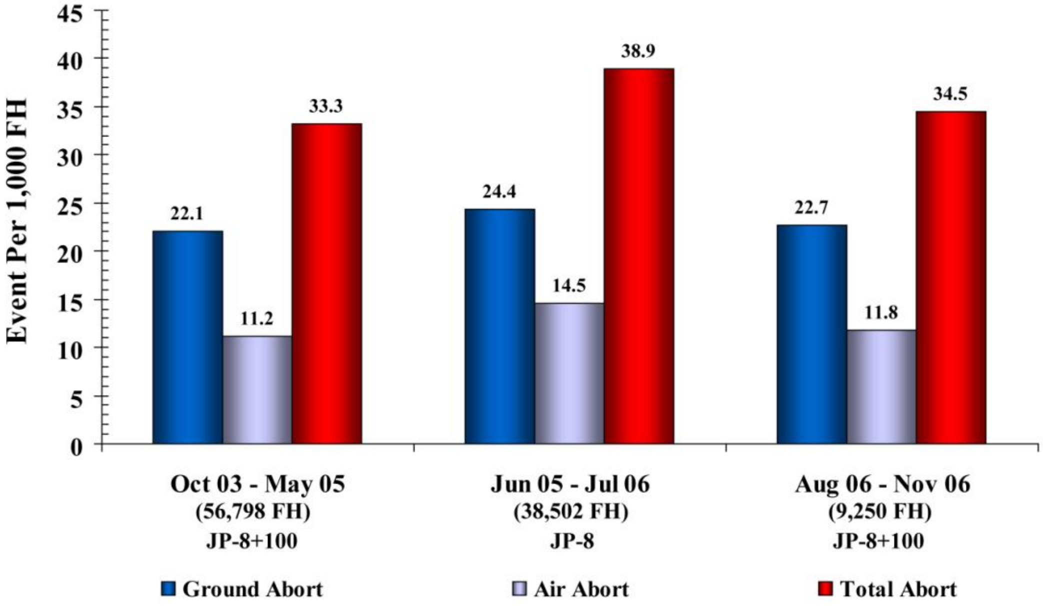


Figure L-7. T-38 Ground and Air Abort Rates at Sheppard

Since replacing the main fuel nozzles, afterburner spray bars or pilot spray bars were not retained tasks at Sheppard, these removal events were not recorded in any engine shop records which eliminated any chance for establishing the number of carbon-related engine removal events at Sheppard. As a result, an alternate approach was selected that analyzed the ground and air abort rates for the T-38 fleet to determine any impact from using JP-8+100 or JP-8. The time period of available data covers from October 2003 through November 2006. Sheppard has consistently used JP-8+100 with exception to a 13 month time period starting in June 2005 when the +100 additive was turned off to resolve media migration and filter coalescer issues in the filtration system of the R-11 refuelers. Once the issues were resolved, JP-8+100 use began again in August 2006. The Ground and Air Abort data are shown in **Figure L-7** where the Ground Abort Rate is shown in blue, the Air Abort Rate in gray and the Total Abort rate in red. While the +100 additive was turned off for 13 months, the Ground Abort Rate increased by 10% and the Air Abort Rate increased by 29% with the Total Abort Rate increasing around 17%. During the brief 4 month period after the +100 additive was turned on again in August 2006, the Ground Abort Rate decreased by 7%, the Air Abort Rate decreased by 19% and the Total Abort Rate by 11%. It is noteworthy that the Air Abort Rate experienced larger increases and decreases that the Ground Abort Rate indicating greater sensitivity of the augmentor to coking. Since the only variable that changed during the time period analyzed was the return to using JP-8 and then back to JP-8+100, it can be concluded that turning off the +100 additive was the root cause for the increase in Air and Ground Aborts. Conversely, use of the +100 additive reduces carbon build up in the fuel spray nozzles and afterburner fuel system that causes engine and augmentor anomalies.

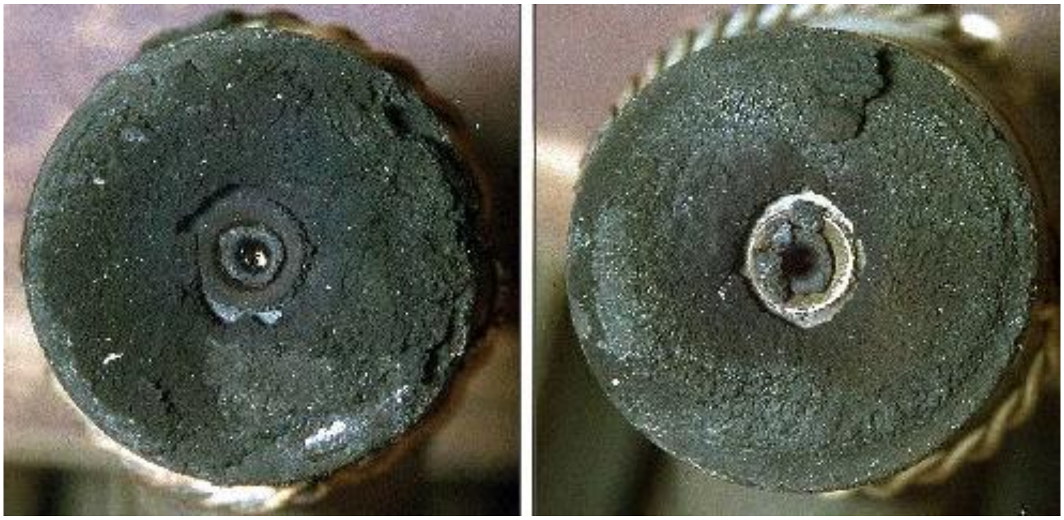


Figure L-8. J85 Main Fuel Nozzles Post Conversion to JP-8 Fuel Circa 1996

Figure L-8 shows the coking on the face of J85 fuel spray nozzles from using JP-8 fuel prior to the conversion to JP-8+100 in 1997. Maintenance personnel at Sheppard confirmed that the coking deposits on these fuel spray nozzles, taken prior to 1997, were typical of coking conditions observed in 2006 after returning to using JP-8 again and were comparable to photos of J85 fuel nozzles at other training unit using JP-8 fuel.

Table L-1. Statistical Analysis of T-38 Fleet

Fuel Type ->>	JP-8+100	JP-8
Ground Abort Rates		
Mean Value	22.578	24.835
Median Value	22.025	23.475
Count	25	13
Confidence Limit	1.851	1.608
Range - High	24.43	26.443
Range - Low	20.727	23.227
Air Abort Rates		
Mean Value	11.269	14.822
Median Value	11.546	14.16
Count	25	13
Confidence Limit	0.961	1.405
Range - High	12.23	16.227
Range - Low	10.307	13.416

Table L-1 summarizes the statistical analyses performed on the data to validate the above observations. A 90% Confidence Limit (CL) was used for both the air and ground abort rates for each fuel type. The mean value for ground abort rates during the JP-8+100 use period was 22.578 and for the JP-8 period of use was 24.835. The test to determine if these values are truly different is whether or not the mean value falls within the respective population ranges based on a 90% CL. Since the mean value for JP-8 (24.835) is outside the confidence interval for JP-8+100 and the mean value for JP-8+100 (22.578) is outside the JP-8 confidence interval, it can be concluded that these two populations are statistically different.

2.2 ERRC Parts Demand Assessment

The Training Command utilizes an ERRC to perform the Hourly Post Operation Inspection (HPO) and the Periodic Inspection (PE) for the J85 and J69 engines. The ERRC also perform engine maintenance for approximately 75% of the J85 and J69 engine fleet. Removal of the engine fuel spray nozzles, afterburner main spray bars and pilot spray bars are tasks performed only at the ERRC where they are cleaned and tested on a flow bench to determine whether the parts can be returned to service or require refurbishment at the Depot or a 3rd party repair facility. **Figure L-9** shows a comparison of parts consumption for the period when JP-8+100 was the primary fuel used at the pilot training Units versus the period when neat JP-8 fuel was used. It is important to note that the parts consumption data for the JP-8 period covers 7 months whereas the parts consumption data while using JP-8+100 cover 15 months. At first glance, total parts consumption appears to be similar during use of JP-8 or JP-8+100, but on a monthly rate basis, the magnitude of parts consumption was nearly 2X (857 vs. 432) when JP-8 was used.

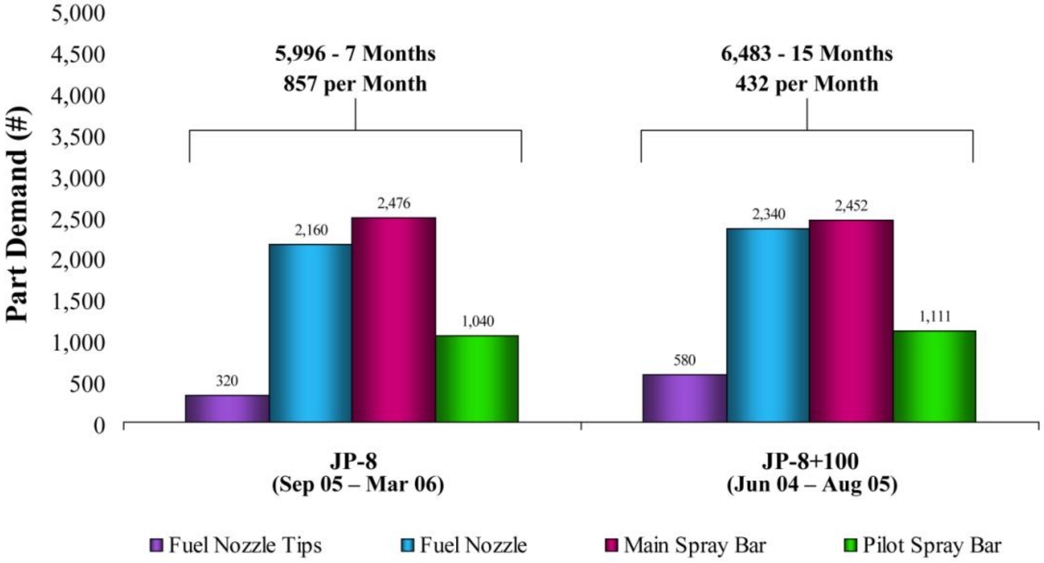


Figure L-9. J85 Parts Demand at the ERRC

Another approach suggested by management at the ERRC in order to provide a more accurate analysis was to trend the number of engines being worked each month and the reasons they were shipped to the ERRC. If for example there were more scheduled engines entering the ERRC for HPO & PE, then that would explain some of the differences noted in the raw data.

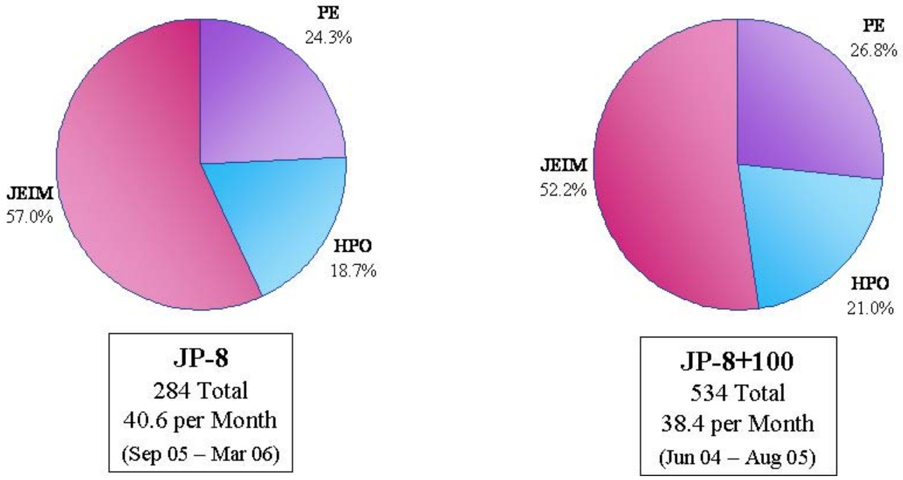


Figure L-10. J85 Engine Input to the ERRC

Figure L-10 shows the percentage of engines input to the ERRC in three categories: JEIM, PE and HPO during the same time periods shown in **Figure L-9**. JEIM is Jet Engine Intermediate Maintenance. The pie charts in **Figure L-10** show that 5.7% more engines were shipped to the JEIM for unscheduled maintenance per month while using JP-8 compared to JP-8+100.

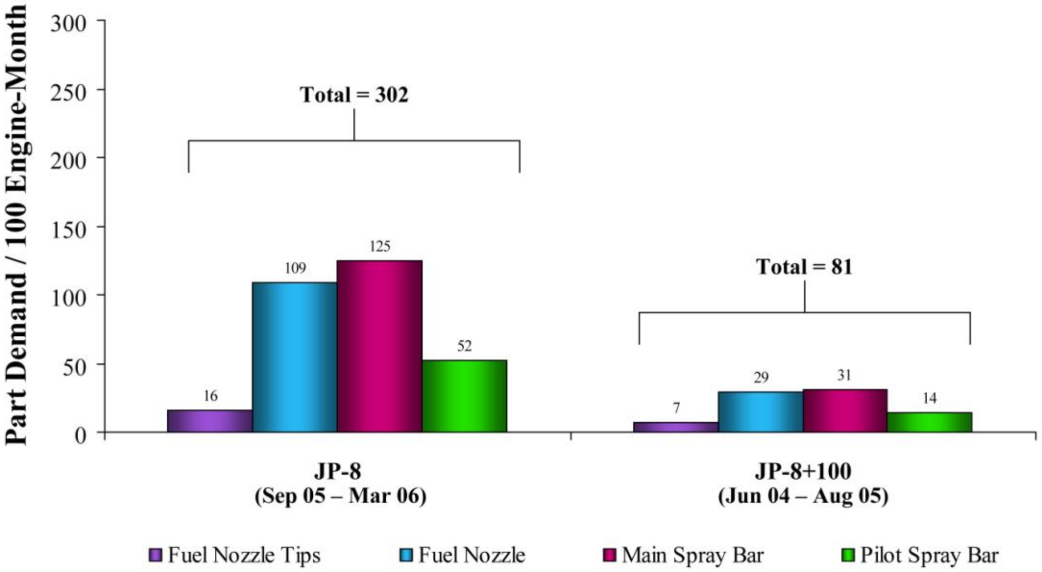


Figure L-11. J85 Parts Demand Comparison

During the 7-month period when JP-8 was used (September 2005 – March 2006), 57% of the engines shipped to the ERRC were for unscheduled maintenance compared to 52.2% during the 14-month period when using JP-8+100 (June 2004 – August 2005). When parts demand data was normalized on the basis of 100 engines per month a shown in **Figure L-11,** a more vivid comparison of the parts demand rates can be shown when JP-8 and JP-8+100 fuel was used. While the raw data shows nearly a 2X difference when JP-8 was used, the normalized data shows almost a 4X difference. This data also supports two comments made by Auxiliary Shop personnel at the ERRC after returning to JP-8 use:

- The maintenance workload increased to meet the fuel spray nozzle RTS demand rate which was also reflected in the number of fuel nozzle tips installed to obtain an acceptable spray pattern during flow bench testing.
- 100% of the pilot spray bars failed the flow bench test after using JP-8 compared to 50 to 60% of the spray bars passing the flow check when JP-8+100 was used.

Use of JP-8+100 in J85 engines at Laughlin provided a 55.3% reduction in Main Fuel Nozzle Tip replacements for the engines that entered the JEIM and from 73 to 75% reduction in the replacement of the Fuel Spray Nozzles, the Afterburner Main Spray Bars and Pilot Spray Bars for engines that entered the JEIM. The maintenance data indicates that the later three parts are replaced when an engine enters the JEIM which is intended to improve the service interval of the installed engines.

Any reduction in unscheduled removal events will help reduce the number of engines returned to the ERRC where the refurbishment tasks are performed. When an engine flange is unbolted, more parts are exposed that may exceed inspection limits defined in Tech Data and need to be replaced. Although Unscheduled Engine Maintenance is a line item in the overall engine maintenance budget, any reduction in unscheduled engine removals will allow more of the already stressed maintenance budgets to be used in the Scheduled Maintenance Program to help improve engine reliability and the average time on wing. Therefore, it is important that new engine parts be available along with improved maintenance procedures in conjunction with using JP-8+100 to reduce the impact of coking in order to increase engine MTBR.

2.3 J85 Unscheduled Removals Reported in CEMS

The third approach to evaluate the benefits of using the +100 additive uses removal data entered in the CEMS database from 1997 through September 2006 to show unscheduled removal trends for J85 engines, the main fuel control and augmentor fuel controls for the USAF fleet of J85 engines. The CEMS database receives input data from engine analysts at each operating Unit to document the maintenance performed on serialized engine components. How Malfunction Codes (HMC) are used to report the reason for a maintenance action involving removals performed under the Unscheduled and Scheduled Maintenance Program.

Figure L-12 shows the unscheduled engine removals for 57 HMCs. A total of 15,012 engine removals were reported to the CEMS database during the Jan 97 – Sep 06 time period with the Top 10 events accounting for 60% of the total. Inability To Start (Ground or Air), Augmentor No-Light and Failed to Operate - Specific Reason Unknown were the top three causes for engine removals. The colored bars represent the total engine removals for all HMCs entered in the CEMS database although only 27 HMCs are listed on the Figure. The Top Ten Events are listed in descending order and correspond to the HMCs on the right of the Figure.

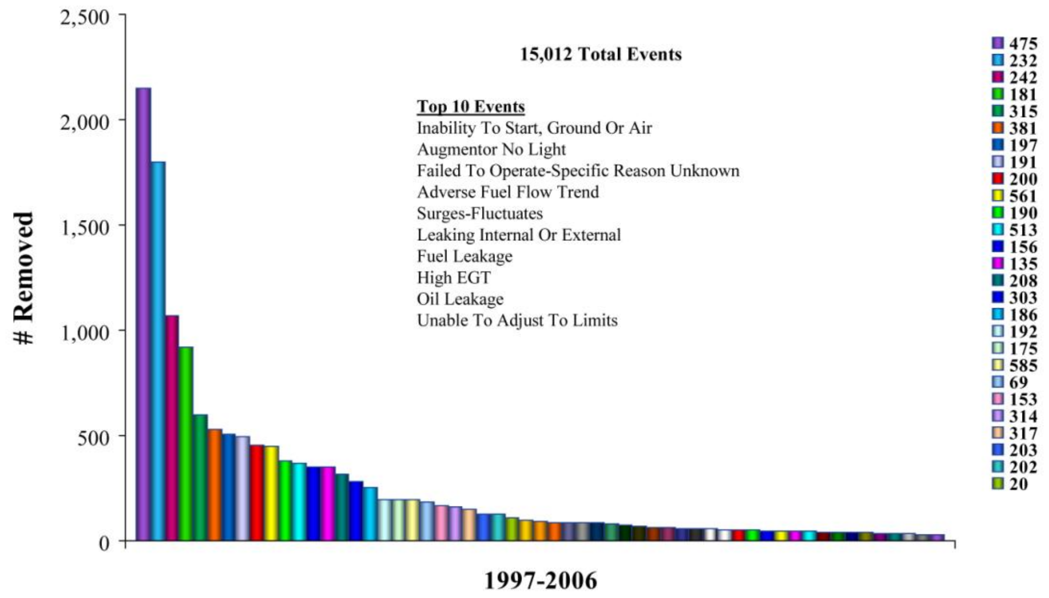


Figure L-12. J85 Unscheduled Engine Removals for all HMCs

Figure L-13 shows the yearly UER Rate for the Top 10 causes for engine removals from 1997 through 2004. Note that the UER Rate for the J85 fleet increased abruptly by 110% in 2005 when the +100 additive was turned off in June 2005 and decreased by 12% after the +100 additive was turned on in July 2006. The per cent (%) utilization of JP-8+100 (NATO F-37) is shown for each year. After conversion to the +100 additive in 1997, utilization averaged above 94%.

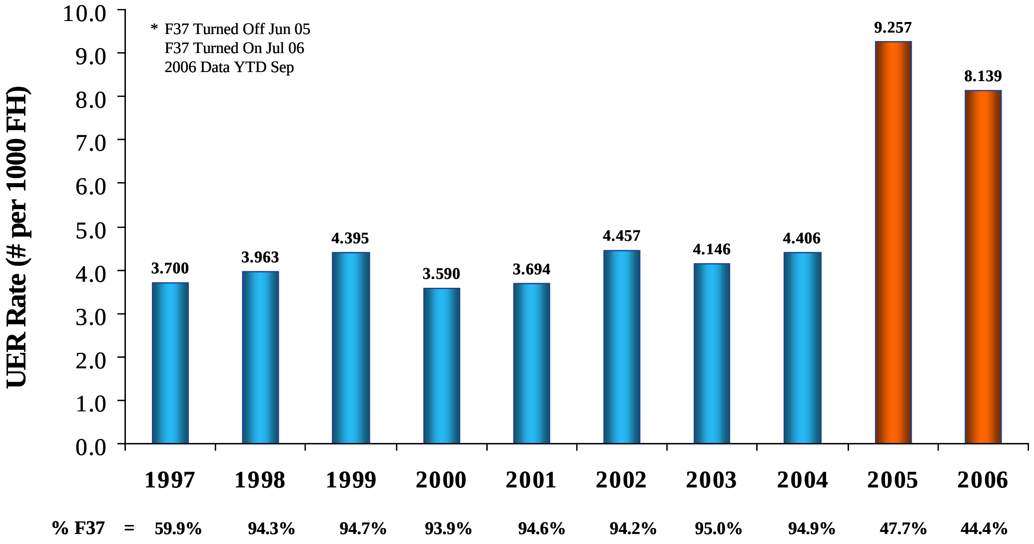


Figure L-13. J85 UER Rate for Top 10 Causes

A smaller subset of HMCs was utilized to determine J85 engine removals due to afterburner coded malfunctions. Although HMCs 69, 156, 207, 223, 231, 232, 233 and 513 are included in the Top 10 codes for afterburner related engine removals, HMC 242, "Failed to Operate - Specific Reason Unknown", was added to the group to include events that could not be diagnosed but needed a fault code. **Table L-2** lists the HMC Subset for analysis of Afterburner Anomalies.

Table L-2. Traditional HMC Subset for Afterburner Anomalies

Description	**HMC**
Flameout	69
Afterburner or Augmentor Problem Repair	156
Augmentor Induced Stagnation	207
Control System Component Malfunction	223
Augmentor Blowout	231
Augmentor No Light	232
Augmentor Rumble	233
Failed To Operate-Specific Reason Unknown	242
Compressor Stalls (Afterburner)	513

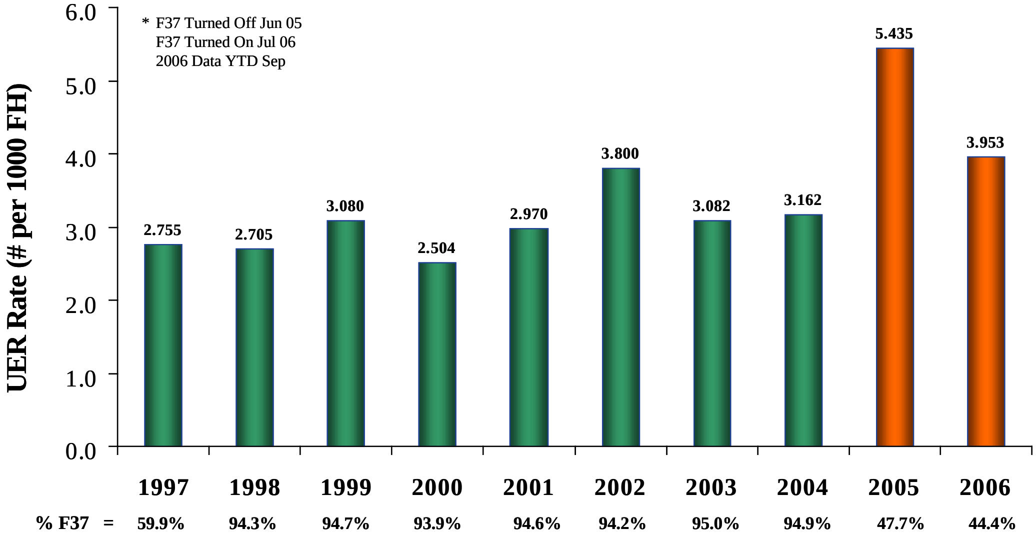


Figure L-14. J85 Afterburner Related Removal Rate Using HMC Subset

Figure L-14 shows the yearly J85 Afterburner Related Removal Rate using the HMC Subset shown in **Table L-2**. The fleet average UER Rate for afterburner removals increased by 72% in 2005 when the +100 additive was turned off compared to 99.7 % increase in UER Rate for the

J85 engine fleet using the same subset. The difference of 27.7% can be attributed to coking issues with the fuel spray nozzles and control components.

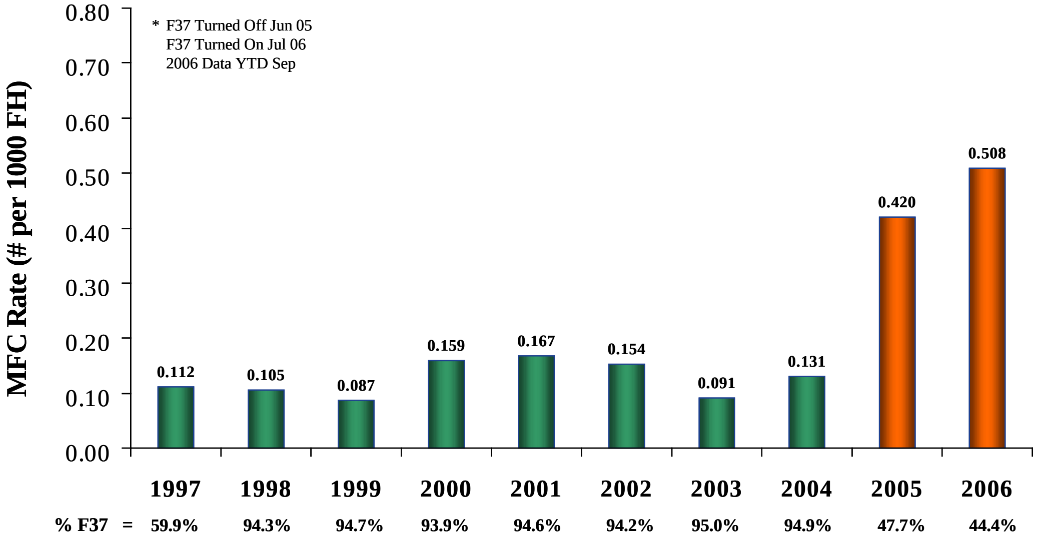


Figure L-15. J85 Afterburner Related MFC Removal Rate Using HMC Subset

Figure L-15 shows the yearly Afterburner Related MFC Removal Rate using the HMC Subset. The fleet average MFC Removal Rate related to afterburner events increased by 221% in 2005 after the +100 additive was turned off in June 2005 and then increased by 21% in 2006 even though the +100 additive was turned on in July 2006. This indicates the extent of maintenance that is performed to fix coking problems and clear engines for service. It is noteworthy that the MFC Removal Rate increased by 44% in 2005 for afterburner coded faults while the MFC Removal Rate increased by 84% for overall engine anomalies.

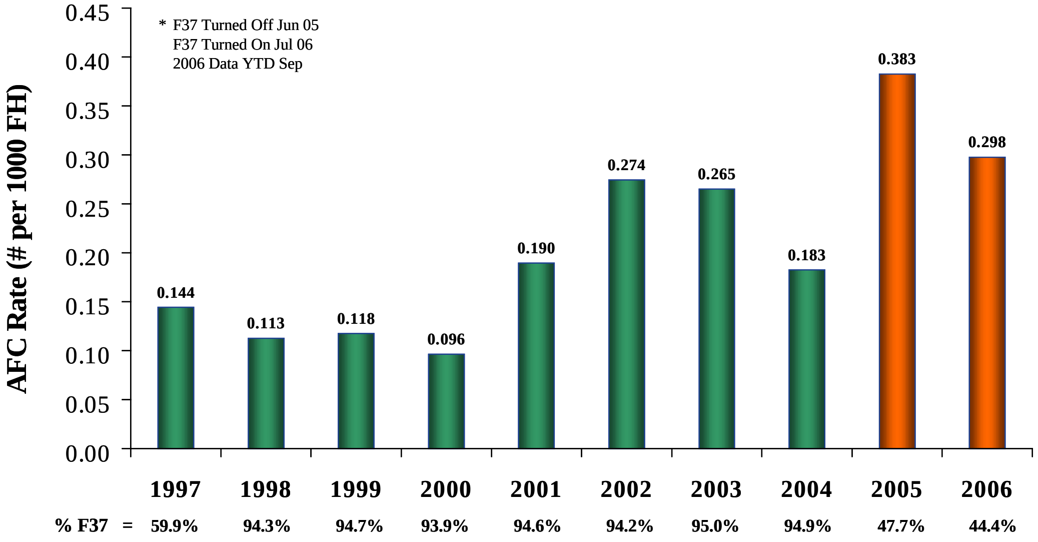


Figure L-16. J85 Afterburner Related AFC Removal Rate Using HMC Subset

Figure L-16 shows the yearly Afterburner Related AFC Removal Rate using the HMC Subset. The fleet average AFC Removal Rate related afterburner malfunction events increased by 109% in 2005 as a direct result of turning off the +100 additive. The 31% reduction in AFC removal rate in 2004 may be the result of replacing fouled or marginal AFCs during 2001 through 2003 that had caused afterburner anomalies. The 109% increase in AFC removal rate in 2005 may have contributed to the 33% decrease in the AFC removal rate in 2006 even though the additive was not turned on until July 2006.

3.0 J69 Carbon Related Removals

Like J85 engines, the J69 engines that power the T-37 are very sensitive to coking and experienced marked increases in engine anomalies after return to JP-8 use. Before direction was received to shut the +100 additive off in May 2005, Sheppard had been using JP-8+100 for over 10 years and had benefited from reductions in engine removals due to coking. Most notable was a 3.9X increase in the engine Flameout Rate after use of JP-8 resumed as shown in **Figure L-17**. However, problems in two other engine fault categories were indicated to include Fire Light and Overheat. During the 3½ years prior to May 2005, this training Unit had experienced a total of 37 coke related events but none related to fire light or overheat light indications. During the 3 months after the +100 additive was turned off in May 2005, the pilots reported 8 coking related events, four of which had not been experience since the mid to late 1990's.

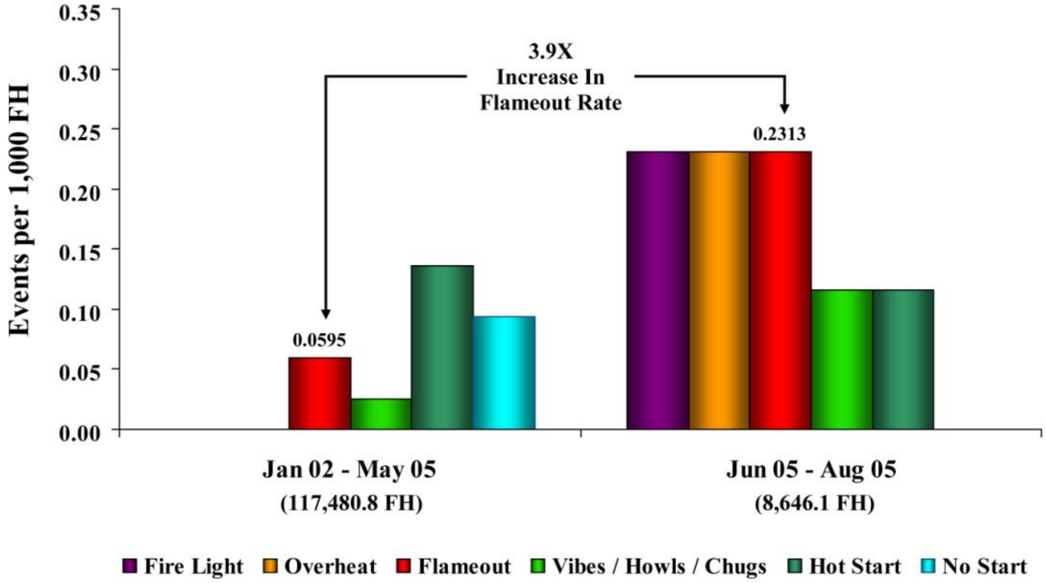


Figure L-17. Incident Rate of Potential Carbon-related Events Impacting J69

Sheppard was the first Unit to report an increase in engine fuel control removals after returning to neat JP-8. Seasoned instructor pilots began reporting operational anomalies that resulted in fuel control removals to fix engine problems. In addition, fuel control valve "sticking" problems were being reported more frequently. The engine mechanics also reported that the J69 fuel filters shown in **Figure L-18** darkened quickly after returning to JP-8. The exposure of JP-8 fuel to hot metal surfaces in the J69 engine during normal recirculation had exceeded the thermal stability of JP-8 fuel since varnishes and carbon deposits begin to form between 200 - 250 °F. The varnishes and coke particles in the fuel would then collect on the fuel filter element that had to be changed more frequently.

Figure L-18. J69 Fuel Control Filter Condition after Using JP-8

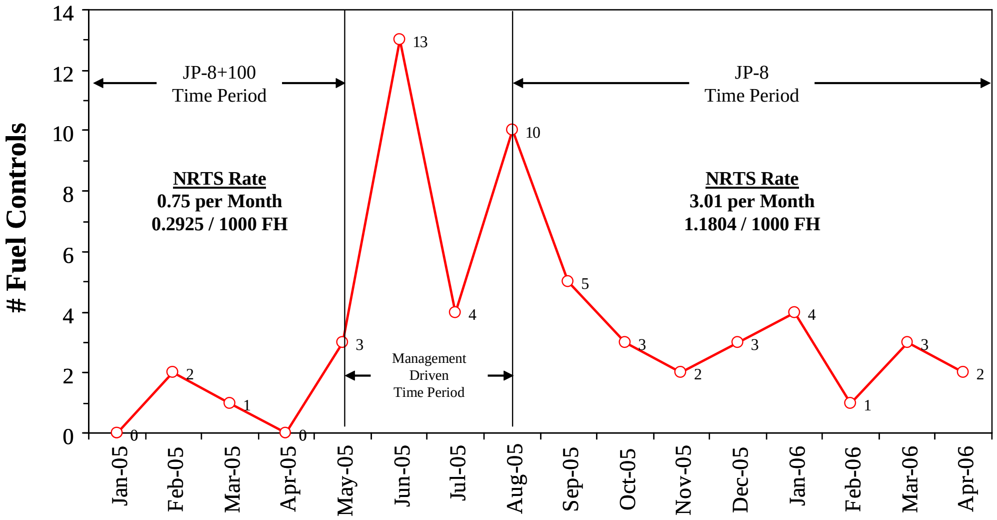


Figure L-19. J69 Main Fuel Control Removals

Figure L-19 shows the fuel control removals covering a 15 month period from January 2005 through March 2006. After the +100 additive was turned off in May 2005, 27 fuel controls were removed by management decision (Scheduled Maintenance) during a 3 month period. Unfortunately, the reasons for the removals were not determined during the site visit but at that time media filters had been removed from the fuel trucks since media had been migrating into the aircraft and engine filters causing sticky valves in several fuel controls. Thus selected controls may have been removed as a precaution but could not be confirmed. Therefore, control removals have been divided into three time periods with appropriate observations noted. During steady state conditions from January 2005 through May 2005 while using JP-8+100, the average J69 MFC removals for the assigned aircraft were 0.75/month or 0.2925/1000 FH. During the transition period from mid May 2005 through mid August 2005 that included the conversion to JP-8 starting in May 2005, 27 MFC were removed during a 3 month period by management decision. During the following 8 month period from August 2005 through March 2006, the average MFC removals were 3.01/month or 1.18/1000 FH to fix engine anomalies caused by coking which is a 4X increase compared to the time period when JP-8+100 was used.

The above example clearly shows the benefits of using JP-8+100 in reducing maintenance workload on the flight line and in the engine shop.

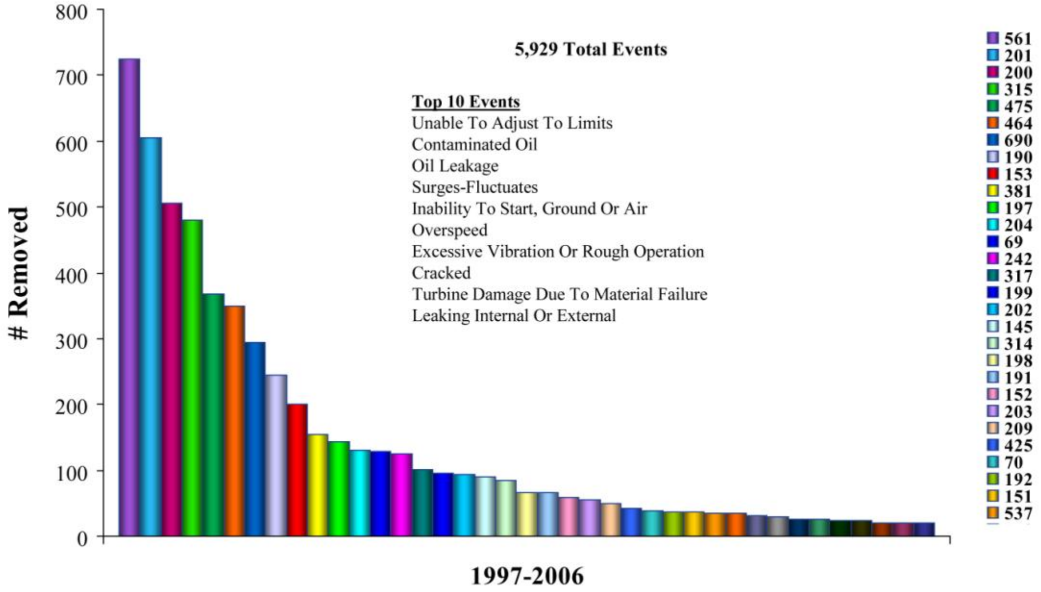


Figure L-20. J69 Unscheduled Engine Removals for All HMC

3.1 J69 Unscheduled Removals Reported in CEMS

The unscheduled and management decision removal of engines and main fuel controls were analyzed for the majority of the J69 fleet from 1997 through September 2006. **Figure L-20** shows the number of the unscheduled engine removals that were documented in the CEMS database for all malfunctions. A total of 5,929 engine removal events were reported during the study period with the Top 10 events comprising 66% of the total. Using the HMC subset to determine potential fuel related removal events, **Figure L-21** shows 2,278 engine removals or 38% of all faults. The Top 10 events within the subset totaled 2,090 events or 92% of the total. The unscheduled engine removals using HMC 561 (Unable to Adjust to Limits) accounts for approximately 35% of the total while HMC 242 (Failed to Operate - Specific Reason Unknown) accounts for only 6%. After the +100 additive was turned off in May 2005 for 13 ½ months, the fleet average UER Rate abruptly increased by 112% in 2005 as shown in **Figure L-22**. The UER Rate had been declining starting in 2000, reached a new low in 2002 and then started a steady increase. Collective maintenance performed during 2005 reduced the UER Rate in 2006 by 38%.

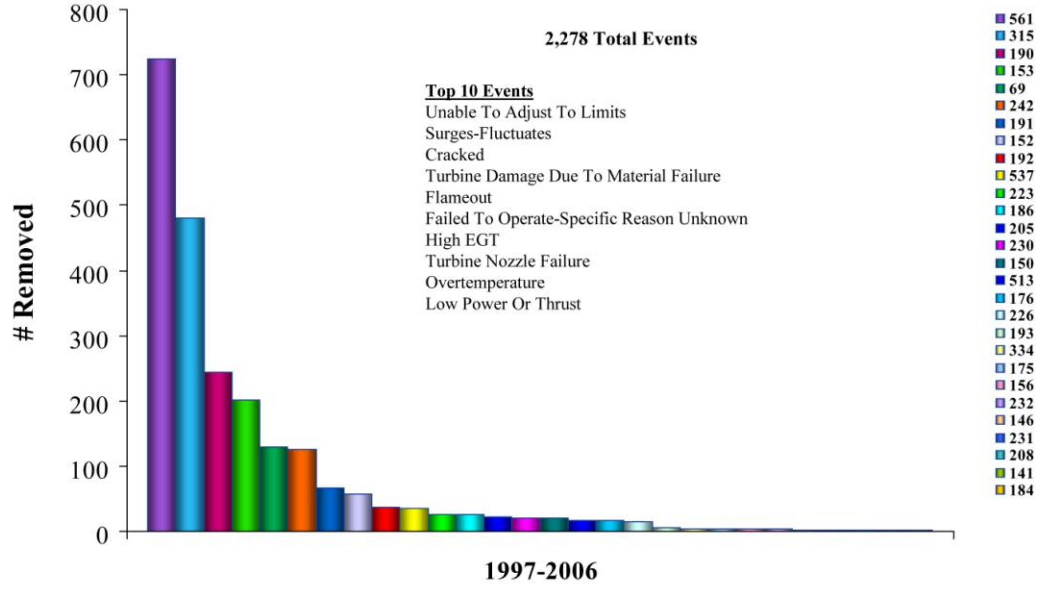


Figure L-21. J69 Unscheduled Engine Removals for Top 10 Removal Events

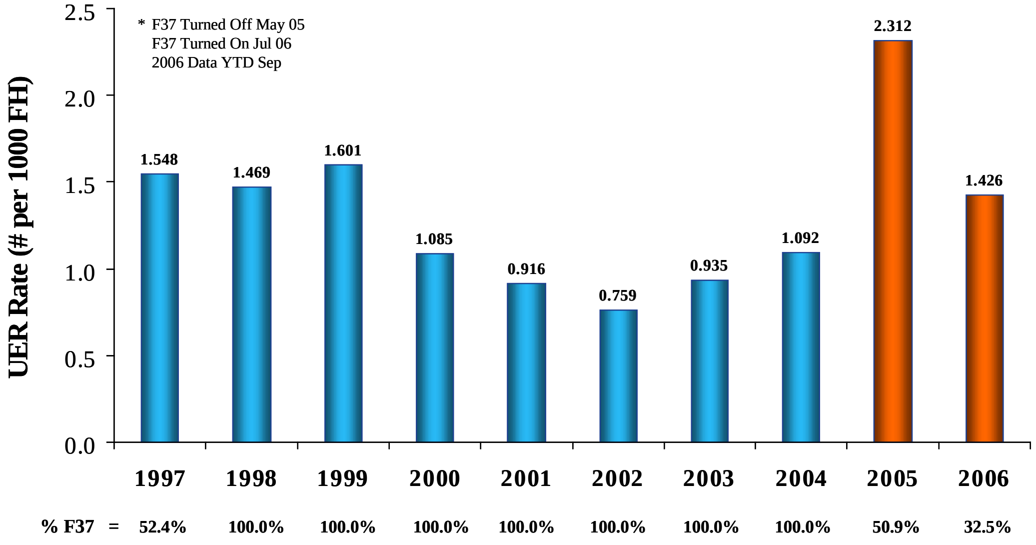


Figure L-22. J69 UER Rate for Top 10 Engine Removal Events

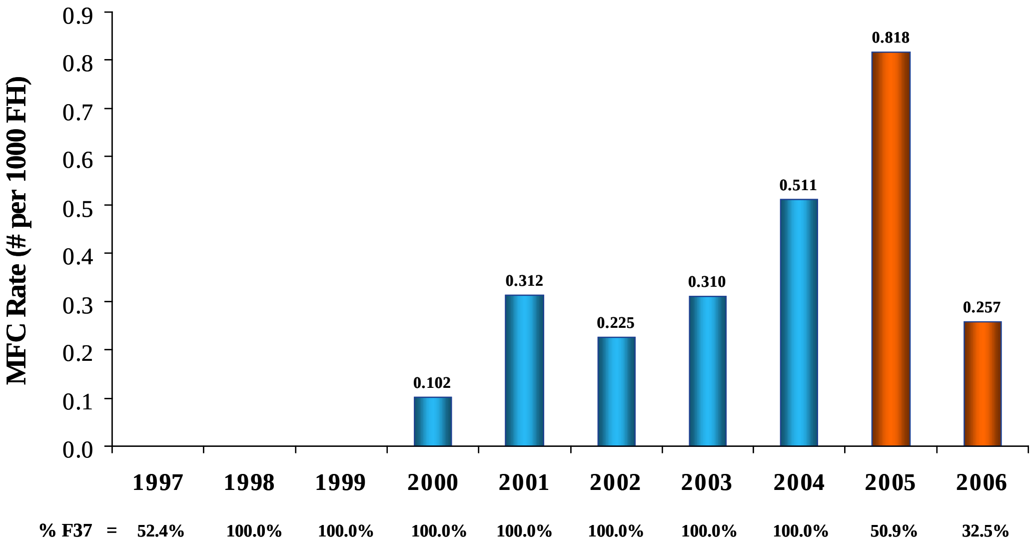


Figure L-23. J69 Unscheduled MFC Removal Rate for Top 10 HMCs

Figure L-23 shows the unscheduled MFC removal rate that increased by 60% in 2005 after the +100 additive was turned off in May 2005. The steady increase in the MFC removal rate starting in 2002 may be related to media migration from water-absorbing filters that caused sticking of valves in the MFC resulting in 38% increase during 2003 and a 65% increase in 2004. The 69% reduction in 2006 may be due to the increased number of MFC that were changed during 2004 and 2005 to deal with valve sticking problems and a partial year when the +100 additive was turned on in July 2006. The management driven MFC removals during the May to August 2005 time period helped purge some MFC with sticking valve problems plus the water-absorbing filter monitors were removed from refueling trucks and replaced with filter coalescers.

4.0 J85/J69 Summary

Soon after conversion to JP-8 in May 2005 after using JP-8+100 for 10 years, the training Units in AETC noted a marked increase in carbon related engine anomalies plus the engine hot section parts were more difficult to clean that increase shop visits and parts demand to fix the problems. In addition, the hot metal surfaces in the J69 engine heated the fuel beyond its thermal stability limit and discolored the fuel filters, which had to be changed more frequently. After the conversion to JP-8+100, AETC found that the impact of coking in the J69 and augmented J85 engines was more manageable but not free from coking problems. Another issue developed when water-absorbing filters replaced the filter coalescer elements that were thought to be defeated by the surfactants in JP-8+100 but later that assumption was proved false based on filtration testing at SwRI® in San Antonio TX. After using water-absorbing filters in the refueler trucks for several years, it was found that the filter media was migrating to the aircraft and engine filters causing fuel starvation and several flameouts.

It is worth mentioning that the analysis of CEMS removal data for the J69 engines showed increases in MFC removals 3 to 4 years prior to identifying the media migration problems. At that time, it was thought the sticking fuel control valve problems was an isolated MFC problem rather than related to the media in the water-absorbing filters.

Using JP-8+100 in the J69 and J85 engines has provided consistent benefits but unfortunately, the benefits are best shown when the +100 additive was turned-off for 13 ½ months starting in May 2005. During this time, the engine flameout rate increased 3.9X after the +100 additive was turned off, the engine NRTS increased from 0.75/mo to 3.01/mo, a 4X increase and the MFC Removal Rate increased by 60%. Prior to 2005, the Removal Rate for MFC increased by 42% in 2003 and 22% during 2004 from sticking valve problems. For J85 engines, the parts demand rate for Fuel Nozzle Tips decreased by 55.3% after conversion to JP-8+100 and a reduction of 73 to 75% were noted for Fuel Nozzles and the Main and Pilot Spraybars in the afterburner. When the +100 additive was turned off, the engine UER Rate increased by 110%, the MFC Removal Rate increased by 152%, the AFC Removal Rate increased by 57% and Augmentor related unscheduled removals increased by 72%.

Without a doubt, use of the +100 additive has shown the avoidance of maintenance workload, reduction in parts demand and helped to increase the reliability and time on wing of J69-T-25 and J85-GE-5 engines.

APPENDIX M

F100-PW-100, -220/E and -229 Maintenance Trends

F100-PW-100, -220/E and -129 Maintenance Trends

1.0 Background

The Pratt &Whitney F100 engine powers several models of the F-15 and F-16 aircraft. **Table M-1** shows the various engine models and associated Model Design Series (MDS) aircraft. The -100 engine was selected to power the twin engine F-15 superiority fighter and later the -200 was developed to power the single engine F-16. The -229 engine has increased performance and thrust for use in the F-15E fighter for longer range. Although -200 engines benefited from use of JP-8+100, data are not included in this section since these engines were retired from AF service circa 1999. Some of the -200 engines were converted to the -220E engine model and used in F-16A/B and C/D fighters, where -220E refers to an Equivalent -220 engine.

Table M-1. Pratt & Whitney Engine Models and MDS Airframes

Engine Model	MDS
F100-100	F-15A/B
F100-200	F-16A/B
F100-220/E	F-16C/D, F-15C/D
F100-229	F-16C/D, F-15E

There are subtle differences in the design of the augmentor fuel system for the -229 engine compared to the legacy -100, -200 and -220 engines that has reduced the impact of coking. Although reference is made to the F100 engine family, the -229 engine in many aspects is a new engine design compared to the -100, -200 and the -220 engines and will be analyzed separately as an engine in the F100 family of engines.

The designers of the -229 engine anticipated the use of JP-8 as the primary fuel and incorporated spray bars and fuel drain features that help to reduce fuel coking issues in the augmentor. However, the legacy F100 engines were designed to use JP-4, a naphtha-based fuel that is highly volatile and evaporates quickly at high temperature whereas JP-8, a kerosene-based fuel, boils off slowly at high temperatures because of its low volatility and forms coke residues starting around 200 to 250 °F. The augmentor design in the legacy -100 and -200 engines and the later release -220 engines use five spray ring zones that were not designed for continuous use of JP-8 fuel, a low volatility fuel that needs to be drained quickly after augmentor shut down to minimize coking. After conversion to JP-8 and then the return to using JP-8 by some Units, coking issues developed that required more frequent baking and thorough cleaning of the spray rings to improve the average time on wing before the augmentor would experience another anomaly due to fuel coking. However, design modifications have been developed and fielded for the Seg II and Seg IV spray rings circa 2004 that have helped purge the fuel upon augmentor shut down but manufacturing release for the Seg III spray ring scheduled for FY07 has been delayed due to funding issues.

With the advances in digital electronic technology, the F100-220/-229 engines were fielded with full authority engine control systems. The control algorithms in the Digital Electronic Engine Control (DEEC) also provide engine self trim and an engine monitoring system that is connected to an engine diagnostic unit. The control algorithms and self trimming capabilities developed for the -220/E and -229 engines helped reduce engine and augmentor anomalies compared to the scheduling control system for the -100 and -200 engines that required more frequent engine trims to stay on top of gas path deterioration and seasonal changes in temperature.

It is important to note that in early 1997, the Air Force initiated the Reliability Centered Maintenance (RCM) Program to achieve the inherent reliability of F100 engines. New spare parts were provided to improve the engine build standards, enhance hot section life and implement procedures for realignment of the life limited components and modules during scheduled and unscheduled maintenance events to improve the average time on wing. The synergies of the RCM Program, the spray ring baking and engine shop cleaning procedures to better managed component coking problems plus the use of JP-8+100 has helped provide a steady decline in the unscheduled engine removals. The steady decline of the UER Rate can be noted on the trend charts for the various F100 engine models in the following sections, however, the UER Rate increased significantly when the +100 additive was turned off for 12-13 months starting in June 2005.

The brief discussions for each Figure attempts to explain the impact of JP-8 and JP-8+100 use based on the HMCs that were reported in the CEMS data base for all maintenance performed on the -100, -220/E and -229 engines.

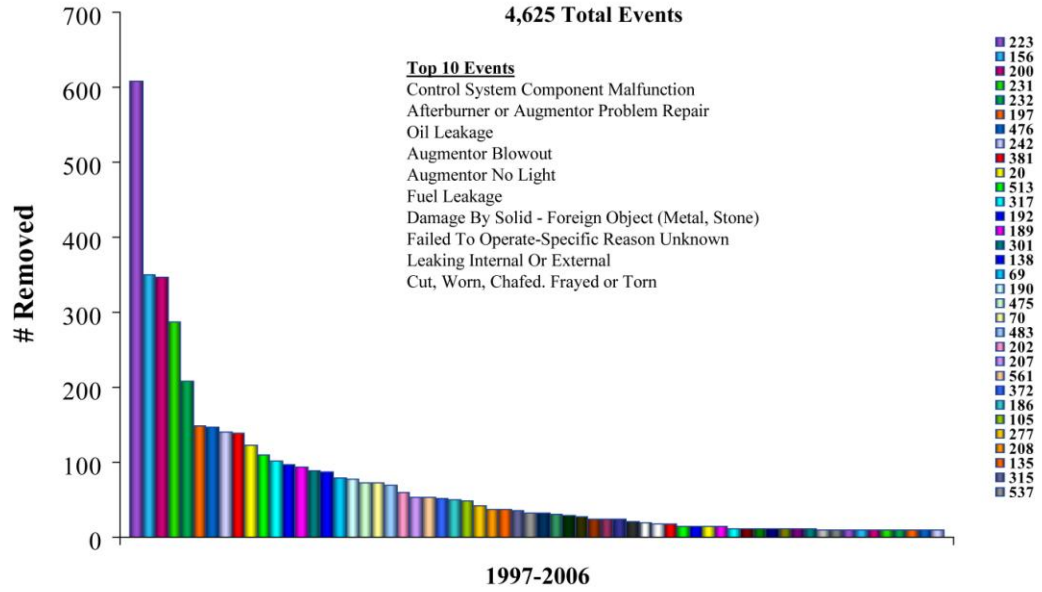


Figure M-1. F100-100 Unscheduled Engine Removals – All HMC

2.0 F100-PW-100 Engines

The unscheduled removal of -100 engines and the Unified Fuel Control (UFC) were obtained from the CEMS data base for the time period from CY97 through September 2006. **Figure M-1** shows the distribution of -100 unscheduled engine removals for all malfunctions. A total of 4,625 removals were recorded during this time period with the Top 10 events comprising 54% of the total. Note that Control System Component Malfunctions, Augmentor Blowout and No-Lights are in the top five most frequent causes for removals with Failed to Operate-Specific Reason Unknown ranked eighth. The synergies of the RCM program initiated in 1997, the baking and cleaning program, evolving engine shop procedures and use of JP-8+100 provided fairly stable conditions to minimize year to year changes in the UER Rate shown in **Figure M-2**. While the number of events declined in 2005, the fleet average UER Rate increased by 15% after the +100 additive was turned off in June 2005 due to fewer flying hours for the F100-100 fleet in 2005 and 2006. **Figure M-3** shows a decline in the Unscheduled Augmentor Removal Rate starting in CY97 but a 26% increase is noted in 2005 and a 33% increase in 2006 compared to 2004 after the +100 additive was turned off but the metric was influenced by fewer flight hours for the -100 engine fleet.

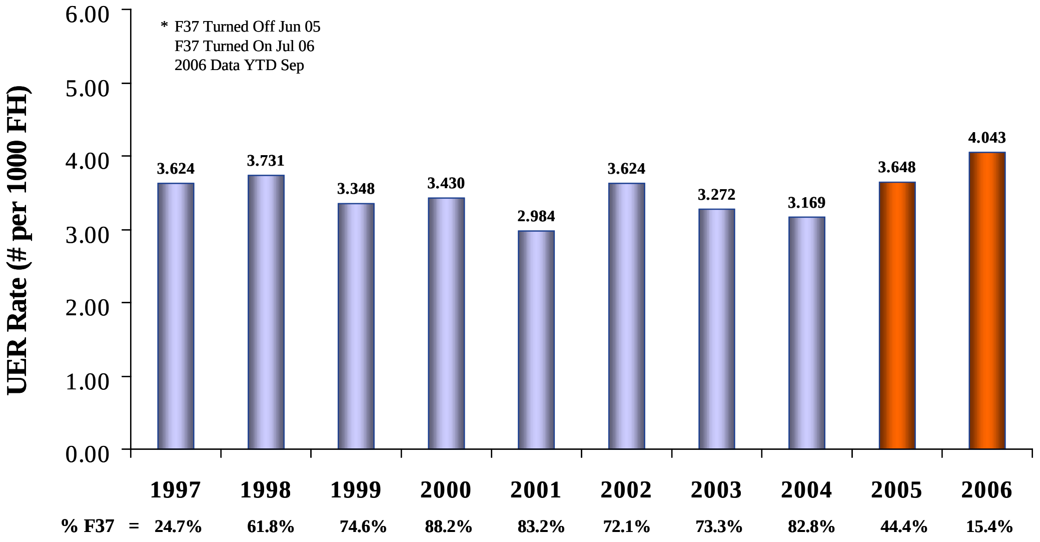


Figure M-2. F100-100 UER Rate Trend for Operational & Gas Path Deterioration

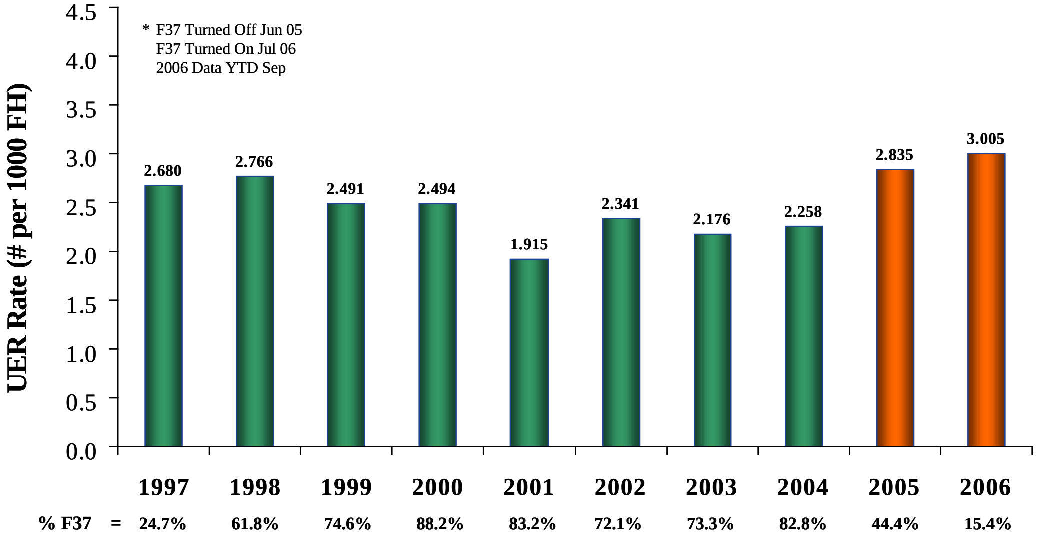


Figure M-3. F100-100 Unscheduled Augmentor Removal Rate using HMC Subset

The F100-100 uses a Unified Fuel Control (UFC) and EEC to regulate the engine variables, augmentor and exhaust nozzle. The UFC is a back to back MFC and AFC that was combined to save engine weight but is removed more frequently to fix engine anomalies. The largest number of UFC removals was recorded using HMC 223 and the second largest HMC 242. HMC 561 removals were ranked fourth. HMC 242 is frequently used when in doubt of the cause of a malfunction. **Figure M-4** shows a steady decline in UFC Removal Rate for Operational and Gas Path Deterioration but the unscheduled removal rate increased 96% in 2005 when the +100 additive was turned off in June 2005 for 12-13 months. Replacing marginal controls in 2005 and performing engine trims provided a significant reduction of UFC Removal Rate in 2006.

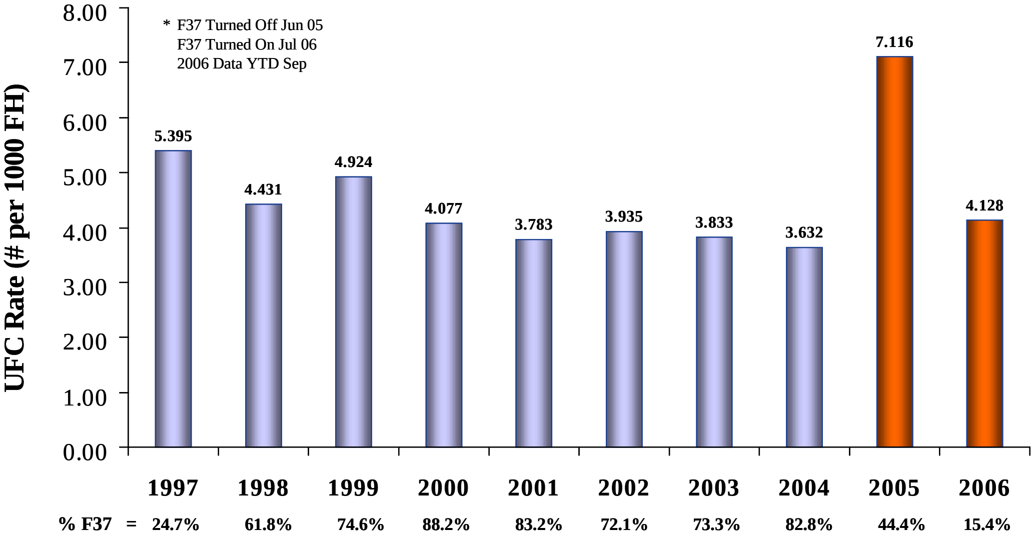


Figure M-4. F100-100 UFC Removal Rate for Operational & Gas Path Deterioration

Figure M-5 shows the UFC Unscheduled Removal Rate for augmentor related malfunctions. Note that the fleet average UFC Removal Rate increased by 103% in 2005 when the +100 additive was turned off and decreased by 42% in 2006 from the marginal controls that were replaced and the engine trims that were performed.

The above examples show that the F100-100 engine fleet experienced maintenance benefits from using JP-8+100. Units using JP-8+100 experienced between 51 to 74% lower UER Rate than Units using JP-8. When comparing ANG Units only with the fleet yearly average UER Rate, use of the +100 additive provided a 25 to 54% lower UER Rate than when using JP-8. When the +100 additive was turned off in June 2005, the ANG Units using JP-8+100 experienced a 153% increase in UER Rate but experienced only a 10% decrease in UER Rate when the +100 additive was turned on again in August 2006. The UER Rate was 20% lower than the UER Rate for Units that had used JP-8 continuously. These examples indicate that use of the +100 additive in conjunction with a well-managed engine maintenance program supplied with engine modules built to higher standards and timely baking and cleaning of the augmentor spray rings can reduce the UER Rate of -100 engines by at least 20%. The potential exists for even greater reductions in the UER Rate using reduced spray ring baking intervals and Opportunistic Maintenance guided by the F100 RCM program.

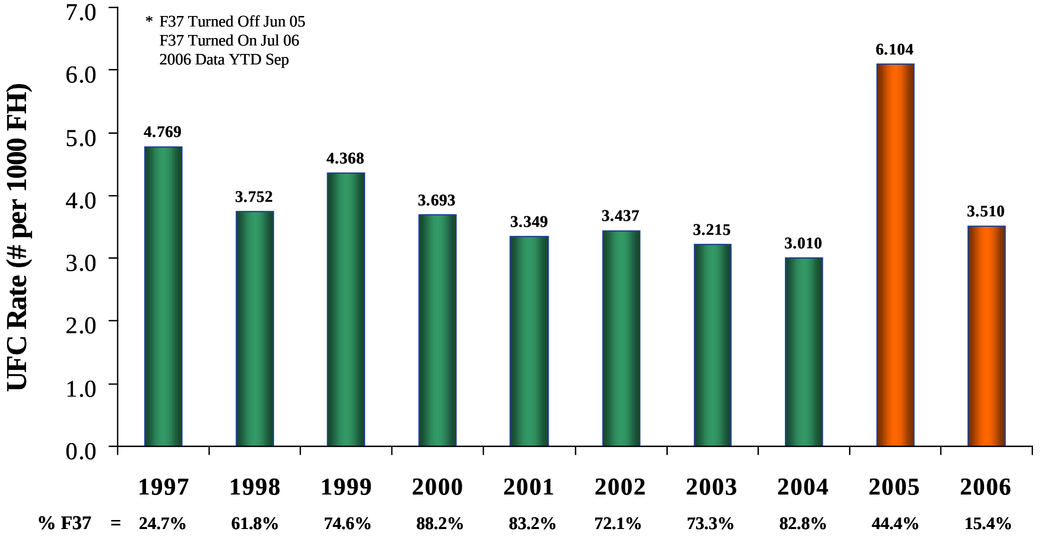


Figure M-5. F100-100 Augmentor Related UFC Removal Rate Using HMC Subset

3.0 F100-PW-220/E Engines

Figure M-6 shows the number of Unscheduled Engine Removals for all malfunctions. A total of 6,724 events were recorded from January 1997 to September 2006. Top 10 events make up 49% of the total. The Top 5 are Oil Leakage, Internal and External Leakage, Turbine Section Distress, Augmentor No-Lights and Control Malfunctions. The unscheduled removal of the main fuel controls and augmentor fuel controls were also analyzed to determine the impact of the evolving maintenance practices to deal with coking and the use of JP-8+100. The steady decline in the UER Rate for the engine fleet shown in **Figure M-7** from 1997 through 2006 is a direct result of the RCM Program that helped improve the reliability of the gas path hardware, the evolving maintenance procedures and the use of JP-8+100. As a result, the gas paths of the engines were approaching more sustainable levels of reliability. When the additive was turned off in June 2005, the Fleet Augmentor UER Rate increased by 20% through the end of 2005 and increased by an additional 5% through September 2006 as shown in **Figure M-8** indicating that coking from JP-8 use had an impact on engine anomalies such as augmentor no light. With improved gas path reliability, the Unscheduled Removal Rate of MFCs experienced at steady decline as shown in **Figure M-9** and had reached a sustainable level starting in 2001 but increased by 52% when the +100 additive was turned off. The top two reasons reported for MFC removals were Control System Component Malfunction (HMC 223) and Failed to Operate-Specific Reason Unknown (HMC 242). HMC 242 is used when the flight line mechanics are unable to fix an engine anomaly and need to remove the engine for further investigation by the engine shop. **Figure M-10** shows the distribution and frequency of events for the malfunction codes that were reported in CEMS for F100-220/E AFC removals from 1997 through July 2006. The Top 10 events represent 75% of the total. The top event, Dirty Contaminated or Saturated by Foreign Material (HMC 230), reports the AFCs that were removed to clean the coke particles and gums that had accumulated in the outlet ports of the fuel manifold. The coking contributed to the Augmentor No Light, Control System Component Malfunction, Failed to Operation-

Specific Reason Unknown and the Augmentor Blowout events that forced removal of an AFC. **Figure M-11** shows the trends for the fleet Augmentor Related AFC Removal Rate. The steady increase in AFC Removal Rate starting in 1997 is due to coking in the fuel manifold outlet ports. Seg III has the most accumulation. Local shop procedures have been developed to remove the gums and coke particles and return the AFC to service. **Figure M-12** shows the fleet AFC Removal Rate caused by carbon/coking related fault codes. As JP-8+100 use decreased from 61.4% in 2000 to 14.9% in 2004, the AFC removal rate increased 33% from 0.215 events/ 1000 FH in 2000 to 0.286 in 2004 and 2005. If the carbon/coke related events were removed from **Figure M-11**, the AFC Removals remained nearly constant starting in 2000 through 2005 indicating that Units were staying on top of the AFC coking problems. When the +100 additive was turned off in June 2005, the fleet AFC Removal Rate increased by 3% in 2005 and 8% in 2006. When JP-8+100 use at one Unit decreased from 100% to less than 50% utilization in 2003, the UER Rate increased by 74% during the following year and an additional 24% increase in 2005 when the +100 additive was turned off in June 2005 providing a clear indication of engine sensitivity to the percent utilization of JP-8+100 in the -220/E engines.

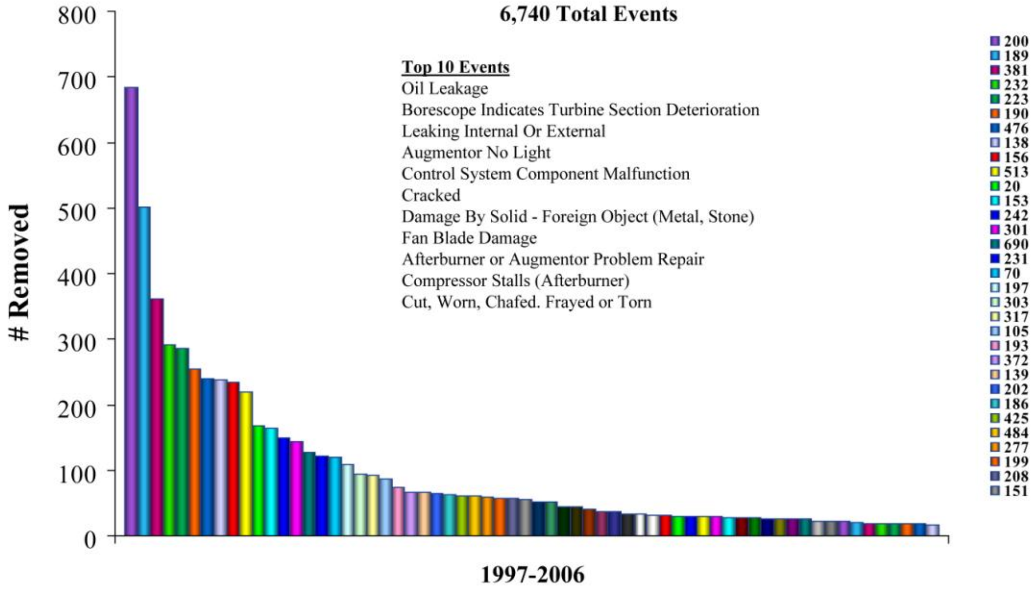


Figure M-6. F100-220/E Fleet Unscheduled Engine Removals for All Faults

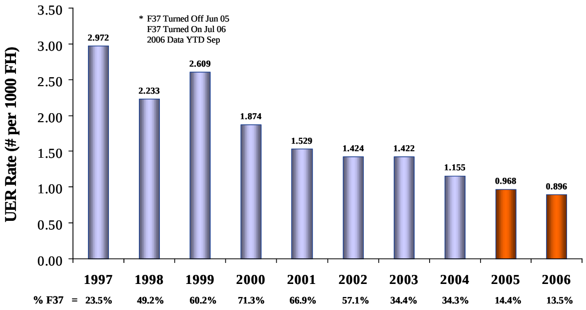


Figure M-7. F100-220/E Fleet UER Rate for Operational & Gas Path Deterioration

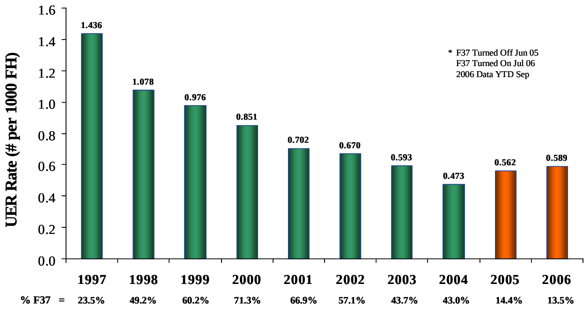


Figure M-8. F100-220/E Fleet Augmentor UER Rate Using HMC Subset

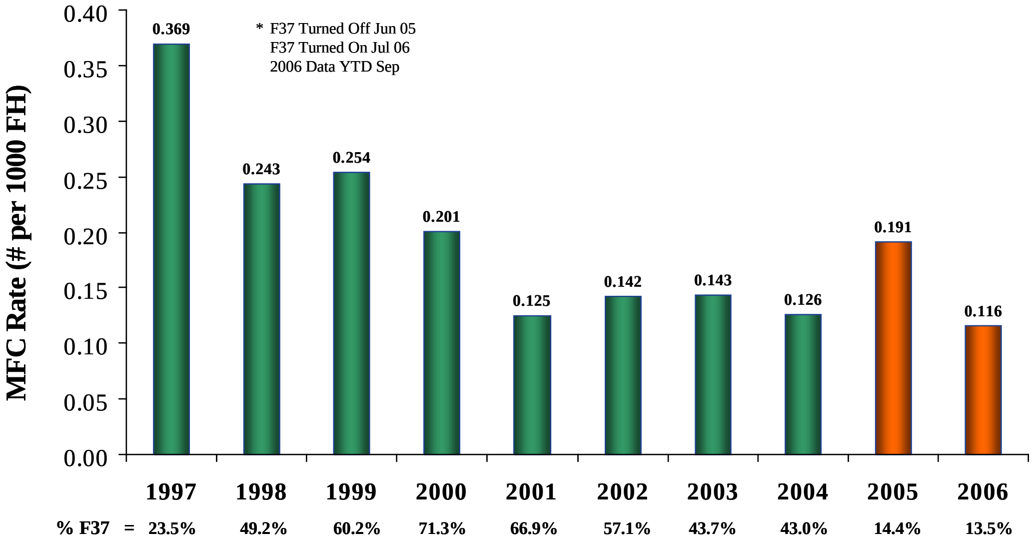
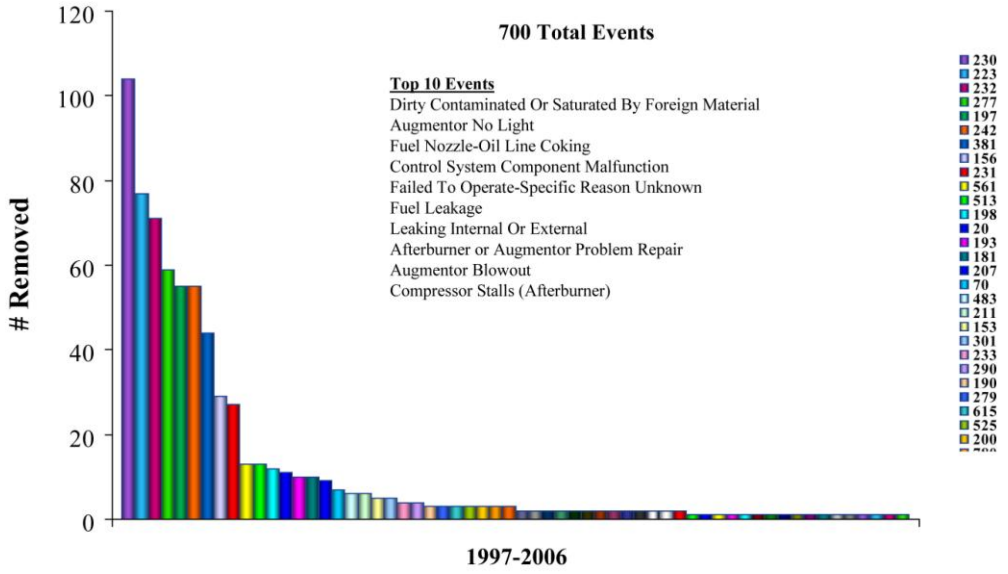


Figure M-9. F100-220/E Augmentor Related MFC Rmvl Rate in F-16C/D for HMC Subset



* Does Not Include Luke AFB Due To
Change In Local MX Procedures with AFC

Figure M-10. F100-220/E Unscheduled AFC Removals for All Faults in F-16C/D Fighters

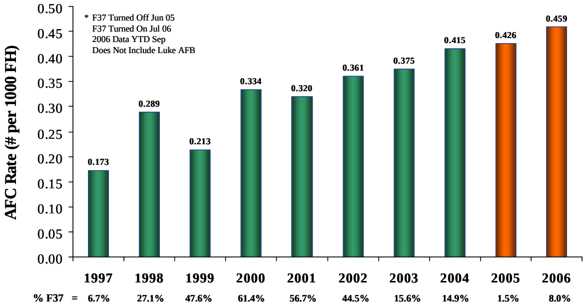


Figure M-11. F100-220/E Augmentor Related AFC Rmvl Rate in F-16C/D for HMC Subset

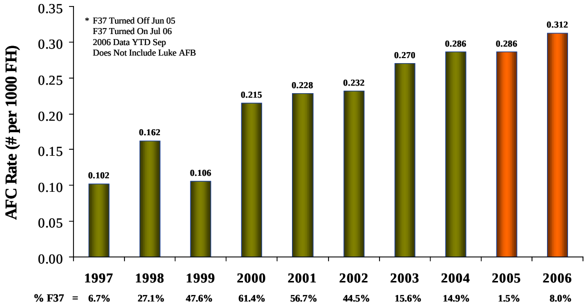


Figure M-12. F100-220/E AFC Rmvl Rate From F-16C/D Related to Augmentor Coking

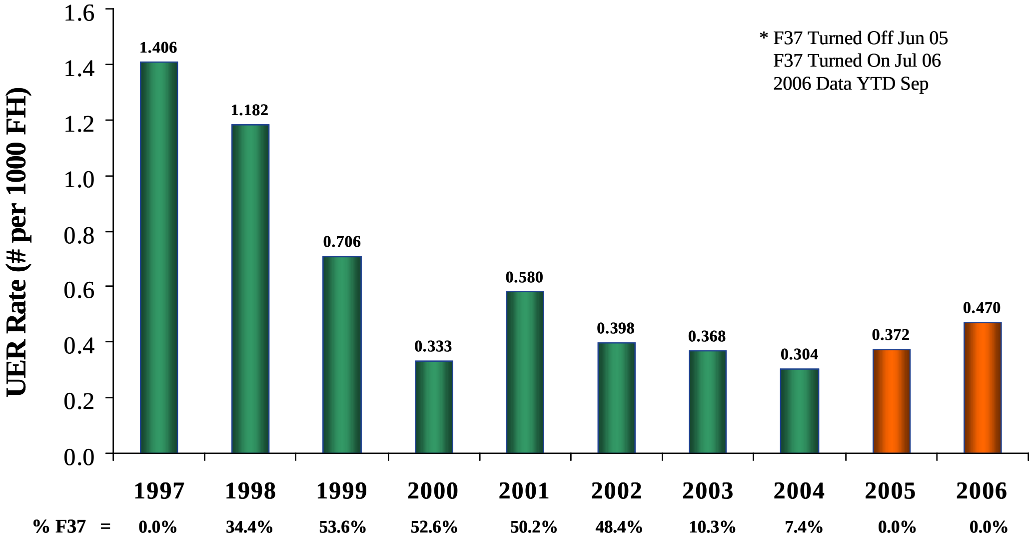
4.0 F100-PW-229 Engines

The -229 engine is basically a new engine compared to -220/E engines with higher thrust performance provided by increased airflow, higher cycle pressure ratio and higher cycle temperatures. Both F-15E and selected F-16C/D fighters use the -229 engine due to its improved performance and thrust capability. The -229 engine also uses a DEEC to provide full authority engine control and self-trim during flight and acceptance runs with an integrated monitoring system that diagnoses engine and control accessory hardware operation for deterioration and malfunctions. The diagnostics functions are performed in the DEEC and forwarded to an engine mounted Engine Diagnostic Unit (EDU) that provides, via codes, a quick review of any engine and control hardware malfunctions.

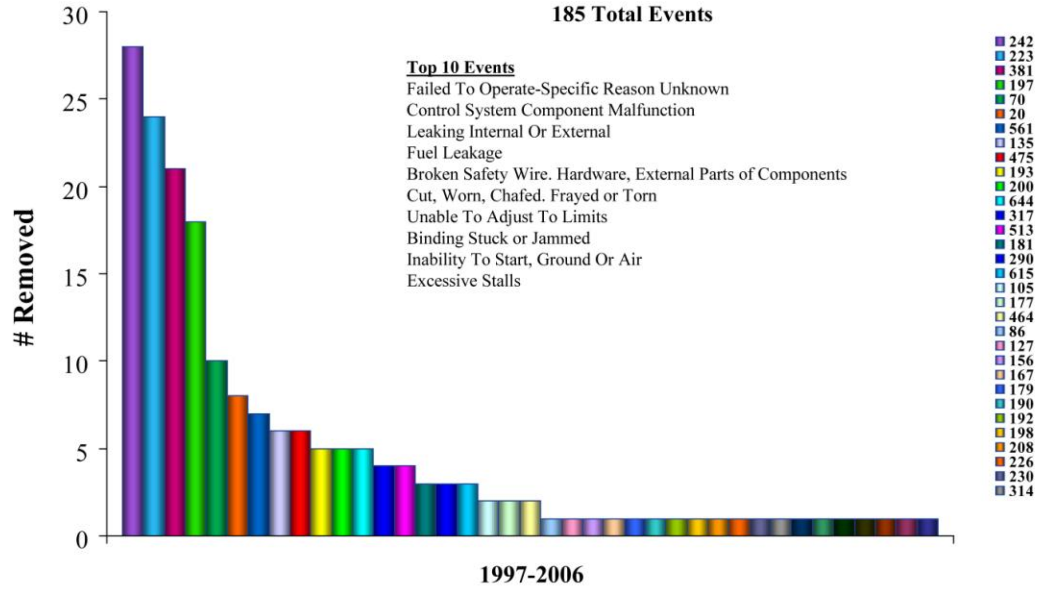
Like the -220/E engine, the -229 received more new parts when the RCM Program was launched. Many of the control algorithms and engine monitoring functions are common to both the -220/E and -229 engines, however, several control algorithm updates have been installed in the -229 engines to improve engine operation in the flight envelope. One difference in the -229 augmentor fuel system compared to the -220 augmentor fuel systems is the use of spray bars that were designed to drain quickly to minimize fuel coking versus spray rings that take more time to drain the residual fuel after augmentor shutdown.

CEMS data were used to determine the removal events for the -229 engine fleet for the 10 year period from 1997 through September 2006. Appling the same methodology to assess the causes for removal of the -229 engine, the MFC and AFC components as used for the -100 and -220/E engines, it was noted that cracked parts, leaking and Turbine Section Deterioration were the Top 4 causes for engine removals. Stalls were ranked number 5 and 7 and FOD events 8 and 9 with Control related removals ranked 11 and 12. **Figure M-13** shows the Augmentor Related UER Rate for the -229 fleet using the HMC Subset referred to earlier. With exception to 2001, UER Rate was continuing to decline through 2004 but the fleet UER Rate for augmentor caused events increased by 22% in 2005 and 26% in 2006 when the +100 additive was turned off from June 2005 through July 2006. However, the increase in augmentor removals events was extremely low considering the number of -229 engines in service. **Figure M-14** shows the frequency of MFC removals for all faults for the -229 engine fleet. A total of 185 MFC removals were reported in CEMS during this time period with the Top 10 events making up 72% of the total. It is noted that the top two causes for MFC removals were Failed to Operate-Specific Reason Unknown and Control System Component Malfunction. **Figure M-15** shows the Fleet Augmentor Related MFC Unscheduled Removal Rate. The large drop in the MFC Removal Rate during 1998 and 1999 was due to new parts and module upgrades from launch of the RCM Program. Although the number of MFC removals was small, a gradual decline in MFC removals occurred from 2000 through 2004. When the +100 additive was turned off in June 2005 and JP-8+100 utilization had decreased to 10.3% in 2003 and 7.4% in 2004, the Unscheduled MFC Removal Rate increased by 97% in 2005 that was attributed to HMCs 223 and 242 and possibly engine stalls while **Figure M-16** using the same HMC Subset shows a 34% decrease in AFC Removal Rate indicating that more MFCs were removed to fix augmentor problems than AFCs. In 2006, the MFC Removal Rate reduced by 76% while the AFC Removal Rate in 2006 shown in **Figure M-16** increased by 15% using the same HMC Subset to assess the removal data. However, **Figure M-13** shows that the Fleet Augmentor Related UER Rate increased by 22% in 2005 and 26% in 2006. Given the small number of MFC and AFC control removals during 2005 and 2006 and limited information of the condition of -229 engines at that time, it would be inappropriate to conclude that using JP-8 for approximately six months during 2005 and 2006 was solely responsible for the MFC and AFC removals as other maintenance issues were influencing these removals. It could be argued that the MFCs that were removed from 2000 through 2003 when JP-8+100 utilization was around 50% had contributed to the significant reduction in 2004 and that after using JP-8 for six months in 2005, the MFC Removal Rate had increased by 97% but without additional information it is difficult to understand the 76% decrease in MFC removals during six month in 2006. The number of AFC removals decreased by 1 in 2005 which is not significant while the AFC Removal Rate actually increased because of reduced flying hours. In any event the CEMS data indicates that the Augmentor related UER Rate increased after the +100 additive was turned off in June 2005 which may be attributable to coking in the augmentor fuel system. Although the MFC and AFC removals had fixed the engine anomalies, other maintenance issues were involved in the control removals that may be understood through further investigation of the CEMS removal data.

Therefore, the -229 engine remains a challenge to determine the benefits from using JP-8+100. Installation of improved gas path parts, especially turbine blades and vanes, and control software changes have contributed to brief periods of improved engine reliability and reduced unscheduled removals. However, the time period of stable maintenance activity was insufficient to sort out the impact of coking on augmentor operation and the unscheduled removal of AFC and MFC components during periods when either JP-8 or JP-8+100 was used. When new engine parts and module realignment procedures were implemented in 1998 under the RCM Program, use of JP-8+100 began also and the UER Rate showed a decline as did unscheduled MFC and AFC removals. During the period of analysis, the synergies of the RCM Program, control software changes, local maintenance procedures and use of JP-8+100 all contributed to brief periods of reduced UER Rate. When the +100 additive was turned off in 2003 to support the surge of aircraft using this Unit as a refueling stop, the UER Rate for the Top 10 removal events increased by 9% and remained the same during 2005 and then decreased in 2006. Use of fuel spray bars in the -229 augmentor and a redesigned augmentor fuel system manifold has significantly reduced coking problems in -229 engines compared to the -220/E and legacy -100 engines. More time will be required to achieve sustainable maintenance conditions in order to determine the benefits from using JP-8+100 in the -229. However, the benefits for the -229 will not be of the magnitude determined for -220/E and legacy -100 engines using spray rings but use of the +100 additive will provide cleaner burning in the engine combustor, cleaner turbine parts and fewer carbon and coke deposits in the augmentor making borescope inspections easier and more reliable.

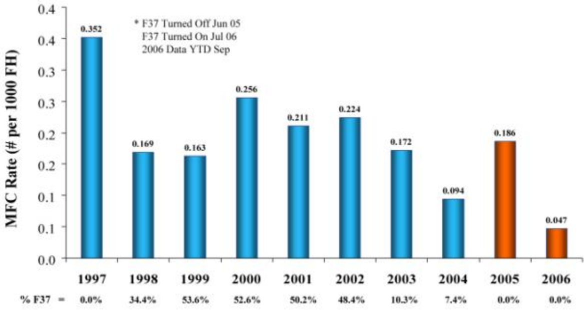


M-13. F100-229 Fleet Augmentor Related UER Rate Using HMC Subset



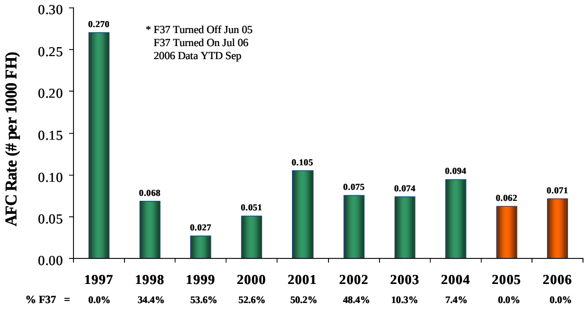
Top 10 Events
Failed To Operate-Specific Reason Unknown
Control System Component Malfunction
Leaking Internal Or External
Fuel Leakage
Broken Safety Wire. Hardware, External Parts of Components
Cut, Worn, Chafed. Frayed or Torn
Unable To Adjust To Limits
Binding Stuck or Jammed
Inability To Start, Ground Or Air
Excessive Stalls

Figure M-14. F100-229 Engine Fleet Unscheduled MFC Removals for All Faults



* F37 Turned Off Jun 05
F37 Turned On Jul 06
2006 Data YTD Sep

Figure M-15. F100-229 Fleet Augmentor Related MFC Removal Rate Using HMC Subset



* F37 Turned Off Jun 05
F37 Turned On Jul 06
2006 Data YTD Sep

Figure M-16. F100-229 Fleet Augmentor Related AFC Removal Rate Using HMC Subset

APPENDIX N

F110-GE-100 and -129 Maintenance Trends

F110-GE-100 and -129 Maintenance Trends

1.0 Background

The analysis of F110 fighter engines has been a real challenge to determine the maintenance benefits from using JP-8+100. The only data available was from the CEMS data base. No site visits were arranged to discuss the maintenance trends from the removal events that were reported in the CEMS data base. However, the data indicates that engine removals to solve potential fuel coking issues were sometimes offset by increased unscheduled engine removals to correct mechanical faults and turbine deterioration issues. Unfortunately, periods of stable maintenance activity were brief for both the -100 and -129 engines limiting useful data to sort out the impact of coking on engine and afterburner operation that may have caused the unscheduled removal of MEC and AFC components when JP-8 or JP-8+100 was used.

In 1998, the Air Force initiated the F110-100B Mod Program that provided new parts to improve the durability of the Combustor and Low Pressure Turbine and the control system was changed to a digital electronic engine control. The -100B Mod Program was ongoing through 2004, however, a Service Life Extension Program (SLEP) was initiated in 2003 to increase the service life of life limited parts in the hot section from 3000 to 4000 cycles. The new engine parts improved engine durability and reliability that provided a steady reduction in unscheduled engine removals but the installation of the new parts in both the F110-100 and -129 engines made it more difficult to sort out any benefits from using JP-8+100. It is noted that the utilization of the +100 additive started to decline starting in 2003 which corresponded to an increase in the unscheduled removal rates for the MEC and AFC although the overall number of control removals was quite small for the engine fleet. The brief discussions for each Figure attempts to explain the impact of JP-8 and JP-8+100 use based on the HMCs that were reported in the CEMS data base for all maintenance performed on the -100 and -129 engines.

2.0 F110-GE-100 Engine

The F110-100 Fleet MEC removals for all faults are shown in **Figure N-1**. A total of 746 removals were reported for the time period from 1997 through 2006 with the Top 10 events contributing 68% of the total MEC removals. HMCs 223 Control System Malfunction, 561 Unable to Adjust to Limits, 242 Failed to Operate-Specific Reason Unknown and 230 Dirty, Contaminated or Saturated by Foreign Material are related to engine malfunctions caused by both control malfunctions and contamination. The total removals reported for these HMCs accounts for 42% of the total MEC removals.

Figure N-1. F110-100 Fleet Unscheduled MEC Removals for all Faults

Figure N-2 shows the F110-100 Fleet Unscheduled MEC Removal Rate using the HMC subset for potential fuel caused events. The removal events increased 27% in 2005 when the +100 additive was turned off and returned to the former level in 2006 when the additive was turned on again in July 2006. Note that the fleet utilization of JP-8+100 had declined to 9.1% in 2004 and 3.3% in 2005. The decline in MEC removals from 1998 - 2001 was more related to hardware installed to improve durability under the -100B Mod Program while the rise in MEC removals from 2002 through 2005 were more influenced by control functional and contamination issues based on HMCs 223, 561, 242, 230 and Flameout (HMC 69) when use of JP-8+100 was declining from 59.4% to 3.3%. The large drop in removals in 2006 was due to reduced control removals (HMC 223 and 242). For this time period, 37% of the removals were for HMC 223, 20% for HMC 561, 18% for HMC 242 and 8% for HMC 230 (Dirty Contaminated or Saturated by Foreign Material). HMC 230 used for fouling/coking.

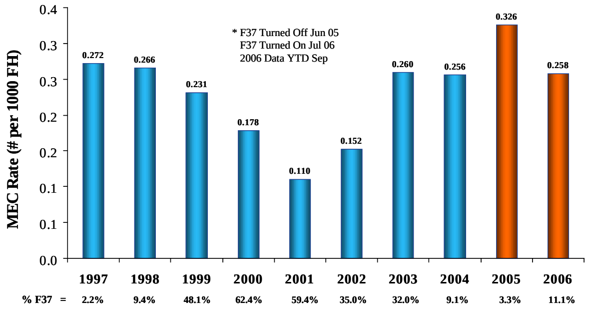


Figure N-2. F110-100 Fleet Top 10 Unsched. MEC Rmvl Rate for Ops & Gas Path Deterioration

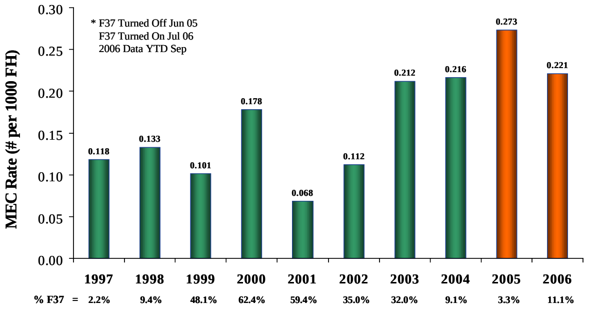


Figure N-3. F110-100 Afterburner Related MEC Removal Rate using HMC Subset

The F110-100 afterburner related MEC unscheduled removal rates are shown in **Figure N-3** using the HMC Subset shown in **Table N-1** for Afterburner Anomalies. MEC removals were accomplished to correct functional and contamination issues reported using the Top 5 HMCs 223, 561, 242, 230 and 315. The increase in MEC removals that began in 2001 may be related to fuel type but the messages provided by the Engine Monitoring System would be needed to understand the HMCs used to report the MEC removals, whether an engine anomaly, a control malfunction or fuel contamination issues. In 2005, MEC removals increased 26% due to afterburner issues but abruptly reduced during 2006 (HMC 223 and 242). For the HMC Subset for this time period, 56% of the removals were for HMC 223 and 31% for HMC 242. The abrupt decrease in 2006 was due to the increased control removals for HMC 223 and 242 that were accomplished from 2002 through 2005 and from improved gas path condition.

Table N-1. Traditional HMC Subset for Afterburner Anomalies

Description	HMC
Flameout	69
Afterburner or Augmentor Problem Repair	156
Augmentor Induced Stagnation	207
Control System Component Malfunction	223
Augmentor Blowout	231
Augmentor No Light	232
Augmentor Rumble	233
Failed To Operate-Specific Reason Unknown	242
Compressor Stalls (Afterburner)	513

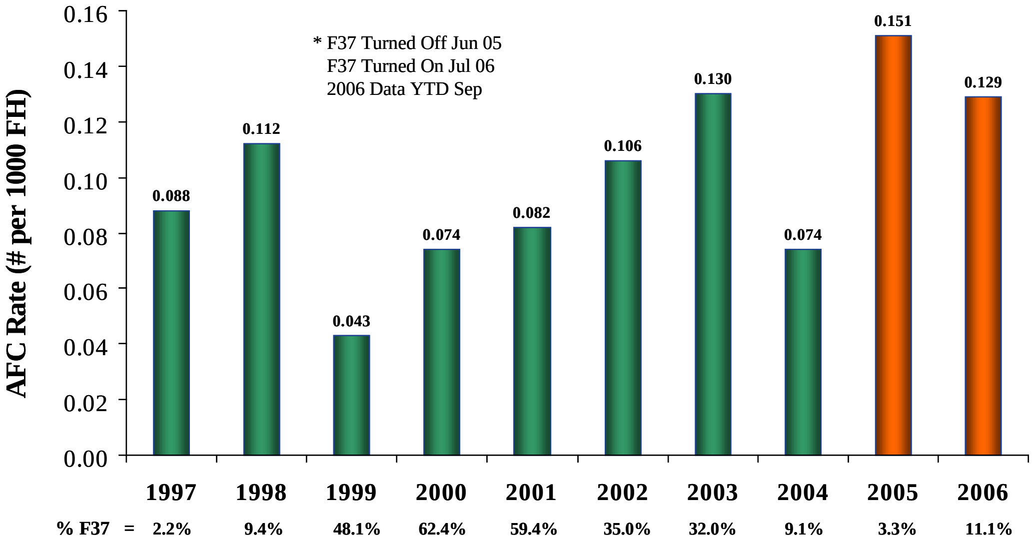


Figure N-4. F110-100 Fleet Afterburner Caused AFC Rmvl Rate using HMC Subset

Figure N-4 shows the F110-100 Fleet Afterburner Caused AFC Removal Rate using the HMC Subset shown in **Table N-1**. Events increased 104% in 2005, however, the absolute number of removals was relatively small. It is interesting to note that the increase in AFC removals from 1999 through 2003 was due to increases in HMC 231 and 232, afterburner blowouts and no-lights suggesting control fouling and coking issues. During the 10 year time period, 31% of the AFC removals were due to HMC 223, 26% HMC 232 (No-Lights) and 24% for HMC 242, Failed to Operate-Specific Reason Unknown. The increase during 2005 was due to control removals using HMCs 223, 232 and 242 while the reduction in 2006 was for HMC 232 and 242 suggesting that the increase in control removals in 2005 helped reduce the No-Lights and HMC 242 removals in 2006. Since gas path deterioration was not an issue, then fouling and coking are considered the cause of the afterburner anomalies.

3.0 F110-GE-129 Engine

The F110-129 MEC Unscheduled Removals for the Fleet for all faults is shown in **Figure N-5**. A total of 189 total events were recorded during the 1997 through 2006 time period with the Top 10 events making up 71% of the total. Only the Top 3 removal events, HMCs 223, 242 and 561 are related to control functional problems due to fouling from using JP-8.

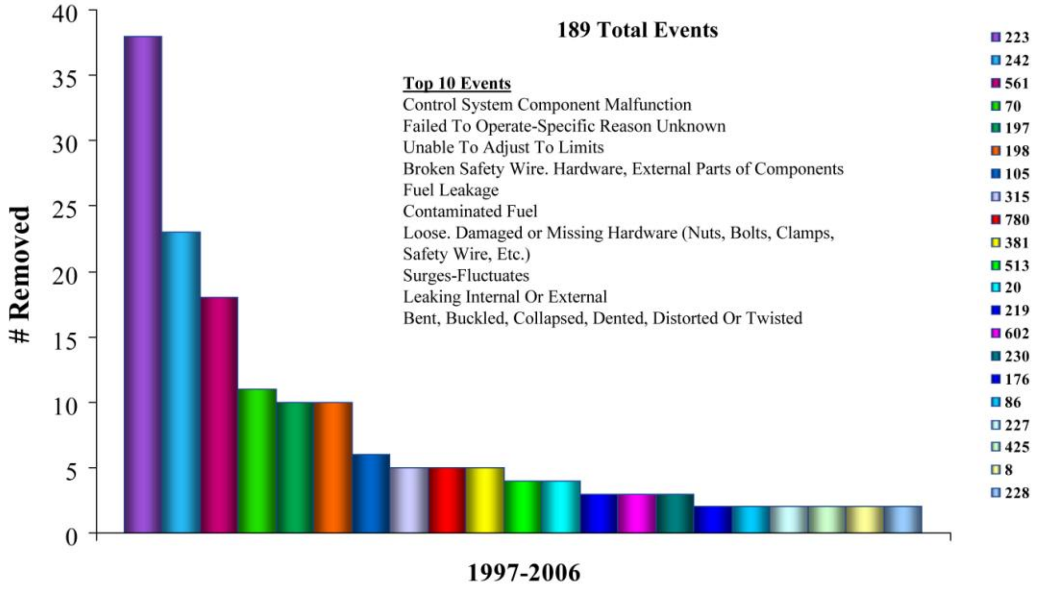


Figure N-5. F110-129 Fleet Unscheduled MEC Removals for all Faults

Figure N-6 shows the F110-129 Unscheduled MEC Removal Rate for the fleet using the HMC Subset for potential fuel caused events along with the fleet utilization of JP-8+100. For this time period, 38% of the MEC removals were for HMC 223, 23% for HMC 242 and 18% for HMC 156. During 1997 when JP-8 was used, 58% of the MEC removals were removed for HMC 223 and 26% for HMC 561. The MEC removals could be attributed to a number of problems to include control fouling, engine deterioration and engine trim issues. One explanation might be that the new engine hardware installed under the -100B Mod Program improved gas path performance reducing control scheduling and regulation issues while another explanation might be that marginal controls were being removed from 1997 through 2000. Another consideration is that control fouling from using JP-8 had reduced the functional performance of the MEC some of which may be confirmed by use of HMC 223 but use of HMC 242 indicates that the Specific Reason for removals is Unknown. The MEC removals reduced to 7 during 2001 and 2002 and then abruptly increased by 4 in 2003 using HMC 242. From 1999 through 2002, utilization of JP-8+100 (F37) was around 73 to 77% but started to decline in 2003. HMC 242 removals increased by 5 in 2003 for a combined level of 12 MEC removals in 2003 using HMCs 223, 242 and 156, 10 in 2004 and 11 in 2005. It is important to note that 2 MEC removals occurred in 2005 for HMC 230 (Dirty Contaminated or Saturated by Foreign Material) a sign that fouling was observed by the engine mechanics. In 2006, the combined control removals decreased to 8 although the +100 additive had been turned off since June 2005. Since there is a 12 to 18 month delay for fouling to become a problem, the removal data may be showing periods of declining MEC removals from the synergies of replacing marginal controls on engines, reduced fouling from use of the +100 additive and the impact of engine deterioration that can be reversed by new parts and gas path hardware built to higher standards. Although the sample size is small, control fouling from use of JP-8 has been shown to be a low level nuisance and caused unscheduled removals of fuel control components.

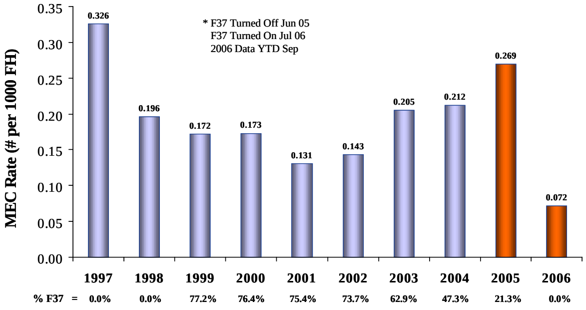


Figure N-6. F110-129 Fleet MEC Rmvl Rate for Ops & Gas Path Deterioration

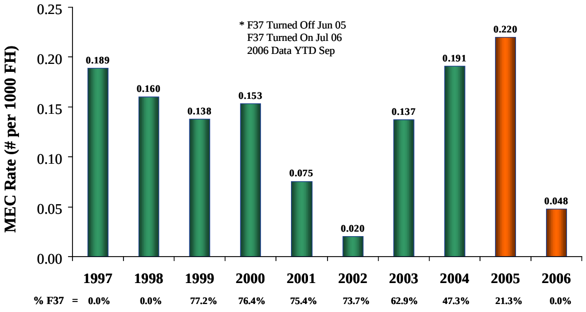


Figure N-7. F110-129 Fleet Afterburner Related MEC Rmvl Rate Using HMC Subset

The F110-129 Fleet Afterburner Related MEC Removal Rates are shown in **Figure N-7** using the HMC Subset shown in **Table N-1**. HMC 223 accounted for 55% of the afterburner related MEC removals and 33% for HMC 242. It is noteworthy that A/B-related MEC removals reached a low of 1 in 2002 one year later than the engine-related MEC removals reached the lowest level of five in 2001. MEC removals, regardless of the cause, are complimentary and help improve engine reliability if the removals were merited; otherwise the control change will not provide a long term fix to afterburner problems reported using HMC 242 or 223. The rationale for selecting HMC 242 (Specific Reason Unknown) 25 to 63% of the time versus HMC 223 to report an afterburner caused MEC removal remains unknown. Also, it would be extremely important to establish if the control change fixed the afterburner problem. Starting with 1 control removal in 2002 using HMC 242, the combined MEC removals for HMC 223 and 242 in 2003 was 7, 8 in 2004, 9 in 2005 and 2 in 2006. The abrupt decline in MEC removals in 2006 may be a result of three years of removing marginal controls that was first noted from 1997 to 2002. Since the Depot reported that the -100 and -129 afterburners do not have coking problems, then there is reason to believe that the MEC becomes fouled at some point in service and must be changed for the engine and afterburner to function as designed. The low number of unscheduled MEC removals each year made it difficult to gain more insight into the causes for the MEC removals. However, use of JP-8+100 did show a maintenance benefit for the MEC in reducing fouling. Removing controls more frequently during certain time periods increases maintenance cost and workload but in one or two years that followed, very few controls were removed. This observation leads to a conclusion that clean engines and control hardware that are sensitive to fouling from using JP-8 will operate longer in service free from functional problems if a thermal stability additive is used continuously but normal performance deterioration and fouling will cause an engine anomaly. Use of the +100 additive may increase the service interval of the MEC by reducing fouling in the precision sleeve valves and servos of the control.

Due to the small number of AFC removals during the 1997 to 2006 time period, no removal trends were plotted.

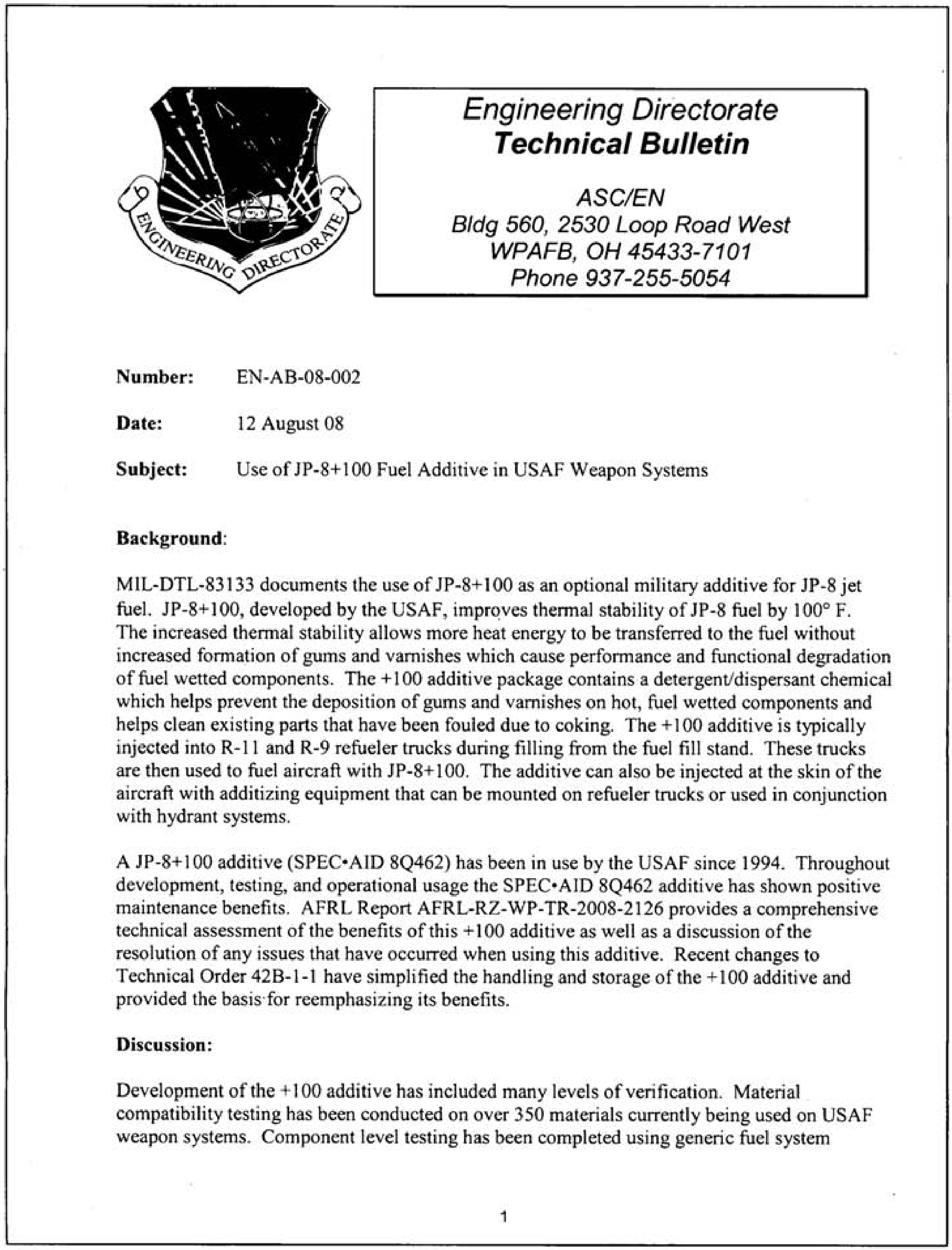
It is important to note that the installation of more durable hot section parts has contributed to periods of improved engine reliability and reduced unscheduled removals but the removal data also indicates that increased control removals during this same time period had contributed to reduced engine and afterburner anomalies by purging what appears to be weak controls resulting in a decline in afterburner no-lights. After three to four years of steady control removals for engine and afterburner anomalies, there would be an abrupt decrease in MEC removals for one year after which the engine anomalies and control removals would start to increase. When HMC 242 (Failed to Operate-Specific Reason Unknown) is used more frequently to report both MEC and AFC removals, fouling must be occurring in the MEC especially when JP-8 utilization increases, or conversely, use of JP-8+100 decreases. However, MEC removals were found to be low in number and that gas path deterioration was not determined an issue in causing the afterburner anomalies. It was noted that MEC removals were performed to fix an engine anomaly and MEC removals were also performed to fix afterburner anomalies but not necessarily on the same engine. However, MEC removals were complimentary in that benefits accrued to control components that depend on the MEC for metering, speed sensing and regulation functions. It was also determined that the number of AFC removals for the entire fleet was very small and that insufficient removal events occurred to determine the impact of fouling on AFC removals.

In spite of the relatively unstable maintenance conditions, the data indicates that using JP-8 +100 helps MEC and AFC function more precisely. Varnishes and coke start to form when fuel contacts hot metal surfaces above 200 °F. Fouling in the MEC and AFC components can cause sticky valves that affect control performance. As the utilization of JP-8+100 decreased, there was a corresponding increase in MEC and AFC removals. The +100 additive also helps fuel to burn cleaner in the engine. Cleaner gas path hardware is easier to borescope while reduced fouling in fuel control components help to reduce unscheduled engine and control component removals. As a result, requests for Depot reparables decrease allowing more time to perform the schedule maintenance program for each engine model.

APPENDIX O

ASC/EN Technical Bulletin EN-AB-002

Dated: 12 August 2008



Engineering Directorate
Technical Bulletin

ASC/EN
Bldg 560, 2530 Loop Road West
WPAFB, OH 45433-7101
Phone 937-255-5054

Number: EN-AB-08-002

Date: 12 August 08

Subject: Use of JP-8+100 Fuel Additive in USAF Weapon Systems

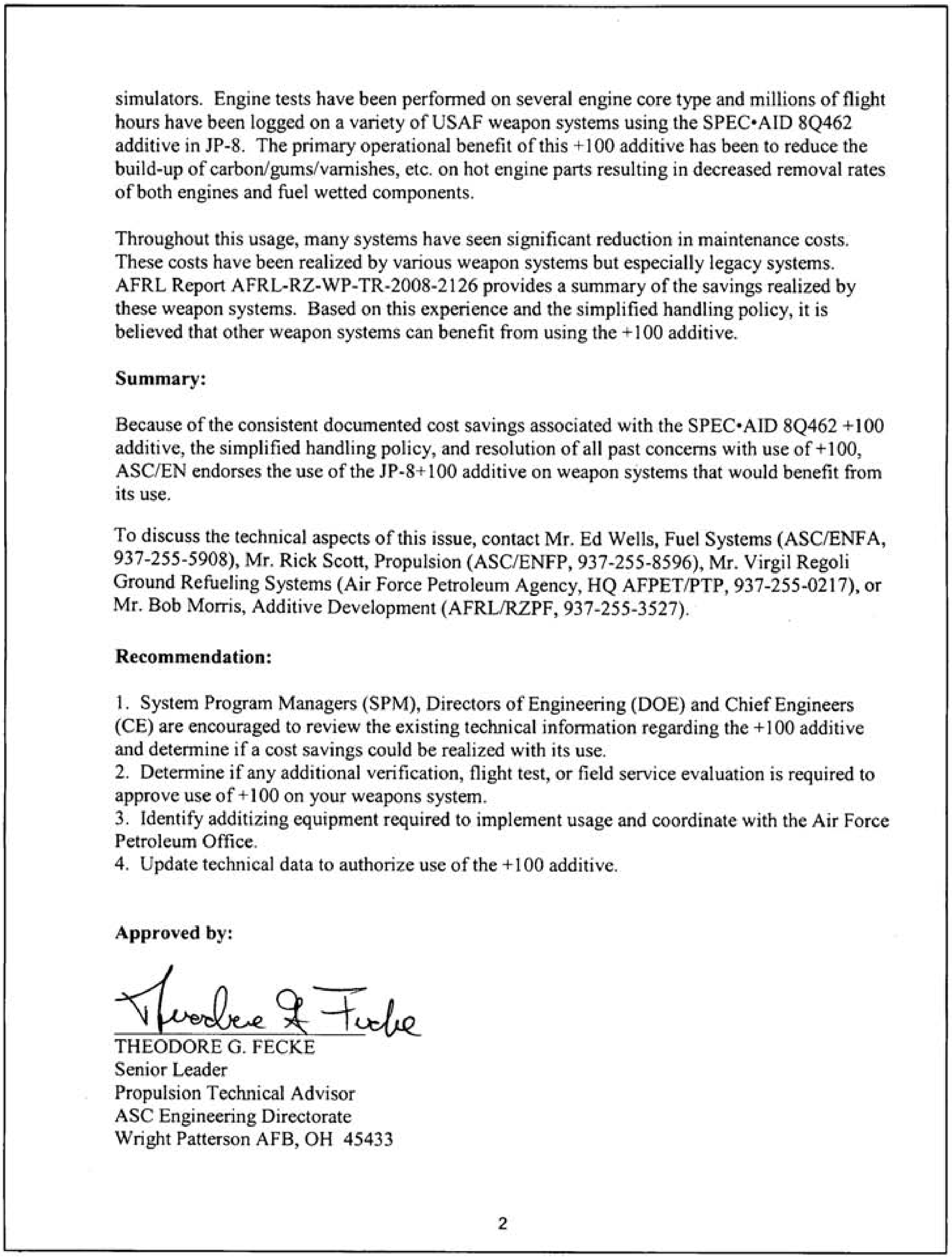
Background:

MIL-DTL-83133 documents the use of JP-8+100 as an optional military additive for JP-8 jet fuel. JP-8+100, developed by the USAF, improves thermal stability of JP-8 fuel by 100° F. The increased thermal stability allows more heat energy to be transferred to the fuel without increased formation of gums and varnishes which cause performance and functional degradation of fuel wetted components. The +100 additive package contains a detergent/dispersant chemical which helps prevent the deposition of gums and varnishes on hot, fuel wetted components and helps clean existing parts that have been fouled due to coking. The +100 additive is typically injected into R-11 and R-9 refueler trucks during filling from the fuel fill stand. These trucks are then used to fuel aircraft with JP-8+100. The additive can also be injected at the skin of the aircraft with additizing equipment that can be mounted on refueler trucks or used in conjunction with hydrant systems.

A JP-8+100 additive (SPEC•AID 8Q462) has been in use by the USAF since 1994. Throughout development, testing, and operational usage the SPEC•AID 8Q462 additive has shown positive maintenance benefits. AFRL Report AFRL-RZ-WP-TR-2008-2126 provides a comprehensive technical assessment of the benefits of this +100 additive as well as a discussion of the resolution of any issues that have occurred when using this additive. Recent changes to Technical Order 42B-1-1 have simplified the handling and storage of the +100 additive and provided the basis for reemphasizing its benefits.

Discussion:

Development of the +100 additive has included many levels of verification. Material compatibility testing has been conducted on over 350 materials currently being used on USAF weapon systems. Component level testing has been completed using generic fuel system



simulators. Engine tests have been performed on several engine core type and millions of flight hours have been logged on a variety of USAF weapon systems using the SPEC•AID 8Q462 additive in JP-8. The primary operational benefit of this +100 additive has been to reduce the build-up of carbon/gums/varnishes, etc. on hot engine parts resulting in decreased removal rates of both engines and fuel wetted components.

Throughout this usage, many systems have seen significant reduction in maintenance costs. These costs have been realized by various weapon systems but especially legacy systems. AFRL Report AFRL-RZ-WP-TR-2008-2126 provides a summary of the savings realized by these weapon systems. Based on this experience and the simplified handling policy, it is believed that other weapon systems can benefit from using the +100 additive.

Summary:

Because of the consistent documented cost savings associated with the SPEC•AID 8Q462 +100 additive, the simplified handling policy, and resolution of all past concerns with use of +100, ASC/EN endorses the use of the JP-8+100 additive on weapon systems that would benefit from its use.

To discuss the technical aspects of this issue, contact Mr. Ed Wells, Fuel Systems (ASC/ENFA, 937-255-5908), Mr. Rick Scott, Propulsion (ASC/ENFP, 937-255-8596), Mr. Virgil Regoli Ground Refueling Systems (Air Force Petroleum Agency, HQ AFPET/PTP, 937-255-0217), or Mr. Bob Morris, Additive Development (AFRL/RZPF, 937-255-3527).

Recommendation:

1. System Program Managers (SPM), Directors of Engineering (DOE) and Chief Engineers (CE) are encouraged to review the existing technical information regarding the +100 additive and determine if a cost savings could be realized with its use.
2. Determine if any additional verification, flight test, or field service evaluation is required to approve use of +100 on your weapons system.
3. Identify additizing equipment required to implement usage and coordinate with the Air Force Petroleum Office.
4. Update technical data to authorize use of the +100 additive.

Approved by:

Theodore G Fecke

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Senior Leader
Propulsion Technical Advisor
ASC Engineering Directorate
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APPENDIX P

Turbine Fuel Management Issues

TABLE OF CONTENTS

1.0 Executive Summary

The +100 additive was developed and fielded by the USAF to reduce coking problems in legacy turbine engines designed to use JP-4 and also provide additional heat sink for advanced weapons systems. The additional surfactants in JP-8+100 were the main reasons for the fuel handling precautions and restrictions that ultimately limited the widespread use of the +100 additive at small fighter and C-130H transport Units. Since CI and FSII had initially exhibited some effects on filter coalescer performance, early perceptions developed among the planners that the +100 additive would disarm filter coalescers. Although the initial perceptions were accurate for many of the candidate +100 additives that **did not** pass the rigorous screening and compatibility testing conducted by AFRL/RZPF, the Spec-Aid® 8Q462 thermal stability additive is a strong dispersant of solids in JP-8 and has no serious detrimental effect on water coalescence in filter cartridges affecting the service life and overall performance of filter separators to remove solids and water.

Based on five years of field experience, two large operational Units report that no fuel truck filter separators have failed due to solids or water from issuing JP-8 or JP-8+100. However, surges of solids and water in delivered fuel and fuel issued from bulk storage have caused an increase in the pressure drop across the receipt filter separators and vessels downstream of bulk storage that may require a scheduled servicing at a future date but none of the fuel issued to the fill stands has exceeded the Test Limits for solids and water. During the three year service interval of the filter separators, these Units issue from 1.6 to 5.6 million gallons of JP-8 from each R-11 fuel truck and 1.9 to 3.2 million gallons of JP-8+100 from each R-11. Since fuel issued to fuel trucks at fill stands is always below Test Limits and differential pressure never exceeded 6 psid, the primary challenge to the API/IP 1581 5th Edition M100 filter separator vessels in the fuel trucks would be any entrained water in the fuel after daily sumping. Since bulk storage systems consistently provide incredibly clean fuel, a water challenge is more likely than a dirt challenge. It is this scenario that guided the protocol for the rigorous laboratory filter separator testing at SwRI®. The 90-day filtration field evaluation that followed in 2005 at Laughlin AFB validated the conclusions and recommendations of the SwRI® test program and **also** proved that the additional surfactants in JP-8+100 did not disarm the API 3rd Edition or the DOD filter separators.

New guidance in Dec 2009 mandated a **1:100** blend back ratio of JP-8+100 to DESC capitalized JP-8 assets thus rescinding the **1:1** blend back ratio approved in July 2006. However, the blend back ratio was then re-revised to **1:10** on 2 April 2010. Although the return of fuel to operating storage is rare or not required at pilot training, fighter and C-130H aircraft Units, apprehensions exist that a finite trace of the +100 additive in the fuel in operating storage issued to a transient aircraft will disarm filter separators at other DOD facilities if a defuel was required. It is clear that these fears are unsubstantiated based on current field experience.

Unwavering support is needed for use of JP-8+100 at Units that will benefit from its use in order to decrease the maintenance workload from engine anomalies and hot section distress caused by coking from kerosene-based fuels. A 1:1 dilution ratio to operating storage tanks free from any fuel handling restrictions would permit widespread use of JP-8+100 at all Units assigned legacy fighter, helicopter and C-130H aircraft. Overwhelming field experience supported by laboratory data has verified that filter separator vessels qualified to the API/IP 1581 5th Edition M100 specification continue to provide water and solids filtration below the allowable spec limits throughout their service interval. A thorough review of years of operational experience and demonstrated performance for current technology API/IP filter separator vessels should allay any concerns and encourage a commitment to again use a 1:1 dilution ratio if return of JP-8+100 to bulk storage is necessary for operational reasons.

2.0 Background

Overly cautious fuel handling procedures and restrictions were mandated for the field service evaluations of JP-8+100 launched in 1994. At that time, the perception existed among the planners that the additional surfactants in the +100 additive, when combined with surfactants in the "military additive package" in JP-8 (FSII, CI/LI and SDA), could defeat the ability of the existing API 3rd Edition and DOD filter separators to remove solids and water from fuel. As a result, water absorbing filters were installed in the fuel trucks. Also, a 1:100 dilution ratio was initially mandated to dilute the surfactants if the need arose to return any JP-8+100 fuel to neat JP-8 in operating storage. Later it was determined that some media from the water absorbing filters issuing JP-8 had migrated to the engine fuel controls causing several flameouts in legacy trainer aircraft but there was no media migration from filtration vessels issuing JP-8+100.

2.1 Unmanageable Fuel Handling Logistics at Small Units

Unfortunately, the mandated fuel handling precautions and restrictions created unmanageable fuel handling logistics at small fighter and C-130H Units with only three fuel trucks since two were usually topped off with JP-8+100 and the other topped off with JP-8 fuel. As a result, there was no mobile capacity to perform quick response aircraft defuels, especially when the other assigned aircraft were deployed. The initial precautions and restrictions included: 1) "One time defuels using an in-service JP-8+100 refueler will be followed with the fuel returned to the same aircraft or the next available program aircraft; used in aerospace ground equipment or at the engine test facility", 2) "As a last resort, JP-8+100 may be blended into bulk fuel stocks provided the blend ratio does not exceed one part of JP-8+100 to 100 parts of JP-8", 3) "If the fuel passes through a filter separator prior to dilution, these elements must be changed" and 4) "return an aircraft to non-program status by flying two consecutive sorties with at least 75% of the aircraft fuel load using non +100 fuel (JP-8)" before leaving the home station.

Thus, the Fuels Management Teams at small Units had decided that return of JP-8+100 to bulk storage was not doable since it was warned that the receipt filter separators in bulk storage would be disarmed if in contact with JP-8+100 and would therefore need to be changed. Additionally, operators knew there were times when only limited volume was available for return of fuel to operating storage. To return 500 to 1,000 gallons of JP-8+100 to operating storage at a 1:100 dilution ratio would require far more neat JP-8 in the available storage tank. However, the large pilot training and fighter Units assigned legacy T-37, T-38, F-15 and F-16 aircraft with a high ops tempo and large fleets of refueling trucks had the flexibility to defuel and transfer small quantities of fuel to the next available aircraft. Through the use of JP-8+100, the large flying Units, both pilot training and operational, began to experience fewer augmentor anomalies, less hot section distress from fuel spray nozzle coking, lower fuel spray nozzle refurbishment costs and reduced maintenance workload. However, the fuel handlers at small Units recommended that the +100 additive be turned off at their location since the overly cautious fuel handling precautions and restrictions made it impossible to perform quick response defuels in the event of a reliability problem with an aircraft scheduled for a support mission and no available backup aircraft to launch that was fueled with JP-8.

As a result of the extra workload and no clear support from higher authority, "urban legends" came into existence regarding real or perceived difficulties in performing defuels and fuel transfers of JP-8+100 at small Units with limited refueler assets even though it could not be confirmed that any JP-8+100 fuel was ever returned to operating storage. The mandated handling procedures and restrictions were also widely circulated thus alerting other flying Units, non +100 program Units, contract carriers, foreign military and commercial operators of the fuel handling precautions for JP-8+100 if a refueling stop was planned at a +100 program base even though JP-8 was available for refueling. Although well intended, the fuel handle precautions and restrictions for JP-8+100 soon gained notoriety among aircraft maintenance and fuel handlers before any engine maintenance benefits could be demonstrated to evaluate the overall benefits to the flying unit.

2.2 Early Filter Separator Testing

The review of an early filtration test program will provide some insight of test results that were used to further support the perception that the Spec-Aid® 8Q462 thermal stability additive used in JP-8 would defeat the ability of filter separator cartridges to remove solids and water. During 1998 and 1999, small element filter coalescer testing was conducted at an engine manufacturer's facility acting as an unbiased independent laboratory. Some of the developmental cartridges available at that time failed the API 1581 3rd Edition qualification protocol during testing at that facility. However, the test rig and procedures used at that facility were considered exploratory in nature and did not fully satisfy the requirements of the API/IP specification compared to the exact science of filter coalescer testing facilities and procedures by today's standards. To meet API/IP requirements, the filtration test rig must conform to rigid design configuration features, materials selection and plumbing details while the small element testing must carefully follow the agreed upon test protocol and procedures using precision calibrated instrumentation. For a filter test to be accepted as meeting the API/IP qualification specifications, an official witness designated by the API/IP committee must be present. Although the exploratory tests were not in full compliance with the filter separator qualification procedures, the test results indicated that JP-8+100 fuel had failed the developmental filter coalescer cartridges following the 3rd Edition protocol. When the final report was published in 2002, it was reported that the prototype filters had passed rigorous qualification testing at the filter manufacturer's facility but often failed testing at the engine manufacturer's facility. The basic difference sited was the use of bulk storage JP-8 available at the test site versus clay treated Jet A fuel at the filter manufacturer's test facility that had the military additives re-injected after the clay treatment. However, the initial perceptions of the planners coupled with the observations made during several progress reviews of the exploratory filtration cartridge testing remained unchallenged until a cooperative filtration test program was begun in late 2003 at the SwRI® in San Antonio, TX.

2.3 Kingsville NAS Field Trial of +100 Additive

In 2003, the need for a rigorous filtration test program gained importance based on the comments from fuel handlers supporting the US Navy field trial of the Spec-Aid® 8Q462 additive in T-45 trainer aircraft at Kingsville Naval Air Station, TX. These field trials started in late 2000 or early 2001 and ended in 2003. Up to this point, the available filtration test data had indicated that 3rd Edition coalescer cartridges would fail if in contact with the +100 additive. However, it was learned that the API 1581 3rd Edition filter coalescer cartridges had **not** been removed from the filter separator vessel on the fuel trucks during the +100 field trial at Kingsville NAS. A test of these filter coalescer cartridges would provide an excellent opportunity to determine if they had failed since it was estimated that over 1 million gallons of JP-8+100 fuel had been issued by the fuel trucks. Thus a cartridge from a fuel truck that had been issuing JP-8+100 was sent to the filter manufacturer for Quality Assurance testing. The results came back that the cartridge coalesced water and was not disarmed which prompted the need for further investigations. The fuel handlers did not seemed surprised by the results since they knew from experience that without large amounts of dirt and/or water, the coalescer elements would not be disarmed and since their systems were clean and had a 3 stage system (a filter monitor after the separator) in the fuel trucks, they felt comfortable not changing out the filter coalescer elements. While the fuel handlers at Kingsville NAS were not surprised, actual field experience had confirmed that the API 1581 3rd Edition filter separators were not disarmed by the +100 additive. This was also verified in mid 2006 during the 90-day field service evaluation at Laughlin AFB for 3rd Edition, DOD and 5th Edition M100 filter separator cartridges using JP-8+100.

2.4 Rigorous Filtration Test Program

In 2004, a rigorous filtration test program was completed in an API/IP qualified facility at SwRI® followed by a 90-day field service evaluation of API 3rd Edition, DOD and 5th Edition M100 filter separators in fuel trucks at Laughlin AFB. The field evaluation validated the conclusions and recommendations of the SwRI® Cooperative Filtration Test Program resulting in the modification or rescinding of the initial fuel handling precautions and restrictions in T.O. 42B-1-1, Change 3 dated 31 July 2006. The initial 1:100 dilution ratio (JP-8+100 to DESC capitalized JP-8) was later changed to 1:1 ratio in August 2008. More explanation of the rationale for the test protocol recommended for the cooperative filtration program will follow in Section 7 of this Appendix.

2.5 Fuel Truck Filter Separator Experience

After nearly five years of using the 5th Edition M100 filters, the Units stated that they have not experienced any failures of filter separators in the R-11 fuel trucks issuing JP-8+100 from high differential pressure, solids or water during the 3 year service interval of the filter separator cartridges. However, small Units are not eager to return to using JP-8+100 due to their initial experience with the fuel handling precautions and restrictions during the Rapid Expansion Program. Some Units had made plans to start using JP-8+100 again in 2010 but the reversion to the 1:100 dilution ratio has forced these Units to rescind their plans and to continue using JP-8 exclusively. It is too early to learn if these Units will reconsider using the +100 additive at a 1:10 return to bulk ratio. Even though larger fighter and C-130H transport Units have reported reductions in engine anomalies, hot section distress and maintenance workload from using JP-8+100, the lack of local experience showing the maintenance benefits from using JP-8+100 has not provided adequate data for leadership at small Units to reconsider using the +100 additive.

2.6 Reversion to 1:100 Dilution Ratio and Then 1:10 Dilution Ratio

Technical guidance published in late December 2009 changed the blend ratio of JP-8+100 back to the initial 1:100 dilution ratio in JP-8 in spite of the overwhelming evidence that filter separator vessels in fuel trucks have not been disarmed after issuing several million gallons of JP-8+100. However, unfounded apprehension may still exist that even a finite trace of the +100 additive in fuel issued to a transient aircraft may disarm filter separator vessels at other DOD facilities if, for operational reasons, fuel is transferred to DESC capitalized fuel in bulk storage. Even with a 1:1 dilution ratio, operational Units with high tempo flying and mobile capacity to quickly transfer fuel to other available aircraft agree that the return of JP-8+100 to operating storage is rare or not needed. Relaxation of the blend back ratio to 1:10 on 2 Apr 2010 helped to reduce the storage volume needed to return large quantities of JP-8+100 to operating storage but provides no real relief for defuels and fuel transfers at Unit with limited refueler assets. Once again, small Units are faced with limited opportunities to accrue long term operational and maintenance benefits from using the +100 additive primarily due to limited mobile and fixed storage volume for blending JP-8+100 back to JP-8 in operating storage at a 1:10 blend back ratio.

3.0 Benefits and Liabilities of JP-8 Fuel

The Air Force faced significant development challenges in the mid 1980's when the OSD made the decision that Air Force aircraft would convert to JP-8 rather than continue using JP-4. The reasons given for the change include: 1) reduce fire hazards in aircraft exposed to ignition sources, 2) improve fuel handling safety and 3) reduce refining costs of jet fuel from crude oil stocks that contain more fractions of kerosene-based fuels. After some delay, the conversion finally occurred in the CONUS during 1993 and 1994 although naval aircraft had converted to JP-5, a kerosene-based fuel with a higher flash point, prior to the Vietnam conflict.

The Air Force development community immediately recognized that legacy fighter, transport and helicopter engines would have problems with JP-8 since these engines had been developed to use JP-4, a highly volatile fuel that evaporates quickly leaving few residues. The higher viscosity JP-8 would impact fuel atomization in the fuel spray nozzles designed to use the highly volatile JP-4 affecting light-off, relight and clean combustion in the main burner of all engines and in the augmentors of some fighter engines. Accelerated coking on the face of fuel spray nozzles in the legacy trainer, C-130H transport and helicopter engines would increase hot distress from fuel streaking while coking in the augmentor spray rings of fighter engines would cause increased anomalies due to no-lights and blow-outs during augmentor transients.

After considering the options, the Fuels Laboratory elected to increase the thermal stability of JP-8 by use of an additive to reduce coking in engine hardware exposed to high temperatures. The immediate benefits would be to reduce engine maintenance workload and contain spare parts costs while the long term benefits would be to help achieve the inherent reliability of engines as new spare parts became available to improve engine build standards. However, it is unclear if these same goals are understood or valued by the infrastructure supporting the war fighters. Eliminating fuel handling barriers such as high blend back ratios of JP-8+100 to JP-8 in operating storage would encourage widespread use of the +100 additive at small operational Units assigned fighter, helicopter and the C-130H transport aircraft and help reduce the maintenance impact of coking from use of JP-8 in the legacy engines designed to use JP-4.

When the conversion to JP-8 occurred, the fuel additives developed for JP-4 were also used in JP-8. These additives include the Static Dissipator Additive (SDA), a Corrosion Inhibitor and Lubricity Improver (CI/LI), and a Fuel System Icing Inhibitor (FSII). These additives are often referred to as the "military additive package" but they do not provide any improvement in the thermal stability of JP-8 fuel. The +100 additive that was developed consists of four proprietary components: a detergent, a dispersant, a metal deactivator, and an antioxidant. Based on prior experience with the surfactants in CI and FSII affecting the capability of coalescers cartridges to remove entrained water in JP-8, the planners of the field service evaluations reasoned that the additional surfactants in the +100 additive could very possibly reduce the effectiveness of current filter separators to remove solids and water in fuel. This reasoning mandated what is now, in retrospect, considered by this author to be overly cautious fuel handling procedures and restrictions that were not based on science at the time the policies were implemented.

4.0 Fuels Management

The management of aviation fuels is complex, disciplined and subject to constant scrutiny and change in order to assure that the highest fuel quality is available for issue to all aircraft at operational bases in overseas locations and the CONUS. The primary document for assuring the quality of fuels and lubricants is the current edition of Air Force technical manual T.O. 42B-1-1, entitled “Quality Control of Fuels and Lubricants”. The technical guidance in this publication applies to the receiving, storing, handling, testing and dispensing of fuels and lubricants at all Air Force installations and updated as needed. Although AFPET at WPAFB, OH has responsibility for updating the T.O. and providing technical support to Fuels Management Teams worldwide, the Defense Energy Support Center (DESC) has overarching control of fuels management through their quality surveillance of US Government owned petroleum products. Through their funding of projects related to the maintenance, repair, environmental compliance, and minor construction of DOD owned fuel handling systems, DESC controls both the fixed and mobile assets of base fuel systems and operator maintenance. At each Unit, quality surveillance is provided by a Fuels Management Team. Once fuel is issued to an aircraft, it no longer is considered a capital asset of DESC. If fuel, such as JP-8+100, is defueled from an aircraft back into a fuel truck, it again falls under quality control surveillance and fuel handling procedures mandated by DESC policy.

It is interesting to note that the Fuels Management Teams at small Units were the most vocal in protesting the fuel handling procedures mandated for JP-8+100. The field evaluations created additional workload with no clear support from higher authority to issue both JP-8 and JP-8+100. The fuel handlers also faced several new problems such as limited refueler assets to perform defuels and fuel transfers and little or no excess storage capacity to accommodate return of more than 500 gallons of JP-8+100 to operating storage at the initially mandated 1:100 dilution ratio.

5.0 Fuel Quality Control

Before discussing filtration system experience with JP-8+100 at operational Units, it is important to briefly review the capability of fuel filtration systems that currently provide high quality fuel to aircraft at Air Force installations, the guidance in the tech manual to assure fuel quality and the types of contaminants in fuel that must be removed.

Where fuel is received from the supplier by pipeline, barge, rail tank car or tanker truck, the fuel must pass through at least two filtrations per T.O. 42B-1-1. Fuel passes through a receipt filter separator to bulk storage and then through a filter separator to the fill stand. Although fuel issued to a fuel truck at the fill stand may or may not receive the +100 additive, the fuel passes through a third filter separator on the fuel truck as it is issued to an aircraft. While water is drained from the fuel truck daily per T.O. 42B-1-1, the differential pressure across the filter separators and flow rate are observed daily but recorded weekly. Fuel samples are taken every seven days or during the next truck fill downstream of the bulk storage filter separators to check for solids and water in the fuel. Refueler trucks and other dispensing equipment are sampled every 30 days. The test limits for water must not exceed 10 ppm issued to the fill stand or hydrant tanks and fuel dispensing equipment to the aircraft while solids will not exceed 1.5 mg/liter upon receipt by pipeline, 1.0 mg/liter by tank truck or tank car receipts and from bulk storage issued to the fill stand and 0.5 mg/liter issued to an aircraft. The determination of the water and solids retained in aviation fuel are performed using procedures per T.O. 42B-1-1 and conducted in accordance with Table 4-1 “Turbine Fuel Sampling and Testing Requirements”.

5.1 Water in Fuel

A brief description of the types and sources of water and solids in aviation fuel is necessary to better understand the fuel handling procedures and the function of the filter separators in the fuel supply system to assure fuel quality. Entrained water is present in fuel as well as other sources of water may be delivered to storage tanks. Other sources are through leaks or introduced as vapor which condenses into water or present as dissolved, entrained or free water. Fuel always contains some dissolved water in solution that is dependent upon temperature and the percent aromatics in the fuel. Entrained water is free water suspended in fuel in the form of fine droplets.

Most entrained water will settle out of fuel provided the fuel does not contain contaminants or materials such as surfactants, which contributes to smaller water droplets that settle more slowly. Entrained water is removed by the coalescing action of filter separators and/or water absorption filters installed in the fuel system. Free water is all water that is not in solution and has settled out of the fuel or has been coalesced into large droplets for removal in the filter separator vessel. Free water is removed from storage tanks and filter separators by daily draining or “sumping” any accumulation on the bottom of each tank and filter separator vessel.

5.2 Solids in Fuel

Sediment appears as dust, powder, grains, flakes and stains. Rust is the most common type of solid contamination. The sources of solids and sediment are from every component and material in contact with fuel. Particles that can cause damage to fuel controls and pumps may be extremely small and measured by the micron scale. Particles larger than 10 micron (0.0004 inch) are considered coarse particles while those smaller than 10 micron are considered fine particles. Some of the extremely fine particles can be held in suspension by surfactants but the dispersants make it easier to break up clumps of particles into individual particles which are smaller and settle more slowly. However, the API/IP 5th Edition M100 filter coalescer cartridges have shown excellent performance in removing extremely fine particles. Removal of particles in the 150 micron range (0.006 inch) and larger size are accomplished with the use of metal screens, filters and the filter separators.

After fuel has passed through the second and third filter separator vessel at low flow which is characteristic of Air Force fuel systems, the quantity and size of the sediment have been shown from field test data to be very low. One beneficial characteristic of the +100 additive is its strong solids dispersant capability even though JP-8+100 has more surfactants than JP-8. However, the Spec-Aid® 8Q462 additive is not a strong water dispersant thus allowing the filter cartridges to coalesce water. In most, if not all engines, a last defense for solids in fuel is an inlet filter or wash filter in the main fuel control for the engine and a wash filter in the augmentor fuel control to remove any particles larger than 35 micron that may be liberated from the aircraft fuel tanks.

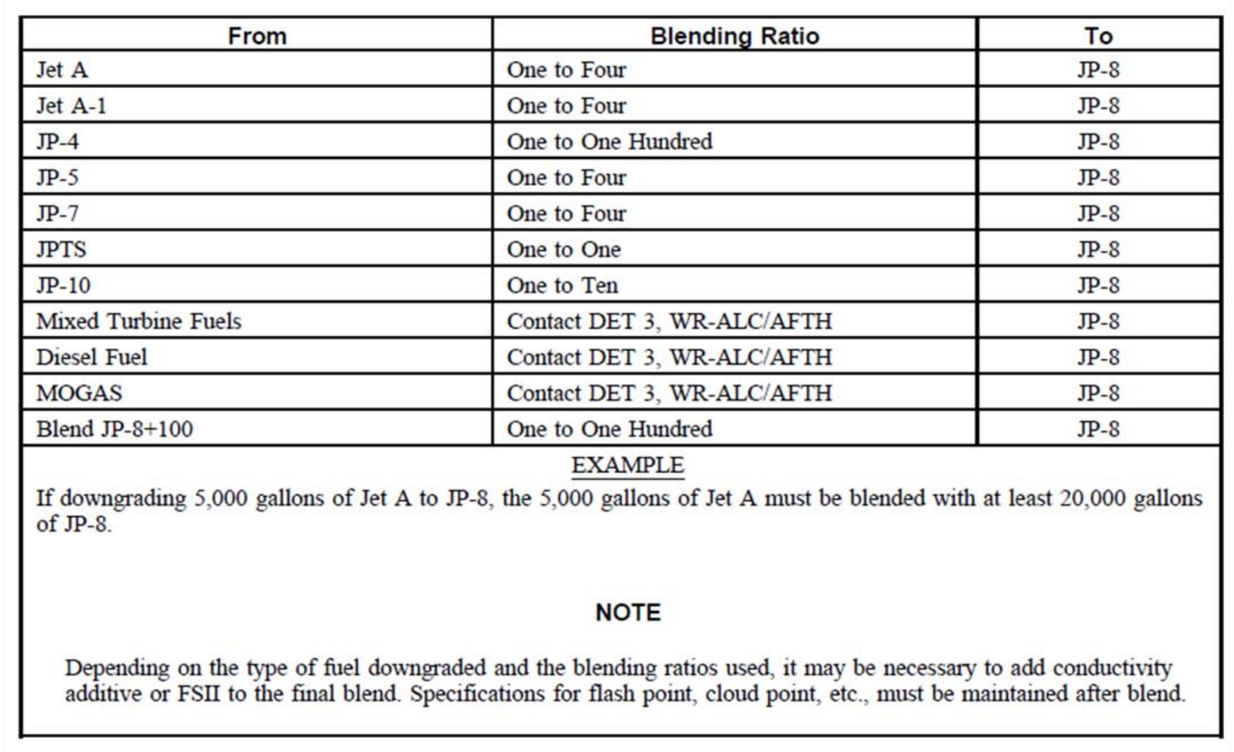
5.3 Fuels Quality Surveillance Program

Although a surge or discharge of solids and water can occasionally occur in fuel delivered from barges, tank cars and older floating roof storage tanks with no structural cover, the surveillance program performed in accordance with T.O. 42B-1-1 provides for timely detection and removal of free water and solids. If the pressure differential limit across the filter separator is exceeded for the measured flow rate, the cartridges are scheduled for removal, the separators and vessel cleaned and the filter coalescer cartridges replaced. Immediate action is also taken to investigate and correct the source of the contaminants.

5.4 Fuel Blending

When JP-8 replaced JP-4 in the 1993 to 1994 time period, technical guidance was provided for the blending of other fuels with JP-8 as shown in **Table 3-2 "Turbine Fuel Blending Table"**, but it was not until Change 1 to T.O. 42B-1-1 dated 1 June 2005 that the initial 1:100 blend ratio for JP-8+100 to JP-8 was entered into Table 3-2. However, JP-8+100 (NATO F-37) became a recognized fuel grade in the T.O. shortly after the initial service evaluations began in 1994. The 1:100 dilution ratio for JP-8+100 returned to JP-8 in operating storage became a significant fuel handling problem for Units to accomplish with only three R-11 fuel trucks. However, several changes have been made in the T.O. to clarify, modify or rescind the fuel handling procedures and precautions for JP-8+100 that were initially mandated by the Implementing Organization. However, Table 3-2 has since been removed for the T.O. but included for any historical value.

Table 3-2. Turbine Fuel Blending Table



From	Blending Ratio	To
Jet A	One to Four	JP-8
Jet A-1	One to Four	JP-8
JP-4	One to One Hundred	JP-8
JP-5	One to Four	JP-8
JP-7	One to Four	JP-8
JPTS	One to One	JP-8
JP-10	One to Ten	JP-8
Mixed Turbine Fuels	Contact DET 3, WR-ALC/AFTH	JP-8
Diesel Fuel	Contact DET 3, WR-ALC/AFTH	JP-8
MOGAS	Contact DET 3, WR-ALC/AFTH	JP-8
Blend JP-8+100	One to One Hundred	JP-8

EXAMPLE

If downgrading 5,000 gallons of Jet A to JP-8, the 5,000 gallons of Jet A must be blended with at least 20,000 gallons of JP-8.

NOTE

Depending on the type of fuel downgraded and the blending ratios used, it may be necessary to add conductivity additive or FSII to the final blend. Specifications for flash point, cloud point, etc., must be maintained after blend.

It is worthy to note that the blending ratios in Table 3-2 vary from 1:1 to 1:100. With the exception of JP-4 which is a highly flammable fuel containing approximately equal fractions of naphtha-based and kerosene-based fuels, the fuels with the low blend ratios are primarily kerosene-based fuels like JP-8 with fuel specifications for specific applications whereas JP-4 and JP-8+100 were assigned the same blend ratio but for different reasons. The 1:100 blend ratio of JP-4 to JP-8 in bulk storage would reduce the naphtha fractions in the fuel blend to mitigate fire hazards while the blend ratio adopted for JP-8+100 to JP-8 was to dilute the surfactants in the +100 additive since there was the perception that the added surfactants would defeat the ability of 3rd Edition filter coalescer cartridges to remove dirt and water.

5.5 Base Fuel Systems

Since fuel systems vary between large and small operational Units, it is important to distinguish between a bulk storage tank that receives delivered fuel and an operating storage tank that issues fuel -- especially when referring to fuel returned to “bulk storage”. Neat JP-8 fuel is delivered by barge, rail tank cars, pipeline or fleets of tanker trucks to large receipt bulk storage tanks. After the receipt bulk storage tank has been filled and time allowed for water and particulates to settle in accordance with T.O. 42B-1-1, fuel is ready for use. Small Units with only two storage tanks will switch their tanks from fuel receipt to operating storage after the fuel quantity used in the operating storage tank has reached a specified level. At large Units, there are two large receipt bulk storage tanks and two large operating storage tanks to supply the quantity of fuel used daily at the fill stands where the +100 additive may be injected. For clarification, when reference is made to fuel returned to “bulk storage”, it is assumed that fuel is returned to the operating storage tank in service unless directed otherwise by AFPET.

5.6 Defuels and Fuel Transfers

Aircraft defuels and fuel transfers are an important part of flight line support. For flexibility, large fighter and pilot training Units use R-11 fuel trucks to issue fuel while the Units assigned wide-body transport and tanker aircraft may have fuel trucks and an underground hydrant system for servicing aircraft. Units with hydrant systems can issue JP-8+100 from in-service operating storage and are capable of transferring fuel to another aircraft on the ramp or back to operating storage. Tanker aircraft frequently off-load fuel to reduce the take-off gross weight (TOGW) and fuel load required to support an airborne refueling mission. The fuel quantity and where the fuel may be transferred can become an issue based on fuel type (JP-8 or JP-8+100), coordination required to off-load large quantities of fuel with the assigned fuel trucks, aircraft availability for transfer of the fuel type, and the available volume in the operating storage tank. Prior to late December 2009, JP-8+100 could be returned to operating “bulk storage” at a 1:1 dilution ratio.

Units with a high ops tempo, such as pilot training and fighters, report that return of fuel to operating storage is rare or not needed since other aircraft are available for immediate fuel transfers. Wide-body and tanker Units must remove all fuel when specific unscheduled and scheduled maintenance tasks are performed. As the operational data will show, Units assigned tanker aircraft historically offload fuel more frequently to better align the onboard fuel load with the mission refueling requirement. The fuel issued to an aircraft and removed are tracked as transactions by Fuels Management since fuel issued to an aircraft at a Unit is considered as a sale of a DESC capital asset at that operating location while a defuel is credited as a return of fuel to DESC inventory. However, the quantity of fuel removed from an aircraft at a Unit can lead to erroneous conclusions if it is assumed that all fuel from aircraft defuels is returned to operating storage since some fuel may be transferred to another tanker or wide-body aircraft.

Below is a table showing a comparison of Defuels/Fuel Issued Ratios for several Units assigned trainer and fighter aircraft, wide-body transport and tanker aircraft and helicopters. The ratios were computed based on the quantity of fuel issued to aircraft and for defuels at Units in the CONUS during 2009 although prior year data were available. While most pilot training Units were included, Units with specific aircraft types were randomly selected that represent a larger population of operational Units to show the ranges of defuels to fuel issued ratios. This table illustrates that the average Defuels/Issued Ratio, as a percentage, is relatively small at pilot training, operational fighter and C-130H Units compared to the average for this ratio at Units assigned Wide-Body Transports and Units assigned both Wide-Body Transports and Tankers.

Table P-1. Aircraft Defuels to Fuel Issued Ratio

(Operational Units in CONUS During 2009)

Aircraft Types Assigned to Units	**Defuels/Issued Ratio** (Note 1)	**Average Defuels/Issued**	**Units Sampled**	**Fuel Transfers to Operating Storage**	**Fuel Trucks Assigned**	**Hydrant System**
Helicopters	0.3%	0.3%	1	None – Next available aircraft	Yes	
Primary Pilot Training	0.6 – 1.5%	< 1%	5	None – Next available aircraft	Yes	
Fighter Pilot Training	2.9%	2.9%	1	None – Next available aircraft	Yes	
Single Engine Fighters	2 – 5.5%	3.5%	10	Rare – Next available aircraft	Yes	
Twin Engine Fighters	2.7 – 5.8%	3.7%	8	Rare – Next available aircraft	Yes	
C-130H Transports	1.1 – 8.8%	4.3%	14	Rare - Transfer to other aircraft	Yes	
Wide-Body Transports	2.6 – 21.7%	9.8%	8	Location Dependent (Note 2)	Yes	Yes
Wide-Body + Tankers	15.6 – 55%	42.5%	10	Location Dependent (Note 2)	Yes	Yes
Note 1: Range of Defuels/Fuel Issued Ratio by aircraft type			Note 2: Fuel transferred to R-11 fuel trucks, Hydrant System or both			

According to Fuels Management personnel, fuel is transferred to the next available aircraft at pilot training and fighter Units and to other C-130H transports if other aircraft are on-station. However, the quantity of fuel removed from wide-body transports and tankers was found to be location dependent due to the maintenance performed and assigned refueling missions. For instance, tire changes and landing gear maintenance as well as accomplishing one or more Time Change Tech Orders may require an aircraft defuel. Note that Tankers assigned to Wide-Body Units caused a significant increase (4.3X) in the average Defuels/Issued Ratio due to fuel load adjustment for the airborne refueling missions supported by the assigned tanker aircraft. Half of the Wide-Body Units with Tankers had Defuels/Issued Ratios ranging from 38% to 43% while half of the Units assigned Wide-Body Transports only had ratios in the range from 2.6% to 3.8%.

At small fighter and C-130H Units assigned three R-11 fuel trucks, the transfer of JP-8 to operating storage was not necessary when only one fuel grade was issued since one empty fuel truck was available for defuels. After conversion to the +100 additive, these Units typically found that emergency defuels and fuel transfers were impossible to perform since it was directed that two fuel trucks would issue JP-8+100 and the other JP-8 leaving no empty R-11 for defuels or fuel transfers. It is noted that the Primary Pilot Training Units have Defuel/Issued Ratios in the range from 0.6 to 1.5% with an average of < 1% indicating that defuels are rare and that returning fuel to operating storage is not needed. Although unscheduled maintenance is a big driver of defuels at single engine fighter Units, one reason for the larger average Defuels/Issued Ratio at Twin Engine Fighter Units is the larger fuel reserve that must be removed before a shop visit. With exception to the Wide-Body Transports and Tanker aircraft, fuel is transferred to the next available aircraft.

6.0 Filter Separator Field Experience

Contact with fuels management personnel at several operational Units provided valuable field information to better understand the quality surveillance program, the quantity of fuel issued and for defuels and the performance of current filter separators. At one large fighter Unit, over 30 million gallons of jet fuel are issued each year. This Unit issues both JP-8 and JP-8+100 using a large fleet of R-11 fuel trucks. The JP-8 fuel is delivered by pipeline from a nearby fuel terminal where the fuel has been run through clay filters and the “military additive package” re-injected to assure fuel quality. The fuel then passes through large receipt filter separators to bulk storage. Fuel issued to the truck fill stands also passes through large filter separator vessels. The +100 additive is then injected at the fill stands as fuel is issued to a fuel truck. The R-11 fuel truck provides a third filtration of the JP-8+100 fuel in a smaller filter separator vessel fitted with the API/IP 1581 5th Edition M100 cartridges before issue to an aircraft.

An estimated 5.6 million gallons of JP-8 are issued by **each** fuel truck during the three-year service interval of the filter separator vessels. Approximately 3.2 million gallons of JP-8+100 are issued from **each** fuel truck. The larger quantity of fuel issued by the JP-8 fuel trucks is due to the fact that 28% of the assigned R-11 fuel trucks are dedicated to issue JP-8 while 44% of the JP-8 fuel is issued to non-program aircraft participating in joint training exercises and to transient aircraft. Scheduled maintenance is performed on each filter separator vessel in the fuel system including the refueler trucks after three years of service. This involves cleaning and inspection of the filter separator vessel, replacing the filter coalescer cartridges and the cleaning and repair of the separator elements. Due to the clean fuel in the fuel system, the Unit proudly reported that **none of the stationary or mobile filter separators have failed due to solids or water over the previous 10 year period and that all filter coalescer cartridges completed the three-year service interval without any problems**.

Another Unit that refuels several types of helicopter aircraft, F-16 fighter and C-130H transport aircraft reported that approximately 5.8 million gallons of jet fuel is issued during each year. Around 36% of the fuel issued was JP-8. The quantity of JP-8 issued by each fuel truck was approximately 1.6 million gallons during the three-year service interval of the filter separator vessels and approximately 1.9 million gallons of JP-8+100 during the three-year service interval for the filter separator vessels in each fuel truck. At this Unit, 40% of the fuel trucks issue JP-8. This Unit has not experienced any receipt filter separator failures from fuel delivered by tanker trucks but did report seasonal problems from rain and rust from their floating roof storage tanks with no structural covers. This fuel storage system is currently being replaced. The surges in water and solids are predictable and a sudden rise in differential pressure across the large filter separator vessels checked during daily surveillance will alert the fuel handlers that a filter separator vessel may need to be scheduled for maintenance before Test Limits are exceeded. However, the quality of fuel to the fill stands and fuel issued by the fuel trucks is always below the Test Limits.

The above experience confirms that the fuel quality surveillance program and monitoring procedures in accordance with the T.O. are working and that bulk storage fuel downstream of the filter separators does not exceed the Test Limits of 0.5 mg/l for solids and 10 ppm for water. In the absence of contaminant surges, this Unit, like the large fighter Unit, reported that the max differential pressure across the filter separator vessels during the three-year service interval has never exceeded 6 psid (pounds per square inch differential). They also report that the 5th Edition M100 filter separators used in the fuel trucks continue to provide much lower levels of measured solids and water than the Test Limits during the service life due in part to the excellent filtration provided by the upstream receipt filtration to bulk storage and the filter separators downstream of the operating storage tanks that issue fuel to the fill stands.

In summary, it is noteworthy that during the three-year service interval of filter separator vessels up to 5.6 million gallons of JP-8 are issued by **each** R-11 fuel truck and from 1.9 to 3.2 million gallons of JP-8+100 are issued by **each** fuel truck at these two Units. Although the fuel volume issued by each fuel truck is staggering, it is incredible that the quality of JP-8 and JP-8+100 is consistently below T.O. Test Limits. Contributing factors include: 1) the API/IP filter separator qualification specifications and procedures, 2) the design, materials selection, fabrication and development expertise of filter manufacturers, 3) the vigilance of the fuels development and quality surveillance organizations within the DOD, and 4) the dedication and superb performance of the Fuels Management Teams, the fuel handlers and QA personnel at Air Force facilities.

The additional surfactants in +100 additive injected in JP-8 at the fill stand have not impacted the performance of the API/IP 5th Edition M100 filter separator vessels during their three-year service interval. They continue to provide fuel with consistently low levels of solids and water even after 1.9 to 3.2 million gallons of JP-8+100 has been issued by each R-11 fuel truck. Since the solids in fuel issued to a refueler are consistently below Test Limits and the refueler tanks are **not** contributing to any surges of solids and accumulated free water is sumped daily, any entrained water in the fuel has not been a problem for the filter separators to coalesce.

Therefore, it is concluded that the sequence of the water challenge in filter separator performance testing should be of greater importance than a solids challenge for filter separators installed in fuel trucks which was the rationale recommended for the test protocol in the Cooperative Filtration Test Program conducted at SwRI®.

7.0 Cooperative Filtration Test Program

In 2003, SwRI® in San Antonio TX, an independent third party with filtration testing expertise, was selected to develop and harmonize a cooperative filtration test program that would be acceptable among the participants. The program was supported by AFPET, DESC, U.S Army AMCOM, GE Infrastructure, Chevron, ExxonMobil, ConocoPhillips, QinetiQ, and MOD/DLO. The goal was to develop a coordinated test protocol for in-service filter coalescer cartridges and then conduct a laboratory test program to: 1) provide technical justification on how much dilution (blend back to bulk storage) would be required to reduce the surfactant impact of JP-8+100 returned to JP-8 fuel stocks, and 2) quantify the surfactancy of typical JP-8+100 additives in isolation and combinations. The team of experts established the test matrices and procedures and the type of data analyses that would be performed to evaluate the test results.

After several meetings, a test protocol for a single element cartridge was adopted and approved by the team members that would reflect larger scale use but reduced the fuel inventory during the test program. To represent field conditions, the dirt challenge was included in the protocol per the API/IP 1581 5th Edition specification but performed after completion of the water removal test protocol. This test sequence was adopted as a change to the standard qualification protocol for filter coalescers since fuel issued from the fill stands at DOD installations has passed through at least two filter separator vessels in the fuel receipt and storage system before issue to a fuel truck thus reducing contaminants below Test Limits. Also, it was considered highly unlikely that any solids would enter the truck fuel tank; however, some entrained water in fuel can become free water in the truck fuel tank but is sumped daily.

Before the test program was initiated, there was also general agreement for the statistical analysis model to be used in evaluating the test data. SwRI® then conducted the single element testing in their API/IP qualified Aviation Fuel Filtration Facility. The test protocol was designed to study water separation in a new, clean element and then particulate filtration as a secondary part following completion of the water tests. Operationally, surfactancy is only manifested as a breakdown of water separability in fuel and so this aspect was key in designing the test protocol.

The operational feature of concern was the relative performance of filter separator vessels used by DOD services to remove dispersed water and particulate contamination. In the qualification protocol, the small element is subjected to a particulate filtration challenge first before being tested exhaustively for water separation. However, the aim of the coordinated protocol was to track water coalescence and dirt filtration as a function of the surfactancy of the fuel additives and combination of additives. It was expected that API/IP 3rd Edition elements would reach a failure point at some relatively low levels of fuel additization, but that it would be possible to continue tracking the additive surfactancy effect by changing to API/IP 5th Edition elements.

Using the API/IP 5th Edition water challenge parameters for guidance, the following protocol was approved by the members of the Cooperative Filtration Test Program:

- Pre-condition --15 minutes
- 100 ppm water challenge -- 60 minutes
- 0.5% water challenge -- 30 minutes
- 3% water challenge -- 30 minutes
- Solids -- 15 psid or one stop/start

The table entitled **Single Element Test Protocol Comparison** on the following page compares the Test Conditions and Protocol of the SwRI® Water Separation Study with the API/IP 1581 5th Edition Qualification Requirements for small elements but is limited in scope to the water and particulate challenges, maximum differential pressure across the filter coalescer and Effluent Test Limits. Note that the Contaminant Addition in the API/IP 1581 5th Edition qualification protocol follows the first 0.01% Water Challenge whereas the Solids Challenge in the SwRI® protocol was conducted after completion of the Water Challenges. Based on the fuel quality surveillance program established by T.O. 42B-1-1 and analyses of fuel systems at several large installations, the occurrence of water challenges in fuel issued from operating bulk storage would be more likely and a greater threat to a filter separator vessel than any liberated solids since fuel in bulk storage and operating storage is consistently clean and below the Test Limits of 10 ppm water and 0.5 mg/l for solids.

Therefore, the SwRI® protocol was designed to study water separation and then particulates filtration as a secondary part following completion of the water tests. The aim was to track water coalescence and dirt filtration as a function of the surfactancy of fuel additives and combination of additives. Additives tested were DCI-4A, STADIS 450, DI-EGME and Spec-Aid® 8Q462. The dirt challenge was conducted after the water challenges which simulated the clean condition of fuel issued from operating bulk storage, hydrant systems and the R-11 fuel trucks at Air Force operational Units although the API/IP 1581 5th Edition specification had reached the conclusion that filtration needed to be equally effective at all points in the fuel handling system.

The API/IP 1581 5th Edition Filter Separator Specification is a rigorous protocol for the qualification of different type filter separators for applications to include: 1) Category "C" Commercial, 2) Category "M" Military and 3) Category "M100" Military with +100 additive. Each filter separator category has specification requirements for the DCI-4A, STADIS 450, DI-EGME and Spec-Aid® 8Q462 additives and testing. The test fuel with additives is prepared according to the filter separator qualification category. During the Pre-conditioning in the Qualification protocol, media migration will not exceed 10 fibers per liter maximum.

Table P-2. Single Element Test Protocol Comparison

(SwRI® Protocol versus API/IP 1581 5th Edition Qualification Requirements)

Type Test	SwRI® Water Separation Study	API/IP 1581 5th Edition Qualification
Pre-conditioning	15 minutes @ 3 gallons/minute with selected additives (a)	30 minutes @ 3 gallons/minute with full additive package (a)
Water Challenge	0.01% water for 60 minutes @ 100% rated flow (b)	0.01% water for 30 minutes @ 100% rated flow (b)
Contaminant Addition	Conducted following water challenges	19 mg/liter for 75 minutes at 100% rated flow (c)
Water Challenge	0.5% water for 30 minutes @ 100% rated flow	(proceed to Dirty Element 0.01% Water Challenge)
Water Challenge	3% water for 10 minutes @ 100% rated flow (d)	(proceed to Dirty Element 0.01% Water Challenge)
Dirty Element (Water Challenge)	(proceed to 19 mg/liter Solids Challenge)	0.01% water for 150 minutes @ 100% rated flow
Dirty Element (Water Challenge)	(proceed to 19 mg/liter Solids Challenge)	3% water for 30 minutes @ 100% rated flow
Solids Challenge (SwRI® Protocol)	19 mg/liter for 75 minutes at 100% rated flow (e)	Conducted after first 0.01% Water Challenge

Notes for Table P-2:

(a) Sufficient fuel volume required for a single pass of fuel through the vessel with no recycling of fuel during the test. Maximum clean initial differential pressure 6 psid across filter coalescer, 10 psid across vessel. During the Pre-conditioning in the Qualification protocol, media migration will not exceed 10 fibers per liter maximum.

(b) Maximum effluent free water - 15 ppm by Aqua-Glo

(c) 15 psid max @ 50 minutes, 45 psid max @ 75 minutes. Contaminants: 90% Ultrafine Test Dust (ISO 12103, A1) + 10% Copperas Red Iron Oxide (R-9998). Effluent Test Limits: Max free water - 15 ppm by Aqua-Glo, Max solids content - 1.0 mg/gal (0.26 mg/l), Holding Capacity: 5.4 grams per gpm of rated flow capacity.

(d) Conduct test only if evaluation passed 0.5% water challenge.

(e) Same Contaminants as (c). Stop when max 15 psid reached or one stop/start.
Effluent Limits: Max free water - 10 ppm by Aqua-Glo, Max solids - 0.5 mg/l solids by Millipore – gravimetric

Comments for Table P-2:

This table compares the Test Conditions and Protocol of the SwRI® Water Separation Study with the API/IP 1581 5th Edition Qualification Requirements for small elements but is limited in scope to the water and particulate challenges, maximum differential pressure across the filter coalescer and Effluent Test Limits.

The SwRI® protocol was designed to study water separation in new clean elements and particulates filtration as a secondary part following completion of the water tests. The aim was to track water coalescence and dirt filtration as a function of the surfactancy of the fuel additives and combination of additives. Additives tested were DCI-4A, STADIS 450, DI-EGME and Spec-Aid® 8Q462. The dirt challenge was conducted after completion of the water challenges which simulated the extremely clean condition of fuel issued from operating bulk storage, hydrant systems and the R-11 fuel trucks at USAF operational Units.

The API/IP 1581 5th Edition Filter Separator Specification is a rigorous protocol for the qualification of different type filter separators for applications to include: 1) Category “C” Commercial, 2) Category “M” Military and 3) Category “M100” Military with +100 additive. Each filter separator category has specification requirements for the DCI-4A, STADIS 450, DI-EGME and Spec-Aid® 8Q462 additives and testing. The order of additive addition to the base fuel (Jet A) is in accordance with the filter separator qualification category tested. The order for Category “C”: 1. STADIS 450 and 2. DCI-4A; for Category “M”: 1. STADIS 450, 2. Di-EGME, and 3. DCI-4A; and for Category “M100”: 1. Spec-Aid® 8Q462, 2. Di-EGME, 3. DCI-4A, and 4. STADIS 450. For the Category “M100” qualification test, note that the Spec-Aid® 8Q462 is added first and STADIS 450 last in accordance with API/IP 1581 5th Edition protocol.

Since the test program was more relevant to military applications, guidance in accordance with T.O. 42B-1-1 was used for the pass/fail Test Limits:

- Water by Aqua-Glo -- 10 ppm
- Solids by Millipore -- 0.5 mg/l gravimetric

The evaluation used a side-by-side element configuration (a filter coalescer and a separator) in a single housing. In addition to recording test time, flow rate, differential pressure, conductivity, and effluent water content by Aqua-Glo, additional data were obtained from the filtration process to evaluate new instrumentation:

- On-line particle counting
- Effluent water by Karl Fischer titration
- Turbidity at 25 and 90 °F.
- Interfacial tension (IFT)
- Dissolved water by Viasala

Since the Karl Fischer titration measures total water, the saturation limit was estimated for each evaluation and subtracted from the Karl Fischer total water value (called the adjusted KF). This allowed direct comparison with the Aqua-Glo free water measurements.

Upon completion of the test matrix and data analyses, the results and recommendations were presented to the team members for review and comments as shown in the Executive Summary for the Aviation Fuel Filtration Cooperative R&D Program **Section 2.10.3** of this report. A more thorough review of the Executive Summary from the SwRI® final report is encouraged. An abbreviated synopsis of the cooperative program is as follows:

The rigorous filter coalescer tests proved **"there was no fundamental difference in average filtration performance between JP-8 and JP-8+100 @ 256"**mg/l. For any portion of the test matrix where JP-8 failed, the equivalent JP-8+100 test failed at the same time or later in the test protocol. However, JP-8 and JP-8+100 performed differently than Jet A as the Jet A tests passed the protocol using the agreed upon failure criteria. Based on the results in the above referenced Execution Summary, it was concluded that **"JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage"**.

Based on statistical analyses of filtration testing of the **"military additive package"**, it was concluded that:

- The Corrosion Inhibitor (CI) has detrimental effects on water removal performance at the 0.5% water challenge.
- The Fuel System Icing Inhibitor (FSII) has detrimental effects on water removal performance at the 100 ppm water challenge.
- The Spec-Aid® 8Q462 thermal stability additive (+100) does not affect the filtration performance for either water or solids. Increases in the +100 additive resulted in decreases in the maximum Aqua-Glo during the 100 ppm water challenge..

It is noteworthy that **CI and FSII have detrimental effects on water removal performance** while it was determined that **the +100 additive does not affect the filtration performance for either water or solids** which is **opposite** to the early perceptions for the +100 additive.

The technical paper “JP-8+100 and Filtration” in **Appendix A** discusses the field testing at Laughlin AFB that verified the conclusions of the SwRI® report for the API 1581 3rd Edition and the API/IP 1581 5th Edition M100 filter separators and the DOD filter separators tested to the API/IP 5th Edition, M class protocol. It is noteworthy that all the filter coalescers continued to perform satisfactorily in service at Laughlin AFB. No filtration failures for particulates or water were reported based on scheduled fuel sampling of the refueler trucks and the prescribed surveillance testing. Also, there were no 3rd Edition, DOD, or 5th Edition filter separators removed for high differential pressure during the 90-day field evaluation or during their three year service interval.

8.0 Conclusions

After reading this report, there should be little doubt that the use of the Spec-Aid® 8Q462 thermal stability additive in JP-8 along with best maintenance practices and procedures has reduced the impact of coking in the engines that power the legacy fighter, C-130H transport, helicopter and pilot training aircraft in the Air Force inventory. More detailed information of the maintenance benefits from using JP-8+100 at these and other Units can be found in **Section 3.2** and **Appendix L** of this report. Also, a more detailed account of the issues caused by the overly cautious fuel handling procedures that were initially mandated can be found in **Sections 2.1.8, 2.10.1** and **8.1** of this report.

Five years of field experience at two large operational Units confirms that JP-8 issued to fill stands as well as the JP-8+100 fuel issued from the R-11 fuel trucks to aircraft are consistently clean and below the Test Limits for solids and water. The additional surfactants in the +100 additive injected in JP-8 at the fill stand have not impacted the ability of the API/IP 1581 5th Edition M100 filter separator vessels to maintain low levels of solids and water during their three-year service interval even after 3.2 million gallons of JP-8+100 has been issued by each of the R-11 fuel trucks.

Although the initial perceptions were accurate for many of the candidate +100 additives that **did not** pass the rigorous screening and compatibility testing conducted by AFRL/RZPF, the Spec-Aid® 8Q462 thermal stability additive is a strong dispersant of solids in JP-8 and has no serious detrimental effect on water coalescence in filter cartridges affecting the service life and overall performance of filter separators to remove solids and water.

The rigorous filter coalescer tests conducted at SwRI®, while admittedly not in strict adherence to the API/IP 1581 5th Edition filter separator qualification protocol, none the less **proved** for typical real-world operational scenarios that **“there was no fundamental difference in average filtration performance between JP-8 and JP-8+100 @ 256”**mg/l and that **“JP-8+100 does not require dilution for JP-8+100 fuel returned to bulk storage”**. The filtration testing of JP-8 concluded that **CI and FSII have detrimental effects on water removal performance** while **the +100 additive does not affect the filtration performance for either water or solids.**

Field testing over a 90-day period at Laughlin AFB verified the conclusions of the SwRI® report that the API 1581 3rd Edition, the API/IP 1581 5th Edition M100 filter separators and the DOD filter separators tested to the API/IP 5th Edition, M class protocol were not defeated by JP-8+100 fuel. As a result, the fuel handling precautions and restrictions in T.O. 42B-1-1 were modified or rescinded in July 2006. The T.O. stated that “Tests have shown that JP-8+100 will not disarm API 3rd Edition and API 5th Edition M100 series coalescer elements” and Change 1-15 August 2008 to T.O. 42B-1-1 stated that “If there are no aircraft available to issue the defueled JP-8+100 and Return to Bulk (RTB) is necessary, no dilution is required, it is recommended to RTB into the fullest operating tank". From field experience at large operational Units with high ops tempo, RTB has been found to be rare or not needed.

Mandating a return to a 1:100 dilution ratio for JP-8+100 in late December 2009 without any technical basis or defendable supporting data tacitly disregarded the body of scientific data and field experience that proved that the surfactants in JP-8+100 do not disarm the current technology filter coalescers qualified to the API/IP 1581 Specification 5th Edition M100 filter separators. Operational and training Units had been using a **1:1** dilution ratio without any issues since 31 July 2006 as recommended by Change 3 to T.O. 42B-1-1. Two other concerns may have influenced this administrative decision: 1) apprehensions that any JP-8+100 returned to bulk storage will infect fuel systems at other installations if a transient aircraft refueled at a +100 'program' Unit and required a defuel or fuel transfer at a 'non-program' installation, and 2) that administrative posturing or leveraging is occurring in the fuels support infrastructure that unfortunately will directly impact the maintenance workload for Air Force aircraft and engines due to coking from use of JP-8.

Amending the RTB dilution ratio to 1:10 on 2 April 2010 may offer some relief but small Units prefer a 1:1 dilution ratio without any handling restrictions to make use of JP-8+100 transparent if, for operational reasons, some fuel must be returned to operating storage. As a result, many of the smaller fighter and C-130H transport Units will not return to using JP-8+100 because of the extra workload for the fuel handlers in performing defuels and fuel transfers to operating storage at the mandated 1:10 dilution ratio with only three assigned R-11 fuel trucks.

Since the return of JP-8+100 to operating storage is rare or not needed at Units with high ops tempo and no filter separator technical issues have occurred or exist with the newer API/IP Specification 5th Edition M100 class filter separator cartridges installed in fuel systems at Air Force installations, any emerging infrastructure support issues and fuel handling restrictions should be openly discussed and objectively resolved.

9.0 Recommendations

Forcing across-the-board fuel handling restrictions by requiring a 1:100 blendback dilution ratio in late December 2009 for JP-8+100 returned to DESC JP-8 capitalized assets and then amending that guidance to a 1:10 dilution ratio on 2 April 2010 will most likely be seen by operational Units as confusing at best and a lack of confidence from 15 years of experience using the +100 additive. Even the 1:10 dilution ratio is not, in the opinion of this author, considered in the best interests of the Air Force and the DOD. Widespread use of JP-8+100 will be limited to large operational Units and increased maintenance workload will result for legacy aircraft engines designed to use JP-4 that are assigned to large and small operational Units.

A decade and a half of using JP-8+100 has not uncovered any filtration issues as speculated or feared nor has any fuel from operating bulk storage with any trace of +100 additive surfactants been inadvertently issued to non-program aircraft. Therefore, a more sensible approach would be to: 1) return to guidance allowing 1:1 dilution ratios and utilize existing approaches to manage defuels of JP-8+100, 2) correct any operational problems with JP-8+100 as they occur, and 3) develop any additional policies and procedures to deal with any unforeseen issues that might occur in the future -- providing they can be defined.

Unfortunately, overly restrictive fuel handling policies will impact mission readiness forcing Units to **not** use JP-8+100. This will inevitably result in maintenance cost implications for current and future maintenance budgets of the MAJCOMs. MAJCOMs should not be saddled with increased financial burdens for sake of a fuels handling event that is feared but has never been experienced or can be handled more effectively by timely problem solving.

Infrastructure support issues need to be settled so that Units can return to the 1:1 dilution ratio for JP-8+100 returned to operating storage. This will again allow the return to widespread use of JP-8+100 free from handling restrictions giving operators the flexibility to perform defuels and fuel transfers with the available R-11 fuel trucks at both large and small Air Force Units.

Collaborative and cooperative endeavors should be initiated with other military services to resolve any perceived fuel handling issues at Air Force installations that are not covered in T.O. 42B-1-1, providing they can be defined, to help allay any concerns that may impact the receipt of JP-8 at Air Force Units capable of issuing JP-8 or JP-8+100 to transient aircraft and during joint service training exercises.

If the dilution ratio continues to be unresolved, the fuel management expertise in AFPET at WPAFB, OH can effectively assist each field Unit in monitoring the surfactancy concentrations in the JP-8 fuel in the operating storage tanks if any JP-8+100 fuel needs to be returned to bulk.

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

+100	Thermal stability additive produced by GE Betz, Spec-Aid® 8Q462
AC	Advisory Circular (FAA)
ACC	Air Combat Command
ACO	Aircraft Certification Office (FAA)
AETC	Air Educational Training Command
AFC	Augmentor Fuel Control (F100), Afterburner Fuel Control (F110)
AFPC	Augmentor Fuel Pump Control (F100)
AFRL	Air Force Research Laboratory, WPAFB OH
AFPET	Air Force Petroleum Office
AFT	Afterburner Fuel Temperature Control (F110 engine)
AGE	Aerospace Ground Equipment
AGETS	Automated Ground Engine Test System
AMCOM	Army Aviation and Missile Command
AMT	Accelerated Mission Test
ANG	Air National Guard
API/IP	American Petroleum Institute/Institute of Petroleum
ASEP	Augmentor Signature Elimination Probe
ATP	Acceptance Test Procedure
ATTC	Aviation Technical Test Center (Army)
BOM	Bill of Material
BUC	Back Up Control (F100-PW-200 Fuel Control)
CAMS	Comprehensive Aircraft Management System
CAR	Commercial Aviation Regulation
CE	Chief Engineer
CEDS	Comprehensive Engine Diagnostic Set
CEMS	Comprehensive Engine Management System
CENC	Convergent Exhaust Nozzle Control (F100)
CET	Combustor Exit Temperature
CETADS	Comprehensive Engine Trending and Diagnostic System
CF	Canadian Forces
CIP	Joint Service Component Improvement Program
CI/LI	Corrosion Inhibitor/Lubrication Improver
CIVV	Compressor Inlet Variable Vane (F100)
CL	Confidence Limit (statistics)
CMB	Contact Memory Buttons
CONOPS	Concept of Operations
CONUS	Continental United States
CU	Conductivity Unit
CY	Calendar Year
DEEC	Digital Electronic Engine Control (F100)
DESC	Defense Energy Support Center
DIFM	Due In For Maintenance
DOD	Department of Defense

DOE	Director of Engineering
DLA	Defense Logistics Agency
EA	Economic Analysis (Army)
ECS	Aircraft Environmental Control System
EDU	Engine Diagnostic Unit
EEC	Electronic Engine Control (F110)
EFH	Engine Flight Hours
EHR	Engine Health Recorder
EIB	Engineering Information Bulletin
EMS	Engine Monitoring System (F110)
EOT	Engine Operating Time
EPR	Engine Pressure Ratio
ERRC	Engine Regional Repair Center
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FARP	Forward Arming Refueling Point
FCF	Functional Check Flight
FH	Flight Hours (Aircraft)
FMC	Fully Mission Capable
FMT	Fuel Management Team
FOB	Forward Operations Base
FOD	Foreign Object Damage
FSII	Fuel System Icing Inhibitor
FW	Fighter Wing
gal	gallon
GSD	General Supply Division
HMC	How Malfunction (Mal) Code (CEMS)
HPO	Hourly Post Operation Inspection
HSC	Home Station Check
IFE	In Flight Emergency
IPT	Integrated Product Team
ISO	Isochronal Inspection – 12 month interval
ISR	Initial Service Release
JEIM	Jet Engine Intermediate Maintenance
JFS	Jet Fuel Starter
LANTIRN	Low Altitude Navigation and Targeting Infrared for Night
lbm	pounds mass
LOD	Light-Off Detector
LRS	Logistics Readiness Support
MAJCOM	Major Command
MDS	Model Design Series
MEC	Main Engine Control (F110)
MFC	Main Fuel Control (F100)
mg/l	milligrams/liter
MIP	Master Implementation Plan
MOC	Maintenance Operations Control

MSB	Main Spray Bar (J85 Afterburner)
MSD	Materials Supply Division
MSDS	Materials Safety Data Sheet
MTBR	Mean Time before Removal
Mx	Maintenance (Abbreviation)
N1	Fan Rotor Speed (RPM)
N2	Core Rotor Speed (RPM)
NAVAIR	Naval Air Systems Command
NMCM	Not Mission Capable due to Maintenance
NMCS	Not Mission Capable due to Supply
NRE	Non-Recurring Engineering (Army)
NRTS	Not Repairable This Station
O/H	Overhaul
O&M	Operational and Maintenance
OC-ALC	Oklahoma City Air Logistics Command
OEM	Original Equipment Manufacturer
OPR	Office of Primary Responsibility
OPTEMPO	Operational Tempo
OSD	Office of the Secretary of Defense
PD	Police Department
PDA	Personal Digital Assistant
PDM	Programmed Depot Maintenance
PE	Periodic Inspection
POL	Petroleum, Oils and Lubricants
PPE	Personnel Protective Equipment
ppmv	Parts per Million by volume
pS/m	pico Siemens/meter
PQDR	Product Quality Deficiency Report
PSB	Pilot Spray Bar (J85 Afterburner)
Psid	Pounds/square inch differential pressure
R2	Remove and Replace
RCC	Resource Control Center
RCM	Reliability Centered Maintenance
RCVV	Rear Compressor Variable Vane (F100)
RDAF	Royal Danish Air Force
ROI	Return on Investment
RT	Refueling Tender (Canadian)
RTB	Return to Bulk
RTS	Return to Service
SA-ALC	San Antonio Air Logistics Command
SAP	Super Absorbent Polymer
SDA	Static Dissipater Additive
SFC	Specific Fuel Consumption
SIR	Savings to Investment Ratio (ARMY)
SLEP	F110 Service Life Extension Program
SPM	System Program Manager

SPO	System Program Office
STC	Supplemental Type Certificate (FAA)
SwRI®	Southwest Research Institute
TAC	Total Accumulated Cycles
TACOM	Army Tank & Automotive Command
TCTO	Time Change Tech Order
TC	Type Certificate (FAA)
TCDS	Type Certificate Data Sheet (FAA)
TAMMS-A	The Army Maintenance Management System-Aviation
TIM	Truck Interface Modules (ARMY)
Tt2.5	F100 Total Temperature at Fan Hub Exit
UFC	Unified Fuel Control (F100-PW-100/-200)
UK MOD	United Kingdom Ministry of Defense
USAFE	USAF in Europe
USN	United States Navy
WPAFB	Wright Patterson Air Force Base (Dayton OH)