SPECIAL REPORT RDMR-AE-16-02

# CERTIFICATION REPORT: ARMY AVIATION ALTERNATIVE FUELS CERTIFICATION PROGRAM

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**13. ABSTRACT (Maximum 200 Words)**

The Department of Defense's primary alternative fuels goal is to ensure operational military readiness, improve battle space effectiveness, and further flexibility of military operations through the ability to use multiple, reliable fuel sources. The Army Aviation Engineering Directorate (AED) developed an Alternative Fuels Certification Program whereas three alternative fuels were tested as part of this program and are detailed in this report. Following completion of the test program, all alternative fuel blends tested were found to be at a Technical Readiness Level (TRL) 7. While this report overall contains unclassified information, several of the supporting test reports do contain proprietary information and as such are not included in this report. Release of those test reports must be coordinated through the appropriate authority.

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## Executive Summary

The Department of Defense's primary alternative fuels goal is to ensure operational military readiness, improve battle space effectiveness, and further flexibility of military operations through the ability to use multiple, reliable fuel sources. The Army Aviation Engineering Directorate (AED) developed an Alternative Fuels Certification Program Plan that was used in the following effort, in collaboration and concurrence with the Tri-Service Alternative Fuels Team. This collaboration minimized duplication and maximized efficiency during the certification tasks. The following report outlines the interactions and resultant tests necessary to ensure that the alternative fuel certification requirements were established and satisfied.

Three alternative fuels were tested as part of this program. Fischer Tropsch-Synthetic Paraffinic Kerosene (FT-SPK), Hydroprocessed Esters and Fatty Acids (HEFA), and Alcohol-to-Jet (ATJ) were blended 50/50 with standard JP-8 and fuel characteristics and aircraft operation with the blends were compared with JP-8. The goals of the alternative fuels certification study was to establish the viability of alternative fuel blends for use in Army Aviation, establish the alternative fuel blends as drop in fuel for Army Aviation, to certify all Army Aviation Platforms for use with these alternative fuel blends, and to modify the JP-8 specifications to accept the blends with no restrictions by 2016 (50% by October 2014). Additionally, the study was to provide for the certification that all GSE and other infrastructure are able to process the three tested alternative fuel blends.

The fuel purchase for this program was through a qualified Defense Logistics Agency – Energy (DLA-E) vendor utilizing funding provided to the Research, Development, Engineering Command (RDECOM) and Aviation and Missile Research Development Engineering Center. (AMRDEC) by a congressional add for alternative energy research. Testing performed for this program was funded under the Army Science and Technology Office and covered Chemistry, Material, Toxicology, Infrastructure and Fire Safety, Aviation Aircraft/Propulsion, and Non-Aviation Engine/Equipment. All testing documentation provided under this program is the property of the Department of Defense.

Although the United States Air Force (USAF), the United States Navy (USN), and the United States Army (USA) had previously collaborated, however it was not until the Tri-Service Alternative Fuels Team was officially formed on June 6th, 2012 that consolidated efforts were outlined to prevent duplication within the alternative fuel certification program. Through this program, the Army collaborated with other DOD agencies to achieve FT-SPK, HEFA, and ATJ certification with a minimal Army investment.

At the completion of this program all the alternative fuel blends were at a Technical Readiness Level (TRL) 7. While this report overall contains unclassified information, several of the supporting test reports do contain proprietary information and as such not included in this report. Release of those test reports must be coordinated through the appropriate authority.

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## 1.0 SCOPE.

### 1.1 Purpose.

This document was developed to report the process used by the Army Aviation Engineering Directorate (AED) and the Tri-Service Alternative Fuels Team to document the certification of the Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK), Hydroprocessed Esters and Fatty Acids (HEFA), and Alcohol-to-Jet (ATJ) fuels.

### 1.2 Description.

In late FY10, the Program Executive Office – Aviation (PEO AVN), the Cargo and Utility Program Managers (PM), and the AED began the process of satisfying certification requirement for alternative fuel blends using FT-SPK and JP-8. FT-SPK uses coal, natural gas and bio mass as its feedstock. In the process of certifying FT-SPK blends, the Army also initiated certification of the bio-renewable fuel blend, HEFA, which is also called Hydroprocessed Renewable Jet (HRJ). HEFA/HRJ fuel is based on more environmentally acceptable, renewable feedstock but is believed to have cost and crop availability concerns. The JP-8 specification MIL-DTL 83133H currently includes blends with both FT-SPK and HEFA.

ATJ fuels can use more readily available feedstocks, timber and agricultural waste. Production facilities were coming on line in FY12 and costs were projected to be competitive with JP-8. In this program, the Army funded specific activities for FT-SPK, HEFA/HRJ and ATJ blend certification, all deriving from MIL-HDBK-510-1A. All non-petroleum fuels must meet all of the requirements of the JP-8 specification, MIL-DTL-83133H. A major difference between JP-8 and each of the non-petroleum bio-fuels is their lack of aromatics. While producing a cleaner burning fuel with high thermal stability, the lack of aromatics presents major challenges. Aromatics are involved in the process that makes self-sealing fuel cells (fuel tanks) seal when penetrated by gunfire. In addition, they are important to the sealing ability of seals in fuel-wetted joints, as within fuel controls and fuel lines.

The purpose of this test program was to ensure that the candidate fuels had no negative impacts on engine safety, durability, or performance or pose any hazard to personnel that would affect the clearance and certification for use. The toxicology evaluations were performed to determine that the candidate fuel did not adversely affect personnel and to ensure the safety of those personnel who would be required to work with it. These objectives was accomplished by investigating the impact of the candidate fuel on fuel specification properties, fit-for-purpose properties, component rig test, engine tests, laboratory tests, and flight demonstrations.

### 1.3 The Certification Process.

The current process for certifying fuel requires each branch of the military to independently determine if the fuel or fuel additive is fit for purpose, meets operational, performance, durability, safety, and other weapon system considerations, and then document the suitability for use as either a primary, alternate or emergency fuel. The main goal of the aerospace fuel certification process is to ensure the desired level of safety, performance, durability, supportability, interoperability, etc. with the least possible economic burden to systems, equipment and infrastructure. Additionally, the process is to certify the fuel in the most cost-effective manner by minimizing duplication of effort and maximizing sharing of data between all systems. The services used MIL-HDBK-510-1A as guidance in the certification activities. Through establishment of the Tri-Service Alternative Fuels Team, MIL-HDBK-510-1A was addressed in the most cost effective, non-redundant manner.

### 1.4 Tri-Service Alternative Fuels Team Organization.

The following is a list of Tri-Service Committees and their members who collaborated on the Tri-Service Alternative Fuels Team. The Team was lead by an Executive committee with representation from the Aviation and Missile Research, Development, and Engineering Center (AMRDEC), Air Force Research Laboratory (AFRL) and Naval Air Systems Command (NAVAIR).. Addressing specific technical areas were a chemistry team, a materials team, a toxicology team, and an Aviation Propulsion team. The teams included representation from the AMRDEC, AFRL, NAVAIR, Tank and Automotive Research, Development and Engineering Center (TARDEC), Naval Research Laboratory (NRL), U.S. Air Force Alternative Fuels Certification Office (AFCO), United States Army Public Health Command (USAPHC), and Naval Medical Research Unit Dayton (NAMRU-D). With this construct, all areas of MIL-HDBK-510-1A were addressed through a collaborative approach.

### 1.5 Scope of Testing.

Guidance for aerospace alternative fuels certification for the Department of Defense testing is outlined in MIL-HDBK-510A (USAF), formerly, MIL-HDBK-510-1A. The scope of testing begins with specification property evaluations followed by fit-for-purpose testing, then component tests, engine tests, and finally flight demonstrations when required. Fit-for-Purpose Properties as agreed upon by the engine manufacturers are shown in Table 1 of ASTM D 4054. Accepted test methods for evaluating the Fit-for-Purpose Properties are shown along with limits. Some Fit-for-Purpose Properties have no well defined limits. In these cases, the effect of the new fuel or new additive on a Fit-for-Purpose property must fall within the scope of experience of the engine manufacturers. To a large extent, MIL-HDBK-510-1A parallels the commercial standard, ASTM-D4054. The MIL-HDBK adds a few military specific areas of test.

#### 1.5.1 Overview of Military Certification Process

##### 1.5.1.1 MIL-HDBK-510A (Formerly MIL-HDBK-510-1A).

This handbook was originally published by the U.S. Air Force Alternative Fuels Certification Office (AFCO) on 13 November 2008 and updated in 4 August 2014 for guidance only. This military handbook documents a lean, knowledge-based process to evaluate, approve, and certify fuels and fuel additives. It was developed to fill the knowledge and experience gaps that exist when considering all aspects related to fuels in a single integrated and costs effective manner instead of a system by system approach. Because JP-8 has been the standard military fuel for more than two decades this handbook compares any new fuel or fuel additive to the JP-8 baseline in terms of safety of operation, performance, durability, survivability, material compatibility, environmental impacts, safety and health. One of the goals, during this certification program, was for each team to update the protocols outlined in each subsection to reflect a common set of tests that each service would agree as required to certify all new alternative fuels. Table 1 below shows an overview of current tasks as outlined in the MIL-HDBK-510A (USAF) and has been agreed upon by each committee as relevant areas to begin establishing future alternative fuels testing protocols.

## Table 1. MIL-HDBK-510A Overview of Tasks

**Chemical Tests (Appendix B)**

- Properties:
  - Chemical description of fuel
  - MSDS issued by supplier
  - Environmental, Safety and Occupational Health (ESOH) review
  - Property test as required per MIL-DTL-83133
  - Properties related to system safety (Table B-I)
  - Flash Point
  - Freezing
  - Viscosity @ -20 C
- Table B-II (System Safety and Performance Related Fuel Properties):
  - Volatility:
    - Autoignition Temperature
    - Vapor Pressure, True vs. Temperature
    - Hot Surface Ignition
    - Flame Speed
  - Combustion:
    - Flammability Limits
  - Fluidity:
    - Viscosity vs. Temperature
    - Density vs. Temperature
    - Bulk Modulus vs. Pressure
  - Contaminants:
    - Water Solubility
    - Trace Elements
    - Electrical Characteristics
    - Dielectric Constant vs. Density vs. Temperature
  - Others:
    - Lubricity
    - Additive Compatibility
    - Storage Stability
    - Specific Heat vs. Temperature
    - Surface Tension vs. Temperature
    - Thermal Conductivity vs. Temperature
- Component Level Evaluation:
  - Auxiliary and Emergency Power Units (APU/EPU) Evaluation
  - Support Equipment and Vehicles:
    - SE&V Certification Process:
      - Fuel Functions
      - Power Generations
      - Lubrication
      - Heat Removal
    - SE&V Properties
- Table B-III (System Performance Related Fuel Properties Characteristics)
  - Hot Surface Ignition Under Turbulent Airflow
  - Thermal Expansion
  - Ignition Energy, Minimum
  - Ostwald Coefficient
  - Cetane Number
  - Electrical Conductivity vs. Temperature
  - Pour Point
  - Velocity of Sound
- Critical Component Level Evaluation
  - Auxiliary and Emergency Power Units (APU/EPU) Evaluation
  - SE&V Properties
  - Subset 2, Performance Verification
  - Additional Equipment Evaluation/Testing
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  - Enthalpy vs. Temperature (0 C – 250 C)
  - Critical Component Level Evaluation:
  - Fuel System Icing Inhibitor (FSII) Rig Test
  - SE&V Evaluation
  - Performance/Durability/Supportability Verification

Additional Equipment Evaluations

**Material Compatibility Tests (Appendix D)**

- Test Temperature (Table D-II & D-III)
- Baseline Test Fluids (Table D-I)
- Additive Testing (Table D-II & D-III)
- Alternative Fuel Testing (Table D-II & D-III)
- Testing Procedures:
- Nonmetallic Material Compatibility Test (Table D-II)
- Metallic Material Tests are as Follows:
- Corrosion Testing
- Light-Optical Evaluation
- Micro-structural Evaluation
- Metallic Specimens have to be weighed during the temperature aging process
- Nonmetallic's (Table D-II)
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- Complete Materials Testing (Table D-IV)
- Related Materials Testing
- System Level Testing

**Toxicity Tests (Appendix E)**

- Toxicity Evaluation
  - Acute toxicity studies
    - Oral or,
    - Inhalation
  - *In vitro* Genotoxicity tests
    - Bacterial reverse mutation
    - Micronucleus
    - Comet assay
    - Human lymphocyte gene mutation
  - Irritation studies
    - Dermal
    - Eye
  - Dermal sensitization
  - Range-finder study
    - 2 week (Pre-study)
    - 90 day inhalation
  - Immunotoxicity
  - Genetic Biomarkers
- Industrial Hygiene (IH) Review (Bioenvironmental Engineering (BEE))
- Health Hazard Assessment (HHA)
- Environmental Review
- Exposure Assessment
- Environmental

**Propulsion Tests (Appendix G)**

- Flash Point
- Freezing Point
- Viscosity @ 20C
- Viscosity vs. Temperature (-40C to +90C)
- Surface Tension
- Vapor Pressure (Reid Vapor Pressure)
- Heat of Combustion, Net
- Latent Heat of Vaporization
- Flammability Limits
- Trace Elements
- Density vs. Temperature (-40C to +90C)
- Bulk Modulus vs. Temperature (-40C to 90C)
- Enthalpy vs. Temperature (0C to +250C)
- Thermal Stability
- Lubricity
- Thermal Conductivity
- Specific Heat vs. Temperature (-40C to +150C)
- Flame Tube Test
- Combustor Rig Testing
- Fuel Injector Coking Rig Description
- Combustor Section Rig
- Full Annular Rig
- Sea Level and Simulated Altitude Engine Testing
- Engine Flight Testing
- Field Service Evaluations (FSE)
- Engine Test Durability Qualification and Accelerating Mission Testing (AMT)
- Engine subsystem Component Testing
- Inspections (Routine or Special)

### 1.5.1.2 Key Military Organizational Participants.

On June 7th, 2012 as a product from the Tri-Service Petroleum, Oils, and Lubricants (POL) Users Group meeting the Tri-Service Alternative Fuels Team was organized with the mission of collaborating on the certification of ATJ fuel for the Department of Defense. Key participating organization in the certification activity were the United States Air Force (UASF) Alternative Fuels Certification Office (AFCO), the Air Force Research Lab (AFRL), the Air Force Petroleum Agency (AFPA), Warner Robins Air Logistics Complex (WR-ALC), the United States Navy (USN) Naval Air Systems Command (NAVAIR), Naval Sea Systems Command (NAVSEA), Naval Medical Research Unit Dayton (NAMRU-D), the United States Army Research Development and Engineering Command (RDECOM), Tank Automotive Research, Development, and Engineering Center (TARDEC), Southwest Research Institute (SwRI), Aviation and Missile Research Development and Engineering Center (AMRDEC), Aviation Engineering Directorate (AED), and the United States Army Public Health Command (USAPHC). Section 9 contains a detailed description and outline of each of these organizations.

## 1.6 Overview of Commercial Standards

As indicated in paragraph 1.5, MIL-HDBK-510-1A parallels ASTM D4054 to a large extent and was used to derive the baseline for the MIL-HDBK. Thus either standard is an acceptable basis for alternative fuel certification with the exception of those requirements that are specific to the military.

### 1.6.1 ASTM D4054 Process.

An overview of the approval process discussed in ASTM D4054 is shown in Fig. 1. The approval process is comprised of three parts: *(1)* Test Program, *(2)* OEM Internal Review, and *(3)* Specification Change Determination. For the military certification of alternative fuels, the Test Program portion of the standard was addressed.

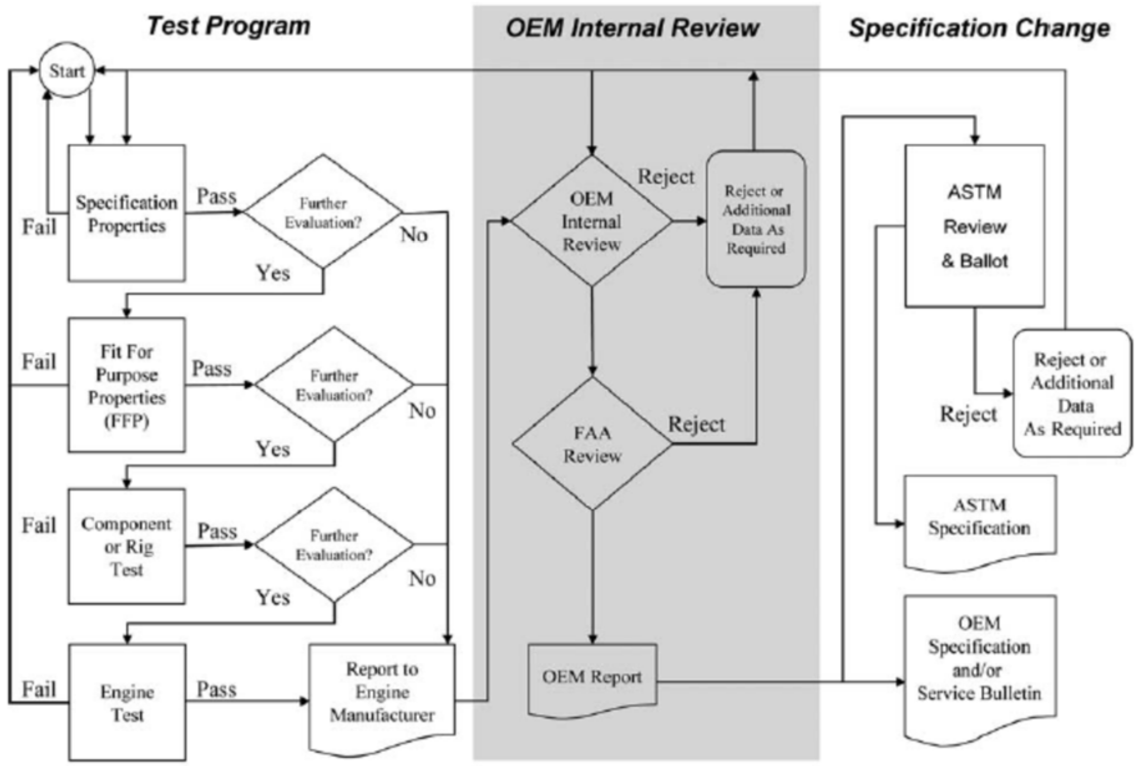



***Figure 1.  Overview of Commercial Fuel and Additive Process***

*Test Program*—The purpose of the test program is to ensure that the candidate fuel or additive will have no negative impact on engine safety, durability, or performance.  This is accomplished by investigating the impact of the candidate fuel or additive on fuel specification properties, fit-for-purpose properties, component rig tests, or engine tests.  Fig. 2 lists elements of the test program; it should be considered a guideline

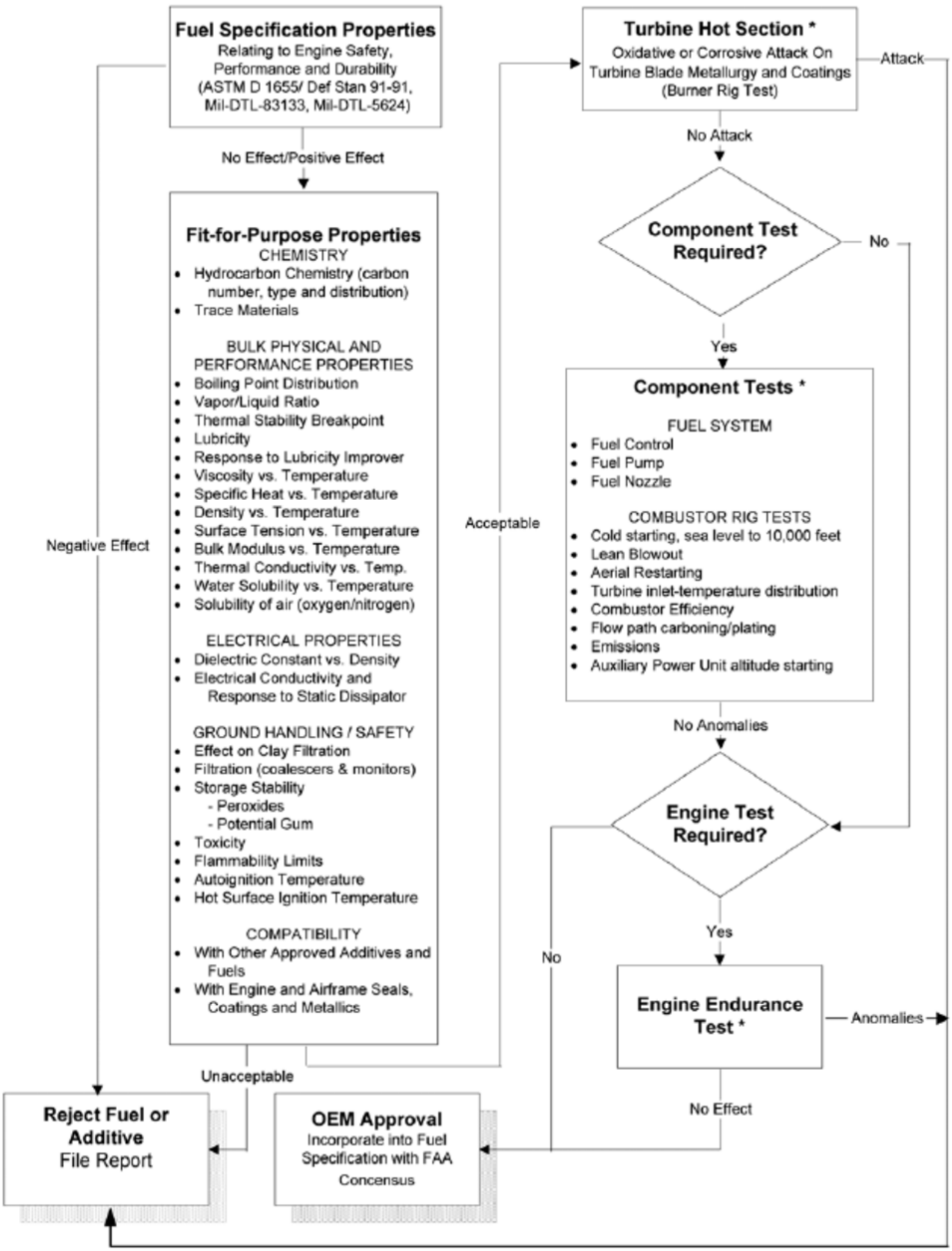



*Figure 2. ASTM Test Program Overview*

## 2.0 Alternative Fuel Process Overview.

### 2.1 General.

Jet fuel is a mixture of a large number of different hydrocarbons. The range of their sizes (molecular weights or carbon numbers) is restricted by the requirements for the product, for example, the freezing point or smoke point. Kerosene-type jet fuel (including Jet A and Jet A-1) has a carbon number distribution between about 8 and 16 (carbon atoms per molecule) wide-cut or naphtha-type jet fuel (including Jet B), between about 5 and 15. The most widely used fuel in the military is JP-8, which the primary feedstocks are crude oils derived from petroleum, tar sands, oil shale, or mixtures thereof. A significant effort is underway to certify synthetic fuels as these fuels may be utilized from more widely available feedstocks leading to less dependence on foreign suppliers. While the feedstocks and process all differ, all test items were blended with JP-8 and synthetic paraffinic kerosene in a 50/50 volumetric ratio. All fuels used during this test included normal military additives, including Fuel System Icing Inhibitor (FSII), Static Dissipater (SDA), and Corrosion Inhibiter/Lubricity Improver (CI/LI) mixed to ratios in accordance with MIL-DTL-83133H. Since all the alternative fuel blends used were as a primary fuel, they had to meet all JP-8 specification requirements and to perform similarly to pure JP-8 fuel. A detailed diagram showing a comparison in the refinery processes are shown in Figure 3.

Section 9 contains detailed explanations for the processes to refine FT-SPK, HEFA, and ATJ.

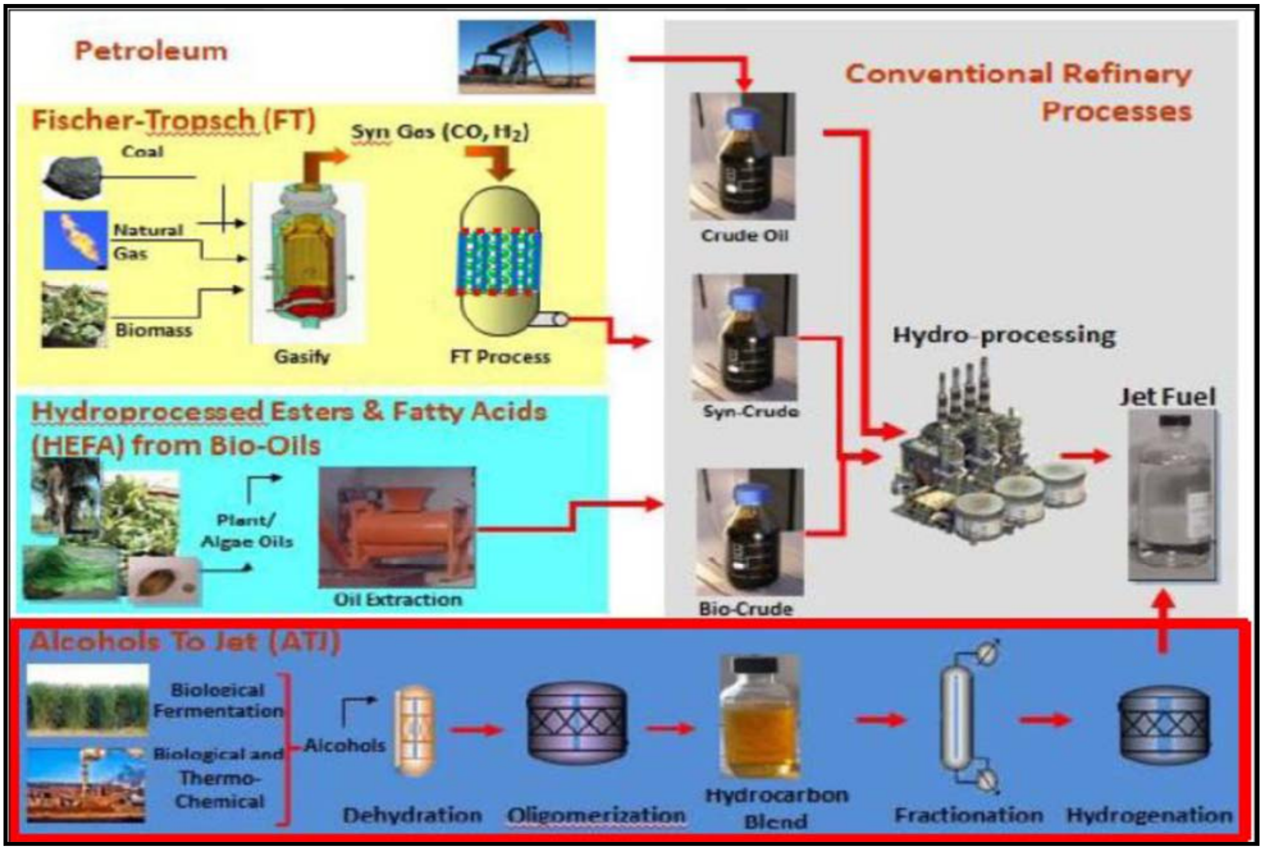



***Figure 3. Comparison of Refining Processes for Alternative Jet Fuels***

## 2.2 Synthetic Fuel Acquisition

The Defense Logistics Agency – Energy (DLA-E) provided a key role in the acquisition of the ATJ fuel required to complete the certification program. A total of 16,150 gallons of fuel was required to complete all testing requirements. DLA-E procured the fuel through Solicitation Number SP0600-13-R-0700 with a contract awarded to Gevo, Inc under Contract Number SP0600-13-D-0466 on March 22, 2013. A copy of the solicitation and final approved contract can be found at https://fbo.gov. The USAF provided all the FT-SPK and HEFA fuel for use in the tests discussed within this document

## 2.3 Alternative Fuels to Jet Baseline Data.

The objective of this certification program was to demonstrate the operational performance, safety, suitability and effectiveness of each fuel blend in order to obtain approval for use as a drop-in replacement for conventional JP-8. It was important that the fuel meet all the baseline criteria outlined in MIL-DTL-83133 with the exception of the specified feedstock limitation for utilizing only petroleum sources. All fuel utilized for this program was blended and additized on site at the AFRL and shipped to the test location. Each batch of fuel was independently sampled with copies of each of the results and the industry (or refiner's) MSDS data retained in paragraph 3.3.

# 3.0 Chemistry Testing.

## 3.1 Scope of Testing.

The chemistry review of the alternate fuels was conducted at the Air Force Research Laboratory (AFRL) located at Wright-Patterson AFB, Dayton, OH. The working collection of data is based on specification compliance and fit-for-purpose requirements in ASTM D4054 and MIL-HDBK-510 for aviation fuel, as modified by the tri-service group to include diesel engine-related properties. The ultimate goal is to determine if the properties of the blends falls within the current experience base based on conventional jet fuels. If not, the experience base can be extended to include the fuel by further testing (such as the testing of SPK and HEFA blends with densities near the 0.775 limit, outside the typical experience base) – or the fuel can be considered to have "failed" for that particular property based on performance shortfalls. The overall result of the evaluations is that all the synthetic alternate fuels behaved similarly and should be considered as specification compliant and fit-for-purpose jet fuels when blended in the appropriate final form. A comphrensive list of all test reports is contained in paragraph 3.3 along with their distribution restrictions.

## 3.2 Chemistry Test Entrance Criteria.

The Chemistry Team determined which chemical tests were required to satisfy chemistry specific aspects of aerospace alternative fuels certification needs. Based on previous testing on both FT-SPK and HEFA, the following tests were identified by the Chemistry Team as necessary to certify ATJ blended fuel for use.  These tests recommendations were approved by the Tri Service Alternative Fuels Team Chemistry Team.

### 3.2.1 Chemistry Testing Overview.

Objective: To conduct chemical analysis required to certify alternative fuels for further testing.

- Phase I:  "Fuel Specification Testing"
- Phase II:  "Fit-for-Purpose Properties"

### 3.2.2 Fuel Specification Testing.

"Fuel specification properties" refers to all property tests as required in Specification D1655, Defence Standard 91-91, MIL-DTL-83133, and MIL-DTL-5624.

### 3.2.3 Fit-for-Purpose Properties Testing Overview.

"Fit-for-purpose properties" refers to properties inherent in a fuel that are not controlled by specification.  Examples include fuel lubricity, seal swell, and dielectric constant.  During the course of the test program special considerations may be identified and investigated to resolve anomalies.  Examples include minimum aromatic level, maximum flash point, and minimum lubricity.  Below was the working list of fit-for-purpose properties that are typically evaluated by the Chemistry Team:

A. Viscosity versus Temperature

B. Density versus Temperature

C. Lubricity

D. Surface Tension versus Temperature

E. Bulk Modulus (versus Temperature)

F. Speed of Sound

G. Dielectric Constant versus Density

H. Specific Heat

I. Thermal Conductivity

J. Electrical Conductivity versus Temperature and SDA Concentration

K. Dissolved Gas Concentration

L. Flammability Limits

M. Storage Stability/Peroxide Formation

N. Vapor Pressure versus Temperature

O. Hot Surface Ignition Temperature

P. JFTOT Breakpoint

Q. Measured Cetane number

R. Hot Flame Autoignition Temperature

S. Additive Compatibility (ASTM D4054-09)

T. Minimum Ignition Energy

U. Water Solubility as f(T)

V. Interfacial Tension

W. Pour Point

### 3.3 Chemistry Test Reports.

Below is a comphrensive list of reports that were used by the US Army during their determination of the acceptability of use:

- Evaluation Report: Comparative Evaluation of Semi-synthetic Jet Fuels, Universal Technology Corporation, CRC Project No AV-2-04a, September 2008. (DISTRIBUTION CODE: A)
- Evaluation Report: Comparative Evaluation of Semi-synthetic Jet Fuels, Addendum: Further analysis of Hydrocarbons and Trace Materials to Support Dxxxx, Universal Technology Corporation, CRC Project No AV-2-04a, April 2009. (DISTRIBUTION CODE: A)
- ASTM Research Report: Evaluation of Bio-Derived Synthetic Paraffinic Kerosenes (Bio-SPKs), D02-1739, June 28, 2011. (DISTRIBUTION CODE: A)
- ATSM Research Report: Evaluation of Alcohol to Jet Synthetic Paraffinic Kerosenes (ATJ-SPKs) WK41378, October 6, 2014. (DISTRIBUTION CODE: A)
- Material Safety Data Sheet, Gevo Jet A/A-1 Blend 50/50 Syn, MSFS Date: 10/18/11. (DISTRIBUTION CODE: A)
- AFPET Lab Report: 2013LA39196001, POSF8030, Gevo Blend A-10 Demonstration. (DISTRIBUTION CODE: A)
- AFPET Lab Report: 2013LA43916001, POSF10283, Gevo Blend, Honeywell Delivery. (DISTRIBUTION CODE: A)
- AFPET Lab Report: 2013LA45145001, POSF10357, Gevo Blend, Redstone Delivery 1. (DISTRIBUTION CODE: A)
- AFPET Lab Report: 2013LA45225001, POSF10357, Gevo Blend, Redstone Delivery 1 (Post Receipt). (DISTRIBUTION CODE: A)
- AFPET Lab Report 2013LA47176001, POSF11678, Gevo Blend, Redstone Delivery 2. (DISTRIBUTION CODE: A)
- AFPET Lab Report 2013LA48315001, POSF11719, Gevo Blend, Redstone Delivery 3. (DISTRIBUTION CODE: A)
- AFPET Lab Report 2014LA48573001, POSF11728, Gevo Blend, Redstone Delivery 4. (DISTRIBUTION CODE: A)

## 4.0 Material Testing.

## 4.1 Scope of Testing.

Material testing of alternative fuels was performed at both the Air Force Research Laboratory (AFRL) located at Wright-Patterson AFB, Dayton, OH and at the Aviation Applied Technology Directorate (AATD) located at Fort Eustis, VA. A comphrensive list of all test reports is contained in paragraph 4.4 along with their distribution restrictions.

Over the years, many material compatibility programs have been performed on various fuels and fuel additives; however previously none of these programs were standardized. Beginning in 1994, the Air Forces Research Laboratory, Materials and Manufacturing Directorate (AFRL/RXSA) was asked to conduct material compatibility testing on JP-8+100 additives. After a survey of fuel tank, fuel system and engine materials, 256 different materials were tested. As a result of the JP-8+100 program, short lists of metallic and nonmetallic materials were compiled for future testing. These two short lists were intended to be representative or worst case products from each type of material. Soak temperatures and durations, test methods, and acceptance criteria were also called out in the short lists. Since the JP-8+100 program, other fuels and additives have been successfully tested for material compatibility using the short lists.

An Integrated Product Team (IPT) was assembled in 2006 to standardize and centralize the process for certifying new fuels. This IPT was charged with reviewing the current process and recommending a standardized process for certification. The current process now includes updated aircraft and engine materials as well as materials commonly found in vehicles, ground support, and the infrastructure/supply chain.

Fuel for testing was purchased from a qualified vendor through DLA-E.

## 4.2 Material Team Test Plan.

The objective of the Materials Team was to determine the tests required to satisfy different aspects of aerospace alternative fuels certification needs. Team goals were to test and verify a variety of alternate fuels for compatibility with materials found in aircraft fuel tanks, fuel systems, engines, ground supply vehicles and the supply chain. The following tests were identified by the Material Team as necessary to certify FT-SPK, HEFA, and ATJ blended fuels for use. These tests recommendations were presented to and approved by the Tri Service Alternative Fuel Materials Team. An overview of the Materials Roadmap is listed below.

- Phase I: Short Materials Lists
- Phase II: Long Materials Lists
- Infrastructure Materials Tests
- Absorbent Materials Tests
- Navy Materials Tests
- References: (MIL-HDBK-510-1A)
    - Baseline Test Fluids (Table D-I)
    - Test Temperature (Table D-II & D-III)

- Additive Testing (Table D-II & D-III)
- Alternative Fuel Testing (Table D-II & D-III)
- Complete Materials Testing (Table D-IV)

### 4.2.1 Material Test Entrance Criteria.

Entrance Criteria for materials testing begins with a chemical description of the fuel. Based upon this chemical description AFRL/RXSA will conduct an analysis to determine if initial laboratory scale testing which compares representative metallic and nonmetallic materials is necessary. This initial testing involves soaking a predetermined set of materials in a baseline fuel and compares the results after soaking in the new fuel which is being certified. This is designed to be a first level screening to provide for an indication of any compatibility problems. If all tests pass then the risk level of the new fuel or additive is minimal. If there are any concerns after completion of the initial testing then a second test is required which involves complete testing of all the materials in the family of materials which failed, an analysis of the root cause of failure, or possibly component or system level tests? Based upon the finding of the second test a third or larger scale test could be conducted to further reduce risk and determine compatibility. The third subset of tests may consist of large scale functional testing and/or flight testing.

### 4.2.2 Material Testing Overview.

The standard 28 days of fuel soak, with a fuel change after 14 days, at elevated temperatures in the selected fuels is followed by standard physical properties testing to measure the effect of the fuels on the materials. The test samples and fuel shall be visually inspected prior to the 14 day fuel change and after the 28 day aging. If the samples appear degraded or the fuel has changed color, the fuel shall be saved and properly labeled so it can be analyzed at a later date.

- Phase I: Metallic and nonmetallic materials testing was performed in accordance with the test matrices provided using the standard 28 days of fuel soak at elevated temperatures in the selected fuels were followed by standard physical properties testing to measure the effect of the fuels on the materials. For the metallic materials, gravimetric analyses and inspection for evidence of corrosion were used to assess compatibility.
- Phase II: Testing utilized the same batch materials tested in the fuels detailed in the previous section as well as an un-aged control. This test set-up will provide a better comparison of test results after aging in both the alternative fuel and the baseline JP-8. Also, questions regarding material batch or age will be eliminated. The standard 28 days of fuel soak, with a fuel change after 14 days, at elevated temperatures in the selected fuels is followed by standard physical properties testing to measure the effect of the fuels on the materials. The test samples and fuel shall be visually inspected prior to the 14 day fuel change and after the 28 day aging. If the samples appear degraded or the fuel has changed color, the fuel shall be saved and properly labeled so it can be analyzed at a later date.

## 4.3 Ballistic Fuel Cell Tests.

The combat environment exposes military aircraft to ballistic threats and with the increased operational tempo the military has long had a continuous need for ballistic fuel cell protection. Aircraft fuel cells must be able to maintain integrity when flying in combat zones and provide self-sealing capabilities against ballistic threats that range from 7.62mm and .50 caliber straight and tumbled projectiles as well as 20mm rounds. Since the 1960s there have been dramatic improvements in technology for the materials used to fabricate fuel cells today. Ballistic fuel cell protection is important as fuel cells that cannot seal allow for fires, both during flight and after the result of a crash. Secondary failures result in the reduction of flight time and combat effectiveness. The test articles, as specified in MIL-DTL-27422, were fabricated by two different manufacturers using their specified tank wall design. Each manufacture produced five test cubes for a total of ten cubes. All three alternative fuel blends were tested in each of the vendor cubes as part of this program. Although testing showed slight degradation in sealing performance with the alternative fuel blends, the fact that worst case aromatic content fuel was used for the test means that the majority of the fuels that would be seen in the field should pose no issues with sealing performance.

## 4.4 Material Test Reports.

Below is a comphrensive list of reports that were used by the US Army during their determination of the acceptability of use:

- Evaluation Report: Compatibility of Fischer-Tropsch Fuel (Materials Evaluation), AFRL/RXS 06-103, September 29, 2006. (DISTRIBUTION CODE: B)
- Evaluation Report: Fischer-Tropsch Compatibility with Selected C-17 Materials (Materials Evaluation), AFRL/RXS 07-083, December 14, 2007. (DISTRIBUTION CODE: C)
- Evaluation Report: Long-Term O-ring Exposure to Fischer-Tropsch Fuel (Materials Evaluation), AFRL/RXS 08-011, February 11, 2008. (DISTRIBUTION CODE: C)
- Evaluation Report: Fischer-Tropsch Compatibility with Selected B-1B Materials (Materials Evaluation), AFRL/RXS 08-017, April 17, 2008. (DISTRIBUTION CODE: C)
- Evaluation Report: Fischer-Tropsch Fuel Compatibility with Selected Epoxy Adhesives (Materials Evaluation), AFRL/RXS 08-025, April 17, 2008. (DISTRIBUTION CODE: C)
- Evaluation Report: Fischer-Tropsch (F-T) Compatibility with Selected F-22 Materials (Materials Evaluation), AFRL/RXS 08-071, October 24, 2008. (DISTRIBUTION CODE: C)
- Evaluation Report: Fischer-Tropsch (F-T) Compatibility with Selected F-15 Materials (Materials Evaluation), AFRL/RXS 08-067, September 17, 2008. (DISTRIBUTION CODE: C)
- Evaluation Report: Material Compatibility of R-8 Synthetic Fuel (Materials Evaluation) AFRL/RXS 10-002, January 2010. (DISTRIBUTION CODE: A)
- Evaluation Report: R-8 Synthetic Fuel Material Compatibility Phase II Testing (Materials Evaluation), AFRL/RXS 10-003, January 28, 2010. (DISTRIBUTION CODE: A)
- Evaluation Report: Compatibility of Alcohol-To-Jet (ATJ) Fuel with Select Spill Absorbent Material (Material Evaluation), AFRL/RXS 13-099, January 9, 2014. (DISTRIBUTION CODE: A)

- Evaluation Report: Compatibility of Alcohol-To-Jet without Aromatics (ATJ-SPK) Fuel with Nonmetallic and Metallic Fuel Systems Materials (Material Evaluation Report), AFRL/RXS 13-015, March 3, 2014. (DISTRIBUTION CODE: A)
- Evaluation Report: Evaluation of Alcohol-to-Jet (ATJ) Fuel Compatibility with Select Ground Supply Equipment Materials, UDR-TR-2013-00044, March 15, 2013. (DISTRIBUTION CODE: D)
- Evaluation Report: Compatibility of Alcohol-to-Jet (ATJ) Fuel with Fuel Tank Materials, Phase II Testing, UDR-TR-2013-00056, April 2, 2013. (DISTRIBUTION CODE: D)
- Evaluation Report: PEO Aviation Alternative Aviation Fuels Gunfire Tests, Evaluation US Army Ballistic Fuel Cell Self-Sealing Performance Test with Alternative Aviation Fuels, Aviation Applied Technologies Directorate (AATD), August 2014. (DISTRIBUTION CODE: A)

## 5.0 Toxicology Testing.

### 5.1 Description.

Toxicology is the study of the adverse effects of chemical, physical or biological agents of living organisms and the ecosystem, including the prevention and amelioration of such adverse effects. The acronym for “Environmental Safety and Occupational Health” is “ESOH”. Only when sufficient toxicity data is available can environmental and occupational exposure standards be developed that are protective of ecosystems (the environment) and workers (occupational medicine and health). Environmental Safety and Occupational Health should be addressed during development of new fuels and weapon systems, not after they are fielded.

### 5.2 Scope of Testing.

Toxicity testing was conducted for all of the alternative fuels at the Air Force Research Laboratory (AFRL) Bioeffects Division located at Wright-Patterson AFB, OH. While testing was completed prior to submittal of this report not all of the technical reports had been cleared for release. A comprehensive list of all testing obtained to date is contained in paragraph 5.5. Additional reports will be generated and added as they become available.

Fuel for testing was purchased from a qualified vendor through DLA-E. Fuel for toxicity testing was obtained from Dr Tim Edwards of AFRL/RQTF, Fuels and Energy Branch. Each fuel contained the JP-8 additive package.

### 5.3 Toxicology Testing Overview.

Tests required to be performed were:

1) Toxicity Screen
    - Analytical comparison to JP-8. Data from RQTF and software developed/modified by RHDJ. No fuel needed by RHDJ.

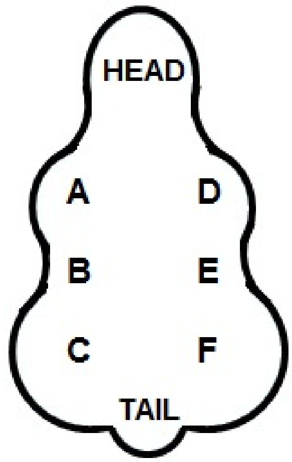
2) In vitro genotoxicity bacterial reverse mutation test. Screen for possible mutagens and carcinogens using bacteria.
3) In vitro genotoxicity mammalian cell gene mutation test. Screen for possible mutagens and carcinogens using human lymphocytes. This test may not be necessary if both the bacterial reverse mutation test and in vivo micronucleus assays are negative.
4) Dermal irritation. Determine potential irritant effects on skin.
5) 90-day with micronucleus.
   - Acute inhalation to be included, if needed
   - Preliminary report targeted for end of FY14
6) $RD_{50}$, if needed/feasible based on 90-day inhalation study.

### 5.4 Toxicology Team Test Plans.

The objective of the Toxicology Team was to determine the tests recommended in Mil Handbook 510 were required to satisfy different aspects of aerospace alternative fuels certification needs for each fuel. The following tests were identified by the Toxicology Team as necessary to certify ATJ blended fuel for use. These tests recommendations were presented to and approved by the Tri Service Alternative Fuels Team Aviation Propulsion Team. A detailed description of the tests is outlined below.

#### 5.4.1 Dermal Irritation Test.

The Environmental Protection Agency (EPA) Office of Chemical Safety and Pollution Prevention (OCSPP) developed a series of harmonized test guidelines for the use in the testing of pesticides and toxic substances, and the development of test data for submission to the EPA. The Health Effects Test Guidelines, or series 870, outlines guiding principles for testing using non-human test subjects. The purpose of the dermal irritation test outlined in the Office of Prevention, Pesticides and Toxic Substances (OPPTS) 870.2500 (Acute Dermal Irritation) is the determination of the irritant and/or corrosive effects on skin of mammals. This test is useful in the assessment and evaluation of the toxic characteristics of a substance where exposure by the dermal route is likely. Generally, the substance to be tested is applied in a single dose to the skin of three experimental animals, each animal serving as its own control. Approximately 24 hours before exposure, the animal is prepared to receive the test dose of the substance by having fur removed from the test area by either clipping or shaving. A dose of 0.5mL of liquid is applied to the test site for 4 hours and observed for the recommended duration. The degree of irritation is read and scored at specific intervals. At the end of the exposure period, residual test substance should generally be removed without adversely altering the existing response. The duration of the study should be sufficient to permit the full evaluation of the reversibility or irreversibility of the effects observed but not exceed 14 days.




Rabbit

**Figure 4. Sample Dermal Dosing Sites**

### 5.4.2 Ames Test.

The Ames test is a widely employed method that uses five strains of bacteria to test whether a given chemical can cause mutations. More formally, it is a biological assay to assess the mutagenic potential of chemical compounds. A positive test indicates that the chemical is mutagenic and therefore may act as a carcinogen, because cancer is often linked to a mutation. This procedure was described in a series of papers in the early 1970s by Bruce Ames and his group at the University of California, Berkley and serves as a quick and convenient assay to estimate the carcinogenic potential of a compound because the standard carcinogen assays on mice and rats are both time consuming (taking between two to three years to complete) and expensive. A simplified overview of the process is shown in Figure 5.

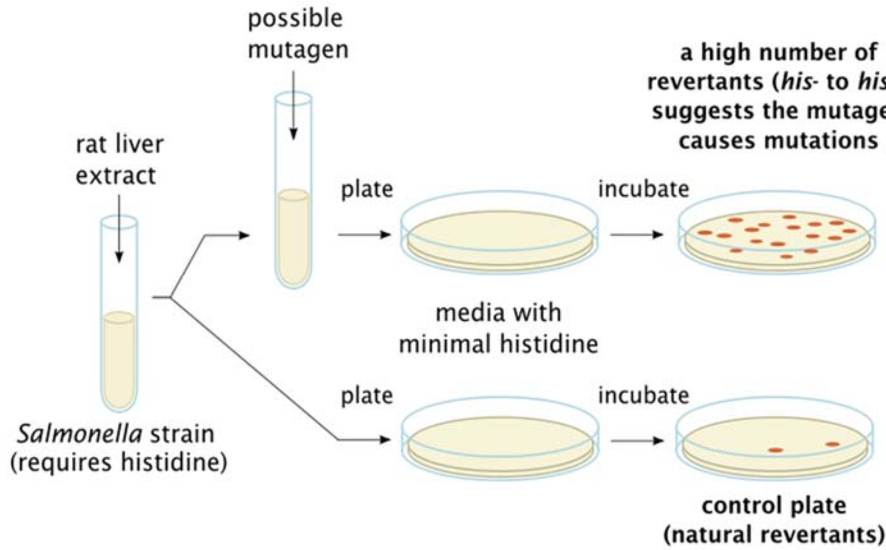



**Figure 5. Ames Test Procedure**

### 5.4.3 90-Day Inhalation Test.

The subchronic inhalation study (or the 90-Day Inhalation Test) has been designed to permit the determination of the no-observed-effect-level (NOEL) and toxic effects associated with continuous or repeated exposure to a test substance for a period of 90 days. Extrapolation from the results of this study compared to humans is valid only to a limited degree and is not capable of determining if those effects that have a long latency period for development (e.g., carcinogencity and life shortening). It can, however provide useful information on health hazards likely to arise from repeated exposures by the inhalation route over a limited period of time. It provides information on target organs and the possibilities of accumulation, and typically required to recommend occupational exposure levels (OELs). A group is an untreated or sham-treated group receiving air alone. With the exception of treatment with the test substance, animals in the untreated control group are handled in a manner identical to the test group animals. A minimum of three additional groups are used at various concentration levels. Concentration levels are spaced appropriately to produce a range of toxic effects and the data sufficient to produce a concentration-response curve. The highest concentration should result in observable outcome from the toxic effects but not produce an incidence of fatalities which would prevent a meaningful evaluation. The lowest concentration should produce no evidence of toxicity but not be so low as to invalidate the data. The intermediate concentration(s) should be spaced to produce a gradation of toxic effects. All animals were exposed for 6 hours per day, 5 days per week for the full 90 days. All animal necropsies were conducted within 24 hours of the final exposure and prepared slides sent to a board certified pathologist for review.

## 5.5 Toxicology Team Test Reports.

Below is a comprhensive list of reports that were used by the US Army during their determination of the acceptability of use:

- Technical Report: Riccio, E., Green, C., and Mattie, D. September 2010. Evaluation of Five Jet Fuels in the *Salmonella-Escherichia coli*/ Microsome Plate Incorporation Assay. Wright-Patterson AFB OH. AFRL-RH-WP-TR-2011-0138. (DISTRIBUTION CODE: A)
- Technical Report: Mattie, D., Sterner, T., Oppong-Nketiah, M., Becker, T., Wallner, B., Wolfram, R., Lutterback, A., and Wagner, D. November 2010. F-T Jet Fuel Reverse Mutation Assay and Chromosome Aberration Test. Wright-Patterson AFB OH. AFRL-RH-WP-TR-2011-0010. (DISTRIBUTION CODE: A)
- Technical Report: Hurly, J., Wagner, D., Sterner, T., and Mattie, D. January 2011. Acute Dermal Irritation Study of JP-8 and S-8 in New Zealand White Rabbits, Wright-Patterson AFB OH. AFRL-RH-WP-TR-2011-0054. (DISTRIBUTION CODE: A)
- Technical Report: Mattie, D., Sterner, T., Wong, B., Dodd, D., Ross, P., Gross, E., Gao, P., Sharma, S., Wang, X., Sochaski, M., Wilson, G., and Wagner, D. February 2011. Acute and Short-Term Inhalation Toxicity Study of FT Fuel. Wright-Patterson AFB OH. AFRL-RH-WP-TR-2100-0107. (DISTRIBUTION CODE: A)
- Technical Report: Mattie, D., Sterner, T., Wong, B., Dodd, D., Kayko, D., Ross, P., Gross, E., Wilson, G., Hinz, J., and Wagner, D. August 2011. 90-Day Inhalation Toxicity Study of FT Fuel. Wright-Patterson AFB OH. AFRL-RH-FS-TR-2011-0014. (DISTRIBUTION CODE: A)
- Technical Report: Hinz, J., Sterner, T., Tewksbury, E., Wong, B., Dodd, D., Parkinson, C., Wagner, D., and Mattie, D. January 2012. Human Health Hazard Assessment of FT Jet Fuel and Sensory Irritation Study in Mice, Wright-Patterson AFB OH. AFRL-RH-WP-2012-0013. (DISTRIBUTION CODE: A)
- Technical Report: Mattie, D., Carter, A., Eden, P., Hezel, J., Dodd, D., Roberts, K., Layko, D., Ross, P., Edgerton, N., Tewksbury, E., Black, M., Wilson, G., Mumy, K., Sterner, T., and Wong, B., September 2012. Acute, Five- and Ten-Day Inhalation Sudy of Hydroprocessed Esters and Fatty Acids – Mixed Fats (HEFA-F) Jet Fuel. Wright-Patterson AFB OH. AFRL-RH-FS-TR-2012-0029. (DISTRIBUTION CODE: A)
- Technical Report: Mattie, D., Hurley, J., Riccio, E., and Sterner, T. January 2013. Acute Dermal Irritation Study and *Salmonella-Escherichia coli*/ Microsome Plate Incorporation Assay of Hydroprocessed Esters and Fatty Acitds (HEFA) Bio-Based Jet Fuels. Wright-Patterson AFB OH. AFRL-RH-WP-TR-2013-011. (DISTRIBUTION CODE: A)
- Technical Report: Wong, B., Howard, W., Sterner, T., Elliott, M., and Mattie, D. June 2013. 90-Day Inhalation Toxicity Study of Hydroprocessed Esters and Fatty Acids (HEFA) Bio-Based Jet Fuel in Rats with Neurotoxicity Testing and Genotoxicity Assays. Wright Patterson AFB OH. AFRL-RH-QP-TR-2013-0109. (DISTRIBUTION CODE: A)
- Technical Report: Sterner, T., Sweeney, L., Mumy, K., Wong, B., James, R., Reboulet, J., Sharits, B., Grimm, M., Gargas, N., Striebich, R., and Mattie, D. June 2013. Hydroprocessed Esters and Fatty Acids (HEFA) Bio-Based Jet Fuels: Sensory Irritation Study and Human Health Hazard Assessment. Wright-Patterson AFB OH. AFRL-RH-FS-TR-2014-0001. (DISTRIBUTION CODE: A)
- Technical Report: Sterner, T., Hurley, J., and Mattie D. February 2014. Acute Dermal Irritation Study of Ten Jet Fuels in New Zealand White Rabbits: Comparison of Synthetic and Bio-Based Jet fuels with Petroleum JP-8. Wright-Patterson AFB OH. AFRL-RH-FS-TR-2014-0045. (DISTRIBUTION CODE: A)
- Technical Report: Sterner, T., Hurley, J., Edwards, J., Shafer, L., and Mattie, D. February 2014. Acute Dermal Irritation Study of Six Jet Fuels in New Zealand White Rabbits:

Comparison of Four Bio-Based Jet Fuels with Two Petroleum JP-8 Fuels. Wright-Patterson AFB OH. AFRL-RH-FS-TR-2014-0046. (DISTRIBUTION CODE: A)

- Combined Whitepaper: Sterner, T., Mumy, K., Sweeney, L., Reddy, G., McCain, W., and Mattie, D. Health Hazard Assessment Summary of Alcohol-To-Jet (ATJ) Alternative Jet Fuel Produced by Gevo, P.A. Case No. 88ABW-2014-4503, September 23, 2014. (DISTRIBUTION CODE: A)
- Technical Report: Sterner, T., Hurley, J., Shafer, L., Striebich, R., and Mattie, D. September 2014. Acute Dermal Irritation Study in New Zealand White Rabbits: Four Alcohol-to-Jet (ATJ) Synthetic Paraffinic Kerosene (APK) Alternative Jet Fuels Compared with Petroleum Deprived JP-8, Wright-Patterson AFB OH. AFRL-RH-WP-TR-2014-0133. (DISTRIBUTION CODE: A)
- Combined Whitepaper: Sterner, T., Mumy, K., Wong, B., Sweeney, L., Reddy, G., McCain, W., and Mattie, D. Health Hazard Assessment Summary of Alcohol-to-Jet (ATJ) Alternative Jet Fuel Produced by Swedish Biofuels, P.A. Case No. 88AFW-2015-2283, 06 May 2015. (DISTRIBUTION CODE: A)
- Technical Report: Sterner, T. Wong, B., Mumy, K., McInturf, S., Grimm, M., Gargas, N., Stoffregen, D., Mattie, D. May 2015. 90-Day Inhalation Toxicity Study of Bio-Derived Gevo Alcohol-to-Jet (ATJ Synthetic Paraffinic Kerosene (SPK) in rats with Neurotoxicity Testing and Genotoxicity Assay, Wright-Patterson AFB OH. AFRL-RH-TR-2015-0031. (DISTRIBUTION CODE: A)
- Technical Report: Sterner, T., Wong, B., Mumy, K., McInturf, S., Gargas, N., Reboulet, J., James, R., Stoffregen, D., Mattie, D. September 2015. 90-Day Inhalation Toxicity Study of Swedish Biofuel Alcohol-to-Jet (ATJ) Synthetic Kerosene with Aromatics (SPA) in Rats with Neurotoxicity Testing and Genotoxicity Assay, Wright-Patterson AFB OH. AFRL-RH-WP-TR-2015-0091. (DISTRIBUTION CODE: A)

## 6.0 Aviation Propulsion Testing.

### 6.1 Scope of Testing.

Aviation propulsion testing encompasses a methodology to identify, evaluate and mitigate safety, performance, durability, and supportability risks associated with utilizing an alternative fuel in an aircraft propulsion system. Test reports for the Aviation Propulsion Testing are outlined in paragraph 6.2 below.

**6.1.1 Fuel Functions.** Aircraft Propulsion systems use fuel to accomplish four main functions: 1) provide performance, 2) lubricate wear surfaces and bearings, 3) provide fueldraulic muscle for actuation devices and 4) remove excessive heat. Each of these functions depends on different properties of the fuel. In order to properly evaluate a candidate fuel one needs to consider each of these functions and weigh their relative importance to proper operation of the aircraft propulsion system.

**6.1.1.1 Performance.** Fuel has to burn to start and operate a propulsion system to provide the amount of thrust necessary to operate the aircraft. There are several steps in the overall combustion process. The fuel has to be atomized and vaporized when passing through the fuel nozzles into the combustor. In the combustor, it is vaporized, ignited and burned to provide the needed heat release and thus required thrust/horsepower. In order to get the fuel to the combustor it has to be pumped from the aircraft tank and metered according to an established set of schedules. Performance relies on fuel properties such as flammability, viscosity, lubricity and density.

**6.1.1.2 Wear Surface Lubrication.** Many propulsion system components rely on fuel lubrication for proper operation and to minimize wear and degradation. Pumps, actuators, hydromechanical controls and servo valves all contain fuel wetted bearings and surfaces that depend heavily on proper fuel lubrication. Proper fuel lubrication relies on fuel properties such as viscosity, lubricity and density.

**6.1.1.3 Fueldraulics.** Aircraft Propulsion system control and thrust scheduling involves many moving parts and depends on fuel driven actuators to move them. Most of today's modern propulsion systems rely on the fuel as a medium for producing the hydraulic muscle (fueldraulics) for these actuators. Fueldraulics relies on fuel properties such as density, bulk modulus and viscosity.

**6.1.1.4 Heat Removal.** One of the biggest propulsion system durability drivers is the ability to remove and dispose of excessive heat. This ―thermal management‖ capability is a major problem because fuel can only absorb so much heat and only so much fuel can be burned through the combustor. Whatever fuel is not burned, is either recirculated to the aircraft tank or recirculated within the fuel system itself, resulting in continual heat loading on the fuel. This high heat loading can result in a number of issues including coking and varnishing. The ability of the fuel to remove excessive heat relies on fuel properties such as specific heat and thermal conductivity.

### 6.2 Aviation: Aircraft/Propulsion Team Test Plan.

The objective of the Aviation Team was to determine the tests required to satisfy different aspects of aviation propulsion certification needs. Through extensive "gap analysis" a comprehensive list was developed to enable multiple fuels to be tested simultaneously to meet the needs without duplicating the test program. The following tests were identified by the Propulsion Division of the Aviation Engineering Directorate as necessary to certify ATJ blended fuel for use in Army Aviation. These tests recommendations were presented to and approved by the Tri Service Alternative Fuels Team Aviation Propulsion Team. An overview of the AED ATJ Propulsion Program Timeline is shown in Figure 6 below.

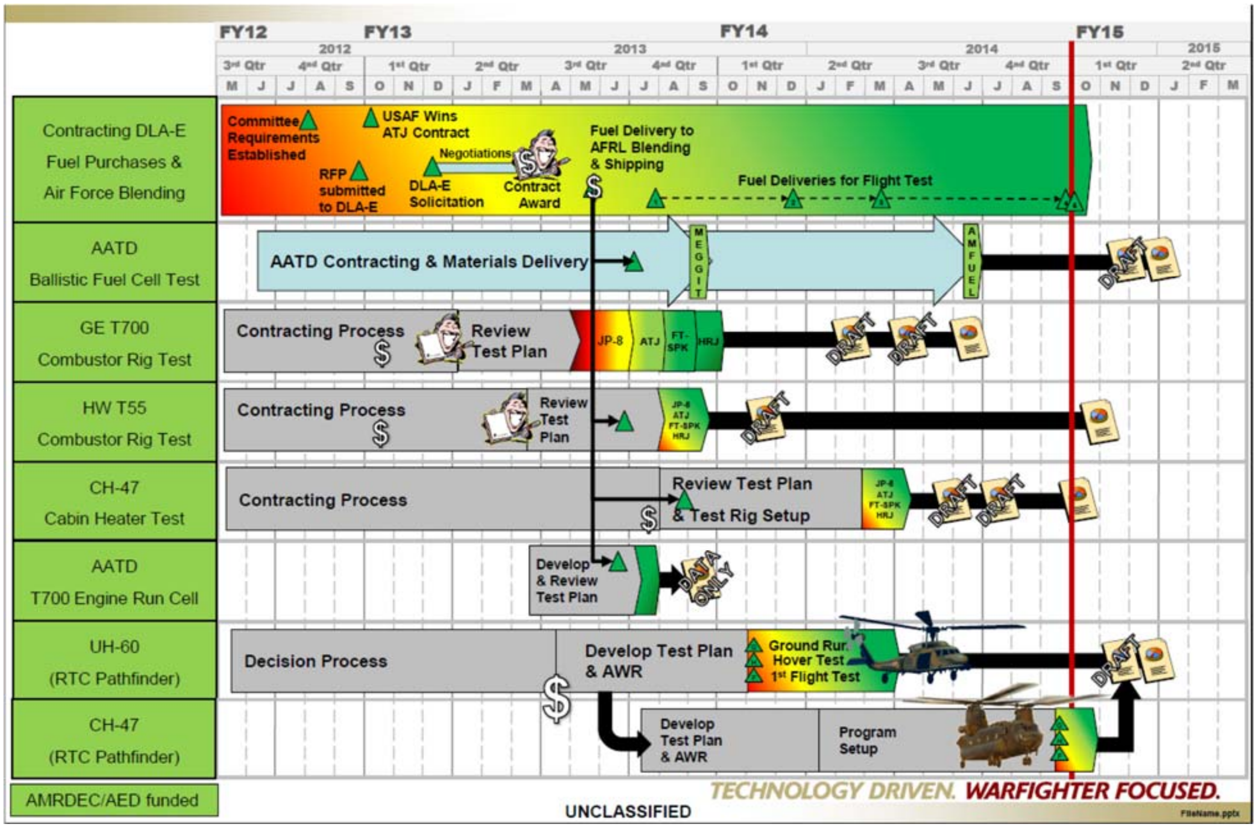



*Figure 6. Propulsion ATJ Program Timeline*

### 6.2.1 Combustor Rig Testing:

The purpose of using a combustor sector rig may be used to address any concerns associated with ignition, re-light, or lean blowout. Although these characteristics could be evaluated in a full scale engine test, a combustor sector rig potentially offers evaluations over a wider range of conditions at lower costs and in a more controlled environment. Results of the test program are carefully reviewed by the respective OEM chief engineers and their discipline chiefs. An OEM airworthiness representative interfaces with the appropriate airworthiness authority. Discipline Chiefs and their staff engineers from organizations responsible for combustion, turbine, fuel system hardware, performance system analysis, system integration, and airworthiness engage in iterative meetings and reviews until the concerns and potential impacts on the engine have been explored and satisfactorily addressed. The product of the OEM internal review is a document or report that either rejects or approves the new fuel or additive. After approval of the new fuel or additives, there may be a requirement for a Controlled Service Introduction (CSI). Under a CSI, engines in the field that are exposed to the new fuel or additive are monitored for an increased level of fair wear and tear. The CSI is directed at identifying possible long-term maintenance effects.

#### 6.2.1.1 GE T700 Combustor Rig Test:

General Electric (GE) Aviation was tasked by the US Army under the T700 Alternative Fuels Combustor Rig Test & Performance Evaluation Statement of Work (SOW) to support evaluating alternative fuels on the T700 Turboshaft engine series. The Utility Helicopter Program Management Office (UHPMO) worked the contract negotiation to set up the GE T700 Combustor Rig Test, under contract W58RGZ-11-D-0119/004, dated 5/17/2012, which was conducted at the GE Aviation facility located at Evandale, OH. There were several Technical Readiness Reviews (TRR) conducted throughout the initial set up of the tests. The testing was conducted on neat JP-8 and three alternative fuel blends. All the alternative fuels were supplied by the Air Force Research Laboratory (AFRL) but specifically the ATJ fuel supplied for this test was provided through the A-10 alternative fuels test program.

Based on combustor component evaluations, on a back-to-back basis, it was concluded that there is no anticipated engine performance impact on hot section durability, sea level starting, or on altitude ignition, using a 50/50 blend of ATJ-SPK/JP-8, or a 50/50 blend of HRJ-SPK/JP-8, or a 50/50 blend of FT-SPK/JP-8 fuel in the T700-GE-701D engine compared to operating the engine using JP-8 fuel only.

Profile Factor / Pattern Factor (PF/PTF) data indicates some differences between the alternative fuels and neat JP-8. However these differences are not anticipated to negatively impact hot section life. Low power temperature rise results show no statistical difference between alternative fuel blends and baseline JP-8. Light-off / Lean Blow Out (LO/LBO) results show greater than or equal to performance for all alternative fuel blends in comparison to neat JP-8.

During the LO/LBO phase of the baseline JP-8 testing there were complications with the air cooling and fuel cooling hardware. The air cooling complication was resolved with procedural and instrumentation changes. The fuel cooling complication limited the controlled, consistent cooling of the fuel to -5°F. This was a deviation from the initial test plan. The issues identified would have required a re-design of the fuel chilling equipment at the Evendale lab facility in order to test at the fuel temperatures in the approved test plan. To continue with the test plan it was decided, with input from ARMY representatives, to test all fuels at -5°F. This allowed testing to continue while retaining back-to-back repeatability and comparison. Future corrective action will be required to modify the cold fuel system to allow cold fuel operation throughout the T700 envelope.

Details of the final approved test report documentation for the alternative fuels tests are outlined in the T700-GE-701D Turboshaft Component Test Report: ESC-04 T700 Alternative Fuels Combustor Component Test Report, R2014AE134R0, June 16, 2014. (DISTRIBUTION CODE: D)

#### 6.2.1.2 Honeywell T55 Combustor Rig Test:

The Cargo Helicopter Program Management Office (CHPMO) was responsible for the contract negotiations to set up the Honeywell T55 Combustor Rig Test which was conducted at the Honeywell Aerospace facility located at Phoenix, AZ. There were several TRRs conducted throughout the initial set up of the tests. The testing was conducted on neat JP-8 and three alternative fuels blends. The ATJ fuel supplied for the test was purchased by AMRDEC and blended by AFRL and shipped directly to the test site. The FT-SPK and HEFA fuels were obtained, blended, and supplied by the USAF based on the needs from previous testing.

All test requirements were successfully completed on T55-GA-714A combustor test rig, P/N R3564201-1, in accordance with the approved test instructions; Honeywell document 21-15262, Test Procedure and Instructions Qualification of Alternate Fuels on the T55-GA-714A Engine.

The FT-SPK, HEFA and ATJ blend performance tests acquired data that were within historical test to test variation. Further the data demonstrated that there were very little differences in results between the alternate fuel blends and conventional JP-8 fuel. The pattern factor, radial profile, metal temperatures, lean stability and altitude ignition measured were similar to the baseline JP-8 results. The combustion performance, operability and durability characteristics of the T55-GA-714A were similar to results with the baseline petroleum derived JP-8 fuel, and were not adversely impacted by the use of FT-SPK, ATJ, and HEFA blends which all conformed to the MIL-DTL-83133H specification. The results of the exhaust smoke and emissions tests showed that the use of alternate fuel blends was not detrimental to overall emissions, and reduced exhaust smoke emissions for some operating conditions and fuels.

Details of the final approved test report documentation for the alternative fuels tests are outlined in the Test Report: Qualification of Alternative Fuels on the T55-GA-714A Engine, 21-15547, dated October 8, 2014. (DISTRIBUTION CODE: D)

### 6.2.2 Component Testing:

With the high number of components in the fuel system, the decision on which components required testing came down to which testing is worth the effort and is not duplicated in another area of testing. Functionality and design are characteristics that must be decided as well as the impact of the fuel on the individual component. Types of test provide the ability to identify and isolate potential fuel related risks on individual components such as pumps, valves, actuators, heat exchangers, and hydro-mechanical controls. While some of these tests can be accomplished using component test stands or system (wet) rigs other tests can be done during observation of normal operations. The only off aircraft test which was identified by the Propulsion Division of the Aviation Engineering Directorate as necessary to certify ATJ blended fuel for use in Army Aviation was the CH-47 Cabin Heater Test. Because the cabin heater burns fuel safety dictated an off aircraft test. This test recommendation was presented to and approved by the Tri Service Alternative Fuels Team Aviation Propulsion Team.

#### 6.2.2.1 T700 Engine Run Cell Demonstration Test:

The Aviation Applied Technology Directorate (AATD) located at Fort Eustis, VA has an engine run cell equipped with a T700-GE-701D engine installed which is capable of functional and performance testing and evaluation of a broad spectrum of engine configurations as well as add on signature suppression technology concepts. The facility is equipped to provide real time acquisition of a wide selection of engine specific parametric performance data as well as supplemental pressure, temperature, vibration and strain data as required. While the overall purpose of this test was not to the level of a qualification the comparison data between a standard JP-8 and ATJ/JP-8 engine run did provide valuable evidence that no significant difference could be expected during the aircraft flight demonstration. Both fuels were setup on a single engine and an average of three “sweeps” was conducted for each fuel. Each sweep was designed with specific timing intervals and targeted temperature stops. After completion of the baseline fuel, JP-8, the entire fuel system and storage tank was completely drained in preparation for the change over to the ATJ/JP-8 blended test fuel.  While there was no final test report published, AED received all the data and made a determination that there was no detrimental differences between the use of ATJ/JP-8 blended fuel and its JP-8 counterpart.

#### 6.2.2.2  CH-47 Heater Alternative Fuels Development Test:

The Cargo Helicopter Program Management Office (CHPMO) was responsible for the contract negotiations to set up the CH-47 Cabin Heater Test.  The contract was set up through the Redstone Aviation Propulsion Test and Research (RAPTR) Facility and testing was conducted at Redstone Arsenal, AL.  The Statement of Work (SOW) for this test was written by the Propulsion Division of the Aviation Engineering Directorate and approved by RTC.  There were several TRRs conducted throughout the initial set up of the tests.  The testing was conducted on neat JP-8 and three alternative fuels blends.  The ATJ fuel supplied for the test was purchased by AMRDEC and blended by AFRL and shipped directly to the test site.  The FT-SPK and HEFA fuels were obtained, blended, and supplied by the USAF based on the needs from previous testing.

The JanAero cabin heater, Model F52C98 is the heater assembly that is installed on the CH-47 Chinook aircraft.  The purpose of its installation is to heat the cabin of the aircraft via combustion, which produces heat by forcing war ventilation air over an airtight burner chamber, where fuel from the aircraft fuel system is ignited and burned.  The air is then disbursed into the aircraft cabin to provide heat.

***Figure 7. JanAero Cabin Heater, Model F52C98 (Typical)***

During the gap analysis it was determined that it would be required to test the JanAero heater due to the operation of the fuel in a combustion chamber. This was more for safety certification than for fuel qualification as the heater is essential during operation in cold climates and the fuel may have an adverse effect within the combustion chamber. JP-8 and the three alternative fuels (FT-SPK, HEFA, and ATJ) were cooled, along with the ambient air, to a consistent temperature between -25ºF and -40ºF to simulate worse case conditions that the heater would be expected to operate. Aircraft operating below -29ºF are generally expected to utilize JP-4 for extended durations. The RTC Propulsion Test Division successfully tested JP-8 and three alternative fuels (FT-SPK, HRJ, and ATJ) in the CH-47 JanAero cabin heater. Each of the alternative fuels were blended at a 50/50 ration with JP-8. Each test cycle was run in a similar manner to minimize inconsistencies and keep all cycles within acceptable tolerances. While not at a lvel of a qualification test, this comparison test met all the requirements and determined that there were no detmimental effects between any of the fuels tested. Final test results indicated that no significant differences were noted between all fuels and none of the alternative fuels were likely to produce additional safety hazards to the heater during operation.

Details of the final approved test report for the alternative fuels tests are outlined in the Test Record for the CH-47 Heater Alternative Fuel Qualification Tests, ATEC Project No: 2013-DT-RTC-ICHXX-F8198, dated June 2014. (DISTRIBUTION CODE: F)

### 6.2.3 Flight Service Evaluations:

An FSE is a proven way to obtain engine performance, operability and durability data under real world operational conditions. It provides a way to evaluate alternative fuels for "unknown-unknown" risks prior to full field implementation. In addition, an FSE can provide invaluable data on maintenance and sustainment (supportability) impacts. FSEs can be conducted at almost any operational base but require significant coordination and a willingness of the Warfighter community to accept the extra responsibility and workload associated with them. In additional, the selected FSE base will have to be able to handle the logistical impacts of carrying the fuel under evaluation.

The objective of the Aviation Team was to determine the necessary tests required to satisfy different aspects of aviation propulsion certification needs. Based on funding, required assets, available assets, and time allotted it was determined that a flight demonstration could be conducted on both the UH-60 and CH-47 helicopters. Due to the high fuel consumption rate of the T55 engine only a T700 engine would be utilized for a long term evaluation. The following tests were identified by the Propulsion Division of the Aviation Engineering Directorate as necessary to certify ATJ blended fuel for use in Army Aviation. These tests recommendations were presented to and approved by the Tri Service Alternative Fuels Team Aviation Propulsion Team.

Details of the final approved test report for the flight service evaluations for both the UH-60 and CH-47 aircraft are outlined in the Test Record, Alcohol-to-Jet/JP-8 Blended Fuel Certification, ATEC Project No: 2014-DT-RTC-AMRDE-F7431, dated 5 January 2015. (DISTRIBUTION CODE: F)

#### 6.2.3.1 UH-60L Flight Demonstration Test:

The two possible flight testing locations which were identified were either the Aviation Applied Technology Directorate (AATD) located at Fort Eustis, VA or the Aviation Flight Test Directorate (AFTD) located at Redstone Arsenal, AL. Both organizations were given the opportunity to provide capabilities and cost analysis outlines to determine the best organization to select for the flight demonstration test location. Both organizations were provided with maximum budget limitations but decision points coupled with timeline restrictions dictated that AFTD at Redstone did not have the same restrictions that AATD at Fort Eustis did. Final decisions which weighed heavily reflected on the basis of the organizations ability to use an aircraft with at least a T700-GE-701C or T700-GE-T701D engine installed, obligate funding on the books, and be able to conduct the flight demonstration without any timeline restrictions. The organization which ultimately received the contract was AFTD.

The UH-60L Flight Demonstration Test consisted of several phases. Phase I was everything needed to setup and teardown the program. This included the baseline and final inspections as well as the setup of the segregated fuel storage area. Baseline inspections included Fuel Cell and Engine Tear-down inspections. The primary purpose was to document the initial condition of the aircraft and engines for later comparison after the Phase III longevity flight tests. An Advanced Aviation Forward Area Refueling System (AAFARS) was provided by TARDEC to use with a 7,000 gallon stainless steel tanker trailer rented from a local company to store and pump the ATJ blend into the aircraft. The airfield maintained the responsibility to pump and track the fuel usage. Phase II pertained only to the initial Flight Safety Evaluation while Phase III was for the longer Field Service Evaluations. During initial inspections in August 2013, it was discovered that one fuel cell and one engine had previous damage which caused delays in the program. The fuel cell required replacement and the engine was sent to Fort Campbell, KY for repairs. After repairs were conducted the flight program ran from November 2013 through March 2014, consisted of flying 93 flights and a total of 180 flight hours utilizing over 12,130 gallons of pre-blended fuel. Final inspections were conducted in April 2014 with no noticeable differences indicated between the ATJ and JP-8 fuels.

#### 6.2.3.2 CH-47D Flight Demonstration Test:

While not initially part of the flight demonstration program it was determined that sufficient funding and ATJ blended fuel would be left over from conduct of the UH-60 flight demonstration. Additional plans were made to conduct a short term demonstration flight test utilizing a CH-47D for up to thirteen flights to provide for additional certification.

The CH-47D Flight Demonstration Test consisted of several phases. Similar to the UH-60 Flight Demonstration, Phase I was everything needed to setup and teardown the program. This included the baseline and final inspections as well as the continued usage of the AAFARS and segregated fuel storage area. Phase II pertained to the initial Flight Safety Evaluation and Phase III was the Field Service Evaluations. During initial inspections in May 2014, it was discovered that both engines had excessive coking and both had been sent to Fort Rucker, AL for more detailed inspections causing substantial delays. Upon more thorough inspections, by the Fort Rucker team, several components were required replacement. The delay caused by the repairs coupled by the reinstallation and following test flight caused a four month delay. Upon successful repair and reinstallation the flight program ran from September to October 2014 and consisted of flying 12 flights and a total of 27.1 flight hours utilizing over 7,370 gallons of pre-blended fuel.

## 7.0 CONCLUSIONS AND RECOMMENDATIONS

The detailed testing and demonstration reports listed show that no adverse reaction to use of blended FT-SPK, HEFA, and ATJ in aircraft fuel systems or turbine engines. No testing has been accomplished on Unmanned Aircraft Systems (UAS) engines, as their requirements are similar to ground vehicles. TARDEC is in the process of testing various additive combinations and a report is expected in the future. Based on the results of their report, further testing may be required to evaluate the suitability with reciprocating engines. For aircraft turbine engines, it is recommended that future revisions of the Turbine Fuel Detailed Specification for JP-8 (MIL-DTL-83133) incorporate blended ATJ not to exceed a 50/50 ratio similar to the already approved FT-SPK and HEFA fuels.

## 8.0 BACKGROUND/SUPPORTING INFORMATION

### 8.1 Department of Defense Energy Policy.

Established in 2010, the Office of the Assistant Secretary of Defense for Operational Energy was created to strengthen the energy security of U.S. military operations. The mission of the office is to help the military services and combatant commands improve military capabilities, cut costs, and lower operational and strategic risk through better energy accounting, planning, management, and innovation. Operational energy, or the energy required to train, move, and sustain forces, weapons, and equipment for military operations, accounted for 75 percent of all energy used by the Department of Defense in 2009.

Pursuant to title 10, U.S.C., section 138c, the Department of Defense (DoD) published the Operational Energy Strategy on June 14, 2011, to transform the way U.S. Armed Forces consume energy in military operations. The Strategy sets the direction for operational energy use within the Office of the Secretary of Defense (OSD), Office of the Chairman of the Joint Chiefs of Staff (CJCS) and the Joint Staff, Combatant Commands, Military Departments, and Defense agencies. The goal of the Operational Energy Strategy is energy security for the Warfighter – to assure that U.S. forces have a reliable supply of energy for 21st century military missions. For DoD to reach this goal, the Strategy provides a three-fold approach:

- **More Fight, Less Fuel:** Reduce Demand for Energy in Military Operations.
- **More Options, Less Risk:** Expand and Secure Energy Supplies for Military Operations.
- **More Capability, Less Cost:** Build Energy Security into the Future Force.

In March 2012 the Secretary of Defense, the Honorable Leon Panetta, signed the Operational Energy Strategy: Implementation Plan outlining the need for the Department of Defense to begin to transform the way we power the current and future force. To that end the goal of the Operational Energy Strategy is energy security for the Warfighter.

### 8.1.1 Department of Army Energy Policy.

The Secretary of the Army and the Army Chief of Staff signed the Army Energy Strategy and Campaign Plan on 8 July 2005. The Strategy sets forth the Army's energy goals for 25 years and the Campaign Plan defines the intermediate actions, approaches, initiatives, and funding over the 25 years to ensure the Army successfully achieves long-range energy and water management goals.

The Strategy sets the general direction for the Army in five major initiatives:

1. **Eliminate energy waste in existing facilities**
   Eliminate and reduce energy inefficiencies that waste natural and financial resources, and do so in a manner that does not adversely impact comfort and quality of the facilities in which Soldiers, families, civilians and contractors work and live.
2. **Increase energy efficiency in new construction and renovations**
   Increase the use of energy technologies that provide the greatest cost-effectiveness, energy efficiency and support environmental considerations.
3. **Reduce dependence on fossil fuels**
   Increase the use of clean, renewable energy to reduce dependency on fossil fuels and to optimize environmental benefits and sustainability.
4. **Conserve water resources**
   Reduce water use to conserve water resources for drinking and domestic purposes.
5. **Improve energy security**
   Provide for the security and reliability of energy and water systems in order to provide dependable utility services.

Although the Campaign Plan was initially implemented in late 2005 and used in the FY 2008-2013 POM development process. The current version was updated to support the FY 2010-2015 POM development. Future Campaign Plans will be reviewed for updates every two calendar years during odd years.

The Army Senior Energy Council and the Office of the Deputy Assistant Secretary of the Army for Energy and Partnerships issued the Army Energy Security Implementation Strategy in January 2009. That plan led to the establishment of the 2010 Energy Security Objectives (ESOs). ESO 3.2b mandated the Army to certify that 100% of its air platforms shall be able to operate on alternative/renewable fuel blends by 2016 (50% by 2014).

## 8.2 Key Military Organizational Participants.

### 8.2.1 United States Air Force (USAF)

*Alternative Fuels Certification Office (AFCO)* – As part of the United States Air Force (USAF) long-term energy vision, the Alternative Fuels Certification Office (AFCO), consisting of a small cadre of systems engineers and managers, was formed in June 2010 at Wright-Patterson Air

Force Base, Ohio to develop and execute repeatable processes to identify viable fuel candidates and certify them for fleet-wide operations. These activities require substantial collaboration with the fuels experts at the Air Force Research Laboratory (AFRL), the Air Force Petroleum Agency (AFPET), and the Defense Energy Support Centre (DESC). One of their mandates was to execute and manage all aspects of the alternative fuel certification process across all USAF platforms (including all aircraft, future weapon systems, appropriate ground support equipment, and fuel delivery systems) in support of SECAF "Assured Fuels" initiative to decrease US dependence on foreign oil. AFCO completed certification of Fischer Tropsch (FT) and Hyrdotreated Renewable Jet (HRJ) Synthetic Paraffinic Kerosenes (SPK) by 2013 and was coordinating Alcohol to Jet (ATJ) testing but was closed in August 2013 due to lack of funding. Testing was reorganized under the Air Force Research Laboratory.

*Air Force Research Laboratory (AFRL)* – A scientific research organization operated by the United States Air Force Materiel Command dedicated to leading the discovery, development, and integration of warfighting technologies for our air, space and cyberspace forces. The Laboratory was formed at Wright-Patterson Air Force Base, Ohio on 31 October 1997 as a consolidation of four Air Force laboratory facilities (Wright, Phillips, Rome, and Armstrong) and the Air Force Office of Scientific Research under a unified command. The Laboratory is composed of 7 technical directorates, 1 wing, and the Office of Scientific Research. It controls the entire Air Force science and technology research budget. Each technical directorate emphasizes a particular area of research within the AFRL mission which it specializes in performing experiments in conjunction with universities and contractors. The 711th Human Performance Wing (711 HPW) at WPAFB is the first human-centric warfare wing to consolidate research, education and consultation under a single organization. Established in March 2008 under the Air Force Research Laboratory, the 711 HPW is comprised of the Human Effectiveness Directorate (RH), the United States Air Force School of Aerospace Medicine (USAFSAM) and the Human Performance Integration Directorate (HP). The Wing's primary mission areas are aerospace medicine, science and technology, and human systems integration.[1]

*Air Force Petroleum Agency (AFPA)* – The Air Force Petroleum Agency is the service control point for all Defense Logistics Agency fuel-related support issues. The agency provides a full range of technical and professional services related to fuels, propellants, chemicals, lubricants, gases, and cryogenics for all aerospace vehicles, systems, and equipment. While the headquarters office is co-located with the Defense Logistics Agency at Fort Belvoir, AFPA has a geographically separated presence and a fuel laboratory at WPAFB, OH. The organization is composed of three directorates -- Operations Support, Business Support and Product Support -- and six area aerospace laboratories with worldwide presence. The directorates provide services to customers and coordination with business partners and act as the single point of contact for most AFPA work. AFPA directly communicates with industry, governmental agencies, other military services, and NATO countries as well as all levels of organizational structure within the Air Force.[2]

*Warner Robins Air Logistics Complex (WR-ALC)* – Located just east and adjacent to the city of Warner Robins, GA and through about 7,000 employees, the WR-ALC provides depot maintenance, engineering support and software development to major weapon systems (F-15, C-

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[1] Air Force Research Laboratory (AFRL), WPAFB, OH, www.wpafb.af.mil/afrl

[2] Air Force Petroleum Agency (AFPA), Fort Belvoir, VA, www.afpa.af.mil

5, C-130, C-17 and SOF aircraft). The Complex achieves command objectives providing a capability/capacity to support peacetime maintenance requirements, wartime emergency demands, aircraft battle damage repair and a ready source of maintenance of critical items.[3]

### 8.2.2 United States Navy (USN)

*Naval Air Systems Command (NAVAIR)* – Headquartered in Patuxent River, MD, with military and civilian personnel stationed at eight locations across the continental United States and one site overseas. NAVAIR's mission is to provide full life-cycle support of naval aviation aircraft, weapons and systems operated by Sailors and Marines. This support includes research, design, development and systems engineering, acquisition, test and evaluation, training facilities and equipment, repair and modification, and in-service engineering and logistics support. NAVAIR is organized into eight "competencies" or communities of practice including: program management, contracts, research and engineering, test and evaluation, logistics and industrial operations, corporate operations, comptroller and counsel. NAVAIR provides support (through people, processes, tools, training, mission facilities, and core technologies) to Naval Aviation Program Executive Officers (PEOs) and their assigned program managers, who are responsible for meeting the cost, schedule, and performance requirements of their assigned programs.[4]

*Naval Sea Systems Command (NAVSEA)* – The largest of the U.S. Navy's five "systems commands," or materiel (not to be confused with "material") organizations. NAVSEA consists of four shipyards, nine "warfare centers" (two undersea and seven surface), four major shipbuilding locations. The NAVSEA headquarters is located at the Washington Navy Yard in Washington D.C. NAVSEA's primary objective is to engineer, build and support the U.S. Navy's fleet of ships and combat systems. NAVSEA accounts for nearly one-fifth of the Navy's budget, with more than 100 acquisition programs under its oversight.[5]

*Naval Medical Research Unit Dayton (NAMRU-D)* – Located at Wright-Patterson AFB, Dayton, OH their mission is to maximize warfighter performance and survivability through world-class aeromedical and environmental health research by delivering solutions to the field, the Fleet and for the future. NAMRU-D researchers are developing and validating *in vitro* methods for rapidly and cost-effectively screening alternative fuels. These methods include primary skin cells, a three-dimensional human skin model (dermal), and various lung models (i.e., inhalation) to assess cytotoxicity as well as inflammatory and irritancy endpoints. NAMRU-D is also assessing alternative fuel toxicity through the use of animal studies. Inhalation toxicity studies in rats are being performed to identify potential adverse physiological, biological, and genotoxic effects of novel jet fuels. Additionally, the effects of fuel exposure on noise-induced hearing loss are also being evaluated. These studies will help establish safe exposure guidelines for use of this important new class of renewable fuel alternatives.[6]

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[3] Warner Robins Air Logistics Complex (WR-ALC), Warner Robins, GA, www.robins.af.mil/units/wrairlogisticscomplex.asp
[4] Naval Air Systems Command (NAVAIR), Patuxent River, MD, www.navair.navy.mil
[5] Naval Seas Systems Command (NAVSEA), Washington Navy Yard, DC, www.navsea.navy.mil
[6] Naval Medical Research Unit-Dayton (NAMRU-D), WPAFB, OH, www.med.navy.mil/sites/nmrc/pages/namrud.htm

### 8.2.3 United States Army (USA)

*Research Development and Engineering Command (RDECOM)* – Headquartered at Aberdeen Proving Grounds, MD their mission is to empower, unburden and protect the Warfighter through integrated research, development and engineering solutions. The U.S. Army Research, Development and Engineering Command are the Army's technology leader and largest technology developer. RDECOM ensures the dominance of Army capabilities by creating, integrating and delivering technology-enabled solutions to our Soldiers. To meet this commitment to the Army, RDECOM develops technologies in its eight major laboratories and research, development and engineering centers. It also integrates technologies developed in partnership with an extensive network of academic, industry, and international partners.[7]

*Tank Automotive Research, Development, and Engineering Center (TARDEC)* – A subordinate command to RDECOM with the mission to develop, integrate and sustain the right technology solutions for all manned and unmanned Department of Defense (DoD) ground systems and combat support systems to improve Current Force effectiveness and provide superior capabilities for the Future Force. TARDEC is headquartered in Warren, MI but operates several world class state-of-the-art testing laboratories at multiple locations.[8]

*Southwest Research Institute (SwRI)* – A government-owned, contractor-operated (GOCO) facility with a staff of nearly 3,000 specializing in the creation and transfer of technology in engineering and the physical sciences. Founded in 1947 SwRI occupies more than 1,200 acres and 2 million square feet of laboratories, workshops, test facilities, and offices at San Antonio, Texas. It is a one-of-a-kind resource where integrated fuels-lubricants-engine systems research and development programs involving combustion, performance characterization, engine cleanliness, vulnerability assessments, and tribology can be performed. Eleven technical divisions offer a wide range of technical expertise and services in such areas as engine design and development, emissions certification testing, fuels and lubricants evaluation, chemistry, space science, nondestructive evaluation, automation, mechanical engineering, electronics, and more.[9]

*Aviation and Missile Research Development and Engineering Center (AMRDEC)* – A subordinate command to RDECOM and the Army's focal point for providing research, development, and engineering technology and services for aviation and missile platforms across their lifecycles. AMRDEC's headquarters is located at Redstone Arsenal, where they have over 1.6 million square feet of laboratory space devoted to innovative work on sensors and electronics, propulsion systems, aerodynamic structures, modeling and simulation, life cycle software development, and technical testing. They also have laboratories at Fort Eustis and Langley, Virginia and Moffett Field, California where Army and NASA aviation facilities, such as instrumented test ranges and wind tunnels, are used for advanced rotorcraft technologies to support their role as lead service for rotorcraft science and technology. The responsibility for aircraft extends to airworthiness release authority for issuing the technical document that provides instructions and limitations for safe flight of an aircraft system, subsystem, or allied

[7] U.S. Army Research, Development, and Engineering Command (RDECOM), Aberdeen Proving Grounds, MD, www.army.mil/rdecom
[8] U.S. Tank Automotive Research, Development, and Engineering Center, Warren, MI, tardec.army.mil
[9] Southwest Research Institute (SwRI), San Antonio, TX, http://www.swri.org/4org/d08/TARDEC/default.htm

equipment. Finally, AMRDEC has personnel devoted to aviation sustainment and engineering located in Corpus Christi, Texas.[10]

*Aviation Engineering Directorate (AED)* - The Directorate of Aviation Engineering is a Directorate of AMRDEC and the Airworthiness authority for Army-developed aircraft and provides matrix support to our customers. Our direct customers are the Program Executive Office for Aviation Programs Project/Product Managers (PMs) and the U.S. Army Aviation and Missile Command (AMCOM) Defense Systems Acquisition PMs. AED's ultimate customers are the Army aircraft crew, passengers, and maintainers that operate the Army aviation systems. Mission and Capabilities categories include Army Aviation Airworthiness and Engineering Subject Matter Expertise. The Aviation Airworthiness includes Airworthiness Release Signature Authority (AWRs), Program Management Systems Engineering, Rapid Fielding and Prototype Qualification, Qualification Bridge for S&T Tech Transfer, Fielded System Technical Support and Liaison Engineering, Aircraft Rework and RESET Technical Support, Parts Acquisition and Fielded Component Quality Control, Battle Damage Assessment and Repair, and Aircraft Accident Investigations. The Engineering Subject Matter Expertise includes Turboshaft Engines and Turbine Engine Subsystems, Rotary-wing Gearboxes and Drivetrains, Rotary and Fixed-wing Aerodynamics, Rotary and Fixed-wing Flight Performance, Rotary and Fixed-wing Handling Qualities, Rotary-wing Airframe Materials, Dynamics and Strength , Rotary-wing Weapons Systems, Rotary and Fixed-wing Military Avionics and Sensor Systems, Rotary and Fixed-wing Cockpit Systems, Displays and Human Factors, and Rotary and Fixed-wing Navigation and Control Systems.[11]

*United States Army Public Health Command (USAPHC)* – Once designated as two separate organizations the former US Army Veterinary Command (VETCOM) combined with the former US Army Center for Health Promotion and Preventive Medicine (CHPPM) to create the new U.S. Army Public Health Command (USAPHC). Headquartered at Aberdeen Proving Grounds, MD with the mission to promote health and prevent disease, injury, and disability of Soldiers and military retirees, their Families, and Department of the Army civilian employees; and assure effective execution of full spectrum veterinary service for Army and Department of Defense Veterinary missions. The USAPHC has five regional subcommands and an Army Institute of Public Health. The various departments within the previous Veterinary Command structure were realigned within each of the five regional subcommands in USAPHC. The Toxicity Evaluation Program (TEP) provides toxicological services for the identification of potential health hazards resulting from occupational exposures and focuses on providing expertise in support of civilian and troop health protection. This is accomplished through identifying chemical hazards and recommending preventive procedures for avoiding or minimizing exposures. We support the Army's Preventive Medicine Program and Soldier readiness by means of consultations, evaluations, and toxicity clearances.[12]

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[10] U.S. Army Aviation & Missile Research, Development & Engineering Center (AMRDEC) , Redstone Arsenal, AL, www.redstone.army.mil/amrdec/About/index.html

[11] Aviation Engineering Directorate (AED), Redstone Arsenal, AL, www.redstone.army.mil/amrdec/RD&E/AED.html

[12] United States Army Public Health Command (USAPHC), Aberdeen Proving Grounds, MD, phc.amedd.army.mil

## 8.3 Overview of Commercial Process

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), is a globally recognized leader in the development and delivery of international voluntary consensus standards. Today, some 12,000 ASTM standards are used around the world to improve product quality, enhance safety, facilitate market access and trade, and build consumer confidence.[13]

*Test Program* – It is unlikely that all of the tests shown in Fig. 2 will need to be performed. The OEMs should be consulted and will provide guidance on which tests are applicable. Applicability will be based on chemical composition of the new fuel or additive, similarity to approved fuels and additives, and engine manufacturer experience. Departure from engine manufacturer experience requires more rigorous testing. The product of the test program is a research report submitted by the fuel or additive sponsor to the engine manufacturers. The research report facilitates a comprehensive review of the test data by the engine and airframe manufacturers, specification writing organizations, and regulatory agencies.

*OEM Internal Review*—Results of the test program are carefully reviewed by the respective OEM chief engineers and their discipline chiefs. An OEM airworthiness representative interfaces with the appropriate airworthiness authority, for example, the FAA and EASA, to determine extent of FAA/EASA involvement. Discipline Chiefs and their staff engineers from organizations responsible for combustion, turbine, fuel system hardware, performance system analysis, system integration, and airworthiness engage in iterative meetings and reviews until the concerns and potential impacts on the engine have been explored and satisfactorily addressed. This exercise can result in requests for additional information or testing. Final approval is made at the executive level based on the recommendation of the chief engineer. The product of the OEM internal review is a document or report that either rejects or approves the new fuel or additive. After the approval of the new fuel or additive, there may be a requirement for a Controlled Service Introduction (CSI). Under a CSI, engines in the field that are exposed to the new fuel or additive are monitored for an increased level of fair wear and tear. The CSI is directed at identifying possible long-term maintenance effects.

*Specification Change Determination*—Approval by the OEMs of a new fuel or additive may only effect OEM internal service bulletins and engine manuals and have no impact on Specification D1655. If the OEM proposes changes to Specification D1655, then the proposed changes must be reviewed and balloted by ASTM D02.J0. Changes to Specification D1655 could include listing the additive or fuel as acceptable for use, changes to published limits, special restrictions, or additional precautions. Fig. 1 shows an overview of the ASTM review and balloting process, which is quite rigorous and typically goes through several iterations before a ballot is successful, culminating in a change to Specification D1655. The OEMs and the regulatory agencies regard the ASTM review and balloting process, and the subsequent scrutiny of industry experts, as an additional safeguard to ensure that issues relating safety, durability, performance, and operation have been adequately addressed. Although not a requirement, the OEMs typically wait for a successful ASTM ballot before changing their service bulletins and engine manuals to accommodate the new fuel or additive.

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[13]American Society for Testing and Materials (ASTM), West Conshohocken, PA, www.astm.org

### 8.3.1 Key Participants and Request for Qualification

*OEMs*—Engine OEMs include but are not limited to Pratt &Whitney (P&W), GE Aviation (GE), Rolls Royce (RR), Honeywell, and Hamilton Sundstrand. Airframe OEMs include but are not limited to Boeing, Airbus, Bombardier, and Lockheed. OEM approval is required for use of a new fuel or additive in aviation gas-turbine engines. OEM review and approval is required to ensure safety of flight, engine operability, performance, and durability requirements are not impacted by the new fuel or additive.

*Regulatory Authorities*—While approval of a new fuel or additive is at the discretion of the OEMs, regulatory organizations such as the FAA and EASA participate in the process. Approval by the regulatory authorities is necessary under the following conditions:

- The new fuel or additive impacts specification properties to the extent that the fuel does not conform to Specification D1655,
- A new specification must be written to accommodate the new fuel or additive, or
- Recertification of the engine or aircraft and aircraft operating limitations is required.

*Airlines*—Airline advocacy for the candidate fuel or additive is important to warrant consideration for qualification. The OEMs need strong support from the airlines to justify committing internal resources to evaluating a new fuel or new fuel additive for use in an aircraft. The airlines must submit written requests to the OEM customer service groups expressing a need and requesting that the fuel or additive be evaluated for qualification and approval. Requests from the airlines facilitate OEM management support, resulting in multidiscipline (combustor, turbine, fuel system hardware, materials, etc.) involvement in assessing impact on engine and aircraft operation.

*Military*—Military participation in the approval process is important because many commercial engines have military derivatives. The U.S. Air Force and U.S. Navy, respectively, have an approval protocol that is specific to the unique considerations of military engines. The protocols are based largely on this practice. Every effort is made to harmonize the commercial and military protocols such that they complement each other.

*ASTM International*:

ASTM Subcommittee D02.J0 on Aviation Fuels promotes the knowledge of aviation fuels by the development of specifications, test methods, and other standards relevant to aviation fuels. Issuance of an aviation fuel specification or test method by ASTM International represents the culmination of a comprehensive evaluation process conducted by ASTM members representing the petroleum industry, aerospace industry, government agencies, and the military. ASTM members are classified as producers (petroleum, additive and other fuel companies); users (aircraft or engine manufacturers, airlines); consumers (pilot or aerospace representative organizations); or general interest (government agencies and other parties). All such organizations or individuals showing ability and willingness to contribute to the work of Subcommittee D02.J0 are eligible for membership and participation in standards development.

The process for qualifying and approving a fuel or additive is initiated by a sponsor who acts as an advocate for promotion of the new aviation fuel. The sponsor approaches the ASTM aviation fuels subcommittee and solicits their support. ASTM members are volunteers and there is no obligation on the part of ASTM members to participate in the specification development activity. Participation of ASTM will be influenced by the quality of the presented material. Participation is unlikely if the initial data is considered sketchy or otherwise inadequate.

The new fuel or additive formulation must be thoroughly established prior to approaching ASTM as major compositional changes cannot be accommodated during the review process. The additive or fuel shall be identified by its specific chemical name or trade name. A chemical description of the fuel or additive shall be provided. If qualification is being sought for an additive, the carrier solvent and recommended concentration shall be provided. If the additive chemistry is proprietary, a generic description shall be provided. If merited, nondisclosure agreements can be placed between the additive manufacturer, the OEMs, and any task force member organization assisting in the investigation. ASTM and the Coordinating Research Council (CRC)[14] cannot enter into nondisclosure agreements or guarantee confidentiality.

A specification for the fuel or additive shall be agreed upon by the producer and OEMs. The specification shall define appropriate limits in sufficient detail that the purchaser can use it to ensure the receipt of the approved material. In cases where the approved material is a single named chemical, the specification shall, at a minimum, define the purity level of the approved chemical.

A technical case shall be presented to the OEMs and Subcommittee D02.J0 establishing need for the fuel or additive. Verifiable data performed by an industry-recognized laboratory shall be presented supporting performance for the specified application. The OEM/ASTM technical body will assess value and need based on the technical case. The assessment will consider scientific approach, source, and credibility of the data presented. The sponsor or investigating body shall submit a written report containing nonproprietary information to the OEMs.

*Coordinating Research Council (CRC)*—The CRC Aviation Fuels Committee has the mission to promote and to be an advocate for aviation fuels, agencies, and associated industries to foster scientific cooperative aviation fuels research. The vision is to be a worldwide forum for the aviation fuel technical community and the leader in cooperatively funded aviation fuel research. The CRC can be viewed as the investigative arm of Subcommittee D02.J0. CRC typically will respond to a request from ASTM to investigate a fuel-related issue. A fuel or additive will be considered for qualification if the OEMs and Subcommittee D02.J0 determines that the fuel or additive fulfills a need or provides a significant benefit to the aviation industry. If additional data or research is required, ASTM may request CRC investigate the fuel or candidate additive in more detail. Involvement of CRC can range from a review of data presented by the additive manufacturer or sponsor to actual testing and research performed by CRC task force members.

### 8.4. Alternative Fuel Processes.

Alternative fuels can be produced using a wide assortment of materials and processes. The Army Alternative Fuels Certification focused on three specific processes.

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[14] Coordinating Research Council, Inc., 3560 Mansell Road, Suite 140, Alpharetta, GA 30022. www.crcao.org

### 8.4.1 FT-SPK.

The Fischer–Tropsch process is a collection of chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. The process, a key component of gas to liquids technology, produces a synthetic lubrication oil and synthetic fuel, typically from coal, natural gas, or biomass. Fischer–Tropsch plants associated with coal or related solid feedstocks (sources of carbon) must first convert the solid fuel into gaseous reactants. This conversion called gasification results in a product called synthesis gas ("Syn gas"). Using the carbon monoxide derived from the hydrocarbons, the next step is to convert the gas to a liquid. The resulting synthetic crude is then processed into jet fuel. Widely used outside the United States, the USAF began exploring sources in 1999 and in December 2006 a B-52 flew for the first time powered solely by a 50/50 blend of JP-8 and FT-SPK.

### 8.4.2 HEFA.

The Hydroprocessed Esters and Fatty Acids (HEFA) process is a commercially deployed technology that converts vegetable oils and animal fats from triglycerides into hydrocarbons suitable for use in diesel and jet fuels. The process using solid second-generation biomass sources such as switchgrass or woody biomass uses pyrolysis to produce a bio-oil, which is then catalytically stabilized and deoxygenated to produce a jet-range fuel. The process using natural oils and fats goes through a deoxygenation process, followed by hydrocracking and isomerization to produce a renewable Synthetic Paraffinic Kerosene jet fuel. Oils extracted form a bio-crude that is finally converted to jet fuel.

### 8.4.3 ATJ.

The Alcohol derived Synthetic Paraffinic Kerosene (ATJ-SPK) jet fuels, are generally made in a two-step process. The first step is the dehydration of the alcohol into the corresponding alkene. Depending upon the catalyst, dehydration of the alcohol can also be accompanied by rearrangement of the resulting alkene to form one or more isomeric alkenes. The dehydration of alcohols to alkenes can be catalyzed by many different catalysts. An acidic heterogeneous or homogeneous catalysts can be used in a reactor maintained under conditions suitable for dehydrating the alcohol. Typically the alcohol is activated by an acidic catalysts to facilitate the loss of water. The resulting alkene exits the reactor in the gas phase The second step is either an isomerization or a selective cracking and isomerization process. ATJ-SPKs can be produced from bioderived alcohols which are created through traditional fermentation processes using carbohydrate feedstocks such as corn starch and sugar cane. Simplified ATJ is a process using the fermentation of cellulose and sugars. Various microbes, yeasts or bacteria are used to process agricultural waste products (stover, grasses, forestry slash, crop straws) to be converted either directly to jet fuel or through a group of alcohol conversion pathways. This is potentially a cheaper process, as the feedstocks are easy to obtain and inexpensive.

## 9.0 REFERENCES

Department of Defense (DoD), MIL-HDBK-510-1A (USAF), Aerospace Fuels Certification, dated 8 February 2010.

Department of Defense, MIL-HDBK-510A (USAF), Aerospace Fuels Certification (Updated), dated 8 August 2014.

Department of Defense, MIL-DTL-83133H, Detail Specification, Turbine Fuel, Aviation, Kerosene Type, JP-8 (NATO F-34), NATO F-35, and JP-8+100 (NATO F-37), dated 25 October 2011.

American Society for Testing and Materials (ASTM) D4054-09, Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives, revised 2009

## 10.0 DEFINITIONS

### A

**Additives:** Compounds used to impart new properties to a product or to improve a property which it already possesses - for example, mixed tertiary butylphenols when added to a fuel to improve its resistance to oxidation.

**Airworthiness:** The property of a particular air system configuration to safely attain, sustain, and terminate flight in accordance with the approved usage and limits.

**Airworthiness certification:** Airworthiness certification is a repeatable process that results in a documented decision by the SM that an aircraft system has been judged to be airworthy. In other words, it meets the approved set of criteria established by the Airworthiness Certification Criteria Control Board, *Airworthiness Certification Criteria),* or the aircraft system carries the appropriate Federal Aviation Administration (FAA) certificates. Airworthiness certification is intended to verify that the aircraft system can be safely maintained and safely operated by fleet pilots within its described and documented operational envelope.

**Airworthiness certification criteria:** The airworthiness certification criteria (MIL-HDBK-516) establish the criteria to be used in the determination of airworthiness of all Air Force flight vehicles. It is a foundational document to be used by the single manager, chief engineer, and contractors to define and tailor their airworthiness programs from the outset, and to assess the viability and quality of their airworthiness plans and activities throughout the program. These criteria must be used throughout the life of the air vehicle and applied whenever there is a change to the functional or product baseline, or where an airworthiness determination is required.

**Alternative Fuels:** An alternative fuel is any fuel determined to be substantially not petroleum, (e.g., non-crude oil sources for liquid hydrocarbons), that yields energy security benefits and environmental benefits. The term "alternative" fuels, as defined in this handbook, is used to differentiate between kerosene-type jet fuels produced from crude oil and similar fuels produced from alternative sources such as coal, natural gas or biomass.

**Alternative Fuels Certification Office (AFCO):** The government team responsible for the implementation and coordination of the fuel certification process. 77 AESW/LF

**Alternate Fuel:** An alternate fuel is one on which the air vehicle can be flown without operational restrictions but which can have long-term durability or maintainability impact if used for continuous operation (multiple flights). Alternate fuels are used only on an occasional or intermittent basis. Use of an alternate fuel should cause no adverse effect on the air vehicle mission(s).

**Approved Fuel:** A fuel(s) approved for use in an aircraft with restrictions or limitations defined, if any.

### B

**Baseline Fuel:** Baseline fuel is defined as a kerosene type turbine fuel that established this handbook‘s pass/fail criteria to which all candidate fuels will be compared. JP-8 in accordance with MIL-DTL-83133F was chosen as the baseline fuel for the handbook as of April 2007.

**Blending:** Blending refers to the procedures by which predetermined quantities of two or more similar products are homogenously mixed to upgrade one of the products or to produce an intermediate grade or quality. The term is also used to define the injection of additives, such as corrosion or icing inhibitors, into fuels.

### C

**Certified Fuel:** Fuel(s) first approved (to a standard) for use in a system certification for flight.

**Clean (Clear) and Bright:** Clean is the absence of visible solids, a cloud, a haze, an emulsion, or free water in the product. Bright is the sparkle of clean, dry product in transmitted light.

**Commingling:** Commingling is the mixing of two or more products of different ownership or grade.

**D**

**Decomposition of Requirements:** For this report, requirements are broken down into parts from requirements documents until the relevant fuel properties/characteristics are identified.

**Derived Requirements:** Derived requirements trace back to a driving requirement. For this report, the derived requirements are the relevant fuel properties/characteristics, and/or interfaces with other systems and other elements.

**E**

**Entrance Criteria:** Key information required to make a determination whether to initiate the fuel certification process. All fuel candidates will meet the general characteristics of a kerosene fuel that meets safety, performance, durability and operational characteristics comparable to the baseline fuel.

**F**

**Fit for Purpose:** A classification of property types which refers to properties inherent of a fuel that are not controlled by specification.

**Fungibility:** Fully interchangeable. Jet Fuels that are totally interchangeable with the same chemical properties which remain as a jet fuel product. This means fuel of the same grade manufactured by different refineries may be mixed and blended together during transit. Fungible fuel would lose its manufacturers identity but have the same chemical properties as the specified product. Fuels containing formulations or characteristics which can be mixed and shipped in common distribution systems. Fuels containing unique formulations or characteristics (e.g., military specifications) are not fungible.

**G**

**Gap Analysis:** Refers to the study and comparison performed to identify those missing pieces of information between 1) the fuels information outlined in the Mil Handbook and documented for the candidate fuel/fuel additive and 2) the systems level analysis of the weapon system, piece of equipment, environmental, safety, occupational health or logistics process required to qualify or certify the fuel for use.

**H**

**High Flash Point Kerosene Type:** High flash point kerosene fuel has essentially the same characteristics as kerosene type fuels, but with a minimum flash point of 60°C (140°F). This higher flash point fuel is required by the Navy for fire safety purposes aboard aircraft carriers.

**I**

**J**

**K**

**Kerosene Fuels:** Petroleum distillates with an approximate boiling range of 165° − 290°C (330° − 550°F).

**Kerosene Type:** Hydrocarbon liquid that has similar chemical and physical properties / characteristics as kerosene fuel.

**L**

**M**

**Micron:** One micron (micrometer, $10^{-6}$ meter) is a thousandth part of one millimeter.

**N**

**O**

**Operational Safety:** The condition of having acceptable risk to life, health, property, and environment caused by a system or end-item when employing that system or end-item in an operational environment.

**Operational Suitability:** The degree to which a system or end-item can be placed satisfactorily in field use, with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime use rates, maintainability, full-dimension protection, operational safety, human factors, architectural and infrastructure compliance, manpower supportability, logistics supportability, natural environmental effects and impacts, and documentation and training requirements.

**P**

**Primary Fuel:** The fuel(s) on which the air vehicle is designed to operate continuously without restrictions and is (are) also used to demonstrate contract compliance for complete steady state and transient operating conditions.

**Q**

**Qualified Fuel:** Fuel(s) that is (are) certified for use in a system with no restrictions.

**R**

**Requirements Decomposition:** For this report, requirements are broken down into parts from source requirements documents, (JSSG, etc.) until the relevant fuel properties/ characteristics are identified.

**S**

**Single Manager:** The single individual specifically designated, under the integrated weapon system management architecture, to be responsible for the life cycle management of a system or end-item. The Single Manager is the program manager vested with full authority, responsibility, and resources to execute and support an approved Air Force program. The term, ―Single Manager‖ will include not only weapon system or equipment managers, but persons responsible for environmental, operational, safety, health or logistics processes related to fuels.

**Subset 1 Testing:** Fuel properties/characteristics critical to personnel safety, system safety and/or system performance.

**Subset 2 Testing:** Fuel properties/characteristics critical to system performance and/or durability. This second subset also contains component level tests that do not directly correlate to a fuel property.

**Subset 3 Testing:** Fuel properties/characteristics critical to the system durability, and supportability requirements.

**Suitable for Use:** May be a certified, qualified, approved, or other fuel which may or may not have flight restrictions.

**Standardized Product:** A product is deemed to be standardized when it conforms to specifications which either have the same technical requirements, or which, in the opinion of the responsible working party, have equivalent technical requirements.

**Synthetic Fuel:** Any liquid fuel produced from coal, natural gas or biomass.

**System:** A specific grouping of subsystems, components, or elements designed and integrated to perform a military function.

**T**

**Technology Readiness Level:** A measure used to assess the maturity of evolving technologies (devices, materials, components, software, work processes, etc.) during its development and in some cases during early operations.

**U**

**V**

**W**

**Wide-Cut Type:** Mixtures of gasoline and kerosene distillate fractions with an approximate boiling range of 35° − 315°C (95° − 600°F).

**X**

**Y**

**Z**

## 11.0 ABBREVIATIONS

| | |
|---|---|
| μg | microgram |
| μL | microliter |
| | |
| A/C | aircraft |
| ACFT | aircraft |
| AFLCMC | Air Force Life Cycle Management Center |
| AFPA | Air Force Petroleum Agency |
| AFPA/PTOT | Air Force Petroleum Agency, Technical Assistance Team |
| AFRL | Air Force Research Laboratory |
| AFTD | US Army Aviation Flight Test Directorate |
| AED | Aviation Engineering Directorate |
| AEP | Aviation Engineering Directorate, Propulsion Division |
| AGL | above ground level |
| ALT | altitude |
| AMRDEC | US Army Aviation and Missile Research Development Engineering Center |
| APU | auxiliary power unit |
| ASN | army serial number |
| ATJ | alcohol-to-jet |
| ATM | aircrew training manual |
| AVN | aviation |
| AWR | airworthiness release |
| | |
| °C | degrees Celsius |
| CH | cargo helicopter |
| cm | centimeter |
| | |
| DLA-E | Defense Logistics Agency - Energy |
| DoD | Department of Defense |
| | |
| °F | degrees Fahrenheit |
| FAA | Federal Aviation Administration |
| FSA | flight safety assurance |
| FSE | field service evaluation |
| FT | Fischer-Tropsch |
| | |
| g, gr | gram |
| GE | General Electric Aviation |
| | |
| HEFA | hydroprocessed esters and fatty acids (aka HRJ) |
| HDBK | handbook |
| HH | (MEDEVAC & CSAR variant of UH) |
| HIT | health indicator test |
| HRJ | hydro renewable jet (aka HEFA) |

| | |
|---|---|
| IAW | in accordance with |
| IPT | integrated product team |
| | |
| JP-4 | jet propellant 4 (NATO Code F-40) |
| JP-5 | jet propellant 5 (NATO Code F-44) |
| JP-8 | jet propellant 8 (NATO Code F-34) |
| | |
| kg | kilogram |
| KIAS | knots indicated airspeed |
| | |
| Max | maximum |
| MEDEVAC | medical evacuation |
| MDS | mission design series |
| mg | miligram |
| min | minute |
| mL | milliliter |
| mm | milimeter |
| MOA | memorandum of agreement |
| MOP | measure of performance |
| MOU | memorandum of understanding |
| MTF | maintenance test flight |
| | |
| NATO | North Atlantic Treaty Organization |
| Ng | engine turbine speed ($N_1$) |
| NSN | national stock number |
| Np | power turbine speed ($N_2$) |
| Nr | main rotor speed |
| N/A | not applicable |
| | |
| OAT | outside air temperature |
| OEM | original equipment manufacturer |
| | |
| PA | pressure altitude |
| PCL | power control lever |
| PEO | Program Executive Office |
| PN | part number |
| | |
| RDA | risk decision authority |
| RDECOM | US Army Research Development and Engineering Command |
| RDMR | US Army Research Development and Engineering Center |
| RFP | request for proposal |
| rpm | revolutions per minute / rotations per minute |
| RTC | US Army Redstone Test Center |
| RTO | responsible test organization |

| | |
|---|---|
| SAS | stability augmentation system |
| sec | second |
| SFC | specific fuel consumption |
| SHP | shaft horse power |
| SOP | standard operating procedure |
| SPK | synthetic paraffinic kerosene |
| TGT | turbine gas temperature |
| TM | technical manual |
| TR | technical report |
| UH | Utility Helicopter |
| USA | United States Army |
| USAF | United States Air Force |
| USG | United States Gallon |
| USN | United States Navy |
| $V_H$ | horizontal velocity (maximum air velocity in level flight) |
| VMC | visual meteorological conditions |
| WBS | work breakdown structure |