ASTM D4054 Users Guide

A Publication of the
Commercial Aviation Alternative Fuels Initiative® (CAAFI) Certification-Qualification Team

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With Support from Members of the ASTM International Emerging Fuels Subcommittee

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1. INTRODUCTION

The current interest in aviation turbine fuels produced from non-petroleum feedstocks has prompted the aviation fuels community to develop a qualification and certification process to support development and deployment of these alternative jet fuels. This process utilizes the ASTM International Aviation Fuel Subcommittee (Subcommittee J) to coordinate the evaluation of data and the establishment of specification criteria for new alternative jet fuels. Subcommittee J has issued two standards to facilitate this process; ASTM D4054 – "Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives", and ASTM D7566 – "Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons".

ASTM D7566 was issued in September, 2009. The specification is structured with annexes that define property and compositional requirements for synthetic blending components that can be mixed with conventional, petroleum-derived jet fuel at specified volumes. D7566 includes a provision to allow fuels meeting this specification to be re-identified as conventional fuels when they enter the distribution infrastructure. ASTM International Standard D1655, 'Standard Specification for Aviation Turbine Fuels, defines the requirements for petroleum derived, conventional jet fuel. This re-identification provision allows the drop-in fuels listed in D7566 to be seamlessly integrated into the infrastructure and on to the aircraft without the need for separate tracking or regulatory approval. This is because the infrastructure is already designed to support D1655 jet fuel, and virtually all civil aircraft are certified to operate with jet fuel meeting specification D1655. So, once a new, alternative jet fuel is added as an annex to D7566, it is ready to fly on commercial airliners.

ASTM D4054 was developed to provide the producer of an alternative jet fuel with guidance regarding testing and property targets necessary to evaluate a candidate alternative jet fuel. D4054 is an iterative process, which requires the candidate fuel developer to test samples of fuel to measure properties, composition, and performance. The testing covers basic specification properties, expanded properties called fit-for-purpose (FFP) properties, engine rig and component testing, and if necessary, full-scale engine testing. This is a rigorous process that requires participation and input from many of the stakeholders at ASTM.

Typically, a producer will be seeking approval of a synthetic blending component for incorporation into D7566 as a new annex. A preliminary specification that lists the controlling properties and criteria for the neat synthetic blending component should first be established by the fuel producer prior to the initiation of the D4054 test program. The D4054 data is used to demonstrate that the proposed specification properties are robust enough to ensure that all synthetic blending components meeting those properties will be fit-for-purpose for use on turbine engines and aircraft when blended with conventional jet fuel. The D4054 data must also substantiate that the proposed specification properties adequately control the blending component and final finished fuel performance when subjected to the process variability that is expected to occur during large-scale production. The D4054 data and the proposed specification properties are then used as the basis for development of a proposed annex for incorporation into D7566 as a drop-in synthetic jet fuel. The iterative nature of this process evolves from the re-adjustment of the initial proposed specification properties that typically occurs upon review of the D4054 test results by the ASTM membership.

This D4054 User's Guide provides information on D4054 Clearinghouse and other facilities that can support the evaluation of candidate alternative jet fuels. The D4054 Clearinghouse provides centralized management and testing support for all phases of the D4054 process. Also provided is an index of other facilities that have demonstrated the technical capabilities necessary to perform the aviation fuel property testing required by D4054, and have expressed an interest in performing those tests in the future. However, this guide does not necessarily include all capable facilities, and alternative fuel developers are urged to seek out other facilities if required. It is also important to note that specific test capabilities, rigs and test facilities of the aircraft and engine original equipment manufacturers (OEMs) are not included in this guide (with one exception). However, the reader is advised that the OEMs are very engaged in testing of candidate alternative jet fuels and a significant amount of testing is typically performed at their facilities. The aircraft and engine OEMs should be contacted directly for information regarding the availability of their facilities for testing (contact information is provided in section 3 of this guide). Also, funding requirements to perform the D4054 tests are not addressed in this document, however contacts at each facility are provided to request additional information.

As a final note, please be advised that ASTM International Standard Practice D4054 has a certain amount of flexibility that is not typical of a Standard Specification. The data generated in satisfying the listed requirements of D4054 alone cannot guarantee approval. Due to the fast pace of change in this dynamic new industry, new requirements may be identified that have not yet been incorporated into the standard. Consequently, approval may not be achieved until these supplemental requirements are satisfied. The tests recommended below reflect the current expectations based on recent industry experience in generating D4054 Fit for Purpose (FFP) data.

2. D4054 OVERVIEW

ASTM D4054 was developed as a guide by the engine and airplane OEMs (original equipment manufacturers) with ASTM International member support. It provides the producer of an alternative fuel with guidance of what is expected in the form of required testing and OEM involvement. It also includes property targets that are based on OEM experience with the impact of fuel or additives on the design and performance of gas turbine engines. An overview of the ASTM D4054 evaluation and approval process is shown in Figure 1. The fuel producer should engage the key organizations within international aviation jet fuel community that typically support the evaluation and approval of new fuels. These include ASTM International, the Coordinating Research Council (CRC), and Commercial Aviation Alternative Fuels Initiative (CAAFI). A task force within ASTM's Emerging Fuel Subcommittee should be formed to solicit stakeholder input regarding testing and preparation of an ASTM research report. Typically, the OEMs will be a part of that task force. An ASTM research report is the vehicle used to submit the data used for gaining final approval for the new fuel to the ASTM membership. This research report will be reviewed by engine and airplane OEMs, airworthiness organizations, and international fuel specification standards groups. Involvement in these organizations is critical because it gives the fuel producer access to the world's foremost authorities in jet fuel and access to the most current work being performed in the development of new fuels. The D4054 Clearinghouse can guide the fuel producer through all of the above steps.

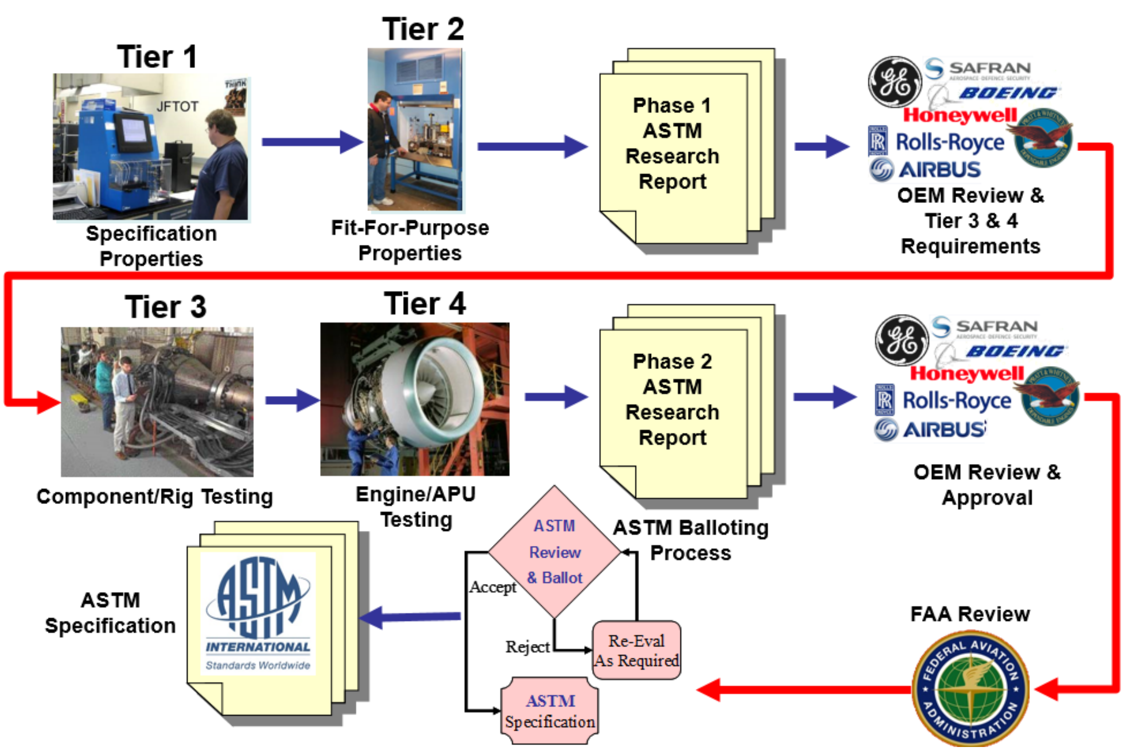


Figure 1. Pictorial Overview of the Fuel and Additive Approval Process

The process is iterative in nature, and is comprised of three parts: 1.) Test Program, 2) OEM Internal Review, and 3.) Specification Change Determination. Figure 2 provides an overview of the three parts of the process.

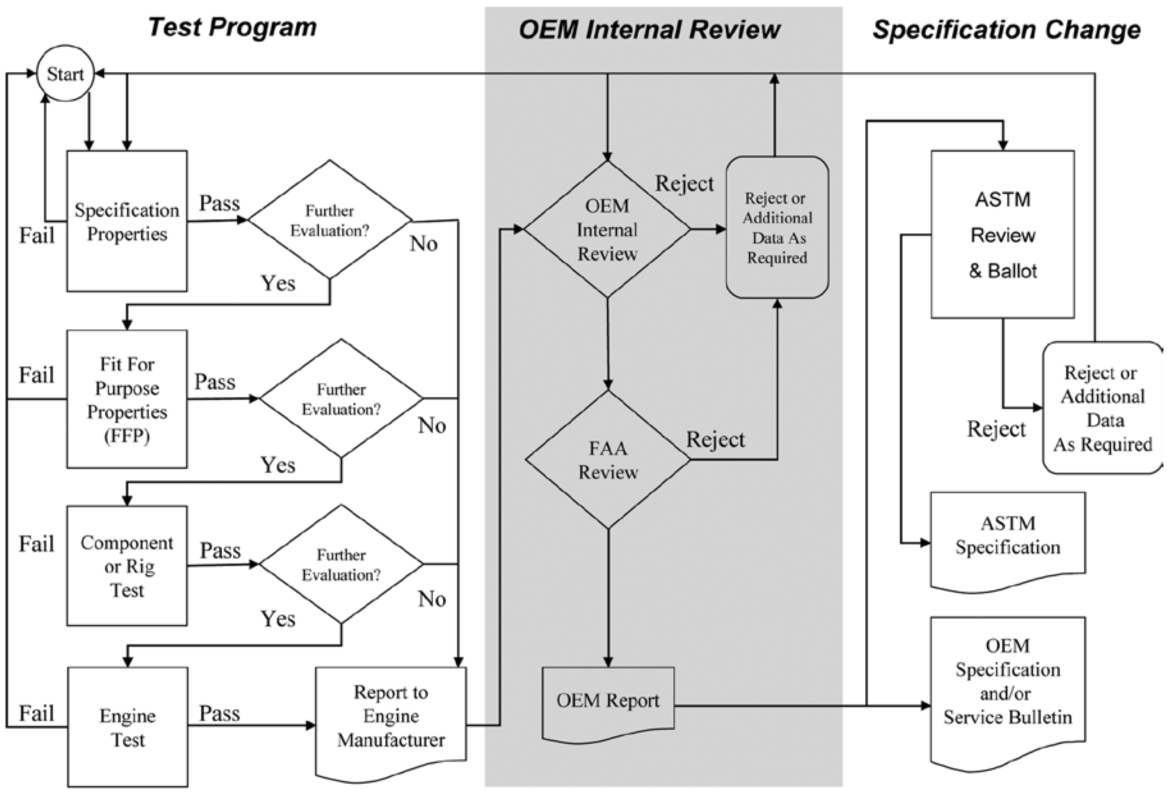


Figure 2. Overview Fuel and Additive Approval from ASTM D4054 Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives

Part 1: Test Program

The Test Program is comprised of four tiers as shown in Figure 3. Tier 1 consists of the Fuel Specification Properties. Tier 2 includes the Fit-For Purpose (FFP) Properties. Tier 3 is comprised of Component Tests. Tier 4 consists of Engine Tests. Samples of both the neat synthetic blending component and the blended jet fuel will be required for evaluation. Most of the testing except for compositional and trace materials analyses are performed with the blended jet fuel. Fuel volumes that may be required are up to 10 gallons (38 liters) for the Specification Tests; 10 to 100 gallons for the FFP tests; 250 to 10,000 gallons (950 to 38,000 liters) for the Component and Rig Tests; and up to 225,000 gallons (852,000 liters) for the engine test. The aforementioned are rough estimates because the extent of required FFP tests is dependent upon the fuel chemistry and results of the Specification tests. Actual quantities could be higher or lower. Component and engine tests may or may not be required depending on results from the Specification

Tests, the FFP tests, and at the evaluation of the OEM team. The quantity of fuel needed for Component and Rig Tests and Engine Tests, depends on the tests required and also the size of the rig or engine used for the test. Similarity of the new fuel chemistry or manufacturing process to one previously approved will also be considered when determining the extent of required D4054 testing. The D4054 Clearinghouse can either conduct the above testing or coordinate with third-party facilities to conduct the testing.

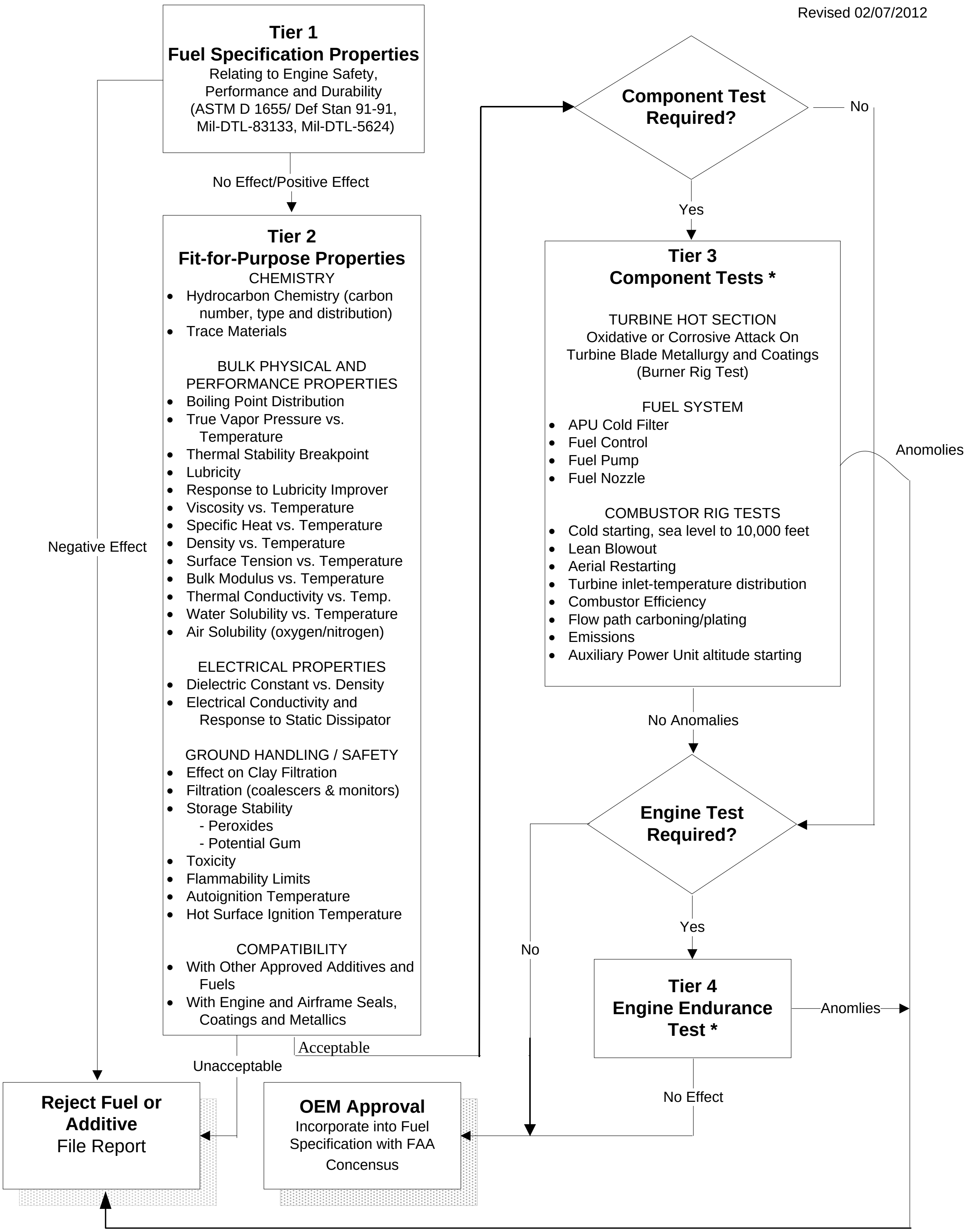


Figure 3. Test Program

The first tier requires measurement of the current jet fuel specification properties of the blended jet fuel. The new fuel progresses no further in the approval process if there is a negative impact on specification properties unless there is a compelling reason to do so. The fuel producer should be prepared to present the specification test results along with the proposed specification criteria and results for the neat synthetic blending component to the OEM team when initiating the dialog. In addition, a high level description of the new fuel process should also be included. It's important to note that the cumulative specification (Table 1) properties required for ASTM D1655, UK(MOD) DS91-91, DOD MIL-DTL-5624 and MIL-DTL-83133 must be presented for evaluation.

The tier 2 FFP properties address fuel properties that are not listed in the specification but are important to the OEM in the design and performance of gas turbine engines. These properties are not part of the jet fuel specification because they are relatively constant for all petroleum-derived kerosene fuels. However, this may not be the case for fuels derived from alternative sources. The OEM team will advise which FFP tests are required based on the specification test results, chemistry of the new fuel, and similarity to processes and fuels currently in ASTM D7566. Test methods, limits, and engine OEM scope of experience for each of the FFP tests are called out in Table 2 of ASTM D4054.

The engine OEMs will determine what, if any, component tests must be performed under tier 3 based on the specification and FFP test results and the chemistry of the new fuel. Typical component tests asked for by the engine OEMs include an atomizer cold spray test, an ignition test comprised of cold starts and altitude relight, a combustion rig test to measure lean blow-out, and emissions; a thermal stability fuel system simulator test, and an Auxiliary Power Unit (APU) cold start test. The tier 4 engine test is the final gate in the test program. The OEMs will determine the need for an engine test based on the chemical make-up of the new fuel, specification, FFP, and component test results. The engine test may address the performance, operability, or durability of the engine when operating on the candidate fuel.

Part 2: OEM Internal Review

Once the testing is completed, the data are compiled in an ASTM research report and submitted to the OEMs for an internal review. The research report should include a detailed description of how the process is going to be controlled such that the fuel that was tested and approved represents the fuel that will be produced at commercial volumes. Additionally, the research report should determine if the new fuel fits in an existing ASTM D7566 annex or if a new annex needs to be created. The OEMs, FAA, and ASTM International will make the final determination. The ASTM research report is prepared by the fuel producer, often with the assistance of an ASTM task force, and presented to the OEMs for review and comment.

During the OEM internal review, chief engineers and discipline chiefs within each OEM organization will review the ASTM research report to see that all concerns have been addressed and that there are no data gaps. The OEMs will discuss details of the research report with the fuel producer and task force and provide recommendations for the way forward. The way forward may include additional testing. The ASTM research report must contain all the data required to support a consensus by the OEMs, FAA, and other ASTM members that the new fuel will have no negative impact on engine and airplane safety, performance, and durability. The D4054 Clearinghouse can coordinate the review of the research report with the OEMs.

Part 3: Specification Change

Once the OEMs and the FAA approve the research report, it is balloted to the ASTM membership for comment and approval. If the research report passes ballot, then an annex that specifies controls for the new fuel should be developed and balloted for incorporation into ASTM D7566. These steps may be conducted concurrently if the research report and proposed specification annex have been developed and reviewed in a concurrent manner.

The ASTM balloting process allows a diverse group of stakeholders from other areas of the fuel and petroleum community to review the data. Consequently, the balloting process may reveal the need for additional data to be added to the research report, or for additional controls to be added to the proposed specification annex.

Other Considerations

- Proxy Fuels: A test fuel assembled from neat chemicals to simulate the properties of the proposed alternative fuel is called a proxy fuel. The use of proxy fuels for qualification efforts should be disclosed and will be carefully considered by the ASTM membership. It is recognized that a proxy fuel could provide an understanding of the performance of the candidate fuel and would provide valid results for many of the FFP tests referenced in D4054. However, the fuel producer should be cautioned that corresponding data from test fuel produced in accordance with the proposed process will also be required in the final research report.
- Surrogate Feedstocks: Some potential fuel sources rely on multiple conversion steps of the raw feedstock to yield a finished product. However, in some cases data may be developed by starting at an intermediary step in the conversion process with a commercially available (surrogate) material. These surrogate feedstocks are typically industrial chemicals that are readily available. Use of a surrogate derived material should be disclosed and reviewed with the FAA/OEM representatives. It should be noted that surrogate derived material is not acceptable for any testing that involves analysis of trace materials or properties.
- Renewable Feedstocks: The source of renewable feedstocks should be defined to the extent necessary to ensure consistent trace materials properties. The evaluation process includes the measurement of trace materials to ensure that the trace metabolites, minerals and other components of the organic material have been eliminated and process generated trace materials are minimized. Control of the trace materials during production should be addressed in the research report.

Aviation Turbine Fuel Additives

The D4054 process may also be used to evaluate aviation turbine fuel additives. An additive concentration of 4X is typically required for the D4054 testing to evaluate the performance effects of overdosing. Additive testing addresses the compatibility of the proposed additive with the existing allowed additives, and additive performance for its intended function. In addition, because additives are active chemical agents that impact the fuel properties, the proposed additive's compatibility with aircraft materials is also evaluated.

The ASTM D4054 additive approval section is currently being revised to give detailed parameters, processes, and guidelines to facilitate the completion of required tests for aviation approval, and to ensure the candidate additive by itself or in combination with other approved additives will perform for its intended function and have no detrimental impact when used in the aviation industry. The new section will encompass testing protocols for additives functional types currently utilized in aviation as listed in ASTM D1655 Table 2, and also types of additives not currently in use in the industry. The testing protocol will be designed to evaluate additive "compatibility", "no harm" and "performance for its intended function".

- The "Compatibility" evaluation will encompass a testing protocol to evaluate physical properties of the new additive when used with existing additives.
- The "No Harm" evaluation phase will be used to determine the impact of the candidate additive on the performance of currently approved additives
- The "Performance for its Intended Function" section will be geared to ensure the additive enhances or corrects the fuel property for which it is being added to the fuel.

3. D4054 Clearing House

The Federal Aviation Administration (FAA) established the D4054 Clearinghouse to guide candidate alternative fuel producers through the D4054 qualification process. It is intended to provide centralized management and testing support for all phases of the D4054 process. The clearinghouse is a project under the FAA's Center of Excellence for Alternative Jet Fuels and Environment (ASCENT) program. ASCENT is a cost-sharing program that the FAA established with academia and industry to conduct research on alternative jet fuels and the environmental impact of aviation. This type of program requires that the ASCENT participants at least match the level of funding contributed by the FAA for each specific project.

The D4054 Clearinghouse project is being managed by the University of Dayton Research Institute (UDRI):

ID	Facility Name	Address	Contact Info
UDRI	University of Dayton Research Institute	300 College Park Rd Dayton OH 45469	Dr. Steve Zabarnick 937-255-3549 Steven.Zabarnick@udri.udayton.edu

An overview of UDRI's testing and analysis capabilities may be found in section 5.

The FAA has provided a level of funding intended to establish the clearinghouse and support a limited amount of fuel testing and review. It is anticipated that other sources of funding or in-kind resources will be required from industry, academia, or other Government agencies to fully support the complete scope of testing for future candidate alternative jet fuel projects.

The Clearinghouse will guide and support the fuel producer through six stages that are encompass the testing, report generation, and OEM engagement necessary to traverse the D4054 process:

Stage 1: Fuel Screening:
- D1655 Table 1 test data is reviewed by the D4054 Clearinghouse for viability
- If Ok, the producer is requested to provide 100 gallons of neat test fuel

Stage 2: Phase 1 Testing and Research Report:
- The fuel producer delivers 100 gallons of neat fuel
- Tier 1 and 2 testing is conducted by UDRI or other contracted facilities
- The Phase 1 Research Report is prepared

Stage 3: Phase 1 OEM Review Process:
- The Clearinghouse coordinates OEM Review
- Additional testing conducted if necessary
- Tier 3 and 4 (Phase 2) test requirements are defined by the OEMs

Stage 4: Phase 2 Testing & Research Report:

- The fuel producer delivers required quantity of test fuel to support Tier 3 & 4 testing
- Tier 3 and 4 testing is conducted by UDRI or other contracted facilities
- The Phase 2 Research Report is prepared

Stage 5: Phase 2 OEM Review Process:

- The Clearinghouse coordinates OEM Review of the Phase 2 Research Report
- Additional testing conducted if necessary
- The Clearinghouse obtains a final Fit-For-Purpose determination from the OEMs

Stage 6: ASTM Balloting:

- The final ASTM Research Report and proposed ASTM D7566 Annex are submitted for ballot

A detailed description of the above D4054 Clearinghouse process is available upon request from UDRI.

4. Test Facility Index

Other Universities and Research Facilities

This section provides a listing of universities and other research facilities that have demonstrated the technical capabilities necessary to perform the aviation fuel property testing required by D4054, and have expressed an interest in performing those tests. Contact information is also provided for each facility.

ID	Facility Name	Address	Contact Info
AFRL	Air Force Research Laboratory	AFRL/RQPF 1790 Loop Road North Wright-Patterson AFB, OH 45433-7103	Dr. James (Tim) Edwards 937-255-3524 James.Edwards@wpafb.af.mil
UDRI	University of Dayton Research Institute	300 College Park Road Dayton OH 45469	Dr. Steve Zabarnick 937-255-3549 steven.zabarnick.ctr@us.af.mil
SwRI	Southwest Research Institute	6220 Culebra Rd. San Antonio, Texas 78238-5166	George Wilson 210-522-2587 gwilson@swri.org
NRCC	National Research Council Canada	Building M-17 1200 Montreal Road Ottawa, ON K1A 0R6 Canada	Wajid Chishty (613) 993-2731 Wajid.Chishty@nrc-cnrc.gc.ca

ID	Facility Name	Address	Contact Info
NaTeF	National Test Facility for Fuels	Purdue University Department of Aviation Technology 1401 Aviation Drive West Lafayette IN 47907-2015	David L. Stanley (765) 494 6266, dlstanley@purdue.edu J. Mark Thom (765) 494 9757, jmthom@purdue.edu Denver Lopp (765) 494 6387, denver@purdue.edu Melanie Thom (765) 743 9812, melanieathom@cs.com
USheff	University of Sheffield	Dept. of Mechanical Engineering Mappin St. Sheffield, South Yorkshire S1 3JD, United Kingdom	Simon Blakey +44-07766-440-466 s.blakey@sheffield.ac.uk
DGA	DGA Essais propulseurs	10 rue Jean Rostand, Saclay 91895 ORSAY FRANCE	Vincent Plana vincent.plana@intradef.gouv.fr +33 (0)1 69 85 00 94
DSTO	Defence Science and Technology Organisation	DSTO Melbourne 506 Lorimer St Fishermans Bend Victoria, Australia, 3207	Dr Chris Hulston +61 3 96267112 chris.hulston@dsto.defence.gov.au
NASA	NASA Glenn Research Center	21000 Brookpark Rd Cleveland, Ohio 44135	See Facility Overview on page 27
DLR	German Aerospace Center	Deutsches Zentrum für Luft- und Raumfahrt e.V. Institute of Combustion Technology Pfaffenwaldring 38-40 70569 Stuttgart Germany	Patrick Le Clercq +49-711-6862-441 Patrick.LeClercq@dlr.de Claus Wahl +49-711-6862-373 Claus.Wahl@dlr.de
ASG	ASG Analytik-Service GmbH	Trentiner Ring 30 D-86356 Neusaess Germany	Juergen Bernath Juergen.bernath@asg-analytik.de 0049 821 450423-11
ONERA[1]	Département Énergétique Fondamentale et Appliquée ONERA -	Centre de Palaiseau BP 80100 91123 PALAISEAU CEDEX	Mickaël Sicard Mickael.Sicard@onera.fr Tél : +33 (01) 80 38 60 52 Fax : +33 (01) 80 38 61 61

[1] Facility overview not provided

Engine and Aircraft OEMs

This section provides a listing of aircraft and engine OEMs that have demonstrated the technical capabilities necessary to perform the aviation fuel property testing required by D4054, and have expressed an interest in performing those tests. Contact information is also provided for each facility.

ID	Facility Name	Address	Contact Info
AIRBUS[1]	Airbus Operations Limited	Airbus Operations Ltd. Building 07L Module 2 Golf Course Lane Filton BS99 7AR UK	Graham Osborn graham.osborn@airbus.com +44 (117) 9363028
BOEING[2]	Boeing Commercial Airplane Group	P.O. Box 3707 MC 67-JX Seattle, WA 98124-2207	James Kinder james.d.kinder2@boeing.com 1-425-237-2347
EMB[1]	Embraer	Av. Brigadeiro Faria Lima, 2170 Sao Jose dos Campos, SP 12227-901 Brazil	Marcelo Goncalves marcelo.goncalves@embraer.com.br 55-12-3927-4621
GE[1]	GE Aviation, General Electric Company	1 Neumann Way, M/D S173 Cincinnati, Ohio 45215	M. Gurhan Andac T + 1 513 552 2720 F + 1 513 552 6050 gurhan.andac@ge.com
HW[3]	Honeywell Aerospace	111 S. 34th St. - P.O. Box 52181 M/S 93-35/503-415 Phoenix, AZ 85072-2181	Brad Culbertson Bradley.Culbertson@Honeywell.com 1-602-231-2423
PW[1]	Pratt & Whitney Aircraft Group	M/S 114-45, Bldg D P.O. Box 109600 East Hartford, CT 06108	Tedd Biddle 1-860-557-1367 tedd.biddle@pw.utc.com
RR[1]	Rolls Royce, Ltd.	P.O. Box 31 Derby, England DE24 8BJ United Kingdom	Alistair Hobday Alastair.Hobday@Rolls-Royce.com +44 (0) 1332 247839
RR[1]	Rolls-Royce Corporation	PO Box 420, Speed Code W-08 Indianapolis, IN 46206-0420	Brad Wall Earl.b.wall@rolls-royce.com 1-317-230-8656
SNECMA[1]	Snecma Villaroche Center	Snecma Site de Villaroche Rond-point René Ravaud. Réau 77550 Moissy-Cramayel. France	Gérard Gauthier +33-1- 60-59-89-51 gerard.gauthier@snecma.fr Eric Hermant +33-1- 60-59-71-04 eric.hermant@snecma.fr
WILL[1]	Williams International	2280 West Maple Road P.O. Box 200 Walled Lake, MI 48390-0200	Jamey Condevaux jcondevaux@williams-int.com 248-960-2811

[2] Test Facility Overviews and Test Facility Locator entries not provided for these OEMs.
[3] Test Facility Overview not provided, but Test Facility Locator entries provided for this OEM.

5. Test Facility Overviews - Universities and other Research Facilities

This section provides an overview of the equipment and capabilities of the universities and other research facilities listed in section 3. The contact information is also included in this section for each facility. Facility overviews are not provided for aircraft and engine OEMs, but readers are urged to directly contact these companies for information regarding the availability of their facilities for testing (contact information is provided in section 3 of this guide).

ID	Facility Name	Address	Contact Info
AFRL	Air Force Research Laboratory	AFRL/RQPF 1790 Loop Road North Wright-Patterson AFB, OH 45433-7103	Dr. James (Tim) Edwards 937-255-3524 James.Edwards@wpafb.af.mil
UDRI	University of Dayton Research Institute	300 College Park Road Dayton OH 45469	Dr. Steve Zabarnick 937-255-3549 steven.zabarnick.ctr@us.af.mil

Facility Overview:

AFRL and University of Dayton Research Institute (and the nearby Air Force Petroleum Agency specification testing lab, AFPET) have the capability to support much of the low TRL/FRL (test readiness level/fuel readiness level) testing of jet fuels. The AFPET lab performs all of the ASTM D1655/MIL-DTL-83133 tests, while the AFRL lab performs ASTM D2425 comprehensive two-dimensional gas chromatography (GCxGC) hydrocarbon composition measurements, viscosity vs temperature, trace species analyses, and various thermal stability tests. Larger-scale tests available to support fuel evaluation include a fuel system simulator, a T63 engine with emissions measurements, and a single-nozzle combustor rig. Typically, other fit-for-purpose testing is contracted out to outside labs such as Southwest Research Institute. To this point (2012), AFRL has been able to offer specification and fit-for-purpose testing at no charge to fuel producers through collaboration with CAAFI. Future budgets will determine the extent of continuing testing. AFRL is also able to support collaborations with engine companies to accomplish engine testing. AFRL maintains a significant stockpile of conventional and alternative aviation fuels for reference purposes and collaborative fuel evaluation programs. AFRL also has access to contracts with major engine, airframe and subsystem manufacturers for collaborative programs. These contracts typically cover rig (e.g., hot section material compatibility, fuel pump) and engine testing. AFRL also has a facility capable of generated test fuels at the 500-gallon level through typical refinery operations (hydroprocessing, distillation).

Detailed Capabilities (specification tests not listed):

1) ASTM D2425, GCxGC for hydrocarbon composition; various capabilities for contaminants/non-hydrocarbon analysis – solid phase extraction, high performance liquid chromatography (HPLC).
2) Scanning Brookfield viscometer – viscosity measurements down to point where fuel becomes too viscous to pump.
3) Inductively coupled plasma optical emission spectroscopy (ICP-OES) for metals analysis (semi-quantitative)
4) Thermal-oxidative stability tests, small scale – Quartz Crystal Microbalance (QCM), several flow reactors capable of running tests in excess of 100 hours and fuel temperatures in excess of 500 C (tests typically run at pressures from 35-70 atm). Carbon deposition assessed by "carbon burnoff" of metal test sections using Leco RC 512 instrument. Fuel volumes range from 60 mL (QCM) to hundreds of gallons for extended duration testing.
5) Advanced reduced-scale fuel system simulator – reduced scale version of fighter fuel system (see AIAA 98-3531, 94-3171), typically runs 100+ hours at varying flows and temperatures corresponding to mission points (cruise, ground idle, etc.). Typical fuel usage ~ 1000 gallons/test. Typical tests have bulk fuel temperatures up to 400 F (200 C), burner feed arm wetted wall temperatures of 500-600 F. The focus of this rig is fuel thermal stability studies. Thermal breakdown of the fuel is detected by valve hysteresis, and post-test carbon deposition analysis of rig components.
6) T63 engine testing – typically used for emissions testing (fuel comparisons similar to other (newer) engines, see Corporan et al, ASME-GT-2012-68656). AFRL/UDRI can assess all emissions (including latest SAE E31 particulate diagnostics) from idle to maximum power. Occasionally run as a durability demonstration (150 hrs demo for HEFA blend). Relatively small engine – can get fairly complete emissions assessment with less than 50 gallons of fuel.
7) Materials compatibility testing – several facilities, ranging in scale from o-ring swell (mL of fuel) to extended duration o-ring test facility capable of multi-month operation at fuel system pressure from fuel freeze point to max use temperature (hundreds of gallons). University of Dayton Research Institute also performs standard 28-day "soak" tests on materials set listed in ASTM D4054/MIL-HDK-510.
8) Toxicology testing – tests as described in MIL-HDBK-510, performed by Tri-Service Toxicology team at WPAFB.
9) Microbial growth potential of fuel – assessment of tendency of fuels to support microbial growth (primarily at fuel/water interface) performed by University of Dayton research Institute.[Mueller et al, 2011 IASH paper]

ID	Facility Name	Address	Contact Info
SwRI	Southwest Research Institute	6220 Culebra Rd. San Antonio, Texas 78238-5166	George Wilson 210-522-2587 gwilson@swri.org

Facility Overview:

D4054 Testing Support at Southwest Research Institute (SwRI)

All testing in support of ASTM D4054 at SwRI is conducted by, or through the coordination of, the US Army TARDEC Fuels and Lubricants Research Facility – SwRI (Army Lab). All testing is conducted in respect to the user interest. While SwRI personnel will provide consulting and guidance, they will not take an advocacy position on proposed fuels or additives.

For nearly 60 years, SwRI has conducted aviation fuel research and testing, continually improving capabilities, facilities, and equipment. The SwRI Fuels and Lubricants Division has achieved certification to ISO 9001 and 14001, ensuring compliance with stringent quality control procedures in design, development, testing, and environmental management.

SwRI Capability Information

Material Compatibility

SwRI has extensive abilities in testing material compatibility across the campus. The limitation is getting the required test material. The Army Lab is equipped to test elastomers and plastics with the following methods. Other Institute resources can be brought to bear on other materials.

- Tensile strength and elongation per ASTM D412
- Volume swell per ASTM D471
- Hardness, Shore A per ASTM D2240
- Hardness, Shore M per ASTM D2240
- Tensile strength and elongation per ASTM D1414
- Compression set per ASTM D395

These tests are routinely used to evaluate the effects on three primary elastomers of interest (nitrile, fluorocarbon and fluorosilicones).

Aviation Jet Fuel Filtration Test Facility

The aviation jet fuel filtration test facility at Southwest Research Institute (SwRI) is currently the only independent and unbiased source for developing and evaluating aviation fuel filtration systems. The state-of-the-art equipment, facilities, and knowledgeable staff offer comprehensive services for filtration manufacturers, distributors, and users, including:

- Developing innovative filtration media and systems
- Performing equipment qualification and validation services
- Developing and validating filtration procedures and methods
- Providing field analysis and contamination assessment services

With broad capabilities in materials science, engine design and development, and fuel and lubricant technologies, SwRI offers aviation filtration manufacturers, suppliers, and users a single resource for engineering services such as:

- Fuel and Additive Compatibility
- Long-term materials compatibility design
- Pipeline and hydrant design and modeling
- Hydrodynamic and flow simulations
- Component and equipment performance testing
- Technical Services

Single-element and full-scale system tests are performed on aviation filters, coalescers, separators, monitors, and microfilters to ensure compliance with national and international specifications according to EI (Energy Institute) and SAE (Society of Automotive Engineers) specifications, including:

- EI 1581 for aviation jet fuel filter and jet fuel separators
- EI 1583 for aviation jet fuel monitors and absorbent-type elements
- EI 1590 for aviation jet fuel microfilters
- SAE J1488 for filtration compatibility screening
- SwRI also performs tests according to military specifications such as MIL-PRF-52308J.

The SwRI aviation jet fuel filtration test facility is routinely used for qualification testing. Filtration manufacturers qualify their products to meet national and international specifications. Additive manufacturers use the process to establish their materials do not interfere with filtration. The SwRI aviation filtration facility is an independent laboratory that provides the aviation industry with unbiased and accurate results.

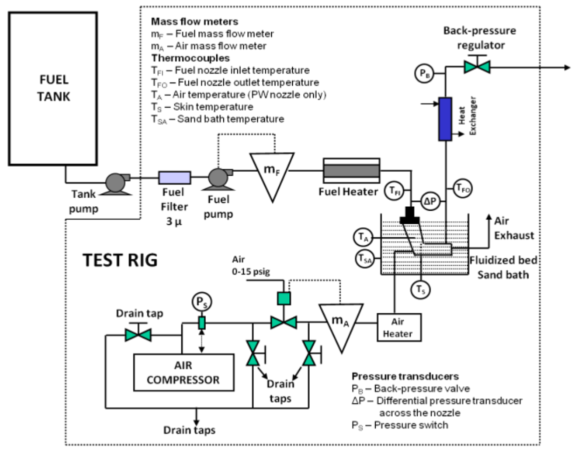
<u>Jet-Engine Nozzle Test Stand and Specialized Fuels Testing</u>

The purpose for this modular test stand is to provide clients with the ability to simulate In situ conditions on a component level.

- The heating system avoids fuel coking issues before the test article due to innovative use of heat transfer oil and high efficiency heat exchangers
    - 3 Independent Fuel Heater Systems

        - 10kW (9.5 BTU/s)
        - 20kW (19 BTU/s)
        - 30kW (28.5 BTU/s)
    - Can be combined in series to provide up to 60kW (57 BTU/s) total capacity
- The fuel pumps are all located on one moveable cart along with the fuel filters for ease of access and maintenance
    - 3 Independently Controlled Fuel Pumps
        - 0.5 to 2.5 gal/min (1.9 to 9.5 L/min) @1000 psi (69 bar)
    - Capacity for higher volume/pressure pumps if needed
    - Specialized micro-flow pump capable of 0-100 mL/min @ 2000 psi
    - Solenoid control valves add flow rate switching capability for testing fuel nozzles with integral valves
- The air supply and heating capacity has been greatly expanded with the addition of piping from our 'air factory'
    - Air Factory:
        - 1400 CFM, 50 psi, 1000 °F max
        - (660 L/s, 3.5 bar, 537 °C)
    - 2 small compressors:
        - 30 to 60 CFM @ 100 psi
        - (14 to 28 L/s) (6.9 bar)
        - Coupled with (4) 2kW (1.9 BTU/s) & (2) 6kW (5.7 BTU/s) heaters in a manifold configuration
- On site fuel storage and blending facility:
    - 10,000 gallon bulk tank (37854 L)
    - 300 gallon blend tank (1135 L)
    - 500 gallon run tank (1892 L)
- Article testing area:
    - May be configured for use of up to 2 nozzles immersed in heated fluidized baths
        - 1000 °F max (537 °C)
    - Completely reconfigurable based on need
    - Feasible options include:
        - LN2 cold bath
        - Induction coil heating system for transient studies
- Current suite of instrumentation includes:
    - 4 fuel mass flow sensors
    - 3 air mass flow sensors
    - 23 pressure transducers
    - 49 thermocouples
    - Data rate of 10 Hz nominal. Up to 10,000 Hz if custom solution required.

Nozzle Test Stand General Configuration



<u>SwRI Gas Turbine Combustor Research and Testing Capabilities</u>

Purpose:

- To attain maximum flexibility for fuels-combustion research the facility was designed as an “air factory” to provide appropriate inlet-conditions for whatever combustor/fuel system is under investigation. Conceptually, any combustion chamber could be “plugged in” and operated within the facility’s air flow, pressure, and temperature operating conditions.
- Current operating parameters are:
    - Total engine air flow – 0.4 to 2.2 lbm/s
    - Combustor inlet pressure – 14.0 to 16.0 atm
    - Combustor inlet temperature – up to 1500 oF

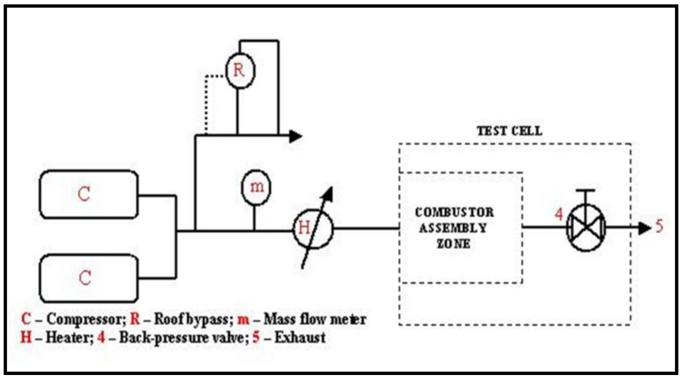
Combustion and Performance Testing:

- Emissions: Horiba MEXA-1600D emissions analyzers use direct sample line to measure CO, CO2, NOx, O2, Hydrocarbons. Full scale calibrated to 1% NIST.
- Particulate matter mass: This is determined by drawing a measured sample through 2 filters in series after passing through a dilution probe. Dry gas meters measure volume flow rate of gas. The difference in weight before and after test provides particulate mass reported to the nearest microgram.
- Particle number, concentration and size distribution: Scanning Mobility Particle Size (SMPS) used for size range: 10-300 nm represents > 99% of particles. Sensitive to low exhaust concentration. Photoacoustic sensor to measure particle mass.
- Toxic organics: Poly-aromatic hydrocarbon speciation measurements. Napthalene’s, pyrene’s, anthracene’s etc.(2-5 rings). Hazardous pollutants (HAPS)

measurement includes aldehydes, ketones, dioxins/furans, most hydrocarbons in C1-C12 range.

- Altitude Re-Light, Ignition and Lean Blow-Out Tests (ground start: sea level up to 10,000 ft), simulating idle, taxi-out, take-off, climb, cruise, idle-descent, landing, and taxi-in conditions, combustor liner temperature, and combustor efficiency.

Combustor Test Stand General Configuration



ID	Facility Name	Address	Contact Info
NRCC	National Research Council Canada	Building M-17 1200 Montreal Road Ottawa, ON K1A 0R6 Canada	Wajid Chishty (613) 993-2731 Wajid.Chishty@nrc-cnrc.gc.ca

Facility Overview:

Specific to ASTM D4054 test program, NRCC facility capabilities are as follows:

1. Metallic and non-metallic material compatibility testing.
2. Burner rig and material/coating analysis for turbine hot section component testing.
3. High pressure spray rig testing and laser diagnostics for fuel nozzles.
4. Combustor rig testing for lean blowout, ignition, pattern factor, instabilities and emissions.
5. Cold start, altitude relight, emissions and APU testing.
6. Full engine testing for operability, performance, endurance and emissions.

Facilities Details:

1. Materials Compatibility Testing:

Test	Method	Materials
Metallic materials compatibility Test	ASTM D4044, Microstructural and visual evaluation, corrosion	Metallic Materials
Long term fuel soaking, various temp.	Oven with controlled environment and temperature	Non-metallic Materials (coatings, films, sealants, O-ring, adhesive, etc.)
Peel Strength	SAE AS5127/1	Non-metallic Materials
Hardness, Shore A, M and Pencil	ASTM D2240, ASTM D3363	Non-metallic Materials
Tape Adhesion	ASTM D3363, D3359	Non-metallic Materials
Tensile Strength, Elongation	ASTM D412	Non-metallic Materials
Volume Swell	ASTM D471	Non-metallic Materials
Compression Set	ASTM D359	Non-metallic Materials
Lap Shear	ASTM D1002	Non-metallic Materials
Interlaminar Shear	ASTM D6272	Non-metallic Materials

2. Burner Rig Testing:

Becon Burner Rigs (Quantity)	2 Rigs
Maximum Gas Temperature:	1600°C
Maximum Gas Velocity:	Mach 0.8
Fuel Types:	Standard jet fuels and marine diesel fuel

Testing Capabilities: Cyclic Oxidation, Hot Corrosion, and Hot Erosion	High velocity cooling is available for both external and internal cooling
	Controlled amounts of contaminants can be added to the fuel or combustion air for hot corrosion investigations
	Controlled amounts of solid particles can be added to the combustion gases for high temperature erosion studies

3. High Pressure Spray Rig Testing:

• Optically accessible single injector sector rig
• 20 bar (300 psig), 4.5 kg/s air delivery
• Spray characterization, FN, drop sizing and velocity, laser sheet imaging
• Laser diagnostics (PDPA, PIV, Malvern)
• 3-D traverse system

4. Combustor Rig Testing:

Air Moving Capability (max.)	21.5 kg/s @ 20 bar (47.5 lb/s @ 300 psia)
Air Preheating Capability	920 K @ 18 kg/s (1200 deg F @ 40 lb/s)
Fuels Available	Natural Gas, Diesel, Jet A-1
Seeding Capability for fuel flexibility tests	Hydrogen, Nitrogen, Ethane, Propane, DME, and others
• 4 combustion test cells • More than 1000 standard and high scan rate channels • Measurement suite for gas turbine gaseous and PM emissions • High pressure optically accessible combustion rig	

5. Altitude chamber for cold start, altitude relight, emissions and APU testing:

Working Section dimensions (Length x internal diameter)	9.7 m (31.8 ft) x 2.6 m (8.5 ft)
Maximum flow rate	11.2 kg/s (24.6 lb/s)
Minimum altitude (with refrigerated air)	914 m (3.0 kft)
Maximum altitude	15,760 m (51.7 kft)
Ambient minimum altitude (non-refrigerated moist air)	91 m (300 ft)
Minimum temperature at a flow rate of 0.23kg/s (0.5 lb/sec)	-48.3 °C (-55 °F)
Minimum temperature at a flow rate of 4.5kg/s (10 lb/sec)	-25 °C (-13 °F) -35 °C (with LN2)
Heated inlet air at a flow rate of up to 1.8 kg/s (4.0 lb/sec)	+48 °C (+118 °F)
1. 1000+ channels for analog inputs @ 50Hz 2. 100+ channels @ 100kHz 3. Gaseous and PM emissions measurement capability 4. Capability to handle turbofan, turbojet, APU, etc.	

6. Engine testing for operability, performance, endurance and emissions:

	Test Cell 1	Test Cell 2	Test Cell 4	Test Cell 5
Engine type	Turboshaft/jet	Turboshaft/jet	Turbofan/jet	Turbofan/jet
Dimensions	4.6 m (15 ft) x 4.6 m (15 ft) x 10.7 m (35 ft)	4.6 m (15 ft) x 4.6 m (15 ft) x 10.7 m (35 ft)	7.6 m (25 ft) x 7.6 m (25 ft) x 22.9 m (75 ft)	4.6 m (15 ft) x 4.6 m (15 ft) x 22.9 m (75 ft)
Thrust/Power	4,000 SHP at 4,500 rpm	9,000 SHP at 3,600 rpm	222 kN (50,000 lbs)	222 kN (50,000 lbs)
Air flow	50 kg/s (110 lb/s)	50 kg/s (110 lb/s)	454 kg/s (1000 lb/s)	227 kg/s (500 lb/s)
Inlet	Heated 90°F at 9.1 kg/s (20 lb/s)	Ambient	Ambient with icing tunnel	Ambient with icing tunnel
Typical testing	Alternative fuels, blade-off, emissions, endurance	Alternative fuels, blade-off, emissions, endurance	Alternative fuels, icing, emissions, endurance	Icing, bird, hail, water ingestion, endurance
Design & Correlation	SAE AIR 4989, SAE ARP 4755		SAE AIR 4869, SAE ARP 741	

- Emissions (Gaseous & Particulate Matter) measurement capability available in any test cell
- 1000+ channel DAS & 36 channels high speed DAS in all test cells
- Conventional and alternative fuels (including biofuels) at flow rates up to 32,500 kg/h (71,500 lb/h)
- 3 working & 4 storage fuel tanks at 40,000 litre (10,567 USgal) capacity

ID	Facility Name	Address	Contact Info
NaTeF	National Test Facility for Fuels	Purdue University Department of Aviation Technology 1401 Aviation Drive West Lafayette IN 47907-2015	David L. Stanley (765) 494 6266, dlstanley@purdue.edu J. Mark Thom (765) 494 9757, jmthom@purdue.edu Denver Lopp (765) 494 6387, denver@purdue.edu Melanie Thom (765) 743 9812, melanieathom@cs.com

Facility Overview:

The National Test Facility for Fuels and Propulsion (NaTeF) at Purdue University includes test cells, engine run stands, a Materials Laboratory, and the Zucrow High Pressure Laboratory; all of these facilities are located at the Purdue University Airport. The fuels testing capabilities of NaTeF include:

Engine Test Cells

- Turbine Engines
  - Data acquisition system for inside test cells
    - Engine pressures and temperatures
    - Atmospheric pressures and temperatures
    - RPM, thrust, and horsepower
    - Exhaust emissions – see below
  - Allison 250 / T63 on a mobile test stand
  - 1330-lb thrust turbofan, inside test cell
  - 1350 SHP turboprop, inside test cell
- Piston engines (expected to be operational by beginning of fall semester, 2012).
  - Dynamometer for analysis of horsepower developed
  - Air conditioning system to control combustion air to engine for both temperature and humidity. Enables "Standard Day" testing under a wide range of ambient atmospheric conditions.
- Exhaust emissions for turbine and piston engines
  - Particulate matter to 2.5 NM
  - Standard five-gases: CO, CO2, O2, NO, NOx, total hydrocarbons
  - FTIR: Hydrocarbons, as required by testing protocol

Zucrow High Pressure Laboratory

- Optically accessible aviation gas turbine combustion test rig
- Heated inlet air system with 5 kg/s flow rates, 1000 deg F temp, 500 psi pressure
- New liquid fuel delivery system with high pressure pump, main and pilot fuel lines
- Optically accessible window assembly, has been operated to 150 psi, designed for 300 psi
- Advanced laser diagnostics including 10 kHz Particle image velocimetry (PIV) and Hydroxide Planar laser-induced fluorescence (OH PLIF), dual-pump Coherent Anti-Stokes Raman Scattering (CARS), fast-frame-rate chemiluminescence (CH and OH) imaging
- Full exhaust emissions sampling rig, tested and validated
- In-line oxygen sensor and fuel sparging for removal of dissolved oxygen

Materials testing:

General laboratory analysis:

Unknown identification using self-developed aerospace Fourier-Transform Infrared (FT-IR) spectral libraries as well as the following lab tests.

Liquids - Fuel/oil testing:

- Density: both by Jolie balance and by hydrometer
- Flashpoint: Pensky Marten Closed Cup, ASTM D93
- UV-Vis spectrum
- FT-IR analysis: liquids, solids, and micro-samples
    - Concentration changes using fixed path length FT-IR
- GC analysis capabilities
- Surface tension - platinum ring, ASTM D1331
- Thermogravimetric analysis (TGA) analysis (similar to distillation)

Polymer/non-metallic testing - on o-rings and flat stock

- Shore A durometer (hardness), ASTM D2240
- Density, by Jolie balance
- Tensile, ASTM D412
- FT-IR analysis
- TGA analysis
- Hyphenated TGA/FTIR analysis (combines the weight change analysis with off gas identification)
- ASTM compression testing: room temperature, oven and freezer, ASTM D395
- Surface adhesion testing, ASTM D3359
- Exposure testing of above properties: room temperature, oven (up to 200C), and cold (down to -80C), including dimensional change following exposure.

- Combine the above and analyze changes.

Specialized testing:
In addition to the above services already available, the NaTeF group will work with your organization to develop specialized testing capabilities where and whenever possible.

Flight test

In order to most economically conduct fit-for-purpose evaluation of alternative fuels, the NaTeF research group will develop an overall test program which establishes a series of gates to qualify the products under development, beginning with those enumerated above. Once a candidate fuel passes successfully through these steps, operational flight testing is a critical final stage of the testing process. The NaTeF research group currently has two means by which to achieve flight test:

- Flight test utilizing a twin-engine Beechcraft Duchess, which may be flown in an experimental category; the test plan and analysis to be overseen by NaTeF.
- Flight test contracted through an outside organization, with both the research procedures and analysis of the results performed in close cooperation with the NaTeF research group.

Future testing capabilities in planning:

Hot fuels

- Impact on components and materials
- Affects on combustion properties

ID	Facility Name	Address	Contact Info
NASA	NASA Glenn Research Center	21000 Brookpark Rd Cleveland, Ohio 44135 USA	See below listing

Facility Overview:

NASA Glenn is a propulsion research center that is currently involved in air breathing propulsion and has the capability to perform propulsion test services to companies interested in certifying alternative fuels. The testing facilities are extensive and range from test cells capable of full engine testing at altitude conditions to those for evaluation of thermal stability performance of alternative fuels. The combustion facilities also include several flametube/sector rigs with capabilities to perform combustion testing. The sector and flametube combustion test rigs have duel fuel capability with the capability to perform online blending of two fuels. A brief summary of the various combustion related test facilities is provided in the following table along with contact information.

Facility Name	Purpose	Test Conditions	Measurement Capability	Fuels Capabilities	Contact	Link
Propulsion Systems Laboratory (PSL)	Engine Testing at altitude conditions	24 ft by 39 ft long test section 5000-90,000 ft altitude	Extensive Pressure, Temperature, measurement capabilities Gaseous Emissions	Liquid Fuels	Thomas Hoffman 216 433-5637	http://facilities.grc.nasa.gov/psl/index.html
Advanced Subsonics Combustion Rig (ASCR)	Annular, Sector Combustion Rig Testing	50 lbs/sec 900 PSIA 1100 F Inlet Temperature	Gaseous and Particulate Emissions	Standard Jet and Alternative Fuel Capability – on line fuel blending	Gwynn Severt 216 433- 8318	http://facilities.grc.nasa.gov/ascr/index.html
CE-5	Flametube Combustion Rig Testing	Stand 1 – 15 lbs/sec, 275 PSIA Stand 2 – 5 lbs/sec, 400 PSIA 1200 F Inlet Temp	Gaseous and Particulate Emissions, Laser–based Diagnostic Measurement Capability High Speed Video	Standard Jet and Alternative Fuel Capability – online fuel blending	Gwynn Severt 216 433- 8318	http://facilities.grc.nasa.gov/erb/index.html
Alternative Fuels Laboratory, B109	Fuel Thermal Stability Measurements	Hot Liquid Process Simulator	Hot Liquid Process Simulator, Ellipsometer		Jennifer Klettlinger 216 433-6095	

ID	Facility Name	Address	Contact Info
USheff	University of Sheffield	Dept. of Mechanical Engineering Mappin St. Sheffield, South Yorkshire S1 3JD, United Kingdom	Simon Blakey +44-07766-440-066 s.blakey@sheffield.ac.uk

Facility Overview:

The Low Carbon Combustion Centre (LCCC) at the University of Sheffield hosts a range of aviation specific test facilities as well as pilot scale combustion facilities from a range of power generation and industrial sectors. The LCCC also has access to specialist fuels specification and forensic analytical labs.

The LCCC has significant experience in involvement in alternative fuels research programmes, including, but not limited to: ECATS, Aeronet, Alfabird, Swafea, Partner and CLEEN. The LCCC has also carried out industrial research for specific fuels and fuel blends with the FAA, Rolls Royce, BA, EI-JIT, BP, Shell and QER.

In addition, the facility has a strong focus on modeling support activities which can assist in the understanding of the performance of alternative fuels and additives.

D4054 Testing Support at Low Carbon Combustion Centre (USheff):

Combustion

Combustion and performance (atmospheric lines)

The lines are capable of supplying air at mass flows of up to 1.5 kg/sec at 0.2bar. Liquid fuel up to 10g/s. The lines are capable of operating at both ambient and elevated temperatures, being fitted with 120kW electric air pre heater which enables it to operate with combustor inlet temperatures of up to 550K. The lines are able to be operated with a variety of fuels – gaseous, liquid and bio-fuels. The facility is designed for ignition and flame stability limit measurements as well as combustor development. The rig is also equipped with high frequency transducers for the measurement of combustor acoustics.

APU (Auxilary Power Unit)

The test bed gas turbine engine is a re-commissioned Honeywell GTCP85 Auxiliary Power Unit (APU). The engine test bed facility provides an ideal experimental platform to evaluate the performance of different alternative and conventional fuels. The rig fits in the range of possible combustion analyses between laboratory bench scale testing of fuels, of the order of a liter of fuel, and full engine tests, requiring 1,000s of liters.

The LCCC also hosts a Rolls Royce RR Artouste MK113 and two Turbec T100 ground based power generation gas turbines, all instrumented and available for alternative fuels research. The LCCC also has developed a range of codes for engine and combustor modelling, including the prediction of alternative fuel performance.

MEL (Mobile Emissions Laboratory)
A mobile emissions laboratory has been set up to carry out analysis of exhaust gases from a wide variety of applications. The laboratory can be used in tandem with the rigs onsite, and has also been used for measurements behind main aircraft engines.

The laboratory is equipped standard emissions measurement devices, carbon dioxide, carbon monoxide, oxygen, nitrogen oxides (NOx), and Richard Oliver SAE smoke analyzers to ARP 1179, 1256 and 1533 standards. These standard facilities are augmented by a range of particle measurement techniques including Rolls Royce optical and a DMS particle sizer. The laboratory is also equipped with an FTIR for the speciation of the unburned hydrocarbons.

Coupled with the traversable gas rake, the laboratory is able to sample and analyze the exhaust from aircraft engines whilst on the ground and can produce maps of temperature and emissions across the engine exhaust.

Rapid Compression Machine
The RCM is available for the measurement of ignition delay times for alternative fuels. It is pneumatically driven and is damped at the end of the stroke by a hydraulic ring and groove system. Currently, a maximum pressure of 20.5bar can be achieved with a compression ratio of 12.5 and stroke of 140.5mm. Compression takes 35ms with a driving pressure of 5 bar. A working time in the region of 60ms is available.

Atomization rig
The LCCC hosts a full scale atomization facility with which is capable of being run with alternative fuels and can be coupled to the fuel delivery system of the atmospheric line. The rig is equipped with Shadow photography, a Malvern particle size analyzer and PdPa.

Shell premix burner
Small scale facilities for combustion and emissions measurement include the Shell premix burner for assessing smoke and particulate emission from fuels. This facility has been further developed at the LCCC to include additional emissions analysis for the screening of small volumes of fuel.

Materials compatibility

Hot End Materials Rig (HEMR)
Experimental capability available for testing the performance of Hot End Materials in exhaust gases from candidate fuels. This capability is run in conjunction with the atmospheric line, providing combustion gases within the correct temperature range and exhaust gas composition to mimic the attack of exhaust gas turbine gases on materials: high temperature corrosion (HTHC) between 800°C and 950°C and oxidation attack at 1100°C. Performance is judged by loss of material from (measured by weight change), or

surface finish / coating failure of sample billets of hot end materials. The test is performed in thermal cycles to further accelerate any potential wear of components.

The LCCC supports research activities modeling reactive particle formation and agglomeration through the combustor, hot end and exhaust section of the engine.

O-ring seal performance measurement

The LCCC elastomer testing capability at is made up of the dynamic measurement of stress relaxation of elastomeric materials in contact with alternative fuels. Tests typically take up to 1000hours and can perform temperature cycling between -80degC and 30degC at 1degC/min with low volumes of fuel (>100mL). The rig is also able to switch load seals with a range of fuels over a defined cycle.

The LCCC supports researchers carrying out more fundamental research work into the chemical and physical mechanisms for seal performance at the fuel – elastomer interface including laboratory analysis of the changes in seal chemical composition over time using FTIR techniques. By linking the seal performance to the absorption of material to and from the seal it is possible to predict the performance of any fuel / seal combination.

Thermal stability

Aviation Fuels Thermal Stability Test Unit (AFTSTU)

The Aviation Fuels Thermal Stability Test Unit is designed to replicate the entire engine fuel system of an aircraft from wing tank to burner feed arm, providing representative operating conditions for in service engines, including the fuel residence time and temperature history within the engine core. Testing at 23L/hr would require around 8000L of fuel for a standard 300 hour test. Data is collected on LP and HP filter and component performance including hysteresis of moving parts in the fuel flow. A simplified burner feed arm is used to measure the formation of deposits from initial wetted wall temperatures from 260degC up to 320degC under standard conditions. Posttest, carbon burn off or sectioning of the feed arm can be carried out to ascertain composition and morphology of deposit.

High Reynold's Number Thermal Stability (HiReTS) and Jet Fuel Thermal Oxidation Tester (JFTOT) rigs

The High Reynold's Number Thermal Stability rig is designed to provide quantitative results on the thermal stability of relatively small fuel samples (around 5L). The testing is carried out in accordance with ASTM D6811-02(2007). The JFTOT is the industry standard for thermal stability measurements for fuel specification to ASTM D3241-13. The LCCC also carries out research beyond the standard test methods using these smaller scale facilities including real time thermal imaging of the hot test components at a range of off-specification temperatures and heat load conditions.

Additional thermal stability equipment

The LCCC also hosts a range of additional thermal stability test facilities including the Mini Injector Feed Arm Rig (MiFAR) and Single Tube Furnace donated by Shell aviation. These facilities require around 1000L for a test, fitting between the laboratory testing capability and the pilot scale AFTSTU rig.

The LCCC supports researchers investigating the critical factors contributing to thermal stability performance under engine operating conditions. A computational fluid dynamics (CFD) based model for the prediction of deposit formation dependent on fuel chemistry has been developed and is applicable to alternative fuel performance modeling.

ID	Facility Name	Address	Contact Info
DGA	DGA Essais propulseurs	10 rue Jean Rostand, Saclay 91895 ORSAY FRANCE	Vincent PLANA vincent.plana@intradef.gouv.fr +33 (0)1 69 85 00 94

Facility Overview:

Fully integrated in the French MoD, DGA Aero-engine Testing is the European leader in the field of air breathing propulsion, and offers test services to engine manufacturers as well as cooperation program with other research centers. Engine testing under simulated altitude conditions is our core activity. Thereby, DGA Aero-engine Testing owns world class testing facilities for military aircraft, business aircraft or UAVs engines (piston engines, turbojets, turbofans, turboshafts, turboprops) and their components (compressors, combustion chambers). The main advantages offered by DGA Aero-engine Testing are:

- Accurate simulation and repeatability of flight and / or icing conditions
- Hazardous tests performed with far less risk than in-flight tests
- Ready access to the test vehicle during the test period
- Highly instrumented test unit (up to 1500 lines).

DGA Aero-engine testing certifications and accreditations guarantee high quality services to customers, in full respect of confidentiality, as well as a full respect of environmental rules.

DGA & ALTERNATIVE FUELS: A FULL RANGE OF CAPABILITIES:
Historically, DGA is mainly using F-34 fuel. Nevertheless, on some facilities, tests with other fuels can be carried out. For example, we have recently made tests on the Rafale M88 engine in the R3 altitude test cell with a blend 50/50 of F-34 and Sasol FT fuel. Combustors or fuel sub-systems could be also tested with alternative fuels subject to specific or adapted ancillaries.

Here is a brief overview of the different facilities that could be used to perform tests with alternative fuels. Contact us for further information.

- FIVE ALTITUDE TEST CELLS: M1, R3, R4, R6 & S1: Test on commercial and military turbofans (aircraft and missiles) within their flight envelope up to 60 000 ft. Test on commercial and military turboshaft, turbo-prop engines (without propeller in test cell), auxiliary power units, at simulated altitude. Tests in icing conditions on air intakes with or without engine, aerodynamic profiles and fuel systems, freezing drizzle, development of freezing rain conditions and ice crystals. Altitude test cell specifications:
    - Altitude Test Facility M1
        - Test of turboprops, turboshaft, piston engines & APU…
        - Pressure from 5 to 150 kPa

        - Temperature from -70°C to +100°C (air) / -55°C to +70°C (fuel)
        - Air flow up to 75 kg/s
    - Altitude Test Facility R3 or R4
        - Turbojet and turboshaft engines
        - Pressure from 5 to 300 kPa.
        - Temperature from -70°C to 170°C
        - Air flow up to 130 kg/s (R3) and 50 kg/s (R4) (with air flow at 100 kPa & 15°C)
        - Flight envelop available on request.
    - Altitude Test Facility R6
        - Turbojet and turboshaft engines
        - Pressure from 5 to 150 kPa
        - Temperature from -60°C to +100°C
        - Air flow up to 175 kg/s (upgradable with wet ambient air if needed).
        - Icing capabilities.
        - Flight envelop available on request.
    - Altitude Test Facility S1
        - Currently dedicated to icing tests but can be reconfigured
        - Pressure from 5 to 150 kPa
        - Temperature from -60°C to +110°C (air)
        - Air flow up to 100 kg/s (with air flow at 100 kPa & 15°C)

- ONE SEA LEVEL TEST BED (TØ): T0 is a sea level test bed, with ambient conditions upstream and downstream the turbojet engine. A gas preheater can be set up upstream the engine inlet in order to increase the air temperature and hence aging the engine. T0 is capable of engine performance evaluations, endurance tests as well as water and sand ingestion tests. T0 has a maximum thrust limitation of 100 kN.

- THREE COMBUSTION TEST RIGS: A06, K8 & K9: DGA has capabilities to perform a large range of combustors development tests:
    - Stability domain with cold fuel in altitude conditions on A06 (up to 38 000 ft)
    - Performance evaluation of the combustor in high pressure (20 bar) and high temperature (800 K) conditions on K8 with combustion efficiency, outlet temperature and pollution measurements
    - Sea level characterization of the combustor on K9 with or without water and steam injection
    - With its dedicated and independent fuel system ancillaries, the A06 facility rig is perfectly adapted for alternative fuels tests.
    - Combustion Rig Specifications:
        - Combustion test rig A06 : stability domain in altitude
            - Up to full annular combustion chamber
            - Pressure from 20 kPa to 120 kPa

        - Temperature from +50 °C to -50 °C for inlet air and down to -55 °C for fuel
        - Air flow up to 4.2 kg/s
        - High speed camera for ignition monitoring
    - Combustion test rig K8 : performances in operating conditions
        - Up to full annular combustion chamber
        - Pressure up to 21 bar
        - Temperature from 20 °C to 520 °C
        - Air flow up to 26 kg/s at standard conditions
        - Traverse gear for temperature & gas analysis measurements on 360° at the outlet of combustor. With its traverse gear, combustion test rig K8 is fully equipped for emissions measurements at the outlet of the combustion chamber: CO, CO2, NOx, HC and Smoke Number. Emissions tests could be adapted to ATF (TBC).
    - Combustion test rig K9 : performances at atmospheric pressure
        - Full annular combustion chamber
        - Pressure at 1 bar
        - Temperature from 20 °C to 520 °C
        - Air flow up to 12 kg/s
        - Steam and/or water injection in the combustor
        - APU test at ambient temperature
            - Already done on K9 with mechanical adaptations (valves, exhaust ducts, specific frame…)

- ONE FUEL SYSTEM ICING FACILITY (GIV): DGA can carry out qualification tests on complete circuits or on elements of the aircraft fuel systems in order to check its performances in icing simulated conditions. The parameters considered can be:
    - Air temperature (climatic chamber)
    - Fuel temperature (conditioning facility)
    - Fuel pollution (solid or water, icing activity)
    - Simulated altitude
    - Quick depressurization
    - Endurance cycling
    - Different fuels can be tested sequentially on this facility.

- ON SITE FUEL ANALYSIS IN A CERTIFIED LABORATORY: DGA Aero-engine Testing is expert in investigations of engine components, associated systems, and fluid analysis. Our laboratory can perform a wide range of analysis on fuels like:
    - Density
    - Viscosity
    - Flash point
    - Heating value

- Freezing point
- Hydrogen content
- Sulfur content
- Aromatics content
- Naphthalene content
- Water content
- Gum content
- Particulate contamination
- Distillation
- GC/MS identification
- Etc…

ID	Facility Name	Address	Contact Info
DSTO	Defence Science and Technology Organisation	DSTO Melbourne 506 Lorimer St Fishermans Bend Victoria, Australia, 3207	Dr Chris Hulston +61 3 96267112 chris.hulston@dsto.defence.gov.au

<u>Facility Overview</u>
The DSTO is the Australian Governments lead agency for applying science and technology to protect and defend and protect Australia and its National Interests. DSTO provides impartial advice and innovative solutions for Defence and other elements of national security.
DSTO has a number of facilities to test and design propulsion systems and related technologies, among these is the Combustion Test Facility (CTF) which is a purpose built facility to test hot section components from gas turbines at simulated engine operating conditions.
The CTF's current operating parameters are:

- Combustor inlet pressures up to 30 atm
- Combustor inlet temperatures from 30°C to 650°C
- Air flow rates up to 9.5 kg/s
- Fuel flow rates up to 1800 kg/hr

Combustion and performance analysis
Emissions:

- Fixed Gases
  - California Analytical Instruments, Inc (CAI) Emissions Cart for the analysis of CO, CO_2, NO_x, O_2 and hydrocarbons
- Particulates
  - TSI Model 3775 condensation particle counter
- Volatile Organics
  - Toxic and/or hazardous pollutants can be sampled and analysed to determine chemical composition of organic emissions eg volatile organic compounds (VOC's), polycyclic aromatic hydrocarbons (PAH's), aldehydes etc

Performance:

- Combustion limits such as ignition, lean blow out, altitude relight
- Combustor liner temperature
- Combustor efficiency
- Fuel Nozzle spray performance

The CTF is capable of testing two fuels simultaneously with a “hot switching” capability to reduce the amount of alternative fuel required for testing. The CTF can be also be used for testing the performance and emissions of developmental combustors, nozzles etc.

ID	Facility Name	Address	Contact Info
DLR	German Aerospace Center	Deutsches Zentrum für Luft- und Raumfahrt e.V. Institute of Combustion Technology Pfaffenwaldring 38-40 70569 Stuttgart Germany	Patrick Le Clercq +49-711-6862-441 Patrick.LeClercq@dlr.de Claus Wahl +49-711-6862-373 Claus.Wahl@dlr.de

<u>Facility Overview:</u>

The DLR Institute of Combustion Technology (DLR-VT) carries out research and project work on the design principles of technical combustion processes. One of the main goals is to support fundamental and applied research for the effective and sustainable use of new, unconventional as well as drop-in fuels and the development and optimization of burner and combustion chamber systems. DLR-VT's expertise and facilities encompasses all aspects of combustion in gas turbines: measurements and modeling of i) key intrinsic properties of liquids and gas, ii) pure species or complex fuel mixtures oxidation kinetics, iii) detailed and high acquisition rate diagnostics on generic flames as well as single burner characterization in terms of flame stability limits, local gaseous and particle emissions, iv) emissions measurements (transportable) during combustor rig testing or full engine ground testing and v) simulation of turbulent reacting multiphase-flows in complex geometries. In addition to providing some key tests for the ASTM D4054 approval process, measurement results, modeling and, analysis allow us to perform a cost-effective pre-selection of a candidate fuel prior to engaging in the approval process.

DLR-VT Capability Information

<u>Fuel specification properties</u>
A subset of specification properties *using ASTM standard tests*

- Smoke point
- Conductivity
- Flash point
- Cold filter plugging point

Additional specification properties *using non-ASTM standard tests*

- GC-MS
- Distillation curve (100 – 300°C)
- Density at 15°C
- Emission measurements on a lab-scale burner at atmospheric pressure

<u>Fit-for-Purpose properties</u> *not part of the ASTM D4054 Approval process*

- Ignition delay times (shock tube)
- Laminar flame speed (cone angle)

Both non-ASTM standard tests and properties not part of the ASTM D4054 approval process are part of the in-house pre-selection process.

<u>Component testing/Fuel system/Fuel nozzle</u> *using OEM downscaled or in-house generic spray burner*

- Spray characteristics under atmospheric conditions
- Spray evaporation under atmospheric conditions
- Spray characteristics under high pressure conditions

The purpose of the generic spray burner is to provide all features found in engine OEM injection systems such as airblast or pressure swirl atomizers embedded in highly turbulent swirling flows. Moreover, the generated database can be useful to a wider community as performance and spray characteristics are not subjected to IP issues.

High-pressure combustor rigs (HBK-S and others):

a. Optically accessible single injector sector rig
b. Droplet sizing and velocity, laser sheet imaging
c. Laser diagnostics (PDPA, PIV, PLIF, Raman, CARS, LII)
d. High speed imaging
e. Gas analysis system
f. Classical measuring techniques (Thermocouples, fast pressure transducers, etc.)

HBK-S Specs:	
Air flow Capability	up to 1.3 kg/s @ 40 bar
Air Preheating Capability	up to 1000 K @ 0.8 kg/s
Thermal power	up to 2MW
Fuels	natural gas/propane blends syngas (H2, CO, N2 blends) liquid HC/alcohol, light oil, kerosene (Jet A-1, SPKs…)
Pressure	< 40 bar
Dimensions of high-pressure casing (optically accessible section)	inner diameter: 0.35 m length: 1.5 m

<u>Emission measurement during combustor rig/full engine testing</u>

Gaseous and particle (from 5-200 nm) emissions measurements on full engine (aircraft or test cell) according to ICAO power settings: diagnostic: EEPS, CPC, FT-IR, SN

ID	Facility Name	Address	Contact
ASG	ASG Analytik-Service GmbH	Trentiner Ring 30 D-86356 Neusaess Germany	Juergen Bernath Juergen.bernath@asg-analytik.de 0049 821 450423-11

Facility Overview:

Working in the field of fuel analysis since 1992, ASG capabilities are as follows:

- ON SITE FUEL ANALYSIS IN AN ACCREDITED LABORATORY:

Full testing acc. ASTM D 7566 (Table 1, Annex 1 & 2)

ASTM D2425, GCxGC TOF MS for hydrocarbon composition

FIT, IQT and AFIDA for determination of ignition properties and DCN (Derived Cetane Number) or CCN (Calculated Cetane Number

6. D4054 Test Facility Locator

This section provides a listing of facilities able to perform each of the D4054 test requirements to facilitate the generation of data necessary for new alternative jet fuel ASTM research reports. Aircraft and engine OEMs are not listed for each test method (with one exception), but readers are urged to directly contact these companies for information regarding the availability of their facilities for testing (contact information is provided in section 3 of this guide).

Tier 1 – Specification Properties

Test Requirement	Reference	Test Facilities	Comments/Limitations
Basic Properties			
Basic Specification Properties	Table 1 ASTM D7566	AFRL/AFPET DGA NATEF (Density & Flash Pt) SwRI DLR (Smoke point, Conductivity, Flash point, Cold filter plugging point) ASG	Specify only properties for which test capability is not available NOT Available at DGA: • Sulfur mercaptant (ASTM D3227) • Smoke point (ASTM D1322) • Thermal stability (ASTM D3241) • Microseparometer (ASTM D3948) • Electrical conductivity (ASTM D2624) • Lubricity (ASTM D5001)

Test Requirement	Reference	Test Facilities	Comments/Limitations
Synthetic Blend Component Annex Properties	Annex A1 & A2 ASTM D7566	AFRL/AFPET DGA SwRI ASG	Specify only properties for which test capability is not available NOT Available at DGA: • Cycloparaffins (ASTM D2425) • Aromatics (ASTM D2425) • Paraffins (ASTM D2425) • Carbon & hydrogen (ASTM D5291) • Nitrogen (ASTM D4629) • Water (ASTM D6304) • Metal (UOP 389) • Halogens (ASTM D7359) • FAME (IP 585 or IP 590)

Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
CHEMISTRY			
Hydrocarbon Types	ASTM D2425	AFRL SwRI ASG ONERA	
Aromatics	ASTM D1319 or ASTM D6379	DGA (only D1319) SwRI ASG ONERA	ONERA: Both ASTM methods + IP 156 (FIA) + IP 436 (HPLC)

Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
Hydrogen	ASTM D5291 or D3701	DGA (only D3701) SwRI ASG ONERA	ONERA: Both methods
Trace materials			
Organics			
Carbonyls	ASTM E411	AFRL SwRI (EPA method (Kerosene BP range oxygenates)) ONERA	
Alcohols	EPA Method 8015	AFRL ONERA	
Esters	EPA Method 8260	AFRL SwRI ONERA	
Phenols	EPA Method 8270	AFRL SwRI (EPA method (Kerosene BP range oxygenates)) ONERA	
Inorganics: N	ASTM D4629	AFRL SwRI ASG ONERA	ONERA: By ASTM D5291
Trace Elements			

Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
Cu	ASTM D6732	AFRL SwRI (D3237, A4 method adapted for Cu analysis) ASG	
Zn, Fe, V, Ca, Li, Pb, P, Na, Mn, Mg, K, Ni, Si	ASTM D7111 or UOP 389.	AFRL SwRI ASG ONERA	
BULK PHYSICAL AND PERFORMANCE PROPERTIES			
Expanded Boiling point distribution	ASTM D86	DGA SwRI ASG ONERA (ASTM method + NF EN ISO 3405)	
Simulated Distillation (Full Range)	ASTM D2887	DGA SwRI ASG ONERA	
True Vapor Pressure vs. Temperature	ASTM D6378	DGA (only Reid VP per D5191) SwRI (Test range: 0° to 120°C, 20° intervals) ONERA (Only RVP per D5191)	
Thermal Stability, JFTOT Breakpoint	ASTM D3241, Appendix X2	AFRL SwRI USheff ONERA (Only NF ISO 6249)	
Deposit Thickness at Breakpoint	Ellipsometer		

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Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
Lubricity	ASTM D5001	SwRI (as received) ONERA	
Response to Corrosion Inhibitor/Lubricity Additive	ASTM D5001	SwRI ONERA	
Viscosity vs. Temperature	ASTM D445	AFRL DGA (from -35°C up to +20°C) SwRI (test points -40°C, 20°C, 25°C, 40°C) ASG ONERA (From -50 °C up to +100 °C)	
Specific Heat vs. Temperature	ASTM E1269	DGA (only at 25°C per D4809) SwRI (Test range: -25°C to 150°C, E2716) ASG ONERA	
Density vs. Temperature	ASTM D4052	DGA (from +5°C up to +35 °C) SwRI (Test range: 5° to 80°C) ASG ONERA (From -50 °C up to +100 °C)	
Surface Tension vs. Temperature	ASTM D1331	NaTeF SwRI (test points -10°C, RT, 40°C) ASG ONERA (From -20 °C up to + 60 °C)	
Bulk Modulus vs. Temperature & Pressure	ASTM D6793	SwRI (SwSOS: Speed of Sound, first principles)	
Thermal Conductivity vs. Temperature	ASTM D2717	SwRI (SwTC: test points 0°C, 30°C, 60°C) ASG	
Water Solubility vs. Temperature	ASTM D6304	SwRI (test points 0°C, 30°C, 50°C, 60°C) ASG ONERA	

Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
Air Solubility (oxygen/nitrogen)	ASTM D2779	ONERA	
Flash Point	ASTM D56/D3828	DGA (per D56) SwRI DLR ASG ONERA (ASTM D56 + IP 170)	
Freezing Point Test Methods –Response to manual vs. Automatic Phase Transition	ASTM D2386 and ASTM D5972	DGA (automatic per D7153) SwRI ASG ONERA (Manual per NF ISO 3013 and Automatic per D7153)	
ELECTRICAL PROPERTIES			
Dielectric Constant vs. Density	ASTM D924	SwRI (SwGood: Goodrich dielectric cell)	
Conductivity Additive Response	ASTM D2624	SwRI (clay treated, 0-4 mg/l SDA) ONERA	
Conductivity vs Temperature	ASTM D2624	SwRI (Test range: -40°C to 40°C) ASG	
GROUND HANDLING PROPERTIES AND SAFETY			
Effect on Clay Filtration	ASTM D3948	SwRI ONERA	
Filtration – Coalescer Filters &	API 1581	SwRI (J1488, SAE Test) ONERA	SwRI Note: API 1581 is specified, but that takes several thousand gallons of fuel. For hydrocarbons, the SAE J1488 test may be proposed for screening candidate fuels.
Monitors (water fuses)			
Storage Stability		ONERA (ASTM D4625)	

Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
Peroxides	ASTM D3703	SwRI (0, 1, 2, 3, 6, weeks at 65°C) ASG ONERA	
Potential gums	ASTM D5304	DGA (only per D381) SwRI (16 hr at 100°C) ASG ONERA	
Toxicity	MSDS Review		See MIL-HDBK-510-1, Appendix E
Flammability Limits	ASTM E681	SwRI (LEL, UEL at 100°C)	
Autoignition Temperature	ASTM E659	SwRI ASG	
Hot Surface Ignition Temperature	FED-STD-791, Method 6053 or ISO 20823	SwRI (FED-STD-791C)	
COMPATIBILITY			
With Other Approved Additives	ASTM D4054, Annex A2	SwRI ONERA	
With Other Approved Fuels	ASTM D4054, Annex A2	SwRI ONERA	

Tier 2 – Fit for Purpose Properties

Fuel Property	Test Method	Test Facilities	Comments/Limitations
With Engine and Airframe Seals, Coatings and Metallics	ASTM D4054, Annex A3	AFRL/UDRI NaTeF SwRI USheff ONERA (Seals and Metallics)	SwRI Note: Evaluating the complete fuel system materials compatibility matrix is an arduous task. The industry has done a significant amount of testing on hydrocarbons, enough to recognize the elastomers as the most sensitive to fuel differences. Therefore, the applicant may propose to test only these elastomers (nitrile, fluorocarbon and fluorosilicones) as an initial screening effort. The screening matrix is currently under review and additional materials may be added.

Tier 3 – Component and Rig Testing[4]

Test Requirement	Test Method	Test Facilities	Comments/Limitations
Turbine Hot-Section Erosion and Corrosion	TBD per test	NRCC SNECMA USheff	SNECMA rig uses fuel contaminated with salt and sulfur. A "clean fuel" reference should be established if this rig was to be used as a fuel comparison test.
Fuel System:			
Fuel Pump	TBD per test	SNECMA DGA USheff HW ONERA	
Fuel Control	TBD per test	SNECMA DGA USheff HW ONERA	
Fuel Nozzle	TBD per test	NRCC SNECMA DGA SwRI DLR USheff HW ONERA	
Combustor Rig Testing	TBD per test	NRCC AFRL DGA	

[4] OEMs not listed should be contacted directly to determine component and rig testing capabilities.

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Tier 3 – Component and Rig Testing[4]

Test Requirement	Test Method	Test Facilities	Comments/Limitations
		NaTeF SwRI (emissions & operability) DSTO USheff HW ONERA	
Auxiliary Power Unit (APU) altitude/cold starting	TBD per test	HW NRCC DGA USheff ONERA	50 gals fuel quantity

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Tier 4 – Engine Testing[5]

Test Requirement	Test Method	Test Facilities	Comments/Limitations
Sea Level Endurance/Durability	TBD per test	NRCC DGA SNECMA NaTeF HW	80,000 to 200,000 gals fuel quantity
Sea Level Performance & Operability	TBD per test	NRCC DGA SNECMA NaTeF HW	
Altitude Performance & Operability	TBD per test	NRCC DGA (5 altitude test cells) HW ONERA	
Emissions	TBD per test	NRCC AFRL SNECMA NaTeF DGA DSTO USheff HW ONERA	
	TBD per test		

[5] OEMs not listed should be contacted directly to determine engine testing capabilities.

Other Testing

Test Requirement	Test Method	Test Facilities	Comments/Limitations
Thermal Stability:			
HiReTS	TBD per test	USheff	
AFTSTU	TBD per test	USheff	2200 gals fuel quantity
ARSFSS	TBD per test	AFRL	900 – 1500 gals fuel quantity
Coking bench test	TBD per test	ONERA	
Rapid Small Scale Oxidation Test	TBD per test	ONERA	ASTM D 7525 covers the quantitative determination of the stability of gasoline (spark ignition fuel), including those containing alcohols or other oxygenates, under accelerated oxidation conditions.
Cold Ignition:			
Cold Ignition (Pipe rig)	TBD per test	HW ONERA DGA	20 gals fuel quantity
Materials Compatibility:			
Dynamic Relaxation	TBD per test	USheff NASA/Glenn	
Other Testing			
FUEL SYSTEM ICING		DGA	qualification tests on complete circuits or on elements of the aircraft fuel systems

Other Testing

Test Requirement	Test Method	Test Facilities	Comments/Limitations
Derived Cetane Number (DCN) by Ignition Quality Test (IQT)	ASTM D6890	SwRI (USAF requirement) ASG	
Calculated Cetane	D976	ASG	US Army requirement for MIL-STD 83133
Fuel oxidation: ignition delay time, laminar flame speed Fuel evaporation Cold start		DLR USheff	Laminar flame speed and ignition delay time
Flowing and rheology test bench (Low temperature behaviour)	TBD Method	ONERA	
Monodisperse stream (characterization of evaporation)	TBD Method	ONERA	