AEROSPACE INFORMATION REPORT

AIR6056

Issued 2014-08

Gas Turbine Engine Lubricant Specifications: Current Technical Review and Future Direction

RATIONALE

Qualification of a turbine oil formulation to AS5780 is now recognized as an integral part of most aviation equipment manufacturer's oil approval processes. The E-34 Committee identified the need to develop this document based on inputs, questions, and concerns from gas turbine lubricant customers, equipment manufacturers, military authorities, and civil aviation authorities. The intent is to provide a clear and concise reference which will help guide the direction of the committee's efforts in refining AS5780.

FOREWORD

Background: During the decade beginning in 2000, there were significant events and milestones that shaped the means by which synthetic turbine oils are approved for engine and other aircraft component use. There were high visibility, in-service events that focused both the Civil Aviation Authority's and Original Equipment Manufacturers' (OEM's) attention on improving the processes used to approve synthetic turbine oils. An E-34 meeting with representatives of the global Airworthiness Authorities was held on September 11, 2003 to discuss Turbine Oil Approval and Control. Coincident to this scrutiny, and after a decade long effort, AS5780 was released in November 2004. AS5780 consolidates the majority of OEM chemical, physical and rig performance requirements short of model specific engine tests. AS5780 also drove the formation of a Qualified Products Group made up of OEM representation that maintains the AS5780 Qualified Product List and oversees change management of the listed products. While these milestones set a framework for OEMs to mutually specify and control oil formulations, in-service events pointed to several gaps in AS5780 that require further development.

Regulations: To understand the role of specifications in the aviation industry, an examination of engine OEM responsibility for certificating engines is necessary. Industry guidance on approving lubricants (and fuels) for certificated aircraft engines is provided by the U.S. Federal Aviation Administration in the form of an Advisory Circular No. 20-24C (see Reference 2.1.1):

- Engine operating limitations are established during the certification of an engine. One such operating limitation is the lubricants which are declared and substantiated during the certification of the engine model.
- Approved lubricants are listed (or referenced) on the engine model's Type Certificate Data Sheet (TCDS).
- Each engine model or engine model series requires separate approval.
- The approved lubricant must be identified and defined by a specification which adequately details its physical properties and associated limits and controls its composition.
- If qualification to a specification alone is not sufficient to approve the synthetic lubricants used in gas turbine engines, then they may be individually approved by formulation and brand name.

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- The Process (see Reference 2.1.1) by which new oils are approved involves:

    a. The Oil Manufacturer providing analysis and performing component, rig or engine testing necessary to comply with the applicable airworthiness standards such to show the new oil will not result in harmful build-up of carbon deposit. In the USA, these standards are 14CFR Part 33 for engines, Parts 23 and 25 for airplanes, and Parts 27 and 29 for rotorcraft accomplished by any combination of engine test, rig test, and analysis based on prior service, experience, or testing.

    b. The FAA accepting data that was generated during the AS5780 qualification process to document that the lubricant has undergone sufficient testing to demonstrate that it will be compatible with the applicable engine. This data will typically address chemical, physical, compatibility and rig performance testing. OEMs have the responsibility to bridge testing gaps to show that, under the conditions in which the lubricant will be used in the aircraft it is compatible with the applicable engine and engine materials, if these are not tested during qualification to AS5780.

    c. The engine test facility documenting the test conditions, oil consumption, analysis of oil before and after engine test, evidence of wear, deposits or attack/deterioration/change of metal or non-metal components.

    d. Responsible parties identifying and controlling the lubricant by the specific oil brand name unless the engine OEM has substantiated that any oil qualified to AS5780 is acceptable for use on the subject engine (see Reference 2.1.2).

- New oil formulations seeking approval to a certificated engine model are approved by Engineering Changes to that model which in turn amends its existing Type Certificate.

- European airworthiness regulations applicable to turbine engine oil are specified in EASA CS-E 570 (g).

Motivation: An engine experiencing an uncontained turbine blade release related to the use of a novel engine/oil combination has focused much attention on the adequacy of aviation industry specifications and OEM engine/oil approval processes. Following an investigation of this incident, the U.S. NTSB issued a Safety Recommendation (see Reference 2.1.3) to revise AC 20-24B to include guidance that ensures new engine/oil combinations are inspected where there is an identified risk for (porous) carbon formation and subsequent hazardous engine behavior. The FAA issued AC 20-24C in response to the NTSB recommendation and has committed to work with E-34 to develop and incorporate enhanced qualification test methods into AS5780 to assess the long-term thermal stability of oil and in particular, the longer term coking of turbine engine lubricants (see Reference 2.1.4).

E-34 Strategy: The E-34 committee determined that it was valuable to produce this AIR as a vehicle toward improving the current specification by:

- Documenting the AS5780 specification requirements in terms of each test's purpose, history, applicability and future direction.

- Critically examining the specification requirements contained in AS5780 in light of current engine designs, operating conditions and maintenance programs for adequacy in maximizing safety and reliability.

- Developing plans for future revisions of AS5780 to bridge performance gaps:

    a. First priority: carbon formation per the NTSB Safety Recommendation

    b. Second priority: rationalize and refine current requirements where there are multiple methods and OEMs are coping with emerging issues (e.g., elastomer compatibility and oil oxidation).

Additionally, it is hoped this document serves as a useful reference to educate in this specialized technical field of synthetic turbine oils.

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1. SCOPE

This AIR describes the current scientific and engineering principles of gas turbine lubricant performance testing per AS5780 and identifies gaps in our understanding of the technology to help the continuous improvement of this specification.

2. REFERENCES

2.1 Applicable Documents

2.1.1 Advisory Circular No. 20-24C, Qualification of Fuels, Lubricants and Additives for Aircraft Engines, U.S. Department of Transportation Federal Aviation Authority, December, 20, 1985.

2.1.2 Memorandum, ACTION: FAA Certification Policy for Turbine Engine Lubricating Oils Qualified to AS5780 – [ANE-2006-33.7-3], U.S. Department of Transportation Federal Aviation Authority, March 29, 2006.

2.1.3 Safety Recommendation, Reference A-06-85 through A-06-87, National Transportation Safety Board, December 14, 2006.

2.1.4 Presentation to SAE E-34 Propulsion Lubricants Committee, Edelweiss Engine Event (NTSB Recommendations, FAA Proposed Responses), September 23, 2008.

2.1.5 Ryder, Earle A., "The Gear Rig as an Oil Tester," presented at the ASLE Gear Symposium, Chicago, Ill., 26-27 Jan. 1959. Consulting Engineer, West Hartford, CT.

2.1.6 “Temporary Methods for Assessing the Load Carrying Capacity of Aircraft Propulsion System Lubricating Oils,” SAE AIR4978, February 14, 1997.

3. HISTORY OF AVIATION GAS TURBINE ENGINE LUBRICANTS

The development of aviation gas turbine engine lubricants has progressed in parallel with the development of aviation gas turbine engines. The engine and lubricant development has relied on a successful partnership between oil companies, military organizations and engine builders/designers. Modern gas turbine engines could not exist without the lubricants that were developed to meet the increases in engine power and severity that have occurred since the first gas turbine engine.

During the late 1930s, several military establishments were sponsoring the mechanical and engineering research related to development of the gas turbine engines. Frank Whittle, a member of the Royal Air Force, is generally credited with leading the construction of the first, experimental gas turbine engine in 1937. Parallel developments were also taking place in Germany and other countries. The individual engineering developments were sponsored by the country's military so results from one laboratory were not known by the other laboratories.

Natural oils, such as castor oil, and moderately refined mineral oils were used to lubricate the low-powered aviation piston engines of the time. These oils lacked the thermal and oxidative stability necessary to lubricate high-temperature mechanical systems, forming gums and lacquers on hot metal surfaces. The natural oils and moderately-refined mineral oils also had poor physical properties, particularly at low temperatures where they tended to gel. Independent, parallel research programs at the U.S. Naval Research Laboratory and the I.G. Farben Industrie began to examine the chemical and physical properties of different classes of organic compounds with an eye towards identifying materials with improved thermal-oxidative stability and desirable physical properties. Both laboratories identified diesters of eight to ten carbon diacids as potential candidates for synthetic lubricant base stocks.

The results of the U.S. Naval Research Laboratory and the I.G. Farben Industrie chemical research began to be published in the open literature after 1945. The U.S. and European militaries needed improved lubricants at this time as increasing numbers of aviation gas turbine engine powered aircraft began to enter their fleets. The U.S. Air Force needed a lubricant which would allow turbojet engine starts at -65 °F while the U.K. Royal Air Force was looking for a heavier viscosity lubricant for the reduction gears in their turboprop aircraft. Both organizations specified mineral-oil-based lubricants suitable to their individual requirements. The engines operating with these lubricants required frequent oil drains but this did not seem too burdensome with a 50 hour duty cycle.

The Air Force's collaborative testing with the engine builders and oil companies demonstrated the superior performance of lubricating oils based on synthetic diesters. The U.S. Air Force issued the MIL-L-7808 specification in 1950, defining the composition and performance requirements for synthetic, diester-based lubricants. These products with a minimum viscosity of 3 cSt at 100 °C are known as Type I lubricants.

The military and the engine builders continued to improve aviation gas turbine engine output power with a commensurate increase in engine operating temperatures. The diester-based lubricant technology was becoming challenged. The U.S. Navy led the oil companies in a development program during the late 1950s to obtain a higher performance lubricant. Synthetic esters based on trimethylol propane or pentaerythritol emerged as base stocks of choice. These fluids had a very high inherent thermal stability and their strong response to added antioxidants gave them excellent oxidative stability. The Navy, not being concerned with the Air Force's requirement for very low temperature operations, was able to direct the oil companies to develop higher viscosity lubricants for improved lubricity and wear protection. The U.S. Navy issued the MIL-L-23699 specification in 1960 defining the composition and performance requirements for synthetic, polyol ester-based lubricants. These products with a minimum viscosity of 5 cSt at 100 °C are known as Type II lubricants.

The ready availability of the Type I and Type II lubricant products was a boon to civil aviation as gas turbine engine powered aircraft became more prevalent. The gas turbine engine powered Boeing 707 and Douglas DC-8 were starting to provide passenger service by the end of the 1950s. The Type I and Type II lubricants defined by MIL-L-7808 and MIL-L-23699 were able to provide safe, reliable lubrication for military and civil aviation gas turbine engines for these and successor aircraft for the next four decades.

In the late 1980s, the manufacturers of gas turbine engines for civil applications could see the demands on lubricant performance in a high by-pass turbofan engine were starting to diverge from those used in the military high performance aircraft. Rolls-Royce's Brian F. Rayner organized the SAE E-34 Propulsion Lubricants Committee to develop laboratory lubricant test methods that would lead to a performance specification for lubricants tailored for civil engines. During this time improvements in antioxidant and synthetic base stock technology led to significant improvements in lubricant performance compared to some of the initial Type I and Type II lubricant products. However, the civil engine builders, with support from the oil companies and military organizations, led the drafting of a new specification, AS5780, defining the composition and performance requirements for modern, civil aviation gas turbine engine lubricants.

The AS5780 specification, now in effect for civil aviation, adopted many of the existing requirements for Type II lubricants and increased the focus on the lubricant's deposition resistance and elastomer compatibility. The new specification also formalized the procedures that dealt with the change management of lubricant componentry. A Qualified Products Group, consisting mainly of engine manufacturer representatives, were empanelled under the auspices of the Performance Review Institute as being the responsible party for assessing whether submitted lubricants comply with the relevant standard and to review any proposed changes in the same manner.

4. SPECIFICATION PROPERTY REVIEWS

The collective of specification testing requirements are classified into six main groups - Physical Properties, Chemical Properties, Compatibility, Stability, Deposition, and Tribology.

4.1 Physical Properties

A physical property of Aviation Gas Turbine Engine Oils is any measurable property, the value of which describes the physical state of the oil which can be measured without changing the composition of the fluid. There are twelve tests within AS5780 which define the physical properties of Aviation Gas Turbine Oils. Four of these properties are also used as batch quality inspection tests to control the fundamental criticalities such as viscosity, flash point, pour point and foaming tendency/stability.

4.1.1 Kinematic Viscosity at 40 °C and 100 °C, ASTM D445/IP71

Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or extensional stress.

History: Kinematic Viscosity is a fluid property that indicates how resistant the fluid is to flow. Historically, scientists such as Newton, Poisseuille and Gay-Lussac who developed the fundamental laws governing lubrication, and the formation of lubricating films in gears, bearings and other liquid lubricated contacts, confirmed viscosity to be a vital property of a lubricant. ASTM Method D445, Method for Kinematic Viscosity of Transparent and Opaque Liquids, was published in 1937 and it was later jointed with the IP Method 71. The methods specify a procedure for measuring the flow of liquids under gravitational forces through a calibrated glass capillary at precise temperatures. Dividing the Kinematic Viscosity measurement by the density of the fluid under test gives rise to the Dynamic Viscosity of the fluid. Standard charts have also been introduced in ASTM Method D341, in order to plot viscosity temperature characteristics and to provide for interpolation and extrapolation, for temperatures other than the temperatures specified by the individual test procedures.

Aims/Purpose: Viscosity is one of the most important properties of lubricating oil. It controls the formation of lubricating films and the heat generated in fluid film lubricated contacts. Equations used in gear and bearing design rely implicitly upon accurate determination of viscosity and the influence of temperature upon viscosity. Oil system design dictates that the oil maintains a fluid film within the range of loads imposed upon it and at the temperatures of the lubricated contacts. Highly accurate determination of viscometric properties is, therefore, essential to the design process and to the quality control of approved lubricants in service. AS5780 specification requires viscosity to be determined at -40 °C, 40 °C, and 100 °C by D445 and at 200 °C by D341.

Applicability: Precise specification of the viscosity of all lubricants approved, or intending to be approved, for each engine application is an imperative. Viscosity measurements are a major quality control tool throughout the manufacture of gas turbine lubricants, from the raw materials to the finished product.

Current Method: ASTM D445 describes a procedure by which the time is measured for a fixed volume of liquid to flow under gravity through a capillary of a calibrated viscometer under a reproducible driving head and at a closely controlled and known temperature. The kinematic viscosity (determined value) is the product of the measured flow time and the calibration constant of the viscometer. ASTM D341 describes the use of kinematic viscosity-temperature charts to plot viscosity data as a straight line provided the viscosity at two temperatures is known. The straight line charts allow for extrapolation to higher temperatures.

Future Methods: ASTM D445, ASTM D341, and IP71 are established methods under the jurisdiction and control of ASTM and the Institute of Petroleum respectively. Those organizations impose rigid control of the methods and review and update them in line with their control policies. No changes, which could impact the application of the methods in specifications, are envisaged.

4.1.2 Viscosity Stability (Low Temperature), ASTM D2532

Viscosity Stability is a measure of an oil's ability to resist changes in viscosity over a period of time.

History: Changes in the viscosity of MIL-L-7808 oils, following low temperature soak, were thought to have an influence on engine starting in rapid deployment situations; the possibility that an increase in viscosity during the soak could influence engine reliability was also considered. The U.S. Air Force, therefore, developed Federal Standard 791 Test Method 307 (FTM 307) and a viscosity change limit was introduced to the specification MIL-L-7808 edition current at the time. The FTM 307 was standardized by ASTM in 1966 as Method D2532, and in 2000 a requirement for testing by the latter method was included in the AS5780 5 cSt oil specification.

Applicability: Method ASTM D2532 is applicable to aviation gas turbine lubricants meeting the AS5780 specification and also to lubricants meeting the U.S. DOD and UK Defense Standards for 3 cSt and 5 cSt gas turbine oils.

Current Test Method: Test Method ASTM D445 requires the kinematic viscosity of a sample to be determined at low temperature at time intervals of 3 hours and 72 hours. Presently for AS5780, only the data generated at 72 hours is required and reported. Precision for the test is established for a soaking temperature of minus 53.9 °C only. However, the test is also applied at minus 40 °C for those oils that are not fluid at the lower temperature. In such cases the same precision limits are recommended.

Future Development: No work is currently taking place to develop a new method, as the current test is considered adequate for use in specifications and for investigation of service events.

4.1.3 Viscosity Index (VI), ASTM D2270/IP226

Viscosity Index is an arbitrary scale for lubricating oils that indicates how viscosity varies with respect to temperature over a specific temperature range.

History: E W Dean and G H B Davis first proposed the use of a Viscosity Index scale in 1929 using a seven points scale based upon Pennsylvanian and Gulf Coast crudes. The scale was used for many years before the method was refined and became ASTM D567 in 1965. The more recent method, ASTM D2270, incorporating changes to simplify the scale, was introduced in 1964 and quickly became the industry standard.

Aims/Purpose: The viscosity index is a widely used and accepted measure of the variation in kinematic viscosity due to changes in the temperature of lubricating oil between 40 °C and 100 °C. A high VI indicates a small decrease in kinematic viscosity with increasing temperature whereas a low VI signifies a larger change of viscosity with increasing lubricant temperature.

Applicability: The viscosity of a lubricant, and how the viscosity changes with variations in temperature are fundamental properties of a lubricant that are required for bearing and gear design and for heat to oil calculations.

Current Test Method: The method for calculating the VI Scale, and the precision attached to it is described in ASTM D2270 (jointed with IP226): The method details how to calculate the VI of petroleum products and related materials from their kinematic viscosities at 40 °C and 100 °C. The practice does not apply to petroleum products with kinematic viscosities less than 2.0 mm^2s^{-1} at 100 °C.

Future Development: Method ASTM D2270 and IP 226 are established methods under the purview of ASTM and the Institute of Petroleum. The methods are stable and no significant changes are anticipated in the foreseeable future.

4.1.4 Pour Point, ASTM D97/IP 15 or ASTM D5950

The pour point of a liquid is the lowest temperature at which a sample of the fluid shows flow characteristics under defined conditions.

History: First generation synthetic oils were based on dicarboxylic acid esters having a viscosity of 3 to 3.5 mm^2/s at 100 °C with an operating temperature of -54 to 177 °C. The pour point specification for such oils was -60 °C maximum. Development of more fuel-efficient turbine engines resulted in higher operational engine temperatures, and those higher temperatures required a superior ester-based lubricant. Thus, the Type II MIL-PRF-23699 5 mm^2/s polyol ester based oils were developed. However, in order to achieve stability at the higher temperatures, the low temperature requirements had to be relaxed, and the approval authorities increased the pour point limit to -54 °C maximum. The change to the pour point requirement did not result in any in-service issues and the requirement still remains in the MIL-PRF-23699 specification. AS5780 incorporated the pour point requirement of -54 °C maximum for 'grandfathered' and new generation civil gas turbine oils which are based on 5 mm^2/s polyol esters.

Aims/Purpose: In order to circulate in an engine immediately after it starts, the lubricating oil must be capable of free flow. High pour point oils could channel and fail to flow if the engine was operated below the pour point temperature of the oil. That could result in seizure of moving parts and serious damage to the engine. The pour point determination correlates to the storage of the oil under low temperature conditions, or where the oil is stationary in an engine oil tank, and exposed to low temperatures, during an overnight stop for instance.

Applicability: The manual pour point test procedure provides adequate precision for the specification requirements and, after completion of a Round Robin and the study of a plethora of data, the committee elected to also include the automated pour point method, ASTM D5950, into the latest revision of the specification, AS5780B.

Current Test Method: After heating, the oil sample is cooled at a specified rate and assessed at intervals of 3 °C for flow characteristics. The lowest temperature at which the movement of the sample is observed is recorded as the pour point.

Future Development: ASTM D97/IP15 and ASTM D5950 are established methods under the purview of ASTM and the Institute of Petroleum. The methods are stable and no significant changes are anticipated in the foreseeable future.

4.1.5 Flash Point, ASTM D92/IP 36

The flash point of a liquid is the lowest temperature at which it can form an ignitable mixture in air. At this temperature the vapor may cease to burn when the source of ignition is removed.

History: The Flash Point method was adopted for use in aviation gas turbine lubricants during the late 1940s, when the original di-basic acid ester formulations were produced. Two basic types of flash point measurement were available, one utilizing an open cup and the other utilizing a closed cup apparatus. The Aviation Industry has been standardized on the ASTM D92 Cleveland Open Cup (COC) procedure.

Aims/Purpose: The Flash Point of the oil is used as an element of the fire risk assessment that takes into account all of the factors pertinent to an assessment of the fire hazard for a particular end use.

Applicability: The flash point of the flammable oil is the lowest temperature at which there can be enough flammable vapor to ignite, when an ignition source is applied above the surface. At this temperature the vapor will cease to burn when the source of ignition is removed. At a slightly higher temperature, the fire point, is defined as the temperature at which the vapor continues to burn after the ignition source is removed. Neither of these parameters is related to the temperature of the ignition source or of the burning liquid, which are higher. The Flash Point determination is a dynamic procedure that depends on defined rates of temperature increase to control the precision of the test method. Flash Point values are a function of the apparatus design, the condition of the apparatus used, and the operational procedure carried out. Flash Point can, therefore, be defined only in terms of a standard test method. No general valid correlation can, therefore, be guaranteed between results obtained by different test methods, or with apparatus different from that specified in any of the methods.

Current Test Method: In the COC test, the cup is filled to a specified level with the test oil. The temperature of the oil is then initially increased rapidly and then at a slower constant rate as the flash point is approached. At specified intervals a test flame is passed across the center of the cup. The Flash point is recorded as the lowest temperature at which application of the test flame causes the vapors of the test oil to ignite.

Future Development: No work is currently taking place to develop a new method, as the current test is considered adequate for use in specifications and for investigation of service events.

4.1.6 Evaporation Loss, ASTM D972

Evaporation Loss is a measure of the volatility (tendency of a fluid to pass from the liquid state into the vapor state) of a fluid at elevated temperatures.

History: The loss of volatile materials from a gas turbine lubricant can adversely affect the physical properties and performance characteristics of the lubricant. It can, therefore, be a significant factor in evaluating a lubricant. The early lubricant developers included a method to assess the volatility of the oil as a specification requirement. In the UK the early specifications used the ASTM D972 test method as well as methods developed by Rolls-Royce to test for volatility under both thermo and thermo-oxidative conditions. In the United States the ASTM D972 test method was adopted. The time and temperature parameters for the tests were selected to provide adequate severity to give an acceptable measure of volatility for the applications.

Aims/Purpose: Since it is possible for the loss of volatile materials from a lubricant to adversely affect its physical properties and performance characteristics, a test to gauge volatility is included in lubricant specifications. The intention being to ensure that the oil volume will not decrease to an extent that would adversely affect operation of engines. A measurement of evaporation loss under the appropriate conditions is used for both a qualification testing and as a batch quality conformance test, thus ensuring that the oil will not evaporate to an unacceptable degree during use in the engine.

Applicability: The current test method provides adequate precision for the determination of volatilization/evaporation loss. Gas turbine lubricants show a degree of variability due to differing base stocks although this effect on volatilization/evaporation loss is minimal. Only a major change in composition would alter this situation.

Current Method: The ASTM D972 test method describes a procedure for measuring the evaporation loss of oil that consists of loading a weighed sample of lubricant into a special evaporation test cell which is then placed in a bath maintained at the desired test temperature. Dry, pre-heated air is passed over the surface of the oil sample at a specified rate for a specified time. The evaporation loss is calculated from the loss in mass of the sample.

Future Development: While the ASTM D972 test method is adequate for current oil formulations, consideration should be given to alternate test methods as new formulations containing additives from different chemical families are proposed. A review of the results obtained by alternate test methods should be undertaken before a hard recommendation for a universally acceptable test method can be agreed.

4.1.7 Foaming Tendency, ASTM D892/IP146

The foaming tendency of oil is the propensity to form foam when aerated or mechanically agitated in air.

History: ASTM Method D892 was originally issued in 1946, to assess the foaming propensity of the mineral based oils in use at the time. It was later jointed with IP 146 and became the standard procedure for measuring foaming propensity. A similar method, but one having different apparatus and a more severe procedure, was adopted by the United States Air Force and standardized in Federal Standard 791, Method 3213; that method was, however, cancelled in 2007. More latterly, requirements for foaming tendency measured by ASTM D892 have been adopted by the international defense agencies and also in the civil specification AS5780. The need to limit and control the foaming propensity of Aviation Turbine Engine Oils, has been defined by specifications for more than 50 years. Foam increases the surface area and can lead to decreased oxidative stability, as well as inadequate lubrication of metal surfaces.

Aims/Purpose: Method ASTM D892/IP146 defines a procedure for the determination of the foaming characteristics of lubricating oils at specified temperatures and provides a means of empirically rating the foaming tendency and the stability of the foam.

Applicability: Mandatory limits and modifications to ASTM D892/IP146 for determining the foaming propensity are specified in civil and military specifications. The test is used by individual accessory and engine manufacturers to measure the foaming propensity of oils submitted for approval, and in the investigation of service problems thought to be associated with excessive aeration, or with lubrication problems arising due to the formation of foam. AS5780 specification utilizes the ASTM D892 definition of foam collapse.

Current Test Method: In ASTM D892/IP146, a sample of the oil, maintained at a temperature of 24 °C, is aerated via a standardized gas diffuser at a rate of 94 mL/min for 5 minutes, and then allowed to settle for 10 minutes. The volume of foam is measured at the end of both periods (Sequence I). The test is repeated on a second sample at 93 °C (Sequence II) and then, after collapsing the foam, at 24 °C (Sequence III). The gas diffuser can be either a porous stone or a metal cylinder as specified in the test method. Typically exit air is measured, using a volume measuring device, in each of the sequences, to ensure there are no air leaks in the system. An alternative procedure allows the use of a calibrated flow meter to measure the inlet air which eliminates the use of the volume measuring equipment. Complete foam collapse is defined as ‘when a bubble layer fails to completely cover the oil surface and a patch or eye of clear fluid is visible’. Deviations from ASTM D892/IP146 - Current turbine engine oil specifications call for complete foam collapse after 1 minute settle time. MIL-PRF-23699F also included a statement which defines foam collapse as: ‘the point at which no more than a single row of bubbles remain around the cylinder and air inlet tube. If this ring of bubbles around the cylinder wall contains segments having two or more layers of bubbles and the difference in height of the foam in the ring is not greater than 10 mL, complete foam collapse is the point at which a break occurs in the ring of bubbles without subsequent reforming of the ring.’ Much debate was had by the SAE committee to the historical origins of this statement as it made sense to streamline the statements in both specifications. The differences in the way the MIL-PRF-23699 and AS5780 specifications define ‘complete foam collapse’ was resolved following further investigation and as the U.S. Navy could not find sufficient evidence to support their previous definition of ring collapse they took the decision to remove it from MIL-PRF-23699G revision thus aligning with AS5780.

Future: ASTM and IP have approved the use of both metal cylinder and spherical stone diffusers; however, there are still concerns by some foaming committee members regarding the standardization and applicability of the cylinders. Work has also been carried out recently to assess how the air flow should be calculated. Aviation turbine engine oils in particular react differently to the differing diffusers and ways at which the air flow is calculated, this has led to oils that would normally be expected to pass, failing the test. Further work needs to be done to understand that phenomenon.

4.1.8 Shear Stability, ASTM D2603

Shear Stability is an important fluid property which determines change in viscosity under shear.

History: ASTM D2603 was originally published in 1967. It remains under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.07.0B on High Temperature Rheology of Non-Newtonian Fluids. The current edition was approved May 1, 2007.

Shear Stability is a requirement in the U.S. Navy Specification MIL-PRF-23699 and it was subsequently adopted into the AS5780 specification, residing in the main body of the specification with a limit of 4% maximum viscosity change at 40 °C.

Aims/Purpose: Since it is possible for the loss of viscosity from a lubricant to adversely affect its physical properties and performance characteristics, a test to evaluate shear stability is included in lubricant specifications. The intention being to ensure that, if oil viscosity modifiers are used in the formulation, they will not degrade to an extent that would adversely affect engine lubrication. Limits for permanent change in viscosity under appropriate test conditions are set for qualification testing, thus ensuring that the oil viscosity will not change to an unacceptable degree during use in the engine.

Applicability: The test method permits the evaluation of shear stability with minimum interference from thermal and oxidative factors which might be present in some applications. Within the limitations expressed in the scope of the test method, it has been successfully applied to hydraulic fluids, transmission fluids, tractor fluids, and other fluids of similar applications. It has been found applicable to fluids containing both readily sheared and shear-resistant polymers that can be added to the oils as viscosity modifiers (VM). Viscosity modifiers also called viscosity index improvers (VII) are polymers used as additives in lubricant compositions for minimizing the viscosity change due to temperature change. Typically oils approved to AS5780A would not contain VI improvers and as such correlation with performance in the case of gas turbine engine applications has not to date, been established.

Current Method: A convenient volume of polymer-containing oil is irradiated in a sonic oscillator for a period of time and the changes in viscosity are determined by ASTM D445. Standard reference fluids containing either a readily sheared or shear resistant polymer are run frequently to ensure that the equipment imparts a controlled amount of sonic energy to the sample. MIL-PRF-23699 requires the measurement of sonic shear to be conducted with the following modifications to ASTM D2603:

1. Measure % viscosity change at 40 °C with maximum change of 4%.

2. Calibrate the sonic shear instrument to achieve 11.5% ± 0.5% viscosity loss to a 30 mL sample of ASTM Reference Fluid A when irradiated for 5 minutes.

3. Using the same power setting, irradiate a 30 mL sample of the turbine lubricant for 30 minutes.

NOTE: ASTM Reference Fluid A is petroleum oil containing a polymer which can be broken down by turbulence at high rates of shear. Typical Reference Fluid A viscosities are 10.7 mm^2/s (cSt) at 100 °C and 57 mm^2/s (cSt) at 40 °C. The specific modifications that reside in MIL-PRF-23699 have not been adopted in AS5780 specification.

Future Development: The ASTM D2603 method is adequate for current oil formulations; however, consideration should be given to alternate test methods as new oil formulations could contain polymers/viscosity modifiers from different chemical families. A review of the results obtained by alternate test methods or alternate test conditions should be undertaken before a hard recommendation for a universally acceptable test method can be agreed.

If the intention of inserting a shear stability requirement into AS5780 was to carry out this testing in line with the modifications that are included in MIL-PRF-23699 then consideration should be given to inserting a footnote specifying this requirement.

4.1.9 Density, ASTM D4052

ASTM D4052 Density and Relative Density of Liquids by Digital Density Meter. The density of a liquid is its mass per unit of volume at a specified temperature. The relative density is the ratio of the density of a liquid at a stated temperature to the density of water at the same temperature.

History: The density and relative density of petroleum and synthetic oils have been very important properties determining the weight of fluid involved in any application. Many methods have been standardized by the industries using specific types of oil. ASTM Method D4052-96 was originally published as D4052-81 in 1981 and remains under the jurisdiction of ASTM Committee D02.

Aims/Purpose: Lubricant density values are used for weight and volume calculations. Engine manufacturers use the reported density values in oil system calculations to predict pressure loss, convection, oil temperature and oil cooler efficiency.

Applicability: ASTM D4052 is applicable to aviation gas turbine lubricants meeting the AS5780 specification and to lubricants meeting the UK and French Defense Standards.

Gas turbine lubricants show a degree of variability due to differing compositions of the ester base stocks, although the net effect on density is minimal. Only major changes in formulation would alter this situation.

Current Test Method: The density and relative density of a sample is determined in accordance with ASTM D4052. The method introduces a small volume of liquid sample into an oscillating sample tube. The change in oscillating frequency caused by the change in mass of the tube is used in conjunction with calibration data to determine the density of the sample. The temperature is also reported along with the density. Density units are kg/m^3 and reported to the fourth decimal place. The digital density meter provides improved precision and ease of use compared to the alternative (ASTM D1298, Standard Test Method for Density, and Relative Density by Hydrometer Method). Presently density is determined at 15 °C, 40 °C, and 70 °C.

Future Development: No work is currently taking place to develop a new method, as the current test is considered adequate for use in specifications and for investigation of service events.

4.1.10 Heat Capacity, ASTM E1269

Heat Capacity is the amount of heat required to raise the temperature of unit mass of a substance by one unit of temperature. Colloquially it is referred as Specific Heat and it is measured in calories per gram per degree centigrade (cgs).

History: An integral part of the design and development process for gas turbine engines, heat capacity has been a requirement to ensure that heat generated within the oil system can be effectively dealt with by the oil cooling system. Data for the specific heat of the oils to be approved for the engine application has, therefore, been an essential requirement. ASTM D2766 was originally developed in 1968 for the purpose of determining the Specific Heat and more latterly a second method (ASTM E1269) has subsequently been introduced. Heat Capacity data still continues to be a requirement of design engineers and, as such, became an integral part of AS5780 specification. AS5780B adopted ASTM E1269 as the sole method of determining Heat Capacity following a recommendation by E-34E Subcommittee.

Aims/Purpose: Engineers use Heat Capacity data when conducting oil system simulation and heat transfer calculations for engine design purposes. Gas turbine lubricants can show a degree of variability due to variation in the composition of the base stock. Heat Capacity is a temperature dependent property and a change in observed values due to temperature is regarded as a change in the thermo dynamic properties of an oil.

Current Test Methods: AS5780B, Appendix A, cites Specific Heat will be determined by ASTM E1269. Data is required to be generated at 15, 40, 100, 150, and 200 °C.

The method and its precision are described in ASTM E1269-05 Standard Test Method for Specific Heat Capacity by Differential Scanning Calorimetry.

The method introduces a small volume of liquid sample into a calibrated differential scanning calorimeter. The sample is rapidly heated at a controlled rate through the temperature range of interest. The difference in heat flow into the test sample and a reference material, or blank, due to energy changes in the material is continually monitored and recorded.

The precision and bias of the method has been determined with a standard reference material. The test statistics were determined at lower temperatures than which are required by AS5780B. The current Heat Capacity method provides improved precision and ease of use compared to earlier calorimetric methods.

Future Development: Heat Capacity is currently a lubricant "report only" property in all specifications. The responsibility for setting limits rests with the organizations controlling the individual specification. Setting lubricant Heat Capacity limits would neither improve the lubricant's composition nor performance. ASTM is responsible for maintaining and up-dating the method as required.

4.1.11 Thermal Conductivity, ASTM D2717

Thermal Conductivity is the property of a material that indicates its ability to conduct heat. Scientifically, thermal conductance is the quantity of heat that passes in unit time through a plate of particular area and thickness when its opposite faces differ in temperature by one degree Kelvin.

History: During the development of the AS5780 Specification, engine manufacturers requested that E-34 committee include a “Report” requirement for the thermal conductivity of oils. A test house known as Holometrix Inc. was approached and a proprietary test cell and test method were developed in the 1990s; that Method is called up by Appendix A of AS5780. However, Appendix A also included the caveat that other test methods can be employed for the determination of Thermal Conductivity provided that the test method is also reported. In addition to the Holometrix method, three ASTM test methods for obtaining thermal conductivity values are currently available. During the revision B of AS5780 and after much work by E-34E sub-committee ASTM D2717 was accepted as the sole method of determining Thermal Conductivity.

Aims/Purpose: The Thermal Conductivity values are used for heat transfer calculation during the design process. Such calculations ensure that oil temperatures are controlled within acceptable limits and that the performance of the oil coolers meets the design purpose.

Applicability: Gas turbine lubricants show a small degree of thermal conductivity variability due to the differing composition of the ester base stocks. Only a major shift in composition base stock would change this situation. The current Thermal Conductivity values are considered acceptable for the present time.

Current Test Methods: ASTM D2717-95 (Re-approved 2005) Standard Test Method for Thermal Conductivity of Liquids.

The method introduces a known amount of energy into the oil sample and measure the resulting temperature rise. These measurements, as a function of temperature, are complicated by the presence of convection currents in the liquid oil samples. Thermal Conductivity is determined at 40 °C, 100 °C, 150 °C, and 200 °C and is presently a ‘Report only’ specification.

Future Development: Thermal Conductivity is currently a lubricant "report only" property in all specifications. The responsibility for setting limits rests with the organizations controlling the individual specification. Setting lubricant Thermal Conductivity limits would neither improve the lubricant's composition nor performance. ASTM is responsible for maintaining and up-dating the method as required.

4.1.12 Electrical Conductivity, ASTM D2624/IP274

Electrical conductivity is a measure of a material's ability to conduct an electric current.

History: ASTM D2624 was originally developed to measure the electrical conductivity of aviation fuels, when build-up of static charges in filter separators and fuel tanks led to explosions and fires. Both on-line and portable test devices were developed for the test purposes.

Prior to the introduction of AS5780 electrical conductivity had not previously been a requirement within oil specifications and, therefore, conductivity tests specific to gas turbine engine oils had not been developed. However, due to in-service issues that were deemed to be associated with the electrical conductivity of oils, accessory and auxiliary power unit manufacturers adopted ASTM D2624 as an investigative tool.

Therefore, when the AS5780 specification was developed, a requirement for electrical conductivity was included in the Appendix A to the specification; however, a caveat to the effect the requirement would be a report item only, until such time that sufficient data could be generated to produce a precision statement, or an appropriate method specific to oil testing could be developed.

Aims/Purpose: The data generated from ASTM D2624 provides an indication of the electrical conductivity of oils under specific test conditions and using test cells calibrated for the purpose. The data is used by engine and accessory manufacturers for design purposes and in the investigation of service problems or events.

Applicability: The method is used by individual accessory and engine manufacturers to measure the electrical conductivity of oils submitted for approval, and in the investigation of service problems thought to be due to changes in electrical conductivity of oils in service use.

Current Test Method: Two electrodes are immersed in a sample of oil under prescribed conditions and a voltage is applied to the electrodes. A small current is generated between the electrodes (in micro amps), which gives a direct reading of the electrical conductivity of the sample in picosiemens per meter. The temperature of the test sample is also reported. Data is generated at 20 °C and 80 °C.

Future Development: Currently there is no intention to develop a method specific to testing of gas turbine oils. The current test method is under the jurisdiction of ASTM and IP, and the test will continue to be reviewed by those authorities. There is movement by some OEMs to consider setting approval limits for this property and as such E-34 committee need to work with these specific OEMs in defining appropriate industry parameters.

4.2 Chemical Properties

Three of the four properties within the Chemical section are used as quality control inspection tests on all production batches of Gas Turbine Lubricants. These properties are: ‘Total Acid Number’; ‘Sediment/Ash’ and ‘Trace Metals Content’. These three tests can also be used to monitor quality of product in service via analysis of the used oil.

The Hydrolytic Stability Test is used as part of the Rolls Royce and United Kingdom’s Ministry of Defense approval process for Gas Turbine Lubricants to determine the oil’s tendency to hydrolyze.

4.2.1 Total Acid Number, ARP5088

The total acid number (TAN) is a measurement of acidity that is determined by the amount of potassium hydroxide in milligrams that is needed to neutralize the acids in one gram of oil.

History: The current AS5780, the United States Navy MIL-PRF-23699 and United Kingdom Ministry of Defense gas turbine lubricant specifications require the reporting of Total Acid Number. There is a specification limit of 1.0 mgKOH/g Maximum for AS5780 and MIL-PRF-23699 via Method ARP5088, whilst the UK MOD requires a report value for the finished lubricant, with a 0.1 mgKOH/g Maximum for the base fluid used. These specifications originally required either ASTM or IP methods to determine Total Acid Number; however, they switched to the SAE method in the early 2000s.

Aims/Purpose: The lubricant Total Acid Number values are used to determine correct quality of base fluid and additives used in the gas turbine lubricant batch as well as to monitor condition of oil over time (storage) and/or in service.

Applicability: This method is fully applicable to the measurement of Total Acid Number in Gas Turbine Lubricants and has been widely adopted across the industry.

Current Test Method: ARP5088. The method and its precision are described in ARP5088A (Revised 2000-09). Test Method for the Determination of Total Acidity in Polyol Ester and Di-Ester Gas Turbine Lubricants by Automatic Potentiometric Titration. The ARP5088 method specifies a test portion of Lubricant is dissolved in a mixture of toluene and propan-2-ol containing a small amount of water and is titrated potentiometrically with alcoholic potassium hydroxide using a glass indicating electrode and a silver/silver chloride reference electrode. The cell voltage corresponding to aqueous pH 11 buffer is taken as the end point.

The Total Acid Number Units are expressed in milligrams of KOH per gram of lubricant. Precision limits are included in the method for repeatability and reproducibility for both new and used oils. ASTM D664 is an alternative method for testing TAN, and is being studied for potential inclusion in AS5780.

A round robin was performed in 2013 resulting in the current draft ARP5088B. Proposed major modifications include use of combination electrodes and recognizing that the volume of samples available from service or laboratory tests may make using a 20 g sample size impractical for clean oils, thus a 2.5 g sample size may be used if the 20 g sample size cannot be obtained. Precision statements have been updated in the proposed ARP5088B document.

Future Development: The test method is under the purview of the SAE E-34 Propulsion Lubricants Committee which is responsible for maintaining and up-dating the method as required.

4.2.2 Sediment/Ash, FED-STD-791, Method 3010

The sediment test is the determination of solid particulate contamination in fresh oil. The sediment is quantitatively converted to inorganic ash.

History: The current AS5780, the United States Navy MIL-PRF-23699 and United Kingdom Ministry of Defense gas turbine lubricant specifications require the reporting of Sediment/Ash. There is a specification limit of 10 mg/L Maximum for Sediment and 1.0 mg/L Maximum for Ash for all of these specifications.

Aims/Purpose: The lubricant's Sediment/Ash values are used to determine production of the gas turbine lubricant batch with minimal solids contamination.

Applicability: This method is fully applicable to the measurement of Sediment/Ash in Gas Turbine Lubricants and has been widely adopted across the industry

Current Test Method: FED-STD-791D, Method 3010. The method and its precision are described in FED-STD-791D (Revised 1986-09). Test Method for the determination of solid particle contamination in aircraft turbine engine lubricants (gravimetric procedure). A known volume of fluid is filtered through a pre-weighed membrane filter. The increase in filter weight is determined after washing and drying the filter then reported as total contaminant. The test filter is ashed and the inorganic material remaining is reported as ash. The Sediment/Ash Units are expressed in milligrams per liter of lubricant. There is currently no incentive to develop any other test methods.

Future Development: The test method is under the purview of the FED-STD-791D administrators who are responsible for maintaining and up-dating the method as required.

4.2.3 Trace Metals by AES

The Trace Metal test is the determination of trace metal concentrations in fresh turbine oil.

History: The current AS5780, the United States Navy MIL-PRF-23699 and United Kingdom Ministry of Defense gas turbine lubricant specifications require the reporting of Trace Metals. There are various specification limits depending on the Trace Metal being measured for all of these specifications.

Aims/Purpose: The lubricant Trace Metal values are used to determine production of the gas turbine lubricant batch with minimal metal contamination.

Applicability: This method is fully applicable to the measurement of Trace Metals in Gas Turbine Lubricants and has been widely adopted across the industry.

Current Test Method: Atomic Emission Spectrometry either by ICP-AES (ASTM D5185) or RDE-AES (ASTM D6595). The Trace metal content of the lubricant shall be determined with an atomic emission spectrometer. Appropriate spectrometric calibration standards, covering the concentration ranges of interest, shall be used. The laboratories used to generate data in order to show compliance with this specification may belong to the supplier, the user, or an independent organization. The Trace Metal Units are expressed in Parts per Million or µg/l. Precision data should be available from the test laboratory conducting the test. There is currently no incentive to develop any other test methods.

Future Development: The test method is under the purview of the FED-STD-791D and Def Stan 05-50 administrators who are responsible for maintaining and up-dating the method as required.

4.2.4 Hydrolytic Stability, DEF STAN 05-50(Part 61), Method 6

Hydrolytic stability is the ability of oil to withstand degradation and acid formation in the presence of water.

History: The current AS5780 and United Kingdom Ministry of Defense Gas Turbine Lubricant Specifications require the reporting of Hydrolytic Stability. There are no limits, however, both require the reporting of: Time in hours to achieve an acidity increase of 1.5 mg KOH/g at 90 °C; the appearance of the oil; dissolved water content and the percentage of free Water hold up.

Aims/Purpose: The hydrolytic stability test is used to determine the relative resistance to hydrolysis of any given gas turbine lubricant. This is done by observing the time it takes for the oil's acid number to rise in the presence of water.

Applicability: This method is applicable to the measurement of Hydrolytic Stability in Gas Turbine Lubricants and has been widely adopted across the industry.

Current Test Method: DEF STAN 05-50 (Part 61)2, Method 6. The method and its precision are described in DEF STAN 05-50 (Part 61)2, Amendment 1, dated August 1 2003. Method 6: Hydrolytic Stability.

A sample of oil, with excess water, is maintained at a temperature of 90 °C. Samples are taken periodically so as to determine the time required for the total acidity of the oil to increase by the equivalent of 1.5 mgKOH/g. The time taken to achieve this is known as D90/1.5 hours. The condition of the oil at this acidity level is examined in respect to water hold up and water solubility after a period standing (24 hours) at room temperature.

Future Development: The test method is under the purview of the DEF STAN 05-50 administrators and Rolls Royce plc who are responsible for maintaining and updating the method as required. Method 6 may become part of the main body of AS5780 if firm limits can be defined by SAE E-34.

4.3 Compatibility

Introduction: An area of concern in the design and operation of gas turbine engines involves the compatibility of gas turbine oils with the materials used in the engine. From experience, two specific compatibility areas have been identified; elastomer compatibility and compatibility with other brand/specification of gas turbine oils. Elastomeric materials are typically used in O-rings, gaskets, diaphragms, etc. as some form of seal between metal parts. Gas turbine oils can degrade some elastomeric materials by causing excessive swelling or deterioration causing the malfunction of the seal leading to an oil leak. To ensure the correct elastomer selection in the engine design phase and for the use of new oils in existing designs, evaluation of elastomer performance in gas turbine oils is necessary.

Fielded engines from time to time are serviced with different gas turbine oils than what is normally used, resulting in a mixture of two oils. There have been incidents where the mixing caused degradation of the oil which could potentially have led to engine damage. The degradation is generally due to an incompatibility between additives in the oils and generally results in some form of sedimentation occurring in the lubrication system. Compatibility testing of oils minimizes the risk of field operation problems for new oils. AS5780 incorporates three test methods to address elastomer compatibility and one test method for oil compatibility. These methods are presented in the following sections.

Conclusion: Elastomer compatibility continues to be a concern as engine life is extended to longer periods between shop visits and design temperatures continue to rise. The test methods listed for oil approval to AS5780 provide good insight into an elastomers performance, but because these are high temperature-short duration test, they may not provide the data needed to properly evaluate elastomer performance for very long term engine operation. Continued work to develop the long-term Snecma test method will address this area. The oil compatibility test methods in AS5780 has been in place in the military oil specifications for many years and have been useful in finding incompatibilities before getting into the field.

4.3.1 Lubricant Compatibility, FED STAN 3403 Mod/Def Stan 05-50(Part 61) Method 24

Lubricant Compatibility is the assessment of lubricants chemical compatibility with all other oils they may come into contact with in the field.

History: Federal Test Method (FTM) 3403, Compatibility of Turbine Lubricating Oils was originally developed by the Air Force Research Laboratory (AFRL) in 1966. It was adopted in the 1960s for both the USN MIL-PRF-23699 and USAF MIL-PRF-7808 turbine engine lubricant specifications. AS5780 adopted this test method from the MIL-PRF-23699 specification. This method is used for determining the compatibility of aircraft turbine lubricants when mixed with specific referee lubricants. This test method gives the DoD increased assurance that newly qualified turbine engine lubricants should not have issues with oil additive precipitation when mixed with other qualified oils within the operating fleets.

Aims/Purpose: Depending on a given sortie mission for DoD aircraft, servicing the aircraft prior to returning to its respective home base frequently means the engines will be topped off with more than one qualified source of oil. Most DoD aircraft can also operate on either MIL-PRF-7808 or MIL-PRF-23699 turbine engine lubricants. Typically engine technical order manuals for a given fleet allow oil mixing via replenishing the engines by top-off. It is recommended that once the aircraft gets back to home base, engines containing a combination of MIL-PRF-7808 and MIL-PRF-23699 oils are drained and filled with the preferred oil noted in the respective engine technical manual. FTM 3403 is a simple bench top test to evaluate potential additive incompatibilities between the two DoD turbine engine lubricant specifications, and the various qualified products governed by these two specifications.

Applicability: This method provides a means of measuring oil compatibility, comparing candidate oils seeking qualification with turbine engine oils already qualified to both MIL-PRF-23699 and MIL-PRF-7808 specifications, respectively. FTM 3403 can uncover potential additive incompatibilities, and help to minimize issues in new qualified products released to the operational fleets.

Current Test Method: This method consists, essentially, of preparing mixtures of the sample lubricant and reference lubricant (200 mL total sample volume) in three concentrations (90/10%, 50/50% and 10/90%). These mixtures are maintained at a fixed temperature (105 °C ± 3 °C) for 168 hours, and when this has elapsed the mixtures are assessed visually and then the solid particle contamination is determined in accordance with FED-STD-791 Method 3010. This involves filtering a known volume of each mixture through a pre-weighed filter and determining the increase in filter weight. Presently a list of the required reference lubricants is obtained from the Qualified Products Group (QPG).

Future Development: No precision statement has been developed for this method. The test method 24 is under the purview of the DEF STAN 05-50 administrators and Rolls Royce plc who are responsible for maintaining and updating the method as required. The test method 3403 is under the purview of the FED-STD-791D administrators who are responsible for maintaining and up-dating the method as required.

4.3.2 Elastomer Compatibility, FED-STD-791, Method 3604

Elastomer Compatibility is the assessment of lubricants chemical compatibility with all elastomeric materials they may come into contact with in the field.

History: Elastomeric goods, such as O-rings, are used to provide an oil-proof seal between two metal surfaces in gas turbine engines. The lubricants used in the engine need to be compatible with the elastomers used in the engine to prevent oil leaks which could lead to premature engine shut down. The current AS5780 and the United States Navy MIL-PRF-23699 lubricant specifications require the reporting of candidate lubricant compatibility with a standard fluorocarbon elastomer. Lubricant-elastomer compatibility is determined by elastomer volume swell after exposure to the candidate lubricant at a specified time and temperature. Both specifications limit the amounts of elastomer volume swell. The required test method for obtaining elastomer volume swell values has remained essentially constant since 1986. The Navy specification requires testing of nitrile and fluorocarbon elastomer specimens. The AS5780 specification only requires fluorocarbon elastomer testing. The test variability has been partially controlled by using a standard, reference fluorocarbon elastomer, AMS3217/4.

Aims/Purpose: The lubricant-elastomer compatibility measurement is needed to demonstrate the candidate lubricant will neither shrink nor excessively swell fluorocarbon elastomers. By using approved reference oil, engine manufacturers can use the method to screen the resistance of candidate elastomers to lubricants.

Applicability: The limits for volume swell determined by Method 3604 in the AS5780 and the United States Navy MIL-PRF-23699 lubricant specifications are set because of historical and current gas turbine engine design practices. Elastomeric O-rings in the oil system are usually in a machined groove facing a flat flange. At least 5% O-ring swell within the groove is necessary to provide a leak-proof seal against the flange. The grooves are designed to accommodate up to a 25% O-ring volume expansion. Insufficient or excessive O-ring swell within the groove can lead to lubricants leaking past the O-ring. Gas turbine lubricants are homogeneous, tightly-defined compositions. Commercial elastomers are heterogeneous mixtures subject to less stringent manufacturing control. The AMS3217/4 reference elastomer minimizes the test variability that would be observed if the method relied on commercial elastomer compositions obtained from multiple suppliers. Other fluorocarbon elastomer compositions may be more representative of the elastomers used in gas turbine engines. The Method 3604 results generally correlate the field performance of fluorocarbon elastomers with Standard Performance Category (SPC) Oils. Some High Performance Category (HPC) Oils are more aggressive towards fluorocarbon elastomers than is indicated by the current method.

Current Test Method: The method and its precision are described in Federal Test Method Standard No. 791C. Lubricants, Liquid Fuels and Related Products; Methods of Testing. Method 3604.2 Swelling of Synthetic Rubber By Aircraft Turbine Lubricants. The Method 3604 procedure requires a modest volume of a candidate lubricant and standard elastomer slabs. The AS5780 and the United States Navy MIL-PRF-23699 specifications require the use AMS317/4 elastomer slabs. Test specimens of defined size are weighed in air and in water, and then immersed in the candidate lubricant for the specified time at the specified test temperature. The test specimens are then removed from the candidate lubricant, cleaned and reweighed. The volume swell is calculated from the initial and final weights of the elastomer test specimen. The Method 3604 procedure is useful for measuring lubricant-elastomer interactions under a wide variety of time and temperature conditions.

Future Development: The Method 3604 could be easily modified to incorporate measurements tracking elastomer hardness changes as a function of exposure to the candidate lubricant. Various ASTM methods already provide means for determining changes in elastomer tensile strength and elongation properties after exposure to test fluids. The industry is still debating the importance of these elastomer property changes in assessing lubricant-elastomer compatibility; modifications of Method 3604 are not likely. The industry has recently developed a lubricant-elastomer compatibility test method based on commercially-available fluorocarbon elastomer O-rings. The volume swell determined by Method 3604 under a specified set of conditions must meet a minimum value and not exceed a maximum value required by the AS5780 and the United States Navy MIL-PRF-23699 lubricant specifications. The responsibility for setting and accepting the volume swell limits rests with the organizations controlling the individual specifications. Changing the elastomer volume swell limits could have an impact on the composition and performance of future lubricants. The test method is under the purview of the FED-STD-791D administrators who are responsible for maintaining and up-dating the method as required.

4.3.3 Elastomer Compatibility, Def Stan 05-50(Part 61) Method 22

Elastomer Compatibility is the assessment of lubricants chemical compatibility with all elastomeric materials they may come into contact with in the field.

History: As gas turbine engines developed with ever increasing operating temperatures and longer on-wing durations, synthetic turbine oil formulations needed to improve to resist oil coke deposit formation. Unfortunately, many of the formulation improvements to polyol ester oils that reduce deposit formation tendencies, can also negatively impact bisphenol cured fluorocarbon swell control and integrity. Silicone specific compatibility issues have surfaced when other oil property attribute improvements were attempted. Early versions of synthetic turbine oil specifications did not have the scope to properly guide the development of these early technology improvements. Therefore, this method was developed by Rolls-Royce to evaluate the effects synthetic lubricants have on the physical properties of various elastomer seal material types. In 1999, Method 22 using O-rings as specimens replaced Method 4 which used dumbbell shaped slabs, because the O-ring specimens were considered more representative of aviation turbine engine application.

Aims/Purpose: Method 22 is a gravimetric process for assessing the compatibility of synthetic turbine lubricants with elastomers. Elastomer swell is defined in terms of weight gain after ageing at elevated temperatures in the oil to be evaluated. Deterioration or embrittlement is also assessed by determining the time required for cracks to develop in the elastomer, following the same ageing. Temperatures were chosen to accelerate the compatibility testing, but are scaled to the elastomer material type's capability. Method 22 provides a cost effective means of conducting compatibility tests on a lab scale, in lieu of costly rig or engine tests. The test conditions selected for this process simulate various temperatures encountered by elastomeric seals, in contact with synthetic turbine oils, within a gas turbine engine. In addition, multiple elastomer materials can be tested to simulate the various material designs within a gas turbine engine. Specification acceptance criteria are based on historical data and in-service experience.

Applicability: This approach can provide a compatibility measurement that can be used to compare and contrast different elastomer/synthetic turbine oil combinations, when new and existing lubricants are evaluated for approval in gas turbine engines. In addition, synthetic turbine oil manufacturers can use this method during development of new base-stocks, additives and fully formulated oils. It is a tool which helps ensure no oils are approved which have a negative impact on gas turbine elastomers.

Current Test Method: A weighed elastomer O-ring test specimen is immersed in a glass tube containing 50 mL of oil to be evaluated, and placed in a heating block at the appropriate temperature, depending upon elastomer type. The test specimen is removed, cooled in fresh test oil, cleaned and weighed after 24 and 120 hours. Results are recorded to the nearest 0.0001 g. Percent weight change after 24 and 120 hours is calculated using initial and final weights, and are reported for each elastomer/oil combination. Embrittlement characteristics of the elastomer test specimen are evaluated after completion of the 120 hour test period. The O-ring is twisted into a figure eight and examined under magnification for evidence of cracks or breakage. This is a pass/fail test, with no evidence of cracks indicating passing. If the test specimen passes the initial 120 hour criteria, it is placed back into the heated lubricant and removed every 24 hours for embrittlement inspection, until 360 hours total accumulated time has transpired. The oil charge is replaced with new oil after 192 hours to avoid excessive degradation of the lubricant. If the test specimen fails the initial 120 hour embrittlement inspection, a new specimen is prepared and subjected to heated oil with embrittlement inspection every 24 hours, up to failure. Based on current test method, results obtained from two separate tests, using identical samples, conducted by different laboratories, should be reproducible within ±2% weight change units. Repeatability should be within ±2% weight change units, when conducted using identical samples within the same laboratory. Test materials include fluorocarbon, low compression set (LCS) fluorocarbon, Nitrile, Silicone and Perfluorocarbon elastomer O-rings.

Future Development: OEMs are also interested in the effect of other elastomer properties such as tensile strength, elongation, hardness and compression set after exposure to lubricant. This method does not directly address these properties, although a correlation could be established by evaluating these properties after the completion of the test method. Additionally this method is flexible to both time and temperature and longer duration testing at lower temperatures may be more applicable and should be considered.

4.3.4 Fluorocarbon Compatibility, Snecma Method

Elastomer Compatibility is the assessment of lubricants chemical compatibility with all elastomeric materials they may come into contact with in the field.

History: The need for synthetic turbine oils to be compatible with the fluorocarbon elastomers used in the engine to prevent oil leaks was previously described. The requirements for fluorocarbon elastomer compatibility currently embodied in AS5780 and the United States Navy MIL-PRF-23699 lubricant specifications utilize short durations of 24 or 120 hours and high temperatures of 204 °C or 200 °C compared to in-service conditions. Snecma developed this oil/fluorocarbon elastomer compatibility method to extend test duration and lower temperatures to more moderate levels in attempt to approximate service experience while still accelerating the acquisition of results.

Aims/Purpose: Snecma included its internal requirements for (bisphenol cured such as Viton A or Viton E™) fluorocarbon compatibility based on this method into the AS5780A Appendix A as a guideline for future oil development. Snecma uses these internal requirements to determine the compliance category of certain Service Bulletins that provide fluorocarbon elastomer material product improvements (typically to peroxide cured fluorocarbons such as Viton GLT™) in the CFM engine product line for which they have lubrication system design responsibility.

Applicability: The guidance limits for volume swell are based on dynamic O-ring applications such as those found in accessory carbon seal assemblies. There is also recognition that deterioration of fluorocarbon seals at higher temperatures is possible and to be avoided by imposing the requirement to check for “no shrinkage” during the course of the 140 °C and 160 °C exposures. By extending test durations and lowering test temperatures compared to prior industry oil/fluorocarbon elastomer compatibility methods, the Snecma method is intended to yield more consistent swell data as well as an indication of the onset of fluorocarbon elastomer deterioration. Snecma also uses this method to evaluate oil compatibility with fluorosilicone elastomer material, but this was not adopted into AS5780B Appendix A. This test offers a promising means to distinguish fluorocarbon elastomer compatibility with oil, but at the cost of long test durations. The test is simple and does not employ expensive measurement techniques.

Current Test Method: This initial version of Snecma’s fluorocarbon compatibility method has had little exposure to laboratories outside of Snecma. The method needs a detailed procedure published to allow other labs to faithfully practice it. At present there is a table of the fundamental test parameters available from Snecma. The Snecma method consists of exposing a Vendor specific slab specimen of Viton E from a specific source to oil at temperatures of 100 °C, 120 °C, 140 °C, and 160 °C. The duration of exposure for each specimen is periodic to at least 1800 hours. At the 1800 hour duration, guidance limits are set for 20% swell maximum for the 100 °C and 120 °C exposures and No Shrinkage for the 140 °C and 160 °C exposures. The “No Shrinkage” term is taken to be no reduction in the % swell of the test pieces as the test progresses (in other words, the test specimen does not shrink from one measurement to another). The onset of shrinkage is intended to determine when and if the specimen begins to degrade. No other measures such as tensile loss, elongation loss, hardness change or compression set are employed to monitor material changes.

Future Development: A detailed test method is absolutely needed as the first priority and is being presently worked through E-34E subcommittee. There also needs to be well defined source and materials control offered for the fluorocarbon test specimens. With a detailed test method and controlled test specimens in hand, an industry round robin needs to be conducted to provide a repeatability and reproducibility statement.

4.4 Stability Properties

The ability of oil to resist oxidation is among the most critical performance parameters. AS5780 utilizes five different methods, each designed to fully test the oils ability to resist degradation by oxidation.

4.4.1 Oxidation and Corrosion Stability, FED-STD-791 Method 5308 (mod)/ASTM D4636 Alt Procedure 2 mod

Oxidation and Corrosion Stability is the ability of an oil to withstand degradation by oxidation and to prevent the formation of acidic, corrosive species.

History: Method 5308, Corrosiveness and Oxidative Stability (COS) of Light Oils (Metal Squares), has been a preferred method for evaluating gas turbine engine oils since the 1960s. AS5780 specification adopted the method from the U.S. Navy's MIL-PRF-23699 gas turbine engine lubricating oil specification that had used the method for bulk oil and corrosion stability assessment since 1963. It is believed that the original method was used even earlier than that time for lower temperature petroleum based lubricating oils and was adapted to measure the performance of high temperature turbine engine lubricants. The U.S. Air Force, in their development of turbine oils, used a similar method, Federal Test Method 5307, "Corrosiveness and Oxidation Stability of Aircraft Turbine Lubricants." Method 5307 was replaced by the ASTM D4636 method. ASTM D4636 incorporates features from both Method 5308 and Method 5307 into one encompassing method. In the latest revision of MIL-PRF-23699 modified ASTM D4636 is accepted.

In general, oxidation rates roughly double for every 10 °C increase in temperature. The specification limits are defined below:

TABLE 1

	175 °C		204 °C		218 °C	
	SPC	HPC	SPC	HPC	SPC	HPC
Viscosity Change, %	-5 to +15	0 to +10	-5 to +15	0 to +22.5	120 max	60 max
TAN change, mgKOH/g	2.0 max	1.0 max	3.0 max	2.0 max	15 max	10 max
Sediment, mg/100 mls	50 max	25 max	50 max	25 max	50 max	25 max
Metal weight change, mg/cm^2						
Steel	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max
Silver	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max
Aluminium	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max
Copper	± 0.4 max	± 0.4max	± 0.4 max	± 0.4max	--	--
Magnesium	± 0.2 max	± 0.2 max	± 0.2 max	± 0.2 max	--	--
Titanium (2 test pieces)	--	--	--	--	± 0.2 max	± 0.2 max

In Method 5308 the 175 °C test is a baseline measurement and has proven useful for examining “low temperature” sludging. The 175 °C SPC COS test has a 15% maximum viscosity change limit and a 2.0 maximum TAN change limit in an attempt to require a reasonable operating life from a lubricant that is only mildly stressed. For many years, a rule of thumb for military turbine engines for changing oil has been to drain when the viscosity has increased by 25% or when the Total Acid Number (TAN) has increased by 2.0 mg KOH/g. These parameters are reflected in the COS 204 °C test limits (or perhaps were derived from them). In addition to the upper viscosity limits at 175 °C and 204 °C there are also lower limits. The reason for lower viscosity change limit of -5% viscosity loss is not clear but is believed to be a carryover from the early years of oil development where the intent was to preclude the addition of an oil thickener into a Type I oil to make it appear as a higher viscosity Type II product. By including a negative viscosity change limit this would stop oil formulators from using non-thermally stable flow modifiers. The 218 °C COS test is an accelerated evaluation and provides data on lubricant performance in extreme environments. The airflow is held at 5 L ± 0.5 L per hour and is a key part of the COS test. The airflow in the test simulates normal seal leakage into the bearing compartments of a gas turbine engine. The airflow to oil volume ratio is approximately 50:1 per hour. The use of dry air is essential or TAN values will soar unrealistically. The purpose of the condenser is to condense oil vapors and degradation products and return them to the test oil charge. There is general debate within the industry on whether condensation occurs in engines at the level that this test employs. The metals use in the COS test are considered to be representative of a least common denominator approach for materials used in the construction of gas turbine engines. Since metal attack is not tolerable the metal weigh change limits for all of the three test temperatures are the same, however, the choice of test metals does differ slightly in the 218 °C test with the removal of magnesium and copper in favor for two titanium specimens. The sludge content limit is required to prevent products that form solid or semi-solid precipitates. Although not seen frequently with modern technology formulations, sludge formation is possible with the use of thermally unstable additives or as a consequence of severe corrosive attack.

Aims/Purpose: The bulk oxidative stability of oil and its compatibility with metals found in engine systems are key parameters in lubricant design. The COS test is used to assess these lubricant characteristics. This method attempts to create a simulated environment to evaluate the oxidative stability and corrosive tendency of the oil. Running the test at three separate temperature conditions develops an oxidative profile of the oil. The temperatures represent increasingly severe conditions and may be representative of normal, mildly hot, and severely hot running engines. Cumulatively, the data from the test series provides the profile of the oxidative stability of the lubricant.

Applicability: This test method correlates to bulk oil stability experience in gas turbine engines. It should evolve (if practical) to incorporate new materials and operating conditions in the future as gas turbines run hotter and remain longer on wing.

Current Test Method: A small oil sample is subjected to high temperatures, bubbling airflow and metals to catalyze the effects. The test is run in duplicate at three specific temperatures, 175 °C, 204 °C, and 218 °C. Metal coupons are tied together in a cradle formation and immersed in 100 mL of test oil for 72 hours while air is blown through at a rate of 5 L per minute. The oil and metal specimens are placed in a large glass test tube (5 cm diameter and 50 cm long) with 30 cm Allihn type condenser attached. At completion of the test, the oil is examined for degradation (changes in viscosity and total acid number (TAN)) and sediment formation. The metal coupons are examined for evidence of corrosive attack. The results are then compared to specification limits established for each test temperature.

Future Development: Precision data is not available for Method 5308 and due to the rationalization movement within E-34 to consolidate the multiple oxidation tests used in AS5780 it is unlikely that further work will be carried out to create this precision data. At this time, the committee is considering consolidating multiple oxidation methods using the COS equipment found in ASTM D4636 (Procedure 1). Future development work will focus on the improvement of the COS test to include additional capabilities and test points to evaluate a lubricants bulk oil stability (induction period, break point, etc.) within a performance envelope. The addition of in-situ sensors may provide better performance measurements to help model a lubricant’s behavior.

4.4.2 Thermal Stability and Corrosivity, FED-STD-791 Method 3411b

Thermal Stability and Corrosivity is the ability of an oil to withstand degradation by high thermal exposures and to prevent the formation of acidic, corrosive species.

History: The Thermal Stability and Corrosivity (TSC) of Aircraft Engine Lubricants method was adopted from the U.S. Navy's MIL-PRF-23699 specification. MIL-PRF-23699 originally had a thermal stability test with no metal present. The U.S. Navy (USN) was made aware of corrosion problems on stationary gas turbines and some commercial aircraft on lubricants that were approved by engine manufacturers at the time. The TSC test was introduced into the specification to prevent the problem in Naval aircraft engines. A research program at the Naval Research Laboratory (NRL) showed that the test could discriminate against oils and that those oils with the antiwear additive, Tricresyl Phosphate (TCP) (or other phosphorus containing compounds), were significantly more stable than oils with no TCP. Further research suggested that the TSC test could be used when formulating oils to determine long-term storage stability, particularly when the lubricant is exposed to moisture.

Aims/Purpose: The purpose of the method is to determine the thermal stability and corrosiveness of aircraft turbine lubricants in an environment free of air and moisture. The catalytic effects of mild steel on the decomposition of the fluids and the corrosion of the steel by thermal degradation products of the lubricant are measured.

Applicability: Although thermal stability and corrosivity of the lubricant is not a major issue in today's engines the method still serves a valuable purpose. The method serves to ensure only high quality formulated oils can withstand the rigorous environment of the turbine engine. As new oils are introduced and others modified the TSC test also ensures that the lessons learned from our past should not be repeated.

Current Test Method: A weighed mild steel specimen is placed in a glass thermal stability test cell with 6 mL of test lubricant. Air and moisture are removed from the test cell by heating and shaking under vacuum prior to sealing the tube. The sealed test cell is then heated at 274 °C for 96 hours. The stability of the lubricants is assessed by determining the change in viscosity, total acid number and the by the appearance of the residual lubricant at the end of the heating period. The steel specimen is weighed and examined under microscope to determine changes due to corrosion.

Future Development: No known steel corrosion issues are associated with thermal degradation of lubricants in today's engines. Therefore, the TSC method is considered a stable method that has not been updated for some time. One area for improvement could be the development of a precision statement.

4.4.3 Oxidative Stability, Def Stan 05-50 (Part 61) Method 9

Oxidation Stability is the ability of oil to withstand degradation by oxidation.

History: Method 9 was originally developed by Rolls Royce during the latter years of the 1950s. It was the first of a series of methods to be used as part of a laboratory-based engine oil approval process, and it was assigned the title RR Method 1001, Issue I. In 1979 the Method was incorporated into the UK Defense Standard 05-50 that contained the test methods stipulated by the various UK Ministry of Defense Lubricant Specifications. Method 9 continues to be an integral part of the Rolls Royce engine approval process and it also provides specification requirements in the UK lubricant Defense Standards and in the Rolls Royce quality requirements for individual oil specifications. Method 9 was included during the development of AS5780 and remains the only stability method to feed engine performance models

Aims/Purpose: Method 9 provides a means of conducting oxidation tests under prescribed conditions for varying times and temperatures in the absence of metals. Property changes in the oxidized oil are measured as 'Volatilization Loss', 'Viscosity Increase', 'Insolubles Increase' and 'Acidity Increase'. Graphical interpretation of the results allows assessment level temperatures to be derived for each of the properties. The assessment level temperatures refer to the time at the specific temperature where the deterioration reaches a prescribed level; the levels being 15% volatilization loss, 15% viscosity increase, 0.5 mg insoluble's per gram of oil and an increase of 1.0 mg of potassium hydroxide (KOH) per gram of oil (that being the quantity of potassium hydroxide to neutralize the acidity contained within one gram of oil) over the new oil value. Utilizing the times for the oil to deteriorate to each assessment level at the different temperatures tested, allows an Arrhenius relationship to be developed for each property; the sophistication being that the Arrhenius relationship allows times to the assessment level to be derived for any temperature from very low to very high for each of the four properties. Mathematical constants from the Arrhenius relationship can then be used in calculations using engine parameters to predict the oil deterioration in engines having a specific flight operational envelope. Thus, reducing sole reliance upon engine tests.

Applicability: This approach to oxidative stability measurement allows a ready set of specification control parameters to be set and can be used to calculate the bulk oil life stability for the individual engine case. From an engine manufacturers' perspective the lubricant bulk oil stability is regarded as a key lubricant performance characteristic. Prior to the insertion of the Method into AS5780 specification, Method 9 was an exclusive requirement of Rolls-Royce plc. Their historical database is such that Rolls-Royce plc uniquely requires oil life stability calculations to be performed as a fundamental material performance requirement.

Current Test Method: Method 9 is defined in the UK Ministry of Defense Standard 05-50 part 61. In the test, 50 mL of oil is contained in a weighed test tube having specified dimensions and immersed in an oil bath (or installed in an Aluminum heater block with holes designed to suit the test tube); the temperature of the oil in the oil bath or of the Aluminum of the heater block is controlled during the prescribed test time. Air is bubbled through the oil sample at a prescribed rate throughout the test period. At the end of a prescribed test time, the tube is removed from the apparatus and allowed to cool before being weighed to obtain the volatilization loss. Fresh oil is then added to restore the tube and degraded oil to the start of test weight. The tube is then returned to the test bath/block and connected to a nitrogen supply (to prevent further oxidation) for a prescribed period to homogenize the oil sample within the tube, before determinations of acidity and viscosity increase and toluene insoluble's content are made. The data from tests conducted for prescribed times at varying temperatures, and at varying times at different prescribed temperatures, are graphically represented to obtain the time and temperature coordinates to give rise to the assessment level of deterioration for each property. And from these data the Arrhenius plots are derived by plotting the time to the assessment levels against reciprocal absolute temperature on a log/linear graph.

Future Development: Precision data for Method 9 have not so far been obtained but for individual tests, repeatability and reproducibility are not considered to be good. However, from experience at Rolls Royce using the multiple time and temperature surveys described above, the precision of data for the determination of the assessment level temperatures and the derivation of the Arrhenius constants are considered to be good. Determination of the actual statistics could be achieved at the behest of Committee E-34.

4.4.4 Thermal Aging, Turbomeca Method

The Thermal Ageing test was designed to evaluate an oils ability to withstand thermal, oxidative changes over long periods of time.

History: Turbomeca Test was developed by Turboméca in the 1980s, and was then introduced in Turboméca and Snecma Validation Practices in 1995. After having acquired a large experience on different oils, approval criteria were extended in 2003 for HTS oils.

Aims/Purpose: The Turboméca test provides a means of conducting oxidation tests under conditions representative of Helicopter turbines: Medium and high temperatures (150 °C and 180 °C) for relatively long duration (750 hours).

Property changes in the oxidized oil are measured as, Viscosity (at 40 °C and 100 °C), Density at 20 °C, Flash Point changes, and Acidity Increase. Graphical interpretation of anti-oxidant depletion rates at two temperatures (150 and 180 °C) allows assessment level temperatures to be derived for oxidation kinetics (Arrhenius plot).

Arrhenius relationship can be used in calculations using engine parameters to predict the oil deterioration in engines having a specific flight operational envelope. Thus, reducing sole reliance upon engine tests.

Applicability: This approach to oxidative bulk-oil stability measurement can be used to calculate the bulk oil life in engines. Comparison of Turboméca test results and experience from the field show a good correlation, giving confidence in the approval process for new oils. Along with coking propensity, Snecma and Turboméca regard bulk oil stability as a key lubricant performance characteristic.

Current Test Method: 3 L of oil is heated in a 3-necked round-bottomed glass vessel at 150 °C and 180 °C for 750 hours, in the absence of additional metal catalysts. The 3 necks accommodate the following – a metal stirrer in the vertical position, a thermocouple and a water-cooled condenser. Oil samples are taken at 150, 330, 550 and 750 hours without make-up with fresh oil.

The following oil analysis is performed on the removed oil samples:

- Density at 20 °C
- Kinematic Viscosity at 40 °C and 100 °C
- Flash point
- TAN
- Anti-oxidant additives concentration by RULER

Parameter changes against the new oil after 550 hours are compared to criteria.

Future Development: The test method is not publically available or standardized. Future work should include incorporating this into an SAE method and standardizing via Round Robin testing. Precision data for the test have not so far been obtained.

4.4.5 Particulate Generation, P&W Method

The Particulate Generation test is designed to test whether an oil will form particulates in a severe environment and evaluate the size of those particulates

History: Formation of black oil films on engine components was observed during the early years of turbine engine technology. The films were limited to certain Pratt & Whitney high-powered engines and they became known colloquially as “Black Oil”. Generally, the films did not adversely affect the engine operation though they were regarded as problematic during overhaul processes. It was, however, considered possible that build-up of the films could cause blockage of filters and small clearance engine passageways. Thus the Particulate Formation Test was developed and issued in 2004 having the intent to ensure that no oils were approved, or about to be approved, which would produce larger particles having the potential to cause engine operational problems.

Aims/Purpose: The Particulate Formation Test subjects the oil to heating in a vessel pressurized to 125 psi (87883.7 kg/m^2) for 18 hours. After the test period the degraded oil is filtered through a 0.45-micron filter and the amount of sediment formed is measured and reported.

Applicability: The Oil Carbon Particulate Formation Test is used by Pratt & Whitney to test oils for approval and to ensure that no oils are approved which could have a negative impact on engine performance, filter life or service reliability.

Current Test Method: The Oil Carbon Particulate Test is a proprietary Pratt & Whitney Method. It was developed for the purpose of measuring the formation of oil insoluble particles, under simulated engine pressure conditions. A 20 mL sample of oil is heated to a temperature of 625 °F (335 °C) in a vessel pressurized to 125 psi (87883.7 kg/m^2) and the weight of any insoluble material formed is measured and reported.

Future Development: Currently, the test can only be carried out in the Pratt & Whitney, ExxonMobil and Air BP (now Eastman Aviation Solutions) laboratories. Further development of the test and procedure would be necessary before the test could become more generally available and before any estimation of method precision could be carried out.

4.5 Deposition

The deposition characteristics or coking propensity of turbine lubricants is so very important because it affects so many engine issues such as operability, safety, and maintenance. The term coking propensity or hot spot stability refers to the tendency of the lubricant to form small amounts of solid carbonaceous materials, commonly referred to as “coke” deposits, at specific locations within the lubrication system. Common locations for coke deposits to form include oil supply lines, oil scavenge lines, and vent/breather tubes. If the internal surface temperature of the supply line, scavenge line or vent tube is sufficiently hot to degrade the oil, then deposits will eventually form. Deposits formed in oil supply lines are typically the result of a solid stream of oil, containing predominantly dissolved air (oxygen), flowing over the hot metal surface (liquid phase deposition addressed in 4.5.1 and 4.5.2). In a scavenge line, there is a mixture of oil, dissolved air and free air (mixed phase deposition addressed in 4.5.4 and 4.5.5). The vent tube sees predominantly free air, with a small amount of oil vapor/mist mixed in (vapor phase deposition addressed in 4.5.3). Variables that can influence the formation of coke deposits include, not only the chemistry of the lubricant, but also the characteristics of the hot metal surface. These characteristics might include surface finish, type of metal and any surface treatments on the metal surface. The consequences of excessive build-up of coke deposits in the oil supply or scavenge lines can include bearing failure or compartment fires.

4.5.1 Erdco Bearing Test

The Erdco Bearing Rig deposition test is designed to assess an oils ability to resist oxidation and deposit formation in a simulated engine environment.

History: The Bearing Rig (BR) test was developed around 1955. In 1959 a panel in deposits and oil degradation characteristics was established within the CRC-Aviation Group on Gas Turbine Lubrication. The first objective of this panel was to select a suitable oil testing device which would produce a reasonable correlation of relative oil deposit and degradation levels to that found in full scale engines. The BR was designed to replicate a gas turbine engine bearing compartment.

Presently, the test is conducted by circulating the test oil into the bearing chamber from a pre-heated oil tank and spraying it onto a heated 100 mm roller bearing, which is vertically loaded, while it rotates at 10 000 rpm. The test oil is then collected and scavenged back to the test oil tank. Humidified air is also introduced to the bearing compartment to further stress the oil being tested. The BR test can be run at various test temperature conditions.

In the 1960-1980 time period, most labs involved in gas turbine specification development owned and operated the Erdco Bearing Rig test. A slow down in lubricant technology development coupled with the high cost of running the Bearing Rig test reduced the laboratories capable of running the test significantly. Today, the US Navy has the only remaining Bearing Rig Test available.

Aims/Purpose: The purpose of this test is to subject an oil to a simulated engine environment to assess its ability to resist thermal and oxidative degradation. Oil degradation products (e.g., varnish, carbon and sludge) are undesirable and can be detrimental to the performance and operation of gas turbine engines. Such oil degradation products can lead to filter plugging, bearing and seal wear, oil leakage and in the extreme even engine failure.

Applicability: The physical size and layout of this test provides the best approximation of a real gas turbine engine lubricant system and bearing chamber found in the specification. The test provides liquid, liquid/air, air/oil mist environments, a heated bearing under load, filtration, bearing compartment pressure balancing (sealing and venting), scavenge and supply oil system and tank. This test provides a realism not found in any other test found in the specification. The results obtained from this test are sufficiently representative of and comparable to many deposit types and levels seen in bearing compartments of gas turbine engines in operation today.

Current Method and Limits: This method describes procedures used to evaluate the thermal and oxidative stability characteristics of gas turbine engine lubricants under varying levels of severity, simulating conditions encountered in engines bearing chambers. The BR is capable of evaluating a test lubricant under various temperatures, times, air flows, load forces.

Typically, a test lubricant is subjected to a specified performance run for a controlled number of hours. Standard and Corrosion Inhibited (AS5780 SPC (STD/CI)) oils are tested for 100 hours. High Thermal Stability (AS5780 HPC (HTS)) oils for 200 hours.

Oil samples taken at 10 hour intervals during and at the end of the test are examined for both physical and chemical changes compared to the new oil. A visual inspection of the bearing and bearing housing is made at the end of the test to assess and rate accumulated deposits.

A weighted numerical rating is given to the test oil. A Total Test Deposit Rating limit for each test category has been established. The acceptable maximum rating for an SPC oil is 80 and for HPC oil is 40.

Data on the relative sludge forming tendency on oil are obtained by weighing the test 40 and 100 mesh filters. The maximum values for the sludge formation in addition to the other test requirements and limits are included in the table below:

TABLE 2

ERDCO Bearing Rig	SPC	HPC
Total Demerit Rating	80	40
Sludge in mg (max)	3.0	1.5
Oil Consumption (max)	2000 mL	4000 mL
TAN change, mgKOH/g (max)	3.0	2.0
Viscosity change, %	-5 minimum; 30 maximum	0 minimum; 35 maximum

Future: In performance testing, it is commonly understood that the closer your test is to reality (in this case a gas turbine engine bearing chamber and lubricant system), the more difficult the repeatability due to the complexity of the test itself. The Bearing Rig test is no exception to this rule. The test does not have a formal repeatability statement. Future work on developing a repeatability statement is desirable in order to ensure the correct amount of testing is performed.

As HPC oils are improved, the Bearing Rig test method severity should be increased to help discern the differences between test oils. The US Navy is considering this approach through increasing the time of the existing test and/or increasing the temperature of the test (i.e., moving from Type 1-½ to Type 2 conditions)

There is significant opportunity to improve (or replace) the existing Bearing Rig test in the future. Inclusion of new materials, test conditions, and technologies (e.g., in-line lubricant sensors) would be beneficial to the development of gas turbine lubricants.

4.5.2 Propensity of Aviation Lubricants using the Hot Liquid Process Simulator (HLPS) Single Phase Flow Technique, ARP5996

This test evaluates the ability of an oil to resist deposit formation in a simulated feed pipe environment.

History: High oil system temperatures, both liquid oil and oil wetted surfaces, increase the risk of deposition problems in gas turbine engines. This can manifest as blocked or restricted oil pipes and can lead to risk of system integrity and reliability. This test methodology was developed jointly by the UK MOD and Rolls-Royce, but has in recent years undergone significant development and improvement, including the generation of precision data under the auspices of the SAE E-34 Propulsion Lubricants Technical Standard Committee. The origin of the test method was the identification of significant levels of deposit build up in a bearing chamber oil feed pipe, which was not predicted by the coking methods of the day. This resulted in the concept of a dynamic flowing representation of a bearing chamber oil feed pipe and the temperature environment through which the pipe passes being developed. An existing piece of laboratory hardware was adapted to provide the basis of the recirculating system and basic proof of concept studies undertaken. Observed results from this early work ranked the oil brands in a similar order to that observed in actual engine oil feed pipes and the apparatus was used with success to identify metal contamination of the oil system as being responsible for the observed in-service deposition. There followed a period of method development and refinement which further highlighted the effectiveness of the method in predicting oil behavior in bearing chamber oil feed pipes. Specifically, the identification of quality escapes undetected by batch quality testing that impacted on engine integrity.

The relevance of this test procedure has been recognized by its inclusion in the requirements of AS5780, with limits established for both Standard Performance Capability and High Performance Capability grade oils and its inclusion in AS5780 batch quality control requirements.

Aims/Purpose: The purpose of this test procedure is to assess the performance of a lubricant under laboratory simulated engine oil feed pipe conditions in a flowing regime. Data generated from the method can be utilized to support:

- The definition of acceptable lubricant performance, both from an engine centric and specification centric basis.
- The provision of engine design data.
- Specification quality control and change management
- In-service investigations.

Applicability: This method was initially targeted at a specific location in a specific gas turbine oil system. However, accepting the limitation on oil flow detailed above the concept of assessing the propensity of a lubricant to generate deposits under single phase, i.e., oil feed pipe conditions is relevant to all gas turbines.

The performance of oil brands in this test procedure was validated against engine experience during its development and this procedure was successfully used to identify batch quality escapes of lubricant brands.

Current Method and Limits: ARP5996B defines the test procedure and apparatus.

A limitation of all this type of laboratory simulation of gas turbine oil systems is the inability, or high levels of difficulty, in achieving representative flows of oil and the associated turbulence in the pipe in the laboratory environment. The required scaling of oil flow to more readily achievable levels makes validation of the results generated to actual engine experience very important.

Future: No further significant changes are expected with this test procedure. Continuous method improvement has resulted in a method with a well-established precision and further work is only envisaged to evaluate and incorporate new procedures to better differentiate oils.

The longer term future of this method, as well as all other methods should rely on the continued relevance to in-service engine experience.

4.5.3 Vapor Phase Coking, ARP5921 (Draft)

This test evaluates the ability of oil to resist deposit formation in a simulated vent pipe environment.

History: Engine vent tube coking is a recognized problem. It forms from inadequate wall washing and cooling effects of engine vent tubes as witnessed in engine teardown. Many methods have been developed from the original Eppi Vapor Phase Coker Model 5400 (Eppi Precision Products of Claredon, IL), all evaluating deposit generated from mist and vapor mixtures in a heated metal tube.

Aims/Purpose: Vapor phase coking is a form of deposition which can be formed by a gas turbine lubricant when it is exposed to high temperatures in a non-oil wetted engine area. After engine shutdown, the airflow through the bearing vent tubes and seals ceases. The mist, vapor mixture is carried in the airflow, condenses in the engine and is subjected to high soak back temperatures. The neopentyl polyol ester molecules typically experience thermal and oxidative degradation which form carbonaceous deposits. Over a period of time coke build up can cause back pressure in bearing compartments and lead to seal malfunction. Vent lines need to be clear for the pressure balance within vented bearing compartments to be maintained, allowing proper sealing of oil within these compartments.