GUIDELINES FOR QUALIFICATION AND SPACE APPLICATION OF NEW FLUID LUBRICANTS

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ABSTRACT

Engineers considering use of a fluid lubricant typically select from a few very long-established products that combine attractive characteristics and seemingly low risk due to prior flight "heritage".

The requirements of new missions, the impact of environmental legislation on products and processes, plus the availability of promising new chemistries suggest that new-to-space lubricants may be more frequently considered in coming years.

This paper introduces new guidelines, which aim to provide clarity concerning ESA's expectations for those who may in future choose to employ a new fluid lubricant in a space mechanism intended for flight qualification.

1 BACKGROUND

Formulated low volatility fluid lubricants (oil and grease products) used today in spacecraft mechanisms are predominantly based on oils from two chemical families: the PFPEs (perfluorinated polyethers, usually of Z-type within Europe), which have been in use since the 1970s [1]; and the synthetic hydrocarbons (commonly multiply alkylated cyclopentanes (MACs)), which originated in the early 1990s [2]. Examples of these oils are Brayco 815Z, Fomblin Z25 and Nye 2001A, and there are many greases derived from them including Braycote 601EF, MAPLUB PF100 and Rheolube 2000. These products have been employed in many qualified space mechanisms. Having such extensive use over many years brings confidence that their adoption in new applications brings relatively low risk, a characteristic sometimes called "heritage".

Heritage products dominate the space market; but have well-known limitations [3]. In general, PFPEs can be used over a wider range of temperatures than MACs and have a lower volatility. However, PFPEs exhibit relatively low tribological lifetimes and generally poorer performance under boundary lubrication than MACs. It can be challenging to select a lubricant for missions requiring some combination of long tribological life, high temperature operation, low speed boundary regime running, and a critical need to avoid contamination.

Furthermore, the remarkable chemical stability offered by PFPEs is a significant benefit in space applications but renders both the oils and their related solvents as environmental contaminants on Earth. Environmental concerns and emerging legislation (especially REACH legislation in Europe) threaten to curtail, and perhaps ultimately prohibit, the production and use of PFPEs within the next 12-15 years [4]. Indeed, this proposed legislation may have wider implications: demanding process changes, and /or restricting (or even prohibiting) production of other fluorinated polymers (e.g. PTFE) widely for space applications in cage materials, plain bushes, electrical wiring and greases as thickeners etc.

At the time of writing, the price, availability and minimum order quantities of PFPE lubricants, and associated fluorinated solvents, remain acceptable. However, the producers of fluorinated materials are clearly concerned by the potential impact of proposed restrictions and the long-term robustness of the PFPE lubricant supply chain for space is therefore unclear.

Finally, the evolution of new products should be considered. New additives, thickener materials and processing routes are constantly being evolved, leading to newly formulated lubricant products, even when based on heritage base oils. Beyond this, new base oil chemistries, such as some ionic liquids [5], whilst not yet widely employed, have some attractive characteristics. These base fluids may soon be offered as fully formulated products with specific benefits for various space applications. These new products (by definition) lack heritage, meaning that their use in a space mechanism can bring perceived risks, which needs to be retired for the new fluid selection to be accepted.

Against this background, ESA has asked ESTL to generate a guideline document, "Guidelines for Qualification of New Fluid Lubricants" [6]. This document is intended to clarify ESA's position on the necessary process verification and product validation data, which are needed as pre-requisites for including a new lubricant (or modified formulation) in a mechanism qualification test campaign. The remainder of this paper presents an overview of the main elements of the document (which can be accessed at ESTL's Member's Area). However, Issue 1 of the document has been released to permit review and further comment by industry. The process that the guidelines propose will also be confirmed for two lubricants by experimental work, planned for later in 2023.

Issue 2 of the guidelines will implement both lessons learned from the experimental programme and any feedback from industry. It is understood that the requirements of the guideline document will become mandatory upon release of Issue 2.

2 QUALIFCATION TERMINOLOGY

Within the space industry, the terms “qualification” or “qualified” are much used, although often incorrectly and frequently mis-understood. The terms “verified” and “validated” also occasionally cause some confusion. Therefore, the guidelines first seeks to provide an appropriate degree of clarification of these terms and the recommended process of qualification relevant to a mechanism lubricated by a fluid lubricant.

Strictly defined by the European Cooperation for Space Standardization (ECSS) [7]:

- Verification is the “process which demonstrates through the provision of objective evidence that a product is designed and produced according to its specifications”. Hence following verification, a product is deemed “verified”.

- Validation is the “process which demonstrates that the product is able to accomplish its intended use in the intended operational environment”. Verification is a pre-requisite for validation.

- Qualification is “that part of verification which demonstrates that a product meets specified qualification margins”.

It is logical to conclude “verification” and “validation” activities are associated with a lubricant product but “qualification” only with the space mechanism that uses the lubricant product (since the mechanism has specific requirements and margins to be demonstrated, whereas the lubricant itself does not). Indeed, ECSS standards [7 & 8] confirm that lubricants shall be treated as materials i.e. “raw, semi–finished or finished substance (gaseous, liquid, solid) of given characteristics from which processing into a component or part is undertaken”, and critically: “Materials are validated. Mechanical parts are qualified. Processes are verified” [8].

Given this, a lubricant cannot itself “be qualified” and so cannot be generically and widely adopted without risk. However, a mechanism that employs a certain lubricant may be subjected to a successful qualification test campaign, and so become a “qualified mechanism”. The lubricant it contains will then have been fully validated for use within that specific, single mechanism application under the specific conditions tested. Importantly: a single, successful mechanism qualification does not imply there is a reduction in the risks associated with the use of the lubricant in a subsequent application. However, over time, if the lubricant is used across a range of space mechanism applications, an increasingly broad envelope of conditions may emerge where the lubricant has been validated, and for operation within this envelope there is some reduced risk.

Paradoxically then, though many lubricants have been used in mechanism qualification models that have been qualified, no lubricants are “qualified lubricants” – lubricants are only validated, so any supplier that claims their lubricant “is qualified” is, strictly speaking, incorrect – it is the mechanism which is qualified.

Given the above, it is clear a lubricant shall first be verified, then the lubricant validated and only after a comprehensive review of the validation data shall it be proposed for adoption in a mechanism, which will be the subject of a qualification campaign that completes the validation of the lubricant for a single application.

Therefore, though this paper highlights our “Guidelines for Qualification” document, in fact, the definition of the actual mechanism product qualification test campaign will be at the discretion and subject to the mutual agreement of the mechanism developer/supplier, customer and relevant Agency. Rather, this document simply seeks to define the minimum pre-requisite steps required and expectations concerning available data for any new fluid lubricant which is slated to be included in a qualification campaign by offering:

- A standardised definition of the lubricant process verification data expected. Note that verified status can only be claimed when at least two manufacturing batches have been produced and shown to be within the specification claimed and separate verification test lots shall preferably not originate from the same manufactured batch.
- A standardised definition of the lubricant validation tests expected (e.g. tribometer or component level tests).
- A reconciliation of the new approach to heritage fluids (to avoid the possibility that this new standardisation of approach might negatively impact heritage space lubricants, which may already have been validated in a wide range of qualification campaigns for numerous applications)

The remainder of this paper outlines the above process steps and the requirements at each stage.

3 OVERVIEW

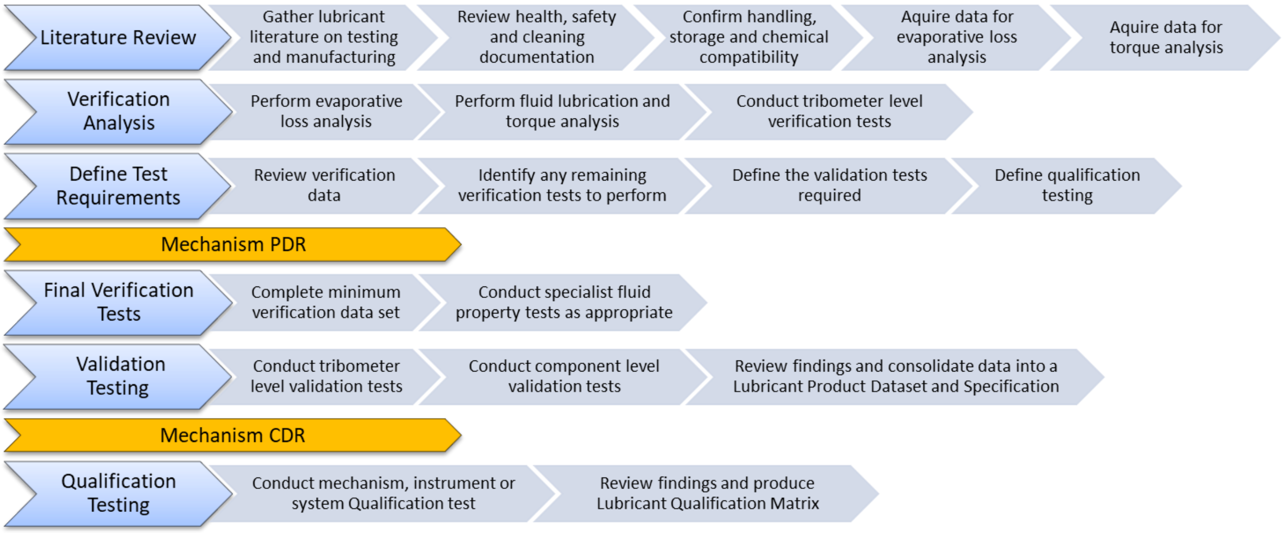

Figure 1: Expected process flow to fully validate a lubricant within a mechanism qualification campaign.

The process flow shown in Fig. 1 above outlines the expected procedure to be followed to fully validate a lubricant within a mechanism. The activities proposed and the approximate sequence in relation to mechanism Preliminary Design Review (PDR) and Critical Design Review (CDR) are summarised below.

3.1 Prior to Mechanism PDR

Literature review: collecting the existing lubricant test, safety, manufacturing, chemical compatibility, handling, storage, and cleaning data. In addition, fundamental viscosity and evaporative loss data must be identified. This stage aims to gather information on any lubricants that may be applicable. At the start of a mechanism development, it is normal for multiple lubricants to be considered and for a preliminary trade-off evaluation, based on the requirements of the application, to take place. If there is a clear, best option then one fluid can be taken forward, but if the trade-off is less definitive multiple options may be considered further.

Verification Analysis: in relation to the top-level mechanism requirements, an analysis of the evaporative losses, lubricant regime, and torque must be conducted. At this stage any necessary tribometer level verification tests will be executed with the aim to show, in principle, that the lubricant(s) under consideration is (are) appropriate for the application. Alternatively, this analysis may support down-selection amongst multiple lubricant options.

Define Test Requirements: in which verification data is reviewed and compiled into a preliminary Lubricant Product Dataset (LPD) document. In preparation for PDR the verification test data gaps are identified, the possible lubrication options ranked (if applicable), and the lubricant validation and mechanism product qualification testing requirements are outlined.

3.2 Mechanism PDR

At mechanism PDR the status of the available lubricant(s) verification data will be assessed, and the planning of subsequent lubricant verification and validation tests (and preliminary mechanism qualification plan) will be reviewed and agreed.

If no clear lubricant trade-off winner is identified at PDR, the ranking and logic for finalisation of the selection should be presented and agreed by all parties.

3.3 Between Mechanism PDR and CDR

After mechanism PDR any outstanding verification tests are completed to enable the minimum verification data set to be defined and any specialised fluid property (verification or validation) tests are conducted.

Whilst multiple lubricant options may remain under consideration after PDR, in practice, depending on the extent of the available data, the programmatic timeline, and costs, will likely force a lubricant baseline to be selected at PDR, with “alternative” options remaining. Both baseline and alternative lubricants may be subjected to verification and /or validation tests post-PDR to provide supporting data to confirm the baseline choice.

Validation testing is also carried out at this stage. This may comprise tribometer and component level tests. Once any critical test milestone is reached, a lubricant assessment meeting will be convened to agree the baseline and confirm the remaining validation data expected at CDR, at which time all findings are consolidated into a full LPD document and a "Lubricant Product Specification" (LPS).

3.4 Mechanism CDR

At CDR all lubricant data will be reviewed, and authorisation will be provided (or not) to include the lubricant in the mechanism qualification test campaign.

3.5 Post - Mechanism CDR

After CDR the mechanism product qualification test campaign is executed, findings reviewed, and a "Lubricant Qualification Matrix" produced for approval at the mechanism Qualification Status Review meeting.

The rest of this paper summarises the specific lubricant verification and validation steps envisaged.

4 LUBRICANT VERIFICATION

Verification of a fluid lubricant production implies the lubricant is produced using established (fixed/frozen) processes and process inputs, and that after production an objective dataset of verification data is available showing that the properties of the lubricant produced are in-line with specification (by reference to defined acceptance criteria, or batch "in-family" criteria).

The expected normal range of variability in these properties when manufactured, which we may call the repeatability of data within a manufactured batch, and the variations which may be experienced from batch-to-batch should also be assessed when the product is re-manufactured to identify acceptance criteria. Hence at least two batches of a lubricant must be produced (from two sets of manufacturing inputs) to complete verification. By this process the specification is refined and the allowable tolerances on parameters defined.

Whilst ideally all data supplied within an acceptance dataset shall have clear and unambiguous acceptance criteria, in some cases data supplied may require expert user interpretation. For example, FTIR spectra are commonly employed but often differ slightly from batch-to-batch. The interpretation of such spectra needs specific expertise (a detailed understanding chemical analysis), and often the interpretation may simply focus on the absence of indicators of specific contaminants. Likewise, statements of lubricant colour, such as "off-white" are common but ambiguous as criterion for acceptance. In such cases acceptance may be based on "in family" characteristics of the product, identified over time.

In the case of a grease, there is the potential for changes to the wetting of the oil and the thickener over time, as well as potential for separation of oil from the bulk phase (known as "bleed"). Such effects may modify the performance of a specific lot drawn from a batch.

For each batch/lot delivered an acceptance dataset must be provided which shows both that the specific delivery has been produced according to its specification (and any agreed deviations and waivers) and that the lot delivered is free from defects (e.g., separation, bleed, oxidation, contamination etc) which might prevent compliance with specification. The lubricant manufacturer's Certificate of Conformance (CoC) or Analysis (CoA) shall warrant that the delivered product has been produced in-line with the established process and meets the manufacturer's product specification. Whenever possible the manufacturer's CoC should cross-refer to the LPS.

It is the duty of the mechanism supplier proposing use of a lubricant to ensure the minimum acceptable tests are met in relation to the LPS. If the lubricant manufacturer-supplied documentation is incomplete with respect to the required testing, then further testing is essential, and the mechanism supplier must issue a subsequent "delta-CoA".

In fact, it is considered best practice to issue a mechanism supplier CoA for the lubricant regardless of the manufacturer supplied CoA; this is to ensure the review of lubricant properties has been formally conducted by the mechanism supplier. This CoA should, whenever possible, cross reference the objective supporting, verification data in the accompanying acceptance dataset and show compliance against the LPS. Only once an appropriate CoA has been produced and accepted, can the batch/lot delivered be said to have been "verified".

4.1 Verification Tests

Verification testing is carried out primarily to ensure lubricant production consistency, and wherever possible includes tests considered to be standard to the industry.

The following, mandatory tests are considered standard within lubricant manufacturing for base oils:

- Density /specific gravity: can impact the fluid flow behaviour and is often essential to know when ensuring proper lubrication volumes.
- Pour point: measures the lowest point a fluid may readily flow, and hence be expected to functions properly as a fluid lubricant
- Viscosity: measures the resistance of a fluid to deformation under a shear stress.
- Viscosity index: although an arbitrary number, it is easily derived from Viscosity measurements to allow easy comparison between fluids.
- Molecular weight distribution: a key fundamental property of the base oil, that is often problematic to measure due to space oil molecules being larger than conventional, terrestrial oil molecules. The best method to use is expected to be dependent on the lubricant chemistry and mass etc. It is for the

lubricant manufacturer to assure that consistent base oil molecule(s) are being produced.
- Evaporation: the loss of volatile constituents of the oil, can occur both under vacuum and in air environments. A standard test in laboratory air to assess evaporation, can readily aid understanding of the lubricant evaporation stability, and /or the potential volatile contaminants in a lubricant.

Similarly, there are several grease lubricant properties that are often measured as standard by lubricant manufacturers, which are also defined mandatory tests:
- Penetration: standard penetration tests shall be used to determine the grease consistency, indicating the correct lubricant mixture and ensure the grease “viscosity” properties required for the application.
- Dropping point: an assessment of the temperature at which the grease loses cohesiveness, that (alongside the chemical degradation temperature of the grease) determines the upper operating temperature.
- Oil separation: measures the separation of the base oil, at elevated temperature, from a grease that can result in a change in consistency of the product and potentially the ability of the grease to lubricate.

Of critical concern to the space industry is the potential for contamination. Hence for both a base oil and a grease product it is also considered to be mandatory for any batch or lot produced to be assessed for:
- Particulate contamination: which can be measured using microscopy techniques.
- Fourier Transform Infra-Red (FTIR) spectroscopy: can used both to assess both the addition of unwanted materials but to analyse the lubricant and confirm the correct, unmodified product chemistry is regularly being produced.

Finally, there are several relatively space-specific tests that, as a minimum, shall be conducted on two batches of a candidate lubricant and may even be regularly assessed as part of the lubricant product assurance:
- Outgassing testing: used to assess the release of vapour from a specimen under vacuum conditions, produced from volatiles within the lubricant itself and absorbed air molecules, which is of critical concern for contamination sensitive applications.
- Vapour pressure: is critical to evaluating the expected evaporative losses in a system and therefore optimising the mechanism lubrication. The ESA (TEC-QEE) Vacuum Balance Quartz Crystal facility should be used to gather the “acceptable” measurements of the vapour pressure of materials. Alternative methods may only be appropriate for quality assurance purposes.
- Tribometer level testing: both ESA and NASA have found the spiral orbit tribometer (SOT) to provide a high degree of repeatability in assessing tribo-chemical degradation of lubricants and SOT has become a standard part of space-fluid analysis.

4.2 Lubricant Information

Alongside the lubricant test data, a body of lubricant “literature” information is required, in particular:
- Appearance: a quick visual examination can provide qualitative indication of the condition of the product, ensuring proper formulation and mixing, whilst permitting comparisons between batches, especially when reference sample images and standard lighting conditions are used.
- General component and process: a broad description of the lubricant, and manufacturing process(es), shall be provided. Comprehensive formulation information is not expected as, in general, it will be commercial sensitive.
- Health and safety: all procured materials must comply with the relevant international and national legal standards with respect to risk management, safe handling, appropriate personal protective equipment requirements and control of hazards.
- Product lifecycle and storage: any sample storage and long-term storage (LTS) recommendations (such as shelf life) shall be recorded. Potential future prohibition must also be considered i.e. legal status checked and reported (even if there are none).
- Solvent and chemical compatibility: as vacuum compatible fluid lubricants are a contamination risk to other hardware within a facility, appropriate solvent compatibility information must be provided in advance of lubricant procurement. Additionally, any chemicals within the cleanroom or assemble environment, should be established as compatible with the lubricant, or measures taken to prevent the chemicals mixing.
- Additive information particulate or chemical: any additives with potential to cause harm to humans or the environment, potentially facing legal restriction, or that may react or degrade materials within a manufacture or storage facility must be reported. In addition, it must be known if there are any additives that are particulate in nature and may be confused with contamination.

5 LUBRICANT VALIDATION

A lubricant lot/batch which has been verified to be within specification (as a pre-requisite) shall then be exposed to validation test campaign to provide objective evidence of its suitability within the intended operating environment.

Validation tests therefore must be conducted in-line with standards and established test methodologies that are relevant for the space industry, although these tests may only need to be conducted in a single campaign prior to qualification. Where a planned validation test activity proves unavailable, or where an alternative test or test provider is substituted, then a validation non-conformance will be required, and the decision to include the lubricant in the mechanism qualification campaign will be at the discretion of ESA following non-conformance disposition and closure.

Validation tests may encompass a wide range of parameters including physical tests (such as outgassing, radiation resistance etc) as well as tribometer level tests and component/unit level tests (e.g., tests of ball bearings or gears). All tests must be done under appropriate thermal vacuum conditions covering the range of temperatures, contact stresses, sliding speeds/slide/roll ratios etc, and the range of lubrication regimes expected in the application. The extent of validation testing required shall be agreed between the mechanism supplier and the Agency. If necessary, validation may focus on the requirements of a first qualification mission only (rather than all missions of the intended mechanism product portfolio), with later mission validations added over time.

Inevitably for a new lubricant, success criteria for validation tests will be a combination of absolute performance requirements (e.g., “torque at cold in xx bearing < yy N.mm” or “life of gearbox with this lubricant >yy revs”) and relative parameters (e.g., SOT test lifetime in-line with other PFPE- based lubricants).

Upon successful completion of the validation test campaign the lubricant is NOT fully validated or “qualified”. In general, validation testing may be fully generic and potentially fully independent of any target mechanism application. However, many risks may remain for lubricants, for example extrapolation to larger size bearings, different speeds, long term storage risks, which may not be retired easily. Qualification of a specific mechanism which is lubricated by the product is a separate, final step in the sequence and provides full lubricant validation for the target application.

5.1 Lubricant Validation Tests

Validation tests will usually include both tribometer level and component level tests.

Validation tribometer testing can be used to rapidly assess the potential tribo-chemical performance of the lubricant over a range of operating temperatures, and possibly including using specific counterface materials (e.g., ceramic balls), and/or a range of contact stress.

The definition of an appropriate tribological validation campaign will be specific to each mechanism or system programme and should be discussed and agreed during the mechanism PDR. Although the SOT is generally preferred for fluid testing, application-specific validation tests may consider appropriate the use of other tribometers such as a pin on disc tribometer.

Component level testing is a highly desirable risk mitigation and may be the final element of validation prior to the development (and test) of a mechanism product qualification model. Such tests may be done at sub-assembly or unit level (e.g., an individual gearbox, motor, assembled actuator, or bearing sub-assembly) or perhaps, in a more “success-oriented programme”, at mechanism or instrument level. But the duration of such tests can be long and early-stage risk-reducing simplified lifetests (e.g., without vibration) are commonly used even though these may be less fully representative of the end-application use.

In general, the scope of component level tests is specific to the application, however tests are expected to meet the requirements of ECSS-E-ST-33-01C Rev.2. The validation tests should be defined and agreed during instrument PDR and must consider operation both on-ground and in-flight including the thermal vacuum environment. It is also critical to define the test success criteria before testing commences.

Component testing conditions may only be partially representative of application conditions as it is often impossible to fully replicate the environment in which a space-mechanism operates, it is also often necessary to accelerate the testing and storage periods as mission durations may be measured in years or decades.

6 OTHER TESTING

In addition to the required tests, if relevant, additional tests to identify application specific properties may be requested by the Agency, including but not limited to:

- Dielectric breakdown potential
- Material corrosion tests
- Rocket fuel or other chemical compatibility
- Creep barrier compatibility
- Ionising radiation tolerance
- U.V. exposure resistance
- Surface energy assessment

It is interesting to note there are several standard tests which are not generally applicable to space lubricants, and so not required as standard, in particular:

- Fretting wear or 4- ball wear tests: commonly assessed, but space guidelines do not allow for metal-on-metal contact resulting in wear [9].
- Terrestrial material corrosion tests: often have no relevance in most space applications as, primarily, they are conducted on copper. If required, material corrosion tests shall be conducted on materials relevant to the specific space application.
- Oxidation stability: used to rapidly assess the resistance of the chemicals to degradation over time during LTS. Space lubricants are often very stable

and often not susceptible to spontaneous decay (as found in historic testing [10]). It is not known if the LTS properties of space lubricants can be inferred from terrestrial testing and an area of ongoing research [11]. However, for novel lubricants it may be applicable to test to show oxidation is not an area of concern.

7 TESTING MATRIX

The test matrix required by the guideline document is shown in Tab. 1.

Table 1: Recommended Lubricant Verification and Validation Tests Required to Prior to Mechanism Qualification

Test No.	Test Category	Method Preferred	Description	Batch Verification	Lot Acceptance (Verification)	Validation	Qualification
1	BASE OIL TESTS	ASTM D4052	Density /specific gravity	X			
2		ASTM D97	Pour point	X			
3		ASTM D445	Viscosity	X			
4		ASTM D2270	Viscosity index	X			
5		FEDSTD79D 3009.3	Particle count	X	X		
6		--	Molecular weight distribution	X			
7		ESA-DOK	Vapour pressure	X		X	
8	GENERAL LUBRICANT TEST REQUIREMENTS	--	Component and process	X			
9		REACH Reg 1907/2006	Health and safety	X			
10		--	Life and storage	X			
11		--	Solvent and chemical compatibility	X			
12		--	Appearance	X	X		
13		--	FTIR	X	X		
14		ASTM D972	Evaporation	X	X		
15		ECSS-Q-ST-70-02	Outgassing	X			
16		ESA-DOK	Vapour pressure			X	
17		--	Other application properties			X	
18		PRA-ESTL-ED-0017	Spiral orbit tribometry	X		X	
19		ECSS-E-ST-33-01C	Component level tests			X	
20	TESTS APPLICABLE TO GREASE ONLY	ASTM D217	Grease penetration	X	X		
21		ASTM D2265	Dropping point	X			
22		ASTM D-6184	Oil separation	X			
23		FEDSTD791D 3005.4	Particulate contamination	X	X		
24		--	Particulate additive information	X			
MECHANISM, INSTRUMENT OR SYSTEM LEVEL QUALIFICATION TESTS							
25		ECSS-E-ST-33-01C	Mechanism qualification tests				X

8 DOCUMENTATION

All of the product data relevant to the lubricant selected shall be compiled into an LPD in a form which can be shared. The LPD is intended to provide more generic information on the fluid lubricant properties. When the LPD is compiled together with the component /mechanism testing information this becomes a full

LQM. Although ideally all testing information should be made widely available, it is recognised that the application-specific information likely contained in the LQM may prohibit its wider distribution.

From the LPD it is required to derive an LPS to control future procurement of the lubricant. The LPS is a quality control document which shall apply whenever a new batch (or lot) of lubricant is obtained. This document is to be used to ensure the appropriate lubricant properties are always obtained from subsequent procurements. These guidelines ensure that after the initial mechanism development and lubricant validation, all lubricants used have a full and accessible data set and are provided with a CoA/CoC by the manufacturer.

9 CONCLUSIONS

This paper provides an overview of the guideline document which is in development with ESA.

Issue 1 of this guideline document proposes the steps deemed necessary to achieve “process verified” status for a new fluid lubricant product or manufacturing process route (or to verify a second or subsequent batch manufactured in accordance with an established processing route), to achieve lot acceptance (or “lot verified” status) for a sample of any size drawn from a manufactured batch, and to validate the performance of a lubricant in representative thermal vacuum conditions. A process flow is also included to aid understanding of these steps.

Though these proposals have been produced in collaboration with ESA and in consultation with some lubricant providers, as a next step it is planned to validate these proposals for real-world practicality during 2023-24, to solicit industrial feedback, to consolidate and document the properties of two lubricants (one new, one having significant heritage) and to update the document based on comments and findings from that activity.

Ultimately, subsequent releases of this document will define mandatory steps to be followed, meaning that:

- A lubricant which has been accepted as having met the defined criteria for verification and validation as pre-requisites might ultimately be employed within a mechanism, instrument or system which will be subjected to a qualification test campaign, but lubricants which have not fully met the pre-requisites should not be employed in such campaigns.

- Only upon completion of the necessary verification and validation assessments AND ultimately also a successful qualification test campaign, can a fluid lubricant be deemed suitable for use in flight hardware.

As a final comment, it should be noted that where a lubricant is employed in a successful qualification programme for one mechanism, at best, this fact merely reduces the risks associated with achieving qualification of a further mechanism employing the same lubricant. The concept of a “qualified lubricant, applicable in many applications” is a fallacy – lubricants are to be treated in ECSS terms as “materials” and wide adoption comes from inclusion of a verified and validated lubricant in multiple individual qualification programmes for diverse space mechanisms. According to ECSS-Q-ST-70C: “Materials are validated. Mechanical parts are qualified. Processes are verified”.

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