



# AEROSPACE INFORMATION REPORT

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Superseding AIR1666A

(R) Performance Testing of Lubricant Filter Elements Utilized in  
Aircraft Power and Propulsion Lubrication Systems

## RATIONALE

The document has been revised to: (1) Include APUs in the scope and clarify the scope as being restricted to testing of filter element performance as opposed to filter assemblies, (2) Remove reference to NIST SRM2806 reference material for particle counter calibration since this material is no longer available, (3) Reference the Multi-pass Filter Element Performance test for measuring filtration efficiencies in terms of Filtration Ratios, and ARP5454 for the Multi-pass Filter Performance test procedure in place of ARP1827 since ARP5454 is applicable to lube filter elements, (4) Remove the gravimetric efficiency and Absolute Rating tests from the sequence of tests in Tables 1 and 3 since they are no longer used for lube filters for the applications referenced in the scope, (4) Clarify the inclusion of Flow Fatigue in the performance test sequence, (5) Clarify temperature and cycle time requirements for Cold Soak and Cold Start tests, (6) Add reference to AIR5455, and (7) Include editorial changes for clarity.

### 1. SCOPE

This SAE Aerospace Information Report (AIR) reviews performance testing parameters for non-cleanable, often referred to as disposable, filter elements utilized in aircraft power and propulsion lubrication systems, including gas turbine engines and auxiliary power units (APUs), propulsion and transmission gear boxes, and constant speed drives and integrated drive generators (IDGs).

This document is confined to laboratory testing of filter element performance to qualify the filtration medium and filter element construction as opposed to qualification of the complete filter assembly. The testing discussed here is usually followed by laboratory and on-engine testing of the entire lube filter assembly (including filter element, housing, valving, etc.), which is outside the scope of this AIR.

#### 1.1 Purpose

Performance testing is necessary to assure that filter elements retain their functional characteristics under operating conditions. Variation in filter element testing methods and requirements make comparison of performance test results difficult. In order to minimize these problems, this AIR describes standard filter element performance test procedures, allowing both manufacturer and customer a common means to specify, control, and evaluate filter elements. This document highlights recommended tests and the appropriate test sequence. The methodology discussed should be incorporated in filter element specifications.

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## 2. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

### 2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

|         |   |
|---------|---|
| ARP24   | Determination of Hydraulic Pressure Drop  |
| AIR887  | Liquid Filter Ratings, Parameters and Tests   |
| ARP901  | Bubble-Point Test Method  |
| AIR4246 | Contaminants for Aircraft Turbine Engine Fuel System Component Testing  |
| ARP5454 | Multi-Pass Method for Evaluating Filtration Performance of Fine Lube Filter Elements Utilized in Aerospace Power and Propulsion Lubrication Systems |
| AIR5455 | Impact of Changes in Test Dust Contaminants and Particle Counter Calibration on Laboratory Filter Element Performance and Fluid Cleanliness Classes |

### 2.2 Military Publications

Available from DLA Document Services, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6396, <http://quicksearch.dla.mil/>.

|            |   |
|------------|---|
| MIL-F-8815 | Filter and Filter Elements, Fluid Pressure, Hydraulic Line, 15 Micron Absolute and 5 Micron Absolute, Type II Systems General Specification for |
|------------|---|

### 2.3 ISO Publications

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, [www.iso.org](http://www.iso.org).

|                 |   |
|-----------------|---|
| ISO 12103-1     | Road vehicles - Test dust for filter evaluation; Part 1: Arizona test dust  |
| ISO 4402 (1991) | Hydraulic fluid power - Calibration of automatic-count Instruments for particles suspended in liquids - Method using classified AC Fine Test Dust contaminant |
| ISO 11171       | Hydraulic fluid power - Calibration of automatic particle counters for liquids  |

## 3. FILTER ELEMENT INTEGRITY AND PERFORMANCE EVALUATION

Filter element integrity and performance are evaluated by a variety of tests using controlled and reproducible procedures. The more prominent tests, currently in use, are listed in Table 1.

In addition, a number of laboratory procedures have been developed, listed in Table 2, which expose filter elements to harsh conditions simulating extreme conditions encountered during service. The generic term for these procedures is Conditioning. Conditioning of filter elements, prior to performance testing, is necessary in order to determine if filter element performance will degrade during actual service.

TABLE 1 - FILTER ELEMENT INTEGRITY AND PERFORMANCE TESTS

| Parameter                | Test Method   | Paragraph |
|--------------------------|---|-----------|
| Filter Element Integrity | Bubble Point  | 5.1       |
| Hardware Integrity       | End Load/Bubble Point   | 5.2/5.1   |
| Clean Pressure Drop      | Flow versus Differential Pressure                                 | 7.1       |
| Dirt Capacity            | Pressure Build-Up versus Contaminant Added                        | 7.2       |
| Filtration Efficiency    | Filtration Ratios from Multi-pass Filter Element Performance Test | 7.3.1     |
| Collapse Rating          | Extreme Differential Pressure                                     | 7.4       |

TABLE 2 - FILTER ELEMENT CONDITIONING METHODS

| Extreme Environment                   | Test Method  | Paragraph |
|---------------------------------------|--------------|-----------|
| Exposure to Heat, Fluid Compatibility | Heat Soak    | 6.1       |
| Exposure to Cold                      | Cold Soak    | 6.2       |
| Cold Start-Up                         | Cold Start   | 6.2       |
| Flow Cycling and Pump Ripple          | Flow Fatigue | 6.3       |

#### 4. QUALIFICATION TEST SEQUENCE

Table 3 depicts a model Qualification Test Sequence. Criteria for acceptance or rejection should be defined in the filter element specification. For filter elements experiencing significant flow cycling or pump ripple Flow Fatigue testing may be incorporated as discussed in 6.3.

#### 5. INTEGRITY TESTS

##### 5.1 Bubble Point Test

In order to ensure that the filter element has been properly manufactured and handled, an integrity check is performed. The Bubble Point Test is an excellent method for detecting punctures and/or tears in the medium, defective seals, and damage from handling. This procedure is non-destructive.

The Bubble Point Test is performed by fully wetting and then immersing the filter element horizontally in a bath of appropriate test fluid. The filter element is positioned so that the upper edge of the filter element medium is 1/2 inch below the fluid surface. The inside of the filter element is then pressured with air. After every pressure increase of 1/2 inch of water column, the filter element is rotated by 360 degrees about its horizontal axis and positioned to ensure that any originating air bubbles are from the top surface of the filter element. The pressure at which the first, steady stream of bubbles issues from the top surface of the filter element is defined as the Bubble Point.

The Bubble Point Test procedure does not measure the filter element efficiency. A high efficiency filter element constructed with one type of filtration medium can have a lower bubble point than a less efficient filter element constructed from a different type of filtration medium. However, the Bubble Point Test is an excellent method to check filter element integrity, useful for quality control as well as for qualification testing. A detailed discussion of the theory and procedure is given in ARP901.

TABLE 3 - MODEL QUALIFICATION TEST SEQUENCE

| Filter Element #1                              | Filter Element #2                               | Filter Element #3 <sup>1</sup>                             | Procedure Paragraph |
|--|---|--|---------------------|
| Examination of Product(Dimensions and Weight)  | Examination of Product(Dimensions and Weight)   | Examination of Product(Dimensions and Weight)              |                     |
| Bubble Point                                   | Bubble Point                                    | Bubble Point   | 5.1                 |
| End Load                                       | End Load  | End Load   | 5.2                 |
| Bubble Point                                   | Bubble Point                                    | Bubble Point   | 5.1                 |
| Heat Soak                                      | Heat Soak                                       | Heat Soak  | 6.1                 |
| Cold Soak                                      | Cold Soak                                       | Cold Soak  | 6.2                 |
| Cold Start                                     | Cold Start                                      | Cold Start   | 6.2                 |
|  |   | Flow Fatigue   | 6.3                 |
| Bubble Point                                   | Bubble Point                                    | Bubble Point   | 5.1                 |
| <b>Filter Element With Lowest Bubble Point</b> | <b>Filter Element With Highest Bubble Point</b> | <b>Filter Element With Second Highest Bubble Point</b>     |                     |
| Clean Pressure Drop                            | Clean Pressure Drop                             |  | 7.1                 |
| Filtration Efficiency: Filtration Ratios       |   |  | 7.3.1               |
|  | Dirt Capacity                                   |  | 7.2                 |
|  |   | Post Flow Fatigue Filtration Efficiency: Filtration Ratios | 7.3.1.2             |
| Collapse Rating: Extreme Differential Pressure | Collapse Rating: Extreme Differential Pressure  |  | 7.4                 |

## NOTES:

1. To be incorporated only if high cyclic flow or pump ripple is encountered in service; see. 6.3.

## 5.2 End Load Test

The end load test is used to verify the bonding of the end caps to the filtration medium pack. Typically, a tensile load (in some cases a compressive load) of 50 pounds (or otherwise specified force) is applied to the end caps, along the axis of the filter element. The Bubble Point of the filter element is then determined to ensure that the integrity of the bond between end caps and filter element pack is retained.

## 6. CONDITIONING

### 6.1 Heat Soak

A primary requirement is that the filter element medium pack, seals, and bonding material be compatible with the maximum temperature experienced by the filter element in the system, and with the operating fluid(s) of the system at this maximum temperature; incompatibility between component materials and the operating fluid(s) is accelerated by high temperatures. Because of the large surface area of filter element medium pack exposed to the fluid(s), a compatibility requirement is of major importance. Problems that may occur when operating at high fluid temperature include degradation of the filter element medium pack and the bonding material used to attach the medium to the support hardware.

Heat soak is performed by immersing the test filter element in the type(s) of lubricant(s) to be used in service, at the highest temperature(s) anticipated in service, typically for a period of 72 hours.

### 6.2 Cold Soak and Cold Start

Since lubricating fluids have high viscosities at low temperatures, forcing cold fluid through a filter element can produce potentially damaging differential pressures. This occurs during system cold starts. In addition, cold temperature embrittlement can amplify any tendency toward filter element damage. In order to evaluate the effects of low temperature on filter elements, Cold Soak and Cold Start Tests are employed.

Cold Soak is performed by immersing the test filter element in the operating fluid(s) at the anticipated minimum temperature that would be experienced by the filter element during service, usually between -40 °F (-40 °C) and -65 °F (-53.9 °C), typically for a duration of 72 hours.

Cold Start testing is performed as a continuation of the Cold Soak procedure. The filter element is subjected to a predetermined number of flow cycles (often 10 cycles) of cold fluid at the required temperature (or viscosity). The flow rate and flow cycle profile are adjusted so that the filter element is subjected to the maximum required differential pressure, typically corresponding to the filter element by-pass valve full flow differential pressure or the filter element Collapse Rating differential pressure (7.4), for a specified duration (usually at least 50% of the cycle time) at the peak of each cycle; typical cycle time is 15 seconds  $\pm$  1 second.

### 6.3 Flow Fatigue

Cyclic flow across a filter element may cause the filtration medium to flex. This movement can result in filter element medium failure. Often, filter element fatigue failures go unnoticed. If the filter element experiences significant flow cycling or pump ripple in service, a Flow Fatigue test should be considered.

In the Flow Fatigue test, the test filter element is subjected to a specified number of flow cycles at a series of specified filter element differential pressures, in increasing order of differential pressure. Typically, a total of 100 000 cycles are specified. The filter element differential pressure is increased to the required differential pressures by sequentially loading the filter element with a specified test contaminant, usually by ingressing the test contaminant in slurry form into the recirculating filter element test circuit at the rated test fluid flow rate and temperature, until the next higher differential pressure is achieved.

At each specified differential pressure, the filter element is subjected to the requisite number of flow fatigue cycles (for that differential pressure), each cycle comprised of varying the flow rate from zero flow rate to a flow rate corresponding to the required filter element differential pressure and then decreasing the flow rate to zero flow. The frequency of the flow cycles (usually 1 to 3 Hz) and the detailed cycle profile are specified. Typically, peak differential pressure is reached within 25% of the cycle and held for at least 50% of the cycle.

## 7. FILTER ELEMENT PERFORMANCE TESTS

### 7.1 Clean Pressure Drop

The clean differential pressure of the filter element is measured in accordance with the procedure in ARP24, typically, as part of the Dirt Capacity test (7.2) and/or the Multi-pass Filter Element Performance test (7.3.1). Where a more comprehensive pressure drop profile is required, the clean differential pressure is determined as a function of increasing fluid flow rate at specified intervals (flow rates) to the maximum specified flow rate. The flow rate is then decreased to zero flow rate and the differential pressures re-determined at the above specified flow rates; this is useful when high flow densities (flow rate per unit filtration area) are involved to determine whether the filtration medium has undergone permanent distortion (compression).

A free-flow dummy element is recommended when determining the differential pressure of the empty filter assembly (i.e., assembly without the filter element) to reduce the impact of any changes in flow patterns on the measured filter element differential pressure. Without the dummy element, the clean filter element differential pressure may actually be determined as a negative number when used in certain filter housings. Typically, the free-flow dummy element is the same as the test element without the filtration medium pack. If the test filter element is not constructed with a rigid core, the dummy element is provided with a core having a minimum open area equal to twice the filter element outlet area and a diameter approximating the inside diameter of the media pack.

### 7.2 Dirt Capacity

There are several versions of this test. All tests are performed utilizing predetermined test parameters: fluid temperature (viscosity), flow rate, and terminal filter element differential pressure. In addition, all methods add a standardized test contaminant (7.2.1) upstream of the filter element until the specified terminal differential pressure across the filter element is attained. The contaminant may be added continuously throughout the test (slurry loading), or in discreet amounts separated by intervals of several minutes (slug loading). Typically, the contaminant is recirculated through the test circuit (multi-pass). The results are reported as the total mass, in grams, of contaminant added to the test system to achieve the terminal filter element differential pressure.

Thus, it should be noted that, in the dirt capacity test, the amount of contaminant retained by a filter element is not determined. By capturing only a small portion of the test contaminant, a coarse filter element may show a higher dirt capacity than a finer filter element which captures most of the test contaminant. Operating with cleaner oil significantly reduces the amount of wear debris generated by operating systems. With fewer particles to capture, a high efficiency filter element may even have longer service life than a coarse filter element. For these reasons dirt capacity test results should only be compared for filter elements having similar filtration efficiencies.

#### 7.2.1 Test Contaminant

Historically, AC Fine Test Dust or AC Coarse Test Dust, conforming to the specification in AIR4246, were the test contaminants specified for the dirt capacity test. Replacement test dusts for the AC Test Dusts, no longer available, have been specified by ISO; ISO 12103-1. The corresponding ISO Test Dusts for AC Fine and Coarse Test Dusts are, respectively, ISO Fine Test Dust (ISO FTD, designated ISO 12103-A2) and ISO Coarse Test Dust (ISO CTD, designated ISO 12103-A4). Dirt capacities with the ISO Test Dusts can differ significantly from the corresponding dirt capacities with AC Test Dusts. This is depicted in Figure 1 for several representative aerospace filter elements.

In general, dirt capacities are reduced with the ISO Test Dusts, by up to ~45 to 50% for finer filter elements rated at 20  $\mu\text{m}$  or less, compared to AC Test Dusts. Users must take this in to account in filter element performance specifications and dirt capacity requirements therein. Additional information is provided in AIR5455.

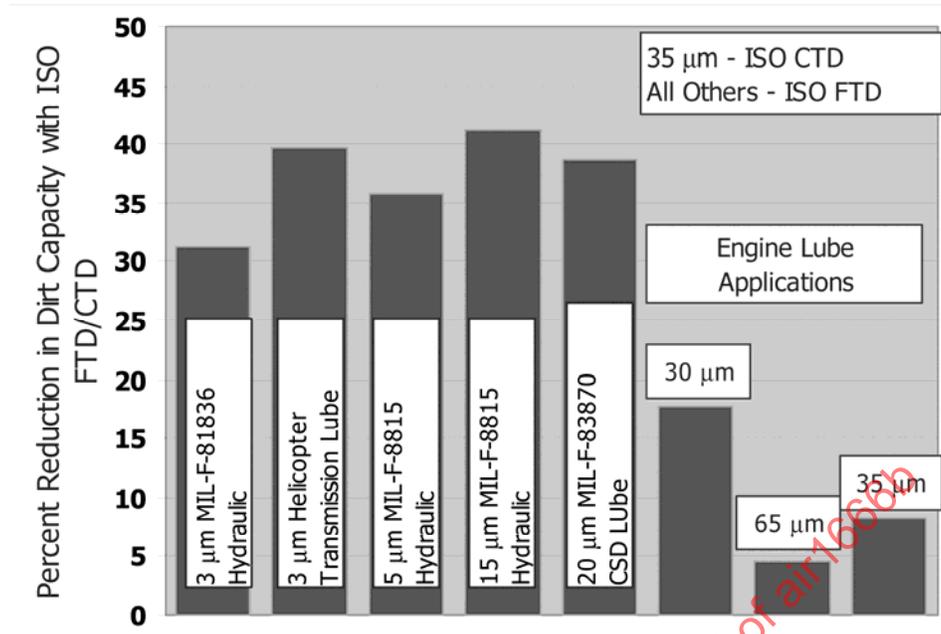


FIGURE 1 - REDUCTION IN DIRT CAPACITY WITH ISO FINE AND COARSE TEST DUST CONTAMINANTS

### 7.3 Filtration Efficiency

Filtration efficiency is a measure of the ability of a filter element to remove and retain particles from a fluid stream. Most procedures for determination of filtration efficiency involve introducing a specified concentration of standardized particulate contaminant upstream of the filter element, under controlled test conditions to ensure repeatable and reproducible results, and measuring the concentration of contaminant downstream of the test filter element. The particles may be counted individually, utilizing light microscopes or automatic particle counters, or collectively (e.g., gravimetric analysis or turbidity measurement). These tests have generated uniform scales, or ratings, of filter element efficiency, and are convenient yardsticks for comparing the performance of different filter elements (AIR887). The preferred method for measuring filter element efficiency is through Filtration Ratios determined from a Multi-pass Filter Element Performance test.

#### 7.3.1 Filtration Ratios from Multi-pass Filter Element Performance Test

The Multi-pass Filter Performance test measures the particle removal efficiencies of filter elements in terms of Filtration Ratios for the specified particle size ranges under specified test conditions. The numerical concentrations (number of particles per unit volume) of particles upstream and downstream of the test filter element are determined for the specified particle size ranges. The filter element efficiency is reported as Filtration Ratios, calculated from the numerical particle concentrations. The Filtration Ratio at a specific size is defined as the ratio of the number of particles upstream of the filter element and the number of particles downstream of the filter element, greater than the specified particle size:

$$\text{Filtration Ratio at particle size } x \mu\text{m} = \frac{\text{Upstream particle concentration } > x \mu\text{m}}{\text{Downstream particle concentration } > x \mu\text{m}} \quad (\text{Eq. 1})$$

The particle removal efficiency, expressed as a percentage, is given by the following equation:

$$\text{Particle Removal Efficiency at } x \mu\text{m} = [1 - 1 / (\text{Filtration Ratio at } x \mu\text{m})] \times 100 \quad (\text{Eq. 2})$$

The particle removal efficiencies for several Filtration Ratios are listed in Table 4.

TABLE 4 - FILTRATION RATIO VERSUS PARTICLE REMOVAL EFFICIENCY

| Filtration Ratio | Particle removal Efficiency(%) |
|------------------|--------------------------------|
| 1                | 0                              |
| 2                | 50                             |
| 10               | 90                             |
| 20               | 95                             |
| 50               | 98                             |
| 100              | 99                             |
| 200              | 99.5                           |
| 1000             | 99.9                           |
| 5000             | 99.98                          |

The Multi-pass Filter Element Performance test is performed in accordance with the procedure in ARP5454. The test contaminant is introduced into the filter element test circuit in slurry form until the required terminal filter element differential pressure (often corresponding to the filter element by-pass valve cracking differential pressure or full-flow differential pressure) is attained. Using on-line sampling techniques, representative portions of upstream and downstream fluid are passed through automatic particle counters throughout the test, and particle counts, corresponding to the size ranges for which filtration ratios are required, are monitored throughout the test. The Filtration Ratios determined per ARP5454 (designated as Beta Ratios) are computed as average values over the test duration per the procedure in ARP5454.

Obtaining filter element efficiency by the Multi-pass Filter Element Performance test provides a more realistic assessment of filtration efficiency:

1. Irregularly shaped test contaminant is employed which is similar to contaminant in operating systems.
2. Efficiencies are measured over a spectrum of particle sizes.
3. Filter efficiency results are averages of filter element performance from the initial clean differential pressure to the terminal differential pressure.

#### 7.3.1.1 Test Contaminants

Historically, AC Fine Test Dust was the test contaminant specified for the Multi-pass Filter Element Performance test, and the calibration of automatic particle counters was in accordance with ISO 4402 (1991). As stated in 7.2.1, ISO Fine Test Dust (ISO 12103-A2) has been selected as the replacement test dust for AC Fine Test Dust. In addition, ISO has also specified a calibration procedure ISO 11171 for automatic particle counters to replace the ISO 4402 (1991) calibration procedure which utilized AC Fine Test Dust. The ISO 11171 calibration procedure uses ISO Medium Test Dust, designated ISO 12103-A3, instead of AC Fine Test Dust.

The definition of particle sizes per the new calibration procedure ISO 11171 differs very significantly from the particle sizes defined in ISO 4402 (1991). In order to distinguish the particle sizes defined in ISO 11171, they are designated as  $\mu\text{m}(c)$  or micrometer(c), the (c) indicating NIST certified sizes. Figure 2 shows the impact of the change in test contaminant, from AC Fine Test Dust to ISO Fine Test Dust (ISO 12103-A2), and the change in automatic particle counter calibration, from ISO 4402 to ISO 11171, on Filtration Ratios (Beta Ratios) for representative filter elements utilized in Aerospace applications.

In general, Filtration Ratios with the ISO Test Dusts and ISO 11171 calibration are reduced below  $\sim 10 \mu\text{m}$ , and increased above  $\sim 10 \mu\text{m}$ . Users must take this in to account in filter element performance specifications and Filtration Ratio requirements therein. Additional information is provided in AIR5455.