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MSFC TECHNICAL STANDARD

Flow-Induced Vibration Assessment Requirements for Metal Bellows and Flexhoses

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DOCUMENT HISTORY LOG

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1. SCOPE

1.1 Introduction

It is well known that the occurrence of flow-induced vibrations (FIV) in convoluted metal bellows and flexhoses used in fluid ducting systems have resulted in fatigue failures which have forced the premature shutdown of some critical fluid systems. These flow-induced vibrations are a result of the coupling of vortex shedding from the flexible line convolutes with the natural frequencies of the flexible line. This document was written for NASA Programs in order to provide requirements for metal bellows and flexhoses with regards to FIV only.

The requirements in this document follow the same general approach used in the Space Shuttle Program via NSTS-08123, Rev. C, "Space Shuttle Certification of Flexhoses and Bellows for Flow Induced Vibration" and also in the Space Launch System Program via SLS-RQMT-166, Rev. A, "SLSP Flexhose and Bellows Design Requirements for Flow-Induced Vibration." The requirements in this document are based upon the philosophy of the Space Shuttle Program and the Space Launch System Program of designing bellows and flexhoses whose operating flow ranges are below the flow ranges which are predicted to produce flow-induced vibrations.

The requirements in this document are applicable to both flight and Support Equipment hardware.

Two other documents are used in conjunction with this requirements document. The first is MSFC-DWG-20M02540, "Assessment of Flexible Lines for Flow Induced Vibration". MSFC-DWG-20M02540 provides an analytical method for determining the susceptibility of metal bellows and flexhoses to flow-induced vibrations. The second is MSFC-SPEC-626, "Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration". MSFC-SPEC-626 specifies the procedures for flow testing metal bellows and flexhoses.

1.2 Scope

This document specifies the requirements for the design and acceptability of all convoluted metal bellows and flexhoses located in both flight and Support Equipment hardware in order to prevent failure from flow-induced vibrations. Flow charts are presented in Figure 3.1-1 and Figure 3.2-1 depicting the process for acceptability.

The following exclusions from this specification shall apply:

a. Metal bellows and flexhoses with full flow liners that preclude flow-induced vibration are excluded from this specification.

b. Metal bellows and flexhoses with steady–state flow of less than one second duration are excluded from this specification.

c. Metal bellows and flexhoses which experience an operating flow environment that is different than the FIV phenomena described in MSFC-DWG-20M02540 or also beyond the capability of MSFC-DWG-20M02540 to predict are excluded from Paragraphs 3.1 and 3.2 of this specification but shall be compliant with Paragraph 3.4. This exclusion should be carefully reviewed and receive approval from the appropriate NASA organization.

The two documents, MSFC-DWG-20M02540 and MSFC-SPEC-626, shall be used in conjunction with this document.

The MSFC-DWG-20M02540 document provides the method for analyzing a design for susceptibility to flow-induced vibrations. In determining the acceptability of the design, the analytical procedures found in MSFC-DWG-20M02540 shall be considered of having two phases.

Phase I – Use MSFC-DWG-20M02540 to calculate the flow range at which FIV of the bellows or flexhose will occur.

Phase II – If Phase I predicts FIV, use MSFC-DWG-20M02540 to calculate the flow-induced stress at the critical flow velocity and use it as the FIV load input in assessing the overall fatigue life of the bellows or flexhose. In addition to loads from FIV, this overall fatigue life assessment shall take into account all other static and dynamic load sources (see paragraph 3.0 in MSFC-DWG-20M02540).

The MSFC-SPEC-626 document provides the methods and criteria for conducting resonant flow tests of bellows or flexhoses.

This document, herein, applies the following: all mandatory actions (i.e., requirements) are denoted by statements containing the term “shall.” The following terms also apply: “may” or “can” denote discretionary privilege or permission, “should” denotes a good practice and is recommended, but not required; “will” denotes expected outcome, and “are/is” denotes descriptive material.

2. APPLICABLE DOCUMENTS

The latest issues of the following documents form a part of this specification to the extent specified herein applicable unless a specific revision is specified. In the event of a conflict between the documents referenced herein and the contents of this specification, the content of this specification will take precedence.

2.1 Applicable Documents

MSFC-DWG-20M02540	Assessment of Flexible Lines for Flow Induced Vibration
MSFC-SPEC-626	Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration

2.2 Reference Documents

NSTS-08123 Revision C	Space Shuttle Certification of Flexhoses and Bellows for Flow Induced Vibration
SLS-RQMT-166 Revision A	SLSP Flexhose and Bellows Design Requirements for Flow-Induced Vibration

3. REQUIREMENTS

3.1 Flight Hardware

The following requirements shall be applicable to all flight hardware regardless of its failure criticality category. Criticality category definitions are found in Appendix A2.0. All flight bellows and flexhoses shall be designed to prevent FIV within their operating flow ranges (+/-10%) or demonstrate thru a resonant flow test that the part life is at least four times the operational life when FIV cannot be eliminated. A Phase I analysis using the MSFC-DWG-20M02540 shall be used to calculate the flow range at which coupling due to FIV occurs. The predicted flow ranges for FIV shall then be compared with the operating flow range of the hardware. When Phase I predicts that no flow-induced vibration due to coupling exists within the operating flow range expected (+/-10%), the design shall be considered acceptable in meeting the FIV requirement. When Phase I predicts coupling to occur within the operating flow range, a redesign shall be required to preclude FIV or a resonant flow test shall be required to demonstrate an acceptable life against FIV. See paragraph 3.3 for requirements to perform a resonant flow test.

For bellows and flexhoses which experience an operating flow environment that is different (atypical) than the FIV environment described in MSFC-DWG-20M02540 or also beyond the capability of MSFC-DWG-20M02540 to predict, the approach in paragraph 3.4 shall be used.

A flow chart depicting the process for acceptability of the design in meeting the FIV requirement for flight hardware is presented in Figure 3.1-1.

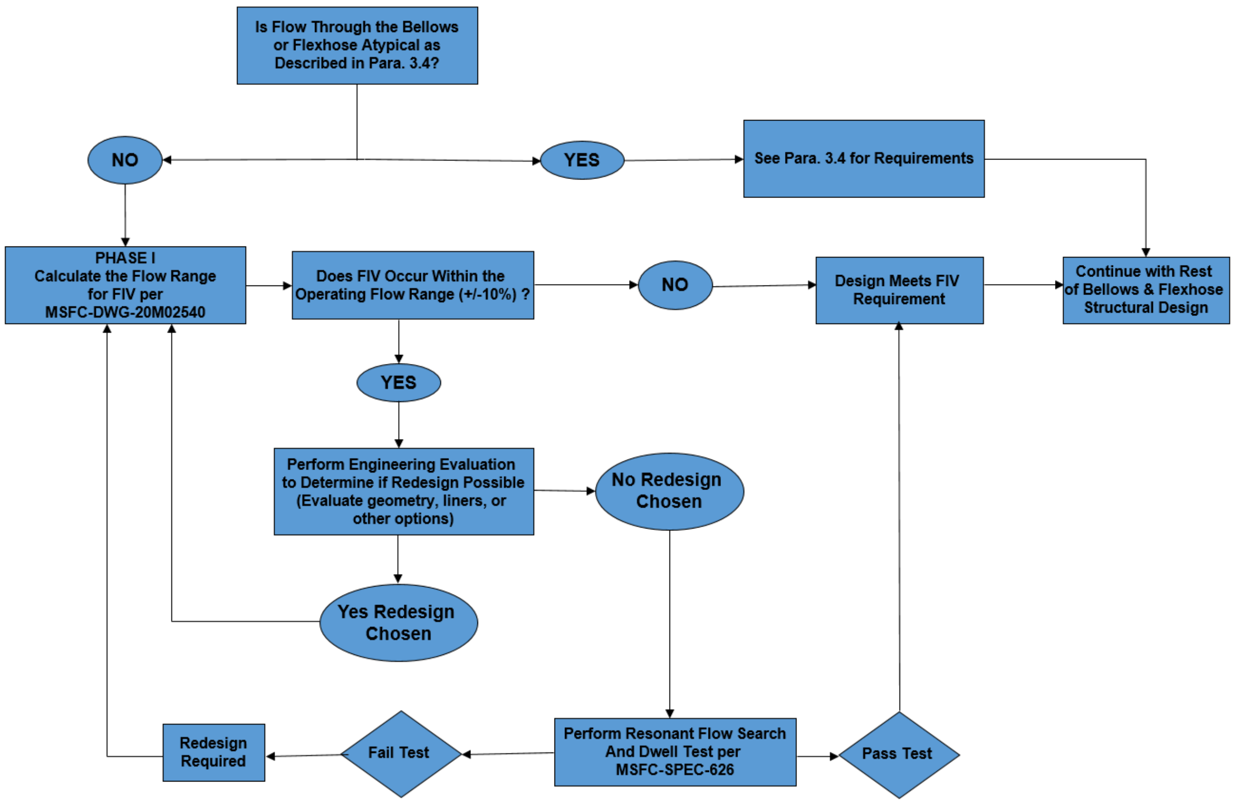

Figure 3.1-1. Flow Chart for Meeting FIV Requirement for Flight Hardware

3.2 Support Equipment Hardware

The following requirements shall be applicable to all metal bellows and flexhoses used in Support Equipment (SE) that interface with flight hardware. Support Equipment is defined herein as any facility, test, or ground support equipment (GSE) that interfaces directly with flight hardware. The requirements are broken down into four different cases below depending on whether a Failure Modes and Effects Analysis (FMEA) is performed or not and depending on the criticality category of a failure. Criticality category definitions are found in Appendix A2.0. For bellows and flexhoses which experience an operating flow environment that is different (atypical) than the FIV environment described in MSFC-DWG-20M02540 or also beyond the capability of MSFC-DWG-20M02540 to predict, the approach in paragraph 3.4 shall be used.

A flow chart depicting the process for acceptability of the design in meeting the FIV requirement for each of these four cases is presented in Figure 3.2-1.

Case 1: For all Support Equipment components where a FMEA is performed and where the worst-case potential failure mode is assessed to be Criticality 1, 1R, 2, or 2R then the requirements shall be the same as for flight system hardware (see Paragraph 3.1).

Case 2: For all Support Equipment components where a FMEA is performed and where the worst-case potential failure mode is assessed to be Criticality 3 and Phase I predicts coupling, then Phase II shall be performed to determine the overall fatigue life of the bellows or flexhose. In Phase II the MSFC-DWG-25M02540 shall be used to calculate the flow-induced stress load. In addition to the load from FIV, this overall fatigue life assessment shall take into account all other static and dynamic load sources (see paragraph 3.0 in MSFC-DWG-20M02540). If Phase II predicts an infinite fatigue life, the bellows or flexhose design shall then be considered acceptable in meeting the FIV requirement. However, the maximum operating flow velocity through the flexible line shall be limited as set forth in MSFC-DWG-20M02540. If Phase II predicts a finite fatigue life, then a redesign shall be required to achieve a predicted infinite fatigue life or a resonant flow test per Section 3.3 shall be required to demonstrate an acceptable life against FIV. See paragraph 3.3 for requirements to perform a resonant flow test.

Case 3: For all Support Equipment components where a FMEA is **not** performed and whose failure due to FIV could result in a situation that jeopardizes the safety of personnel or causes damage/degradation of flight hardware during test operations or ground processing then the requirements shall be the same as in Case 1 above. Each NASA Program Office should determine the appropriate method for assessing which metal bellows and flexhoses should be covered by this Case.

Case 4: For all Support Equipment components where a FMEA is **not** performed and whose failure due to FIV does not result in a situation that jeopardizes the safety of personnel or causes damage/degradation of flight hardware during test operations or ground processing then the requirements shall be the same as in Case 2 above. Each NASA Program Office should determine the appropriate method for assessing which metal bellows and flexhoses should be covered by this Case.

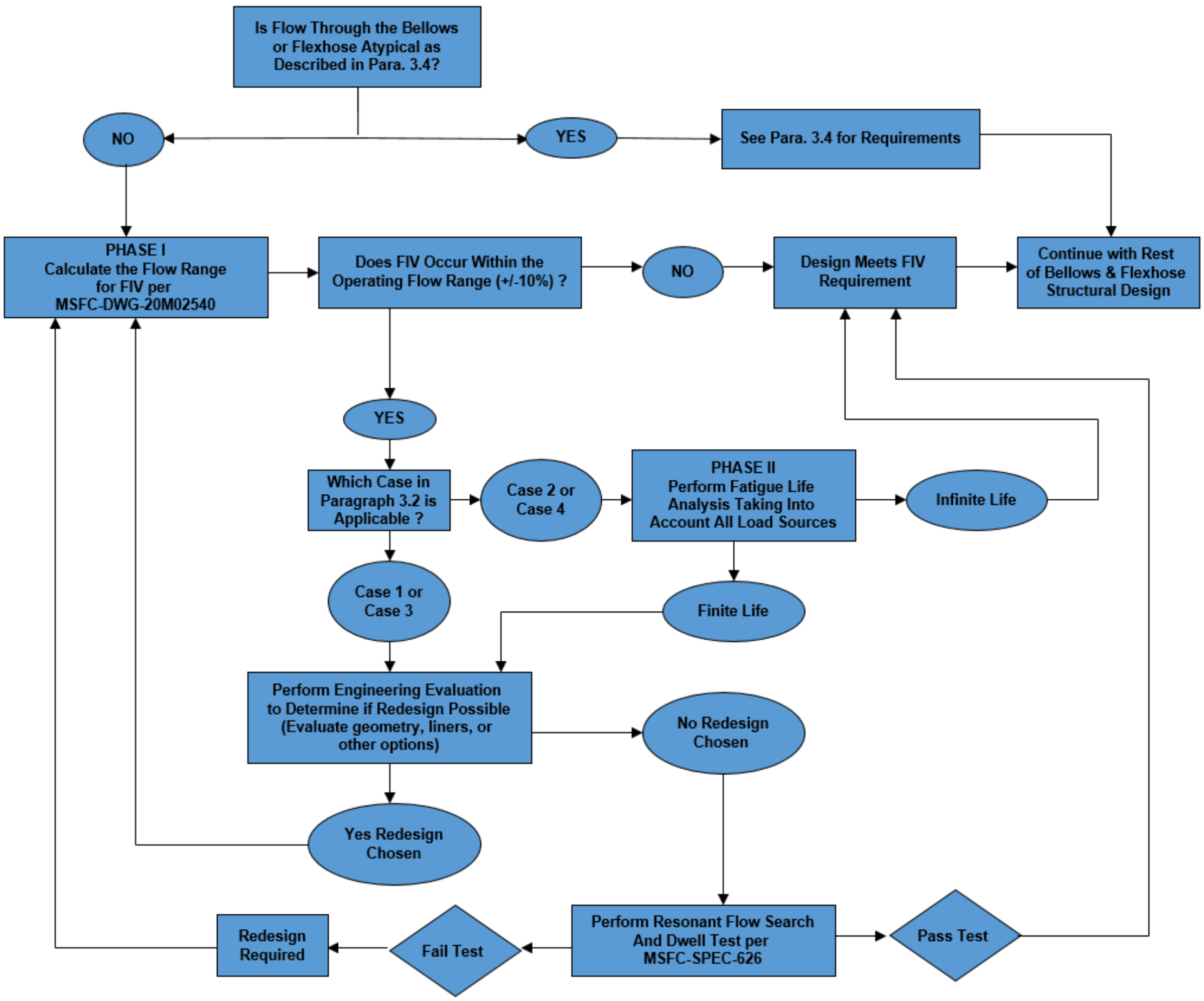

Figure 3.2-1. Flow Chart for Meeting FIV Requirement for Support Equipment Hardware

3.3 Resonant Flow Test

A resonant flow test is defined as one in which the bellows or flexhose is instrumented to measure the presence and level of FIV. Strain gages are the preferred measurement device over accelerometers as they can provide both frequency and strain measurements directly on the convolutes. If a resonant flow test is needed, then it shall be conducted in accordance with MSFC-SPEC-626. A resonant flow test consists of two parts. The first part is a resonant search test to determine if flow coupling occurs and, if so, at what flowrate and frequency. The second part is a resonant dwell test to demonstrate an acceptable life of the bellows or flexhose against FIV while flowing at the most severe resonant conditions. This resonant dwell test to demonstrate acceptable life shall consist of dwelling for four times the operational life at the most severe resonant conditions. If the bellows or flexhose survives this flow test (i.e., shows no indication of fluid leakage or detrimental damage), the design shall be considered acceptable in meeting the FIV requirement.

3.4 Bellows with Atypical Flow Environments

The analysis technique described in MSFC-DWG-20M02540 is used when the flow excitation mechanism is the vortex formation and shedding from the tips of the bellows and flexhose convolutions. This flow excitation mechanism is created when there is a grazing flow across the convolute roots. When the frequency of this vortex shedding coincides with one of the natural longitudinal resonant frequencies of the bellows or flexhose, then a strong flow-induced vibration ("lock-in") can exist. This type of flow excitation phenomena is illustrated in Figure 3.4-1. Note in the Figure, the upstream inside diameter of the bellows smooth wall guiding the main flow is close to the same inside diameter at the convolution roots for this flow excitation to occur. The MSFC-DWG-20M02540 was developed to analyze bellows and flexhoses experiencing this type of flow phenomena. An evaluation should be made in the design process for each bellows and flexhose to determine if the MSFC-DWG-20M02540 is applicable or not. For those metal bellows and flexhoses which experience an operating flow excitation environment that is different than the FIV phenomena analyzed by MSFC-DWG-20M02540 or beyond the capability of MSFC-DWG-20M02540 to predict, then an alternative analysis technique shall be used. This different flow excitation environment, herein, is called "atypical flow". Some examples that can cause atypical flow would be:

a. Strong back flow swirl from a turbopump located just downstream of a bellows that alters the flow across the convolutes.

b. Partial flowliners where several of the bellows convolutes are not protected from the flow by the partial flowliner.

c. A bellows or flexhose where the inside diameter of the convolute roots is greater than the inside diameter of the smooth wall just upstream of the convolutes (i.e. the design has convolutes recessed from the main flow field).

d. A bellows or flexhose in an angulated state due to line deflection. Some examples that can cause a bellows or flexhose to angulate are line deflections caused by thermal movement of the line assembly or by mechanical angulation of the line assembly from engine gimballing. The current analytical method in MSFC-DWG-20M02540 assumes the bellows or flexhose are in a straight configuration and not in an angulated state.

e. A bellows or flexhose configuration such as welded disc, toroidal shaped convolutes, or ring reinforced convolutes. The current analytical method in MSFC-DWG-20M02540 assumes the bellows and flexhose consist of formed annular convolutes as described in the document.

This exclusion from MSFC-DWG-20M02540 and the use of an alternative analysis technique shall be approved by the appropriate NASA organization. The alternative analysis technique and assumptions used during the design phase shall be shown to be conservative through an appropriate test program. This test program shall be approved by the appropriate NASA organization.

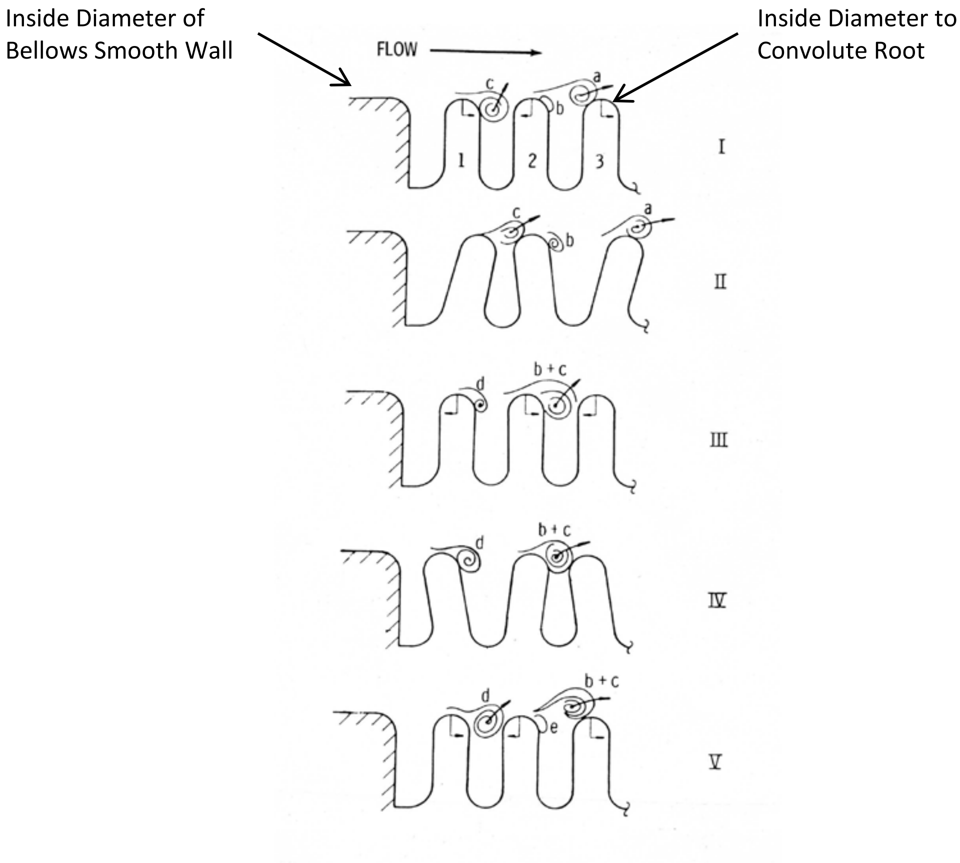

Figure 3.4-1. Sequence of Coupled Fluid-Convolution Events

4. VERIFICATION

4.1 Flight Hardware

The design of metal bellows and flexhoses to prevent flow-induced vibration shall be verified by analysis using MSFC-DWG-20M02540. The verification shall be considered successful when the analysis indicates no FIV exists within the operating flow range (+/-10%) thru the bellows and flexhose.

4.2 Support Equipment Hardware

For metal bellows and flexhoses that fall into the Case 1 and Case 3 category, the verification shall be the same as in paragraph 4.1. For metal bellows and flexhoses that fall into the Case 2 and Case 4, the verification shall be considered successful when the overall fatigue life analysis indicates a theoretical infinite fatigue life and the maximum operating flow velocity is limited as specified in paragraph 3.2.

4.3 Resonant Flow Test

If FIV is predicted by the analysis and no alternative design solutions exist to eliminate FIV, then the design shall be verified by performing a flow test. The verification shall be considered successful when the test demonstrates the part life is four times the operational life with no indication of fluid leakage or detrimental damage.

4.4 Bellows with Atypical Flow Environments

The design of metal bellows and flexhoses with atypical flow environments shall be verified by an alternative analysis and test. The alternative analysis approach shall be performed to determine if any FIV occurs within the operating flow range (+/-10%). A test shall be performed to demonstrate the alternative analysis approach is valid. The verification of the alternative analysis approach shall be considered successful when the alternative analysis is shown to be conservative by the test program.

5. PACKAGING

Not applicable.

6. NOTES

None.

APPENDIX A. ACROYNMS, ABREVIATIONS, AND GLOSSARY

A1.0 Acronyms and Abbreviations

FIV	Flow-Induced Vibration
FMEA	Failure Modes and Effects Analysis
GSE	Ground Support Equipment
NASA	National Aeronautics and Space Administration
SE	Support Equipment
SLSP	Space Launch System Program
OPR	Office of Primary Responsibility

A2.0 Glossary of Terms

Term	**Description**
Criticality 1	Single failure that could result in loss of life or vehicle, injury, or cause an emergency system to fail to detect, mitigate, or operate when needed during an emergency condition.
Criticality 2	Single failure that could result in a loss of mission.
Criticality 1R	Redundant hardware that, if all failed, could cause loss of life or vehicle, injury, or cause an emergency system to fail to detect, mitigate, or operate when needed during an emergency condition.
Criticality 2R	Redundant hardware that, if all failed, could result in a loss of mission.
Criticality 3	All other failures.
Bellows	A flexible element where convolutes have unrestricted movement when exposed to fluid flow impingement.
Flexhose	A flexible element that consists of a convoluted innercore restrained at the crowns by wire braid.
Flexible Line	A metal bellows or flexhose assembly that joins two duct sections and permits relative motion between the ducts in one or more planes.
Support Equipment	Non-flight facility, test, or ground support equipment, specifically designed and developed for a physical or direct functional interface with flight hardware during post manufacturing.
Operational Life	The time accrued when the number of missions is multiplied by the mission system operation flow time plus any ground checkout operation flow time.
Resonant Flow Test	A flow test in which the bellows or flexhose is instrumented to measure the presence and level of flow-induced vibrations. This flow test is conducted using the operating fluid or an acceptable alternative fluid.