SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP1665 REV. A

Issued 1983-03
Revised 1997-12
Reaffirmed 2007-12

Superseding ARP1665

Definition of Pressure Surge Test and Measurement Methods for Receiver Aircraft

FOREWORD

Changes in this revision are format/editorial only.

TABLE OF CONTENTS

1. SCOPE:

The test procedure applies to the refueling manifold system connecting the receiver aircraft fuel tanks to the refueling source fuel pump(s) for both ground and aerial refueling. The test procedure is intended to verify that the limit value for surge pressure specified for the receiver fuel system is not exceeded when refueling from a refueling source which meets the requirements of AS1284 (reference 2). This recommended practice is not directly applicable to surge pressure developed during operation of an aircraft fuel system, such as initiating or stopping engine fuel feed or fuel transfer within an aircraft, or the pressure surge produced when the fuel pumps are first started to fill an empty fuel manifold.

1.1 Purpose:

The need for large fuel loads requires high refueling rates for both ground and aerial refueling to minimize refueling time. Stopping the high refueling fuel velocity in a short period of time causes a pressure in the refueling system (both aircraft systems and refueling equipment) higher than the normal operating pressure. This higher pressure, called surge pressure, or water hammer, is described in reference 1, section 3.10, “Fluid Transients.” The intensity of the surge pressure is dependent upon the interaction between the aircraft refueling system and the refueling source system. This document establishes a standard procedure for testing an aircraft refueling system when combined with a refueling source (refueling truck, hose cart, hydrant system, or aerial refueling tanker) to verify that the surge pressure within the receiver aircraft does not exceed the value specified for the system.

2. REFERENCES:

1) Aerospace Fluid Components Designer’s Handbook, Revision C, Technical Documentary Report No. RPL-TDR-64-25, November 1968.

2) AS1284, Standard Test Procedure and Limit Value for Shutoff Surge Pressure of Pressure Fuel Dispensing Systems

3) Coordinating Research Council (CRC) Aviation Handbook, Fuels and Fuel Systems, NAVAIR 06-5-504, dated 1 May 1967

4) MIL-F-87154 (USAF), Fuel Systems, General Design Specification, dated 15 Aug 80.

5) MIL-F-17874B, Fuel Systems: Aircraft Installation and Test of; dated 20 Aug 65

6) MIL-T-83219 (USAF), Truck Tank A/S32R-9

7) Fuel Transient Analysis (FUELTRAN) Computer Program Technical Memorandum, ENFEF-TM-81-03, dated March 1981.

8) Aircraft Hydraulic System Transient Analysis (HYTRAN) Report MDCA3060, Revision A, dated 3 March 1975.

3. CRITICAL PARAMETERS:

3.1 Refueling Source:

1. Refueling source pump(s) characteristics (pressure versus flow) measured at the inlet of the refueling nozzle or refueling coupling.

2. Pressure or flow regulator characteristics (if applicable).

3. Surge damper characteristics (if applicable).

4. Check valve characteristics (if applicable).

3.2 Receiver Aircraft:

1. Pressure drop versus flow characteristics (including pressure drop versus flow of refueling source nozzle or coupling).

2. Shutoff or level control valve characteristics (closure time versus flow rate at beginning of closure and rate of flow area change during closure).

3. Surge damper characteristics (if applicable).

4. Pressure or flow regulator characteristics (if applicable).

5. Check valve characteristics (if applicable).

3.3 Combined System:

1. Length of combined refueling source piping and aircraft receiver system piping.

2. Pressure wave velocity through combined systems. The pressure wave velocity can be estimated by the following equations which illustrate the relationship of the system parameters and the material properties.

$$Vs = \frac{68.094}{\sqrt{W\left(\frac{1}{B} + \frac{d}{Eb}\right)}}$$

(Reference 1 Equation 3.10.3C)

Where: Vs = Velocity of pressure waves, ft/second
W = Specific weight, lb_f/ft^3
B = Bulk modulus of fluid, lb_f/in^2
d = Pipe inside diameter, inch
E = Modulus of elasticity of pipe, lb_f/in^2
b = Pipe wall thickness, inch

The value of the pressure wave velocity for a compound system consisting of several pipes of different diameters in series, wall thickness and material can be estimated as follows:

$$Vse = \frac{1_t}{\frac{1_1}{Vs_1} + \frac{1_2}{Vs_2} + \frac{1_3}{Vs_3}}$$

(Reference 3, paragraph 2.4.5.2.5)

Where: Vse = Equivalent pressure wave velocity for compound system, ft/second
1_t = Total length of pipe, ft
1_1, 1_2, 1_3 = Length of particular section, ft
Vs_1, Vs_2, Vs_3 = Pressure wave velocity of particular section, ft/second

4. SURGE PRESSURE DEFINITION:

Surge pressure is generally defined as a transient pressure rise or fall in fluid pressure, usually as a result of operation of system valves. For receiver system testing, surge pressure limit is defined as the total pressure anywhere within the receiver system consisting of the normal static fuel pressure, plus the incremental pressure rise resulting from valve closure. The parameter of interest is the total pressure in the system, and not the value for the normal and surge components of the total pressure. References 4 and 5 use the term surge pressure or maximum surge pressure for the limit of total pressure which occurs when fuel flow is stopped or reduced within the system.

5. INSTRUMENTATION:

Quantity and Location

Sufficient pressure measurement points should be provided in the system to characterize the surge pressure wave in the system. A pressure measurement should be made just downstream of the pump(s) and at a point approximately midway between the flow cutoff instrumentation point(s) and the pump(s) instrumentation point(s). Additional pressure measurements should be added at any position considered critical for the system. A pressure measurement should be made at the dead end of any side branch of the main flow line.

Multiple pressure measurement points allow the pressure wave to be identified and the wave speed to be verified as well as providing backup capability in case of pressure transducer failure.

A pressure versus time trace obtained from a measurement point just upstream of a flow cutoff valve will exhibit fewer pressure increase/decrease cycles during the valve closure than a trace taken from an instrumentation point closer to the pumps. Slow closing shutoff valves may produce only one major pressure increase/decrease cycle during the valve closure. Pressure measurements taken upstream of the shutoff valve should exhibit the period of the pressure wave and produce several pressure increase/decrease cycles during the valve closure.

Strain gages may be desired for installation on the fuel tube near the shutoff valve or other critical areas in the system. This instrumentation would provide a backup if other transducers in the system are lost or are overcome by noise, interference or air bubbles.

5. (Continued):

Response

The instrumentation should have sufficient response to measure the pressure pulse resulting from rapid valve closure. A rapid valve closure is when closure time T is equal to or less than 2L/Vs (Reference 1)

Where L = pipe length from shutoff valve to refueling source pump
Vs = effective pressure wave velocity

A pressure transducer of the strain gage type with a response in the order of 1 to 10 milliseconds is recommended with the pressure recorded in a continuous trace using a galvanometer light beam type oscillograph with a response time compatible with the pressure transducer. This type equipment is specified by references 4 and 6. A minimum paper speed of 1 inch per second should be used to provide a good display of the pressure trace.

Transducer Location, Accuracy and Range

Pressure transducer entrance points should be located to minimize the effects of air in the system and cavitation bubbles or eddying turbulence. A pick-up point on the side of the line is recommended. In pick-up point selection, consider the effects of close proximity to sharp bends or a line expansion or reduction. Verify, by static pressure calibration that the error of the transducer and recorder measured at 120 psig (830 kPa) is not greater than ±1%. The range of the pressure transducer/recorder should be suitable for the ultimate pressure rating of the system.

6. PRETEST CALIBRATION:

Each refueling source to be used in testing a receiver system should be pretested in accordance with AS1284 (reference 2). This standard requires the use of a test system incorporating a test shutoff valve which closes "within 0.5 seconds in a near linear manner." AS1284 does not define "near linear manner," however, it is generally interpreted to mean a linear change of flow area with respect to time. A tolerance or allowable deviation from linear is not specified.

The flow area reduction characteristics of the test shutoff valve during the 0.5 second interval is critical. The flow area (or poppet/gate position) versus time of the test shutoff valve should be measured during the pretest for all flow rates expected during the test to determine the extent of deviation from the specified near linear closure.

With an actual refueling source or an accurate simulation of the refueling source(s) and a detailed characterization of the test shutoff valve, the worst case refueling source need not be fabricated and tested, however, this case can be evaluated analytically for effect on the receiver system. A transient analysis technique using a digital simulation process has been developed which treats the fluid lines with distributed parameters, applying the concepts of wave mechanics and including the effects of nonlinear friction. The fluid line equations are solved with the help of the method of characteristics. A Fuel Transient Analysis (FUELTRAN) computer program (reference 7) has been developed by the Air Force using as a basis the Hydraulic Transient Analysis Program (HYTRAN) (reference 8).

6. (Continued):

Using this approach to obtain a computer simulation match of the actual test condition, the computer simulation of the refueling source can be modified to evaluate the effects of the worst case refueling source.

Prior to conducting the surge test, the following stead state data should be measured on the test hardware:

a. Pressure versus flow of the refueling source measured at the inlet to the refueling nozzle or refueling coupling.

b. Pressure drop versus flow for the receiver system, including the pressure drop of the refueling nozzle or refueling coupling. Data should be measured for each receiver fuel tank open singularly and all likely tank open combinations.

c. Flow area versus time during closure for each flow control valve in the receiver system (both fuel level control valves and system isolation valves) for flow/pressure ranges to be encountered in service. The pressure distribution across the poppet of a fuel level control valve is critical in relation to the valve closure time, therefore, the test hardware preceding the valve inlet should duplicate the aircraft installation.

For fuel level control valves which have a surge relief feature, the cracking pressure and main poppet response time should be determined.

7. TEST PROCEDURE:

Conduct pressure surge tests by establishing maximum stabilized fuel flow for the specified tank open condition for a minimum of 10 seconds and then stopping the fuel flow by closing the shutoff valve. Each mode of closing the valves (primary and secondary solenoid, precheck activation, etc.) should be tested to determine the most critical (fastest) closure mode. Tests should be repeated until repeatable data are obtained for the test condition. Maximum fuel flow is obtained by applying rated refueling operating pressure, normally 55 psig (380 kPa), to the inlet of the refueling connection. Actual refueling source hardware may not have sufficient flow capacity to maintain rated refueling operating pressure at the inlet to the refueling connection, especially for high capacity, low pressure drop receiver systems. Surge test results from an insufficient capacity refueling source cannot be extrapolated to verify surge compatibility for higher capacity refueling sources.

Measure surge pressure under the following conditions:

a. Each tank refueling individually - Close level control valve

b. All tanks refueling simultaneously - Close system isolation valve