Flight Qualification of Omnisafe Anti-Torque, Multi Mate/Demate Fitting

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A new multi mate/demate metal face seal fitting has recently been flight qualified at JPL. The Omnisafe fitting incorporates a torque elimination feature that prevents misalignment of components and damage to the sealing surfaces. This fitting which has been used for ten years in the semiconductor industry and at Lawrence Livermore National Laboratories, has successfully maintained leak integrity after flight qualification testing. Following ten mate/demate cycles, this qualification included exposure to shock & vibration, thermal cycling, and pressure cycling that simulate flight conditions. Fluid delivery applications in xenon gas propulsion and liquid Freon cooling service have been proposed for this fitting. This robust, reusable fitting enables flight subsystems to be built and tested independently and in parallel. Fittings also facilitate late integration of fluid system components, unlike most welded systems. This reusable coupler can be used to modularize flight systems and reduce integration costs.

I. Introduction

The Omnisafe metal face seal fitting has been primarily used in semiconductor manufacturing over the last 10 years. The fitting is used as a connector in the gas systems that deliver UHP, often hazardous, process gases to the chambers where chips are produced. The Omnisafe torque elimination fitting "crossed over" to the aerospace industry after previous less rigorous shock/vibration[1] and particle testing[2] indicated flight qualification was probable.

The DAWN program required fittings on its Ion Propulsion System in order to integrate the NSTAR ion engines after the start of spacecraft integration and test. These fittings are used on lines that deliver regulated xenon gas from the Xenon Feed System (XFS) to the engines. In the engines, Xenon gas is ionized by electrons emitted from a cathode and then accelerated electrostatically through a pair of grids, resulting in a very large exit velocity and high specific impulse. The Xenon is supplied at very low pressure, less than 40 Torr. Also, in this application, the fitting could not be leak tested after the final mate on the spacecraft, so flawless assembly and test during the qualification test were required. Successful flight qualification of the Omnisafe fitting provides program engineers the data needed to show performance for this application which exceeds mission requirements and is an improvement on legacy metal face seal fittings.

II. Dawn Mission Overview

- May 27, 2006:
  Launch from Cape Canaveral on a Delta 7925H rocket

- July 30, 2010 - July 3, 2011:
  Rendezvous with Vesta (nine month study)
  Orbit at 420 and 80 miles

- July 3, 2011 - August 20, 2014:
  Cruise to Ceres

- August 20, 2014 - July 26, 2015:
  Rendezvous with Ceres (nine-month study)
  Orbit at 530 and 80 miles

- July 26, 2015:
  Observation of Ceres concludes
  Possible continuing exploration in the asteroid belt

III. Aerospace Applications

Two features of the Omnisafe fitting make it more reliable than legacy connectors for aerospace applications.

A. Deformable, sacrificial gasket – sealing surfaces called torroids on each of the glands being joined are embedded into opposite sides of a deformable gasket. This creates a seal that is much less sensitive to surface defects and particles than the legacy connector used on the DS-1 program. The legacy connector seal is made via elastic deformation of two sealing faces against each other without a gasket. Damage to either sealing surface requires its reconditioning or replacement. The Omnisafe fitting is relatively forgiving of defects/damage on the surface of the glands because of the amount of penetration, plastic deformation, into the Nickel gasket that is achieved with 45-90 degrees of nut rotation past 'finger tight'.

B. Torque eliminators – these two identical components are positioned between the male/female nuts and their glands on the Omnisafe fitting. As the fitting is brought to finger tight the tongs of the torque eliminators engage before the seal is formed. The engaged pair of torque eliminators prevent differential rotation of the sealing surfaces during seal formation.

As the torroids of the glands are pushed straight into the gasket, with no torque from the male and female nuts while tightening, they form smooth repeatable seals without galling or degradation of the sealing surfaces[3]. The softer nickel gasket material exhibits plastic deformation as it conforms to the shape of the two torroids as they are pushed together. The torroidal shape compresses elastically during seal formation so that seal integrity is maintained during thermal cycling and shock/vibration of the flight qual.

Without torque elimination, legacy male and female nuts, as they are tightened, transfer opposing torque and rotation into the tubing connecting the components. As the sealing surfaces move across each other during compression galling occurs and is a source of particles. The torque installed into the system during this rotation may lead to loosening during thermal cycling and shock/vibration.

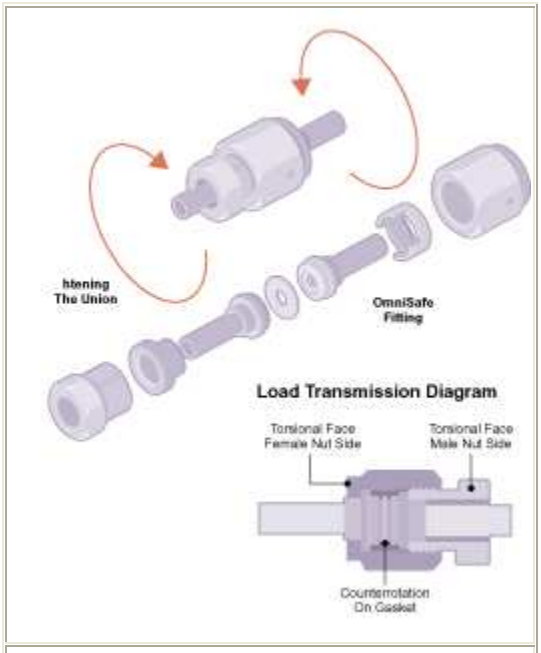

Figure 1. *:* The engaged torque-eliminator collars in the OmniSafe fitting prevent twisting of the sealing glands and metal gasket when the male and female nuts are tightened together. This prevents galling and particle generation from the sealing surfaces.

IV. Tribological evaluation

Female nut plating – To minimize the amount of particulate generated during assembly, the silver plating was removed from the threads of the female nuts for the flight configuration. Since the silver plating acts as a lubricant and prevents thread damage during assembly, the unplated thread has a reduced number of mate/demate cycles. Consequently, the following changes were implemented:

1) Requirement for mate/demate cycles was relaxed from 20 to 10 cycles
2) Requirement for degree of nut rotation past finger tight was relaxed from 90 deg minimum to 45 deg minimum (90 deg max)
3) The thread on the male nut would be rolled rather than cut, resulting in a cleaner, harder thread.
4) Both male and female nuts would be electro-polished prior to delivery.

V. The DAWN configuration

The fittings with 316 Male nuts using rolled thread, 316 Female nuts using standard thread, and electro-polishing were found to have the lowest and most consistent torque values, acceptable sealing performance, and acceptable particulate generation. This configuration was further modified with the addition of holes for lock wire installation and selected for flight qualification testing on the DAWN spacecraft.

VI. Cleaning, assembly procedures
Protection of sealing areas

During the first test cycle it was found that some glands and gaskets had an unacceptable amount of damage on the sealing surfaces. After review of the handling of the parts, much of this damage is thought to have come from a combination of the original batch precision cleaning procedure and a flaw in the assembly procedure that resulted in a blind assembly and potential damage to the gasket. The cleaning procedure has since been revised to exclude gaskets from precision cleaning since they are delivered clean from the manufacturer and to clean each gland individually. A thorough screening of all parts was then conducted and inspection is now performed on all gaskets prior to assembly. The assembly procedure has been revised to control contact between sealing surfaces and other parts. In summary, the key elements to the final procedure for handling and testing DAWN Omnisafe fittings are as follows:

1) Screen parts for defects before processing/testing.
2) Clean glands individually using Teflon tools and baskets to prevent damage to sealing surfaces.
3) Assemble fitting so that gasket cannot be damaged during assembly.

Figure 2. 1/8 inch Fitting Assembly: Setup showing gland separation distance.

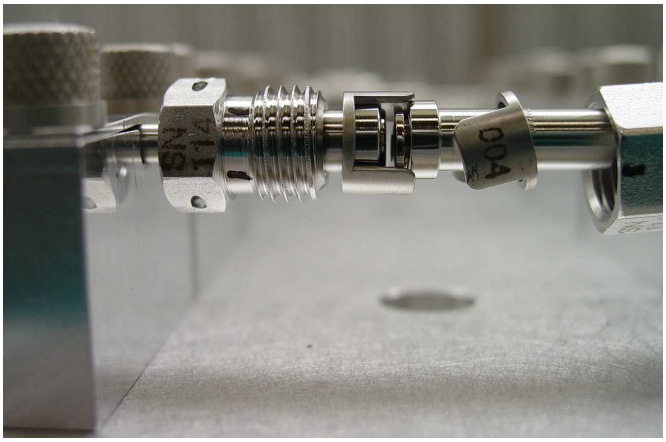

Figure 3. 1/8 inch Fitting assembly: Gasket installed and captured by Torque Eliminator.

VII. Performance metrics

Table 1. Omnisafe Test Requirements for DAWN

Parameter	Test Requirements
Proof Test	300 psig
External Leakage	<1 x 1.0 E-5 sccs GHe
Mating/Demate Cycles	10 minimum
Qual Random Vibration	Per JPL D-25841, Rev.A
	50-500 Hz… 0.2 g^2/Hz
	Overall: 13 grms
	Duration: 120 sec/axis
Pyroshock Test	Per JPL D-25841, Rev.A
	100 Hz……..…10 g's
	1000Hz-10000Hz…….1000 g's
	2 shocks per axis
Thermal Cycling	Per JPL D-25841, Rev.A
	-115 C to +145 C 3 cycles
Burst Test	>2200 psig
Cleanliness	JPL Cleaning Specification FS504574, Level D2 prior to assembly.
Assembly Procedure Repeatability	No leaks allowed on any assembly.

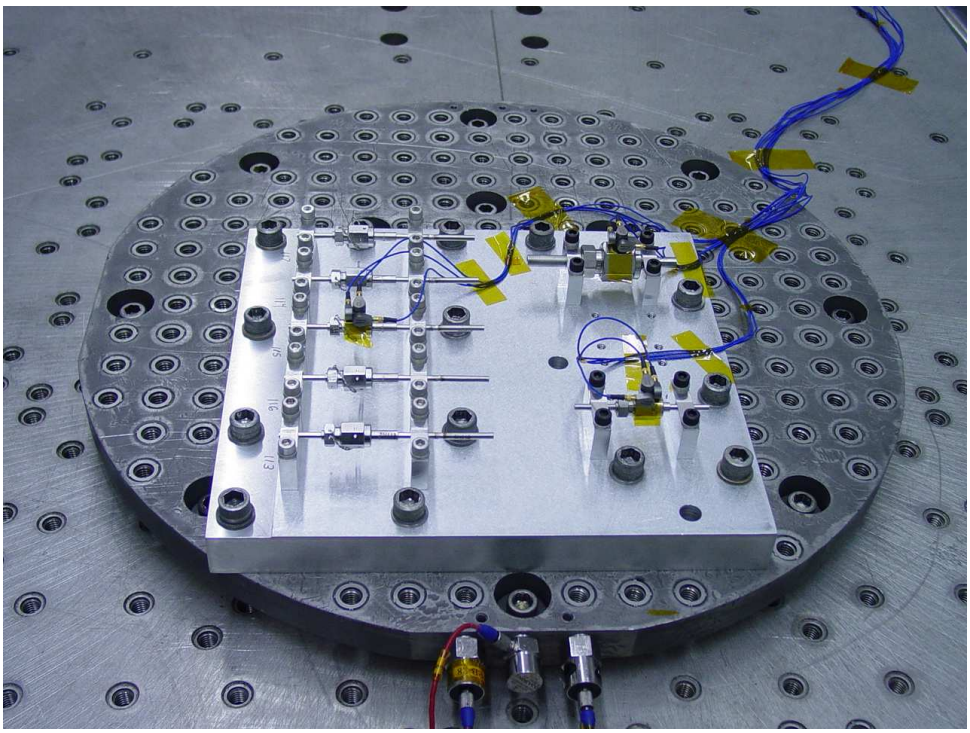

Figure 4. DAWN Omnisafe Fitting Random Vibration and Pyroshock Test.

VIII. Mars Science Laboratory

The Omnisafe fitting has successfully completed the first phase of qualification for the Mars Science Laboratory (MSL) Heat Rejection System.

Details of the application – This system utilizes 3/8" flex lines connected by Omnisafe 1/4" high flow fittings. This testing will compare both stainless steel and nickel gaskets for selection in the final configuration. The system contains liquid Freon CFC-11 at 200 psia and 100C for a minimum of three years. The test requirement is that the fluid hardware will never see leakage greater that 1X10-7 sccs GHe

Table 2. Omnisafe Test Requirements Mars Science Laboratory (passed during the 1st phase of testing)

Parameter	Test Requirements
Qual Random Vibration	
	20 Hz…….. 0.024 g^2/Hz
	20-50 Hz……... +3 dB/oct
	50-500 Hz…….. 0.06 g^2/Hz
	500-2000 Hz……..… -3 dB/oct
	2000 Hz……. 0.015 g^2/Hz
	Overall:……. 8.4 grms
	Duration:……..120 sec/axis
Pyroshock Test	
	100 Hz……..…20 g's
	1600 Hz……..…2000 g's
	2500 Hz…….2000 g's
	2 pulses @ 0 dB

IX. Mass Customization

The goal of the mass customization (MC) manufacturing model is the production of high quality highly customized systems at mass production costs and speed. Business drivers in the aerospace industry that point to MC methodologies for flight systems include high degrees of customization of these systems necessitated by unique mission parameters. One of the solutions to managing the resulting complex variety of systems is the product platform which is often defined by means of the product architecture[5]. The product platform has been defined as a set of subsystems and interfaces that form a common structure from which a stream of related products can be developed and produced efficiently. Baldwin and Clark[4] define three aspects of the underlying logic of a product platform:

(1) Its modular architecture;
(2) The interfaces (the scheme by which the modules interact);
(3) The standards (the design rules to which the modules conform).

Standardization and flexibility of products and processes are an important parts of any mass customization initiative. This is achieved primarily through modularization of products, processes, and the supply chain.

Modularization of flight hardware allows parallel build and test of subassemblies decreasing total assembly time and potentially reducing cost. Modularizing the supply chain enables the system integrator to outsource subsystems that are not part of their core business. Modularization is practical only through standardization of component physical interfaces. The Omnisafe metal face seal fitting provides a potential solution for a secure, reusable interface between fluid handling components in flight systems.

X. Conclusion

The Omnisafe metal face seal fitting has been flight qualified for a low pressure Xenon application on the Dawn spacecraft and has successfully completed the first phase testing for a higher pressure application with Freon on MSL. The Omnisafe fitting is a potential flight qualified alternative for joining fluid systems for spaceflight. Its strengths include an anti-torque feature that minimizes cycle life damage to the sealing surfaces, and its tolerance of surface defects through the use of a deformable and sacrificial Nickel gasket.

Acknowledgments

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