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Investigative Report

High Pressure Quick Disconnect Particle Impact Tests

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High Pressure Quick Disconnect Particle Impact Tests

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National Aeronautics and Space Administration
Johnson Space Center
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Laboratories Office

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Abstract

To determine whether there is a particle impact ignition hazard in the quick disconnects (QDs) in the Environmental Control and Life Support System (ECLSS) on the International Space Station (ISS), NASA Johnson Space Center requested White Sands Test Facility (WSTF) to perform particle impact testing. Testing was performed from November 2006 through May 2007 and included standard supersonic and subsonic particle impact tests on 15-5 PH stainless steel, as well as tests performed on a QD simulator.

This report summarizes the particle impact tests completed at WSTF. Although there was an ignition in Test Series 4, it was determined the ignition was caused by the presence of a machining imperfection. The sum of all the test results indicates that there is no particle impact ignition hazard in the ISS ECLSS QDs.

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Abbreviations

ABO	Aviator's Breathing Oxygen
ECLSS	Environmental Control and Life Support System
HP	High Pressure
ISS	International Space Station
JSC	Johnson Space Center
QD	Quick Disconnect
ROOBA	Recharge Oxygen Orifice Bypass Assembly
SS	Stainless Steel
WSTF	White Sands Test Facility

1.0 Introduction

Gas velocities inside the Parker^{®1} 683-15179 quick disconnects (QDs) in the Environmental Control and Life Support System (ECLSS) on the International Space Station (ISS) are great enough to raise concerns about a possible particle impact ignition hazard. These high velocities will occur any time the QDs are mated under pressure, when the airlock tanks are used to repressurize the system, and when the recharge oxygen orifice bypass assembly (ROOBA) is used to bypass the 16 lbm orifice during pressurization of the airlock tanks. As a result of concerns that the high gas velocities could cause ignition due to particle impact in the quick disconnects, Rajib Dasgupta/ES4 at Johnson Space Center (JSC) requested White Sands Test Facility (WSTF) perform particle impact testing to determine whether there is a particle impact ignition hazard in the QDs.

Testing was performed from November 2006 through May 2007 and included standard supersonic and subsonic particle impact tests on 15-5 PH stainless steel (SS), as well as tests performed on a QD simulator. The particulate mixture used was consistent with the system materials of construction. This report summarizes the testing completed at WSTF.

2.0 Objective

The objective was to determine if particle impact samples and a QD simulator composed of 15-5 PH SS would ignite and burn when impacted by particulate, and to determine the effect of the impact at the given temperatures, pressures, and flow rate.

3.0 Test Methods

The selection of test materials, the test series, and the test procedures are described in the following sections.

3.1 Materials

The following paragraphs discuss the particulate mixtures, the test target and QD Simulator materials, and sample preparation.

3.1.1 Particulate Mixtures

Two particulate mixtures were used, as described in Table 1 and shown in Figures 1 and 2. The materials that made up the particulate mixtures (stainless steels, Inconel^{®2} alloys, and Monel^{®2} alloys) are materials that are native to the ISS ECLSS. The ISS ECLSS was initially cleaned to Level 200 for particulate, which dictates no particles greater than 200 µm in size and a maximum allowed distribution for particles smaller than 200 µm. There could be small amounts of assembly and operationally generated particulates in the system.

¹ Parker[®] is a registered trademark of Parker-Hannifin Corporation, Cleveland, Ohio.

² Inconel[®] and Monel[®] are registered trademarks of Inco Alloys International, Inc., Huntington, West Virginia

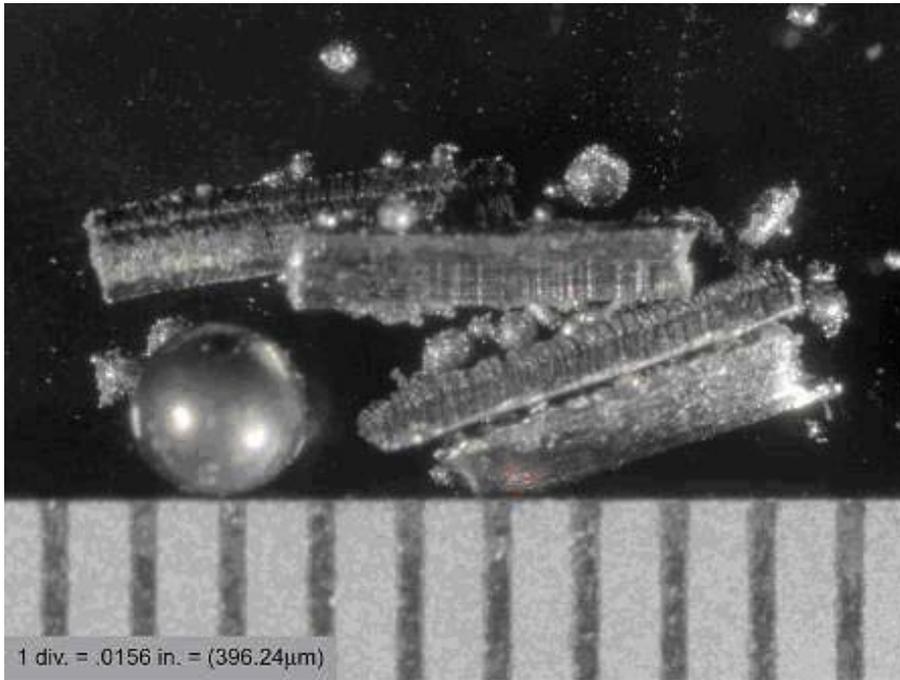
Table 1
Particulate Mixtures Used for Testing

Particulate Mixture	Material	Size and Configuration	Amount
A	Annealed 304 SS	794 μm sphere	QTY-1
	Inconel 718 ^{®a}	-100 mesh ^b powder	3 mg
	304 SS	-20 mesh ^b powder	3 mg
	Inconel 718	250 X 250 X 2000 μm sliver ^c	QTY-4
B	Inconel 718	-100 mesh ^b powder	3 mg
	304 SS	-20 mesh ^b powder	3 mg
	Monel ^{®a}	250 X 250 X 2000 μm sliver ^c	QTY-4

^a Inconel[®] and Monel[®] are registered trademarks of Inco Alloys International, Inc., Huntington, West Virginia.

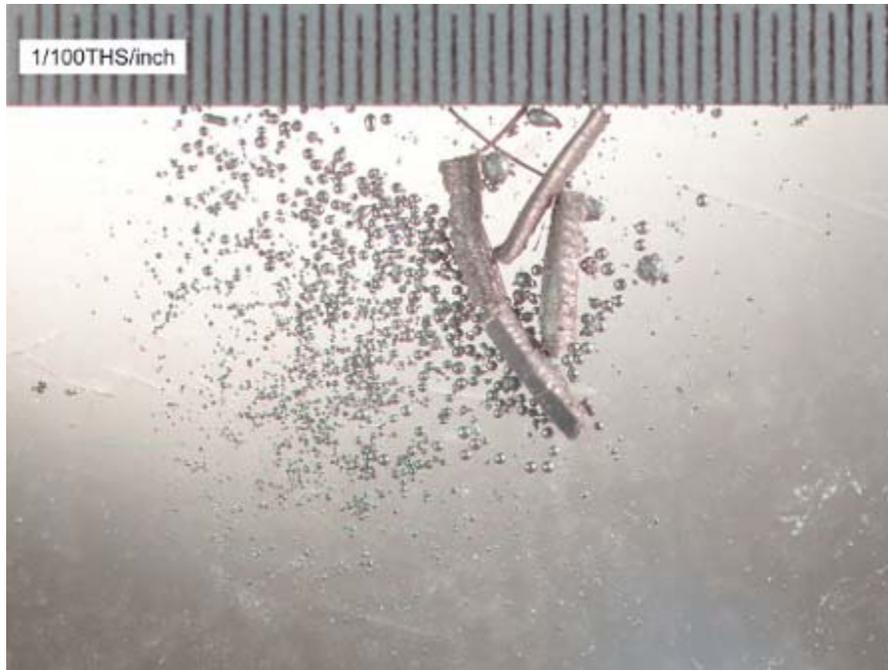
^b Powders used are commercial products. 100 mesh corresponds to sieve openings of 149 μm . 20 mesh corresponds to sieve openings of 841 μm . The "-" before the sieve mesh size indicates that the particles pass through the sieve. Typically, 90 percent or more of the particles will lie within the indicated range.

^c Slivers were manufactured in the WSTF machine shop.



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Figure 1
Particulate Mixture A



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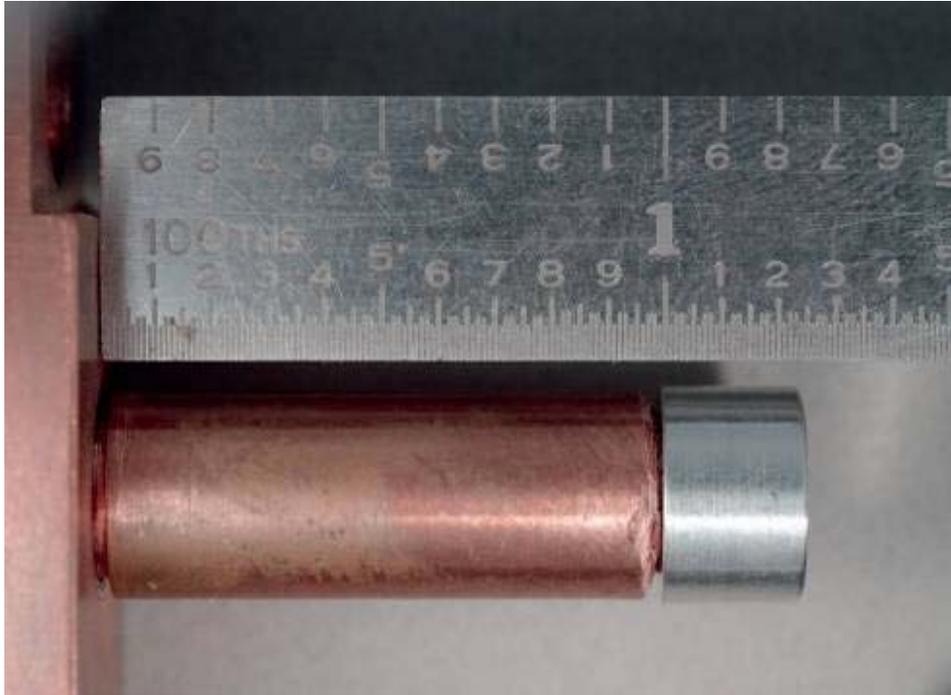
Figure 2
Particulate Mixture B

In previous particle impact tests on the Space Shuttle flow control valve, calculations were performed to determine the amounts of particulate allowed in the propulsion system, external tank, and main engine, based on the surface areas in those systems. The calculated amount of allowed particulate was then multiplied by a safety factor, and the resulting amount used for testing was 10 mg. Similar calculations have not been performed for the ISS ECLSS system; however, the surface area of the ECLSS system would be much smaller than the Shuttle propulsion system, external tank, and main engine. Given this history, the materials and quantities of particulates used in both Mixture A and Mixture B are considered to be extremely conservative, since the amount of particles is in the same order as those used for the flow control valve tests. In addition, the size range of the particles encompasses those that would be allowed in the system by the cleanliness level, as well as larger particles.

3.1.2 Test Target and Quick-Disconnect Simulator Materials

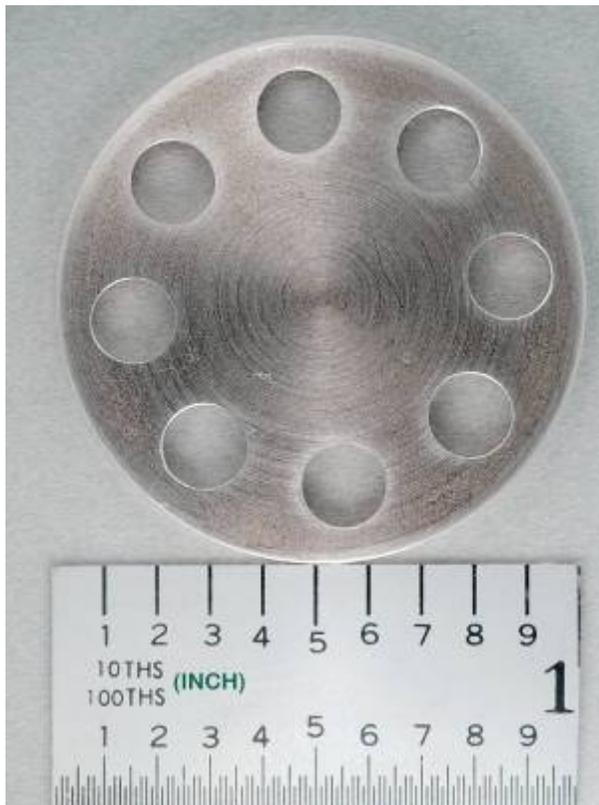
The standard supersonic and subsonic configurations used 15-5 PH SS targets, corresponding to the material used at the impingement points inside the ISS ECLSS QDs. For the supersonic tests, these targets were configured in a cup shape with an outside diameter (0.375 in.) that allowed flow over and around the 0.060-in.-thick target surface. Each supersonic target sample was press-fit onto a copper sample holder, as shown in Figure 3. The standard subsonic configuration targets were 0.060-in.-thick flat discs with holes drilled radially to allow flow over and through the target, as shown in Figure 4.

The QD simulator tests were performed using parts, machined at WSTF, composed of 15-5 PH SS. The design of the QD simulator parts replicated the relevant parts inside the flight QDs and was based on information supplied by Parker, the manufacturer of the flight QDs. Figure 5 shows a cross section of the QD simulator used for testing.



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Figure 3
Standard Supersonic Target Configuration



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Figure 4
Standard Subsonic Flat Target Configuration

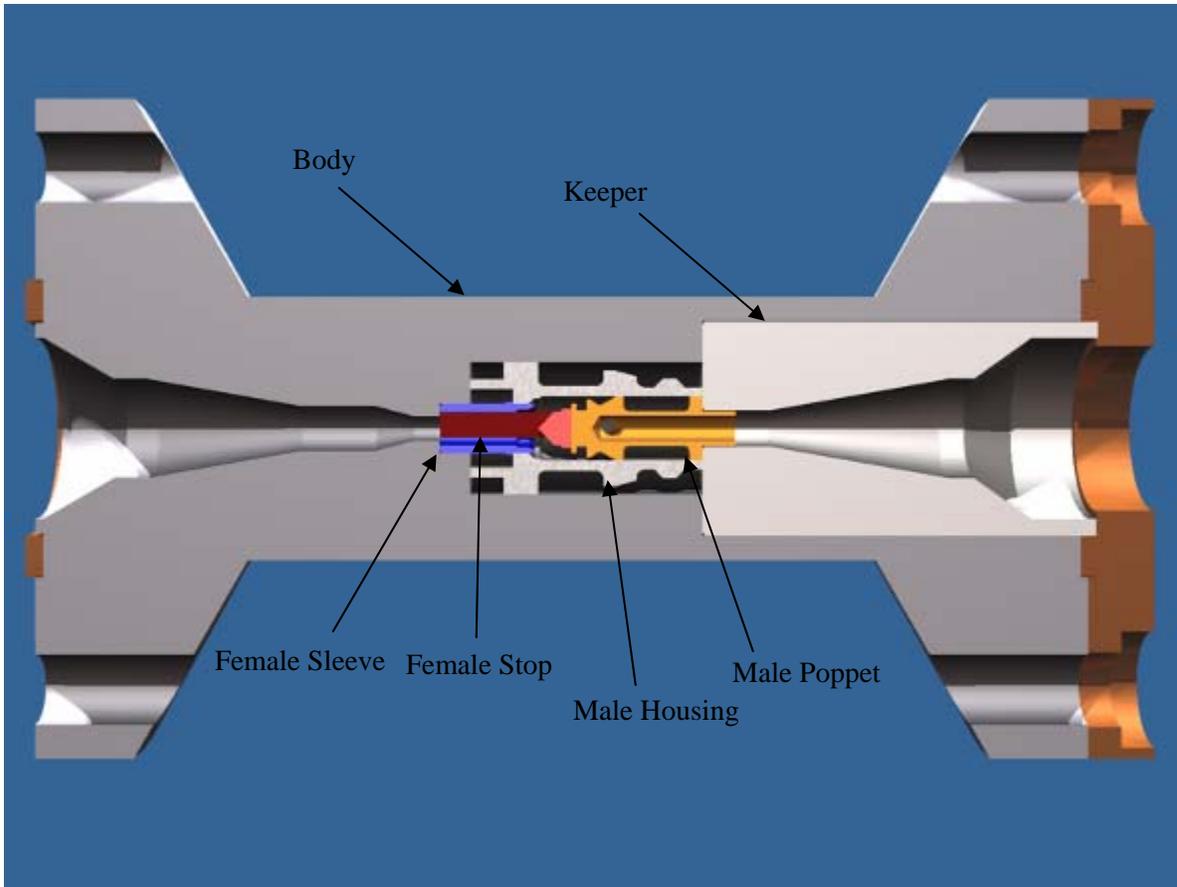


Figure 5
Cross Section of QD Simulator

3.1.3 Sample Preparation

Before testing, all samples were prepared at WSTF according to WJI-250-0007¹, which includes washing in a mild detergent. The samples were then sealed in polypropylene bags until testing. From this point, the targets and simulator parts were handled with clean latex gloves to maintain cleanliness.

3.2 Test Series and Procedures

All tests were performed in the WSTF 250 Area. During particle impact testing, the parameters of concern are temperature, pressure, particle composition, target, and configuration. The maximum pressure in the ISS ECLSS QDs is 3000 psi, and the maximum temperature is 115 °F. The test temperature for all tests was 115 °F. Six test series were performed, as described in Table 2.

For Test Series 1 and 2, the supersonic nozzle was installed on the outlet of the subsonic injector assembly. The particulate was loaded into the injector, and the injector cap was then threaded onto the housing. The target sample and copper posts were then positioned at the end of the nozzle (Figure 6). An untested sample was used for each test.

¹ In-house document. WJI-250-0007. *250 Area Supersonic/Subsonic Particle Impact Testing*. February 17, 2006.

Table 2
Particle Impact Test Series

Test Series	Test System Configuration	Particulate Mixture ^a	Test Pressure (psig)
1	Subsonic Injector with Supersonic Nozzle	A	1050
2	Subsonic Injector with Supersonic Nozzle	A	1700
3	Subsonic Injector with Subsonic Nozzle	A	3000
4	QD Simulator	A	3000
5	QD Simulator	B	2500
6	QD Simulator	A	3000

^a Particulate mixtures are described in Table 1 of this report.

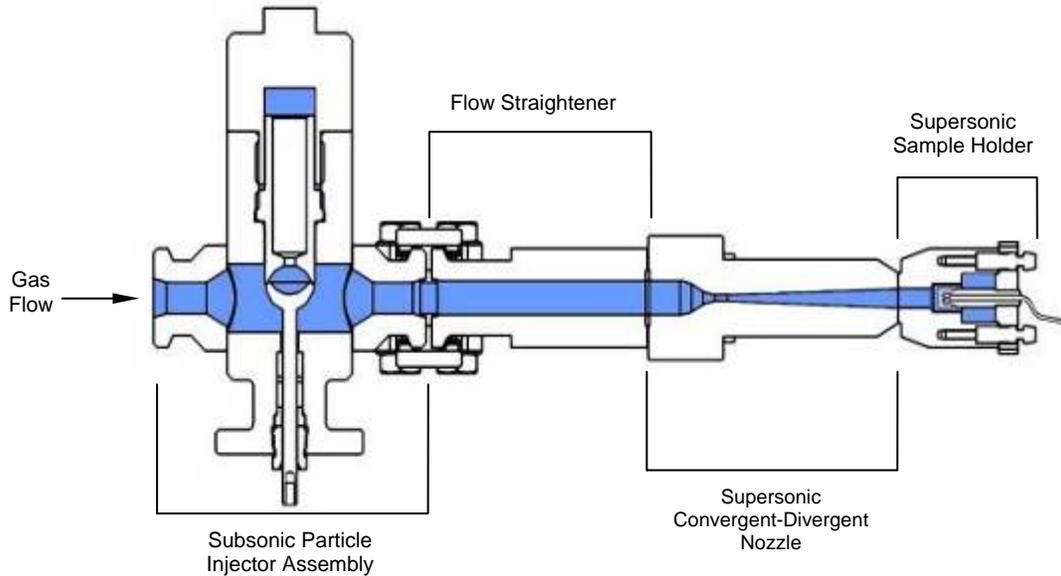


Figure 6
Subsonic Injector with Supersonic Nozzle Used for Test Series 1 and 2

For Test Series 3, the subsonic injector and nozzle were used. The particulate was loaded into the injector, and the injector cap was then threaded onto the housing. The target sample and orifice (for controlling the gas velocity) were then positioned on the end of the subsonic nozzle (Figure 7). An untested sample was used for each test.

For Test Series 4, 5, and 6, the QD simulator was installed on the outlet of the flow straightener and subsonic particle injector assembly (Figure 8). The particulate was loaded into the injector, and the injector cap was then threaded onto the housing. The same QD simulator was used for all tests.

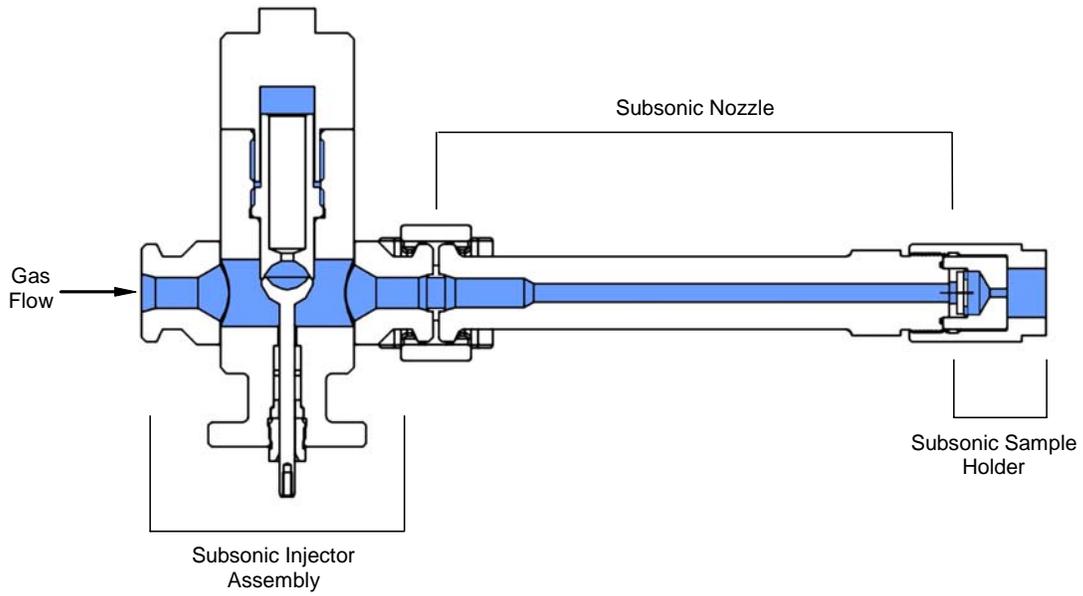


Figure 7
Subsonic Injector and Nozzle Used for Test Series 3

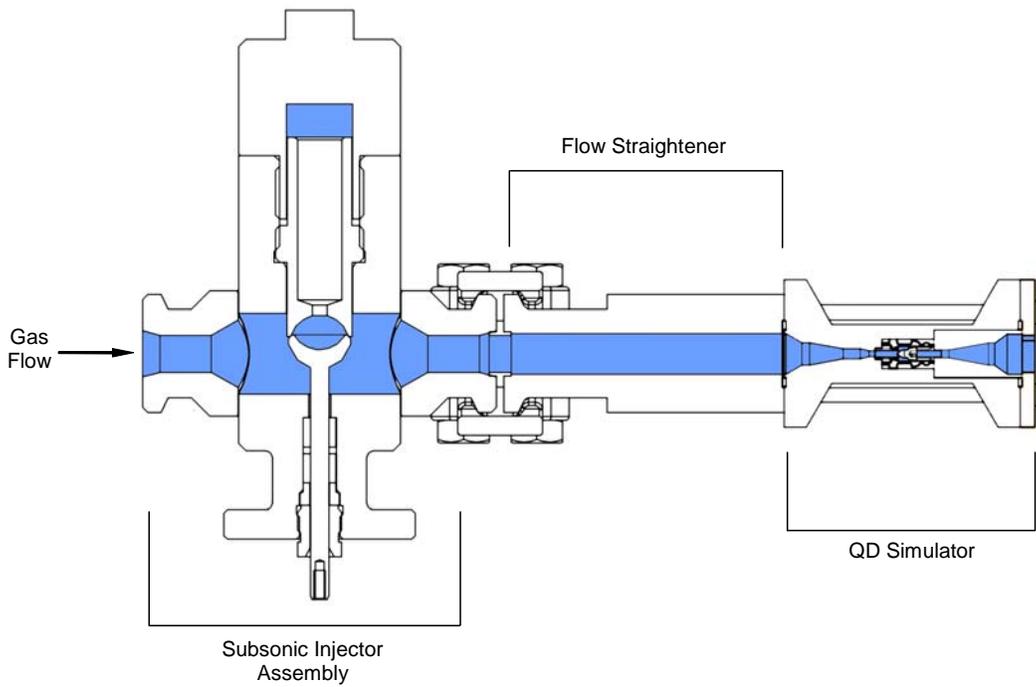


Figure 8
QD Simulator Test System Used for Test Series 4, 5, and 6

For all test series, after system preparation was completed the test area was cleared of personnel and placed in “red” status. A video camera was positioned to record any reaction visible at the end of the test fixture. Test conditions were entered into the test computer, and the computer established the conditions in the test facility. Heated gaseous aviator’s breathing oxygen (ABO) at test pressure was allowed to flow until the temperature of the target sample was achieved and the gas flow stabilized. Upon command, the test computer activated the particle injection system and the particulate was injected into the chamber. After evidence of impact, the oxygen flow was terminated and the test system was allowed to vent down to ambient pressure (which was ~ 4 s after particle injection). During Test Series 1, 2, and 3, each target sample was visually inspected after each test to verify that particle impacts had occurred. Each sample was then individually bagged in its original bag and labeled with test information. The test computer saved the test and system data. The test pressure, test temperature, and average flow meter reading were recorded in the 250-Area test log book. Videotapes of the test were recorded and stored. At the completion of test data storage and sample inspection, the procedure was repeated.

4.0 Results and Discussion

The effect of impact on the test sample at the given temperatures, pressures, and flow rate was determined visually and characterized as follows in accordance with NASA-STD-6001 (1998):

- For testing materials
No Ignition – characterized by no evidence of combustion. A material that does not ignite may show one or more particle indentations on the surface of the material, which may include localized erosion
Ignition – a portion or the entire sample is consumed and the target is not recoverable.
- For testing components
No Ignition – characterized by no evidence of combustion. A component that does not ignite may show one or more particle indentations on the inside surface of the component, which may include localized erosion
Ignition – characterized by obvious consumption of the component, which may include burn-out.

For a summary of all the test results, see Table 3.

Table 3
Particle Impact Test Results Summary

Test Series	Test System Configuration	Particulate Mixture ^a	Test Pressure (psig)	Test Temperature (°F)	Number of Tests	Number of Ignitions
1	Subsonic Injector with Supersonic Nozzle	A	1050	115	100	0
2	Subsonic Injector with Supersonic Nozzle	A	1700	115	85	0
3	Subsonic Injector with Subsonic Nozzle	A	3000	115	60	0
4	QD Simulator	A	3000	115	1	1
5	QD Simulator	B	2500	115	60	0
6	QD Simulator	A	3000	115	60	0

^a Particulate mixtures are described in Table 1.

4.1 Test Series 1

In Test Series 1, 100 tests were performed in 100 percent oxygen with a target pressure of 1050 psi and a target temperature of 115 °F. There were no ignitions of the test samples in 100 tests. When Test Series 1 was performed, the test pressure was chosen to simulate the environment in the low pressure ECLSS QDs. It was not yet known that there would be particle impact concerns in the high pressure ECLSS QDs, which have a maximum pressure of 3000 psi. Figure 9 shows a typical posttest test sample.

4.2 Test Series 2

In Test Series 2, 85 tests were performed in 100 percent oxygen with a target pressure of 1700 psi and a target temperature of 115 °F. There were no ignitions of the test samples in 85 tests. Although higher test pressures were desired to simulate the maximum pressure in the high pressure ECLSS QDs, 1700 psi was the maximum capability of WSTF's supersonic particle impact test system due to the large pressure drop through the supersonic nozzle. Figure 10 shows a typical posttest sample.



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Figure 9
Typical Test Series 1 Supersonic Posttest Sample
at 1050 psi



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Figure 10
Typical Test Series 2 Supersonic Posttest Sample
at 1700 psi

4.3 Test Series 3

In Test Series 3, 60 tests were performed in 100 percent oxygen with a system pressure of 3000 psi and system gas temperature of 115 °F. Unlike the supersonic tests, these subsonic tests measured the pressure and temperature upstream of the test sample. There were no ignitions of the test samples in 60 tests. The orifice size used was 0.344 in, which led to an average gas velocity of 425 ft/s (calculated from results obtained by the system mass flow meter). This test series was performed because greater test pressures could not be obtained in Test Series 2. Figure 11 shows a typical posttest sample.

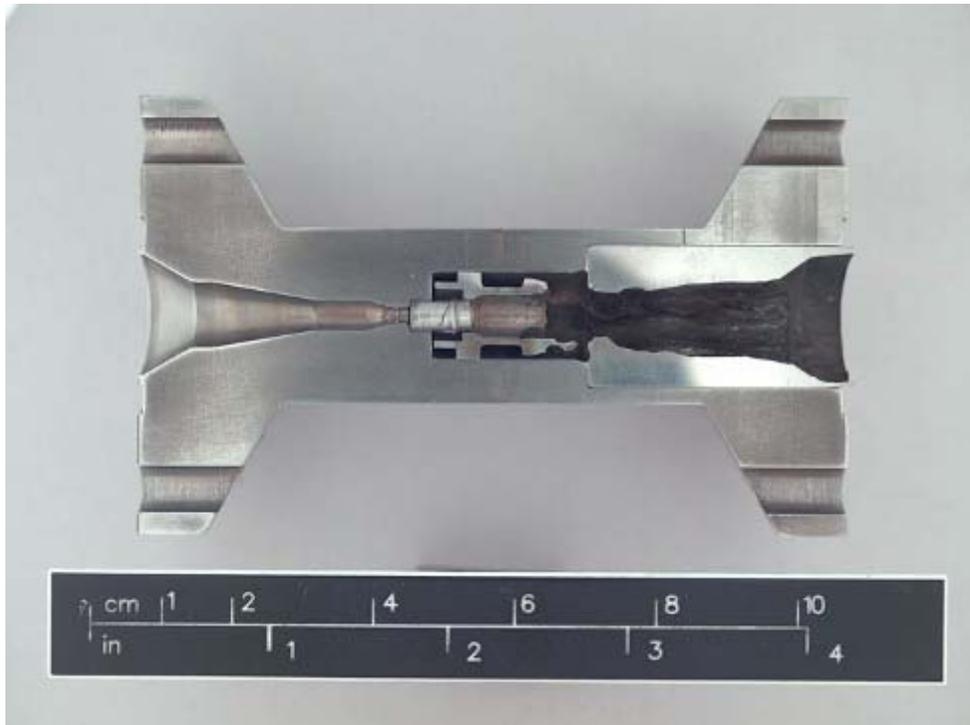
4.4 Test Series 4

In Test Series 4, one test was performed in 100 percent oxygen with a pressure at the inlet of the QD simulator of 3000 psi and system gas temperature of 115 °F. There was an ignition of the QD simulator on the first test. The flow direction in the QD simulator was from the female side to the male side. Figure 12 shows the burned QD simulator. Following the ignition, the QD simulator was sectioned to allow inspection of the internal parts and burned area. Upon inspection, a machining imperfection was found at the inlet of the throat (Figure 13). It was believed that the machining imperfection caused the velocities to increase and become turbulent prior to the parts of the QD simulator that replicated the flight QD. These increased velocities made the test unnecessarily severe and unrealistic since the flight QDs would not have similar imperfections. Therefore, a new QD simulator was machined for the subsequent test series.



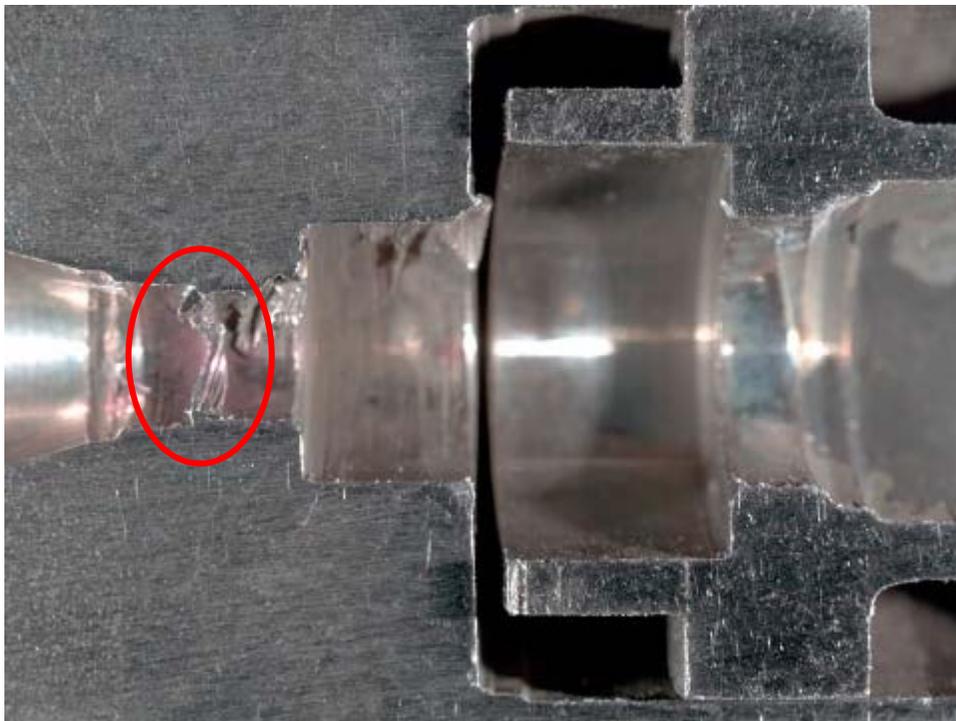
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Figure 11
Typical Test Series 3 Subsonic Posttest Sample at 3000 psi



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Figure 12
Burned QD Simulator

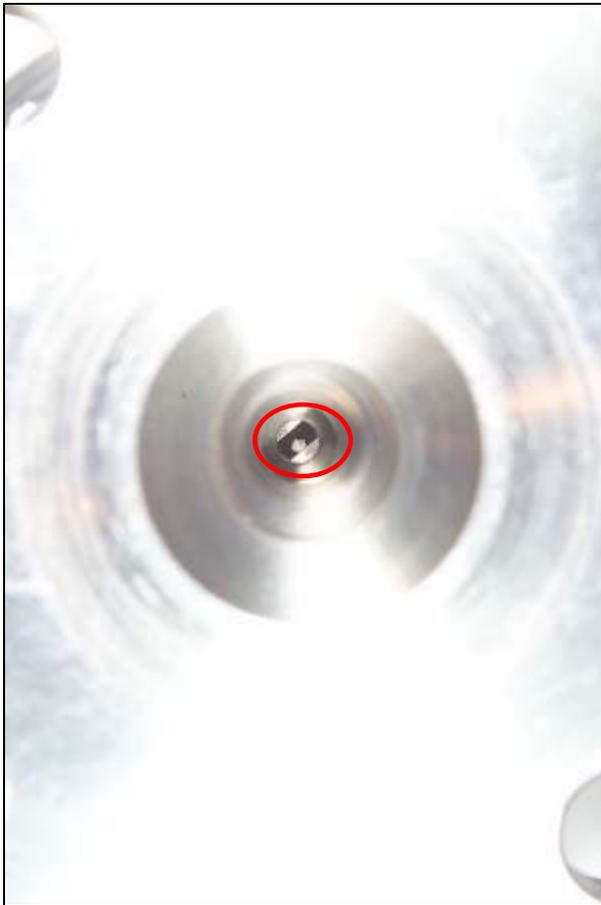


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Figure 13
Location of Machining Imperfection

4.5 Test Series 5

In Test Series 5, a new QD simulator was used that had been verified to have no machining imperfections. 60 tests were performed in 100 percent oxygen with a pressure at the inlet of the QD simulator of 2500 psi and a test gas temperature of 115 °F. Test Series 5 was the only series which used particulate Mixture B. Because the ignition in Test Series 4 raised many concerns about upcoming ISS ECLSS operations, the test pressure was chosen to envelop the worst-case pressure in near-term operations and the particulate mixture was made less severe, as Mixture A was considered to be overly conservative. There were no ignitions of the QD simulator in 60 tests. Posttest inspections revealed that the larger particulates were getting caught inside the QD simulator in various locations, as shown in Figures 14, 15, and 16. Therefore, after each test was performed, the QD simulator had to be disassembled, cleaned, and reassembled.



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Figure 14
Particulate Caught in Inlet of Female Stop



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Figure 15
Particulate Caught in Outlet of Female Stop



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Figure 16
Particulate Caught in the Inlet of the QD

4.6 Test Series 6

In Test Series 6, tests were performed to repeat the same test conditions where the ignition occurred in Test Series 4, but without the machining imperfection. 60 tests were performed in 100 percent oxygen with a pressure at the inlet of the QD simulator of 3000 psi and a test gas temperature of 115 °F. There were no ignitions of the QD simulator in 60 tests. Just as in Test Series 5, posttest inspections revealed that the larger particulates were getting caught inside the QD simulator in various locations, as shown in Figures 14, 15, and 16. The results of Test Series 6 indicate that the machining imperfection found in Test Series 4 was the cause of the ignition.

5.0 Conclusions

The results of Test Series 6 indicate that the ignition in Test Series 4 was caused by the presence of the machining imperfection. The sum of all the test results indicates that there is no particle impact ignition hazard in the ISS ECLSS QDs.

References

NASA. *Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion*. NASA-STD-6001, Test 15. Marshall Space Flight Center, Alabama, February 9, 1998.

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