

SLM Produced Hermetically Sealed Isolation Valve

James Richard*

Abstract

Marshall Space Flight Center (MSFC) has developed a valve concept to replace traditional pyrotechnic-driven isolation valves. This paper will describe the valve design and development process. The valve design uses a stem/wedge to support a disk inside the valve. That disk hermetically seals the pressurized fluids. A release mechanism holds the stem/wedge and a large spring in place. When required to open, a solenoid is energized and pulls the release mechanism allowing the spring to pull the stem/wedge away from the disk. Now the disk is unsupported and the pressure ruptures the disk allowing flow to the outlet of the valve. This paper will provide details of this design, describe the development testing, and show the results from the valve level tests performed. Also, a trade study is presented to show the advantages of this design to a conventional pyrotechnic-based valve.

Introduction

National Aeronautics and Space Administration (NASA) spacecraft and commercial payloads are faced with similar issues of isolation of toxic propellants, limited propellant or pressurant resources, precision of timed events, reliability of operations, and/or limited budgets. Hermetically sealed valves that use pyrotechnics to rupture internal passages are the state of the art in achieving the isolation, resource, and timing objectives. However, handling issues associated with pyrotechnics, quality control issues requiring lot sampling of valves, and costs associated with the handling, access, and design of these devices has made the state-of-the-art valves a costly and involved solution. This effort was to utilize the Selective Laser Melting (SLM) technology to offer valve solutions that would reduce or eliminate the cost and handling disadvantages of the state-of-the-art valves, while maintaining the necessary sealing requirements of the valves. Valve vendors have in the past endeavored to manufacture these valves, but the costs associated with the actuators, sealing elements, and other production costs kept this from becoming a reality.

NASA missions have had disconcerting experiences using the state-of-the-art pyrovalves. MSFC generally used these valves for launch vehicles and larger payloads. Goddard Space Flight Center (GSFC) uses these valves in their fleet of earth observation satellites. Others NASA centers have had issues using these devices for everything from deep space missions to manned vehicles. Each had different needs and concerns and each had concepts to resolve the issues. MSFC and GSFC teamed to provide a proposal to pool ideas and resources, and design a valve that could replace pyrovalves at similar costs and equal or greater reliability.

Discussion

Generally, the approach was to combine the MSFC and GSFC application requirements into a single set of performance requirements that enveloped the needs of both centers' missions, develop concepts for the valves, perform a trade study of various concepts based on the performance requirements, select a single design, complete a detailed Design, Develop, Test, and Evaluation effort for that single concept, and perform limited testing to demonstrate viability.

* Marshall Space Flight Center, Huntsville, AL

Risk & Cost Study

Before this work began, a study was conducted revealing the risks and costs associated with the current pyrotechnic valves. Elimination of these risks and costs was the primary goal of this effort and the reason for the effort.

MSFC and GSFC each provided input to this study. The team's data and experience showed that there were three areas of concern: 1) Spacecraft System Development Costs driven by component reliability, 2) Component Development and Qualification Cost associated to the single use nature of the components, and 3) Spacecraft Operational Costs driven by the operational proximity of the personnel and payload to pyrotechnic devices.

Spacecraft Development Costs: Given that the pyrotechnic valves offer no redundancy of operation, should the main charge fail, the designers of the systems require multiple pressurant and propellant fluid system legs with multiple valves in series and/or parallel to ensure reliability of the spacecraft. This is based on operational history where failures of these valves result in the loss of the spacecraft or loss of the mission. Many examples were found where incorrect wiring, loose wiring, or failed igniters resulted in a spacecraft valve not opening/closing and the mission was lost. So, designers now routinely install parallel (and often series in addition) fluid legs assuring opening (or closing) actions. Design of these systems with multiple parallel (and/or series) legs drives the vehicle costs. If the valves can be assured to have true redundancy and high reliability, multiple paths could be eliminated and the development cost of the spacecraft reduced. A goal for these new valves was to allow end-to-end verification of the electrical system, and to have capability for true redundancy in the actuation system.

Component Development Costs: This area has at least two costs associated with the total. The first is an igniter system. The second is the method required to qualify the valves/systems for spaceflight. The first requires development and qualification of the igniter subsystems and controls to ensure the system meets all performance requirements. Generally, pyrotechnic valves use a chain of explosive events consisting of multiple pyrotechnics, each more stable and more energetic than the one before. As an example, an electrical impulse is used to set off a small squib in the igniter, which sets off a high explosive, which ignites a low explosive. These low explosives are used to generate the high pressure gases needed to open the valve. Figure 1 shows a typical pyrovalve cross-section and the location of each of these explosive elements. Each of the elements, the interconnections, and the controllers, which provide the initiation, all have to be designed, tested, qualified, and installed on the spacecraft. These costs must be considered when looking at the total cost of a spacecraft. A new pyrotechnic system development cost can be \$2 to \$5 million dollars, depending on the operational requirements, number of interlocks required for range safety, and the type system chosen. For this reason, many spacecraft use previously designed systems and stay within the previously qualified requirement ranges. This introduces additional analysis and spacecraft design costs. Elimination of these systems and changing to standard solenoid driver systems offers large program-level component development cost savings beyond the cost of the valve itself. However, the valves also must be developed and qualified. Each valve must be shown to be reliable through batch and or lot testing. As many as 5 to 10 valves can be lost from a build due to lot testing required to assure the valves function as specified. These tests destroy the valves, so the cost to the must include these lot/batch testing units. If there are only 4 valves on a spacecraft, lot testing could more than double the unit cost of the valve.

Operational Costs: Operations costs associated with working around pyrotechnic devices can be significant. The vehicles must be designed for late in-process access to install the devices' igniters. These generally have been removed to prevent inadvertent initiation caused by stray electrical signals and system check-outs. When the spacecraft systems are loaded onto the launch vehicle and the vehicle is rolled to the launch pad, technicians must install the initiators/igniters within a few hours of the launch. This late access costs time and money, not only in the manpower to actually do the work, but in the design of the spacecraft, launch systems, and ground towers to allow access late in the launch flow.

From these considerations, it is easy to see that if the costs of the valves themselves are similar, the total savings to a spacecraft (and the development program) could be very significant.

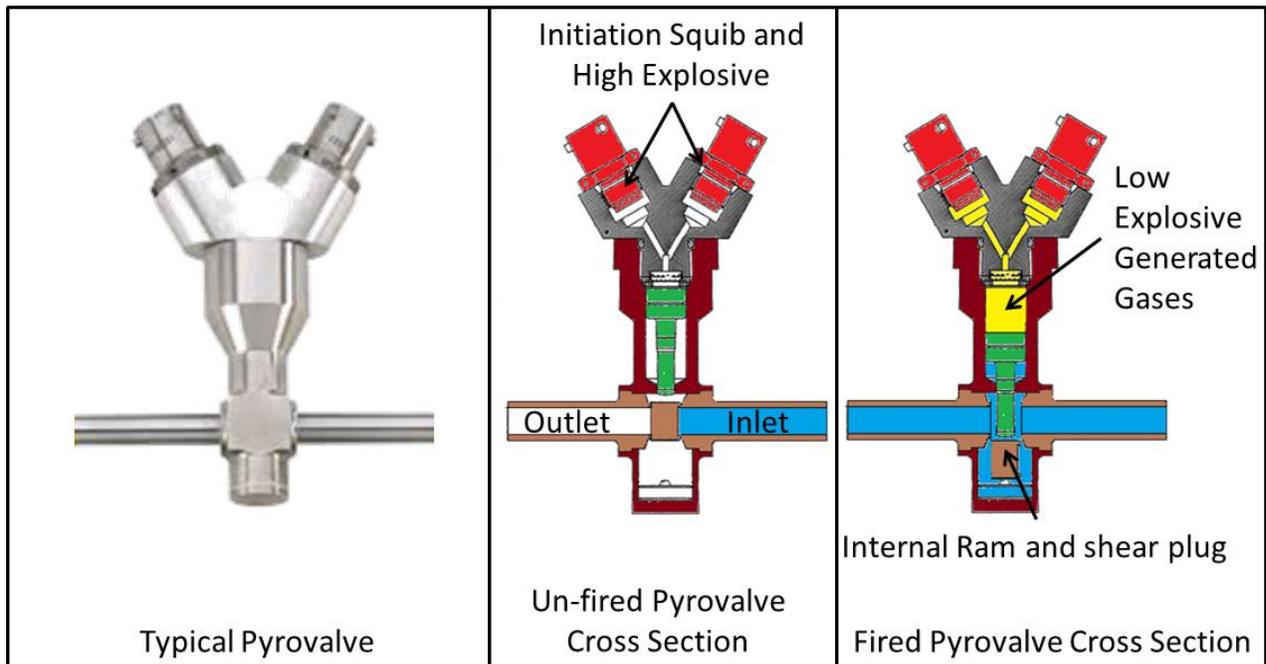


Figure 1. Typical Pyrotechnic Valve and Explosive Chain

Accomplishments

This project produced many accomplishments over the year. Although generally in chronological order, some of the accomplishments were a result of the entire effort. This report will detail these accomplishments by category.

Teaming: MSFC led the effort. GSFC provided Dan Ramspacher, a committed designer, and systems engineering overview. Mr. Ramspacher and his supervisor, Caitlin Bacha, were instrumental in making this team work. Ms. Bacha provided Mr. Ramspacher with the resources needed for the detailed design, offered peer review of the project, and provided leadership in the development of the task and team.

The team had weekly teleconference calls, worked issues as they arose, interacting and communicating well as they performed the assigned tasks. Generally, MSFC provided overall project control: managed schedule and funding, made top-level technical decisions, and performed most of the reporting activities. MSFC and GSFC each performed technical tasks. MSFC provided valve engineering, launch vehicle, engine, and cryogenic payload expertise. GSFC provided additional valve engineering, small near-earth satellite, and operations/handling expertise.

This effort has resulted in a relationship that will extend well beyond this project and has established a collaborative environment for the two centers in the areas of valve and actuation systems, and component design and development.

Requirements Definition: The first task the team performed was to define a set of performance requirements that satisfied the needs of all systems. MSFC provided launch vehicle and stage requirements, as well as long duration experiments. GSFC provided requirements for handling, reliability, and near-earth satellites.

Table 1 provides the results of that collaboration. This single sheet of requirements formed the basic specification for the valve design effort. This also became the list used in the selection of trade study Figures of Merit (FOM) and weighting factors.

Table 1. Valve Performance Requirements

Hermetically Sealed Isolation Valve Performance Requirements		
Requirement	General	Detail Requirement Goals
Media	Inert Gas, Solvent, Propellant Compatibility	Wetted surface non-reactive with helium, nitrogen, argon, IPA, hydrazine. MMH, NTO, kerosene, dimethylhydrazine, etc.
Internal Leakage	Shall provide a leak-tight seal until actuated	Internal and external leak rate < 10^{-6} sccs - Parent metal seal is fractured during actuation.
Pressure Rating	Maximum Design Pressure and ability to be actuated over a range of pressures	Minimum operating pressure shall be 350 psig (2,400 kPa); design shall be shown as extensible to up to 4500 psig (31,000 kPa).
Actuation Time	Low Response Time	Response in less than 50 msec.
Repeatability	Actuations repeatable within a narrow range	Repeatable to within 10 msec.
Actuator Force Margin	Force available from the actuator should be significantly greater than required to operate the valve	All external inputs (e.g., heat, electrical interference, vibrations, or other external stimuli) must not cause the valve to actuate prematurely and actuator shall provide a required 100% margin to these loads.
APT and In Situ Testing	Ability to actuate individual valve during testing without loss of seal	The valves shall withstand testing pressurized or depressurized without loss of the hermetic seal. This will ensure individual valve functionality, which will significantly mitigate mission risks and decrease overall unit cost.
Particulate generation	Particulate generation shall be minimized	Particulate can clog filters and plug components downstream; must be minimized both in number and size. Largest passable particulate is 0.5 micron.
Construction and End fittings	All-welded fluid flow path	This is a basic requirement of in-space propulsion system components to limit the possible propellant leak paths. Mechanical fitting-type or O-ring seals cannot be used as primary seals. Proposed valve uses a parent metal seal, which is fractured during actuation, maintaining all welded fluid path. Development valves can be bolted, but must show path to all welded design.
Flow Rate and DP Performance	Low pressure drop/ High Flow Coefficient	$\Delta P < 3$ psia (20kPa) @ 0.15 kg/s – from pyrovalve spec from SDO. – typical of in-space propulsion systems
Interfaces	General interface requirements, valve designs shall be show extensibility to larger and smaller requirements.	1/4" to 1/2" inlet/outlet tube fittings. Electrical connector or leads. Mechanical mounting feet to allow for integration to spacecraft structure.
Electrical Requirements	Typical of in-space propulsion system electric limits.	Power < 60 W, Voltage < 28 V, E < 1 Wh, Current > 2 amps.
Mass	Mass should be comparable to existing pyrovalves.	Mass should be less than 2.5 lbm (1.1kg).
Construction	To the extent possible, SLM shall be used for this valve	Using SLM offers the opportunity to design new and complex geometries to meet the performance requirements. Designs that utilize SLM are required.

Concepts Development: MSFC and GSFC each were then asked to develop a set of concepts that met the above requirements. They were given a few weeks to perform a preliminary analysis of each concept and present the ideas back to the team. Figure 2 shows these concepts.

MSFC developed 4 concepts:

- 1) A modified version of the Vacco design developed in 2002,
- 2) A shear disk or “Dual Disk” Valve,
- 3) A wedge-supported rupture disk or “Wedge Seat” Valve, and
- 4) A piloted balance disk or “Pilot Pressure” Valve.

GSFC developed a concept for a fracture plate or “Linear Disk” Valve based on previous work.

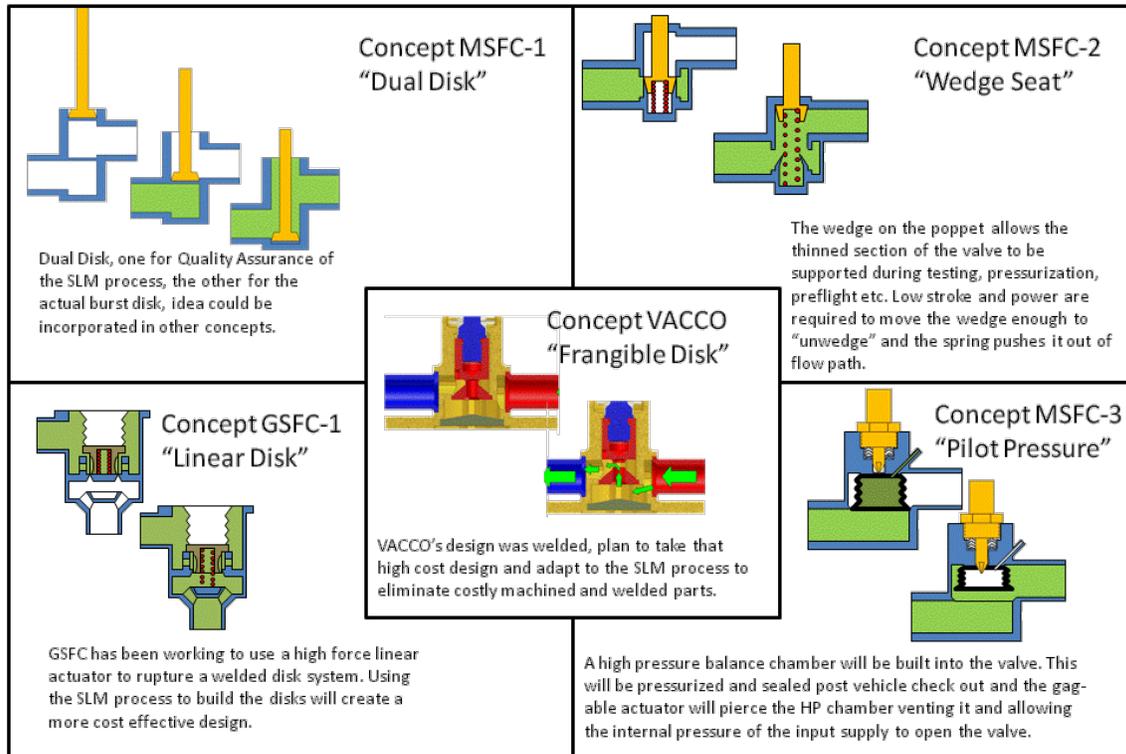


Figure 2. Concepts Used in the Trades.

The Vacco design was attractive given that they had fully developed the valve concept. However, they encountered large manufacturing costs, which could not be reduced with their current suppliers and assembly methods. The valve was designed to have a small poppet embedded in the body that was supported by the actuator. The pressure times area (PA) and spring (Sp) loads are carried through to the actuator at all times. This loads the actuator with high forces from time the valve is assembled until it is used. Thus the actuator requires some method to limit travel during testing. MSFC’s concept for this valve was to use an actuator that had been developed under a task for the NASA Engineering and Safety Center (NESC). This design could hold these loads continuously and release them through the use of a traditional solenoid system. This actuator uses a unique ball latch system. The MSFC concept for modifications to the Vacco design was to reduce the high touch labor valve parts using SLM manufacturing methods. This concept was analyzed and found to be possible, but the valve body would still require some machine time and some welding. The forces required for this valve were directly tied to the supply pressure and would escalate with pressure, going up with the square of the area. Scaling up would further increase the actuator load requirements.

The MSFC Dual Disk design was conceived to have an internal fracture disk that was sheared by the release of a large spring load. That spring would push a shear plunger through the internal hermetic seal.

This design required a large-force high-stroke actuator. This could be made possible with the use of a very long stroke spring and the same actuator. This would be simple conceptually, but resulted in high loads causing an increase in weight. It also would have limited extensibility to larger or smaller designs and higher pressure systems.

The MSFC Wedge Disk design incorporated a wedge to support a thin disk internally. The wedge would support the PA loads on the disk. The disk was to be thin enough to rupture reliably at roughly $\frac{1}{2}$ the minimum MDP (hence 100% margin). The biggest unknown was how the loads would scale with the pressure and disk size. Quick calculations showed it should scale linearly and assuming a very high coefficient of friction (0.9), the spring loads required for a wide pressure range were manageable. The NESC actuator could easily handle these variable loads. The valve could be made to have a relatively short stroke and a high equivalent square edged orifice diameter.

The pilot design was conceived to use one of the other concepts as a pilot system to balance scaling for pressure or size. The idea was to develop a small pilot system that was reliable and light, and then build a valve that had internal force balancing of the PA and Sp loads. As this concept was developed, it became clear that it was going to be costly and complex. But the valve looked feasible and was the most scalable of all the designs considered.

The GSFC valve used a fracture plate that supported the inlet pressure, but could be overloaded with the addition of a high force, low stroke actuator. This concept had much heritage to previous work and was simple, scalable within a range of sizes and pressures, and was a fairly mature concept. The main issue was the original concept used a Nitinol bar stroke actuator. This actuator, although reliable and capable of very high loads, was very slow and depending on the initial temperature, varied in response time. So, MSFC and GSFC conceived a magnetostrictive actuator. This actuator was based on MSFC-patented valve concepts, but is high force, low stroke as required, and is very fast. These two concepts (the GSFC valve and the modified MSFC actuator) were combined into the GSFC valve that was included in the trade space.

Trade Study

With the five concepts fleshed out, each was evaluated by a team of MSFC and GSFC personnel. The first step was to develop a methodology for evaluation. This consisted of a matrix of figures of merit and weighting factors in a pair-wise analysis to provide a ranking of each concept.

The figures of merit were derived from the performance requirements shown in Table 1, but down-selected to those felt most critical. Team members each voted on a weighting factor for each requirement. Table 2 and Table 3 show the teams suggested figures of merit and weighting factors, respectively.

Down Selection

The results of this trade showed that two concepts, the MSFC Wedge Seat Design and the GSFC Fracture Disk Design, were nearly equal in performance.

With GSFC needing to develop a detailed analysis of the actuator, but having a nearly completed the valve design, and MSFC only needing to complete the NESC actuator design started to do a new valve design. It appeared there was manpower available to do both designs. A review of the budget showed that with the rapidly de-escalating costs of SLM due to increased competition in the market, there was budget to build and test an example of each. With the total cost to design, build, and test both valves within the available resources allocated for this program, the decision was to produce both designs and have a real hardware trade study down-select at the end of the program.

Table 2. Figures of Merit and Pair-wise Study Analysis Matrix

Pairwise Comparison								
	9	5	3	1	3	5	9	
Unit Cost				X				Force Margin
Unit Cost				X				Repeatability
Unit Cost				X				Serviceability
Unit Cost				X				Scalability
Unit Cost				X				Integration
Force Margin				X				Repeatability
Force Margin				X				Serviceability
Force Margin				X				Scalability
Force Margin				X				Integration
Repeatability				X				Serviceability
Repeatability				X				Scalability
Repeatability				X				Integration
Serviceability				X				Scalability
Serviceability				X				Integration
Scalability				X				Integration

Table 3. Weighting Factors Applied to the Designs

FOM Ranking	Vector	Weight
Unit Cost	1.348	0.177
Force Margin	1.348	0.173
Repeatability	1.348	0.176
Serviceability	1.348	0.163
Scalability	1.348	0.161
Integration	1.348	0.152
	8.088	1.0018

Detailed Design

The following will provide details of the analysis and design efforts performed to develop the MSFC valve design. GSFC will write a separate paper on the development of their valve, so it is not covered in this paper. A future development activity will down-select to the final single valve using the performance, cost, and reliability data obtained from this testing and activity.

MSFC's Design

The original concept of the wedge design was to have a conical internal disk in the SLM body that was supported radially by a removable conical wedge. The concept was to have the SLM disk as a feature built directly to the needed thickness and sizes in the body. This was thought to only require a minor reaming machine operation for clean-up of the wedge interface surfaces before assembly. Working with

the builders of SLM hardware, it became clear that the tolerances required by the design to achieve reliable rupture performance were beyond the capability of the SLM equipment. Thus access to both sides of the disk would be required to clean up the build material. The radial design would have not allowed 360 degrees of access to the underside of the disk for the machine operations.

The design was changed to a linear wedge configuration. Figure 3 shows the basic concept for each. The overall design of the radial concept would have been smaller given the flow area was larger for a specific design. The linear wedge design allows access to both sides and is simpler to manufacture. This concept was the one taken to final design and used for development testing.

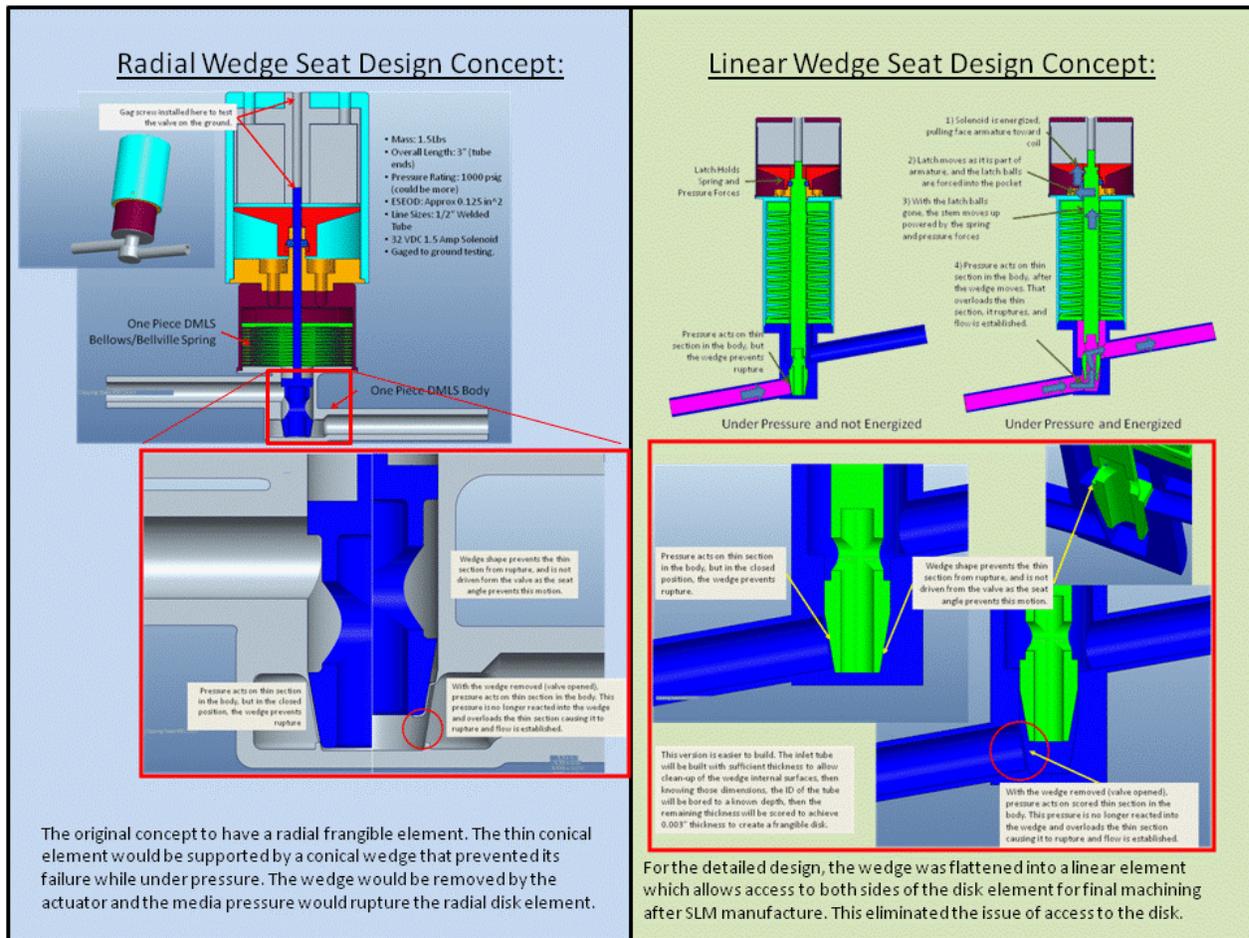


Figure 3. Comparison of the MSFC Radial Wedge vs. Linear Wedge Designs

From this point, the analysis for the actuator load spring sizes and other calculations was performed. Four big issues were uncertain:

1. First was the variability of the coefficient of friction between the wedge and the disk. This drove the loads as a function of supply pressure from as few as 30 (130 N) to nearly 350 lbf (1560 N), depending on the values of pressure and coefficient.
2. The second was whether the valve would generate particulate greater than allowed.
3. The third uncertainty was the actual spring rate and capability of the unique spring/bellows concept.
4. And the final uncertainty was the consistency of the as-ruptured flow discharge coefficient.

To address the first concern, a 10-degree angle was selected to minimize the effect of load on the force needed to pull the wedge from the pressurized disk, however, the actual effect was uncertain, because

this type of analysis was highly dependent on actual coefficients and the nominal load transmitted through the diaphragm. To address that part of the issue, development tests were performed to determine the actual loads needed to remove the wedge as pressure was varied. The development tests were performed with materials that had higher than as-designed couples to drive the coefficient of friction to the highest possible. The valve was to be all Inconel 718. The development test was performed with an Inconel 718 wedge and an aluminum body. These tests showed that the 350-lbf (1560 N) maximum design point was twice the highest value recorded. Twenty tests were run and none had loads greater than 185 lbf (823 N), with pressure ranging from as little as 100 psig (600 kPa) to over 3500 psig (24,000 kPa). With a requirement for 100% force margin, the spring load required was set at 700 lbf (3000 N).

An unforeseen issue was found during testing. We showed that the analysis of the disk, assuming a thin membrane, was predicting failure at much lower pressures than those found. Using a disc diameter of 0.25 in (6.4 mm) and thickness of 0.002 to 0.003 inch (0.051 to 0.076 mm), a Roark's pure membrane analysis indicated that rupture would occur at around 50 psig (344 kPa) to 150 psig (1,000 kPa). Testing showed this to be a variable from 300 (2,000 kPa) to 900 psig (6,200 kPa). Review of the actual failure and analysis from the MSFC analysis branch showed that the actual failure mechanism is a combination of shear, bending, and membrane type failures. An empirical method was developed to match the test data to the analysis, and it was determined that disk area needed to increase as thickness could not be consistently controlled to less than 0.002 inch (0.051 mm). This drove the disk size to a 0.75-inch (0.02-m) diameter.

Figure 4 shows some of the development test articles and a graph of the load results. Visually, the test revealed that the rupture disk stayed intact, fractured cleanly along the "petals", and opened fully to achieve the required flow area. Flow testing of this design will be performed to prove the flow is acceptable. This was to be accomplished following final assembly or the completed design later in the development effort. Flow testing was never an objective of this development. Additional development testing showed this to be satisfactory given that no test article failed to rupture at 250 psig (1,700 kPa) or less. So, this larger disk concept was incorporated into the valve.

To address the second concern, the fluid used to burst the development valves was collected and sampled for particulate generation. This testing showed that there were no particles over the limit of 0.5 micron found. In fact, none were ever detected. This validated the burst disk design features of a circular cut 340 degrees around the edge of the opening and an "X" shape in the center to force the ruptured disk to open like pedals when the disk failed. For each test, the development hardware disk failure matched this configuration.

The third issue was the spring-rate. MSFC built two trial springs (see Figure 5) and each was tested. Even though neither was heat treated, a minimum spring rate of 4000 lbf/in (700,000 N/m) was achieved. The actual loads are assumed to be 10% to 20% greater when heat treated. Even this lower number provided the ideal 800 lbf (3600 N) required at 0.200-in (5-mm) stroke for this design, and still yielded the required 100% margin.

The results of these test showed that the spring/bellows system and the disk concept were valid, and the design was completed. The only remaining concern was the flow consistency. This could only be addressed with the final design and in a lot test program. Additional funding was requested and obtained later in the year. The results from that effort will be reported when available. The development testing resulted in similar failures for each test over the wide range of test pressures. The concern was mitigated with this qualitative data. Hard quantitative data is to be obtained later in Fiscal Year (FY) 14.

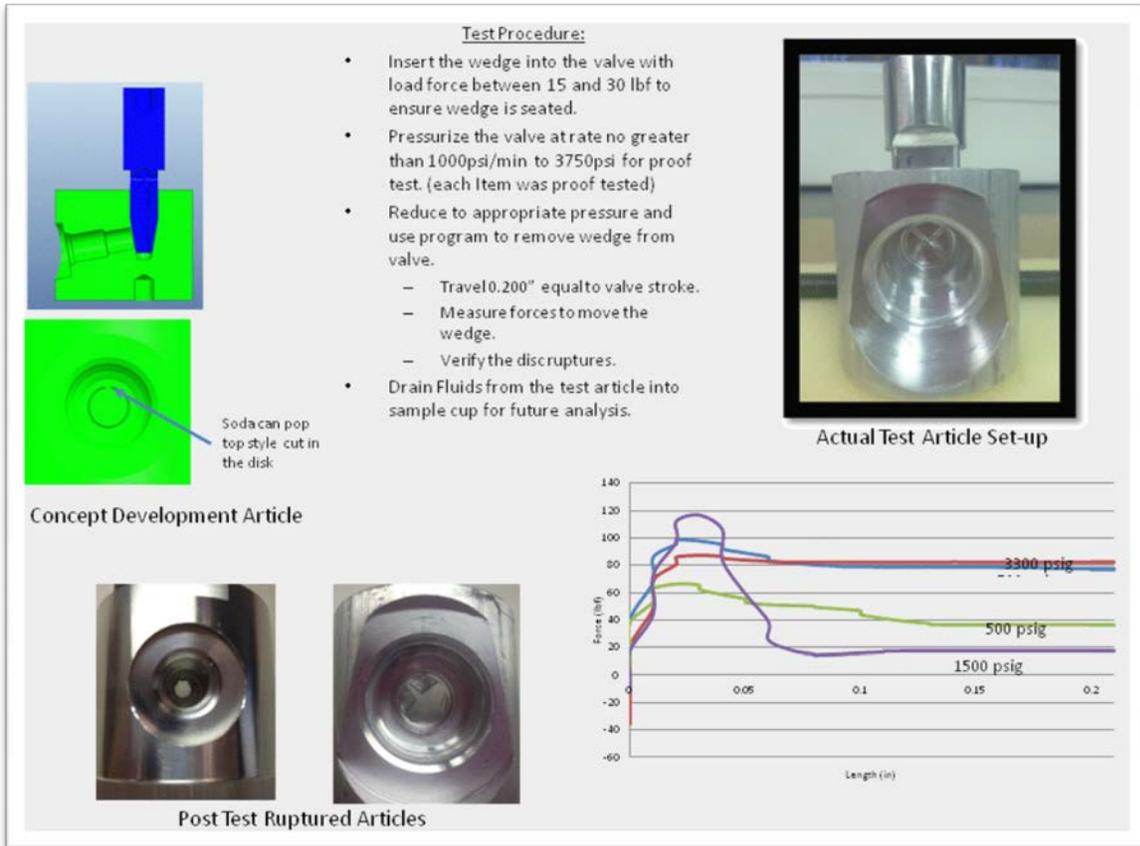


Figure 4. Development Test Results



Figure 5. Trial Spring Builds Showed Acceptable Build and Performance Goals were achieved

Once the spring design was completed and assured that the loads were well known, the actuator design was adjusted to provide the needed load holding and release capability. The biggest obstacle was to size the solenoid to provide the needed loads. A free-body loads analysis was used to define the actuator load.

$$\text{Spring Force} = F_s = 700 \text{ lbf (3100 N)}$$

$$\text{Reaction Load Per Ball on the Slip Ring} = F_r = F_s/4 \text{ balls} * \sin 10 = 30 \text{ lbf (130 N)}$$

$$\text{Actuator Pull Requirement } I = F_a$$

$$F_a = 24 \text{ lbf (110 N)} = \{(30 \text{ lb (130 N) reaction load)} * (0.2 \text{ coefficient of friction}) * (4 \text{ balls})\}$$

This is the force needed for the actuator. With a 100% force margin, the required solenoid force is 48 lbf (213 N). Figure 6 shows this in detail. Several available solenoids were tested, and a Marotta MV583 coil was selected. Tests showed the coil needed 0.04-in (1-mm) stroke to generate the 48 lbf (213 N) required. However, with the need for 0.0625-in (1.6-mm) actuator stroke (1/2 of the ball 0.125-in (3-mm) dia), the design required a slip feature, such that the ball would push the slip ring axially past the stroke of the armature to allow the ball to completely unlatch. This feature and a spring incorporated to reset the balls following actuation.

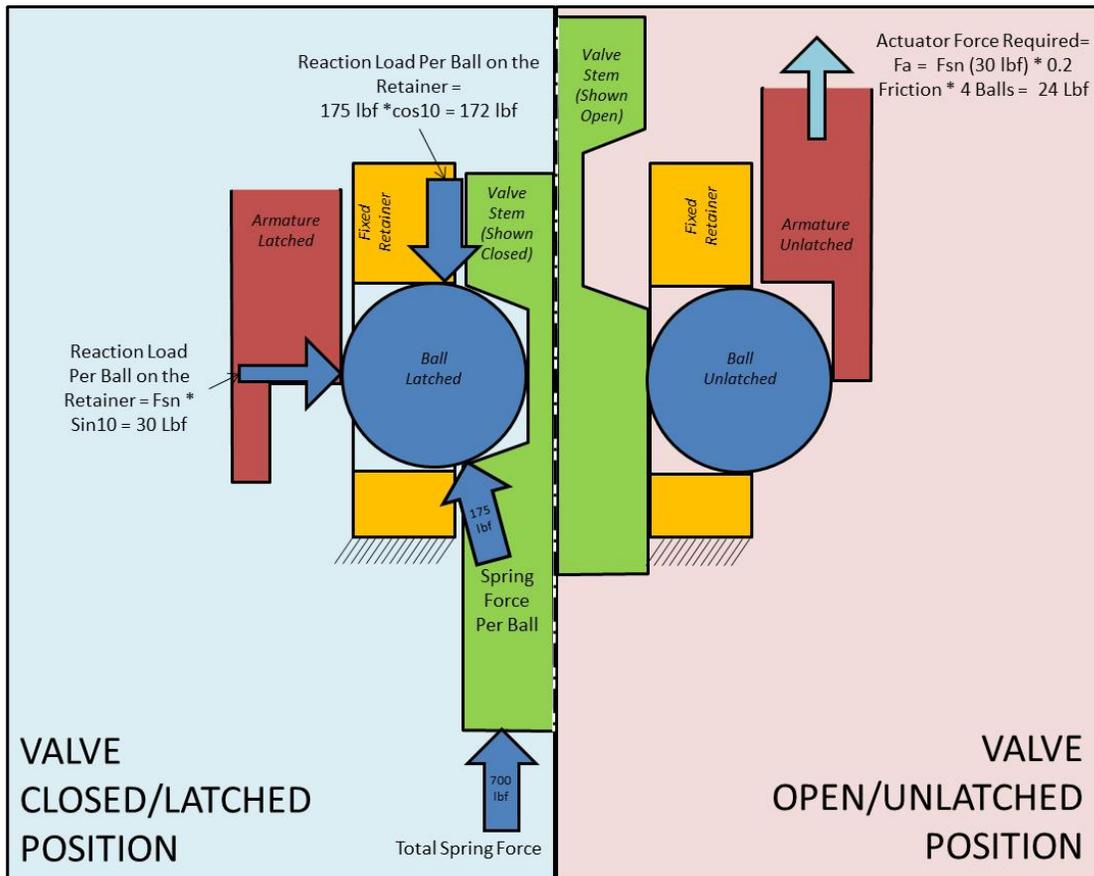


Figure 6. Actuator Detail Layout

The final MSFC valve drawings were completed and the hardware has been manufactured. Some of the hardware is shown in Figure 7. The final assembly drawing is shown in Figure 8. Final assembly and testing is underway as of the date of this paper's writing.



Figure 7. Fabricated Hardware

Summary

The MSFC hermetically sealed valve isolation valve has been designed as a replacement for the traditional pyrotechnic valve. This valve was designed from the ground up to address the system designs, which result in operational complexity. This effort has shown that this design, although maybe not optimal for all applications, does meet the requirements of many pyrotechnic valve applications for spacecraft, launch vehicle, and lander applications.

The valves MSFC built were “one off” and the cost was high. An estimate of the unit production cost is provided in Table 4. At roughly \$10K per valve, this cost is very similar to the costs of an existing pyrovalve. So, the direct cost of the valve is a “wash”. The savings from the system design simplifications and operations enhancements are the primary benefits to be expected. Additionally there is no requirement for lot testing and depending on the size of the program, the cost of lot test units can be anywhere from \$30K to \$100K.

Table 4. Projected Unit Costs

MSFC Hermetically Sealed Isolation Valve Costs Data					
Part Name	Hours To Build	Hourly Rate	Part Labor Costs	Material Cost	Total Part Cost
Machined and DMLS Body					\$ 2,500.00
Machined and DMLS Bellows/Spring					\$ 1,150.00
Direct Purchased Coil					\$ 550.00
Machined Coil Housing					\$ 150.00
Machined Spring Housing					\$ 250.00
Machined Tube Adapter					\$ 275.00
Machined Adapter Rings					\$ 50.00
Machined Armature					\$ 250.00
Machined Wedge					\$ 150.00
Ball Support					\$ 75.00
Gland Adjuster					\$ 150.00
Washer					\$ 20.00
Balls					\$ 20.00
Wavy Spring					\$ 25.00
O-ring					\$ 10.00
Bellows Clamp					\$ 15.00
Misc Shims					\$ 15.00
Misc Screws					\$ 100.00
Welding Labor					\$ 2,100.00
Assembly Labor					\$ 600.00
ATP Labor and Consumables					\$ 2,250.00
				Projected Unit Cost	\$ 10,705.00

Details Not Provided

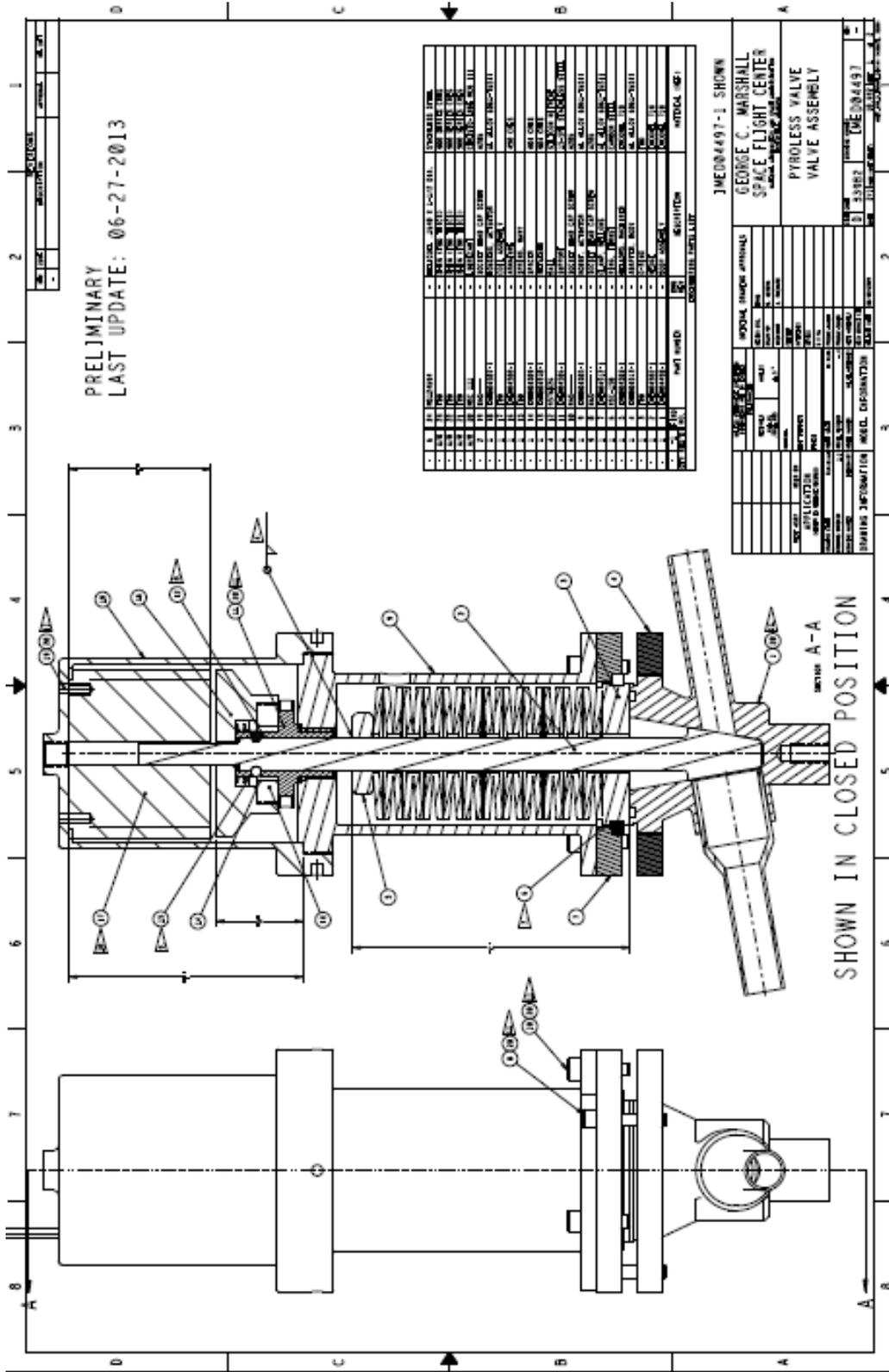


Figure 8. Final Drawing

Conclusions

The MSFC hermetically-sealed valve has been shown to meet the general requirements as a replacement for traditional pyrotechnic valves. The valve design offers the potential of being cost

competitive with pyrovalves at the component level. If this is true, the systems utilizing these designs could potentially save millions of dollars relating to simplification of system architecture design, qualification, and operations.

Cost and reliability data is to be determined from a follow-on task that is currently being worked at NASA/MSFC.

Discussions with several projects have indicated interest in this concept and an e-mail from the Project Manager of the Lunar Prospector Project has suggested that with more cost and reliability data, it could be considered as a flight alternative for their low-cost project.

A valve vendor has been shown the concepts and they have expressed interest in using some of these concepts in their product line. They would also like to see additional cost and reliability data. They have provided a letter stating this interest.

Publications and Patent Application

Three NASA Technology Report (NTR) disclosures have been submitted.

1. The unique latch system was submitted as an NTR. The application of a standard ball release appeared to be a unique design.
2. The retractable wedge support system for the disk was considered unique. No other systems like this were found, so an NTR was submitted.
3. The use of the two previous innovations makes the valve itself a unique design, so an NTR was issued for the valve concept.

These NTR's will be evaluated to determine the uniqueness and patentability of the design(s). MSFC submitted a final report on the two designs (MSFC and GSFC valve) in late November 2013 to the funding organization.

Status of Investigation

The final steps required to complete this effort include final machining of the undelivered parts, assembly, and the noted basic testing. This should be performed before February 2014.

Planned Future Work

Production of a complete lot of valves for testing and evaluation focused on the manufacturing costs, reliability, and performance necessary to meet projected goals. This effort was submitted as a follow-up TIPs proposal. If not funded in FY14, it will be submitted again in FY15. Additionally, the proposal was submitted to the ED Technology Excellence committee for potential funding. If the TIPs follow-on is not awarded, then the TE board has said that it will fund this effort.