DEVELOPMENT OF SEPARABLE CONNECTORS FOR THE SATURN S-IV STAGE

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ABSTRACT.

The success of the Saturn S-IV Stage in flight and ground operations, to this time, is an excellent demonstration of the effectiveness of the connectors employed in its propulsion systems.

There are relatively few people who ever give more than a passing thought to the fluid line connectors used in the stage installations. To these relative few, however, the significance of the proper performance of these connectors is not lost.

How effective were these connectors? What type of connectors were they and who made them? How were they evaluated and selected? What were the criteria for their performance? How were they assembled and tested?

These are only a few of the questions generated by this subject. This paper attempts to answer some of the more important ones in a, hopefully, interesting and informative way.

THE PURPOSE OF THIS PAPER is to present information in the area of separable connectors as they pertain to the Saturn S-IV Program. We propose to delve into the philosophies, constraints and ultimate decisions of design; and the problems, methods, and practices of manufacturing. We shall review the installation process and attempt to probe into all its aspects; and finally, we shall summarize and analyze the checkout of the systems of the separate stages. It is only within the matrix, we believe, that a total evaluation of the effectiveness of the connectors, as they were employed in the S-IV stage, can be made.

It is hoped that this paper will focus most of the variables of this ostensibly simple technical area into a comprehensive and well defined source of information for the fluid line connector field. We particularly wish to emphasize that the process necessary to bring the drawing board concept into a hardware reality is difficult, expensive, and at times, quite frustrating. To interject some serious humor, "There has never been a leak in any of the various connectors of a piping installation -- on the drawing board!"

Assumptions that hardware will or can be built exactly to the specifications and standards set forth in drawings and their associated documents sometimes are fallacious. The accuracy and appropriateness of some specifications and standards are also sometimes open to question. Criteria that must govern the imposition of specifications and standards are as follows:

1. Are the specifications and standards capable of being met?

2. What mechanisms will verify compliance?

Neglect of these criteria can result in a profusion of problems and may lull designers and engineers into a false sense of security.

Design conclusions and decisions based on laboratory test results and one-shot prototype studies must be tempered with good judgment or expensive penalties will result. It must constantly be kept in mind that human beings of various degrees of skill and knowledge are involved in the total process. Motivation, pride of workmanship, man/machine interfaces, and communication effectiveness must be considered in the achievement of acceptable end results.

The task facing the designers of the S-IV tankage and pneumatic installations seemed formidable at the outset. They had the dual problems of containing considerable quantities of the low density gases, helium and hydrogen, and the cryogenic liquids, hydrogen and oxygen, and doing so with minimum (hopefully zero) leakage. These, of course, are not generally insurmountable problems, but they had the added problems of high-vibration levels and extreme temperature environments to contend with. Topping off the problems was the restriction to accomplish the task with flight-weight hardware.

The easy solution to the elimination of leakage in a system such as the S-IV Propulsion System is to eliminate the separable connectors. This is theoretically simple but practically impossible at this stage of development. The first step in seeking theoretical simplicity for S-IV was to minimize the number of separable connectors to those absolutely necessary. The tradeoff limit was soon reached, however. Transportation and handling restrictions, installation factors, and the necessity for allowing some flexibility for changes and improvements still demanded a significant number of separable connections.

In the S-IV Program a high rejection rate of welded pipe assemblies was encountered, particularly in the smaller diameter pipe sizes. This was one of the problems resulting from the effort to minimize separable connections by use of welded subassemblies. Where the quality of the welded pipe assemblies was acceptable, each welded joint was one less connection that had to be leak checked. However, each welded pipe assembly subsequently removed and replaced, for whatever the reason, was that much more expensive and involved the breaking of the multiple connections incorporated in the welded assembly.

Selection and evaluation of seals and connectors suitable for the intended service was based, as much as possible, on past performance and known test results. There was very little data on elements suitable for liquid hydrogen temperature service. To remedy this, testing of seals and connectors was initiated simultaneously at MSFC and Douglas. Testing of metallic seals was given high priority at Douglas. It was evident at the beginning, that no startling new development in the connector and seal area would be immediately forthcoming. There was no time! The field of choice in commercial connectors and seals was quite limited and it took no great amount of testing to narrow the field even more. Good prospects within this limited group were the metal "crush" washers, pressure actuated flange seals, various metal conical gaskets, MS flares, and NAS 1367 flared tube fittings (AN fittings with baked-on molybdenum disulfide lubricant). For AN boss type connections, a metallic boss seal was the only promising candidate.

The decisions were finally made under pressure of schedule commitments and the necessity of early procurement. For tubing one inch in diameter and under, MS flares and NAS 1367 fittings were selected. Tubing over an inch in diameter was selected to be connected with Aeroquip's Marman couplings. Low-pressure ducting would also be connected by Marman couplings. Certain large ducting and components would be joined by bolted flanges utilizing metal seals (pressure actuated flange seal) to conform to interface requirements. Voishan copper and aluminum seals were to be used on flared tube connectors. The Marman metal conoseal was to be used with the bolted flange and V-Band coupling and spring loaded metal seals (metal boss seals) would be utilized on all AND 10050 ports.

Some concern was evidenced regarding some of the decisions, and Douglas was advised against the use of metal crush washers throughout the systems. This philosophy was based on in-house testing results and the desire to develop connectors for 1-inch and smaller diameter tubing that would not be dependent on seals for achieving leak-tight joints. The designers, however, viewed the metal crush washers as particularly promising, especially the Voishan conical metal seal. The metal boss seal was not quite as promising, but for its application, there seemed to be no better choice.

Checkout engineering, frankly, viewed the conical metal seals with some apprehension for the following reasons:

1. The seal in effect created an additional possible leak path.
2. The possibility of shredding during torquing of the connection was considered to have a high probability in cases of careless positioning of the seal.

Initially the results tended to support the first reason, but gradually as the technicians became familiar with their use the leakage rates dropped or repairs were effected generally on the first try. It became apparent that most leaks were due to undertorquing at these particular connections.

As for the second reason, to one of the writer's knowledge, during production checkouts there was only one definite known incident of a shredded conical seal. This appeared on the cold helium fill line at the first flexible hose connection. Immediately upon start of pressurization a distinctly audible leak was discovered and pressurization halted. Disconnection of the joint revealed complete shredding of the seal. The lines up to the two in-line filters were all removed, including the filters, and sent out for inspection and cleaning. Loss of one checkout shift resulted, but there was no permanent damage sustained by system components. This incident was utilized as a highly effective example for all concerned of the necessity for exercising the utmost care in installation and assembly.

The metal boss seal was used throughout the propulsion system, but particularly in the ambient helium, cold helium, and fuel tank pressurization subsystems. During checkout with ambient helium or nitrogen pressurant, either a seal could not be effected or it was effected only after multiple, very careful, attempts. These seals were therefore eliminated from the ambient helium subsystems installations and replaced by MS 28778 packing ("O" rings) and MS 28778 packing with MS 28777 rings. In the cold gas subsystems there was no alternative except to use the seal for the remainder of the program. Teflon "O" ring seals were considered but not utilized. The torques used were felt to be excessive for the cold flow characteristics of Teflon. One critical aspect of the use of the metal boss seal is that when a connection is disassembled, for whatever reason, the seal has to be cut off for removal from the fitting. Consequently, great care must be exercised by the technician to preclude damaging the fitting.

There was some concern over the use of the packing and rings in the ambient helium subsystems because generally they were applied to the control elements of cryogenic components. However, connector leakage was very noticeably reduced and results to date indicate no deleterious effects on system performance. Some minor contamination has been encountered, but not enough to be considered serious. The cure date factor has to be considered here, but the short life of the S-IV provides a safety, and freedom from maintenance, factor.

Marshall did not consider the Marman coupling with metal conoseal a particularly desirable application because of the lack of adequate test data. Douglas, based on limited test data, experience with other programs, and the fact that P&WA was using a similar type angle gasket in RL-10 bolted flange connections, had confidence in the connector and seal. It proved to be an effective connector for cryogenic lines of over 1-inch diameters. The major problem is that the making of a good connection requires considerable care and skill. Distortion of flanges during welding is also a prevalent problem.

Experience on Saturn S-IV production acceptance checkout revealed the following sources of connector leakage:

1. Poor Installation Practices - a) No seals installed, b) Poorly installed seals, c) Preloaded lines, d) Lack of specific instructions.

2. Wrong Seal Application - a) Metal boss seals, b) Pressure actuated flange seals,

3. Poor Torquing - a) Low torque, b) Lack of torque.

4. Damaged Connectors - a) Damaged flares, b) Damaged fittings, c) Warped flanges, d) Damaged bosses, e) Damaged seals.

5. Contamination -

Lack of trained and skilled personnel during the early part of the program accounted for the first source. The second source was due to unwise selection of seals for the following reasons:

1. The pressure actuated flange seal is a hard flat flange seal incorporating a number of annular ridges on the inner periphery. The ridges are teflon coated and a groove is cut into the inner diameter for spring effect and pressure-actuated sealing. It was found that the seals were easily scratched, nicked, and the teflon flaked off. The majority of this was probably caused during installation. Also, the mating flanges were too rough a finish to seal against the smooth surfaces of the seal.

2. The problems in the application of the metal boss seal appeared to be primarily a dimensional one and secondarily a torque problem. In too many cases it was discovered that no sealing action occurred because no pressure had been applied to the seal. This resulted from too much clearance in the assembly or improper seating of the jam nut on the bearing surface. In many instances, it was questioned whether proper torquing was being applied, i.e., indicated torque was due to friction and not tightening torque.

The subsystems and subassemblies making up the Saturn S-IV Propulsion System are shown in Table 1. The approximate number of each type of separable connector for each subsystem is also given. The system as it finally evolved

Table 1 - Subsystem Separable Connectors (External)

Subsystem	Flared Tube	Bolted Flange	AND Boss	V-Band Coupling	Approx. Total
Pneumatic Control	266	-	68	-	334
Fuel Tank Pressurization	93	1	17	10	121
Oxidizer Tank Pressurization	100	-	35	-	135
Oxidizer Tank	32	11	5	15	63
Fuel Tank	30	9	5	15	59
Fuel Tank Make-up Pressurization	31	-	6	-	37
Engine Vent Purge	47	-	15	-	62
Cold Helium Bubbling	53	-	10	-	63
Engine Injector Purge	60	-	-	-	60
Common Bulkhead Vacuum Monitoring Sys.	21	-	9	-	30
Nonpropulsive Venting	66	2	12	-	80
Internal Engine Vent	26	3	13	18	60
External Engine Vent*	-	-	-	-	-
Engine (6)	150	-	84	-	234
	975	26	279	58	1338

* Not installed during factory checkout

contained approximately 1338 external separable connections, excluding those of the engines. The pneumatic control subsystems of the six engines alone contained an approximate total of 234 connections. The connections on the other engine subsystems were not counted.

Initially the system was conceived as a four-engine propulsive system, but was then redesigned as a six-engine system. As the system evolved through its development, four subsystems (two major and two minor) were added and two subsystems were expanded to include purge subassemblies. Over 300 connections were added by these changes.

Table 2 gives the fluid media contained in the various subsystems of the Propulsion System and also gives the approximate temperature and pressure environments.

The Saturn S-IV Checkout Program was set up as follows:

PRODUCTION ACCEPTANCE CHECKOUT

FACTORY - Leak and functional tests were performed at the completion of manufacturing. This was perhaps the most extensive and thorough of all the checkouts. In practice, it was many times conducted in parallel with manufacturing operations.

Table 2 - Subsystem Operating Environments

Subsystem	Medium	Temperature	Pressure
Pneumatic Control	Helium	420-625° R	3000/455
Fuel Tank Pressurization	He, H_2	100-280° R	200, 300
Oxidizer Tank Pressurization	Helium	38-100° R	3000/250
Oxidizer Tank	LOX, He	160-300° R 162-166° R	45-48 psia
Fuel Tank	LH_2, He GH_2	60-255° R 38-42° R	30-32 psia
Fuel Tank Makeup Press.	Helium	420-625° R	3000
Engine Vent Purge	Helium	420-625° R	3000/620
Cold Helium Bubbling	Helium	100° R	3000/320
Engine Injector Purge	Helium	420-625° R	3000/620
Common Bulkhead Vacuum Monitoring	Vacuum	-	1/4 psia 1 psig
Nonpropulsive Venting	He, GH_2 GOX	160-300° R 60-255° R	30-50
Internal Engine Vent	He, GH_2	60-420° R	15
Engine	He, GOX LOX, LH_2 GH_2	-	-

PRESTATIC FIRING CHECKOUT

STATIC TEST SITE - Generally a less extensive and thorough checkout than production acceptance checkout was performed to prepare the stage for static firing. Subsystems modified after Phase I checkout were given a very thorough and extensive check.

POSTSTATIC FIRING CHECKOUT

STATIC TEST SITE - A check of a generally higher level than Phase II checkout was performed to evaluate system performance and to isolate any real or incipient problem areas resulting from the firing.

PRELAUNCH CHECKOUT

LAUNCH SITE - A thorough checkout of the stage was performed to isolate transportation induced discrepancies and to prepare the system for launch operations. This checkout was concerned also with testing integrity of the system after retro-fitting of modifications.

While the systems checkouts were basically the same, emphasis was applied on different aspects of system functions and installations in these four major checkout phases. Thus the total resultant stage system checkout for each stage was the optimum checkout possible.

Table 3 shows a broad comparison of system connector leakage. Unfortunately, retrieval of this information in a more accurate form was not possible because of inconsistencies in reporting and recording leakages. An inordinate amount of analysis and evaluation would also be required to make the comparison data meaningful because of the continuing development of the stage propulsion systems during their lifetimes.

Formulating the leak detection criteria and methods for the S-IV Program was one of the most difficult and unpleasant tasks experienced by the checkout groups. At the beginning, it seemed a frustrating and hopeless task. The extent of helium and cryogenic fluid containing lines and pressure vessels was considerable. Our problems were compounded by the fact that the leak checks would be conducted at ambient conditions and, of course, with constraints on the types of fluid media. In general, test pressures were considerably below subsystem operating pressures because of safety considerations. Some correlation of test results with the operating pressures, fluids and cryogenic environments would be necessary. The launch and static-firing vibration level environments were also factors to be considered.

Table 3 - System Leakage at Factory Checkout

C/O	Stage Desig. DAC	Stage Desig. NASA	Approx. No. of Leaks	Approx. No. of Connections
1	2	Facility	40	500
2	Test	ASV	80	800
3	1	S-IV-5	*	900
4	3	S-IV-6	110	900
5	4	S-IV-7	70	1000
6	5	S-IV-9	70	1100
7	6	S-IV-8	90	1200
8	7	S-IV-10	60	1300

* Information not available

A survey of all available leak detector devices, methods, and philosophies was initiated, but unfortunately little or no documentation of this extensive and important effort was made. This omission was the subject of considerable regret later on and as a consequence much of this effort had to be duplicated.

The mass spectrometer, helium leak detector, and the halogen leak detector appeared promising at first. Initial cost, mobility, portability, maintainability, operator training, and lack of confidence in test results were prominent factors in their final discard after detailed analysis and evaluation. A mass spectrometer was procured, however, for further testing and experimentation at the static-firing site.

A big factor in selection of liquid oxygen compatible bubble solution as a prime leak detection method was the extensive and successful use of the fluid on the Thor system. Also, there was a record of unsatisfactory results in some applications of the halogen leak detector at Douglas. Cognizant personnel felt the bubble solution was a known quantity that produced positive results while the other methods were too much of an unknown nature in practice, although excellent in theory. The cost and nature of the S-IV Program dictated some conservatism, particularly in view of the schedules.

The bubble solution and audible detection were finally selected as the prime leak detection methods to be used in conjunction with flow meters for valve seat leakage measurements. Sometime later in the program, Douglas was directed to utilize the halogen leak detector for bellows and flexible metal hose leakage checks.

Audible leak detection is overlooked by many people as a particularly effective and inexpensive method of detecting major and medium rate leakage. In conjunction with this, tactile checks are also useful and effective. The use of bubble solution to detect minor - but not insignificant - leakage was quite effective and was a major part of leak testing operations on the S-IV. There were some problems to be overcome and there are certain disadvantages to its use; but, the basic objection to bubble solution for leak testing seems to be its lack of sophistication.

The philosophy of the checkout group was that leakage rates undetectable by the bubble solution test were insignificant as far as the mission of the S-IV was concerned. It was felt that detection of such leakage was maximization without justification. There was little assurance that attempts to repair or correct such leakage would not be an impractical effort.

The criteria utilized in the S-IV propulsion system leak checks were that no leakage was allowable at any of the system's separable connections. The term "No Leakage Allowable" was defined as the complete absence of any visual formation of bubbles at a pressurized connection upon the application of LOX compatible bubble solution -- to the complete satisfaction of a qualified inspector. Selective assembly of components was sometimes necessary to achieve this "zero leakage" condition.

The general procedure used in leak checks was as follows:

1. Pressurization of the subsystem or subassembly at a slow rate while audible monitoring was performed.

2. Termination of pressurization at prescribed steps to allow careful audible leak checks.

3. Pressurization to the maximum test pressure at which time bubble solution checks were made.

4. Tagging and recording of detected leaks followed by rinsing of the connector with distilled water and drying.

5. Depressurization, inspection and repair of leaking connections.

6. Repetition of the above process until all of the leakage was eliminated.

If audible leakage was detected at any time in the operation, a quick evaluation of the leak was made and pressurization either continued or discontinued according to the severity of the leak. Initial checks were made with nitrogen and final checks were performed with helium, except for the tank checks which were made with nitrogen as the pressurant.

The first checkouts of S-IV at the Santa Monica production acceptance facility were on the Facility/Dynamics Stage (#2) and the All-Systems Test vehicle. The Facility/Dynamics Stage was an installation incorporating only those subsystems essential for propellant loading and tank pressurization. The All-Systems Test vehicle was an abbreviated version of the then current flight system and incorporated dummy (simulated) engines which were later replaced with Battleship RL-10A3 engines. It was immediately obvious that less than acceptable workmanship had been performed in installation and assembly of pneumatic components. Lack of experience was a significant factor. While leakage was prevalent throughout the installations, the major problem areas were at the Marman conoseal connections, the metal boss sealed connections, and the pressure actuated flange sealed connections.

These problems persisted through subsequent stage checkouts until the following actions were taken:

1. The metal boss seal was eliminated altogether from the ambient helium subsystems and replaced with MS 28777 rings and/or MS 28778 packing.

2. A search for a replacement of the pressure actuated flange seal was initiated and culminated in the procurement of the Creavy Astro-Seal. The Creavy Astro-Seal is a bolted flange-type aluminum seal incorporating a close-wound Inconel spring, enclosed by a teflon sleeve. This is bonded to the inner periphery of the seal. The sealing qualities of this seal were excellent and eliminated all problems at bolted flange connections. An additional benefit of this seal is that it may be reused with no deleterious effect on its sealing qualities, assuming no damage to the element.

3. Careful monitoring of the Marman V-Band Coupling installation revealed malpractices in the installation of the seal. Wrong indexing and/or inadvertent slight deformation were occurring during positioning of the seal. These malpractices were corrected and resulted in faster repairs of leaking connections and, subsequently, better first installations.

4. Checkout personnel received proper training and instruction and were certified by process engineering in all aspects of pneumatic and cryogenic systems installations.

These corrective actions by no means eliminated all these problems, but they minimized them to an acceptable degree.

The major remaining problems were the use of the metal boss seal in the cold helium subsystems and the V-Band couplings on the 1-1/2" fuel tank pressurization tubing. Throughout the remainder of the program, leakage problems were concentrated in these two areas.

Two other problems experienced on the S-IV Program were:

1. Procurement of a poor quality lot of NAS 1367 fittings and their eventual use in a couple of stages before the problem was isolated. The molybdenum disulfide coating was of inferior quality and flaked off during normal assembly and disassembly of components. System contamination and malfunction of components resulted.

2. Procurement of a lot of sleeves and "B" nuts that had been heat treated per the wrong process. These elements later had to be replaced.

Leak checking of the initial system installations revealed an excessive amount of connector leakage. Much of this leakage was of a severe type. There seemed to be no consistency in the type of connector affected -- the consistency was in the prevalence of leakage. Repairs of the leaking connectors seemed to be a hopeless task at first. Torque checks, retorquing, disassembly of connections with replacement of seals seemed to have little effect in reducing leakage. An evaluation of corrective actions was immediately initiated. Process engineering was requested to review their torque standards for adequacy in this application. On-the-spot demonstrations and instruction on assembly of separable connectors, torquing of fasteners, and lubrication of fittings, and seals were presented by process engineering for the benefit of checkout technicians and assemblers. Close (magnified) visual inspection of tube flares, fittings, and seals was performed on specimens that had been assembled, repaired and disassembled. Component bosses were also inspected with fittings installed and removed. No particularly significant discrepancies were discovered, except for a suspicion of the torquing and growing belief that the metallic boss seal used on port connections was a poor application.

A step-by-step analysis of the installation process was undertaken by checkout engineering in an attempt to isolate any possible discrepancies in methods, practices, or techniques. A possible discrepancy was noted in the normal installation process which consists of: (1) installing the individual components on the stage as they become available, (2) connecting mating parts as continuity is achieved by tightening fasteners to finger pressure, (3) afixing of an inspection seal to the connection, and (4) when the assembly or subassembly is completely installed, the installation is torqued to the proper values. Upon completion of torquing, the connections are torque striped, where authorized.

Standard practices call for initial torquing to the minimum allowable value; when leakage is present this allows retorquing to the nominal and if necessary, retorquing to the maximum value. The technician performing the component installation and assembly is not necessarily the one performing the torquing. Many instances of failure to install seals were recorded and there was much evidence to indicate that seals were poorly installed, substandard parts were installed, lines were assembled in a preloaded condition, and a significant number of cases in which fasteners were not torqued but torque stripes were applied.

Douglas technicians performing torquing operations on contract end items must be trained and certified by Process Engineering or else be supervised during the torquing operation by certified inspection personnel. This is an area where a high degree of skill and knowledge is required. These requirements are not always met, and this is why checkout becomes so necessary!

An item worth noting here is that in a majority of cases the personnel doing the installation and assembly of fluid systems are never cognizant of whether their work is poor, average, good, or excellent. Unless one performs a leak check of fluid line connectors, one can never be certain whether the connections are leak free. In the Saturn Program at Douglas, checkout technicians were normally not engaged in performing initial installation and assembly. At the end of the S-IV Program (factory checkout phase), the checkout technicians were, generally speaking, much superior to the average installer or assembler in the quality of their work. They had a higher incentive, were very aware of the problems involved in making good installations, and exhibited a high degree of pride in workmanship.

It should be pointed out that as the S-IV Program proceeded, the propulsion system grew in extent and complexity. The number of separable connectors was probably doubled from the first conception of the flight system to the final design as it evolved from the manufacturing process, checkouts, static firing, launches, and added mission requirements. Simultaneously, improvements in installation and over-all decrease of leakage occurred. In summary, the success of the S-IV stage in flight and ground operations to this time is an excellent demonstration of the effectiveness of the connectors employed in the propulsion system. There is, of course, always room for improvement and mission requirements must always dictate applicability and appropriateness of hardware.