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DISCONNECT COUPLING DESIGN CRITERIA FOR FLUORINE CONTAINING OXIDIZERS

P.W. Van Horn and G.F. Dole

Technical Report AFRPL-TR-67-149
June 1967

AIR FORCE ROCKET PROPULSION LABORATORY
Research and Technology Division
Air Force Systems Command
Edwards, California

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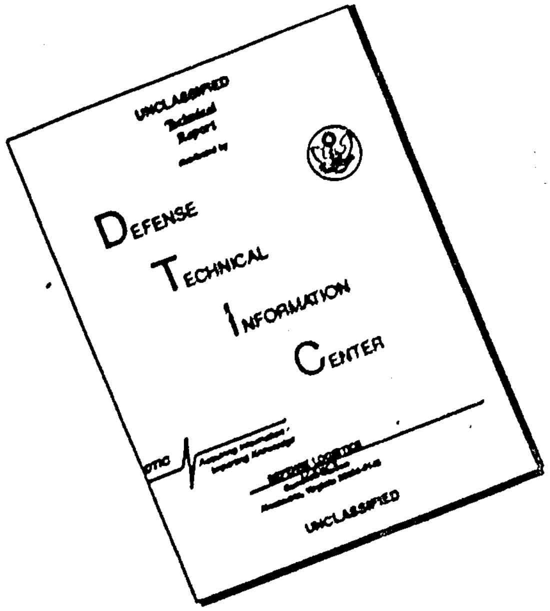

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NOTICES

ERRATA FOR APPENDIX XII (page 1 of 2)

AFRPL-TR-67-149 DISCONNECT COUPLING DESIGN CRITERIA FOR FLUORINE CONTAINING OXIDIZERS

Page No.	Part No.	Stock Size	Material Description
398	1D00804	4-3/4 Dia x 4.75	CRES BAR, 304L, QQ-S-763
399	1D00805	3-1/2 Dia x 2	CRES BAR, 304L, QQ-S-763
402	1D00808	4 Dia x 2-1/4	CRES BAR, 304L, QQ-S-763
404	1D00810	1 x 10.25 x 10.25	CRES PLATE, TYPE 321, MIL-S-6721
405	1D00811	7/16 Hex x 1.50	CRES BAR, 304L, QQ-S-763
406	1D00812	1-1/4 Dia x 3	CRES BAR, 304L, QQ-S-763
407	1D00813	1-1/4 x 4 x 7	AL PLATE, 2024-T351, QQ-A-250/4
408	1D00814	2-1/4 Dia x 6.5	CRES BAR, A286, AMS 5737
409	1D00815	0.651 x 1.5 x 3.25	AL BAR, 2024-T351, QQ-A-225/6
410	1D00816	0.50 x 1 x 2	AL BRONZE BAR, QQ-B-679
411	1D00817	0.31 Dia x 1.75	CRES BAR, 304L, QQ-S-763
412	1D00818	0.032 Dia x 24	CRES WIRE, TYPE 302, QQ-W-423
413	1D00819	0.187 x 2.5 x 2.5	SHT. INCONEL 718, AMS 5596
414	1D00820	2.50 Dia x 0.25	CRES BAR, 304L, QQ-S-763
415	1D00821	1-3/8 Dia x 0.50	CRES BAR, 304L, QQ-S-763
416	1D00822	1-3/8 Dia x 2.75	AL BAR, 2024-T351, QQ-A-225/6
417	1D00823	1-1/2 Dia x 1.25	CRES BAR, 304L, QQ-S-763
418	1D00824	0.112 x 3 x 3	CRES SHEET, TYPE 321, MIL-S-6721
419	1D00825	1.38 Dia x 0.50	CRES BAR, 304L, QQ-S-763
420	1D00826	0.090 x 3 x 3	AL SHEET, 1100-0, QQ-A-250/1

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Page No.	Part No.	Stock Size	Material Description
421	1D00827	1/4 x 3 x 3	AL PLATE, 1100-0, QQ-A-250/1
422	1D00828	3.75 Dia x 1.0	CRES BAR, A286, AMS 5737
423	1D00829	1/2 x 1.25 x 4	CRES BAR, A286, AMS 5737
424	1D00830	1 x 1.5 x 4	CRES BAR, A286, AMS 5737
426	1D00832	1 x 1.5 x 4	BAR, RENÉ 41, AMS 5713
427	1D00833	5/8 Hex x 1.50	CRES BAR, A286, AMS 5737
428	1D00834	5/16 Dia x 1.25	CRES BAR, AM 355, AMS 5743
429	1D00835	9/16 Dia x 2.5	CRES BAR, A286, AMS 5737
430	1D00836	5/8 Dia x 3.25	CRES BAR, 304L, QQ-S-763
433	1D00839	12 O.D. x 10 I.D. x 2.25	TEFLON TUBE, AMS 3651
434	1D00842	3-1/2 Dia x 2.5	CRES BAR, 304L, QQ-S-763
436	1D00844	0.81 Dia x 5.5	CRES BAR, A286, AMS 5737
438	1D00846	1 SQ. x 1.25	CRES BAR, A286, AMS 5737
439	1D00847	2 Dia x 0.75	CRES BAR, A286, AMS 5737
440	1D00848	1/4 Dia x 1-1/2	AL EXTR, 2024-T4, QQ-A-200/3
441	1D00849	2 x 12.25 x 12.25	AL PLATE, 6061-T651, QQ-A-250/11
442	1D00850	1/2 x 10.25 x 10.25	AL PLATE, 6061-T651, QQ-A-250/11

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MISSILE AND SPACE SYSTEMS DIVISION
Douglas Aircraft Company
Santa Monica, California
Douglas Report DAC-58548

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AIR FORCE ROCKET PROPULSION LABORATORY
Research and Technology Division
Air Force Systems Command
Edwards, California

FOREWORD

This is the final report on the Disconnect Coupling Design Criteria for Fluorine Containing Oxidizers Program, performed by the Douglas Aircraft Company for the Air Force Rocket Propulsion Laboratory under Contract AF-04(611)-10798, dated 3 May 1965. The period of performance covered by this report is from 1 July 1965 to 15 April 1967. J. R. Lawrence (RPRP) was AFRPL Project Engineer.

Douglas personnel who contributed to the reported effort are G. F. Doel; Dr. W. D. English, Ph.D.; J. W. Orr; A. R. Rowswell; H. H. Spieth; and P. W. Van Horn, who served as Project Engineer.

The report has been given Douglas Report No. DAC 58548. It has been reviewed and is approved.

James R. Lawrence
Sr. Project Engineer

ABSTRACT

This report documents the results of a study conducted to define criteria for quick disconnect (QD) couplings for use with fluorine and fluorine containing oxidizers. For this study a number of vehicle systems were examined to determine the fundamental requirements for couplings. Identified are the requirements imposed on a typical upper stage oxidizer fill-and-drain QD by vehicle and AGE considerations and disconnect technology capabilities. It was determined that remote coupling of the disconnect was neither necessary nor desirable, that the coupling should remain connected until vehicle launch is committed, and that the coupling should not provide oxidizer flow control or fluid shutoff provisions.

Design development and criteria demonstration tests were conducted using both liquid nitrogen and liquid fluorine on two test model QD's during the Phase II portion of this study. Specifically studied were the parameters influencing leakage, connect/disconnect, the draining and purging of fluorine, and compatibility. A detail specification was prepared along with detail drawings for a prototype QD coupling based on the criteria of Phase I and the test results of Phase II. One prototype QD was fabricated and acceptance tested prior to delivery as a part of this contract. The criteria established has been demonstrated by design, fabrication and testing of a fluorine QD.

The primary conclusion resulting from this program is that the design criteria established have provided a quick disconnect that is capable of servicing vehicles utilizing liquid fluorine.

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SECTION I

INTRODUCTION

The awareness of the potential of high-energy propellants for use in advanced propulsion systems has stimulated considerable interest in the possible application of fluorine or oxidizers containing fluorine. Such use would require the establishment of design criteria for use in the design of vehicle support hardware. Of particular significance is the vehicle-to-ground oxidizer servicing line interface connector, which is usually a quick-disconnect (QD) coupling, because its design criteria are dictated by both vehicle and aerospace ground equipment (AGE) requirements and considerations. These criteria also directly influence both vehicle and support equipment design.

This has prompted the Air Force Rocket Propulsion Laboratory to initiate a three-phase program to (1) define criteria, (2) design, develop, and test two test model couplings, and (3) fabricate and deliver a prototype coupling for use with fluorine. The Air Force indicated its intent in the following paragraphs from Exhibit A of the contract*:

> This effort is intended to provide criteria to support the servicing requirements for future military space vehicle propulsion systems as well as existing weapon systems considered for upgrading for use with fluorine-containing oxidizers, and establish design criteria for quick disconnects for use with fluorine, fluorine compounds, or mixtures containing fluorine.
>
> The Requirements Section of the contract contains the following:
>
> "The couplings to be designed and fabricated in this procurement are intended for use at a launch complex and will be used to connect an AGE propellant servicing line to a line on the vehicle for loading or unloading propellant. This will consist of a flight assembly which will be mounted as an integral part of the vehicle structure and an AGE assembly which will be a part of the servicing system."

The high toxicity and reactivity of these oxidizers imposed the most severe and restrictive requirements on the coupling: low leakage and the use of compatible materials. The last requirement all but eliminates the use of nonmetallics as primary sealing and valve seat materials. Further, these reactive and toxic characteristics demand that the device be extremely

*Contract AF 04(611)-10798, dated 3 May 1965 effective and be reliable in its sealing mode of operation. On the other hand, the possibility of such requirements as misalignment, remote connection, and so on, increase coupling complication and reduce inherent reliability.

The contracted program was divided into three Phases: (1) fluorine quick disconnect requirements, (2) test model quick disconnect development, and (3) prototype quick disconnect development, which are reported in detail in sections II, III and IV, respectively. The Phase I activity has also been documented in a special Phase I report, dated June 1966. That report is identified as follows: Disconnect Coupling Requirements for Fluorine Containing Oxidizers, AFRPL-TR-66-89, Douglas Report No. DAC-59241.

Phase I activity reviewed a number of systems and components in selecting a theoretical fluorine-hydrogen upper stage vehicle system as a model upon which to establish coupling requirements. This approach identified the requirements imposed on the QD coupling by vehicle and AGE considerations, and simultaneously identified disconnect technology capabilities. Phase I is summarized in Section II, 3.0, as a listing of established criteria.

Based on the results of the Phase I effort, two test model QD couplings were designed and tested in Phase II. The testing served two primary functions: (1) to demonstrate the applicability of the Phase I criteria, and (2) to evolve basic design data for the various elements of a fluorine QD. Liquid and gaseous fluorine and nitrogen were used in the Phase II testing.

From the data generated during Phases I and II, a prototype QD coupling was developed in Phase III. This included: (1) the preparation of a Preliminary Contract End Item (CEI) Specification, (2) detail design, (3) fabrication, and (4) acceptance testing of the prototype coupling.

The design criteria thus established and documented in this final report are for the specific requirements imposed by the fluorine-hydrogen upper stage study vehicle. Further, the criteria have, wherever possible, allowed for maximum flexibility in design and operation. Also, these criteria are equally applicable for other fluorine containing oxidizers such as OF_2, N_2F_4, NF_3, etc.

SECTION II

FLUORINE QUICK DISCONNECT REQUIREMENTS

1. INTRODUCTION

Section II documents the Phase I activity which was conducted to establish the requirements for an upper stage fluorine fill-and-drain QD. A systems analysis approach was used to identify these requirements; i.e., the QD operational and functional requirements were determined from a synthesis of vehicle, AGE, launch facility, personnel, and regulatory agency considerations. The pertinent findings of this Phase I effort are summarized in 3.0 of this section.

1.1 General

Quick disconnect couplings (QD's) are separable connectors for use at the Vehicle/AGE interface. They are likely to be used in fluorine fill and vent systems when any of the following conditions are required:

Rapid connecting or disconnecting.
Remote disconnecting.
Breakaway connections.

A number of vehicle systems were examined to determine the fundamental requirements for couplings and the methods used to fulfill those requirements. Data for this effort were obtained from literature, government and industry contracts, and from studies and investigations conducted at Douglas.

Realistic data on launch facility regulations, toxicity imposed requirements, and toxic material dispersion phenomenon and prediction were gathered for the formulation of appropriate criteria for the use of fluorine and fluorine containing oxidizers in space vehicles. From these data, allowable leakage for the coupling was established.

1.2 Oxidizer Quick Disconnect Sub-Components

A necessary step in the process of estalishing design criteria for an oxidizer QD is the indentification of tentative elements and the definition of the purpose and probable requirements for each. If problem areas exist, they must be identified and effort expended to find suitable solutions. The most probable QD sub-components are presented in the following paragraphs.

a. Bodies

A QD necessarily consists of two halves; one half as part of the vehicle and the other as part of the AGE. The body of each is a shell that performs the functions of containing the fluid at its operating pressure, carrying loads imposed by its attached piping, and providing a mount to the supporting structure. Consideration should be given to making the vehicle-half the simpler and lighter weight portion when used to connect a servicing line to a flight vehicle. Other primary considerations for the body are its internal and external environment; for extreme temperature applications, the effect of temperature on the physical properties and dimensional changes of the material must be taken into account.

b. Interface Seal

The usual function of the interface seal is to prevent escape of internal fluid to the external surroundings. However, should the system operate with an internal pressure lower than the external pressure, or if the high-pressure potential alternates between the inside and outside of the system, it may be necessary to provide a seal that performs its function in the reverse direction or in both directions. The allowable leakage past the interface seal depends primarily on the type of fluid used in the system. For nonreactive fluids, such as air or GN_2, substantial leakage may be permissible. However, for highly toxic and reactive fluids, such as F_2, a near-perfect seal is essential. Limits of F_2 leakage are discussed in Section II, 2.1.2. An F_2 oxidizer system interface seal further requires that it be easily cleaned, inspected, and replaced. A multiple cycle life for the seal is highly desirable, but not necessarily an absolutely essential requirement.

c. Latching Mechanisms

The normal functions of the latching mechanism are to hold the two QD halves together, to supply the sealing load, to withstand external loads transmitted through the piping, and to separate reliably to allow the coupling to disconnect. On QD's that contain shutoff valves, the latching mechanism is sometimes utilized to hold the valves open. The latching mechanism may be operated manually or by remote control for either the connect or disconnect mode. Existing manually operated QD's usually utilize screw threads, ball locks, or collet type locks for latching. Remotely actuated couplings often use linear actuators; screw-thread connections cannot be conveniently used. Ball locks, collets, and toggle locks are adaptable to remote operation.

For application on a space vehicle using a highly reactive fluid such as F_2, it appears highly desirable to be able to disconnect the QD by remote control. Remote disconnecting has been demonstrated to be feasible on the Saturn IV-B and the Centaur vehicles. Remote connection of a QD on a space vehicle application is much more difficult because of the three dimensional space problem of bringing the two coupling halves together when considering the relative motions of the structures supporting the coupling halves during the mating process.

High-speed operation and protection from the fluid usually are not required during connection. Remote actuation requirements are discussed further in Section II, 2.2. Five possible latching schemes for providing manual connecting and remote disconnecting for an F_2 QD are presented in Section II, 2.2.4. The basic requirements for a latching mechanism for an F_2 QD are that it should be simple, reliable, and add minimum weight to the vehicle.

d. Valves

Valves are not a necessary requirement in a QD, but they may be included in one or both halves of the coupling. When included, they are used to help prevent entry of contamination into the system and to prevent fluid spillage or leakage when the coupling is disconnected or separated. Generally, the valves are spring loaded closed when the coupling is separated and are designed so that the actual mating and latching of the coupling opens them and holds them open. For special applications, the valves may be provided with an independent actuation system and may be used to control the flow through the QD. The basic requirements for valves are that they should operate reliably, be made of compatible materials, have minimum pressure drop under flow conditions, and provide a seal with tolerable leakage for the application. Design considerations for this type of valve are discussed in Section II, 2.1.4.

e. Actuators

Actuators are used when remote control of connecting or disconnecting of the valves is required. For an application on a servicing line to a space vehicle, the actuation mechanism would normally be included in the AGE-half of the QD to minimize vehicle weight. The actuator can be designed as an integral part of the QD; it can be component mounted on the exterior of the QD; or it can be component remotely mounted and connected to the QD with a linkage or cable system. Power to drive the actuator can be extracted from any available power source--peneumatic, hydraulic, electric, or chemical (including explosive). The basic requirements for an actuator are that it should be simple and operate reliably.

For use in remote separation of a fluorine QD, redundant actuators should be utilized. A pneumatic actuator would probably be a first choice for use with a fluorine system because it could be designed so that no incompatible materials would be introduced in the vicinity of the fluorine system. If an explosive device is used, it should be designed so that all products of operation are contained within it.

f. Purge, Vent, and Drain System

A purge, vent, and drain (PV&D) system is not a general requirement for QD's. However, for special applications, such as for use with toxic or reactive fluids, it may be required. There are several functions that can be performed with a PV&D system. It can be used for disposal of leakage past the interface seal. For a coupling utilizing valves in both halves, the PV&D system can be used for extraction of trapped air from the coupling separation cavity prior to flow and for extraction of trapped fluid from the same cavity after flow. Where the QD contains no integral valves and the primary shutoff valves are downstream of the QD, it will be desirable to use a PV&D system to expel the propellant from appropriate portions of the transfer system that contains the QD. Methods of performing this task are discussed in Section II, 1.3 and 2.3.3. The PV&D system also may be used to detect leakage past the primary valves prior to QD separation.

The basic requirement for a PV&D system for use in connection with a fluorine QD is that it be made of fluorine-compatible materials. Typical PV&D system components which would interface with the fluorine system are: connectors, check valves, shutoff valves, flex lines (bellows), seals and metal tubing. The same stringent cleaning requirements applicable to the main oxidizer system also would be applicable to this system. A further requirement is that the purge fluid must be fluorine compatible and free from contamination.

g. Shroud

A shroud is a shield or barrier used to provide a zone of isolation between a component and its normal environment. For the general application of QD's, it would not be required. However, for cryogenic applications it is useful, when combined with a dry gaseous purge, as a means of isolating the cold surface of the QD from atmospheric water vapor, thus preventing the buildup of ice, which could interfere with latch or valve operations. A shroud is also required with some PV&D systems. Further discussion of a specific shroud for a fluorine QD is presented in Section II, 2.2.

h. Bellows

Bellows offer flexibility to absorb thermal expansion and contraction, installation misalignment, structure deflection, and vibration. Bellows may find application in connection with a QD in several ways. A primary application is the main fluid line, which must be flexible to provide the movement required for alignment and connection of the QD halves and for QD separation. They may be used to provide both the preload and a pressure energized loading for the interface seal and to transmit motion for valve operation without the use of sliding seals.

The basic requirements for bellows when used in a fluorine oxidizer system include use of compatible materials, adequate fatigue strength at the environmental temperatures and flow conditions, and use of a shape that permits cleaning and inspection of all surfaces exposed to the oxidizer. Because of the thin material from which bellows are constructed, they are highly vulnerable to a drastic loss of strength if surface corrosion or pitting occurs; therefore, careful attention must be given to the selection of a compatible material for this element. It has been demonstrated that there is approximately a 30% reduction in the life expectancy of bellows when exposed to fluorine (see Reference 79). Because fluorine and FLOX are cryogenic, it is necessary to ascertain that any bellows materials used with these oxidizers have adequate physical properties at cryogenic temperatures. Bellows used for fluorine service should always be of the open convoluted type to facilitate cleaning. Welded nested bellows are extremely difficult to clean and to inspect for cleanliness and should not be used for this application. Lap welded seams in bellows, as well as multiple bellows, should also be avoided because of possible contaminant entrapment.

i. Leak Detection

A leak detector is not a general requirement for OD's. However, because of the high toxicity and reactivity of fluorine oxidizers, a means for detecting leakage and quantitatively monitoring atmospheric contamination is necessary. The permissible limits of atmospheric contamination from a luanch facility using toxic propellants are presented in Section II, 2.1. There are various ways in which leak detectors could be used advantageously at this type of facility. One would be to locate sensors at strategic points and to conduct a continuous or scheduled intermittent sampling of the atmosphere for F_2 contamination. For a specific component such as a QD, which because it is a separable joint may have a higher than average probability of leakage and because it is proposed to use an intert-gas purged shroud around the QD to keep atmospheric water vapor away, it may be desirable to use F_2 sensors to monitor the discharging purge gas for possible F_2 leakage through the QD interface seal and thus obtain the earliest possible indication of seal leakage. Another use for a leakage sensor is to monitor the F_2 concentration in the vent side of the QD PV&D system to determine when the oxidizer transfer line is adequately purged to permit QD separation. This same sensor could also serve as a failure indicator if the shutoff valve on either side of the QD did not close properly.

The basic requirements for a leak detector are that it reliably measure F_2 concentration, have a short response time, and have a reasonably long service life. Although some work has been done with F_2 leak detectors, actual experience is limited and an adequate system for use at a launch facility will undoubtedly require additional development. Several possible F_2 leak detection devices are discussed in Appendix VII.

1.3 Vehicle and AGE Requirements

1.3.1 General

The servicing of upper stage vehicles with oxidizers containing fluorine should be conducted under favorable meteorlogical conditions, with little or no release of the oxidizer, and under the direct control of qualified personnel. In general, the transfer equipment and techniques will be much the same as those presently used with liquid nitrogen and liquid oxygen. However, the toxic and reactive nature of fluorine severely limit material selection, require leaktight systems, and require ducting of vented oxidizer to safe disposal areas. Oxidizer filling and draining of the vehicle can be performed through the same Vehicle/AGE interface coupling; however, separate Vehicle/AGE interface couplings will be required in the oxidizer vent system.

In establishing specific requirements for these couplings, the following must be considered: interrelations between the location of the Vehicle and AGE oxidizer shutoff and isolation valves, requirement for, and location of, redundant valving, permissible quantities of toxic vapors that may be released into the atmosphere at time of coupling release, capability of the oxidizer drain and purge systems to reduce oxidizer concentrations to acceptable limits, need for remote connection, and need for remote and/or rapid release at time of disconnect. The discussion to follow covers the important and controlling aspects of these considerations.

1.3.2 Fluorine-Hydrogen Vehicle Model

Figure 2-1 represents a possible vehicle configuration for application to high-energy space missions. This theoretical configuration was used to afford a concise physical frame of reference upon which to base the ensuing discussions. A detailed discussion of such a fluorine-hydrogen stage can be found in Reference 35.

Propellants are fed to the engine through low-pressure ducting, A, as shown schematically in Figure 2-2. At engine shutdown, the LF_2 in the feed line is trapped between the tank-mounted valve, B, and the engine prevalve, C. The LF_2 in the vicinity of the engine is vaporized as a result of engine heat feedback, and the vaporized fluorine is displaced through the bleed line, D, into the tank to prevent excessive pressure buildup in the feed line during coast.

The fill line has a shutoff valve E, that seals the tank prior to launch. This valve is located close to the tank wall in the highly insulated portion of the system to keep liquid out of the fill line during coast, thereby reducing heat leakage into the system and minimizing the trapping of unusable oxidizer. The umbilical propellant transfer line is connected to the vehicle fill system with a QD coupling F, which does not have internal valves to trap oxidizer.

Both tanks are vented during propellant filling through separate vent lines connected to the vehicle sidewalls. Incorporated in each vent line is a shutoff valveG, that seals the tank prior to launch. This valve is located close to the tank, thereby reducing heat leakage into the propellant. The vent QD coupling H, does not have any internal shutoff provision, thus allowing emergency venting during the mission.

2. Detail Requirements

2.1 Sealing Requirements

2.1.1 General

The design criteria of a quick disconnect assembly suitable for fluorine service ideally includes a no-leak capability. Experience with the best designed QD assemblies developed for transfer of cryogenic liquids (or

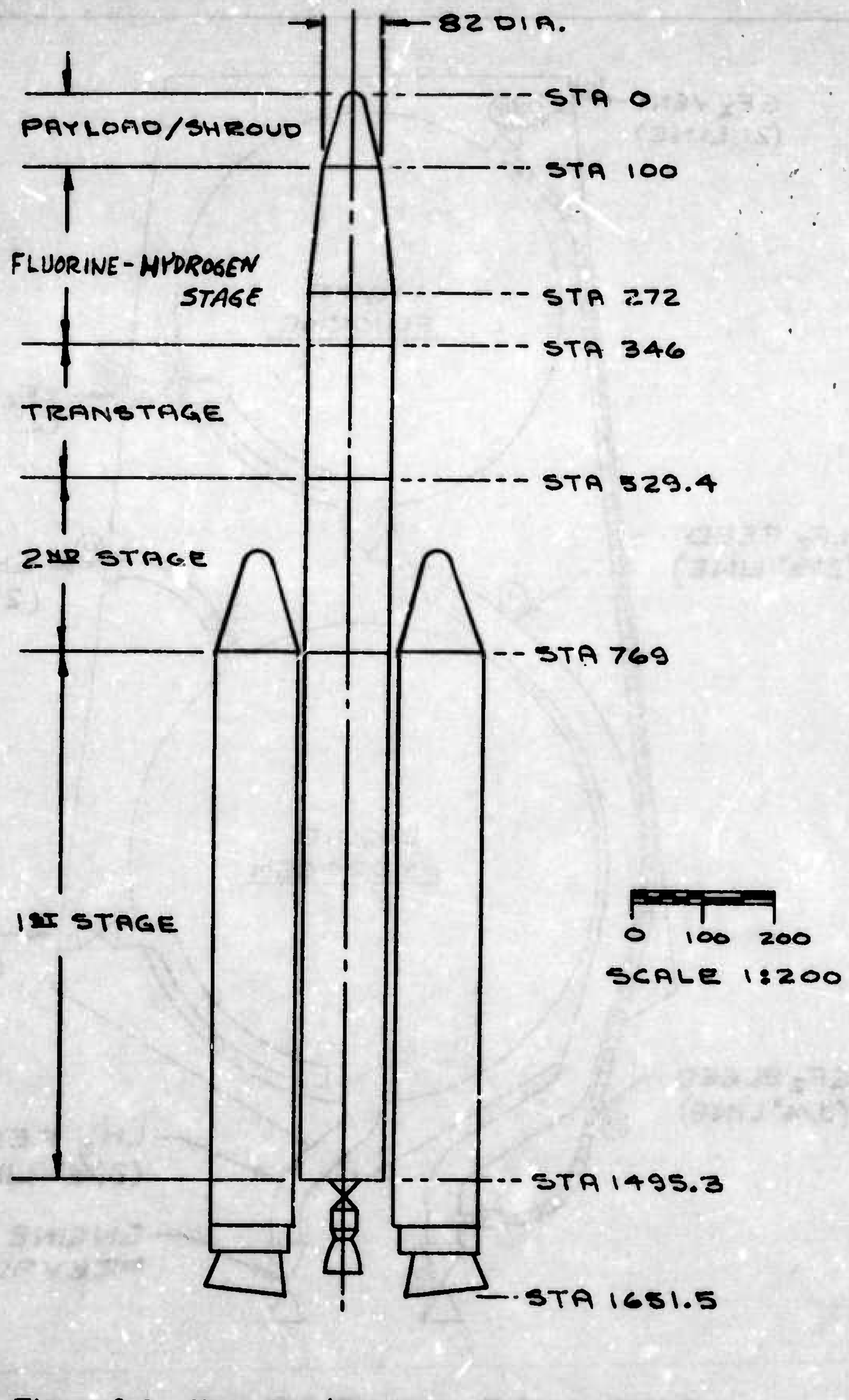


Figure 2-1. Titan III C/Fluorine - Hydrogen Vehicle

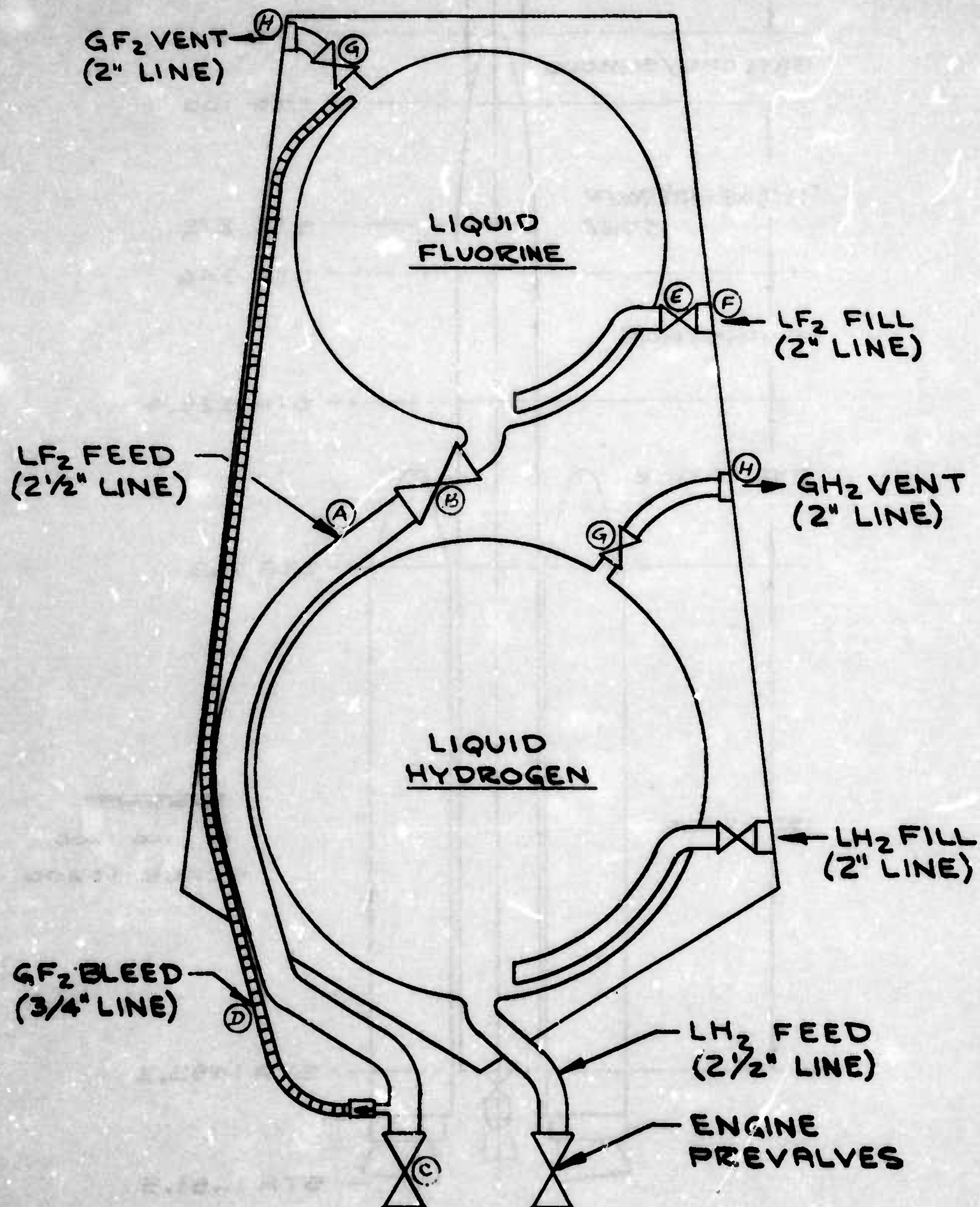


Figure 2-2. Fluorine - Hydrogen Vehicle Fill and Feed Schematic

corrosive cryogens) indicates that complete sealing to achieve repeated "no-leak" performance is virtually impossible.

A more realistic approach must accommodate the view that leaks are going to occur as a consequence of (1) limitations on seal efficiency during pressure and temperature cycling, (2) corrosive action action of the oxidizer on sealing surfaces (reactivity, effects of trace impurities, and so on), and (3) unanticipated mechanical malfunctions.

2.1.2 Allowable Leak Rate

The allowable leak rate, which should be as low as possible without prejudicing reliability, probably depends on considerations of the toxic hazards and possible hypergolicity problems arising from the intermixing of small amounts of oxidizer with fuel.

Few data are currently available to assess the true nature of the hypergolicity problem, but certain engineering design steps can be instituted to prevent mixing of oxidizer and fuel in the vicinity of the QD device, the service tower, and within the vehicle. These factors are discussed further in Appendix I.

When minor malfunctions or system anomalies occur, leak criteria are of importance since personnel may have to go into the area to correct the situation to continue a countdown or return the system to a standby condition.

The toxic hazard is the principal factor that must be considered, and a limiting value for the leak rate must be determined to define the engineering design requirements. An approach to defining an allowable leak rate follows.

Adopting a worst case rationale for a single point leak source, let the following conditions be assumed at the QD:

a. Absolutely stagnant (isotropic) atmospheric conditions; no temperature convection or wind or air movement.

b. Leak rates of fluorine (for example) ranging from 10^{-4} to 10^{-6} scim.

c. The leak is constant and originates from a single orifice or point.

d. Standard conditons of temperature and pressure exist.

e. Maximum allowable concentrations of fluorine from 1 to 3 ppm are in the vicinity.

Figure 2-3 shows the geometrical model for evaluating the rate of diffusion and mixing of fluorine with air and the rate of concentrational advance radially outward with time.

$$\nabla^2 \phi - \frac{1}{D}\frac{\partial \phi}{\partial t} + C = 0$$

where

ϕ is any function dependent on time (t) and distance (r),
D is the diffusion constant, and
C is a constant.

One solution of the above differential equation is:

$$\phi = \frac{1}{\sqrt{t^3}} e^{-\frac{r^2}{4Dt}}$$

where

r is the distance.

Partially differentiating ϕ with respect to time gives

$$\frac{\partial \phi}{\partial t} = \frac{e^{-\frac{2}{4Dt}}\, t^{-\frac{5}{2}}}{2}\left(\frac{r^2}{2Dt} - 3\right)$$

Now, ϕ is defined as the concentration.

At the time of maximum concentration

$$\frac{\partial \phi}{\partial t} = 0$$

and

$$\left(\frac{r^2}{2\,Dt} - 3\right) = 0$$

or

$$t = \frac{r^2}{6D}$$

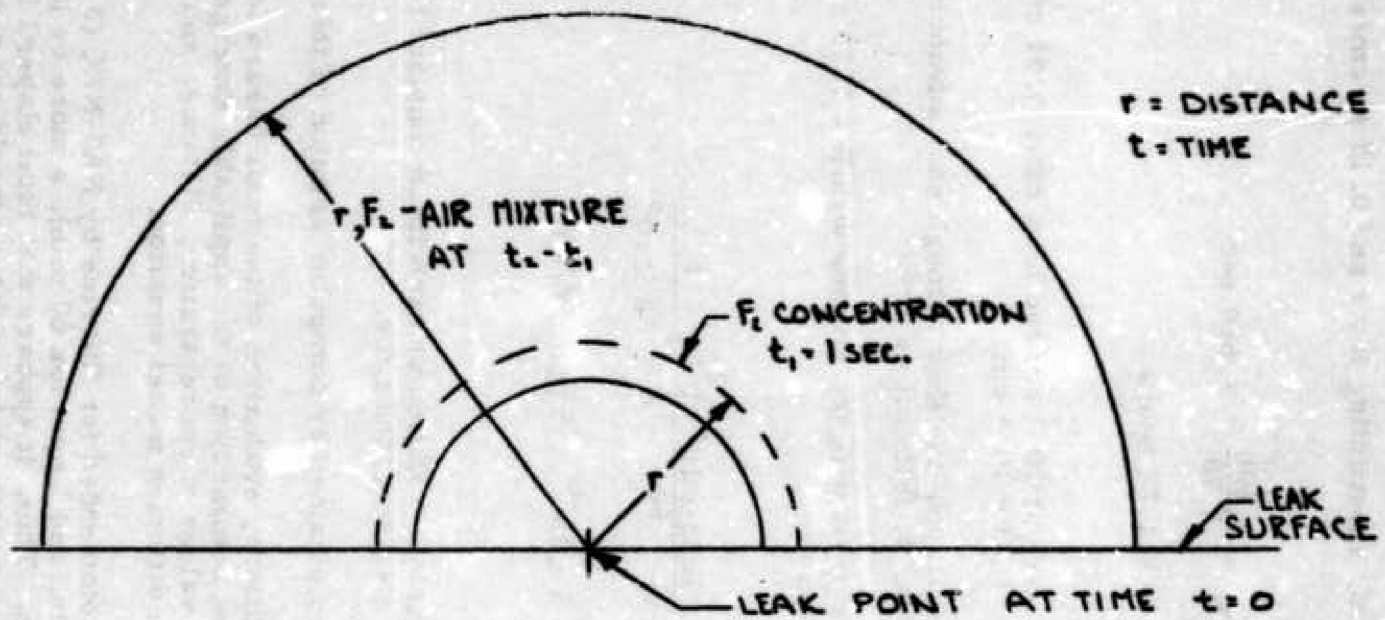


Figure 2-3. Diffusion Model for F_2 Leak

D, the diffusion coefficient, was estimated by the method of Othmer and Chen (Reference 4) using the critical molar volumes of fluorine and the average for air, giving 0.13 sq cm/sec.

At arms length, r ≈ 60 cm, substituting for r and 0.13 sq cm/sec for D in the last expression:

$$t = \frac{r^2}{6D} = \frac{3,600}{0.78} = 4,620 \text{ sec}$$

$$= 1.28 \text{ hours}$$

After the first sec, t + 1 sec, at 10^{-2} cc/sec leak rate, 0.01 cc occupies a volume with a radius $r = 1.33 \times 10^{-1}$ cm.

For steady state leak conditions, the flow through each advancing shell is a constant concentration, ϕ, falls off as r^{-2}.

Assuming that pure F_2 is present in the volume with $R = 1.33 \times 10^{-1}$ cm at t + 1 sec arms length (60 cm)

$$\phi \frac{F_2}{Air} = \left(\frac{1.33 \times 10^{-1}}{60}\right)^2 = \frac{1}{2 \times 10^5} \quad (2)$$

$$= 5 \times 10^{-6} = 5 \text{ ppm (V/V)}$$

occurring in 1.28 hours.

The formula provides a unique solution at each fixed constant leak rate in terms of concentration, distance, and time.

Table 2-1 lists the values obtained by computer solution of this equation.

Under the assumed conditions, evaluation of the toxic hazard for close emergency work requires comparison of the applicable Emergency Exposure Limits (EEL's) with the values of concentration, distance, and elapsed leak time calculated from the diffusion model equation.

Recalling the EEL's recommended for fluorine by NAS-NRC (3 ppm for 10 min, 2 ppm for 30 min, and 1 ppm for 60 min), a more or less objective comparison can be made. Thus, it appears that total elapsed leak times ranging from 0.6 hours to approximately 8 hours would not result in concentrations much above 1 to 3 ppm at approximately normal working distance (30 cm), when the leak rates are in the range of 10^{-4} or 10^{-5} scim.

Table 2-1

F_2 CONCENTRATION AS A FUNCTION OF DISTANCE WITH TIME OF DIFFUSION MIXING WITH AIR
(Based on Diffusion Model-Isotropic Conditions)

Concentration (ppm F_2)	Leak Rate (SCIM)	Distance (Inches)	Time (Hours)
1.0	10^{-2}	133.65	41.04
	10^{-4}	28.79	1.90
	10^{-5}	13.36	0.41
	10^{-6}	6.20	0.08
2.0	10^{-2}	94.50	20.52
	10^{-4}	20.36	0.95
	10^{-5}	9.45	0.20
	10^{-6}	4.38	0.04
3.0	10^{-2}	77.16	13.68
	10^{-4}	16.62	0.63
	10^{-5}	7.71	0.13
	10^{-6}	3.58	0.02

The worst-case isotropic conditions used to develop the argument for selection of a reasonable leak criteria would almost never occur in practice. Range safety would not permit operations to proceed without a minimum wind velocity and the proper wind shift and vertical temperature-lapse conditions predicted for assuring maximum safety.

As long as personnel avoid the down wind side of the leak and are cognizant of the safety rules, the hazard risk resulting from leaks on the order of 10^{-4} scim will be low. In any event, safety clothing and breathing gear will be required if downwind work is necessary for longer than a few minutes.

2.1.3 Sealing Schemes and Analysis

2.1.3.1 Mode of Interface Deformation

The compatibility requirement eliminates at this time plastics and elastomers from consideration as the primary seal material. Since metals must be used, the two surfaces to be forced together to form a seal may be either of the following:

Case I Superfinished to produce an elastically deformed sealing interface.

Case II Machine finished to a good surface and plastically deformed to produce a sealing interface.

The configuration for Case 1 is one of two flat mating surfaces as shown in Figure 2-4(a). When pressed together, sufficient force must be applied to elastically deform the peaks of roughness and waviness asperities so that leakage through any gaps and voids which remain is reduced to an allowable value. The low viscosity of the oxidizer vapor and helium leak-test medium to be used in the quick disconnect requires that remaining voids and gaps be extremely small, but, due to the nonhomogeneous nature of metals at the microscopic level, such gaps cannot be completely eliminated.

The configuration for Case 2 is a hard, wedge-shaped surface biting into a soft gasket as shown in Figure 2-4(b). When first contact is made, a high stress concentration develops at the contact points, and plastic deformation results. An increase in load causes plastic shear flow within the soft gasket, and the surface contact area around the circumference of the seal increases directly as the applied load. This bulk shear flow of the softer material results in close conformation of the mating surfaces whenever contact has been made. As in Case I, however, even the softer metals are not homogeneous, and leakage still results after the apparent contact area forms a complete line of contact at the sealing interface. Futher application of load increases the width of contact, decreasing the probability of interconnecting voids and thus decreasing leakage.

An analytic comparison of these two approaches shows leakage characteristics for various applied loads. The model for this analysis is shown in Figure 2-5, and the leakage equation is the same for both cases:

$$\text{Leakage} = Q = \frac{\pi D(Pi^2 - Po^2)}{12\mu\, PoL} h^3 + \frac{1.06\epsilon\lambda_o (Pi + Po)}{\mu L} Dh^2 \qquad (3)$$

where:

Q = leakage rate (in.^{3}/sec at STP)

D = mean diameter of seal; L = width of seal surface

Pi = internal pressure psia = 53.7

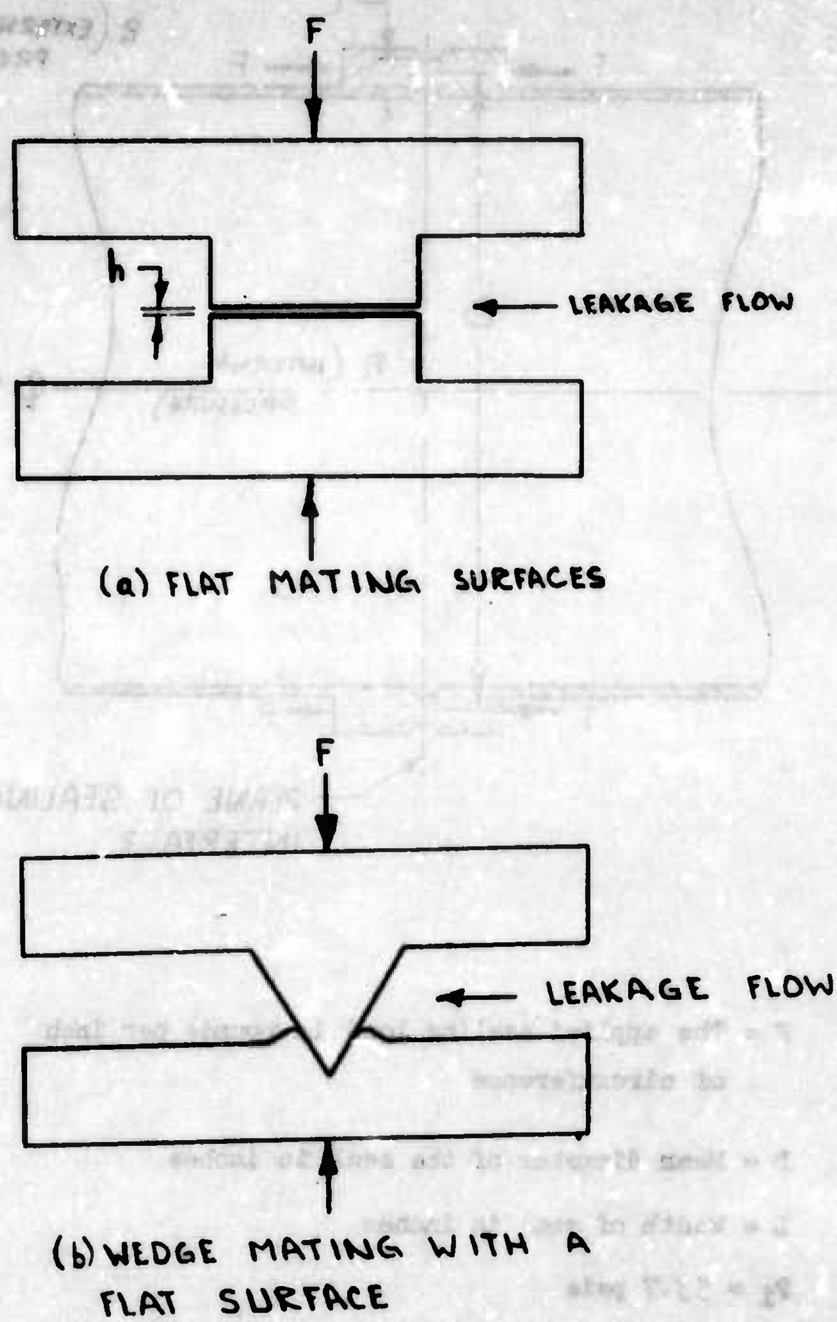
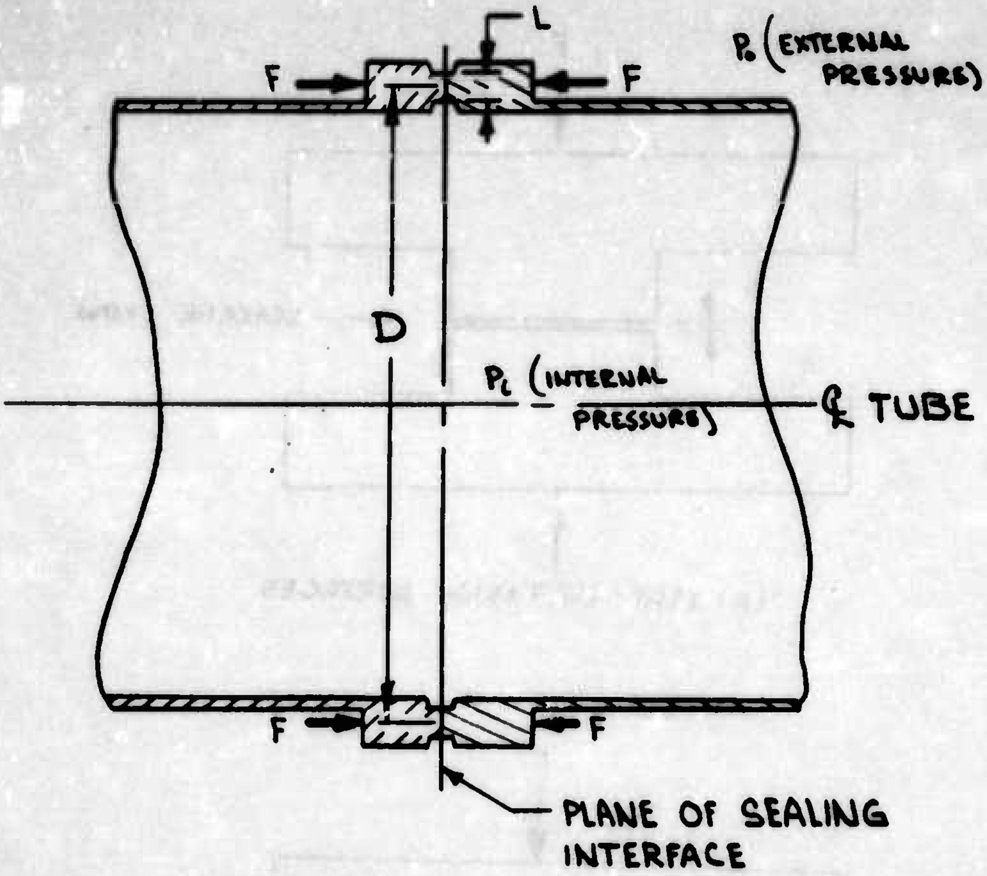


Figure 2-4. Seal Interface Configurations Model for Primary Seal Leakage Analysis



F = The applied sealing load in pounds per inch of circumference

D = Mean diameter of the seal in inches

L = Width of seal in inches

P_i = 53.7 psia

P_o = 14.7 psia

Figure 2-5. Model for Primary Seal Leakage Analysis

Po = external pressure psia = 14.7

μ = viscosity of leaking medium

$$He = 2.8 \times 10^{-9} \frac{\text{lb-sec}}{\text{in.}^2}$$

ϵ = correction factor, 0.9 for a single gas

λ = molecular mean free path, 13×10^{-6} in.

h^3 = conductance parameter, in.^{3}.

The conductance parameter is a measure of the effective separation distance of two sealing surfaces.

a. Determination of Leakage for Case I

Material properties for the two surfaces are assumed to be similar to 17-4 PH steel, and seal width (L) is assumed to be 0.006 in.

The empirical data developed in Reference 5 are used to determine the conductance parameter. A modified stress ratio is defined as:

$$\text{Stress Ratio} = \frac{(F)^{2/n'}/A_A}{\sigma m} \qquad (4)$$

where:

F = applied load lb/in.

A_A = apparent contact area = 0.006 in.^{2}/in.

σ_m = Meyer stress for the material = 238,000 psi

n' = Meyer index for the material = 2.2

then:

$$\text{Stress Ratio} = 0.0007(F)^{0.91}$$

Using this definition of modified stress ratio, Figure 2-47 of Reference 5 "Design Criteria for Lapped and Polished Surfaces," is replotted for the range of loads of interest in the QD coupling primary seal and appears as Figure 2-6 of this report.

The leakage Equation 1 is used, together with the conductance parameter from Figure 2-6, to express leakage versus applied sealing load; results are plotted in Figure 2-7.

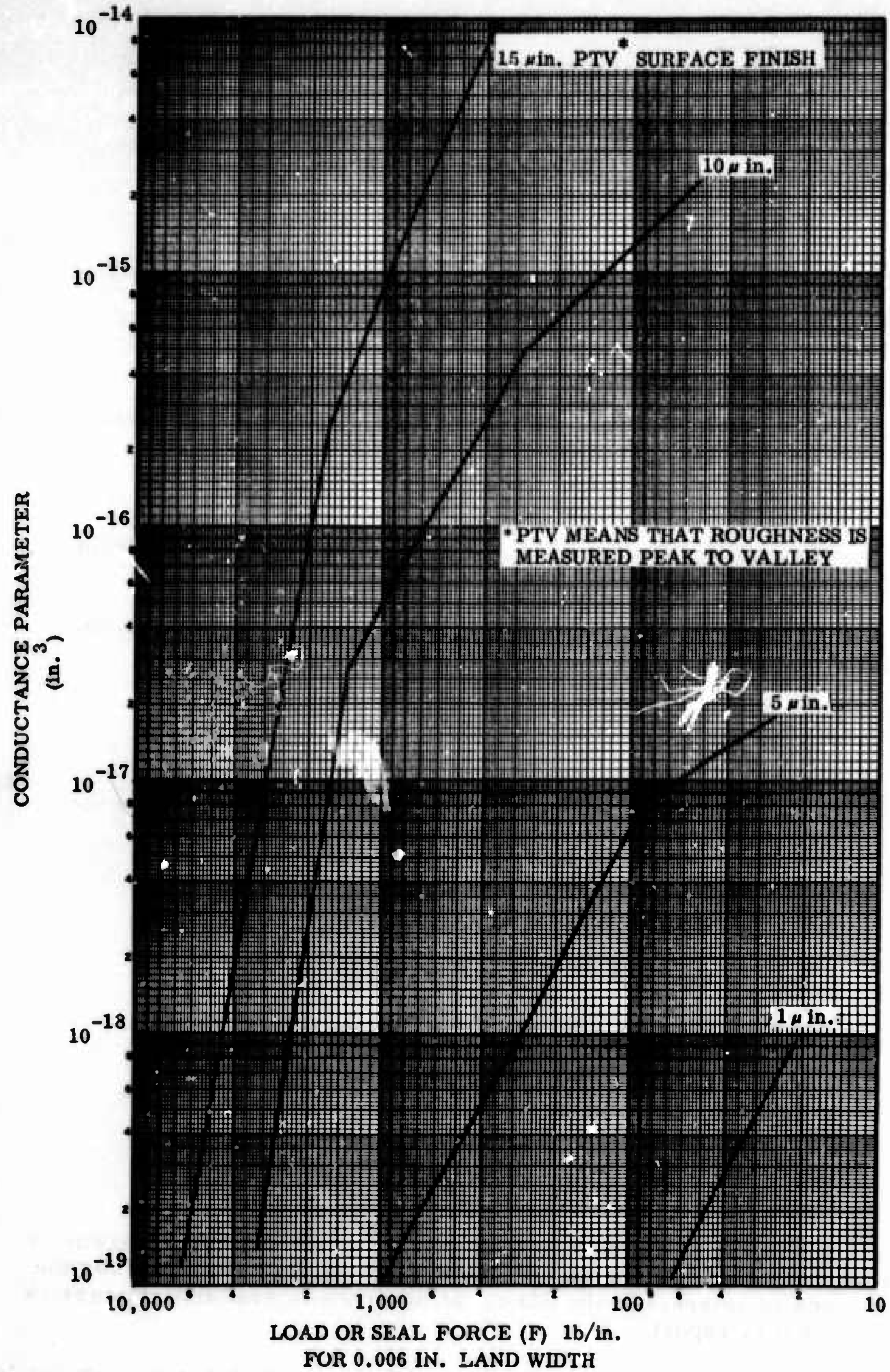


Figure 2-6. Conductance Versus Load for Case 1

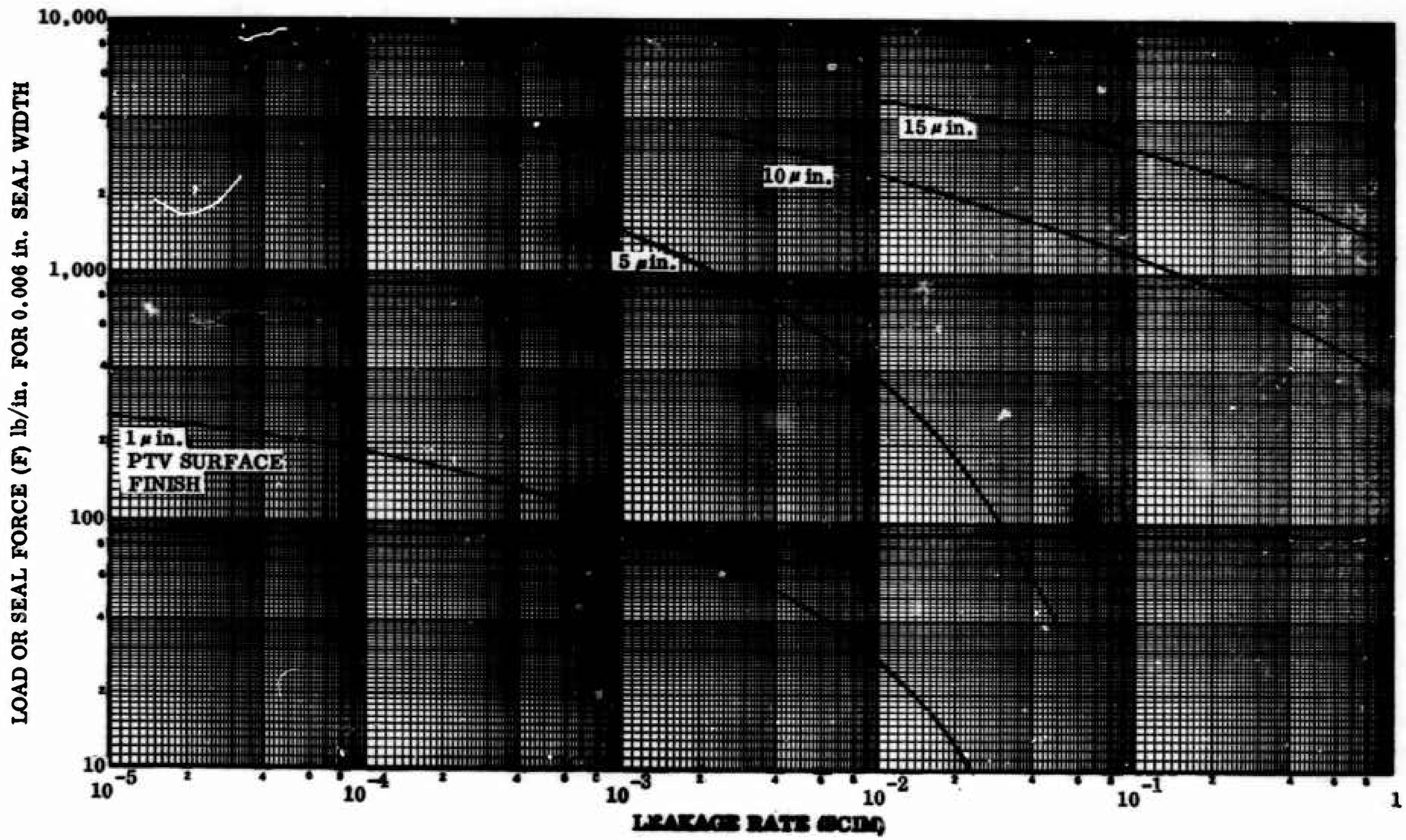


Figure 2-7. Estimated Helium Leakage for Case 1

b. Determination of Leakage for Case 2

Material for the soft (gasket) surface is assumed to be similar to 1100-C aluminum. Material for the wedge is assumed to be as hard or harder than 1141 steel.

As sealing load is applied, plastic deformation of the gasket causes the apparent contact area to increase. If the surfaces were perfect, leakage would approach zero at low sealing load. In the actual case, however, the load must be increased until the wedge cuts deeply enough into the soft metal to close all gaps caused by waviness and roughness asperities.

Tests have been conducted at Illinois Institute of Technology (Reference 5) which indicate load versus contact area relationships. The load versus leakage tests conducted and reported by the same source are so similar to the Case 2 model that the results can be used directly and are repeated here as Figure 2-8. Conditions for the load-leakage test were:

$P_i - P_o = 39$ PSI

Test medium = helium

Surface finish -- both surfaces were lathe turned with 0.003-in. spiral ridge

σ_m -- Meyer Stress, wedge = 308,000 psi

σ_m -- Meyer Stress, gasket = 49,000 psi

Comparison of Figures 2-7 and 2-8 shows that with an applied load of 200 lb/in., the desired leakage rate of less than 10^{-4} SCIM can be obtained by plastic deformation of the interface (Case 2) or by elastic deformation with a surface finish equal to or better than 1 μ in. (Case 1).

The superfinished surfaces of Case 1 have several disadvantages. They are difficult and expensive to fabricate, vulnerable to handling damage during transport and assembly, and susceptible to surface damage by corrosion. Further, the macroscopic geometry of the sealing surfaces must be held to extremely close tolerances, flatness, parallelism, etc., and warpage of sealing surfaces must be prevented.

Correspondingly, the wedge shaped surfaces of Case 2 are not as easily damaged as the superfinished surfaces since the actual sealing surface is generated by shear flow of the softer material during coupling.

2.1.3.2 Interface Geometry

The two basic choices available are flat mating surfaces and wedge-shaped surface mating against a flat surface. These are both axial seals as shown in Figure 2-9. A third choice, the radial sealing method used in the AFRPL "bobbin seal" would be simple and effective, but may jeopardize

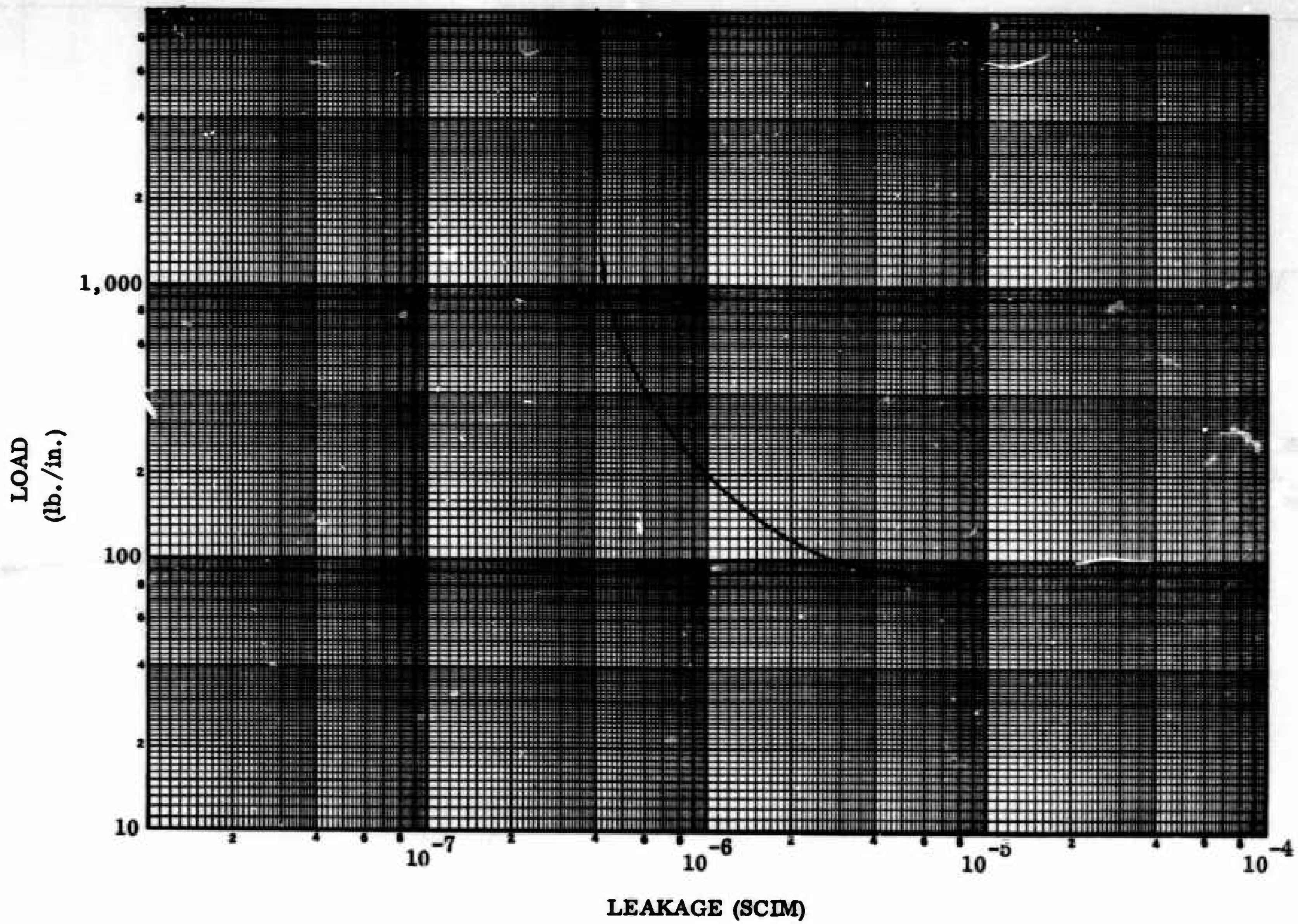


Figure 2-8. Estimated Helium Leakage for Case 2

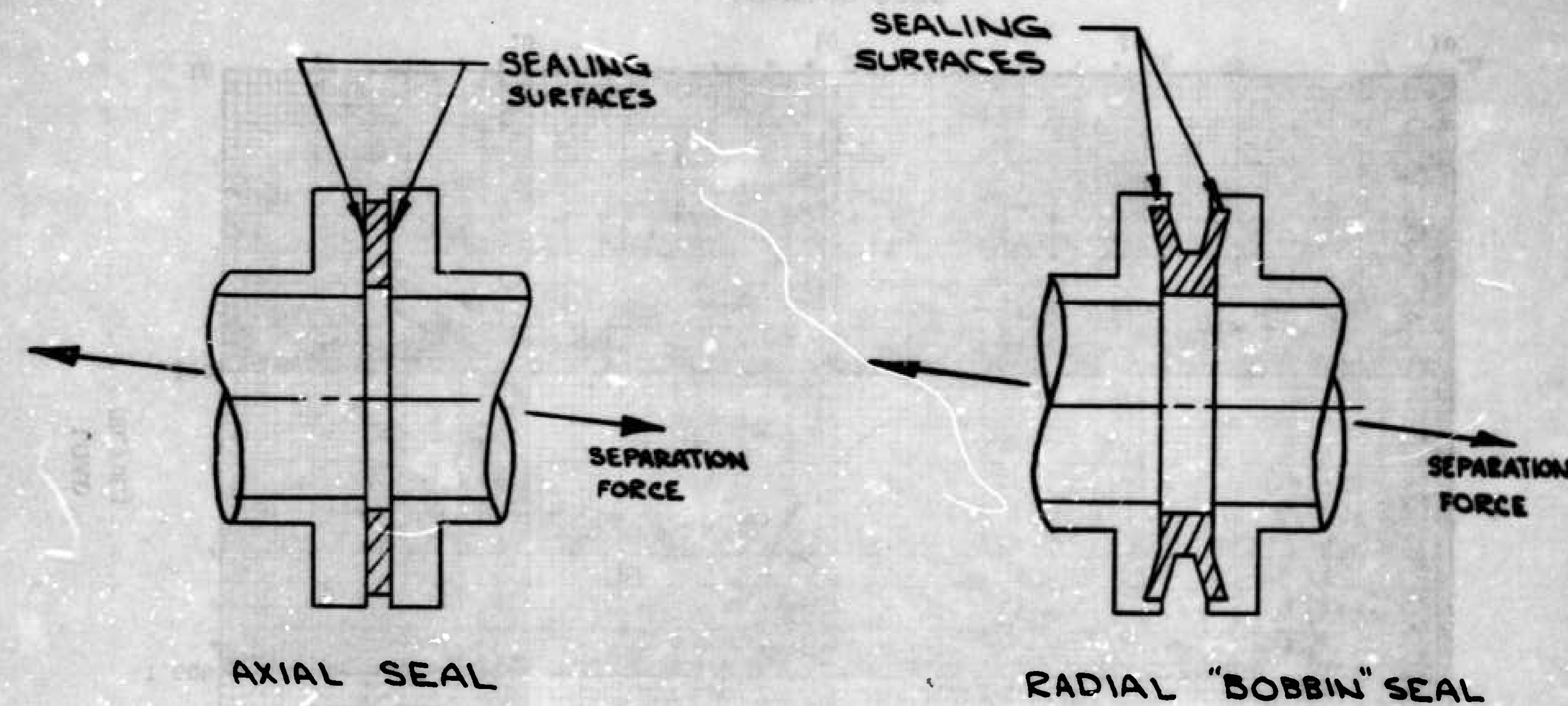


Figure 2-9. Axial and Radial Sealing Methods

a clean separation. Plastic strain of the seal material at the radial interface (Figure 2-9) does not relax when axial loads are removed and a separation force must be applied to shear the deformed seal material.

Flat surfaces (Figure 2-4a) require that a superfinish be manufactured on both halves of the seal and that these surfaces be maintained through assembly, handling, and installation of the connector.

The wedge mating against a flat surface (Figure 2-4b) provides the required concentration of stress to deform the roughness of a standard machined surface with minimum loads. It is essential however, that the soft surface be protected from handling damage until ready for use. It may have to be replaced before each recoupling. When these conditions are met, the wedge and deformable surface concept appears to meet all the requirements for quick-disconnect coupling seal, although other concepts may be equally appropriate.

2.1.3.3 Structural Configuration

If the required sealing interface loads can be applied and maintained as the loading and temperature environments vary, the structural configuration for this application is relatively unimportant. Oxidizer transfer will be at low pressures, which eliminates any advantage of pressure activated seals whose structural shape is most significant at pressure in excess of 2,000 psi.

During final design of the coupling seal, analysis of seal shape will be requred to relate the deformation of the seal structure to the load acting at the interface. For the case of a plastically deformed gasket, this includes determination of load versus deflection and optimum gasket thickness.

Several commercially available seals which provide the type of deformation necessary for sealing flat mating surfaces (Case 1) are shown in Figure 2-10. The surface finish on these commercial seals is approximately 5 μ in., and further surface finishing of the seals, if practical, would be necessary to provide the desired load-leakage characteristics. Figure 2-10d shows a soft metal gasket plastically deformed between hard metal wedges for sealing (Case 2).

2.1.3.4 Material Properties

All components of the primary seal must be compatible with dynamic liquid oxidizer. To ensure the desired plastic flow characteristics, it may be necessary to select a material such as aluminum for the soft gasket. Aluminum, however, has a moderate corrosion rate with hydrogen fluoride. Thus, extreme caution must be taken to preclude the induction of moisture through the sealing interface during periods subsequent to passivation or oxidizer flow.

2.1.3.5 Hysteresis

When two surfaces are pressed together under load as a seal, a given leakage may result. When the load is released, little change in leakage rate is noticed until the load is sufficiently relaxed, whereupon a significant

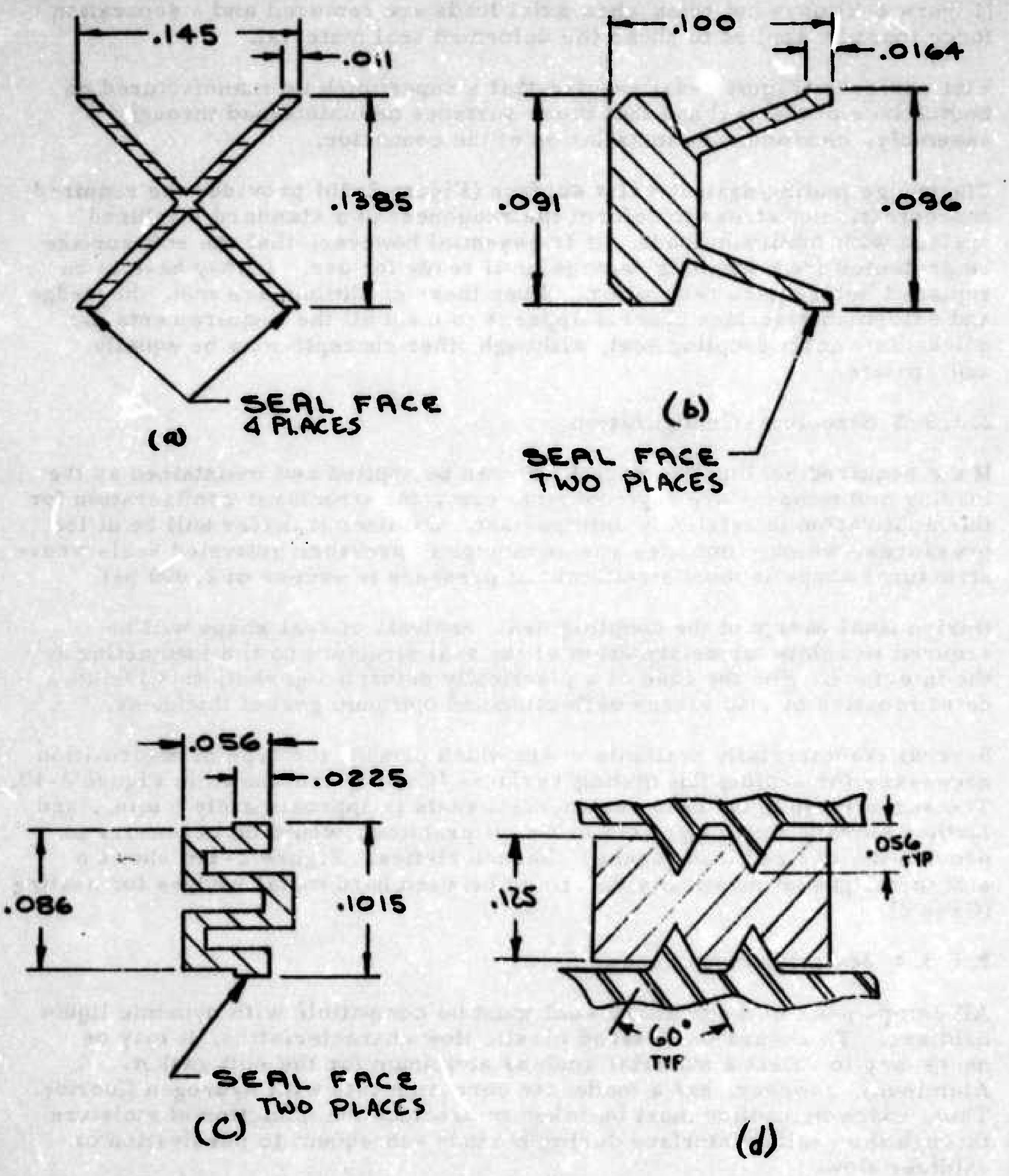


Figure 2-10. Commercially Available Seal Shapes

increase in leakage occurs. This lag in leakage increase as load decreases (hysteresis) is necessary to assure good seal performance when thermal gradients or dynamic structural stresses cause seal load relaxation. The maximum allowable load relaxation (without significant increase in leakage) depends on the maximum applied stress. Figure 2-11, taken from Reference 5, shows that a 50% reduction in the loads for the previously examined Case 2 can be effected with less than 50% increase in leakage. It is also noted from the same reference that if the surfaces are disjoined and rejoined in exactly the same position, full plasticity and, thus, good sealing will result if the sealing load is increased 5% of the original load.

2.1.3.6 Handling Damage

A seal design may be clearly optimum for the ideal conditions persent in a laboratory. A good seal design, however, must perform satisfactorily after being handled and assembled be experienced technicians.

If the surface hardness is at least DPH = 400 (diamond point hardness), a 220-lb load on the Vickers diamond will cause an impression approximately 0.004-in. deep and 0.020-in. wide. It is unlikely that a greater load would be applied or that a harder, sharper instrument would be used in damaging the surface. Damage resulting from careless handling procedures may take the form of a notch in the wedge of shape similar to that of the Vickers diamond impression. By using this as the model for leakage of a damaged surface, the hydraulic radius (ratio of flow area to the wetted perimeter) resulting from a notch 0.020-in. wide and 0.004-in. deep is 0.001 in.

For the case of a liquid fluorine seal, the damaged area may allow gaseous leakage if sufficient heat is available to vaporize the liquid as it flows through the leak path or, if the coupling body is prechilled, liquid leakage may result. In either case, gas or liquid temperature is assumed to be 150°R, and internal pressure 100 psia.

Gaseous fluorine flow through an orifice, assuming choked flow, is:

$$\dot{W}_g = CAP_i \sqrt{\frac{g\gamma}{RT_i}\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \qquad (5)$$

where:

$\dot{W}_g$ = gaseous flow rate lb/min.

A = $(0.001)^2 \pi$ in.^{2}

P_i = internal pressure = 100 psia

R = 5,861 in./°R (for fluorine)

T_i = 150°R

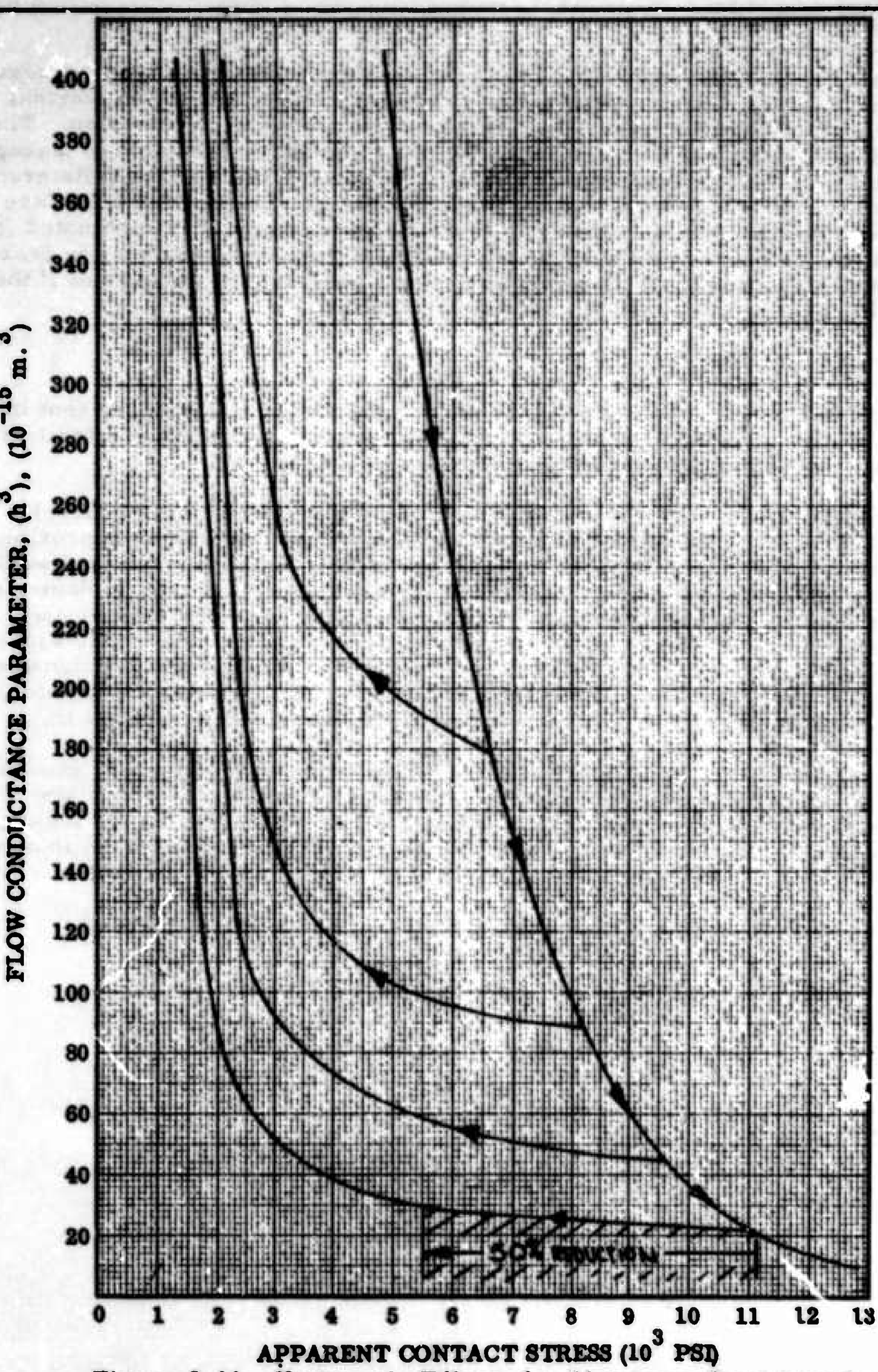


Figure 2-11. Hysteresis Effects for Aluminum-Steel Interface

g = gravitation conversion factor

= 1.39×10^6 in./min.^{2}

γ = ratio of specific heats for fluorine = 1.4

C = nozzle discharge coefficient = 0.95

then:

$$\dot{W}_g = 0.0087 \text{ lb/min.}$$

Liquid flow through the same orifice, assuming turbulent flow conditions, is:

$$W_L = \rho C A \quad 2g \frac{\Delta P}{\rho} \qquad (6)$$

where:

ρ = LF_2 density = 0.054 lb/in.^{3}

ΔP = 85.3 psi

then:

$$W_L = 0.00285 \text{ lb/min}$$

The density of fluorine gas at ambient conditions is 5.62×10^{-5} lb/in.^{3} so that the liquid leak corresponds to 50.8 standard cubic inches per minute (SCIM) and the gas leak corresponds to 15.7 SCIM. The plastic deformation of the soft metal gasket by a 60° wedge as shown in Figure 2-12 will tend to reduce the size of leak path caused by handling damage so these leakage estimates are somewhat larger than would be experienced in the real case.

It should be mentioned at this point that fabrication of a circular wedge surface with the apex in a flat plane is difficult. Test surfaces of Reference 5 typically varied 0.002 in. from the flat plane. Closer control of manufacturing methods will result in a probable tolerance of ±250 μ in. from a flat plane. The variation of the wedge surface, local roughness, variation of thickness of the deformable gasket, and handling damage to either surface can reduce the penetration of the wedge and result in excessive leakage. For this reason it is recommended that a redundant wedge be used to eliminate the possibility of leakage caused by the noted local surface imperfections.

Special handling is required for soft metal gaskets. Because clean replacement parts must be available, only a small additional cost will be incurred to provide an individual rigid container for each gasket. If the container remains unopened until just before installation, a clean, undamaged gasket will be assured.

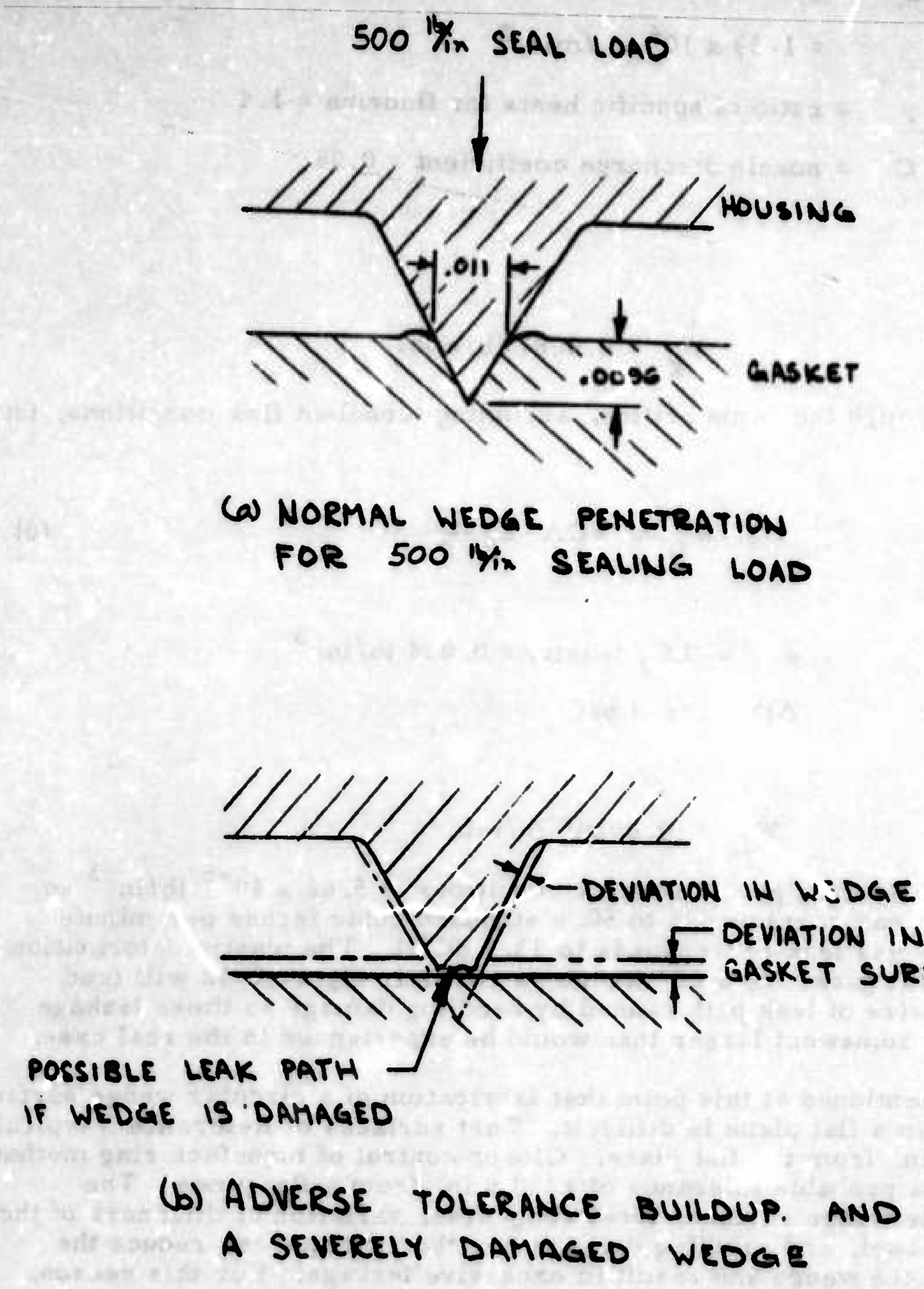


Figure 2-12. Plastic Deformation of a Soft Metal Gasket

2.1.3.7 Seal Housing Deformation

In addition to the structural forces applied by the missile and AGE to the connector, the variable thermal environment must be considered. The major effects of the thermal environment on the connector are as follows:

(a) Reduction in contact stress at the seal as a result of creep or relaxation of the attachment mechanism.

(b) Differential thermal expansion resulting from differences in material of the seal and housing assembly and from temperature gradients during initiation of flow of cryogenic fluids.

In general, the connector mechanism must be designed to provide the required sealing loads to the seal interface at all times. The mechanical and thermal effects on the final housing design should be evaluated to assure that thermal deformations acting in conjunction with mechanically induced loads will not cause relaxation of the sealing loads beyond the 50% allowed by hysteresis of the seal material.

2.1.3.8 Primary Seal Failure

After the coupling is connected and sealing load has been applied to the seal interface, a leak check must be accomplished. Helium or nitrogen can be introduced to the volume between the vehicle and AGE shutoff valves and system pressure applied. The coupling will probably not be separated again until propellants have been loaded and the vehicle is committed to lift off the launch support structure. If leakage should develop during the interim, the possible causes are as follows:

(a) Relaxation of the sealing load.

(b) Corrosion of the interface.

(c) Relative motion between the sealing surfaces.

(d) Structural failure of the seal material.

2.1.3.9 Structural Failure

Structural failure of the seal material is not probable if an adequate quality control procedure has been followed in selection of the material and during the manufacture of the coupling.

2.1.3.10 Relative Motion

If the two opposing surfaces which sandwich the gasket are allowed to move laterally with respect to each other, the possibility of breaking the seal exists. Either the gasket material will deform or sliding will occur at the interface. If sliding occurs, the microscopic contact is lost, probably opening a leak path. Transverse structural loads should not be carried by the seal if the coupling is properly designed, but differential thermal expansion resulting from dissimilar materials, gasket shape, or severe temperature gradients could cause relative motion. When the thermal gradient disappears, the seal may return to a different condition of stress equilibrium, with loads sufficiently reduced to cause increased leakage.

Dynamic relaxation of stress, caused by superposition of an alternating stress on a highly stressed region, could be significant if vibration and/or shock conditions are encountered during propellant transfer and valve shutoff. Leakage then results, as previously discussed, when sealing loads are reduced and surface contact is lost.

Because of the unknowns involved in the dynamic and thermal stress relaxation cases, it is recommended that a closed cavity external to the primary coupling seal be designed into the coupling from which a continuous or at least periodic sample can be taken to verify that there is no seal leakage before and during propellant transfer. This cavity can be continuously evacuated or purged and the vent gas disposed of safely in the event of leakage. If the vent gas is monitored, any fluorine leakage which might develop can be detected in time to avert a failure.

2.1.3.11 Summary

(a) The primary seal must be made of metal because it is exposed to liquid propellant flow.

(b) The primary seal must be designed for a leak rate less than 10^{-4} scim when tested with ambient gaseous helium at the expected system pressure. This value satisfies the "no-leak" specification of the Study Vehicle QD Requirements.

(c) Study of surface finish and load required to form a seal indicates that plastic deformation of one surface . the best method of sealing for this application.

(d) For the 100 to 500 lb per in. range of loads available for this application, a hard wedge acting on a soft aluminum surface provides an excellent seal.

(e) The circular wedges must be made of the hardest compatible material available. Hard materials will minimize mechanical handling damage.

(f) The possibility of liquid leakage will be reduced by the use of a redundant wedge.

2.1.4 Seat Analysis and Design

During the initial QD evaluation study, design and analysis were carried out to determine the capabilities of a poppet check valve, designed as an integral part of the QD vehicle half. Several concepts for the valve design were evolved and evaluated. One concept utilized spherical poppets and seats for the valve and another utilized spherical poppets and seats for the valve and another utilized flat poppets and seating surfaces. Conical mating surfaces for the valve were considered, but the conical concept was eliminated early because it appeared to be more vulnerable to the buildup of adverse tolerances during fabrication than either the flat or spherical configuration. Figure 2-13 is a concept of a 2-in. quick disconnect showing probable arrangement and size of poppet and seat.

2.1.4.1 Leakage Analysis

The following paragraphs discuss a preliminary analysis to estimate the leakage of a flat seat made from Inconel X with yield strength (y) in the range of 95,000 to 110,000 psi. In this analysis, surfaces of the poppet and seat are considered to be flat within 6 μ in. and smooth within 1 μ in. peak to valley (PTV). Waviness is considered to be surface variations with a wave length greater than 0.035 in. Also, the poppet must be angularly unrestricted so the surfaces will be parallel when closing. Case 2 is a baseline with the above restrictions; Case 1 and Case 3 will show the effect of changing surface finish variables.

The Reference 6 method will be used to predict leakage which requires use of the surface finish variable θ, a measure of the average asperity slope as well as h, the effective asperity height. Because slope is difficult to measure directly, this may be represented by:

$$\theta = \frac{2h}{\text{peak-to-peak wave length}} \tag{7}$$

The equation for leakage estimation is:

$$Q = \frac{4.71\, Ds \left(P_1^2 - P_2^2\right)}{\mu \ell T} \left\{ 1.36 \left[h - \frac{3}{4} \left(\frac{36\ ^2\, S^2 h^3}{\phi^2} \right)^{1/3} \right] \right\}^3 + \frac{1.42 \times 10^5\, Ds}{\ell} (P_1 - P_2) \sqrt{\frac{R}{T}} \left\{ 1.22 \left[h - \frac{3}{4} \left(\frac{36^2 S^2 h^3}{2} \right)^{1/3} \right] \right\}^2 \tag{8}$$

where:

Ds	= seat mean diameter	= 2.25 in.
P_1	= internal pressure	= 64.7 psia (max.)
P_2	= external pressure	= 14.7 psia (max.)
ℓ	= seat land width	= 0.006 in.

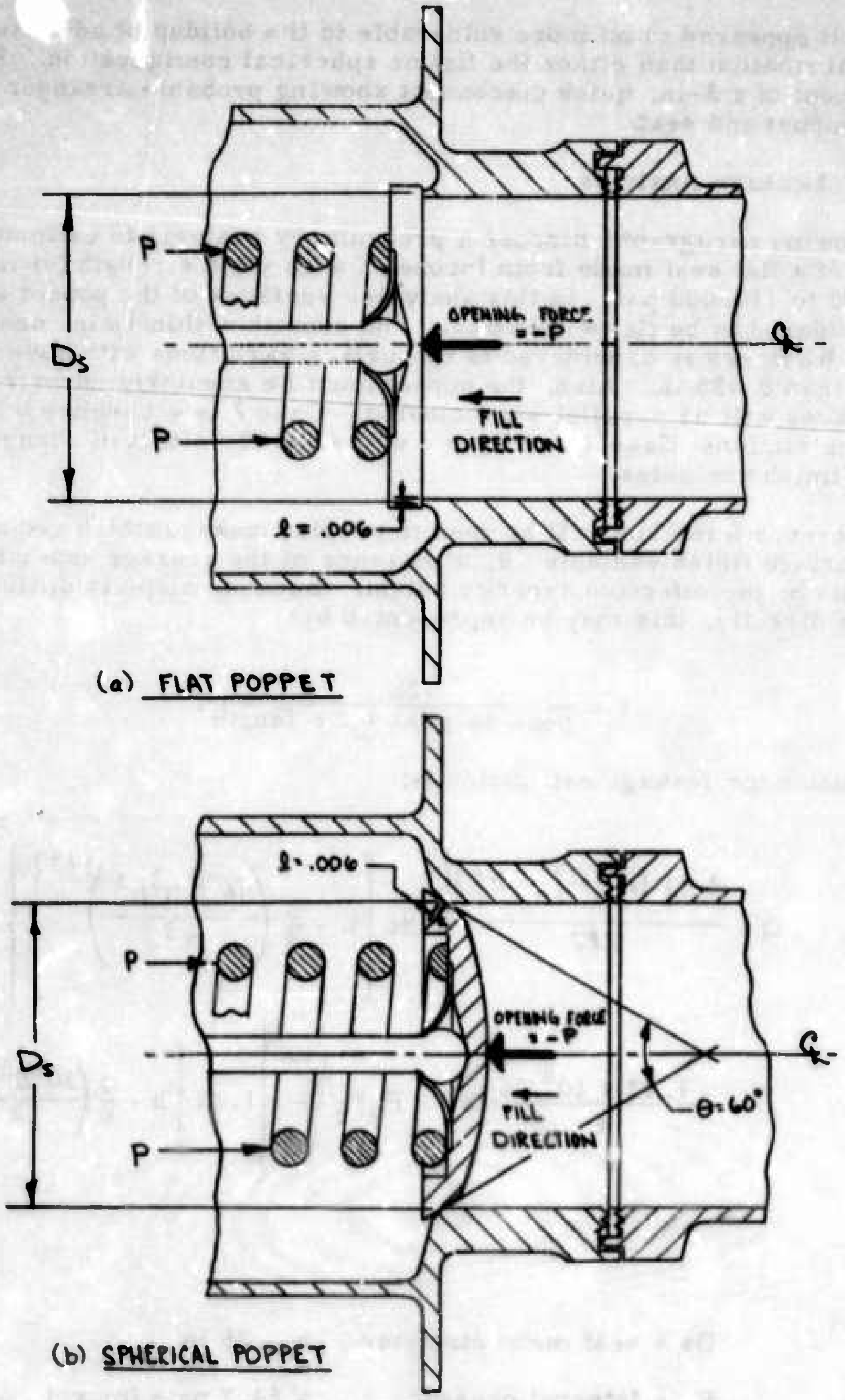


Figure 2-13. Propellant Check Valve Concepts

μ = fluid viscosity = $4.72 \times 10^{-11} \frac{\text{lb-min.}}{\text{in.}^2}$ (for helium)

R = gas constant = $4632 \frac{\text{lb.min.}}{\text{lb}^\circ\text{R}}$ (for helium)

T = absolute temperature = 540°R

α = elastic constant = $2(1 - \nu^2)/E = 5.87 \times 10^{-8}$ in.^{2}/lb (for Monel)

S = apparent contact stress = $\frac{P}{\pi D_S \ell}$

h = PTV roughness of one surface

h' = PTV waviness of one surface

ϕ = average asperity slope (roughness)

ϕ' = average asperity slope (waviness)

ℓ = width of seal contact

Because minimum weight and complexity for the QD vehicle half is a design goal, the spring force required for sealing must be kept to a minimum. For the 2-in. coupling of Figure 2-13, the range of available load from a simple spring is from 100 to 600 lb, resulting in an apparent sealing stress of 2,500 to 14,000 psi. Listed in Table 2-2 and plotted in Figure 2-14 are the calculated values for helium leakage versus apparent contact stress for the following surface conditions:

Case 1 -- Roughness h = 1μ in AA = 3μ in PTV

$\phi = 1/4^\circ = 1/229$ radians

Waviness h' = 2-1/2μ in PTV

$\phi' = 1.43 \times 10^{-4}$ radians

Case 2 -- Roughness h = 1/3μ in AA = 1μ in PTV

$\phi = 1/4^\circ = 1/299$ radians

Waviness h' = 12μ in PTV

$\phi' = 6.86 \times 10^{-4}$ radians

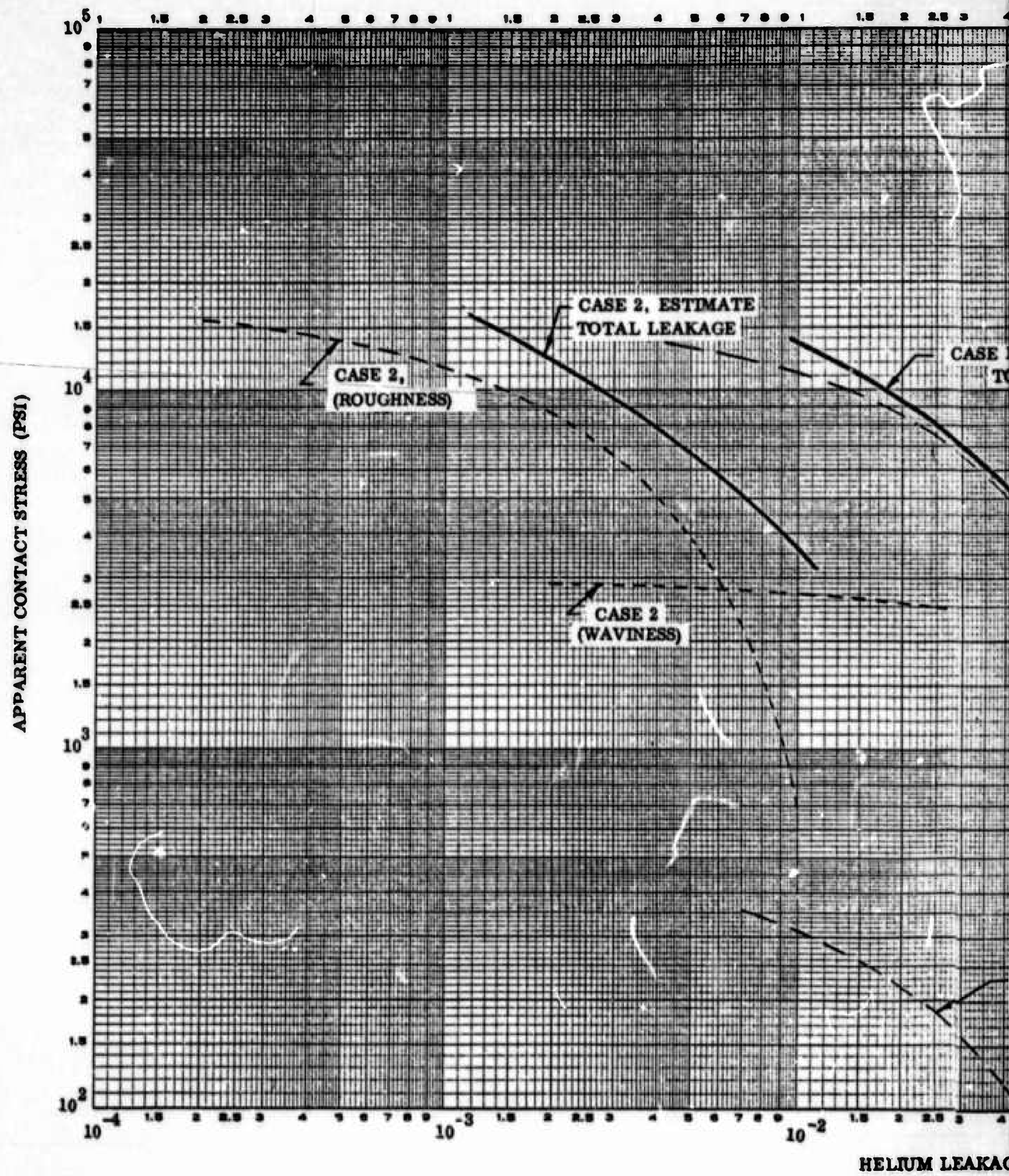
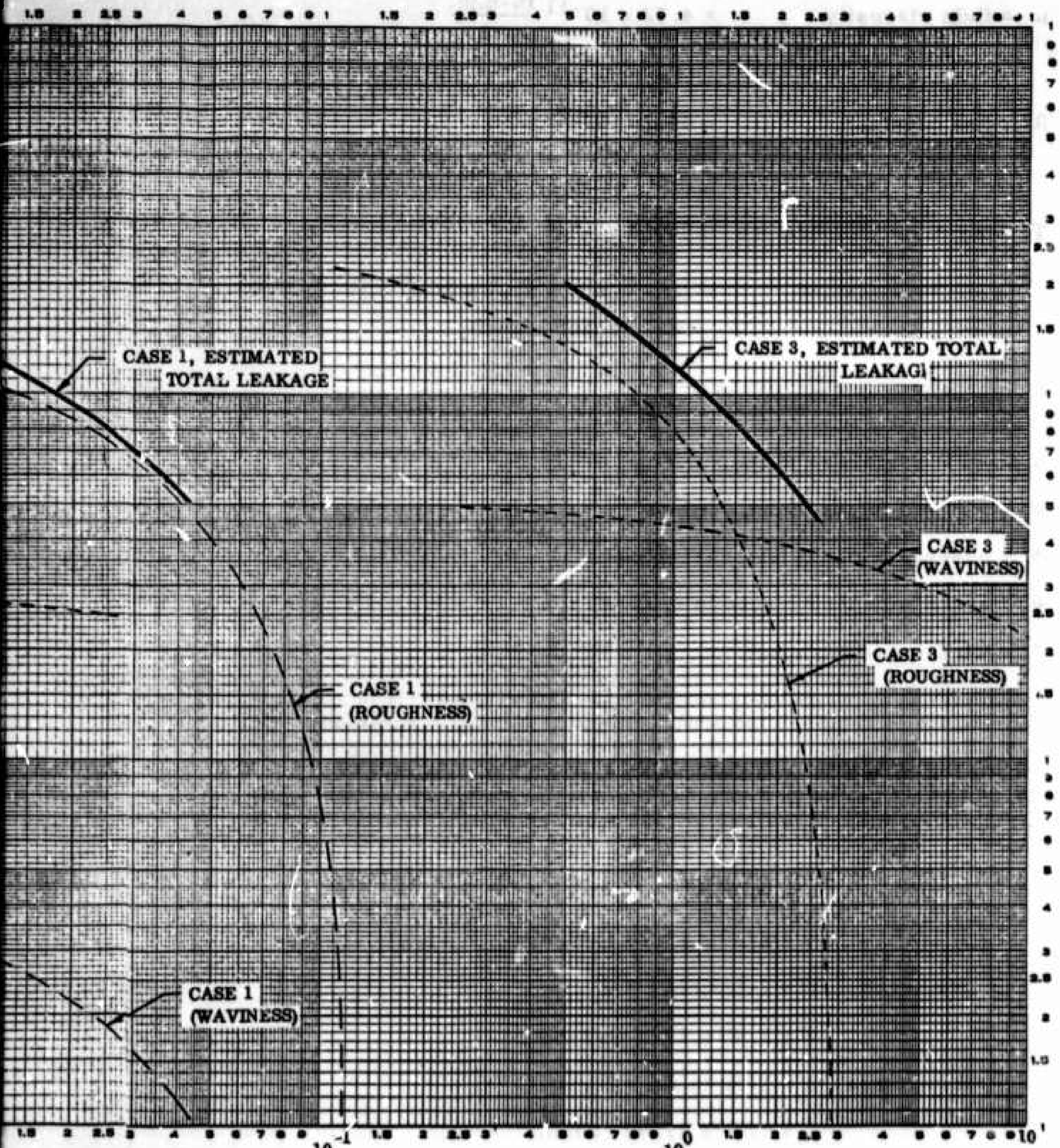


Figure 2-14. Stress Versus Leakage for V



s Leakage for Various Surface Conditions

Table 2-2

STRESS AS A FUNCTION OF LEAKAGE FOR VARIOUS SURFACE CONDITIONS

	h(μ in. PTV)	ϕ (Radians)	h' μ in. (PTV)	ϕ' (Radians)	Asperity type	S (psi)	Q (SCIM)
Case 1	3	$\frac{1}{229}$			Roughness	10,000 3,000 -0-	1.36×10^{-2} 5.88×10^{-2} 12.35×10^{-2}
Case 1			2-1/2	1.43×10^{-4}	Waviness	625 400 100	-0- 5.09×10^{-3} 49.50×10^{-3}
Case 2	1	$\frac{1}{229}$			Roughness	10,000 3,000 1,000	1.45×10^{-3} 5.92×10^{-3} 12.38×10^{-3}
Case 2			12	6.16×10^{-4}	Waviness	3,000 2,500 2,000	-0- 2.23×10^{-2} 6.53×10^{-2}
Case 3	12	$\frac{1}{115}$			Roughness	18,000 10,000 -0-	0 0.256 0.83 2.86
Case 3			24	13.72×10^{-4}	Waviness	6,000 3,000 -0-	-0- 5.12 16.32

Case 3 -- Roughness $h = 4\mu$ in AA $= 12\mu$ in PTV

$\phi = 1/2^{\circ} = 1/115$ radians

Waviness $h' = 24\mu$ in PTV

$\phi' = 13.72 \times 10^{-4}$ radians

The analysis indicates that a well designed check valve with a good poppet and seat surface finish, represented by Case 3, will result in leakage of approximately 1 SCIM. The best known (Reference 6) surface finish, represented by Case 2, will result in a leakage rate of 10^{-2} to 10^{-3} SCIM. From the standpoint of controlling the excessive loss of liquid propellants, any of the cases investigated would be more than adequate. Should this type of valve be required to seal the oxidizer from areas inhabited by personnel, the capability of a poppet check valve is questionable, and a different valving approach is presently indicated.

2.1.4.2 Poppet Configuration

A spherical poppet acting on a narrow seat as shown in Figure 2-13 has several advantages over a flat seat, as follows:

(a) The spherical poppet provides a smoother flow path for the flowing fluid.

(b) The valve seat can be machined as an integral part of the valve housing.

(c) The valve seat will be easier to refurbish if it should be damaged by pits or scratches.

(d) Because of its geometry, a spherical poppet has a greater seating force than a flat poppet.

The disadvantages of the spherical concept are as follows:

(a) Spherical surfaces are generally more difficult and costly to produce than flat surfaces.

(b) Measurement of roughness and waviness on a spherical surface is more difficult than on a flat surface.

The spherical seat may be formed by lapping with a tool of diameter identical to the poppet or by coining with an extremel smooth hardened tool of poppet diameter.

Lapping surfaces to the required degree of smoothness requires special care on the part of the machinist. The tool must be constantly checked and compared against a master for wear and expansion resulting from the heat of lapping.

The manufacture of precision surfaces by coining requires the fabrication of a hardened steel tool with a surface better than the desired seat surface. Experimental evidence described by Archard (Reference 7) indicates that metal surfaces pressed flat by a carefully polished hardened steel anvil assume a surface contour similar to the anvil. It was shown by electron microscopic examination that the resulting slopes of the asperities were in all cases less than 1-1/2° and were completely elastic in that the asperities could be pressed just flat without plastic flow. Having confidence from these results that coining will produce a satisfactory seat, the required coining load can be determined. To produce a 2.25-in. diam seat of 0.006-in. width at an included angle of 60° (assuming full plastic flow of the seat material at an apparent stress level of 3y = 300,000 psi),

$$P = 0.006\,(7.07)\,(300,000)\,\sin 30° = 12,700\text{ lb}$$

2.2 Latching and Release Requirements

2.2.1 General

Present vehicle systems do not use remotely connected QD couplings because of their added complexity, reduced reliability and increased cost. Also, airborne contaminants can more easily be trapped between the mating halves of the coupling during a remote connection than during an environmentally controlled manual engagement. Engagement and latching of the QD at cryogenic temperature presents an additional problem, that of trapping frost and ice within the coupling. The reaction of fluorine with moisture introduces one or more of several hazardous conditions: the formation of hydrofluoric acid, an extremely corrosive substance; the formation of impact-sensitive frost-fluorine or ice-fluorine compounds; and the introduction of solid particles that could clog or otherwise functionally impair the operation and safety of the system.

Fluid couplings, once mated and checked out, and not usually disconnected until the launch is aborted or until the launch is committed (lift-off). This is particularly true for cryogenic systems, where the cryogens must be topped off to the 100% level and prepressurized immediately prior to launch. Launch delays following prepressurization usually result in venting of the propellant tank and repeating the last portion of the countdown, including propellant topping prepressurization. It is therefore impractical to separate the QD prior to launch. To do so would impose many additional operational delays, unduly adding to the complexity and uncertainty of the system.

In view of the foregoing, it was determined that the fluorine QD coupling, for the upper stage vehicle considered by this program should be: (1) manually connected, and (2) remotely disconnected at vehicle liftoff (launch committed).

2.2.2 Alignment and Engagement

A fluorine QD coupling should be so designed to permit easy manual alignment and engagement without the need for special tools or fixtures. Smooth unrestricted engagement into latched and sealed position should be possible with misalignment between coupling halves, at initial engagement contact, of ±2° at 1/4 inch radial displacement. No requirement exists for rotational indexing of the coupling halves above their axial centerlines. All sealing surfaces must be afforded good physical protection during engagement.

2.2.3 Loads on Coupling and Seal

The QD Coupling must be designed to withstand both internally and externally applied loads that act to separate the coupling halves, rotate the coupling halves relative to each other (torsional effect), and slide the coupling halves relative to each other (transverse to their common axis). Loads from the following sources must be considered in the design:

(1) Load Caused by Internal Fluid Pressure--The internal pressure produces a separation load at the seal interface that must be resisted by the connecting mechanism (bolts, threads, latches, and so forth). Properly designed, the interface seal can be made to take advantage of the internal pressure to increase the sealing forces as the pressure increases. This is done by making the seal self-energizing, possibly by using a V-shape with the apex of the V oriented outward. Another method of increasing the sealing forces with pressure is to use bellows behind one of the seal seating surfaces with a larger mean diameter than the effective diameter of the seal.

An increase in the sealing force adds directly to the load on the latches. The pressure and separation load on the disconnect coupling may be amplified if a vehicle shutoff valve is used to control the propellant flow. The magnitude of pressure amplification depends on the closing rate of the shutoff valve. The location of the shutoff valve and the magnitude of the pressure amplification factor, if applicable, must be determined before final design of the disconnect coupling.

(2) Wind Load on the Umbilical Line-- The most general method for connecting an AGE propellant servicing line to an upper stage vehicle is to use a flexible or semiflexible umbilical line for the span from the servicing mast or tower to the fill port on the vehicle. This span, of course, varies for different vehicles. When the distance between the vehicle and the mast is great, a support boom is used to provide intermediate supports for the line. The QD must be designed to support its share of the load from the final span of umbilical line and all hardware attached to the QD (actuators, valves, sensors, and so forth). A wind loading normal to the umbilical line produces a tension load, a lateral load, and a bending moment on the coupling. For cryogenic propellants, the umbilical line may be insulated with a vacuum jacket or a layer of insulation material that increases its profile area and, therefore, also increases the wind load on the line. An estimate of the wind load can be obtained by using the formula for aerodynamic drag on a cylinder in a flow field.

$$D = C_D A q$$

where

D is the drag force (pounds),

C_D is the coefficient of drag (dimensionless),

A is the profile area of the umbilical line (square feet)

and

q is dynamic pressure (pounds per square foot).

For a smooth cylinder in a low Mach number air stream, C_D is on the order of 1.2. A realistic maximum limit of wind velocity to be used for design of the umbilical is 70 mph. The drag corresponding to a 70 mph wind velocity and $C_D = 1.2$ is 15 psf. Douglas curently uses a value of 30 psf for the ultimate wind load on cylindrical umbilicals. This value provides an extra margin of safety to account for some undefinable conditions, such as whipping of the lines as a result of unsteady wind conditions and increased drag from local protuberances on the umbilical line. For analysis of loads into the coupling, it may be assumed that the flexible has a catenary shape as a result of the uniformly distributed wind loading.

(3) Load Resulting from Weight of Umbilical Full of Propellant-- This is a uniformly distributed load along the umbilical line that causes the line to assume a catenary shape, as noted, for the wind loading The direction of this load is perpendicular to the direction of the wind loading; however, the two loadings can be combined vectorially and analyzed as a single loading. A convenient method for calculating the tension loads in a catenary shape is presented in tabular form in Reference 1.

(4) Dynamic Load Resulting from Curvature of the Flow Path Through the Umbilical Line--Flow through the umbilical may or may not produce a significant load on the disconnect coupling, depending on the amount of curvature in the umbilical and the velocity of flow. The magnitude of this load may be determined by use of the impulse-momentum principle of fluid mechanics.

(5) Load Resulting from Oscillatory Motion Between Vehicle and Umbilical Mast or Tower--Wind loading on the vehicle and on the umbilical mast or tower produces an oscillatory motion in both that causes the distance between the support points for the two ends of the umbilical line to vary as a function of time. When the support points move apart, the catenary shape of the umbilical becomes a flatter curve and the tension in the line increases. The design analysis of the umbilical loads must account for this maximum tension condition. The umbilical line must have sufficient length so that it is never stretched taut as a result of the oscillatory movements of the end points.

(6) Load Required to Disconnect Coupling--The load imparted to the coupling during decoupling depends on the design of the disconnect mechanism. If the coupling is designed to be ruptured by a tension force, this will be the maximum force experienced by the coupling. However, if a latching mechanism is used, the decoupling loads may be small compared to the other loads previously noted.

(7) Loads Induced by Thermal Changes Within the Coupling--A thermal gradient caused by flowing a cold fluid through the coupling generally results in contraction of the compressive members of the coupling. This causes a load decrease in the tension members of the connector, and as a result sealing loads are often accordingly reduced. The sealing load relaxation must not be so great as to result in unacceptable leakage. A detailed analytical approach to this problem is presented in Reference 2.

2.2.4 Latching and Release Schemes and Analysis

2.2.4.1 Latch Requirements

Possible configurations for the latch and quick release mechanism for the QD coupling have been investigated. Consideration has been given to means for ensuring the attainment of the desired pre-load on the interface seal. One method is to use the latch as the mechanism for applying the seal preload. An alternate approach is to make the engagement of the latch the initial step in the procedure and to use an additional mechanism, such as a set of adjustment screws, to apply the desired preload to the seal. It appears that the latter approach is the more effective method because it can accommodate a wider range of tolerances on detail parts and also permits a simpler latch design.

One of the more restrictive design goals is to provide a redundant release mechanism. This could be provided by incorporating a breakaway section that would rupture should the normal release mechanism fail. Another and perhaps more desirable method is to provide two independent release mechanisms at the same separation interface.

The possibility of providing a safeguard to prevent inadvertent actuation of the coupling release mechanism was considered. Separation of the coupling could be disastrous if it occurred during oxidizer transfer and significant quantity of oxidizer is spilled. Coupling separation cannot be considered hazardous if it occurs when the transfer line is dry, however, it could result in a delay of launch if it occurred in the final stages of prelaunch activities.

Precautions must be taken to preclude inadvertent separation of the coupling during the oxidizer transfer operation. System design criteria should provide for an interlock between the oxidizer transfer system control and the QD release mechanism such that the QD cannot be released manually during an oxidizer transfer.

Before establishing a requirement for a safety device to prevent inadvertent manual decoupling when the transfer line is dry and personnel are working in the area, the effects of such a device on the reliability of the coupling release function must be thoroughly evaluated. If such a safety device adds mechanical or system complexity, it will almost certainly lower the reliability of the coupling separation system for a normal release.

On some of the latch designs considered, a shear pin could be incorporated in the latch, thus increasing the force required for unlatching and decreasing the probability of an inadvertent decoupling. One of the hazards of this method is that a shear pin of improper strength might be unintentionally substituted and prevent actuation of the unlatching mechanism. Also, the actuation forces for this type of device are directly additive to the forces required for the normal unlatching. Because the normal unlatching force is a highly variable quantity as a result of its dependence on frictional effects and possible galling of sliding surfaces, the total force required for unlatching might become excessively great.

Another scheme for a safety device to reduce the possiblity of inadvertent manual decoupling is to design a breakaway device (such as a shear pin) that is broken before the unlatching load is transmitted to the latch. This could be accomplished by a slack cable or a slotted linkage that breaks the safety device during its initial motion.

Although the inadvertent decoupling of a dry line does not result in a hazardous situation, it could stop or delay a launch, and either a safety device should be provided or the latch design should be such that inadvertent manual actuation is virtually impossible.

All of the latch designs considered will be vulnerable to possible jamming and higher unlatch loads if ice is allowed to form on the cold surfaces as a result of precipitation and freezing of atmospheric water vapor. Ice or frost also represents an additional hazard because it will become impact sensitive if any fluorine leaks from the transfer line is absorbed by it. For these reasons, it will be necessary to exclude the atmospheric air from the vicinity of QD coupling during transfer of the cryogenic oxidizers LF_2 and FLOX. It appears that the most feasible method for excluding air is to provide a shroud around the QD coupling and purge it with a dry inert gas, such as N_2.

To minimize the potential fire hazard that could be created if even a minor amount of F_2 escapes from the transfer system, only F_2-compatible materials should be used in the construction of a shroud. The use of Teflon in limited quantities is permissible if seals are needed to reduce gross leakage. A continuous flow of the relatively warm purge gas is necessary to prevent the shroud itself from becoming cold and bulding up a layer of ice that could cause operating problems with latch actuating system.

A sketch of a possible shroud configuration is shown in Figure 2-15. It consists of a cylindrical metal bellows sufficiently large to enclose the QD coupling and its latch mechanism. The bellows is supported by a bulkhead that attaches to the AGE-half of the coupling. To provide access to the latching mechanism when the coupling is being mated, the shroud bellows is moved axially along the umbilical hose to uncover the latching

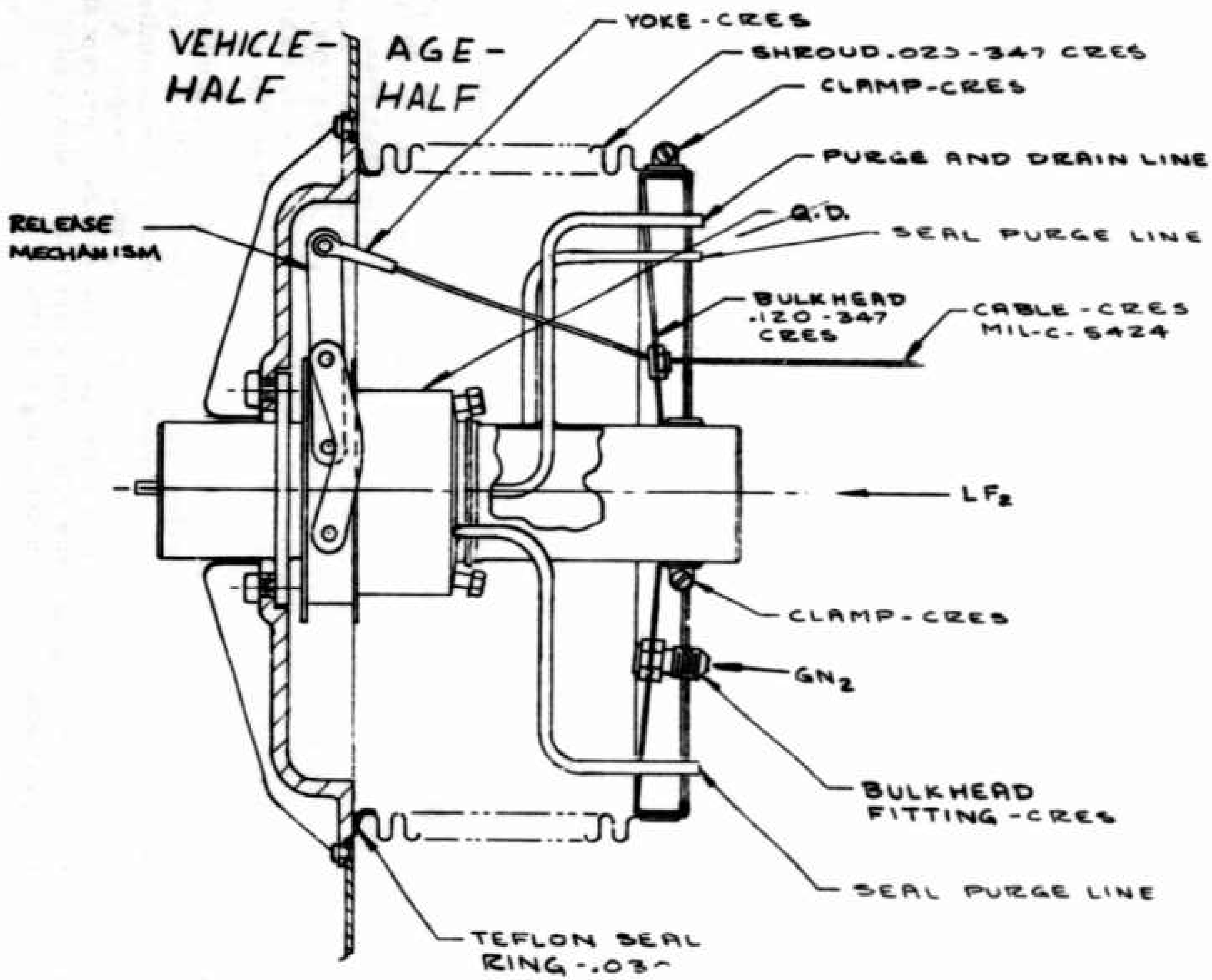


Figure 2-15. General Arrangement of Shrouded Test QD Coupling

mechanism. After the coupling halves have been mated and the interface seal preloaded and leak checked, the shroud is moved to its normal position with the bellows lightly compressed against the vehicle and clamped to its supporting bulkhead.

2.2.4.2 Evaluation of Latch Designs

An evaluation of five configurations for the QD coupling latch and quick release mechanism is presented in the following discussion. A comparison of the merits of each of these configurations is presented in Table 2-3. The recommendations contained herein formed the starting point for the Phase II test model design, the details of which are contained in Section III, 3.2. The same basic interface seal has been assumed for all of the configurations. The seal consists of a soft metal gasket that is plastically deformed on each side by two concentric knife-edge serrations machined into the hard metal flanges of the coupling. The soft seal is constrained within the AGE-half of the coupling by a wire retaining ring. For the purpose of evaluating the latch release loads for each of the configurations, the seal preload was calculated as 8,200 lb. This is based on a total seal length of 13.7 in. and a sealing load of 600 lb/in. Figure 2-8 in Section II, 2.1.3 indicates that a seal load of 200 lb/in. would provide a leakage rate of 10^{-6} SCIM of helium. However, to maintain a seal of this quality, a higher loading is required to account for stress relaxation of the seal material caused by temperature cycling and by external loads on the QD. A factor of three was assumed to assure that an adequate sealing stress would always be maintained.

The knife-edge serrations on each half of the coupling are afforded some degree of protection from physical damage by recessing the sealing surface from the flange face. The flange faces are designed to nest within each other to provide radial alignment of the two coupling halves.

(1) Latch Configuration I

The Configuration I latching and release mechanism is shown in Figure 2-16. The vehicle half of the coupling consists of a simple flanged fitting (A) containing the two sealing knife edges on its interface surface. The AGE half of the coupling contains the soft metal seal (K) and the latching and release components. The latching components consist of six 1/2-in.-dia balls (G) fitted into radial holes in the body (C) of the coupling. When the two halves of the coupling are mated, the balls are forced into a circumferential groove in the vehicle half flange (A). The balls are locked into place by the band (D) and the three over-center toggle latches made up of links (E) and arms (F). Preloading of the seal is accomplished by torquing the bolts (H) to the desired preload value. To release the coupling, the arms (F) are pulled by means of cables attached to actuators. Actuation of any one of the three latches will disconnect the coupling. The retaining pins (J) restrict the travel of the band (D) so that the balls cannot escape from their positioning holes the coupling is unlatched. The maximum depth of engagement of the balls with the flange of fitting (A) must be such that frictional effects will not cause the balls to hang up when the over-center latches are released. Figure 2-17 shows the loads on the various components of the latching mechanism assuming (1) that no lubrication is used and (2) that all sliding surfaces are lubricated with molybdenum disulfide. Case Numbers 3 and 5 in Figure 2-17

Table 2-3

COMPARISON OF MERITS OF LATCH CONFIGURATIONS

Configuration No.	Description	Unlatching Load (Total)		*Advantages	Disadvantages
		Unlubricated	Lubricated		
I	Ball latch with expanding retainer band	1116#	171#	1. Provides redundant release feature since actuation of any one of the three latches will permit coupling to separate. 2. Precision balls are commercially available at relatively low cost.	1. High contact stresses generated by the balls are usually accompanied by brinelling or galling of the mating surfaces unless they can be made of a very hard material. 2. Dependent on low friction coefficients for reasonably low release load.
II	Ball latch with sliding retainer sleeve	5364#	711#	1. Precision balls are commercially available at relatively low cost.	1. Release loads are relatively high with or without lubrication on sliding surfaces. 2. The coupling will not release if the retainer sleeve "hangs up." 3 †Not readily adaptable to incorporation of a redundant release scheme. 4. High contact stresses generated by the balls are usually accompanied by brinelling or galling of the mating surfaces unless they can be made of a very hard material.
III	Finger latch with sliding retainer sleeve	1272# + spring load	372# + spring load	1. Motion of the retainer sleeve during the release phase positively opens the latching fingers and permits unobstructed release of the vehicle-half flange. 2. Adequate finger bearing area to prevent brinelling of the vehicle-half flange can be provided easily.	1. Same as for configuration II. 2. Same as for configuration II. 3. Same as for configuration II.
IV	V-band clamp with over-center toggle latches	206#	79#	1. Provides redundant release feature since actuation of either of the two latches will permit coupling to separate. 2. Not dependent on low friction coefficients for low release loads. 3. Adequate clamp bearing area to prevent brinelling of the vehicle-half flange can be provided easily.	1. Accurate seal preload values will be difficult to determine because they are dependent on a highly variable parameter, the frictional resistance between the outer clamp ring (C) and the adjustable lugs (D).
V	Finger latch with over-center toggle lock	885#	228#	1. Motion of the release ring during the release phase positively opens the latching fingers and permits unobstructed release of the vehicle-half flange. 2. Adequate clamp bearing area to prevent brinelling of the vehicle-half flange can be provided easily.	1. Not adaptable to incorporation of a redundant release scheme. 2. Dependent on low friction coefficients for reasonably low release load.

*All of the latch configurations have the following desirable features:

1. After the latch is released the coupling will not "hang up" as a result of a pitch or yaw motion along with the axial separation motion.
2. Preloading of the seal is independent of the latching operation thereby simplifying the latch requirements.

†Possibly the retainer sleeve could be made frangible so that a load higher than the normal operating load would cause it to rupture.

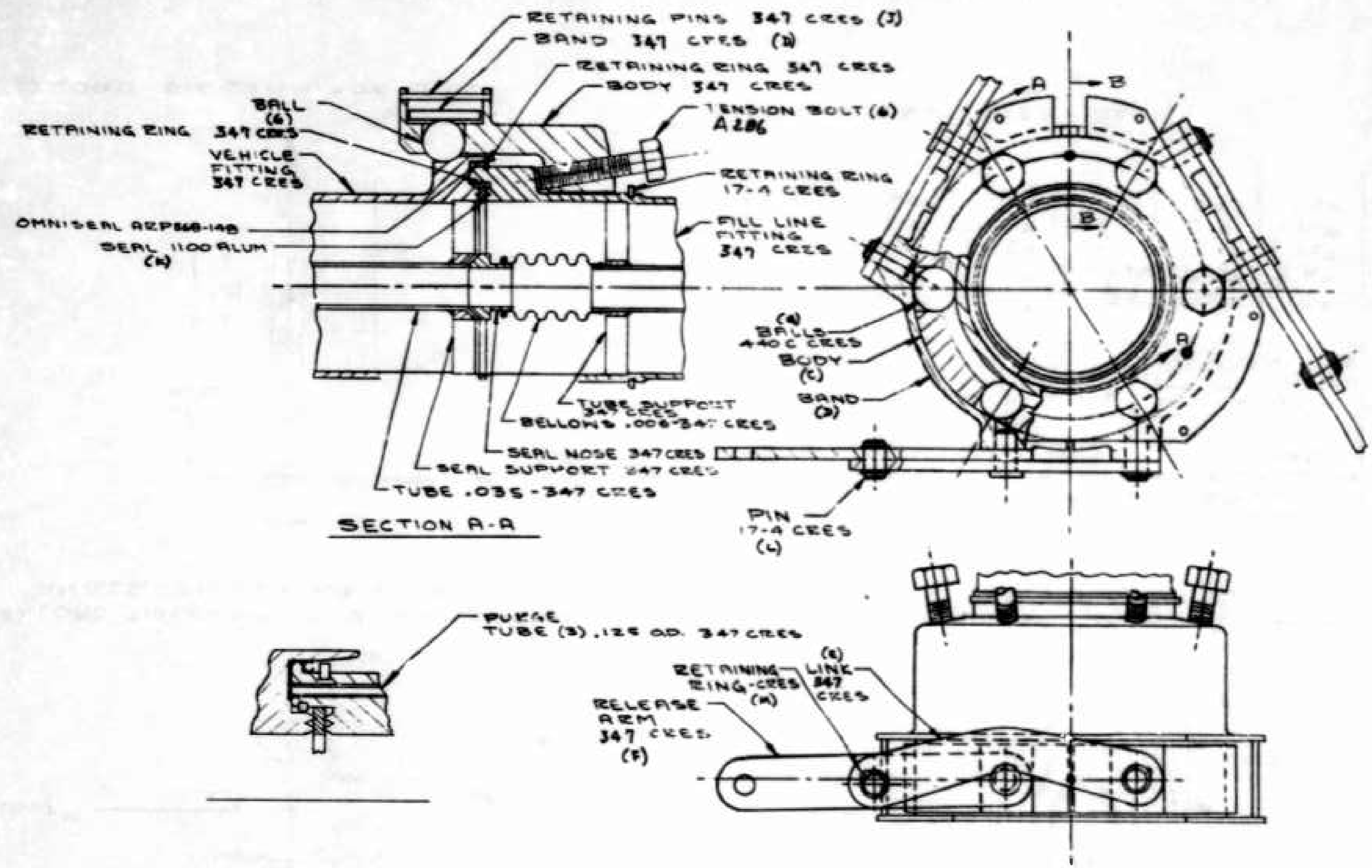
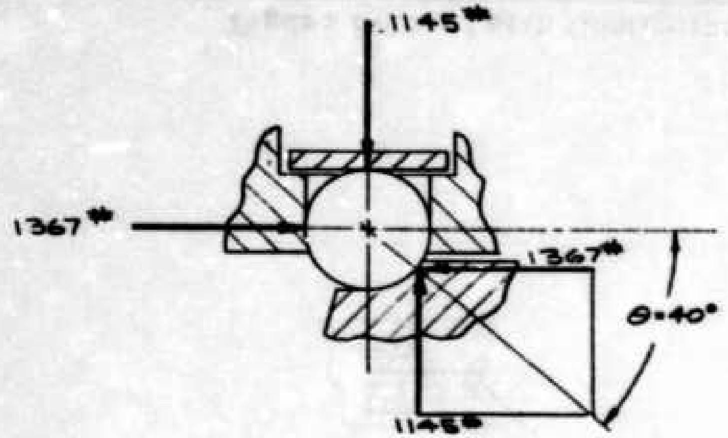
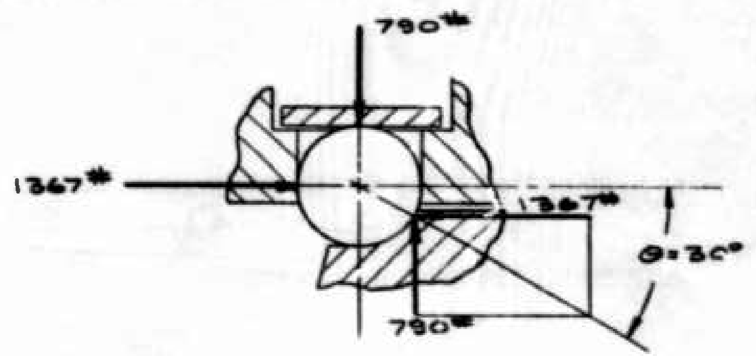


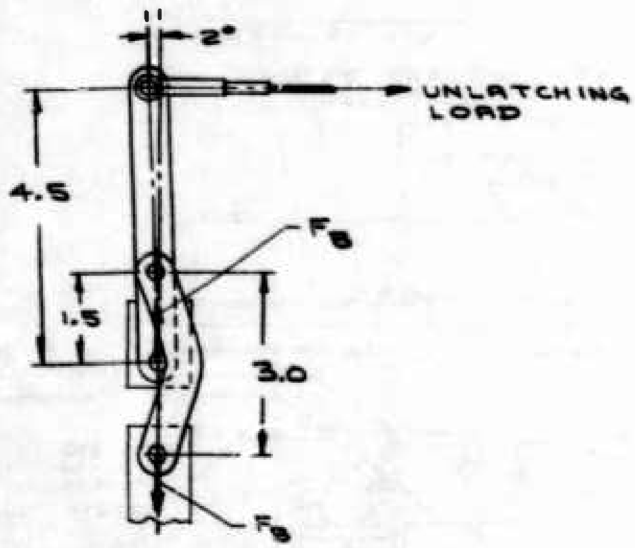
Figure 2-16. Latch Configuration I--Ball Latch with Expanding Retainer Band



(a) LOAD DIAGRAM FOR 40° LOADING ANGLE ON LATCHING BALL



(b) LOAD DIAGRAM FOR 30° LOADING ANGLE ON LATCHING BALL



(c) LOAD DIAGRAM FOR LATCH

EFFECT OF VARIATIONS IN BALL LOADING ANGLE (θ) AND STATIC FRICTION COEFFICENT (μ_s) ON UNLATCHING LOAD.

CASE NO	θ	BAND LOAD F_B	μ_s	UNLATCHING LOAD PER LATCH	TOTAL UNLATCHING LOAD
1	40°	1145#	0.78 (DRY)	372#	1116#
2	40°	1145#	0.15 (MoS_2)*	72.5#	218#
3	40°	1145#	0	13.3#	40#
4	30°	790#	0.15 (MoS_2)*	57#	171#
5	30°	790#	0	9#	27#

*MOLYBDENUM DISULFIDE.

Figure 2-17. Load Diagrams for Latch Configuration I are ideal, cases assuming no friction, and are included to indicate the minimum unlatching loads that might be obtained if a highly efficient lubricant such as an oil or grease could be used. For a design using no lubricant and the assumed friction coefficient of 0.78, the ball loading angle always must be 38° or larger, otherwise the balls will remain locked after the band is released.

(2) Latch Configuration II

The Configuration II latching and release mechanism is shown in Figure 2-18. The vehicle half of the coupling is essentially the same as that for Configuration I. The AGE half of the coupling contains the soft metal seal (L) and the latching and release components. The latching components consist of six 1/2-in.-dia balls (E) fitted into radial holes in the body (C) of the coupling. When the two halves of the coupling are mated, the balls are locked into the latched position by the spring loaded sleeve (D). Preloading the seal (L) is accomplished by uniformly torquing the bolts (K) in the same manner as for Configuration I. A cable harness consisting of three equally spaced cables (N) connects the ball locking sleeve (D) to an actuator. The coupling is released by pulling the sleeve axially until a circumferential groove in its inner surface is in line with the balls and provides space for them to move out of their latched position. The sleeve is stopped before the balls are completely uncovered and free to escape from their positioning holes by compressing the spring (F) to its solid height against the retainer ring (H). Continuing pull by the cables after the sleeve is fully retracted forces the balls out of their latched position and separates the two coupling halves. The same consideration as noted for Configuration I for establishing the maximum depth of engagement for the balls is applicable. Figure 2-19 shows load diagrams for two conditions: (1) no lubrication and (2) all sliding surfaces lubricated with molybdenum disulfide.

(3) Latch Configuration III

The Configuration III latching and release mechanism is shown in Figure 2-20. The vehicle half of the coupling is similar to Configurations I and II, except that the latch engaging surface of the flange of fitting (A) is tapered rather than grooved. The latching mechanism consists of a series of metal fingers (D) that hook over the tapered flange (A) and are locked in position by a spring loaded sleeve (E). Preloading the seal (N) is accomplished by uniformly torquing the bolts (M) in the same manner as for Configurations I and II. A cable harness consisting of three equally spaced cables (K) connect the latch locking sleeve (E) to an actuator. Coupling release is effected by pulling the sleeve axially. Because the inner surface of the sleeve is conical, its initial motion relieves the positive loads holding the fingers in the latched position. However, frictional forces between the fingers and the fitting (A) may prevent immediate disengagement. After the sleeve (E) has moved past the pivot pins (G) it engages the ramps on the fingers (D) and provides a positive opening force to cause the fingers to release the fitting (A).

Also shown on the configuration is a secondary seal (P) made of Teflon and placed outside of the primary seal. Ports are provided to the cavity between the two seals, and line (Q) provides for vacuum scavenging of any oxidizer leakage past the primary seal. This is an alternate sealing concept that

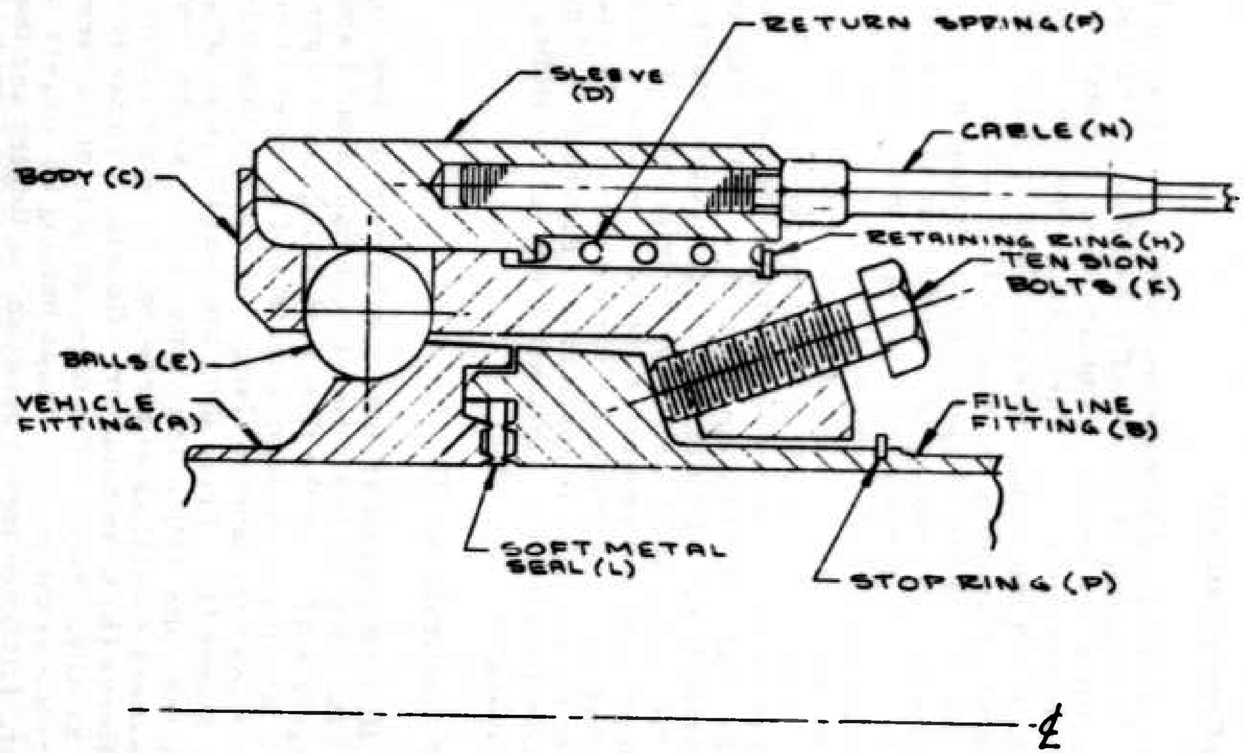


Figure 2-18. Latch Configuration II--Ball Latch with Sliding Retainer Sleeve

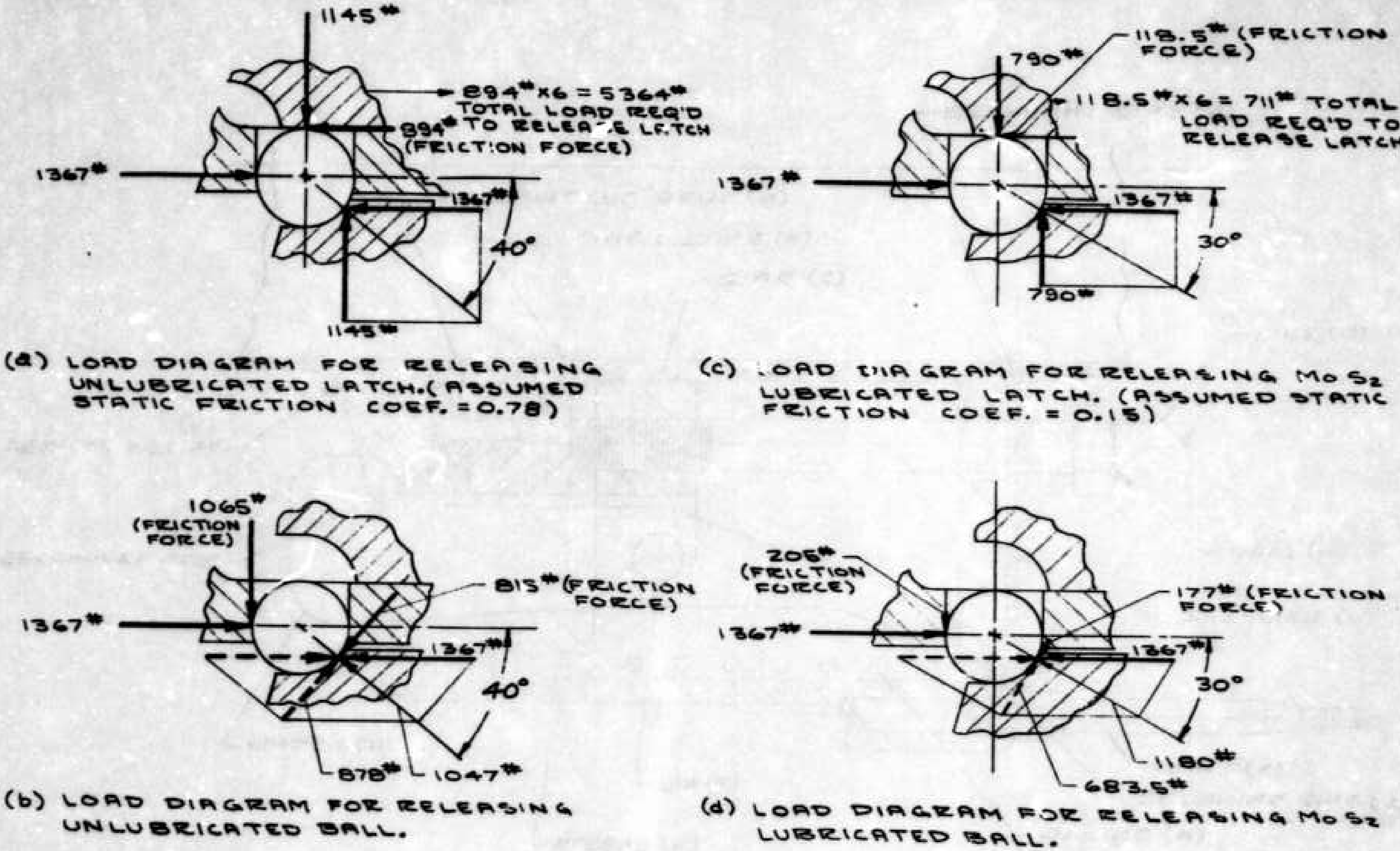


Figure 2-19. Load Diagrams for Latch Configuration II

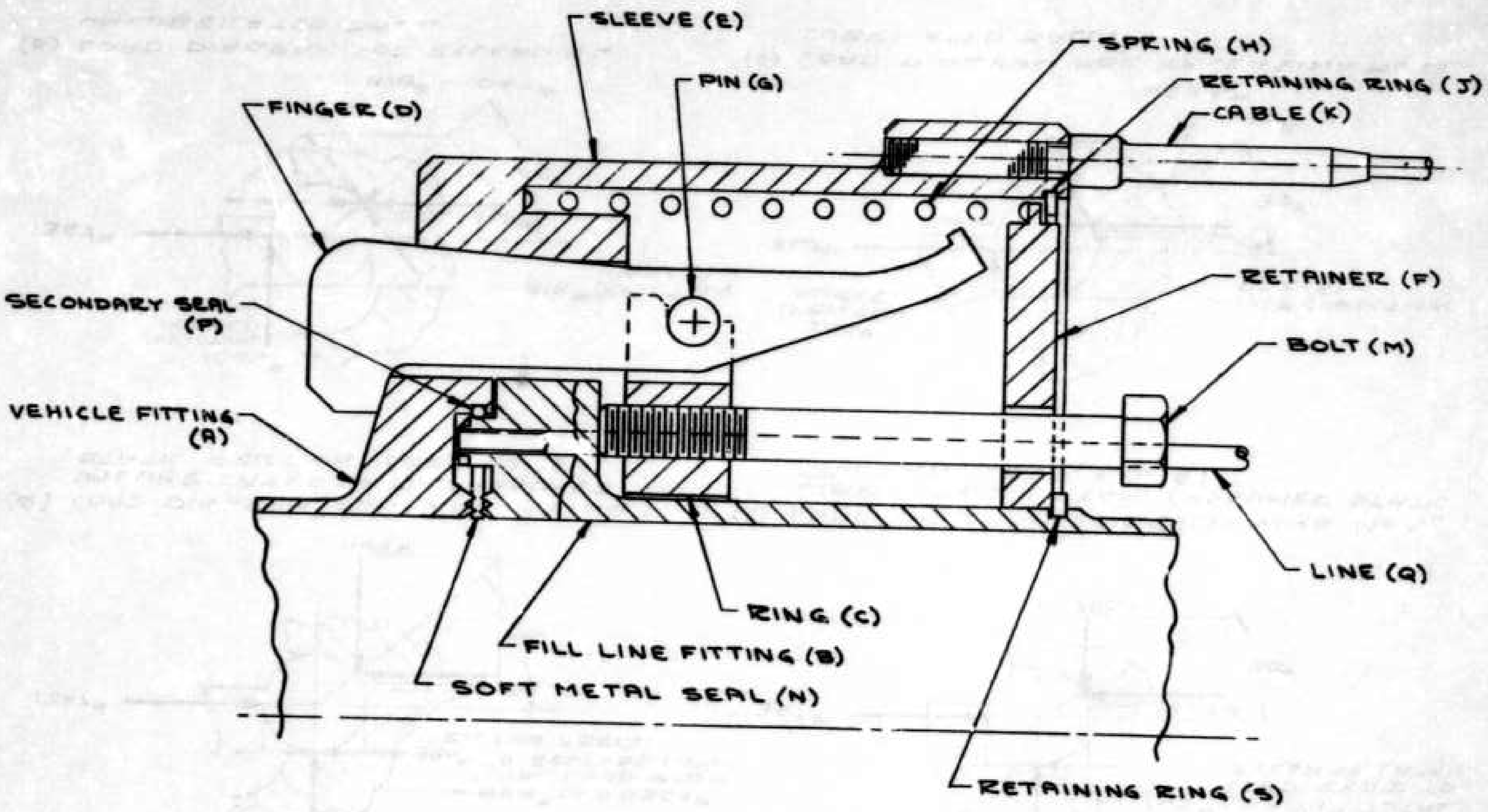


Figure-2-20. Latch Configuration III--Finger Latch with Sliding Retainer Sleeve could be used if the single seal concept does not prove adequate. Figure 2-21 shows load diagrams for two conditions: (1) no lubrication and (2) all sliding surfaces lubricated with molybdenum disulfide.

(4) Latch Configuration IV

The Configuration IV latching and release mechanism is shown in Figure 2-22. The vehicle half of the coupling is the same as for Configuration III, except that the flange is tapered at a larger angle from the plane of the coupling interface. The latching mechanism consists of two identical halves of a V-band clamp that fits over tapered flanges on the two mating halves of the coupling. The V-band clamp that fits over tapered flanges on the two mating halves of the coupling. The V-band clamp ring halves are locked together with two over-center toggle latches. After the clamp is locked into place, the seal (H) is preloaded by torquing the bolts (G). The body of the clamp (C) is slotted between the bolts (G) to provide sufficient flexibility so that the clamp can expand when the latches are unlocked. The design requires that the clamp be machined to a diameter larger than its installed diameter so that when either of the latches are released it will expand to a diameter large enough to slip off of flange (A) on the vehicle and permit the coupling to separate. Lugs (D) form the movable side wall of the clamp. They are tapped to receive the seal preloading bolts (G). To release the coupling, the levers (F) are pulled by means of cables attached to actuators. This moves the toggle links (E) out of their over-center locked position and opens the clamp. The slopes of the side walls of the clamp are designed so that frictional effects will never prevent release of the clamp after either of the toggle latches have opened. Figure 2-23 shows load diagrams for two conditions: (1) no lubrication used and (2) all sliding surfaces lubricated with molybdenum disulfide.

(5) Latch Configuration V

The Configuration V latching and release mechanism is shown in Figure 2-24. The vehicle half of the coupling is similar to that for Configuration III. The latching mechanism consists of six metal fingers (C) that hook over the flange on the vehicle fitting (A). A set of toggle links (D and E) forms an over-center lock for each finger. The roller (G) is utilized as an antifriction device for the unlatching mode. The seal (K) is preloaded by uniformly torquing the bolts (N) against the fingers. The release ring (F) is attached to the inboard pivot point of each of the toggle links (E). A cable harness consisting of three equally spaced cables (N) connects the release ring to an actuator. Coupling release is effected by pulling the release ring axially, which unlocks the toggle links and permits the fingers to open and release the flange (A). The release system can be made semiredundant by attaching two independent actuation devices to the release ring. Because the release ring is not in sliding contact with any other member, it is not vulnerable to hang up.

Because the latch mechanism is AGE and its weight is not critical, all of the components can be over designed so that the possibility of a rupture-type failure would be extremely remote. The only single failure that could prevent release would be a lock up of a joint in one of the finger latches or toggle linkages preventing movement of the release ring. By providing a

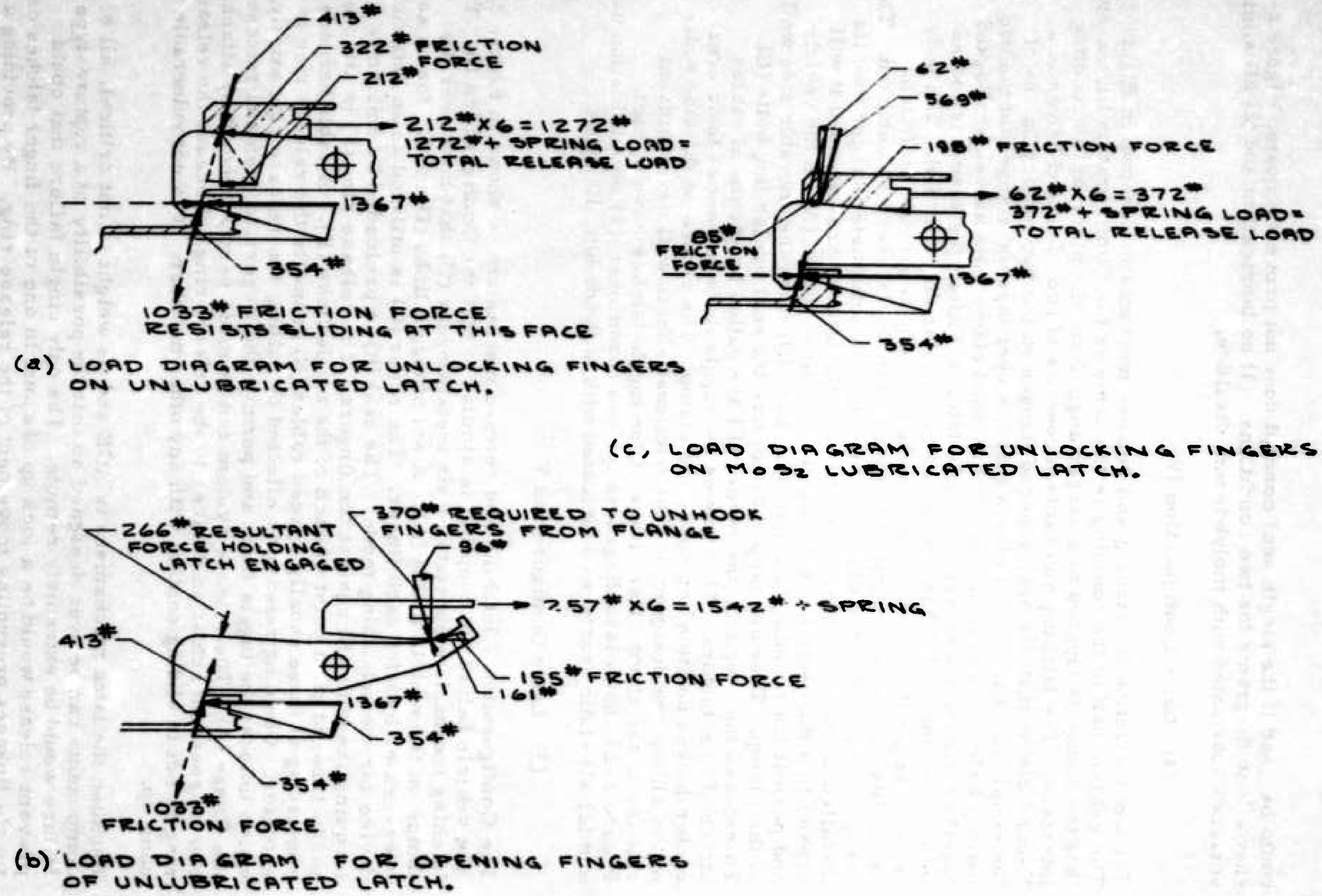


Figure 2-21. Load Diagrams for Latch Configurations III

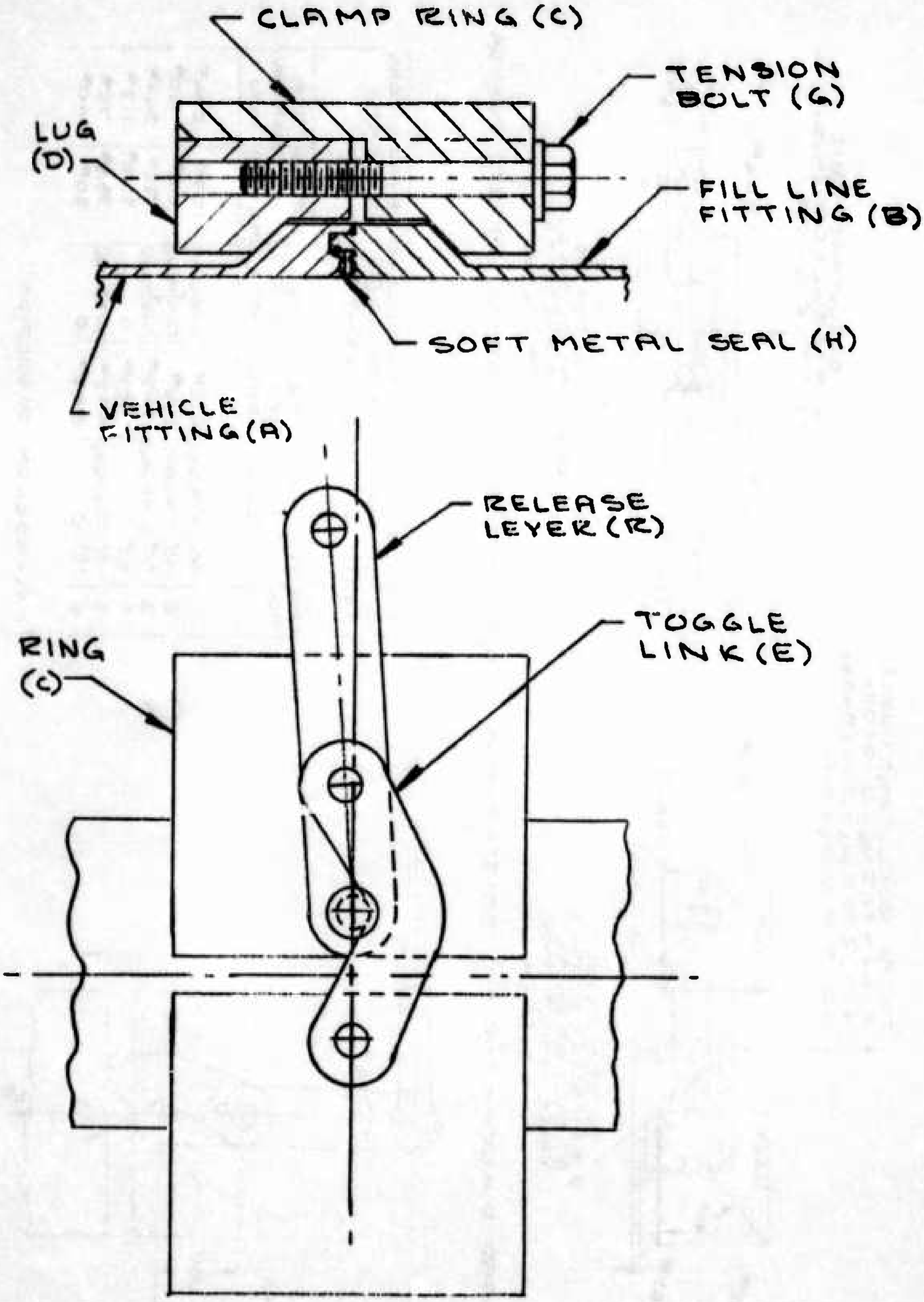
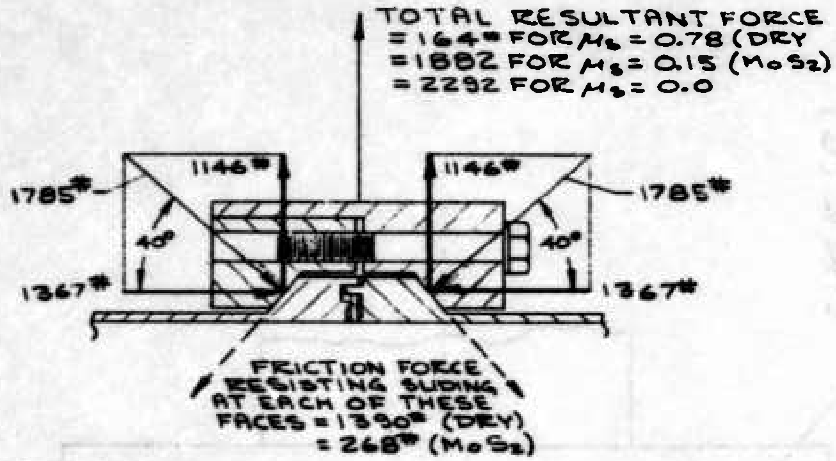
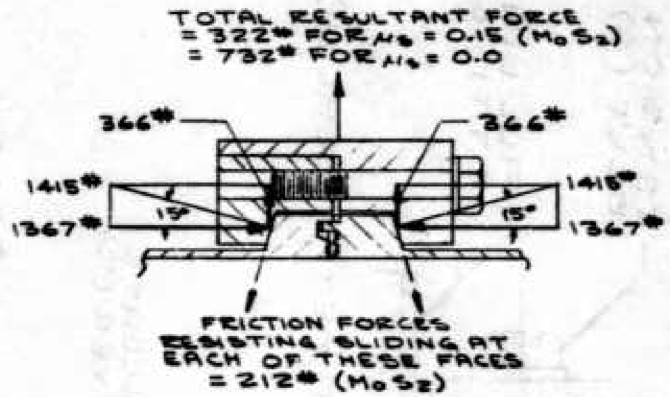


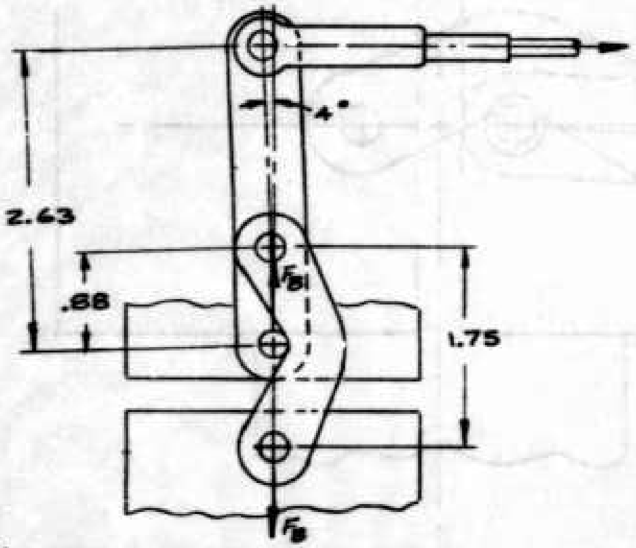
Figure 2-22. Latch Configuration IV V-Band Clamp with Over-Center Toggle Latches



(a) LOAD DIAGRAM FOR 40° TAPERED FLANGE



(b) LOAD DIAGRAM FOR 15° TAPERED FLANGE



(c) LOAD DIAGRAM FOR LATCH

EFFECT ON UNLATCHING LOAD OF VARIATIONS IN FLANGE TAPER ANGLE (θ) AND STATIC FRICTION COEFFICENT (μ_s)

CASE NO.	θ	μ_s FOR FLANGE	F_B BAND LOAD	μ_s FOR LATCH	UNLATCHING LOAD PER LATCH	TOTAL UNLATCHING LOAD
1	40°	0.78(DRY)	275#	0.78(DRY)	103#	206#
2	40°	0.78(DRY)	275#	0.15(MoS_2)	25#	50#
3	40°	0.15(MoS_2)	1993#	0.15(MoS_2)	182#	364#
4	40°	0	2403#	0	56.5#	113#
5	15°	0.15(MoS_2)	433#	0.15(MoS_2)	39.5#	79#
6	15°	0	843#	0	20#	40#

*MOLYBDENUM DISULFIDE

Figure 2-23. Load Diagrams for Latch Configuration IV

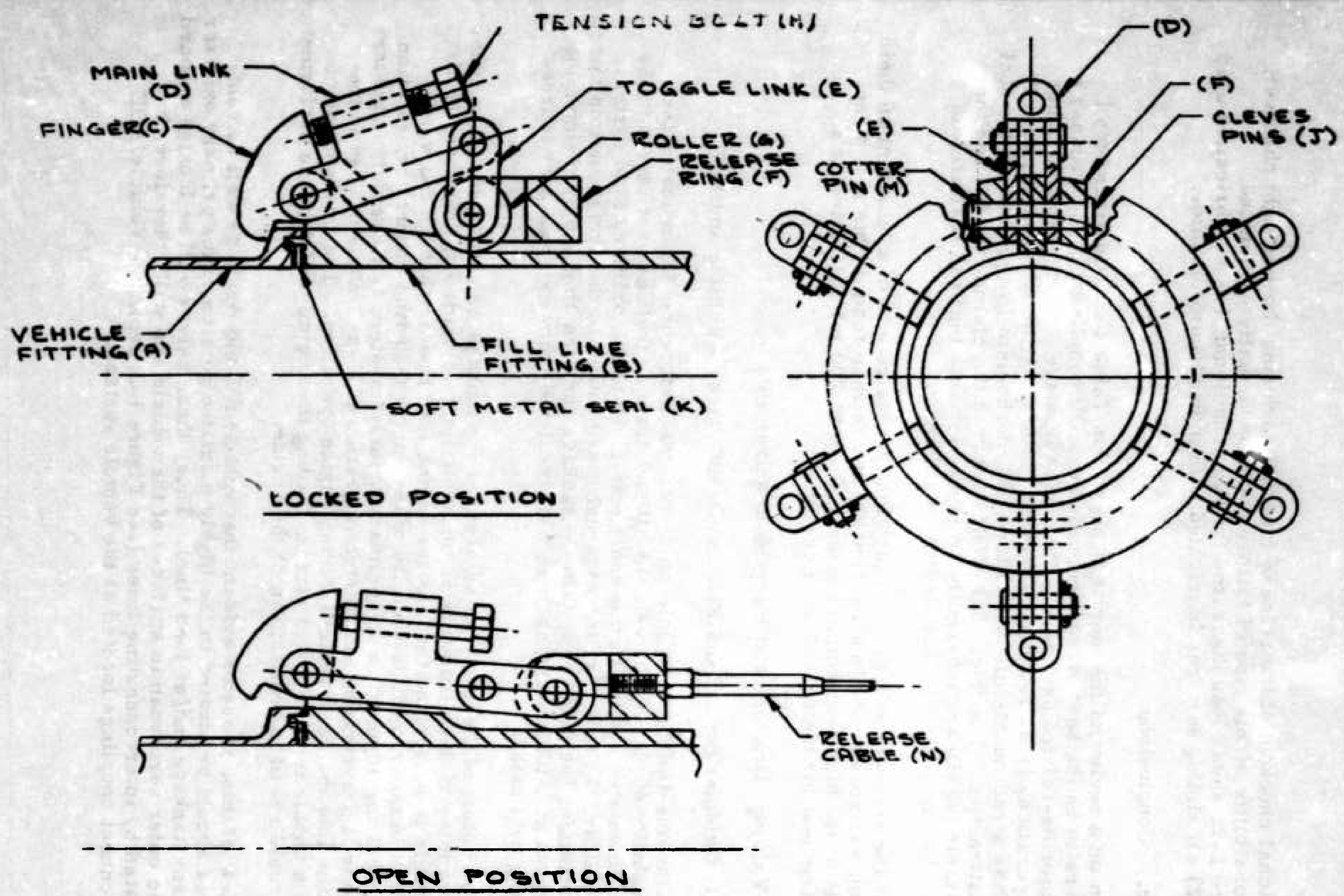


Figure 2-24. Configuration V--Finger Latch with Over-Center Toggle Lock

functional checkout of the release mechanism during the preflight checkout, the possibility of this type of failure could be virtually eliminated. Figure 2-25 shows load diagrams for two conditions: (1) no lubrication used and (2) all sliding surfaces lubricated with molybdenum disulfide.

c. Conclusions

Based on a review of the merits presented in Table 2-3, Configuration I appears to be the best overall concept for a QD coupling for use with any of the fluorine-related oxidizers. Its chief advantage over three of the other configurations is its redundant-release feature. Although Configuration IV also has a redundant-release feature, its mechanism for preloading the seal is unattractive. The frictional effects between the clamp ring (C) and the adjustable lug (D) are inherently so highly variable that the seal preload cannot be predicted with any degree of accuracy.

All of the concepts except Configuration IV require use of a lubricant on their sliding surfaces to obtain a reasonable low release load. This is a direct result of the high seal-compression preload (8, 200 lb) calculated as a requirement for the type of seal chosen.

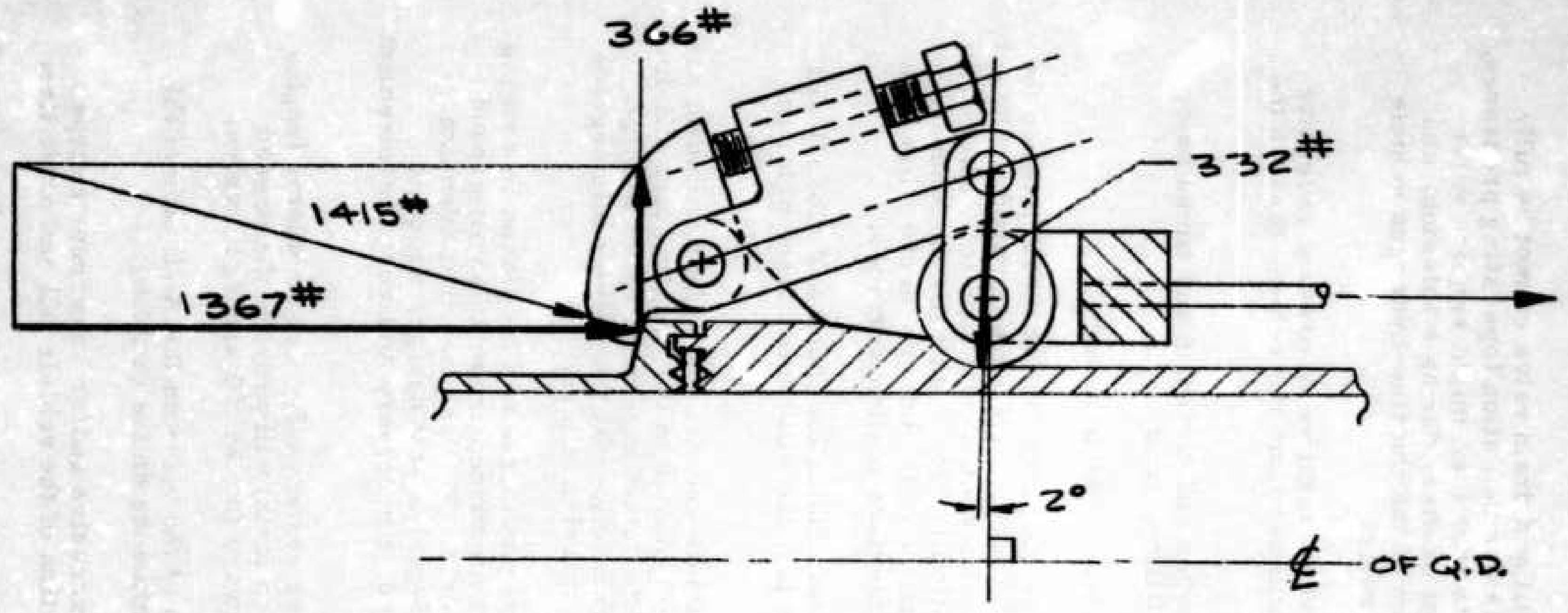
2.3 Valving, Draining and Purging Requirements

2.3.1 Oxidizer Shutoff and Fill and Drain Valves--Vehicle and AGE

The fluorine-hydrogen vehicle study results (Reference 35) indicates the desirability of placing the vehicle fill and drain as well as vent valves in the highly insulated portion of the vehicle as close to the primary fluid system as possible. In so doing, the external heat leakage to the system is minimized by containing the oxidizer within the tankage and feed line and by maintaining the valve at oxidizer temperature well insulated from external heat sources by long heat paths.

The mounting of these valves adjacent ot the tankage or feed system precludes the trapping of (thus isolating as unusable) liquid oxidizer. Further, if fill and drain is performed through the engine feed line or through the wall of the tank in the immediate vicinity of the engine feed line connection, location of the valving adjacent to the primary oxidizer system is extremely important because it prevents the inadvertent ingestion of a gas bubble formed in the fill line into the feed system during engine operation. The introduction of such a bubble into the liquid stream feeding the engine will degrade performance and could result in destruction of the engine.

In view of this, it seems evident that vehicle fill and drain as well as vent valves should be located in the highly insulated portion of the primary oxidizer system (tankage and/or feed line). Thus, these valves will be located onboard of the outer aerodynamic surfaces of the vehicle and will, therefore, be isolated by interconnecting lines (see Figure 1-2) from the Vehicle/AGE disconnect couplings located at the vehicle surface.



ASSUMED STATIC FRICT. COEF.	UNLATCHING LOAD PER CABLE	TOTAL UNLATCHING LOAD
0	23#	69#
0.78 (DRY)	295#	885#
0.15 (MoS_2)	76#	228#

Figure 2-25. Load Diagram for Latch Configuration V

Design requirements for this vehicle fill and drain valve cannot be fully specified without better vehicle and mission definition (operating pressures, operational environment, mission operations that might require valve functioning, maximum allowable loss of oxidizer during a mission, and so forth). Particularly in consideration of the fluorine-hydrogen vehicle study concept, the following should be noted:

(1) The Vehicle fill and drain valve is required to prevent excessive and/or hazardous escape of oxidizer from the vehicle through the fill and drain line.

(2) The valve is actuated (cycled open and closed) many times prior to launch (checkout, testing, filling, etc.).

(3) The valve is not actuated following vehicle launch.

(4) The valve does not serve as the contamination barrier between the vehicle oxidizer system and the atmosphere during ground, nonlaunch, operations (shipping, testing, checkout, connection to AGE, etc.). The barrier to this contamination is required at the disconnect coupling to preclude contamination of the interconnecting line, the valve, and the Vehicle/AGE interface sealing surfaces.

(5) Electromechanical valve position indication (open and closed) will be available for use to ensure that the valve has closed prior to launch.

(6) Oxidizer detectors (an appropriate unit has yet to be developed; see Appendix III for further details) located in the coupling and fill-line purge-gas vent would be used to detect excessive valve leakage. This greatly decreases the probability that the valve could degrade mission capabilities or cause mission failure.

These considerations suggest that great confidence can be placed in knowing that the vehicle fill and drain valve has functioned properly in all ground operations, including launch of the vehicle. This implies that adequate sealing techniques have been used in the valve seat design, which is, regardless of where the valve is located, a necessary and basic requirement for all valves used in the vehicle.

Solution of the other mandatory oxidizer system valve use problems (engine valves, pre-valves, vent valves, and so forth) will provide the needed technology and, potentially, even hardware for the fill and drain valve.

The following is pertinent to definition of the valve on the AGE side of the disconnect coupling, and the valve's influence on the coupling:

(1) The valve must prevent the excessive and/or hazardous escape of oxidizer from the AGE portion of the vehicle fill and drain line.

(2) The valve probably will serve as the primary oxidizer flow-control device during fill, topping just prior to vehicle launch, and during draining of oxidizer from the vehicle.

(3) The valve cannot serve as the contamination barrier between the AGE oxidizer system and the atmosphere during ground, nonlaunch operations. The barrier to this contamination is required at the disconnect coupling to preclude contamination of the valve, the vehicle/AGE interface sealing surfaces, and the interconnecting line.

(4) Electromechanical valve position indication will be available for use to ensure that the valve has closed prior to launch.

There do not appear to be any particular restrictions on size, weight, or location of the valve. The umbilical mast and oxidizer fill and drain line support and retraction boom can be made structurally adequate to permit location of the valve at any desired point. Location close to the vehicle/AGE disconnect coupling minimizes the amount of trapped oxidizer to be drained and purged from the line between the valve and the vehicle oxidizer fill and drain valve.

Packaging the AGE portion of the disconnect and the AGE valve into a single unit may have several advantages (fewer external leak paths, reduced weight, and so forth). More important, however, is that sealing and other operational characteristics should in no way be reduced or impaired.

2.3.2 Draining of Liquid Oxidizers from Lines and Components

Installation of lines and components in Vehicle and AGE liquid oxidizer systems should provide rapid and complete drainage of liquid under gravity-flow conditions.

Where components and lines cannot be arranged for gravity-flow drainage and liquid trap points cannot be avoided, a variety of approaches are potentially applicable for scavaging the liquid. These approaches can be categorized into one of the three following classes:

(1) Vaporization and removal as gas. Pressurization and purge gases can be effectively used to remove liquid from trapped areas in components, lines, and fittings by promoting heat and mass transfer under turbulent flow conditions, thus resulting in vaporization and gas-stream entrainment of the liquid in the purge gas.

(2) Removal by mixing and displacement with another liquid (probably an inert and otherwise compatible fluid).

(3) The use of special drain lines and/or fittings to promote gravity-flow drainage.

The use of a liquid to mix with and displace the oxidizer has obvious drawbacks: (1) the mixture must be vented or otherwise disposed of, thereby probably requiring specialized disposal or venting equipment; (2) eventually the displacement liquid trapped in the system must be removed because its presence during a subsequent operation of the system would result in oxidizer contamination and dilution and could lead to degradation of performance and hardware integrity.

A significant consideration involved in the liquid displacement approach is the type and availability of the displacement liquid. Undoubtedly, liquid nitrogen will be plentiful at liquid fluorine and liquid FLOX installations and would be a suitable purging fluid for these oxidizers if the cleanliness of the nitrogen and its transfer system can be assured. Great care must be taken to preserve the integrity of the system for oxidizer service.

Liquid oxygen is a possible displacement fluid for both fluorine and FLOX. The addition of filtering and purification processes to maintain adequate system cleanliness is quite likely because oxygen systems normally contain more nonmetallic particulate than are allowable in fluorine systems. The use of oxygen further introduces another hazardous, although nontoxic, fluid.

Gas-phase removal following vaporization of the liquid is straightforward. The primary problem is effecting the vaporization. This becomes more difficult when the trapped liquid is in a highly insulated (low-heat leak or subcooled) portion of the system. To promote vaporization, deliberate introduction of the heat of vaporization from external sources may be necessary; hot purge gases may be the answer and can be applied both externally and internally.

Externally applied purges usually will be far more difficult to handle because of the added complexity of having to effectively shroud the exterior of the component or line containing the trapped liquid. If these trap points are buried inside of a complex device or a highly insulated areas of the system, the external purge approach to vaporization of trapped liquid is useless.

Much more effective are internally applied purges because they permit direct contact of the warmer purge gas with the liquid to be vaporized. One notable exception is dead-ended areas of the system, components, and instrumentation lines. It is desirable to force purge gases under highly turbulent flow conditions into these trap points, to cause the liquid to break up into droplets (by agitation or other suitable means), to force the mixing of these droplets with the purge gases, and to promote the rapid turnover (replacement) of purge gases in the system. Special techniques or devices may be required to adequately effect these desired results.

In the vehicle fill and drain system, the line from the vehicle/AGE interface coupling to the vehicle fill and drain valve is dead-ended and will probably contain several trap points, even if slightly elevated to promote liquid drainage. These trap points are found in bellows, at component and line connection points, and in valves. Should the vehicle design be such that it is impossible to prevent trap points in the fill line, the trapped oxidizer must be purged from the system or effectively isolated and carried along as inert unusable weight. The last approach is undesirable because every pound of unusable propellant directly reduces the vehicle payload capability.

If the vehicle lines are short, a high-velocity stream of purge gas directed from the ground half of the coupling might prove adequate for oxidizer removal.

When the vehicle line is long, or has a large L/D, another approach must be used. Two possible vehicle fill and drain line configurations are shown in Figure 2-26. Configuration 1 results in trapping of liquid in the convolutes of the bellows. Removal of liquid through application of turbulent gas flow will require that the purge gas be introduced near the dead-ended portion of the line. This could be achieved by introducing the purge gas through a concentric purge line located inside the fill and drain line, as shown in Configuration 1. The purge gas would then promote the rapid and effective evaporation and removal of the trapped oxidizer.

Configuration 2 results in the trapping of liquid in a low spot in the fill and drain line in addition to that trapped in the bellows. Removal of the bulk of the trapped liquid can be accomplished through use of an internal drain line positioned to drain from the low spot, as shown in Configuration 2. The liquid would be forced through this drain line by use of purge gas in the main fill line. The cycle could be reversed once the bulk of the liquid was removed, and the purge gas could be introduced through the internal purge and drain line. Implementation of either of these approaches requires the addition of a small line to the vehicle and the connection of this line to the ground (AGE) purge and drain system. Both requirements can be met easily and reliably, as shown in Detail A. By keeping this auxiliary purge and drain line and its vehicle/AGE connection inside the vehicle fill and drain line and coupling, the problem of leakage and/or spillage is eliminated, the complexity of the system minimized, and the reliability of the system is improved.

All protrusions through the wall of the fill and drain line to bring in purge gases and to duct away purged fluids can be made on the AGE side of the coupling, thus minimizing vehicle system weight and complexity. The separable joint between the vehicle and AGE portions of this purge and drain line is an off-the-shelf connector used extensively by the chemical industry in making simple and effective laboratory test setups. Leakage at the connector is relatively unimportant as long as the substantial flow of the purge gas and/or purged fluids pass through the purge line. However, leakage could be minimal because the mating surfaces could be lapped to provide good sealing characteristics. Sealing loads are applied by compression of a bellows, shown in the AGE side of this line, as the fill and drain coupling is brought together and sealed. No other sealing or latching loads or connections are required with this approach.

Vaporization can also be enhanced by providing a partial vacuum in the system containing the trapped liquid oxidizer. This approach is most useful where external heat sources are available to keep the liquid from becoming cooled to the point where it might freeze. In highly insulated systems, freezing is almost certain and therefore limits the effectiveness of this approach for oxidizer removal from traps in the system.

Drain lines of fittings externally installed at trap points in the oxidizer system offer a positive approach to the removal of trapped liquid, even from highly insulated areas. Through appropriate valving and ducting, it is conceivable that all trap points in a system could be remotely drained of all liquid. The obvious disadvantages are increased complexity, increased weight (of particular concern for vehicle systems), and reduced reliability.

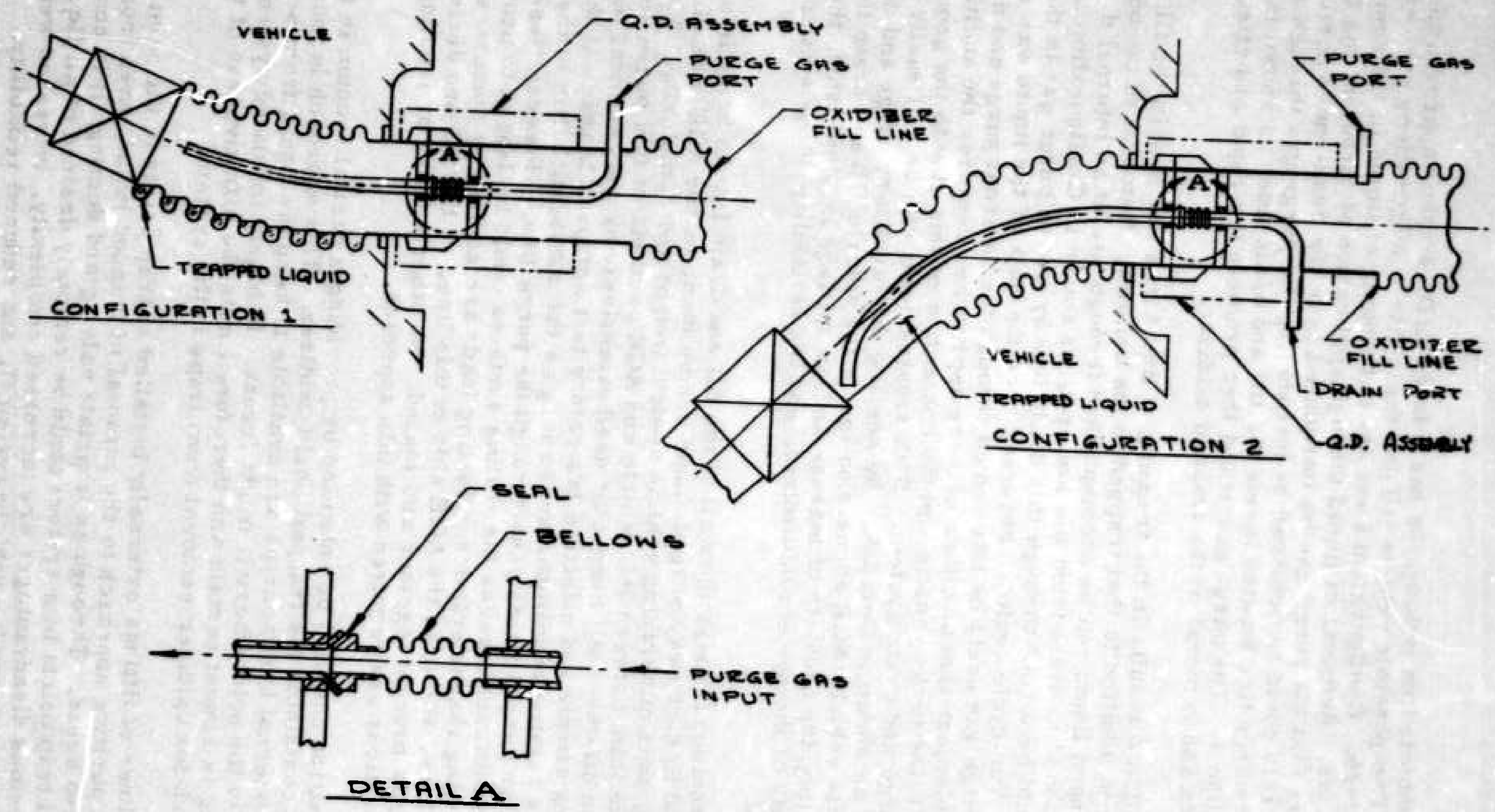


Figure 2-26. Vehicle Fill and Drain Line Configurations

2.3.3 Analysis of Liquid Fluorine Vaporization and Removal

2.3.3.1 Purge System Description

The purpose of this section is to interrelate the fluid flow and heat transfer parameters and develop methods of predicting flow rates and time necessary to ensure removal of the oxidizer from the trapped portions of the fill and drain line located between the vehicle and AGE shutoff valves. For this purpose, an example based on the transfer line shown in Figure 2-27 is chosen. A typical launch position is shown in Figure 2-29.

Following liquid fluorine transfer, the line is gravity drained through Valve E, but some liquid remains as a result of convolutions in the flex line and other trap points in the line. It estimated that 5% of the total line volume is trapped in the convolutes (Figure 2-28a), and an additional 15% of the total line volume is trapped at Section BB (Figure 2-28b) as a result of line sag.

Nitrogen purge gas at 38 psia and 80°F is introduced through Valve C (Figure 2-27) and directed into the vehicle fill and drain line through directional nozzles. The gas is allowed to exhaust through Valve E to a vent and disposal system at a static pressure of 15.7 psia.

Sonic flow through Valve E will result when the internal pressure reaches

$$Pi = \frac{Pv}{\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}}$$

$$Pi = \frac{15.7}{0.5283} = 29.8 \text{ psia}$$

where

Pv = vent system pressure = 15.7 psia

and

γ = ratio of specific heats for nitrogen = 1.4.

Weight flow rate, $\dot{W}_E$, through this orifice at sonic velocity is

$$\dot{W}_E = C_D A_o Pi \sqrt{\frac{g\gamma}{RTi}\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma + 1}{\gamma - 1}}}$$

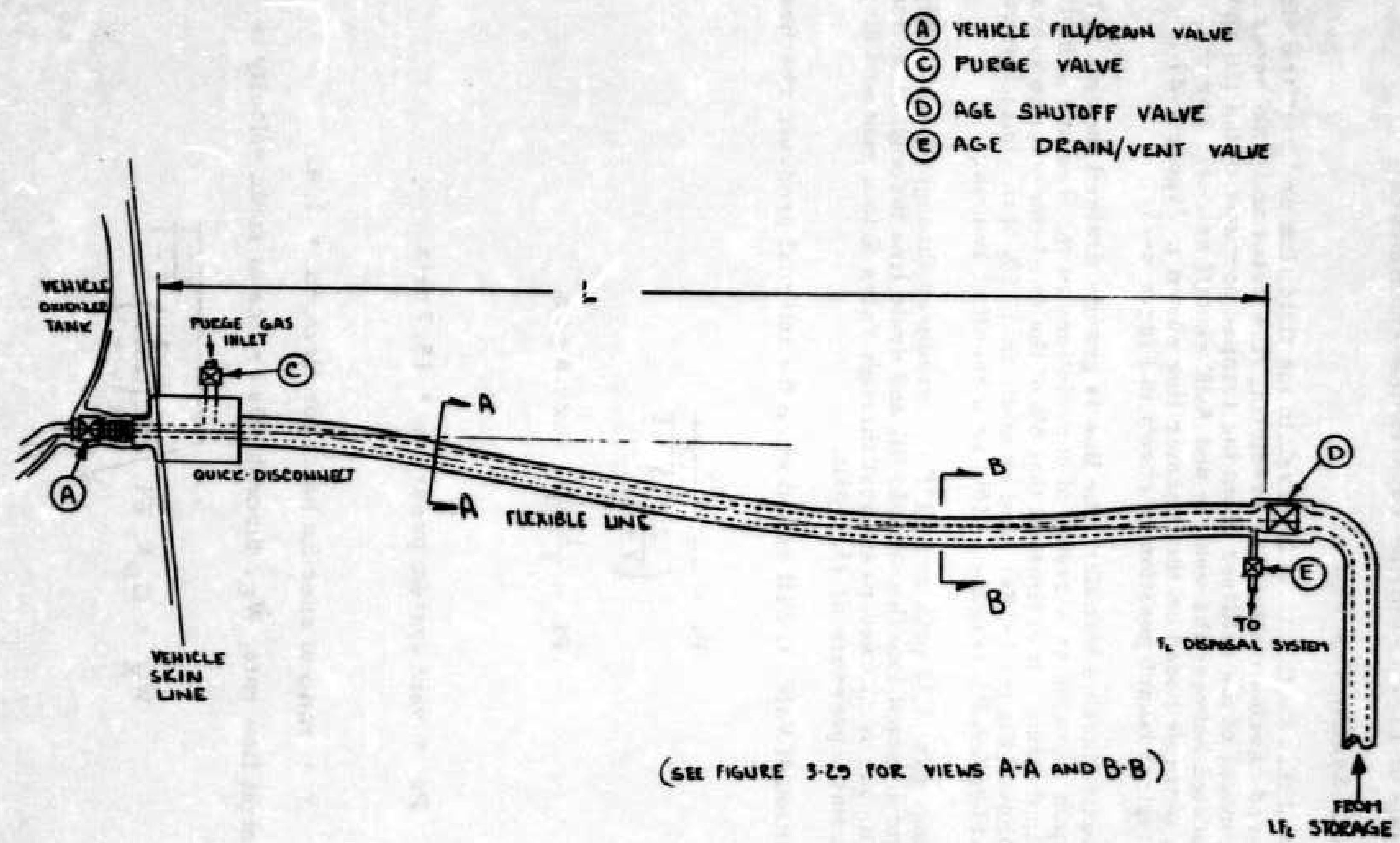


Figure 2-27. Typical Fill and Drain Line Installation

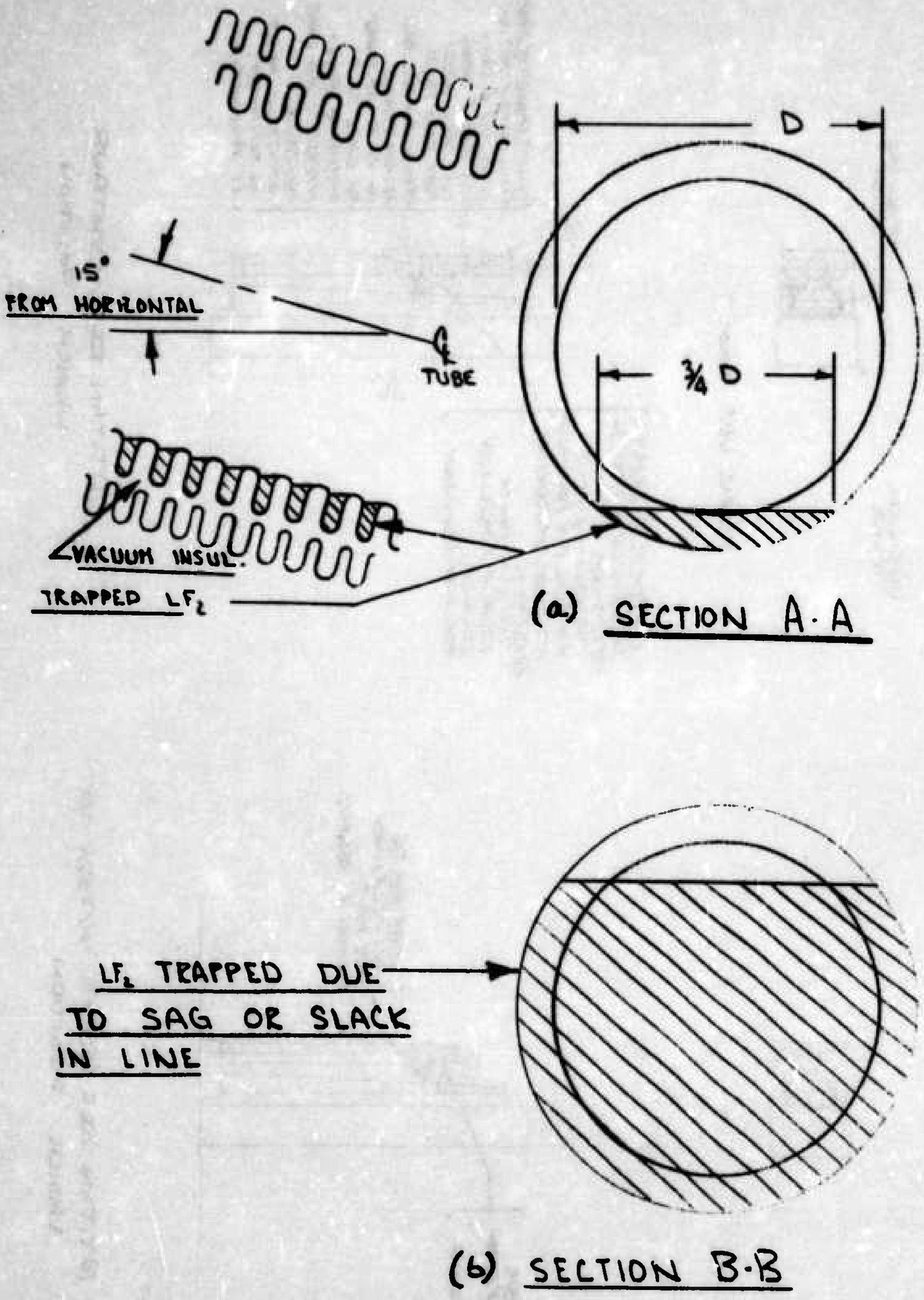


Figure 2-28. Fluorine Trap Points

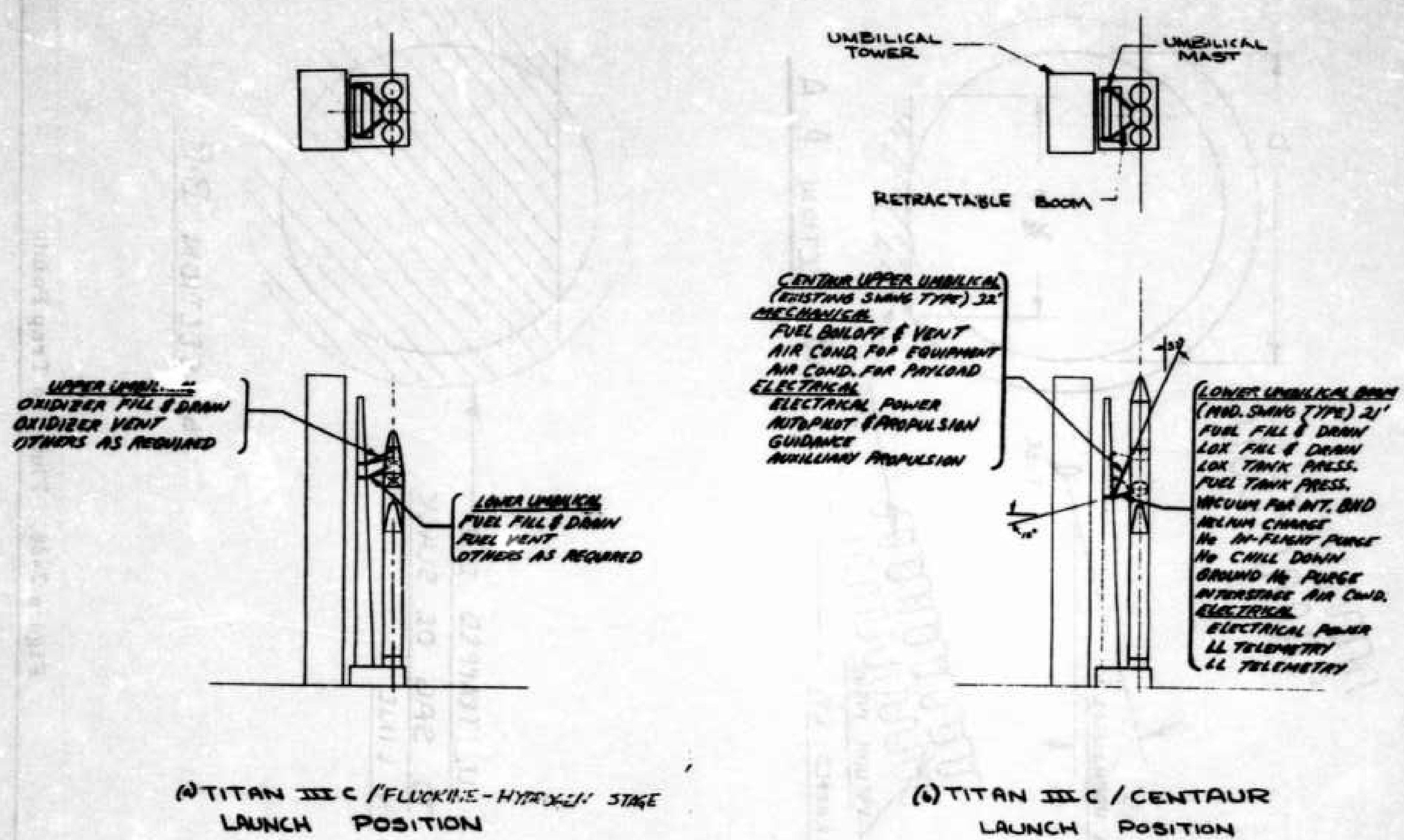


Figure 2-29. Launch Positions

where

$$\dot{W}_E = \text{weight flow rate (lb/sec)},$$

$$Ao = \text{orifice area, ft}^2$$

$$R = \text{gas constant (lb-ft/lb}^{\circ}\text{R)},$$

$$Ti = 540^{\circ}\text{R},$$

then

$$C_D = \text{orifice discharge coefficient} = 0.8, \text{ for a short tube}$$

and

$$\dot{W}_E = 77.1\ Ao, \text{ lb/sec}$$

When steady-state purge-gas flow has been established, the subcritical weight flow rate through Valve C is approximately equal to the weight flow rate through Valve E.

$$\dot{W}_c = C_D\, Ao_c\, \rho_o \left(\frac{Pi}{Po}\right)^{\frac{1}{\gamma}} \sqrt{2g \frac{\gamma}{\gamma - 1} RTo \left[1 - \left(\frac{Pi}{Po}\right)^{\frac{\gamma - 1}{\gamma}}\right]} \tag{12}$$

where

$$Ao_c = \text{orifice area at C(ft}^2\text{)},$$

$$\dot{W}_c = \text{weight flow rate (lb/sec)},$$

$$\rho_o = \text{density of purge gas upstream of C(lb/ft}^3\text{)},$$

$$Po = \text{pressure of purge gas upstream of C} = 38 \text{ psia},$$

$$To = 540^{\circ}\text{R},$$

then

$$\dot{W}_c = 82\ Ao_c\text{(lb/sec)},$$

because

$$\dot{W}_c \approx \dot{W}_E$$

$$Ao_c \approx 0.94\ Ao$$

The heat required to vaporize trapped liquid may be added by passing warm purge gas through the transfer line. Area-of-surface contact between warm gas and liquid depends on the local geometry of the tube, but is assumed to average 3/4 diameter-to-length ratio over the total tube length.

$$A_s = \frac{3/4\ D\ L}{12}$$

where

D = transfer line diameter = 2 in.,

and

L = transfer line length (ft),

then

Additional heat will be transferred to the tube walls, but because of the thin section of the tube wall the rate of heat transfer to the liquid is small. It is, therefore, conservative to neglect heat transferred to the tube walls.

The rate of heat transfer to the trapped liquid is

$$q = hA_s\ T$$

$$q = \frac{0.125\ Lh\ T}{3600} = 3.475\ Lh\ T \times 10^{-5}\ \text{Btu/sec} \qquad (14)$$

where

T is the difference in temperature between the GN_2 and the trapped liquid.

h = the film coefficient of heat transfer

$$h = 0.023\frac{k}{D}(Re)^{0.8}(Pr)^{0.4},\ \text{Btu/hr ft}\ ^{\circ}F$$

where

k = thermal conductivity of GN_2 = 0.015 Btu/hr ft $^{\circ}$F

Pr = Prandtl number = 0.7 (approx for GN_2)

Re = Reynolds number = $\frac{D\rho v}{\mu}$

D = tube diameter (ft),

since

$$\dot{W} = A v \rho$$

v = purge gas velocity, ft/sec

μ = visicosity of nitrogen = 12×10^{-6} lb/sec ft

ρ = density for GN_2, lbs/ft^3

then

$$v = \frac{\dot{W}}{A\rho} = 286\, \dot{W} \text{ ft/sec}$$

and

$$Re = 6.4\, \dot{W} \times 10^5$$

The GN_2 temperature drop (ΔT) due to LF_2 vaporization is

$$\Delta T = \frac{q}{\dot{W}\, Cp} \qquad (15)$$

where

Cp = specific heat, constant pressure = 0.25 Btu/lb ^oF.

Now the time required to vaporize all the trapped LF_2 can be determined as follows:

$$t = \frac{V \lambda \rho}{q} \qquad (16)$$

where

t = time (sec)

λ = heat of vaporization for LF_2 - 74.1 Btu/lb,

V = initial volume of trapped liquid, ft^3,

and

ρ = density of LF_2 = 94.3 lb/ft^3,

then

$$t = \frac{2V}{Lh\, \Delta T} \times 10^8$$

Figure 2-30 represents time required to vaporize 20% trapped liquid from a 20-ft transfer line as GN_2 purge gas flow rate is increased. Figures 2-31, 2-32, and 2-33 represent the variation of time required to vaporize all LF_2 with line length for several GN_2 flow rates.

2.3.3.2 Residual Liquid in the Vehicle Fill and Drain Line

For simplicity in the purge system, the GN_2 should be introduced through the ground half of the QD coupling. If the vehicle portion of the fill and drain line is short ($L/D<6$), residual liquid trapped in convolutions can be removed by introducing purge gas through nozzles pointing into the tube at a 45° angle to the axis, as shown in Figure 2-34. Because the gas must flow inward near the walls and outward near the center of the tube, a conservative estimate of velocity at the wall is made by assuming expansion from the nozzles to half the area of the tube and that velocity diminishes linearly to zero at the closed end. Because the nozzles are directed at a 45° angle to the tube axis

$$v = \text{initial velocity at wall} = \sin 45^\circ \left(\frac{\dot{W}RT}{PA}\right) \text{ ft/sec}$$

$$v_2 = \text{velocity at closed end} = 0 \text{ ft/sec} \qquad (17)$$

If

$$\dot{W} = 0.15 \text{ lb/sec}$$

$$R = 55.3 \text{ ft/}^\circ\text{R}$$

$$P = 38 \text{ psia}$$

$$T = 530^\circ\text{R}$$

$$A = \frac{1}{2}(2)^2\frac{\pi}{4} = 1.57 \text{ in.}^2$$

then

$$\bar{v} = \text{average velocity at wall} = \frac{v_1 + v_2}{2} = 26 \text{ ft/sec}$$

The Reynolds number is

$$Re = \frac{D\rho v}{\mu}$$

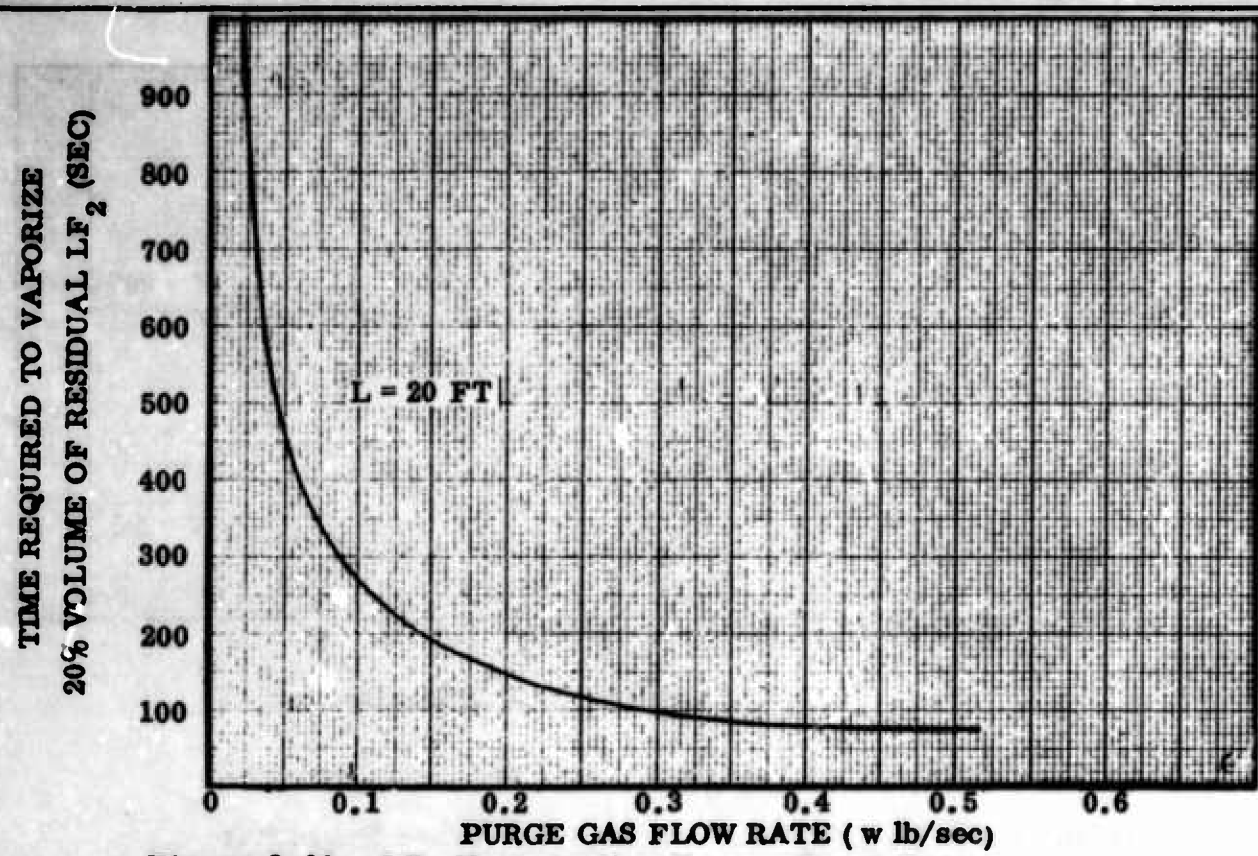


Figure 2-30. LF_2 Vaporization Versus Purge Rate

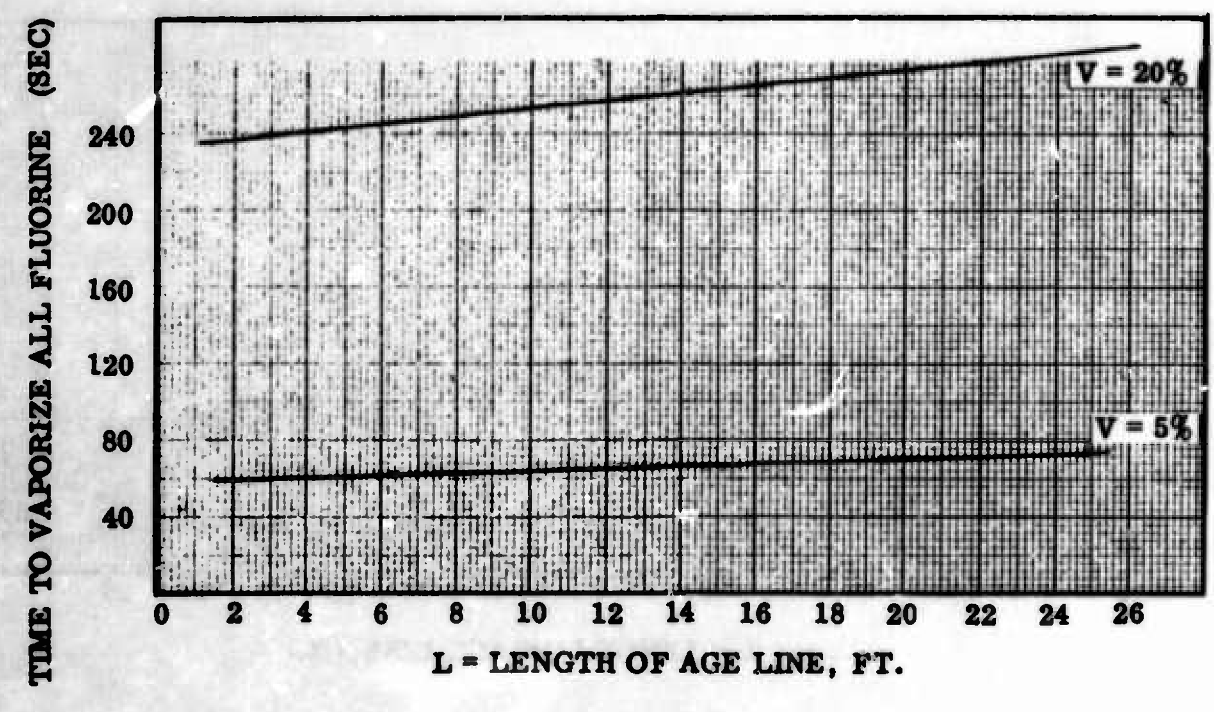


Figure 2-31. LF_2 Vaporization for 0.10 lb/sec Purge Rate

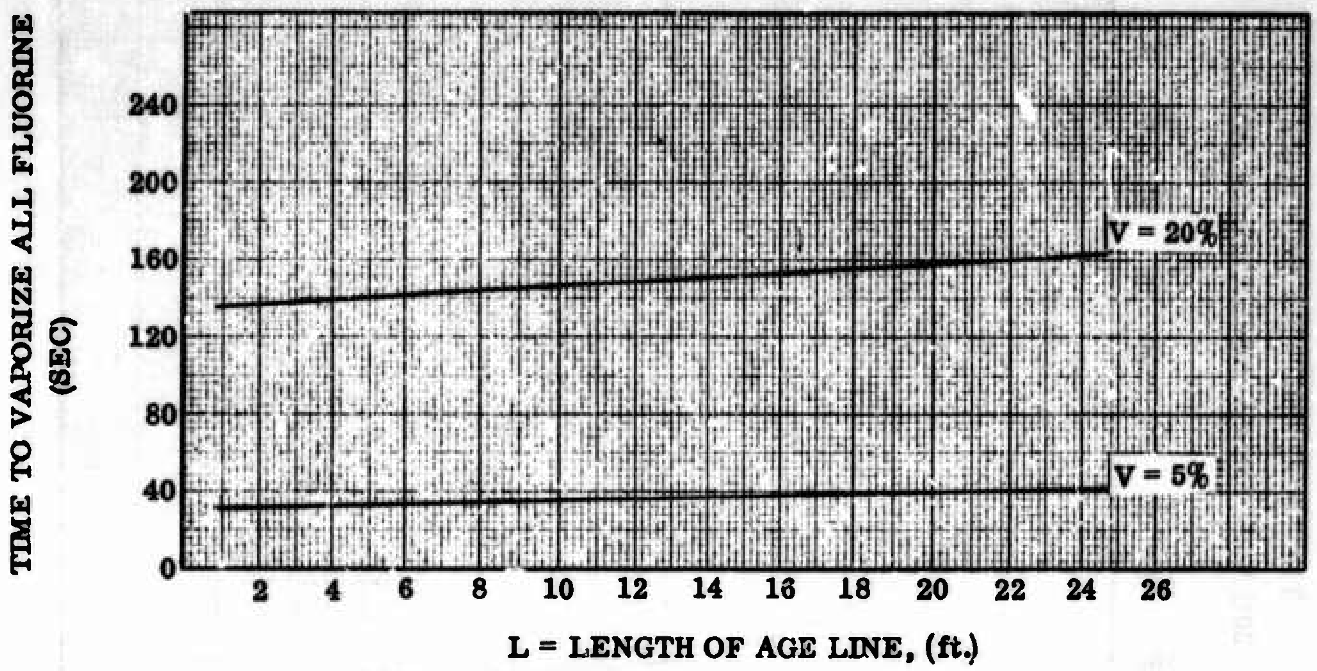


Figure 2-32. LF_2 Vaporization for 0.20 lb/sec Purge Rate

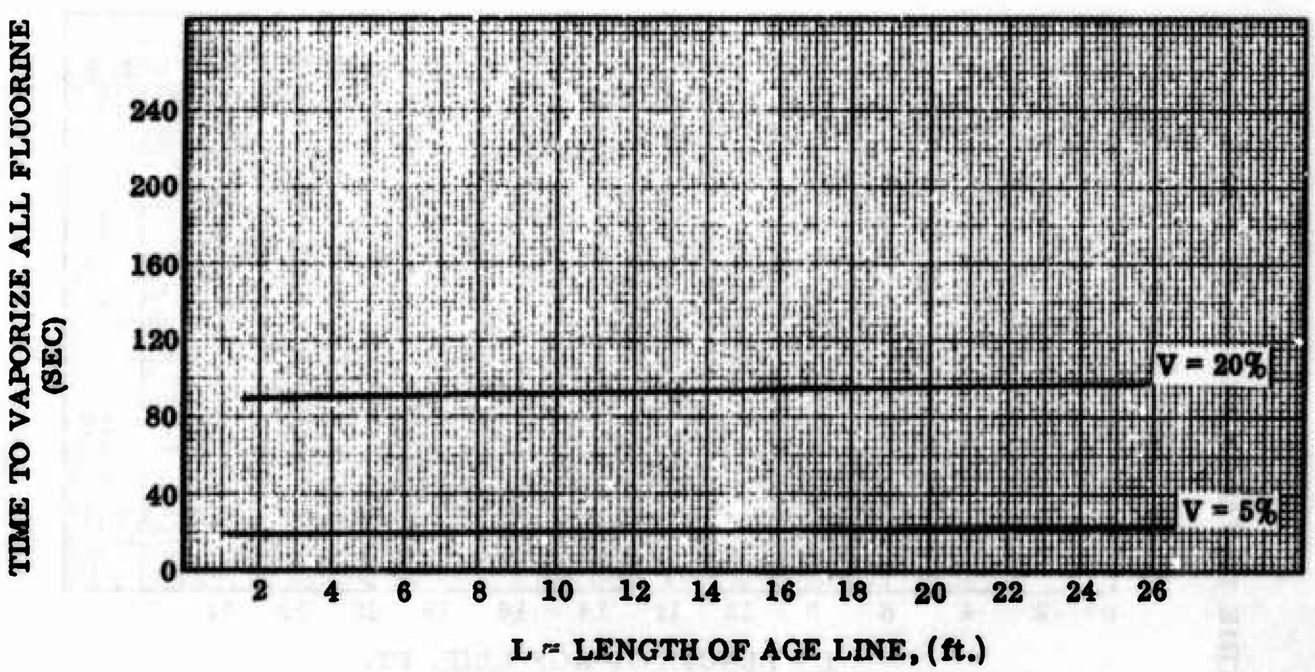


Figure 2-33. LF_2 Vaporization for 0.40 lb/sec Purge Rate

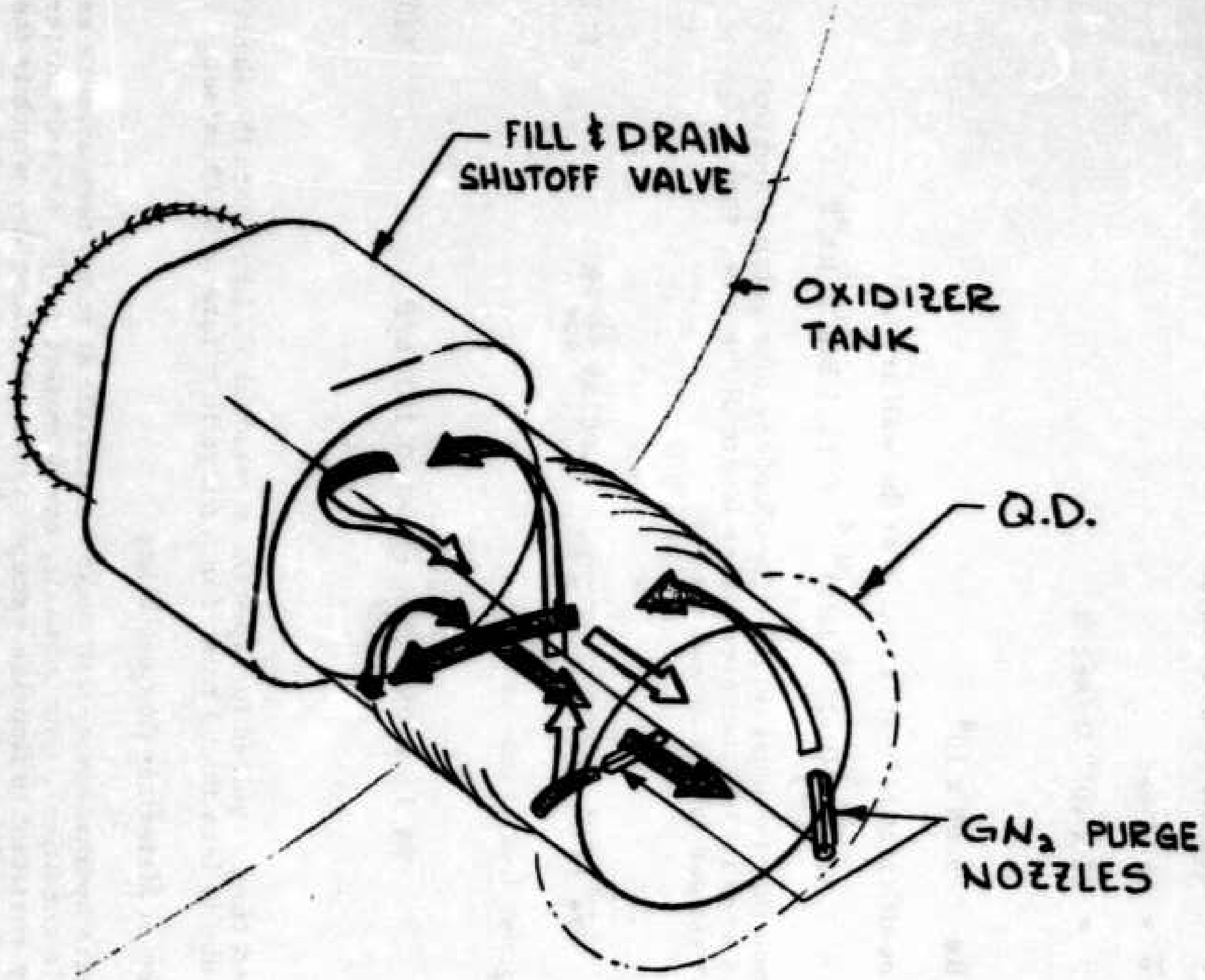


Figure 2-34. Forced Circulation of Purge Gas in a Short Vehicle Fill and Drain Line

where

$$D = 1/6 \text{ ft}$$

$$\rho = \text{density} = 0.14 \text{ lb/ft}^3$$

$$\bar{v} = 26 \text{ ft/sec}$$

$$\mu = 12 \times 10^{-6} \text{ lb/sec ft}$$

then

$$Re = 5.08 \times 10^4$$

and the film coefficient of heat transfer at the wall is

$$h = 0.023 \left(\frac{k}{D}\right)(Re)^{0.8} (Pr)^{0.4} = 11.3 \text{ Btu/ft}^2\text{hr}^\circ\text{F}$$

If it is assumed that residual liquid fills 5% of the tube volume and that liquid surface area is 3/4 diameter times length of the tube, then LF_2 vaporization rate per foot of tube length is

$$\frac{q}{74.1 l} = \frac{h A_s \Delta T}{3600 \times 74.1 \times l} = 0.00185 \frac{\text{lb}}{\text{sec}}/\text{ft} \tag{19}$$

Residual LF_2 per foot of tube is

$$94.3 \times 0.05 \times \left(\frac{1}{6}\right)^2 \frac{\pi}{4} = 0.103 \text{ lb/ft} \tag{20}$$

The calculated time required to vaporize a residual 5% LF_2 from the short dead-ended tube is less than 1 min. for a purge flow rate of 0.15 lb/sec.

2.4 Summary of Materials Compatibility

Fluorine reacts spontaneously with many materials at room temperature and, under suitable conditions, with virtually every material. No organic material is completely resistant to fluorine except carbon tetrafluoride, which is the stable end product of the reaction between fluorine and carbon. Fluorine also reacts with most inorganic materials, except the light inert gases and metal fluorides in their highest valence states. The reaction with most metals is comparatively slow at room and lower temperatures but vigorous at elevated temperatures (Reference 9). Insofar as compatibility with materials in concerned, the oxidizers may be divided into two groups, cryogenics (liquid fluorine, LF_2, and FLOX) and storables (chlorine trifluoride, or CTF, and Compound A). In general, materials which are compatible with F_2 are compatible with FLOX and materials which are compatible with CTF are compatible with Compound A. The metals most resistant to LF_2

are nickel, Monel, low-silicon stainless steel, aluminum, copper, and magnesium (see Reference 10, 37, 38, 39 and 40). Wrought Monel is one of the most satisfactory materials for use with LF_2. In addition to resisting LF_2, Monel also resists attach be hydrogen fluoride (HF) which is a common contaminant in LF_2. The corrosion resistance of metals is apparently based on the formation of fluoride films which protect the metal from further attack. However, permeability of the metal is one of the controlling factors in corrosion rate, and the fluoride coating varies with the material. The least reactive, or the most resistant metals, are the least dependent on the fluoride film.

Water vapor is a prime potential source of trouble; it reacts with fluorine to form a mixture of oxygen and hydrogen fluoride and containing small amounts of ozone, hydrogen peroxide, and oxygen fluoride. Some of the corrosive properties assigned to fluorine by early workers to explain apparatus failures were actually caused by contamination of the gas by hydrogen fluoride.

The fluoride film formed on most metals exposed to F_2 becomes hydrated when exposed to water and turns to a loose powdery substance which easily separates from the metal. Nickel forms fluoride films which are fairly resistant to hydration although they absorb moisture. Aluminum fluoride films hydrate slowly after an indiction period. Copper fluoride films hydrate immediately. Hydrogen fluoride will also disrupt protective fluoride films of some metals by forming bifluoride complexes. Fluorine systems will have to be either kept dry or dried to remove absorbed moisture; the passivity of most metal fluoride films is destroyed by traces of moisture.

Based on information gathered and published by the Defense Metals Information Center (Reference 10) metals which should not be used in LF_2 service include low-carbon steel, cast iron, cast Monel, lead, molybdenum, tantalum, titanium, columbium, and zirconium. Almost all of the nonmetals react rapidly with LF_2 and cannot be used. No nonmetals are currently recommended for fluorine service. Teflon TFE is the only fluorinated resin that can be considered for use, and then only in a static environment where it is protected from the flow field and encased sufficiently to ensure conduction of heat away from the Teflon. A minimum of surface area should be exposed to F_2. Burrs and feather edges must be avoided. Extreme precautions must be taken to insure that the Teflon is free from contamination. Other nonmetallic materials, such as synthetic sapphire, Norbide, and Kentanium, reportedly react very slowly in F_2 and may be suitable for certain applications.

The common structural metals most resistant to CTF and Compound A, roughly in the order of decreasing resistance, are nickel, Hastelloy C, Monel, copper, Inconel, aluminum, 300 series stainless steels, low-carbon steel, and magnesium. Teflon and Kel-F can be used under limited and controlled service conditions. They should never be used in service with these oxidizers when subjected to heat, shock, or flow conditions. References 42 through 46 present more detailed compatibility data.

Metals known to be unsuitable for use with CTF and Compound A include titanium, columbium, molybdenum, uranium, zirconium, lithium, vandium, niobium, tungsten, mercury, boron, silicon, arsenic, and antimony. Almost all of the organic compounds react with these oxidizers. Carbon and graphite with plastic binders are also incompatible.

With fluorine, the key to using compatible materials has not been so much the choice of metals as the cleanliness. Most erratic behavior and ignition of metals has resulted from contamination. Most metals show little or no signs of corrosion following prolonged exposure to contaminant-free LF_2. However, most metals are attacked severely by HF, particularly in the presence of free moisture (Reference 11). By choosing basically compatible materials, corrosion problems involved in handling any of the fluorine oxidizers will be relatively insignificant if HF can be excluded from the system and the oxidizer kept in a high state of purity.

NASA has conducted tests with streams of LF_2 impinging on material samples at flow velocities up to 400 psf and pressures up to 1,500 psig. No measurable physical attack occurred with nickel, stainless steel, aluminum, or brass specimens. The results of the tests showed that turbulence, fluid friction, and impact effects resulting from high-pressure, high-velocity LF_2 flow through clean tubing or past irregularly shaped or sharp-edged objects will not initiate system failures (Reference 11).

2.5 Manufacturing and Inspection Techniques

The primary components of the QD coupling will be made from metal by machining processes. These parts include the bodies for the two coupling halves, the interface seal, the latching mechanism, and the release mechanism. For a 2-inch diameter coupling, the bodies will probably be machined from bar stock. Other possibilities are to start with a forging billet or a casting. For the limited quantities which will be required for development hardware, it is not economically justifiable to make the tooling for forgings. The use of castings presents other problems which have not been sufficiently investigated to warrant their use. These problems include contaminant inclusions and difficulties in welding.

The most critical machined areas are the sealing surfaces. They must be relatively flat, smooth, and free of imperfections such as nicks and scratches.

The machinings much more critical for the hard-to-hard (elastic deformation) metal seal approach. The amplitude of waviness of the mating surfaces must not exceed a few microinches and a surface roughness in the order of 1 μ in. or less is necessary if a reasonably low leakage rate is to be achieved. The usual methods for achieving these near-perfect surfaces is to use a lapping technique. The production of surfaces to this degree of flatness and smoothness requires special care and skill on the part of the machinist.

Flat surfaces are the easiest and least expensive to lap because they may be produced on a flat lapping table, whereas for contoured surfaces such as spherical or conical surfaces, a contoured lap of the same size and shape as the finished surface must be made. One of the principal problems in lapping of flat surfaces is the tendency of the edges of the surfaces to round off as a result of the particles in the lapping compound piling up in front of the surface being lapped as it is moved over the lapping table.

Additional problems are encountered in protecting the surface from damage after it has been machined. It must be handled carefully to keep it from being damaged by contact with hard objects such as tools, work tables, and inspection instruments. When the two sealing surfaces are being mated, they must be aligned before contacting each other and must not be permitted to slide with respect to each other because the sliding motion can cause scratches or galling which could prevent a satisfactory seal.

The matching of the components for the soft metal seal is much less critical. Since the sealing loads cause the harder mating components to cut into the soft seal, a surface finish of 125 arithmetical average (AA) μ in. is adequate for the soft part. It is not permissible to have pits or scratches in the surface which are deeper than the specified maximum surface roughness. It is desirable to have the surface produced by a turning operation so that the machining grooves form a circular lay and there will be a minimum number of these grooves crossing the sealing area. The sharp corners or knife edges on the hard components must be free of nicks. The roughness of the intersecting surfaces which form the sealing edges should not exceed 32AAμin.

Although the soft metal seal version does not have as stringent requirements for surface finishes as the hard seal version, it is also vulnerable to damage from careless handling and must be given the same considerations during handling and mating of the coupling as noted above for the hard seal version.

It is expected that normal tolerances and surface finish requirements will apply to the remainder of the machining operations on the coupling and it will be capable of being produced in any machine shop with standard milling and turning machine shop with standard milling and turning machines.

Inspection methods for surfaces finished to the tolerances specified above for the hard metal seal coupling must be limited to optical methods of measuring flatness and smoothness. The use of inspection equipment such as a Profilometer or a Proficorder which utilize a stylus to trace over the surface for measuring roughness are not permissible because the stylus may cut a groove deeper than the surface irregularities being measured and thereby create a leak path. The optical inspection devices which are useful in measuring the quality of a surface finish are the optical flat and the interference microscope. Both of these devices make use of the phenomenon of optical interference.

Besides machining, the manufacturing processes which may be applicable to the QD are welding and brazing. Since it is desirable to control the leakage of the toxic fluorine related oxidizers to a minimum the transfer systems should contain a minimum number of mechanical joints. Welding or brazing should be used wherever possible for joining components. Typical applications for welding include joining the body of the coupling to the vehicle fill line, joining the body of the coupling to the AGE umbilical fill, adding bosses to the body for attachment of drain and purge lines, and addition of external flanges and lugs to the body for mounting to the vehicle or for attachment of the latch mechanism. Weld joints should be carefully designed so that after welding there will be no cavities or crevices formed by layers of metal exposed to the oxidizer. Weld joints should be butt joints rather than lap joints.

The following procedures for welding a pipe joint for a fluorine system is recommended in Reference 11 and is applicable for any welding required on the QD.

Pipe ends to be welded should be beveled suitable for full-penetration V-notch butt welding. Sleeve joint should be avoided unless the overlap joint can be brazed or isolated by welding. Welding should be performed by a qualified welder using a shielded arc (heliarc) with an inert gas backup so that the inside of the pipe is not contaminated by slag or other contaminants which cannot be cleaned off by normal cleaning procedures. The weld should be protected by purging with argon or helium gas before welding is started. The purge may be reduced during welding to prevent blowout of the weld. Gas protective devices should be in place during all of the welding process. An appropriate filler ring should be used on the first pass. The remaining passes may be metal-arced to minimize distortion and carbon precipitation in susceptible alloys and to increase welding speed. The weld penetration or depth of fusion must be to the bottom of the vee groove (excess penetration of a bead 1/16-in. high on the inside of the pipe is acceptable if the based is smooth and well rounded.

There must be no cracks, crater defects, pinholes, or slag. After the first pass, the welder should inspect the weld carefully for defects. Craters, cracks, and rough lumpy spots must be ground or chipped out before continuing the weld.

The arc should not be broken at the centerline of the weld. The welding rate should be accelerated until the weld pool becomes small, then the arc should be moved off to the side of the groove before being broken. The bead, where broken, should have a tapered end. It is recommended that the work be turned to allow down hand welding wherever possible.

Welded joints should be stress-relieved, if necessary by heat treating. Welded seams and connections used in fluorine/FLOX installations require X-ray inspection of all welded joints. Welds with poor penetration, flux or slag inclusions, pockets, bubbles, or surface flaking cannot be permitted. Welded connections must be cleaned and passivated before being placed in fluorine service.

There are few comments to be found in the published literature concerning experience with brazing in fluorine systems. Gold-nickel and copper brazing alloys should be compatible with fluorine; however, it is expected that silver brazing would not be compatible. Douglas experience indicates that some silver braze alloys are rapidly attacked by fluorine as well as by a dilute nitric acid solution which is sometimes used in the cleaning of components. Before using any brazing alloy in a fluorine system, a brazed sample made from the actual metals to be joined should be exposed to fluorine and hydrogen fluoride to establish that the material actually is compatible. If brazing is used, the finished joint must be thoroughly inspected to make certain that there are no unfilled crevices remaining and that all traces of brazing flux have been removed.

All brazed joints should be X-rayed to ensure that no hidden cavities or flux and slag inclusions are present. When defects in the brazed joint are found, the component must be rejected.

2.6 Contamination

2.6.1 Importance of Contamination Control

The importance of contamination control on components or systems used for service with any of the fluorine-related oxidizers cannot be overemphasized. The principal areas of concern are reaction of the contaminant with the oxidizer and system malfunction as a result of the contamination. Because fluorine reacts vigorously with most of the nonmetal materials, as well as with some of the metals, the presence of these materials as contaminants could initiate a reaction and cause a system overpressure of a burn-through of the walls of the oxidizer system. Types of system malfunctions which can be caused by particulate contamination are plugging of orifices or other small passages and interference with mechanical functions such as valve closing.

2.6.2 Types of Contamination

For most fluid systems, the primary contaminants may be grouped into three categories:

(1) Noncombustible contaminants (particulate matter such as metal chips or sand)

(2) Combustible contaminants

(3) Water.

These categories are not really suitable for application to fluorine because water and many of the contaminants normally considered noncombustible are highly reactive with fluorine. Some of the less reactive contaminants such as metal chips, particles of metal oxides and metal fluorides, and some forms of carbon particles may remain in the fluorine oxidizers as solid particles for a sufficient time to cause a system malfunction.

The most common forms of combustible contaminants are organic materials such as preservatives, lubricants, paint, solvents, lint, etc., which may produce fire or an explosion hazard. Although a sufficient quantity of water would consitute a fire or explosive hazard, it may also be detrimental when present in the small quantities found in the atmosphere because its reaction with fluorine produces hydrogen fluoride which promotes corrosion of the metal components of the system. Also, in the case of the cryogenic oxidizers, the water may build up as frost or ice on the outside of the system and create an explosive hazard in the event of an oxidizer leak.

2.6.3 Sources of Contamination

Sources of contamination of the hardware in a fluid system can be divided into the following two groups:

(1) Internal contamination (contaminants initially in the system or generated by the system).

(2) External contamination (includes airborne contaminants, contaminated fluids, and contaminants introduced by negligence in handling or maintenance of the hardware)

Considering a complete oxidizer transfer system which would be required in conjunction with the subject QD coupling, internal contamination may be present before the system is operated for the first time. The sources of this type of contamination are from the manufacturing, assembly, and installation operations, as well as from contaminated storage tanks and test fluids. Some types of contaminants resulting from manufacturing operations may be hard to detect and remove. If abrasive grinding or lapping materials are used, they may be left imbedded in the surface of the metal component. Also, if welds are made in areas which are inaccessible for inspection and cleaning operations, they may contain slag and scale which could cause trouble when the oxidizer is introduced. During assembly and installation, contamination may be introduced by the mechanic in the form of oil or dirt particles from his hands, as well as from his tools and work bench. Also, there is the possibility of a noncompatible lubricant being used to mate close fitting parts. During functional testing, components may be contaminated from test fixtures used as sealing closures as well as from a contaminated system supplying the test fluid.

System-generated contaminants result from the wear and deterioration of components through mechanical and chemical action. Mechanically generated particles may result from the movement of surfaces with respect to each other such as the opening and closing of valves. Particles resulting from chemical action may be in the form of metal fluorides or oxides which have formed on the metal surfaces and subsequently become dislodged.

External contamination may be a problem to both the interior of the system and to the exterior of the hardware if external mechanisms are used. The interior of the system may be exposed to airborne contaminants, such as sand, dust, lint, and water, at any time it is opened to mate the propellant transfer line to the vehicle, to connect the propellant transport trailer to the vehicle loading system, to connect the vent and purge system, and to replace components. Contamination may enter an opened system from the use of a temporary closure which is either contaminated or made of a material which can leave a residual contaminant in the system when the closure is removed. The fluids used in the system are also a possible source of contamination. Any solid contaminants in the oxidizers would probably not be chemically reactive but could be a source of trouble for the satisfactory operation of mechanical components such as shutoff valves. The gases used for leak checking and purging the system could carry contaminants such as water, oil, or solids which are chemically reactive with the oxidizers into the system. Contamination of the exterior of the hardware is of concern in areas where it could lead to a system malfunction such as failure of the disconnect latching mechanism to operate or failure of a shutoff valve to operate. Of primary concern in the case of the cryogenic oxidizers is the exclusion of water which not only could cause a malfunction by the formation of ice around an operating mechanism but also could become an explosive hazard if it becomes contaminated with fluorine.

2.6.4 Effects of Contaminants

The principal problems caused by contaminants in a transfer system suitable for the four oxidizers under consideration are as follows:

(1) Interference with moving mechanisms.

(2) Damage to sealing surfaces.

(3) Chemical reactivity with oxidizers.

(4) Incompatibility with filters.

(5) Plugging small orifices.

The types of moving mechanisms that may be found in an oxidizer transfer system include shutoff valves for the oxidizer and purge systems and the latching and retraction mechanism for the QD coupling. Close-fitting sliding surfaces are especially vulnerable to jamming by solid particles, which wedge into the clearances, thus increasing friction and, in extreme cases, causing weldment of metal surfaces.

Damage to sealing surfaces of shutoff valves or of the interface seal in the QD coupling may be caused during assembly or installation by the presence of hard contaminant particles on the sealing surfaces when they are brought together. The damage may be in the form of scratches across the sealing areas or the particles may become partially imbedded in one of the surfaces and thus hold the sealing surfaces apart. For the shutoff valve, contaminant particles may damage the sealing surfaces by abrasion during flow of the oxidizer. Another possibility of damage to the sealing surfaces is that, if a contaminant particle caught between two sealing surfaces reacts chemically with the oxidizer, a leakage path larger than the initial particle size may be created as a result of a portion of the seal being consumed during the reaction.

The chief concern about chemical reaction of contaminants with the oxidizers is that the reaction may have sufficient energy to cause a rupture of the system. Other lesser effects are degradation of the oxidizer and possible physical damage to some of the internal components of the system, and the jamming of orifices and close-fitting surfaces with the reaction by-product.

Use of filters in particular with liquid fluorine, has been generally unsuccessful. The filter elements usually disappear after very short period of use. It is suspected that the entrapment of contaminant particles in the filter may cause an acceleration of the corrosive effects of the fluorine on the filter element.

2.7 Cleanliness Requirements

2.7.1 Component Cleaning

Because the fluorine related oxidizers are so highly reactive with all organic compounds, such as oils, grease, etc., the cleaning procedures for the components and systems used to handle these oxidizers must ensure that essentially all such reactive materials are removed prior to exposure to the oxidizer. On the basis of present experience with liquid fluorine systems, it must be asssumed that filters are not compatible with the oxidizer, and therefore particles in the fluid large enough to cause a malfunction of any of the system components must be excluded be exercising the strictest control in the cleaning of components and maintaining of system cleanliness.

Each user of the fluorine oxidizers develops special cleaning procedures for the oxidizer handling equipment. Cleaning methods recommended by NASA, Rocketdyne, and Bell Aircraft are presented in Reference 9. Douglas now uses a modified version of the cleaning procedures developed over a number of years for liquid oxygen components. Additional work in determining cleaning requirements for fluorine hardware is currently being accomplished by Douglas to fulfill the requirements of a NASA development program for a liquid fluorine rocket feed system. The materials and procedures presently used with complete success are as shown in Appendix X.

2.7.2 Installation Requirements

Care must be taken to prevent contamination of the components at the time of installation. It is frequently impossible to require that the installation of components be made in a clean room. In the case of the QD coupling under consideration, it will be necessary to install the coupling half for the vehicle in a vehicle assembly area, and the AGE half will be installed at a launch site in an outdoor environment. Observance of the following guide lines for installation of the coupling halves will limit the contamination of the components to an acceptable level:

(1) Ascertain that the environmental atmosphere is reasonably still, dry, and free of dust. Good housekeeping practices in the indoor assembly area should keep the dust level acceptably low. For installation at the launch site, operation should be restricted to a period when wind conditions are calm and atmosphere is reasonably free of dust and dry (no rain or fog). If these conditions cannot be met and it is not feasible to wait for favorable atmospheric conditions, then a shelter with a controlled atmosphere, and suitable for making the coupling installation, should be improvised.

(2) Components to be joined will have been cleaned for fluorine service at the component level and should remain in their sealed containers until actual installation is ready to begin, thus controlling the exposure of the critical internal surfaces to the external atmosphere to a minimum time.

(3) Visually inspect components being installed for evidence of contamination or corrosion.

(4) Keep hands away from surfaces that will be exposed to the oxidizer to prevent contamination with oil from the skin.

(5) Do not use a lubricant on any of the components.

(6) Purge the interior of the system with a clean, dry inert gas during installation is recommended.

(7) Seal the open ends of the coupling with expendable closures after purging.

(8) Cover the exterior of the coupling with a plastic bag containing a dessicant to keep dirt and moisture away from the mating surfaces and latching mechanism.

2.7.3 Mating of Coupling Halves

Because the joining of coupling halves will be accomplished in an outdoor environment at the launch site, care must be exercised to ensure that contamination of the internal areas is kept to a minimum. The following procedures should be used:

(1) Take precautions, as necessary, to ensure that the environment is as clean and dry as practicable. The coupling should not be mated under conditions of high wind or precipitation.

(2) Remove the temporary closures and visually inspect both halves of coupling for evidence of contamination or corrosion.

(3) Join the coupling halves and tighten until the design load is applied to the seal.

(4) Purge the transfer line with dry clean He, then raise the He pressure to the design pressure for the transfer system and check for leaks.

(5) If propellant loading is scheduled within 48 hours, leave a small positive He pressure on the system until it is time to load the propellant. Then passivate the transfer system with gaseous F_2 just prior to propellant loading.

(6) If propellant loading is not scheduled within 48 hours after the leak check is completed, close the valves that isolate the purge system from the transfer system; then cover the exterior of the coupling with a plastic bag containing a dessicant to keep out dirt and moisture.

2.7.4 Passivation

Passivation of metals, as reported in Reference 9 and based on Douglas experience, with gaseous F_2 prior to exposure to liquid F_2 is not a substitute for cleaning, but is considered useful for removing traces of moisture adsorbed on metal surfaces. Passivation with gaseous F_2 at normal temperature and pressure will not remove traces of hydrocarbons from metal surfaces (Reference 9). Passivation should be accomplished just prior to fluorine service and the passivated surfaces must be kept in a dry inert atmosphere or the protection afforded by the fluoride film is lost. Initial passivation involves the introduction of gaseous F_2 diluted by a dry inert gas (usually N_2 or He). This held for a few minutes, then the pressure is vented to just above atmospheric pressure. Further passivation is accomplished by increasing the F_2 concentration in steps. Final passivation should utilize pure F_2 at a temperature and pressure above contemplated operating conditions.

3. SUMMARY OF PHASE I-- ESTABLISHED CRITERIA

Summary of the design criteria established in the preceeding sections of this report are here for the specific requirements imposed by the study vehicle concept presented in Section II, 1. 3. These criteria have provided for maximum flexibility in design and operation whenever possible.

The design objective for a coupling servicable in a system containing any of the fluorine-related oxidizers must be a leakproof separable connector that can be easily cleaned and kept free from contamination. The coupling must be adequate for transferring oxidizer from an AGE storage facility to a flight vehicle under potential temperature, vibration (induced either from the vehicle or servicing tower), wind, moisture, dust, etc., environments. It must be suitable for draining the oxidizer from the vehicle under the potential environments should a launch abort becomes necessary after the oxidizer has been loaded. It must be capable of remaining attached until vehicle launch is committed and then separating cleanly and reliably.

Because of the highly reactive and toxic nature of the oxidizer, the oxidizer should not be loaded into the vehicle until all tasks requiring personnel in the immediate area have been completed and the personnel evacuated. All operations involving oxidizer transfer, draining of the vehicle tank is required, draining and purging of the transfer line after transfer, and separation of the coupling at time of launch should be done by remote control.

Facility and Regulatory agencies place further restrictions on the oxidizer loading and the vehicle launch activity. These regulations provide protection of employees, civilians, plant and animal life, and property on and off the site in case of inadvertent release of fluorine. The Weather Information Network Display (WIND) system controls launch operations involving toxic propellants at Eastern Test Range (ETR) and Western Test Range (WTR). The system considers persistency of meteorological factors, range boundary distances form the operational site, quantities of toxic propellant being handled, etc. to determine go/no-go operational conditions. As a specific application of these restrictions, the oxidizer system of the study vehicle has two separate flow paths between the AGE and the vehicle to provide fill and drain and vent.

For presently conceived vehicles, there is no apparent reason to require remote connection capability. This capability would greatly increase the complexity of the design, lowering the reliability of the device and increasing maintenance problems.

The following requirements, applicable for the fluorine-hydrogen vehicle system as well as for any other system using a fluorine oxidizer, consider operations, flow, and mechanics.

3.1 General

a. The coupling should be manually connected and capable of providing positive indication of being mechanically latched.

b. The coupling must be designed for fly-away as well as for manual disconnect operations.

c. The fly-away disconnect provision must be highly reliable. (A redundant release provision may be the appropriate provision.)

d. The coupling should not provide oxidizer flow control or fluid shutoff provisions. (No integral valves would be required.)

e. The coupling must be capable of sealing against fluorine leakage in excess of 10^{-4} SCIM's when subjected to the operational limit conditions (system proof pressure, vacuum, ambient, and cryogenic temperatures.

f. The coupling must adequately provide for draining and purging of wetted fluid lines between the vehicle and shutoff-isolation valves of the AGE oxidizer.

g. Provisions are required for the determination of oxidizer concentration in the purge gas from the vehicle/AGE disconnect purge and drain system.

h. External leakage through the coupling seal must be safely disposed of through a duct.

i. Provisions are required for the detection and measurement of primary seal leakage.

j The vehicle half of the coupling must withstand repeated (more than 25 use without damage or functional degradation and without needing peculiar or extensive maintenance of rework. It must be designed to guard against potential damage when not in use.

k. It is desirable that the ground (AGE) half be capable of repeated use although this half could be expendable if required.

l. The coupling must be capable of carrying all externally applied loads (wind, propellant weight, thermal stresses, etc.) without degradation to the coupling-to-coupling seal and without rendering the coupling inoperable.

m. The coupling halves must be sealed not in use to prevent mechanical and chemical damage.

n. The coupling must be adequately isolated or otherwise protected to prevent formation of ice or frost which could potentially result in a coupling malfunction (freezing of the quick-release mechanism, etc.)

3.2 Detail Design

a. Avoid the use of bellows with welded nested configuration and multiply construction because these configurations are difficult to clean and impossible to inspect for contamination. Make the bellows from either seamless tubing or from butt-welded wrapped sheet that is 100% X-rayed. Avoid possible hidden contamination in this weld. Bellows must be made from oxidizer-compatible materials capable of being formed into convolutions and have good fatigue properties throughout the potential temperature ranges.

b. Eliminate all possible dead-end passages.

c. Make the interior of the coupling smooth and free of cavities that could collect contaminants.

d. Make interior surfaces exposed to the oxidizer capable of being visually inspected, wherever possible.

e. Minimize pipe and tubing runs. The shortest length will have the smallest area and, correspondingly, the lowest potential source of contaminants. Minimize the number of tees, crosses, elbows and other fittings that generate and trap particles. Use manifolds wherever possible.

f. Eliminate all close-fitting dynamic parts capable of generating contaminant particles.

g. Avoid exposing threaded joints to the oxidizer. These joints form a trap for contaminants and can generate particulate contaminants during mating of the threads.

h. Avoid threaded connections. If impossible to avoid threaded connections, arrange them so that the flow does not scrub particles out of the threaded crevices and carry them into the vehicle.

i. Place gaskets or seals to minimize contact with the bulk of the working fluid.

j. Design critical sealing surfaces to have some inherent protection (e.g., recessed surface) from damage because of handling during coupling mating.

k. Provide a pilot or guide for aligning the mating halves of the coupling before the primary seal is engaged.

l. Avoid the necessity for rotational indexing of the coupling at the interface between the two halves.

m. Eliminate all loose hardware when the coupling separates (seals must be retained).

n. Use only clean, bagged, and sealed components to assemble the system. Inspect the bags for the presence of foreign matter.

o. Preclude moisture (water vapor, frost, and ice) from inside and adjacent to components.

p. Perform assembly and disassembly in environmentally controlled areas commensurate with the degree of cleanliness in the components being used.

q. Minimize the need for assembly and installation of fittings on a component after it has been cleaned and assembled.

3.3 Materials

a. Choose materials on the basis of the best possible compatibility with the oxidizer, consistent with the function of the part.

b. Require testing of the material with the oxidizer before using it in a component if there is doubt about compatibility.

c. Avoid the use of platings and coatings on metals wherever possible.

d. Avoid the use of nonmetallic materials in areas exposed to oxidizer flow. If Teflon TFE is used as a static seal for the storable oxidizers, use it in small sections, closely surrounded by metal, and with minimum surface area exposed to the oxidizer. Teflon (TFE) may also be used for a seondary seal if the cavity between the primary and secondary seals is either vacuum scavenged or purged with an inert gas.

e. Do not use lubricants or pipe compounds on joints in the fluid systems.

f. Do not use soft or stringy valve stem packings requiring periodic replacement; they are gradually deposited in the fluid stream.

g. Investigate before using two different metals in direct contact with each other to determine whether they are compatible from the galvanic corrosion standpoint.

h. Use nonporous castings (if castings are necessary), free of sand and other foreign materials. Porous castings (particularly aluminum and bronze) should not be used because they are difficult to clean. All castings should be X-rayed. Dye penetrant inspection shall not be used. Detailed criteria for use of aluminum castings can be found in Section 3.5.1 of Reference 79.

SECTION III

TEST MODEL QD DEVELOPMENT

1. INTRODUCTION

1.1 General

Two test model QD couplings were designed, fabricated and tested as the Phase II effort under this contract. The designs were based on the basic design criteria established during the Phase I effort reported in Section II, 3. One test QD was designed for manual engagement, latching, and application of sealing loads. This unit was subjected to testing with both liquid nitrogen and liquid fluorine. The second test model coupling was capable of rapid-remote latching and sealing following initial manual engagement. This latter QD was subjected to extensive design evaluation testing with liquid and gaseous nitrogen.

1.2 Nomenclature

The following nomenclature has been used throughout the remainder of this Section:

Nomenclature (unless otherwise specified)

A	cross sectional area, ft^2
a	cross sectional area, $in.^2$
b	width of section in stress calculation, in.
C	circumferential distance, in.
C_D	discharge coefficient for orifices
c	distance from neutral axis to extreme fiber, in.
D	diameter, ft
d	diameter, in.
E	Young's modulus of elasticiity, psi
F	force, lbs
F_n	normal force, lbs
F_{bry}	bearing yield stress of material, psi

F_{su}	ultimate shear stress of material, psi
F_{tu}	ultimate tensile stress of material, psi
F_{ty}	tensile yield stress of material, psi
f	friction factor
f_b	calculated bending stress, psi
f_c	calculated compressive stress, psi
f_s	calculated shear stress, psi
f_t	calculated tensile stress, psi
f_{br}	calculated bearing stress, psi
g	acceleration of gravity = 32.2 ft/sec^2
h	static pressure of fluid, ft
h	height of section in stress calculations, in.
I	moment of inertia of area, $in.^4$
K	fluid flow resistance coefficient = f L/D
L	length, ft
L/D	equivalent length of a resistance to flow, in pipe dia
l	length, in.
M	moment, in.-lbs
M. S.	margin of safety
N	normal force, lbs
P	pressure, psig
P'	pressure, psia
Q	rate of flow, gallons per minute (GPM)
R	individual gas constant, ft/°R
R	force as specified, lbs
r	radius, in.
T	temperature, °R

t	thickness in stress calculations, in.
t	time, sec
v	velocity, ft/sec
W	weight, lbs
W	restraining force in stress calculations, lbs
$\dot{w}$	flow rate, lbs/sec
y	unit of length, in.
z	unit of length, in.

Subscripts (unless otherwise specified)

(O)	indicates initial conditions
(1)	indicates inlet conditions
(2)	indicates outlet conditions
(CAV)	indicates purge cavity conditions
(h)	indicates static pressure head conditions
(H)	indicates horizontal conditions
(PS)	indicates purge supply conditions
(QD)	indicates quick disconnect conditions
(T)	indicates vertical conditions
(V)	indicates vertical conditions

Greek Letters (unless otherwise specified)

Δ	differential between two points
δ	deflection, in.
γ	ratio of specific heat at constant pressure to specific heat at constant volume = C_p/C_V
π	3. 14
ρ	density of fluid, lbs/ft^3
μ	coefficient of static friction
ν	Poisson's ratio
Σ	summation designation

2. DESIGN REQUIREMENTS

The folowing is a basic statement of the design requirements used for this effort:

"Two couplings shall be designed. One shall be capable of being remotely latched and sealed following manual engagement, and the second shall require that these functions be performed manually. These couplings must also meet the requirements generated during Phase I, and documented in Section II, 3."

3. DESIGN AND ANALYSIS

3.1 Performance Analysis

3.1.1 Flow Diameter Sizing

The primary variables which determine the coupling flow diameter are: time available to fill and drain the vehicle, allowable pressure loss, and coupling weight. These variables are, however, primarily configuration and operation dependent; e.g., the location of the fluorine stage (on the ground or atop launch vehicle), and the fill time requirement (2-3 min or 15-20 min). For the purpose of this development, the size was determined by the following analysis and assumes the vehicle configuration shown in Figures 2-1 and 2-2.

Assumptions:

1. The fill and drain times are not critical (15-20 minutes available to fill and an equal amount available to drain if required).
2. Fluorine must be raised vertically 150 feet from the ground storage tank to flight vehicle.
3. The length of the transfer line from the ground storage tank to the flight vehicle is 250 feet.
4. The vehicle tank back pressure during fluorine transfer will average 10 psig.
5. The final 5-10% (topping) will take place with the vehicle tank pressurized to 10 psi above its vapor pressure to preclude boiling and permit accurate level determination in the vehicle fluorine tank.
6. The amount of fluorine to be loaded is approximately 15,000 pounds.
7. The ground storage tank maximum working pressure should be 150 psig.

Calculations:

1. Head Pressure (P_h):

$$P_h = \frac{\rho h}{144} = \frac{95 \times 150}{144} = 99 \text{ psid}$$

2. **Flow Pressure Loss (ΔP):**

$$\Delta P = (\dot{w})^2 \left(\frac{K}{d^4}\right) \frac{1}{\rho (0.525)^2} \quad \text{(psid)}$$

$$\Delta P = (\dot{w})^2 \left(\frac{K}{d^4}\right) (0.0375)$$

K values for lines with various diameters (d) (K_1):

d (in.)	1.5	1.7	2.0	3.0
K/100 ft	17	14	11	7

Reference 80.

K values for fittings and valves (f = 0.02):

	flex	valve	elbow	entrance	exit
K/element	7.0	7.0	0.6	1.0	1.0

K values for valves and fittings for loading system (K_2):

Quantity	Item	K
3	Valve	21.0
3	Flex	21.0
10	Elbows	6.0
1	Entrance	1.0
1	Exit	1.0

Total K_2 = 50.0

System K values (K_{sys}):

$$K_{sys} = K_1 \left(\frac{L}{100}\right) + K_2$$

d(in)	1.5	1.7	2.0	3.0
K_{sys}	92	85	77	67

The range of flow rates ($\dot{w}$) which was considered is:

$$\dot{w}_{min} = \frac{15,000 \text{ lbs}}{(20 \text{ min})(60 \text{ sec/min})} = 12.5 \frac{\text{lbs}}{\text{sec}}$$

$$\dot{w}_{max} = \frac{15,000 \text{ lbs}}{(15 \text{ min})(60 \text{ sec/min})} = 16.7 \frac{\text{lbs}}{\text{sec}}$$

Solutions of the flow pressure loss equation as a function of flow rate ($\dot{w}$) and system flow diameter (d) are:

		ΔP (psi)			
$\dot{w}$ $\frac{lb}{sec}$	$\dot{w}^2$	d = 1.5	d = 1.7	d = 2.0	d = 3.0
10	100	68.3	38.3	18.0	3.1
15	225	154.0	86.0	40.5	7.0
20	400	273.0	153.0	72.0	12.4

These data are shown graphically in Figure 3-1.

Allowable System Pressure Loss (ΔP_{sys}):

ΔP_T = (head) + (back press) + (flow loss)

$\Delta P_T = 99 + 10 + \Delta P_{sys} = 109 + \Delta P_{sys}$

ΔP_{Tmax} = max ground storage working pressure = 150 psig

$\Delta P_{sys} = 150 - 109 = 41$ psid

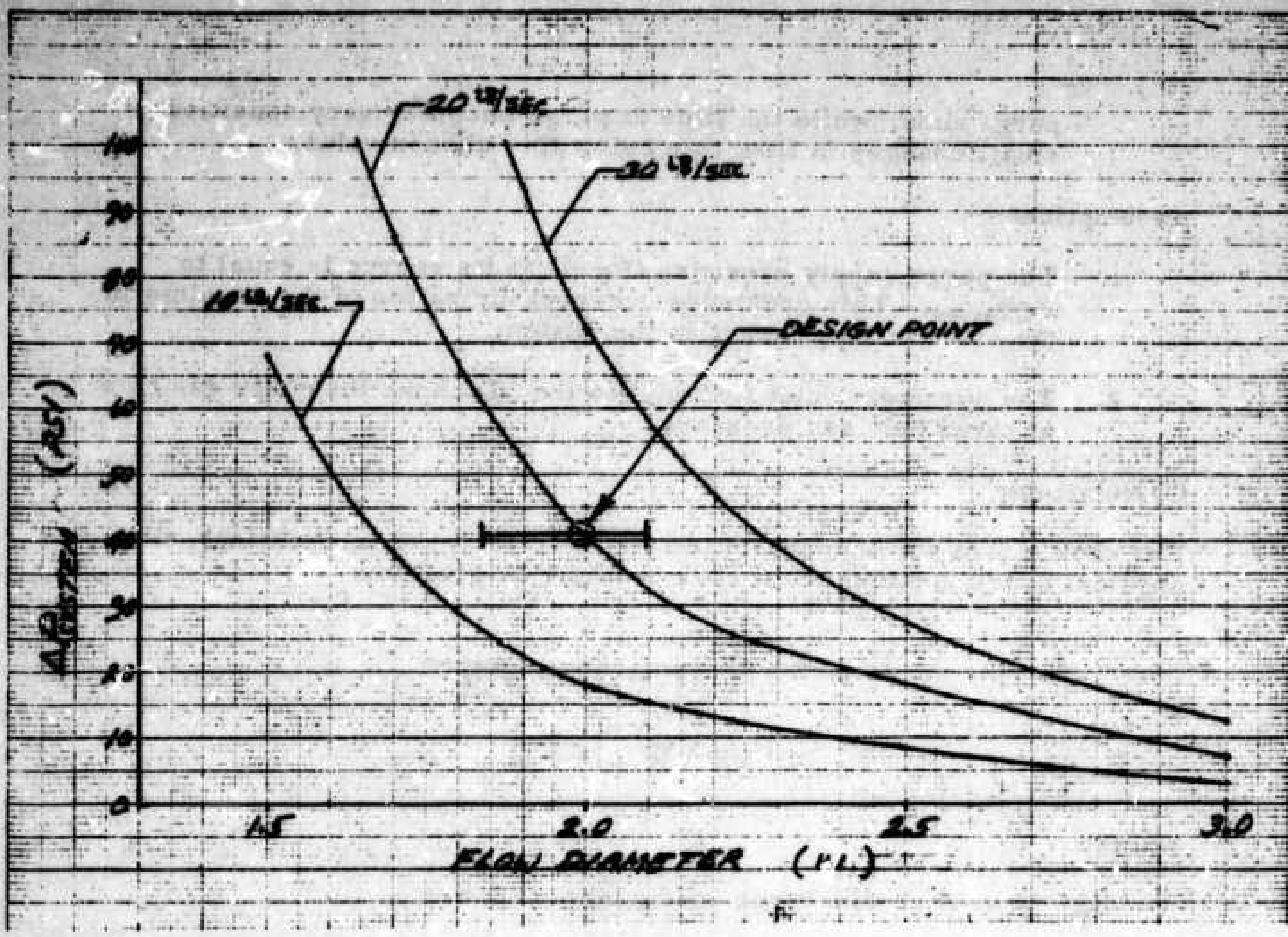


Figure 3-1. System Pressure Drop Versus Flow Diameter

Results:

The heavy horizontal line on Figure 3-1 at ΔP_{sys} = 41 psid, represents a combination of flow rates and coupling diameters, all of which are restricted to the assumptions made at the beginning of this analysis. A 2-in. internal flow diameter for the test model QD couplings was chosen on the basis that it is the only standard line size within the noted design envelope.

3.1.2 Purge Line Sizing

Two separate purge systems were determined necessary in Phase I. One system directs gaseous nitrogen (GN_2) through the purge cavity surrounding the primary coupling seal. The second system provides gaseous nitrogen for draining and purging fluorine from the QD prior to uncoupling.

3.1.2.1 Drain and Purge Gas Supply Line

Given:

1. Maximum coupling working pressure ($P_{QD_{max}}$) = 100 psig.

2. Purge gas flow rate ($\dot{w}$) = 0.15 lbs/sec of gaseous nitrogen. This value was selected as being optimum after a review of Figure 2-30. Higher flow rates afford little reduction in required

purge time, while the time to purge becomes very sensitive to small changes in flow rate below this chosen value.

Assumptions:

1. The purge supply pressure (P_{PS}), at its source is equal to $P_{QD_{max}}$. This precludes overpressurization of the coupling in the event of P_{PS} lockup in the system.

2. The purge gas inlet fitting(s) to the QD choke the purge gas flow at rated flow and pressure.

Calculations:

For choked flow through an orifice (representative of inlet fitting), the physical cross sectional flow area required is given by:

$$a = \frac{\dot{w}}{C_D P_{PS} \sqrt{\frac{g\gamma}{RT} \left[\frac{2}{\gamma + 1}\right]^{\frac{\gamma+1}{\gamma-1}}}}$$

where:

C_D	=	orifice discharge coefficient = 0.8
$\dot{w}$	=	weight flow rate = 0.15 lb/sec
P_{PS}	=	pressure of purge gas upstream of orifice = 100 psig
T	=	temperature of gas upstream of orifice = 560°R
γ	=	ratio of specific heats for nitrogen = 1.4
R	=	gas constant for nitrogen = 55.16 lb-ft/lb °R

then:

$$a = 0.085 \text{ in.}^2$$

This area represents a fitting internal diameter (d) of:

$$d = \sqrt{\frac{4a}{\pi}} = 0.329 \text{ in.}$$

The following listing represents several combinations of standard MS or AN fittings which could be used to provide the required purge gas flow area.

Size OD (in)	Diameter ID (in)	Area ($in.^2$)	Required (no.)	Total Area ($in.^2$)
1/2	0.391	0.120	1	0.120
5/16	0.234	0.043	2	0.086
1/4	0.172	0.023	4	0.092

A configuration using two 5/16-inch fittings was selected as representing the overall best physical packaging for the test model QD couplings.

3.1.2.2 Seal Cavity Purge Line

The seal cavity purge system can be represented by the sketch shown in Figure 3-2. It is assumed that the inlet and outlet purge lines in the immediate locale of the seal cavity are the controlling flow restrictions in the system, and thus their size determines seal cavity purge gas flow capability.

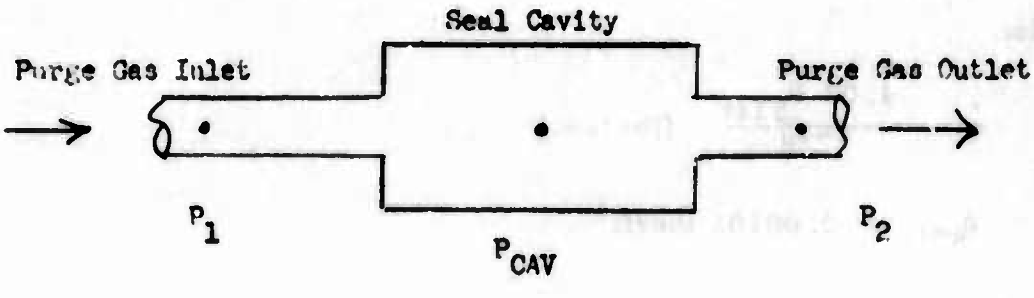


Figure 3-2. Seal Cavity Purge System Schematic

Assumptions:

1. Flow through the purge gas outlet line is critical (choked).
2. Maximum inlet pressure (P_1) is 100 psig.
3. Minimum outlet pressure (P_2) is 30 psig.
4. Minimum gaseous helium purge gas flow rate is 1,000 ml/min (1.07 in.^{3}/sec) at standard conditions.

Calculations:

$$a_2 = \frac{\dot{w}}{C_D P_{CAV} \sqrt{\frac{g\gamma}{RT}\left[\frac{2}{\gamma + 1}\right]^{\frac{\gamma+1}{\gamma-1}}}}$$

where

C_D = 0.8

P_{CAV} = 30 psig

γ = 1.66 for gaseous helium

R = 386.3 lb-ft/lb °R for gaseous helium

also

$$\dot{w} = \frac{1.07\ \rho_{STD}}{1728} \quad \text{(lbs/sec)}$$

ρ_{STD} = 0.00105 lbs/ft^3

thus

a_2 = 0.0000303 in.^{2}

d = 0.00622 in.

The calculated flow diameter of 0.00622 in. represents the minimum acceptable cross-sectional flow area. A larger flow diameter is acceptable. Therefore, standard 1/8 inch tubing and AN fittings (minimum practical size) were selected for ducting the purge gas into and out of the primary seal purge cavity. The flow diameter of a 1/8-in. AN fitting is 0.062 in. See Section 3.2 for design definition.

3.1.3 Coupling Loads

The Quick Disconnect coupling must be designed to withstand several types of loads, which may be imposed individually or in combination. These loads are defined in Section 2.2.3, and will be analyzed here for the test model QD. The configuration used in this analysis is shown in Figure 3-3.

Loads:

F_1 = QD and flex line flanges and miscellaneous hardware weight = 18 lb.

F_2 = actuator (two required) and mounting weight = 18 lb.

F_3 = transverse component of flex line weight, including fluid and wind loads

F_4 = pressure force

F_5 = axial component of flex line loads

F_4 : $F_4 = P\frac{\pi}{4} d_i^2$

P = internal pressure = 115 psia

d_i = seal diameter = 2.1 in.

F_4 = 398 lbs

with six (6) bolts,

F_4/bolt = 398/6 = 66 lb/bolt

F_3 and F_5 :

Liquid weight:

LF_2:

$W_1 = \rho \times V = (0.055 \text{ lb/in.}^3) \left(\frac{\pi}{4}\right) (2.25)^2 (60)$

W_1 = 13.2 lbs

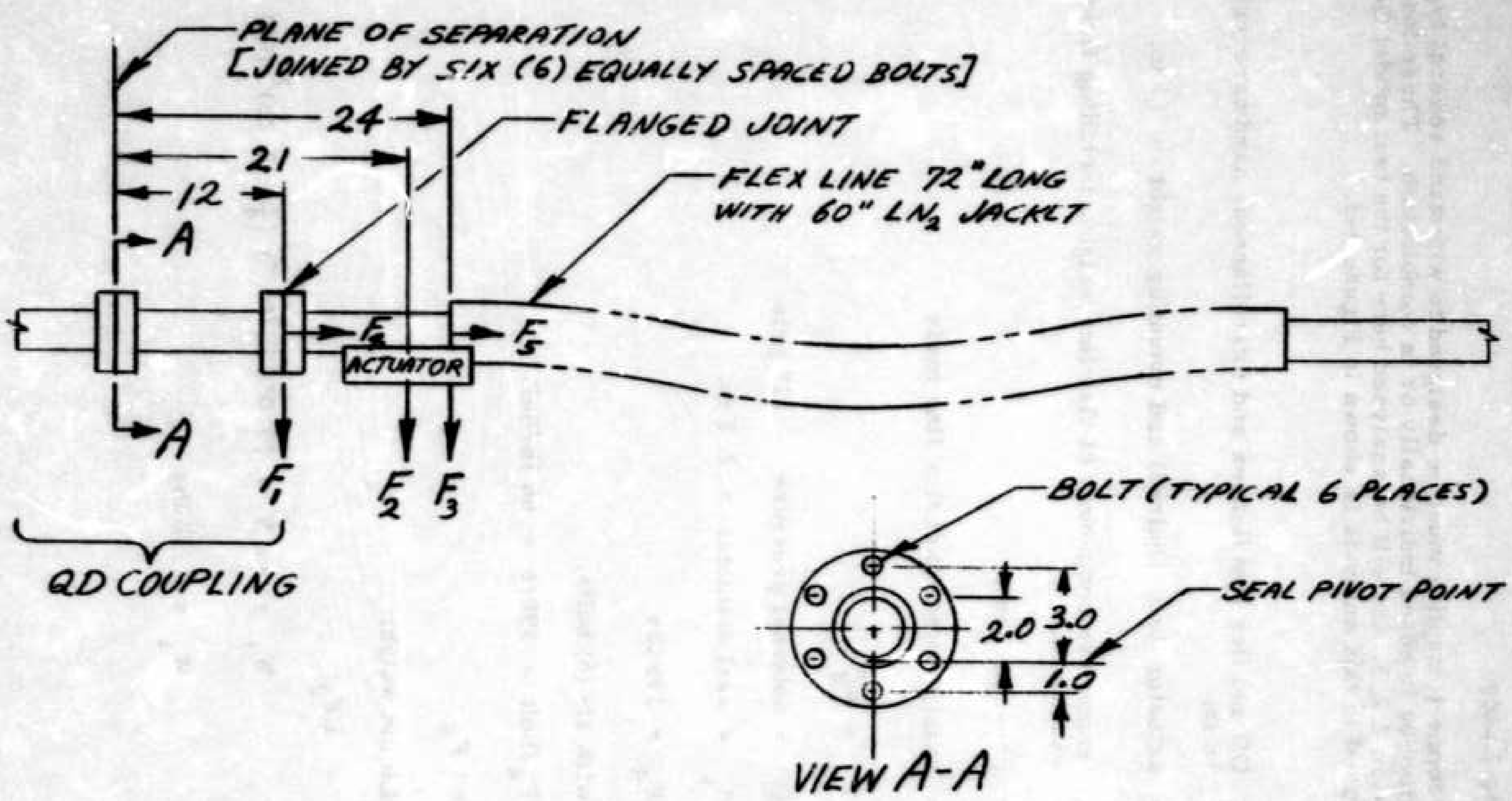


Figure 3-3. QD Loading Diagram

LN_2:

$$W_2 = (0.0292)\left(\frac{\pi}{4}\right)\left[(4.25)^2 - (2.25)^2\right](60)$$

$$W_2 = 18.4 \text{ lbs}$$

Summary of weights (vertical) (W_V):

$LF_2 = 13.2$

$LN_2 = 18.4$

Line $= 50.0$

$W_V = 81.6$ lb

Wind loads (W_W):

Wind loads are assumed to be zero as the flexible line connecting the QD to the rigid AGE-line should be well supported in a trough-type structure from the umbilical mast. Such an arrangement provides a reasonable degreee of installation and operational flexibility, while at the same time precluding the adverse effects of wind, excessive sag, and sway of the flex line on the QD.

Calculation of F_3 and F_5 was accomplished by using the procedure and tables shown on Pages 142 and 143 of Reference 1, for end loads on a catenary. For the calculations, the following was assumed:

1. The weight per unit length of flex line (W') is:

   W' = 81.6/60 = 1.36 lb/in.

2. The 60-in. flex line is supported at its center point.
3. $F_3 \approx 1/2\, F_5$

The calculations resulted in the following:

$F_3 = 20$ lb

$F_5 = 39$ lb

Moment (max) on QD:

$$M = 12\,F_1 + 21\,F_2 + 24\,F_3 = 216 + 378 + 480$$

$$M = 1074 \text{ in.-lb}$$

Calculate the changes in tension loads in the six QD bolts carrying sealing loads. These bolts are located as shown in Figure 3-3, and carry loads as shown in Figure 3-4. From Figure 3-4, it is seen that these loads are related as follows:

$$\frac{F_{B_3}}{3} = \frac{2F_{B_2}}{2.0} = \frac{F_{B_4}}{1.0} \qquad F_{B_4} = 1/3\,F_{B_3} = 0.333\,F_{B_3}$$

$$F_{B_2} = \frac{F_{B_3}}{3} = 0.333\,F_{B_3} \qquad F_{B_1} = 0$$

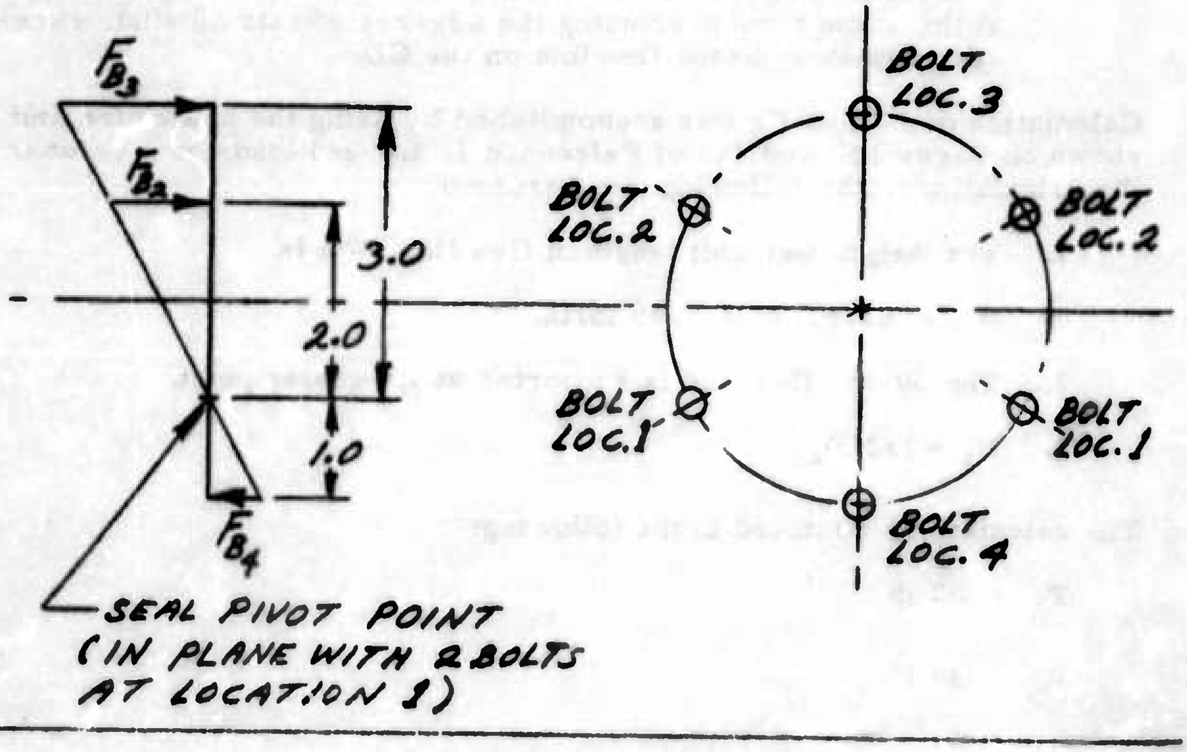


Figure 3-4. QD Bolt Loading Diagram

$$M = 3 F_{B_3} + F_{B_4} + 2(2F_{B_2})$$

$$M = 3F_{B_3} + 0.333 F_{B_3} + 4(0.333 F_{B_3})$$

$$M = 4.67 F_{B_3}$$

$$F_{B_3} = \frac{M}{4.67} = \frac{1074}{4.67} = 230 \text{ lb}$$

$$F_{B_3} = 230 \text{ lbs}$$

Total maximum relaxation load/bolt (at constant temp):

$$F_T = F_4/\text{bolt} + F_{B_3} + F_5/6 = 66 + 230 + 7 = 303$$

$$F_T = 303 \text{ lb}$$

The effect of temperature gradients is covered in Section 3.1.4.

3.1.4 Sealing Loads Analysis

This test model QD sealing loads analysis is based on the sealing configuration shown in Figure 3-5. This configuration was selected as a result of the investigations documented in Sections 2.2.3 and 2.2.4 of Section II. Figure 2-8 indicates that design seal loads (F') less than 250 lb per inch of wedge circumference should be avoided because of the very large change in leakage with moderate changes in seal load, and that seal loads greater than 500 lb per inch of wedge circumference result in negligible decrease in seal leakage. The nominal and minimum design seal loads were selected at 500 and 250 lb per inch of wedge circumference, respectively, thus providing a reasonable envelope within which to design and operate a seal loading system. The following analysis will consider the seal load degradation effects resulting from internal and external forces as defined in Section 3.1.3, and the effects of thermal changes within the QD during cooldown and LF_2 transfer.

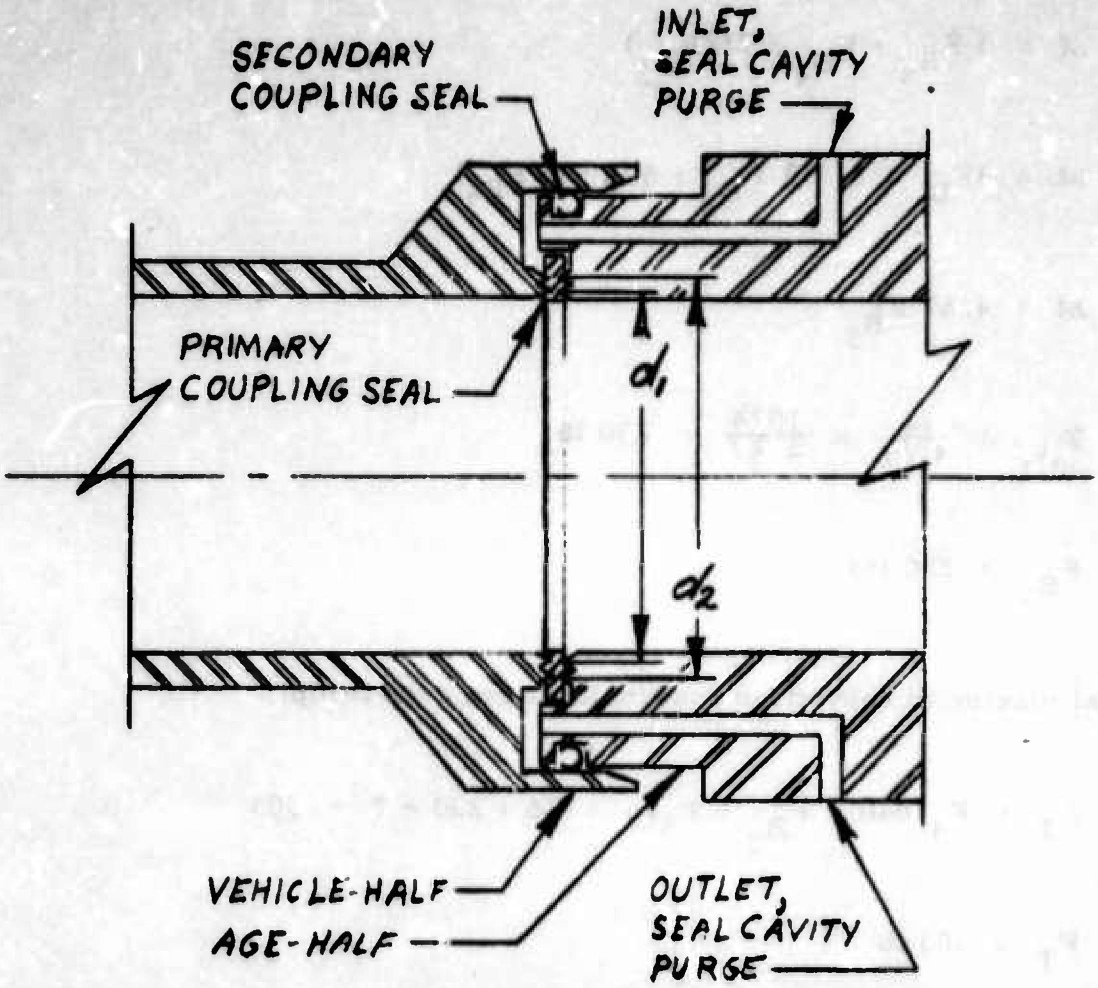


Figure 3-5. Test Model QD Seal Configuration

3. 1. 4. 1 Initial Sealing Analysis

From Figure 3-5,

$$d_1 = 2.125 \text{ in.}$$

$$d_2 = 2.275 \text{ in.}$$

Therefore, the total circumferential length (C) of the two concentric sealing wedges is

$$C = \pi d_1 + \pi d_2 = 6.67 + 7.15 = 13.82 \text{ in.}$$

The total required coupling load (F) is

$$F = F'C = (500)(13.82) = 6,920 \text{ lb}$$

From Reference 5, paragraph 2.2.2, Page 34

$$a_p = F'/\sigma_m$$

where

a_p = projected contact area per inch of wedge circumference (in.^{2}/in.)

σ_m = Meyer Hardness of softer material = 48,700 psi

thus

$$a_p = 500/48,700 = 0.0103 \text{ in.}^2/\text{in.}$$

Comparison of this value with that obtained from an experimental program by IIT, Page 35 of Reference 5, shows excellent agreement:

Calculated: $a_p = 0.0103$ in.^{2}/in.

Experimental: $a_p = 0.011$ in.^{2}/in.

Error: $[(0.011 - 0.0103)/0.011]\ 100 = 6.4\%$

The wedge-gasket interface thus assumes the configuration as shown in Figure 3-6.

Assuming six (6) bolts will be used to provide the load, the sealing conditions per bolt are:

F_B = 1,154 lbs/bolt $\qquad$ a_p = 0.0238 in.^{2}/bolt

3.1.4.2 Sealing During Operation

In service the coupling will be subjected to internal and external forces which tend to separate or reduce the load on the seal. Thus, to insure that these forces do not reduce the sealing load to below the 250 lb per inch minimum value, the connecting members of the coupling must be preloaded in excess of that required for minimum seal loading, and be capable of assuring adequate sealing loads during operation.

The QD is essentially a bolted flange connection where the flanges and seal are the compressive members and the latching and bolting components are the tension members. Figure 3-7 is a model used to analyze the QD, and is representative of six equally spaced connecting bolts.

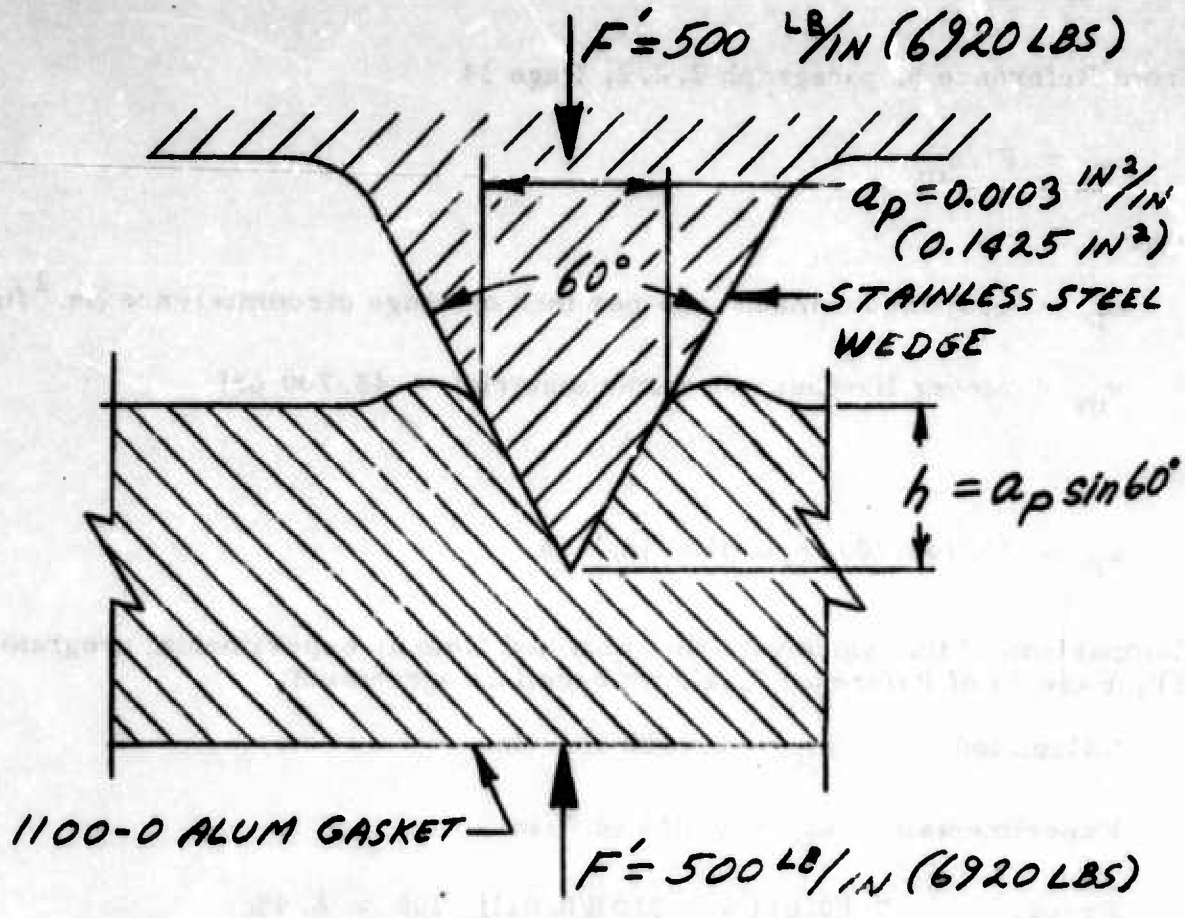


Figure 3-6. Plastic Sealing of Wedge and Soft Metal Gasket

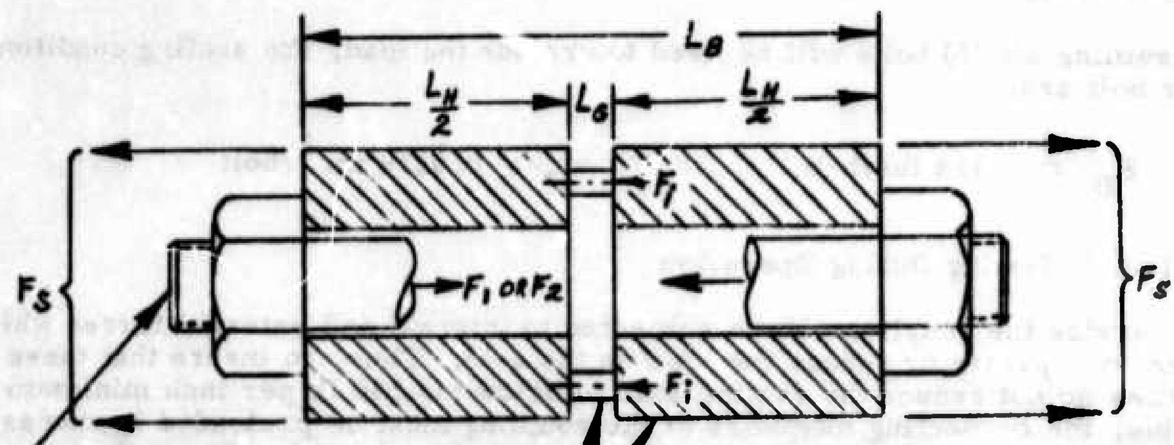


Figure 3-7. Model of Simplified Preload Theory

When the nut on the bolt is tightened, there will be an increase in the bolt length and a decrease in the length of the housing and seal gasket, given by:

$$\delta_B = \frac{F_1 L_B}{E_B A_B}, \quad \delta_H = \frac{F_1 L_H}{E_H A_H}, \quad \delta_G = \frac{F_1 L_G}{E_G A_G}$$

where subscripts B, H and G refer to the bolt, housing, and gasket, respectively, and:

F_1 = initial bolt axial load (lb)

L = free axial length (in.)

E = modulus of elasticity (psi)

A = cross-sectional area (in.^{2})

A_H is very large compared to A_G, in the case of the QD coupling, and therefore δ_H is assumed to be zero.

When a load F_S is applied (pressure and external loads), the force on the bolt changes to F_2, and:

$$\delta_{B_2} = \frac{F_2 L_B}{E_B A_B}, \quad \delta_{G_2} = (F_2 - F_S) \frac{L_G}{E_G A_G}$$

The increase in length of the bolt is equal to the increase of length of the gasket (the housing is assumed rigid), thus:

$$\delta_{B_2} - \delta_B = \delta_G - \delta_{G_2}$$

or

$$(F_2 - F_1)\left(\frac{L_B}{E_B A_B}\right) = (F_1 - F_2 + F_2)\left(\frac{L_G}{E_G A_G}\right)$$

The spring constants for the bolt and the seal gasket, R_B and R_G, respectively, are, therefore:

$$R_B = \frac{L_B}{E_B A_B}, \quad \text{and} \quad R_G = \left(\frac{L_G}{E_G A_G}\right)$$

thus

$$(F_2 - F_1) R_B = (F_1 - F_2 + F_S) R_G$$

collecting terms,

$$F_1(R_B + R_G) = F_2(R_B + R_G) - F_S R_G$$

$$F_1 = F_2 - \frac{F_S}{1 + \frac{R_B}{R_G}}$$

Graphical representation of these relations is shown in Figure 3-8, where F_1 is the load existing at the gasket.

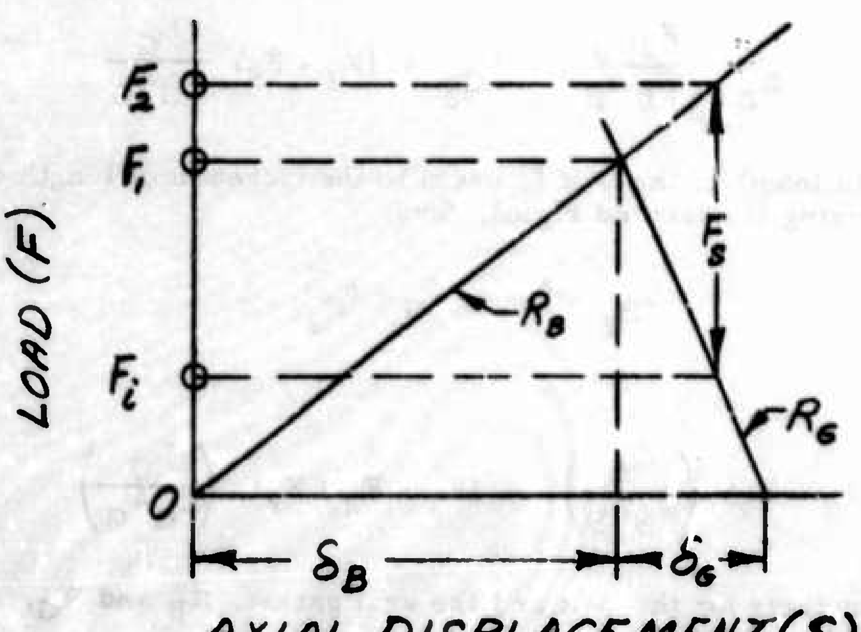


Figure 3-8. Graphical Illustration of Preload Theory

Specifically for the QD coupling:

$F_{i_{min}}$ = 600 lb/bolt, (250 lb/in.)

F_S = 303 lb, (non-cryogenic loads--reference Section 3.1.3)

F_1 = 1,154 lb/bolt; use F_1 = 1,200 lb/bolt

L_G = 0.090 in.

E_G = 10×10^6 psi

A_G = a_P = 0.0238 in.^{2}/bolt, use A_G = 0.024 in.^{2}/bolt

When the coupling is suddenly subjected to the flow of liquid fluorine the sealing gasket (directly exposed to the LF_2) contracts at a more rapid rate than the tension carrying bolts which are externally located on the coupling away from the liquid fluorine. Thus, a thermal gradient is established and the contraction of the gasket causes a shift of the R_G(RT) line to the left R_G (cold) as shown in Figure 3-9.

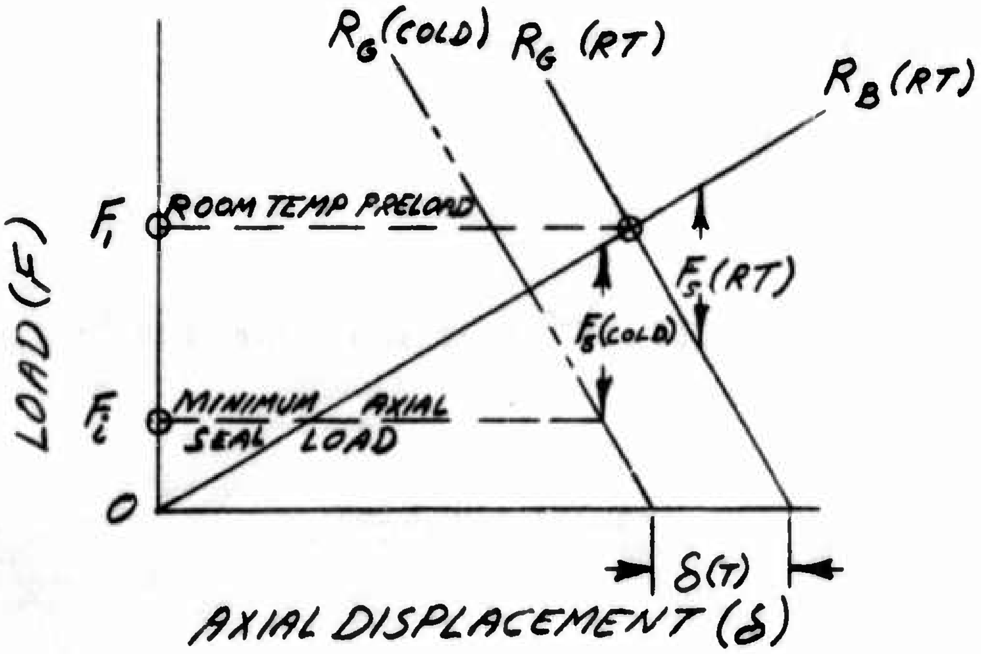


Figure 3-9. Effect of Temperatuie on Preload Theory

The shift to the left of the R_G line due to the temperature gradient is given by $\delta(T)$, and is equal to the combined changes in length of the housing $\delta L_H(T)$ and gasket $\delta L_G(T)$ due to their decrease in temperature:

$$\delta(T) = \delta L_H(T) + \delta L_G(T)$$

From the initial sketches of the QD coupling the following is obtained:

$$L_H = 2.5 \text{ in.}$$

thus

$$\delta L_H(T) = \alpha_H L_H \Delta T_H$$

where

$$\alpha_H = 0.61 \times 10^{-5} \text{ in./in./°F, (stainless steel)}$$

$$\Delta T_H = T(RT) - T(LF_2)$$

$$T(RT) = 80°F\text{, maximum}$$

$$T(LF_2) = -320°F\text{, minimum}$$

$$\Delta T_H = 80 + 320 = 400°F$$

then

$$\delta L_H(T) = (0.61 \times 10^{-5})(2.5)(400) = 0.61 \times 10^{-2} \text{ in.}$$

Also

$$\delta L_G(T) = \alpha_G L_G \Delta T_G$$

where

α_G = 1.3×10^{-5} in./in./°F, (aluminum)

$\Delta T_G = \Delta T_H = 400°F$

L_G = 0.090 in.

then

$$\delta L_G(T) = (1.3 \times 10^{-5})(0.090)(400) = 0.047 \times 10^{-2} \text{ in.}$$

and

$$\delta(T) = (0.61 \times 10^{-2}) + (0.047 \times 10^{-2}) = 0.0065 \text{ in.}$$

The task now is to find R_B. R_B is the inverse of the slope of that line which passes through the origin (0) and intersects F_1 and R_G (RT) as shown in Figure 3-10. The line defined by R_B is further restricted to assure that the seal unloading face F_S does not reduce the axial seal load F_i below $F_{i\ min}$ when the OD is cryogenically shocked (R_G cold).

Referring to Figure 3-10, the analysis proceeds as follows:

$$\frac{x_1}{y_1} = R_B, \text{ also } \frac{x_2}{y_2} = R_G$$

$$y_2 = F_1 - F_i \text{ min} = 1{,}200 - 600 = 600 \text{ lb}$$

$$y_1 = y_2 - F_S = 600 - 303 = 297 \text{ lb}$$

$$x_2 = y_2 R_G = (600)\left(\frac{L_G}{E_G A_G}\right)$$

$$x_2 = (600)\left(\frac{0.090}{10 \times 10^6 \times 0.024}\right) = (600)(3.75 \times 10^{-7})$$

$$x_2 = 2.25 \times 10^{-4} \text{ in.}$$

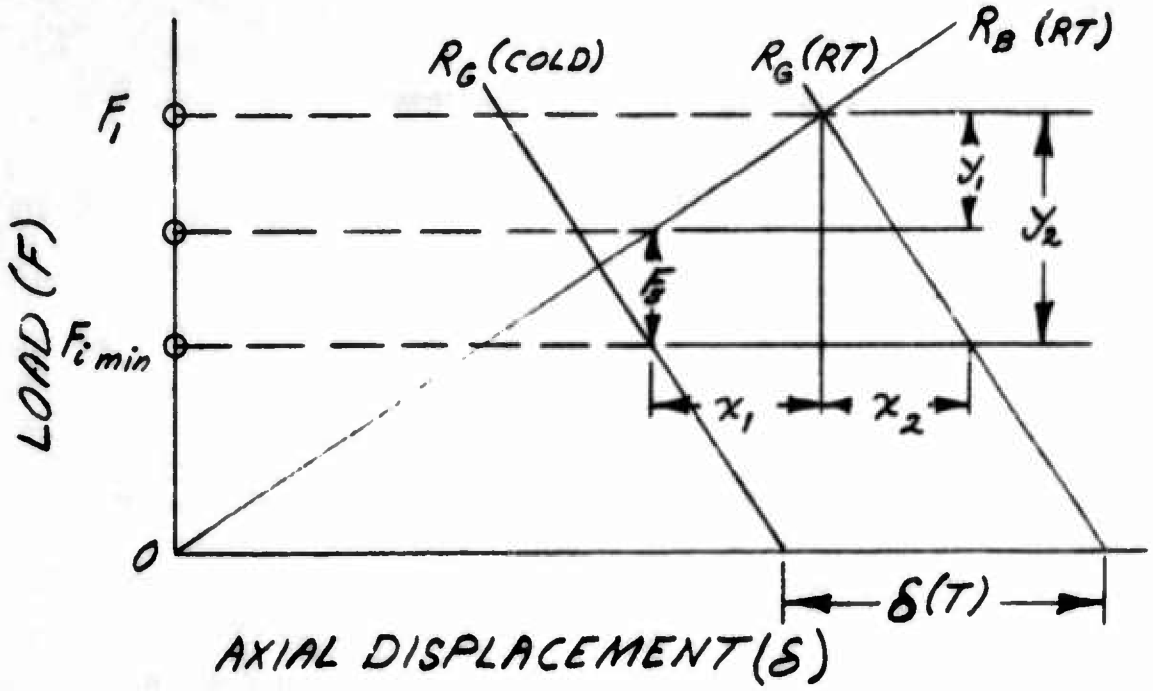


Figure 3-10. Illustration of Preload Theory with Temperature Effects

$$x_1 = \delta(T) - x_2$$

$$x_1 = 0.0065 - 0.0002 = 0.0063 \text{ in.}$$

$$R_B = \frac{x_1}{y_1} = \frac{0.0063}{297} = 2.12 \times 10^{-5} \text{ in./lb}$$

For purposes of design, a 20% increase in these values will be used to provide for realistic variations between actual and calculated responses.

Therefore, values used in design are:

$$F_S = 303 \times 1.2 = 364 \text{ lb/bolt, and}$$

$$\delta(T) = 0.0065 \times 1.2 = 0.0078 \text{ in.}$$

and,

$$y_1 = 600 - 364 = 236 \text{ lb/bolt}$$

$$x_1 = 0.0078 - 0.0002 = 0.0076 \text{ in.}$$

The spring constant required for each of the six QD connecting bolts is,

$$R_B = \frac{x_1}{y_1} = \frac{0.0076}{236} = 3.22 \times 10^{-5} \text{ in./lb}$$

3.2 Layouts

Several concepts of mechanisms for latching the QD halves together, loading the seal, and releasing the coupling were laid out and evaluated. Initially the concept which appeared to be most promising during the Phase I study and shown in Figure 2-16. This concept utilized six one-half inch diameter balls for the latching components. The balls were retained by a three-segment band held in the locked position by over-center toggle latches. Seal preloading was effected by torquing six bolts after the coupling halves were engaged and the ball retaining band was secured.

A major problem in the use of balls for latching was discovered when a structural analysis was made (see Section 3.3.1). The loads which the balls must carry are relatively high and the bearing area between the balls and the vehicle-half adapter is small so that Brinnelling of the adapter would result. It was also found that the circular retaining band was an impractical structural member for carrying the six equally spaced radial loads. In order for the band to carry the load it would either have to be sufficiently thick to carry the load in bending or would have to deform until the radial load from the latch could be transformed into tension in the band. If the band were made thick it could not freely expand to a larger diameter to release the latching components when the release mechanism was actuated. Permitting permanent deformation in a thin band is an unsatisfactory alternative, therefore this concept was abandoned.

In order to eliminate the undesirable Brinnelling caused by the balls, a design was evolved which used pivoted hooks for the latching components (Figure 3-11). Sufficient bearing area can readily be provided on these hooks and they can be restrained in the latched position by a retaining ring similar to that required for the ball concept. Two basic ideas were studied for the latch retaining members. One concept, shown in Figure 3-12, consisted of a three-member strap arrangement. The straps were thin and straight and terminated in a fitting at each end which served the dual purpose of providing a pad for reacting the radial latch loads and also structure suitable for attaching the release mechanism. The second concept was a continuous linkage consisting of six rigid links pinned together at each end. When one pinned joint is

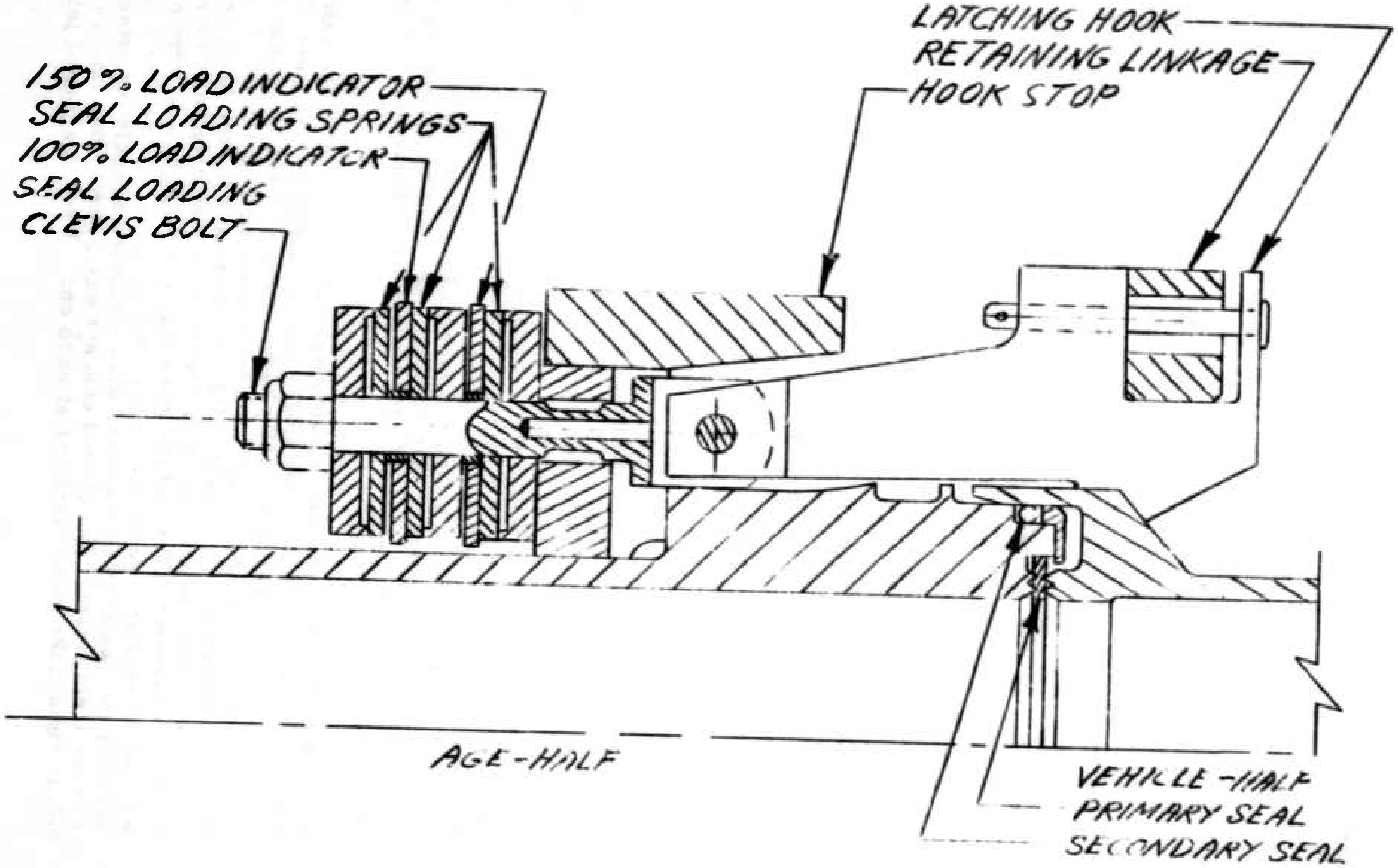


Figure 3-11. Pivoted Hook Latching Configuration

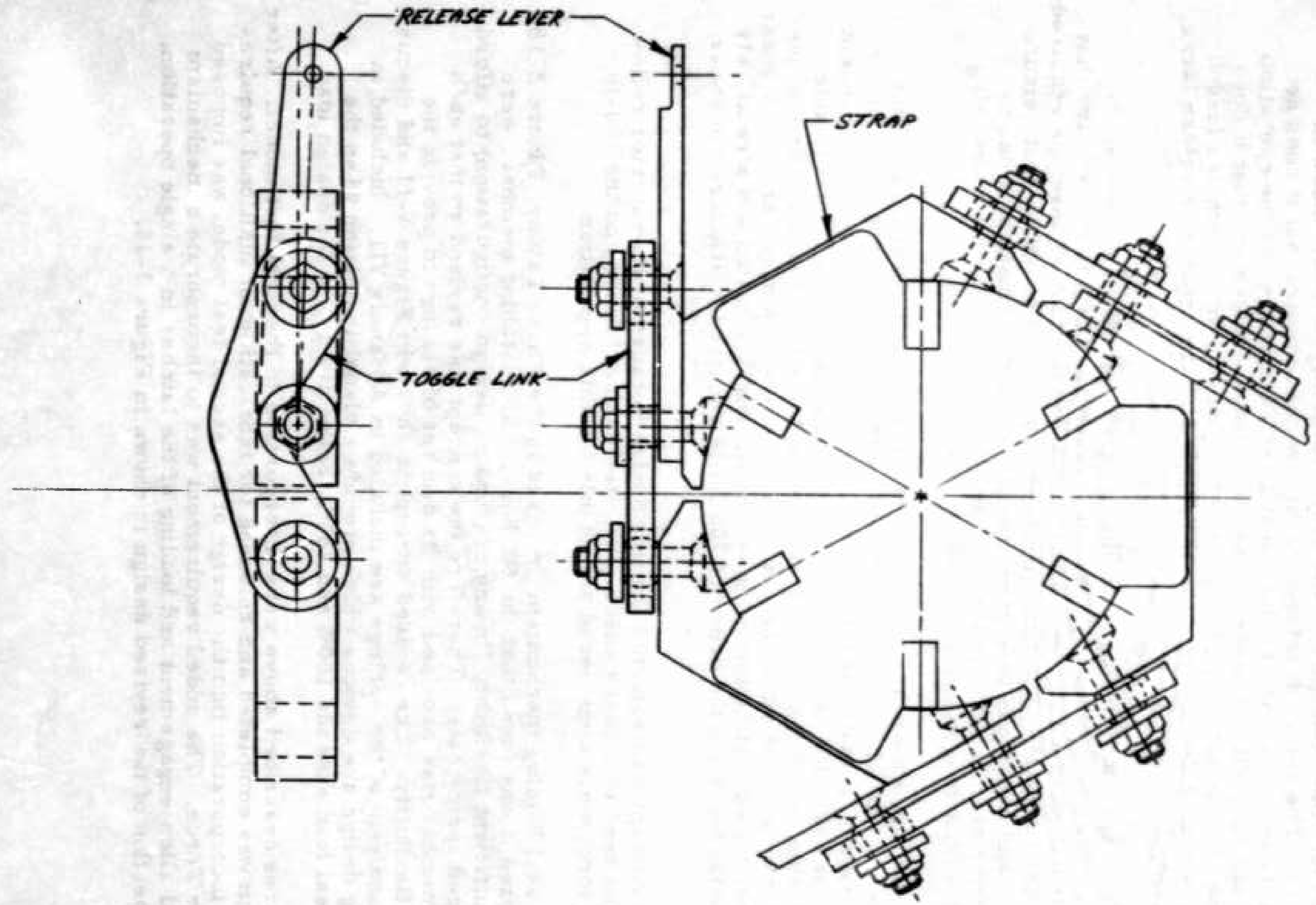


Figure 3-12. Strap and Toggle Latch Retaining Linkage

released the linkage is free to expand and release the latching hooks. Several variations of this concept were studied before the one shown in Figure 3-13 was selected as the most suitable for this application.

Three basic concepts for releasing the latch retaining linkage were laid out and evaluated. One concept was the over-center toggle latch shown in Figure 3-12. The chief advantages of this mechanism are that it does not contain parts which require replacement after each usage and the operation is simple and basically reliable. The chief disadvantages are that it does not provide an efficient load path through the pinned joints which are loaded in bending and also the operation of the toggle linkage requires a rather large space envelope.

A second concept consisted of installing tapered pull pins as shown in Figure 3-14 at three of the joints. The chief advantages of this concept are that it can be installed in a relatively small space and the motion envelope required for operation is small. The chief disadvantage is the possibility that seizure of the pin could occur due to surface roughness or deformation or due to contamination or corrosion in the joint and thus prevent the pin from being withdrawn with a reasonable extraction force.

The third concept shown in Figure 3-13 utilizes shear pins at three of the linkage points. Latch release is effected by fracturing any one of the shear pins by means of a lever operated cam. The chief advantages of this concept are that it is basically very reliable and the unlatching load is predictable and repeatable, subject only to variations due to material strength and dimensional tolerance variation of the pin. The chief disadvantages are that a shear pin is expended each time the release mechanism is actuated and a relatively high actuation force (in the order of 700 lb) is required to fracture the shear pin.

The third concept was selected for this design because of its superior reliability. The need to replace shear pins after each actuation and the 700-lb actuation force were considered acceptable for this application.

When the seal loading mechanism proposed in the Phase I study, Figure 3-16, was analyzed it was found that the OD housing and latching members were without sufficient flexibility (in any reasonable design configuration) to afford the required spring rate. Therefore the concept was revised so that each latching member was provided with its own set of springs to provide the required flexibility. The revised concept is shown in Figure 3-11 and discussion and analysis of the springs are included in Appendix VII. Included in the spring design are devices which provide a visual indication when the applied seal load exceeds 100% and 150%, respectively, of the design load.

The features described above were incorporated in the first test model. After this design was completed and released for fabrication an additional requirement for incorporation into the design of the second test model was imposed by the Air Force. The added requirement was to incorporate a mechanism that would allow engagement and loading of the latches in a single operation. A cross section of the revised design is shown in Figure 3-15.

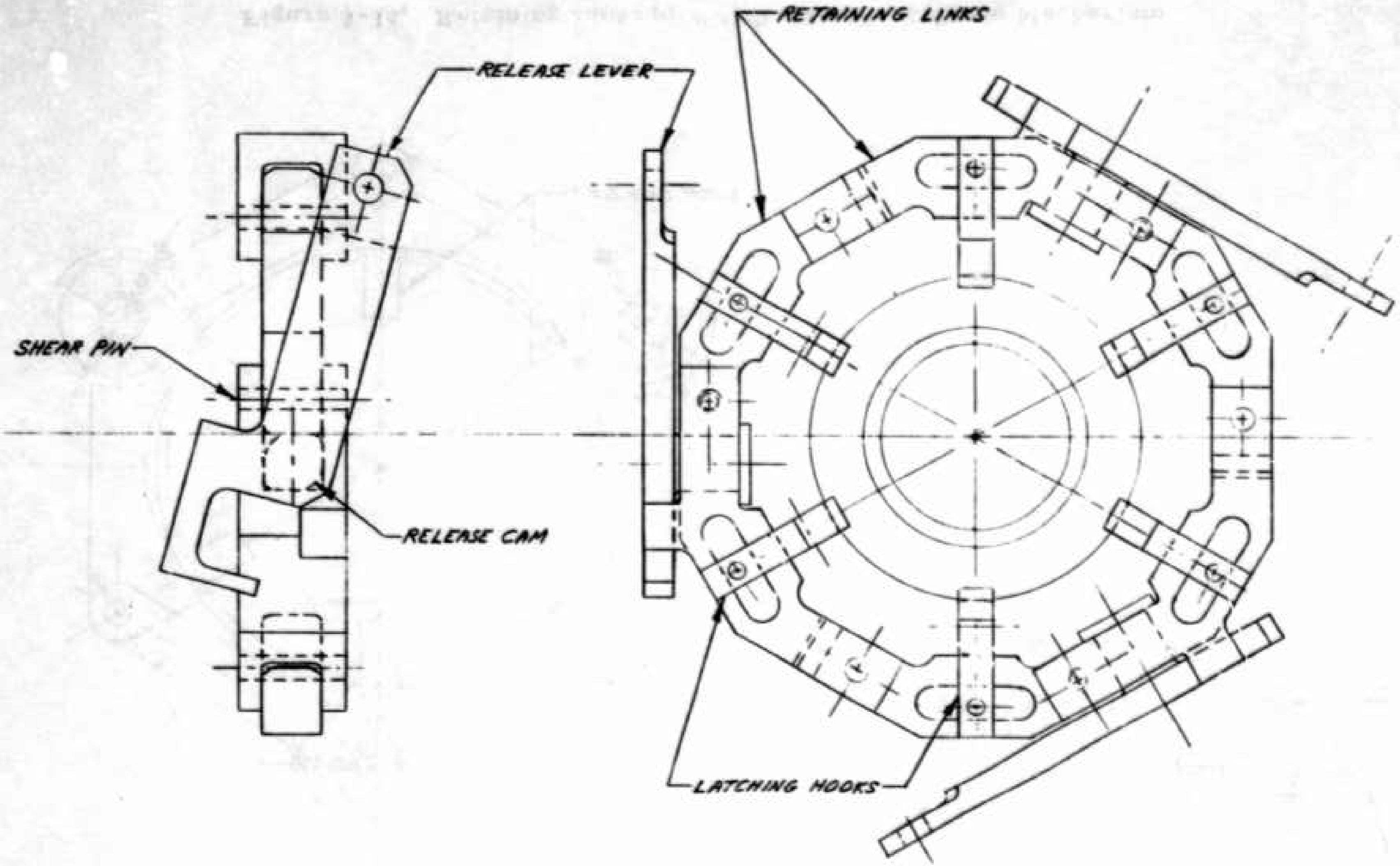


Figure 3-13. Retaining Linkage With Shear Pin Release Mechanism

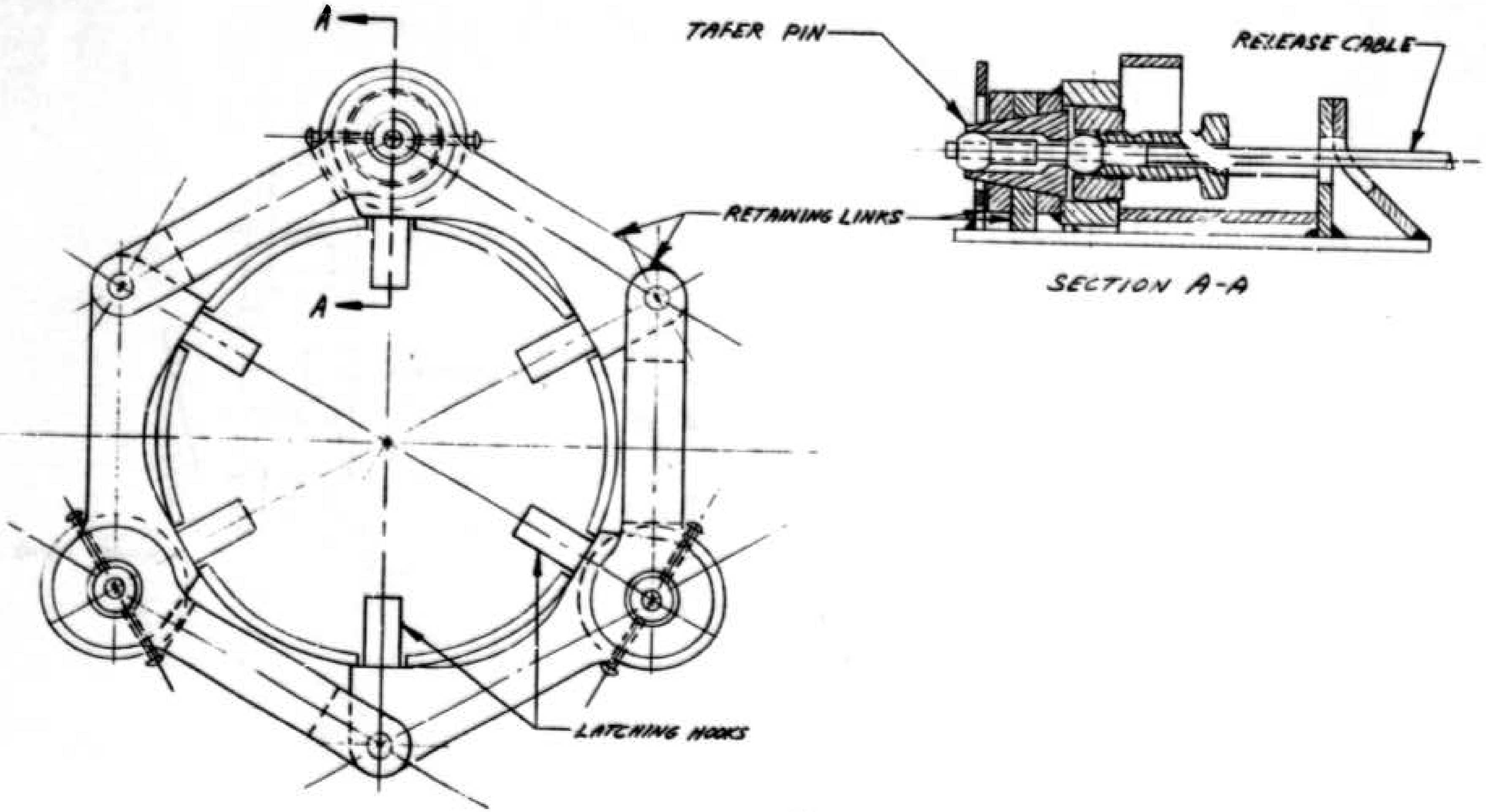


Figure 3-14. Retaining Linkage With Taper Pin Release Mechanism

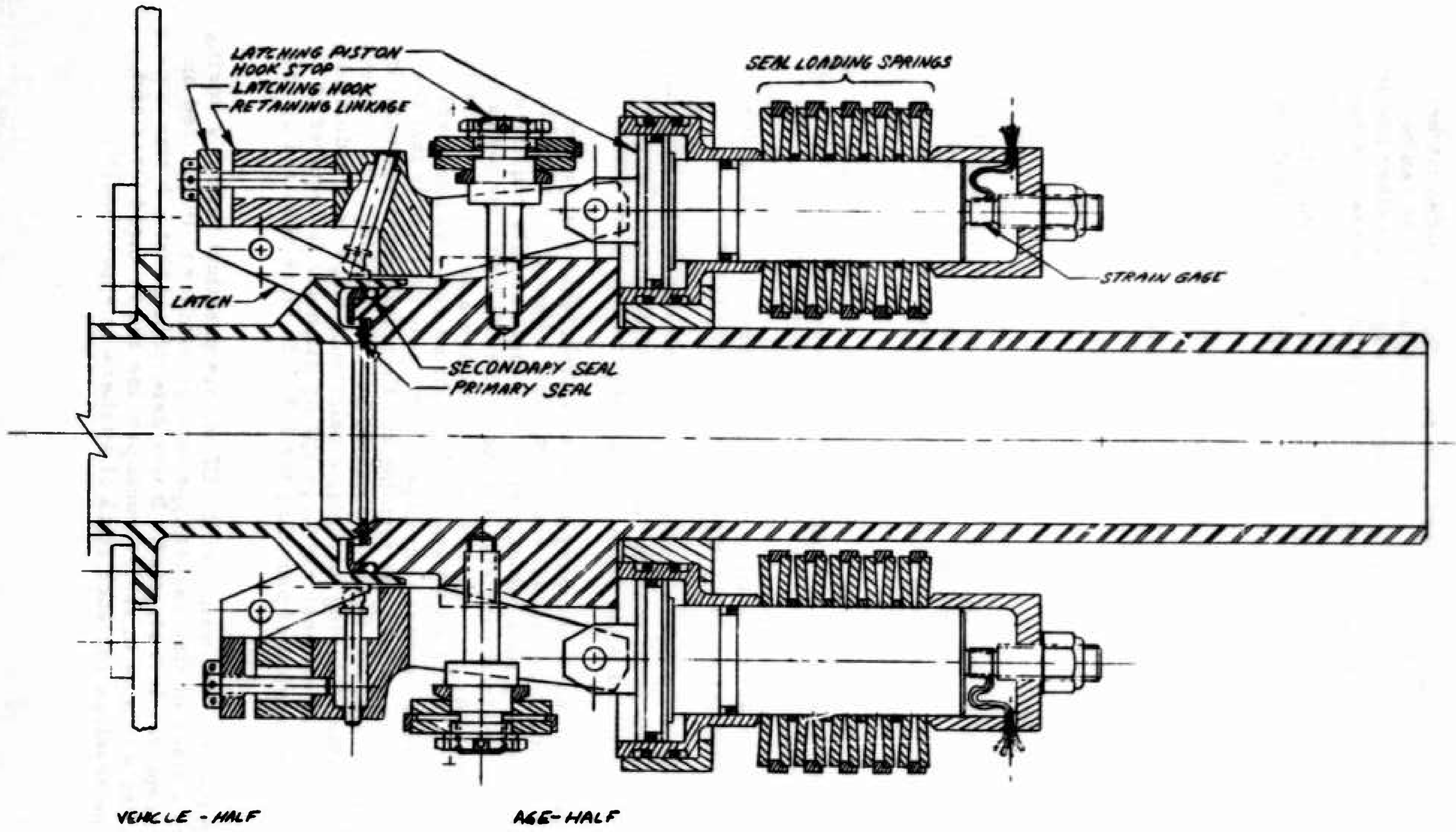


Figure 3-15. Cross-Section of Second Test Model QD Coupling

Two significant changes in the design were required. Spring loaded latches were incorporated in the latching hooks so that the coupling halves can be mated without opening a joint in the latch retaining linkage. The other major change is incorporation of a set of pneumatic cylinders to compress the seal loading springs which have been increased in number from 3 to 10 per latch to provide for the greater spring deflection necessary to enable the latches to engage when the coupling halves are mated. The sequence of operations required to connect the coupling halves is:

a. Apply pneumatic pressure to extend the latching members.

b. Bring the two coupling halves together and allow the latches to snap over the flange on the vehicle-half.

c. Release the pneumatic pressure allowing the latch loading springs to preload the seal.

An effort was made to use helical compression springs made of either round or rectangular wire rather than the flat disc springs for seal loading. However, the required envelopes were undesirably large and obtaining springs made from a material suitable for a cryogenic environment was a major obstacle.

The normal materials for "shelf item" die springs are low alloy, high strength steels such as chrome vanadium or chrome silicon steel which have a torsional elastic limit strength of 100,000 to 130,000 psi. However, these materials become brittle at cryogenic temperatures and it was recognized that further effort would be required in the detail design phase to provide a spring design utilizing a material with better low temperature characteristics.

The design requirements for these springs were given to several spring manufacturers for design, two local manufacturers, California Spring Company and Seaboard Pacific Division of Associated Spring Corporation, were contacted.

The sales engineer from each company stated that stainless steel or a high nickel alloy such as Monel or Inconel should be used. Except for type 302 CRES steel, which they normally stock, these materials usually require a mill run to obtain the desired wire size and therefore the lead time for procurement is excessive. An attempt was made to design a spring or coaxially nested springs from Type 302 CRES steel. No solution could be found which would fit within a reasonable space envelope. The basic problem is that the material cannot be heat treated after forming and therefore must be wound in the spring tempered condition which is obtained by cold working. To prevent destruction of the material during forming, a relatively large bend radius is required and therefore an excessively large spring diameter is required to obtain a configuration capable of providing the 1,800 lb force required by the design.

In order to keep the size and weight of the QD within practical limits, a spring concept utilizing a stack of flat washer type springs similar to those used on the previous concept was investigated. It was determined that a design consisting of 10 spring washers in series would provide the required force and spring rate. The envelope for each stack of washers is approximately

2-1/2 in. diam by 2-1/2 in. length which can be conveniently accommodated by the design. The design was therefore modified to utilize this spring configuration.

3.3 Structural Design and Analysis

A structural analysis was conducted on those components which are subjected to loads sufficiently high to develop a relatively high stress level. The main body structure for both coupling halves was made with relatively thick walls to avoid distortion which could result in a seal leakage. This resulted in a very low stress level in these components, and no formal stress analysis was made. The latching components, however, were designed for relatively high loads and for these parts it was necessary to make stress analyses which are included in this section. As noted in Section 3.1.4, the 100% design load for each latch is 1,200 lb, and the components were designed for loading to 150% of design load or 1,800 lb. per latch during the test program. Detailed structural calculations for the two test model QD couplings are found in Appendix VII.

4. FABRICATION, ASSEMBLY AND CHECKOUT

The detail fabrication drawings were submitted to four machine shops for bids. The bids were for the fabrication of all detail parts for the two test model QD's and the required spares.

Allied Pacific Manufacturing Company, Compton, California, was selected on the basis of lowest costs and best schedule.

The completed components were delivered to Douglas for inspection, installation of instrumentation, a limited amount of component testing, assembly, and preliminary checkout prior to testing.

Most of the component parts were designed for fabrication by conventional machining methods: turning, milling and grinding. Since weight was not considered a critical factor, the test parts were designed to be strictly functional. Square corners and straight sides were used wherever possible and no special machine cuts were required for weight reduction. The smoothest surface finish required was 32AA and this was limited to areas where O-rings and other elastic seals were used. The knife edge serrations used for plastic sealing of soft aluminum gaskets were given a 63AA finish.

The elements of the seal loading mechanism had the most stringent requirements for fabrication. The seal loading springs discussed in Section 3.2 required a material with a tensile yield strength of 210,000 psi, inherent corrosion resistance and adequate impact strength at cryogenic temperature. Inconel 718 was selected as the most suitable material for the application. To achieve the required tensile properties it was necessary to buy sheet stock with excess thickness, cut it into convenient sized strips, cold reduce it 30% in a rolling mill, perform the final machining operations, and heat treat the parts to obtain the desired physical properties.

After the cold reduction operation test specimens were cut from each strip of material and tested in a tensile testing machine. The results of the tensile tests are shown in Table 3-1. The tensile yield stress values for these specimens ranged from 142,620 to 155,380 psi. Based on data from Reference 84, the following tensile yield properties should be obtained by cold reduction and ageing:

Amount of cold reduction	20%	30%
Yield strength after cold reducing	147,000 psi	180,000 psi
Yield strength after cold reducing and ageing	193,000 psi	227,000 psi

Thus, it appeared that the yield strength obtained corresponds more closely to 20% than to 30% cold reduction of the material. However, the projected 193,000 psi yield strength after ageing was only 8.1% lower than the 210,000 psi yield strength used in the calculation and it was decided that the strength of the parts would be adequate. Additional coupons from each material strip were subjected to the ageing process with the finished parts for possible future analysis. These coupons were never cut into test specimens and tested because the completed springs performed their required function with no evidence of permanent distortion. The final machining operations consisted of trepanning discs from the strips and grinding the flat surfaces to the required thicknesss and degree of parallelism. The seal load indicators and their spacers used on the first test model were machined to a thickness tolerance of ±0.0005 in. and a flatness of 0.0001 in. over the diameter of the part.

Fabrication was scheduled so that the parts with the highest priority would be delivered first. Included in the first priority group were those parts requiring instrumentation, the two main adapters for the coupling halves and the latch clevis bolts.

Instrumentation on the vehicle half adapter consisted of three copper-constantan thermocouples spot welded to the adapter at points selected to measure as closely as possible the temperature of the main fluorine duct wall, the primary seal, and the secondary seal. A fourth copper-constantan thermocouple was built into a CRES steel-encased removable probe which was inserted through a fitting in the pipe wall into the main fluid channel to measure the LF_2 temperature gradient in the thick walled section of the AGE-half adapter adjacent to the latching mechanism three holes of depths 0.550, 0.344, and 0.093 in. were drilled in an area with an 0.62 in. thick wall and a copper-constantan thermocouple was spot welded to the bottom of each hole.

The six clevis bolts (Figure 3-11) which transmit the latch loads to the AGE-half adapter on the first test model were instrumented with two strain gages on each bolt and a thermocouple was buried in the strain gage bonding cement to permit temperature compensation of the test data taken at cryogenic temperature.

Table 3-1

Tensile Test Results For Inconel 718 Spring Material

Specimen No.	Material Strip Code	Width (in.)	Thickness (in.)	Area ($in.^2$)	Yield Load (lbs.)	Yield Stress (psi)	Ultimate Load (lbs.)	Ultimate Stress (psi)	% Elongation 1" Gage
1	39	0.250	0.1152	0.0288	4430	153,820	4960	172,220	11
2	39	0.250	0.1150	0.0288	4475	155,380	4950	171,875	11
3	97	0.250	0.1434	0.0359	5550	154,595	6160	170,475	11
4	97	0.249	0.1435	0.0357	5520	154,620	6090	170,590	11
5	159	0.249	0.1821	0.0453	6630	146,355	7400	163,355	15
6	159	0.251	0.1811	0.0455	6500	142,855	7390	162,115	15
7	169-1	0.253	0.1430	0.0362	5320	146,960	5960	164,640	15
8	169-1	0.253	0.1420	0.0359	5120	142,620	5810	161,840	15
9	169-2	0.252	0.1426	0.0359	5340	148,745	5850	162,950	15
10	169-2	0.252	0.1421	0.0358	5100	146,550	5780	161,450	15
11	169-3	0.251	0.1417	0.0356	5170	145,225	5800	162,920	14
12	169-3	0.251	0.1411	0.0354	5060	142,935	5680	160,450	15
13	169-4	0.250	0.1421	0.0355	5150	145,070	5770	162,535	15
14	169-4	0.249	0.1421	0.0354	5120	144,630	5740	162,145	15

Sealing loads applied to the primary seal of the QD can be determined by direct reading of the strain gages or by measuring the deflection of the seal load springs. Three separate calibration curves were run on each bolt in order that their load-strain-temperature relationships could be adequately defined and thus assure the acquisition of meaningful data. These curves are:

1. Load versus strain at ambient temperature (72°F). Sampel shown in Figure 3-16.

2. Load versus strain at cryogenic temperature (-320°F). Sample shown in Figure 3-16.

3. Strain versus temperature at no load (72°F to -320°F). Sample shown in Figure 3-17.

Curves in Figure 3-16 are completely linear but of different slopes. The change in slope is caused by a change in the modulus of elasticity of the bolt material with temperature; the modulus increases with a decrease in temperature, and thus the slope of the load versus strain curve increases with a decrease in temperature.

The third calibration curve is required to compensate for the change in strain gage reading caused purely by temperature, "zero shift".

As the strain gage and the clevis bolt, on which the gage is attached, change temperature, the no-load (0) reading of the strain gage changes. This is caused by several factors; change in resistance of the gage, change in actual length of the bolt, differences in the expansion properties of the bolt and the gage bonding materials, etc.. The dominant factor is the actual change in length of the bolt, resulting in a positive indication of change in strain. Thus, an ambient temperature strain reading at load X, will not be the same as a strain reading for load X at -300°F or at +300°F; the load, however, is the same, and a correction is required to compensate for the effect of temperature. This strain versus temperature curve is not linear, and a typical curve is shown in Figure 3-17.

The two strain gages are mounted on opposite sides of each bolt and are wired to indicate only tension loading of the bolt; bending effects are cancelled out.

Three shear pins are utilized in the test model. The fracture of any one of these pins in sufficient to permit separation of the QD. The pins were designed to fracture at a nominal shear load of 4000 lb. The pins are loaded in double shear and have two minimum diameter sections. Six pins were fractured in a tension testing machine to establish the actual breaking strength. Actual test model links were used to load the pins. Two pins had 0. 147-in. diam shear sections, one had 0. 146-in. diam sections, and the fourth had 0. 145-in. diam sections. All fractured in the range from 4, 900 to 5, 160 lb. These loads are approximately 25% higher than the design load, but present no problem since the associated hardware has more than adequate strength to handle the higher loads. Figure 3-18 is a typical load-deflection curve for the shear pin destruction test. The deflection was measured by the head travel of the testing machine and includes not only the shear pin deflection but also the deflection in all the connecting linkages.

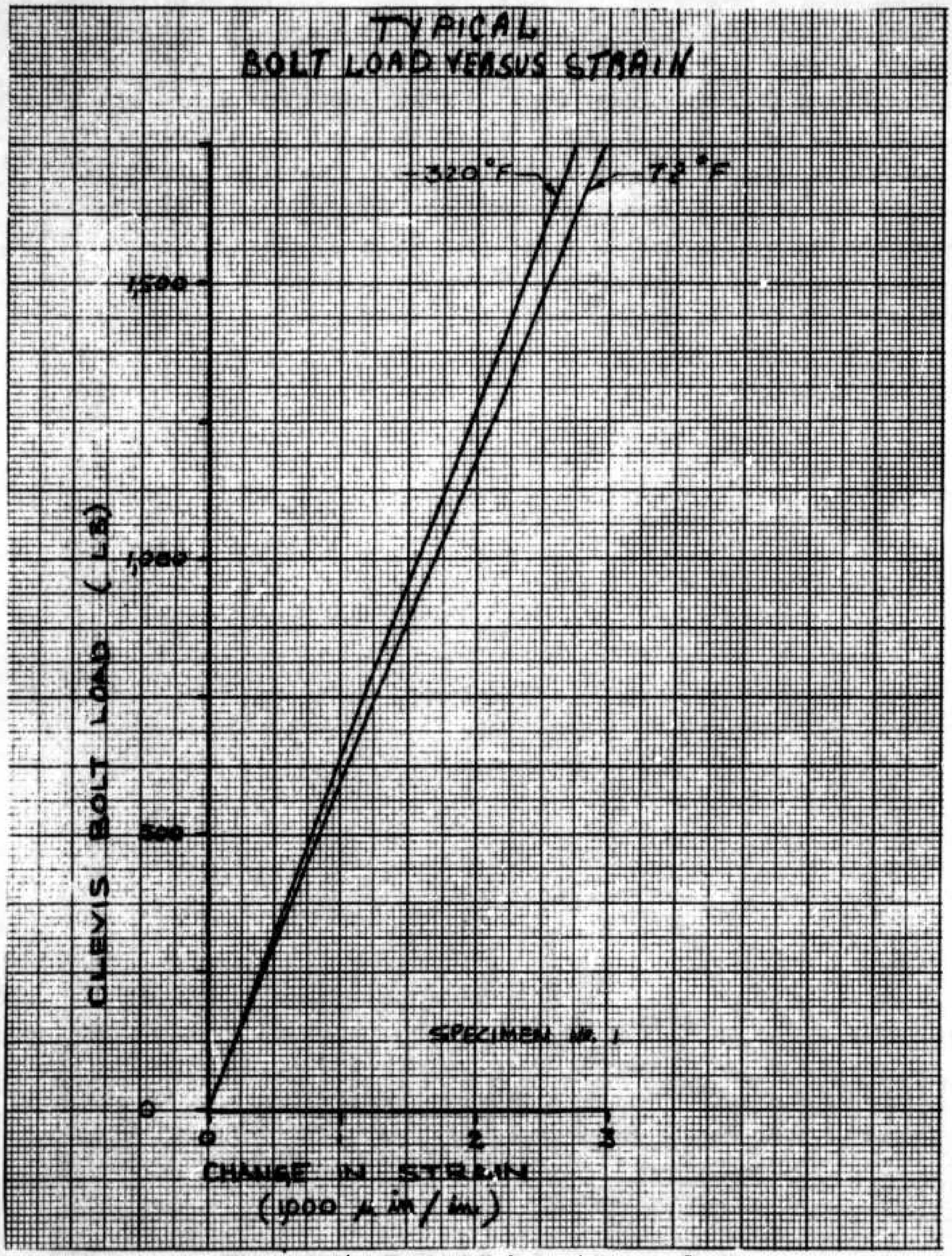


Figure 3-16. Typical Bolt Load Versus Strain

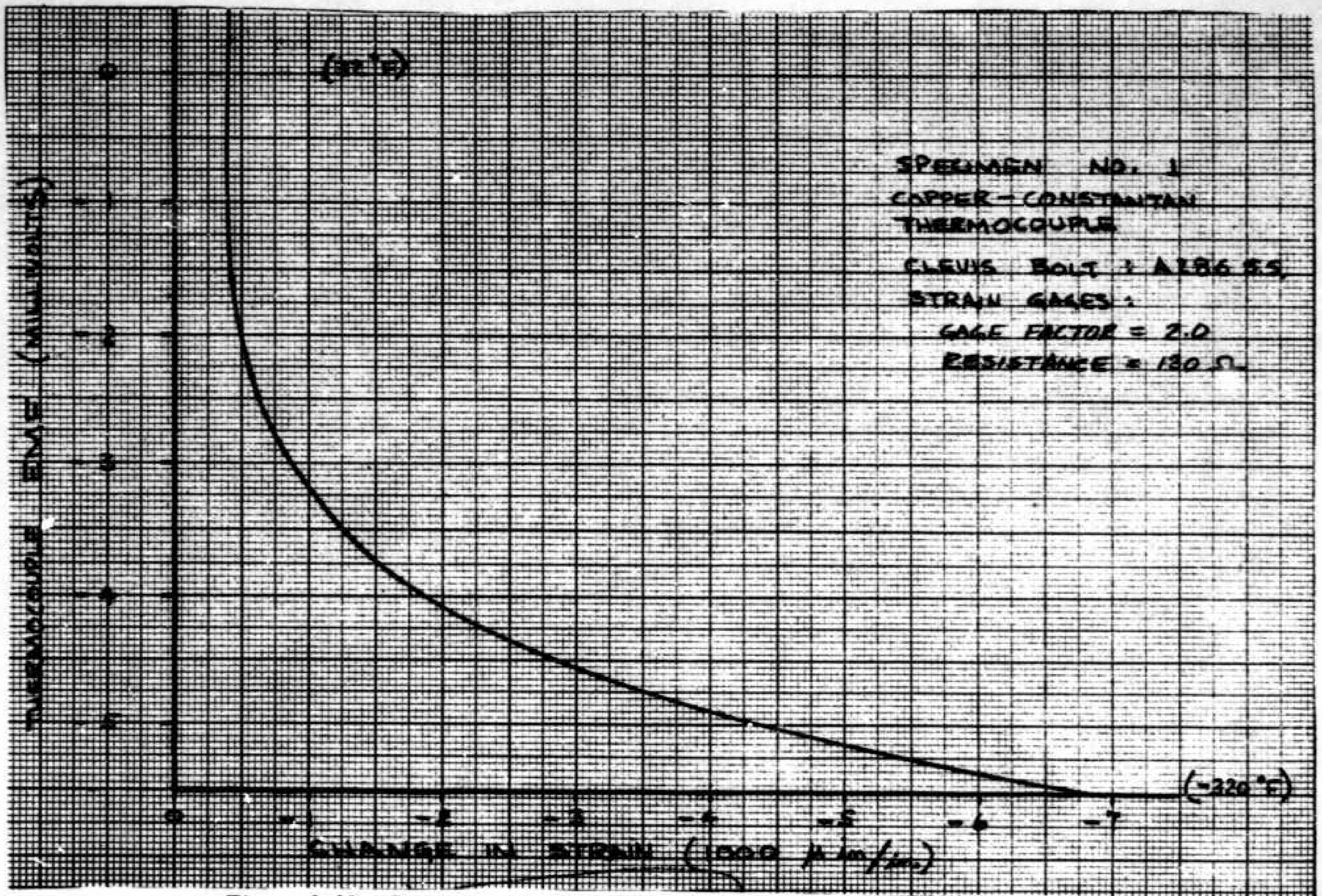


Figure 3-17. Strain Versus Temperature at no Load (Typical for Each Bolt)

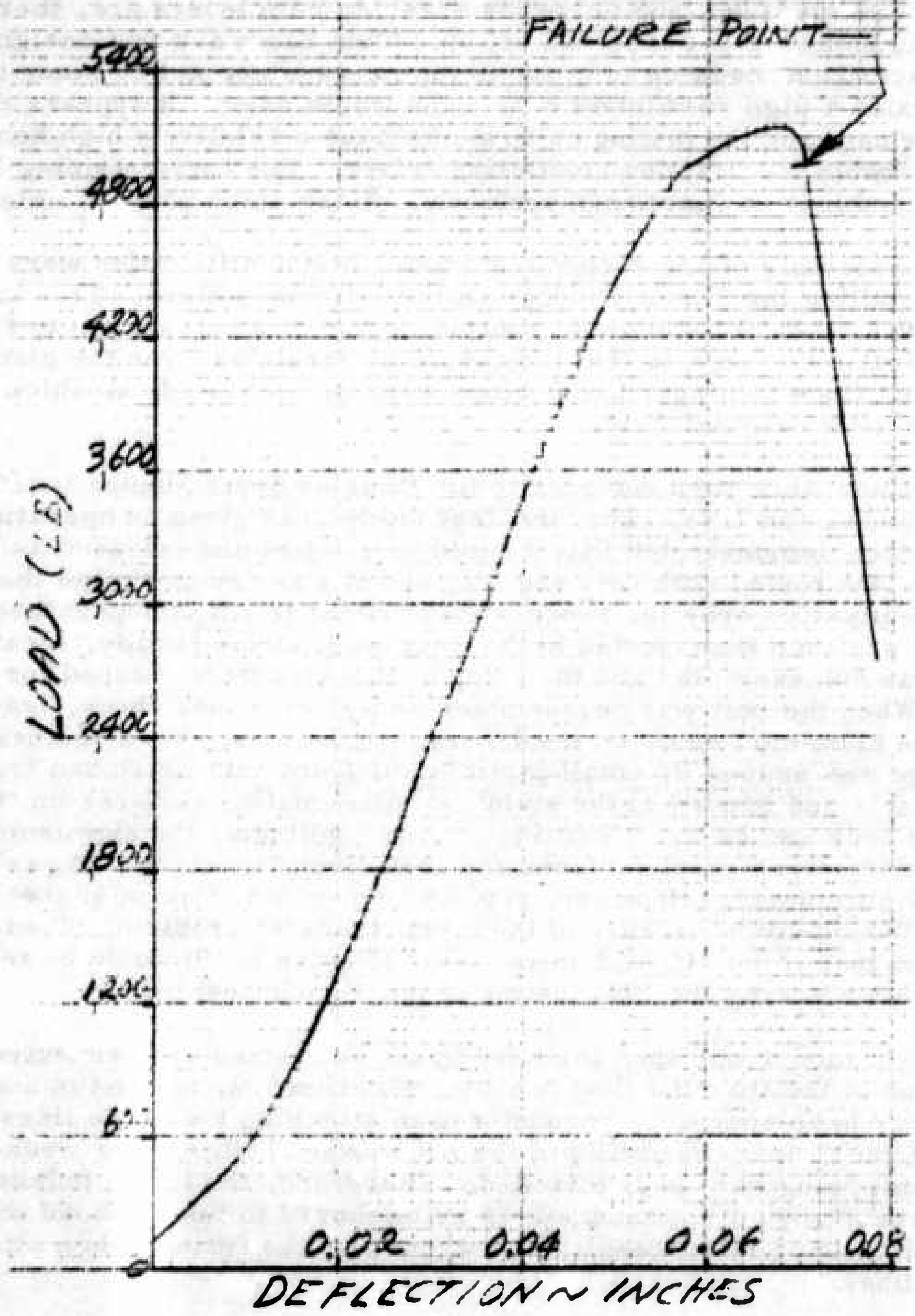


Figure 3-18. Typical Load-Deflection Curve for Shear Pin Destruction Test

Subsequently, shear pins were fractured on the test model by use of the pneumatic decoupling actuators. The actuator was a two-inch diameter cylinder and the pressure required to fracture the pins ranged from 215 lb. to 240 lb. The loads applied to the pin breaking cam levers are, therefore, estimated to be between 650 lb and 750 lb. This hardware was designed to withstand actuation loads up to 2, 100 lb on the assumption that since the cam is unlubricated a high coefficient of friction would exist. It appears that because the cam and its mating components have a relatively high heat treat that a reasonably low friction coefficient exists. The cam-retaining link-shear pin combination functioned perfectly, giving quick positive release.

During the assembly of the second test model minor difficulties were encountered in installing the Teflon O-rings on the latching pistons. This installation operation was rendered somewhat routine by use of a hot-air gun to first warm the Teflon O-rings so that they could be stretched over the piston during installation. Once in place, the O-rings were again heated, at which time they returned to their original shape.

The assemblies were then returned to the Douglas Santa Monica location for testing with GN_2 and LN_2. The first test model was given an operational checkout which demonstrated that it could be latched and released as designed. It was then leak tested with GN_2 and LN_2 and it was demonstrated that the seals were effective over the range from ambient to LN_2 temperature. This disconnect was then transported to the Douglas fluorine facility, location A23, where it was disassembled and the component parts were cleaned for fluorine service. When the unit was reassembled and given a leak check, leaks were found at the aluminum seals on the 1/8-in. AN fittings. It was determined that leakage was caused by small particles of aluminum which had transferred from the seals and bonded to the stainless steel mating surfaces on the Quick Disconnect body and on the AN fittings. After polishing the aluminum particles off the stainless steel surfaces and installing new aluminum gaskets, the leaks were eliminated. However, replacement of this type of gasket will always be troublesome because of the metal transfer problem. Therefore, it was decided that some MC-252 metal seals (Figure 3-19) would be tested for this application during the LN_2 testing of the second test model.

The first test model was then installed in the test stand and connected into the test loop of the fluorine flow facility. (Section 5. 2, test setup and operation.) Minor problems were encountered in attaching the purge lines to the test model due to inaccessibility of the AN bulkhead fittings for wrenching when the anti-icing shroud is installed. Therefore, the tubing bulkhead fittings were modified so that they can be anchored to the bulkhead with screws, thereby eliminating the necessity of a wrench on the fittings when attaching the purge lines.

After leak checking the test setup it was passivated internally with gaseous fluorine for approximately 40 min. No problems developed during passivation. A very slight temperature rise (4°F) was noted on the temperature probe inserted through the wall of the QD vehicle-half. After passivation the test setup was purged with GN_2 for four minutes and a trial operation of the line purge GF_2 detection system was made. The detection system functioned normally and indicated a fluorine concentration of approximately

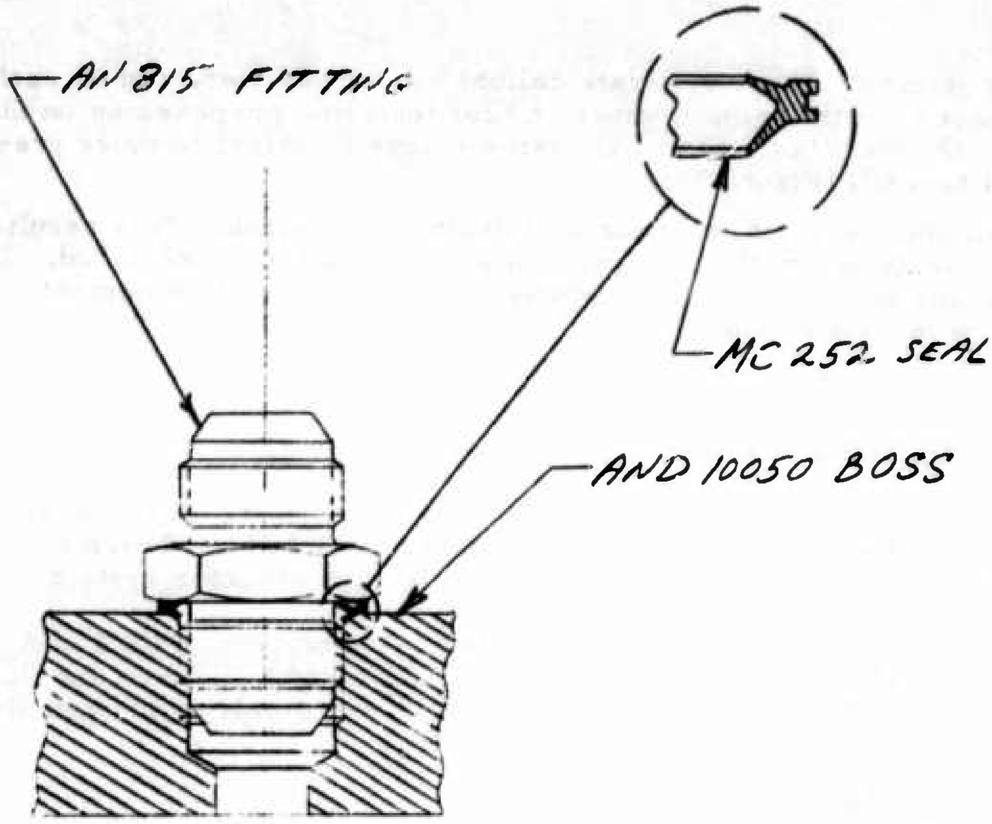


Figure 5-19. Typical Installation of MC252 Metallic Seal

90 ppm. The primary seal cavity leakage system was operated during the passivation, and there was no indication of fluorine leakage past the primary seal. The QD was then ready for the test program described in Section 5.

The second test model was given a preliminary functional checkout, consisting of (1) actuating the latching pistons with the QD separated, (2) engaging the AGE and Vehicle-halves of the QD using pneumatic operated latching pistons, (3) quick disconnect of the coupling by breaking one release shear pin, (4) repeating the above steps 1-3 and, (5) carefully examining all hardware for proper functions and for any damage. During the performance of step 1, and interference was discovered, due to improper assembly, which prevented three of the latching pistons from retracting fully. Adjustment of the assembly corrected this condition.

The remainder of the preliminary functional checkouts (engagement, release, inspect, engagement, release, and inspect) revealed that all systems functioned as designed except that some gas leakage was noted at one of the latching pistons; this did not preclude successful engagement and latching of the QD. Upon disassembly, it was discovered that one of the Teflon backup rings for the Teflon O-rings had been cut during installation.

Following these initial checks, the latching pistons were removed for installation of strain gages and thermocouples, which were required to determine the sealing loads being applied to the primary seal of the QD. As was the case with the first test model, two strain gages were mounted on each of the six latching pistons. Three separate calibration curves were run on each set of strain gages, in the same manner and for the same purposes as on the first test model. The results of these calibrations were identical to those presented for the first test QD (Figure 3-16).

These strain gages became unbonded during calibration. This resulted in a schedule delay of ten days because these gages had to be replaced. The new strain gages were successfully bonded using a new batch of cement and all six pistons were re-calibrated.

5. EXPERIMENTAL PROGRAM

5.1 Test Objectives, Requirements, and Procedures

The IT20586 Liquid Fluorine Quick Disconnect Coupling Test Model consists of a quick-release, separable coupling and associated hardware that forms the interface between a vehicle-and-AGE fluorine oxidizer system.

Two 1T20586 Test Models were subjected to the tests specified in Appendix IX. The 1T20586-1 Test Model was subjected to both non-fluorine and fluorine testing; the 1T20586-501 Test Model was subjected only to the non-fluorine tests.

5.1.1 Test Objectives

The primary objective of the test program was to prove that the designs represent good functioning concepts which are compatible with the use of liquid fluorine as an oxidizer.

5.1.1.1 The major areas of concern were:

a. Fluorine Detection was investigated to determine the required attributes of a fluorine detector for the purge and drain system and for seal leak detection and measurement.

b. Drain and Purge Systems were investigated to establish controlling parameters and to evaluate techniques and procedures for adequate removal of fluorine from the fill-and-drain line adjacent to the quick disconnect (QD).

c. Separation Mechanism Effectiveness was tested to verify design concept for primary separation method.

d. Interface Seals were investigated to demonstrate their sealing capabilities under the expected field assembly and use conditions with liquid fluorine. In addition, investigations to determine the effect of varying key sealing parameters were conducted to indicate the true factors of safety involved and the capability for scaling the critical elements of the design.

e. F_2 Compatibility. The QD was exposed to typical service conditions involving F_2 to prove compatibility.

f. Anti-Icing Shroud Purge effectiveness for preventing the formation of ice and frost on the QD latch and separation mechanism was investigated.

5.1.1.2

Two separate test setups were made: non-fluorine test setups, which were made at the Douglas Santa Monica facility; fluorine test setups, which were made at the Douglas A23 fluorine flow facility.

5.1.1.3

The non-fluorine tests were divided into (a) Pre-fluorine Readiness Tests and (b) Design Evaluation Tests. Objectives of this test phase were:

a. Determine sealing capability

b. Investigate sealing parameters

c. Determine seal purge capabilities

d. Determine engagement and latching capabilities

e. Determine separation capability

5.1.1.4

The fluorine test objectives were to:

a. Demonstrate compatibility with LF_2 flow

b. Demonstrate separation capability after F_2 exposure

c. Determine F_2 sealing and seal purge system capabilities

d. Investigate F_2 leak detection techniques to establish real requirements

e. Investigate effectiveness of purge-and-drain system and operating procedures.

5.1.2 Test Requirements and Procedures

Detail test requirements and procedures are found in Appendix IX.

5.2 Test Methods, Apparatus and Setups

5.2.1 Non-Fluorine Testing

5.2.1.1 Test Setups

A wooden test fixture was built to support the test model QD's during non-fluorine testing. Figure 3-20 is a photograph of the 1T20586-1 Test Model QD in this fixture. This apparatus was installed in a research laboratory at Douglas Santa Monica location.

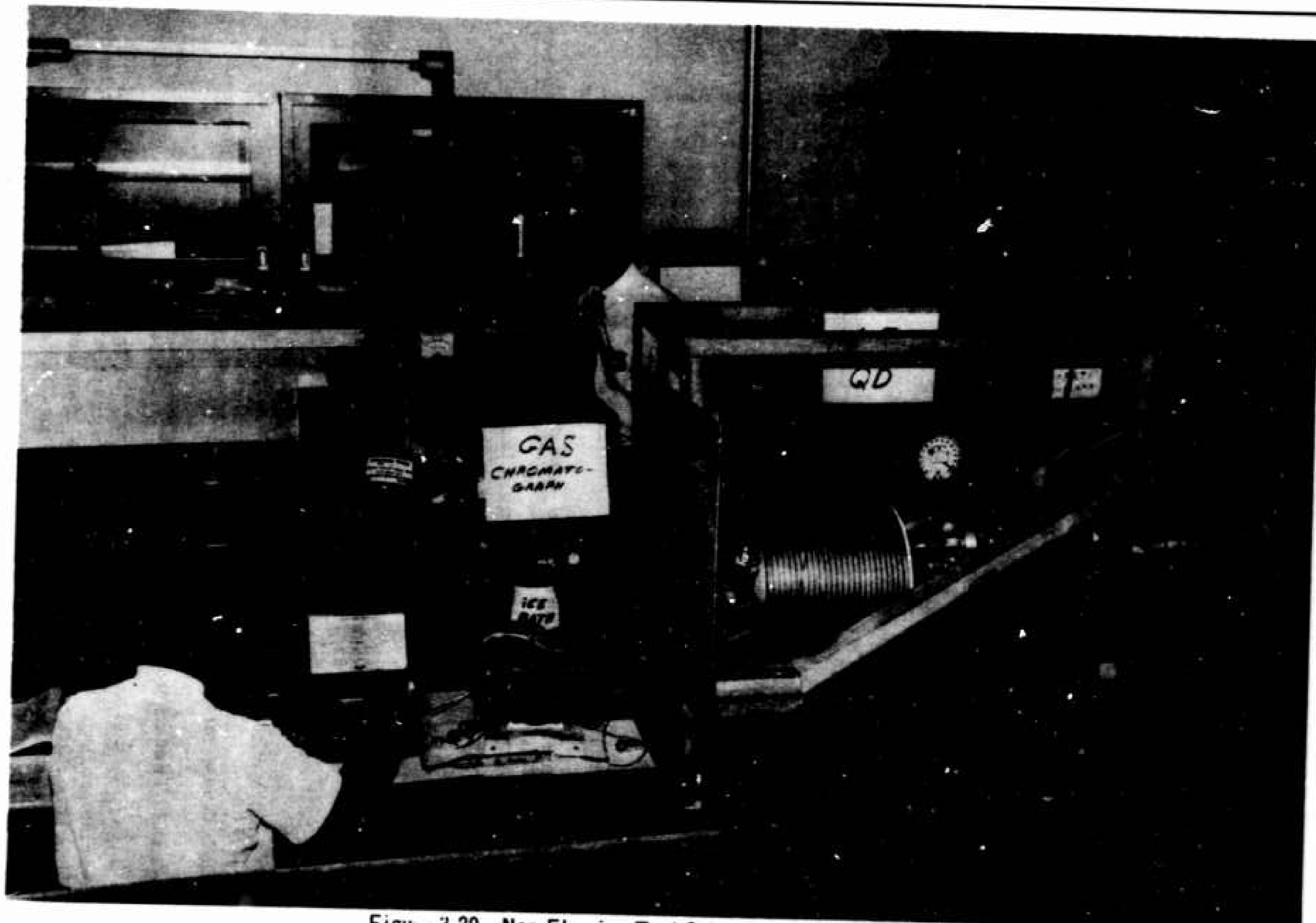


Figure 3-20. Non-Fluorine Test Setup for Test Model QD's

The setup for LN_2 testing of the QD is indicated in Figure 3-21. The QD vehicle-half was capped with a blind flange with two 1/2 in. ports. One port was connected to a 100-liter LN_2 dewar and the other to a pressure relief valve. The QD AGE-half was capped with a welded fixture which served as a support for the decoupling pneumatic actuator and also contained a 1/2-in. port on which a 1/2 in. manually operated ball valve was mounted. For QD chilldown LN_2 flowed from the dewar, through the QD and ball valve, and was dispersed into the atmosphere.

A gaseous helium (He) supply was connected to the seal cavity through a Gas Chromatograph, the operation of which is described in paragraph 5.2.1.3, Leak Detection and Measurement.

Gaseous nitrogen (GN_2) was supplied to the QD purge port and used to pressure the QD during primary seal leak checks.

A supply of gaseous argon (GA_r) was connected to the outer anti-icing shroud cavity, and used in determining secondary seal leakage at ambient temperature.

5.2.1.2 Temperature and Pressure Measurements

Pressure measurements were made using Bourdon tube type pressure gages. Pressure readings were made visually and recorded on test data sheets as required throughout each test sequence.

Temperatures were measured at some 12 locations on the QD. This was accomplished by using copper-constantan thermocouples resistance welded directly to the QD. An ice bath was used for the reference thermocouple junction, and the emf produced by each couple was measured using a precision laboratory millivolt meter with visual readout. A manually operated stepping switch was used to switch the millivolt meter from one thermocouple to another, requiring about 90 sec to record the emfs produced by the 12 thermocouples. Standard millivolt versus temperature (°F) tables were used to convert these recorded observations to meaningful temperature data.

5.2.1.3 Leak Detection and Measurement

The primary seal of the QD was leak tested by gas chromatography at both ambient and cryogenic temperatures. The experimental setup was as shown in Figures 3-20 and 3-22.

The detection method selected is capable of monitoring the leakage rate values of 10^{-2} to 10^{-6} SCIM, since the detection sensitivity of instrumentation for nitrogen in helium is in the parts per million range. Instrumentation consists of a standard, hot-wire thermal conductivity detector, controlled by a power supply and amplifier - attenuator arranged with the reference and sensor elements electrically connected across a wheatstone bridge. By close flow control of the helium gas through the detector, the output is calibrated against known nitrogen-helium mixtures by measurement of scale deflection on a 1 mv full-scale L&N recorder. The quantity of nitrogen leaking from the quick disconnect seals into the helium sweep gas stream flowing through the cavity per unit time is calculated in terms of SCIMS. Both ambient temperature GN_2 leakage and LN_2 gas phase leakage was checked using this method.

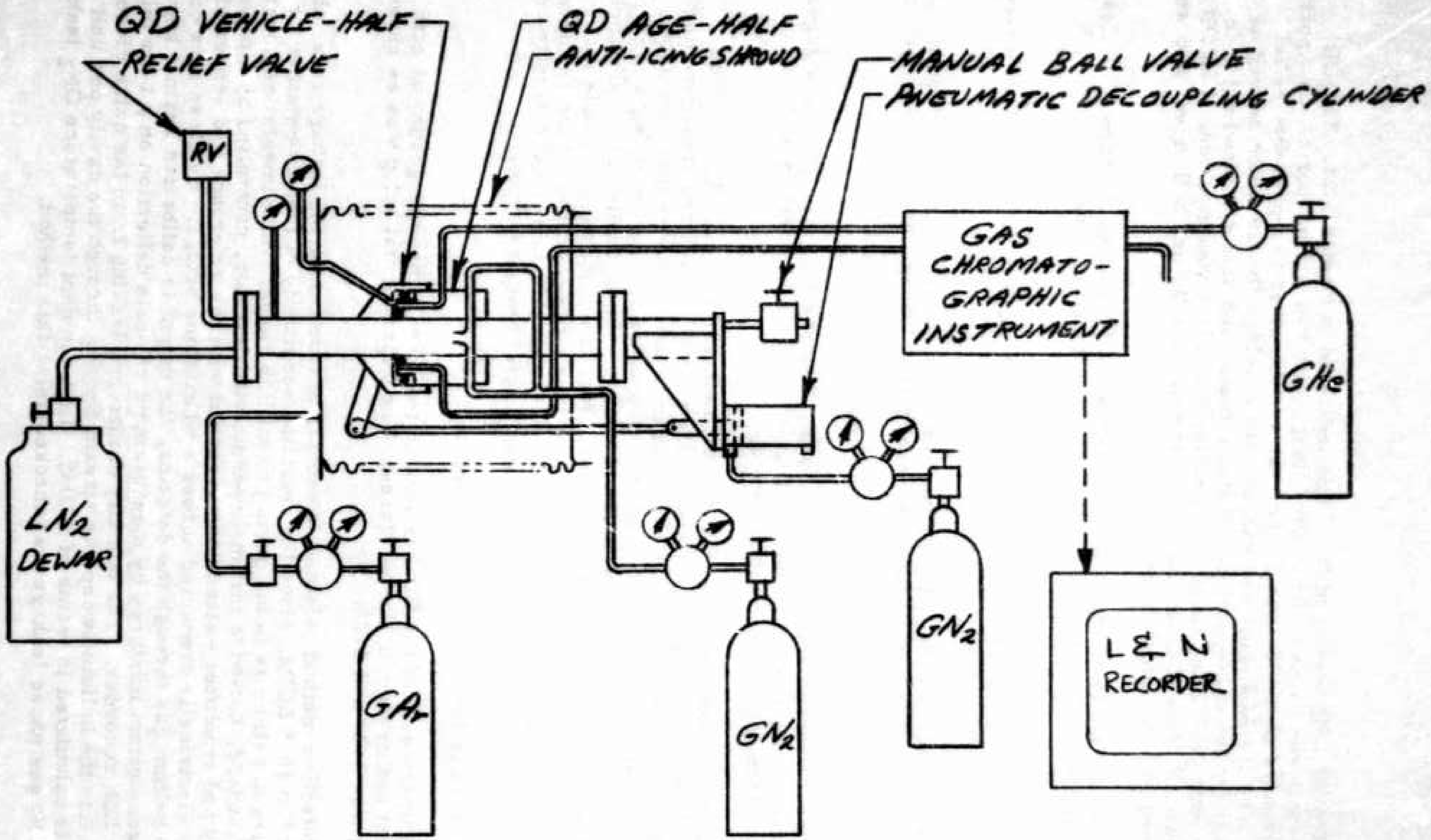


Figure 3-21. Schematic of LN_2 Test Setup For LF_2 QD

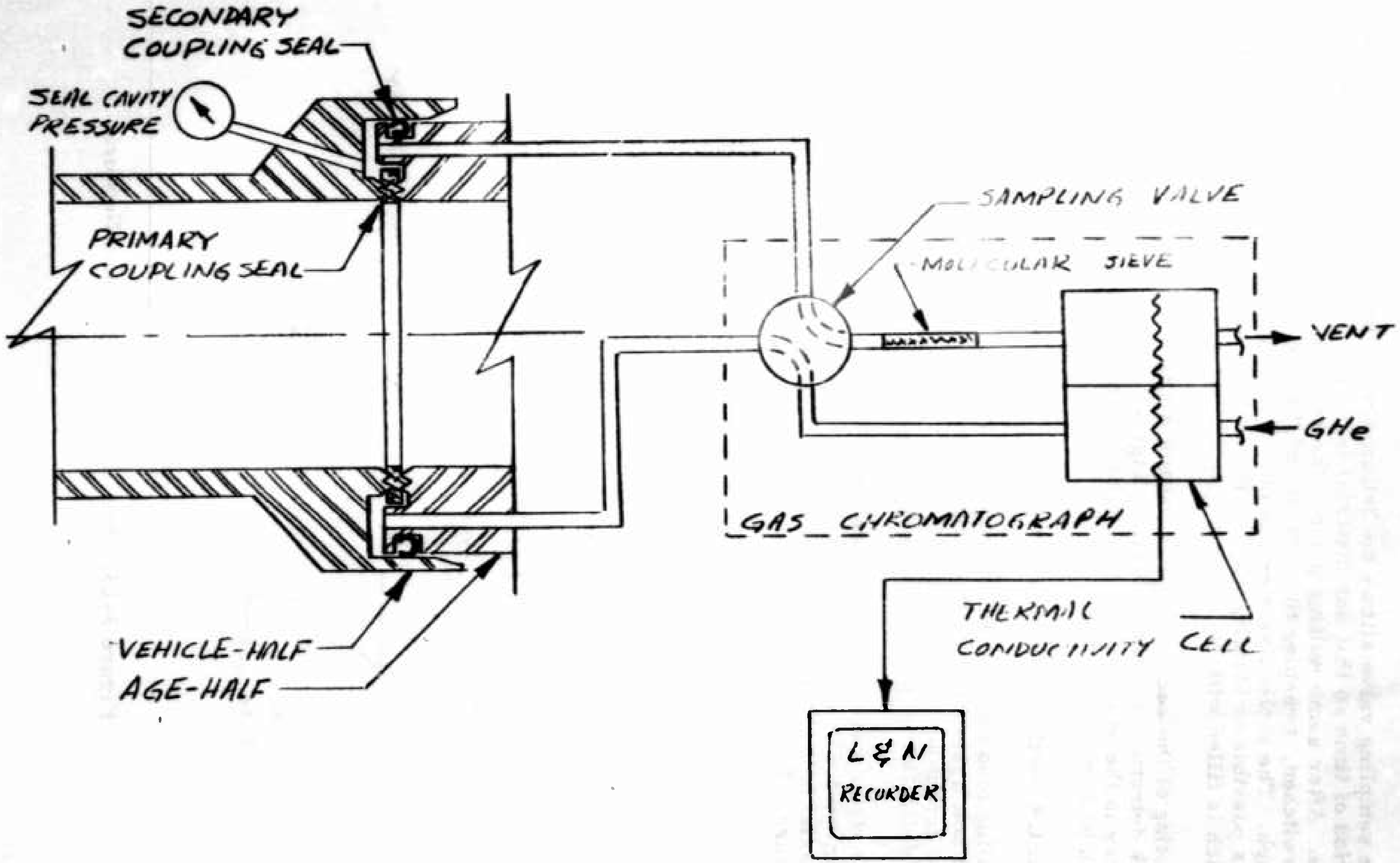


Figure 3-22. Seal Leak Detection and Measurement Setup

The sampling valve allows the helium flow to be interrupted for any desired period of time so that any material leaking into the seal cavity could accumulate. After some waiting period, the sampling valve on the gas chromatograph is switched, sweeping the contents of the seal cavity into the gas chromatograph. The molecular sieve column separates oxygen and nitrogen, so that it is possible to identify whether the leakage is from the main line of the QD which is filled with N_2, or from atmospheric leakage past the secondary seal.

Testing of the secondary seal and the AN fittings was done using a CEC helium leak detector, and the overall leakage was found by measuring the pressure decay in the seal cavity, after it had been pressurized to approximately 30 psig with helium.

5.2.1.4 Sealing Load Measurements

Sealing loads were determined by measuring deflections within the six spring and bolt assemblies of the QD seal loading system (Section 3.2 for details). Two techniques were used: (1) strain gages on the six connecting bolts, and (2) deflection of the seal load springs.

The strain gages, installed and calibrated, as discussed in Section 4., were connected as part of a full-bridge network to provide a direct measurement of axial bolt strain only. The system was as shown in the schematic of Figure 3-23.

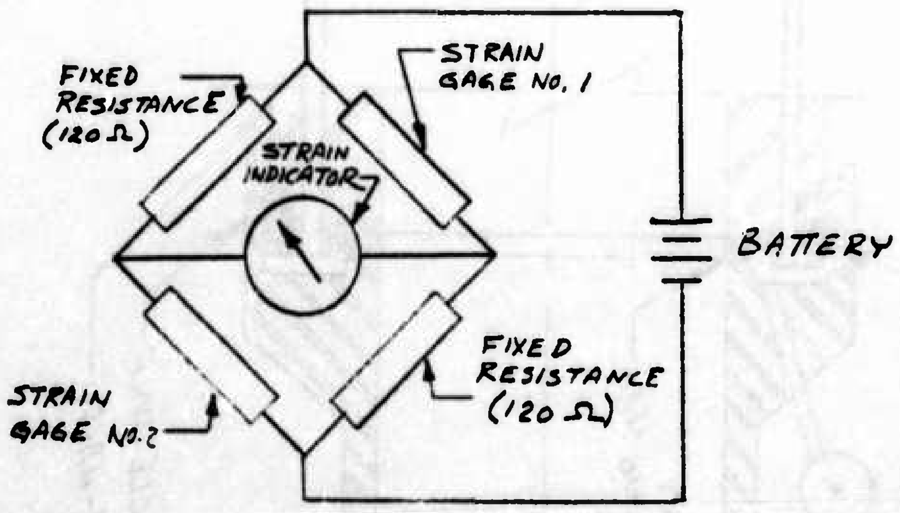


Figure 3-23. Full-Bridge Strain Gage Network

Deflection of the flat washer springs of the spring assemblies is directly proportional to the applied sealing load. These deflections are easily determined by measuring the change in gap between the flat washer springs as the spring loads are increased or decreased. Standard shim stock gages are used to measure these gaps. Built in deflection indicators are provided on the 1T20586-1 model QD for easy field adjustment of the spring assemblies to 100% or 150% of design seal load. These indicators are located between the washer springs (Figure 3-11) as to stop spring deflections at the design spring loads. Thus, at the 100% load condition, the 100% load indicator is no longer capable of free unobstructed motion, but is pinched between the two 100% load springs.

5.2.1.5 Engagement and Latching

The wooden test fixture, Figure 3-20, was used to rigidly support the vehicle-half of the QD coupling, while the AGE-half remained unattached to the fixture and easily moveable. The outer sleeve of the vehicle-half provides a slight bellmouth entrance which permits the AGE-half to be manually engaged with an 8° angular displacement. This angular misalignment from the centerline of the vehicle-half of the QD is possible from all orientations within an 8° cone about this centerline. Further, indexing is not required between the two halves of the coupling because of the completely circumferential symmetry of the vehicle-half of the QD.

Latching of the two test model QD's was quite different; the 1T20586-1 design was latched through a multi-step manual procedure, while latching of the 1T20586-501 test model was a one-step pneumatic operation. Detail discussion of these designs is found in Section 3.2.

The latching operation for the -1 coupling is outlined below:

1. Engage coupling halves (manual).
2. Place latching hooks in latching position (manual).
3. Install hook retaining link assembly (manual).
4. Increase the load on each of the six seal spring assemblies to 100% design load (manual).

At this point, the coupling was joined, latched and sealed.

The -501 test model QD is latched as follows:

1. Engage coupling halves (manual).
2. Apply pneumatic pressure to the built-in latching pistons, observe that latches have engaged, and release pressure (pneumatic).

5.2.1.6 Release and Separation

Evaluation of the quick-release and separation characteristics of the couplings were made using the wooden test fixture of Figure 3-20 as a support structure. As shown in Figure 3-21, gaseous nitrogen was used to pressurize the pneumatic decoupling cylinder. The release load was determined by measuring the decoupling cylinder pressure at time of release and multiplying that pressure by the pressure area of the cylinder. Functional and qualitative performance characteristics of the release operation (nature of shear pin failure, motion of latching and separation mechanisms, overall QD motion, integrity of parts, etc.) were determined by visual observation of the release operation, and hardware examination following coupling release.

The AGE-half of the coupling was supported following separation by two chains and a rope from the overhead members of the test fixture. These afforded no support prior to release and separation, and were used only to restrict the overall movement of the AGE-half of the QD in order to preclude damage to the QD, adjacent test equipment and personnel. Separation effectiveness was qualitatively evaluated on the basis of visual observations during separation and close examination of the QD following separation.

5.2.2 Fluorine Testing

5.2.2.1 Test Setup

The Douglas A23 fluorine test facility was used to test the 1T20586-1 test model QD with fluorine. The test model QD was installed in a transfer loop between two liquid fluorine storage tanks located on a concrete pad shown in the right hand portion of Figure 3-24. Flow control and instrumentation readout were from the right hand trailer also shown in Figure 3-24.

The QD was mounted within an L-shaped aluminum test box which served as the QD support structure and to contain any leaking or spilled fluorine. The setup is shown in Figures 3-25 and 3-26, and represented schematically in Figure 3-27. A flexible transfer line was provided to permit the movement required during QD disconnect testing when the AGE-half of the coupling is physically separated from the vehicle-half. An AGE-half support fixture was added to the L-shaped box to guide, support, and stop the AGE-half of the QD during separation testing. This fixture was no way supported or restrained the QD while engaged, latched and sealed, and acted only to prevent damage during QD separation.

Liquid fluorine flow was from the storage tank through the liquid nitrogen jacketed transfer line to the test section inlet shutoff valve FP-200, through the liquid nitrogen jacketed flexible line, through the QD, and through FP-201 on to the fluorine receiver tank. The liquid fluorine was returned to the storage tank through a bypass line prior to the subsequent flow testing.

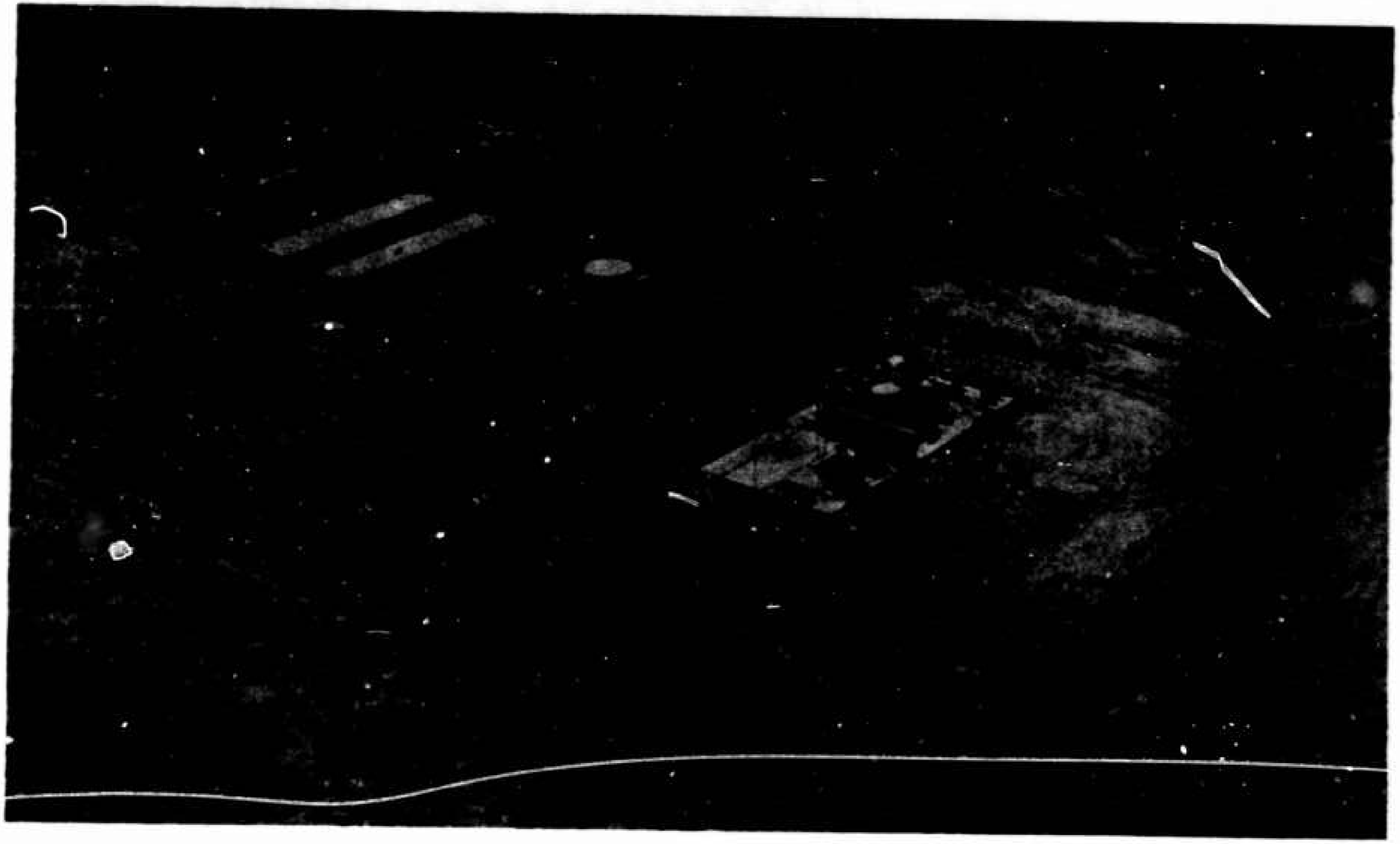
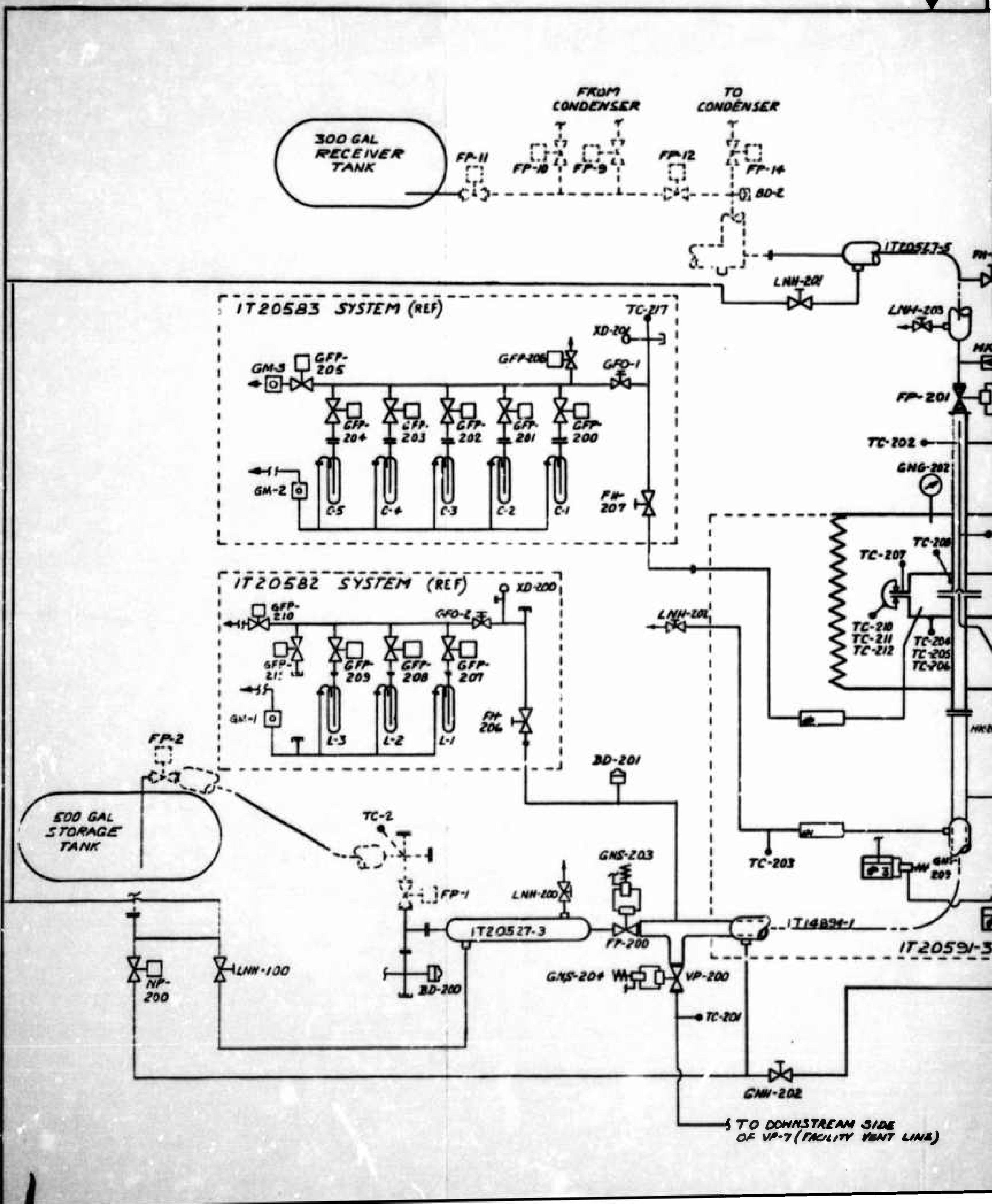


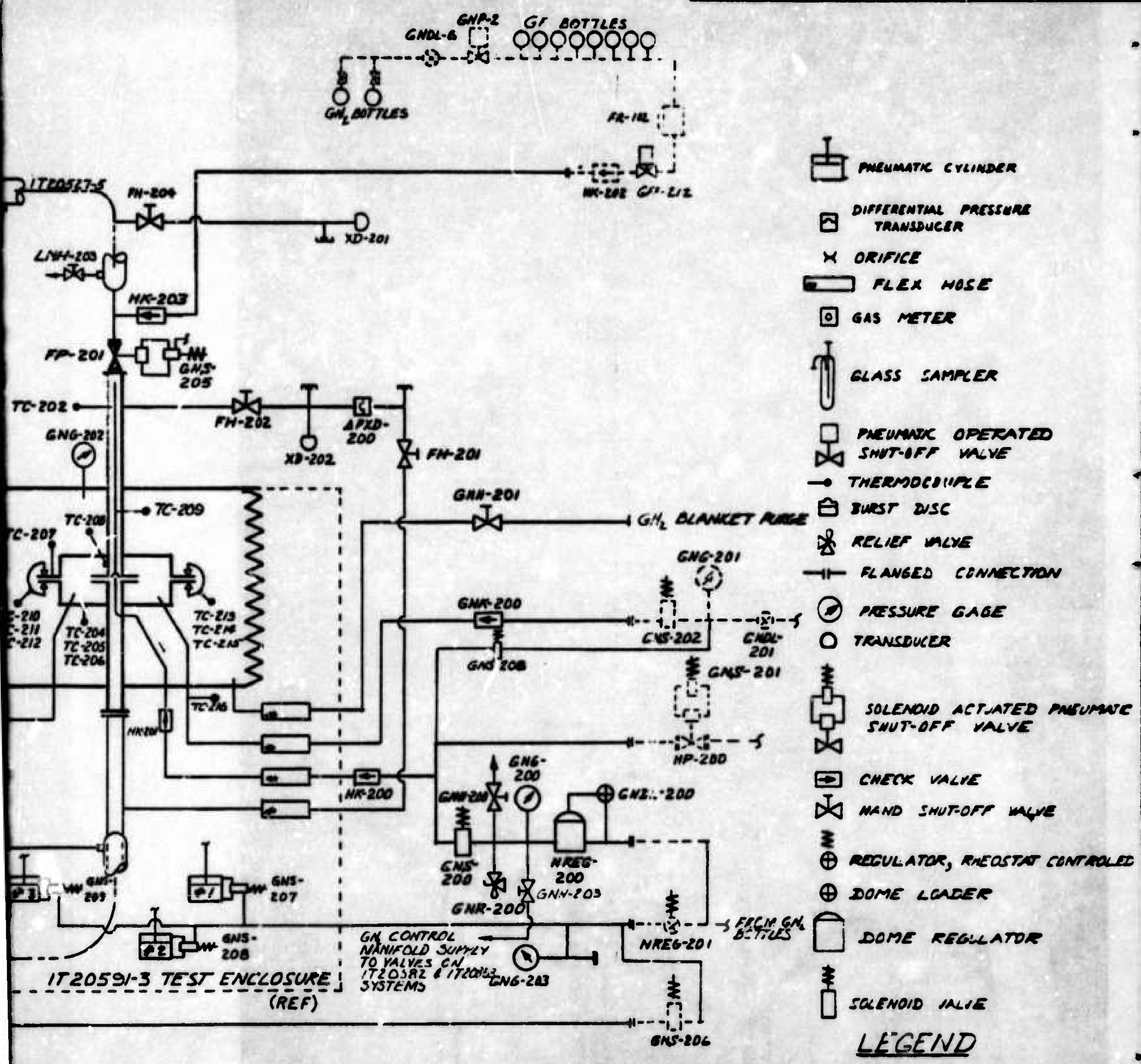
Figure 3-24. Douglas LF_2 Facility

Figure 3-25. LF_2 Test Setup

Figure 3-26. QD in LF_2 Test Setup


300 GAL RECEIVER TANK
FROM CONDENSER
TO CONDENSER
FP-11
FP-10
FP-9
FP-12
FP-14
BD-2
IT20527-5
LNH-201
LNH-203
IT20583 SYSTEM (REF)
TC-217
XD-201
GFP-206
GFO-1
GM-3
GFP-205
GFP-204
GFP-203
GFP-202
GFP-201
GFP-200
GM-2
C-5
C-4
C-3
C-2
C-1
FH-207
FP-201
TC-202
GNG-202
TC-208
TC-207
TC-210
TC-211
TC-212
TC-204
TC-205
TC-206
IT20582 SYSTEM (REF)
XD-200
GFP-210
GFO-2
GFP-211
GFP-209
GFP-208
GFP-207
GM-1
L-3
L-2
L-1
FH-206
LNH-202
FP-2
BD-201
500 GAL STORAGE TANK
TC-2
FP-1
LNH-200
GNS-203
IT20527-3
FP-200
IT14894-1
IT20591-3
TC-203
NP-200
LNH-100
BD-200
GNS-204
VP-200
TC-201
GNH-202
TO DOWNSTREAM SIDE OF VP-7 (FACILITY VENT LINE)

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED
NEW	INITIAL RELEASE		
A			
B			



MATERIAL	FINISH
SEE ENGINEERING RECORDS FOR USAGE DATA	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.

TOLERANCES
FRACTIONS ± ~
DECIMALS ± ~
ANGLES ± ~

MAT'L	
WT CHK	
STR CHK	
CHECK	
PR ENGR	
DES ENGR	
GR ENGR	
PREP BY	R. WARE

FIRST RELEASE OF PRINTS
ORIGINAL DATE OF DRAWING
DESIGN ACTIVITY APPROVAL
CUSTOMER APPROVAL

DOUGLAS AIRCRAFT COMPANY, INC — SANTA MONICA, CALIFORNIA

SCHEMATIC, FLUORINE TEST SETUP, LF_2 CD

CODE IDENT NO	SIZE	
18355	D	IT20581
SCALE		SHEET 1 OF

Gaseous nitrogen was swept through the seal cavity of the QD to the 1T20583 Seal Leak Measurment System. Further discussion of this system is found in Section 5.2.2.3.

Gaseous helium and nitrogen were supplied to the QD purge port and used in the pressurized draining and purging of the QD and flexline following liquid flourine transfer. The fluorine was drained and purged through valves FP-200 and VP-200, respectively. More detail is found in Section 5.2.2.7.

5.2.2.2 Temperature, Pressure and Flow Measurements

Temperature and pressure measurements were from direct sensing elements within the system, while flow rate was not directly measured but was calculated from other measured data. Pressure was sensed by bellows/potentiometer type pressure transducers and recorded on a Honeywell recording oscilograph in the control trailer.

Temperatures were measured using copper-constantan thermocouples. Where fluid temperatures were measured, the thermocouple was embedded in the tip of a stainless sheath which encapsulated the lead wires and prevented their exposure to fluorine. The resulting temperature probe was then inserted through a swagelock fitting, mounted on the QD, such that the tip of the probe was positioned in the fluid whose temperature was to be measured.

Temperature measurements external of the fluorine system were obtained by using resistance bonded copper-constantan thermocouples. These were the same thermocouples as were used during the liquid nitrogen testing described in Section 5.2.1.2. The emf generated by each couple was recorded on a L&N Multipoint Temperature Recorder which was located within the Control Trailer.

Flow rate ($\dot{w}$) determinations were calculated from differential pressure (ΔP) measurements between the top and the bottom of the fluorine supply tank as a function of time (t) during fluorine transfer. The relationship between ΔP, $\dot{w}$ and t is:

$$\dot{w}_{0-1} = \frac{w_0 - w_1}{t_1 - t_0}, \quad \text{and } (w_0 - w_1) = f(\Delta P_0 - \Delta P_1),$$

for the supply tank. $\dot{w}$ is the average value of flow rate from the time designated by t_0 to the time corresponding to t_1.

Differential pressure measurements were obtained by using a Statham Model PM280TC differential pressure transducer. The output of this transducer was displayed in the Control Trailer on a califbrated millivolt meter where periodic visual readings were taken and recorded.

5.2.2.3 Leak Detection and Measurement

Fluorine leak detection and measurements were made using two wet-chemical analytical methods. In each case, any fluorine leaking past the primary coupling seal is swept from the QD seal cavity (see Figure 3-27) by gaseous nitrogen, and the mixture is bubbled through an absorbing wet-chemical contained in the glass samples of the 1T20583 Leak Measurement System. The system is so sized and calibrated to absorb all the leaking fluorine.

Method number one is based on the ability of the fluorine (F_2) to oxidize methyl red. As the oxidation process takes place, the absorbing methyl red solution undergoes a color change from red to colorless. Using a previously calibrated system (purge gas flow rate and mass of methyl red given), the average seal leak rate at any given time can be determined by noting the time required to decolorize the methyl red absorbing fluid. To ivestigate the efficiency of this technique, five solutions of varying concentrations of methyl red were prepared and standardized with chlorine. F_2 - N_2 gas standards were used to check the standardization. The flow rate was set at 10.5 cc/sec on the rotometer and the time required to decolorize the solutions was measured. Using 100 ml of solution in the C type bubbler and 500 ml in the L type impinger, good agreement between prediction and test was obtained for the amount of F_2 gas required to decolorize the solution. Fluorine absorption was accomplished with 90% efficiency.

The second method uses colorless sodium hydroxide (NaOH) to react with the fluorine. The reaction results in the formation of sodium fluoride the quantity of which can be measured in the laboratory following each test. By knowing the concentration and quantity of NaOH, and the quantity of purge gas passing through the NaOH for a given time interval it is possible to calculate the amount of fluorine leaking past the primary seal for that time interval. Using 0.01 M NaOH to absorb the fluorine, 100% scrubbing efficiency was obtained.

Method one (methyl red) was used in conjuction with the primary seal leakage measurement system to detect gross leakage. If during the first 60 seconds of fluorine transfer through the QD there was no detectable color change in the methyl red solution, the seal cavity purge gas was redirected to flow through a NaOH absorber for the remainder of the test. Seal leakage was determined by post-test analysis of the NaOH.

In later flow tests, the methyl red solution was eliminated altogether, and two NaOH absorbers were utilized to gather seal leakage data during transient (0-60 sec) and steady state (60 sec to end of test) test conditions.

5.2.2.4 Sealing Load Measurments

Sealing loads were set at the 100% design point prior to each fluorine test. This pre load was determined by using the built-in 100% load indicators as described in Section 5.2.1.4.

During each test the load variations were monitored using the built-in strain gages in much the same manner as during the non-fluorine testing (Section 5.2.1.4). The measured stains were recorded on the Honeywell recording oscillograph located in the Control Trailer.

Direct deflection measurements of the flat washer springs were not possible during fluorine testing, as the toxic and reactive nature of fluorine restricts personnel from systems and components undergoing fluorine testing.

5.2.2.5 Engagement and Latching

The aluminum L-shaped test box, Figure 3-26, was used to rigidly support the vehicle-half of the QD coupling. The AGE-half remained unattached, except through its flexible transfer line, to the test box, and could thus be engaged with the vehicle-half without restriction. Except for the noted differences in test setups, engagement and latching of the QD was accomplished in the same manner as during the non-fluorine testing as specified in Section 5.2.1.5.

5.2.2.6 Release and Separation

Evaluation of the quick-release and separation characteristics of the coupling following several exposures to liquid fluorine were made using the separation guide and support fixture described in Section 5.2.2.1. Two separate pneumatic cylinders were used in this test, one for release, and one for separation. These are shown schematically in Figure 3-27 of Section 5.2.2.1.

Release was accomplished by slowly increasing the pressure to the release cylinder by adjusting the remote controlled pressure regulator, NREG-201, until the release mechanism functioned. The release pressure was determined from GNG-203.

Following release, the separation system was activated by pressurizing the separation actuator. The discharge port of this actuator was restricted to result in a separation rate of approximately 0.5 ft per second. By so doing, the 100 frames per second motion picture coverage resulted in good QD motion definition during both release and separation. The camera was located above and at a slight angle to the coupling, with a field of view approximately that shown in Figure 3-26.

5.2.2.7 Drain and Purge

Draining and purging of the QD and the attached five foot flexible transfer line was effected by first using gaseous helium (GHe) to force some of the liquid back into the supply system, followed by a gaseous nitrogen (GN_2) purge to scavange the remaining fluorine and discharge it through the facility vent system. The QD and the flex line are contained in the same horizontal plane, except for the natural droop of the flex line between its end and mid-section support points. A drain and vent port is provided on the bottom of the line at the end of the flex hose away from the QD and adjacent to the fluorine supply shutoff valve FP-200. The GHe and GN_2 used for draining and purging are supplied to the system through the QD purge port. This test setup is shown in Figure 3-25 and 3-27.

At the beginning of the purge and drain process, the liquid nitrogen jacket on the flexline is purged of all liquid nitrogen. This ambient temperature GN_2 purge continues throughout the fluorine purge and drain operation, adding heat for vaporization of the liquid fluorine.

The time required to drain and purge the QD-flexline combination of liquid fluorine was investigated by: (1) measurement of temperature changes followed by continued increase in the temperature of the fluid being discharged through the drain and vent systems, and (2) periodic measurment, during the drain and purge process, of pressure rise rate within the QD-flexline combination when physically isolated from all external pressurizing and venting systems. The presence of liquid fluorine in the system results in a rapid pressure rise, in sharp contrast to a slow pressure increase caused by gradual warming of the entrapped gas.

Gaseous fluorine remaining in the system had its concentration continuously reduced by continuing the GN_2 purge following liquid removal. The rate at which this concentration diminished was determined through the periodic sampling of the effluent purge gas and measuring the percentage fluorine in the sample. This operation was accomplished by closing the purge and drain valve VP-200, and ducting the purge gas (GN_2 - GF_2 mixture) through a 1/4 inch stainless steel line to the 1T20582 Fluorine Concentration measurement system shown in Figure 3-27. The purge gas mixture is bubbled through one of three methyl red solutions, contained in glass samplers, and the fluorine is absorbed by the methyl red.

This is the same chemical process which was described in Sectiob 5.2.2.3, and as noted therein, the time required to decolorize the methyl red is indicative of the quantity of fluorine absorbed. Thus, by knowing the purge gas flow rate and the time required to decolorize the methyl red, it is possible to calculate the concentration of fluorine in the purge gas. By using three different concentrations of methyl red in each of three samplers, it was possible to provide a measuring system sensitive to a wide range of fluorine concentrations 10 ppm to greater than 10,000 ppm. Sampling times should be greater than 10 seconds to assure a reasonable degree of accuracy, but little is gained by exceeding 60 second intervals. With the longer sampling times, the color change is more gradual and thus it is more difficult to detect the exact time the solution became colorless.

5.2.2.8 Anti-Icing Shroud

The anti-icing shroud was purged of all air and moisture prior to and during fluorine flow tests with low pressure gaseous nitrogen (GN_2), which was provided from the 5 psig Facility Blanket Purge System. This arrangement is shown schematically in Figure 3-27. The purpose of the purge was to surround the QD coupling with a dry atmosphere, thus preventing moisture from condensing and freezing on the coupling during fluorine transfer. The effectiveness of this purged shroud to preclude moisture was determined by simply removing the shroud from the QD shortly following fluorine transfer test, and visually determining the existence of non-existence of frost, ice or condensed moisture on the QD or in the bottom of the shroud. These areas should be completely free of all such indications if the anti-icing shroud has effectively performed its function.

5.3 Test Results and Analysis

5.3.1 Non-Fluorine Tests

Pre-fluorine readiness tests on the first test model (1T20586-1) and design evaluation tests on the second test model (1T20586-501) were conducted in a temperature controlled room in the Materials Research Laboratory at Douglas location A in Santa Monica. The control temperature for the room was 72°F. The test models were supported in a wooden test fixture (1T21035-1) and the setup of experimental equipment was as noted in Section 5.2.1. The primary test fluids were gaseous and liquid nitrogen and gaseous helium.

5.3.1.1 Pre-fluorine Readiness Tests

After the first test model (1T20586-1) had been installed in the test fixture with the necessary instrumentation and checked out, a series of tests were run to determine its leakage characteristics. Initially an attempt was made to determine the primary seal leakage by gas chromatography at both ambient and cryogenic temperatures. The experimental setup used is shown in Figure 3-21.

Helium was used as the sweep gas, and the seal cavity was attached to the gas chromatograph in the position normally occupied by a gas sampling loop. This allowed the seal cavity helium flow to be interrupted for any desired period of time so that fluid leaking into the seal cavity could accumulate. After some waiting period, the sampling valve on the gas chromatograph was switched, sweeping the contents of the seal cavity into the gas chromatograph. The molecular sieve column separates oxygen and nitrogen, so that it is possible to identify whether any gas found came from the main line of the QD which was filled with N_2, or from atmospheric leakage.

Leakage from the secondary seal and the three AN fittings with Teflon O-rings attached to the seal cavity was found to be much greater than leakage through the primary seal. This made it necessary to install a shroud purged with argon around the entire QD. Under these conditions, and with the inner line at 100 psig and the seal cavity at 25 psig, the leakage through the primary seal was found to be very low both at ambient and at LN_2 temperatures. In no case was it large enough to be detected by the gas chromatograph which had a lower limit of detection under the conditions of the test of approximately 1.2×10^{-5} scim. Therefore, the leakage was no greater than that value at LN_2 temperatures and probably it was even less at ambient temperatures. A qualitative test of the primary seal leakage at ambient temperatures was also performed; with 15 psig helium in the seal cavity, it was found that there was no detectable increase of helium in the main cavity of the QD, using the CEC helium leak detector as the measuring instrument.

Testing of the secondary seal and the AN fittings was done using a CEC helium leak detector, and the overall leakage was found by measuring the pressure decay in the seal cavity, after it had been pressurized to approximately 30 psig with helium. It was found that at ambient temperatures the leakage was extremely low, less than 10^{-3} scim but as the assembly was cooled, leakage increased to more than 10^{-1} scim.

The results of the first LN_2 chilldown test are shown in Figure 3-28. It may be noted that the 1T20586-95 anti-icing shroud was not installed on the first three tests. As the QD cooled the seal cavity pressure dropped gradually until the adapter temperature reached approximately 0°F, then started dropping at a much more rapid rate. At -80°F adapter temperature gross leakage occurred and attempts to repressurize the cavity at this temperature were futile. The LN_2 flow was shut off when the adapter temperature reached -120°F. As the QD warmed up periodic attempts were made to repressurize the seal cavity. When the adapter had warmed to approximately -20°F the cavity resealed with only a moderate leak rate remaining.

By use of the CEC helium leak detector it was found that the greatest leakage paths were past the S0046T10 Teflon O-rings used as seals on three 1/8 inch diameter AN815-2C fittings utilized to attach the two seal cavity purge lines and a seal cavity pressure monitoring line to the QD adapter. For the second chilldown test two Teflon O-rings were installed on two of the AN815 fittings and a flat Teflon gasket handmade from 1/16-in. thick sheet was installed on the third AN815 fitting. Another variation from the first test was that the vehicle-half mounting plate (PN 1T20586-11), an 18-in. square by 1/4-in. thick aluminum plate, was removed. This plate was a large capacity heat source and without it the adjacent hardware cooldown rate increased appreciably. The results of the second test are shown in Figure 3-29. The supply of LN_2 available for this test was exhausted when the adapter reached approximately -100°F. An appreciable improvement in the rate of seal cavity leakage compared to the first test may be noted, however, the CEC helium leak detector indicated that the major source of leakage was still at these AN fitting seals.

Prior to the start of the third test style AR1091 Omniseals made of Teflon (TFE) were installed on two of the AN815 fittings and a flat 1100-0 aluminum seal handmade from1/16-in. thick sheet was installed on the third AN815 fitting. The 1T20586-11 aluminum mounting plate again was not installed for this test. The results of the third test are shown in Figure 3-30. The seal cavity pressure had decayed form 30 psig to 5 psig by the time the adapter had cooled to approximately -225°F. At this point the cavity was repressurized to 30 psig and it decayed at a very rapid rate as the QD was chilled until the adapter stabilized at approximately -300°F. During this test it was determined with the CEC detector that the soft aluminum seal sealed much more effectively than the Teflon Omniseals. Also, it was found at the lowest temperatures that the large AR10105-234 A1Q Omniseal used as the secondary seal to contain the purge flow through the seal cavity was indicating a marked increase in leakage at the -300°F temperature as compared to ambient temperature. Although it was not possible to make an accurate determination of leakage past the secondary seal at cryogenic temperatures, the leakage was qualitatively estimated (from readings on the CEC leak detector) to have increased by a factor of 400 to 500; to approximately 10^{-1} SCIM leakage.

For the fourth test handmade 1/16-in. thick 1100-0 aluminum gaskets were installed on each of the three AN815 fittings and the 1/4-in. thick aluminum plate (PN 1T20586-11) was reinstalled but the anti-icing shroud (PN 1T20586-95) was not installed for the initial part of the test. The results of the first phase of the test are shown in Figures 3-31 and 3-32. Temperatures were

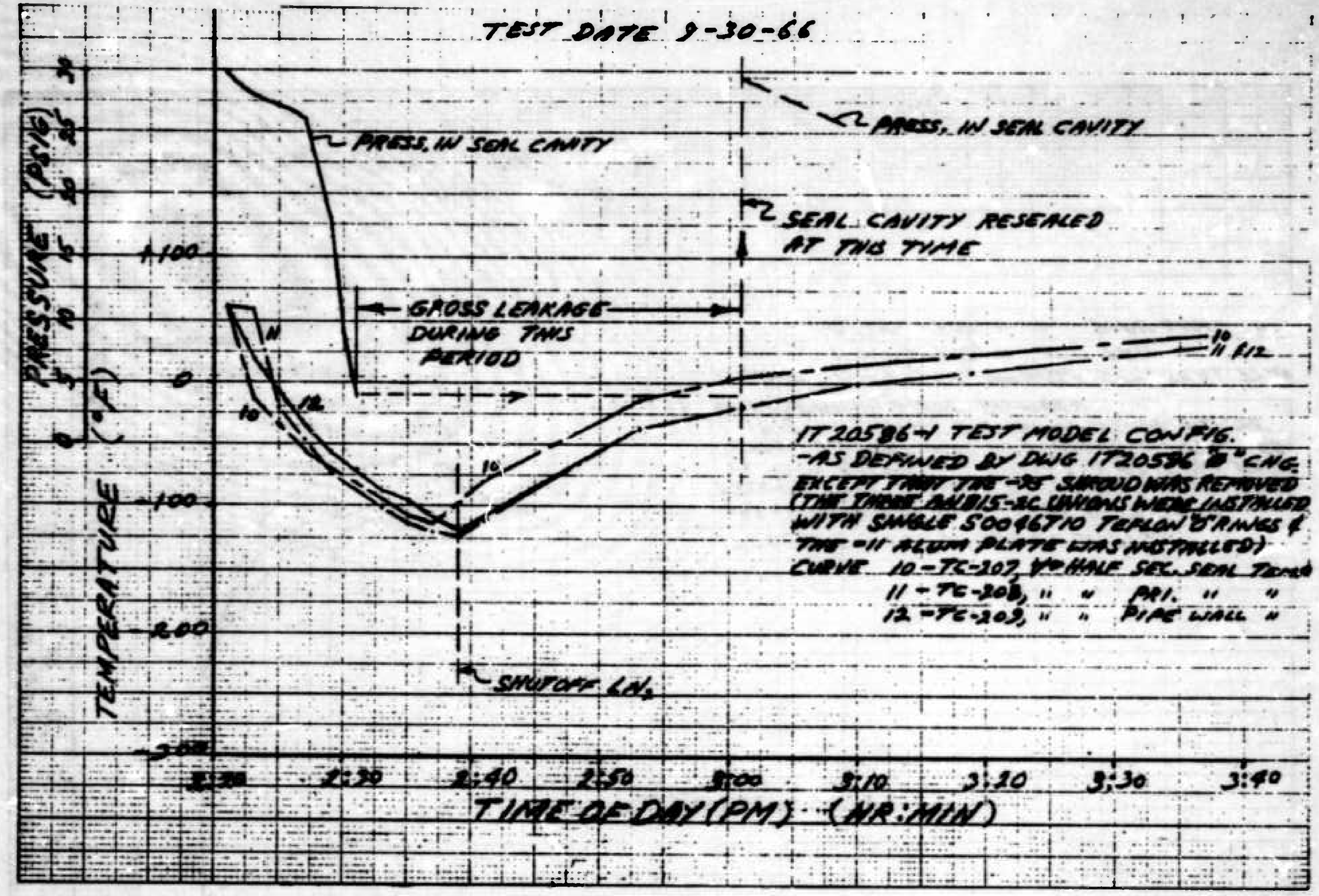
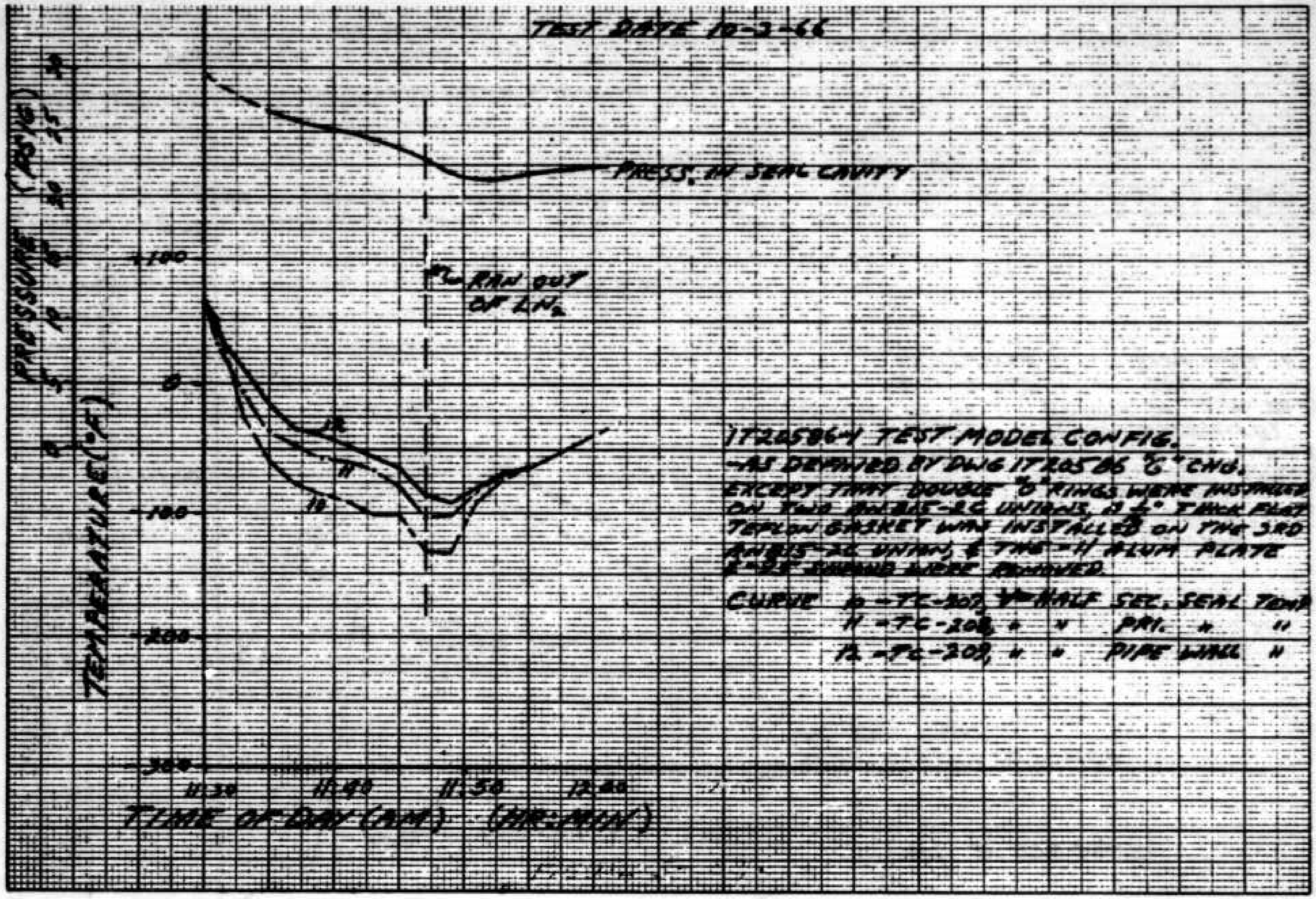
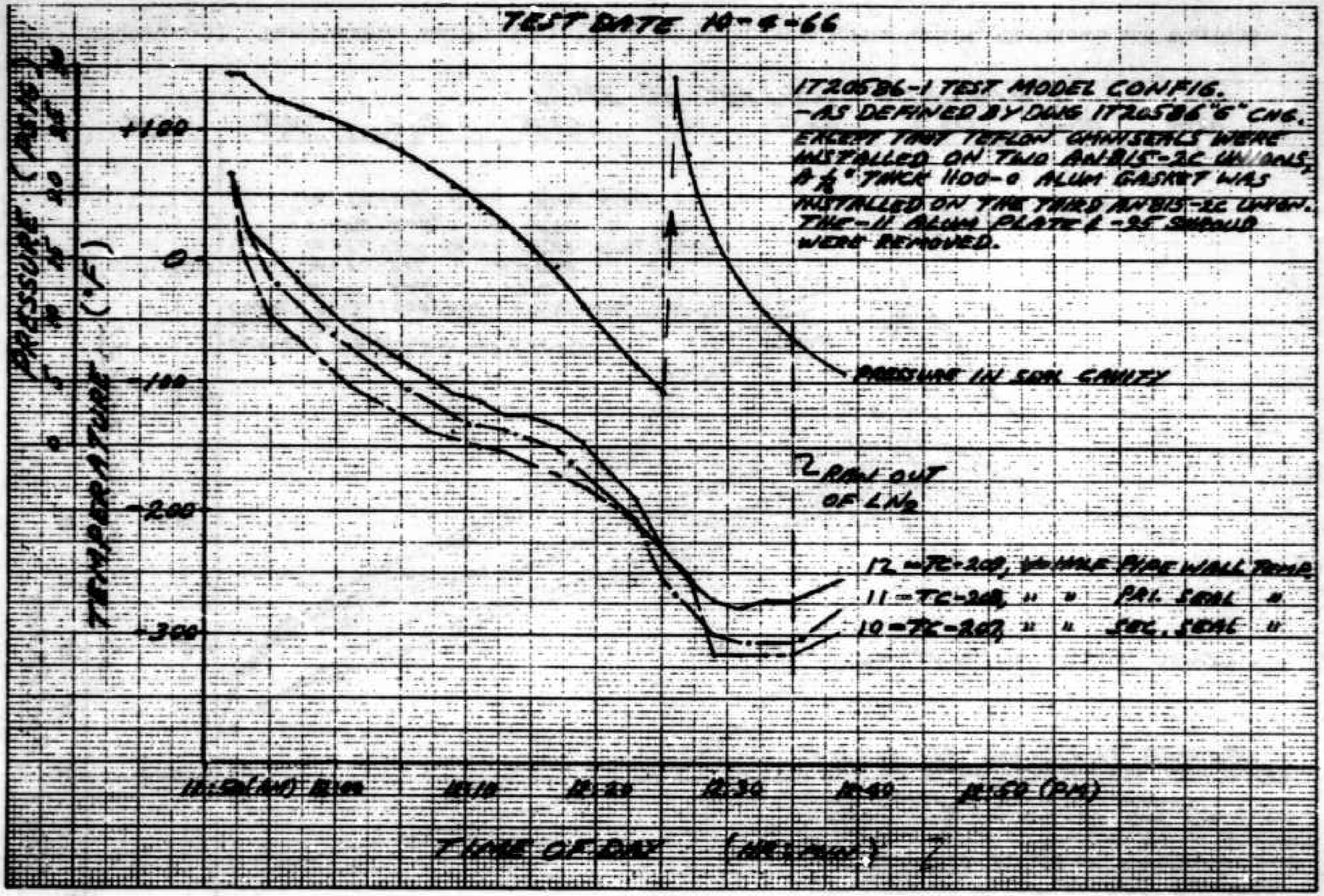


Figure 3-28. Inner-Seal Cavity Sealing Characteristics During QD Childown With LN_2 and Subsequent Warmup



TEST DATE 10-3-66
PRESS. IN SEAL CAVITY
#3 RAN OUT OF LN2
1T205864 TEST MODEL CONFIG.
CURVE 10 - TC-207, 1st HALF SEC. SEAL TEMP
11 - TC-208, " " PRI. " "
12 - TC-209, " " PIPE WALL "
TEMPERATURE (°F)
PRESSURE (PSIG)
+100
0
-100
-200
-300
11:30
11:40
11:50
12:00
TIME OF DAY (AM) (HR:MIN)


TEST DATE 10-4-66
1720586-1 TEST MODEL CONFIG.
-AS DEFINED BY DWG 1720586 "G" CHG.
EXCEPT THAT TEFLON GAMISEALS WERE INSTALLED ON TWO AN815-2C UNIONS, A 1/8" THICK 1100-0 ALUM GASKET WAS INSTALLED ON THE THIRD AN815-2C UNION. THC-11 ALUM PLATE & -25 SHROUD WERE REMOVED.
PRESSURE IN SEAL CAVITY
RAN OUT OF LN_2
12 - TC-209, WHALE PIPE WALL TEMP.
11 - TC-208, " " PRI. SEAL "
10 - TC-207, " " SEC. SEAL "
TEMPERATURE (°F)
PRESSURE (PSIG)
+100
0
-100
-200
-300
11:50 (AM)
12:00
12:10
12:20
12:30
12:40
12:50 (PM)
TIME OF DAY (HRS:MIN)

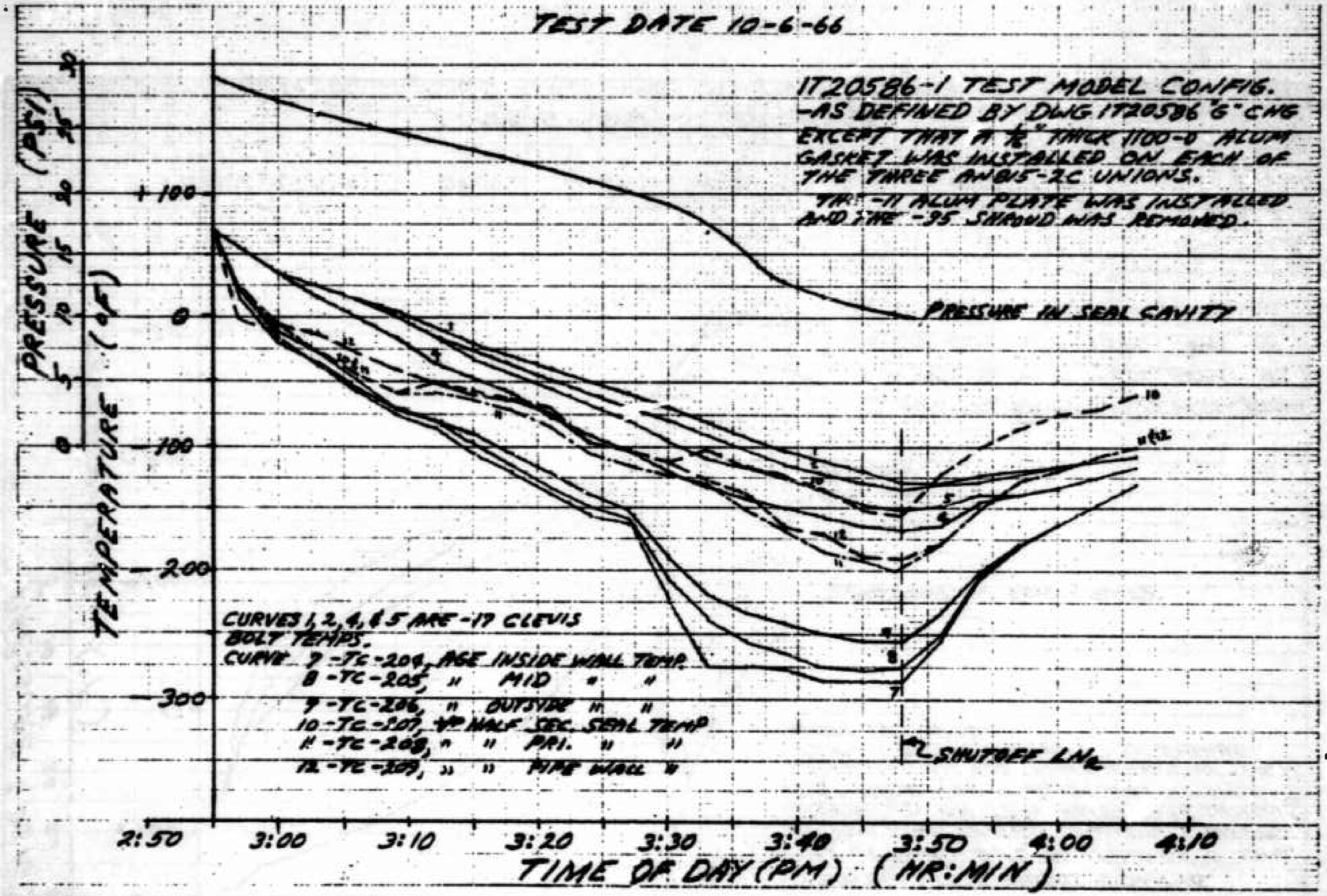


Figure 3-31. Temperature and Pressure-Time Relationships During an LN_2 Chilldown and Warmup

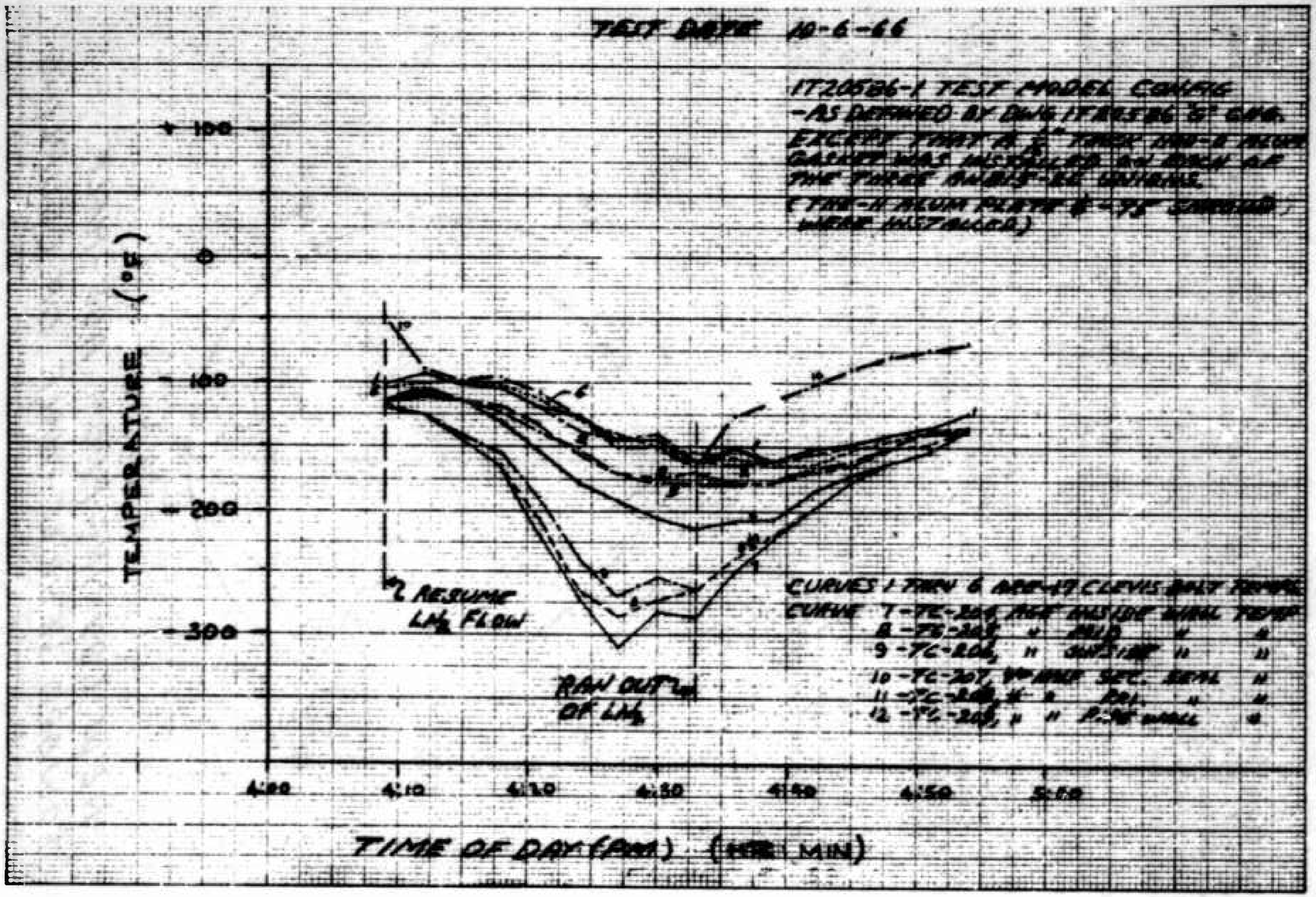


Figure 3-32. Temperature-Time Relationships during LN_2 Childown and Warmup

read at approximately 3-min intervals for each of the six seal loading clevis bolts and for the three instrumented points on each of the two QD adapters. It may be noted that the seal cavity pressure decay rate was much improved over that on the previous tests.

It was found that with aluminum gaskets on the fittings the leakage from the seal cavity was mainly due to the secondary seal. Calculations showed that the total leakage was less the 6 cc/minute. By using a purge rate of 600 cc/minute through the seal cavity less than 1% of the purge gas would escape into the shroud.

From the leakage tests that were performed, it appeared that there should be no problems either with leakage through the primary seal or with leakage through the secondary seal and the fittings on the seal cavity.

For the tests a latch position numbering system was devised and is shown in Figure 3-33. Any variations in the data attributable to the latch position on top, bottom, or side could thus be recorded. No load data was available for the loading bolt at position No. 1 (top) because one of its strain gages had an open circuit.

During the initial testing phase, load-deflection measurements were made on the seal loading springs 1T20586-39 & -97 at latch positions No. 2 through No. 6. The results are presented in Figures 3-34 through 3-38 where the curve for -39 represents two springs and the curve for -97 is for one spring.

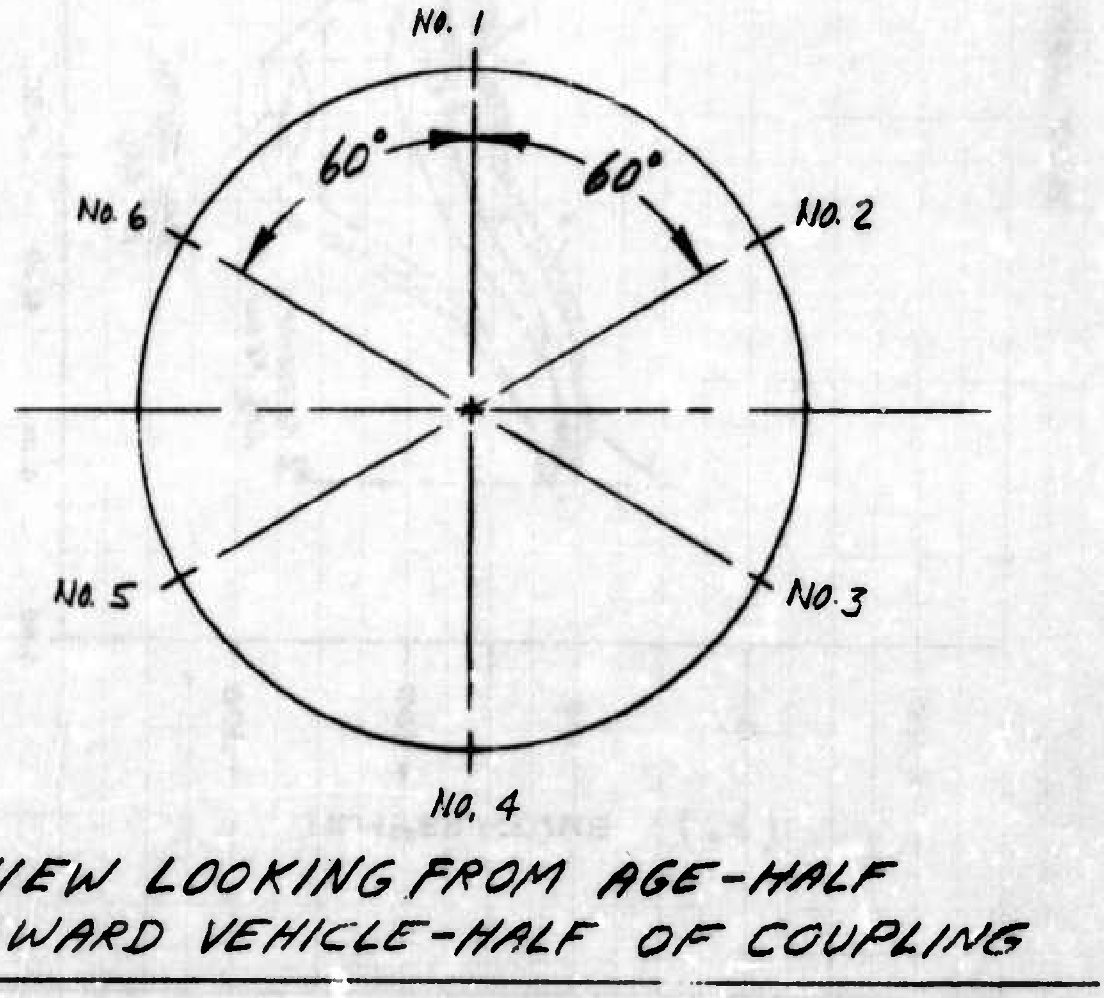


Figure 3-33. Latch (Bolt and Piston Numbering System for Models IT20586-1 and -501

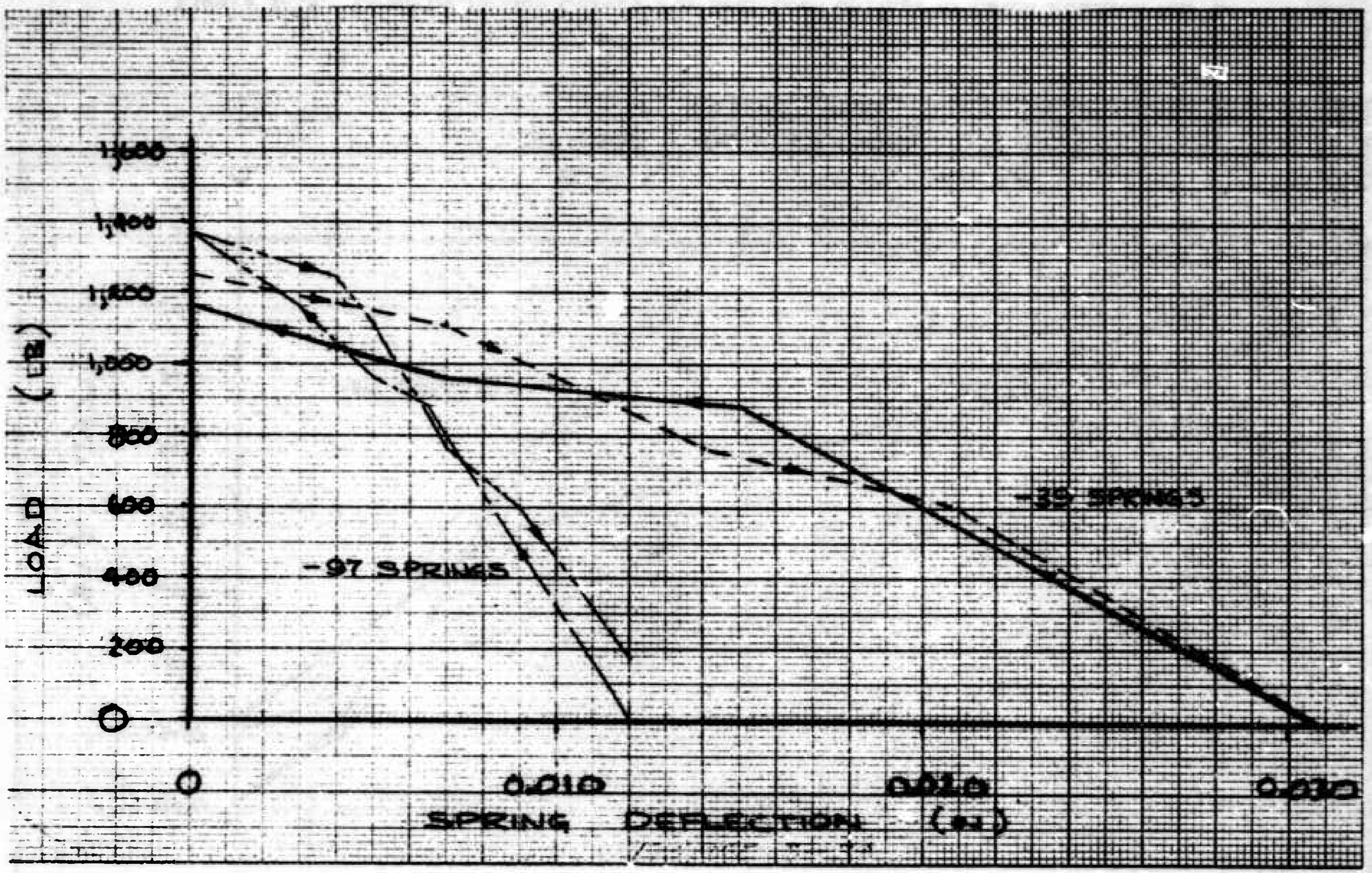


Figure 3-34. Load-Deflection Curves For Seal Load Springs at Latch Position No. 2

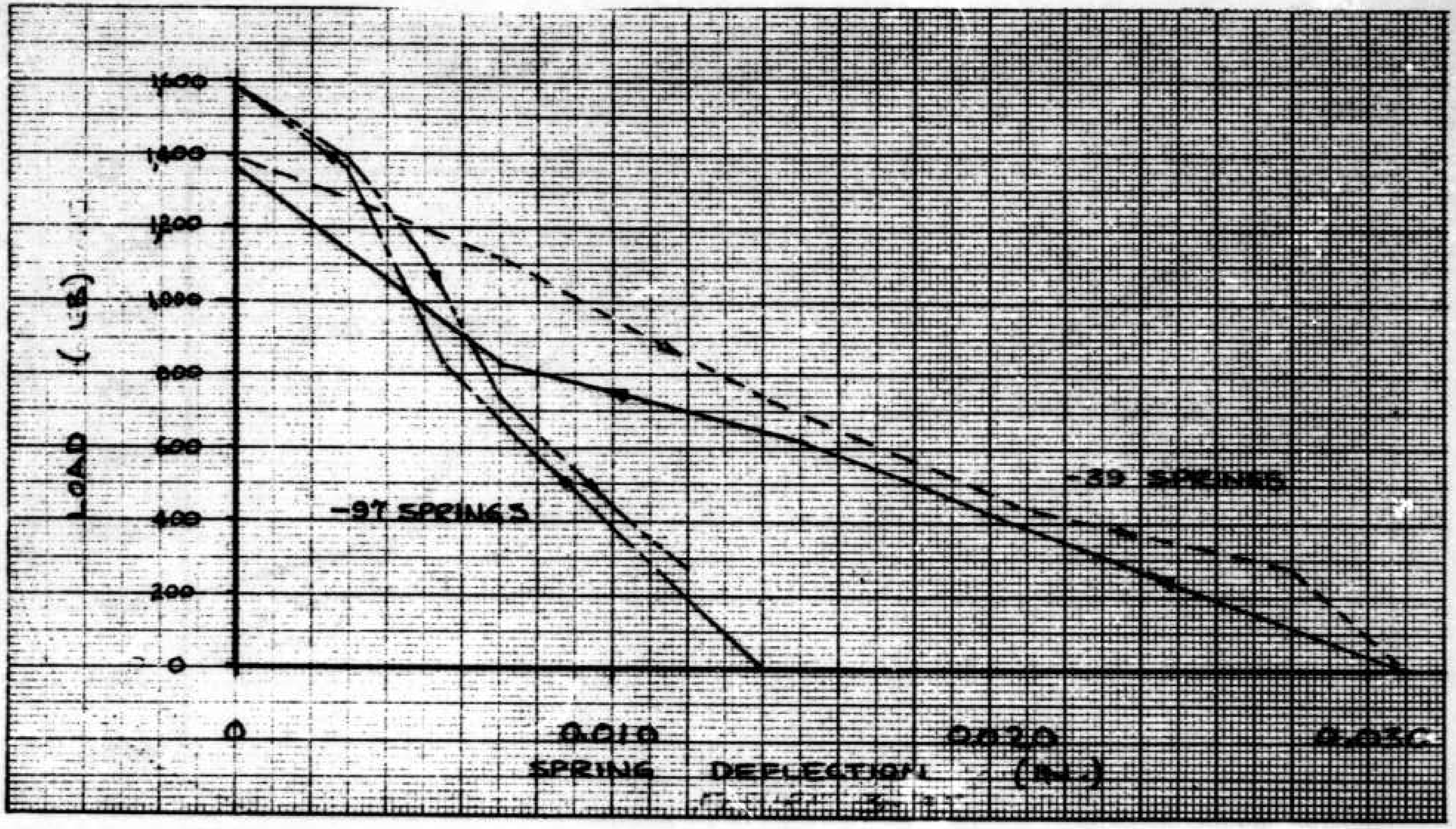


Figure 3-35. Load-Deflection Curves For Seal Load Springs at Latch Position No. 3

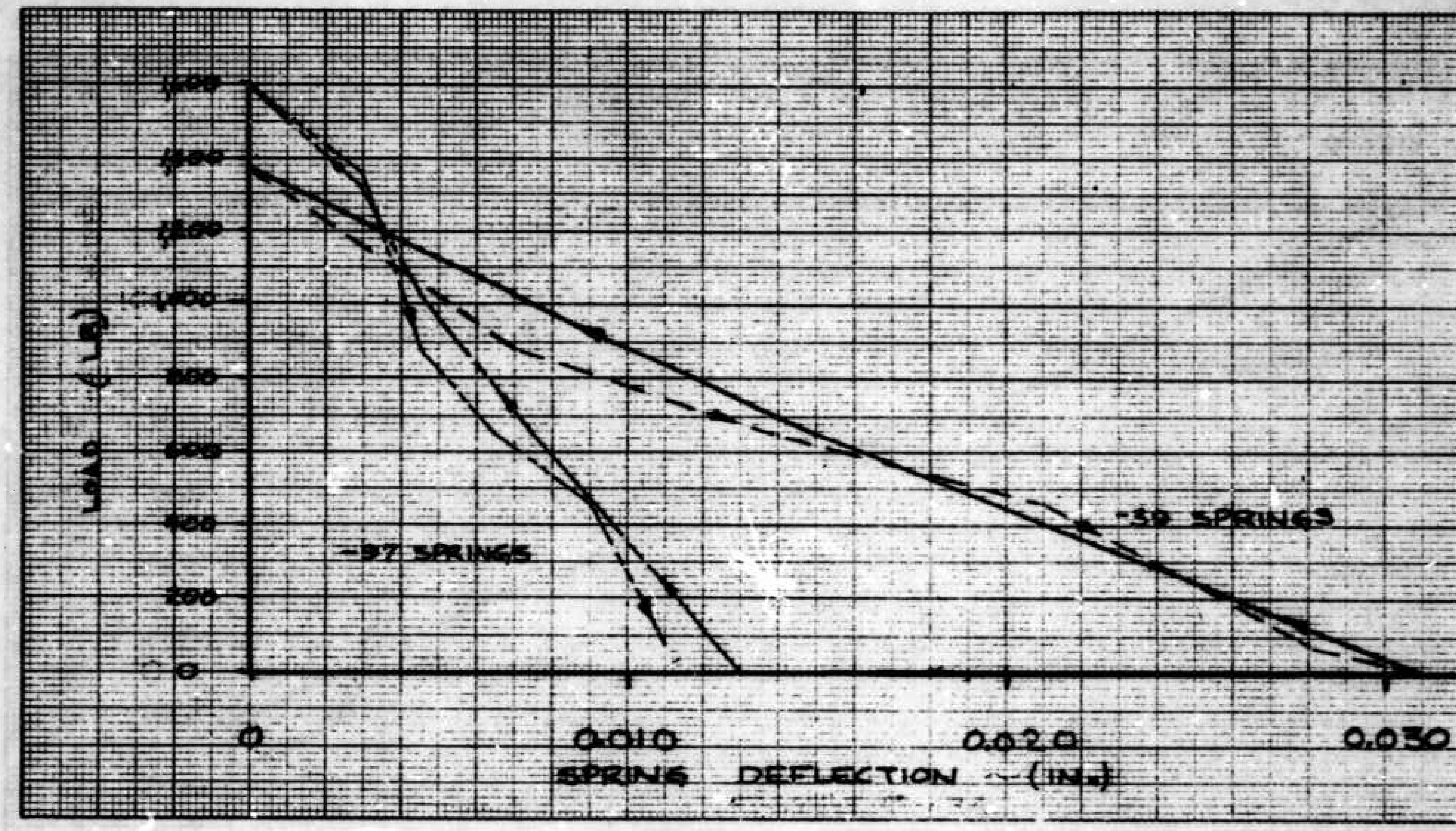


Figure 3-36. Load-Deflection Curves For Seal Load Springs at Latch Position No. 4

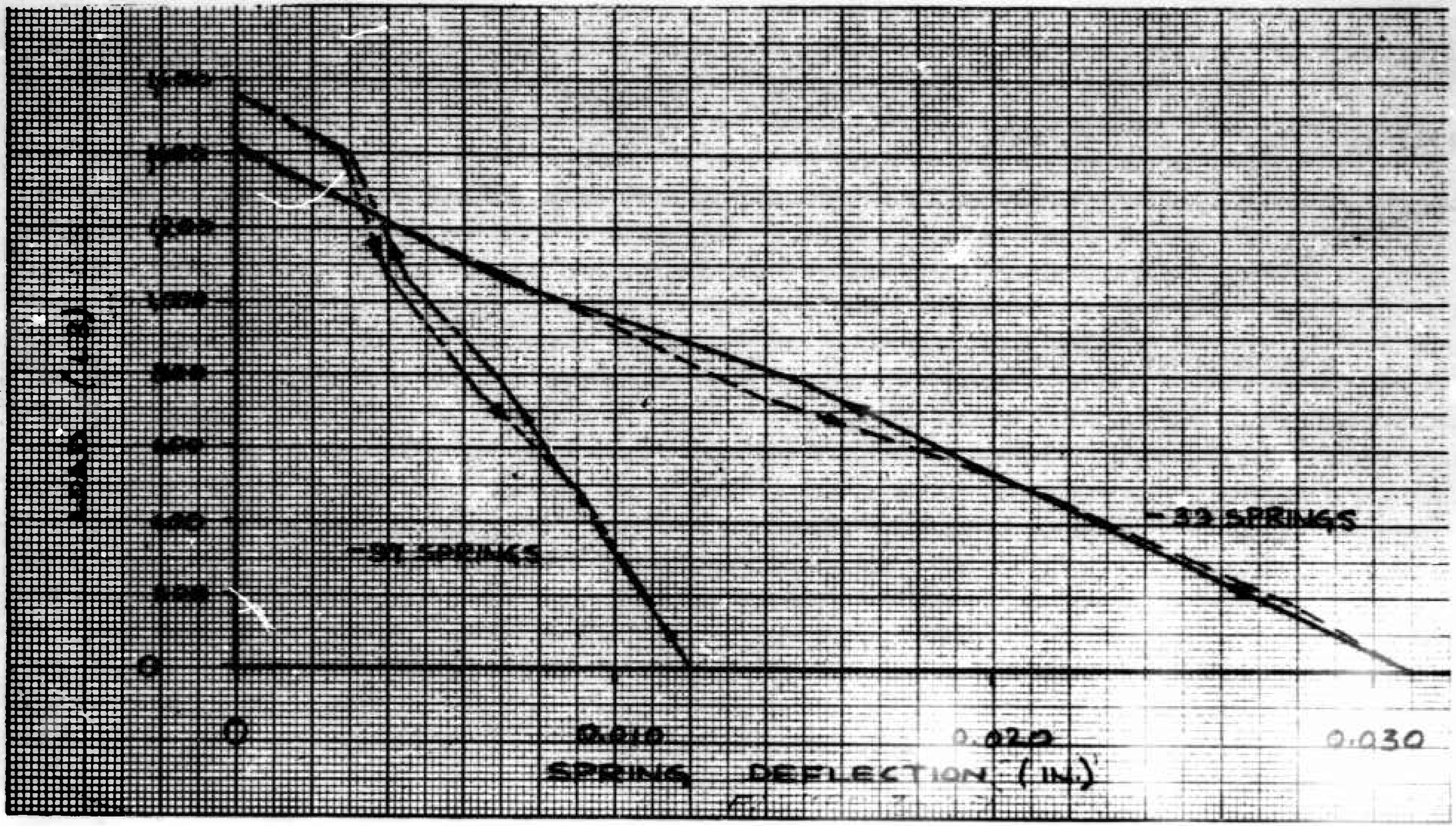


Figure 3-37. Load-Deflection Curves For Seal Load Springs at Latch Position No. 5

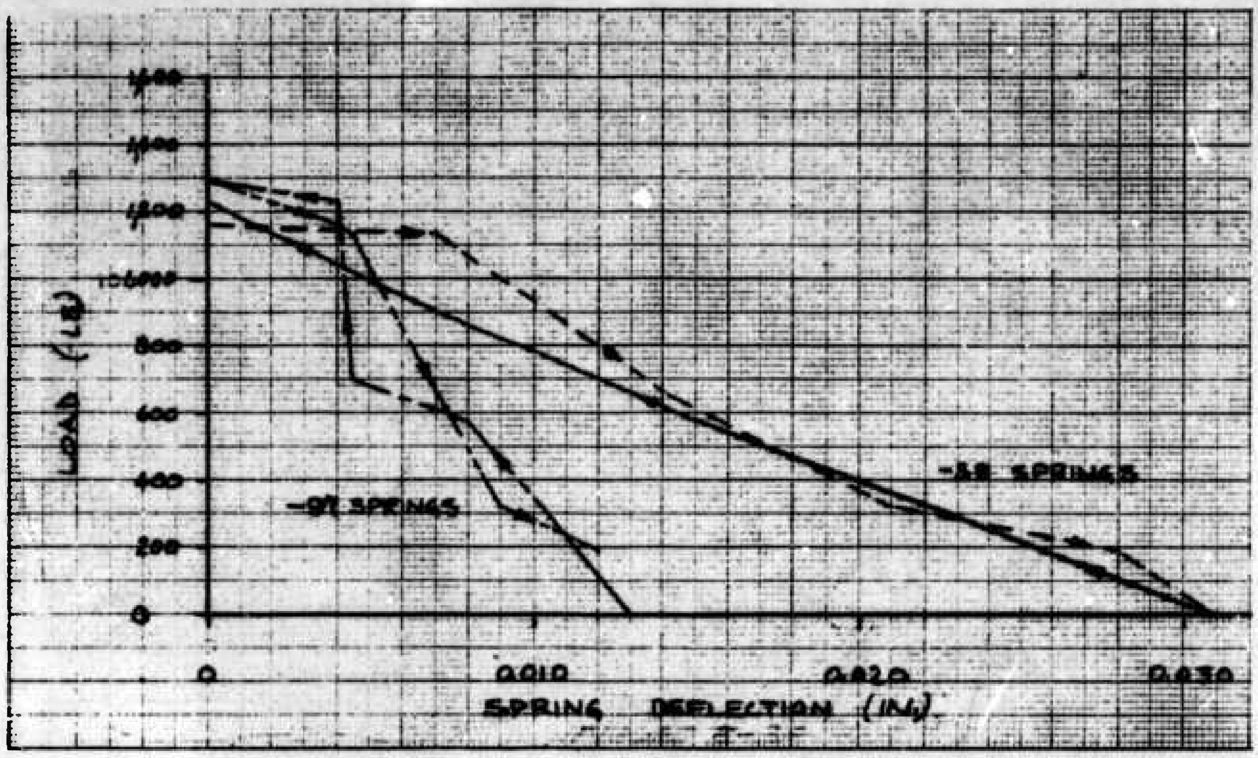


Figure 3-38. Load-Deflection Curves For Seal Load Springs at Latch Position No. 6

All of the springs were made of Inconel 718 material and were 1.550 in. diam. There are two -39 springs (0.100 ± 0.001-in. thick) and one -97 spring (0.122 ± 0.001-in. thick) at each position. The spring design is discussed in Section 3.3.2 and the installation arrangement is shown if Figure 3-15. The data was obtained at room temperature by applying the load with the nut on the 1T20586-17 clevis bolt, reading the load by means of the strain gages, and obtaining deflection by measuring the gap between the springs and adjacent components with a feeler gage.

During the LN_2 tests on the -1 test model seal, loading data was not recorded until the fourth and final test. On this test, strain readings were taken over a 22-min interval starting 5 min before stopping the LN_2 flow. It may be noted from the temperature data in Figures 3-31 and 3-32 that the minimum bolt temperatures are essentially coincident with termination of LN_2 flow and the bolts as well as the QD adapter hardware started to warm up immediately thereafter.

The bolt strain gage data was corrected for temperature effects and converted to load in pounds by use of the calibration curves previously made for the bolts and discussed in Section 4. The corrected data is shown in Figure 3-39 plotted versus real time to permit correlation with the bolt temperature data

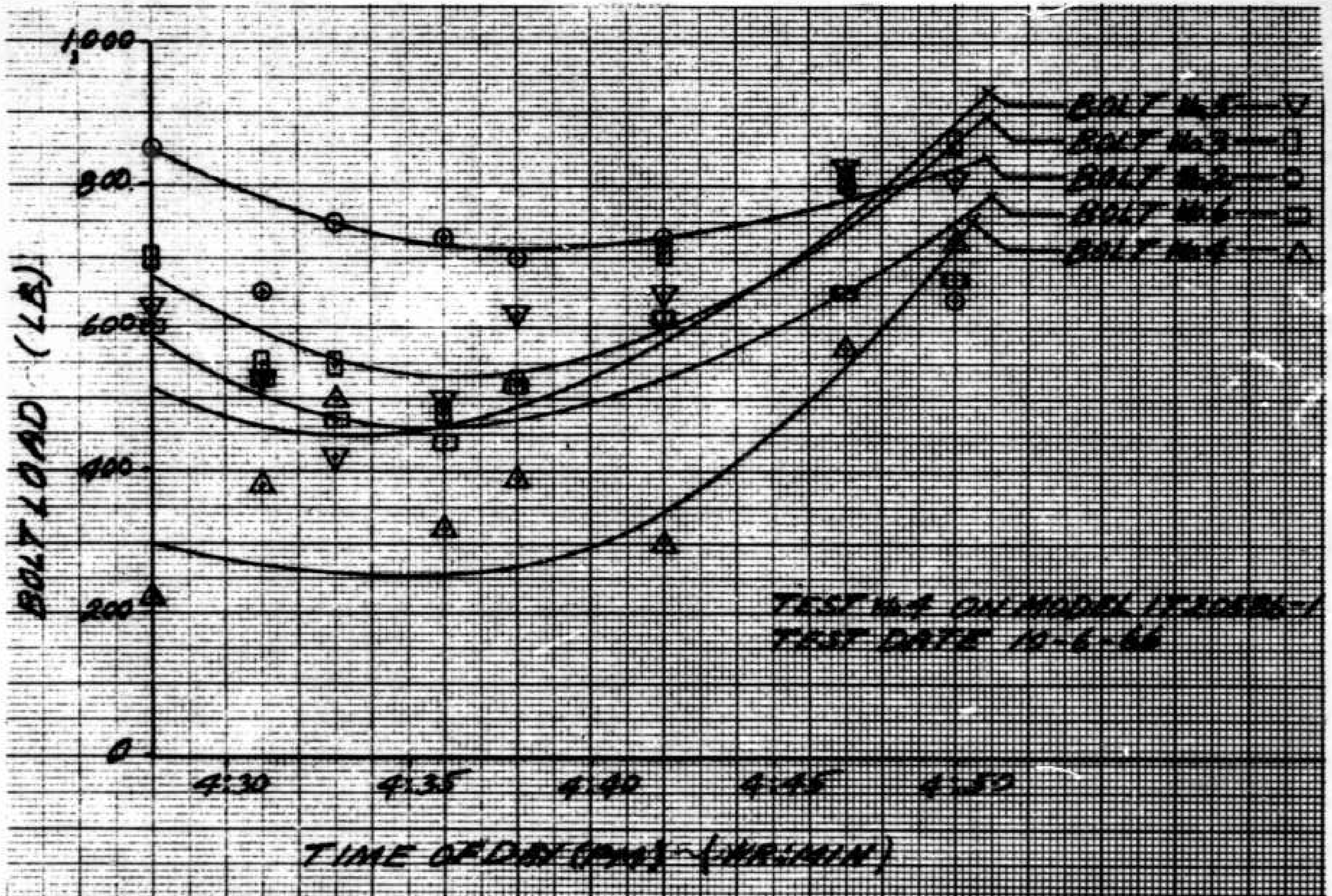


Figure 3-39. Load-Time Relationships During an LN_2 Chilldown and Warmup

in Figure 3-32. There was a considerable amount of scatter in the data points, however a set of faired curves were drawn to indicate the general trend and also to obtain a reasonable approximation of the minimum load value on the bolts.

The minimum bolt loads from Figure 3-39 are:

Bolt No.	Load (lb)
2	700
3	530
4	250
5	450
6	460

The lowest load, 250 lbs, occurred at position No. 4 (bottom) which was to be expected, since the temperaure data indicates that bolt to be the coldest. The bottom position was probably coldest because of natural convection currents around the outside of the unit causing the surrounding gaseous atmosphere to flow downward as it was cooled by contact with the cold metal components of the QD. Because of the great rigidity of the QD adapter flanges it is unrealistic to assume that the load applied to the seal varies with each individual bolt load. A better assumption is that the minimum seal loading occurring on the lower half of the seal is the average of the loads in the three bolts below the horizontal centerline, or:

$$\text{Average bolt load} = \frac{530 + 250 + 450}{3} = 410 \text{ lb}$$

In all of the LN_2 tests the bolts were loaded to the 100% design load of approximately 1,200 lb per latch at the beginning of the test. The final seal load is, then 410/1,200 or 34% of the initial load.

The bolt load and temperature data are plotted Figure 3-40 to show the effects of change in temperature on the bolt loads. Although the scatter in data points creates a rather wide band, the trend indicated by the two dash lines is a rather large change in load per degree temperature change (approximately 7 lbs/°F) in the temperature range shown.

During the testing the coupling separation was demonstrated several times by fracturing a shear pin with the separation actuator which consisted of a 2-in. diam, 3-in. stroke pneumatic cylinder with an effective piston area of 2.835 in.^{2}. Cylinder pressure was monitored on a Bourdon type gage as it was applied slowly to the cylinder through a manual vlave. On the first demonstration the primary seal was very lightly loaded (essentially zero load) and the observed pressure required to fracture the pin was 240 psig. For

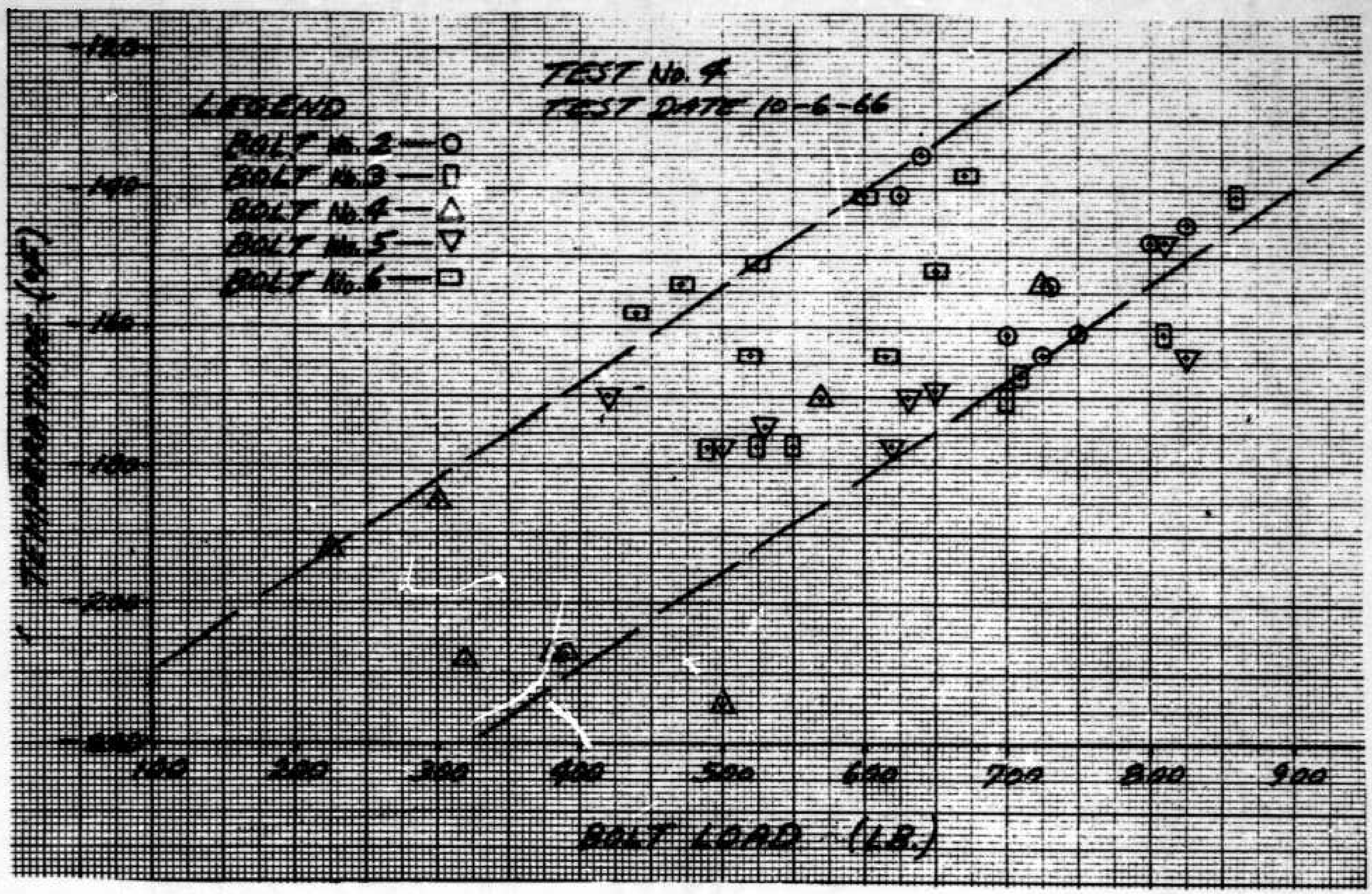


Figure 3-40. Variation of Bolt Loads With Temperature (Model 1T20586-1)

subsequent demonstrations the seal was loaded to the 100% design load and pressure readings ranging from 200 to 215 psig were observed at the instant of pin fracture. Converting these pressures to loads applied at the lever on the release cam (1T20586-45) gives the following results:

Cylinder Pressure	Lever Load
240 psig	680 lb
215 psig	610 lb

In Appendix VII the lever load required to fracture the shear pin was conservatively calculated to be 2,040 lb. Thus the actual release load required with no load on the seal is 680/2,040 = 33% of design load and with the 100% design load on the seal is 610/2,040 = 30% of design load. These results indicate that the 1.5 design factor and 1.0 coefficient of static friction used in the analysis were ultraconservative. Because of their high heat treatment condition the shear pins fractured in their reduced diameter shear sections with no evidence of yielding or distortion of either the pin or the pin bearing surfaces in the retaining links. The links opened readily and the AGE-half of the coupling disengaged from the vehicle-half, fell free, and was caught by a set of suspension chains. No external separation forces were required, the coupling weight was sufficient to effect separation after fracture of the shear pin.

The following significant results were noted from the temperature data recorded during the tests. On the AGE-half body the minimum recorded temperatures ranged from -310°F inside wall temperature to -269°F outside wall temperature. On the vehicle-half body the minimum recorded temperatures ranged from -210°F at the primary seal to -164°F at the flange on the outside of the seal cavity. The considerably warmer temperatures on the vehicle-half are a result of the heat transfer from the -11 mounting plate (1/4 in. x 18 in. x 18 in.). On one run with the -11 plate removed, the vehicle-half temperature was also reduced to below -300°F. The minimum recorded temperatures of the latch bolts, measured at the points where the strain gages are located, ranged from -214°F for the bolt on the bottom of the unit, to -161°F for the bolt on the top.

The results of these tests indicate that, due to the extremely small amount of leakage past the primary seal, testing with LF_2 could be safely accomplished. For the LF_2 tests the Teflon O-rings on the AN fittings must be replaced with soft 1100-0 aluminum gaskets.

5.3.1.2 Design Evaluation Tests

After completion of the pre-fluorine readiness tests on test model 1T20586-1, test model 1T20586-501 was installed in the test fixture and the series of design evaluation test specified in Section 5.1 was conducted. The results of these tests is presented in Table 3-2.

Table 3-2

MODEL 1T20586-501 QD COUF
(NON-FLUORINE DESIGN EVALU

Test				Seal Configuration				Test		
				Primary		Secondary				
No.	Date	* Objective	† Procedure	No. of Serrations	New Seal	Type	New Seal	Fluid	Press. Psig	Temp.
1	11-2	a, b, e	h-m	2	Yes	Omni	Yes	LN_2 GH_e	100	LN_2
2	11-3	a, b	n-t	2	Yes	Omni	Yes	LN_2 GH_e	100	LN_2
3	11-7	a, b, e	n-t	2	No	Omni	No	GH_e	30	Amb
4	11-8	a, b	u-aa	2	Yes	Omni	No	GH_e	30	Amb
5	11-8	a, b	u-aa	2	No	Omni	No	GH^e	11.5	Amb
6	11-8	a, b	u-aa	2	No	Omni	No	GH_e	30	Amb
7	11-8	a, b	u-aa	2	No	Omni	No	GH_e	30	Amb
8	11-8	a, b	u-aa	2	No	Omni	No	GH_e	30	Amb
9	11-8	a, b	u-aa	2	No	Omni	No	GH_e	30	Amb
10	11-8	a, b	u-aa	2	No	Omni	No	GH_e	30	Amb
11	11-8	a, b	ab-ad	2	No	Omni	No	GN_2	100	Amb
12	11-9	a, b	ab-ad	2	No	Omni	No	LN_2 GN_2	0 to 100	LN_2
13	11-11	a, b	ab-ad	2	No	Omni	No	GH_e	50 to 100	Amb

able 3-2

501 QD COUPLING TESTS

SIGN EVALUATION TESTS)

s.	Temp.	Latch Loads %	Notes On Installation	Results
	LN_2	100	QD axis horiz, chain supports used for alignment	Pri. seal leakage $< 6 \times 10^{-6}$ SCIM, both amb. & cryo. temps. Sec. seal leakage $< 7 \times 10^{-4}$ at amb., $< 10^{-1}$ at cryo. temp.
	LN_2	100	QD axis horiz, chain supports used for alignment	Pri. seal leakage $< 6 \times 10^{-6}$ SCIM, both amb & cryo temps Sec. seal leakage $< 7 \times 10^{-4}$ at amb, $< 10^{-1}$ at cryo temp
	Amb	100	Same as for #2 except 30 psig GH_e locked-up in seal cavity	0.2 psi in 1 hr pressure decay.
	Amb	50	Same as for #3	2.0 psi/min pressure decay rate
	Amb	56	Same as for #3 except 11.5 psig GH_e locked-up in seal cavity	10 psi/hr pressure decay rate
	Amb	63	Same as for #3	10.4 psi/hr pressure decay rate
	Amb	70	Same as for #3	4.4 psi/hr pressure decay rate
	Amb	75	Same as for #3	2.6 psi/hr pressure decay rate
	Amb	80	Same as for #3	0.9 psi/hr pressure decay rate
	Amb	85	Same as for #3	0.9 psi/hr pressure dec.., rate
	Amb	85	Same as for #2	Negligible leakage indicated by gas chromatograph.
	LN_2	85	Same as for #12	Negligible leakage--essentially same results as for tests #1 & #2
	Amb	85	Same as #12 except water displacement device connected to seal cavity	No bubble leakage from seal cavity was observed in 20 min.

Table 3-2.

Test				Seal Configuration				Test		
				Primary		Secondary				
No.	Date	* Objective	† Procedure	No. of Serrations	New Seal	Type	New Seal	Fluid	Press. Psig	Ten
14	11-11	a, b	ab-ad	2	No	Omni	No			An
15	11-11	a, b, e	ab-ad	2	No	Omni	No	---	---	An
16	11-11	a, b, d	ae-af	2	Yes	Omni	No	GH_e	50	An
17	11-11	a, b	ae-af	2	No	Omni	No	GH_e	50	An
18	11-11	a, b	ag-ah	2	No	Omni	No	LN_2 GH_e	50	LN
19	11-15	a, b	ai	2	No	Omni	No	LN_2 GN_2	10 & 100	LN
20	11-15	a, b	ai	2	No	Omni	No	LN_2	10	LN
21	11-15	a, b	ak-ao	2	No	Omni	No	LN_2	10	LN

ble 3-2. Continued

Test Press. Psig	Test Temp.	Latch Loads %	Notes on Installation	Results
	Amb	85	Test fixture rotated 90° to put vehicle-half of QD UP.	No leakage measurements were made--no significant change in bolt strains noted.
---	Amb	85	Test fixture inverted from position of tests 1 thru 13.	No leakage measurements were made--no significant change in bolt strains noted.
0	Amb	≅85	Same as #15, chain supports used for alignment.	No bubble leakage from seal cavity in 10 min with 50 psig GH_e applied internally.
0	Amb	50	Same as for #16	No bubble leakage from seal cavity in 1 hr with 50 psig GH_e applied internally.
0	LN_2	50	Same as for #16	QD chilled to -300°F & pressurized with GH_e at 50 psig. Moderately high leakage (not quantitatively determined) was noted initially by bubbles in a water displacement device. Leak rate decreased as QD warmed. 2.7×10^{-2} leak rate was determined at approx -100°F.
0 & 00	LN_2	50	Same as for #16	6.5×10^{-3} SCIM primary seal leakage at LN_2 temp with 10 psi ΔP. 5.7×10^{-3} SCIM at 100 psi ΔP after terminating LN_2 flow.
0	LN_2	75	Same as for #16	Negligible leakage with 10 psi ΔP.
0	LN_2	75 & 50	Same as for #20 except 3 bolts backed off to 50% load.	Negligible leakage with 10 psi ΔP.

2

Table 3-2. Contin

Test				Seal Configuration				Test			L L
				Primary		Secondary					
No.	Date	* Objective	† Procedure	No. of Serrations	New Seal	Type	New Seal	Fluid	Press. Psig	Temp.	
22	11-15	a, b, e	ak-ao	2	No	Omni	No	LN_2 GN_2	100	LN_2	5
23	11-16	a, b, d	ap-at	1	Yes	Omni	No	GN_2	100	Amb	1
24	11-16	a, b	ap-at	1	No	Omni	No	GN_2	100	Amb	7
25	11-16	a, b	ap-at	1	No	Omni	No	GN_2	100	Amb	6
26	11-16	a, b, e	ap-at	1	No	Omni	No	GN_2	100	Amb	5
27	11-16	a, b, d	au-ax	1	Yes	Omni	No	GN_2	<30	Amb	25
28	11-16	a, b	au-ax	1	No	Omni	No	GN_2	<30	Amb	75
29	11-16	a, b	au-ax	1	No	Omni	No	GN_2	100	Amb	10
30	11-16	a, b	au-ax	1	No	Omni	No	GN_2	100	Amb	12
31	11-16	a, b, e	au-ax	1	No	Omni	No	GN_2	100	Amb	15
32	11-16	a, b, d	ay	1	Yes	Omni	No	GN_2	100	Amb	12
33	11-16	a, b	ay	1	No	Omni	No	GN_2	100	Amb	75
34	11-17	a, b	ay	1	No	Omni	No	GN_2	100	Amb	50
35	11-17	a, b	ay	1	No	Omni	No	GN_2	100	Amb	25
36	11-17	a, b	ay	1	No	Omni	No	GN_2	100	Amb	13

-2. Continued

Temp.	Latch Loads %	Notes on Installation	Results
LN_2	50	Same as for #21 except all 6 bolts reduced to 50% load	Negligible leakage with 10 psi ΔP. When 100 psig GN_2 was applied, leak rate increased to approx 2×10^{-3} SCIM. After warmup to 72°F leak rate was less than 10^{-5} SCIM.
Amb	100	OD inverted, chain supports used for alignment.	No press rise in seal cavity with 100 psig GN_2 applied internally for 5 min.
Amb	75	Same as for #23	No leakage in 5 min.
Amb	63	Same as for #23	No leakage in 5 min.
Amb	50	Same as for #23	1.6×10^{-2} SCIM leak rate
Amb	25	OD inverted, chain supports lengthened 1 link each side.	Gross leakage.
Amb	75	Same as for #27	Gross leakage
Amb	100	Same as for #27	1.2×10^{-1} SCIM leak rate
Amb	125	Same as for #27	2.2×10^{-2} SCIM leak rate
Amb	150	Same as for #27	No leakage in 6 min.
Amb	125	OD inverted, hand aligned during latching	No leakage in 6 min.
Amb	75	Same as for #32	No leakage in 10 min.
Amb	50	Same as for #32	No leakage in 10 min.
Amb	25	Same as for #32	No leakage in 8 min.
Amb	13	Same as for #32	1.5×10^{-1} SCIM leak rate.

2

Table 3-2

Test				Seal Configuration				Test	
				Primary		Secondary			
No.	Date	* Objective	† Procedure	No. of Serrations	New Seal	Type	New Seal	Fluid	Press. Psig
37	11-17	a, b	ay	1	No	Omni	No	GN_2	100
38	11-17	a, b	ay	1	No	Omni	No	GN_2	30
39	11-17	a, b	ay	1	No	Omni	No	GN_2	100
40	11-17	a, b	ay	1	No	Omni	No	GN_2	100
41	11-17	a, b	ay	1	No	Omni	No	GN_2	100
42	11-17	a, b	ay	1	No	Omni	No	GN_2	100
43	11-17	a, b, e	ay	1	No	Omni	No	GN_2	100
44	11-17	a, b, d	ay	1	Yes	Teflon "O" ring	Yes	GN_2	<30
45	11-17	a, b	ay	1	No	Teflon "O" ring	No	GN_2	<30
46	11-17	a, b, d	ay	1	No	Teflon "O" ring	No	GN_2	100
47	11-18	a, b	ay	1	No	Teflon "O" ring	No	GN_2	100
48	11-18	a, b	ay	1	No	Teflon "O" ring	No	GN_2	100
49	11-18	a, b	ay	1	No	Teflon "O" ring	No	GN_2	100

Table 3-2 Continued

Test		Latch Loads %	Notes on Installation	Results
ress. Psig	Temp.			
00	Amb	13	Same as for #32	Side load applied--gross leakage after side load removed.
30	Amb	25	Same as for #32	Gross leakage
00	Amb	38	Same as for #32	4.7×10^{-2} SCIM leak rate
00	Amb	50	Same as for #32	4.0×10^{-3} SCIM leak rate
00	Amb	63	Same as for #32	2.3×10^{-3} SCIM leak rate
00	Amb	75	Same as for #32	No leakage in 1 hr.
00	Amb	75 & 0	Same as for #32 except 3 bolts at 75% load & 3 bolts at zero load	1.04×10^{-1} SCIM leak rate
30	Amb	38	QD inverted, hand aligned during latching	Gross leakage
30	Amb	63	Same as for #44	Gross leakage
00	Amb		Pneumatically unloaded seal, hand aligned QD during reloading	1.5×10^{-1} SCIM leak rate
00	Amb	75	Same as #46	1.14×10^{-2} SCIM leak rate
00	Amb	88	Same as #46	1.16×10^{-3} SCIM leak rate
00	Amb	100	Same as #46	No leakage in 20 min.

Table 3-2. Conc

Test				Seal Configuration				Test		
				Primary		Secondary				
No.	Date	* Objective	† Procedure	No. of Serrations	New Seal	Type	New Seal	Fluid	Press. Psig	Temp.
50	11-18	a, b, d	ay	1	Yes	Teflon "O" ring	No	GN_2	100	Amb
51	11-18	a, b, d	ay	1	Yes	Teflon "O" ring	No	GN_2	100	Amb
52	11-18	a, b, d	ay	1	No	Teflon "O" ring	No	GN_2	100	Amb
53	11-18	a, b, d	ay	1	No	Teflon "O" ring	No	GN_2	100	Amb
54	11-18	a, b, d	ay	1	No	Teflon "O" ring	No	GN_2	100	Amb
55	11-18	a, b, d	ay	1	No	Teflon "O" ring	No	GN_2	100	Amb
56	11-18	a, b, d	ay	1	Yes	Teflon "O" ring	Yes	GN_2	100	Amb

*Refer to Section 5. 1. 1. 1. 3 for corresponding test objective.
†Refer to Section 5. 1. 2. 2 for corresponding procedural instruction.

3-2. Concluded

Temp.	Latch Loads %	Notes on Installation	Results
Amb	100	QD inverted, hand aligned during latching	8.7 x 10^{-4} SCIM leak rate
Amb	100	QD inverted, AGE-half supported by chains during latching.	8.9 x 10^{-2} SCIM leak rate
Amb	100	Pneumatically unloaded seal, hand aligned QD during reloading	4.35 x 10^{-3} SCIM leak rate
Amb	100	Pneumatically unloaded seal, chain supports used for reloading	5.2 x 10^{-2} SCIM leak rate
Amb	100	Pneumatically unloaded seal, hand aligned QD during reloading.	No leakage in 30 min.
Amb	100	Lengthed support chains until latch hooks supported QD weight when unloaded. Reloaded seal without hand alignment.	5.7 x 10^{-3} SCIM leak rate
Amb	100	Rotated QD axis veritcal, vehicle-half down--hand aligned	No leakage in 22 min.

2

A total of 56 tests are identified, however, some of these individual tests are part of a series. Eight of these tests were conducted at LN_2 temperature and the remainder were ambient temperature tests.

The test configuration was the same as that for the -1 test model. The first test revealed that the leakage experienced on the -1 coupling at the AN fittings had been completely eliminated (at ambient and LN_2 temperatures) by the use of a Teflon coated metallic boss seal, MC252 This is a George C. Marshall Space Flight Center Standard. The seal is designed for use with standard AN and MS fittings, and installation is covered by MC245. A sketch of this seal and how it is installed is shown in Figure 3-19. Leak tests were performed on the QD at both ambient and at liquid nitrogen temperatures with the 100% design load applied to the primary seal. The leakage was determined to be very small; in fact, less than on the first(-1) test model. Primary seal leakage was determined by pressurizing the QD to 100 psig with nitrogen and detecting the leakage of nitrogen past the primary seal into the seal purge cavity. Any leakage of nitrogen is mixed with the helium purge gas and swept through a thermal conductivity cell where the presence of the nitrogen causes an unbalance in the cell corresponding to the amount of nitrogen present. The primary seal leakage at both ambient and at LN_2 temperatures was determined to be less than 6×10^{-6} SCIM of nitrogen at 100 psig. This was the sensitivity limitation of the instrument as calibrated in the actual test setup.

For most of the tests helium gas was used to pressurize the seal cavity to 30 psig at ambient temperature, the pressure and temperature in the seal cavity were allowed to stabilize, and the pressure decay was measured as a function of time. Helium leakage from the seal cavity and all connecting lines was determined to be less than 7×10^{-4} SCIM. For the initial testing a CEC helium mass spectrometer again was used to detect leakage from this cavity and its fittings. As the QD was chilled to liquid nitrogen temperatures no leakage could be detected from any of the fittings, and leakage past the large Teflon Omniseal was observed to increase by approximately 400-500 times. Thus, leakage from the seal purge cavity was less than 10^{-1} SCIM with the QD filled with LN_2.

The testing concentrated on the evaluation of the primary seal and on identifying any mechanical problems on the mating of the QD halves. Since the secondary seal configuration on both the first and second test models are identical, its performance was evaluated on the first unit. The secondary seal testing on the second unit was limited to bubble solution testing at ambient temperature, to assure no gross leakage, and monitoring with a CEC helium mass spectrometer during the initial LN_2 chilldown test which established that leakage was of the same order-of-magnitude as for the first unit.

Figures 3-41, 3-42 and 3-43 are curves showing the time histories of the QD component temperatures and latch loads during the LN_2 chilldown and warmup of test No. 1. These curves are typical of the data taken on the other LN_2 tests of the -501 test model. For this test the seal was initially loaded to 100% of design load. Figure 3-41 shows the time history of

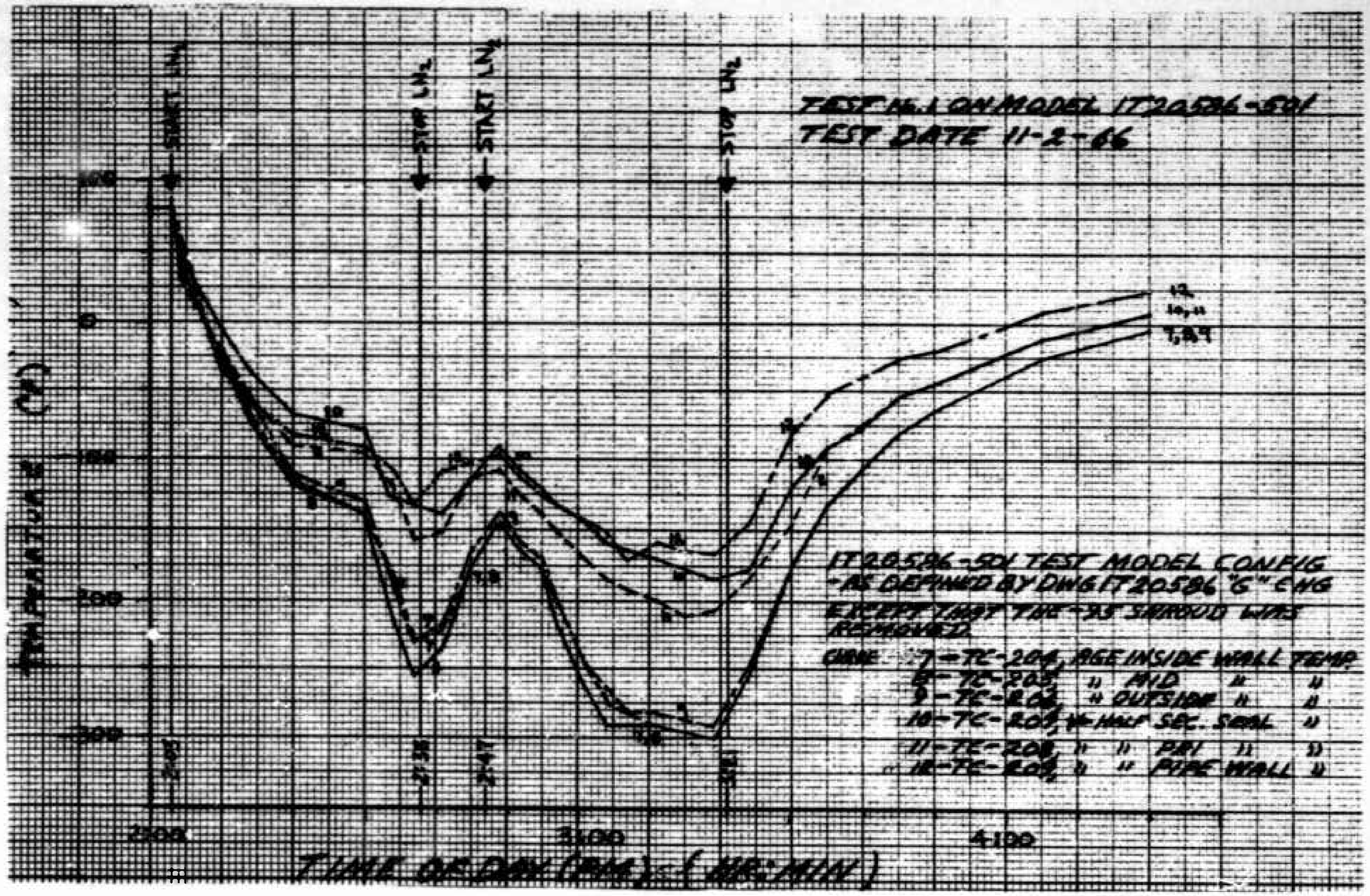


Figure 3-41. Temperature-Time Relationships During LN_2 Childown and Warmup

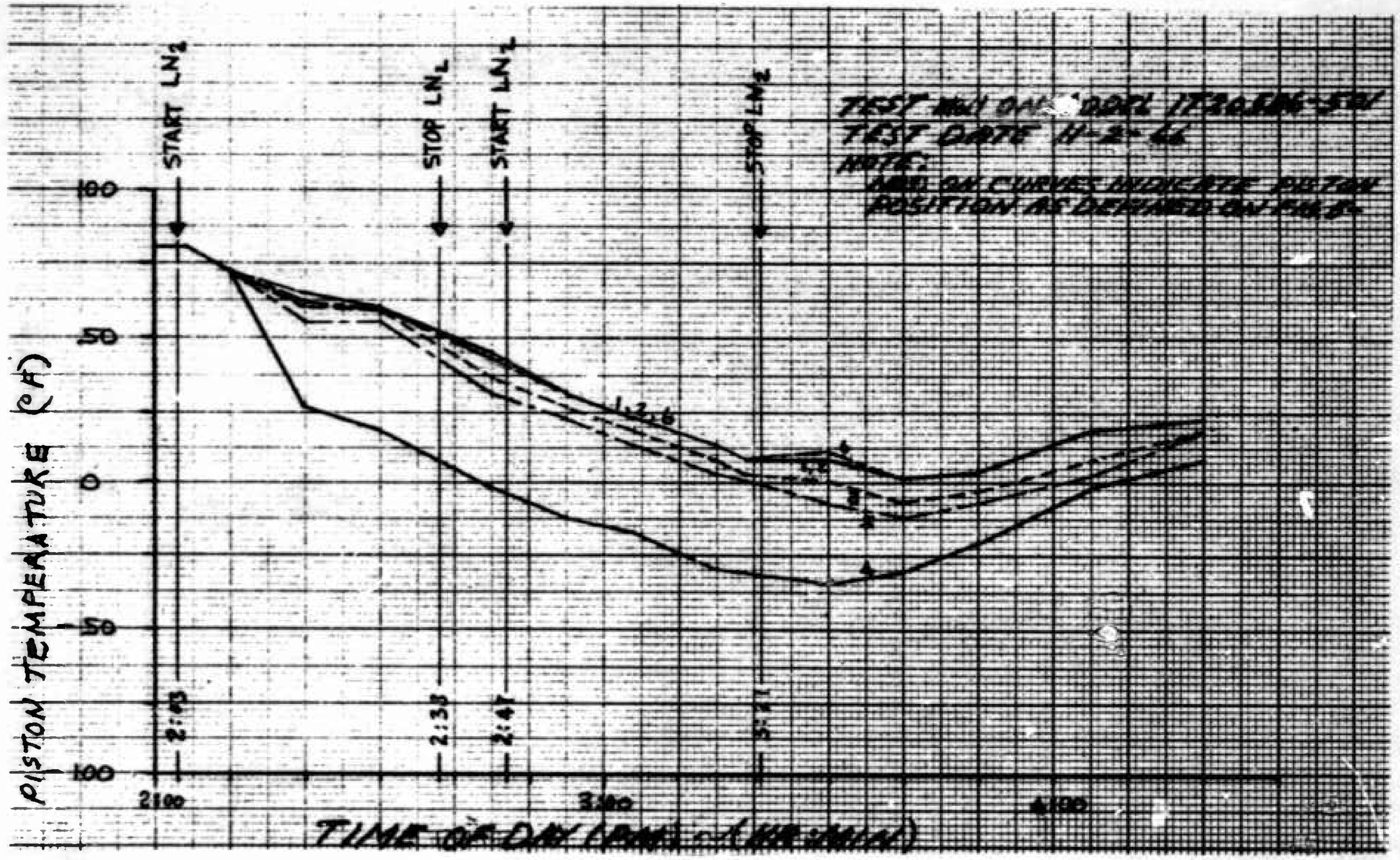


Figure 3-42. Temperature-Time Relationships During LN_2 Chilldown and Warmup

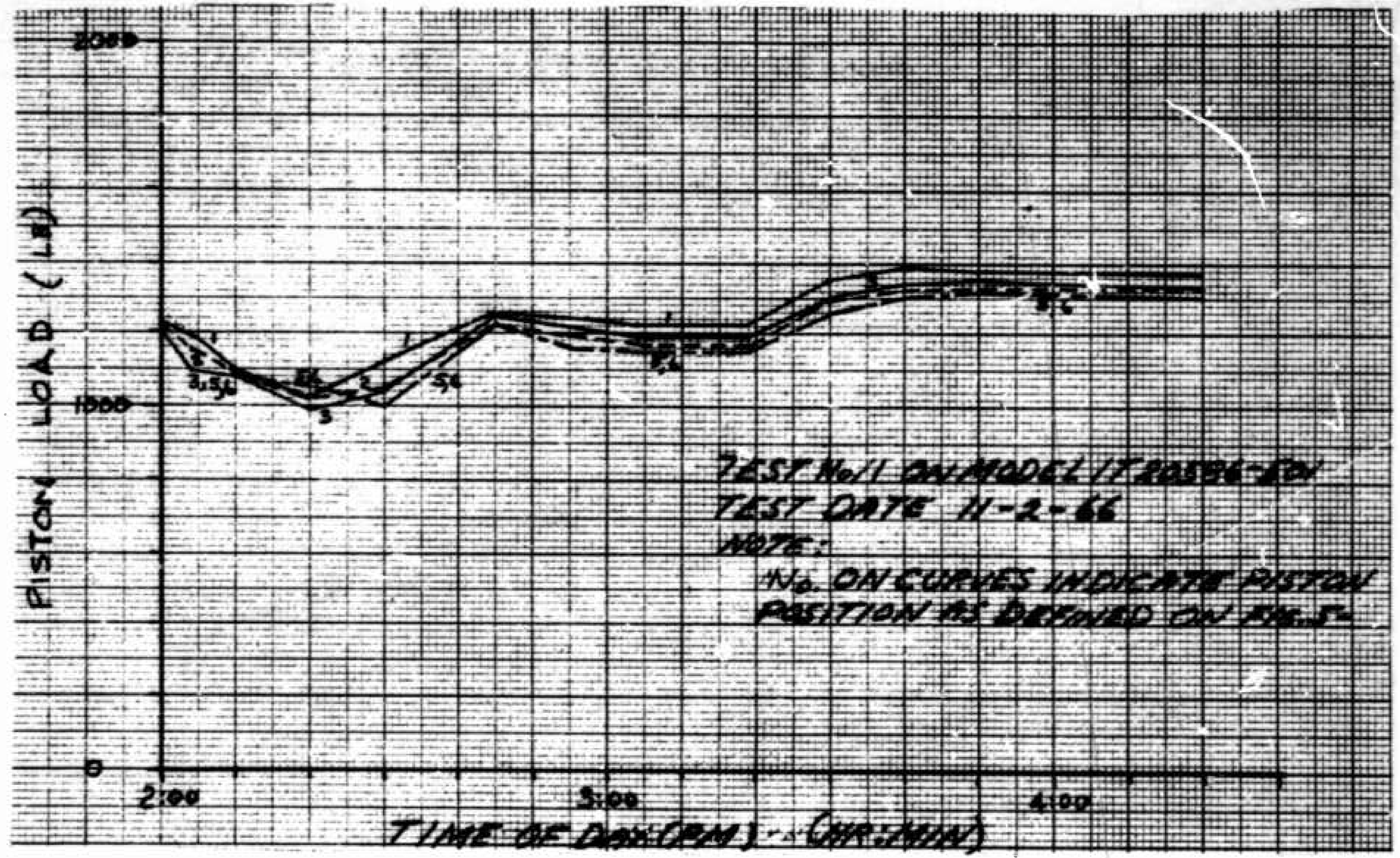


Figure 3-43. Load-Time Relationships During LN_2 Chilldown and Warmup

temperatures at the three instrumented points on both the vehicle and AGE adapters. The test was started with 100 liter LN_2 Dewar that had been previously partially emptied. This LN_2 supply was depleted before a stabilized cold temperature was reached. During the 9 minute delay required to connect a second LN_2 Dewar the adapter temperatures increased as shown on the curves. After LN_2 flow was resumed the adapter temperatures were brought to a stabilized cold condition. It may be noted that the curves numbered 7, 8 and 9, which are the temperatures of points on the AGE adapter, reached a minimum of approximately -300°F, whereas the curves numbered 10, 11 and 12, which represent points on the vehicle adapter, reached a minimum value in the range of -170 to -210°F. This is the same phenomenon noted in Section 5.3.1.1. The 1T20586-11 aluminum mounting plate attached to the vehicle adapter acts as a heat source and heating fin which holds this adapter at a higher temperature level than the AGE-half. Curve No. 12, which has the highest minimum temperature, represents the thermocouple location nearest to the -11 plate.

Figure 3-42 shows the temperature time histories for the six 1T20586-161 latching pistons. The same trend that was noted on Figure 3-39 for the -17 latch loading clevis bolts of the -1 test model is apparent in Figure 3-42. The warmest temperatures are recorded at the No. 1 or top position and coldest temperatures at the No. 4 or bottom position (Figure 3-42). The major significant difference is that the minimum seal loading bolt temperatures for the -1 configuration were much lower than for the -501 configuration. The No. 4 bolt reached a minimum of -314°F on the -1 unit whereas the No. 4 piston reached a minimum of -35°F on the -501 unit. This is the result of the -161 pistons being more thermally isolated from the cryogenic internal fluid than are the -17 clevis bolts. Also the springs and associated hardware on the -161 piston have a larger surface area for heat transfer by convection and radiation.

Figure 3-43 shows the seal load time histories of the -161 latching pistons at positions No. 1, 2, 3, 5 and 6. One of the two strain gages on the piston at the No. 4 position had an open circuit. The remaining strain gage was monitored throughout the tests but the resulting data was not considered sufficiently accurate to include in the test results. The piston load variations shown in Figure 3-43 were unpredicted. The results were unlike those for the -17 clevis bolts discussed in the previous section, where the bolt loads continuously dropped with lowering temperatures and at minimum temperature the loads were reduced to 34% of the initial load. The -161 piston loads initially decreased with decreasing temperature for approximately the first 20 minutes of the test, then started to increase. Using the data from the No. 3 position, the minimum load was approximately 83% of the initial load and occurred when the piston temperature was 60°F. The piston loads then rose for the next 25 min and leveled out on a plateau, essentially the same as the initial value and remained constant until the adapter temperatures stabilized at a minimum value and the LN_2 flow was terminated. Immediately thereafter the adapter temperatures rose rapidly while the warmer piston temperatures continued to decrease. During this period the loads in the pistons again increased and in 20 minutes reached new plateaus between 9 and 17% above the initial load. The loads remained at this level until the data acquisition was terminated with the hardware temperatures in the range of 0 to 25°F. After allowing the temperatures to stabilize overnight to the 72°F ambient room temperature the loads returned to approximately the same values as at the beginning of the test. This same characteristic was noted in all of the LN_2 tests on the -501 model. The loads varied only a minor amount above or below the initial setting. Although there is no obvious explanation for each of the changes of slope in the load curves it was expected that the decrease in seal loads for the -501 configuration would be considerably less than for the -1 configuration because the spring rate of the seal load springs for the -501 (4600 lb/in.) is much less than for the -1 (28,500 lb/in.). The ratio of spring rates is 1:6.4, whereas the ratio of load loss is 1:4 for the -501 versus the -1 coupling. The fact that the temperature of the -161 pistons stays relatively high compared to that of the -17 bolts plus a longer load path through the latching mechanism for the -501 coupling can be used to account for this apparent disparity between the deflection ratios and the load variation ratios.

The cryogenic testing with LN_2 established that the primary seal loading was less affected by the chilldown on the second model than on the first. With initial loading at 100% of design load the reduction in load during chilldown was in the order of 17% on the second model whereas under the same initial conditions on the first model the seal loading was reduced by approximately 66%. The principal reason for the improved seal load characteristics on the second model is that it has ten disc springs per latch compared to three per latch on the first model. This provides a lower spring rate (lbs per inch of deflection) which results in any temperature induced dimensional changes having a lesser effect on the seal load.

The results of the cryogenic testing on the two serration seal configurations indicate that initial sealing loads 75% of the design load and above will all provide an adequate seal for fluorine service. The leakage rate was below the sensitivity of the equipment used for measurement (less than 6×10^{-6} scim of N_2). When the initial sealing load was reduced to 50% of design load, a detectable increase of leakage rate (in the order of 10^{-2} scim) was noted at LN_2 temperature.

During this testing a QD mating problem was discovered. The nature of the problem is that reasonably close axial alignment of the two QD halves is required during the application of the sealing loads in order to obtain a uniform plastic deformation of the aluminum seal by the knife edge serrations. The outer sleeve of the QD vehicle-half has a slight entrance bellmouth which permits the AGE-half to be engaged with a small angular misalignment.

Because the vehicle-half serrations are recessed approximately 0.3 in. beyond the starting point of the cylindrical inside diameter of the sleeve, an angular misalignment causes the initial serration point to be displaced radially inward from its contact point during an aligned engagement. As the latching loads are applied, the serration cuts into the seal at this initial contact point forming a pivot about which the AGE-half must rotate into alignment with the vehicle-half. This off-center mating produces an interference fit between the external cylindrical surface of the AGE-half and the internal surface of the vehicle-half sleeve at a point diametrically opposite the point of initial contact with the seal. A portion of the latch loads adjacent to this interference point are dissipated in overcoming the friction between the two rubbing surfaces. Therefore, the two halves of the QD remain misaligned at a slight angle, and the serrations cut unsymmetrically into the seal forming grooves deep on one side and shallow on the other. The result is that much higher than normal latch loads must be applied to effect a seal for the misaligned condition.

The single serration seal was tested at ambient temperature only. For this configuration latch loads 50% of the design load for the two serration configuration were considered to be 100% load. The test results indicate that latch loads from 100% to 150% are required to effect an adequate seal. However, on one series of tests, after leakage has been reduced to a negligible value by increasing the seal loading in 25% increments to 150% load, the seal was unloaded in the same incremental steps and no leakage was detected until the loads were reduced below 25%.

5.3.2 Fluorine Tests

Two basic test categories were used to gather the required data; flow tests and purge tests. While the latter series was designed to rapidly and economically gather data on the purging of residual fluorine from the QD and flex line, the flow tests also provided purge data. Purge system evaluation was thus based on data from all fluorine tests. Further, all fluorine tests contributed to the establishment of compatibility data for the coupling. Fluorine tests were numbered consecutively in chronological order. Table 3-3 summarizes these results.

5.3.2.1 Fluorine Flow Tests

Five (5) separate liquid fluorine flow tests were conducted on the 1T20586-1 test model QD coupling. The first three were made on three separate days during November 1966, and encountered a series of minor procedural problems. The last two tests were made on the same day in early December 1966. They went without incident, provided data consistent with prior test observations, and confirmed the design and operating concept of a non-valved fluorine quick disconnect coupling.

a. Flow Test No. 1 (Test No. 1)

The first fluorine flow test without incident until start of the purge operation. At that time, a procedural error resulted in the failure to isolate the QD-flex line combination from the supply line (valve FP-200, see Figure 3-27, remained open during purge through VP-200). As a result, the fluorine supply line upstream of FP-200 (this line contains fluorine and is dead ended during QD purging) provides a ready source of fluorine to mix with the purge gas passing from the flex line and through VP-200. The purge gas fluorine sampling system, 1T20582, extracted its purge gas samples at the tee fitting physically connecting the flex line, valve VP-200 and valve FP-200, and thus gathered a sample influenced by the open valve FP-200.

Table 3-3

LIQUID FLUORINE TE

Test No.	1	2	3	4	5
Test Date	11-9-66	11-10-66	11-21-66	11-29-66	12-1
Test Type & No.	Flow-1	Flow-2	Flow-3	Purge-1	Purg
Pre-Test Seal Load (%)	100	100	100	100	125
Primary Seal Leakage (SCIM)	2.9×10^{-5} (1)	3.3×10^{-5} (1)	3×10^{-4} (2)	-	-
Liquid Fluorine Flow Rate (GPM)	40	36	40	-	-
QD Pressure Drop ΔP (PSID)	0.2	0.2	0.4	-	-
Weight of Condensed F_2 (lbs)	-	-	-	3.0	2.5
Liquid Drain Time (min)	5	4	3	-	-
QD Purge No. 1 Time (min)	5	3	5	3	2 (3)
QD Purge No. 2 Time (min)	-	-	2 (3)	1	3
QD Purge No. 3 Time (min)	-	-	-	-	1
QD Purge No. 4 Time (min)	-	-	-	-	-
Purge Gas F_2 Concen. No. 1 (ppm)	~2,500 (4)	6,000 (4)	1,900	3,500	-
Purge Gas F_2 Concen. No. 2 (ppm)	-	-	15	200	400
Purge Gas F_2 Concen. No. 3 (ppm)	-	-	-	-	20
Purge Gas F_2 Concen. No. 4 (ppm)	-	-	-	-	-
Fluorine Compatibility	(5)	(5)	(6)	(5)	(5)
Separation Actuator Press. (psig)	-	-	-	-	-
Separation Effectiveness	-	-	Good	-	-
Shroud Purge Effectiveness	-	Good	Good	Good	-

NOTES:
1. For period of flow from 1 min to end of flow.
2. For period of flow from 0 to end of flow.
3. Gaseous helium flow ≈ 1/2 flow rate of gaseous nitrogen flow used elsewhere.
4. Procedural errors make data questionable.
5. QD not separated. External examination revealed no changes.
6. Interior of QD was clean; slight corrosion at secondary seal; no damage to QD.

able 3-3

LUORINE TESTS

	5	6	7	8	9	10	11
29-66	12-1-66	12-1-66	12-2-66	12-5-66	12-5-66	12-7-66	12-7-66
ge-1	Purge-2	Purge-3	Purge-4	Purge-5	Purge-6	Flow-4	Flow-5
	125	≈100	125	100	<100	125	≈100
	-	-	-	-	-	4.3×10^{-3} (2)	5.6×10^{-4} (1)
	-	-	-	-	-	38	58
	-	-	-	-	-	0.3	0.45
	2.5	2.4	2.6	2.5	2.5	-	-
	-	-	-	-	-	2	2.5
	2 (3)	2.5 (3)	3	2	2.5	2	2
	3	3	1	1	1	1	1
	1	1	-	1	1	1	1
	-	-	-	-	1	-	-
0	-	-	4,500	11,500	15,000	8,000	7,600
	400	200	250	675	675	750	1,000
	20	10	-	280	735	210	240
	-	-	-	-	280	-	-
	(5)	(5)	(6)	(5)	(5)	(5)	(6)
	-	-	-	-	-	-	~210
	-	-	Good	-	-	-	Good
	-	Good	Good	-	-	-	Good

where.

to QD.

2

The average flow rate was approximately 40 GPM for a total transfer of 240 gallons of liquid fluorine. Maximum flow rate of 800 lb/min (64 GPM) was recorded at the beginning of the transfer. The subsequent decrease and then rise again in flow rate, as shown in Figure 3-44, was caused by back pressure buildup downstream of the QD in the condenser and receiver tank complex of the fluorine facility.

The pressure drop data for the coupling are also shown in Figure 3-44. The absolute value of pressure drop at any given time cannot be stated with any degree of certainty, as the data presented have been smoothed to provide more meaningful average values and trends. A value of 0.2 psi pressure loss at 400 lb/min would be consistent with the data and is characteristic of what was expected.

The temperature profiles for Test No. 1 are shown in Figure 3-45. These data indicate that the thermal characteristics of the QD throughout the test were transient in nature with the single exception of the flowing fluorine. A steady state liquid fluorine temperature within the QD was established within the first 20 sec of transfer. The shape of the remaining profiles was as expected based on the results obtained in the Pre-Fluorine Readiness Tests of Section 5. Comparing the data from these two tests, it is concluded that steady state thermal profiles had been closely approached, and no significant changes in temperatures would have been expected had it been possible to continue the transfer of liquid fluorine through the quick disconnect coupling.

The transition from liquid fluorine transfer to drain operations was accompanied with distinct change in several temperature profiles, as is evidenced by a review of Figure 3-45. The QD fluid temperature (TC-202) rose rapidly during the drain period and remained at a fairly warm temperature throughout the subsequent purge operations. This was as expected since the gaseous helium inlet to the QD was through a pruge nozzle which directed the helium flow at the TC-202 thermocouple located only 3 inches from the nozzle. Thermocouples TC-201 and TC-203 (see Figure 3-27 for locations) also underwent significant changes in slope at this transition point. These thermocouples measure the discharge purge gas temperatures for the QD/flexline and the liquid nitrogen jacket of the flexline respectively.

QD and flexline warmup during drain and purge follows very closely the same temperature versus time profile, and this profile could be described equally well by any one of the five thermocouples; TC-201, TC-203, TC-204, TC-208, and TC-209.

The sealing characteristics of the primary coupling seal in fluorine service was investigated as outlined in 5.2.2.3 of Section 3. For the first 60 sec of fluorine transfer, the seal cavity purge gas was bubbled through a solution of methyl red to indicate the presence of large seal leakage (>1 scim). During this initial period no leakage was detected (no noticeable decolorization of the methyl red), and the purge gas was then bubbled through the NaOH solution for the remainder of the transfer. Post test analysis of this latter solution indicated an average primary seal leakage of 2.9×10^{-5} scim of fluorine.

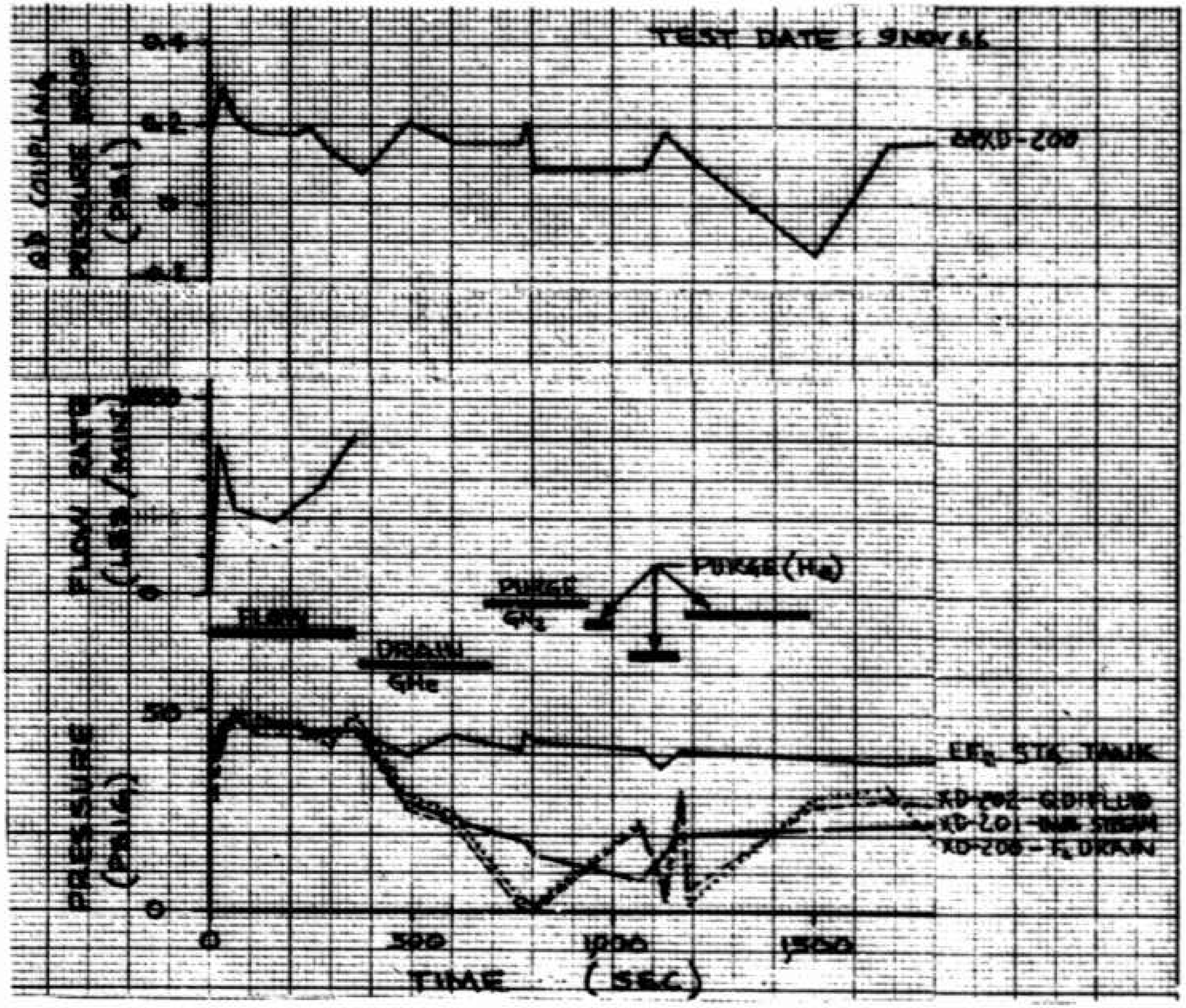


Figure 3-44. Pressure and Flow Rate Relationships Fluorine Flow Test No. 1

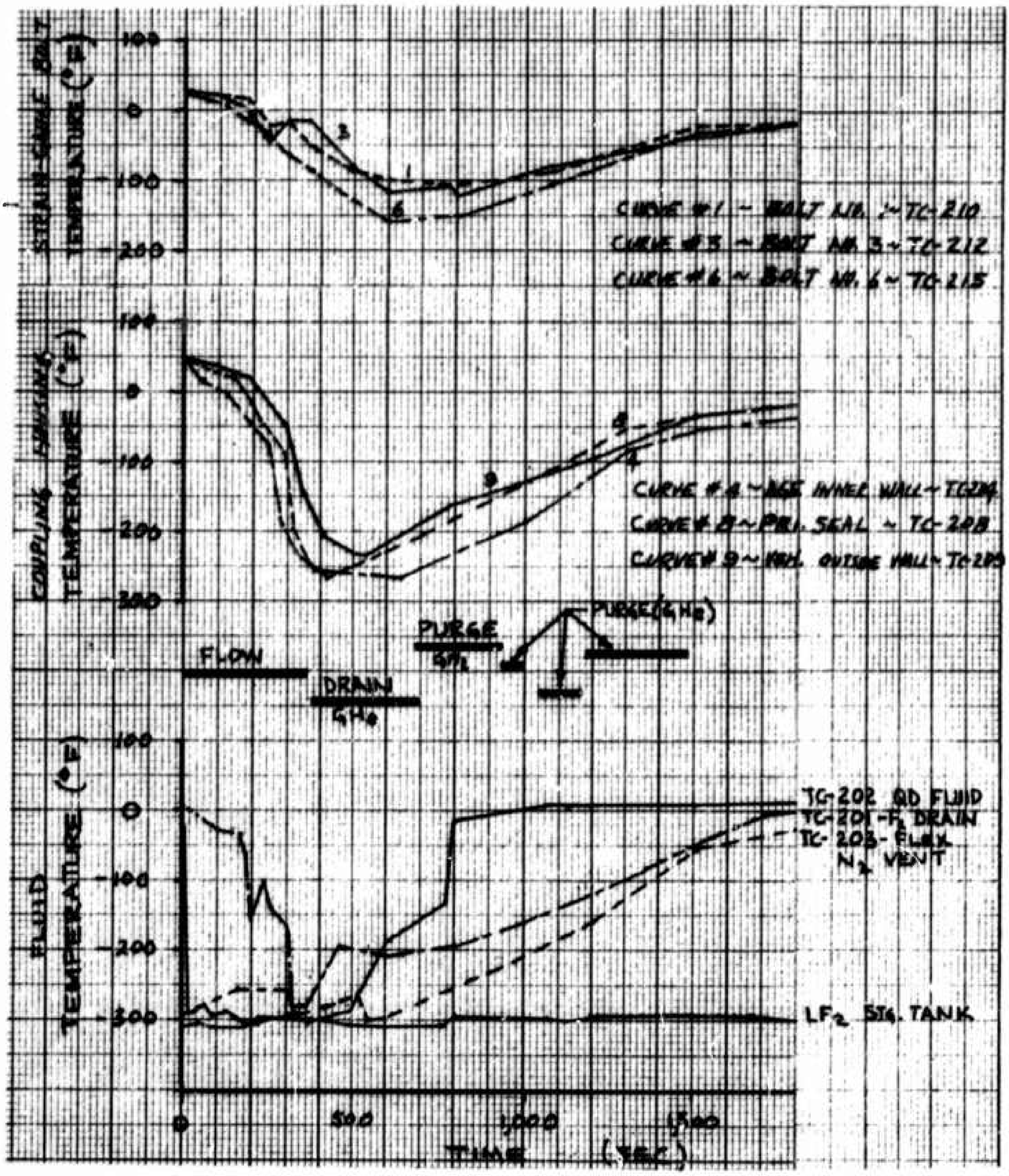


Figure 3-45. Temperature Relationships Fluorine Flow Test No. 1

Careful examination of the entire test setup for any evidence of fluorine leakage or other anomilies revealed nothing.

b. Flow Test No. 2 (Test No. 2)

The second transfer test (see Figures 3-46 and 3-47) was accomplished in approximately 6 minutes at an average flow rate of 450 lb min (36 GPM). High system back pressure caused by the fluorine condenser, in the downstream portion of the flow loop, was responsible for restricting the flow rate. The indicated average pressure loss of approximately 0.2 psi is consistent with the results of Test No. 1.

The temperature profiles of Figure 3-47 are markedly different, during the drain interval, from those of Test No. 1. During Test No. 1, and during the remaining three flow tests, there was a pronounced temperature rise at three separate thermocouples (TC-201, TC-202 and TC-203) at the transition between termination of fluorine flow and the beginning of the drain operation. However, during Test No. 2 no such rise took place, and the expected change did not occur until the beginning of purge following the drain sequence. Unfortunately, thermocouple TC-202 which measures the fluid temperature within the QD was inoperative during this test. Nevertheless, comparison of gathered data with those of the other 4 tests suggests that the liquid fluorine was not being removed, to any significant degree, from the QD and flexline during the drain time period. This would indicate that either the source of gaseous helium for draining was isolated or the drain path was obstructed.

A careful review of the limited data available leads to the conclusion that the gasesous helium supply valve was opened (this valve is known to have functioned later in this same test), but that fluid head and system back pressure prevented any flow. Added to the system back pressure (condenser inlet pressure) is that pressure caused by an approximately 12 foot high column of liquid fluorine which exist at the beginning of the draining operation at the condenser inlet. The observed decrease in both condenser inlet pressure (system back pressure) and QD fluid pressure during the drain period are consistent with the expected operation of the test/flow facility configuration under these conditions. The condenser, as well as the liquid nitrogen jacketed lines, remove heat from the system reducing the pressure as noted.

Fluorine leakage past the primary seal was small; 3.3×10^{-5} SCIM. This leakage was an average value overall but the first 60 seconds of transfer. As was the case in Test No. 1, all seal leakage during the first minute was bubbled through methyl red to check for large leakage; none was detected.

Post test examination revealed that the QD and the inside of the anti-icing shroud were completely free of frost, ice and condensed moisture, indicating that the low pressure (approximately 0.1 psig within the shroud) gaseous nitrogen purge was adequate to preclude moisture from the coupling. The entire system was clean, free of damage, and provided no evidence of fluorine leakage.

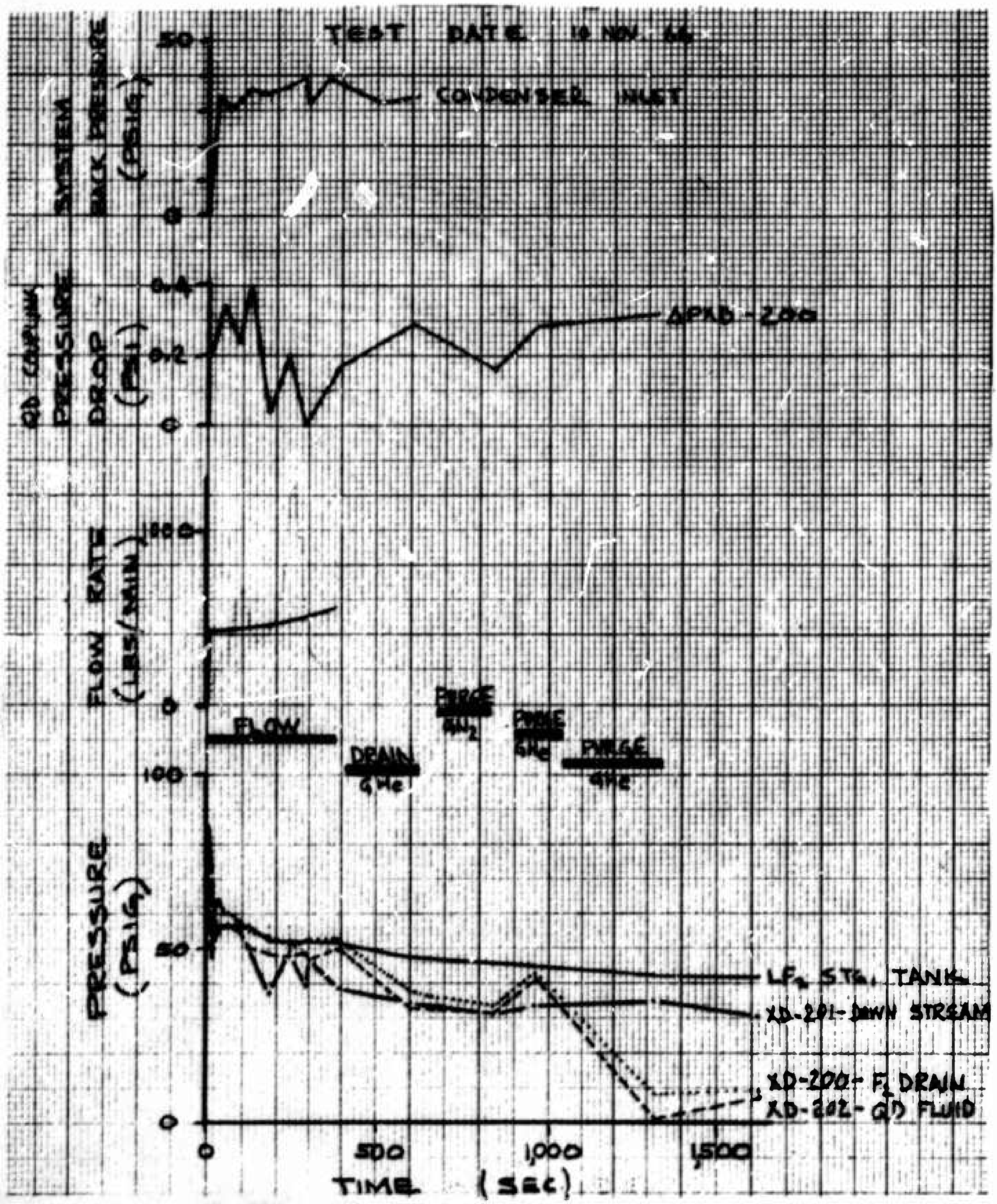


Figure 3-46. Pressure and Flow Rate Relationships
Fluorine Flow Test No. 2

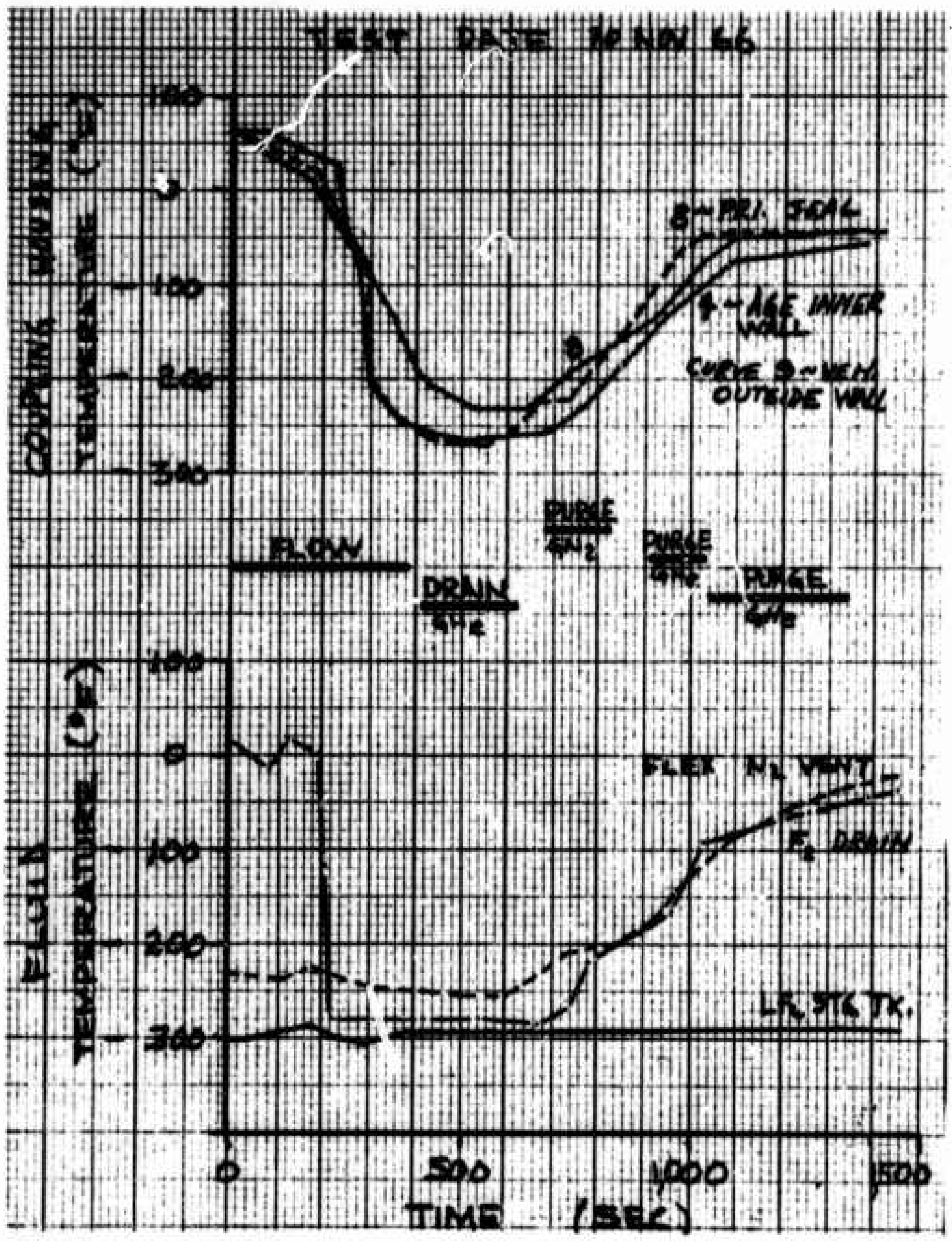


Figure 3-47. Temperature Relationships Fluorine Flow Test No. 2

c. Flow Test No. 3 (Test No. 3)

Test No. 3 provided a good set of test data. The flow lasted for nearly 5 minutes at an average flow rate of 500 lb/min (40 GPM), and resulted in the transfer of approximately 2500 lb of liquid fluorine through the QD coupling.

Since no gross leakage was observed on either of the first two tests, the third test was performed with the entire seal leakage being captured for post test analysis. Leakage of 3×10^{-4} SCIM was detected; an average increase of 10 times the first two tests. If it is assumed that the primary seal sealed as effectively as in tests 1 and 2, it is concluded that the average indicated leak rate was thus increased by a still larger transient leak during the first one minute of fluorine transfer. If this was the case, and tests 10 and 11 suggest that it was, the average leak rate during the first minute of liquid fluorine transfer would have been 2×10^{-3} scim, followed by an average leakage of 3×10^{-5} scim for the remainder of the flow.

The data for the QD and its test setup are presented in Figures 3-48 and 3-49, and are consistent both with test operations and prior test data. These data do not, however, permit a detailed determination of the temperature history for the aluminum primary seal. In all probability its temperature history follows more closely that of the fluorine than the main body of the coupling for the following reasons:

1. It is exposed to the flowing fluid.

2. The seal is in intimate contact with the stainless steel housing of the QD at only a small percentage of its total surface area (thus somewhat isolated).

3. It has a much larger coefficient of thermal conductivity than the stainless steel QD.

The aluminum seal is also subject to temperature gradients both in the radial and circumferential directions as a result of the manner it is wetted by the flowing fluid, and the puddling of liquid in the bottom of the QD at this seal during the two-phase flow present early in the fluorine transfer operation. These transient phenomena are undoubtedly the controlling factors in any substantial increase in seal leakage during the initial 60-90 sec of liquid flow.

Following the purge tests, the anti-icing shroud was removed, the coupling disconnected, and all surfaces carefully examined. No condensation or other evidence of moisture was found within the shrouded area of the QD. Some slight yellowish-white colored corrosion product was found on the sealing surface of the cavity wall in the area where the Teflon Omniseal (cavity seal) contacts the cavity wall. This sealing surface was washed with freon and then blown dry with gaseous nitrogen, resulting in a clean but slightly stained surface. No further attempt was made to remove the stain prior to reassembly of the QD for subsequent testing.

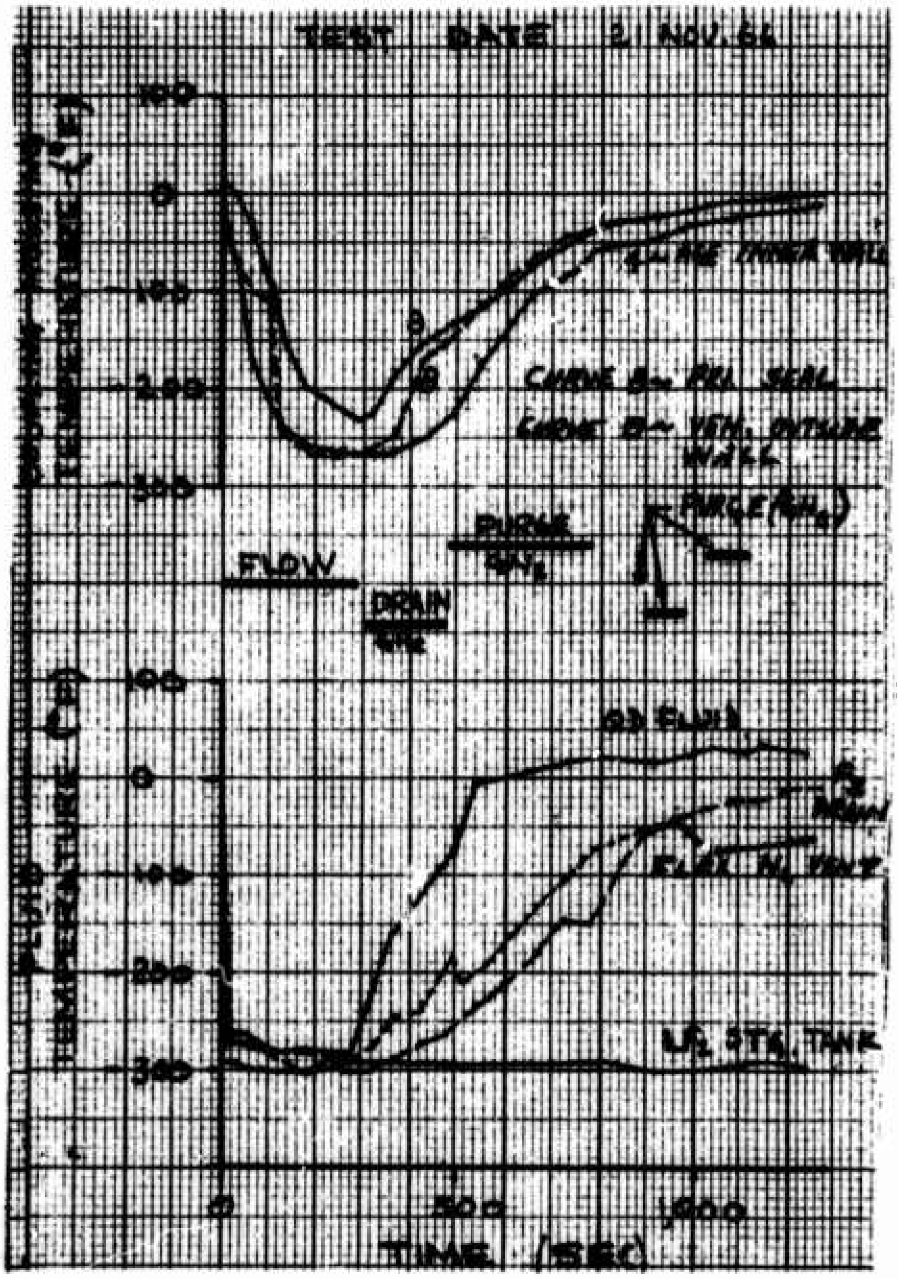


Figure 3-48. Temperature Relationships Fluorine Flow Test No. 3

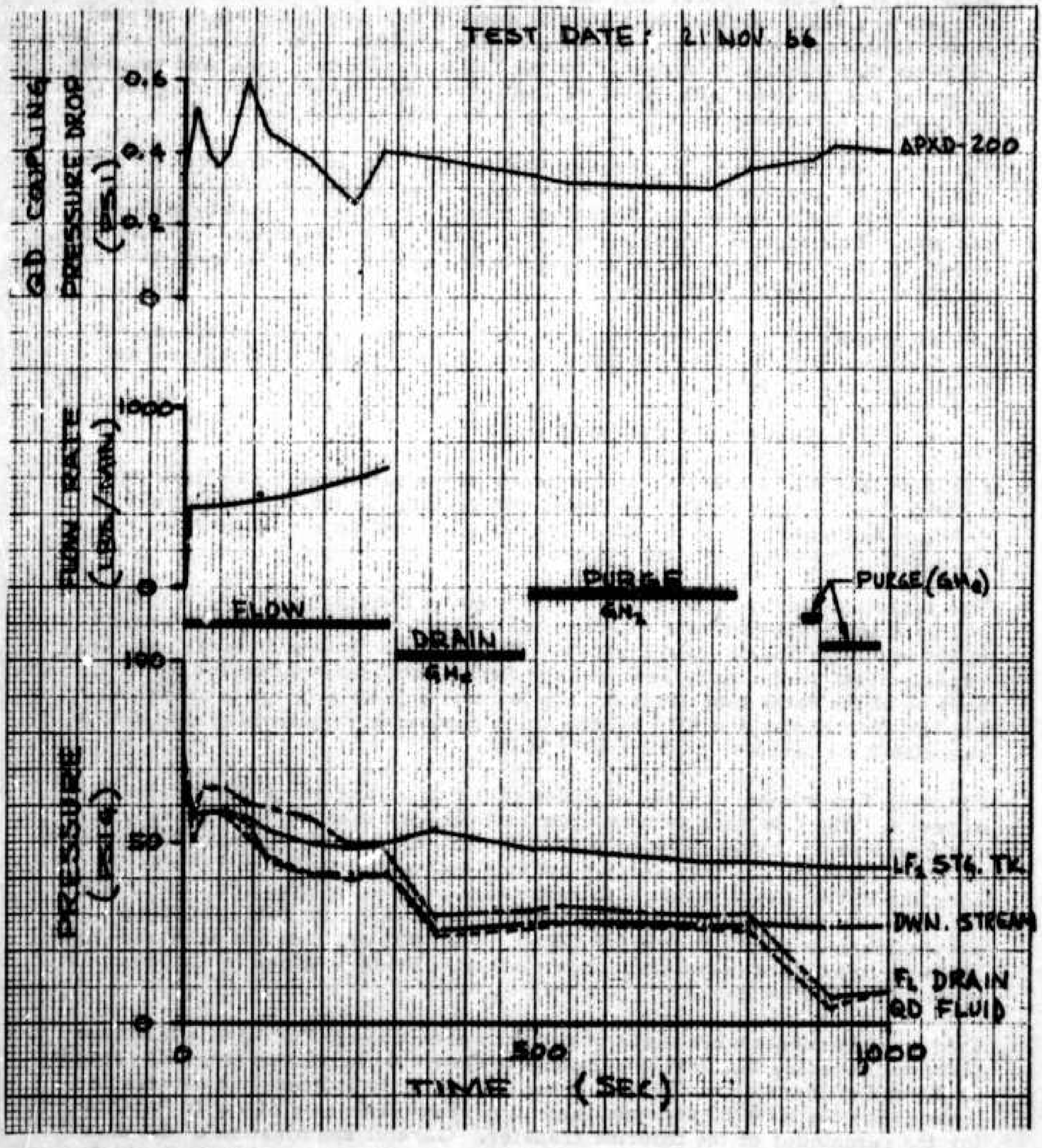


Figure 3-49. Pressure and Flow Rate Relationships Fluorine Flow Test No. 3

Two possible causes of this corrosion are presented as being the most likely. In the first, it would appear that the small quantities of fluorine leaking past the primary seal, combine with equally small quantities of moisture trapped at the Teflon seal to form the noted corrosion product. The second possibility suggests that fluorine is absorbed by the Teflon seal during test, and remains following test to react with moisture from the atmosphere surrounding the QD subsequent to stopping the shroud purge at the end of each test.

The exact mechanism or sequence of events resulting in the presence of both moisture and fluorine at the Teflon/stainless steel interface may be some combination of the processes described above, or some completely different process. This type of corrosion has been seen elsewhere in other components, specifically at the Teflon stem packings in the system valves as reported in paragraph 4. 5 of Reference 85.

The remainder of the QD coupling, both internal and external surfaces, was in excellent condition and revealed no evidence of damage or deterioration from exposure to fluorine.

d. Flow Test 4 and 5 (Tests 10 and 11)

Fluorine flow test 4 and 5 were conducted on the same day. The first was a short flow, lasting only 83 seconds, and resulted in the transfer of 640 lb of liquid fluorine through the QD. The average flow rate was 480 lb/min (38 GPM). See Figures 3-50 and 3-51.

The transient thermal character of the coupling during maximum thermal gradient and maximum rate of change of that gradient, are almost identical to those of test No. 3. See Figures 3-52 and 3-53. It would, therefore, be expected that the primary seal leakage during this transient period would also be of the same magnitude for the two tests. The average seal leakage for test No. 10 was 4×10^{-3} SCIM, which compares very favorably with that calculated for test No. 3 of 2×10^{-3} SCIM.

Fluorine flow number 5 directly followed the drain and purge of operations of test 4. The flow facility was completely chilled from the prior test with the Receiver Tank downstream of the QD containing approximately 50 gallons of liquid fluorine; the only section not cold and wetted with fluorine was the coupling itself. As a result of this increased degree of pre-chill, the system back pressure was greatly reduced, and the average flow rate increased proportionately to 720 lb/min (58 GPM). Thermal profiles and pressure-time characteristics are completely consistent with those obtained in the previous tests. (See Figure 3-51.)

Two measurements were made of primary seal leakage during this last flow test; one covering the first one-minute of flow and the second from 60 seconds to the end of transfer at 201 sec. Post test analysis indicated no detectable leakage for the first 60 seconds, and an average leak rate of 6×10^{-4} SCIM for the remainder of the fluorine transfer. Careful examination of the data and sequence of test events did not result in any explanation for the lack of detectable leakage during the initial portion of the transfer; all systems in the test setup operated normally. A possible explanation is that as a result

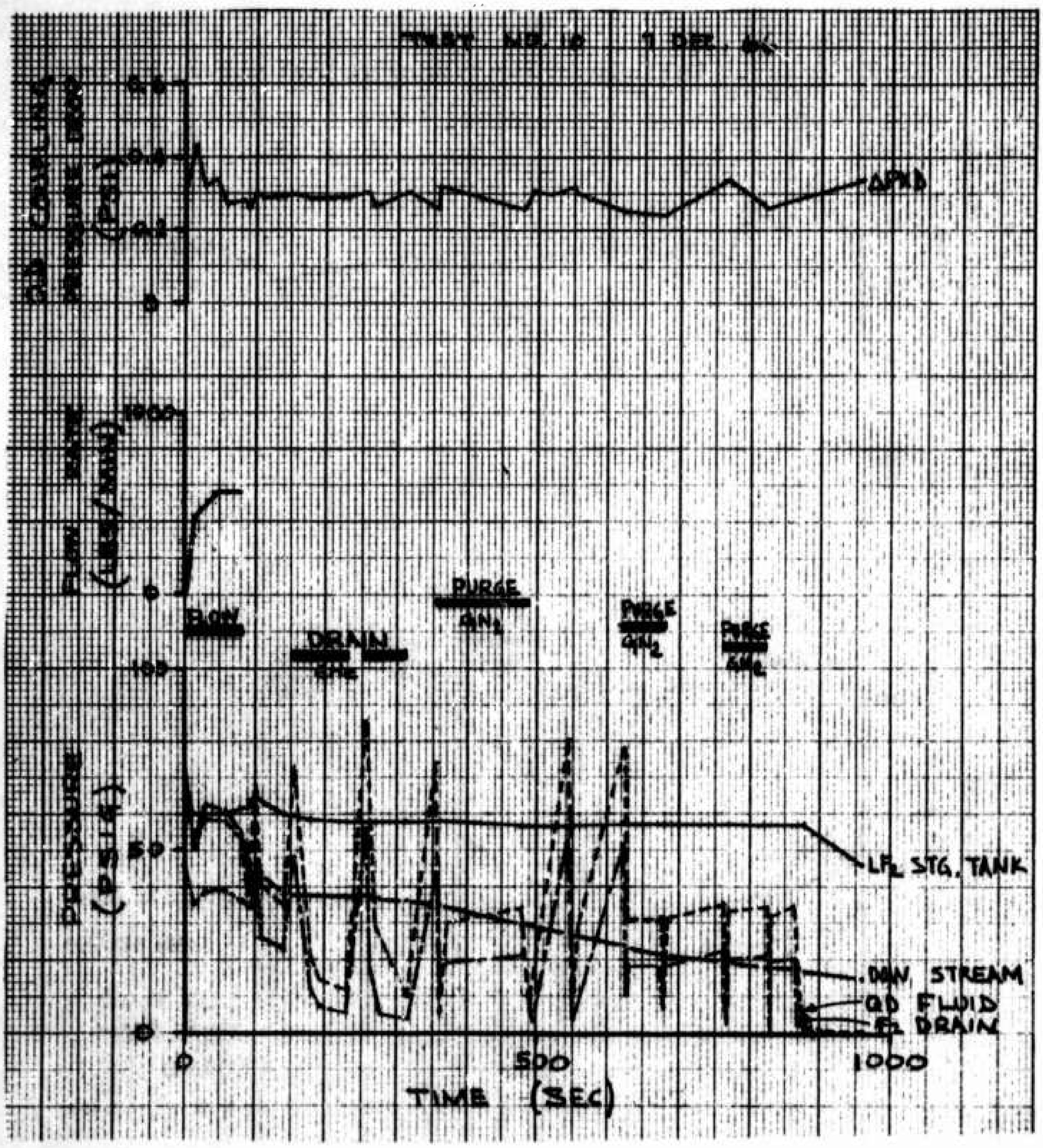


Figure 3-50. Pressure and Flow Rate Relationships Fluorine Flow Test No. 4

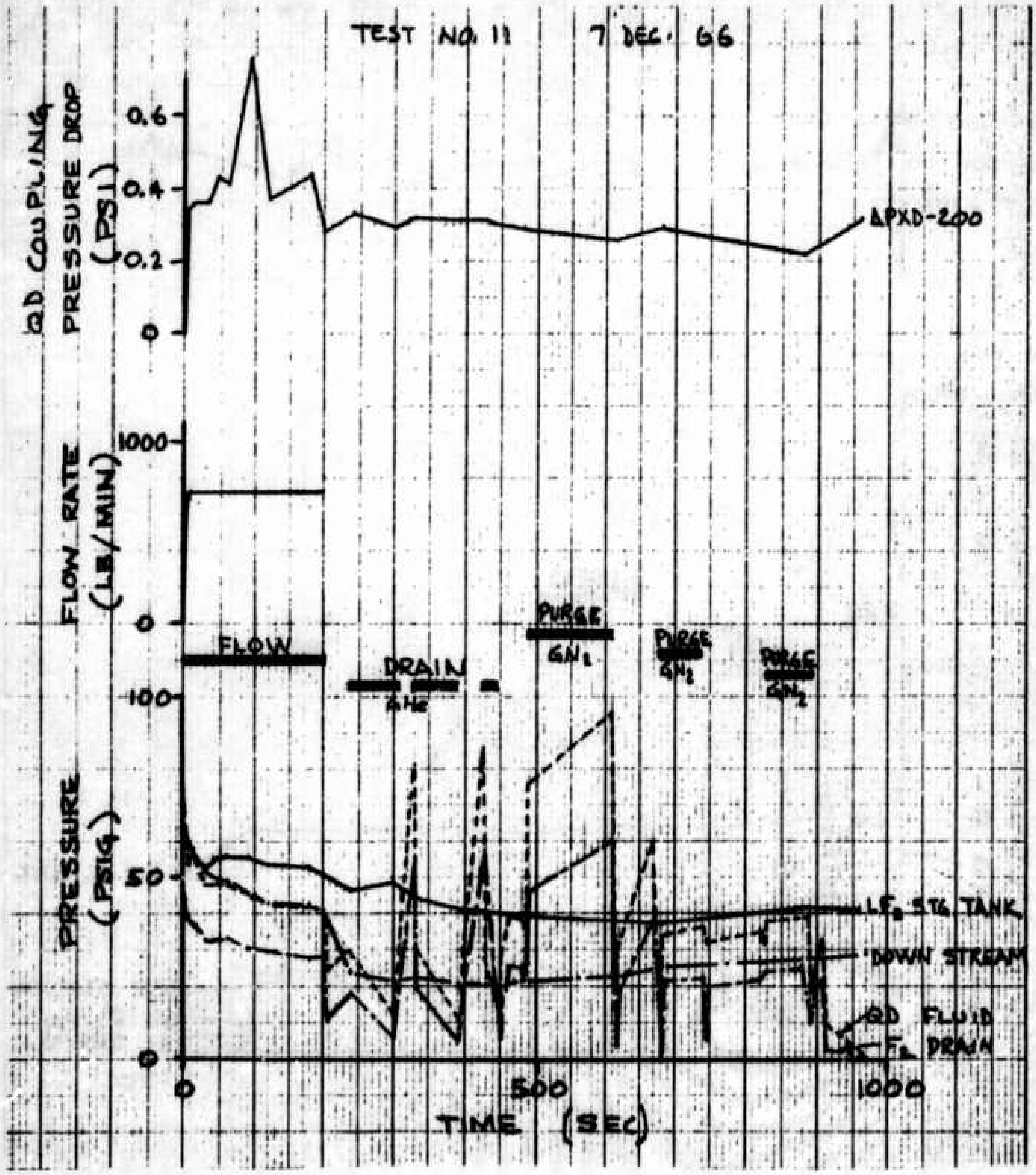


Figure 3-51. Pressure and Flow Rate Relationships
Fluorine Flow Test No. 5

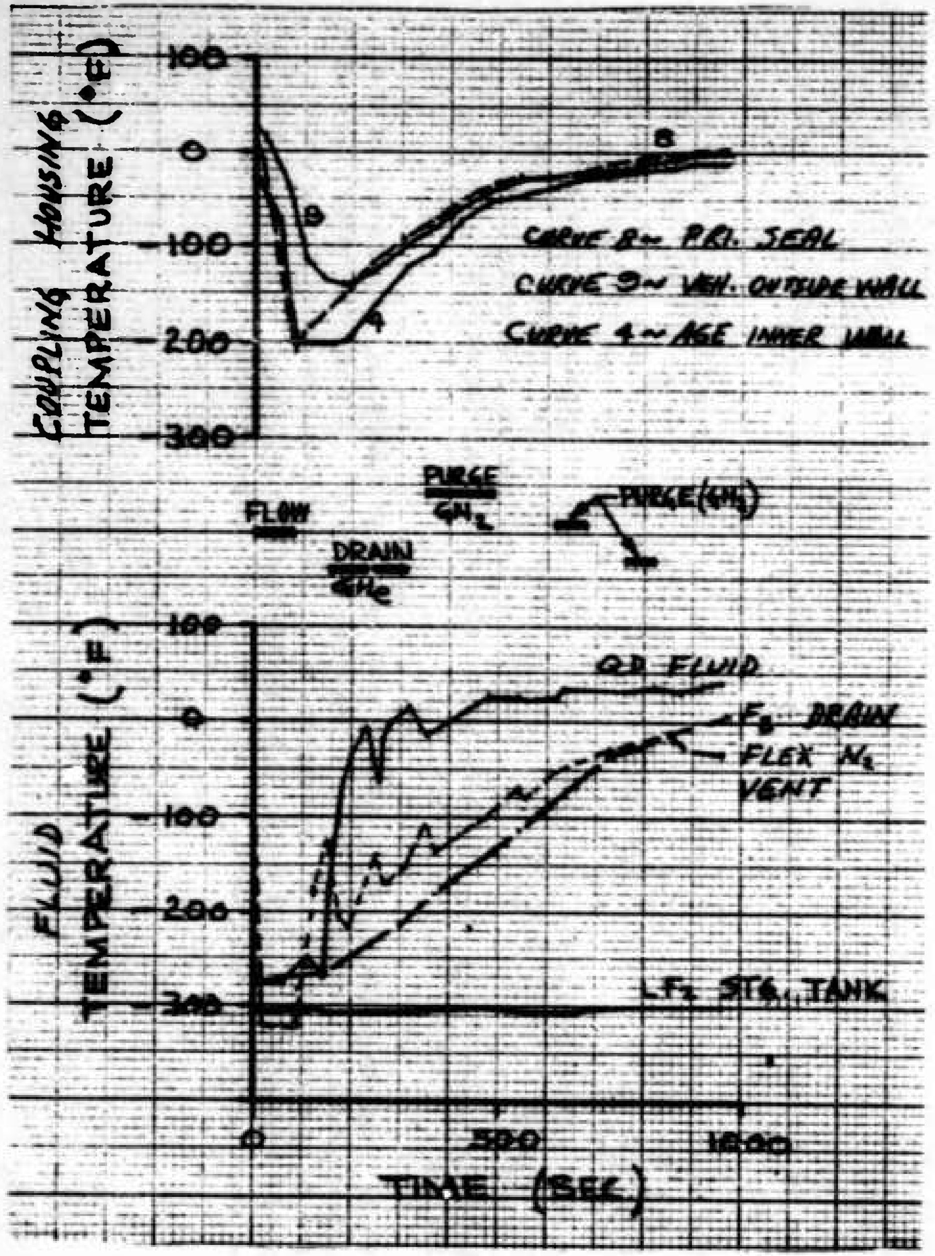


Figure 3-52. Temperature Relationships Fluorine Flow Test No. 4

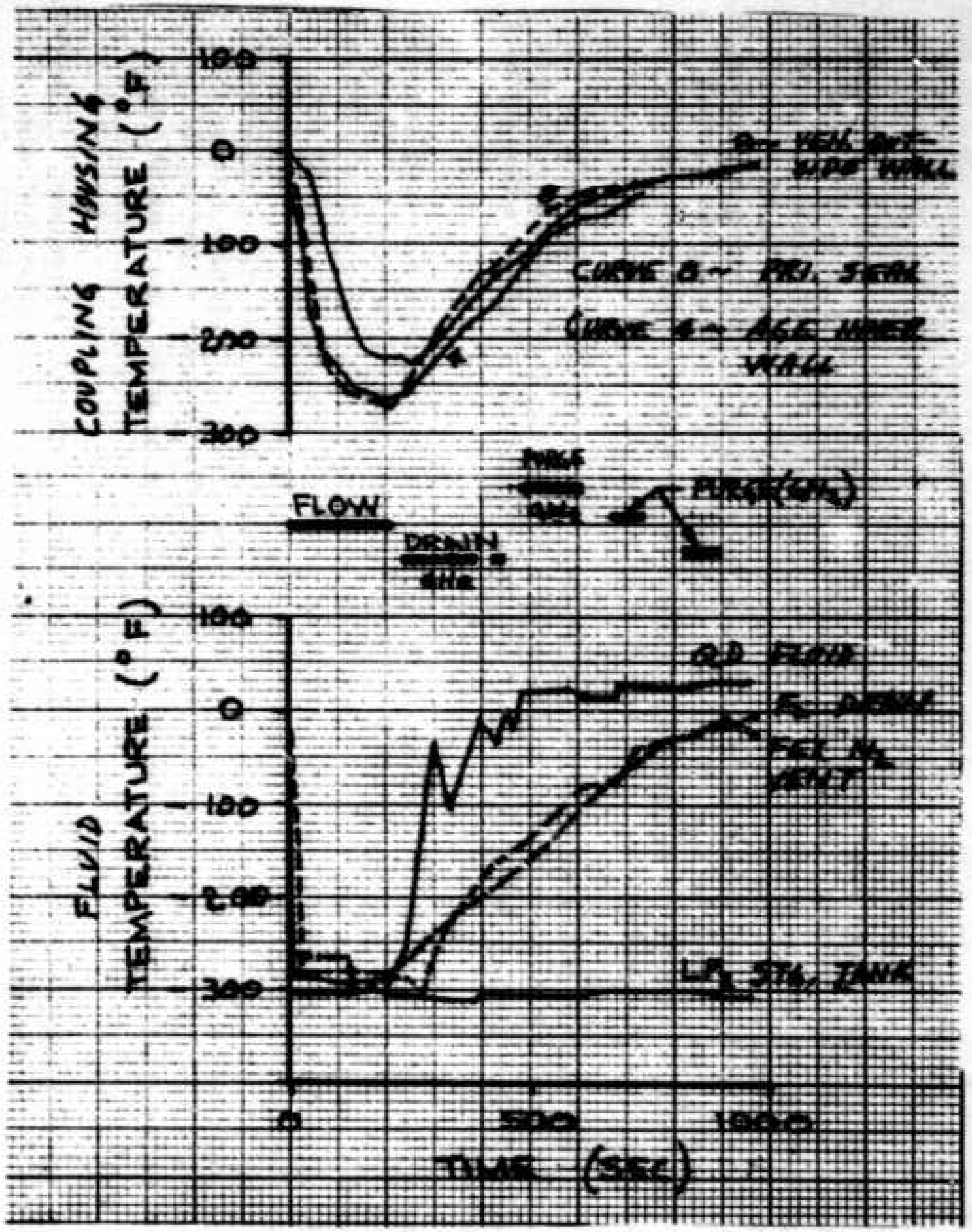


Figure 3-53. Temperature Relationships Fluorine Flow Test No. 5

of the prior test operation (flow test 4), the sealing surfaces were in intimate contact (possibly even mechanically locked) at initiation of flow test 5, and that during the initial portion of that test these interlocking contacts resisted the separation of the sealing surfaces, thus preventing fluorine leakage past the seal. Such a seal would be metastable and susceptible to being destroyed by the slightest perturbation. This undoubtedly happened during the second sample period and would suggest a probable cause for the indicated average leak rate for that period.

It is important to note that there were no adjustments of any kind made on the QD coupling between fluorine flow test 4 and 5, and that the capability of the sealing system to limit leakage to an acceptable value proved adequate in both cases.

The coupling was released and the AGE-half retracted along guide and support rails directly following the drain and purge operations of flow test 5. These operations proceeded without incident and confirmed expected results. Release pressure was approximately 200 psig, the same as experienced during the non-fluorine testing. Visual observation of the QD during separation via closed circuit TV and motion picture coverage, revealed that the coupling separated smoothly and with no evidence of any fluorine spillage or discharge from the separated coupling. Direct visual examination immediately following this separation revealed no evidence of any fluorine being present in the QD at time of separation. All hardware appeared to be in excellent condition.

The coupling and shroud were free of moisture at time of separation. However, as the open coupling remained exposed to the atmosphere of the test site, moisture did condense on its cold surfaces (approximately 20-30°F). The purged shroud again demonstrated its capability to preclude moisture from the QD coupling.

Post test examination revealed the presence of a slight surface stain on the inside machined 304L CRESS bore of the QD.

This stain appears in two separate forms; one as a general surface phenomena over a large portion of the bore, and the other appears as a discolored strip about 1/2-in. wide the length of the bore. The latter occurrance is located on the bottom of the coupling as it was used in test. It was in this area that the last of the liquid fluorine settled, prior to its removal by evaporation in the purge process. Similar stains have been noted throughout the fluorine facility in areas where final liquid fluorine removal was by evaporation (Reference 85, Page 44). In all cases, the stain was superficial, having no adverse effects on the component.

The aluminum primary seal gasket was removed following separation of the coupling and examined. The seal was essentially at ambient temperature at time of removal, but was covered with moisture condensed from the atmosphere while it was still cold. The moisture was wiped from the seal and the seal carefully examined. There was no visible evidence of corrosion or discoloration at that examination. The seal was then wrapped in aluminum foil to await further examination at a later date. Approximately five hours later the seal was removed from the aluminum foil only to find it covered with condensation. The moisture was again wiped from the seal to reveal the following:

1. On the AGE-half of the seal there was a green stain at the innermost indentation caused by the sealing serration. This stain appeared to be brown when viewed with a microscope.

2. The area of the seal on the AGE-half between the indentations made by the two sealing serrations had darkened to a near charcoal color. It is assumed that fluorine absorbed on the surface of the seal reacted with the condensed moisture to form an aluminum fluoride-hydrate.

Minor deposits were found at the Teflon-stainless steel interface of the purge cavity seal on the vehicle-half of the coupling. They were of the same nature as those found in the same area following flow test 3. Neither the Teflon nor the 304L stainless was damaged, and the deposit was removed from the CRES by rubbing with cotton soaked with water.

5.3.2.2 Fluorine Purge Tests

Purge data were obtained from all eleven (11) fluorine tests, 5 flow tests and 6 purge tests. The test setup and procedures were as outlined in 5.2.2 and 5.1.2.3.

A review of Figures 3-44 through 3-53 brings attention to several factors which were common to all 5 of the flow tests.

1. The drain period of the overall drain and purge operation was always conducted using gaseous helium as the pressurant.

2. The major purge interval following each drain operation always used gaseous nitrogen as the purge fluid.

Another common factor, not discernable from the presented data, is that gaseous helium was always used as the pressurant during purging through the sampling system for determination of fluorine concentration in the purge gas. This was done to assure uniformity in the sampling process. Also, at the beginning of each sampling flow, the sampling line was swept clear of any fluid trapped from the previous sampling. This was accomplished by flowing purge gas through GFP-210, shown in Figure 3-27, for 60 seconds prior to passing the sample gas through the methyl red solutions of the 1T20582 Sample System. Section 5.2.2 gives more details on this setup.

During tests 1, 2 and 3 draining of the liquid fluorine was through the transfer system isolation valve FP-200, shown in Figure 3-27, back into the transfer system. Draining for the remaining 8 tests was through the purge vent valve VP-200.

Procedural errors on both of the first two tests resulted in questionable drain and purge data. The failure to isolate the transfer system during purging in test 1 was discussed in 5.3.2.1. Test 2 data are of limited value in that the helium purges were inadvertantly ducted through the low capacity sampling system vent line rather than through VP-200 as planned. The resultant low purge rate proved ineffective in rapidly reducing the fluorine concentration within the QD-flexline combination. The questionable results of these two tests are presented in Table 3-3, which summarizes all 11 fluorine tests.

Figure 3-54 depicts graphically the resultant purge data for these tests. Tests 1 and 2 are not shown as their data were invalid as previously stated. Tests 5 and 6 used gaseous helium followed by gaseous nitrogen for purging, while the remaining 7 tests used only gaseous nitrogen for purging. The gaseous helium flow rate was approximately one-half that of the nitrogen, preceeded the nitrogen flow, and is assumed to be responsible for the data of tests 5 and 6 being shifted to the right. Had the flow rates all been equal, the data of tests 5 and 6 would have been expected to be more consistent with the remainder of the data. Curves showing corrected data are also shown in Figure 3-54.

The slope of these curves does not change as all data points were taken following GN_2 purges.

Data from test 3 is found to be far to the right of all other GN_2 purge data. The probable explanation for this is that the QD-flex line portion of the system contained an appreciable quantity of liquid fluorine at the beginning of the gaseous nitrogen purge operation, and that some fraction of that gaseous nitrogen purge time is used in draining and not in purging the line. This possibility seems justified as valve FP-200, through which the fluorine was transferred during the drain period, has a glove-type body which permits, in the case of the test installation, a maximum of one-half of the liquid to be removed from the QD-flexline by purging. Beyond that drain point, the gaseous helium passes over the liquid fluorine remaining in the QD-flexline and through FP-200 into the transfer system. The valve acts as a liquid barrier when the line is less than half full. When the purge gas vent valve VP-200, located on the bottom of the line being drained and purged, is opened, the bulk of the remaining liquid can then be removed. From that point on the operation becomes one of purging and not draining.

Drain time, through VP-200, were found from tests 10 and 11 to be 2-3 minutes starting with the QD-flexline full of liquid fluorine. If this line were only half full at the beginning of GN_2 purge, a 1-1/2 minute drain time would appear reasonable. It might even be longer, as the last of the liquid is removed more slowly.

Therefore, if it is assumed that the first 1-1/2 minutes of the indicated purge operation of test 3 were really used for draining, the concentration versus purge time curve for test 3 of Figure 3-54 should be shifted to the left by 1-1/2 minutes. A plot of such a shift in data is found on Figure 3-54.

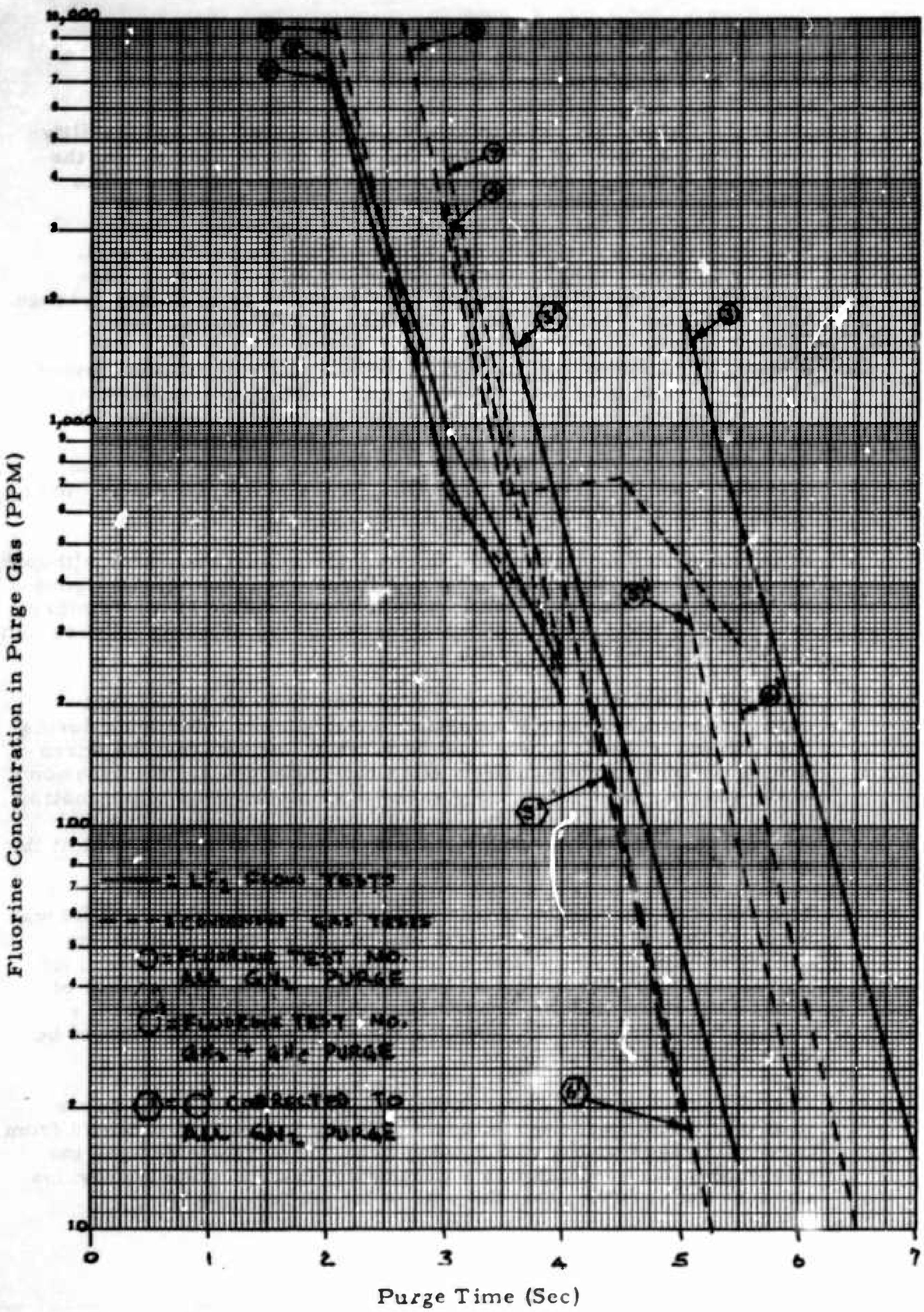


Figure 3-54. QD Coupling/Flexline Fluorine Purge Characteristics

6. SUMMARY OF PHASE II--Conclusions and Recommendations

The results of the Phase II effort effectively demonstrated the applicability of the Phase I criteria, and indicated that the basic design approach of the two test model QD couplings was adequate to meeting that criteria. The following summarizes the pertinent findings of the Phase II program:

1. Excellent sealing results were obtained from the primary seal, clearly demonstrating the capability of the selected sharp-edge serration and soft gasket sealing system to restrict fluorine leakage to less than 10^{-4} SCIM at both ambient and LF_2 temperatures.

2. Although both the single and double serration configurations tested for the primary seal indicated very good sealing characteristics when loaded to the 100% design load of 500 lb per linear inch of serration, the latter is superior and should be used on future designs because it has the inherent advantage of redundancy and provides greater assurance of sealing in the event of a minor imperfection on one of the sealing surfaces.

3. Engagement and latching of the QD was easily accomplished, although one problem of coupling hang-up was discovered during misaligned engagements. This resulted in non-uniform loading of the primary seal, but did not prevent adequate sealing of the coupling. Corrective action is outlined in paragraph 4.

4. On designs using the sharp-edge serration and soft gasket seal configuration which require angular misalignment tolerances during engagement, consideration must be given to the fact that the serration is not free to shift radially after the initial plastic deformation of the gasket. Therefore, to prevent possible hang-up of the mating halves during engagement the connector must be designed so that the serration initially engages and plastically deforms the seal at the radial location where final sealing will be achieved.

5. The seal load spring configuration used on the second test model was superior to that used on the first test model as evidenced during chilldown with LN_2 by a loss of only 17% (204 lb) of the initial load (1,200 lb) on the second model compared to a 66% (790 lb) loss of load on the first model. Therefore, seal loading springs with a spring rate similar to that used on the second test model should be used for future designs.

6. The 100% seal load indication provided by the slip washers on the first test model correlated closely with the load values obtained from the strain gages on the seal loading bolts. For future designs the slip washer load indicator is a worthwhile feature since it provides a means for verifying that the seal is loaded adequately.

7. The seal configurations used for the secondary seal (style AR10105, Omniseal) and for the seal cavity purge ports (Teflon O-rings) suffered a drastic reduction in sealing capability when the QD was chilled to cryogenic temperatures and should not be used for these applications on future design. This was due to shrinkage of the Teflon seals at a faster rate during chilldown than the surrounding stainless steel structure. MC 252 metallic seals were a satisfactory replacement fot the Teflon O-rings and it appears that the style AR10108 Omniseal should have better sealing characteristics for cryogenic applications than the style AR10105 Omniseal, and should therefore be used.

8. The release mechanism functioned faultlessly in all tests and was demonstrated to be over-designed. Correlation of the data on the coupling release loads and the release shear pin fracture strength obtained in a tensile testing machine indicate that the friction effect between the release cam and the latch retaining links was negligible. It appears that this is primarily the result of the hardness of the materials. The cam was heat treated to 170,000 psi and the links to 140,000 psi. No special smoothness requirements were specified. The cam was ground to approximately 63 microinches AA and the mating surfaces on the links were approximately 125 microinches AA. For future design on similar configurations the friction effect may be neglected (or reduced to a very low value) in the calculation of release loads.

9. Moisture, frost and ice were precluded from forming on the QD during liquid fluorine transfer by the use of a gaseous nitrogen purge within the anti-icing shroud used on the test models. The purge pressure within the shroud was less than 0.5 psig.

10. The one-piece anti-icing shroud used on the test model was functionally adequate. When the QD halves were connected the shroud could be moved axially a few inches to obtain access to the latching mechanism. During the testing this arrangement proved to be very cumbersome and unduly restricted access to the mechanism. A completely removable (two-piece) shroud should be provided on future designs.

11. The basic concept of a non-valved QD coupling for fluorine service was demonstrated to be both feasible and practical for a typical upper stage vehicle. Draining and purging of fluorine from the QD was accomplished under installation conditions which trap liquid fluorine, but was satisfactorily achieved in 3 to 4 minutes. This time could be significantly reduced (probably less than one minute) with installations designed to promote draining and purging of liquid.

12. Testing was conducted with the vehicle-half coupling mounted directly to an aluminum structural member, and a significant amount of heat transfer from this mounting structure to the QD was observed. This indicates that for a flight installation the vehicle-half QD adapter should be insulated from the vehicle structure to prevent excessive heat transfer from the structure into the QD coupling.

13. Materials used in the two test model QD couplings proved to be completely acceptable for their selected use conditions. No material degradation was found, although some superficial stains were noted.

14. Fluorine leak detection and measurement was easily and accurately obtained through use of wet-chemical analytical methods. Leak rates were average values over the sample period, which were usually 30 to 60 seconds in duration. These methods produced accurate results consistent with those obtained during liquid nitrogen testing with the Gas Chromatograph (thermal conductivity detector). Instantaneous leak rate measurements were not possible.

15. On both the first and second test models energy absorbing stops were provided for the latching hooks when they open for coupling release. Visual observations during the testing program indicated that very little energy was imparted to the stops during coupling release and therefore solid stops should be adequate for future design.

SECTION IV

PROTOTYPE QD DEVELOPMENT

1. INTRODUCTION

1.1 General

Development of a Prototype Quick Disconnect (QD) Coupling for liquid fluorine service was the activity of Phase III. This development included the preparation of a Preliminary Contract End Item (CEI) Specification for the prototype, a detail design complete with drawings and design analyses, fabrication of the coupling, and acceptance testing of the completed QD. The basic design was patterned after that of the -501 test model of Phase II. Several improvements were added as suggested by the Phase II test results, and are discussed in 3.2.

1.2 Nomenclature

Unless otherwise specified, the nomenclature of Section III, Paragraph 1.2, is used throughout Section IV.

2. PROTOTYPE COUPLING DESIGN REQUIREMENTS

Design requirements for the Prototype Quick Disconnect Coupling are found in Appendix XI, as Section 3 of Part I of the Preliminary Contract End Item Specification. These requirements cover performance, design, and construction applicable to the Prototype QD, and were developed from the design, fabrication and testing of two test model QD couplings during Phase II of this contract. Phase II is reported in detail in Section III.

The incorporation of these requirements into a prototype design is discussed in Section 3. The approach was to build and improve upon the design of the Phase II test models as the practical means for implementing the requirements of Section 3 of Appendix XI.

3. PROTOTYPE COUPLING DESIGN AND ANALYSIS

3.1 Performance Analysis

The prototype coupling design was based on the performance analysis for the Phase II test models (3.1 of Section III). Design improvements suggested in 6. of Section III required no new performance analysis. For example, the relocation of the secondary seal to lie in the same plane as the primary seal does not alter the coupling sealing analysis.

3.2 Layouts and Drawings

The prototype design was based on the second test model concept. The coupling retains the features of quick coupling by use of pneumatically actuated latches and redundant release from three independent release systems. The test results from the two test models indicated that several design improvements should be made. It was also recognized that the test models were heavier and more bulky than necessary. The following list represents the goals for basic design improvements considered for incorporation in the prototype design:

(1) Maintain same 2 inch internal diameter flow channel but scale down external envelope.

(2) Eliminate QD mating hang up on misaligned engagements.

(3) Improve low temperature leakage characteristics of the secondary seal.

(4) Reduce weight and safety margins.

(5) Improve purge line routing and give consideration to brazed or welded joints to eliminate potential leakage areas.

(6) Reduce release mechanism loads and make release mechanism more compact.

(7) Design for use of same pneumatic pressure source on latching pistons and release cylinders.

(8) Incorporate 100% seal load indicators.

(9) Reduce number of separable parts.

(10) Eliminate energy absorbing stops for latching hooks.

(11) Improve access to QD by redesign of anti-icing shroud.

(12) Utilize lighter weight bolted flanges for end connectors in lieu of ASA type pipe flanges.

The first problems investigated during the layout stage were those of improving the low temperature sealing characteristics of the secondary seal and eliminating the QD mating hangup on a misaligned engagement. Because of the excellent test results on the primary seal its configuration was not changed. The same 0.090 inch thick 1100-0 aluminum seal was used with two knife edge serrations of the identical size and shape used on the test models.

The hang-up problem noted during testing of the second test model was corrected by reducing to a minimum the distance which the vehicle-half serrations are recessed beyond the lip of the outer sleeve.

It appears that the secondary seal leakage problem is the result of a difference in the coefficients of expansion of the Teflon Omniseal and its surrounding stainless steel structure. Because the Teflon seal has a higher expansion coefficient than the stainless steel, it shrinks away from the outer sealing surface (and seals tighter against the inner sealing surface) as the temperature is lowered. To circumvent this adverse effect a concept with a radial flange on its outer diameter was investigated. The Teflon flange can be mechanically locked to the outer surface, thus preventing separation and leakage when the unit is chilled. Several variations of the Aeroquip style AR10108 Omniseal were studied. This Omniseal has a thin Teflon flange on its outer diameter that can be mechanically gripped by the seal retaining device. Aeroquip recommends the use of an annular serration on the sealing side of this flange to assure a positive seal.

The first impression of the AR10108 Omniseal was that the thin ($\frac{0.027}{0.024}$ thick) flange might be vulnerable to handling damages and possible variations were evaluated. A typical example is shown in Figure 4-1. On this concept the extended flange was made thicker and wedge shaped so that as the seal shrinks and moves radially inward on chilldown the wedge shape would compensate for the reduction in flange thickness. The possible effects of the proposed variations were discussed with Aeroquip Engineers who pointed out some of the problems which had been encountered in the development of the Omniseal. A fundamental requirement which they had discovered during the seal development was that the amount of squeeze on the flange must be limited. If too much compressive load is applied and the flange material is forced to flow radially inward it will cause the basic sealing section of the Omniseal to roll and thus destroy its sealing capability on the inner diameter.

Another concept which was evaluated for the secondary seal is shown in Figure 4-2. It is an all metal concept consisting of a labyrinth type face seal made integral with a bellows type seal loading device. A threaded retainer attaches this seal to the AGE-half of the QD and an AFRPL Bobbin type seal is utilized to seal the attached end of the secondary seal. Although the desirability of a metal seal for a fluorine service component is recognized it was felt that there were too many unproven facets on this concept and development beyond the scope of this program might be required to make it workable.

The Teflon seal concept appeared to be the most feasible for this application. It was decided that without going through a seal development test program it would be unwise to modify the Aeroquip seal design and therefore the prototype QD has been designed to utilize the existing style AR10108 Omniseal.

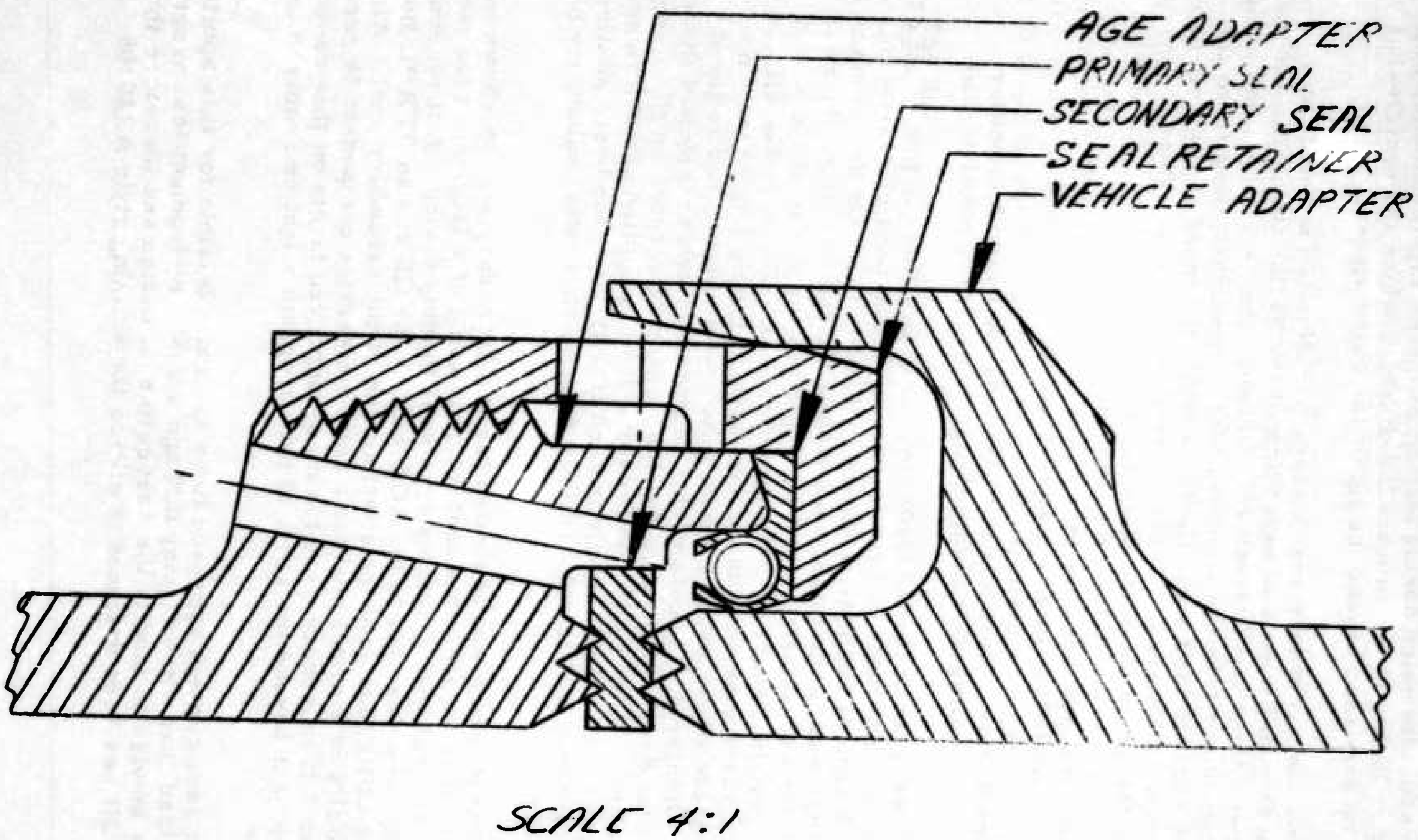


Figure 4-1. Modified Omniseal Design

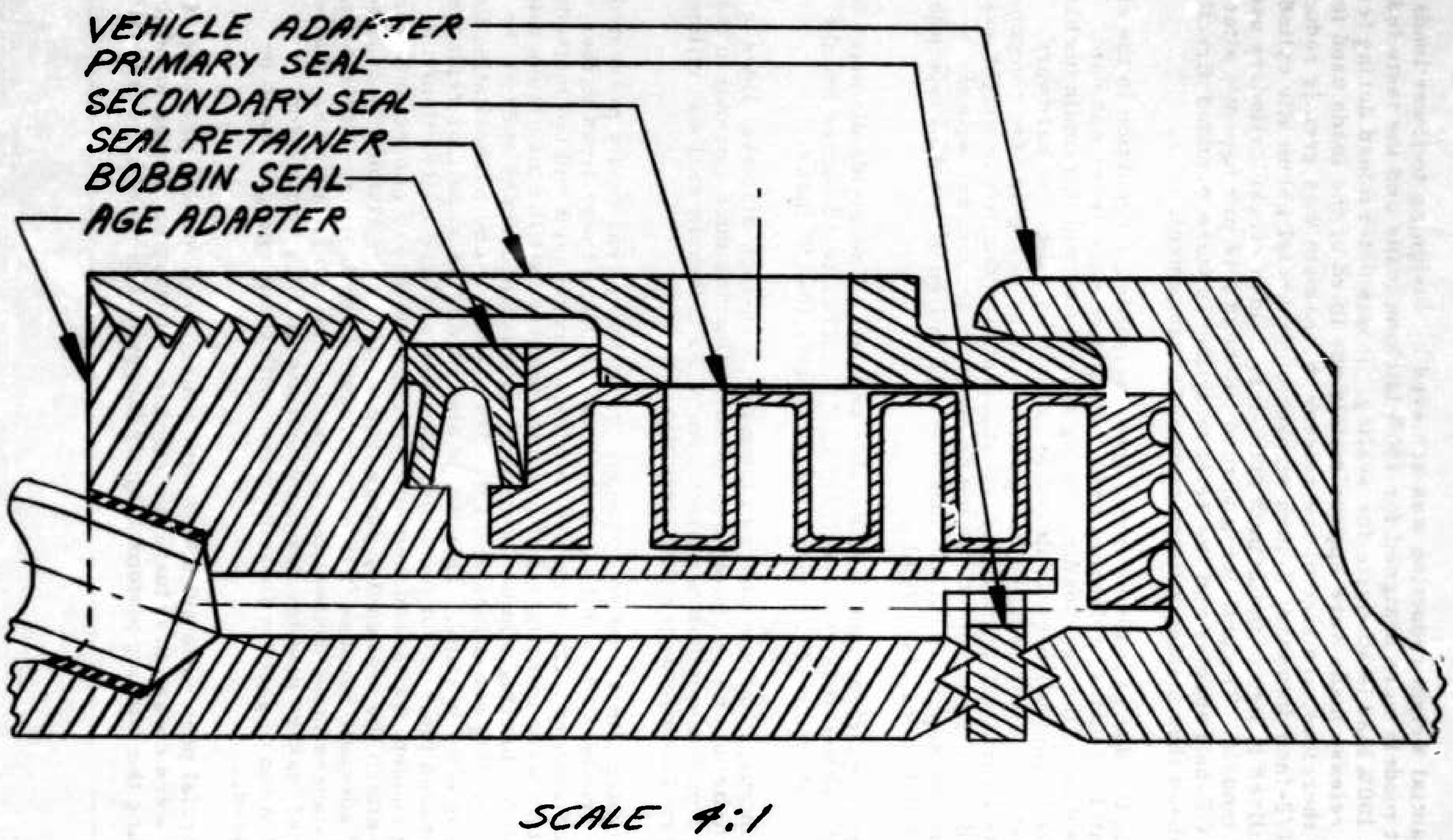


Figure 4-2. Metal Secondary Seal Design

A substantial weight reduction was achieved by designing to lower loads. The test models were designed for 150% latching loads and the tests indicate that the 100% load is adequate for sealing. It was determined during testing that the release loads were approximately one third of the loads used for design, therefore, the size of the release mechanism was greatly reduced. Two 1-1/2-inch diameter, 2-inch stroke, commercial pneumatic cylinders were utilized in lieu of the 2-inch diameter, 3-inch stroke cylinders used on the test models. The anti-icing shroud bulkhead was permanently attached to the AGE-half adapter and the release cylinders were mounted directly on the bulkhead thus making a more compact arrangement.

Reducing the design loads as noted above permitted a reduction in the size of the latching hooks, retaining links, and the release lever and cam. With the exception of the seal loading spring assemblies which remain unchanged, weight reduction has been achieved in essentially all of the hardware components by using reduced design loads and by designing the components with less liberal safety margins. A substantial reduction in weight was achieved by utilizing bolted flanges designed in accordance with the procedure in Report No. RTD-TDR-63-1115 in lieu of the ASA type pipe flanges used on the test models.

The overall envelope was considerably reduced. The inside diameter of the anti-icing shroud was reduced from 12-1/4 inches to 10 inches and the shroud length from 14 inches to approximately 10-1/2 inches.

The main purge line was changed from two 5/16-inch diameter lines to one 1/2-inch diameter line and enters the main fluorine duct external to the shrouded mechanism compartment. An AFRPL Bobbin seal was utilized at the external connector for the purge line.

The two purge lines used to scavenge the primary seal cavity presented a greater problem. The initial concept was to braze these lines to the AGE-half adapter. However, as the design progressed and the methods of fabrication were investigated it became apparent that the high temperature required for brazing would distort critical machined areas such as the primary sealing serrations and threaded areas thereby necessitating final machining after brazing. This would also mean that repair or replacement of the brazed tubes is not possible. Because of these restrictions the brazing concept was abandoned and tapered pipe thread connections were used to attach the seal cavity purge tubes. This type connection is considered adequate because it is a low pressure application. Under normal circumstances these connectors will not be exposed to fluorine. If a small amount of leakage past the primary seal should occur only a low concentration of gaseous fluorine mixed with the purge gas would be anticipated.

Commercial pneumatic cylinders with a maximum working pressure of 750 psi were chosen to actuate the release mechanism. It was found that by making the latching pistons slightly larger and the piston rods smaller in diameter that 750 psi would be adequate to compress the seal loading springs and extend the latching hooks for coupling engagement. Therefore, these changes to the pistons were incorporated so that a common pressure source can be used for both the latching and separation functions.

Energy absorbing stops were provided on the test models to prevent damage to the latching hooks when they were released and forced to swing outward after the coupling release shear pin is fractured. It was expected that the cable force applied to break the pins plus the energy stored in the seal loading springs would impart an appreciable amount of momentum to the hooks on separation. However, it was observed during tests of the release mechanism that the hook impact loads against the stops were small. Therefore solid stops were considered adequate for the prototype coupling.

The 1T20586-1 test model has a device for indicating 100% seal load based on sensing the deflection of the seal loading springs. The 1T20586-501 test model did not incorporate the device. Based on the experience with these two units it was decided that the 100% load indicator is very much worthwhile as a visual inspection aid to assure that the seal is adequately loaded, and thus it has been included in the prototype design.

The anti-icing shroud for the test models was a one piece cylindrical shroud designed to be moved axially to uncover the QD latch and release mechanism. During the testing this was discovered to be a cumbersome arrangement which made accessibility to the QD difficult. In the prototype design the shroud has been split into two semi-cylinder half-shells held together with quick release latches. Thus the shroud can be completely removed to provide unobstructed accessibility to the mechanism.

The prototype design has been put on a drawing format in conformance with MIL-D-70327. The top drawing 1D00800 (see Appendix XII) depicts the complete assembly including both coupling halves. The details and subassemblies are defined in the drawing series 1D00801 through 1D00850 inclusive, and are located in Appendix XII. Figure 4-3 is a typical cross section showing the interface between the two coupling halves and the latch and seal loading spring arrangement. Figures 4-4, 4-5, and 4-6 are photographs of the coupling and its two halves.

Weight of the prototype coupling was determined to be:

1D00801 (Vehicle-half weight) = 9 lb

1D00802 (AGE-half weight) = 47 lb

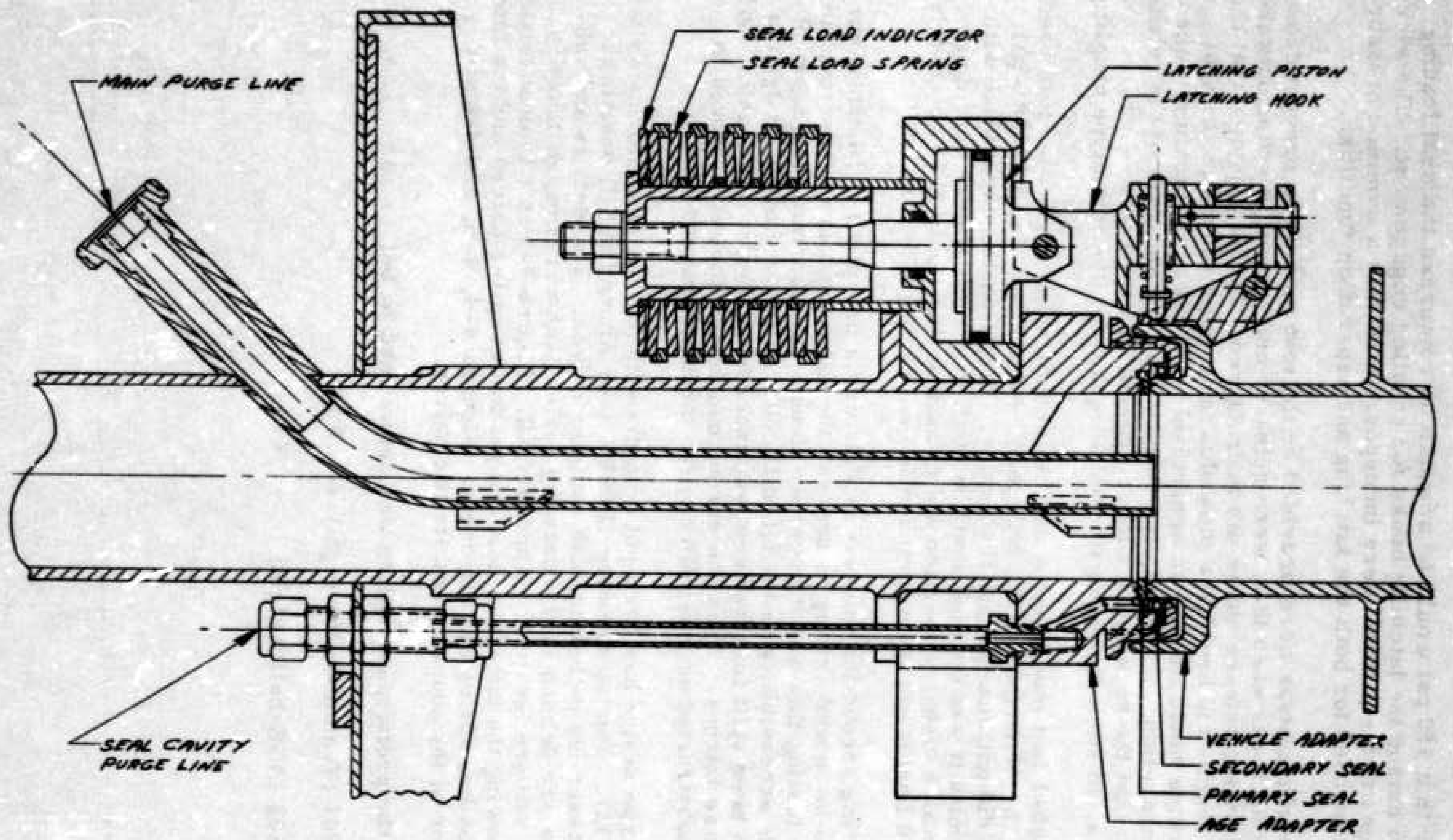


Figure 4-3. Profile Section of Prototype QD

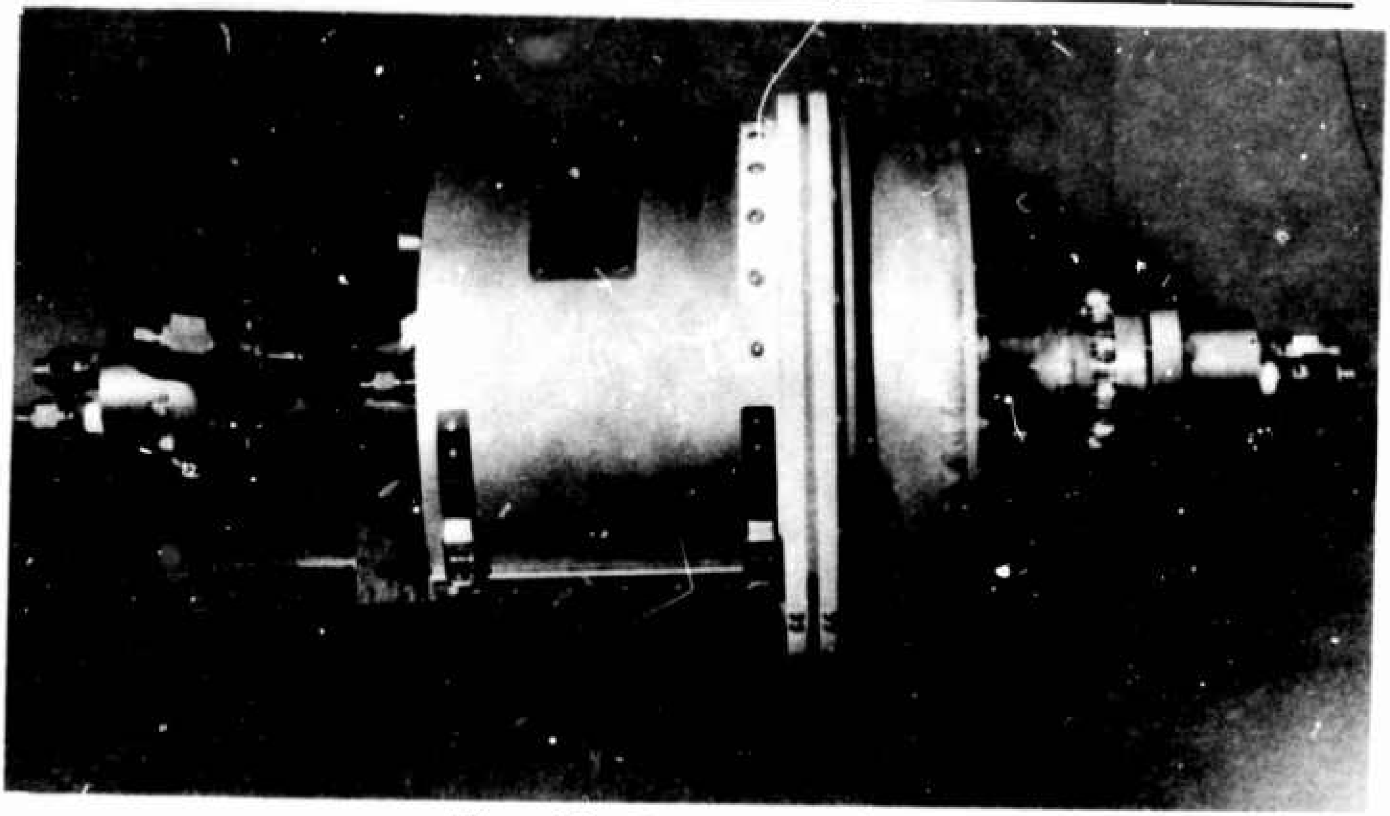


Figure 4-4a. Prototype QD Coupling

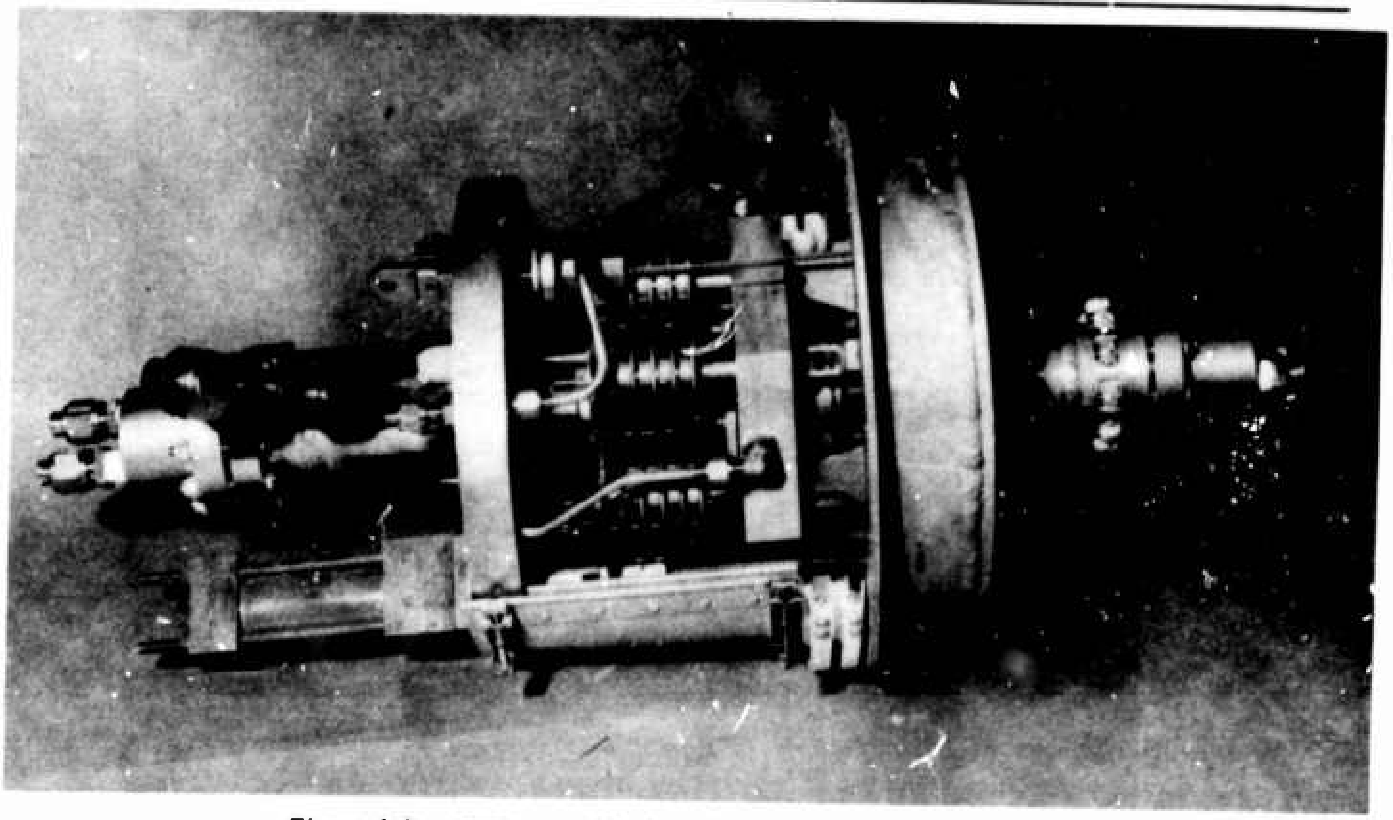


Figure 4-4b. Prototype QD Coupling, One-Half Shroud Removed

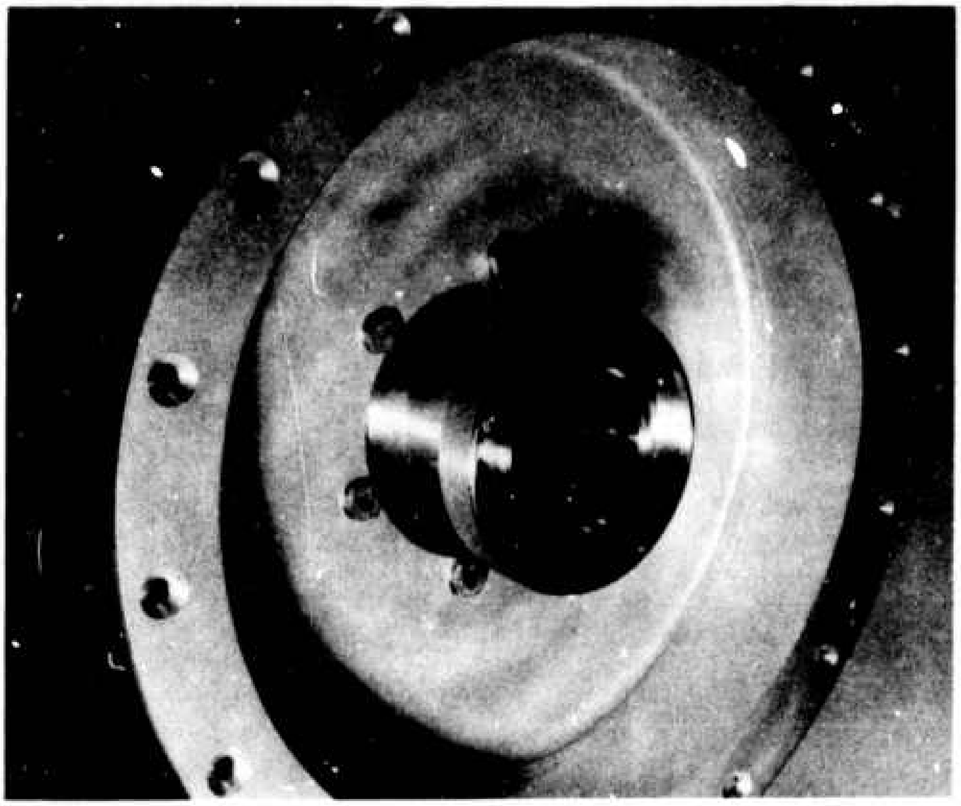


Figure 4-5. Prototype QD, Vehicle-Half

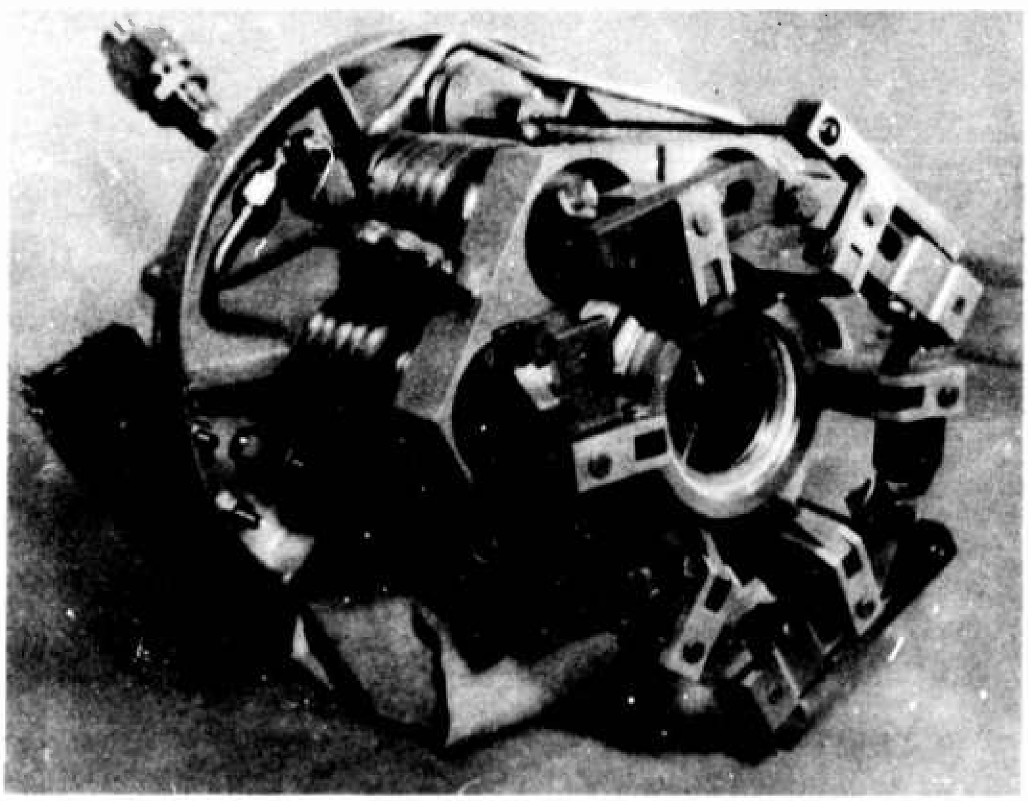


Figure 4-6. Prototype QD, AGE-Half

3.3 Design Analysis

A structural analysis was conducted on those highly stressed components such as the latching and release mechanisms. The basic seal loading was maintained at the same 1200 lbs per latch used for the test models, therefore, the seal loading springs are identical to those used on the 1T20586-501 Test Model and the spring analysis in 2.2, Appendix VII is applicable. The body structure of the two coupling halves was reduced in section thickness to reduce weight but rigidity is still the controlling factor for these parts. Thus the stress level is still low and an analysis was unnecessary. The components for the latching and release mechanism were redesigned to remove weight. Detail structural analyses are provided in Appendix VIII.

4. FABRICATION, ASSEMBLY AND CHECKOUT

Because of the similarity between the prototype model and the second test model the same outside manufacturer, Allied Pacific Mfg. Company, was utilized to fabricate the metal parts for the prototype. For those parts, made from A-286 CRES steel and René 41, the manufacturing procedure was changed in the following respect. Whereas the test model parts were machined from annealed material and then heat treated, the material for the prototype parts was purchased in the heat treated condition and the components were machined directly from these high strength materials.

A problem was experienced in the procurement of the René 41 raw stock for the separation mechanism cam and lever. A 1 x 1-1/2 x 36 (inches) bar of the material was forged and heat treated to 170,000 psi minimum ultimate tensile strength in accordance with specification AMS 5713. This specification requires that a specimen be machined from the material stock and subjected to a stress rupture test at 1350°F with 85,000 psi axial stress applied and shall not rupture in less than 30 hours. After failing four (4) of the specimens in less than the specified time the necessity for meeting this requirement was re-evaluated. Since the environment for the part will never exceed normal ambient temperatures and because the normal loading will be only of very short time duration it was decided that the high temperature properties which this test was designed to verify are not essential for this application. Therefore, the requirement was waived and the material was accepted for manufacture of parts thus averting further delay in the manufacturing schedule.

One other detail part contracted to an outside manufacturer was the Teflon bellows used to seal the anti-icing shroud against the simulated vehicle surface. This contract was let to The Fluorocarbon Company.

The welding and radiographic inspection of all QD weld joints which will be directly exposed to liquid fluorine was accomplished in the Douglas shop. Welds in non-critical areas which did not require inspection were made by the component fabricator, Allied Pacific. The completed components were delivered to Douglas for inspection, a limited amount of component testing, cleaning for fluorine service, assembly, and preliminary checkout prior to testing.

Two specimens of the release mechanism shear pin (P/N 1D00834-1) were fractured in a tension testing machine to establish the actual breaking strength. The two specimens were selected at random from the lot of 15 manufactured shear pins, all of which had shear sections cut to the minimum diameter of 0.145 inches. One pin fractured at 4255 lbs and the other at 4180 lbs load. These loads indicate an ample margin of safety over the pin design load which was calculated to be 1220 lbs and are within the 5000 lbs breaking force used for designing the release mechanism. Figure 4-7 is a typical load-deflection curve for the shear pin destruction test. The deflection was measured by the head travel of the testing machine and includes not only the shear pin deflection but also the deflection in all the connecting linkages.

The component parts were taken to the Douglas Fluorine Facility (A23) for cleaning, assembly and checkout prior to acceptance testing. Assembly and checkout were accomplished with the following minor difficulties:

A. Latching Piston O-ring Leakage

The S0046T112 Teflon O-ring would not effect an adequate seal between the Latching Piston (1D00814) and the Cylinder Block (1D00813). The apparent cause was that the Teflon O-ring would not recover from the severe physical distortions received during its insertion into the Cylinder Block. This problem was adequately solved by using a S0046S112 Silicon O-ring.

B. Release Lever and Link Interference

The Release Lever (1D00832) would not fit into the 0.500 slot of the Release Cam Retaining Link (1D00830) due to an interference between 3.50 lever arm of the Release Lever and the 0.84 x 0.250 lever stop of the Retaining Link. This problem was eliminated by reducing the thickness of the stop from 0.250 to 0.190. This fix is reflected in the "A" change to the 1D00830 drawing.

C. Latching Hook Hangup on Seal Retainer

During assembly of the AGE-half of the QD, difficulty was encountered in completing the hookup of the 1D00830 and 1D00829 links. The problem was the inability to install the third and final NAS 1004-7A bolt as the attachment holes in the links could not be brought together. The problem was that the 1D00816 Latch was in the fully extended position and was interfering with the flange on the 1D00828 Seal Retainer. This prevented the Latching Hooks (1D00815) to move radially inward, thus, preventing the final alignment of the attachment holes in the links.

Assembly was possible by partially deflecting each of the six latches into the Latching Hooks, thus eliminating the interference problem. The operation was cumbersome and required two persons to effect the assembly; one to hold the latches in a deflected position, and the second to insert the final attachment bolt.

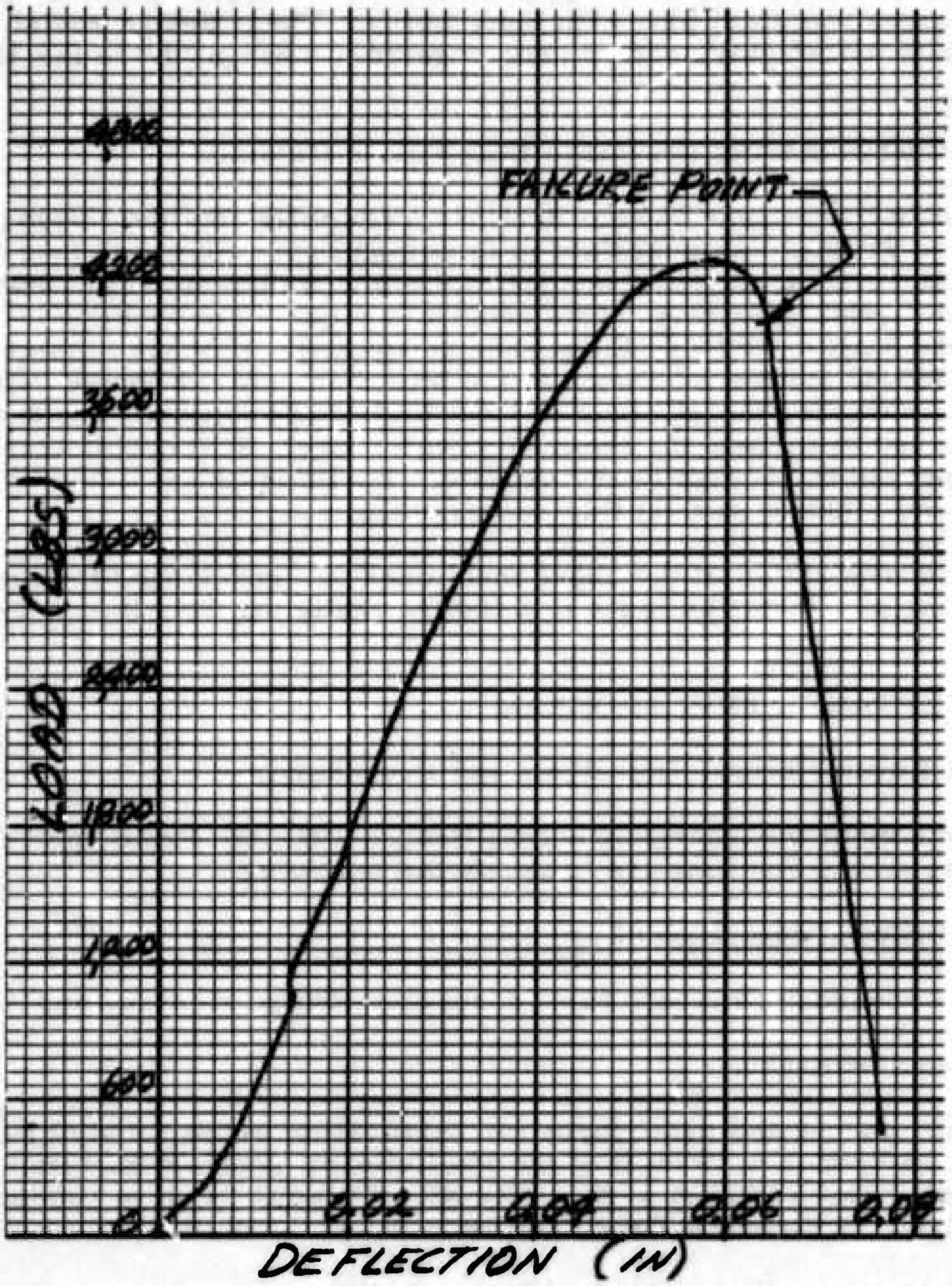


Figure 4-7. Typical Load-Deflection Curve for Shear Pin Destruction Test

A satisfactory solution was found which eliminated the hangup altogether; the flange on the 1D00828 Seal Retainer was removed. The function of the flange, that of providing spanner wrench slots used during assembly and removal operations, was replaced by providing two 1/8-inch diameter holes, 180° apart, on the front face of the Seal Retainer. Assembly and removal torque for the Seal Retainer is applied by using a simple hand held tool which engages two steel pins with these holes. These design revisions proved quite satisfactory and are documented in change "B" to the 1D00828 drawing.

D. Containment of the Purge Line Nozzle Retainer

The 1D00836 Purge Line Nozzle Retainer assembles into the 1D00812 Main Line Purge Fitting. An oversight in drawing preparation, and thus in subsequent fabrication, failed to incorporate a 0.625 diameter by 0.060 counterbore in the 1D00812 Fitting. This recess in required to permit the insertion of a standard AN960C616 CRES washer between the 1D00836 Retainer and the MS27855-12 Bobbin Seal used at the inlet flange of the Purge Fitting. Without this washer the retainer was not locked in position. The fitting was reworked to include the required counterbore. Subsequent assembly and test proved the design to be adequate. Revision "A" to drawings 1D00812 and 1D00802 reflect this design change.

With the incorporation of the above mentioned design changes the prototype QD coupling was installed in its test fixture ready for Acceptance Testing (see 5.).

5. ACCEPTANCE TEST PROGRAM

5.1 Test Requirements, Objectives and Procedures

The objectives of the Acceptance Test Program for the Prototype Fluorine Quick Disconnect Coupling are to verify the following:

(a) Drawing compliance.

(b) Standards of manufacture, manufacturing processes, and production.

(c) Performance.

Test requirements and procedures for verification of the noted objectives are found in Section 4, Part II of the Preliminary Contract End Item (CEI) Specification which is part of Appendix XI. These tests were conducted at the Douglas A23 Fluorine Flow Facility.

5.2 Test Methods, Apparatus and Setups

The wooden test fixture used to support the test model QD's during the non-fluorine testing of Phase II, served the same function for these Acceptance Tests. Figure 4-8 is a photograph of the 1D00800 Prototype QD in this fixture, and connected ready for test. This apparatus was installed at the Douglas A23 Fluorine Flow Facility.

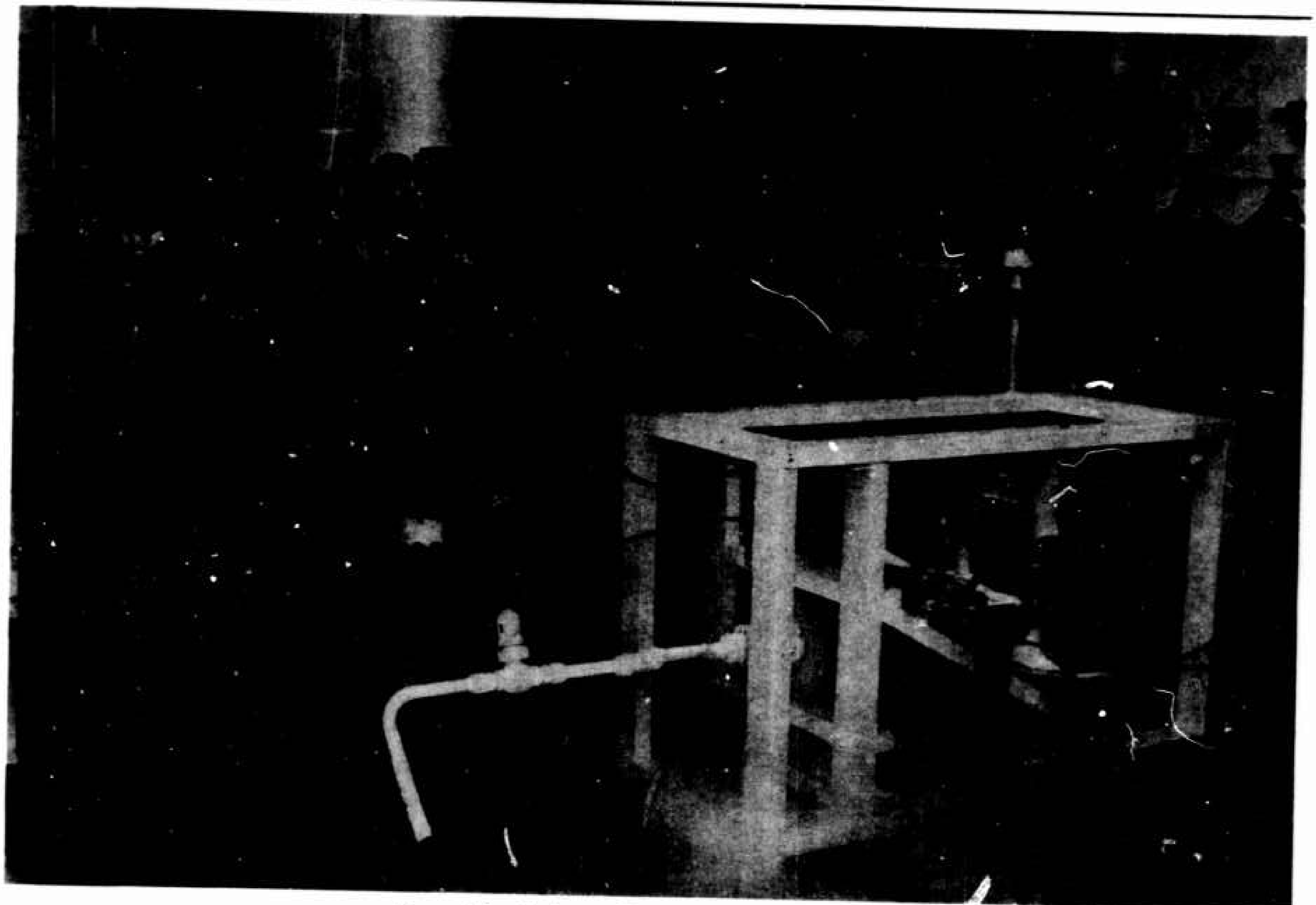


Figure 4-8. Protorype QD Assembled in Test Setup

The vehicle-half of the coupling was rigidly mounted to the test fixture and connected to the liquid nitrogen vent as shown. The AGE-half was unattached to the fixture except by two chains which were used only to restrict its overall movement in order to preclude damage to the QD upon separation of the coupling.

Primary seal leakage was detected and measured by pressurizing the QD with gaseous helium while sweeping gaseous nitrogen through the seal cavity, and detecting the presence of helium in the sweep gas. More specifically, a capillary leak port was placed in the system as shown in Figure 4-9, for extracting mass spectrometer samples from the sweep gas. This technique provides a wide leak measurement range for the coupling seal while maintaining the sensitivity of the mass spectrometer. The system was calibrated by introducing into the nitrogen sweep gas an accurately measured amount of helium. Two flow meters were used. One was used to establish the sweep gas flow for all measurements and the other was used to determine the flow of calibrating gas.

Engagement, latching and sealing of the coupling halves proceeded in much the same manner as discussed in 5.2.1.5 of Section III, for the 1T20586-501 test model. The sequence of events followed those outlined in 4.2.3 of Part II of the CEI Specification (Appendix XI).

Disconnect operations followed the procedures outlined in 4.2.3 of Part II of the CEI Specification. The apparatus and methods used to carry out these procedures were the same as those described in 5.2.1.6 of Section III.

5.3 Prototype QD Coupling Test Results

The prototype QD was coupled two times and released once following the assembly and checkout operations of 4.0. The rapid manual connect mode of operation proved adequate, requiring 750 and 780 psig latching cylinder pressure, respectively, for the two connections. Had it been necessary, the latching pressure could have been increased to 1000 psig to permit maximum travel of latching hooks. More than adequate piston travel is provided by the prototype QD design to insure engagement and latching together of the coupling halves. During the second engagement, it was noted that one of the latching hook-piston assemblies had rotated about its axial axis by about 30 degrees. This rotation was easily corrected prior to release of the latching load by rotating the latching hook back to its neutral position. A visual check for proper alignment should be made prior to engagement.

Upon release of the latching pressure, the seal loading springs provided adequate force to firmly secure the AGE-half to the Vehicle-half of the QD. Visual inspection revealed that all six (6) latching hooks were properly engaged. Examination revealed that the six (6) 1D00824 Seal Load Indicators were not tight following each of the two connections. The gap between the indicator and the seal load spring was less than 0.002 in. in all cases (less than 8.3% below the nominal design load of 1200 pounds). Since the gaps were uniform and the spring loads were very close to nominal, no adjustments were made prior to performing primary seal leak checks.

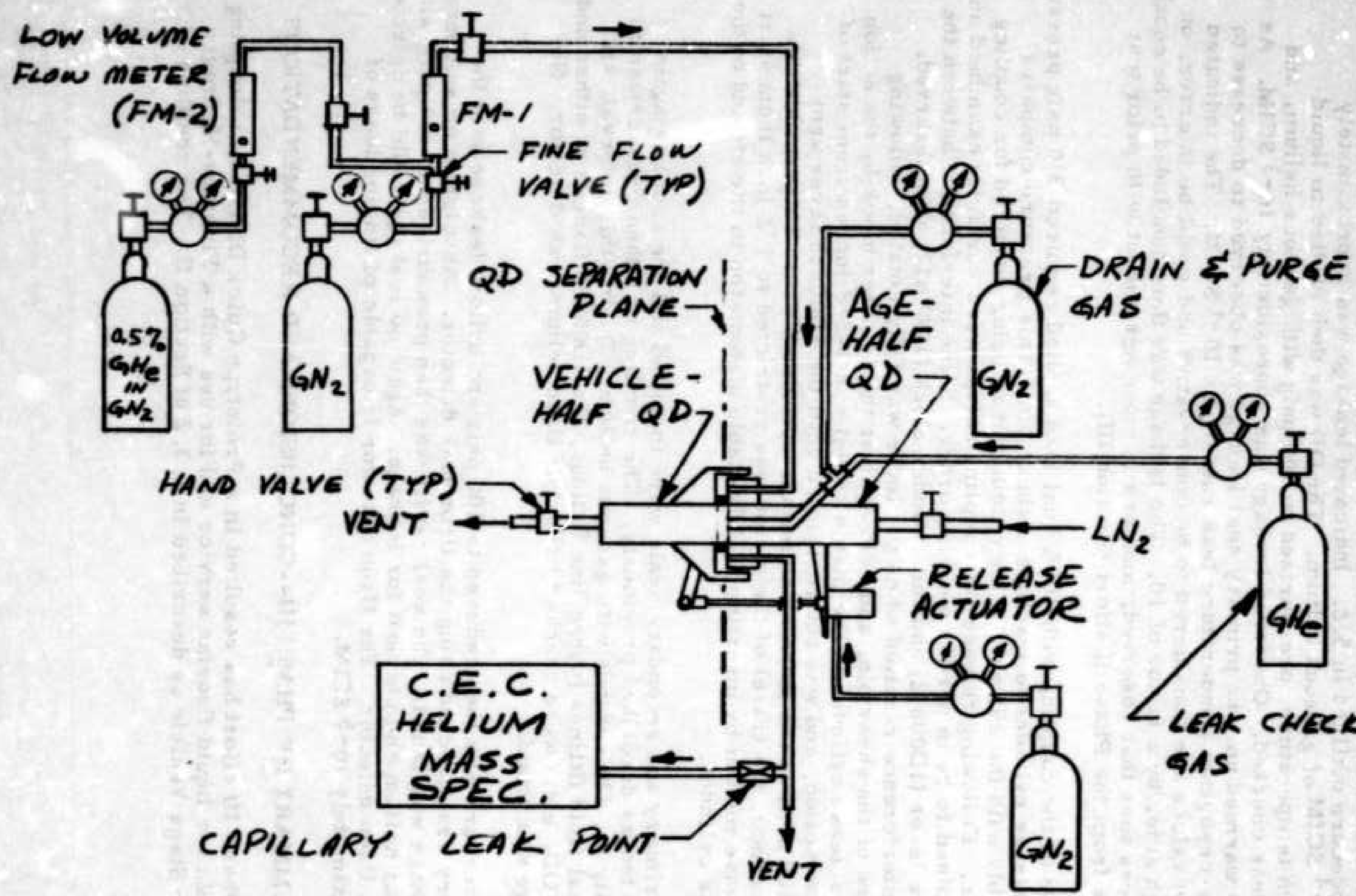


Figure 4-9. Schematic, Prototype QD Test Setup

Following the first QD connection, the primary seal was initially leak checked at ambient temperature using gaseous helium at 100 psig, following the procedure outlined in 5. 2. Indicated leakage was approximately 2×10^{-4} SCIM of gaseous helium. The QD was then chilled to liquid nitrogen temperature, pressurized to 100 psig with gaseous helium, and again leak checked. Observed leakage was approximately 10^{-3} SCIM. As the QD warmed up, the primary seal leakage was observed to decrease to the pre-cryogenic temperature leak rate of 2×10^{-4} SCIM. The indicated leakage values are considered to be conservative and could be in error, on the high side, by a factor of 10. The leakage was thus concluded to be equal to or less than that observed, and was in close agreement with prior test results from the Phase II effort (Section III).

Release of the coupling with 100% seal load applied required 310 psig pressure on a release cylinder to fracture a shear pin. This pressure compares favorably with the 295 psig value calculated as being required for coupling release. Following release the coupling halves were carefully examined and determined to be in perfect working order. Some interference between the release lever (1D00832) and the cylinder block (1D00812) was observed. This interference resulted when the lever was fully rotated, following fracture of the shear pin, and held against the cylinder block by the action of the release cylinder. The piston travel was 1-5/8 inches from start of release motion, and was not restricted until the 1D00832 lever arm impacted against the 1D00813 aluminum cylinder block. To preclude this interference, the travel of the piston was restricted to 1/2 inch from start of release motion by inserting an adjustable piston stop in the aft end of the release cylinder.

New primary and secondary seals were installed and the coupling again connected as described previously. The coupling was then pressurized to 150 psig for 120 seconds with gaseous helium. During this interval, all external fluid fittings (purge line fittings, the 1D00805 flanges at either end of the QD, etc.) were checked using the Uson helium leak detector. No leakage was found.

The pressure was then reduced to 100 psig and helium leakage past the primary seal checked using the Uson leak detector. Absolutely no evidence of leakage was found. The seal cavity was then pressurized to 100 psig with gaseous helium and checked for leakage. Again no leakage could be detected by the Uson detector. The Uson detector is capable of finding leaks of approximately 10^{-5} SCIM.

6. SUMMARY OF PHASE III--CONCLUSIONS AND RECOMMENDATIONS

The Phase III effort has resulted in a Prototype Quick Disconnect Coupling suitable for liquid fluorine service and for use with a Fluorine-Hydrogen Upper Stage Vehicle as described in 1. 3. 2 of Section II. The coupling is described in a Preliminary Contract End Item (CEI) Specification in adequate detail to permit fabrication, checkout and acceptance testing of the QD. The following summarizes the pertinent findings of the Phase III program:

1. The relocation of the coupling-to-coupling engagement bellmouth of the Vehicle-half of the QD to the plane of the primary seal, eliminating the coupling hangup discovered during misaligned engagements of the test model couplings of Phase II.

2. The two-piece anti-icing shroud proved to be both functionally adequate and far more convenient than the cumbersome one piece shroud of the test model couplings.

3. The structural redesign of the latching and release mechanism to significantly reduce weight while retaining functional similarity to the Phase II -501 test model, was demonstrated to be completely adequate.

4. The AR10108 Omniseal proved to be an improvement over the AR10105 Omniseal used on the Phase II test models.

5. The 100% seal load indicator proved to be a satisfactory method for gaging required seal loads. It was discovered that the only adequate way to preset the seal loading spring assemblies was to connect the QD and then provide final adjustments to each of the six seal spring assemblies (until the indicator would no longer turn). This would be done in the assembly and checkout area. The QD would then be separated, a new seal installed, and the QD would then be ready for use.

6. Primary seal leakage was found to be within specification and in close agreement with the test results of Phase II. This further verified the acceptability of the sealing technique and the detail design. In addition, a new leakage measurement technique was introduced, the Helium Mass Spectrometer, for this application. Although further effort is needed to perfect this technique for precise quantitative measurements of small leaks, it did provide meaningful data; i.e., the leakage was less than the indicated value.

7. The latching pistons were designed to provide latching loads at 750 psig maximum. Acceptance test results indicated that this pressure is marginal and should be increased. It is therefore recommended that the latching pressure be increased to 1000 psig maximum. At this pressure, and with the seal load springs set to provide 100% of nominal seal when connected, the latching pistons will have moved to their maximum extended position (further increase in piston pressure would result in no further piston travel). This would always assure that the latching hooks have extended far enough for easy engagement and latching.

8. The latching-hook piston assembly as presently designed is subject to rotation about its axial centerline. This rotation takes place primarily during QD separation. Manual alignment of the latching hooks prior to engagement of the coupling halves and a visual check for proper position prior to release of the latching pressure will preclude any problems due to piston rotation. The rotation could be eliminated by a design change, thus negating the necessity for the above procedures.

The recommended design change would prevent piston rotation by indexing each of the six pistons to the 1D00807 Adapter Assembly as shown in Figure 4-10.

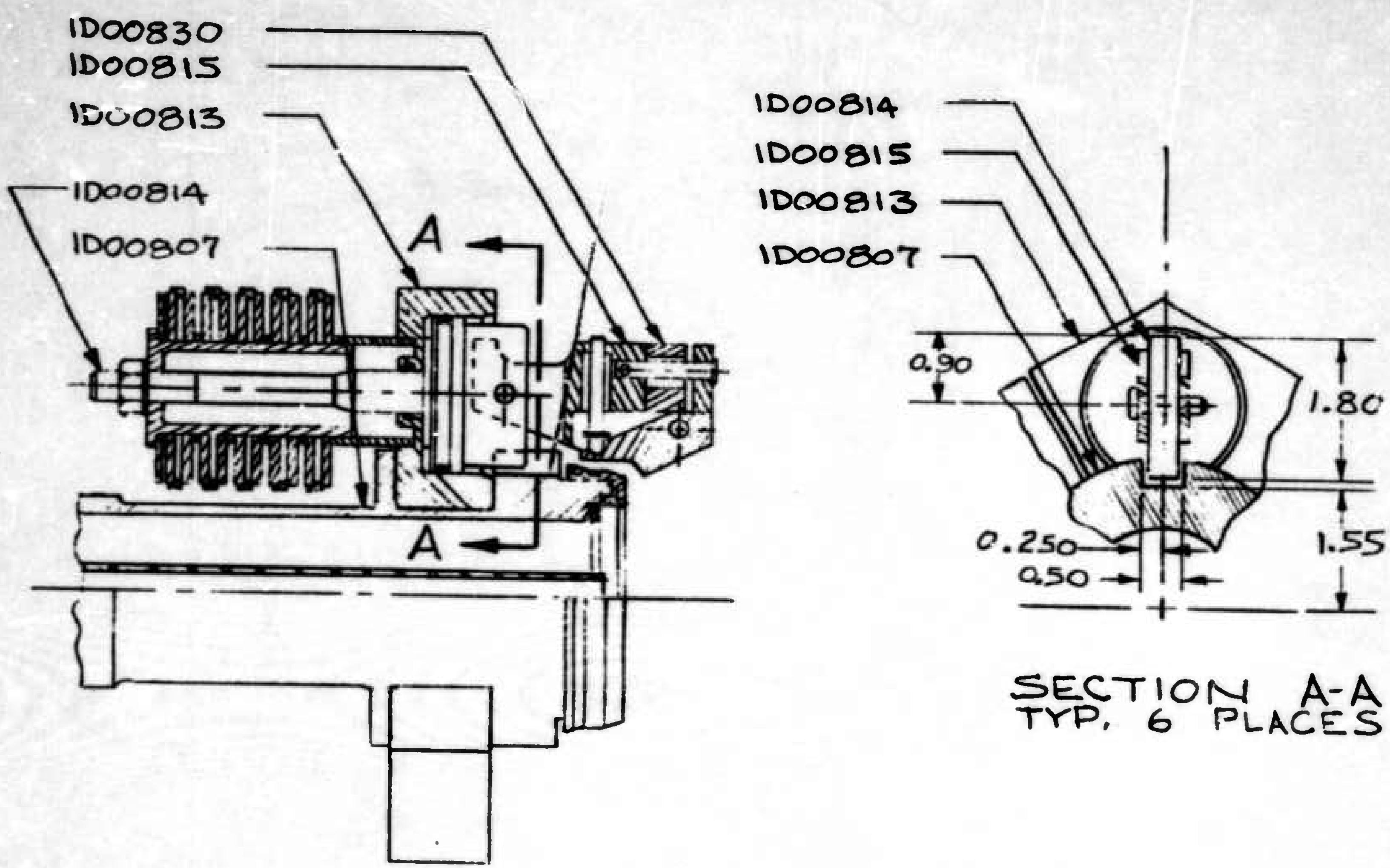


Figure 4-10. Piston Anti-Rotation Design

Section V
CONCLUSIONS

The program has resulted in the following conclusions:

1. Established design criteria documented in this final report are for the specific requirements imposed by the fluorine-hydrogen upper stage study vehicle. However, these criteria are equally applicable for other fluorine-containing oxidizers such as OF_2, N_2F_4, NF_3, etc.

2. Excellent sealing results can be obtained using a 60° sharp-edge serration against a soft aluminum gasket. Helium, nitrogen and fluorine leakage can be reduced to below 10^{-4} SCIM using either a double or a single serration loaded at 500 lbs per linear inch of serration.

3. The concept of a non-valved QD coupling for fluorine service has been demonstrated to be both feasible and practical for a typical upper stage vehicle using liquid fluorine. Draining and purging of fluorine from the QD can be accomplished under installation conditions which trap liquid fluorine. QD coupling installations should be designed to promote, not trap, draining and purging of liquid.

4. Moisture, frost and ice can be precluded from forming on the QD during liquid fluorine transfer by providing a blanket of gaseous nitrogen around the coupling. This can be successfully accomplished by passing a low pressure (0.5 psig) gaseous nitrogen purge through a physical envelope shrouding the QD coupling.

5. Fluorine leak detection and measurement can be easily and accurately obtained through use of wet-chemical analytical methods. Instantaneous leak rate measurements are not possible, but average values over 30 to 60 second intervals can be determined quite easily and accurately.

6. Allowable fluorine leakage from an upper stage fluorine QD coupling is limited by the potential toxic hazard resultant from fluorine leakage. Based on highly conservative assumptions, allowable fluorine leak rate was determined to be 10^{-4} SCIM at 100 psig.

7. Rapid-manual engagement, latching and sealing of QD couplings for fluorine service can be accomplished using the criteria established in this report.

8. A reliable and redundant quick release mechanism was developed and demonstrated. The mechanisms functioned faultlessly, adequately verifying the design concept.

Appendix I

FAILURE MODE ANALYSIS

1. GENERAL

Failure of the QD could result in the release of oxidizer in quantities that may vary from 100% of the liquid material in a brief instant of time to a slow passage of gas through minute openings or leaks in sealing surfaces or metal imperfections. The problems which can arise upon development of oxidizer escape will, of course, depend upon the rate of escape, and their severity is probably some exponential function of this rate. Another more serious factor that must be considered is the possibility of simultaneous escape of fuel and oxidizer.

Another facet of the leakage problem that must be subjected to careful analysis in fluorine oxidizer systems is that of passage inward of unwanted contamination from the outside of the system. Any perforation or leak can allow passage of materials in either direction--during periods of relatively low internal pressure (subcooled LF_2), there is the possibility of materials passing inward, while, if the system is held at close-to-atmospheric pressure, repeated cycles of inboard-outboard materials transfer (breathing) become of consequence.

Consider a typical cycle of vehicle fill and drain operations as shown in Table I-1. The possible modes of inadvertent escape of oxidizer or entry of contaminants for each operation are listed in the right-hand column. For purposes of this argument, it is assumed that properly operational, cleaned, and protected quick-disconnect couplings have been installed on the vehicle before the start of the operations listed in Table I-1.

Table I-1

INADVERTENT OXIDIZER RELEASE VS VARIOUS OPERATING MODES

Operation	Propellant Escape or Contamination Sources
Connection of vehicle to umbilical	No propellant is present. Aerosol contamination during time connector elements are outside of wrappers and before connection is made. Degree of contamination is small because of selection of proper weather conditions and purges on elements.

Table I-1. Continued

Operation	Propellant Escape or Contamination Sources
Leak check of Connection	
1. Pressure	No propellant present. No inboard contamination because of excess pressure during leak check.
2. Vacuum	Some inboard contamination possible because of vacuum in system. Serious contamination unlikely because (1) previous pressure check tentatively OK'd system, (2) large leak would indicate failure of connector (or lines).
Cryogenic check of connection	No propellant is present. Inboard leak possible if thermal contraction opens up seals, but should not happen if previous design and testing is adequately done. Severe contamination would arise from inboard leak because of condensation or frost.
Passivation with GF_2	Propellant present, fairly low pressure (above atmospheric), ambient temperature. Outboard escape of oxidizer in connector area should be small enough to be handled by normal GN_2 purge of area. Concentration should be monitored to determine rate of escape and size of escape path. Increase of rate with time would be dangerous and would require correction. Connector should be enclosed to prevent access of escaping F_2 vapors onto other structural (vehicle or AGE) systems to prevent corrosion because of HF from $F_2 + H_2O$ (air) $\rightarrow$ 2HF + 1/2 O_2. Inboard contamination unlikely because of excess pressure inside the system. Complete failure of connector or seal would release a cloud of F_2 or F_2 - N_2 gas (depending on time of occurrence). This could be of considerable volume during passivation. Partial failure of connector or seal could result in impingement of jet of GF_2 onto inside of connector enclosure and then out purge exhaust. The automatic controls on the valves (above) might not respond rapidly, and considerable F_2 may pass out purge exhaust.

Table I-1. Continued

Operation	Propellant Escape or Contamination Sources
Purge removal of passivation gas	Situation similar to passivation except that concentration of F_2 is continually decreasing. Contamination may be introduced by purge gas. No inboard leaks are assumed.
Static hold of empty passivated vehicle	Only traces of propellant present. Two conditions are possible: (1) lines at atmospheric pressure -- breathing through seals and leaks introduces moisture and causes deterioration of passive film and galvanic corrosion; (2) lines held at positive pressure -- any leak is outward and is not a problem. Pressure monitoring will detect leakage.
Vehicle fill	The period when LF_2 is being pumped through the fill line and connectors is obviously the most critical time in relation to inadvertent escape of oxidizer. If the connector is designed with a venturi present, inward leaks of contaminant may also develop. The most serious single incident which might occur would be a parting of the line or connector. The most serious time for this to happen would be during the period when LF_2 is flowing at its maximum rate into the vehicle tank. Simultaneous failures that would increase the problem would include: 1. Failure of the vehicle fill and drain valve to close if the fill coupling parted, so that all oxidizers pumped into the vehicle could be discharged to the atmosphere. 2. Failure of the AGE shutoff valve, so that LF_2 continues to be pumped from a separated coupling until backup valving could be activated. At the connector that is enclosed in a purge box, a jet of escaping LF_2 would impinge on the inside of the box, evaporate rapidly, and be swept out the purge vent. F_2 sensors located in the vent would announce the existence of the leak and shut off the flow of LF_2.

Table I-1. Continued

Operation	Propellant Escape or Contamination Sources
	Smaller openings could be expected to allow only GF_2 to escape, again in the connector area to be swept away in the purge gas stream. Leaks developing downstream of the connector, i.e., inside the skin of the vehicle, would pose problems. It is unlikely that the vehicle portion of the fill and drain plumbing will be vacuum jacketed, but is more likely to be covered by multilayer (super) insulation. It has been shown that Dimplar and NRC-2 are not easily ignited by static LF_2, GF_2, or by low-pressure GF_2 jets although they do show impact sensitivity when immersed in LF_2. In general, it would be expected that other fluorine-incompatible materials would be present inside the skin of the vehicle and that a major leak would probably result in an extremely hazardous situation. The effects of LF_2 emmissions would probably depend on the material upon which they impinged. Evaporation would be rapid, and the internal inert gas purge necessary to maintain the integrity of the system would be extremely large, if not impractical. The cycle of conditions to which the connector will be subjected during a fill operation will be as follows: 1. GF_2, ambient temperature, volume flow rate about 10^3 greater than that of the LF_2. This GF_2 is boiloff resulting from cooldown of hot plumbing. 2. GF_2, temperature decreasing steadily toward the boiling point of LF_2 at the pressure at which it is being transferred. 3. Mixture of GF_2 and violently boiling LF_2. 4. LF_2 containing some entrained GF_2 plus a certain amount of boiling from surfaces. This flow will continue until the tank in the vehicle is filled.

Table I-1. Continued

Operation	Propellant Escape or Contamination Sources
	5. A short interval when flow ceases because of closure of the AGE shutoff valve. This interval lasts until the vehicle fill and drain valve closes and purge valves are opened. 6. Reverse flow of boiling LF_2, GF_2, and purge gas (GH_e) from the fill and drain line on the AGE side of the vehicle fill and drain valve to the disposal or recovery facility. It is highly probable that flow during periods 1 through 3 and perhaps the first part of 4 will not be at a constant rate, nor will the pressure remain constant. Pressure and flow pulsations are to be expected. At the end of the fill cycle, the AGE shutoff valve is closed, then the vehicle fill and drain valve, followed immediately by opening of the fill line drain and purge valves. If the last two do not open successfully with the main valves closed, a pressure rise can be expected which could lead to bursting of the line containing the trapped liquid. An uninsulated 2-in. line (heat transfer of 600 Btu/hr/ft) will probably burst (200 psi) in less than 10 sec.; a vacuum jacketed line of similar rating would not reach this point until 5 to 10 min. had passed. Rupture would cause a spray of rapidly boiling fluorine in all directions.
Topping off	During the topping of the propellant tanks, it is likely that both LF_2 and LH_2 will be transferred at the same time. Simultaneous leaks in any portion of the system will lead to the possibility of the two propellants mixing. If both systems leak into the interior of the vehicle, it is likely that ignition would occur, resulting in severe damage to some components and possible destruction of the vehicle. Slow leaks might be purged away before reaching the other propellant, especially if there is a barrier between the areas around the LH_2, and LF_2 tankage.

Table I-1. Continued

Operation	Propellant Escape of Contamination Sources
Coupling disconnect	Two situations are possible: (1) disconnect following ground checkout and flow operations. The coupling and fill and drain system has been completely warmed to ambient temperature and thoroughly purged using an inert gas until no liquid oxidizer is present. Only trace amounts of oxidizer present is absorbed from or in trapped areas, and then at very small concentrations. Aerosol contamination is possible during the interval between disconnect of coupling and sealing of coupling halves for storage. The degree of contamination is small because of selection of proper weather conditions, use of purges on the elements, and use of protective shrouds. (2) disconnect at time of launch. Residual oxidizer remaining in interconnecting lines as a result of drain and purge system failure could cause a spray of rapidly boiling fluorine from both the vehicle and the AGE oxidizer fill and drain lines. The maximum quantity is that which could be trapped between the vehicle and AGE fill and drain valves. Although localized surface reactions and the possibility of fire is ever present, the highly turbulent and reactive launch vehicle first-stage exhaust products are of a potentially far more significant nature. The rapid retraction of the oxidizer fill and drain umbilical boom will result in the rapid dispersal of residual oxidizer. This, coupled with the motion of the vehicle and the air movement caused by the exhaust products, should result in the very rapid evaporation, dilution, and dispersion of the residual oxidizer.
Unloading vehicle oxidizer	If vehicle launch is aborted following filling of the vehicle with propellant, it will be necessary to unload these propellants. Three possible conditions exist:
	1. Extreme vehicle hazard -- a condition (propellant leakage, uncontrollable pressure rise, fire, and so forth) exists that could, at any instant, result in a catastrophe.

Table I-1. Concluded

Operation	Propellant Escape or Contamination Sources
	2. Possible vehicle hazard -- a malfunction or abnormal condition exists that is of unknown degree or potential effect (failure of booster engine to ignite, failure to receive a component or system signal needed to launch the vehicle, and so forth). 3. Nonvehicle imposed aborts (poor weather, mission cancellation, range problems, and so forth). The conditions imposed by the first two situations suggest the rapid removal of all propellants from the vehicle to a safe storage area so that the hazard can be reduced and hopefully eliminated. The problems of propellant escape that might arise during the emptying are the same as those during fill. The situation of condition 3 impose no requirements for rapid or simultaneous propellant unloading. The problems are, therefore, no different from those associated with filling the vehicle.

2. EFFECTS OF FLUORINE ESCAPE AND/OR INBOARD LEAKAGE OF CONTAMINANTS

Other than toxicological effects, the problems associated with the escape of fluorine from the connector and associated apparatus are of three main categories. These are as follows:

a. Local effects on structural materials through which the escape takes place.

b. Effects on materials upon which the escaping propellant impinges.

c. Problems which may arise if both LF_2 and LH_2 escape at the same time.

Inboard leakage of contaminants, possibly through the same pathways as that of F_2 escape, can again result in several effects as follows:

a. Local damage on structural materials through which the contaminant passes.

b. Degradation of other structural materials in the propellant system through corrosion caused by the contaminant.

c. Interaction with the propellant to degrade the latter or cause unsafe conditions to develop.

d. Clogging or otherwise restricting the proper functioning of the system and its components.

In many cases, it may be expected that inboard leak of contaminants and escape of fluorine would be combined (though usually not at the same time). This would usually result in a considerable increase in magnitude of effects. The areas included in this discussion are ones that have not been carefully studied. In most test programs, leak-tight systems are a prerequisite. If leaks develop, their effects are generally not studied; instead, the system is shut down until the leak is corrected.

Nevertheless, some observations have been made as to what were the effects of the leaks, and some data collected in other studies can be applied to the leak problem. These are discussed below, and the remaining information voids are pointed out.

(1) Local Effects on Structural Materials Involved in the Leak Path-- Nonquantitative observations have been reported in which the claim is made that flourine has the property of increasing the diameter of extremely small leak paths. It is claimed that minute openings through metal-metal and metal-Teflon seals, which will pass GH_e but not GN_2, will be large enough to allow passage of GN_2 and GF_2 after a period of exposure of F_2. Like observations on integral metal structures (such as porosities in castings) have not been reported.

The observations were not sufficiently controlled to determine whether leakage in only one direction was possible, or whether there could have been a breathing action with alternate attack by fluorine and airborne contaminants caused by H_2O reacting with F_2. Nor were other conditions defined, so that individual effects of pressure difference, temperature, time, initial diameter of opening, materials, and so forth, could be isolated.

If potential contaminants, especially water, are drawn inward, the behavior to be expected is related but not identical. First, if LF_2 is present or added shortly thereafter, the formation of ice crystals, which are shock-sensitive with LF_2, is assured.

Moisture in the presence of ambient temperature, GF_2, reacts rapidly to yield HF. The presence of HF will increase corrosion rates. In addition, if the HF then dissolves in LF_2, it makes the now impure LF_2 an electrical conductor. This introduces the possibility of electrochemical corrosion. Electrochemical corrosion in fluorine has not been investigated. A mixture of HF and CTF is a sufficiently good electrolyte to be considered for fuel cell applications, and there are isolated but sufficient reports of electrochemical corrosion in impure LF_2 (Reference 25) to indicate that the effect can be serious.

If alternate passage of materials both into and out of the system at the same opening (breathing) takes place, there generally are reactive substances available on the receiving side to combine with the substance passing. Thus, as H_2O enters, there is sufficient GF_2 nearby to react immediately and the HF formed then attacks the immediately adjacent structure. For the reverse situation, the same reactions occur when F_2 passes outward. This appears to be the best explanation of observations of certain occurrences at the Douglas Fluorine Flow Facility. Corrosion is confined to the immediate area of the leak and is fairly severe. The maximum distance from the leak that corrosion occurred was about eight inches.

One type of danger that has not yet been explored is that posed by metal fluoride hydrates. Most metal fluorides are efficient absorbers of moisture to form hydrated crystals of various stoichiometries. Initial findings at Douglas indicate that these hydrated compounds are not impact sensitive in LF_2.

A system in which leak paths increase in size with time is much more dangerous than one in which leak path size remains constant. Small leaks can be neutralized by purges or vents, but if the passage size grows, such remedies will not suffice. Accurate definition of this situation is required to preclude the possibility of potentially hazardous or catastrophic results.

(2) Effects on Nearby Structural Materials -- The effects to be studied in this area will depend to a large extent on the rate at which the active materials (F_2 outward or H_2O inward) reach the materials in question. The majority of structural metals are almost unaffected by elemental fluorine, either liquid or gaseous. Static corrosion rates in pure fluorine are found to be less than 0.1 mil/year.

Frost with GF_2 and LF_2 are impact sensitive, although tests have not completely defined all variables.

The results of the studies conducted on frost -- F_2 impact sensitivity with an ABMA impact tester are presented in Table I-2.

The specimens were as shown in Figure I-1.

Table I-2

FROST-FLUORINE IMPART SENSITIVITY

100% GF_2 on Frost*			FLOX-20 on Frost*			LF_2 on Frost* LF_2 at -320°F	
Specimen Number	Approx Temp (°F)	Impact Reaction	Specimen Number	Approx Temp (°F)	Impact Reaction	Specimen Number	Impact Reaction
1	-300	No	1	15+15	No	1	Yes
[illegible]	-275	No	1	15+15	No	1	Yes
3	-250	No	1	15+15	No	1	Yes
4	-225	No	1	15+15	No	1	Yes
5	-200	No	1	15+15	No	1	Yes
6	-175	No	1	15+15	No	1	Yes
7	-150	No	1	15+15	No	1	Yes
8	-125	No	1	15+15	No	1	Yes
9	-100	Yes	1	15+15	No	1	Yes
10	-75	Yes	20	15+15	No	20	Yes

*All impacts at 72 ft-lb. (U)

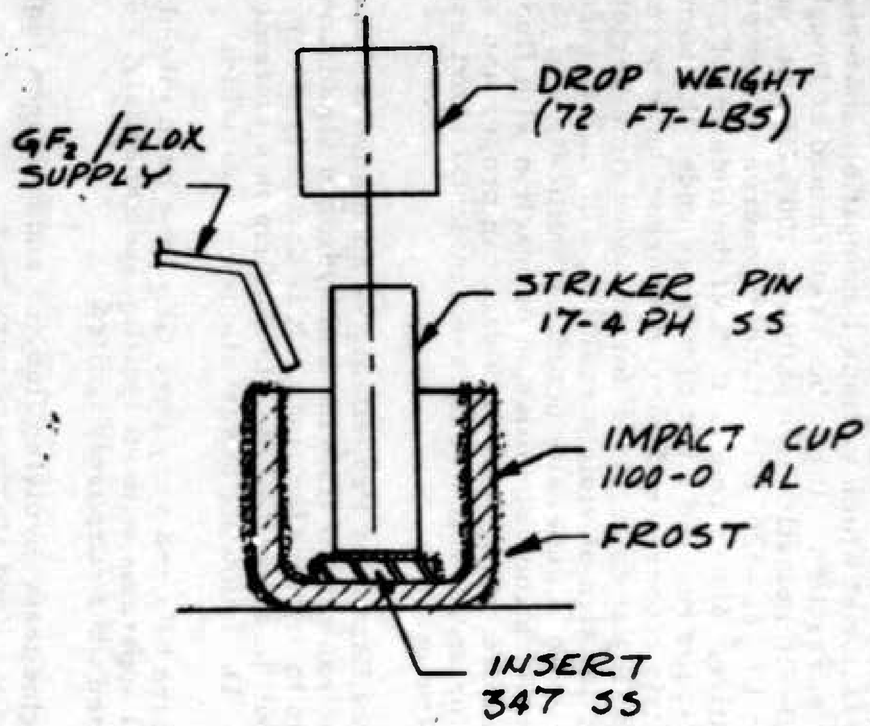


Figure I-1. Frost-Fluorine Impact Sensitivity Test Setup

Thus far, in the discussion of the effect of escaping F_2 on surrounding structures, we have focused solely on metals. But it is a rare structural device that does not contain other materials. This includes structures both within or outside the vehicle. Many of these other materials are organic; plastics, wood, paint, lubes and greases, potting compounds, paper, etc. Others include concrete, glass, fired clay and other similar substances. Many of these substances are basically spontaneously reactive with fluorine. But at this point, another void becomes apparent. Under what conditions will such spontaneous reactions start? There is almost no information about the fluorine concentration, the temperature, or the time factor at which various incompatible materials are susceptible to reaction. It has been determined at Douglas that Mylar and H-Film plastics are stable to 100% GF_2 at room temperature and to LF_2 at -320°F in static exposure. However, both are shock sensitive. Mylar reacts 100% of the time in LF_2 at a 72 ft lbs drop; H-Film reacted 2 out of 9 times under the same conditions. Certain rubbers (red gum, neophrene) have been used in contact with GF_2 at up to 200°F for extended time periods, generally without any sign of violent reaction, although hardening to a non-elastic solid is generally noted. Identification of the major parameters which control initiation of reaction with fluorine is seriously needed. Only with such data can proper and safe design be applied for areas which could see accidental short exposure fluorine releases.

(3) Simultaneous Escape of Propellants -- Spontaneous fluorine reactions can be expected if fluorine and hydrogen simultaneously escape from their transfer lines. It is obviously a very serious problem, but the amount of data to confirm this statement is negligible. The following observations are available:

(a) Very pure GH_2 and very pure GF_2 have been mixed in a special apparatus without igniting spontaneously. The mixture detonated when purposely ignited.

(b) All engine tests involving fluorine and hydrogen ignited spontaneously. Hard starts are very rare.

(c) Injection of LF_2 into the GH_2 ullage of an LH_2 tank did not result in a spontaneous reaction. A violent reaction was then experienced. It was hypothesized that the LF_2 froze, dropped thru the LH_2 until it came to rest at a point where there was a heat leak (closed valve body).

(d) An accidental occurrence in which plumbing to cylinders of GH_2 and GF_2 sprang simultaneous leaks about 15 feet apart occurred. There was no ignition, although the odor of F_2 was quite prominent in the neighborhood of the H_2 leak.

The problem is complicated by the fact that the system is not simply F_2-H_2, but in reality F_2-H_2-O_2-N_2. Special mixing tests would be of interest as a method of rapidly determining the scope of the hazards. This must include basic data related to ignition limits and explosion limits of F_2-H_2-O_2-N_2 mixtures.

3. TOXIC RELEASE AND DISPERSION

While the information required to determine the site and range operational constraints would require an evaluation of the whole system, certain useful conclusions concerning the relationship of OD leakage to toxic spill criteria may be arrived at by application of empirically derived atmospheric dispersion formulas. The purpose here is to determine the contribution of the fluorine oxidizer credible release modes of the OD to the potential toxic hazard risk to range personnel and to the population outside the boundaries.

Two general types of release modes must be considered:

a. Hot Release

Major spills will probably produce a hot reaction on contact with oxidizable material. The highly reactive character of fluorine oxidizers will produce fires with oil, grease, asphalt, plastics, rubbers, adhesives, paints and vegetation. Limited reactions can occur even with sand, gravel, limestone, etc.

b. Cold Response

Large sized spills which do not ignite materials by contact with either liquid or gaseous oxidizer, are defined as cold releases.

Because of the cryogenic temperature (-306°F) of fluorine, high flash-off rates would be expected, due to the difference in temperature between the LF_2 and the contacting surface. However, the gas produced will be more dense and tend to hug the ground for a time, flowing along the low spots in the terrain. This is a specially hazardous condition during times when wind movement is low and thermal gradients are absent. Further complications in defining rate of boiloff (emission or source strength) arise, depending on the character of the surface upon which the spill occurs. Boiloff rate will be highest from surfaces of high heat capacity and conductivity. Reduction in rate will result where puddling, containment, or contact with materials of low heat capacity or conductivity occurs.

Considerable theoretical and empirical work exists which attempts to predict mathematically the air pollution hazard in terms of the mode of release, quantity released, distance downwind, and various meteorological and topographical variables known to exist in a test area. Beginning with the atmospheric turbulent diffusion equations for continuous and point sources developed by Sutton (Reference 26), a number of extensive experimental programs were initiated to improve the predictability.

Some of the more favored range dispersion equations applicable to toxic rocket propellant releases have evolved out of Projects Prairie Grass (Reference 27) Ocean Breeze and Dry Gulch (Reference 28), Sand Storm (Reference 29), and a Travelers Research Center study (Reference 30).

Statistical methods were employed to simplify the prediction equations and obtain data upon which reliability figures could be stated.

For predictions of fluorine oxidizer turbulent diffusion arising as a consequence of the credible release modes of a QD associated with a flight vehicle, the behavior of both quasi-instantaneous and continuous point sources must be known. A leak developed during fueling or off-loading of a propellant tank is probably best described by considering it a continuous point source if the release time extends for a period of 10 to 30 minutes and occurs at a low level near the ground. A rapidly occurring relatively large cold spill which has been contained and boils off at some average rate over a similar period of time at ground level may also possibly be treated as a continuous point source.

The prediction equation favored for continuous point sources, developed out of the Projects Ocean Breeze and Dry Gulch, has the following form:

$$C_p/Q = K\,X^a\,U^{-b}\,\sigma(\theta)^c\,(\Delta T + k)^d$$

Where:

C_p = peak concentration at a given downwind, (milligrams/ cubic meter, or ppm by volume)

Q = source strength (grams/sec., lbs./min., etc.)

$\bar{U}$ = mean-wind speed (knots, or miles/hr.)

X = distance, downwind of the sources (meters, feet or miles)

$\sigma(\theta)$ = standard deviation of the wind direction (degrees azimuth)

ΔT = difference between the temperature at two levels above ground. (A negative ΔT indicates a decrease of temperature with height. The quantity k is added to ΔT to avoid raising a negative number to a power)

K/a/b/ c/d = parameters of fit (estimating equation co-efficients) determined by least-squares regression techniques

These factors operate in the following way to describe the diffusion rate.

The mean wind speed, $\overline{U}$, is an indicator of the downwind "stretching" of the cloud emitted from a continuous source. In general, the higher the mean wind speed, the lower the concentration at a given travel distance.

The standard deviation of wind direction fluctuations, $\sigma(\theta)$, as an indicator of the horizontal rate of mixing. As the value of $\sigma(\theta)$ increases, the rate of horizontal mixing increases and the concentrations decrease. Further, as the cloud grows in size, smaller eddy sizes become increasingly less effective in diffusing the cloud. In practice, this means that smoothing the wind direction data fluctuations before computing the standard deviation of the wind direction tends to increase its prediction "efficiency" for the travel distance of interest here.

The vertical temperature gradient, ΔT, is an indicator of the vertical rate of mixing. If the temperature decreases with height, the rate of vertical mixing is enhanced, and the concentrations are relatively low. If the temperature increases with height, the rate of vertical mixing is inhibited, and the concentrations are relatively high.

One quantity of immediate interest to a pollution problem is the peak or maximum inhalation level concentration, Cp, at a fixed distance downwind from the source. By definition, this is the concentration found on the axis of the diffusing cloud. Concentrations decrease as one moves off the axis of the cloud.

Another factor pertinent to the development of the diffusion prediction equation is the amount of material released per unit time. The downwind concentrations are obviously directly related to this factor, called the source strength, Q. As a result, one usually speaks of a "normalized peak concentration" C_p/Q; i.e., a peak concentration divided by the source strength.

The final factor to be considered is the distance, X, downwind from the source, since the peak concentration can be expressed as a power law of downwind travel distance. In actuality, it is travel time that is important to the diffusion process rather than travel distance; however, for micro-scale motions such as those considered here, travel time is usually discussed in terms of mean travel time to some fixed travel distance as a function of wind speed.

A large amount of experimental data was introduced into a computer program to determine the parameters of fit (K, a, b, c, d) and to test the prediction efficiency of the resulting equation.

This equation in simplest form as it is now used is:

$$C_p/Q = 0.00211\, x^{-1.96} (\Delta T+10)^{4.33} \quad (\theta)^{-0.506}$$

Where

C_p/Q = the normalized peak concentration in sec/m^3

X = downwind travel distance in meters

$\sigma(\theta)$ = standard deviation of wind directions in degrees azimuth, with a 15 second smoothing interval

ΔT = the temperature difference in the atmosphere between 54 ft and 6 ft altitudes, in °F

The number 10 was added to the ΔT term in order to avoid handling the logarithm of a negative number.

It will be noted that the mean wind velocity, $\bar{U}$, has been eliminated from the operating formula. Because an evaluation of prediction accuracy showed that wind velocity correlates with the wind shift $[\sigma(\theta)]$, and temperature lapse (ΔT). Inclusion of U does not improve prediction accuracy.

The diffusion equation is basic to the operation of the Weather Information Network Display System (WINDS) which has been developed to control toxic propellant launch operations both at ETR and WTR (Reference 31). The system is computerized and takes into account persistency of various meteorological factors, range boundary distances from the operational site, quantities of toxic propellant being handled, etc., to determine go/no-go operational conditions.

At Cape Canaveral, the WIND System is set to predict C_p/Q for a downwind distance of 1.5 miles; at Vandenburg, three different distances are used depending on the location of the launch emplacement. A sample graphical solution of the equation for fluorine is included in the Appendix IV, Figure IV-1.

It must be emphasized that application of the WINDS equation for predicting C_p/Q is strictly limited to ground level continuous point sources of about 10 to 60 minutes duration and to downwind distances of 5 to 10 miles.

In the case of a fast liquid flow from an uncoupled QD, the source would be elevated as shown in Figure 2-29. The WINDS system is not presently designed, therefore, to predict downwind distances and dosages for elevated releases. Oxidizers released under these conditions could be characterized by considering them as elevated point or line sources. Some work has been done to improve the original Sutton equations for these cases (Reference 32 and 33).

What rational can be adopted, then, for determining the degree of hazard risk for elevated source leakage from the QD?

There are various possible ways in which a sizeable spill of liquid oxidizer might occur during fueling; the line might rupture or the disconnect coupling might inadvertently release. For example, if pumping were not in progress at the time, probably only the gaseous and liquid fluorine in the line would spill. For a 2-inch diameter, 30 foot line, completely full of liquid fluorine, this would result in spilling only about 62 pounds of fluorine.

For the situation where a break occurs, or the QD becomes uncoupled during a filling operation, much more fluorine would be released. Assuming a pumping rate of 20 pounds/second, and delay of 30 seconds before initiation of AGE valve closure to cut off the supply, 600 pounds of fluorine would be spilled.

Although there have been several studies made of the dispersion behavior of contaminant clouds or puffs resulting from a leak or spill, it is not possible to apply them accurately to the spill situation described above, as the oxidizer spill will be occurrring at a considerable distance above the ground.

The shape of the cloud developing downwind is difficult to predict since it will depend on one or more of the following factors:

(1) The flow forces set up by the oxidizer jetting may cause the transfer line to whip around in several directions.

(2) Spreading may occur due to impingement on adjacent vehicle or AGE surfaces.

(3) Downward streaming may occur because of the low temperature of the cryogen and its vapor density difference from that of the atmosphere.

(4) LF_2, or high concentrations of gas may come in contact with intervening inflammable materials and develop into a hot spill.

(5) Meteorological conditions existing at the time including wind speed, wind direction, ambient temperature, temperature lapse rate with altitude, and atmospheric eddy currents will alter the shape.

Qualitatively, the relative toxic hazard associated with instantaneous and continuous releases may be evaluated as follows (Reference 28).

With the instantaneous type of release, a puff of some magnitude and original dimensions is generated which will expand and be diluted by turbulent diffusion as it travels with the wind. Turbulent eddies larger than the dimensions of the puff will cause it to meander across the terrain with but a small spreading effect as it travels downwind. With the continuous source, however, large eddies tend to spread concentrations over a wider area relative to the instantaneous puff width. Assuming no significant difference in the rate of vertical mixing and assuming an equal total amount of material is released, a lower dosage in terms of time integrated peak concentrations will result at the center of a plume from a continuous source of 10 to 30 minutes duration, than at the point passed by the center of an instantaneous puff.

Instantaneous sources released at some height or those which rise because they become hot spills produce inhalation level concentrations which differ from continuous ground sources. As a rule, the toxic hazard is greatly reduced at shorter travel distances simply because the elevated source vaults over the near areas and provides a greater depth of atmosphere between the source level and the inhalation level. This is illustrated in the Figure I-2.

At travel distance A, a wide margin of safety exists for the elevated source as compared to the ground-level source. At travel distance B, the maximum inhalation level concentration occurs, but this is a function of the effective source height and the atmospheric stability. In gene al, as with effluent from chimneys, greater source heights and greater atmospheric stabilities tend to increase the distance at which maximum concentrations occur. At travel distance C, however, little difference in breathing level concentrations will be noted between elevated and continuous ground sources.

As a first approximation to evaluation the toxic hazard rising from the hypothetical elevated spill described above, the following ground level conditions will be assumed:

(1) Instantaneous, point source

(2) 600 pound total quantity

(3) Ground level surface

(4) No reaction with other materials

(5) Density of release material equal to atmospheric density (approx)

All of these assumptions are more or less inaccurate for the release being considered, but are necessary in order to calculate a downwind dosage using existing diffusion equations.

Equations similar to the following were developed in Project Sandstorm (Reference 29) to describe diffusion of an instantaneous point source:

$$\frac{Ep}{Q} = 0.180\ X^{-1.59} \quad \text{(mean value formula)}$$

Where:

$\frac{Ep}{Q}$ = the peak dose normalized for source strength, seconds/meter^3

X = distance from the source in meters

0.180 = coefficient to accommodate units.

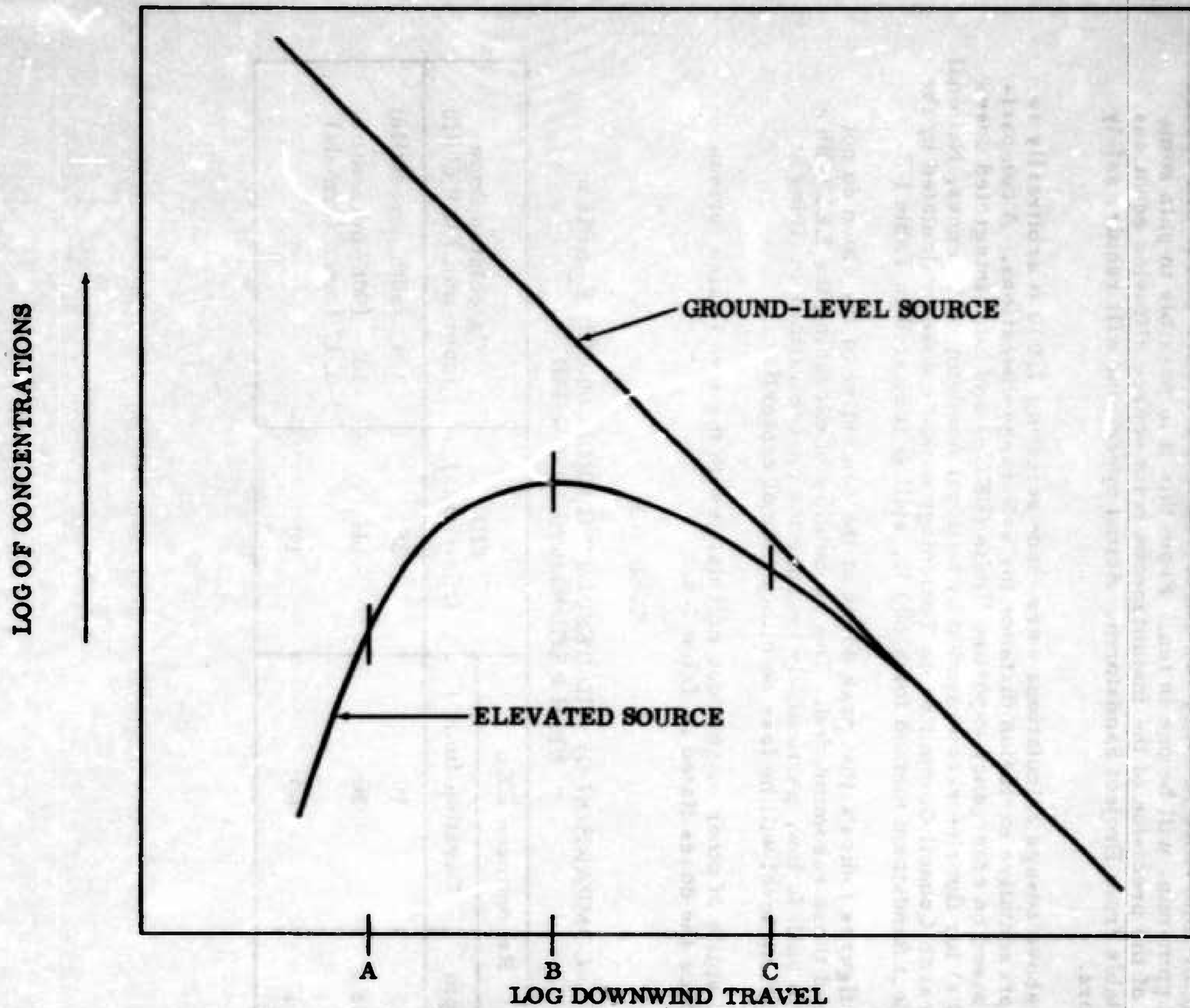


Figure I-2. Ground Level Versus Elevated Source Dispersion

At 7,000 ft downwind of a 600 lb spill, the mean dosage, Ep, will be 2.47 ppm-min. Similarly using the improved formulas (Reference 29) for the 50th and 90th percentile confidence levels the calculated dosage will be 3.4 ppm-min. and 10.2 ppm-min., respectively. In other words, the dose 7,000 ft downwind and along the centerline of the source will be greater than 3.4 ppm-min. once in every two cases, while the chance that it will exceed 10.2 ppm-min. will be one in ten. From this it is possible to gain some idea of the precision of the instantaneous point source diffusion equations available from Project Sandstorm. Actual operations will require safety factors.

The above dosage calculations were made selecting 7,000 ft arbitrarily as a representative exclusion distance for safe range operations. A comparison based on emergency exposure limits (EEL's) and total integrated doses (TID's) for fluorine recommended by National Academy of Sciences, National Research Council Committee on Toxicology with the doses calculated by the Project Sandstorm method for a 600 lb, spill is indicated in Table I-3.

The figures indicate that peak doses at the centerline of the cloud do not exceed those recommended. The probability of exceeding the EEL with a 600 lb spill is low, particularly because the concentrations arriving at inhalation level will be less on either side of centerline.

Cold spills of other magnitudes calculated with the mean value formula produce the doses listed in Table I-4.

Table I-3

COMPARISON OF TID RESULTING FROM 600 LB F_2 SPILL WITH RECOMMENDATION TID

Recommend EEL		TID	Calculated Dose
ppm	Duration (min.)	(ppm-min.)	(ppm-min.) Q = 600 lb
3	10	30	3.4 (50th percentile)
2	30	60	10 (90th percentile) 2.47 (mean formula)
1	60	60	

Table I-4

FLUORINE DOSES 7,000 FT DOWNWIND FROM COLD SPILLS OF VARYING STRENGTH

(Instantaneous Source, Mean Value Equation)

Q (lb/min.)	Dose (Ep) (ppm-min.)
1	0.004
2	0.008
5	0.020
10	0.041
20	0.081
50	0.204
100	0.409
200	0.818
500	2.046
1000	4.092

Cp/Q is the continuous source equation and Ep/Q in the instantaneous source equation are normalized peak doses, i.e. grams of contaminant per cubic meter (g/m^3) divided by grams of contaminant spilled or evaporated per second (g/sec). Thus, the normalized ratio is given in seconds per cubic meter (sec/m^3).

To obtain parts per million per pound per minute at standard termperature and pressure, multiply Cp/Q (sec/m^3) by 1.7×10^5 and divide by the gram molecular weight of the oxidizer:

To obtain:	Multiply Cp/Q (sec/m^3) by:
ppm F_2 / lb/min.	4.47×10^3
ppm ClF_3 / lb/min.	1.84×10^3

To obtain:	Multiply Cp/Q (sec/m³) by:
ppm OF_2 / lb/min.	?.15 x 10^3
*ppm HF (at 70°F) / lb/min.	3.3 x 10^3

The *average gram molecular weight of hydrogen fluoride (HF) at ambient temperature (70°F) is estimated to be 51.3. Conversion nomographs relating Cp/Q (sec/m^3) to Q, source strength (lb/min), at various peak concentrations in parts per million for fluorine and chlorine trifluoride are shown in Figures I-3 and I-4 respectively.

The nomographs aid in assigning a numerical value of the normalized peak concentration (Cp/Q) that can be substituted into the diffusion equation most nearly describing the particular spill or leakage mode for the purpose of determining the distance downwind beyond which the EEL established for the site (or other limit) is not exceeded.

For example, returning to a consideration of the hypothetical 600 lb/min. fluorine spill: If the EEL value that must not be exceeded is 10 ppm-min., what is the exclusion distance when the Cp/Q resulting from the spill is substituted into the instantaneous point source formula. Entering the fluorine nomograph, Figure I-3, when Cp/Q exceeds 3.7 x 10^{-6} second per cubic meter, one would expect the 10 ppm level to be exceeded at the distance for which Cp/Q is predicted when the source strength exceeds 600 lb/min.

Using the distance form of the formula,

$$X \text{ (meters)} = 0.340 \frac{Ep}{Q}^{-0.629}$$

and substituting the value for Ep/Q, 3.7 x 10^{-6} sec/m^3, obtained from the nomograph, the distance is computed as follows:

$$X = 0.340 (3.7 \times 10^{-6})^{-0.629}$$

$$\log X = \log 0.340 - 0.629 \log (3.7 \times 10^{-6})$$

$$= 2.993$$

$$X = \text{antilog } 2.933$$

$$= 984 \text{ meters} = 3{,}260 \text{ feet downwind}$$

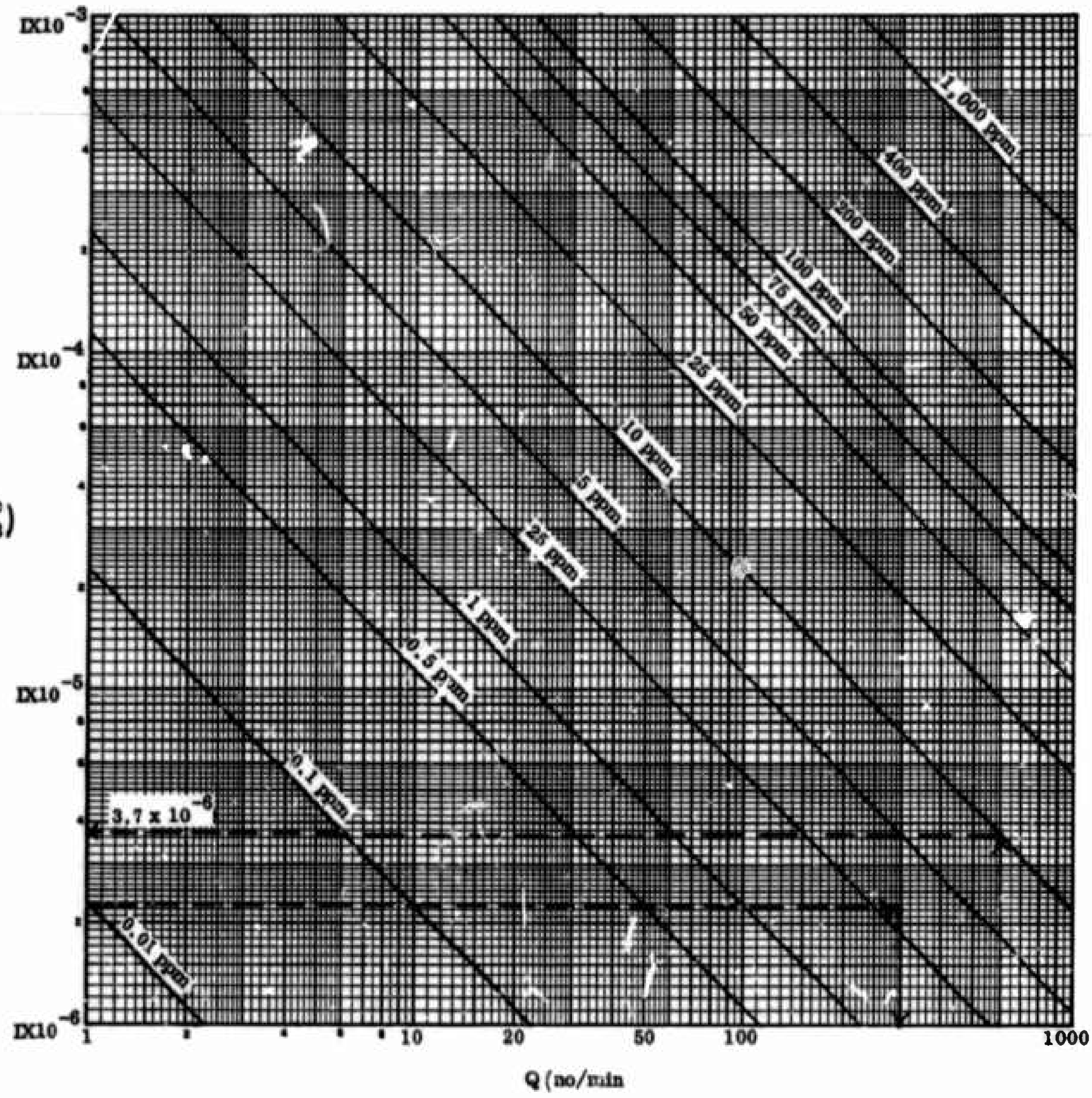


Figure I-3. Conversion Nomograph F_2

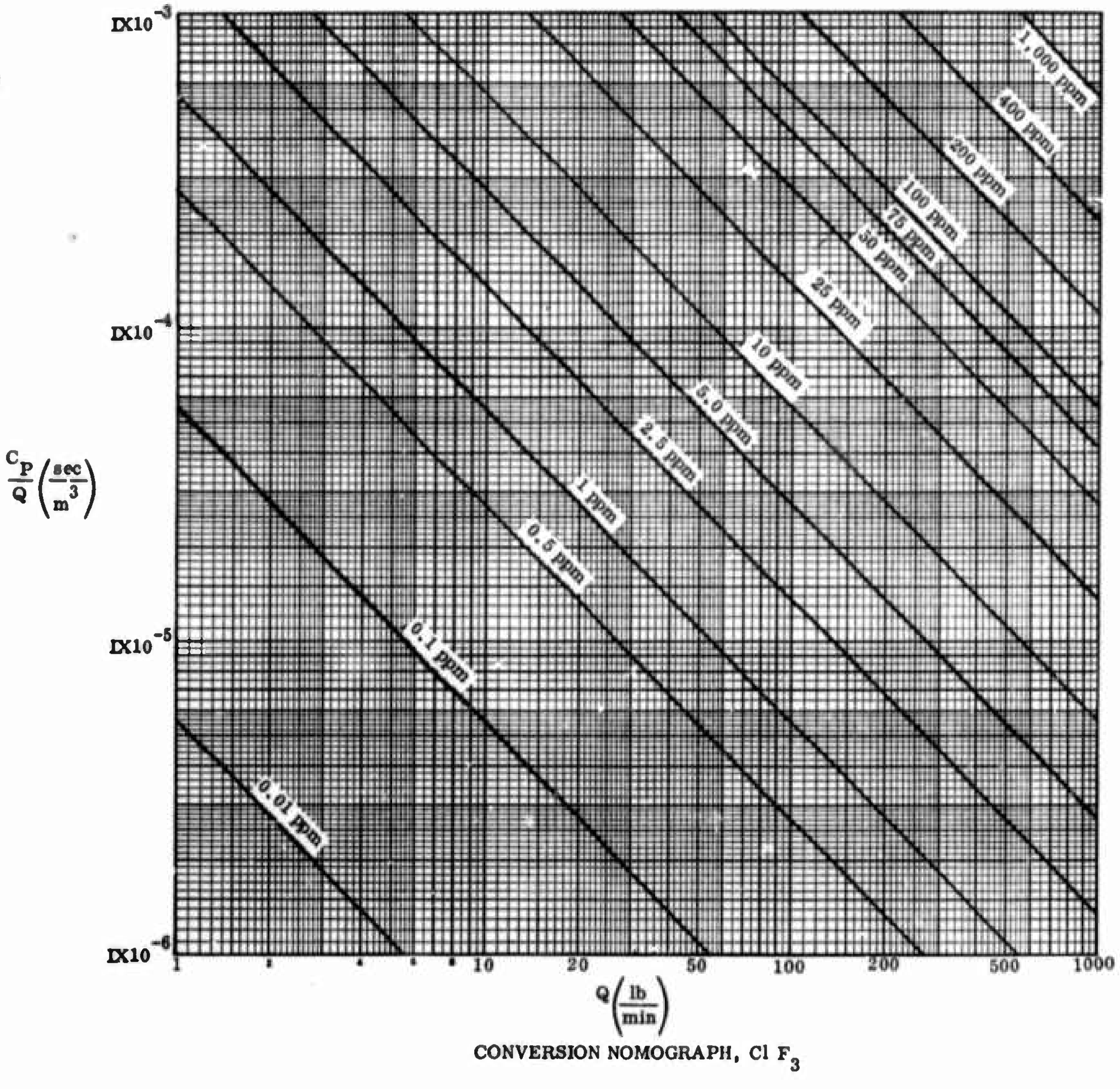


Figure I-4. Conversion Nomograph ClF_3

If 10 ppm-min. is the EEL for the control of the operations set by the cognizant range safety organization, and the nearest personnel are beyond 3,260 feet, the toxic hazard risk would be acceptable.

For the type of cold spill where some degree of containment has been provided, and the oxidizer is evaporating at ground level, the period of time may be extended. Dispersion under these conditions will be most reliably described by the WINDS continuous point source equation currently in use at ETR and WTR.

Here again, the nomograph, Figure I-3 for fluorine may be used to illustrate how the toxic hazard associated with a spill can be predicted when employed along with the continuous point source equation. Suppose that with some degree of confidence, the meteorological factors registered in the WIND system yields a normalized peak concentration (Cp/Q) of 2.24×10^{-6} sec/m^3 at a distance of 7,000 feet downwind (the site exclusion distance) and that the fluorine peak concentration permitted is 3 ppm. What is the source strength, Q, that can not be exceeded in order that a concentration of 3 ppm will not be carried beyond 7,000 ft downwind? Entering the conversion nomograph, it is found that about 300 lb of fluorine released per minute will equal a peak concentration of 3 ppm.

These examples oversimplify the problem of range management. Actually the prediction accuracy in terms of a confidence limit must be determined for each situation which takes into account the meteorological forecasting accuracy and the statistical accuracy of the WINDS equation or other applicable equation. The prediction accuracy of the instantaneous point source equation has been discussed previously.

The accuracy of WINDS equation for continuous sources is somewhat better. Briefly, it appears that multiplying the Cp/Q obtained from the equation by 2 gives 86% confidence that the predicted peak concentration will not be exceeded. The same confidence level is achieved for the predicted distance by multiplying by 1.4.

During the foregoing discussion to explore the various possible most credible release modes involving a QD and its associated AGE, it was assumed that personnel would be excluded from the site. Furthermore, the additional assumption of a 30 second delay before cut-off of the AGE valve closure resulting in a 600 lb/min. emission (at the rate of 20 lb/sec.) is probably longer than would actually be the case during a blockhouse monitored, critical transfer operation.

It is reasonable to conclude therefore that the toxic hazard risk under these conditions is quite low, if the operation has been placed on a site with sufficient distances to the nearest range industrial complex, and to the nearest populated areas.

There is some concern among various knowledgeable range safety personnel concerning the difficulties of prediction in all cases (Reference 34). More data on higher atmosphere behavior, including wind deviations, speeds, and particularly the deviations brought about by upper atmosphere wind shear are needed to improve prediction accuracy.

At ETR, an additional 500-ft tower has been erected for the purpose of gathering such data in order to correlate it with that already feed into the WINDS system from lower altitude equipment.

Finding adequate "weather winds" for launch purposes may become a problem. Diurnal variations in wind velocity, deviation, and temperature lapse in coastal areas limit the times when certain types of launches could be made. With on-shore breezes, +1°F vertical temperature lapses, and standard wind shift deviations of less than 10°, the WIND system prediction may not permit a launch operation to proceed.

APPENDIX II

OXIDIZER CHARACTERISTICS

A summary of the information on the characteristics, principal byproducts, and contaminants of the four oxidizers under consideration is shown in Tables II-1 and II-2.

For liquid fluorine (LF_2) it may be noted that in addition to F_2 the primary reactive constituents are hydrogen fluoride (HF) and oxygen difluoride (OF_2); both products are formed from moisture contamination. Oxygen (O_2) is considered mildly corrosive and the remaining constituents are either inert or have negligible corrosive effects.

For chlorine trifluoride (CTF), the most reactive constituent is also HF. Perchloryl fluoride (ClO_3F), chlorine monofluoride (ClF), and chlorine (Cl_2) are also corrosive but to a lesser degree than HF. The remaining constituents are either inert or have negligible corrosive effects.

FLOX, a mixture of liquid fluorine and liquid oxygen, may contain all of the contaminants noted for liquid fluorine plus those which are common to liquid oxygen. Oxygen is produced by liquefaction of air, and its principal contaminants are nitrogen and argon, which are inert. In general, LO_2 contains a higher percentage of hydrocarbons than gaseous oxygen. When FLOX is prepared in large quantities, it is usually prepared by combining LO_2 and LF_2. Reaction between LF_2 and the hydrocarbons may cause an appreciable increase in the HF present in the FLOX. Smaller amounts of the contaminants per unit volume should be present in FLOX than in LF_2, and as would be expected, FLOX has been shown to be less corrosive. Rocketdyne has reported that in tests which they have conducted, the compatibility of metal materials with FLOX with concentrations below 40 or 45% fluorine is essentially the same as for liquid oxygen. With high concentrations of F_2, the FLOX reacted with metals to a degree approaching the reactions with LF_2.

Table II-1

LIQUID FLUORINE AND TYPICAL CONTAMINANTS

Formula	Name	Melting Point °C	Boiling Point °C	Relative Reactivity with Materials of Construction	Typical Quantities Present	Remarks
F_2	Fluorine	-219.6	-188	Highly corrosive	98.5+%	Both liquid and gaseous states are reactive in varying degrees with essentially all materials of construction.
HF	Hydrogen fluoride	-83.1	-19.54	Highly corrosive in liquid and gaseous states	0.15%	Apparently non-corrosive in solid form. Presence of HF is generally attributable to the reaction of gaseous F_2 with moisture from the atmosphere.
O_2	Oxygen	-218.4	-182.96	Mildly corrosive	0.15%	Compared to F_2, O_2 is only mildly corrosive to most materials of construction. A product of moisture.
N_2	Nitrogen	-209.86	-195.8	Noncorrosive	0.45%	Inert gas
CF_4	Carbon tetrafluoride	-184	-128	Noncorrosive	0.01%	Characterized by extreme chemical inertness at ordinary and low temperatures. A product from carbon electrodes.
CO_2	Carbon dioxide	-56.6 @ 5 ATM.	-78.5 Sublimes	Noncorrosive	0.001%	Negligible corrosion rates with the common materials of construction. A product from impure electrolyte. Has impact sensitive reaction with LF_2.
OF_2	Oxygen difluoride	-223.8	-144.8	Highly corrosive	Not Determined	Short term tests of LF_2 containing 10% OF_2 suggest that OF_2 accelerates corrosion. At levels it is normally present it appears unlikely that it would have a measurable effect. A product from moisture in the F_2 generator.
COF_2	Carbonyl difluoride	-114	-83.1	Not identified as corrosive	↑	Essentially insoluble in LF_2 and apparently does not contribute to corrosion. A product from impure electrolyte.
SO_2F_2	Sulfuryl fluoride	-136.7	-55.4	Not identified as corrosive	|	Essentially insoluble in LF_2 and apparently does not contribute to corrosion. A product from impure HF.
SF_2	Sulfuryl hexafluoride	-50.5	+63.8	Noncorrosive	|	Essentially insoluble in LF_2 and comparable to N_2 in chemical inertness. A product from impure HF.
SiF_4	Silicon tetrafluoride	-90.2	-86	Not identified as corrosive	|	Essentially insoluble in LF_2 and apparently does not contribute to corrosion. A product from glass (not normally present). May form from silicon in metal alloys.
H_e	Helium	-272.2	-268.9	Noncorrosive	|	Inert gas
H_2	Hydrogen	-259.14	-252.8	Noncorrosive	↓	Negligible corrosion rates with common materials of construction.
Metal F	Metal fluoride	-	-	Noncorrosive	Not Determined	Forms on all metals in contact with F_2. May be present as solid particles in the fluid as a result of being separated from the base metal. Increases electrical conductivity of the fluid and causes increased galvanic corrosion.

Table II-2

CHLORINE TRIFLUORIDE AND TYPICAL CONTAMINANTS

Formula	Name	Melting Point °C	Boiling Point °C	Relative Reactivity with Materials of Construction	Typical Quantities Present	Remarks
ClF_3	Chlorine trifluoride	-83	+11.3	Highly corrosive	99% Spec. Min.	One of the most reactive of the halogen fluorides. Made from chlorine and fluorine at 200°C.
HF	Hydrogen fluoride	-83.1	+19.54	Highly corrosive in liquid and gaseous states	0.5%	Presence of HF is generally attributable to reaction of fluorine with moisture from the atmosphere.
Cl_2	Chlorine	-103±5	-34.6	Corrosive	Not Determined	Dry chlorine is moderately corrosive to metals. Chlorine combined with water is highly corrosive to metals.
ClF	Chlorine monofluoride	-154±5	-100.8	Corrosive	0.25%	ClF is less reactive than ClF_3, therefore should not accelerate the corrosion rate.
ClO_2	Chlorine dioxide	-59.5	+9.9	Not identified as corrosive	Not Determined	ClO_2 is a very unstable and explosive compound. It is debatable whether significant quantities would be present.
ClO_2F	Chloryl fluoride	-115	-6	Not identified as corrosive	0.25%	ClO_2F is unstable and shock sensitive. Dense white fumes of HF are formed when exposed to moist air. Chemical reactions have not been studied extensively.
ClO_3F	Perchloryl fluoride	-146	-46.8	Corrosive	Not Determined	ClO_3F is a stable compound. Not corrosive to most metals in anhydrous state; but moist gas is severely corrosive to aluminum and steel.
CF_4	Carbon tetrafluoride	-184	-128	Noncorrosive		Characterized by extreme chemical inertness at ordinary and low temperatures. An impurity from the manufacture of F_2.
CO_2	Carbon dioxide	-56.6 @ 5.2 ATM.	-78.5 Sublimes	Noncorrosive		Negligible corrosion rates with common materials of construction. An impurity from the manufacture of F_2.
Metal F	Metal fluoride	-	-	Noncorrosive	Not Determined	Forms on all metals in contact with F_2. May be present in solid particles in the fluid as a result of being separated from the base metal. Increases electrical conductivity and causes increased galvanic corrosion.
						NOTE: Some explosions in ClF_3 systems which have happened as ClF_3 evaporates have been tentatively blamed on chlorine oxides and oxyfluorides present in the ClF_3.

APPENDIX III

LEAK DETECTION AND MEASUREMENT

a. General

The checkout, tests, and qualification of a QD coupling designed for use with fluorine oxidizers require sensitive and reliable instrumental physico-chemical methods to detect concentrations, ideally, in the range of 0.1 ppm to several percent in air or purge gas.

A variety of chemical reactions known to give traceable reaction products has been tested in the laboratory and has been used to detect leaks. In most cases the chemicals and sampling equipment are awkward to handle and require a highly trained engineer or chemist to use them successfully. Some development of specialized instrumentation has taken place and several types are now available. Others are in the laboratory developmental stage or have been constructed only for in-house use. The operational criteria for a satisfactory detector for use in the field are as follows:

(1) Sensitivity--The minimum concentration of a substance that can be detected and indicated by an analytical instrument or method. At least 0.1 ppm full scale.

(2) Specificity for fluorine, CTF, FLOX, and Compound A--The ability of an instrument to detect one substance without interference from impurities or other foreign substances. Less than 1% interference from other oxidizers.

(3) Precision and accuracy--Precision--the degree to which the analytical instruments or method repeatedly indicates the concentration of a substance. Accuracy--the measure of the difference between the indicated concentration and the true concentration, assumed or accepted on the basis of a standard independent method. ±10% or better in ppm range; ±2% or better in percent range.

(4) Response--(Response Time)--The time interval required for an instrument or device to detect and measure the concentration of a substance. Automatic gas sampling rates permitting the following:

(a) Dynamic response--80% of final reading in 10 sec or better.

(b) Integrated Data (Total Dose)--Direct readout in ppm-minutes or ppm-hours.

(5) Range of concentration detected--0.1 ppm to 100,000 ppm full scale.

(6) Read out

(a) Alarm--Visual and sound.

(b) Remote--Recording in blockhouse.

(7) Maintainability

(a) Corrosion Resistance--Against weather and acid gases.

(b) Detector Life--Maximum possible or paralled units.

(c) Ease of Calibration--Internal or simple standard source.

(8) Portability--Not over 75 lb with batteries and amplifier.

(9) Cost--$5, 000 or less.

b. Commercially Available Instruments

Four instruments are commercially available for leak detection and on-site monitoring. The salient features of these instruments are compared in Table III-1.

c. Noncommercial Methods for Detection of F_2 and F_2 Compounds

(1) Methods based on direct F_2 measurement

(a) Spectrophotometric (Ultraviolet Absorption)

The F_2 concentration in F_2-O_2 mixtures has been determined by completely vaporizing a liquid sample, allowing it to expand into a special 10-cm-long spectrophotometer cell, and measuring the intensity of the broad absorption band for fluorine in a spectrophotometer (Reference 13). Because of the corrosive properties of fluorine, the cell was constructed of stainless steel and coated with Teflon, which served to minimize the absorptive effects of the metal. Sapphire windows were used because of their adequate ultraviolet transmission characteristics and resistance to attack by fluorine. A Beckman Model DK-1 recording spectrophotometer was used for the intensity measurements. The intensity of the absorption at a wavelength of 278. 0μ, which is a function of the fluorine concentration, was measured. Unknown concentrations can be determined immediately by reading the intensity and comparing it with calibration curves prepared from known concentrations. The liquid fluorine mixtures were sampled with a Cosmodyne sampler and transferred to a spectrophotometer cell through a system containing a vacuum pump and manometer.

Concentrations of F_2 that can be analyzed range from 0. 5% to 100%. The precision and accuracy claimed for the method are 0. 3% and ±0. 6%, respectively. This method is not applicable to CTF and Compound A analyses since they will not absorb at the same wavelength of the ultraviolet spectrum. This technique could possibly be adapted to in-line monitoring of F_2 concentrations.

Table III-1

COMMERCIALLY AVAILABLE INSTRUMENTS FOR F_2 DETECTION

Manufacturer	Tracerlab	Mine Safety Appliances Company	Teledyne Systems Company	Davis Instruments
Detection Principle	Dry Krypton-85 Clathrate	Ionization Chamber Detects on Aerosol	Transducer operated on the principle of a micro fuel cell 200 L/min	Measurement of conductivity after gas sample ionizes in water 0.2 to 5L/min
Sample Flow Rate	0.5 L/min	4 to 10L min	200 L/min	0.2 - 5L min
Ranges	0 to 10, 0 to 30, 0 to 100 ppm full scale	0 to 5, 0-200 ppm	0 to 5, 0 to 50, 1-2000 ppm	0 to 10, 1 to 100 ppm
Sensitivity	0.1 ppm	0.05 ppm at 5-ppm range, 2 ppm at 200-ppm range	0.1 ppm	1 ppm as HF
Precision & Accuracy	±10% full scale	±2% of full scale	±2% of full scale	±2% of full scale
Selectivity	Selective to F_2 and F_2 compounds	Not selective	Not selective	Not selective
Interferences	Humidity, HF	Other acid gasses--HF, HCl, N_2, O_4, etc.	All oxidizers	Any ionizable gas, such as NH_3, CO_2, SO_2, HCl, N_2H_2, etc.
Portability	Small (19 in. x 14 in. x 16 in.), compact, rugged	15 lb	Weight < 15 lb	Portable, 50 lb with batteries
Maintainability	Clathrate cell life limited	Fill reagent container and charge batteries every 24 hours	Maintenance required every 3 to 6 months	After 8 hours continuous use, batteries must be charged
Operational Period	Calibration good for 3 months with continuous operation at 5 ppm	1% change in calibration every 30 days	Calibration required every ? to 4 weeks	Must be calibrated for specific gas; seldom need to change ion exchange resin
Warning System	Adjustable alarm set at all ranges	Alarm-- audio and visual	Audio and visual alarms	Alarms available
Effect of Overdose	Shuts off	Recovers after overdose	Has presetable high-concentration cutoff	Will saturate
Cost	$3,000	$1,250 to $4,000	$3,500 + accessories	$3,000 to $6,000
Remarks	AEC license for 50 mc of Kr-85 required	Remote recorder readout possible; need radioactive source license	Remote read out, probe mode, multiple sampling systems all available	Cannot determine F_2 accurately because of F_2 hydrolysis to HF

(b) Radiochemical Exchange by Use of Kryptonates

Radioactive Krypton (Kr-85) is incorporated in the surface of solid silver iodide (AgI) and is released when F_2 reacts with the AgI (Reference 14). The proportionate amount of Kr-85 is detected by a Geiger tube.

A kryptonate differs from a clathrate in that a kryptonate consists of any solid material into which Kr-85 has been incorporated, while a clathrate consists of a three-dimensional organic crystalline cage in which a second component such as the inert gas, krypton, has been trapped. The most commonly used clathrate is hydroquinone krypton 85. In this clathrate, the element or compound to be detected must oxidize the hydroquinone to release Kr-85, which in turn is radiochemically counted. It can be used to detect F_2, O_3, ClO_2, and other oxidizers. One of its severest shortcomings is its sensitivity to relative humidity, which must be compensated for in calibration.

In the kryptonates, the Kr-85 is entrapped in a lattice of solid. To release the Kr-85, the kryptonated solid must undergo a chemical reaction to destroy the surface layers. Presumably the kryptonates can be made to have greater specificity for detecting gases, because a solid can be used that will only react with the gas to be detected. Parametrics, Inc., have developed a kryptonate in which the F_2 reacts with AgI to form AgF and release I_2, which in turn releases the Kr-85, which is radiochemically counted. This company has developed one instrument for use at Wright Field. It is superior to the clathrate because it is selective for F_2 and is not sensitive to relative humidity, HF, or O_3. The kryptonated cell has a life of several weeks at the 1-ppm level but will only last 1 hour if used at the 1 to 5% F_2 level. From the weight of the kryptonate, and knowing flow rate and F_2 concentration, cell life can be calculated. FLOX, CTF and Compound A should also be detected by this instrument, because, they will react with the AgI.

(c) Electrochemical

This oxidation-reduction instrument was designed and assembled at General Dynamics/Astronautics (Reference 15). The cell consists of a glass tube in which a platinum gauze electrode and a silver wire electrode are immersed in a lithium chloride solution. When an atmospheric sample is bubbled through the lithium chloride solution, any fluorine present will oxidize an equivalent amount of chloride to chlorine. The electromotive force (EMF) developed by the cell is a function of the partial pressure of chlorine and, therefore, of the partial pressure of fluorine in the atmospheric sample. The EMF developed in the cell produces a proportional electric current in the external circuit, the value of which is continuously recorded on a strip-chart recorder. In the absence of fluorine, the cell still produces a small EMF as a result of the difference in electrochemical potential of the silver and platinum electrodes, but this is nulled by a bucking voltage provided by a small battery.

The atmospheric sample is drawn through a cell at a nominal flow rate of 220 cc/min.

The instrument is 14-1/2 in. wide by 10-1/2 in. high by 11 in. deep and weighs 32 lb. It is completely portable and powered by batteries. No provision is made for remote readout.

Normal ranges of concentrations of fluorine determined are 0 to 5 ppm and 0 to 10 ppm. It could possibly be adapted, by buffering the electrolyte, to 1,000 ppm detection. The response is approximately 90% in 30 sec in the 0 to 5-ppm range.

While the instrument is selective to fluorine, with no HF interference it should also detect CTF, FLOX and Compound A, individually, since they undergo similar reactions with lithium chloride.

The cost to build the instrument was reported as $1,200.

(d) Mercury Reaction

Gaseous fluorine oxygen mixtures are introduced into an apparatus and mercury is added to react with the fluorine (Reference 16). As a result of the reaction, in which the fluorine gas is reduced by the mercury to form mercuric fluoride, the pressure in the apparatus is reduced. After completion of the reaction, Kel-F polymer oil is added to restore atmospheric pressure in the apparatus. The volume of oil plus the volume of mercury equals the volume of fluorine in the sample. The apparatus is a simple glass setup, not requiring vacuum-type stopcocks, because it is operated at near-atmospheric pressures. A manometer and vacuum manifold (to 1 mm Hg pressure) are needed. Part of the apparatus is submerged in a constant temperature bath. This technique was used to analyze fluorine in approximately 30% fluorine oxygen mixtures. A precision of ±0.3% was indicated from 5 tests.

These operations would be limited to laboratory use and to the determination of percentage amounts of fluorine, such as in FLOX, CTF and Compound A could be analyzed in the same manner, since they will also react with mercury.

(e) Chemical Fluorine and Fluoride Dosimeter

General Dynamics Corporation has also packaged this instrument, which operates as an absorber of atmospheric contamination and, as such, gives only the total integrated dose for the test run. In operation, an atmospheric sample is purged through a cylinder containing an absorber solution of 1% potassium iodide and then is expelled through the outlet tubing. The potassium iodide solution absorbs both fluoride (from any hydrogen fluoride formed from hydrolysis of fluorine) and fluorine and further reduces the absorbed fluorine to fluoride, and equivalent amount of iodide being oxidized to iodine in the process.

At the conclusion of a test run, the absorber solution is removed to the laboratory and analyzed for total fluoride and iodine. The iodine is probably titrated with sodium thiosulfate. One of a number of methods could be used to determine total fluoride. The amount of iodine present is proportional to the amount of fluorine absorbed and the total fluoride present minus the fluorine absorbed is proportional to the amount of hydrogen fluoride absorbed. Alternately, the fluorine and hydrogen fluoride content could be determined as Levy and Copeland (Reference 17) did by titrating the liberated iodine with sodium thiosulfate to determine the fluorine content, and then, by adding potassium iodate solution, further iodine is formed from the hydrogen fluoride present and is then titrated with sodium thiosulfate.

The packaged instrument, prepared by General Dynamics, is 14 in. wide by 12-1/2 in. high by 8-1/2 in. deep and weighs 24 lb.

The nominal instrument sampling rate is 220 cc/min.

Power to operate the pump is supplied by batteries.

The approximate cost of the instrument is $1, 000.

The range of concentration determined is 20 to 200 ppm for fluorine and 0 to 550 ppm for hydrogen fluoride.

This type of detection should also determine FLOX, CTF, and Compound A since they will oxidize iodide to iodine.

(f) Gas Titration Analyzer (Continuous Monitor)

An automatic fluorine analyzer was developed at Oak Ridge National Laboratory by C. W. Weber for monitoring on-stream gas systems (Reference 18). It is based upon a gas titration of fluorine with sulfur dioxide and the detection of the subsequent reduction in molar flow. A gas titration consists of transferring two gases, each from a chamber called a buret, into a reactor, where chemical combination is reduced. The volumes of all chambers, or at least the relative volumes, have been predetermined. The titration is followed by plotting the pressure changes in the reactor after each incremental addition of the titrant gas. The method is applicable to most gaseous reactions that bring about a change in molar volumes. The change in molar flow is apparent in the reaction

$$SO_2 (g) + F_2 (g) \rightarrow SO_2 F_2 (g).$$

The greater the fluorine content of the sample gas, the greater the flow change. Adapting the gas titration to a continuous analyzer involved the continuous introduction of the reactants and removal of the products, proper reaction conditions, and appropriate means of detecting the molar flow changes, which indicate the concentration of the unknown. This was accomplished by use of metering capillaries, pressure control valves, and pressure transmitters, which converted the gas pressure signals to air pressure signals, various pressure gages, and so on. The resultant gas flow product, which varies with the fluorine concentration, was reflected in the forepressure-signal changes at an exit constriction. The exhaust gases from the analyzer were removed and disposed of with chemical traps and a mechanical vacuum pump. With the reactor maintained at 200°C, reaction was complete for 0. 1 to 91% fluorine. The residence time in the reactor was

2.5 to 5.0 sec. The flow rate for sample and reagent was 25 standard cc min. Seventy samples analyzed in the range from 5 to 60% fluorine matched a calibration curve within ±2.5% fluorine at the 95% confidence level. Precision is ±1% fluorine. Neither oxygen nor hydrogen fluoride interfere; therefore, it would be possible to analyze FLOX by this method. Materials similar to CTF and Compound A were not tested but UF_6 did not react.

(g) Thin Film Sensor

This method is based on the detection of toxic vapors by their reaction with thin metal films to reduce the mass of the metal. The rate of metal removal is dependent on the concentration of the vapor. Because the electrical resistance of a conductor is inversely dependent on its cross-sectional area, a reduction in metal mass results in a reduction of cross-sectional area and thus an increase in electrical resistance. The amount and rate of reaction of the thin film under controlled conditions, therefore, is proportional to the amount and rate of change of electrical resistance and can be measured with proper instrumentation.

Thin film sensors for the detection of low concentrations of nitrogen tetroxide and fluorine were developed by the Magna Corporation (Reference 19). They found that silver films deposited on plastic substrates and sensitized with potassium chloride had the highest sensitivity for both nitrogen tetroxide and fluorine. The effects of temperature and humidity were studied and found to be significant in some cases, but not large enough to prevent use of the sensors over a wide range of atmospheric conditions. The sensors can be used to provide an indication of exposure to toxic vapors of nitrogen tetroxide and fluorine. A portable instrument was devised that could be carried in a pocket or worn on a belt. The instrument will respond to nitrogen tetroxide in concentrations of 0.05 ppm and to fluorine in concentrations of 1 ppm, in air, within ±30% of the true value. The effects of other toxic vapors were not studied. The instruments were developed as a study for the Air Force, hence the company has not pursued further development or manufacture.

(2) Methods Based on Replacement of Fluorine with Chlorine and Its Subsequent Detection

Fluorine quantitatively displaces an equivalent amount of chlorine by reaction with sodium chloride and, in turn, the quantity of liberated chlorine is determined by various methods, which could not readily be applied to fluorine directly.

(a) Thermoconductivity Measurement

This technique has been applied to analysis of fluorine in fluorine-oxygen mixtures, where the measurement of fluorine is too similar to oxygen to be detected but where chloride can be readily detected (Reference 20). These detectors work on the principle that gases differ in their heat conduction properties. The sample gas is passed over a heated wire in an analysis cell. The resulting change of temperatures of the wire will change its resistance. This results in unbalancing a bridge circuit that has been calibrated in terms of concentration of the gas to be detected. While the detector is portable, the sodium chloride reactor may restrict the method to the laboratory. Concentrations of fluorine from 0 to 20% in oxygen were analyzed by this method. It should be applicable to the determination of CTF and Compound A, because these also will displace chlorine from sodium chloride.

(b) Photometric

The concentration of chlorine, liberated from the reaction of fluorine with sodium chloride, is measured by passing the gas through a chlorine-sensitive colorimeter, which generates an electrical signal directly related to the concentration of fluorine in the samples (Reference 21). The analyzer consists of the heated sodium chloride reactor, flow colorimeter, pressure-control system, flow limiter, a vacuum pump for drawing a continuous sample through the analyzer, and a recorder. The colorimeter used was a Beckman Model 3700 flow colorimeter, fitted with spectral filters to measure the chlorine absorption at the wavelength of 360μ. A 10-cm-long nickel cell with fluorothene windows was used for the optical cell. The range for the instrument with the 10 cm cell length and 500 mm of Hg pressure was 0.05 to 15% fluorine. With a shorter cell or a lower pressure, up to 100% fluorine could be determined.

Hydrogen fluoride has no effect on the analyzer, but while bromine and certain oxides of nitrogen cause optical interferences. Ozone would probably interfere by liberating chlorine. CTF, Compound A, and FLOX could be determined by the analyzer because they also liberate chlorine.

The analyzer requires intermittent renewal of the sodium chloride, the chemical trap, and the recorder chart, occasional replacement of the tungsten source lamp in the colorimeter, and cleaning of the colorimeter cell as indicated by inspection.

The relative standard deviation of the analyzer is about ±1.5% above 0.8% fluorine.

(3) Methods

(a) Gas Chromatography

A gas chromatograph utilizing only Monel and stainless steel parts was designed at Rocketdyne for analyzing fluorinated materials (Reference 22). A gas chromatographic substrate was developed from 50% Kel-F polymer plasticized with 50% Halocarbon oil. This substrate is classified as a monophase gel and is vastly superior to the duophase columns for separating fluorinated materials. A hot-wire thermoconductivity detector, with the hot wires coated with Teflon, was used. Rocketdyne claims analyses of fluorine, CTF, and HF are possible, and from its data it appears that the compounds could be determined even if present in mixtures. Small gas samples were used for analysis, and no attempt was made to use the instrument for in-stream analysis. Gas liquid chromatography was applied to in-line analyses of plant streams containing CTF, Cl_2, HF, and other reactive gases at the United Kingdom Atomic Energy Installation at Capenhurst, England (Reference 23). A split-column chromatograph was developed and automated.

Clemons and Altshuller (Reference 24) used a Micro-Tek dual-column gas chromatograph, equipped with an electron-capture detector mounted in parallel with a flame ionization detector, for studying various halogenated compounds. It is interesting to note that they made sample dilutions of 250, 000, 000 to 1 with nitrogen.

(b) Radioactive Cl-36

This technique is being developed at Douglas. Radioactive sodium chloride will be prepared from Cl-35. The fluorine to be determined will be passed over the sodium chloride to release radioactive Cl-36. This chlorine, equivalent to the amount of fluorine, will be detected by radiochemical counting techniques.

(c) Infrared Absorption

Infrared absorption might be used for detecting CTF and Compound A directly or by their reaction with carbon to form CF_4, which, in turn, could be detected by infrared absorption. The conversion to CF_4 could be used for fluorine and FLOX detection. Detectors have been developed using infrared absorption for N_2O_4 and UDMH.

(d) Microwave Detectors

Microwave (1 mm to 30-cm wavelength) detectors are being developed where positive identification of specific compounds is possible.

The interaction of a unique microwave frequency with a molecule of vapor will result in its partial absorption by the molecule. This energy can be detected and measured by electronic methods.

d. Summary

None of the instruments available commercially or those known to be for laboratory test satisfactorily fulfill all the requirements for leak test measurement and site monitoring.

A new instrument or an adaptation of a currently available instrument should be used to detect and measure leaks in the QD coupling for the following:

(1) Internally--From the vehicle or AGE shutoff valves following transfer and purging.

(2) Externally--From the sealing surfaces into the volume surrounded by the frost-prevention shroud.

APPENDIX IV

FACILITY, RANGE, AND REGULATORY AGENCY CONTROLS

1. TOXIC LIMIT DATA

Maximum allowable concentrations (MAC) or (more recently) threshold limit values (TLV) adopted by the American Conference of Governmental and Industrial Hygienists (ACGIH) for fluorine and CTF are fixed at the same value, 0.1 ppm by volume (Reference 48). A sample graphical solution of the equation for fluorine is shown in Figure IV-1. TLV's are based on the best available information from industrial experience, experimental animal studies, experimental human studies, and a combination of all three, when possible. As such, they are intended to be used as guides of time-weighted average concentrations to which most workers could be exposed for 8 hours each day, 5 days per week, for life without adverse effect.

Following World War II, the production and use of large quantities of fluorine by the Atomic Energy Commission (AEC) and the chemical industry, and its planned use for rocket propulsion prompted more extensive toxicological investigations to determine realistic short-term exposure values applicable to operational personnel. Some toxicity studies on hydrogen fluoride (HF) were completed in 1934 and 1935 by W. Machle, et al. (References 49 and 50). HF was a well known and much-used chemical, whereas fluorine usage was slight, which may explain the dearth of toxicological data available up to 1945. Additional work was reported on fluorine (F_2) in that year by N. Eriksen, H. Stokinger, et al (References 51 through through 53), with F_2 and HF data by Voegtlin and Hodge (Reference 54) and later work on HF by Carson, et al in 1961 and 1963 (References 55 and 56). A distinct difference in chronic toxicity between F_2 and HF has been noted, but for short exposures, both exhibit fast-acting irritant action on the eyes and respiratory mucosa. With high concentrations, exposed personnel would be forced to vacate the area because of involuntary choking or spasm.

One manufacturer of fluorine has found that 25 to 35 ppm F_2 forces the vacating of an area (Reference 57).

Fluorine is easily detectable by odor, and personnel are trained to leave an area in a few minutes if the odor is detected. However, odor detection is of limited value, in that it is impossible to determine concentrations quantitatively.

The amounts by which the concentrations may exceed the TLV recommended values (F_2--0.1 ppm, HF--3 ppm) up to the intolerable concentrational values for short periods without injury to health depends on a number of factors:

a. Whether high concentrations even for short exposures produce acute poisoning.

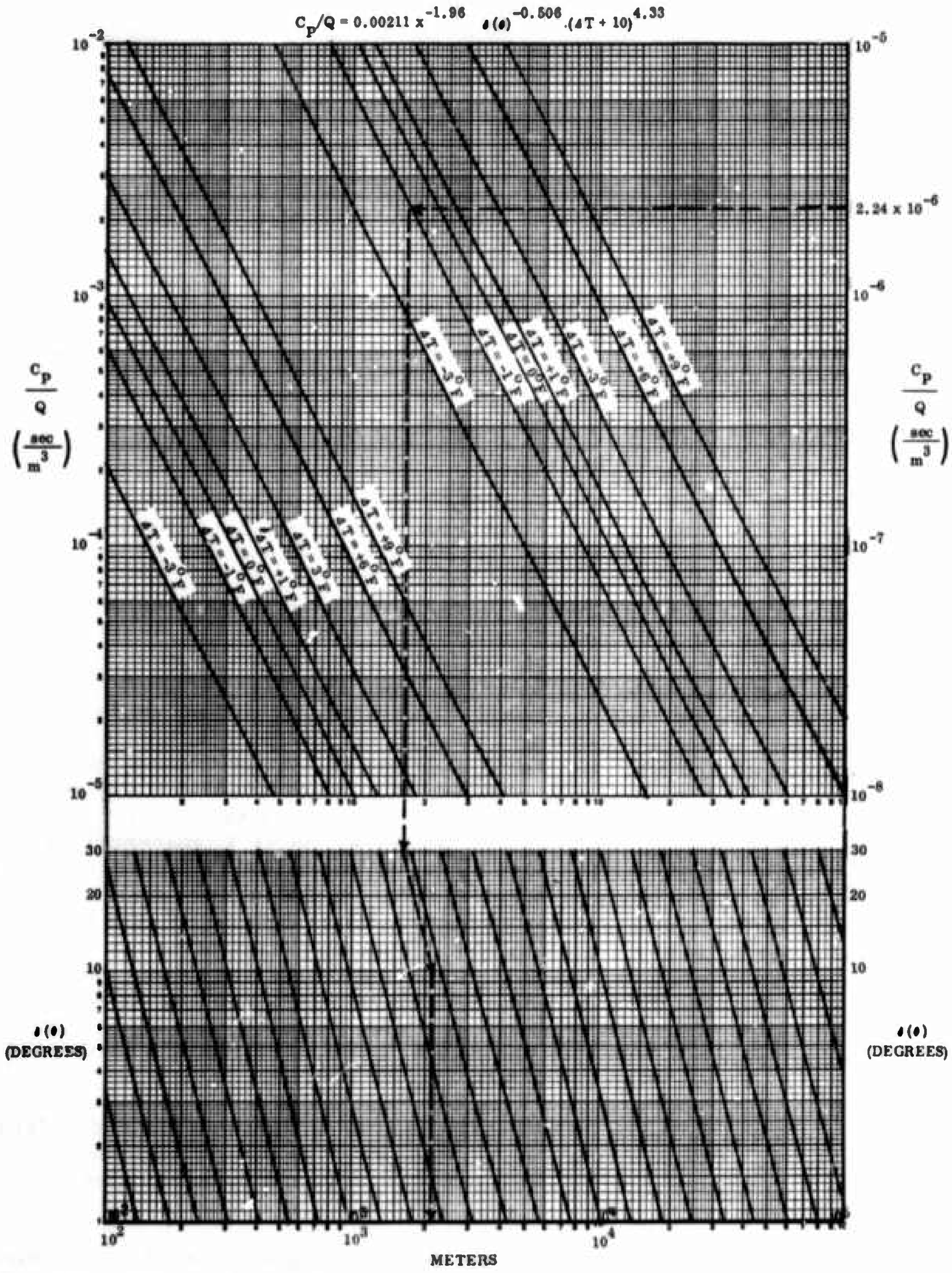


Figure IV-1. Graphical Solution of WINDS Prediction Equation

b. Whether the effects are cumulative.

c. The frequency and duration of the exposures.

For fast-acting substances, a more appropriate limit, known as a ceiling (c) limit, was agreed to be more applicable than the TLV. Certain ceiling limits have been agreed to and adopted and published by the ACGIH 26th Annual Meeting, April 1964. In general, the bases for assigning a (c) value rest on whether exposure to concentrations above a proposed limit for periods up to 15 min. may result in:

a. Intolerable irritation.

b. Chronic or irreversible tissue change.

c. Narcosis of sufficient degree to increase proneness to accident, impair self-rescue, or materially reduce work efficiency.

In addition to these values, the AGCIH, in conjunction with the Advisory Center on Toxicology of the National Academy of Sciences (NAS) National Research Council (NRC) have recommended emergency tolerance limits (ETL) and emergency exposure limits (EEL) for fluorine oxidizers (Reference 58). The limits are set to give guidance in the control of single short-duration exposures of personnel to toxicants released to atmosphere.

ETL and EEL values differ only in the degree of hazard risk encountered operationally. ETL's are guideline levels for control of predictable short-duration occupational exposures that may be repeated with competent medical control. On the other hand, EEL's are guideline levels for control of short-duration occupational exposures of the rare, but unpredictable variety. EEL values are concentrations which the normal individual can tolerate without permanent adverse effects, but not necessarily to the exclusion of irritation or mild discomfort. EEL's are based on the following:

a. Exposures at these levels will be from unplanned accidents, not the result of engineering controls designed to hold exposures at these levels.

b. Normally prevailing values of airborne contamination in the occupational environment will be below TLV for continuous exposure and below ETL for short-time exposures.

c. Normally prevailing values of airborne contamination for the nonoccupational, off-base environment will be below standards of good community atmospheric pollution control.

d. These accidental exposures will be single events; that is, if a man were exposed at these levels, further exposure would be prevented until he regains his normal resistance.

e. Men who could be exposed under these conditions will not be hypersensitive to or predisposed to disease from the specific contaminant.

f. Persons who could be exposed under such conditions would be under medical surveillance.

g. The probable severity of injury from secondary accidents, resulting from impairment of judgment and coordination, will be considered in applying these values. A degree of temporary intoxication that prevents self-rescue is not considered acceptable.

h. Safety factors such as those used in deriving TLV's and air-quality guides are not applied to EEL's except in cases of low confidence in the extrapolation of animal data to man.

i. Mixtures of contaminants that may produce possible interactions, such as potentiation or antagonism, have not been considered in proposing EEL values.

j. EEL's are intended to provide a finite number which could be introduced into atmospheric diffusion equations to predict downwind vapor hazards for the purpose of siting facilities within a Government reservation.

Because the risks attendant upon the use of EEL criteria are great, an intensive effort to define more certainly fluorine-containing oxidizer hazards is currently underway, funded by the NASA and the Air Force. Results from these study programs will probably not become available in full force until 1966 or 1967 (Reference 59).

Recent contacts with personnel of the Aeromedical Research and Development Laboratory, Toxic Hazards Branch (Reference 60) indicate that preliminary results from current animal toxicity work with fluorine are not expected to change the recommended EEL's promulgated by NAS-NRC.

A summary of the toxic hazard concentrational limits of fluorine and fluorine containing oxidizers appears in Table IV-1. The lethal concentration (LC 50) values are preliminary average figures reported by P. Ricca, KSC Safety Center. This work, funded by NASA, done by M. Keplinger at the University of Miami, is progressing and is expected to yield gross pathological and toxic effects data on rats, mice, guinea pigs, and rabbits exposed to lethal concentrations of fluorine.

H. F. Smyth, Jr. and coworkers (Reference 58) pointed out that there is no justification for distinguishing between ETL's and EEL's, since it is recognized that both occupational and nonoccupational exposures can occur at predictable time intervals. Repeat exposures to EEL concentrations will be permitted only with medical monitoring and authorization.

Table IV-1

INHALATION LIMITS AND TOXICITY OF FLUORINE CONTAINING PROPELLANTS

Propellant	TLV		EEL				LC 50	
			Occupational		Community			
	PPM (Vol)	Time	PPM (Vol)	Time (min.)	PPM (Vol)	Time (min.)	PPM (Vol)	Time (min.)
Fluorine F_2	0.1	8 hr	3 2 1	10 30 60	0.5	10	~700 ~370 ~270 ~160	5 15 30 60
Hydrogen fluoride HF	3	8 hr	20 10 8	10 30 60	5	10	4060 ~2600 ~1800	5 15 30
Chlorine trifluoride CTF	0.1	8 hr	7 3 2	10 30 60				
Oxygen difluoride	0.05	8 hr	0.5 0.2 0.1	10 30 60				
Compound A*	0.1*	8 hr*						

*TLV not officially established, but will probably be the same as for F_2 and CTF. EEL and LC 50 values have not been determined as of January 1966 (Reference 60).

TLV -- Threshold Limit Value.
EEL -- Emergency Exposure Limit.
LC 50 -- Lethal Concentration (50% deaths in test animals).

Safety factors, often used in arriving at TLV's, are not applied to the EEL except in cases of low confidence in the extrapolation to man of animal-derived data (usually LC 50 values). TLV safety factors often are established at levels of 10x or more, depending on the degree of industrial experience and known pharmacology of the toxicant.

Because EEL's are established for cases in which personnel may be exposed to higher concentrations for short periods of time, they are intended as guides for the specialist in range safety and toxicology, to aid him in making realistic judgments which will give maximum protection consistent with efficient launch site operations.

Employed by the specialist in this way, EEL's are used as peak values that should not be exceeded except in emergency cases where health risks are justifiable in order to prevent a still more serious event or in the advance planning for particular launch or test site emergencies. The use of these limits as fine-line exposures, discriminating between dangerous and tolerable exposures, is not implied, and should be avoided. Extrapolations of these limits to other exposure periods by means of calculations adjusted from concentration-time product or total integrated doses (TID) are not necessarily valid. For example, the 1966 peak concentration limit recommended by NAS-NRC for 10-min. exposure to fluorine is 3 ppm. The TID in this case equals 30 ppm-min. Using this value to calculate a peak concentration allowable for 0.5 min. exposure (30 ppm-min./0.5 min.) yields 60 ppm, a peak concentration which is intolerable even for 0.5 min. Thus, it is clear that peak concentrations are as important as exposure time in judging the degree of hazard. However, total integrated doses based on peak concentration x time are more valid in terms of the toxic hazard if the concentration does not exceed intolerable levels; e.g., 10 ppm-min. dose is equivalent to 1 ppm-10 min.

The emergency exposure limits imposed by cognizant authorities for control at a number of sites after careful evaluation show a considerable spread in permissiveness. During the past 3 years, special sets of EEL's, ETL's, TLV's, and total or average dosage values have been established for sites under contract to do fluorine R&D for the Air Force and NASA. These include those set by the USAF Surgeon's Office, SSD, Los Angeles, for Rocketdyne and TRW (Reference 61) for specific use at rocket engine test sites on the west coast. Other facilities include those sited under NASA contracts for GD/A at Sycamore Canyon and Douglas at Edwards AFB (A-23 location)(Reference 62). Table IV-2 summarizes the specific site deviations permitted or recommended by various cognizant authorities.

Several of the assumptions listed as basic conditions applicable to the use of EEL values for control of personnel subjected to short-term inhalation of fluorine oxidizers serve to emphasize certain vague informational areas. Much animal toxicity research presently underway must be completed to define the limits. Furthermore, in the case of fluorine, the toxicity situation is continuously changing during emissions into air because of reaction with water vapor to form HF. The rate of conversions is not accurately known and a more or less subjective approach must therefore include EEL's for both substances.

Table IV-2

HISTORICAL SUMMARY OF TOXIC LIMITS IMPOSED FOR USE OF F_2 AT ROCKET TEST FACILITIES, 1963 TO 1966

Toxicant, Facility, and Date	Exposure Time (min.)	Conc. in Air (ppm) (V/V)	TID (ppm-min.)	Toxicity Population Category	Expected Effect on Humans	Reference and/or Authority
LF_2 NASA-Lewis and others Aug. 1963 1963	5 15 30 60 Repeat exposures	2.0 1.5 1.0 0.5 0.5 0.1	10 23 30 30	ETL's (rare single events) ETL on-site TLV off-site	No pathological changes or sensory discomfort No pathology changes Detected by odor	NAS-NRC Advisory Center on Toxicology NAS-NRC
LF_2 NASA sites incl. KSC June 1964	5 15 30 60	25 15 10 5	125 225 300 300	EEL's for Group I - controlled personnel	Discomfort with no permanent health impairment (single event)	ACGIH (includes 2x safety factor due to lack of data)
HF NASA sites incl. KSC June 1964	5 15 30 60	300 150 100 50	1500 2250 3000 3000	ibid	ibid	
LF_2 NASA sites incl. KSC June 1964	5 15 30 60	5 3 2 1	25 45 60 60	EEL's for Group II uncontrolled community	No health impairment; slight discomfort	ACGIH
HF NASA sites incl. KSC June 1964	5 15 30 60	30 15 10 8	150 225 300 480	ibid	ibid	
LF_2 Rocketdyne GD/A, DAC Nov. 1964	5 15 30 60	5 3 2 1	25 45 60 60	EEL (ETL) on-site exposures recovery from repeat exposure is implied	No impairment of health; some discomfort	NAS-NRC committee of toxicology meeting, NASA Safety Director, and USAF
HF Rocketdyne GD/A, DAC Nov. 1964	5 15 30 60	30 20 10 8	150 300 300 480			
LF_2 NASA-Lewis March 1965	5 15 30 60	2-5 1.5-3 1.0-2 0.5-1	10-25 23-45 30-60 30-60	ETL's	No health impairment; mild discomfort	Suggested to NAS-NRC by NASA-Lewis

The primary effects of short-duration exposures to F_2 and HF at levels above the ETL are caused by their irritant actions on the tissues of the eye and respiratory tract tissues. P. Ricca (Reference 63) points out that industrial and animal studies demonstrate that acute exposures cause pathological lung changes long before the occurrence of significant biochemical, hematological, weight, or skeletal changes. Reference 63 also shows that the LC 50 animal studies of Carson, Eriksen, and Machle correlate quite well and ETL's and EEL's can be established at 0.6% and approximately 4% of the LC 50 values obtained for HF from animal experiments, respectively. However, fluorine ETL's and EEL's will probably be found to establish at levels of less than 2% of the LC 50 animal values.

Other difficulties involve the reliability and accuracy of chemical methods or instruments available for determining when limits have been exceeded. Another problem is the number of repeat exposures and length of recovery periods in between which can be tolerated without encountering secondary pathological changes. This probably varies considerably among healthy normal individuals.

It should be emphasized that there is sufficient research data (References 49 through 56) to fix the chronic tolerance levels for HF and F_2 at 6 and 1.7 mg/m^3, respectively (3 ppm HF and 1 ppm F_2). Above these levels, the ability of the body to reject these quantities is jeopardized; fluorosis can be the long-term result.

Another fluorine toxicity value which so far remains somewhat inviolate is the minimum lethal dose (MLD). Continuous exposure to 200 ppm of fluorine gas for 3 hours has proved fatal to human beings (Reference 64). An MLD set at 200 ppm-hours, therefore, appears to be a realistic figure. Currently established EEL's giving doses of 30 to 60 ppm-min. are quite conservative and provide better than a 200-fold safety factors under the MLD value.

The following listing summarizes the toxic hazard data and knowledge important for establishment of guidelines on engineering design, range planning, operational constraints, personnel risk criteria on missile sites, and avoidance of legal risk arising from exposures of off-site population to fluorine oxidizers.

a. The guideline EEL's established for the fluorine oxidizers as promulgated by NAS-NRC should be followed to control range personnel.

b. Deviations should be allowed only after intensive evaluation by an informed specialist with the concurrence of the cognizant range safety or siting authority.

c. In all cases, the general provisions of the Clean Air Act must be met.

d. Instrumental analytical monitoring should be set up to confirm that the operational and safety procedures used to minimize toxic hazards both on-site and in adjacent uncontrolled populated areas are valid.

e. Operations must provide a go-no go criteria based on the toxic hazard expected in case of a most credible incident which gives maximum assurance that dosages in uncontrolled areas do not exceed the ETL value (applicable only by permission of local authorities) or the TLV established for the particular oxidizer.

2. CLEAN AIR ACT

The Clean Air Act is the basic federal instrument defining the procedures and controls imposed on organizations planning to use toxic propellants (Reference 65). The provisions of the act are administered through the U.S. Department of Health, Education and Welfare.

In accordance with the requirements of the Act, range management and operating personnel are jointly responsible for conducting those studies necessary to provide clear-cut operational limits. Conformance requires (in part) the following procedures:

a. Notify and work with local pollution control authorities (state, county and/or municipal control boards for air, soil, and water pollution).

b. Provide pollution sampling and detection instrumentation for documenting peak and integrated pollution concentrations at the boundaries of the exclusion area and at facility boundaries.

c. Select weather windows which will not permit pollutant drift of hazardous quantities downwind into populated area, taking all precautions to prevent exposure of humans, animals, and valuable plant life outside the exclusion area.

d. Perform soil and water sampling and chemical analyses before and after tests to record and document possible pollution.

3. FACILITY REGULATIONS

Facility regulation is of primary importance in order to provide adequate safety controls for the protection of employees, the population, plant and animal life, materials, equipment, and other property both on- and off-site.

Failure analyses specifically instituted for a particular site and facility should be undertaken to achieve maximum safe operation. All the possible modes of failure must be anticipated so that correct engineering design and operation procedures may be employed to minimize unpredicted fluorine releases.

Most credible release evaluations should be undertaken to design adequate facilities for disposal, purging, containment, and control of fluorine to atmosphere. Sources of fluorine or its principal reaction product, hydrogen fluoride, include the following:

a. Ruptures of lines, diaphragms, valve seals, pumps, and quick disconnects.

b. Rupture of storage or condensation tanks.

c. Rupture of missile tanks during launch.

d. Exhaust products from vehicle engines.

e. Residuals from lines and other hardware after passivation, from parts being repaired or replaced, and from vent lines or parts under test.

Range regulations at launch sites agreed upon by safety personnel of the cognizant agencies are set in each case in accordance with the provisions of the Clean Air Act and state or local air and water pollution laws and ordinances. Toxicity levels (EEL's), permissible emission rates, duration, and meteorological conditions must be evaluated in order to adequately locate (site) a toxic propellant operation.

The responsibilities reserved by ETR safety authorities and those required of the range user for control of fluorine launch programs are abstracted (below) from Reference 66:

1. The basic philosophy applied to the determination of responsibility of conducting studies of the type described in referenced correspondence is: the Range will conduct those studies required to determine the capability of the Range to accommodate a program using hazardous material; the Range User is expected to conduct those studies necessary to assess a potential hazard to the Range resulting from the use of hazardous material.

2. Taking the foregoing into account, the following describes the studies and analyses required and the agency responsible for initiation of the studies.

   a. Range Studies:

      (1) Background Ecology. This study will determine existing levels of material from natural and/or artificial sources.

(2) Routine Ecology Studies and Analysis. This will be done at intervals of time (depending on frequency of use of the hazardous material) to measure rate of increases when compared with initial background studies (Sub-Paragraph 2. a(1) above).

(3) The Range will analyze Range User studies of emission rates (see below).

(4) The Range will conduct air sampling and sensing programs. This will be primarily "off complex" activity; however, it must be closely coordinated with "on complex" sensing, which will be done by the Range User (Subparagraph 2. b(5) below).

(5) The Range will determine hazard radii and will develop and implement plans for the control of people.

(6) The Range will, based on analysis of Range User Emission Rate Studies, establish propellant handling, transfer and launch operations restriction to those times when assured that hazardous material above the emergency tolerance limit does not exceed a boundary line two miles inside the Range boundary.

(7) The Range will dispose of contaminated propellants.

(8) The Range will analyze the vehicle propulsion system to to determine validity of the Range User's Emission Rate Study. Complete schematics with stress specifications will be required.

(9) The Range, through Medical Service people, will prescribe pre- and post-exposure medical examinations.

(10) The Range will evaluate and approve, personal protective equipment and devices proposed for use by the Range User.

(11) The Range will site a facility using fluorine to minimize influence on adjoining facilities, if appropriate. If an existing complex is converted to fluorine use, siting would not be appropriate.

(12) Sampling and analysis will be accomplished by the Range. Maximum lead time prior to use of fluorine is required to allow procurement of necessary equipment. A minimum of six months is estimated to be required.

b. The Range User:

(1) Conduct Emission Rate Studies. The complete propellant storage, transfer and loading system, as well as the vehicle, must be analyzed to determine likelihood of leaks and spills. The amount of material versus time versus meteorological conditions versus surface area and materials of construction must be considered to determine rounds per minute of vapor emitted. The launch abort following flight termination action or other incident must be included.

(2) Conduct studies to determine expected ecological effects.

(3) Determine methods of decontamination and neutralization.

(4) Determine composition of products of combustion and significant followon reactions.

(5) Maintain a sensor and repair crew on the complex while fluorine is on the complex. Portable sensors to scan components of the complete plumbing system must be used to discover leaks. A team of people qualified to operate the system to effect repairs and minimize loss of material will be required.

(6) Identify and propose for use, protective clothing, equipment and devices suitable for fluorine use.

(7) Plan and schedule use of the material to correspond with meteorological restrictions imposed by the Range.

(8) Determine emergency tolerance limits to which people may be exposed.

3. The foregoing attempts to describe work required of both the Range and the Range User. The list is not necessarily complete, but should serve as a guide to identify the total work required.

4. It should be noted that initiation of studies, scheduling of work, progress reports, etc., are dependent on a firm commitment to to use fluorine. The location and amounts to be used, including back-up supplies, must also be identified.

4. STATE AND LOCAL REGULATIONS

The California Standard of Ambient Air Quality, administered by the California Department of Public Health, Bureau of Air Sanitation, does not prescribe any legal limits on the quantity of fluorides or fluorine in the atmosphere. There is some discussion of undesirable concentrations (2 to 5 ppm of HF being regarded as causing skin and mucosa irritation), but these are not legal limits. Most counties in California with Air Pollution Control Boards follow the recommendations and limits determined by the

Los Angeles County Air Pollution Control Board (LA APCB). There are no regulations of the LA APCB directly applicable to fluorine or fluorides. Rule 50 deals with making the air opaque by aerosols, smoke, and other means. The limit on opacity is 40%. Rule 52 states that particular matter, including aerosols, shall be emitted at a concentration of greater than 0.4 grain (mass)/cu ft of air. Total solid effluent allowed depends on the amount of material handled (Rule 53); for a throughput of 60,000 lb/hour, the legal maximum of solid effluent is 40 lb/hour. Data for Florida (ETR) are not at the moment available; air pollution in that state is under the control of Bureau of Sanitary Engineering, State Board of Health.

APPENDIX V

SUMMARY OF CURRENTLY USED QUICK DISCONNECTS

A survey was made of existing quick disconnect (QD) couplings for possible adaptation to fluorine service. The specific couplings which have been reviewed are those used on Thor, Saturn IVB, Titan II, Centaur, and the APOLLO service module.

Six-in. -diam couplings are utilized on the Thor. The ground half of the coupling is manually inserted into the vehicle half, an operation which also opens the vehicle poppet. No latching mechanism is used and decoupling as well as closing of the vehicle poppet is effected at liftoff by a combination of the forward motion to the vehicle and lateral movement of the ground half by an AGE actuator. The coupling is too large to be considered for the current fluorine QD program, and it utilizes soft seals incompatible with fluorine.

Four-in. -diam QD couplings are used for loading propellants on the Saturn IVB. There are no shutoff valves in either half of the coupling. The coupling is manually installed and preloaded against a Teflon seal on the vehicle from a carrier plate which supports a majority of the umbilicals to the stage. Decoupling is accomplished at vehicle liftoff by pulling a release pin and moving the carrier plate clear of the vehicle with an AGE actuator. The coupling is too large to be used on the fluorine QD program, and the Teflon seal would not be compatible with flowing fluorine.

The 2-in. -diam Titan II coupling is in the proper size range to be a possible candidate for the fluorine QD application. It is designed for manual coupling and decoupling and has no quick release feature and no provisions for misalignment between the coupling halves. The coupling halves are joined by means of Acme threads. After initial engagement, manual rotation of the outer sleeve mates with the interface seal and further rotation opens the conical seat poppet valves in each half of the coupling to permit propellant transfer. Edge-welded metal bellows are utilized in the ground half of the coupling to provide positive sealing between moving parts and to provide a pressure-energized force on the interface seal during propellant transfer.

The Titan II QD could not be readily modified to provide a quick release mechanism, The Teflon seals incompatible with fluorine under dynamic flow conditions (modification to modification to metal seals would require major redesign), and proper cleaning of the metal bellows to ensure compatibility for fluorine service would be very difficult. Therefore, the Titan II QD is not suitable for this adaptation.

Quick disconnect couplings of a 2 1/2-in. diam are used for loading propellants on the Centaur. Both the vehicle and ground halves of the couplings have shutoff valves controlled by the same AGE actuator. The valve in the vehicle half is spring-loaded closed and is opened by the opening motion of the valve in the ground half of the coupling.

The QD is manually connected and held together by two frangible bolts which are designed to rupture within narrow applied-load tolerances. The interface seal is a U section, pressure-energized Teflon seal which utilizes a metal spring to maintain its shape prior to pressurization. Because of the low strength of the frangible bolts, the attaching nuts are torqued only fingertight.

To prevent the formation of ice at the parting joint of the QD, a garter-type Mylar bag is installed across the separation flanges. The bag and joint are purged with helium to keep air and moisture away, and the bag slips off when the QD is decoupled.

Disconnect of the QD is accomplished at liftoff. Lanyards are attached between the ground half of the QD and a retraction mechanism triggered by a liftoff switch. The two frangible bolts in the QD are ruptured by a suddenly applied load from the retraction mechanisms through the lanyards, and the ground half of the QD and fill line are pulled free from the vehicle.

The Centaur QD design is not suitable for use in fluorine service. The Teflon interface seal is incompatible with flowing fluorine and the use of low-rupture-strength attach bolts (low margin of safety for inadvertent loads) is not consistent with the required safety precautions for such a highly toxic and reactive fluid.

A QD that is 2 1/2-in. in diameter is utilized in the Centaur H_2 vent system. The coupling is mated in a slightly recessed butt joint and locked together with two adjustable overcenter toggle latches. The interface seal is a sheared Teflon flat gasket and the housings are aluminum castings which form a 90° elbow when mated. The design pressure is 12 psig and permissible external leakage is 10 cc per hour, or approximately 10^{-2} SCIM. The coupling must be manually engaged and adjusted to the desired preload; decoupling is accomplished by pulling a lanyard. The coupling contains no valves although it does have an orifice mounted in a swinging plate in the vehicle half which closes and effects a flow restriction when the QD is decoupled.

Although some of the basic principles of this coupling might be utilized for the fluorine QD, the coupling would have to be redesigned to withstand a higher pressure and the interface seal would have to be changed to a material compatible with LF_2 under dynamic flow conditions.

The Apollo service module utilizes 1-in. diam manually operated QD couplings similar in design to the Titan II couplings. They are too small for present fluorine application, and the connector is incompatible with fluorine for the same reasons discussed for the Titan II QD.

Roylyn submitted a candidate QD for evaluation, a 2-in.-diam prototype developed for a high-temperature pneumatic application. It was of all-metal construction, utilizing stainless steel for the body. The interface seal consisted of flat, precision-lapped surfaces with a machined Inconel X bellows to furnish the preloading force. A ball lock was used for latching mechanism and a lever-operated sliding sleeve served as a retainer for the balls in the latched position. The latch could be operated remotely by attaching a linear actuator to the lever. The AGE half of the QD contained a hinged shutoff valve actuated by the same lever that controls the latching mechanism.

Although the QD was constructed of fluorine-compatible materials, there were several features in the design not acceptable for a QD for fluorine service. The interface seal on the vehicle half of the QD was vulnerable to damage during the mating operation. It is most unlikely that a suitably low leakage rate could be achieved with the type of seal used. The seal bellows would be very difficult to clean and inspect for cleanliness. Lap-type weld joints are used in the body and it would be impossible to determine that the lap joints were sufficiently clean for fluorine service. The latching mechanism is not adaptable for a redundant release system, a highly desirable feature for a QD for fluorine service.

Concurrent with the survey of existing QD's, a survey of six vehicles (existing and study phase) was made to collect data on various weight, structural, and propellant parameters. The summarized data from this survey is presented in Table V-1 to indicate some of the previous thinking regarding propellant loading requirements.

Table V-1
VEHICLE CLASSIFICATION

Vehicle	High Energy Upper Stage (Study Vehicle)	Saturn IV
Vehicle parameters		
Gross weight	20,000 lb	115,337 lb
Vehicle type	High energy upper stage	Booster second stage
Propellants	LF_2/LH_2	LO_2/LH_2
Oxidizer weight	15,000 lb	83,000 lb
Oxidizer tank volume	163 ft^3	1262 ft^3
Oxidizer tank pressure	75 psia	46.5 psia
Fill-line size	2" dia. (tentative)	3"
Vent-line size	2" dia. (tentative)	5"
PU System	Not determined	Closed loop (capacitance)
Structure		
Shell	Frame stiffened, corrugated skin	Integral with tanks
Oxidizer tank	Spherical, 82" dia. 0.032 aluminum	200" dia., elliptical, common blkhd
Insulation	High performance on tanks (ground purge)	Interior of tk. and in common blkhd
Umbilical		
Oxidizer	LF_2 vent, LF_2 fill/drain	LO_2 fill/drain
Fuel	LH_2 vent, LH_2 fill/drain	LH_2 vent, LH_2 fill/drain
Propellant loading parameters		
Oxidizer flow rate	Not determined	(Total fill time = 20 min.)
Hold time	No known limit	7 min. max. while pressurized
Oxidizer tank pressure	Near ambient during fill	48.5 psia (vent)
Oxidizer condition	Possible slight subcool (-307 F; -315 F)	Boiling point at ambient press.
Remarks		Final topping while pressurized Vehicle Q. D. and line are drained and purged prior to liftoff. Disconnect by actuator at liftoff.
Reference	67	68

IV	Saturn IVB	Centaur	Delta
lb	245,000 lb	32,000 lb	14,000 lb
e	Booster second/third stage	High energy upper stage	Second Stage Booster
H_2	LO_2/LH_2	LO_2/LH_2	IRFNA/UDMH
lb	184,000 lb	23,400 lb	8,000 lb
	2828.6 ft^3	407 ft^3	82 ft^3
a	37-41 psia	32 psia	340 psia
	4"	2.5 in.	3/4"
	5"	2.5 in.	1/2" (overflow and vent)
nce)	Closed loop (capacitance)	Closed loop (ΔP.)	Open loop
	Integral with tanks	Integral with tanks	Integral with tanks
common blkhd	Elliptical, common blkhd	10' dia., elliptical	55" dia., cylindrical, common blkhd
common blkhd	Interior of tank and common blkhd	Plastic, exterior, jettisonable	None
	LO_2 fill/drain	Not determined	Manually connected MS fittings
rain	LH_2 vent, LH_2 fill drain	LH_2 vent, LH_2 fill/drain	Fill and drain ports capped after fill
nin.)	Approx 30 min.	500 GPM (max.)	20 GPM
essurized	3 min. while pressurized	2.1 min. after topping	Launch 1 day after fill
	44 psia (vent)	29 psia	Ambient
ent press.	Boiling point at ambient press.	Boil off for 20 min. in veh. tank	Ambient
ressurized	Final topping while pressurized.	External leakage = 5 scim max.	Propellant loading valves are hand operated.
are drained liftoff.	Vehicle Q. D. and lines are drained and purged just prior to liftoff.	For all couplings at interface vehicle - half valve (fill and drain)	Fill tanks until liquid comes out the overflow and then drain "x" lbs.
r at liftoff.		Both ox. and LF_2 = 500 scim.	
	69	70, 71, 72, and 73	74

2

APPENDIX VI

SUMMARY OF LF_2 QD's AND RELATED STUDIES

1. INTRODUCTION

A review of the available literature on fluorine research and experimentation indicates that there have been very few attempts to define or build a QD for fluorine service. In one instance, a QD was designed, built, and tested by NASA at the Lewis Research Center (LeRC), Cleveland, Ohio. A preliminary design concept for an LF_2 QD has been suggested by Aerojet-General Corporation and is presented in this section.

The present work by Douglas was initially aimed at meeting a set of requirements for an LF_2 QD defined by the Request for Proposal, Reference 76. A preliminary concept to meet these requirements was evolved and is presented herein.

2. NASA LeRC QD

A prototype QD coupling for ground to vehicle transfer of LF_2 or FLOX was designed, fabricated, and demonstrated at LeRC in 1963 (Reference 77). The primary features of this QD coupling include remote separation capabilities and negligible F_2 spillage when disconnected.

Each half of the coupling has its own poppet-type shutoff valve spring-loaded to the closed position. The interface surfaces are basically plane surfaces with deep intermeshing serrations which serve to align the two halves during mating and also form a labyrinth path between the inner and outer interface seals. Two metal V-ring seals located concentrically on the separation interface and with vertex of each V oriented outward are used to prevent external leakage. The concept for sealing is that any leakage past the inner V-seal will gasify between the labyrinth faces from normal heat transfer, thereby building up pressure in the interseal cavity and causing the gas to leak back into the liquid flow passage, since the orientation of the V-seals offers less resistance to leakage in the inward direction.

Latching is accomplished by three mechanical fingers which pivot on the AGE half coupling and lock over a flange on the vehicle half coupling. Pneumatic cylinders were used to operate the latches and move the AGE half coupling in and out of engagement. The coupling valving is opened by pressurizing an integral pneumatic cylinder in the AGE half coupling which opens both poppet valve simultaneously. When the pneumatic pressure is vented, the valve springs return the poppets to their respective seats.

The coupling was subjected to a limited amount of function testing and operation was reported satisfactory within the range of imposed test conditions.

3. QD CONCEPT FROM LF_2 AGE HANDBOOK

General design approaches for both insulated and uninsulated LF_2 QD couplings are presented in Reference 78. The concepts are similar, except that overlapping vacuum-jacketed areas are proposed for the insulated concept.

The design has shutoff valves in each half and both coupling and decoupling are manual operations. Soft metal is proposed for the interface seal, which is accomplished by bringing the two halves of the coupling together and latching with a ball lock mechanism. An interlocking pin prevents opening the valves before the coupling halves are engaged and locked together.

An outer sleeve on the AGE half housing is rotated on a coarse screw thread to open the valve poppets. A Monel bellows seal permits axial motion to be transmitted to the poppets and prevents leakage past the operating mechanism.

A positive interlock is provided so that the coupling cannot be separated when the valves are open. Stainless steel conical poppets with soft copper or aluminum seats are proposed.

The design aim for the coupling is to prevent any spillage, or to permit only a small wetted area on the coupling halves when separated. A simple enclosure built around the disconnect and supplied with an inert gas purge was proposed for dissipating any F_2 remaining on the interface between the coupling halves.

4. ORIGINAL DOUGLAS CONCEPT

The first concept considered by Douglas was based on a set of design requirements which were defined by the Request for Quotation, Reference 76. The significant features of this concept were as follows:

a. Remote coupling and decoupling.

b. Shutoff valves in both halves of the coupling.

c. Misalignment capability.

d. Double seat at interface.

e. Purged interface seal cavities.

f. Redundant release mechanism.

Figure VI-1 is a sketch of the concept for the vehicle half of the coupling. It consists of a valve body with a spherical outer shape for an interface with the AGE half of the coupling. The shutoff valve in the vehicle half coupling consists of a spring-loaded spherical poppet which closes against a narrow land seat formed by the intersection of two spherical concave surfaces, to produce a perfectly circular seat. The desired seat width would be formed by a combination of coining with a hard tooling ball and lapping with a spherical lap.

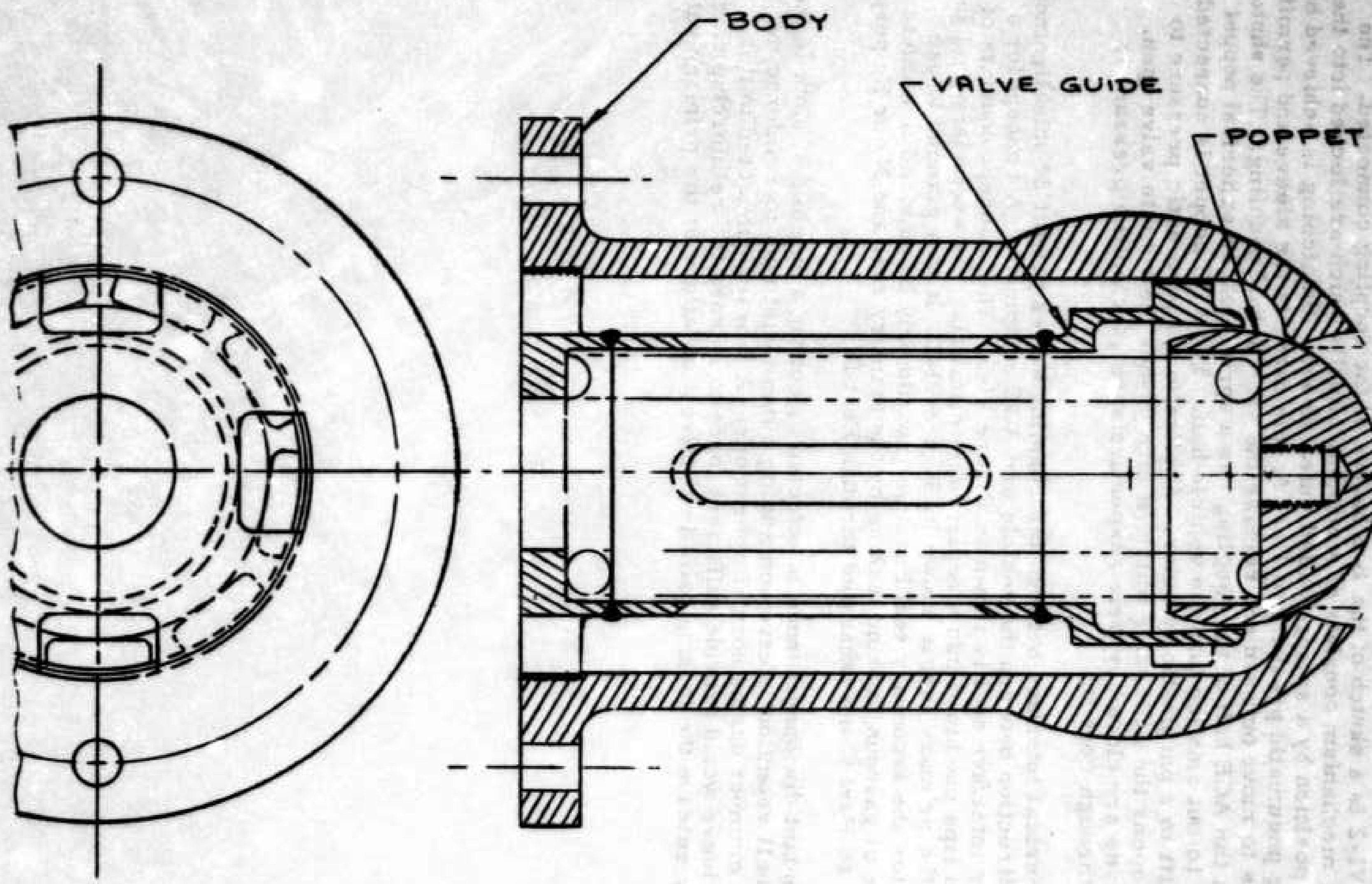


Figure VI-1. Vehicle-Half of Quick Disconnect

Figure VI-2 is a sketch of the two halves of the coupling connected. The latching mechanism consists of a number of balls which are locked into the latched position by a spring-loaded outer sleeve. Unlatching is achieved by applying pneumatic pressure to Port A; this retracts the sleeve and permits the balls to move outward and release the vehicle half coupling. The shutoff valve in the AGE half of the coupling has a spring-loaded spherical poppet similar to but smaller than the vehicle half. The AGE poppet is connected by a shaft to a pneumatic cylinder. Application of pneumatic pressure to Port B opens the AGE valve which in turn pushes the vehicle valve open. The valves are closed by their respective springs when the pressure is vented through Port B.

The spherical interface between the coupling halves permit 2° misalignment in any direction between the vehicle and AGE equipment. A concept for a primary interface seal is shown in Figure VI-3. This concept consists of two thin lips machined into a replaceable metal ring. A secondary seal just ouside the primary seal is shown in Figure VI-2. It was planned to use Teflon for the secondary seal because it would only be exposed to a dilute mixture of gaseous fluorine leaking by the primary seal and N_2 or He purge applied to Port C and exhausted through Port D.

A redundant disconnect mode is effected by cutting a number of slots in the outer (ball retention) sleeve and adding a thin metal ring to reinforce the slotted member during normal operations. A lanyard connected to this outer sleeve would provide sufficient force to rupture the reinforcing ring and thereby release the locking balls in the event of failure of the primary release.

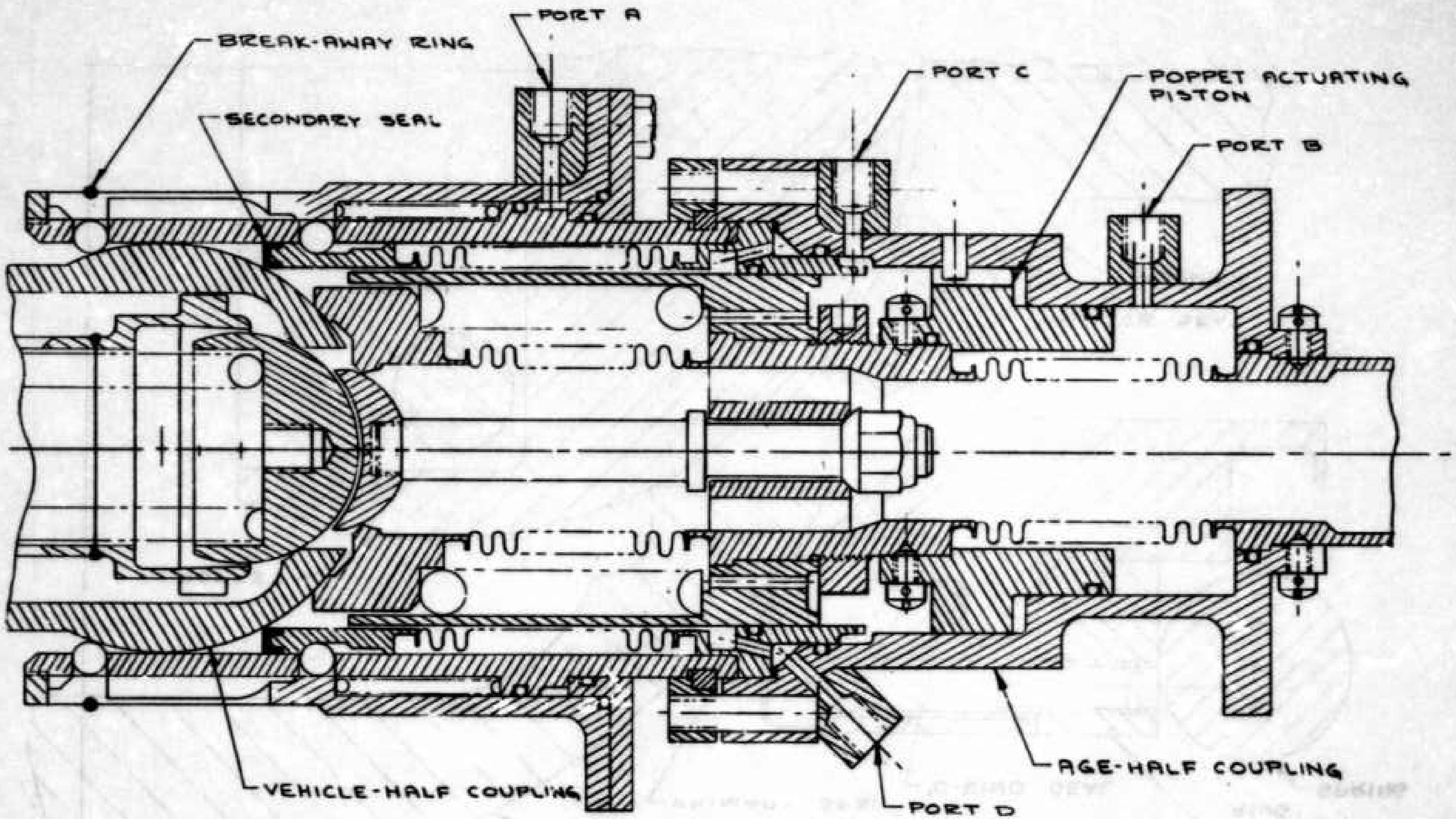


Figure VI-2. Quick Disconnect, Latched and Valves Closed

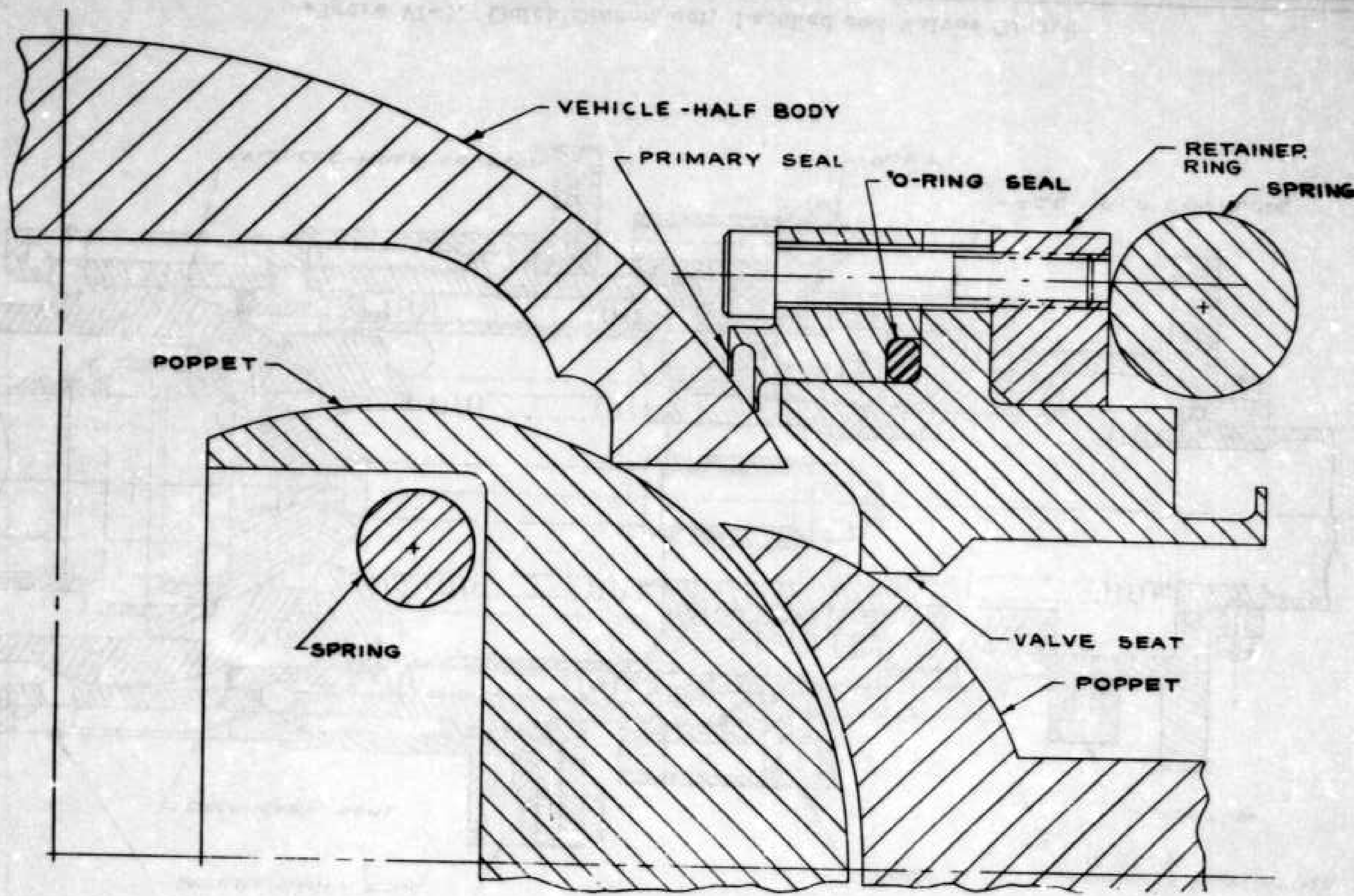


Figure VI-3. Interface Seal Concept

APPENDIX VII

DETAIL STRUCTURAL DESIGN AND ANALYSIS FOR THE TEST MODEL QD COUPLINGS

1. LATCHING MECHANISM

In the initial concept, the latching elements consisted of six one-half inch diameter balls. The typical load diagram for each ball is shown in Figure VII-1. The maximum normal force F_n (for 150% design load) between the ball and the vehicle-half adapter is:

$$F_n = \frac{1200 \times 1.5}{\cos 40°} = 2,355 \text{ lbs}$$

For a rough estimate of the maximum bearing stress between the ball and the adapter the formulas from Table XIV, Case 1 of Reference 81 were used. The formulas are for a sphere bearing on a flat plate and although the actual case is that of a sphere bearing on a concave contoured shoulder on the external surface of a cylinder the calculation represents a reasonable and conservative approximation of the bearing stress between the ball and its mating surface.

$$\text{Max } f_c = 0.918 \frac{F_n}{d^2 \left[\frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2}\right]^2}$$

where

f_c = unit compressive stress

F_n = normal force = 2,355 lbs

d = diameter of ball = 0.5 inch

ν_1 = Poisson's ratio for the ball = 0.26

ν_2 = Poisson's ratio for the adapter = 0.26

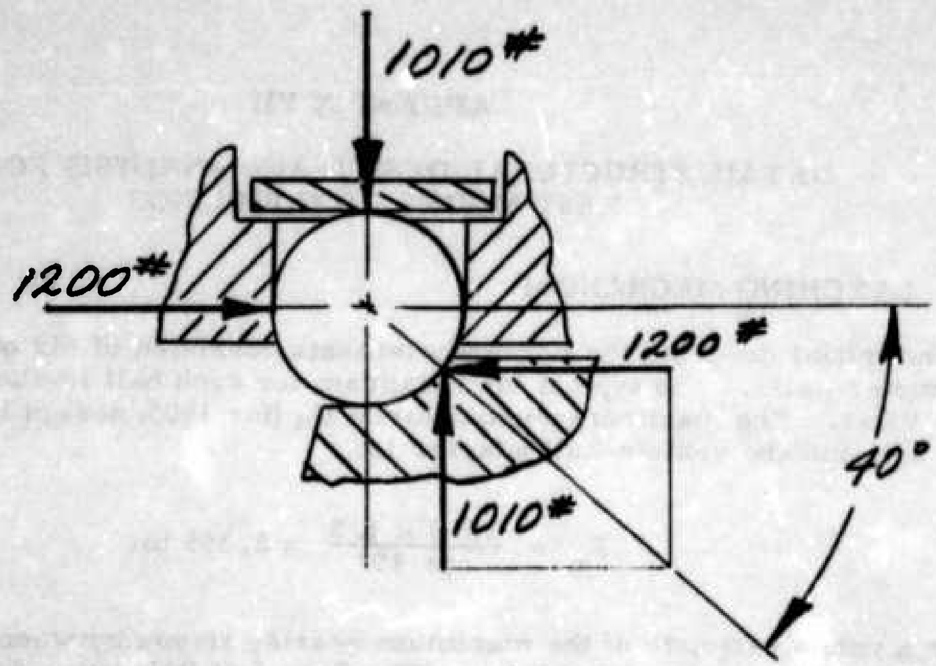


Figure VII-1. Load Diagram for Ball Latch

E_1 = modulus of elasticity in compression for the ball = 29×10^6 psi

E_2 = modulus of elasticity in compression for the adapter = 28×10^6 psi

(Assumed material is 440C CRES for the ball and 340 L CRES for the adapter.)

then:

$$S_c = 1.19 \times 10^6 \text{ psi}$$

For annealed 304L bar the allowable bearing yield stress is approximately 50,000 psi and the allowable bearing ultimate stress is approximately 150,000 psi. Since the calculated stress is an order of magnitude higher than the allowable stress it is obvious that application of the required latching loads by this concept would cause Brinnelling of the adapter by the harder balls. The possibility of increasing the size and number of balls was investigated but there appeared to be no reasonable configuration which would reduce the stress to an allowable level, therefore this concept was abandoned.

As a solution to the problem of excessive stress developed by the balls as latching elements, the design was modified and hinged hooks replaced the balls. The hook concept for the first test model QD is shown in Figure 3-11.

For the stress analysis of the latching components it was assumed that the friction factor is zero between the hook and the adapter in the static latched conditions. This is a conservative assumption which will result in components with greater than minimum required strength.

From the functional aspect of decoupling the two halves of the QD the friction between the hooks and adapter cannot be neglected. Aluminum bronze was selected for the hook material primarily because it has a reasonably low coefficient of static friction, (μ), 0.45 when used against steel (Reference 12), and also has good structural properties which are not adversely affected by cryogenic temperatures. Figure VII-2 is a load diagram illustrating the effect of friction and indicates that the hooks will be free to open and release the adapter when the restraining force W is removed.

The zero friction load diagram for the hook is shown in Figure VII-3 and the dimensions necessary to calculate the loads and stress at critical points in the hook are shown in Figure VII-4. For the 150% design load of 1,800 lbs per latch the following loads result:

$$R_{AH} = N_H = 1,800 \text{ lbs}$$

$$N_V = \tan 40° \times 1,800 = 1,510 \text{ lbs}$$

$$\Sigma M_A = 0$$

$$3.03W - 1,510 \times 2.75 - 1,800 \times 0.44 = 0$$

$$W = 1,630 \text{ lbs}$$

$$F_V = 0$$

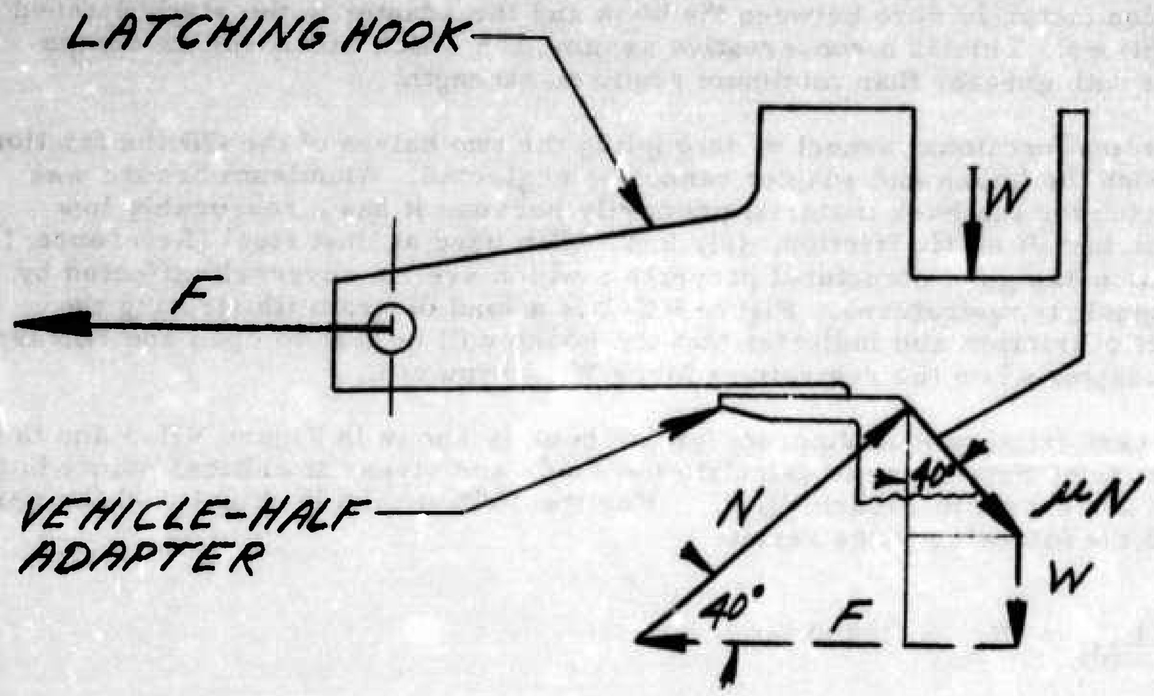
$$W - R_{AV} - N_V = 0$$

$$R_{AV} = 1,630 - 1,510 = 120 \text{ lbs}$$

$$\tan \theta_A = 120/1800 = 0.0667$$

$$\theta_A = 3°49'$$

$$R_A = 1800/\cos 3°49' = 1,804 \text{ lbs}$$



IT IS ASSUMED THAT THE COEFFICIENT OF STATIC FRICTION $\mu = 0.45$ AT THE INTERFACE BETWEEN THE ALUMINUM BRONZE HOOK AND THE CRES 304L ADAPTER.

THE RELATIONSHIP BETWEEN THE FORCES IN THE ABOVE DIAGRAM IS:

$$F = N \cos 40° + \mu N \sin 40°$$

$$N = \frac{F}{\cos 40° + 0.45 \sin 40°} = 0.948\,F$$

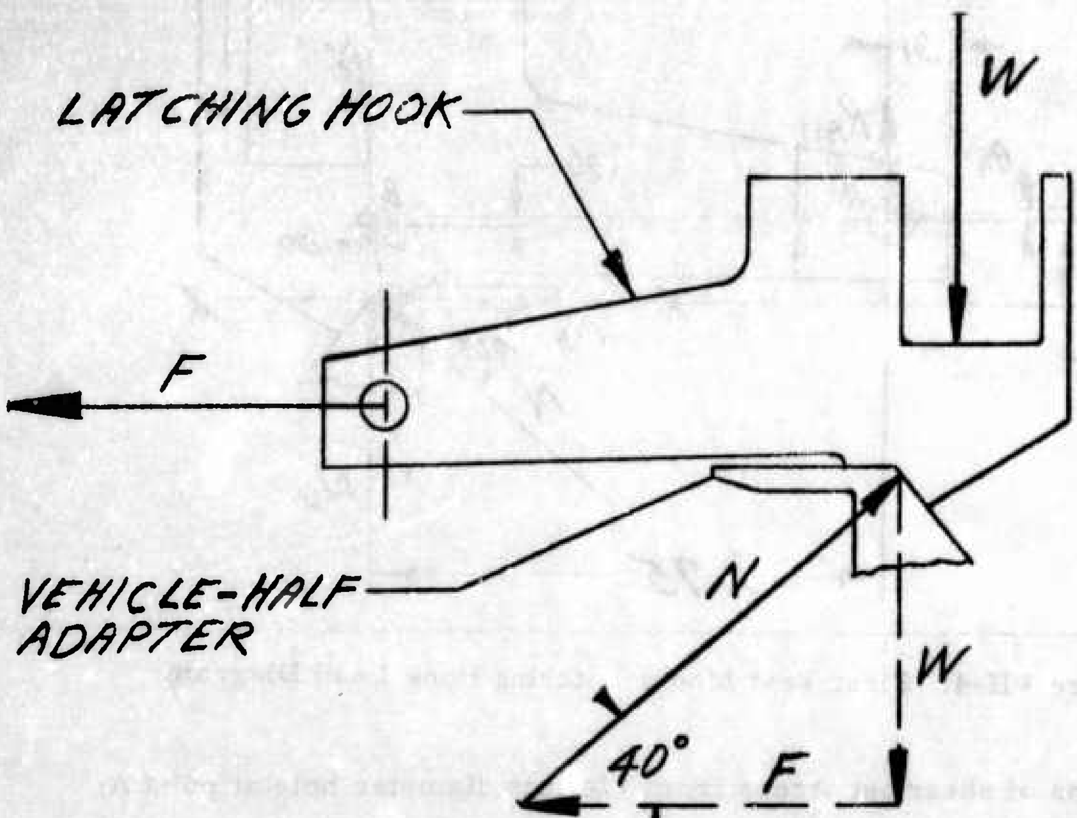
$$W = N \sin 40° - \mu N \cos 40°$$

$$= N(\sin 40° - \mu \cos 40°) = 0.298\,N$$

$$= 0.282\,F$$

CONCLUSION: THE HOOK WILL SLIP WHEN THE RESTRAINING FORCE W IS REMOVED.

Figure VII-2. Latching Hook Load Diagram With Friction



THE RELATIONSHIP BETWEEN FORCES IN THE ABOVE DIAGRAM IS:

$$N = \frac{F}{\cos 40^\circ} = 1.305\,F$$

$$W = F \tan 40^\circ = .839\,F$$

Figure VII-3. Latching Hook Load Diagram Neglecting Friction

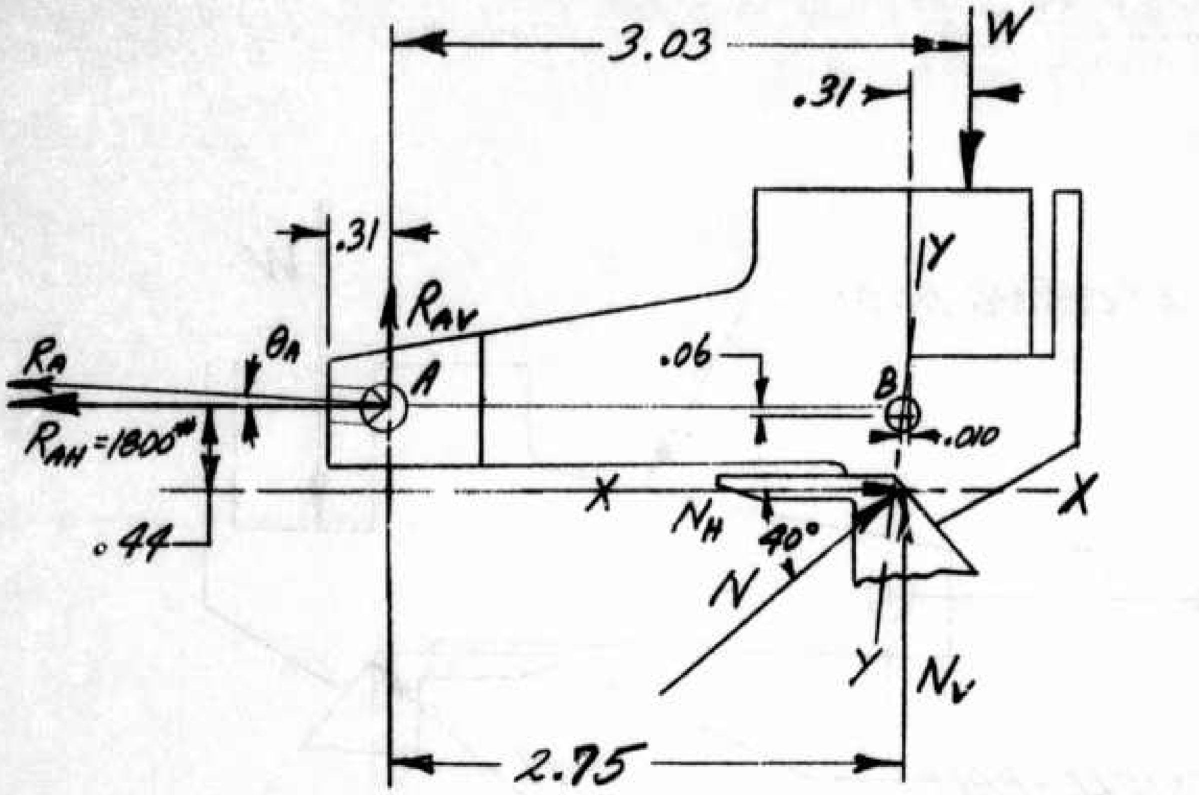


Figure VII-4. First Test Model Latching Hook Load Diagram

Calculations of shear out stress from 1/4 inch diameter hole at point A:

The lug thickness = 0. 188 in.

Shear area = 2 x 0. 188 x 0. 2 = 0. 075 sq in.

f_s = 1804/0. 075 = 24, 100 psi

For aluminum bronze:

F_{su} = 47, 000 psi

M. S. = 47, 000/24, 100 x 1. 5 -1 = 0. 3

Calculation of bending stress at section Y-Y:

My - y = 1630 x 0. 32 - 1510 x 0. 04 - 1800 x 0. 38 = -233 in. lb

f_b = $6M/bh^2$ = $6 \times 223/0.375 \times 0.625^2$ = 9, 150 psi <u>low</u>

F_{ty} = 42, 500 psi

Calculation of bearing stress on hook point:

Assume bearing area is 1/4 x 1/4 = 0.0625 sq in.

$N = 1.305 \times 1800 = 2,350$ lb

$f_{br} = 2,350/0.0625 = 37,600$ psi

$F_{bry} = 51,000$ psi

$M.S. = 51,000/37,600 - 1 = 0.35$

The hook concept for the second test model QD was modified to include a spring loaded retractable latch. This concept is shown in Figure VII-5. For the stress analysis it has been assumed that the friction factor is zero. The vehicle-half adapter is identical for both the first and second test models. Therefore, as discussed for the previous configuration, the hook will be free to slide off the adapter when the restraining force W is released. For the 150% design load of 1,800 lbs per latch the following loads result:

$R_{AH} = N_H = 1,800$ lbs

$N_V = \tan 40° \times 1,800 = 1,510$ lbs

$\Sigma M_A = 0$

$3.44W - 1,510 \times 3.16 - 1,800 \times 0.875 = 0$

$W = 1,840$ lbs

$F_V = 0$

$W - R_{AV} - N_V = 0$

$R_{AV} = 1,840 - 1,510 = 330$ lbs

$\text{Tan}\ \theta_A = \frac{330}{1,800} = 0.183$

$\theta_A = 10°22'$

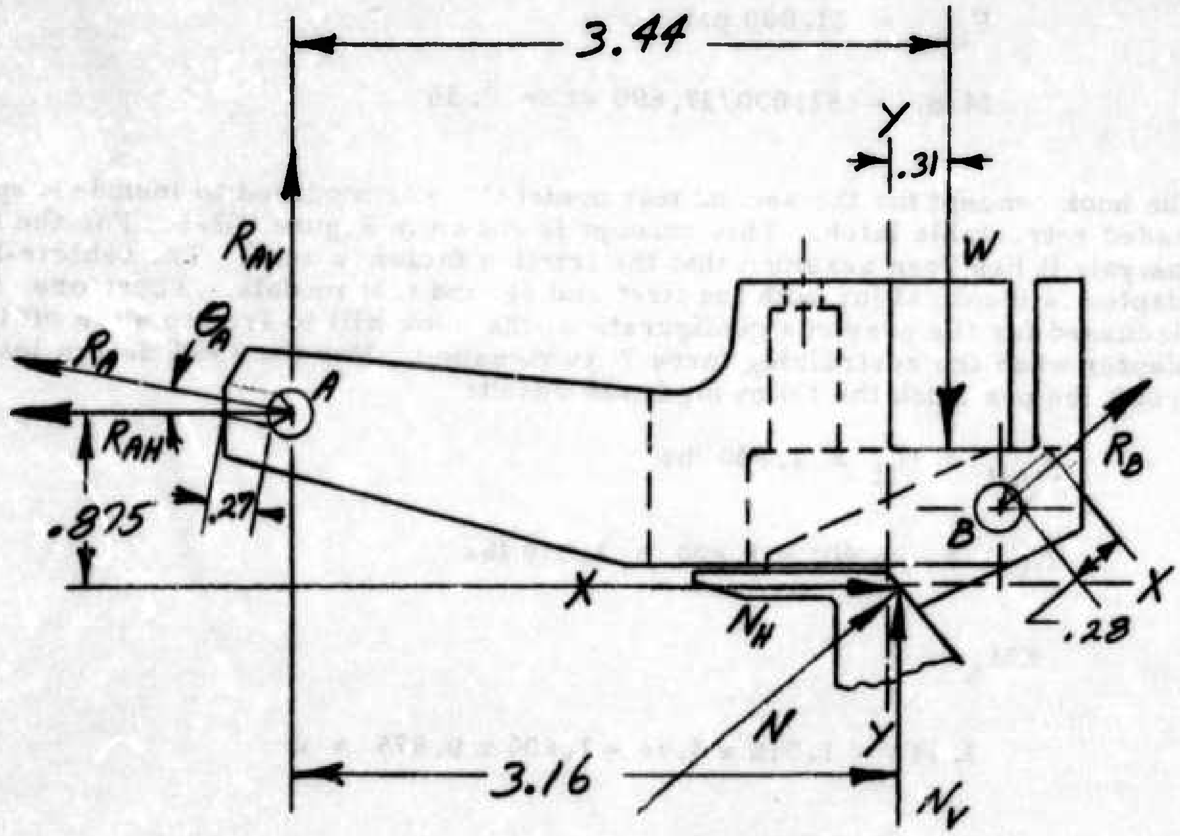


Figure VII-5. Second Test Model Latching Hook Load Diagram

$$R_A = \frac{1,800}{\cos 10°22'} = 1,830 \text{ lbs}$$

Calculation of shear out stress from 1/4 inch diameter hole at point A;

The lug thickness = 0.375 in.

Shear area = 2 x 0.375 x 0.27 = 0.202 sq in.

$$f_s = \frac{1,830}{0.202} = 9,050 \text{ psi } \underline{\text{low}}$$

F_{su} = 47,000 psi for aluminum bronze

Calculation of bending stress at section Y-Y:

M_{y-y} = 1,840 x 0.31 - 1,510 x 0.03 - 1,800 x 0.39 = -177 in. lb

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 177}{0.375 \times 0.594^2} = 8,050 \text{ psi } \underline{\text{low}}$$

F_{ty} = 42,500 psi for aluminum bronze

Calculation of shear stress on latch point, section X-X:

Shear area = 0.375 x 0.360 = 0.135 sq in.

$$f_s = \frac{1,800}{0.135} = 13,350 \text{ psi } \underline{\text{low}}$$

F_{su} = 47,000 psi

The bearing area and bearing stress on the latch hook point are the same as for the first test model. Therefore,

f_{br} = 37,600 psi

F_{bry} = 51,000 psi for aluminum bronze

Calculation of shear out stress from 1/4 inch diameter hole at point B:

$R_B = N = 1.305 \times 1,800 = 2,350$ lbs

The lug thickness = 0.375

Shear area = $2 \times 0.375 \times 0.28 = 0.21$ sq in.

$f_s = \frac{2,350}{0.21} = 11,200$ psi <u>low</u>

$F_{su} = 47,000$ psi for aluminum bronze

Each latching hook on the first test model is attached to a clevis bolt, Figure VII-6, which transmits the latch loads into the AGE-half adapter through a stack of special seal springs described in Section 3.3.2. The 3/8 inch diameter shaft of the clevis bolt has a section reduced to 0.250 diameter for the installation of load measuring instrumentation in the form of strain gages and a thermocouple for temperature compensation. The center of the shaft is

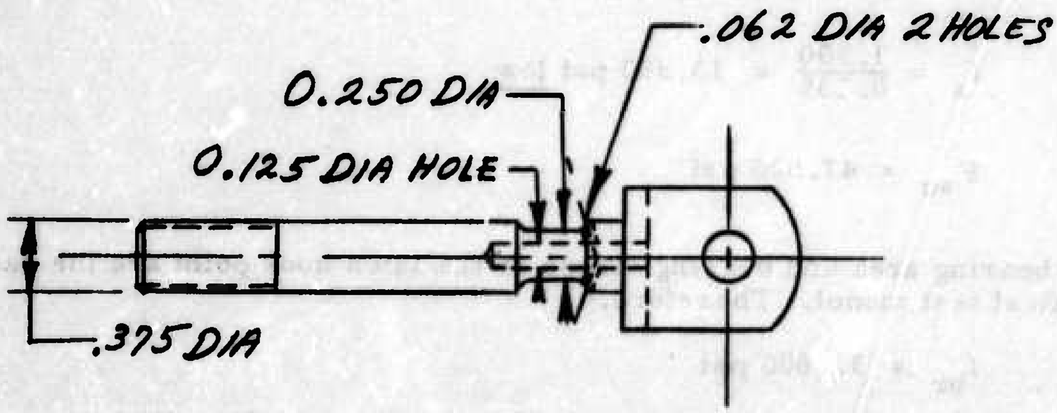


Figure VII-6. Seal Loading Clevis Bolt

hollow, with a 0.125 diameter bore and two 0.062 diameter holes pierce the walls of the reduced section to permit installation of the instrumentation wiring. The minimum cross sectional area is:

$$a_{min} = \frac{\pi}{4} (0.25^2 - 0.125^2) - 0.062\ (0.25 - 0.125) = 0.029 \text{ sq in.}$$

$$f_t = \frac{1,800}{0.029} = 62,000 \text{ psi}$$

$$F_{tu} = 140,000 \text{ psi for A-286 CRES steel}$$

$$\text{M.S.} = \frac{140,000}{62,000 \times 1.5} - 1 = 0.5$$

2. SEAL LOADING MECHANISM

2.1 First QD Test Model (-1)

It was found that the QD housing and the latching members were without sufficient flexibility (in any reasonable design configuration) to afford the required spring rates. Therefore, a special Seal Spring Assembly was designed (all other members assumed rigid) to provide the required load-deflection characteristics. This assembly used flat washer type springs as discussed in 3.2.

The equations for design of flat spring washers are given below from Reference 82.

$$f_b = k \frac{f}{t^2}$$

$$\delta = k_1 \frac{Fr_1^{\,2}}{Et^3}$$

K and k_1 are functions of the ratio of r_1/r_2, see Figure VII-7 where:

r_1 = washer outside radius, in.

r_2 = washer inside radius, in.

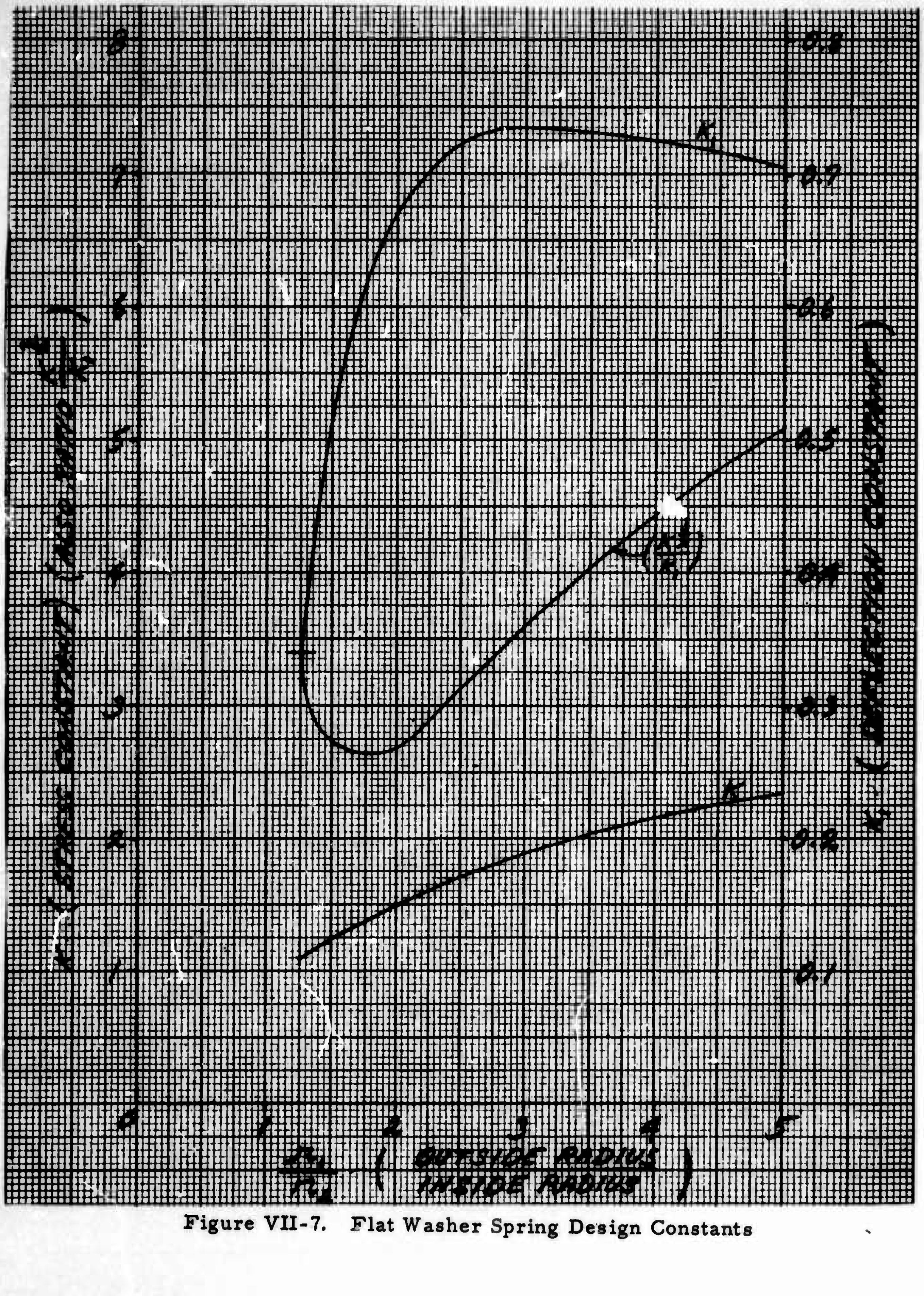


Figure VII-7. Flat Washer Spring Design Constants

A high strength material will be chosen for the spring design with the following properties:

$$f_{by} = 220,000 \text{ psi}$$

$$E = 30 \times 10^6 \text{ psi}$$

Also, the total spring deflection required per bolt for sealing is given by:

$$\delta = FR_B = (1,200)(3.24 \times 10^{-5}) = 3.89 \times 10^{-2} \text{ in.}$$

where

$$F = 1,200 \text{ lbs/bolt and } R_B = 3.24 \times 10^{-5} \text{ in./lb from 3.1.4}$$

Thus

$$t = \left[\frac{kF}{f_b}\right]^{1/2} = k^{1/2}\left(\frac{1,200}{200,000}\right)^{1/2} = 0.0739\, k^{1/2}$$

$$r_1 = \left[\frac{\delta E t^3}{k_1 F}\right]^{1/2} = \left[\frac{3.89 \times 10^{-2} \times 30 \times 10^6 \times (0.0739\, k^{1/2})^3}{k_1 \times 1,200}\right]^{1/2}$$

$$r_1 = 0.626\left[\frac{k^{3/2}}{k_1}\right]^{1/2}$$

A plot of $k^{3/2}/k_1$ is shown on Figure VII-7. Select a value of $k^{3/2}/k_1$ to minimize r_1. Thus, from Figure VII-7:

$$\frac{k^{3/2}}{k_1} = 2.65, \quad r_1/r_2 = 1.75, \quad k = 1.40, \quad \text{and } k_1 = 0.625$$

$$r_1 = 0.626\,(2.65)^{1/2} = 1.02 \text{ in.}$$

$$r_2 = 1.02/1.75 = 0.583 \text{ in.}$$

$$t = (0.0739)(1.40)^{1/2} = 0.0875 \text{ in.}$$

check:

$$f_b = (1.40)\left[\frac{1,200}{(0.0875)^2}\right] = 220,000 \text{ psi}; \quad \text{o.k.}$$

check:

$$\delta = (0.625)\left[\frac{(1,200)\,(1.02)^2}{(30 \times 10^6)\,(0.0875)^3}\right] = 3.88 \times 10^{-2} \text{ in.}; \quad \text{o.k.}$$

The calculated design for a single spring is:

OD = 2.04 in.

ID = 1.166 in.

t = 0.0875 in.

Using such a single washer spring on each of six connecting bolts results in an awkward design as the connecting bolts must be placed at great distances from the axial centerline of the QD. Layouts of the coupling indicated that a more reasonably packaged spring assembly should limit the washer spring diameter to about 1.75 in. (see Figure 3-11 for a view of this area). In order to provide the required load-deflection characteristics within this reduced spring diameter limitation, it was necessary to provide three washer-springs in series.

The spring assembly is made up of a series of flat spring washers, the deflection of which produces the sealing load. Sandwiched between these deflective members are slip washers whose purpose is to indicate when the spring has deflected a distance calculated to produce the desired sealing load. Prior to reaching the desired deflection, the slip washer is free to move freely between the springs. As the springs deflect under load, the space between the springs and the slip washer is reduced eventually eliminating this gap, and thus the movement of the slip washer is no longer possible. When this takes place, the required load has been applied.

The particular design shown in Figure VII-8 uses two springs (No. 1 and 2) to gage the nominal sealing load of 1,200 lb/bolt, and a third spring (No. 3) to indicate when an 1,800 lb/bolt (150% of design) seal load has been obtained. Tolerances on each of the subcomponents of the spring assembly are reasonably tight, but the simplicity of the individual parts should result in no particular manufacturing problems.

Figure VII-9 presents the load-deflection characteristics of the resultant spring assembly design.

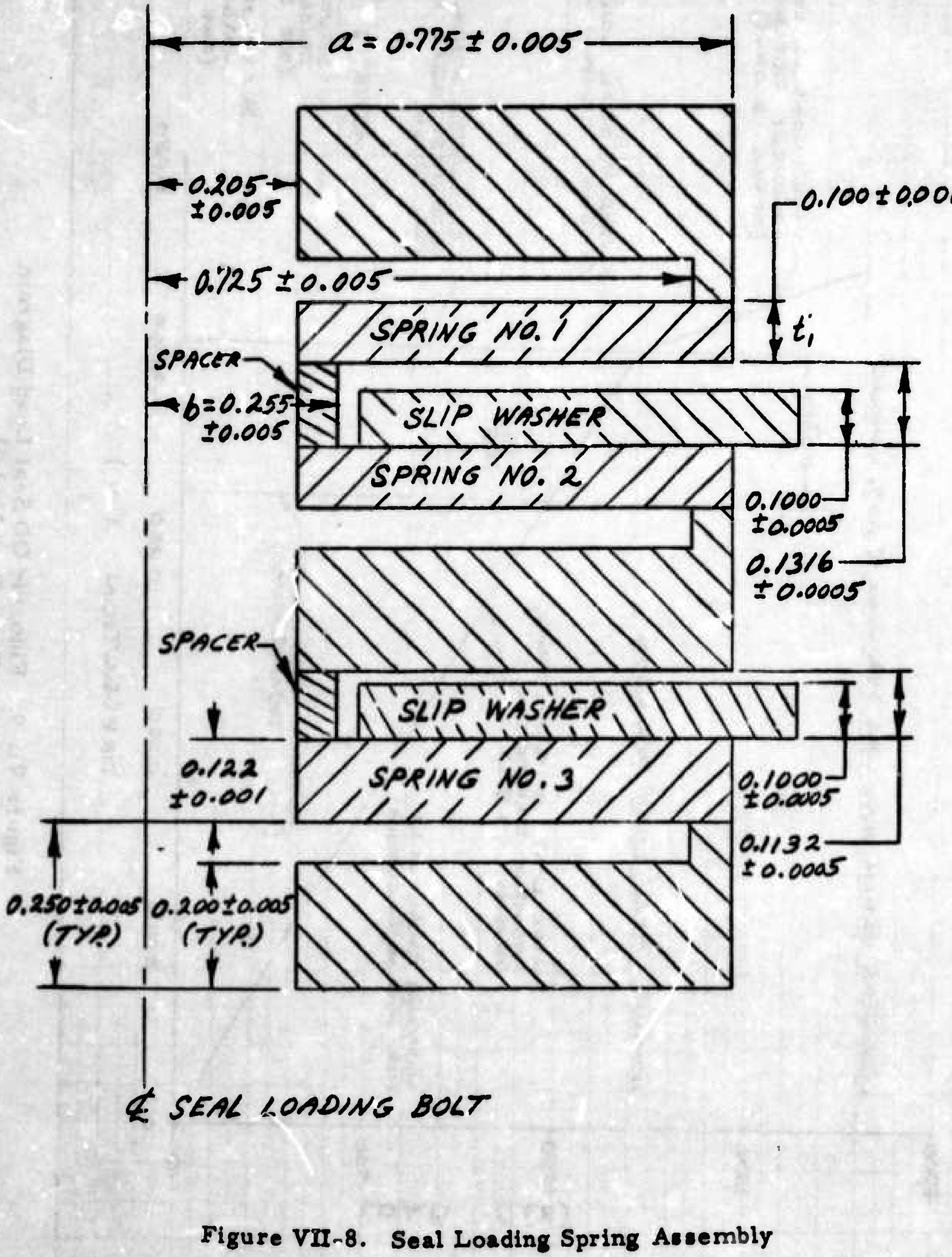


Figure VII-8. Seal Loading Spring Assembly

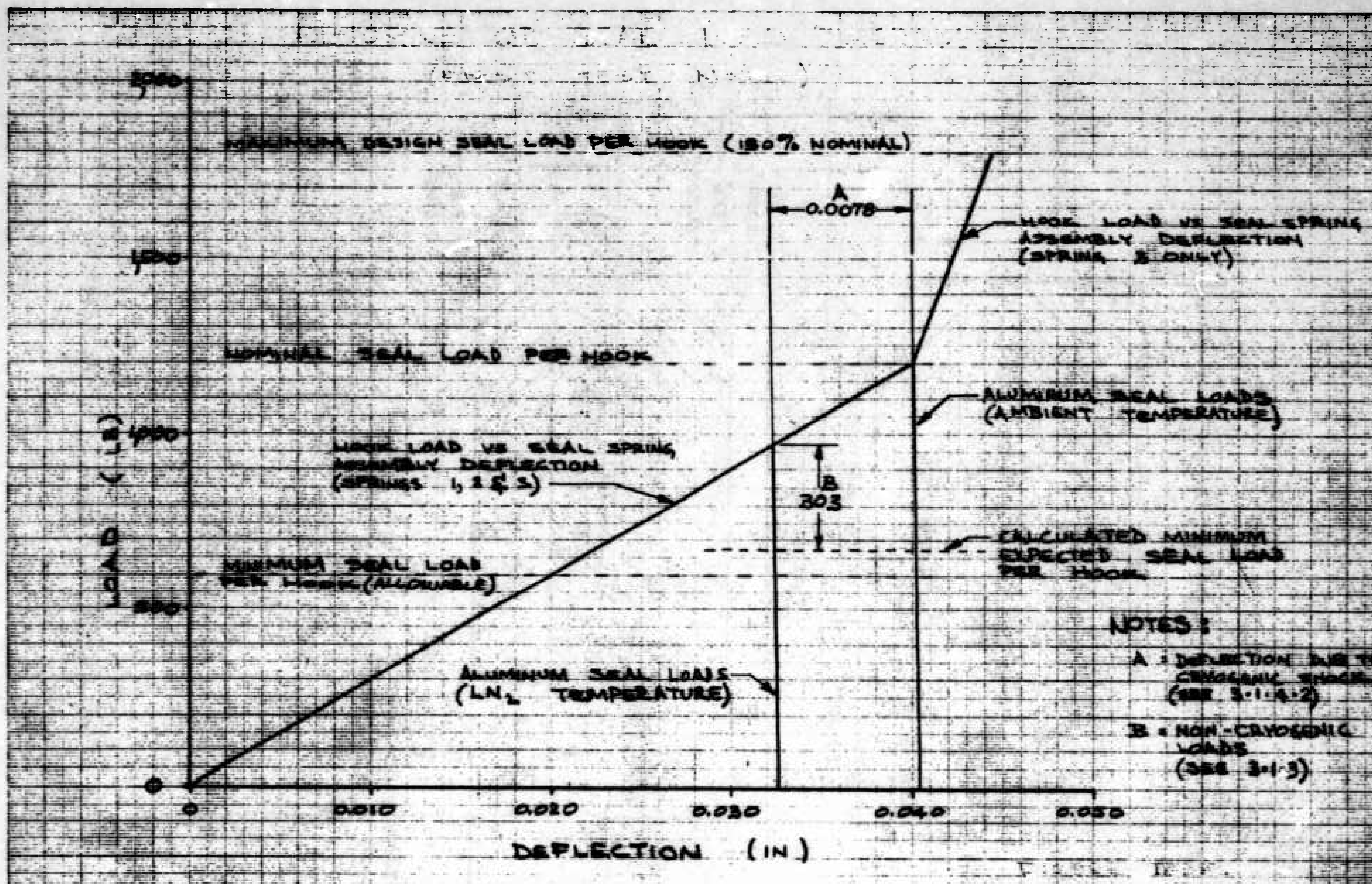


Figure VII-9. Fluorine QD Seal Load Diagram
(First Test Model)

2.2 Second QD Test Model (-501)

For the second test model, shown in Figure 3-15 and described in Section 3.2, it was necessary to modify the design of the seal loading springs to provide sufficient overtravel to permit the latches to engage the vehicle-half of the coupling when the springs are fully compressed and still provide the required seal load when the pneumatic cylinder pressure is released. One-eighth inch was selected as the nominal magnitude for overtravel. This provides for 0.025 inch plastic deformation of the primary seal and leaves 0.1 inch for angular misalignment of the coupling halves, tolerances in the latching components, and clearance to permit latch engagement.

Since it was desired to be able to test the QD at a seal loading 150% of the design load it was decided to design the loading springs with a maximum capacity of 150% design load thus making the 150% load deflection the fully extended position of the latches for engagement of the QD halves. The spring deflection varies linearly with the force and since it is a requirement of the design to have full design load on the seal without any adjustments after mating is effected, the deflection δ_d corresponding to 100% design load is determined by the following relation:

$$\frac{\delta_d}{100} = \frac{\delta_d + 0.125}{150}$$

$$\delta_d = 0.25 \text{ in.}$$

$$\delta_{max} = \delta_d + 0.125 = 0.375 \text{ in.}$$

In order to load the seal above the 100% load it is necessary to use a wrench to apply the additional load by torquing the nuts on the shafts through each stack of loading springs.

It was determined by layout that a 2.5-in. dia envelope for each stack of loading springs resulted in reasonably efficient use of the available space. The spring elements were made with a 2.4 inch outside diameter allowing 0.1 inch for the outer spacers separating the springs and providing space for deflection. The mean diameter of the loading area for the outer edge of each spring is 2.34 inches and the mean loading diameter for the spring inner edge is 1.253 inches. These values were used for the spring thickness and deflection calculations.

The spring design was based on the same theory used for the first test model springs and noted at the beginning of this section.

$$\delta = \frac{k_1 F r_1^2}{Et^3}, \quad \text{and} \quad t = \left[\frac{kF}{f_b}\right]^{1/2}$$

Therefore,

$$\delta = \frac{r_1^2 f_b^{3/2}}{EF^{1/2}} \left[\frac{k_1}{k^{3/2}}\right]$$

Since the parameters r_1, f_b, E and F for the design are determined independently it follows that the deflection δ is maximum when $k^{3/2}/k_1$ is a minimum, which, from Figure VII-7, is found at a value of $r_1/r_2 = 1.75$. There is little variation from this minimum for values of r_1/r_2 from 1.6 to 2.0. Therefore, a value of $r_1/r_2 = 1.87$ was used for the design. The material selected for the springs was Inconel 718 cold reduced 30% and aged. The physical properties of the material pertinent to the spring design are:

$$F_{ty} = 210,000 \text{ psi} = f_b$$

$$E = 29 \times 10^6 \text{ psi}$$

The calculations for the spring thickness required to support an 1,800 lb load and the number of springs required to provide 0.375 inch total deflection are as follows:

The effective outer radius a = 2.34/2 = 1.17 inches

The effective inner radius b = 1.253/2 = 0.6265 inches

From Figure VII-7,

$k = 1.42$

$k_1 = 0.65$

$$t = \left[\frac{kf}{f_b}\right]^{1/2} = \left[\frac{1.42 \times 1,800}{210,000}\right]^{1/2} = 0.1105 \text{ inches}$$

Allowing 0.002 total tolerance for thickness,

$$t = \frac{0.110}{0.112}$$

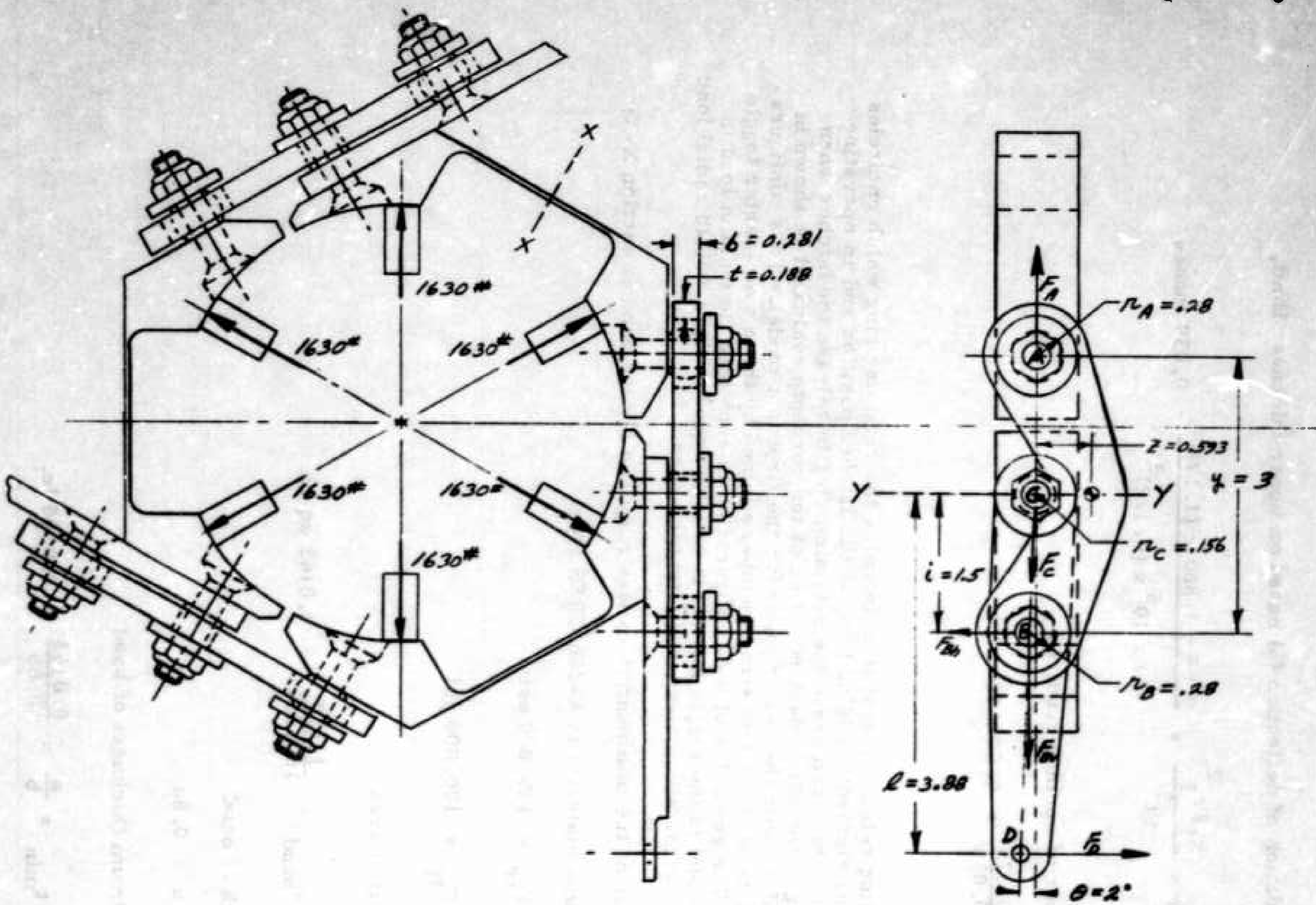


Figure VII-10. Load Diagram For Toggle Latch Release Mechanism

Calculation of deflection (δ) based on upper thickness limit,

$$\delta = \frac{k_1 F r_1^2}{Et^3} = \frac{0.65 \times 1,800 \times (1.17)^2}{29 \times 10^6 \times (0.122)^3} = 0.039 \text{ inches}$$

Number of springs required

$$\frac{0.375}{0.039} = 9.6 \text{ or } 10$$

The coupling release mechanism includes the retaining ring which encircles the latching elements holding them in the latched position and an operating mechanism which can cause the retaining ring to release the latches when decoupling of the QD is desired. One of the concepts evaluated is shown in Figure VII-10 with the design loads for the first test model. This configuration consists of three thin strap members joined by three over-center toggle latches. The geometry of the configuration is such that the tension load in the straps and in the toggle latches is exactly equal to the 1,630 lb radial load from each of the six equi-spaced latching hooks.

Calculation of the minimum thickness required for the band at section X-X:

Assume material is A-286 CRES steel

$$F_{t\mu} = 150,000 \text{ psi}$$

$$F_{ty} = 100,000 \text{ psi}$$

Required area

$$a_{band} = \frac{1,630}{100,000} = 0.0163 \text{ sq in.}$$

Width of band

$$b = 0.88$$

Minimum thickness of band

$$t_{min} = \frac{a}{b} = \frac{0.0163}{0.88} = 0.0185 \text{ in.}$$

Calculation of loads in toggle latch:

Assume that the rotating joints are unlubricated and the static coefficient of friction $\mu_S = 0.78$ for steel on steel (Reference 12).

$$F_A = -F_{BV} = 1,630 \text{ lb}$$

$$F_B = F_C = \frac{F_{BV}}{\cos 2°} = \frac{1,630}{0.9994} = 1,631 \text{ lb}$$

The force F_D required to release the latch is the resultant of several factors which will be calculated separately.

$$F_D = F_{DO} + F_{DB} + F_{DC}$$

where:

F_{DO} is the component due to the geometry without any friction effects.

$$F_{DO} = F_B \sin\theta \frac{i}{l} = 1,631 \times 0.0349 \times \frac{1.5}{3.88} = 22 \text{ lb}$$

$$F_{DA} = F_A \mu_S \frac{r_A}{b} \frac{i}{l} = 1,630 \times 0.78 \times \frac{0.28}{3} \times \frac{1.5}{3.88} = 46 \text{ lb}$$

$$F_{DB} = F_B \mu_S \times \frac{i + r_B}{l} = 1,631 \times 0.78 \frac{1.5 + 0.28}{3.88} = 584 \text{ lb}$$

$$F_{DC} = F_C \mu_S \frac{r_C}{l} = 1,631 \times 0.78 \times \frac{0.156}{3.88} = 50.5 \text{ lb}$$

$$F_D = 22 + 46 + 584 + 51 = 703 \text{ lb}$$

Calculation of bending stress in link AB at section Y-Y:

$$M_{y-y} = F_A Z$$

$$M = 1,630 \times 0.593 = 952 \text{ in. -lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 952}{0.28 \times 0.75^2} = 36,300 \text{ psi}$$

This link could be made from 2024-T4 aluminum with $F_{ty} = 40,000$ psi or from an 18-8 CRES steel 1/4 hard with $F_{ty} = 75,000$ psi.

Assume that the bolts at points A, B, and C are made of A-286 CRES steel with the following properties: (Reference 83)

F_{tu} = 150,000 psi

F_{ty} = 100,000 psi

F_{su} = 90,000 psi

F_{bry} = 200,000 psi

The shear stress on the 5/16 diameter bolts is

$$f_s = \frac{F_A}{a_{bolt_s}} = \frac{1,630}{0.07669} = 21,200 \text{ psi; } \underline{\text{low}} \text{ compared with } F_{su}$$

The bolt bearing area required to support the 1,630 lb load is:

$$a_{bolt_b} = \frac{F_A}{F_{bry}} = \frac{1,630}{200,000} = 0.00815 \text{ sq in.}$$

$$\text{bearing length} = \left(\frac{a}{d}\right)_{bolt} = \frac{0.00815}{0.312} = 0.026 \text{ in.}$$

bolt bending arm = 0.188 + 0.013 = 0.201 in.

M = 1,630 x 0.201 = 328 in.-lb

$$f_b = \frac{MC}{I} = \frac{328 \times 0.156}{0.0004682} = 110,000 \text{ psi}$$

F_b = 250,000 psi for round steel bars with F_{tu} = 150,000 psi (Reference 83)

$$M.S. = \frac{250,000}{110,000 \times 1.5} - 1 = 0.5$$ (neglecting the low shear stress calculated above)

Calculation of shear out from bearing mounting hole in link AB:

$$A = 2\,bt$$

$$A = 2 \times 0.281 \times 0.188 = 0.106 \text{ sq in.}$$

$$f_s = \frac{F_A}{A} = \frac{1,630}{0.106} = 15,400 \text{ psi; } \underline{\text{low}} \text{ compared with } F_{su}$$

In a second release mechanism concept which was considered the retaining ring was made up of six rigid links pinned together at the ends. Taper pins attached to a cable release system were used in three of the six joints. A load diagram using the design loads for the first test model is shown in Figure VII-11. As noted for the previous configuration the geometry of the retaining ring linkage is such that the tension load in each link is equal to the 1,630 lb radial load from each latching hook.

Calculation of force required to retract the tapered pin:

If friction were zero the force required to hold the pin with a 10° half angle taper in place would be:

$$F_o = 2 \times 1,630 \tan 10° = 575 \text{ lbs}$$

If the materials of both the pin and links are hard steel and the static friction coefficient $\mu_S = 0.78$ (Reference 12), the force required to remove the pin is:

$$F = 2 \times 1,630 \times 0.78 - 575 = 1,965 \text{ lbs}$$

If the material is hard steel for the pin and aluminum bronze for the links and the static friction coefficient $\mu_S = 0.45$ (Reference 12), the force required to remove the pin is:

$$F = 2 \times 1,630 \times 0.45 - 575 = 890 \text{ lbs}$$

The third release concept considered also had a retaining ring made up of six rigid links pinned together at the ends. In this concept release was effected by fracturing any one of the three release pins specially designed of a hard brittle material with a notched section so that rupture would occur in a controlled area with very little deformation of the pin material. The force to fracture the pin is applied by a lever actuated cam. This concept is shown in Figure 3-13. A-286 CRES steel heat treated to 140,000 psi ultimate tensile strength (UTS) was selected for the links because a material with a high bearing strength is required at the load points for the shear pin and for the cam. AM 355 CRES steel heat treated to 190,000 psi UTS was selected for the shear pin material because it most closely fulfilled the desired requirements stated above. René 41 heat treated to 170,000 psi UTS was selected for the cam which required a strong, tough material with a high allowable bearing stress. It is

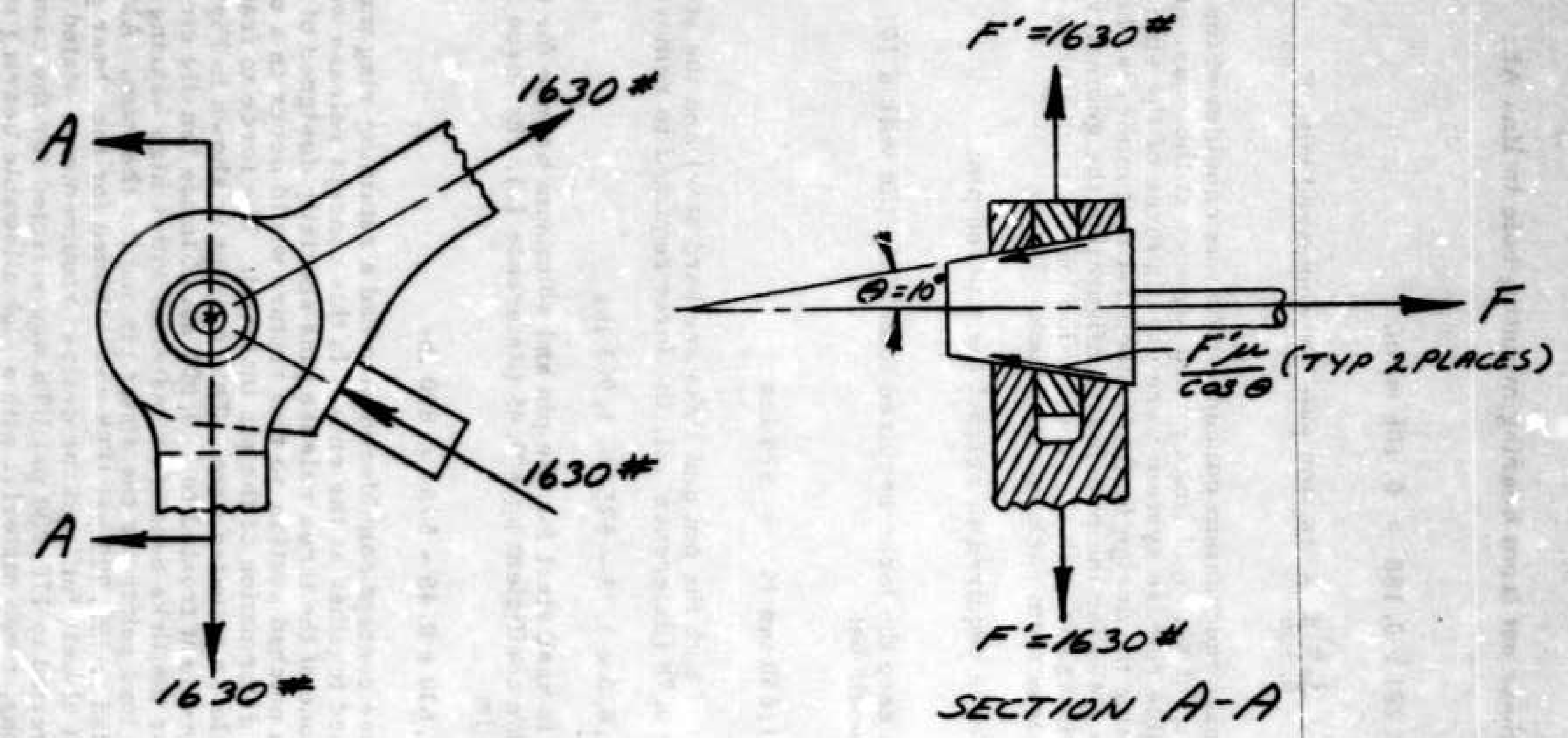


Figure VII-11. Load Diagram For Taper Pin Release Mechanism also desirable to have a low coefficient of friction between the cam and its reaction surfaces on the links and although no data was available on the coefficient of friction between René 41 and A-286 CRES it was reasoned that the coefficient should decrease as hardness increases since it is well known from practical experience that when two interfacing surfaces of CRES steel in the annealed condition are subjected to high loading they gall easily and gross seizure may occur whereas a very hard CRES steel such as type 440C has a much lesser tendency to gall.

As noted in Section 3.2 this concept was selected for use on the test models. For both the first and second test models the retaining links, the shear pins, and the release cams were identical. In Section 3.3.1 it was noted that the radial force required to retain each latching hook on the first test model was 1,630 lbs versus 1,840 lbs on the second model. Therefore, the 1,840 lbs load has been used in the stress calculations. There are three each of two different links which make up the retaining ring. The smaller link is 0.60 inch wide and 0.88 inch deep at the maximum bending section whereas the larger link is both deeper (1.25 inches) and wider (1.13 inches) to form a clevis joint with the small link. Therefore, only the stress analysis for the small link subjected to the normal latch loads is included.

Calculation of stress in retaining link (see Figure VII-12):

Due to geometric considerations the radial load from the latch F_L is equal to the loads at the pin joints A and B.

$$F_L = F_A = F_B = 1,840 \text{ lbs}$$

Determine the tension load in the outer bar of link. Assume right hand half of link as a free body including forces F_C and F_D.

$$\Sigma M_D = 0$$

$$F_B \times 0.63 - F_C \times 0.63 = 0$$

$$F_C = F_B = 1,840 \text{ lbs}$$

Stress in the outer bar of the link is :

$$f_t = \frac{1,840}{0.60 \times 0.19} = 15,900 \text{ psi; } \underline{\text{low}} \text{ compared with } F_{tu} = 140,000 \text{ psi}$$

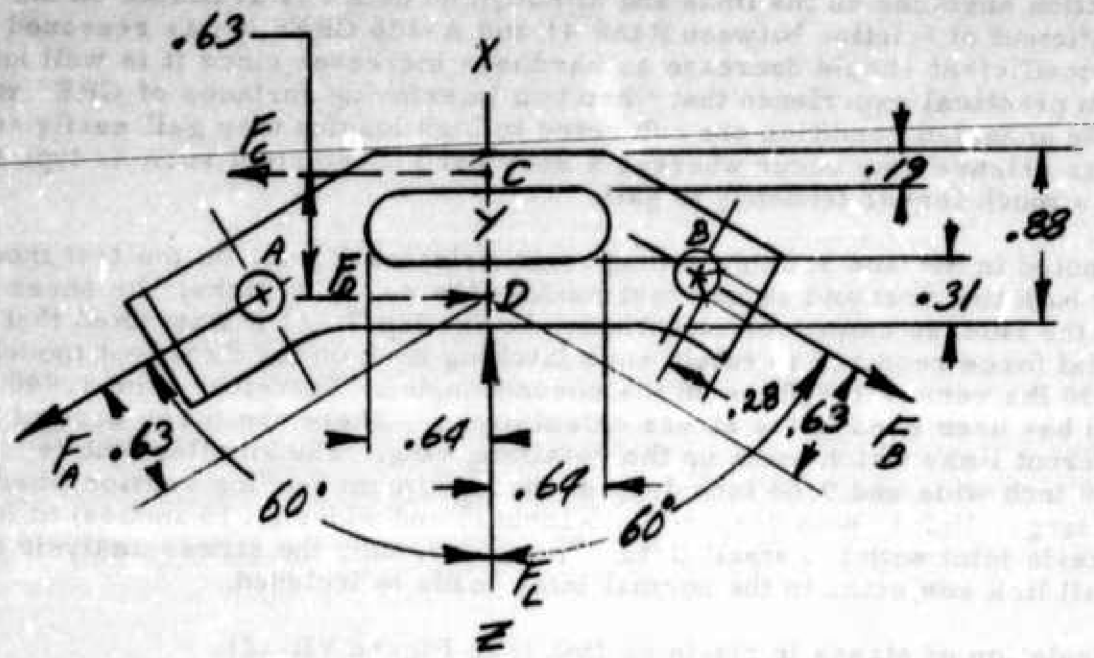


Figure VII-12. Load Diagram For Retaining Link

Check the local bending stress in the inner bar of the link. Assume a pin joint beam with concentric load in center. Maximum moment is at Section Y-Z.

$$M_{max} = 1/2 \times 1,840 \times 0.64 = 590 \text{ in.-lbs}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 590}{0.6 \times 0.31^2} = 61,500 \text{ psi}$$

$$M.S. = \frac{140,000}{61,500 \times 1.5} - 1 = 0.52$$

Shear out from 1/4 inch hole at point B. Shear area,

$$A_s = 2 \times 0.28 \times 0.6 = 0.336$$

$$f_s = \frac{1,840}{0.336} = 5,500 \text{ psi; } \underline{\text{low}} \text{ compared with } F_{su} = 84,000 \text{ psi}$$

Design of latch release shear pin (see Figure VII-13):

As noted above, the design load at the pin joints in the retaining links is 1,840 lbs. In order to ensure a conservative margin of safety for the shear pin, 4,000 lbs was selected for the design load.

$$\text{Shear Pin M.S.} = \frac{4,000}{1,840 \times 1.5} - 1 = 0.45$$

The shear pin material is AM 355 CRES steel with the following physical properties (Reference 83):

$$F_{tu} = 190,000 \text{ psi}$$

$$F_{ty} = 165,000 \text{ psi}$$

$$F_{su} = 123,000 \text{ psi}$$

$$F_{bru} = 313,000 \text{ psi}$$

The pin is loaded in double shear, therefore, each shear section must be designed to rupture with 2,000 lbs force applied. The required shear area is:

$$A_s = \frac{F}{F_{tu}} = \frac{2,000}{123,000} = 0.01625 \text{ sq in.}$$

The required diameter for the shear section is:

$$d_s = \sqrt{\frac{4A_S}{\pi}} = \sqrt{\frac{4 \times 0.01625}{\pi}} = 0.145 \text{ in.}$$

The bearing stress at the pin 0.06 wide band is:

$$f_{br} = \frac{2,000}{0.25 \times 0.06} = 133,000 \text{ psi; low for the pin}$$

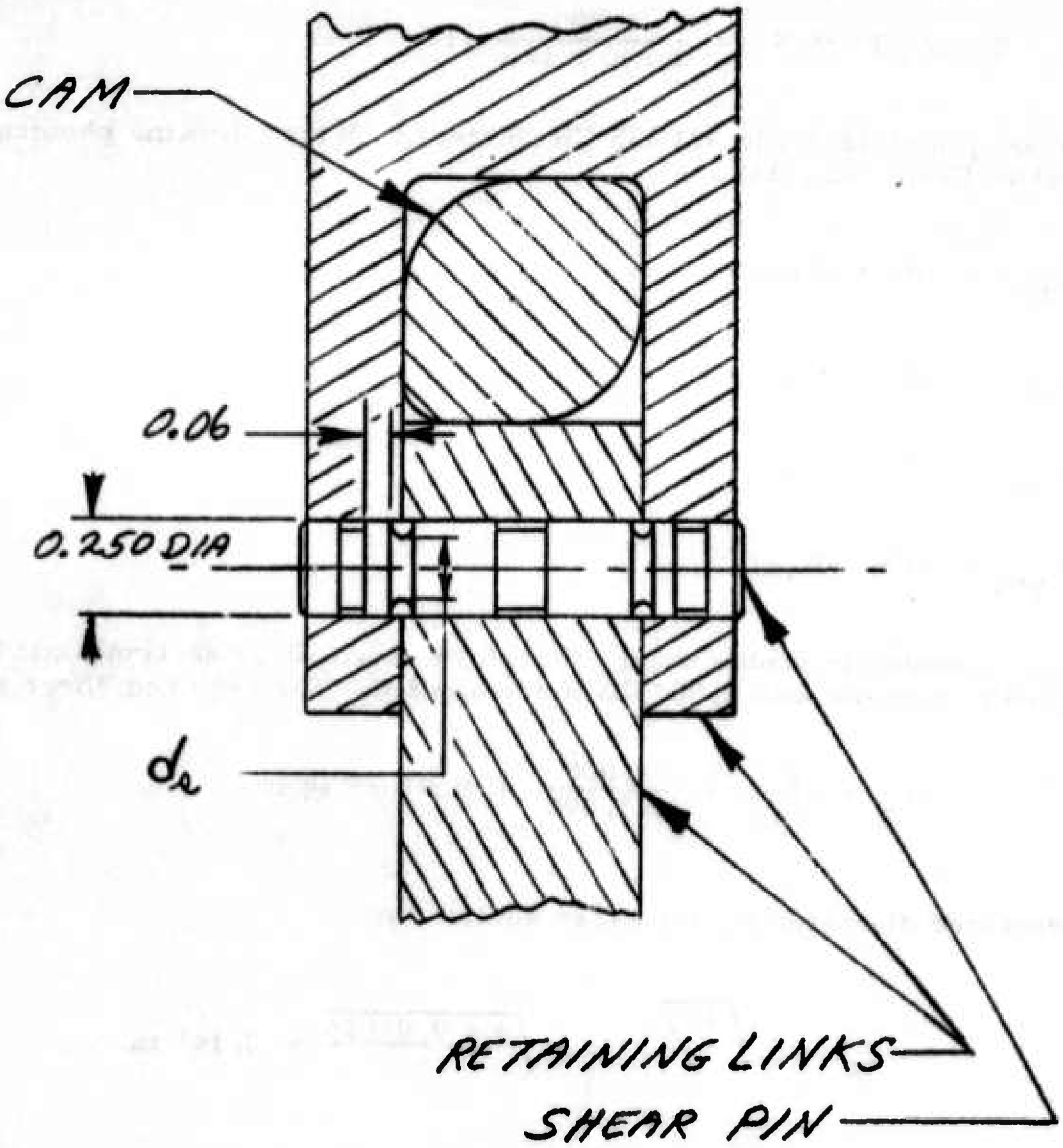


Figure VII-13. Detail of Release Mechanism Shear Pin

For the A286 retaining link:

$$F_{bru} = 215,000 \text{ psi}$$

$$M.S. = \frac{215,000}{133,000 \times 1.5} - 1 = 0.075$$

Calculation of loads and stress in release cam and lever (see Figure VII-14):

Since the design load to rupture the shear pin is 4,000 lbs, $F_C = F_D = 4,000$ lbs. To calculate the force F_B required to actuate the cam the following assumptions were made:

1. The static coefficient of friction between the cam and the retaining links, $\mu_S = 1.0$.
2. A design factor of 1.5 is required to ensure the availability of a sufficient force to rupture the pin.

$$\Sigma M_A = 0$$

$$3F_B = 1.5 \left[F_C \times 0.2 + F_C \times 0.31 + F_D \times 0.2 + F_D \times 0.31\right]$$

$$3F_B = 1.5 \left[F_C (0.2 + 1.0 \times 0.31) + F_D (0.2 + 1.0 \times 0.31)\right]$$

$$F_B = \frac{1.5}{3} 4,000 \times 1.02 = 2,040 \text{ lbs}$$

This force could be provided from a commercially available 2-inch diameter pneumatic cylinder operated at 750 psi pressure.

The torque applied to the cam is:

$$T = 3 \times 2,040 = 6,120 \text{ in.-lbs}$$

From Reference 81 the maximum shear stress on a solid elliptical section is:

$$f_{s_{max}} = \frac{2T}{\pi a_1 b_1^2}$$

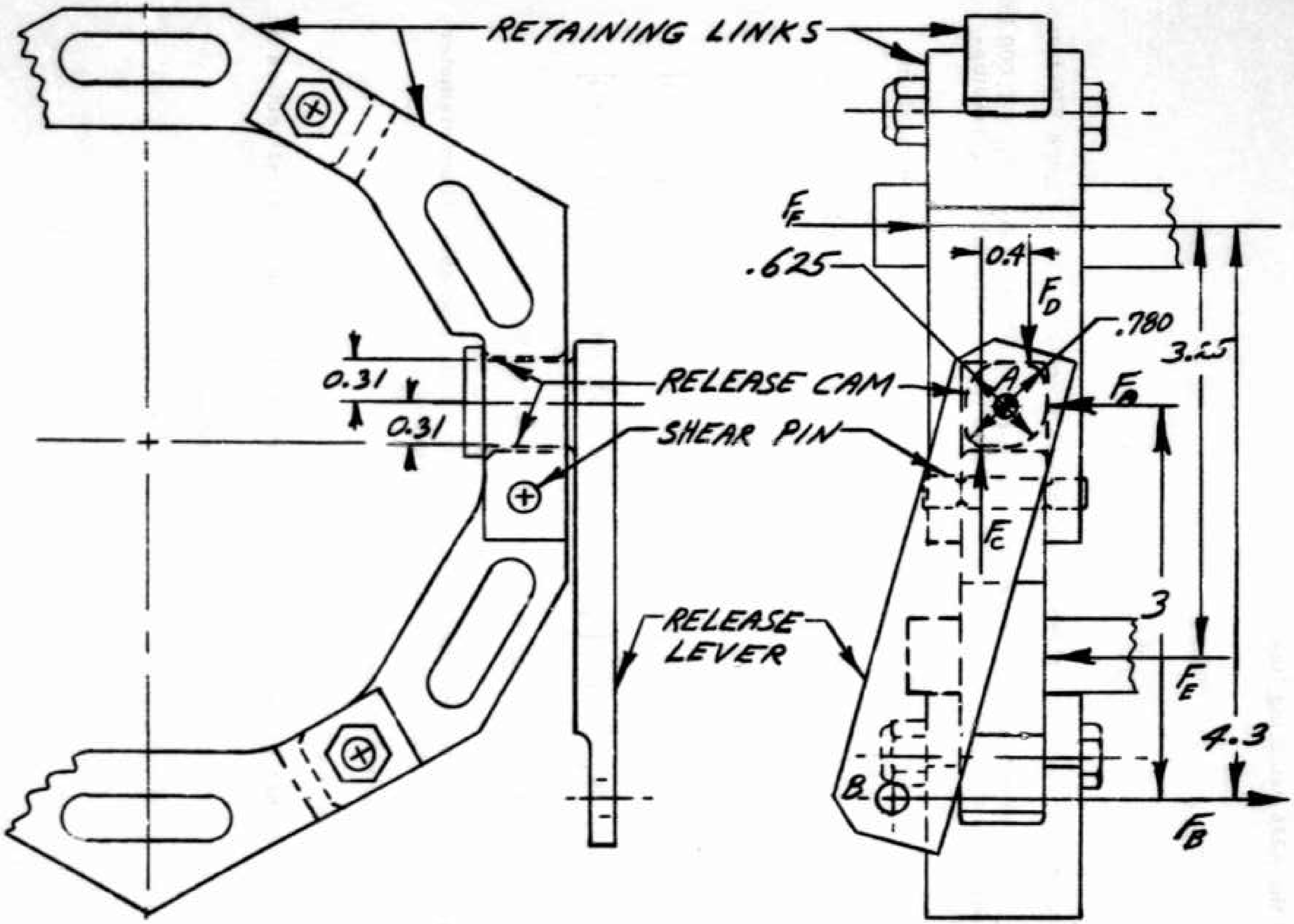


Figure VII-14. Load Diagram For Release Cam and Lever

where

T is the twisting moment, in. -lb

$2a_1$ is the major diameter, in.

$2b_1$ is the minor diameter, in.

$$f_{s_{max}} = \frac{2 \times 6,120}{\pi \times 0.39 \times (0.31)^2} = 104,000 \text{ psi}$$

From Reference 83 the torsional modulus of rupture of alloy steel bars heat treated to F_{tu} = 180,000 psi is F_{st} = 142,000 psi. It was assumed that this value is also applicable to René 41.

$$M.S. = \frac{142,000}{1.5 \times 104,000} - 1 = -0.09$$

Although a negative margin is indicated it is only a small fraction of the 1.5 design factor applied above, therefore, the strength was considered adequate.

The bending moment in the lever adjacent to the cam is:

$$M = F_B (3 - 0.31) = 2,040 \times 2.69 = 5,500 \text{ in. -lbs}$$

$$f_b = \frac{6m}{bh^2} = \frac{6 \times 5,500}{0.31 \times (0.89)^2} = 135,000 \text{ psi}$$

F_{ty} = 130,000 psi for René 41

$$M.S. = \frac{130,000}{130,000} - 1 = -0.035$$

The margin is again negative but small compared to the 1.5 design factor and the strength was considered adequate.

Calculation of shear out stress from hole at point B:

$$a_s = 2 \times 0.31 \times 0.19 = 0.118 \text{ sq in.}$$

$$f_s = \frac{2,040}{0.118} = 17,300 \text{ psi } \underline{\text{low}}$$

F_{su} = 100,000 psi for René 41

The forces F_E and F_F (Figure VII-14) are the latching hook reactions to the release force F_B on the lever.

$$\Sigma M_{F_F} = 0$$

$$F_E = 3.25 = F_B \, 4.3 = 0$$

$$F_E = \frac{2,040 \times 4.3}{3.25} = 2,700 \text{ lbs}$$

$$F_F = F_E - F_B = 2,700 - 2,040 = 660 \text{ lbs}$$

When the unlatching force F_E is superimposed on the normal loads for the first test model hook the following loads result (see Figure VII-15):

$$F_E = 2,700 \text{ lbs}$$

$$R_{AH} = 1,800 \text{ lbs}$$

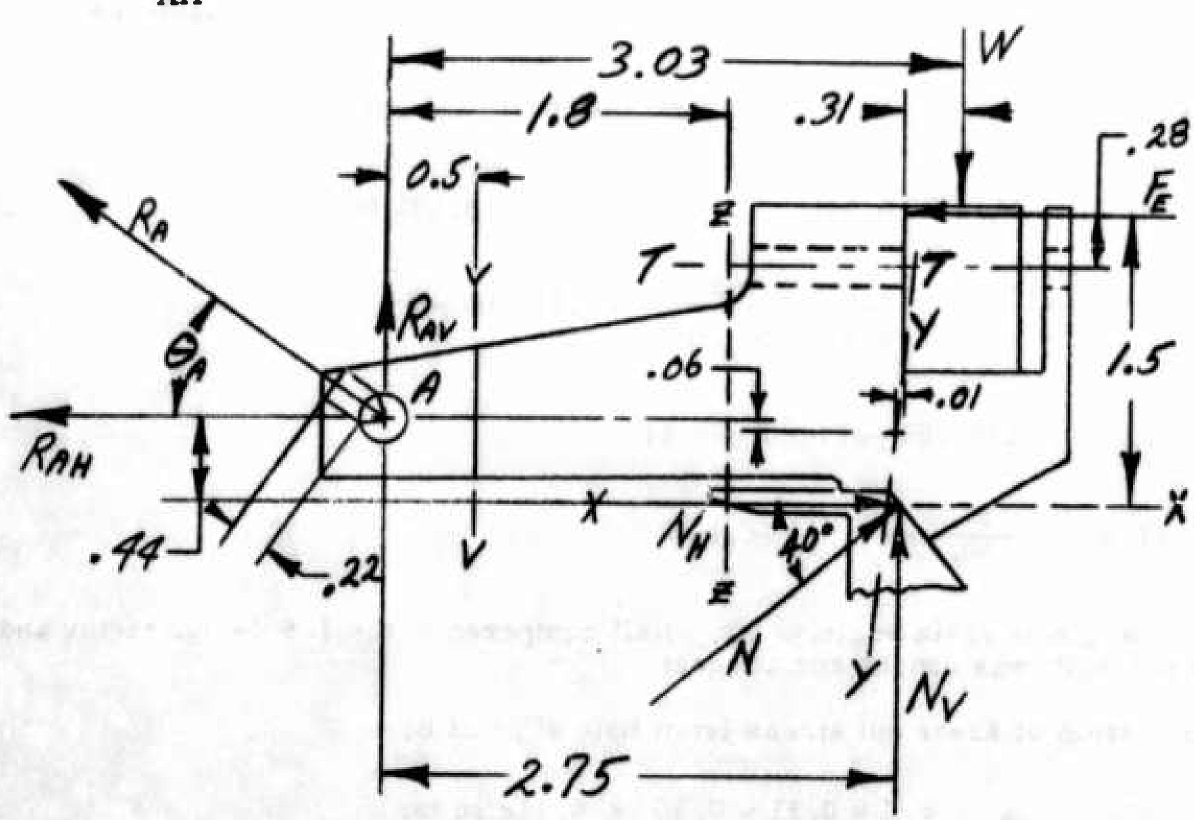


Figure VII-15. First Test Model Latching Hook Load Diagram

N_H = 2,700 + 1,800 = 4,500 lbs

N_V = N_H tan 40° = 4,500 x 0.839 = 3,780 lbs

ΣM_A = 0

$-F_E \times 1.06 + W \times 3.03 - N_V \times 2.75 - N_H \times 0.44 = 0$

$$W = \frac{2,700 \times 1.06 + 3,780 \times 2.75 + 4,500 \times 0.44}{3.03} = 5,040 \text{ lbs}$$

R_{AV} = W - N_V = 5,040 - 3,780 = 1,260 lbs

$$\text{Tan } \theta = \frac{R_{AV}}{R_{AH}} = \frac{1,260}{1,800} = 0.7$$

θ_A = 35°

$$R_A = \frac{R_{AV}}{\cos 35°} = \frac{1,800}{0.819} = 2,200 \text{ lbs}$$

Calculation of shear out stress from 1/4 inch diameter hole at point A:

Shear Area = 2 x 0.22 x 0.188 = 0.083 sq in.

$$f_s = \frac{2,200}{0.083} = 26,500 \text{ psi}$$

F_{su} = 47,000 psi

$$\text{M.S.} = \frac{47,000}{26,500 \times 1.5} - 1 = 0.18$$

Calculation of shear stress on hook point, Section X-X:

Shear Area = 0.44 x 0.375 = 0.165 sq in.

$$f_s = \frac{4,500}{0.165} = 27,200 \text{ psi}$$

F_{su} = 47,000 psi

$$M.S. = \frac{47,000}{27,200 \times 1.5} - 1 = 0.15$$

Calculation of bearing stress on hook point:

Bearing Area = 0.31 x 0.375 = 0.116 sq in.

$$N = \frac{4,500}{\cos 40°} = 5,875 \text{ lbs}$$

$$f_{br} = \frac{5,875}{0.116} = 50,600 \text{ psi}$$

F_{bry} = 51,000 psi

$$M.S. = \frac{51,000}{50,600} - 1 = 0.01$$

Calculation of bending stress at Section Y-Y:

$$M_{y-y} = W \times 0.32 - N_V \times 0.04 - N_H \times 0.38 = -251 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 251}{0.375 \times (0.625)^2} = 10,300 \text{ psi} \quad \underline{\text{low}}$$

F_{ty} = 42,500 psi

Calculation of bending stress at Section Z-Z:

$$M_{z-z} = R_{AV} \times 1.8 + R_{AH} \times 0.15 = 2,535 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 2,535}{0.375 \times (0.9)^2} = 50,000 \text{ psi}$$

F_{ty} = 42,500 psi

$$M.S. = \frac{42,500}{50,000} - 1 = -0.15$$

A negative margin is indicated but the design was considered adequate because of the conservative factors used to calculate the loads.

Calculation of bending stress at Section T-T:

$$M_{T-T} = F_E \times 0.28 = 2,700 \times 0.28 = 756 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 756}{0.18 \times 0.81^2} = 38,500 \text{ psi}$$

$$M.S. = \frac{42,500}{38,500} - 1 = 0.1$$

Calculation of bending stress at Section V-V:

$$M_{V-V} = R_{AV} \times 0.5 = 1,260 \times 0.5 = 630 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 630}{0.19 \times (0.69)^2} = 41,750 \text{ psi}$$

$$f_t = \frac{R_{AV}}{0.19 \times 0.69} = \frac{1,800}{0.131} = 13,750$$

$$M_S = \frac{42,500}{41,750 + 13,750} - 1 = -0.235$$

The margin is again negative but the design was considered adequate because of the conservatively computed loads and also because aluminum bronze has an ultimate tensile strength (F_{tu} = 85,000 psi) which is twice the yield strength (F_{ty} = 42,500 psi) (Reference 83).

When the unlatching force F_E is superimposed on the normal loads for the second test model hook the following loads result (see Figure VII-16):

$$F_E = 2,700 \text{ lbs}$$

$$R_{AH} = 1,800 \text{ lbs}$$

$$N_H = 2,700 + 1,800 = 4,500 \text{ lbs}$$

$$N_V = N_H \tan 40° = 4,500 \times 0.839 = 3,780 \text{ lbs}$$

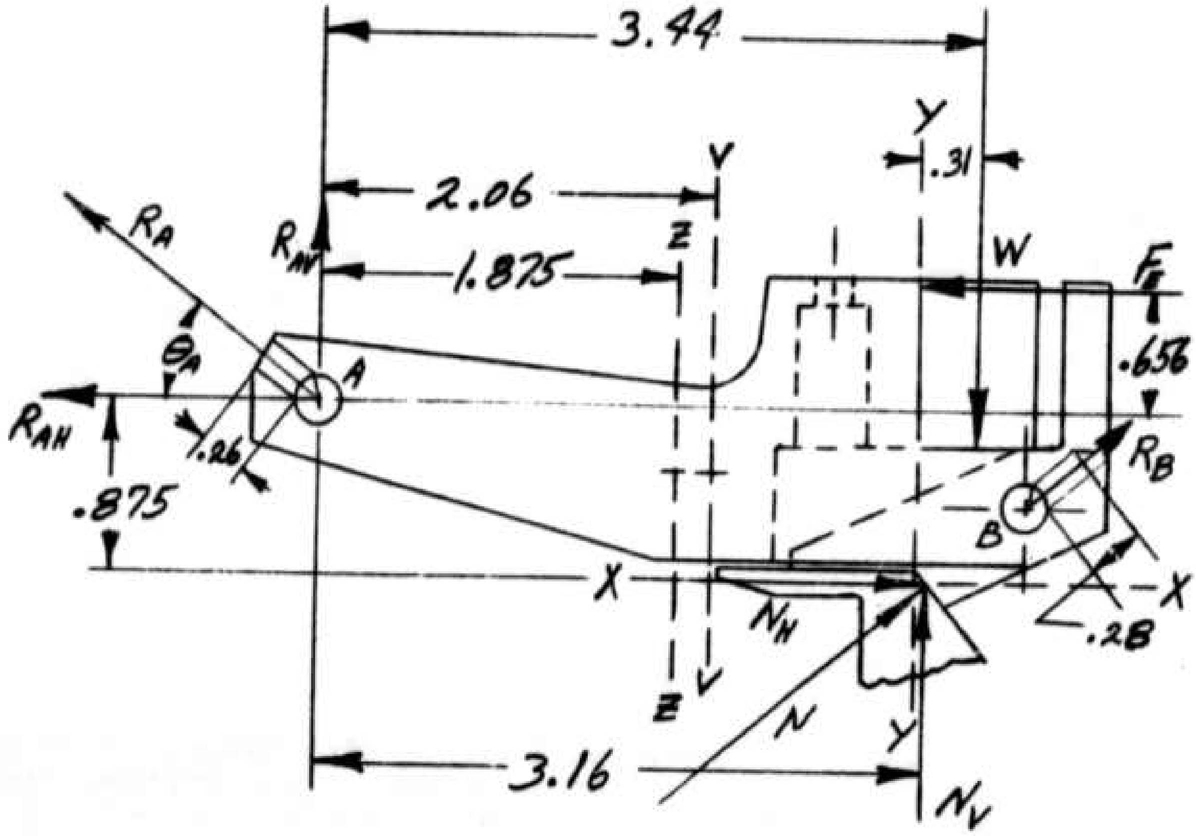


Figure VII-16. Second Test Model Latching Hook Load Diagram

$$N = \frac{N_H}{\cos 40°} = \frac{4,500}{0.766} = 5,875 \text{ lbs}$$

$$\Sigma M_A = 0$$

$$-F_E \times 0.656 + W \times 3.44 - N_V \times 3.16 - N_H \times 0.875 = 0$$

$$W = \frac{2,700 \times 0.656 + 3,780 \times 3.16 + 4,500 \times 0.875}{3.44} = 5,130 \text{ lbs}$$

$$R_{AV} = W - N_V = 5,130 - 3,780 = 1,350 \text{ lbs}$$

$$\text{Tan } \theta_A = \frac{R_{AV}}{R_{AH}} = \frac{1,350}{1,800} = 0.75$$

$$\theta_A = 36°52'$$

$$R_A = \frac{1,800}{\cos 36°52'} = \frac{1,800}{0.80003} = 2,250 \text{ lbs}$$

Calculation of shear out stress from 1/4 inch diameter hole at point A:

Shear Area = 2 x 0.26 x 0.52 = 0.27 sq in.

$f_s = \frac{2,250}{0.27} = 8,350$ psi <u>low</u>

$F_{su} = 47,000$ psi

Calculation of shear stress on latch point Section X-X:

Shear Area = 0.375 x 0.360 = 0.135 sq in.

$$f_s = \frac{4,500}{0.135} = 33,300 \text{ psi}$$

$$M.S. = \frac{47,000}{33,300 \times 1.5} - 1 = -0.06$$

The conservatively computed loads compensate for the small negative margin.

Calculation of bearing stress on latch point:

$$\text{Bearing Area} = 0.22 \times 0.36 = 0.079$$

$$f_{br} = \frac{N}{0.079} = \frac{5,875}{0.079} = 74,500 \text{ psi}$$

$$f_{bry} = 51,000 \text{ psi}$$

$$\text{M.S.} = \frac{51,000}{74,500} - 1 = -0.315$$

This is a relatively large negative margin, however, the ultimate bearing strength for the material is sufficiently high (F_{bru} = 101,000 psi) so that it appeared unlikely that rupture could occur even with application of the conservatively computed design loads.

Calculation of shear out stress from 1/4 inch diameter hole at point B:

$$R_B = N = 5,875 \text{ lbs}$$

$$\text{Shear Area} = 2 \times 0.28 \times 0.53 = 0.297 \text{ sq in.}$$

$$f_s = \frac{5,875}{0.297} = 19,800 \text{ psi}$$

$$\text{M.S.} = \frac{47,000}{19,800 \times 1.5} - 1 = 0.58$$

Calculation of shear stress on 1/2 inch diameter A-286 CRES steel pin at point B:

$$\text{Area} = (0.25)^2 \frac{\pi}{4} = 0.0491 \text{ sq in.}$$

$$f_s = \frac{5,875}{2 \times 0.0491} = 60,000 \text{ psi}$$

$$F_{su} = 85,000 \text{ psi}$$

$$\text{M.S.} = \frac{85,000}{1.5 \times 60,000} - 1 = -0.055$$

The design was considered adequate with the small negative margin.

Calculation of bending stress at Section Y-Y:

$$M_{Y-Y} = W' \times 0.31 - N_V \times 0.03 - N_H \times 0.39 = 5,130 \times 0.31$$

$$- 3,780 \times 0.03 - 4,500 \times 0.39 = -273 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 273}{0.53 \times (0.59)^2} = 8,900 \text{ psi} \quad \underline{\text{low}}$$

$$F_{ty} = 42,500 \text{ psi}$$

Calculation of bending stress at Section V-V:

$$M_{V-V} = R_{AV} \times 2.06 - R_{AH} \times 0.34 = 1,350 \times 2.06 - 1,800 \times 0.34$$

$$= 2,170 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 2,170}{0.91 \times (0.88)^2} = 18,500 \text{ psi}$$

$$M.S. = \frac{42,500}{18,500} - 1 = 1.3$$

Calculation of bending stress at Section Z-Z:

$$M_{Z-Z} = 1,350 \times 1.875 - 1,800 \times 0.325 = 1,945 \text{ in.-lb}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 1,945}{0.53 \times (0.9)^2} = 27,200 \text{ psi}$$

$$M.S. = \frac{42,500}{27,200} - 1 = 0.56$$

APPENDIX VIII

DETAIL STRUCTURAL ANALYSIS FOR THE PROTOTYPE QD COUPLING

1. LATCHING MECHANISM

The prototype latching mechanism has the following notable changes from the 1T20586-501 Test Model design. The latching hooks were made shorter and from 2024-T351 aluminum rather than aluminum bronze. Six (6) identical hooks are used rather than 3 each of 2 hook configurations. In order to maintain the low static coefficient of friction for coupling separation provided by the aluminum bronze latches they are identical to those on the -501 coupling except the thickness was reduced from 0.360 to 0.300 inch. It was necessary to maintain the basic circumferential size of the retaining linkage in order to preserve the feature of coupling release by fracturing any one of the three (3) shear pins. However, the width of the individual links was reduced thereby effecting a substantial weight saving. On the test models the wider link was 1.13 inches wide and the thinner link was 0.610 inches wide. The basic width for both links on the prototype is 0.500 inch.

The zero friction load diagram for the latching hook with the dimensions necessary to calculate the loads and stress at critical points is shown in Figure VIII-1. For the 100% design load of 1,200 lb per latch the following loads result:

$$F_{AH} = F_{BH} = 1,200 \text{ lb}$$

$$F_{AV} = 1,200 \tan 40^\circ = 1,010 \text{ lb}$$

$$F_A = \frac{1200}{\cos 40^\circ} = 1,565 \text{ lb}$$

$$\Sigma M_B = 0$$

$$1200 \times 0.875 + 1010 \times 1.656 - 2.03\, F_D = 0$$

$$F_D = \frac{1050 + 1670}{2.03} = 1,340 \text{ lb}$$

$$F_{BV} = 1340 - 1010 = 330 \text{ lb}$$

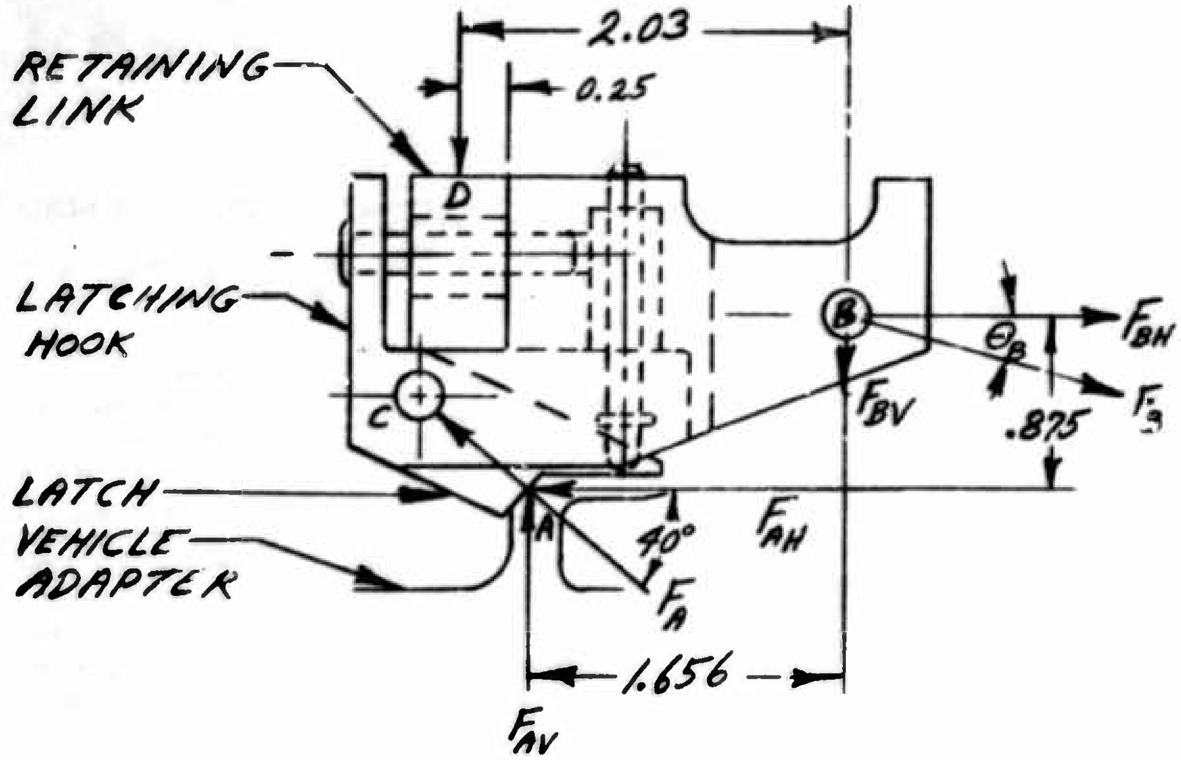


Figure VIII-1. Load Diagram For Latching Hook

$$\tan \theta_B = \frac{330}{1200} = 0.275$$

$$\theta_B = 15° \ 22'$$

$$F_B = \frac{1200}{\cos 15° \ 22'} = 1,250 \text{ lb}$$

Shear out of lugs at "B"

Shear area = 2 x 0.25 x 0.3 = 0.15 in.^{2}

$$f_s = \frac{1250}{0.15} = 8,330 \text{ psi} \quad \underline{\text{low}}$$

F_{su} = 37,000 for 2024-T351 aluminum bar

Tension area at "B" = 0.375 x 0.25 = 0.094 in.^{2}

$$f_t = \frac{1250}{0.094} = 13,300 \text{ psi} \quad \underline{\text{low}}$$

F_{ty} = 40,000 psi

Shear out of lugs at "C"

Shear area = 2 x 0.19 x 0.375 = 0.142 in.^{2}

$$f_s = \frac{1565}{0.142} = 11,000 \text{ psi} \quad \underline{\text{low}}$$

Tension are at "C" = 2 x 0.15 x 0.340 = 0.102 in.^{2}

$$f_t = \frac{1565}{0.102} = 15,300 \text{ psi} \quad \underline{\text{low}}$$

$$F_{ty} = 40,000 \text{ psi}$$

Figure VIII-2 shows the load diagram and the dimensions necessary to calculate the loads at the pin joints for the retaining linkage. The value F_D = 1,340 lb for the six (6) equally spaced radial loads was calculated above. Because of loading symmetry each of the resultant loads F_A and F_B are typical for 3 pin joints. Considering the three (3) upper links as a free body the following pin loads are calculated:

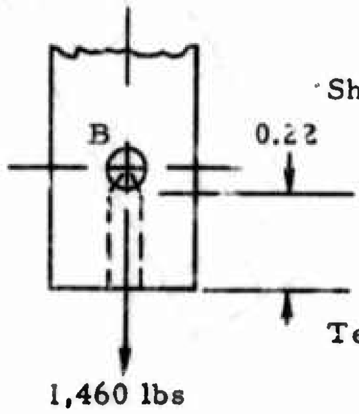
$$\Sigma M_A = 0$$

$$\frac{1340}{2} \times 1.27 - 1340 \times 3.36 - \frac{1340}{2} \times 5.46 + 6.19 F_B = 0$$

$$F_B = \frac{1340 \times 6.725}{6.19} = 1,460 \text{ lb}$$

$$F_A = 2 \times 1340 = 1,460 = 1220 \text{ lb}$$

Stress in lugs at "B"



Shear out area = 2 x 0.25 x 0.22 = 0.11 in.^{2}

$$f_s = \frac{1460}{0.11} = 13,300 \text{ psi} \quad \underline{\text{low}}$$

$$F_{su} = 91,000 \text{ psi}$$

Tension area = 0.375 x 0.25 = 0.0094 in.^{2}

$$f_t = \frac{1460}{0.094} = 15,500 \text{ psi} \quad \underline{\text{low}}$$

$$F_{tu} = 140,000 \text{ psi}$$

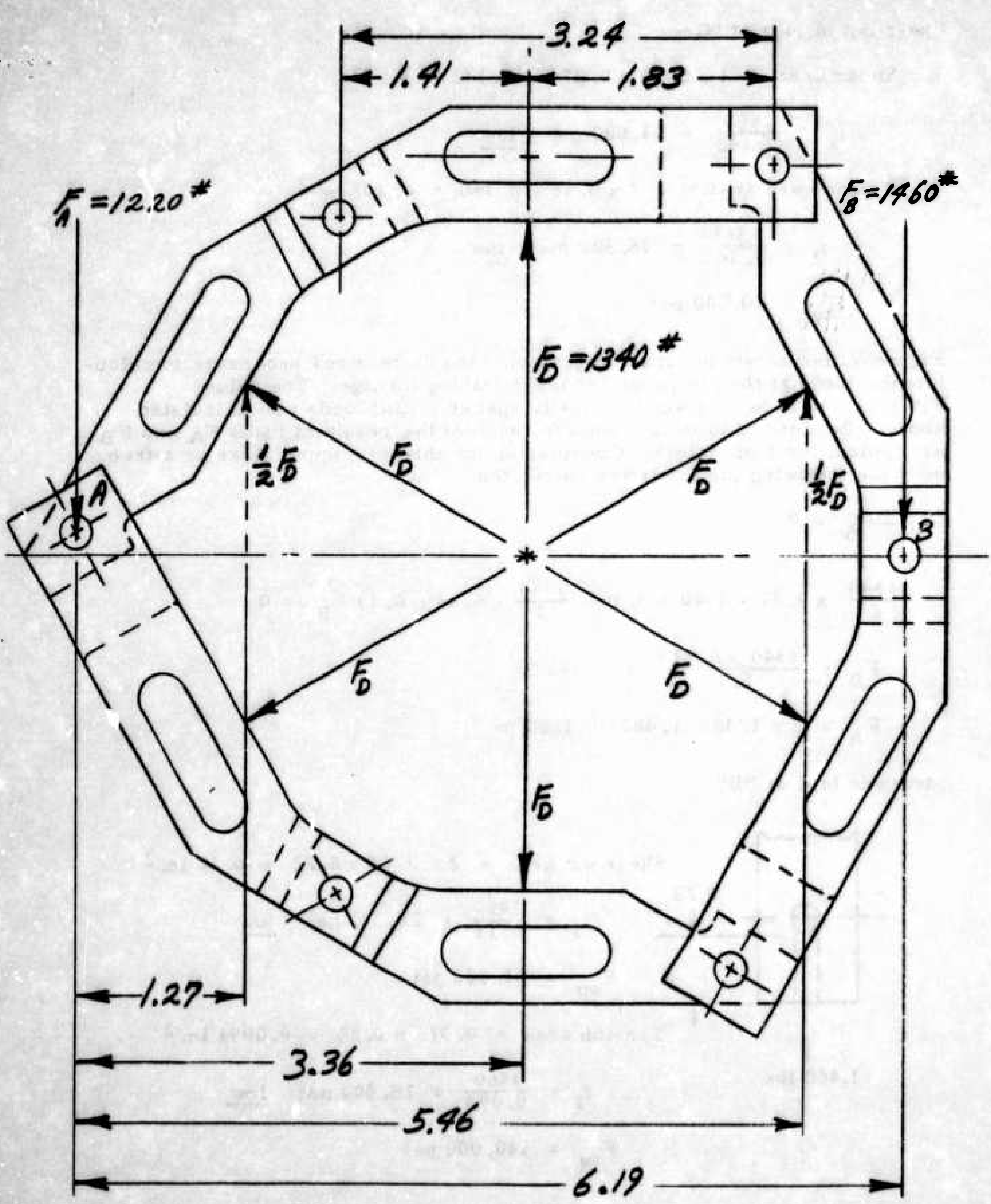


Figure VIII-2. Load Diagram For Latch Retaining Linkage

$$\text{Bearing area} = 0.25 \times 0.25 = 0.625 \text{ in.}^2$$

$$f_{br} = \frac{1460}{0.0625} = 23,400 \text{ psi} \quad \underline{\text{low}}$$

$$F_{bru} = 215,000 \text{ psi}$$

Calculation of pressure required to actuate latching pistons:

Force required to compress load springs and fully extend latching hooks = 150% x 1200 lb = 1,800 lb. Assume 300 lb force required to overcome "O" ring friction.

$$\text{Total force, } F_T = 1800 + 300 = 2,100 \text{ lb}$$

The piston area:

$$A = \frac{\pi}{4}(D^2_{piston} - D^2_{rod}) = \frac{\pi}{4}(1.99^2 - 0.5^2) = 2.92 \text{ in.}^2$$

The required actuation pressure:

$$p = \frac{F_T}{A} = \frac{2100}{2.92} = 720 \text{ psi}$$

Since $p < 750$ psi (the maximum working pressure for the release cylinders) the design goal to make it possible to use the same pressure source for the latching and release functions has been met.

2. COUPLING RELEASE MECHANISM

The test results discussed in Section III indicated that the load required to fracture a shear pin and release the coupling could be substantially reduced from the design loads used for the test models. The prototype shear pins are the same basic size and were designed to fracture at the same load (5,000 lb) as for the test models. The cam minor diameter was reduced from 0.610 in to 0.500 in. The load diagram for the release lever and cam is shown in Figure VIII-3 and the force required from the release cylinder is calculated as follows:

$$\Sigma M_A = 0$$

$$F \times 2.8 - 5000 \times 0.3 = 0$$

$$F = 536 \text{ lb}$$

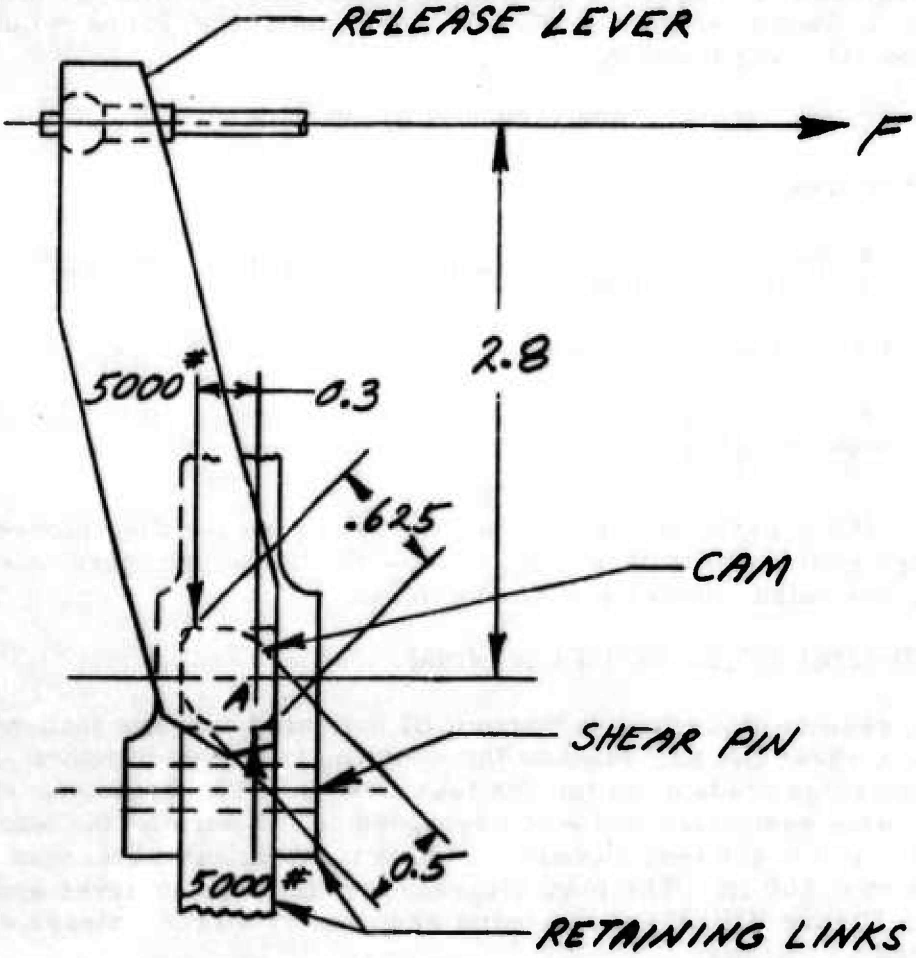


Figure VIII-3. Load Diagram For Release Lever and Cam

The release cylinder selected has a 1-1/2 in. diameter piston with a 0.625 in. diameter rod.

$$a = \frac{\pi}{4}(1.5^2 - 0.625^2) = 1.46 \text{ in.}^2$$

$$\text{Cylinder pressure required} = \frac{536}{1.46} = 368 \text{ psi}$$

Assume 700 psi minimum supply pressure

$$M.S. = \frac{700}{368} - 1 = 0.9$$

Stress in lever

Maximum moment = 1,500 in.-lb

$$f_b = \frac{6\,M}{b\,h^2} = \frac{6 \times 1500}{0.31 \times 0.72} = 59,000 \text{ psi}$$

$F_{ty} \cong 130,000$ psi for René 41 with $F_{tu} = 170,000$ psi

Shear stress due to torque on cam

$$\text{MAX } f_s = \frac{2M}{\pi a_1 b_1^2} \text{ (Reference 81)}$$

where:

a_1 = one-half major diameter of cam, in.

b_1 = one-half minor diameter of cam, in.

The required torque to break the shear pin is 5000 x 0.3 = 1500 in.-lb

$$fs = \frac{2 \times 1500}{\pi \times 0.312 \times (0.25)^2} \; 49,000 \text{ psi}$$

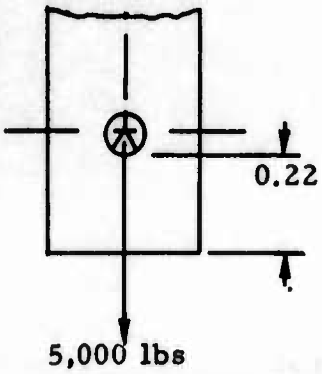
$$F_{su} = 100,000 \text{ psi}$$

$$M.S. = \frac{100,000}{1.5 \times 49,000} - 1 = 0.36$$

Stress in link lugs due to breaking shear pin

$$\text{Shear out area} = 2 \times 0.5 \times 0.22 = 0.22 \text{ in.}^2$$

$$f_s = \frac{5,000}{0.22} = 22,700 \text{ psi} \quad \underline{\text{low}}$$



$$F_{su} = 91,000 \text{ psi}$$

$$\text{Tension area} = 0.55 \times 0.5 = 0.275 \text{ in.}^2$$

$$f_t = \frac{5,000}{0.275} = 18,200 \text{ psi} \quad \underline{\text{low}}$$

$$f_{tu} = 140,000 \text{ psi}$$

$$\text{Bearing area} = 2 \times 0.25 \times 0.062 = 0.031 \text{ in.}^2$$

$$f_{br} = \frac{5,000}{0.031} = 161,000 \text{ psi}$$

For A286 CRES steel

$$F_{tu} = 140,000 \text{ psi}$$

$$F_{bry} = 162,000 \text{ psi}$$

$$\text{M.S.} = \frac{162,000}{161,000} - 1 = 0.006$$

Calculation of loads in hooks and linkage due to actuating release mechanism (see Figure VIII-4):

First assume that 536 lb load at "E" produces a moment about axis A-B as fulcrum and reacted at axis C-D.

$$\Sigma M_{C-D} = 0$$

$$536 \times 3.7 - 2.75 F_{A-B} = 0$$

$$F_{A-B} \; \frac{536 \times 3.7}{2.75} = 722 \text{ lbs}$$

$$F_{C-D} = 722 - 536 = 186 \text{ lbs}$$

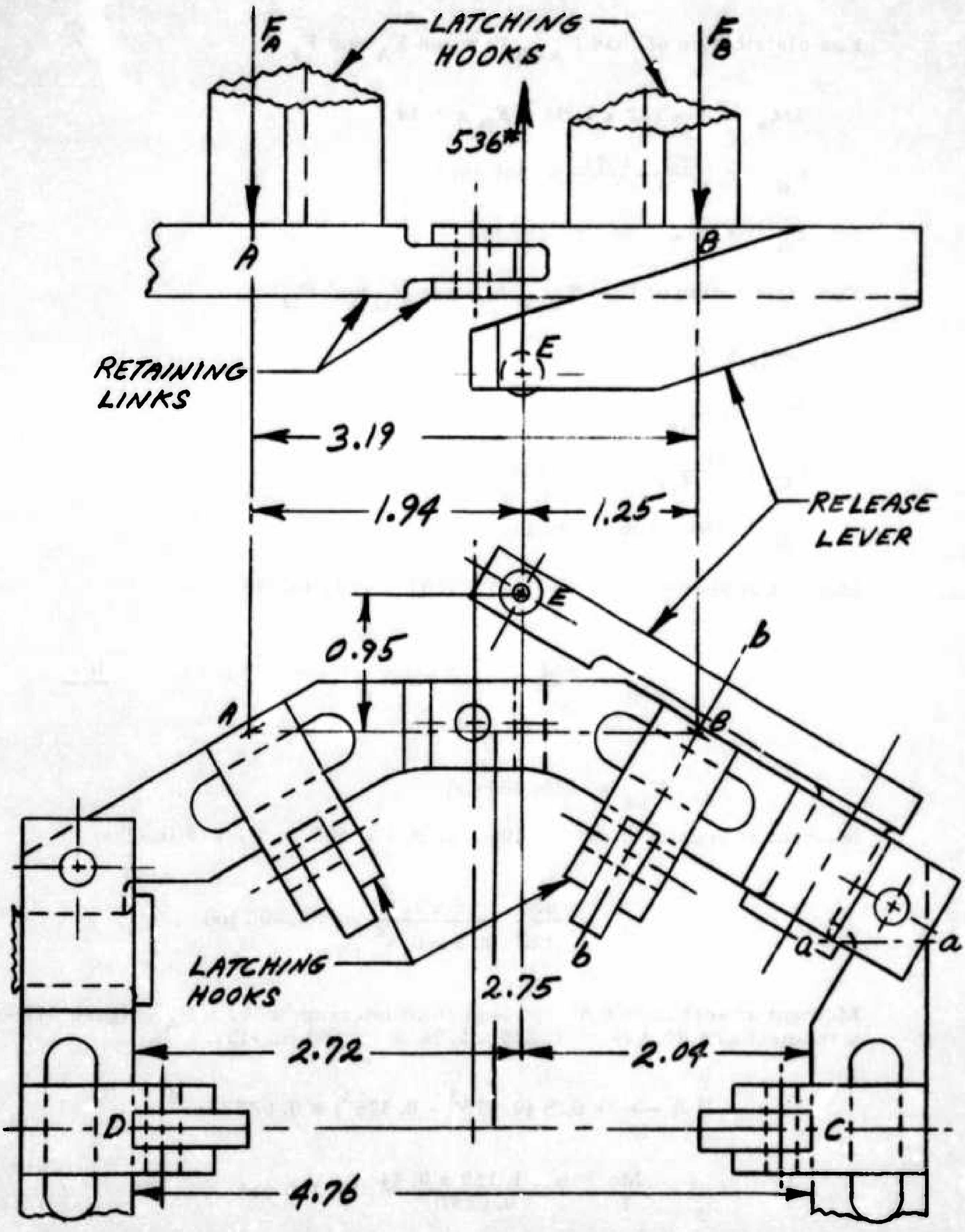


Figure VIII-4. Load Diagram For Release Mechanism

For distribution of load F_{A-B} between F_A and F_B

$$\Sigma M_A = 0 - 722 \times 1.94 + F_B \times 3.19$$

$$F_B = \frac{722 \times 1.94}{3.19} = 440 \text{ lbs}$$

$$F_A = 722 - 440 = 282 \text{ lbs}$$

For distribution of load F_{C-D} between F_C and F_D

$$\Sigma M_D = 0$$

$$186 \times 2.72 - 4.76\, F_C = 0$$

$$F_C = \frac{186 \times 2.72}{4.76} = 106 \text{ lbs}$$

$$F_D = 186 - 106 = 80 \text{ lbs}$$

Moment at section "a-a" = 106 x 1.31 = 139 in.-lb

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 139}{0.5 \times 0.5^2} = 6,700 \text{ psi} \qquad \underline{\text{low}}$$

$$F_{tu} = 140,000 \text{ psi}$$

Moment at section "b-b" = 106 x 2.66 - 1,500 = -1,218 in.-lbs

$$f_{b_1} = \frac{6M}{bh^2} = \frac{6 \times 128}{0.5 \times 0.5^2} = 58,800 \text{ psi}$$

Moment at section b-b due to load from latching hooks = F_A (Figure VIII-4) x moment arm (0.94) = 1,220 x 0.94 = 1,150 in.-lbs.

$$I \cong \frac{1}{12} \times 0.5\,(0.875^3 - 0.375^3) \cong 0.0257 \text{ in.}^4$$

$$f_{b_2} = \frac{Mc}{I} = \frac{6 \times 1,150 \times 0.44}{0.0257} = 19,700 \text{ psi}$$

Combined bending in two planes

$$f_{b_1} + f_{b_2} = 58,800 + 19,700 = 78,500 \text{ psi}$$

$$M.S. = \frac{140,000}{1.5 \times 78,500} - 1 = 0.185$$

Bending stress in inner bar of slotted link:

Assume center loaded beam with pinned end supports (Figure VIII-5).

$$f_t = \frac{1,460}{0,094} \; 15,500 \text{ psi}$$

$$f_b + f_t = 66,300 + 15,500 = 81,800 \text{ psi}$$

For A286 CRES steel with $F_{tu} = 140,000$

$$M.S. = \frac{140,000}{1.5 \times 81,800} - 1 = 0.14$$

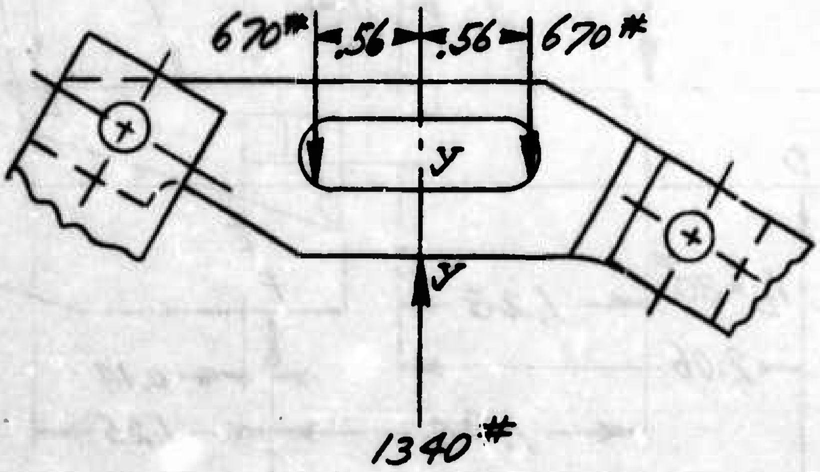


Figure VIII-5. Load Diagram, Latching Link

Moment at section E-E = 536 x 0.14 - 2.08 x 282 + 286 x 80 = 282 in.-lbs

$$I = \frac{1}{12}\ 0.625(0.5^3 - 0.25^3) = 0.0057\ \text{in.}^4$$

$$f_b = \frac{Mc}{I}\quad \frac{282 \times 0.25}{0.0057} = 12,400\ \text{psi}$$ low

$$M_{y-y} = 670 \times 0.56 = 375\ \text{in.-lbs}$$

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 375}{0.5 \times 0.31^2} = 58,100\ \text{psi}$$

$$M.S. = \frac{140,000}{1.5 \times 58,100} - 1 = 0.60$$

Check of loads on retaining linkage calculated above (see Figure VIII-6).

$$\Sigma M_F = 0$$

$$440 \times 1.25 - 106 \times 2.04 = 282 \times 1.94 + 80 \times 2.72 = 550$$

$$-216 - 547 + 218 \cong 0$$

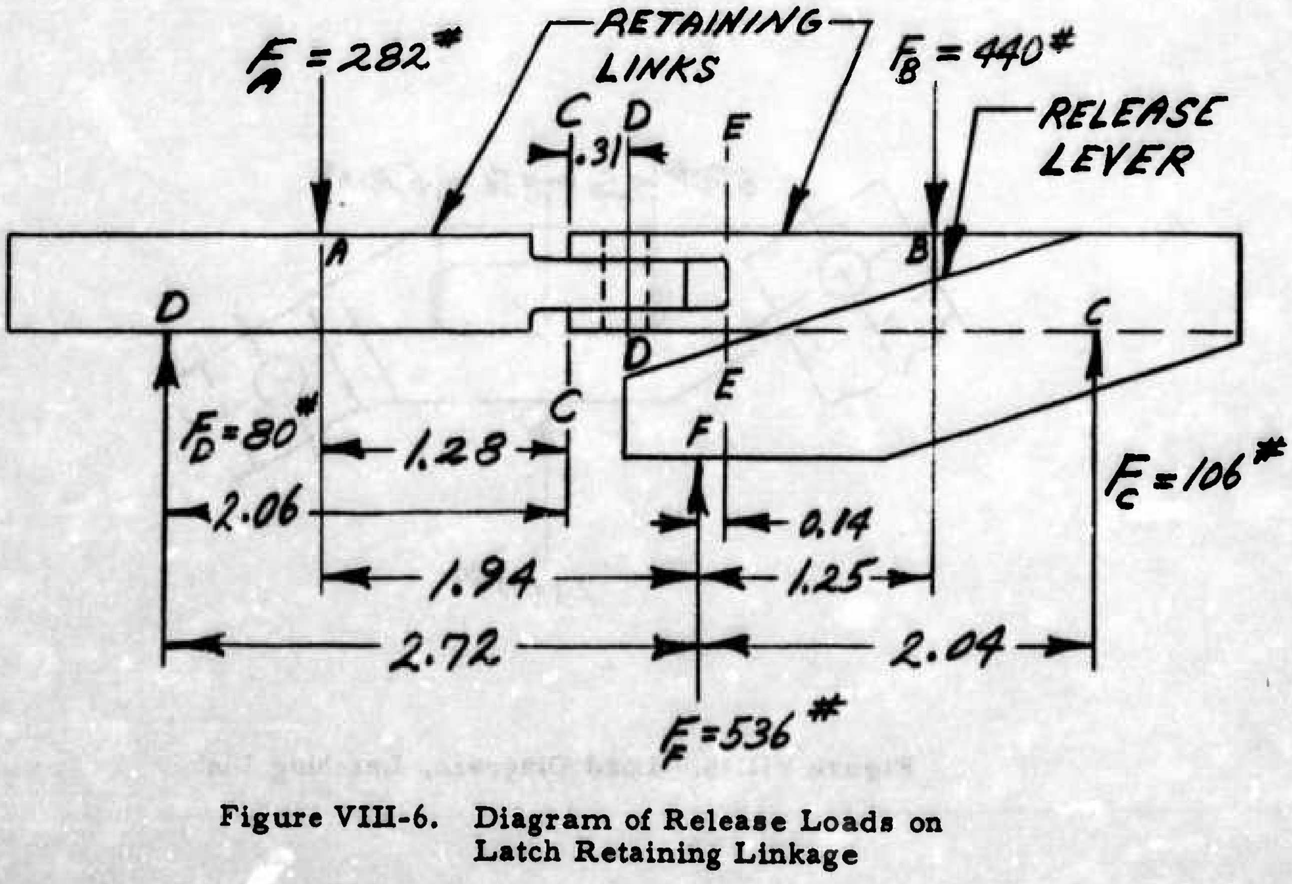


Figure VIII-6. Diagram of Release Loads on Latch Retaining Linkage

Moment at section c-c = 80 x 2.06 - 282 x 1.28 = -196 in.-lbs

$$f_b = \frac{MC}{I} = \frac{6 \times 196}{0.625 \times 0.25^2} \quad 30,000 \text{ psi}$$ **low**

$$F_{tu} = 140,000 \text{ psi}$$

Moment at section D-D = 80 x 2.37 - 282 x 1.59 = 260 in. -lbs

$$f_b = \frac{6M}{bh^2} = \frac{6 \times 260}{0.375 \times 0.25^2} = 66,300 \text{ psi}$$

$$M.S. = \frac{140,000}{1.5 \times 66,300} - 1 = 0.41$$

Assuming friction factor = 0 for latches

Tension load on joint at D-D = 1,460 lbs (F_B, Figure VIII-2)

Tension area of links = 0.25 x 0.375 = 0.094 in.^{2}

APPENDIX IX

DETAIL TEST REQUIREMENTS AND TEST PROCEDURES FOR PHASE II TESTING

1. TEST REQUIREMENTS

1.1 Pre-Fluorine Readiness Tests

a. Axial loads in each tension member applying sealing force (range: 0 F 2,000 lb); typical 6 places.

b. Leakage rate past the primary seal (range: 10^{-2} to 10^{-6} SCIMS).

c. Leakage rate past purge cavity seal (range: 10 to 10^{-4} SCIMS).

d. QD internal pressure (range: 0 to 100 psig).

e. Coupling separation actuator pressure (range: 0 to 500 psig).

f. Vehicle-half QD housing temperature at primary seal (range: 100 to -300°F).

g. Vehicle-half QD line temperature on outer surface (range: 100 to -300°F).

h. Vehicle-half QD housing temperature at cavity seal (range: 100 to -300°F).

i. AGE-half QD housing temperature at inner section (range: 100 to -300°F).

j. AGE-half QD housing temperature at midsection (range: 100 to -300°F).

k. AGE-half QD housing temperature at outer section (range: 100 to -300°F).

l. AGE-half QD tension members (positions 1-6) temperature (range: 100 to -200°F).

m. Vehicle-half QD internal fluid temperature (range: 100 to -320°F).

n. Seal cavity purge gas flow rate (range: 0 to 1,000 ml/min).

o. Deflection of each spring in seal load spring assembly (range: 0 to 0.040 in. at 0.001 intervals).

1.2 Design Evaluation Tests

a. Axial loads in each tension member apply sealing force (range: 0 < F < 2,000 lb); typical 6 places.

b. Leakage rate past the primary seal (range: 10^{-2} to 10^{-6} SCIMS).

c. Leakage rate past purge cavity seal (range: 10 to 10^{-4} SCIMS).

d. QD latch actuation system pressure (range: 0 to 1,500 psig).

e. QD internal pressure (range: 0 to 100 psig).

f. Coupling separation actuator pressure (range: 0 to 500 psig).

g. Vehicle-half QD housing temperature at primary seal (range: 100 to -300°F).

h. Vehicle-half QD housing temperature at cavity seal (range: 100 to -300°F).

i. Vehicle-half QD line temperature on outer surface (range: 100 to -300°F).

j. AGE-half QD housing temperature at inner section (range: 100 to -300°F).

k. AGE-half QD housing temperature at midsection (range: 100 to -300°F).

l. AGE-half QD housing temperature on outer section (range: 100 to -300°F).

m. AGE-half QD tension members (positions 1-6) temperature (range: 100 to -300°F).

n. Vehicle-half QD internal fluid temperature (range: 100 to -320°F).

o. Seal cavity purge gas flow rate (range: C to 1,000 ml/min).

p. Deflection of each spring in seal load spring assembly (range: 0 to 0.040 in. at 0.001 intervals).

1.3 Fluorine Test Measurement Requirements

a. Axial load in each tension member applying sealing force (range: 0 < F < 2,000 lb); typical 6 places.

b. Leakage rate past the primary seal (range: 10^{-2} to 10^{-6} SCIMS).

c. QD internal pressure (range: 0 to 100 psig).

d. QD coupling pressure drop (ΔP) (range: ± 5 psid).

e. Anti-icing shroud internal pressure (range: 0 to 5 psig).

f. Seal cavity internal pressure between primary and purge cavity seals (range: 0 to 100 psig).

g. QD purge gas supply pressure (range: 0 to 300 psig).

h. Flex hose drain point internal pressure (range: 0 to 100 psig).

i. Coupling separation actuator pressure (range: 0 to 500 psig).

j. Fluorine concentration in vent-and-drain system purge gas (range: 10 ppm to 10%).

k. Vehicle-half QD housing temperature at primary seal (range: 100 to -300°F).

l. Vehicle-half QD housing temperature at purge cavity (range: 100 to -300°F).

m. Vehicle-half QD line temperature on outer surface (range: 100 to -300°F).

n. AGE-half QD housing temperature at inner section (range: 100 to -300°F).

o. AGE-half QD housing temperature at midsection (range: 100 to -300°F).

p. AGE-half QD housing temperature at outer surface (range: 100 to -300°F).

q. Flex hose drain point internal temperature (range: 100 to -300°F).

r. Facility fluorine supply line fluid temperature (range: 100 to -320°F).

s. Flex hose nitrogen jeacket vent line fluid temperature (range: 100 to -320°F).

t. Vehicle-half QD internal fluid temperature (range: 100 to -320°F).

u. AGE-half QD tension members (positions 1-6) temperature (range: 100 to -200°F).

v. Seal cavity purge gas flow rate (range: 0 to 1,000 ml/min).

w. QD purge gas flow rate (range: 0 to 0.5 lb/sec).

x. Deflection of each spring in seal load spring assembly (range: 0 to 0.040 in. at 0.001 intervals).

2. TEST PROCEDURES

2.1 Pre-Fluorine Test Outline

a. Install 1T20586-1, Test Model in test setup, using an aluminum primary seal gasket and a teflon cavity seal gasket, and apply 100% of design sealing load.

b. Disconnect the coupling, at ambient temperature and 1 psig GN_2 internal pressure, using the coupling separation actuator. (Measure the actuator pressure required to effect this separation.)

c. Using new primary and cavity seal gaskets, connect QD, and apply 100% of design sealing load.

d. Repeat step b.

e. Install an aluminum primary seal gasket and a teflon purge cavity seal gasket, connect the QD, and apply 100% of design sealing load.

f. Leak check the seals with 100 psig GN_2.

g. Fill QD with LN_2 until the temperature stabilizes. Check changes (probable increase) in primary seal leakage during chilldown.

h. With the QD filled with LN_2, pressurize with GN_2 to 100 psig and measure primary seal leakage.

i. Warm the QD to ambient temperature and measure primary seal leakage with the QD pressurized to 100 psig GN_2.

j. Measure and record the strain gage readings on each bolt.

k. Mount a 0-30 psig pressure gage at the outlet port of the seal purge cavity, and pressurize the seal cavity to 29.5 psig with GHe. Leak check entire system, allow system to thermally stabilize, and isolate seal cavity and connecting lines while pressurized to 29.5 psig.

l. Record pressure change as a function of time. Also, continuously leak check all fittings and lines in this system during this pressure time period. Record for at least one hour.

m. Introduce LN_2 into the QD and monitor the pressure in the seal purge cavity as a function of time. Read and record QD temperatures in the area of the primary and secondary seals as a function of time during chilldown. If adverse leakage occurs, locate leaks and move to step o.

n. With the QD filled with LN_2 and thermally stabilized, monitor as a function of time the pressure in the seal purge cavity.

o. Warm the QD to ambient temperature, pressurize the seal cavity to 29.5 psig with GHe, allow the system to thermally stabilize, and isolate the monitor the seal purge cavity pressure as a function of time. Continuously check for external leaks at fittings, lines and valves.

p. Rework as required to eliminate major leaks, and repeat steps k through o.

q. Disconnect the coupling, at ambient temperature and 1 psig GN_2 internal pressure, using the coupling separation actuator. (Measure the actuator pressure required to effect this separation.)

r. Using new primary and cavity sealing gaskets, connect the QD, and apply 100% of design sealing load.

s. Install the anti-icing shroud, purge with 1-10 psig GA_r and measure primary seal leakage with 100 psig GN_2 in the QD.

t. Fill the QD with LN_2 and allow to thermally stabilize (measure temperature and strain gage readings during childown).

u. With the QD at LN_2 temperature, pressurize the 100 psig and leak check the primary seal.

v. Warm the QD to ambient temperature, measure primary seal leakage at 100 psig GN_2, and record strain gage readings.

w. Repeat step q.

x. Disassemble the QD and ship to A23.

2.2 Design Evaluation Test Outline

a. Adjust the sealing spring assemblies of the 1T20586-501 Test Model QD for minimum calculated load. Record strain gage readings for each bolt for the deflection of each spring. (QD separated)

b. Pressurize the latching pistons to assure complete latching piston travel. Record piston pressure, strain gage, readings, and spring deflections.

c. Leak check the latching pistons and depressurize.

d. Using an aluminum primary seal and a teflon cavity seal, engage the AGE-half with the Vehicle-half of the QD, pressurize the latching pistons, check for latch engagement, and release the pressure to the latching pistons.

e. Measure and record strain gage readings for each bolt and the deflection of each spring. Adjust spring loads as required to obtain minimum bolt loads; record all such adjustments.

f. Pressurize the QD coupling with 1 psig GN_2, and disconnect the coupling using the QD release actuator.

g. Adjust the sealing spring assemblies of the 1T20586-501 Test Model QD for nominal spring load. Record strain gage readings for each bolt and the deflection of each spring.

h. Using new primary and cavity seal gaskets, engage the AGE-half with the Vehicle-half of the QD, pressurize the latching pistons, check for latch engagement, and release the pressure to the latching pistons.

i. Measure and record strain gage readings for each bolt and the deflection of each spring. Adjust spring loads as required to obtain nominal bolt loads; record all such adjustments.

j. Leak check the primary seal with 100 psig GN_2, and the purge cavity seal with 30 psig GHe.

k. Fill QD with LN_2 until the temperature stabilizes. Check changes (probably increase) in primary and cavity seal leakage during chilldown. (Measure and record all temperature and strain gage readings as a function of time during chilldown.)

l. With the QD filled with LN_2, pressurized with GN_2 to 100 psig and measure primary seal leakage.

m. Warm the QD to ambient temperature and measure primary and purge cavity seal leakage with the QD pressurized to 100 psig GN_2, and the seal cavity to 30 psig with GHe. (Measure and record all temperature and strain gage readings during warmup.) Disconnect QD.

n. Install a new primary seal and mount a 0-30 psig pressure gage at the outlet port of the seal purge cavity, and pressurize the seal cavity to 29.5 psig with GHe. Leak check entire system, allow system to thermally stabilize, and isolate seal cavity and connecting lines while pressurized to 29.5 psig.

o. Record pressure change as a function of time. Also, continuously leak check all fittings and lines in this system during this pressure time period. Record for at least one hour.

p. Introduce LN_2 into the QD and monitor the pressure in the seal purge cavity as a function of time. Read and record QD temperatures in the area of the primary and cavity seals as a function of time during chilldown. If adverse leakage occurs, locate leaks and move to step r.

q. With the QD filled with LN_2 and thermally stabilized, monitor as a function of time the pressure in the seal purge cavity.

r. Warm the QD to ambient temperature, pressurize the seal cavity to 29.5 psig with GHe, allow the system to thermally stabilize, and isolate and monitor the seal purge cavity pressure as a function of time. Continuously check for external leaks at fittings, lines and valves. Disconnect QD.

s. Rework as required to eliminate major leaks, and repeat steps n through r.

t. Pressurize the QD with 1 psig GN_2, and disconnect the coupling using the QD release actuator. (Measure and record the actuator pressure required for separation.)

u. Adjust the sealing spring assemblies of the 1T20586-501 Test Model QD for minimum calculated load. Record strain gage readings for each bolt and the deflection of each spring.

v. Using an aluminum primary seal and a teflon cavity seal, engage the AGE-half with the Vehicle-half of the QD, pressurize the latching pistons, check for latch engagement, and release the pressure to the latching pistons.

w. Measure and record strain gage readings for each bolt and the deflection of each spring. Adjust and record as required to obtain minimum load on each bolt (50% latch load).

x. Pressurize the seal cavity with 29.5 psig GHe and check for seal cavity leakage, with the QD at ambient temperature and pressure.

y. Uniformly increase spring loads in uniform increments (approximately 5% of nominal) until leak rate no longer decreases. Measure and record strain gage readings, spring deflections, and leakage at 29.5 psig GN_2 at each new load.

z. Measure pressurized primary seal leakage at ambient and LN_2 temperatures with the QD at 100 psig. (Measure and record all temperatures, pressures and strain readings during chilldown.)

aa. Depressurize and purge all LN_2 from the QD. Pressurize, at ambient temperature, to 100 psig GN_2 and leak check the primary seal. Pressurize the seal cavity to 30 psig with GHe and leak check.

ab. Pressurize the QD to 1 psig GN_2, and disconnect using the QD release actuator.

ac. Adjust sealing springs for minimum sealing load to effect seal as determined in aa. Install primary and cavity seal gaskets, engage the coupling, pressurize the latching pistons, check for latch engagement, and release the pressure to the latching pistons.

ad. Measure and record strain gage readings for each bolt, the deflection of each spring, and primary seal leakage at 100 psig GN_2 and cavity seal leakage at 30 psig GHe. If leakage is negligible, reduce the seal load to 50% of design and leak check.

ae. Fill the QD with LN_2 until the temperature stabilizes. Pressurize to 100 psig and note change (probably increase) in primary and purge cavity seal leakage. (Measure and record all temperatures, pressures, and strain readings.)

af. Drain the QD of all LN_2, warm to ambient temperature and leak check primary and cavity seals. (Measure and record strain readings and spring deflections.)

ag. Repeat steps ae and af and increase seal loading as required to effect negligible leakage.

ah. Adjust three of the sealing springs to 50% design load.

ai. Measure and record strain gage readings for each bolt, the deflection of each spring, and primary seal leakage at 100 psig GN_2, and cavity seal leakage at 30 psig GHe.

aj. Fill the QD with LN_2 until the temperature stabilizes. Pressurize to 100 psig and note change (probably increase) in primary seal leakage. (Measure and record all temperatures, pressure and strain gage readings during chilldown.)

ak. Drain the QD of all LN_2. Pressurize, at ambient temperature, to 100 psig GN_2 and leak check.

al. Repeat steps ai through ak with all six spring assemblies at 50% load.

am. Pressurize the QD to 1 psig with GN_2 and disconnect the coupling using the QD release actuator.

an. Adjust the sealing spring assemblies for 50% design load.

ao. Using a new single serration aluminum primary seal (seals on one serration only), engage the coupling, pressurize the latching pistons, check for latching engagement, and release the pressure to the latching pistons.

ap. Measure and record strain gage readings for each bolt, the deflection of each spring, and the primary seal leakage at 100 psig.

aq. Uniformly decrease spring loads in 15-20% increments until gross primary seal leak rate is realized, or until the spring load has been reduced by 50%. Measure and record strain gage readings, spring deflections, and primary seal leakage at each new load.

ar. Pressurize the QD to 1 psig with GN_2 and disconnect the coupling using the QD release actuator.

as. Adjust the sealing springs for 25% load for the single serration seal configuration.

at. Using a new single serration aluminum seal engage the coupling, pressurize the latching pistons, check for latching engagement, and release the pressure to the latching pistons.

au. Measure and record strain gage readings for each bolt, the deflection of each spring, and the primary seal leakage at 100 psig.

av. Uniformly increase spring loads until negligible leakage is detected. Record strain gage readings, spring deflections, and primary seal leakage at each new load.

aw. Repeat any or all of steps an through av as required to define coupling engagement sealing characteristics and interactions.

ax. Remove the QD coupling from the test system and throughly inspect the QD and associated systems for any changes.

2.3 Fluorine Test Outline

a. Install the 1T20586-1 Test Model QD in the test setup, using an aluminum primary seal gasket and a teflon cavity seal gasket, and apply 100% of design sealing load. Record SG-1 through SG-6 and their corresponding temperatures, and record the deflection of each spring.

b. Purge and dry the lines and components of the test setup (coupling, fill-and-drain lines, vent and purge systems, instrumentation lines, etc.) in preparation for passivation.

c. Leak check entire test setup and passivate all systems which could possibly see fluorine. Purge these systems and repeat leak check in preparation for testing with LF_2. (During passivation, check for proper functioning of the fluorine detection and measurement systems; measure primary seal leakage.)

d. Purge all GN_2 from the fluorine system using GHe and fill the liquid fluorine transfer line cooling jackets with LN_2.

e. Transfer approximately 200 gallons of LF_2 through the QD coupling at approximately 30 gpm. Record all temperatures, pressures, and strain gage readings, monitor for excessive fluorine leakage past the primary seal gasket, and gather samples of seal cavity purge gas for post-test fluorine content analysis.

f. Drain the fluorine line from the QD to the Storage Tank with GHe until the temperature sensor in this line indicates a distinct temperature rise. Simultaneously purge all LN_2 from the LF_2 flex hose jacket using GN_2.

g. Isolate the QD and its flex hose from the transfer system and purge the QD and flex hose with GN_2 through the purge and drain system. Monitor flex hose drain point temperature, flex hose nitrogen jacket vent line fluid temperature, and vehicle-half QD internal fluid temperature. During this purge period, monitor the concentration of fluorine in the vented purge gas as a function of time.

h. Warm the system to ambient temperature while continuously purging.

i. Leak check the coupling at ambient temperature with coupling pressurized to 100 psia.

j. Readjust the six seal spring assemblies to 100% load, and leak check entire test setup.

k. Repeat steps d through h, except at approximately double the fluorine flow rate.

l. Separate the coupling in a dry environment, using a gaseous nitrogen purge to preclude the entrance of contaminants into the QD. Thoroughly inspect the coupling and associated systems for any changes.

m. Using new primary and cavity seals, connect the QD and apply 100% sealing load. Record strain gage readings.

n. Purge, dry, passivate and leak check as required to assure QD is ready for fluorine testing.

o. Purge all GN_2 from the fluorine system using GHe and fill the flexible transfer line cooling jacket with LN_2.

p. Supply 2-3 pounds of gaseous fluorine to the QD/flexline portion of the system, and continue LN_2 flow through the flexline cooling jacket until the QD pressure indicates that the bulk of the fluorine has been condensed and steady state conditions have been reached.

q. Purge the fluorine from the system while simultaneously purging all LN_2 from the flexline jacket. Monitor flexline drain point temperature and flexline nitrogen jacket vent line fluid temperature. During this purge period, monitor the concentration of fluorine in the vented purge gas as a function of time.

r. Warm the system to ambient temperature while continuously purging.

s. Readjust the six seal spring assemblies to 100% load, and leak check entire test setup.

t. Repeat steps o through r as required to obtain consistent data on the purge characteristics of the QD/flexline combination.

u. Repeat steps l through n.

v. Purge all GN_2 from the fluorine system using GHe and fill the liquid fluorine transfer line cooling jackets with LN_2.

w. Transfer approximately 100 gallons of LF_2 through the QD coupling at approximately 70 gpm. Record all temperatures, pressures, and strain gage readings, monitor for excessive fluorine leakage past the primary seal gasket, and gather samples of seal cavity purge gas for post-test fluorine content analysis.

x. Purge the liquid fluorine from the QD with GHe. Simultaneously purge all LN_2 from the LF_2 flex hose jacket using GN_2.

y. Isolate the QD and its flex hose from the transfer system and purge the QD and flex hose with GN_2 through the purge and drain system. During this purge period, monitor flex hose drain point temperature, flex hose nitrogen jacket vent line fluid temperature, vehicle-half QD internal fluid temperature, and the concentration of fluorine in the vented purge gas as a function of time.

z. Before the entire system has warmed up, establish liquid nitrogen flow through the flex hose jacket in preparation for a flow test.

aa. Transfer approximately 150 gallons of LF_2 through the QD coupling at approximately 80 gpm. Record all temperatures, pressures and strain gage readings. Gather samples of seal cavity purge gas for post-test fluorine content analysis.

ab. Prior to system warmup, directly after obtaining the purge test data, remotely release and separate the QD. Provide motion picture coverage of this release and separation operation. Measure actuator pressure at time of release.

ac. Throughly inspect the coupling and associated systems for any changes.

ad. Repeat any of the above tests as required to gather the required test data.

ae. Remove the QD coupling from the test system and thoroughly inspect it and associated systems for any changes.

APPENDIX X

PRELIMINARY SPECIFICATION FOR THE PROCESSING OF COMPONENTS FOR FLUORINE SERVICE

A. CLEANING MATERIALS

A. 1 Vapor Degreasing

Solvent used for vapor degreasing cleaning processes shall be per 0-T-634, Type 2, Trichloroethylene, except the nonvolatile residue shall not be greater than 0.020 gr per liter.

A. 2 Component Cleaner

A. 2. 1 Trichlorotrifluorethane

This solvent, when used in the final cleaning processes, shall be per MSFC-SPEC-237.

A. 2. 2 Methylene Chloride

This solvent, when used in the final cleaning processes, shall be per MIL-06998, Grade A.

A. 3 Drying or Preservation Gas

A. 3. 1 Air

Air used in the drying and preservation processes shall be prefiltered to a 100 mc level (absolute), the hydrocarbon content shall not exceed 0. 5 parts per million by weight in terms of n-cetane, and the moisture content shall not exceed 26. 3 ppm by weight.

A. 3. 2 Nitrogen

Nitrogen gas used in the drying and preservation processes shall be in accordance with MIL-P-27401, Type 1, and in addition, shall adhere to the purity requirements listed in Paragraph A. 3. 1.

B. PRECLEANING

Components, except those made of Teflon, requiring precleaning shall be processed outside the clean room and shall include removal of dirt, grit, chips, grease and other major contaminants by flushing with compressed air, scrubbing with methylene chloride using a bristle brush, and again flushing with compressed air. Repeat any or all of this procedure until the component is visually free of these major contaminants.

C. FINAL CLEANING

Clean all component exterior surfaces, except Teflon, by vacuuming and/or air purging, and purge the interior of the part with gas, per Paragraph A. 3. 1 or A. 3. 2, if possible prior to transferring into the clean room.

C. 1 Single Material Metallic Components and Subcomponents

C. 1. 1 Flush all significant surfaces (those surfaces that will come in contact with the system fluid) with trichlorotrifluorethane of methylene chloride per Paragraph A. 2 for 2 to 5 minutes.

C. 1. 2 Place in an oven at a temperature of 240 to 260°F and bake for 1 hr.

C. 1. 3 Package per Paragraph F if assembly into a component is not forthcoming within a reasonable time.

C. 2 Teflon Subcomponents

C. 2. 1 Wash all significant surfaces with a solution of water containing 0. 1 to 0. 5% (by volume) of non-ionic detergent; that is, Pluronic L-62LF or equivalent.

C. 2. 2 Rinse thoroughly with distilled water.

C. 2. 3 Place in an oven at a temperature of 240 to 260°F and bake for 1 hour.

C. 2. 4 Package as noted in Paragraph F if assembly into a component is not forthcoming within a reasonable time.

C. 3 Component Assembly

C. 3. 1 All necessary component assembly shall be accomplished per the applicable drawing, after individual subcomponent final cleaning has been completed.

C. 3. 2 Package as noted per Paragraph F.

D. HANDLING

Handle clean significant surfaces only with polyethylene or rubber gloves. If line-gree wipers contact a significant surface, the surface must be flushed with solvent.

E. LUBRICANTS

No lubricants shall be used during the assembly of, or the attachment of test lines to, fluorine parts.

F. PACKAGING

F.1 Components

Components and/or assemblies that are sufficiently small or possess external significant surfaces shall be packaged as follows:

F.1.1 Thoroughly purge the component and wrap all significant surfaces and/or openings thereto with a minimum of two layers of MIL-A-148 annealed aluminum foil. Secure the foil with PPP-T-60, class 1, tape, completely covering all loose ends, obtaining as tight a seal as possible. Under no conditions shall the tape contact any significant surface.

F.1.2 Place the component in a polyethylene bag.

F.1.3 Purge the exterior of the bag with gas conforming to Paragraph A.3. Exhaust the gas atmosphere from the bag by hand.

F.1.4 Heat seal the open bag end.

F.1.5 Identify as noted in Paragraph F.3.

F.2 Identification

Firmly affix a tag to the outside of the packaged component without penetrating any portion of the protective bag that forms the contaminant barrier for the component. The tag shall contain the following information:

F.2.1 Part name.

F.2.2 Part number.

F.2.3 Manufacturer's serial number, if applicable.

F.2.4 Cleaned for fluorine service.

F.2.5 Date of cleaning.

F.3 Packaging for Shipment

F.3.1 Small Components

Small parts shall be protected by wrapping with protective material and placing each part in a container prior to transporting. The parts shall be packed with the container to prevent movement.

F.3.2 Large Components

Place large components in compartmented padded box, one part per compartment. Large components may also be placed on a pallet or within an individual container with designed padded covers. These components shall be secured to the pallet or within the container to prevent movement.

APPENDIX XI

PRELIMINARY

CONTRACT END ITEM DETAIL SPECIFICATION (PRIME EQUIPMENT)

PERFORMANCE/DESIGN AND PRODUCT CONFIGURATION REQUIREMENTS

Coupling Assembly, Quick Disconnect
Liquid Fluorine

PRELIMINARY

PRELIMINARY

CONTRACT END ITEM DETAIL SPECIFICATION

PART I. PERFORMANCE/DESIGN AND QUALIFICATION REQUIREMENTS

Coupling Assembly, Quick Disconnect, Liquid Fluorine

1. SCOPE

This part of this specification establishes the requirements for performance, design, test and qualification of one mission-design-series of equipment identified as Coupling Assembly, Quick Disconnect, Liquid Fluorine, Contract End Item (CEI), herein referred to as the Quick Disconnect (QD). This QD is used to provide the space vehicle-to-AGE liquid fluorine servicing line interface connector through which the liquid fluorine is loaded or unloaded. This QD requires a source of gaseous nitrogen and gaseous helium for coupling, purging, and disconnecting the QD.

2. APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and detail content of Sections 3, 4, 5 and 10, the detail requirements of Sections 3, 4, 5 and 10 shall be considered a superseding requirement.

SPECIFICATIONS

Military

MIL-F-7179	Finishes and Coatings, General Specification for Protection of Aircraft to Aircraft Parts
MIL-P-116E	Methods of Preservation
MIL-P-7936B	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL-R-11468	Radiographic Inspection, Soundness Requirements for ARC and Gas Welds in Steel
MIL-S-8512	Support Equipment, Aeronautical. Special, General Specification for the Design of
MIL-W-8604	Process for Welding of Aluminum Alloys
MIL-W-8611A	Process for Welding, Metal Arc and Gas, Steels, and Corrosion and Heat

STANDARDS

Federal

FED-STD-102	Preservation, Packaging and Packing Devices
FED-STD-595	Color Requirements for Individual Color Chips

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-143	Order of Preference for the Selection of Specifications and Standards
MIL-STD-447	Definitions of Interchangeable Substitute and Replacement Items
MIL-STD-453	Radiographic Inspection
MIL-STD-803A-1	Human Engineering Design Criteria for Aerospace Systems and Equipment. Part #1--Aerospace Systems Ground Equipment
MIL-STD-810 Table 508-1	Environmental Test Methods for Aerospace and Ground Equipment
MIL-STD-1247	Identification of Pipe, Hoses, and Tube Lines for Aircraft, Missile, and Space Systems
MS-33586	Definition of Dissimilar Metals

OTHER PUBLICATIONS

Manuals

Air Force Systems Command

AFSCM 375-1 1 June 1964	Configuration Management During Definition and Acquisition Phases

3. REQUIREMENTS

Performance, design, and construction requirements specified herein are applicable to the Quick Disconnect. This section includes the functional requirements for the Quick Disconnect and establishes the requirements which are suitable for proof during test.

3.1 Performance

3.1.1 Functional Characteristics

The Quick Disconnect shall provide the space vehicle-to-AGE liquid fluorine servicing line interface connector through which the liquid fluorine is loaded or unloaded. The Quick Disconnect shall provide capability for rapid manual connect, "leak proof" operation, and rapid remote controlled separation. There shall be a capability for draining and purging all liquid fluorine from the Quick Disconnect.

3.1.1.1 Primary Performance Characteristics

The Quick Disconnect shall include the following performance characteristics:

a. The primary Quick Disconnect seal, located between the vehicle and the AGE halves of the coupling, shall prevent fluorine leakage in excess of 10^{-4} SCIM under the following conditions:

   1. Temperature: 100° to -320°F.

   2. Pressure (Internal): 0 to 100 psia.

   3. Maximum limit loads as defined in 3.1.1.1-c.

b. The working pressure shall be 100 psia maximum.

c. The limit load shall be 1,000 in.-lbs of moment applied in any plane perpendicular to the AGE-half inlet flange face, combined with a shear load of 82 pounds applied in any direction along the AGE-half flange face.

d. The flow through the Quick Disconnect shall be a minimum of 100 gpm of liquid fluorine with an inlet pressure of 100 psia.

e. Pressure drop across the Quick Disconnect shall not exceed 2.0 psi with 100 gpm liquid fluorine flow.

f. The purge and drain pressure shall be a maximum of 100 psia.

g. The purge and drain flow rate shall be a minimum of 0.15 pounds-per-second of gaseous nitrogen at a temperature of 72°F and at 100 psia.

3.1.1.2 Secondary Performance Characteristics

a. The latching and disconnect pressures shall be 1,000 psia maximum.

b. The disconnect pressure shall be 750 psia maximum.

c. The seal cavity shall be capable of flowing a minimum of 100 SCCS of gaseous helium at a maximum seal cavity inlet pressure of 100 psia.

d. The Quick Disconnect anti-icing shroud shall be capable of being pressurized to 1 psig with gaseous nitrogen.

3.1.2 Operability

3.1.2.1 Reliability

Required entry not practical at this time.

3.1.2.2 Maintainability

3.1.2.2.1 Maintenance and Repair Cycles. Required entry not practical at this time.

3.1.2.2.2 Service and Access. The Quick Disconnect shall comply with the following requirements:

a. Accessibility to replaceable or adjustable components shall be provided.

b. Caps and/or covers shall be provided for all liquid or gas ports to prevent entry of dirt, moisture or other foreign material when ports are not in use.

c. Structural members shall not prevent access to components.

d. Latches and fasteners shall be positive locking.

e. Equipment and components, attachments, and connectors shall be marked, keyed, or otherwise identified to preclude improper installation or connection.

3.1.2.3 Useful Life

Required entry not practical at this time.

3.1.2.4 Environmental

The Quick Disconnect shall be designed to withstand the following environment for both the operating and nonoperating modes:

a. High Temperature--A maximum of 160°F.

b. Low Temperature--A minimum of -320°F.

c. Humidity--Cycling from 30 to 100 per cent relative humidity within a 12-hour period at temperatures which include water condensation and frost.

d. Atmospheric Pressure--14.7 psia.

e. Salt Atmosphere--Exposure to 20 per cent by weight, salt spray for periods of 50 hours.

f. Sand and Dust--The Quick Disconnect shall be capable of withstanding exposure to sand and dust of a density from 0.1 to 0.25 grams per cubic foot in an atmosphere not to exceed 30 per cent relative humidity, with a temperature of 77° to 160°F and a sand and dust velocity of 100 to 500 feet per minute for a minimum of 6 hours. The sand and dust is commercially known as 140 mesh silica flour.

g. Rain--Exposure equivalent to 4 inches per hour for up to 2 hours.

h. Fungus--An equivalent of a minimum of 28 days exposure to selected fungi described in Table 508-1, Fungus, of MIL-STD-810; in an atmosphere of 86°F and 95 per cent relative humidity.

i. Vibration--The vehicle half of the Quick Disconnect shall withstand:

   (1) Sinusoidal vibration of 40 to 2,500 cps at 40 g's (rms) acceleration level or 1/2 inch double amplitude on all component axes, at a temperature of -320°F.

   (2) Random vibration having a bandwidth of 20 to 2,000 cps and an acceleration density of 0.1 g^2/cps on all component axes, at a temperature of -320°F.

j. Acceleration--The vehicle half of the Quick Disconnect shall be capable of satisfactory operation after subjection to ten minutes of 30 g linear acceleration, at a temperature of -320°F.

3.1.2.5 Transportability

The Quick Disconnect shall comply with the following transportability requirements:

a. Preservation, packaging, and packing shall be designed to meet the environmental requirements of 3.1.2.4 a. through h.

b. The primary mode of shipment for the QD shall be highway transportation.

c. The Quick Disconnect shall be transported in the connected position, and tied-down to its shipping crate at the following two locations:

(1) At the vehicle-half structural attach point.

(2) At the AGE-half liquid fluorine inlet flange.

d. Handling provisions shall be provided as specified in Paragraph 3.3.4, Handling Provisions, of MIL-S-8512.

e. The Quick Disconnect, as packaged for shipment, shall have maximum dimensions of 18 x 18 x 36 inches and shall weigh no more than 75 pounds.

3.1.2.6 Human Performance

a. The Quick Disconnect shall be of such size, accessibility, and configuration that it can be operated and maintained by personnel whose body dimensions shall fall between the 5th and 95th percentiles. These dimensions shall be in accordance with Paragraph 9.1.2 of MIL-STD-803A-1.

b. Labeling shall be in accordance with Paragraph 8, Labeling, of MIL-STD-803A-1.

3.1.2.7 Safety

3.1.2.7.1 Flight Safety. Not applicable.

3.1.2.7.2 Ground Safety. The design and operation of the Quick Disconnect shall comply with the following ground safety requirements in addition to all other requirements noted elsewhere in this specifications.

a. The QD shall be designed to eliminate hazards identified as Class IV, Paragraph 3.2.6.2.1, System Failure Hazards Classification of MIL-S-38130; those identified as Class III shall be eliminated or reduced to an acceptable minimum.

b. The QD shall not be disconnected following a fluorine flow without being first drained and purged to below 1,000 PPM of fluorine and the QD's internal pressure reduced to not more than 5 psig.

3.1.2.7.3 Nuclear Safety. Not applicable.

3.1.2.7.4 Personnel Safety. The design of the QD shall be in accordance with Paragraph 13.2.1, Equipment Marking, and 13.3.2.3, Edges and Corners, of MIL-STD-803A-1. The following personnel operating restraints are also imposed:

a. The QD shall not be disconnected in the presence of personnel following a fluorine flow.

b. Personnel shall not be permitted in the area of the QD during passivation, test and operation with fluorine.

c. Personnel shall not be permitted to come in direct contact with any surface which has been exposed to fluorine prior to completing one of the following:

(1) Ambient temperature (70 ± 10°F) gaseous nitrogen purge for 24 hours.

(2) Elevated temperature (120°F or above) gaseous nitrogen purge for 2 hours.

(3) Brief dip or flush with either liquid nitrogen or liquid Freon-14 (CF_4).

NOTE: The brief dip described is extremely effective in removing all excess fluorine from metal surfaces, thus making them both safe to handle and all but eliminates further corrosion.

3.1.2.7.5 Explosive and/or Ordnance Safety. Not applicable.

3.2 Quick Disconnect

3.2.1 Interface Requirements

The Quick Disconnect shall have the following interfaces:

a. Vehicle liquid fluorine fill and drain system (nomenclature and CEI number are not practical at this time).

b. AGE liquid fluorine fill and drain system (nomenclature and CEI number are not practical at this time).

3.2.1.1 Schematic Arrangements

See Figure 1.

3.2.1.2 Detailed Interface Definition

Not applicable at this time.

3.2.2 Component Identification

3.2.2.1 Government Furnished Property List

Not applicable.

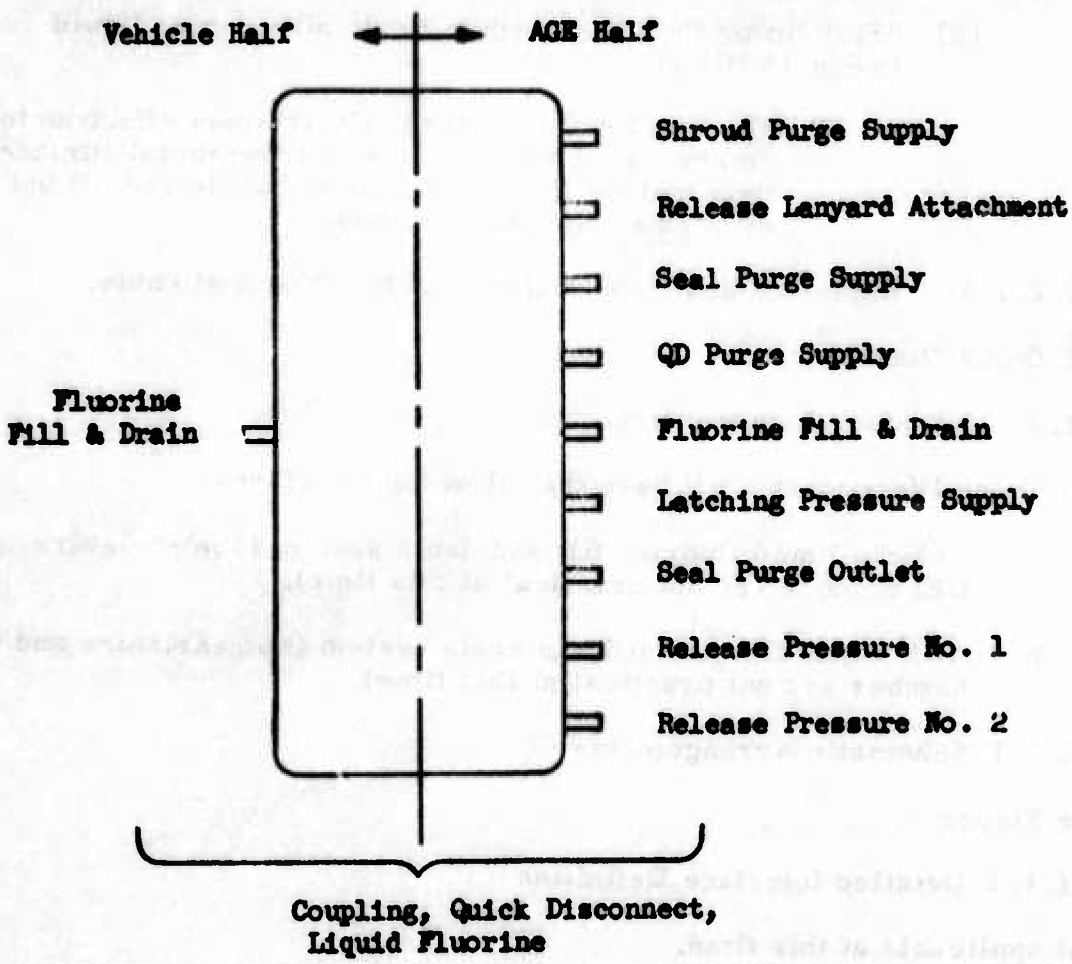


Figure XI-1. Coupling, Quick Disconnect, Liquid Fluorine - Interface Requirements, Schematic Block Diagram

3.2.2.2 Engineering Critical Component List

Not applicable.

3.2.2.3 Logistics Critical Component List

Not applicable.

3.3 Design and Construction

3.3.1 General Design Features

The Quick Disconnect shall have the following general design features:

a. The design shall use existing, proven, component and equipment design wherever possible.

b. Primarily standard tools and servicing will be used for test, service, adjustment and repair.

c. Components which carry high pressure gases or fluids shall have a four-to-one burst-pressure-to-maximum operating-pressure ratio.

d. The capability of withstanding a proof pressure of 1.5 times the maximum operating pressure.

e. The Quick Disconnect shall be capable of rapid manual connection. This rapid manual connect operation shall result in the latching together of the vehicle and AGE halves of the Quick Disconnect, and the application of coupling-to-coupling sealing loads in a single operation.

f. Provisions are required for positive indication that the Quick Disconnect is engaged and mechanically latched.

g. The QD shall be designed for fly-away as well as manual disconnect operations.

h. The fly-away disconnect provision must be highly reliable, incorporating redundant pneumatic release provisions and an independent backup lanyard operated release system.

i. The Quick Disconnect is not required to provide any oxidizer flow control or fluid shutoff provisions; no integral valves are required.

j. The Quick Disconnect shall adequately provide for draining and purging of all fluorine wetted surfaces.

k. The design shall provide for ducting all primary coupling-to-coupling seal leakage away from the Quick Disconnect for leak detection and safe disposal.

l. The entire Quick Disconnect, with the exception of replaceable seals and shear pins, shall be designed for repeated usage without damage or functional degradation and without the necessary for extensive maintenance or rework.

m. The Quick Disconnect shall be provided with an anti-icing shroud which can be purged with gaseous nitrogen to prevent the formation of frost or ice on any of the release mechanism and on the Quick Disconnect at the vehicle-to-AGE disconnect separation plane.

n. The QD design shall comply with the following detail requirements:

(1) Avoid the use of welded bellows with nesting convolutions because they are difficult to clean and impossible to inspect for contamination. Make the bellows from either seamless tubing or from 100% X-rayed butt-welded wrapped sheet. Avoid possible hidden contamination in this weld. Bellows must be made from oxidizer compatible materials which are capable of being formed into convolutions and have good fatigue properties throughout the environmental temperature ranges that will be encountered.

(2) Eliminate all possible dead-end passages.

(3) The interior of the coupling should be smooth and free of cavities which could collect contaminants.

(4) Wherever possible, all interior surfaces exposed to the oxidizer should be capable of being visually inspected.

(5) Minimize pipe and tubing runs. The shortest length will have the smallest area and correspondingly, the lowest potential source of contaminants. Minimize the number of tees, courses, elbows, and other fittings that generate and trap particles. Use manifolds wherever possible.

(6) Eliminate all possible close fitting dynamic parts capable of generating contaminant particles.

(7) Avoid threaded joints exposed to the oxidizer. They not only form a trap for contaminants but also can generate particulate contaminants during mating of the threads.

(8) Arrange threaded connections so that the flow does not scrub particles out of the threaded crevices and carry them into the vehicle.

(9) Place gaskets or seals to permit minimum contact with the bulk of the working fluid.

(10) Design critical sealing surfaces so that they have some inherent protection (e.g., recessed surface) from damage due to handling during the coupling mating operation.

(11) Provide a pilot or guide for aligning the mating halves of the coupling before the primary and secondary seals are engaged. (Prevents damage to these seals.)

(12) Avoid the necessity for rotational indexing of the coupling at the interface between the two halves.

(13) There shall be no loose hardware when the coupling separates (seals and shear pins must be retained).

(14) Use only clean, bagged, and sealed components to assemble the system.

(15) Preclude moisture (water vapor, frost, and ice) from inside and adjacent to components.

(16) Perform assembly and disassembly operations in environmentally controlled areas commensurate with the degree of cleanliness required in the components being used.

(17) Minimize the need for assembly and installation of fittings on a component after it has been fabricated and cleaned.

3.3.2 Selection of Specifications and Standards

Specifications and standards for the identification and control of materials, parts, and processes of this equipment shall be selected in accordance with MIL-STD-143. All standards and specifications, other than those established and approved for use by the Air Force, must be approved by the procuring agency prior to incorporation into the CEI Specification.

3.3.3 Materials, Parts, and Processes

All materials, parts, and processes shall be compatible with the performance and environmental criteria for this equipment. Manufacturing processes and associated materials used on off-the-shelf hardware or hardware previously developed on other Government contracts, shall be acceptable provided the hardware meets all other requirements of this specification.

3.3.3.1 Metallic Parts

All metals shall be corrosion resistant type unless suitably protected to prevent corrosion during the specified service life and storage life. The following requirements are applicable to this CEI:

a. Choose materials on the basis of the best possible compatability with liquid fluorine, consistent with the function of the part.

b. Avoid the use of platings and coatings on metals wherever possible.

c. Non-magnetic metals shall be used for all metallic parts of the Quick Disconnect except where magnetic metals are essential.

d. The use of castings should be avoided. Where their use is essential, castings shall be nonporous and free of sand and other foreign materials. All castings should be X-rayed to ensure that voids, cracks and inclusions are not present.

3.3.3.2 Non-Metallic Parts and Materials

There shall be no nonmetallic materials used on contact with liquid fluorine. The following requirements are applicable to this QD:

a. Teflon may be used for a secondary seal if a cavity is provided between the primary and secondary seals, and if this cavity is either vacuum scavenged or purged with an inert gas.

b. The use of lubricants in direct fluorine service is not permitted.

c. The use of lubricants in non-fluorine service shall be kept to a minimum.

3.3.4 Standard and Commercial Parts

Standard parts and components shall be used wherever they are suitable for the purpose, and shall be identified by part number where practical. Commercial utility parts such as screws, bolts, nuts and cotter pins may be used, provided they have suitable properties and are replaceable by the standard part without alternation. In applications for which no suitable standard part or component is in effect on date of invitation for bids, commercial parts and components may be used provided they conform to the requirements of this specification.

3.3.5 Moisture and Fungus Resistance

Nonnutrient materials shall be used which resist damage from moisture and fungus. Protective coatings shall not be acceptable as moisture and fungus preventives on parts which will lose the coatings during the normal course of operation, inspections, maintenance, and periodic testing.

3.3.6 Corrosion of Metal Parts

Finishes shall be applied to metal parts which are subject to corrosion to ensure adequate protection in anticipated environments. Consideration shall be given to weight and thermal properties. Protective treatment shall be in accordance with the requirements of MIL-F-7179 with the exception of Paragraph 3.1.2, Contractors Finish Specification. Dissimilar metals, as defined in MS 33586, shall not be used in corrosive environments unless adequate protection is provided to prevent electrolytic corrosion.

3.3.7 Interchangeability and Replaceability

Interchangeability and replaceability requirements shall be as defined in MIL-STD-447.

3.3.8 Workmanship

Workmanship shall be in accordance with Paragraph 3.12, Workmanship, of MIL-S-8512.

3.3.9 Electromagnetic Interference

Not applicable.

3.3.10 Identification and Marking

The Quick Disconnect shall be identified and marked as follows:

a. Identification and marking shall be in accordance with Paragraph 6.5, Equipment Identification Nameplates and Markings of AFSCM 375-1, Exhibit XI.

b. Colors shall be in accordance with FED-STD-595.

c. Pipe and tube line function, content hazard, direction of flow, and color shall be marked as specified in MIL-STD-1247.

3.3.11 Storage

The Quick Disconnect shall comply with the following storage requirements.

a. Preservation and packaging for storage in excess of 90 days, but not to exceed one year shall be in accordance with Level B, as defined in FED-STD-102. The storage environment shall not exceed the requirement of 3.1.2.4.

b. Preventative maintenance, except for desiccant replacement, shall not be required during storage.

4. QUALITY ASSURANCE PROVISIONS

The basis for verification of the performance, design, and construction requirements delineated in Section 3 shall be as specified in this section.

4.1 Ground Tests

4.1.1 Engineering Test and Evaluation (Development Tests)

Tests shall be conducted to verify the design, to determine equipment compatibility, to evaluate performance, and to develop procedures. The requirements of Section 3 shall be verified through one or more of the following methods:

a. Inspection.

b. Analyses.

c. Test.

4.1.1.1 Inspection

The following requirements of Section 3 shall be verified by inspection as indicated:

a. 3.1.2.2 Service and Access--Compliance with service and access requirements for checkout, maintenance and setup of the Quick Disconnect shall be demonstrated. All other service and access requirements shall be visually inspected for conformance with this specification.

b. 3.1.2.5 Transportability--Visual inspection of the Quick Disconnect shall be made to assure compliance to transportability requirements.

c. 3.1.2.6 Human Performance--Human performance requirements of the Quick Disconnect shall be verified by visual inspection for compliance.

d. 3.2 QD Definition--QD definition shall be verified by visual inspection to determine conformance with this specification.

e. 3.3.1 General Design Features--The requirements shall be verified by visual inspection of the Quick Disconnect for compliance with this specification.

f. 3.3.6 Corrosion of Metal Parts--Hardware shall be visually inspected to verify that protective coatings and finishes have been properly applied.

g. 3.3.8 Workmanship--Equipment shall be visually inspected to verify quality of workmanship.

h. 3.3.10 Identification and Marking--Visual inspection of the Quick Disconnect shall be made to verify conformance with this specification.

4.1.1.2 Analysis

The following requirements of Section 3 shall be verified by analysis as described:

a. 3.1.1 Functional Characteristics--The compliance to the performance requirements of 3.1.1.1 and 3.1.1.2 shall be verified by analysis of drawings and vendor data to assure that the Quick Disconnect is in conformance with this specification.

b. 3.1.2.4 Environmental--Verification of compliance to environmental requirements shall be accomplished by analysis of vendor specifications and test data on components and materials.

c. 3.1.2.5 Transportability--Compliance with transportability requirements shall be verified by analysis of drawings to determine total shipping weight and size.

d. 3.1.2.6 Human Performance--Requirements for human performance shall be verified by analysis of engineering drawings to verify compliance with applicable portions of MIL-STD-803A-1.

e. 3.1.2.7 Safety--The verification of compliance to safety requirements shall be determined by analysis of failure data, test results, equipment drawings and math models.

f. QD Definition--The requirements for QD definition shall be verified by analysis of engineering drawings to determine compatibility at the physical and functional interfaces.

g. 3.3.1 General Design Features--The requirements of this section shall be verified by analysis of the engineering drawings, operating procedures and vendor data.

h. 3.3.2 Selection of Specifications and Standards--Selection of specifications and standards shall be verified by analysis of engineering drawings.

i. 3.3.3 Materials, Parts and Processes--Vendor specifications on materials, parts, and processes shall be analyzed to assure compatibility with performance and environmental criteria for this equipment.

j. 3.3.4 Standard and Commercial Parts--Compliance to the requirements shall be verified by review of vendor drawings and specifications for materials, parts, and components.

k. 3.3.5 Moisture and Fungus Resistance--Vendor specifications and applicable engineering drawings shall be analyzed to verify compliance.

l. 3.3.6 Corrosion of Metal Parts--Requirement compliance shall be verified by analysis of vendor material and parts specifications and test data.

m. 3.3.7 Interchangeability and Replaceability--Conformance to the requirements shall be verified by analysis of vendor material and parts specifications, test data, and applicable engineering drawings.

n. 3.3.11 Storage--Vendor specifications on materials and parts comprising the Quick Disconnect shall be analyzed to assure compliance to the storage requirements called out in Section 3.

4.1.1.3 Test

The following requirements of Section 3 shall be verified by functionally testing as described:

a. 3.1.1 Functional Characteristics Requirements--

1. Requirements--The capability for rapid manual connect, "leak proof" operation, draining and purging all liquid fluorine from the Quick Disconnect, and rapid remote controlled separation shall be verified during development tests on a Quick Disconnect design.

2. Measurements required:

(a) Leakage

(b) Temperature

(c) Pressure

(d) Flow Rate

(e) Pressure Drop

(f) Latching Pressure

(g) Disconnect Pressure

(h) Fluorine Concentration

(i) Time

b. 3.1.1.1a Primary Seal Leakage

1. Requirements--Verify Quick Disconnect sealing capability.

2. Measurements required:

(a) Time

(b) Nitrogen leakage per unit time at 100 psia and at the following temperatures:

(1) 72°F.

(2) -320°F.

c. 3.1.1.1b Working Pressure

1. Requirements--Verify capability of operating at 100 psia maximum.

2. Measurements required--Pressure 0 to 300 ± 3 psia.

d. 3.1.1.1c Limit Loads

1. Requirements--Verify capability of operating at specified limit load conditions.

2. Measurements required:

(a) Load 0 - 82 pounds.

(b) Moment 0 - 1,000 in.-lbs.

e. 3.1.1.1d Flow

1. Requirements--Verify capability to operate at specified flow rates.

2. Measurements required:

(a) Flow Rate 0 - 100 gpm.

(b) Pressure 0 - 100 psia.

f. 3.1.1.1e Pressure Drop

1. Requirement--Verify compliance with pressure drop requirement.

2. Measurements required--Differential pressure across the Quick Disconnect with 100 gpm liquid fluorine flow (0 - 5 psi).

g. 3.1.1.2a Latching Pressure

1. Requirement--Verify capability of latching at 1,000 psia maximum.

2. Measurements required--Pressure 0 - 1,000 ± 10 psia.

h. 3.1.1.2b Disconnect Pressure

1. Requirement--Verify capability of disconnecting at 750 psia maximum.

i. 3.1.1.2c Seal Cavity Purge

1. Requirement--Verify capability of purging with gaseous helium at a minimum rate of 100 SCCS at 100 psia maximum.

2. Measurements required:

   (a) Flow Rate 0 - 200 SCCS.

   (b) Pressure 0 - 200 psia.

j. 3.1.1.2d Shroud Purge

1. Requirement--Verify capability of pressurizing the anti-icing shroud to 1 psig with gaseous nitrogen.

2. Measurements required--Pressure 0 - 5 ± 0.5 psig.

4.1.2 Preliminary Qualification Tests

Not applicable.

4.1.3 Formal Qualification Tests

Not applicable.

4.1.3.1 Inspections

Not applicable.

4.1.3.2 Analyses

Not applicable.

4.1.3.3 Demonstrations

Not applicable.

4.1.3.4 Tests

Not applicable.

4.1.4 Reliability Tests and Analysis

Not applicable.

4.1.5 Engineering Critical Component Qualification

Not applicable.

4.2 Flight Tests

Not applicable.

SECTION 5. PREPARATION FOR DELIVERY. Not applicable.

SECTION 6. NOTES. Not applicable.

SECTION 10. APPENDIX. Not applicable.

PRELIMINARY

CONTRACT END ITEM DETAIL SPECIFICATION

PART II. PRODUCT CONFIGURATION AND ACCEPTANCE TEST REQUIREMENTS

Coupling Assembly, Quick Disconnect. Liquid Fluorine

1. SCOPE

This specification establishes the requirements for complete identification and acceptance of all units of Coupling Assembly, Quick Disconnect, Liquid Fluorine, Contract End Item (CEI) hereinafter referred to as the Quick Disconnect (QD), to be formally accepted by the Air Force, subsequent to establishment of the product configuration baseline.

The product configuration baseline shall be established by First Article Configuration Inspection (FACI) of serial number 1. This unit and subsequent units, regardless of intended use, shall be accepted to the configuration defined by serial number 1 unless changes thereto have been formally approved as required by ANA bulletin No. 445.

2. APPLICABLE DOCUMENTS

The following documents, of exact issue shown, form a part of this specification to the extent specified herein. In the event of conflicts between documents referenced here and detail content of Sections 3, 4, 5 and 10, the detailed requirements of Sections 3, 4, 5 and 10 shall be considered a superseding requirement.

SPECIFICATIONS

Military

MIL-P-116E	Methods of Preservation
MIL-P-7936B	Parts and Equipment, Aeronautical, Preparation for Delivery
MIL-R-11468	Radiographic Inspection, Soundness Requirements for ARC and Gas Welds in Steel
MIL-W-8604	Process for Welding of Aluminum Alloys
MIL-W-8611A	Process for Welding, Metal Arc and Gas, Steels, and Corrosion and Heat

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-453	Radiographic Inspection

DRAWINGS (See Appendix XII).

1D00800	Coupling Assembly, Quick Disconnect, Liquid Fluorine
1D00801	Coupling Half, Quick Disconnect, Liquid Fluorine
1D00802	Coupling Half
1D00805	Flange
1D00806	Mount
1D00814	Piston, Latching
1D00815	Hook, Latching
1D00817	Pin, Latch Spring Guide
1D00819	Spring, Flat, Seal Loading
1D00820	Spacer
1D00821	Spacer
1D00824	Indicator, Seal Load
1D00838	Shroud, Anti-Icing
1D00844	Link, Separation Mechanism

3. REQUIREMENTS

This section specifies performance, product configuration and standards of manufacture, manufacturing processes, and production techniques which must be verified at time and place of delivery to establish the quantity of the Quick Disconnect as manufactured.

3.1 Performance

The Quick Disconnect shall include the following characteristics:

a. The primary Quick Disconnect seal, located between the vehicle and the AGE halves of the coupling, shall prevent nitrogen leakage in excess of 10^{-4} SCIM under the following conditions:

1. Temperature: 70° ± 10°F and -300 ± 2[illegible].
2. Pressure (Internal): 100 ± 10 psia.

b. The capability of withstanding a proof pressure of 150 ± 15 psia at 70° ± 10°F for 2 minutes. There shall be no evidence of structural failure or permanent distortion.

c. The Quick Disconnect shall be capable of rapid manual connection. This rapid manual connect operation shall result in the latching together of the vehicle and AGE halves of the Quick Disconnect, and the application of coupling-to-coupling sealing loads in a single operation. The following specific requirements are applicable:

1. No more than 1,000 psia of gaseous nitrogen shall be required to effect this latching operation.

2. The 1D00817 Pin, Latch Spring Guide shall not protrude above the surface of the 1D00815 Hook, Latching by more than 1/8 inch, when the Quick Disconnect is latched together.

3. The 1D00824 Indicator, Seal Load shall be tight (not moveable by hand), when the Quick Disconnect is latched together and sealed, and when all latching pneumatic pressure has been removed from the Quick Disconnect.

d. The Quick Disconnect shall be capable of remote rapid disconnection by one of the following:

1. Application of not more than 750 psia gaseous nitrogen to either of the two Release Cylinders.

2. Application of not more than 1,100 pounds to the 1D00844 Link, Separation Mechanism.

3.2 Production Configuration

3.2.1 Production Drawings

The configuration of this QD shall be in accordance with 1D00800, and drawings and engineering data assembled thereunder.

3.2.2 Government Furnished Property List

Not applicable.

3.2.3 Standards of Manufacture, Manufacturing Processes, and Production

The following documents of exact issue shown, form a part of the Quick Disconnect configuration baseline to the extent specified herein:

a. MIL-W-8611A Welding, Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys; Process for

b. MIL-STD-453 Change 1 — Inspection, Radiographic

c. MIL-R-11468 — Radiographic Inspection, Soundness Requirements for Arc and Gas Welds in Steel

4. QUALITY ASSURANCE

The manufacturing contractor of this CEI is responsible for accomplishment of each test/verification specified herein.

4.1 Product Performance and Configuration Requirements/Quality Verification Cross Reference Index

See Verification Cross Reference Index on Page II-11 of 16.

4.2 Test/Verification

4.2.1 Drawing Compliance

Verification that the QD, as fabricated and assembled, is in conformance with the drawings specified in paragraph 3.2.1 of Part II, shall be as follows:

a. Written certification from the manufacturer, based on material, inspection and production records, that the QD is in accordance with 1D00800, and drawings and engineering data thereunder.

b. Visual and/or physical inspection of each of the 1D00801 Coupling Half, Quick Disconnect, Liquid Fluorine--Vehicle; the 1D00802 Coupling Half, Quick Disconnect, Liquid Fluorine--AGE; and the 1D00838 Shroud, Anti-Icing shall be performed to assure compliance with the following:

1. All visible components and parts are assembled in conformance with the configuration specified by the noted drawings. This inspection shall be performed in such a manner so as to assure that the items being inspected are maintained in a fluorine clean condition as required by the drawings.

2. The gap between the 1D00819 Spring, Flat, Seal Loading and the 1D00824 Indicator, Seal Load shall be 0.001 ± 0.001 with the 1D00814 Piston, Latching in the fully retracted position with no axial play between any of the 1D00819 Springs and their 1D00820 and 1D00821 Spacers.

   NOTE: The 1D00802 Coupling Half is a separate subassembly at this acceptance point; it is not joined with the 1D00801 Coupling Half or with the 1D00838 Shroud.

4.2.2 Standards of Manufacture, Manufacturing Processes, and Production

Verification that the QD, as fabricated and assembled, has been manufactured and processed in conformance with the requirements of paragraph 3.2.3 of Part II, shall be by written certification from the manufacturer, based on manufacturing and process records.

4.2.3 Performance

The following requirements of paragraph 3.1 of Part II shall be verified by functionally testing as described:

a. Primary Seal Leakage (3.1a).

1. Requirements--Verify Quick Disconnect sealing capability.

2. Test Configuration--The 1D00800 Coupling Assembly shall be connected to permit filling with liquid nitrogen, pressurization to 100 ± 10 psia with gaseous nitrogen, and determination of primary seal leak rate.

3. Measurements:

(a) Time (seconds).

(b) Nitrogen leakage (less than 10^{-4} SCIM) per unit time at 100 ± 10 psia and at the following temperatures:

(1) 70° ± 10°F.

(2) -300° ± 20°F.

b. Proof Pressure (3.1b).

1. Requirements--Verify capability of Quick Disconnect to withstand a proof pressure of 150 ± 15 psia at 70 ± 10°F for 2 minutes. There shall be no evidence of structural failure or permanent distortion.

2. Test Configuration--The 1D00800 Coupling Assembly shall be connected to permit pressurization to 150 ± 15 psia with gaseous nitrogen. The coupling assembly shall be so mounted or held during test so as to impose no external loads or restraints.

3 Measurements:

(a) Time: 0 - 2 minutes (± 1 second).

(b) Pressure: 0 - 150 ± 15 psia.

(c) Temperature: 70° ± 10°F.

c. Rapid Manual Connection (3.1c).

1. Requirements--Verify that the 1D00802 Coupling Half, Quick Disconnect, Liquid Fluorine--AGE can be rapid-manually connected to the 1D00801 Coupling Half, Quick Disconnect, Liquid Fluorine--Vehicle, in accordance with the requirements specified in paragraph 3.1c of Part II.

2. Test Configuration:

(a) The 1D00801 Coupling Half shall be mounted in a fixed position with its centerline contained in a horizontal plane and with its connecting surface accessible for engagement of the 1D00802 Coupling Half.

(b) Manually engage the 1D00802 Coupling Half with the 1D00801 Coupling Half. In this position all six 1D00817 Pins, Latch Spring Guide shall be protruding above the surface of the six 1D00815 Hooks, Latching by a minimum of 3/8 inches.

(c) Apply gaseous nitrogen pressure at 1,000 psia maximum to the 1D00814 Pistons, Latching. All six 1D00815 Hooks should move towards the 1D00801 Coupling Half and the six 1D00817 Pins should not protrude above the surface of the 1D00815 Hooks by more than 1/8 inches.

(d) Release the pressure to the 1D00814 Pistons, and observe the 1D00801 and the 1D00802 Coupling Halves are firmly latched together by checking the following:

(1) That all six 1D00817 Pins are not protruding above the surface of the 1D00815 Hooks by more than 1/8 inches.

(2) That all six 1D00824 Indicators, Seal Load are tight (not moveable by hand).

3. Measurements:

(a) Pressure: 0 - 750 psia.

(b) Distance: 0 - 1/2 ± 1/16 inch.

d. Disconnect (3. 1d).

1. Requirements--Verify that 1D00802 Coupling Half can be remotely and rapidly disconnected from the 1D00801 Coupling Half, in accordance with the requirements specified in paragraph 3. 1d of Part II.

2. Test Configuration:

(a) Assemble the 1D00800 Coupling Assembly, Quick Disconnect, Liquid Fluorine with its centerline in a horizontal plane, with the assembly supported by attachment at the vehicle structural attach point of the 1D00801 Coupling Half, and with a regulated gaseous nitrogen pressure source connected to one of the release cylinders.

(b) Apply pressure to the release cylinder in an amount not to exceed 750 psia. Note pressure at time of coupling release, and restrict travel of the 1D00802 Coupling Half at time of release to prevent damage to personnel, test equipment and to the Quick Disconnect.

3. Measurements--Release Pressure

0 - 750 psia maximum.

VERIFICATION CROSS REFERENCE INDEX

METHOD LEGEND

N. A. --NOT APPLICABLE
1--INSPECTION
2--REVIEW OF ANALYTICAL DATA
3--DEMONSTRATION
4--TEST

LEGEND

A--ENGINEERING DESIGN TEST
B--R&D ACCEPTANCE TESTS
b_1--QUALIFICATION TESTS
b_2--RELIABILITY TESTS & ANALYSIS
b_3--ENGINEERING CRITICAL COMPONENT QUALIFICATION
C--SYSTEM TEST

Section 3 Requirement Reference	Verification Method (s)					Test Category					Section 4 Verification Requirement
	NA	1	2	3	4	A	b_1	b_2	b_3	C	
3.1a					X		X				4.2.3a
3.1b					X		X				4.2.3b
3.1c					X		X				4.2.3c
3.1d					X		X				4.2.3d
3.2.1		X									4.2.1
3.2.3		X									4.2.2

5. PREPARATION FOR DELIVERY

The QD shall be prepared for delivery in accordance with the requirements specified herein.

5.1 Methods of Preservation and Packaging

5.1.1 Cleaning

Prior to final assembly of the QD, each part shall be cleaned in accordance with Appendix III-6 of NASA CR-72064. Precautions shall be taken to avoid contamination during subsequent operations (assembly, checkout, preservation, and packaging).

5.1.2 Drying

Immediately after cleaning, items of the QD shall be thoroughly dried in accordance with Appendix III-6 of NASA CR-72064.

5.1.3 Preservatives

Not applicable.

5.1.4 Packaging

The QD shall be packaged in accordance with Method III- Packaged for Mechanical and Physical Physical Protection Only, as specified in paragraph 3.5.7 of MIL-P-116E.

5.1.5 Physical Protection

The QD shall be physically protected by cushioning, blocking, bracing or bolting as applicable to prevent free movement within rigid containers and physical damage due to transmission of shock and vibration.

5.1.5.1 Cushioning

Cushioning materials (or devices) shall be used in the accomplishment of the method of preservation to protect the contents and the preservation and packaging components from physical damage. The cushioning medium shall be placed as close to the item(s) as practicable to insure against free movement in rigid containers.

5.1.5.2 Blocking and Bracing

Unless, otherwise secured, item(s) which do not completely fill the container shall be blocked and braced to prevent movement inside the container. Blocking or bracing shall be applied against areas of the item(s) that are of sufficient strength and rigidity to resist damage. Distribution of supports to several points or to a large area of the item shall be provided. Ends of wood blocks or braces shall not be fastened to a wood container by end-grain nailing, toe nailing, or similar methods; they shall be fastened to sturdy parts of areas of the container, or held in grooves formed by parallel cleats or securely socketed.

5.1.5.3 Bolting

Item(s) such as machines or subassemblies having bolt holes in part of the item which is sturdy enough to resist breakage when rough-handled shall, if practical, be bolted to one face of the container. In instances involving nonprecision bolt holes, the diameter of the bolt shall be nearest standard size consistent with the diameter of the hole. In instances involving precision bolt holes, precautions shall be taken to insure precision fitting bolts of proper characteristics to prevent marring or elongation; lag screws or lag bolts shall not be used in either instance. Holes bored through containers or mounting bases shall be the same size as the diameter of the bolt used. When container bases are provided with skids, the bolts shall extend through the skids whenever practical, and the bolts countersunk in the outer surface of the skid. Standard cut washers shall be used under nuts to contact with wood. To insure that the nuts will not come loose in transit, they must be positively secured by upsetting or nicking the threads of the bolt beyond the nut; applying asphaltum, paint or lacquer on the threads; by use of lock nuts; or by use of cotter pins with nuts. Bolts and nuts without corrosion-resistant finish shall not be used.

5.2 Levels of Preservation and Packaging

5.2.1 Requirements

The QD shall be preserved and packaged to the extent that, as an assembled unit, it meets the requirements of Level C as specified herein.

5.2.2 Level A

Not applicable.

5.2.3 Level B

Not applicable.

5.2.4 Level C

Preservation and packaging shall be such as to afford minimum degree of preservation during the period of time required for shipment from the contractor's plant to the first destination. It shall be the responsibility of the contractor to afford a level of protection adequate to prevent damage during this shipment. This protection shall conform to the contractor's commercial practices, shall employ the methods outlined in paragraph 5.1 of Part II of the CEI Specifications and conform to the following:

a. Preservatives are not permitted on this QD or on any of its parts.

b. The QD shall be packaged in the assembled condition as defined by 1D00800.

c. The QD shall be bolted to the container or appropriate bracing at the 11.125 diameter bolt hole pattern of the 1D00806 Mount, and at the bolt hole pattern of the 1D00805 Flange of the 1D00802 Coupling Half, Quick Disconnect, Liquid Fluorine--AGE.

5.3 Levels of Packaging

5.3.1 Requirements

The QD shall be packaged and shipped in a single container (one QD per shipping package), and shall be in accordance with Level C as defined in MIL-P-7936B, and specified herein.

5.3.2 Level A

Not applicable.

5.3.3 Level B

Not applicable.

5.3.4 Level C

Exterior containers of the type acceptable to common carriers shall be used. The unit container shall be the same as the shipping container and shall be one that assures safe transportation at the lowest rate to the point of delivery, and shall meet as a minimum, the requirements of the following rules and regulations, as applicable to the mode of transportation selected:

a. Postal Regulations.

b. Interstate Commerce Commission Regulations.

c. Civil Air Regulations.

d. Consolidated Freight Classification Rules.

e. Trucker's Association Rules.

f. Other applicable carrier rules.

5.4 Packaging Design Requirements

Not applicable.

5.5 Special Handling, Loading Techniques, and Devices

Not applicable.

5.6 Design Drawings

Not applicable.

5.7 Method of Detailing Requirements

Not applicable.

5.8 Marking

The combined unit/shipping container shall be marked in accordance with the provisions of MIL-STD-129. No special markings are required.

SECTION 6. NOTES. Not applicable.

SECTION 10. APPENDIX. Not applicable.

APPENDIX XII

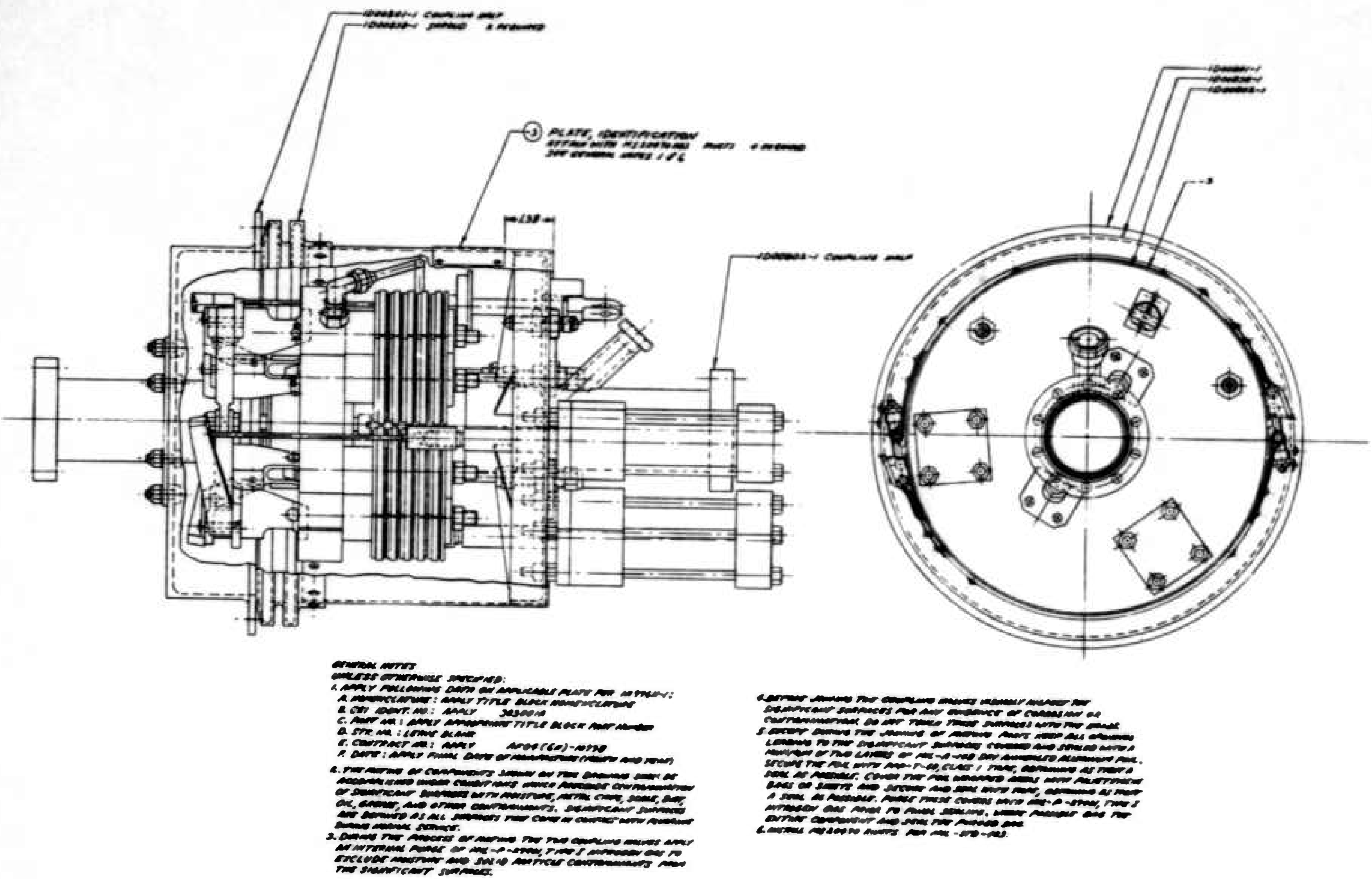


Figure XII-1. Coupling, Quick Disconnect, Liquid Fluorine (1D00800)

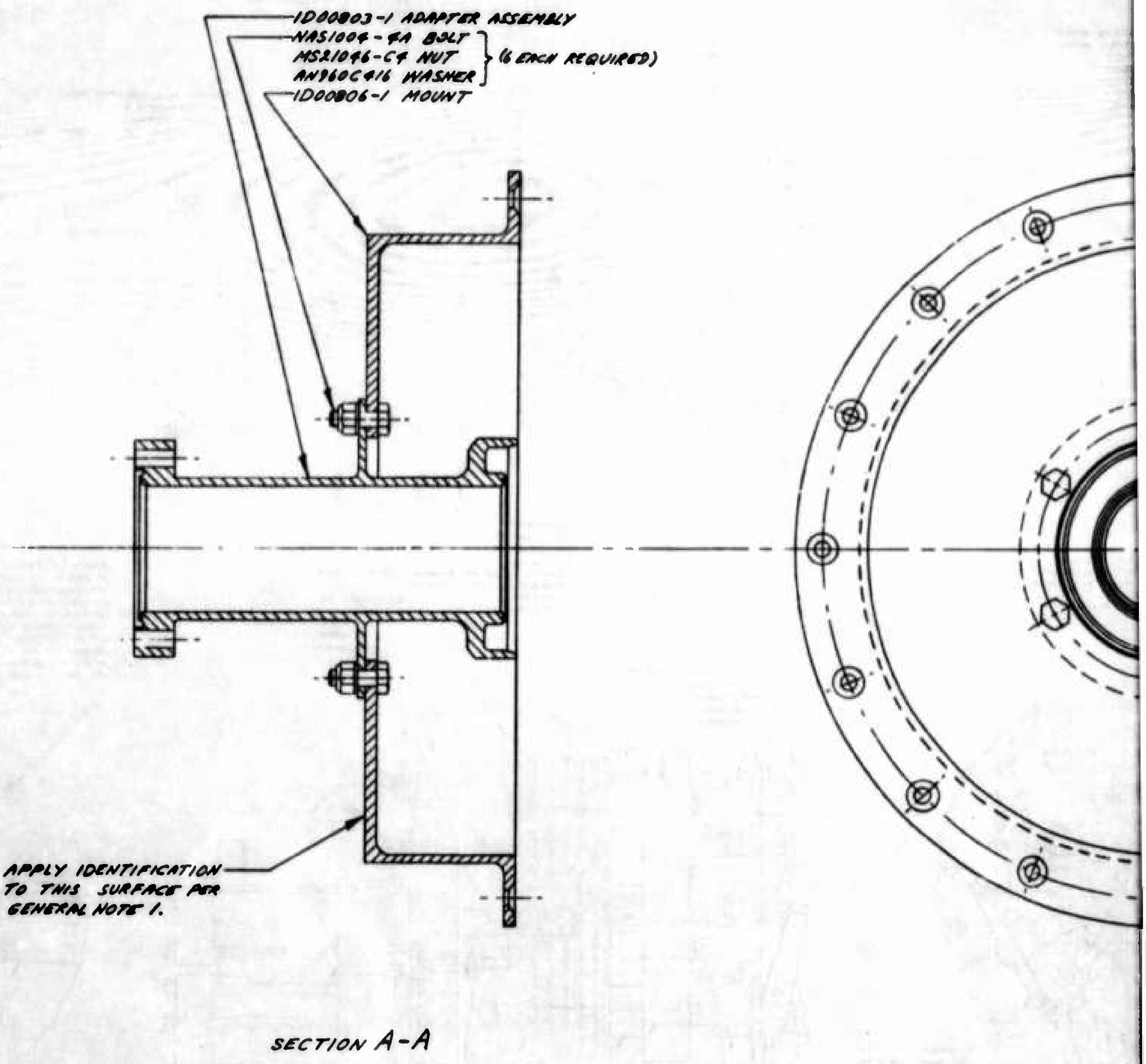
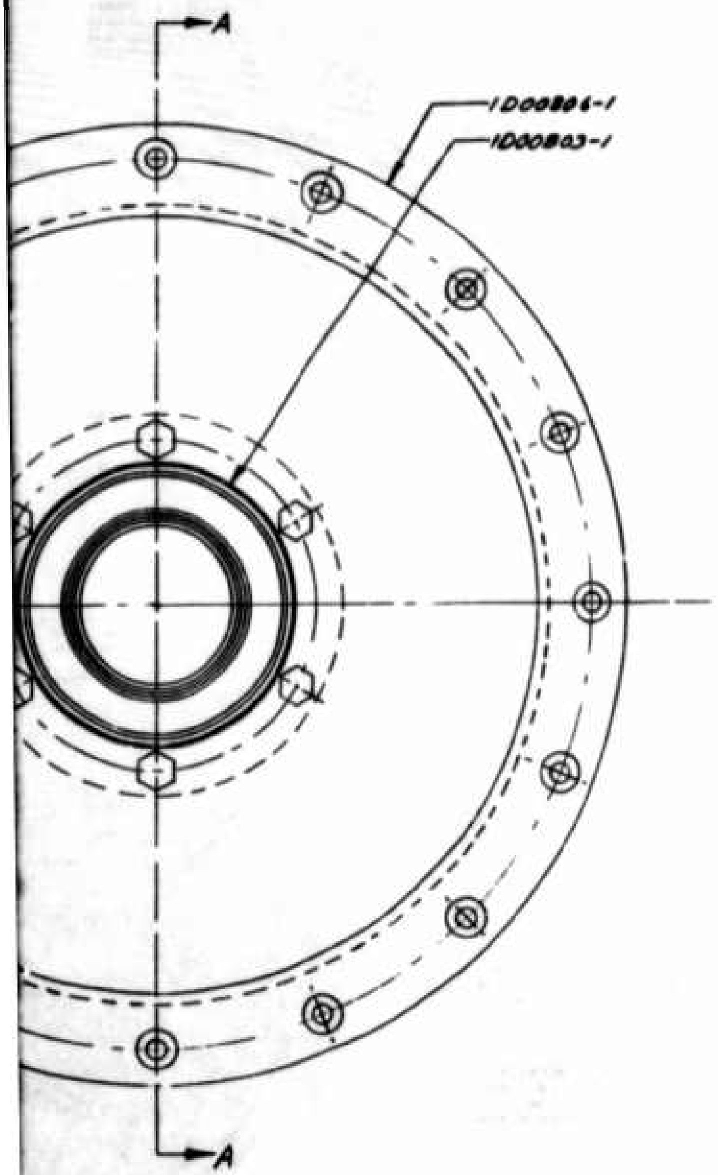


Figure XII-2. Coupling Half, Quic

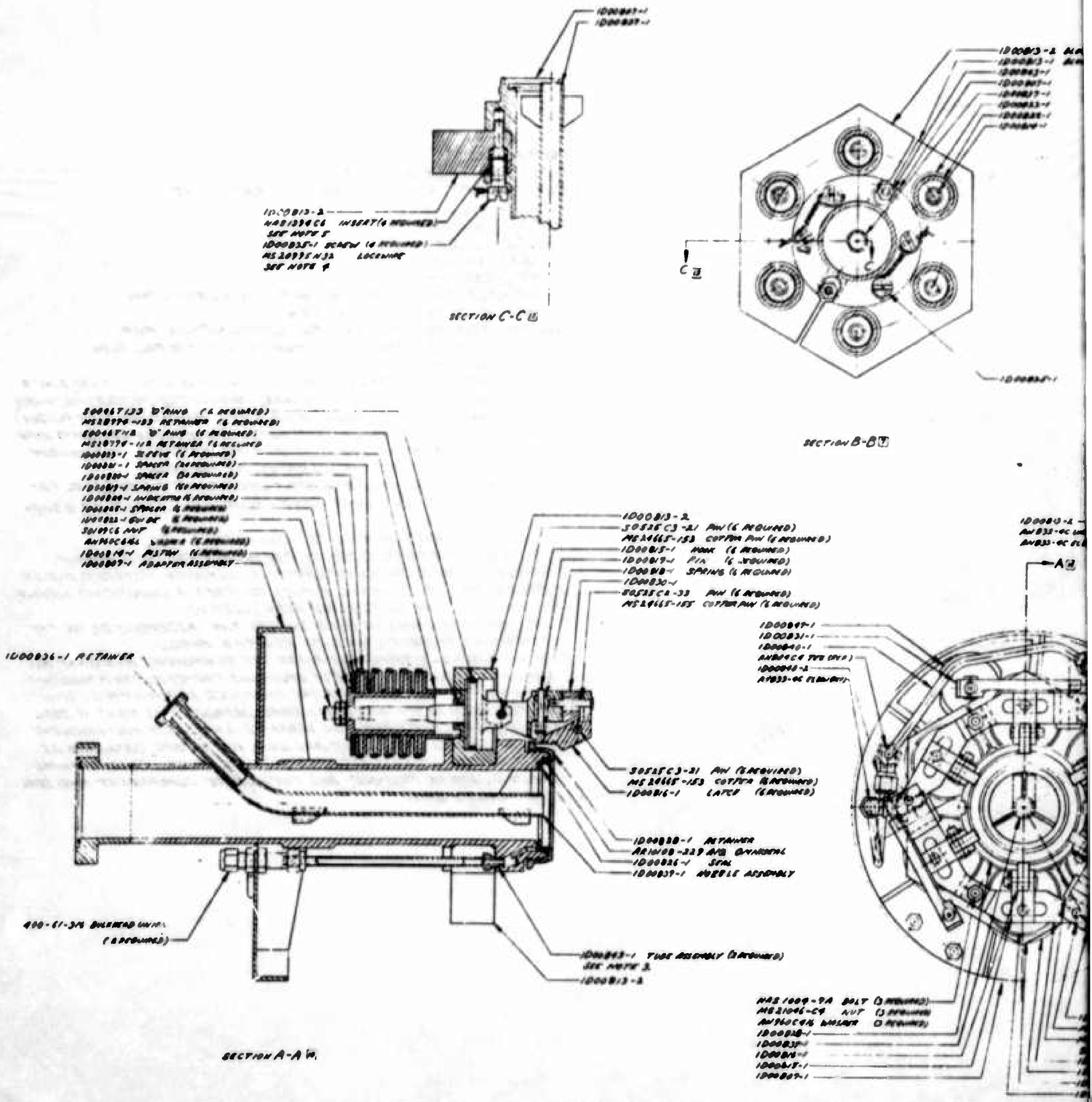


GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ELECTRO-ETCH THE FOLLOWING IDENTIFICATION IN AREA NOTED:
   COUPLING HALF
   P/N 1D00801-1
   PART OF CEI
   NO. 303001A
2. ASSEMBLE THE COUPLING HALF IN A CLEAN ROOM TO MINIMIZE CONTAMINATION.
3. BEFORE ASSEMBLY PROCESS ALL COMPONENTS FOR LIQUID FLUORINE SERVICE PER 1P00071 WITH THE FOLLOWING ADDED REQUIREMENTS:
   A. CLEAN METAL PARTS BY DEGREASING OR FLUSHING WITH O-T-634, TYPE 2 TRICHLOROETHYLENE (0.020 G/L MAX. NONVOLATILE RESIDUE), MIL-D-6998, GRADE A METHYLENE CHLORIDE (0.020 G/L MAX. NONVOLATILE RESIDUE) OR MSFC-SPEC-237 TRICHLOROTRIFLUOROETHANE. OVEN DRY PARTS WITH SOLVENT ENTRAPMENT AREAS AT 240 TO 260°F FOR 1 HOUR MINIMUM.
   B. TEFLON PARTS ARE TO BE CLEANED AS FOLLOWS:
      1. WASH WITH A SOLUTION OF WATER CONTAINING 0.1 TO 0.5 % (BY VOLUME) OF NON-IONIC DETERGENT (PLURONIC L-62LF OR EQUIVALENT).
      2. RINSE THOROUGHLY WITH DISTILLED WATER.
      3. OVEN DRY AT A TEMPERATURE OF 240 TO 260°F FOR 1 HOUR MINIMUM.
   C. HANDLE CLEAN SIGNIFICANT SURFACES ONLY WITH POLYETHYLENE OR RUBBER GLOVES. IF LINT-FREE WIPERS CONTACT A SIGNIFICANT SURFACE, THE SURFACE MUST BE FLUSHED WITH SOLVENT.
   D. NO LUBRICANTS SHALL BE USED DURING THE ASSEMBLY OF, OR THE ATTACHMENT OF TEST LINES TO, FLUORINE PARTS.
   E. AFTER ASSEMBLY, THOROUGHLY PURGE THE COMPONENT AND WRAP ALL SIGNIFICANT SURFACES AND/OR OPENINGS THERETO WITH A MINIMUM OF TWO LAYERS OF MIL-A-148 DRY ANNEALED ALUMINUM FOIL. SECURE THE FOIL WITH PPP-T-60, CLASS 1 TAPE, OBTAINING AS TIGHT A SEAL AS POSSIBLE. COVER THE FOIL WRAPPED AREAS WITH POLYETHYLENE BAGS OR SHEETS AND SECURE AND SEAL WITH TAPE, OBTAINING AS TIGHT A SEAL AS POSSIBLE. PURGE THESE COVERS PRIOR TO FINAL SEALING. WHERE POSSIBLE, BAG THE ENTIRE COMPONENT AND SEAL THE PURGED BAG.

alf, Quick Disconnect, Liquid Fluorine – Vehicle (1D00801)

2


SECTION C-C
SECTION B-B
SECTION A-A
1D00836-1 RETAINER
1D00813-2

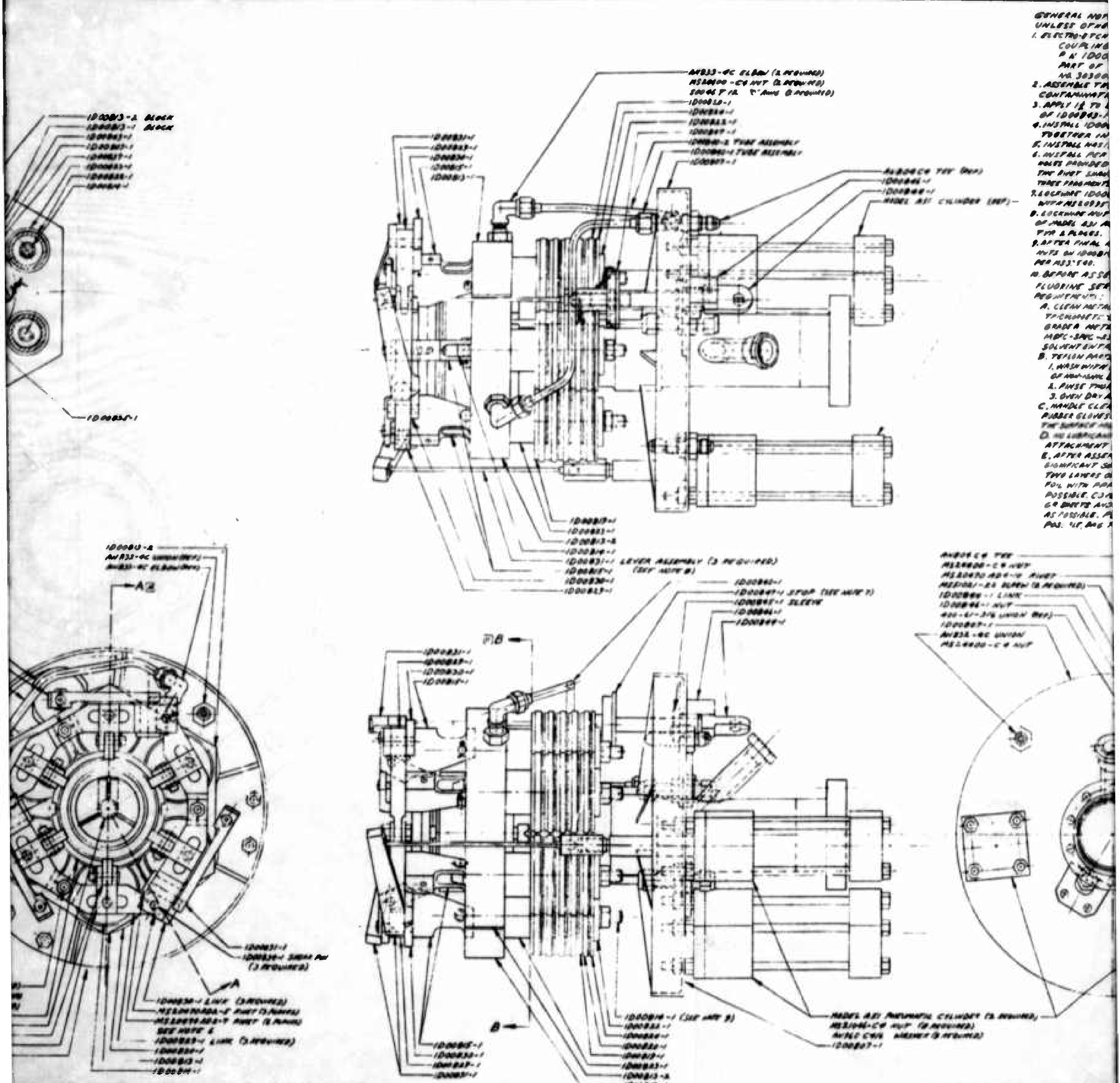
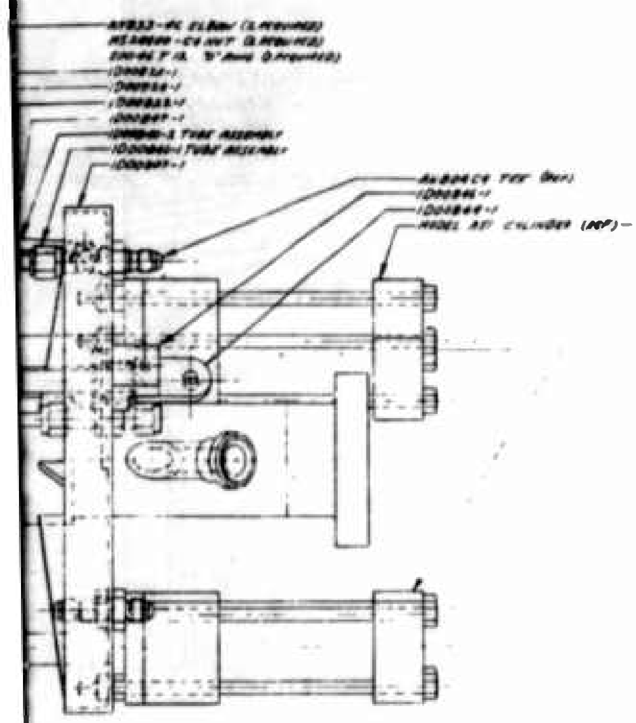


Figure XII-3. Coupling

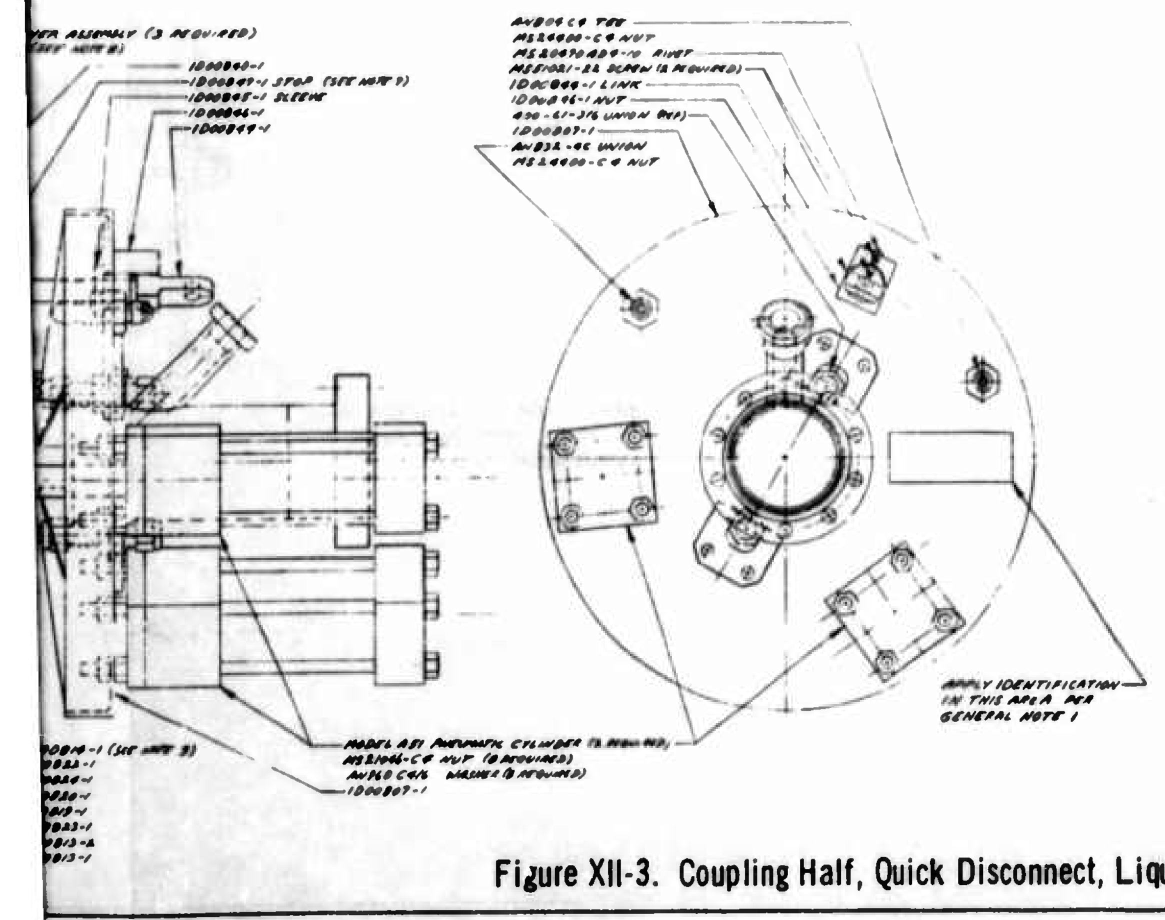
2



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ELECTRO-ETCH THE FOLLOWING IDENTIFICATION IN AREA NOTED.
   COUPLING HALF
   P N 1D00802-1
   PART OF CEI
   NO. 3030010A
2. ASSEMBLE THE COUPLING HALF IN A CLEAN ROOM TO MINIMIZE CONTAMINATION.
3. APPLY 1½ TO 2 TURNS MIL-T-27730 TAPE TO MALE THREADS OF 1D00843-1 TUBE ASSEMBLY EXCLUDING ... THREADS.
4. INSTALL 1D00835-1 SCREWS FINGER TIGHT AND LOCKWIRE TOGETHER IN PAIRS WITH MS20995N32 PER MS33540.
5. INSTALL NAS1394C06 INSERTS PER METHOD 80812.
6. INSTALL PER MIL-STD-403 THE NOTED MS20470 RIVETS IN THE HOLES PROVIDED IN THE 1D00829-1 AND 1D00830-1 LINKS UPSETTING THE RIVET SHANKS AGAINST THE 1D00834-1 PIN SO THAT THE THREE FRAGMENTS ARE RETAINED WHEN THE PIN IS RUPTURED.
7. LOCKWIRE 1D00847-1 STOP TO NUT ON 1D00831-1 LEVER ASSEMBLY WITH MS20995N32 LOCKWIRE PER MS33540.
8. LOCKWIRE NUT ON 1D00831-1 LEVER ASSEMBLY TO PISTON ROD OF MODEL A51 ACTUATOR WITH MS20995N32 PER MS33540, TYP 2 PLACES.
9. AFTER FINAL ADJUSTMENT OF SEAL LOADING SPRING FORCE, LOCKWIRE NUTS ON 1D00814-1 PISTONS TOGETHER IN PAIRS WITH MS20995N32 PER MS33540.
10. BEFORE ASSEMBLY PROCESS ALL COMPONENTS FOR LIQUID FLUORINE SERVICE PER 1P00091 WITH THE FOLLOWING ADDED REQUIREMENTS:
    A. CLEAN METAL PARTS BY DEGREASING OR FLUSHING WITH O-T-634 TYPE 2 TRICHLOROETHYLENE (0.020 G/L MAX. NONVOLATILE RESIDUE), MIL-C-81302, GRADE A METHYLENE CHLORIDE (0.020 G/L NONVOLATILE RESIDUE), OR MSFC-SPEC-237 TRICHLOROTRIFLUOROETHANE. OVEN DRY PARTS WITH SOLVENT ENTRAPMENT AREAS AT 240 TO 260°F FOR 1 HOUR MINIMUM.
    B. TEFLON PARTS TO BE CLEANED AS FOLLOWS:
       1. WASH WITH A SOLUTION OF WATER CONTAINING 0.1 TO 0.5% (BY VOLUME) OF NON-IONIC DETERGENT (PLURONIC L-61 OR EQUIVALENT).
       2. RINSE THOROUGHLY WITH DISTILLED WATER.
       3. OVEN DRY AT A TEMPERATURE OF 240 TO 260°F FOR 1 HOUR MINIMUM.
    C. HANDLE CLEAN SIGNIFICANT SURFACES ONLY WITH POLYETHYLENE OR RUBBER GLOVES. IF LINT-FREE WIPERS CONTACT A SIGNIFICANT SURFACE, THE SURFACE MUST BE FLUSHED WITH SOLVENT.
    D. NO LUBRICANTS SHALL BE USED DURING THE ASSEMBLY OF OR THE ATTACHMENT OF TEST LINES TO, FLUORINE PARTS.
    E. AFTER ASSEMBLY, THOROUGHLY PURGE THE COMPONENT AND WRAP ALL SIGNIFICANT SURFACES AND/OR OPENINGS THERETO WITH A MINIMUM OF TWO LAYERS OF MIL-A-148 DRY ANNEALED ALUMINUM FOIL. SECURE THE FOIL WITH PPP-T-60, CLASS 1 TAPE, OBTAINING AS TIGHT A SEAL AS POSSIBLE. COVER THE FOIL WRAPPED AREAS WITH POLYETHYLENE BAGS OR SHEETS AND SECURE AND SEAL WITH TAPE, OBTAINING AS TIGHT A SEAL AS POSSIBLE. PURGE THESE COVERS PRIOR TO FINAL SEALING. WHERE POSSIBLE, BAG THE ENTIRE COMPONENT AND SEAL THE PURGED BAG.

REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION
1	1D00807-1	ADAPTER ASSEMBLY
1	1D00813-1	BLOCK
1	1D00813-2	BLOCK
6	1D00814-1	PISTON
6	1D00815-1	HOOK
6	1D00816-1	LATCH
6	1D00817-1	PIN
6	1D00818-1	SPRING
60	1D00819-1	SPRING
	1D00820-1	SPACER
30	1D00821-1	SPACER
20	1D00822-1	GUIDE
6	1D00823-1	SLEEVE
6	1D00824-1	INDICATOR
6	1D00825-1	SPACER
1	1D00826-1	SEAL
1	1D00828-1	RETAINER
3	1D00829-1	LINK
3	1D00830-1	LINK
3	1D00831-1	LEVER ASSEMBLY
3	1D00834-1	PIN
4	1D00835-1	SCREW
1	1D00836-1	RETAINER
1	1D00837-1	NOZZLE ASSEMBLY
1	1D00840-1	TUBE ASSEMBLY
1	1D00840-2	TUBE ASSEMBLY
2	1D00843-1	TUBE ASSEMBLY
3	1D00844-1	LINK



REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION
1	1D00845-1	SLEEVE
1	1D00846-1	NUT
1	1D00847-1	STOP
2	MODEL A51 1 1/2 IN. BORE 2 IN. STROKE NON-CUSHIONED STANDARD ROD	MILLER DIVISION FLICK-REEDY CORP. BENSENVILLE ILL.
1	AR10100-220A10 OMNI SEAL	AEROQUIP CORP AIRCRAFT DIVISION BURBANK, CALIF.
1	AN804C4	TEE
1	AN832-4C	UNION
2	AN833-4C	ELBOW
4	MS24400-C4	NUT
2	400-61-316	SWAGELOK UNION
2	S6844F12	O-RING
6	S6844F132	O-RING
6	S6844F130	O-RING
6	MS28774-132	RETAINER
6	MS28774-130	RETAINER
2	MS51021-22	SET SCREW
3	NAS1306-7A	BOLT
11	MS21046-C4	NUT
11	AN960C416	WASHER
6	S0001C6	NUT
6	AN960C616L	WASHER
4	NAS1394C06	INSERT
12	S6825C3-21	PIN
6	S6825C2-33	PIN
12	MS24665-153	COTTER PIN
6	MS24665-155	COTTER PIN
4	MS20470AD4-10	RIVET
3	MS20470AD2-6	RIVET

Figure XII-3. Coupling Half, Quick Disconnect, Liquid Fluorine – AGE (1D00802)

3

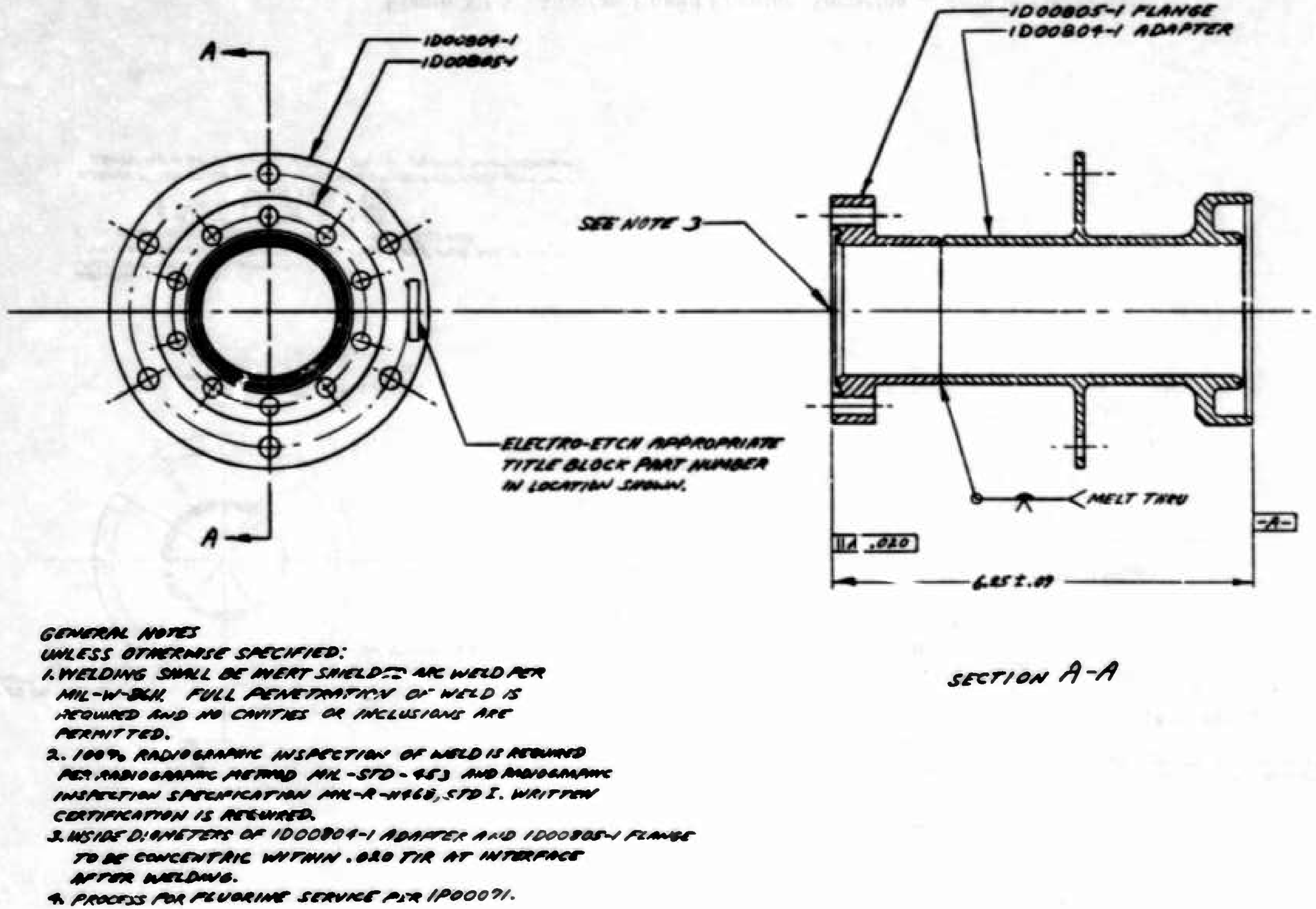
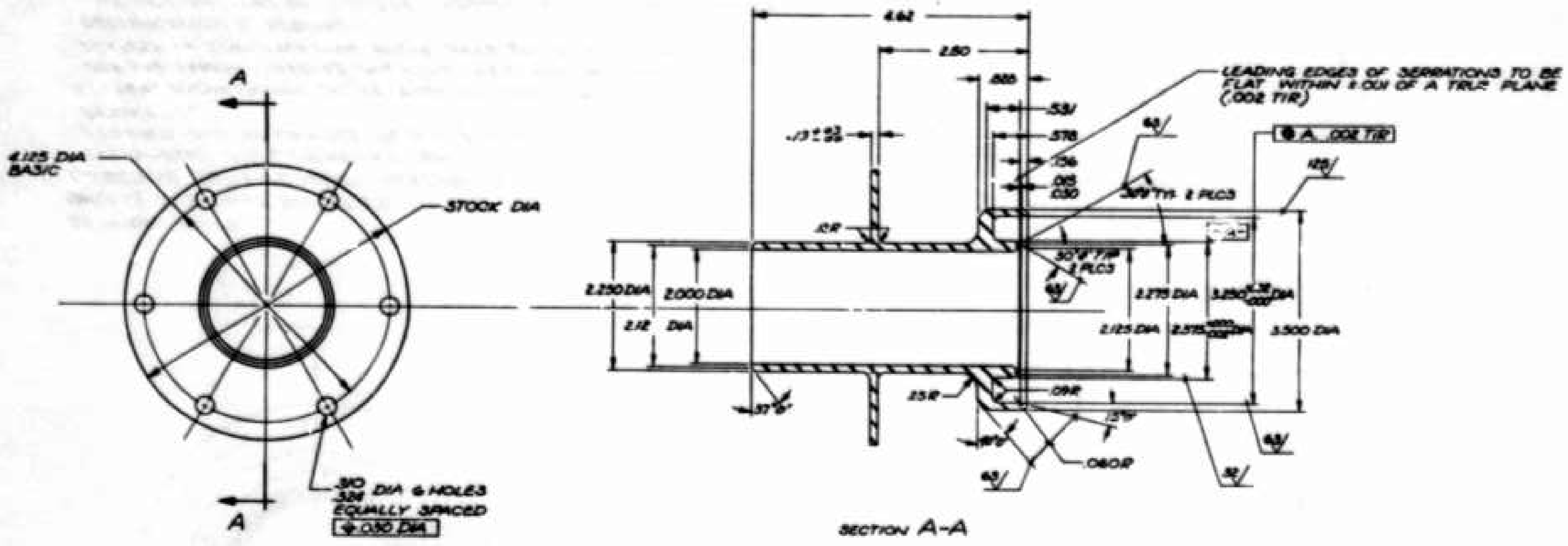


Figure XII-4. Adapter, Liquid Fluorine, Servicing – Vehicle (1D00803)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL MACHINED SURFACE ROUGHNESS 250/ PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE AS FOLLOWS:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ±0°30'
3. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.

Figure XII-5. Adapter, Liquid Fluorine, Servicing – Vehicle (1D00804)

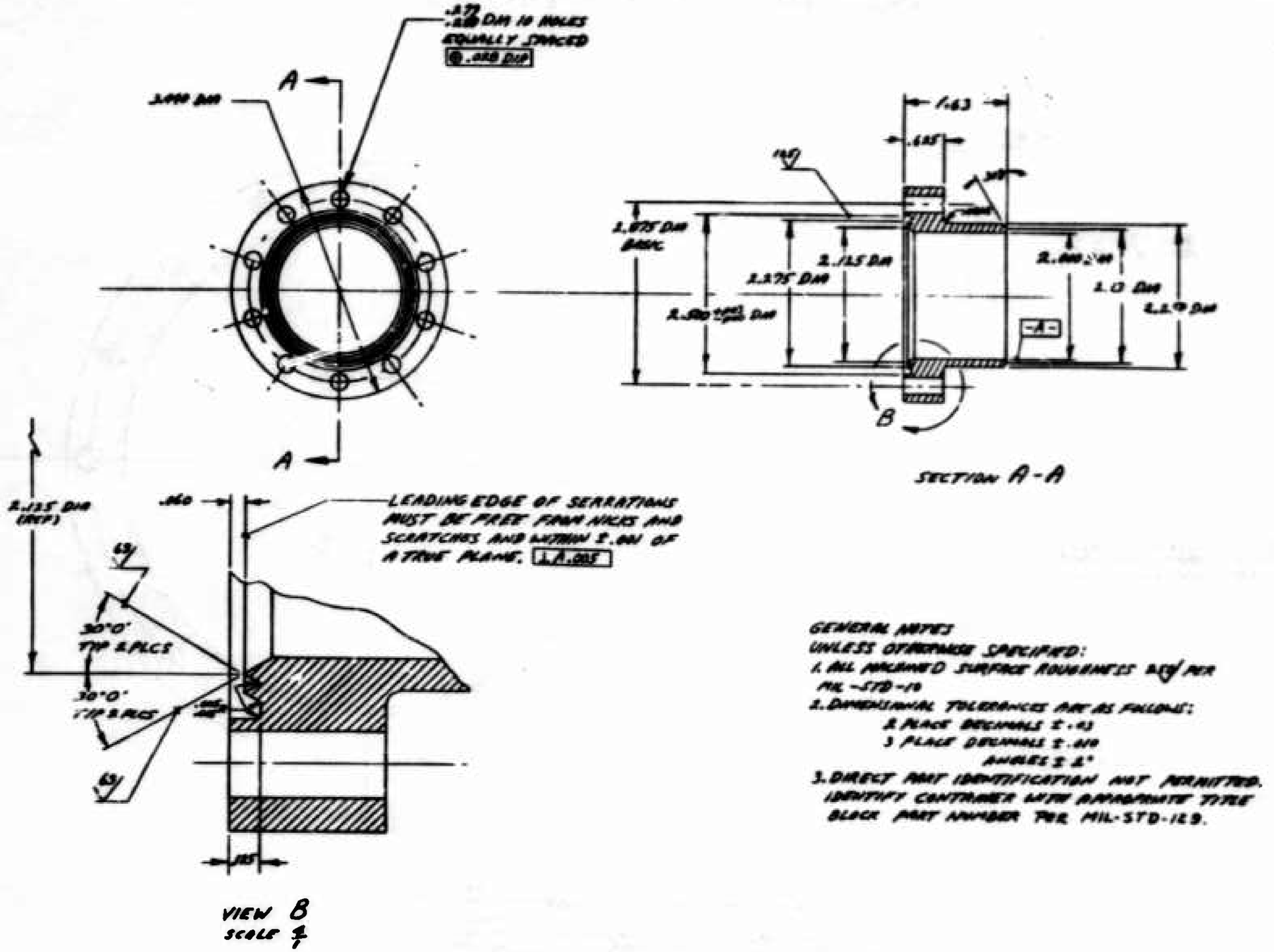


Figure XII-6. Flange, Pipe (1D00805)

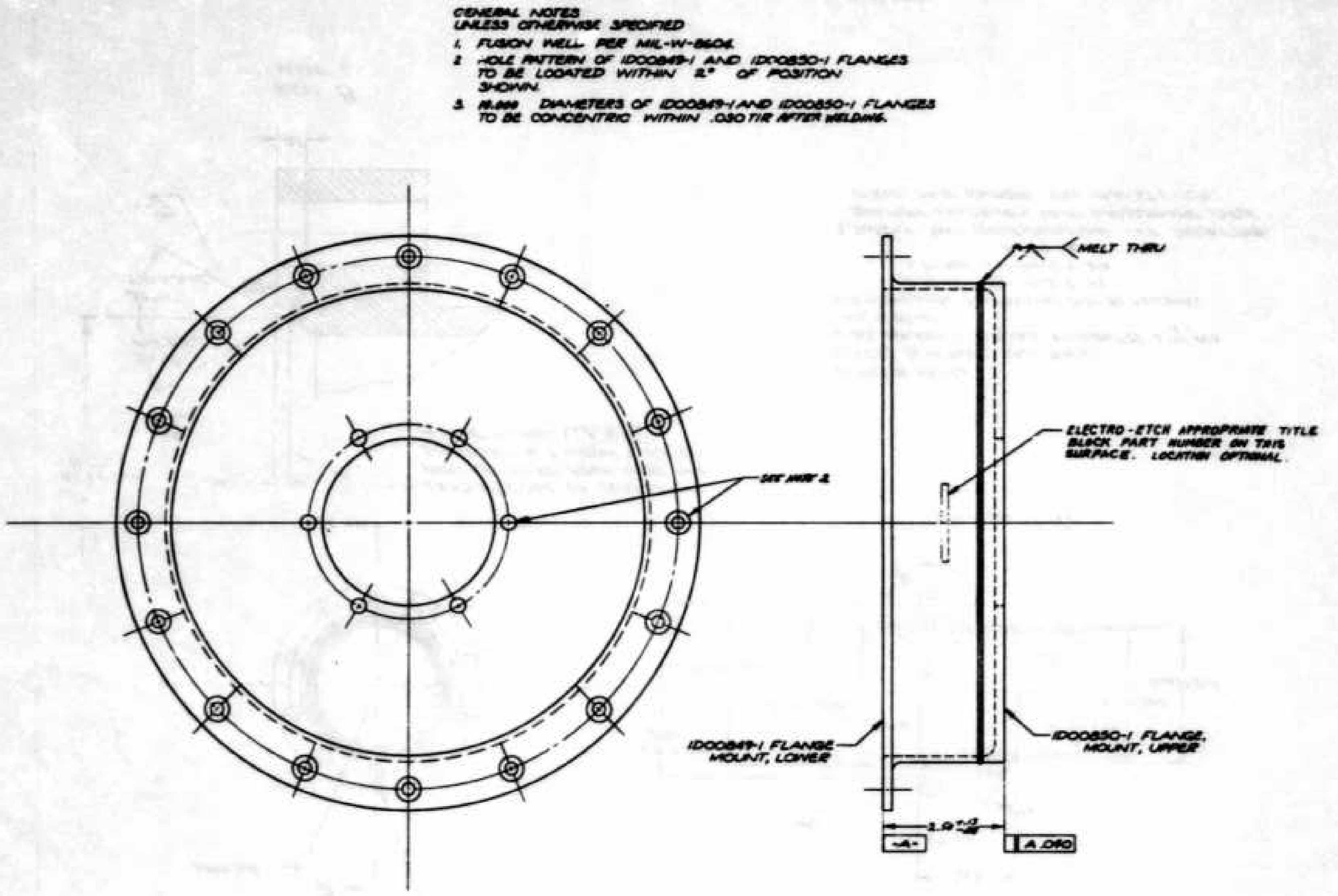
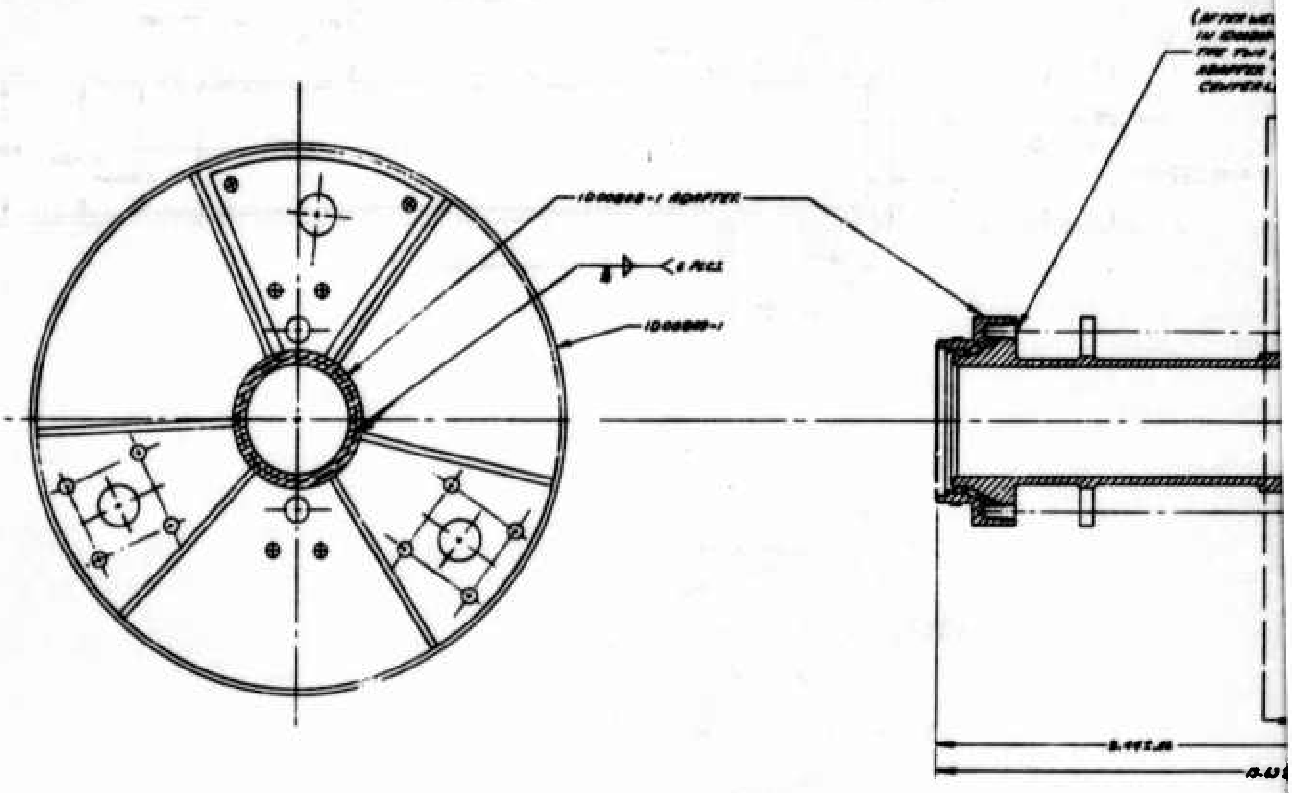


Figure XII-7. Mount, Coupling Half (1D00806)



SECTION C-C

SECTION

Fi

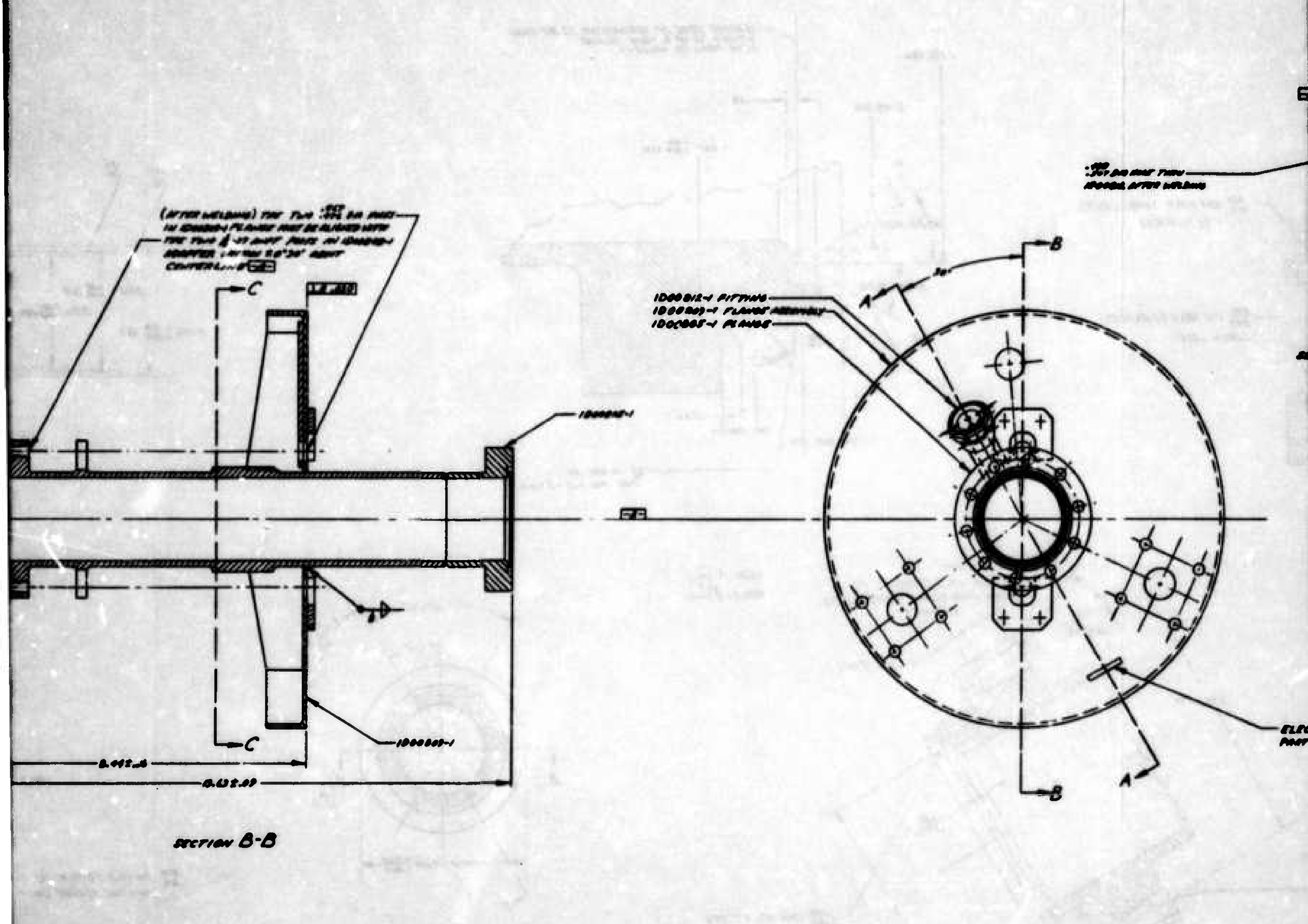
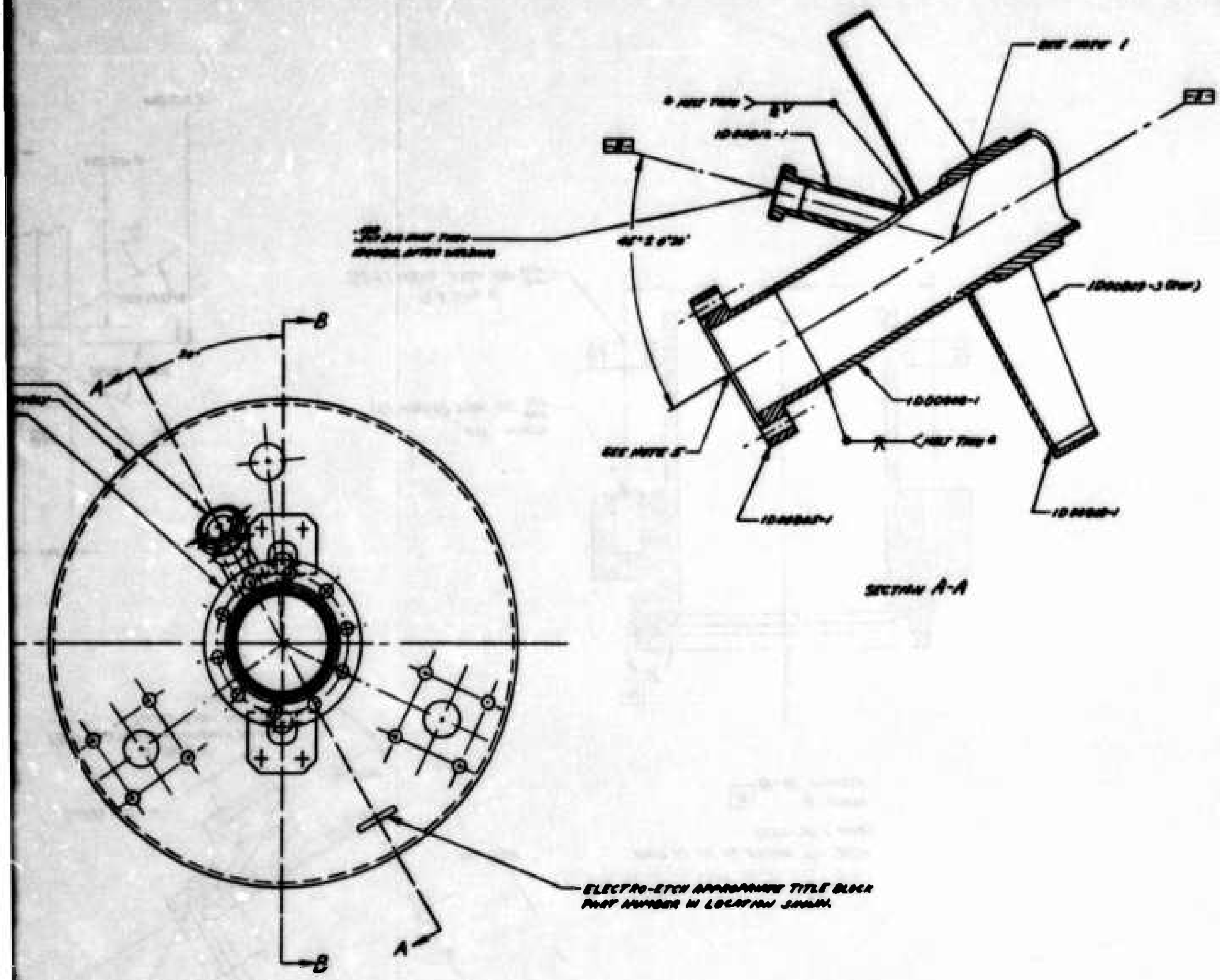


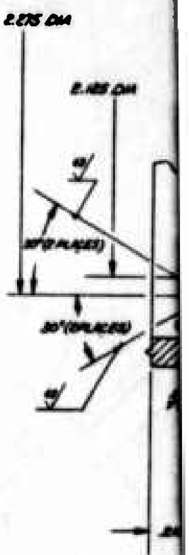
Figure XII-8. Adapter Assembly, Liquid Fluorine, Servicing – AGE (1D00807)

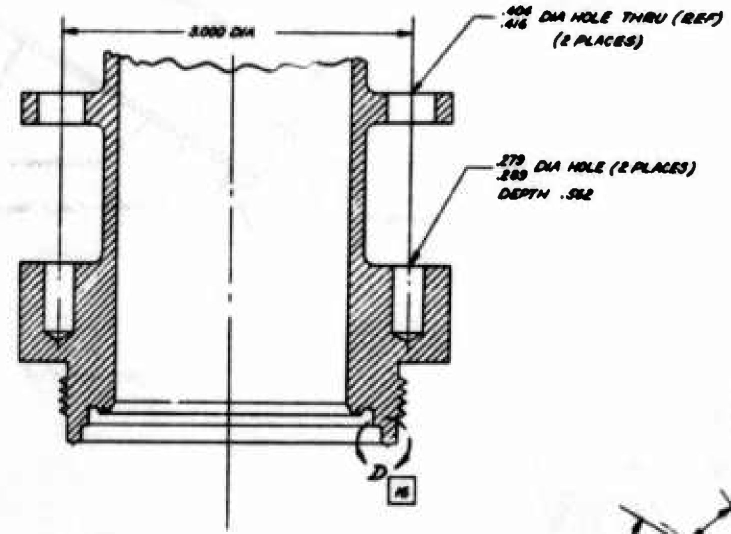


GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:
1. PERMISSIBLE MISMATCH BETWEEN CENTERLINES A AND B IS .030 MAX.
2. TOLERANCES ARE AS FOLLOWS:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ±1°
3. WELDING SHALL BE INERT SHIELDED ARC WELD PER MIL-W-[illegible]. FULL PENETRATION OF WELD IS REQUIRED AND NO CAVITIES OR INCLUSIONS ARE PERMITTED.
4. [illegible] RADIOGRAPHIC INSPECTION OF WELDS MARKED THUS [illegible] IS REQUIRED PER RADIOGRAPHIC METHOD MIL-STD-453 AND RADIOGRAPHIC INSPECTION SPECIFICATION MIL-R-[illegible], [illegible] [illegible] CERTIFICATION IS REQUIRED. RADIOGRAPHY OF OTHER WELDS IS NOT REQUIRED, HOWEVER THEY SHALL BE FREE OF SURFACE CRACKS OR [illegible].
5. [illegible] DIAMETERS OF [illegible] AND [illegible] FLANGE TO BE CONCENTRIC WITHIN .020 TIR AS [illegible] AFTER WELDING.
6. [illegible] FOR [illegible] SERVICE PER [illegible].

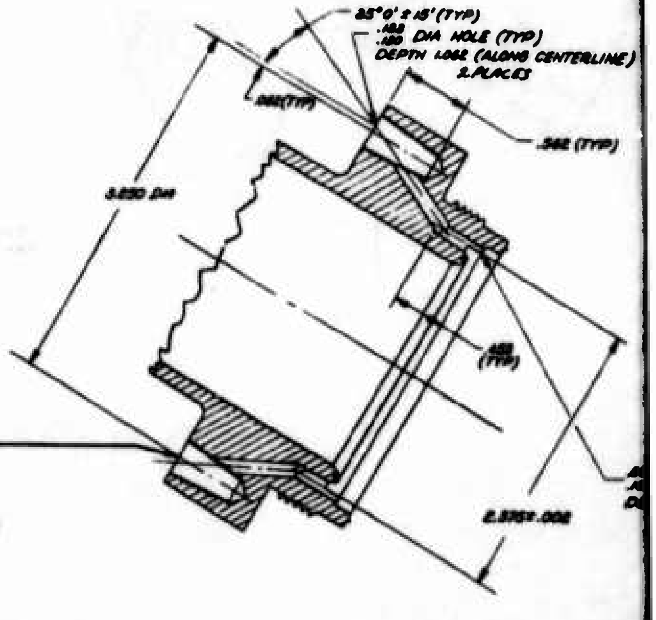
— AGE (1D00807)

3

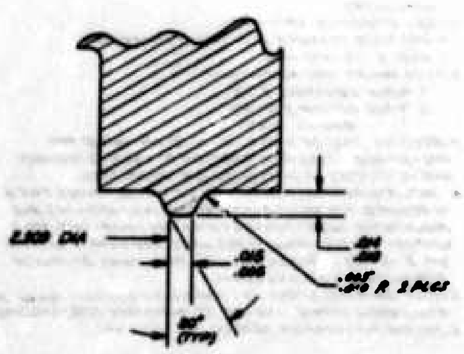




SECTION B-B
SCALE: $\frac{1}{1}$ 10
(TYP 2 PLACES)
NOTE: ALL HOLES TO BE IN LINE



SECTION C-C
SCALE: $\frac{1}{1}$ 10



VIEW D
SCALE: NONE 14

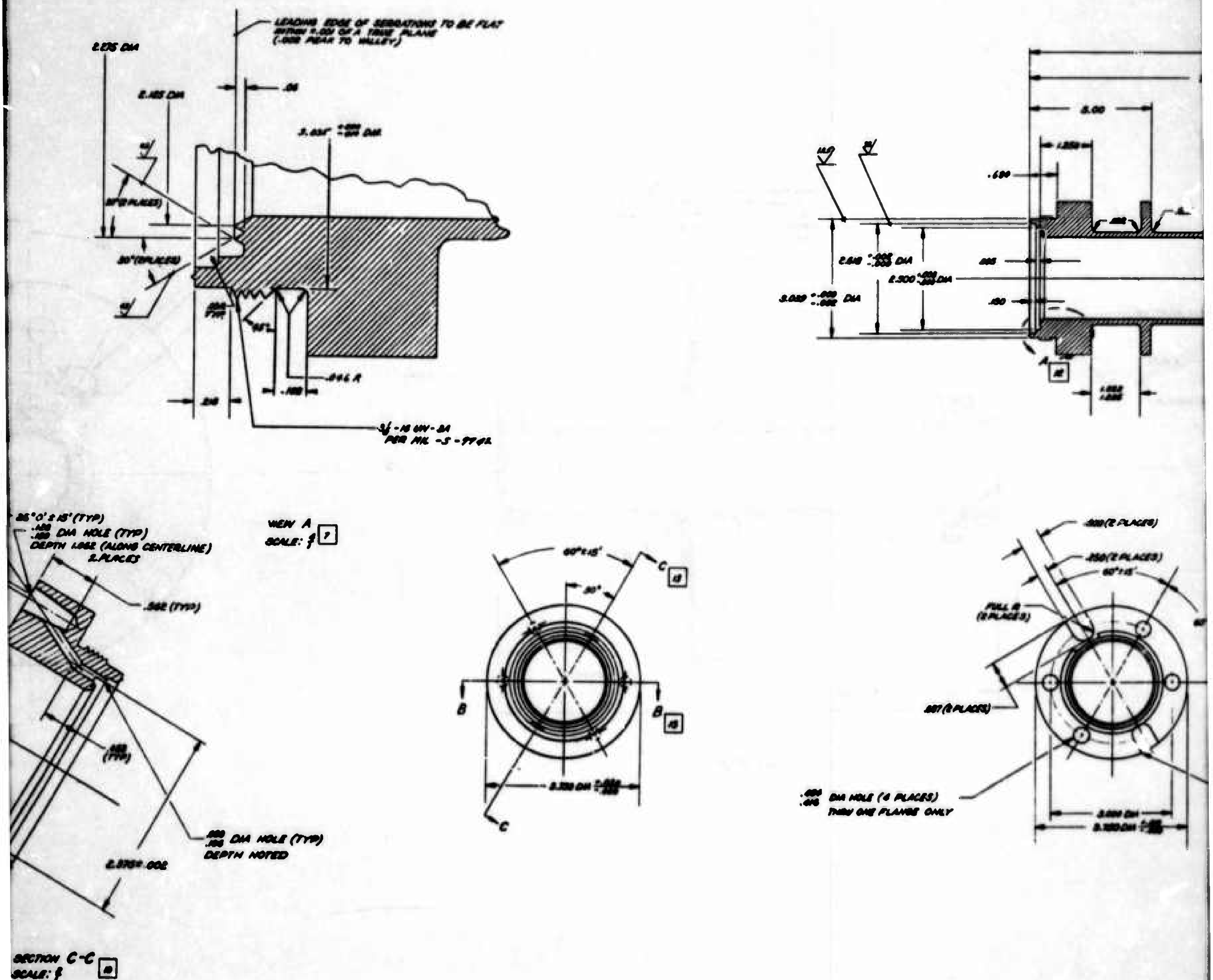
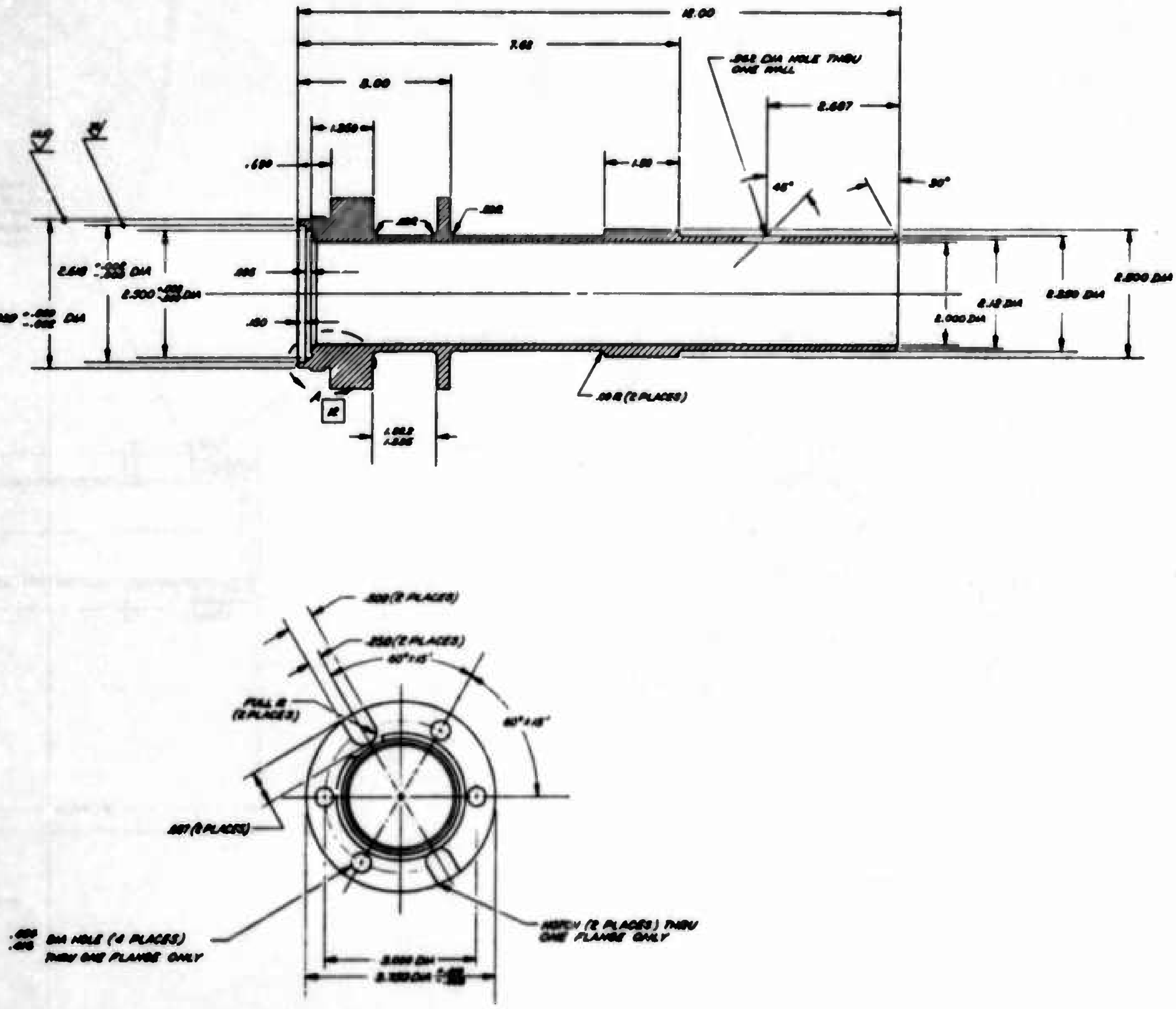


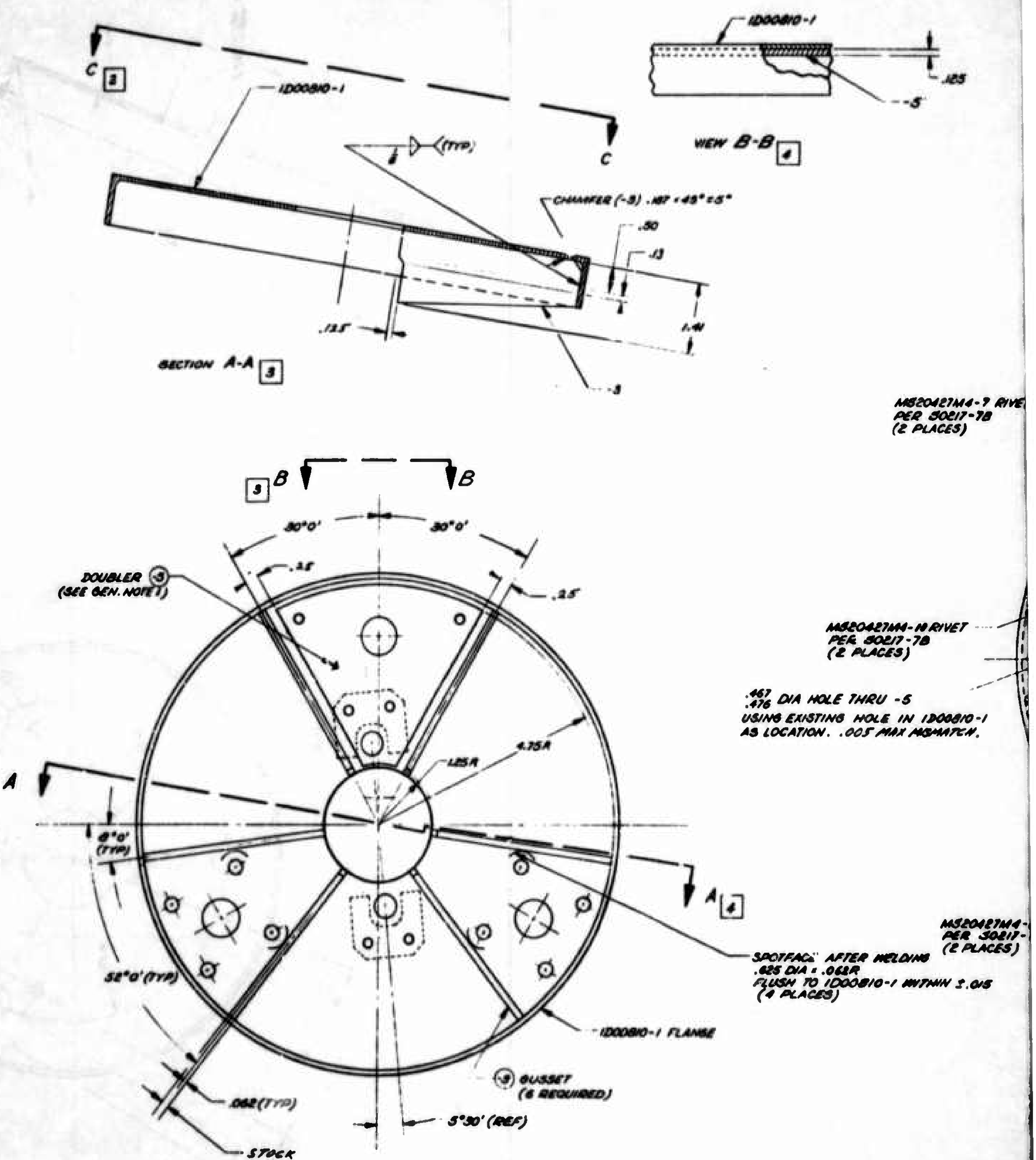
Figure XII-9. Adapter, Liquid Fluorine, Servicing – AGE (1D00808)



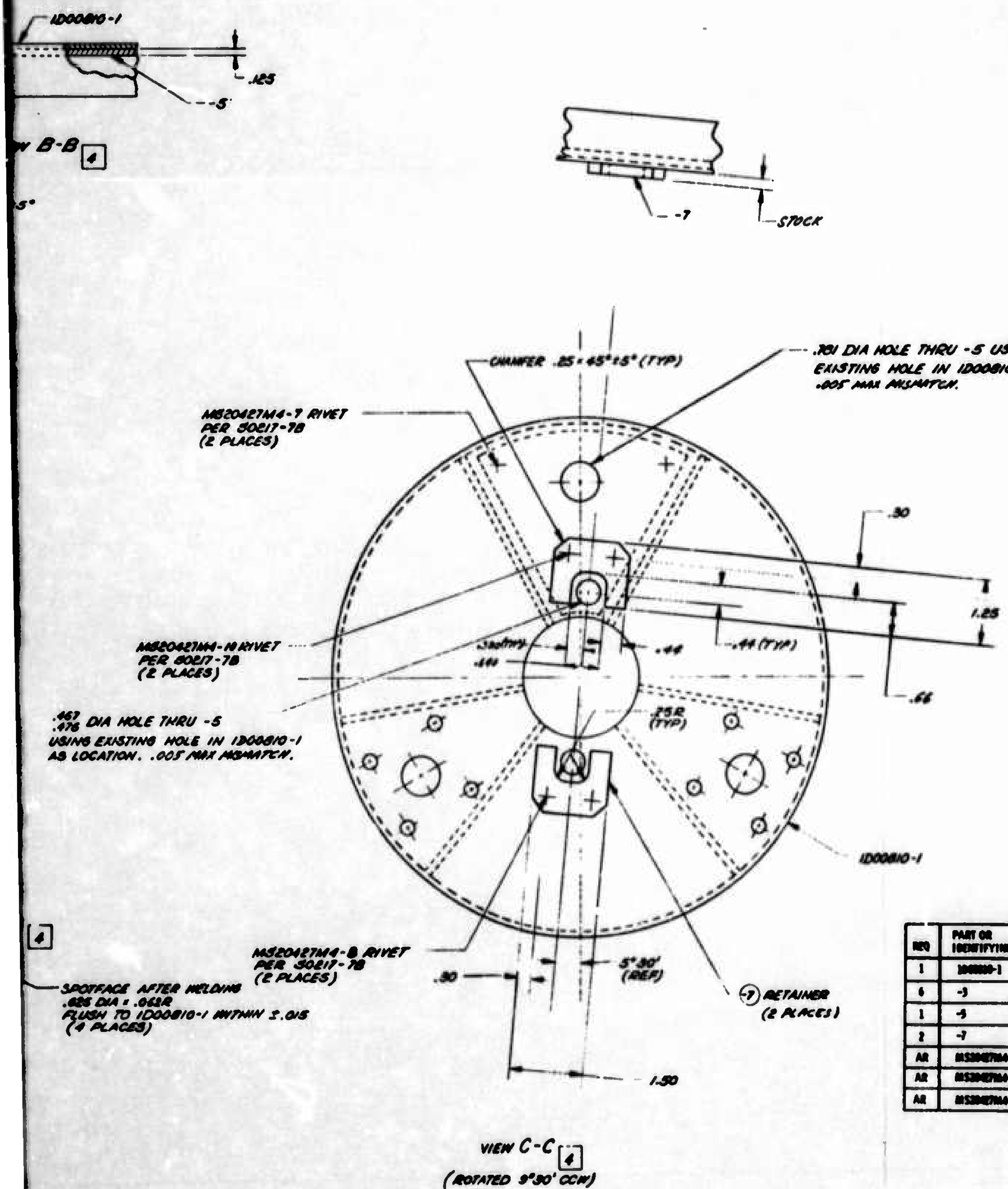
GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS [illegible]√ PER MIL-STD-10
2. DIMENSIONAL TOLERANCES ARE AS FOLLOWS:
   - 2 PLACE DECIMALS ±.03
   - 3 PLACE DECIMALS ±.010
   - ANGLES ±0°30'

AGE (1D00808)



C 2
1D00810-1
(TYP)
C
VIEW B-B 4
.125
-5
CHAMFER (-3) .187 × 45° ± 5°
.50
.13
1.41
.125
SECTION A-A 3
-3
MS20427M4-7 RIVET
PER 30217-7B
(2 PLACES)
3 B
B
30°0'
30°0'
DOUBLER -5
(SEE GEN. NOTE 1)
.25
.25
MS20427M4-10 RIVET
PER 30217-7B
(2 PLACES)
.467
.476 DIA HOLE THRU -5
USING EXISTING HOLE IN 1D00810-1
AS LOCATION. .005 MAX MISMATCH.
1.25R
4.75R
A
8°0' (TYP)
A 4
MS20427M4-
PER 30217-
(2 PLACES)
SPOTFACE AFTER WELDING
.625 DIA × .062R
FLUSH TO 1D00810-1 WITHIN ±.015
(4 PLACES)
52°0' (TYP)
1D00810-1 FLANGE
-3 GUSSET
(6 REQUIRED)
.062 (TYP)
5°30' (REF)
STOCK



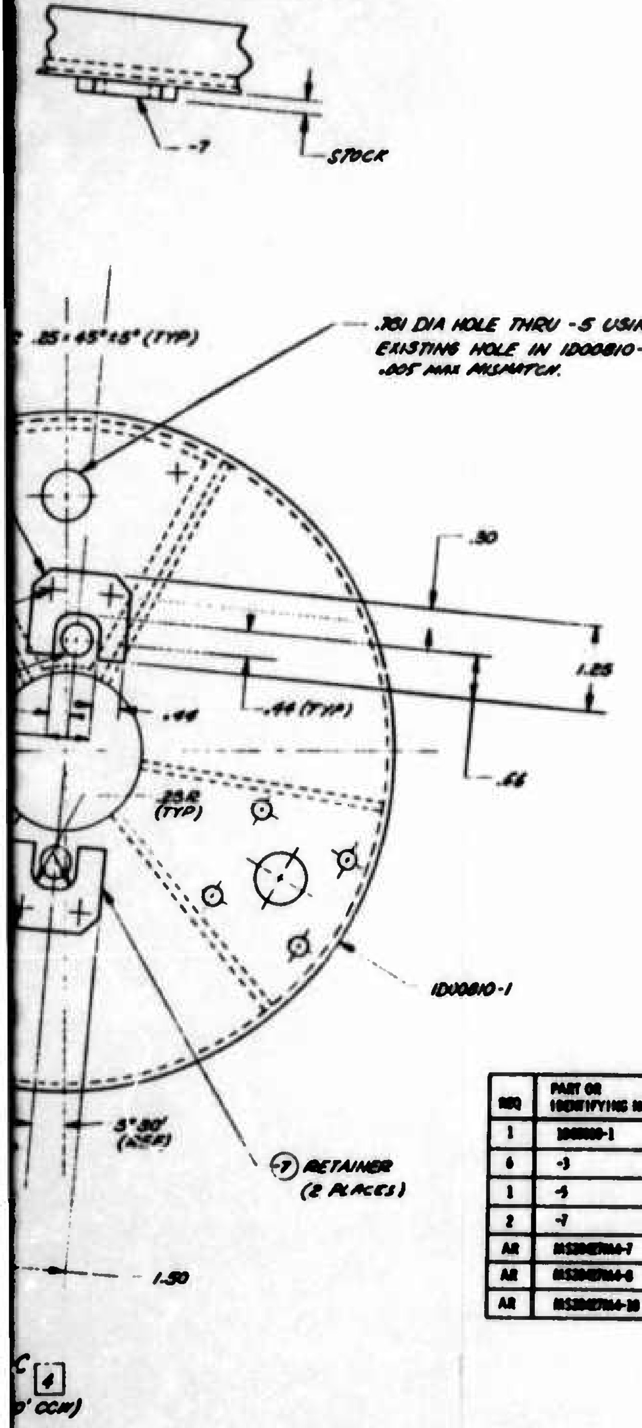
GENERAL NOTES:
UNLESS OTHERWISE SPECIFIED:

1. 1D00809-5 DOUBLER MAY BE HAND GA[illegible]
ALONG EDGES WHICH INTERFERE [illegible]
WELDED AREA.
2. DIRECT PART IDENTIFICATION NOT PERM[illegible]
IDENTIFY CONTAINER WITH APPROPRIA[illegible]
TITLE BLOCK PART NUMBER.
3. TOLERANCES ARE AS FOLLOWS:
2 PLACE DECIMALS ± .03
3 PLACE DECIMALS ± .010
ANGLES ± 30'
4. RIVET EDGE DISTANCE FOR ALL
RIVETS IS .25
5. FUSION WELD PER MIL-W-[illegible].
6. NO RADIOGRAPHIC INSPECTION OF WELD[illegible]

REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIA DISCRIPTION
1	1D00810-1	FLANGE		
6	-3	GUSSET	0.125 x 1.50 x 4.00	SHEET 321
1	-5	DOUBLER	0.125 x 4 x 5	SHEET 321
2	-7	RETAINER	-.1875 x 1.50 x 1.75	PLATE 321
AR	MS20427M4-7	RIVET		
AR	MS20427M4-8	RIVET		
AR	MS20427M4-10	RIVET		

Figure XII-10. Flange Assembly

2



GENERAL NOTES:
UNLESS OTHERWISE SPECIFIED:

1. 1D00809-5 DOUBLER MAY BE HAND GROUND ALONG EDGES WHICH INTERFERE WITH WELDED AREA.
2. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.
3. TOLERANCES ARE AS FOLLOWS:
   2 PLACE DECIMALS ± .03
   3 PLACE DECIMALS ± .010
   ANGLES ± 30'
4. RIVET EDGE DISTANCE FOR ALL RIVETS IS .25
5. FUSION WELD PER MIL-W-[illegible].
6. NO RADIOGRAPHIC INSPECTION OF WELD REQUIRED

REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIA DISCRIPTION
1	[illegible]-1	FLANGE		
6	-3	GUSSET	0.125 x 1.50 x 4.00	SHEET 321
1	-5	DOUBLER	0.125 x [illegible] x 5	SHEET 321
2	-7	RETAINER	-.1875 x 1.50 x 1.75	PLATE 321
AR	[illegible]-7	RIVET		
AR	[illegible]-8	RIVET		
AR	[illegible]-10	RIVET		

Figure XII-10. Flange Assembly, Quick Disconnect (1D00809)

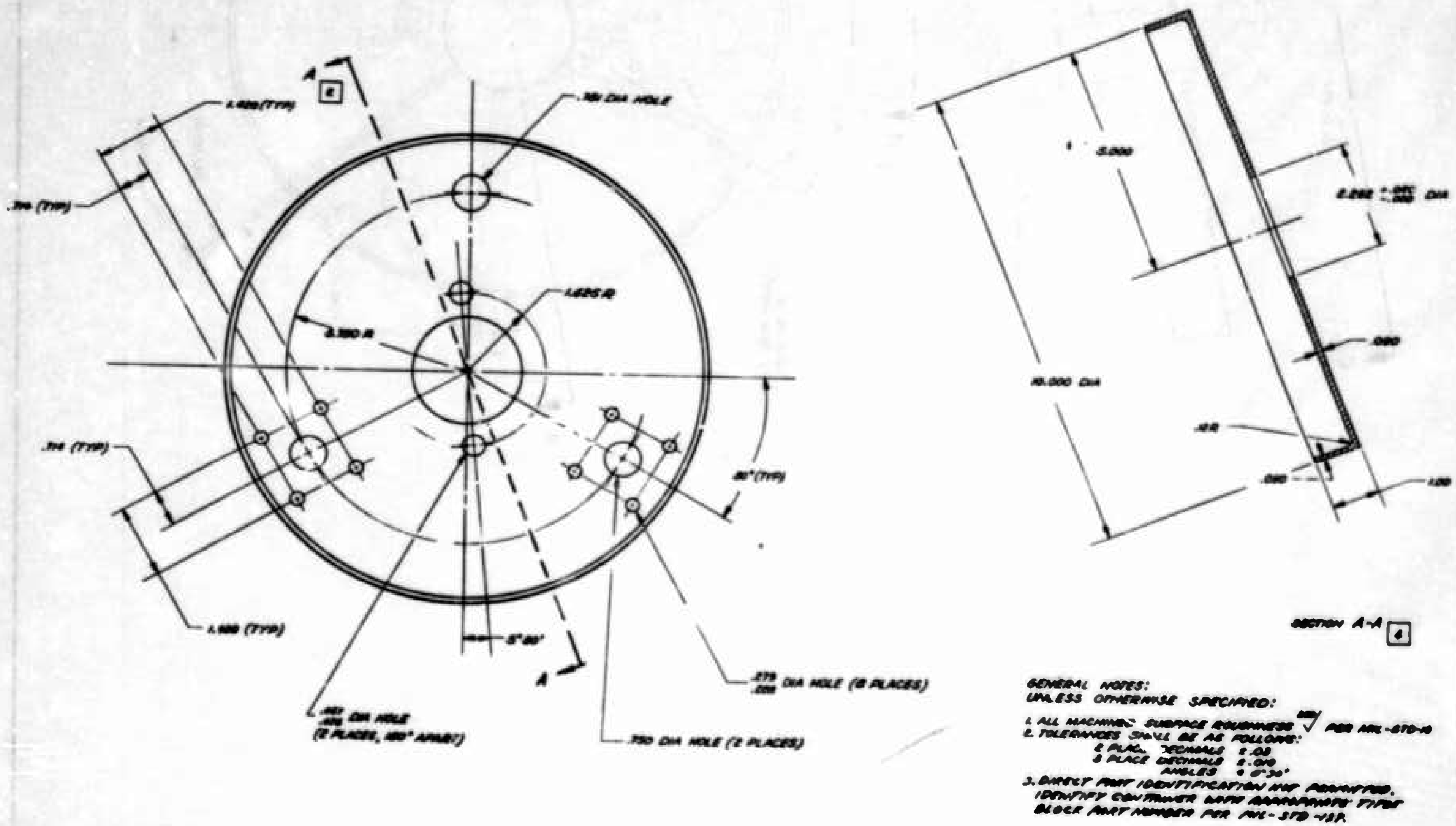
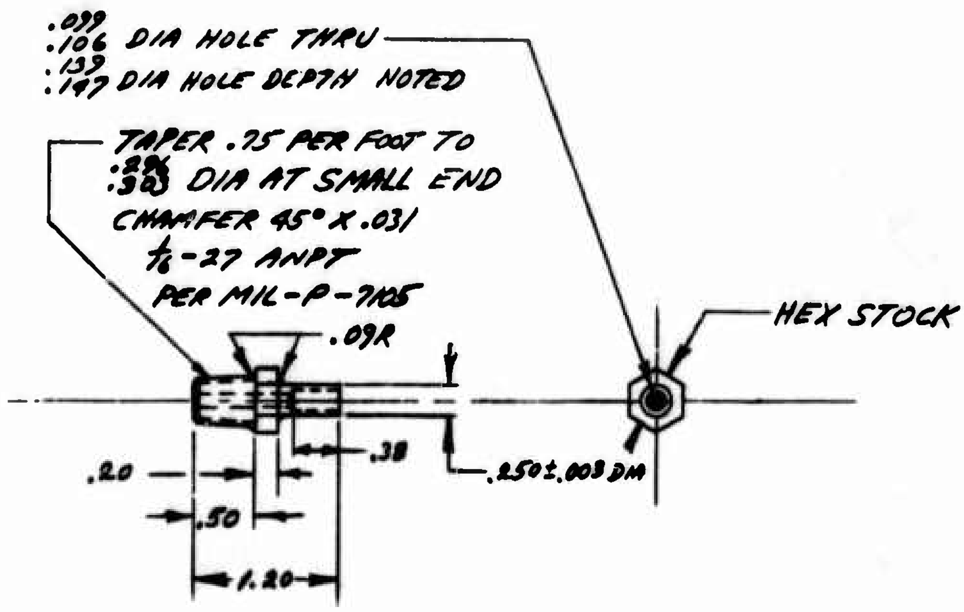


Figure XII-11. Flange, Quick Disconnect (1D00810)



GENERAL NOTES

UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS 125
PER MIL-STD-10.

2. DIMENSIONAL TOLERANCES ARE:

2 PLACE DECIMALS ±.03

3 PLACE DECIMALS ±.010

ANGLES ±2°

3. DIRECT PART IDENTIFICATION NOT PERMITTED.
IDENTIFY CONTAINER WITH APPROPRIATE TITLE
BLOCK PART NUMBER.

Figure XII-12. Fitting, Seal Cavity Purge (1D00811)

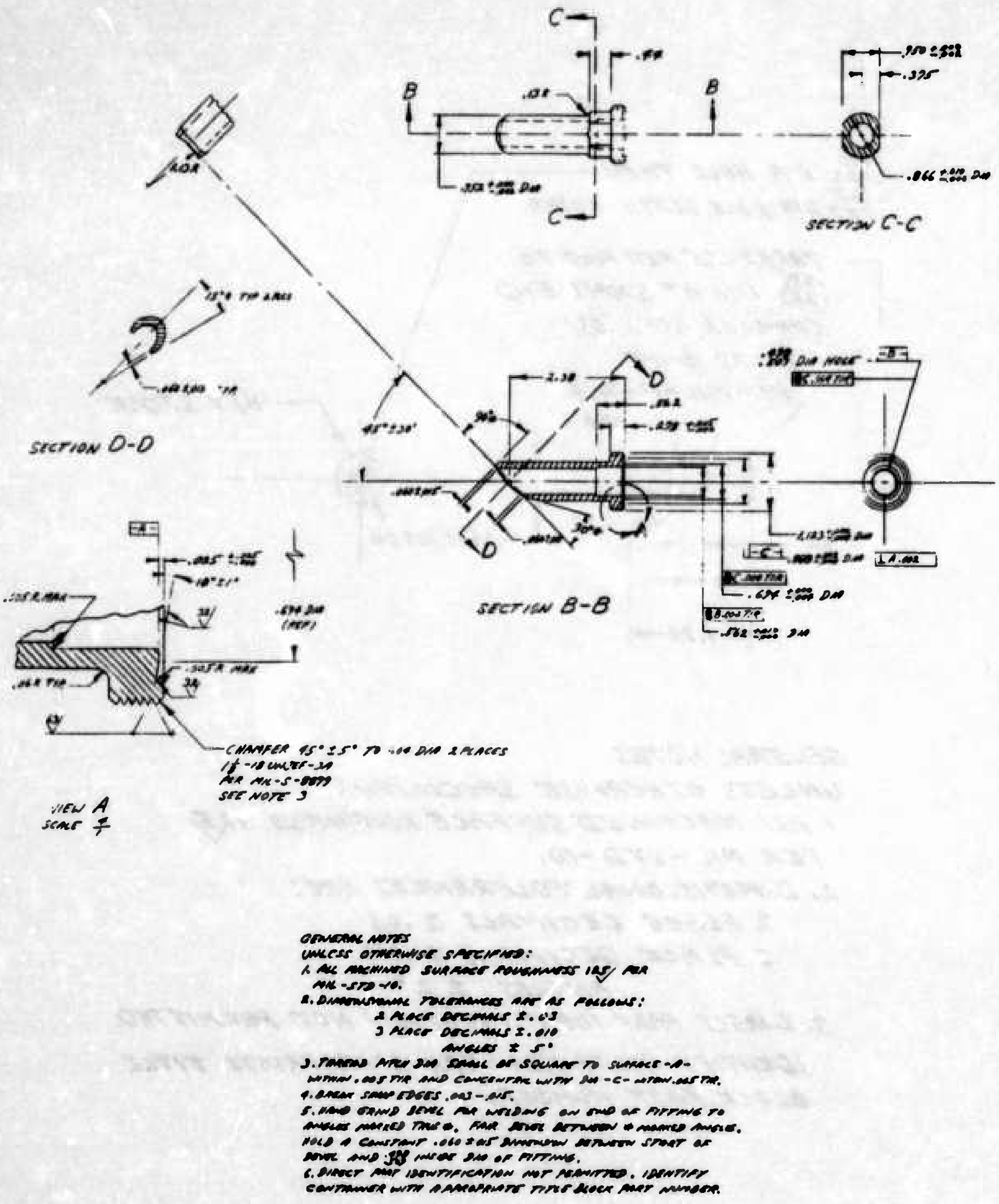


Figure XII-13. Fitting, Main Line Purge (1D00812)

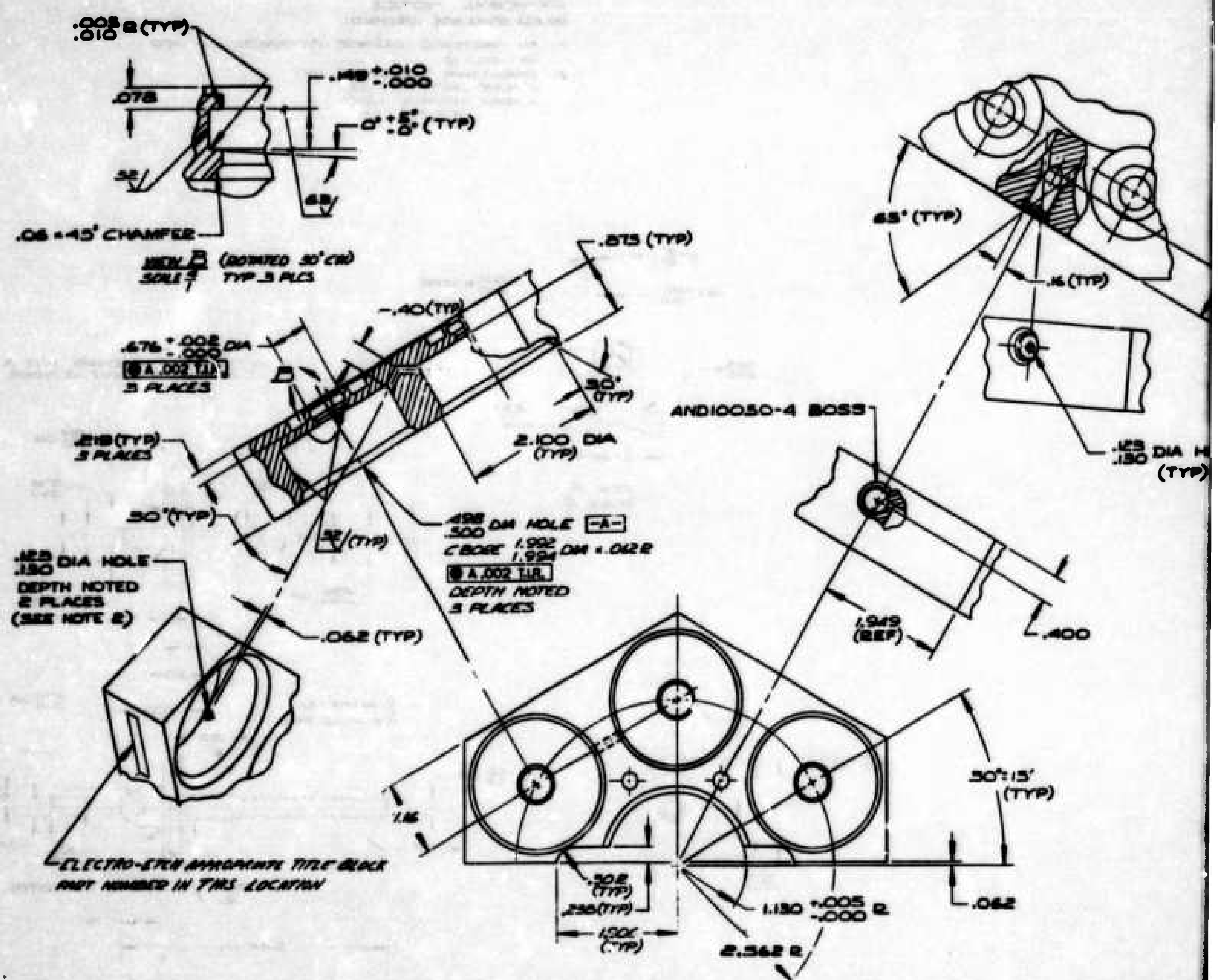


Figure XII-15. Piston, Latching (1D00814)

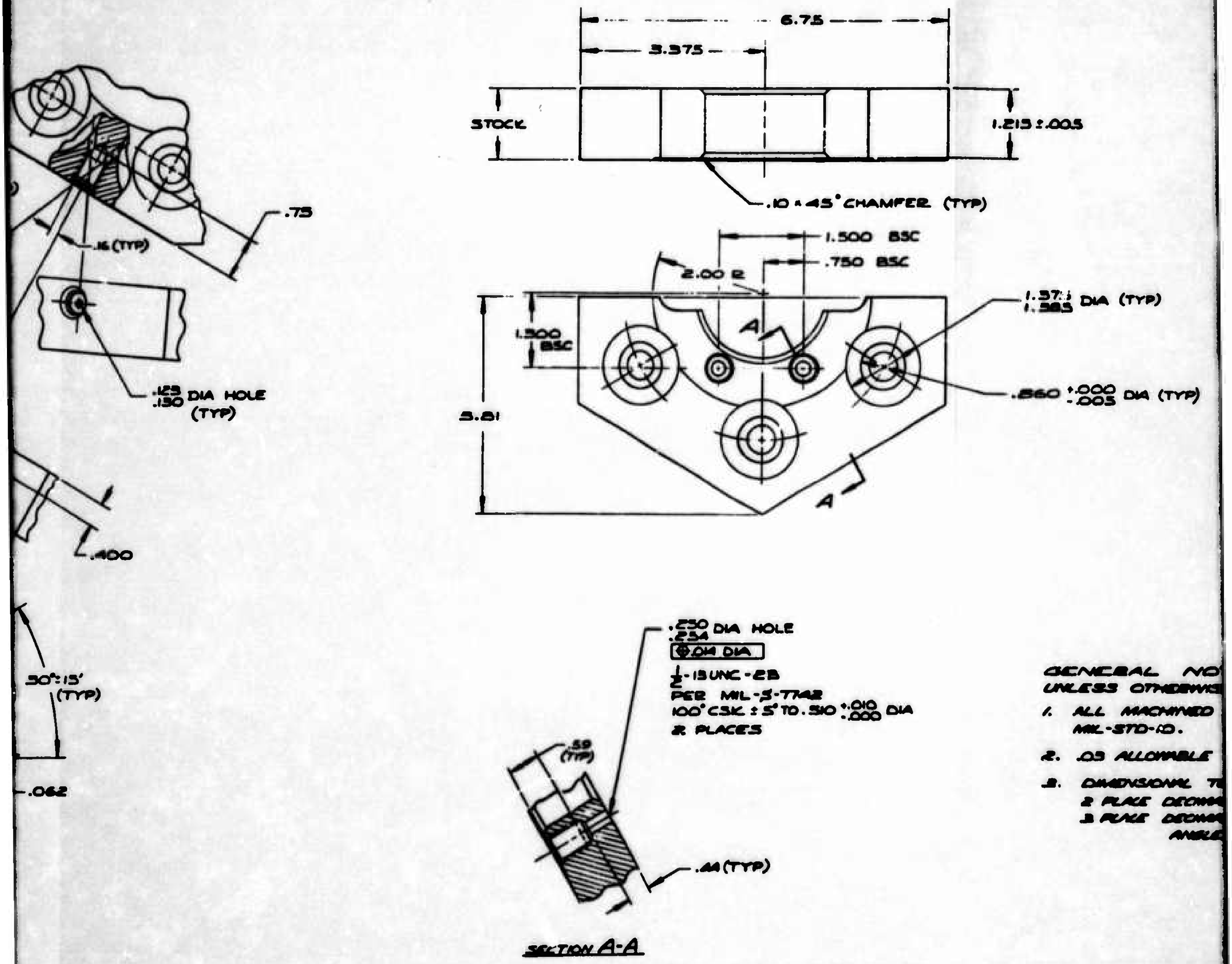
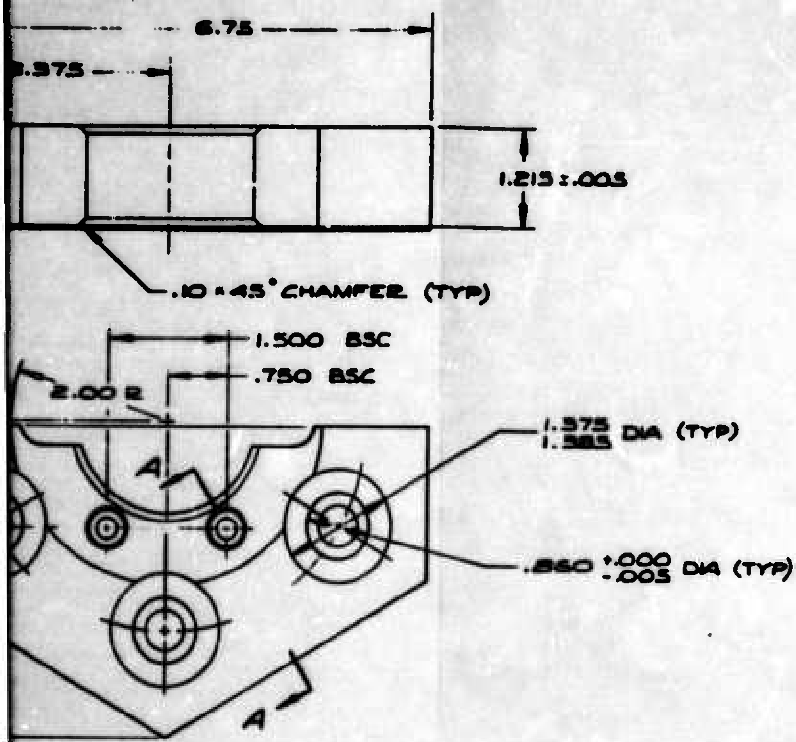


Figure XII-14. Block, Cylinder (1D00813)



.250 / .234 DIA HOLE
.014 DIA

1/2-13UNC-2B
PER MIL-S-7742
100° CSK ±5° TO .510 +.010 / -.000 DIA
2 PLACES

.44 (TYP)

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS 125/ PER MIL-STD-10.
2. .03 ALLOWABLE MISMATCH ON INTERSECTING HOLES.
3. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ±.03
   3 PLACE DECIMALS ±.010
   ANGLES ±0°30'

2

3

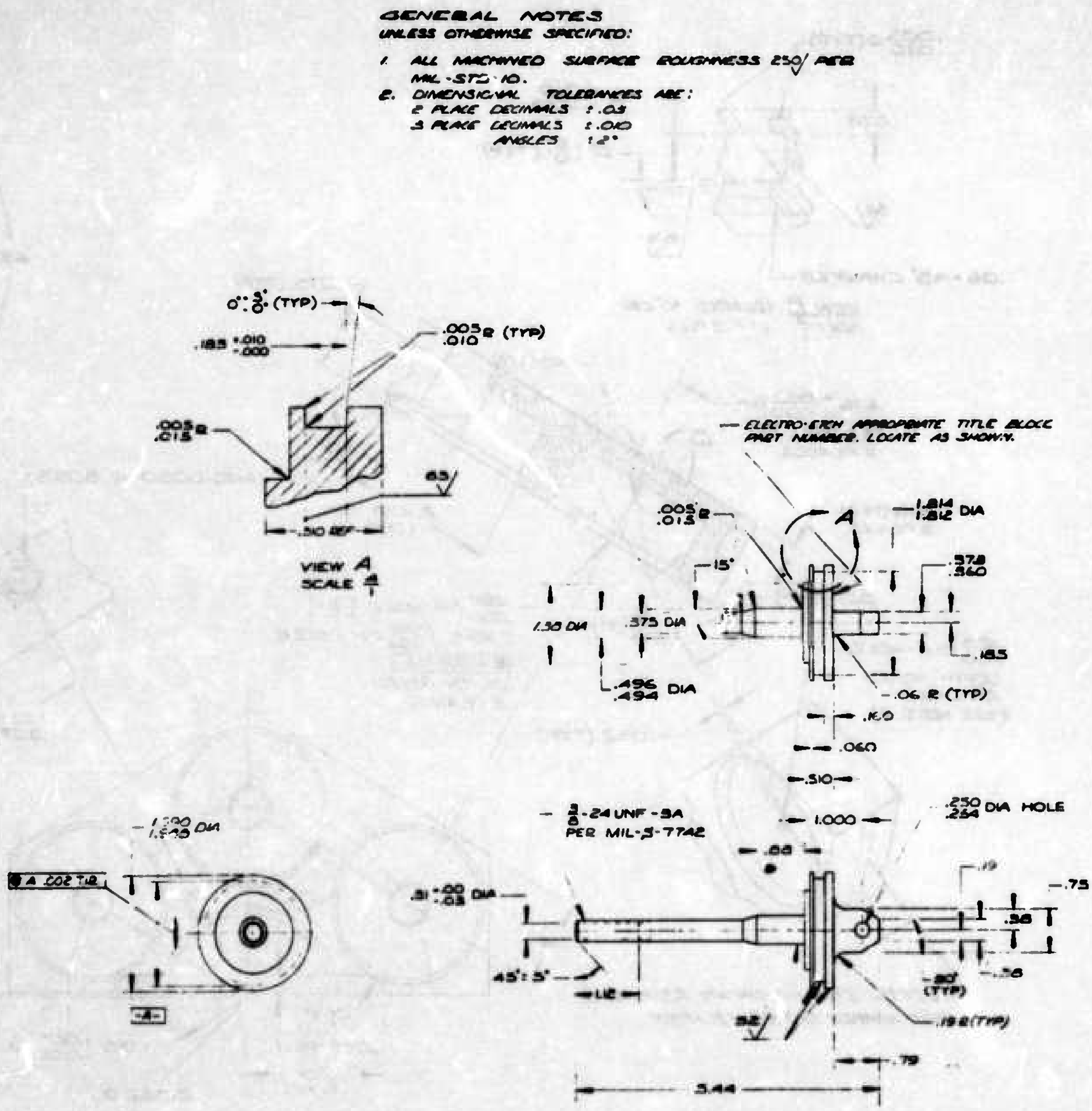


Figure XII-15. Piston, Latching (1D00814)

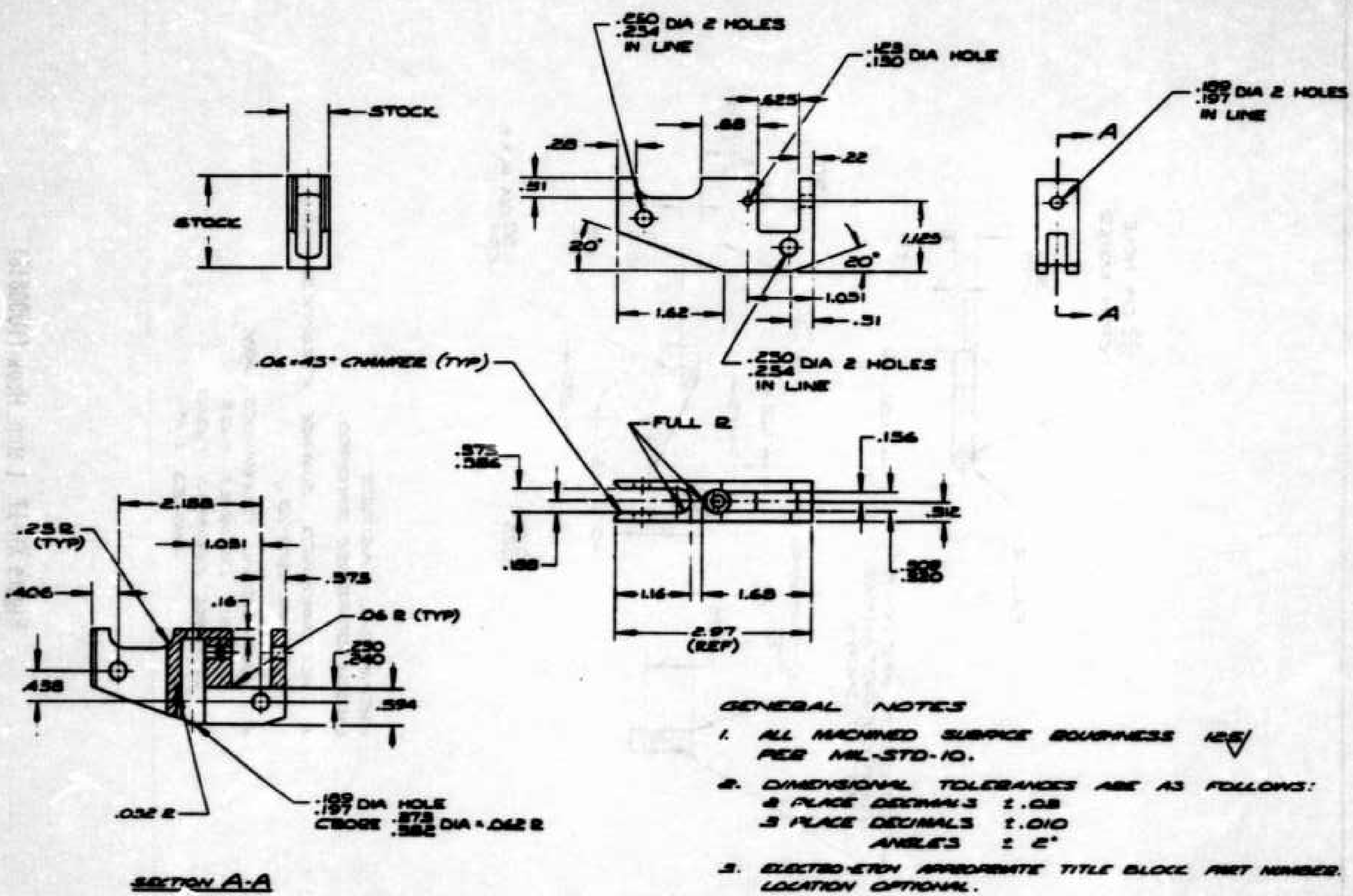
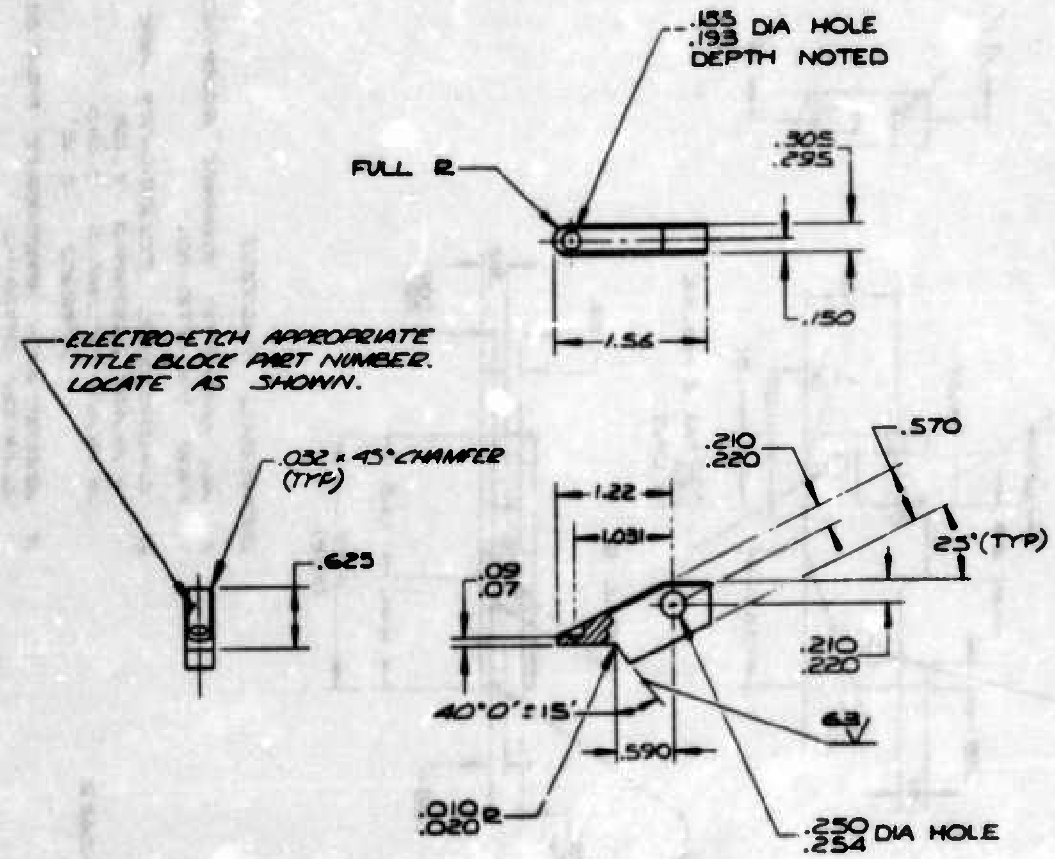


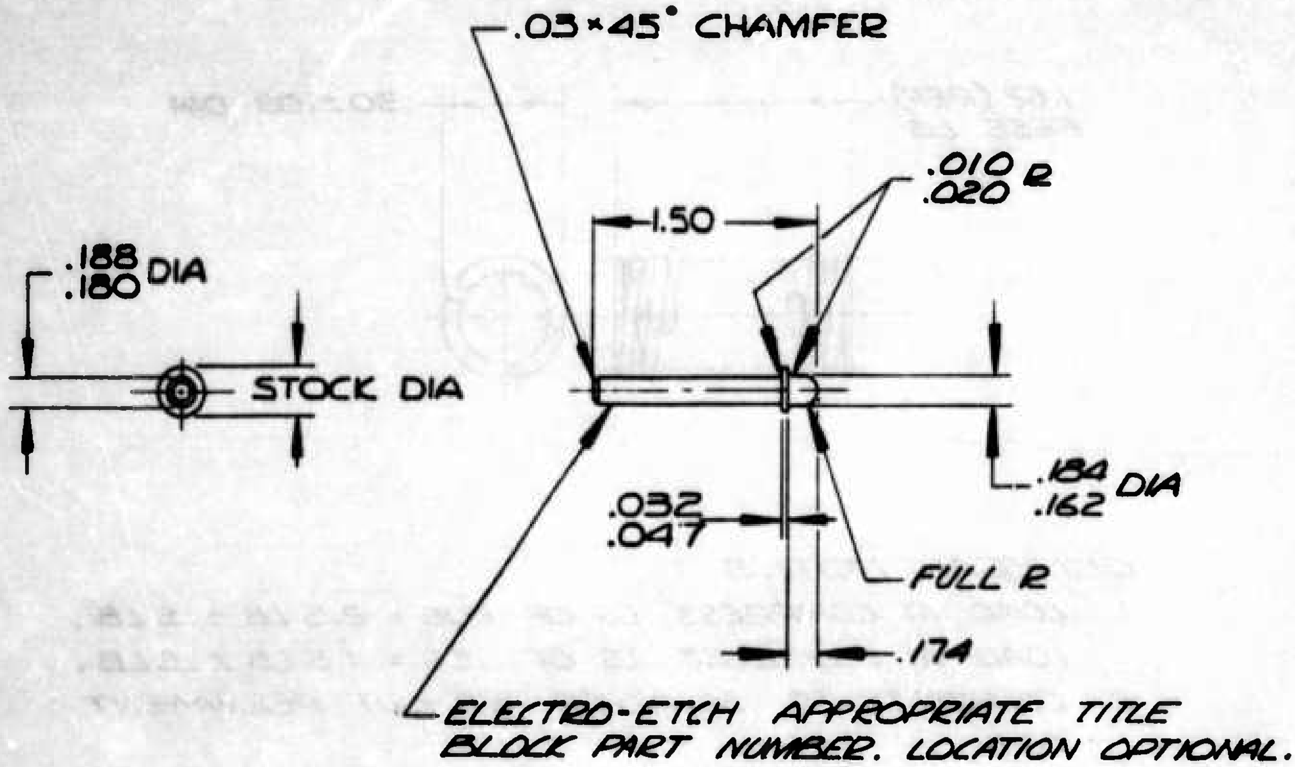
Figure XII-16. Hook, Latching (1D00815)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS 125 PER MIL-STD-10
2. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ±.03
   3 PLACE DECIMALS ±.010
   ANGLES ±1°

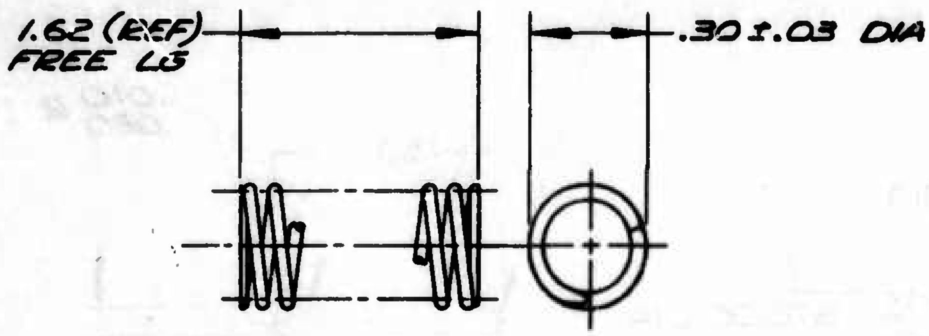
Figure XII-17. Latch, Hook (1D00816)



GENERAL NOTES

1. ALL MACHINED SURFACE ROUGHNESS 63√ PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ± .03
   3 PLACE DECIMALS ± .010
   ANGLES ± 2°

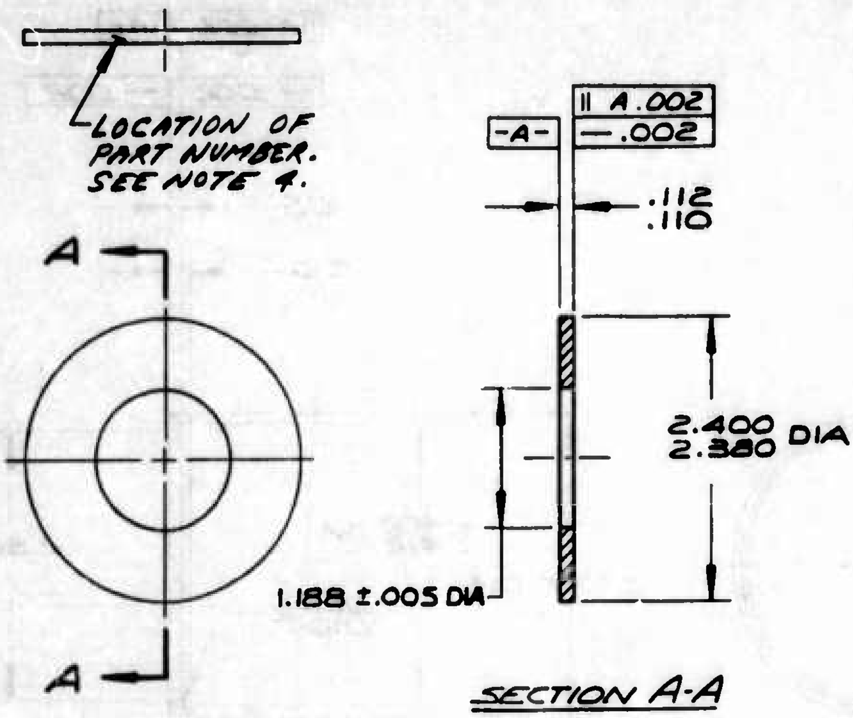
Figure XII-18. Pin, Latch Spring Guide (1D00817)



GENERAL NOTES

1. LOAD AT COMPRESS LG OF 1.06 = 2.5 LB ± .5 LB.
   LOAD AT COMPRESS LG OF .56 = 4.5 LB ± .5 LB.
2. COMPRESS TO .56 INCHES WITHOUT PERMANENT SET.
3. TOTAL COILS 17.5 REF.
4. ENDS TO BE WOUND CLOSED AND GROUND SQUARE WITHIN 3° OF AXIS. GROUND SURFACE TO BE 270° ± 30°. DRESS EDGES OF GROUND SURFACES .005 R MINIMUM.
5. ADJACENT COILS TO BE HELICAL AND CONCENTRIC WITHIN .015 T.I.R.
6. DIRECTION OF HELIX OPTIONAL.
7. STRESS RELIEVE AFTER FORMING PER MIL-S-6715.
8. IDENTIFY PER MIL-STD-129. DIRECT PART IDENTIFICATION NOT PERMITTED.

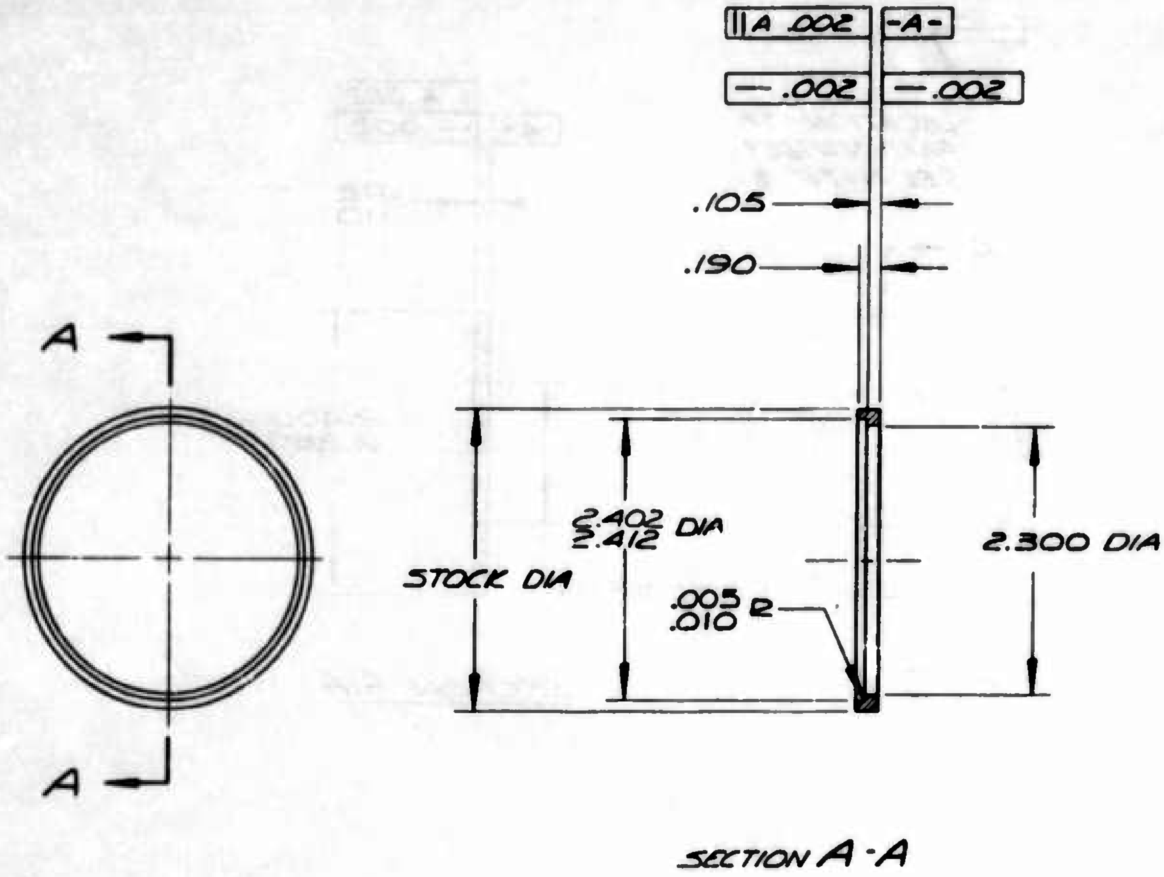
Figure XII-19. Spring, Helical Compression (1D00818)



GENERAL NOTES

1. ALL MACHINED SURFACE ROUGHNESS 63/ PER MIL-STD-10.
2. SPRING MATERIAL TO BE COLD REDUCED 30% BEFORE FINAL MACHINING & AGED AFTER MACHINING TO ACHIEVE 200,000 PSI MINIMUM YIELD STRENGTH.
3. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ±.03
   3 PLACE DECIMALS ±.010
   ANGLES ± 2°
4. ELECTRO-ETCH APPROPRIATE TITLE BLOCK PART NUMBER. LOCATE AS SHOWN.

Figure XII-20. Spring, Flat, Seal Loaded (1D00819)



GENERAL NOTES

1. ALL MACHINED SURFACE ROUGHNESS 63
PER MIL-STD-10.

2. DIMENSIONAL TOLERANCES ARE:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ± 2°

3. ELECTRO-ETCH APPROPRIATE TITLE BLOCK PART NUMBER ON OUTER CYLINDRICAL SURFACE.

Figure XII-21. Spacer, Loading Spring, Outer (1D00820)

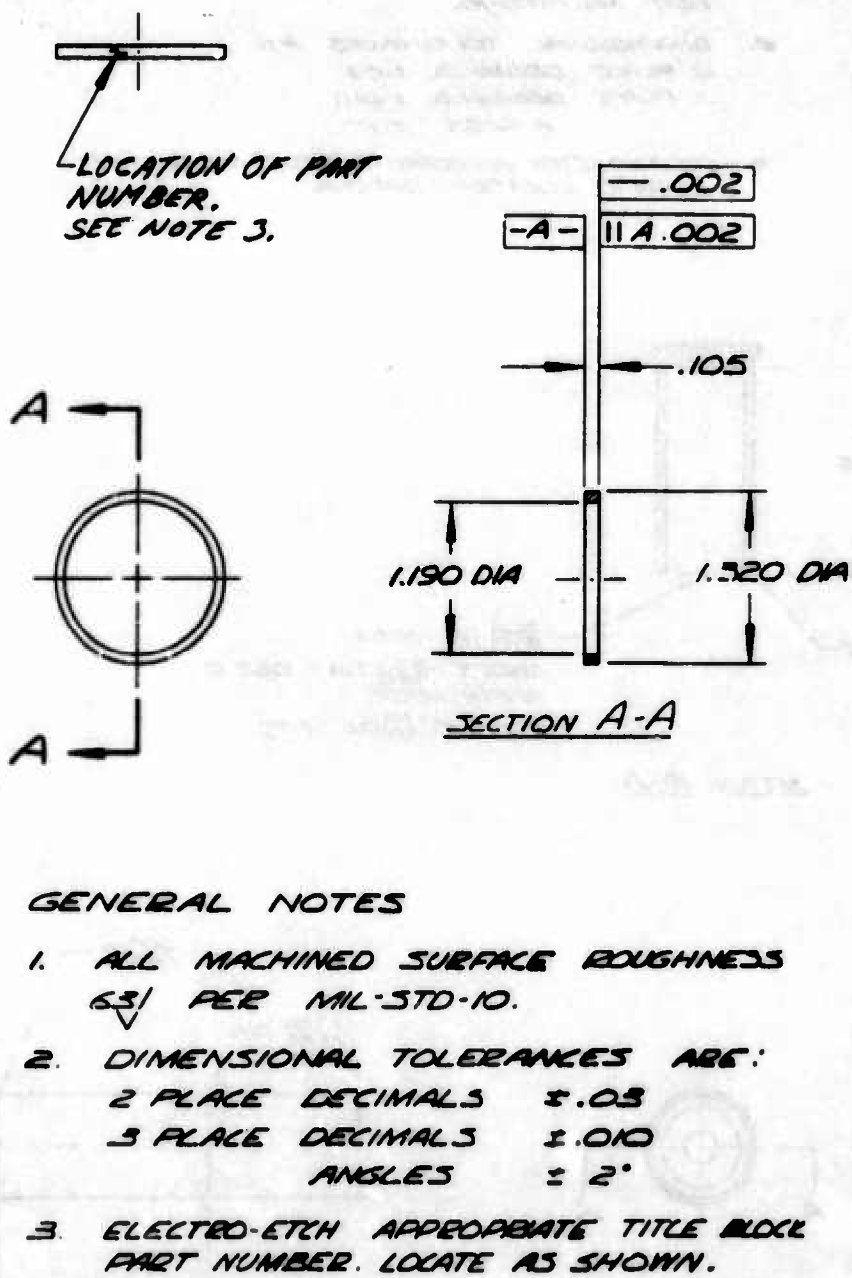


Figure XII-22. Spacer, Loading Spring, Inner (1D00821)

GENERAL NOTES

1. ALL MACHINED SURFACE ROUGHNESS 125/ PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ±.03
   3 PLACE DECIMALS ±.010
   ANGLES ± 2°
3. ELECTRO-ETCH APPROPRIATE TITLE BLOCK PART NUMBER. LOCATION OPTIONAL.

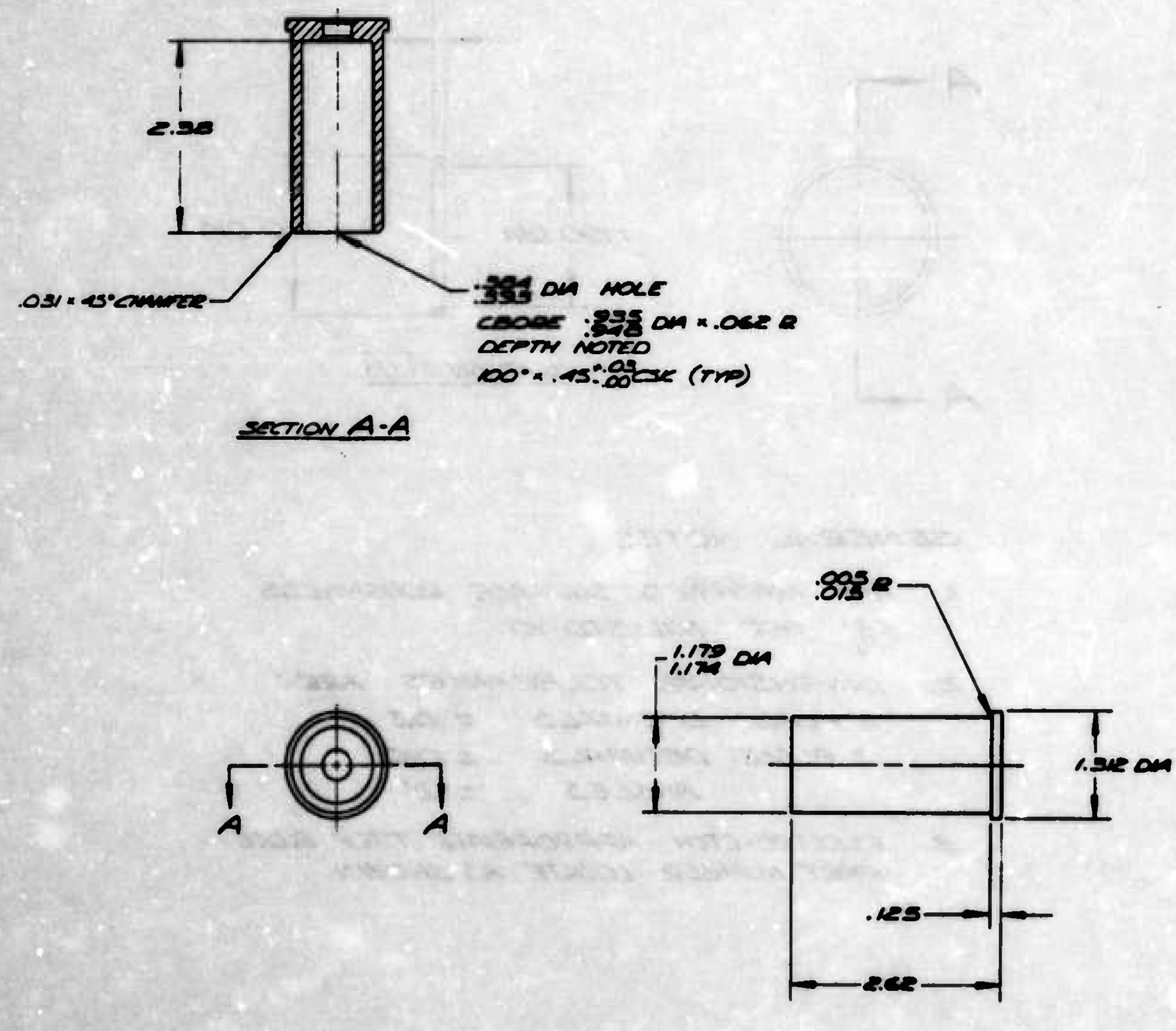


Figure XII-23. Guide, Seal Loading Spring (1D00822)

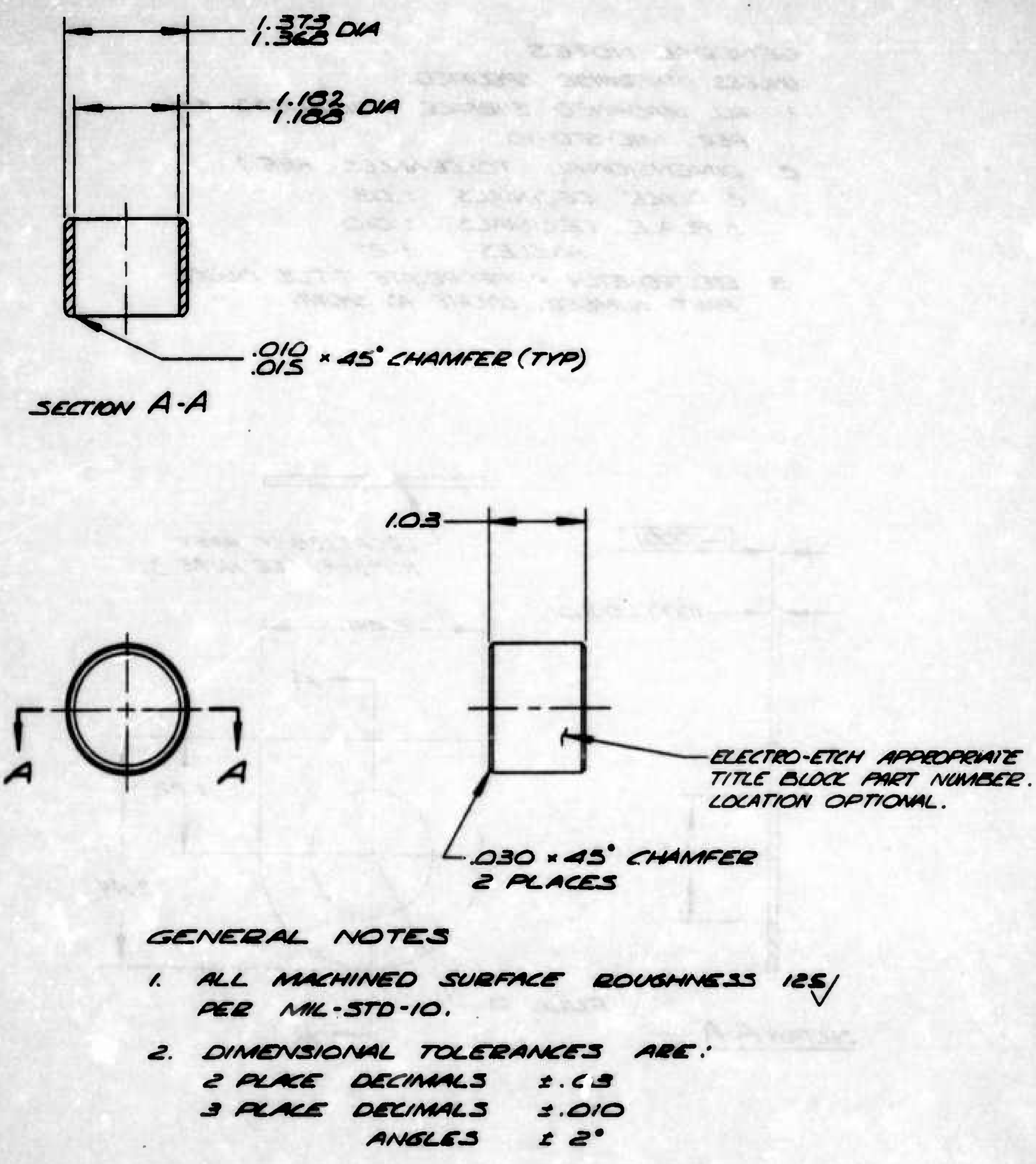


Figure XII-24. Sleeve, Seal Loading Spring (1D00823)

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS 63√ PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ±.03
   3 PLACE DECIMALS ±.010
   ANGLES ± 2°
3. ELECTRO-ETCH APPROPRIATE TITLE BLOCK PART NUMBER. LOCATE AS SHOWN.

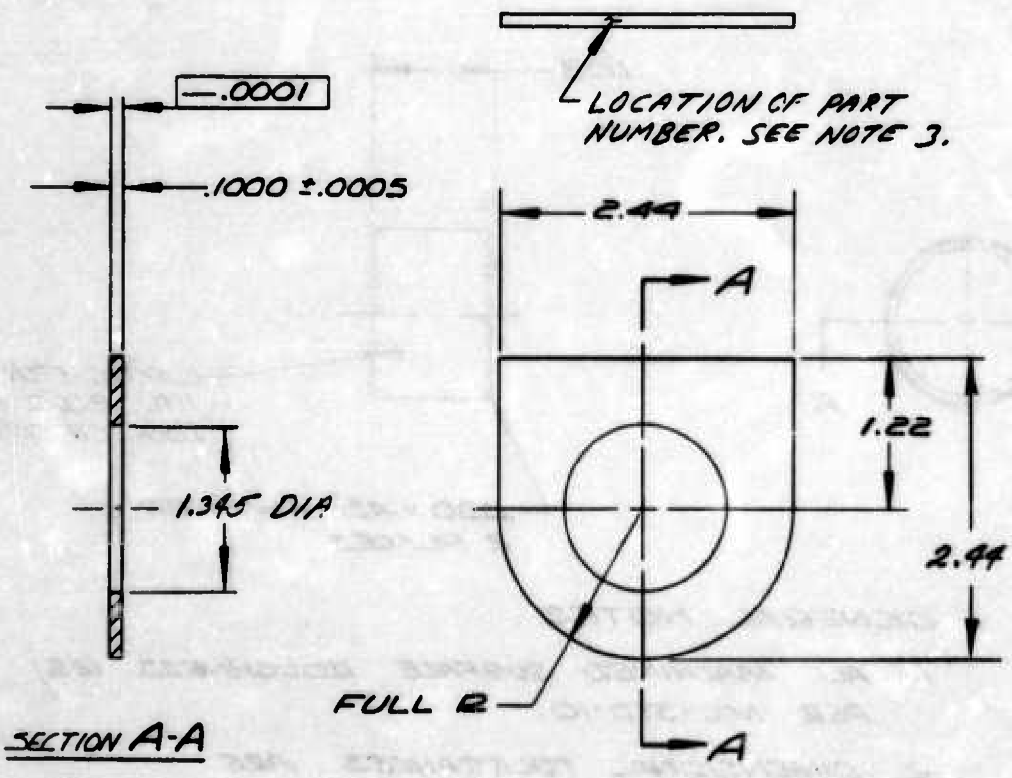
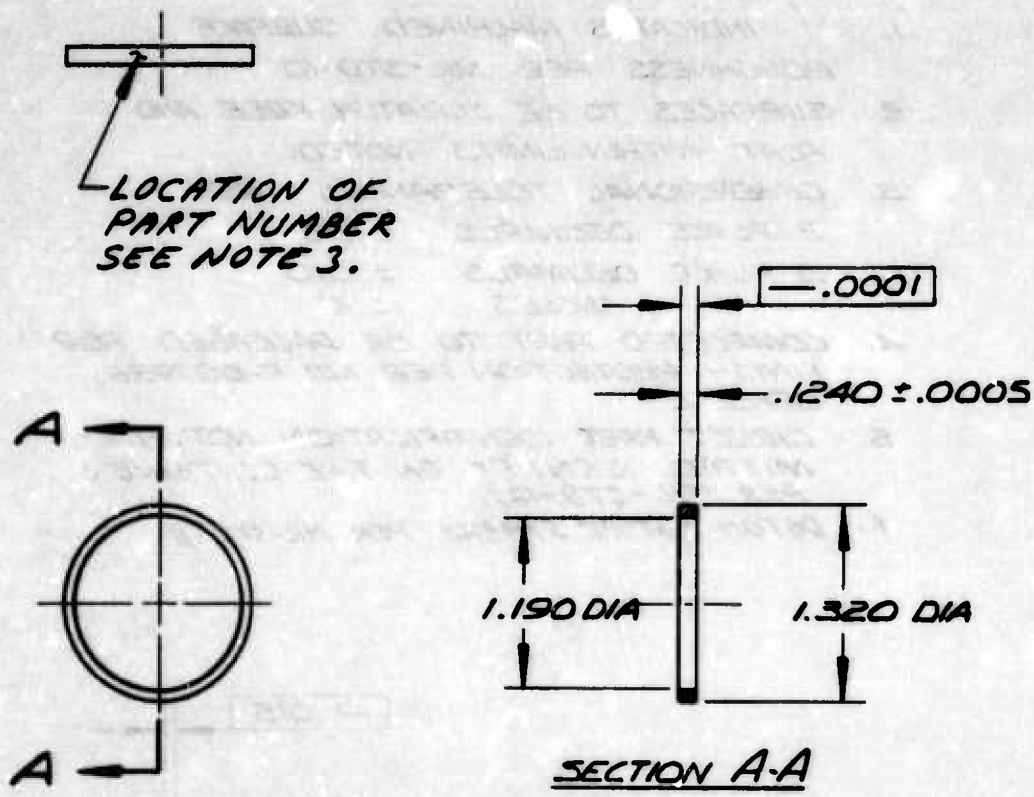


Figure XII-25. Indicator, Seal Load (1D00824)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS 63 PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE:
   - 2 PLACE DECIMALS ±.03
   - 3 PLACE DECIMALS ±.010
   - ANGLES ±2°
3. ELECTRO-ETCH APPROPRIATE TITLE BLOCK PART NUMBER. LOCATE AS SHOWN.

Figure XII-26. Spacer, Seal Load Indicator (1D00825)

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. √ INDICATES MACHINED SURFACE ROUGHNESS PER MIL-STD-10.
2. SURFACES TO BE SCRATCH-FREE AND FLAT WITHIN LIMITS NOTED.
3. DIMENSIONAL TOLERANCES ARE:

2 PLACE DECIMALS	±.03
3 PLACE DECIMALS	±.010
ANGLES	± 2°

4. COMPLETED PART TO BE PACKAGED FOR FINISH PROTECTION PER MIL-P-007936, LEVEL C.
5. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY ON THE CONTAINER PER MIL-STD-129.
6. DATUM FEATURE SYMBOLS PER MIL-STD-8

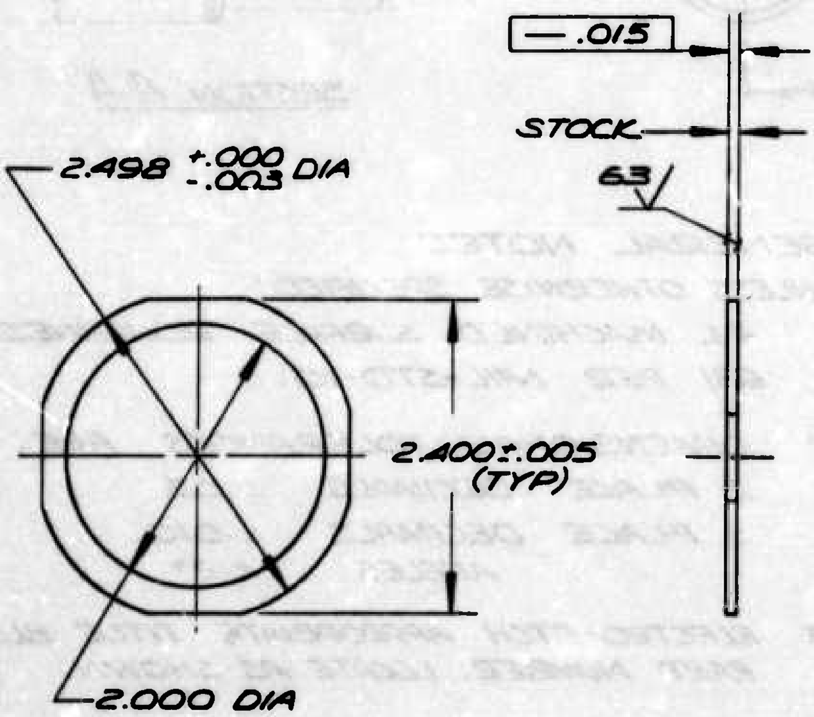


Figure XII-27. Seal, Metallic – Primary (1D00826)

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

1. ALL MACHINED SURFACE ROUGHNESS 125/ PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE:
   2 PLACE DECIMALS ±.03
   3 PLACE DECIMALS ±.010
3. SURFACES TO BE SCRATCH-FREE AND FLAT WITHIN LIMITS NOTED.
4. AFTER FABRICATION, PARTS ARE TO BE PACKAGED FOR FINISH PROTECTION.
5. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.

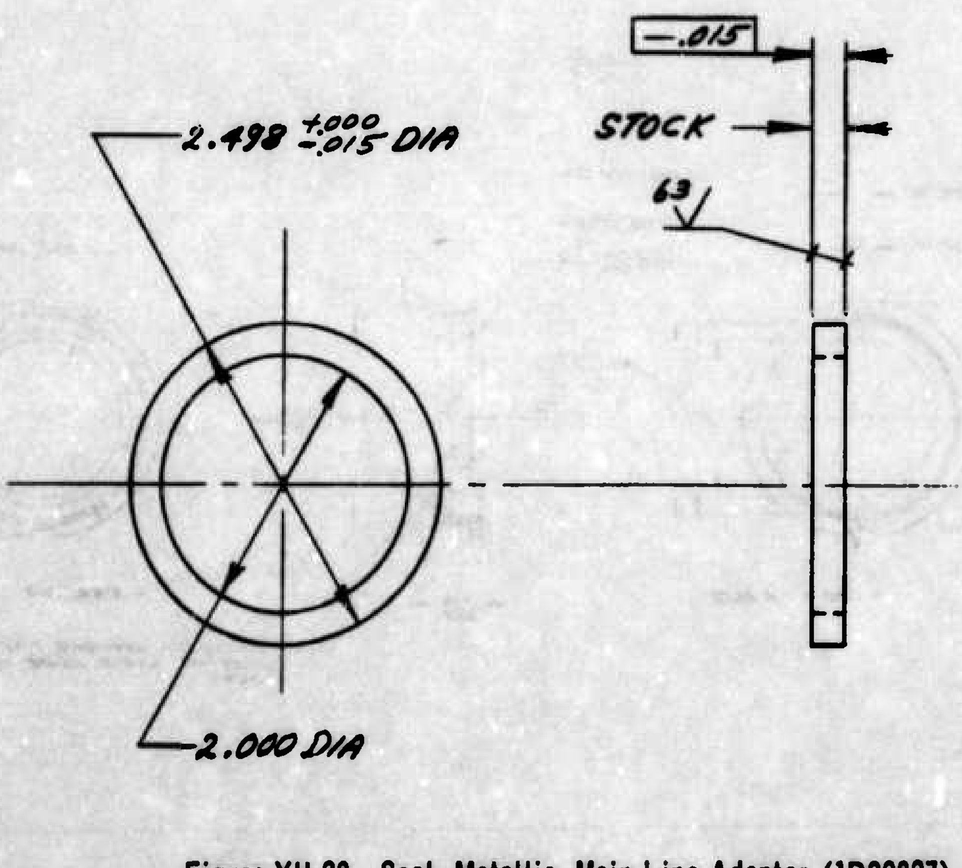


Figure XII-28. Seal, Metallic, Main Line Adapter (1D00827)

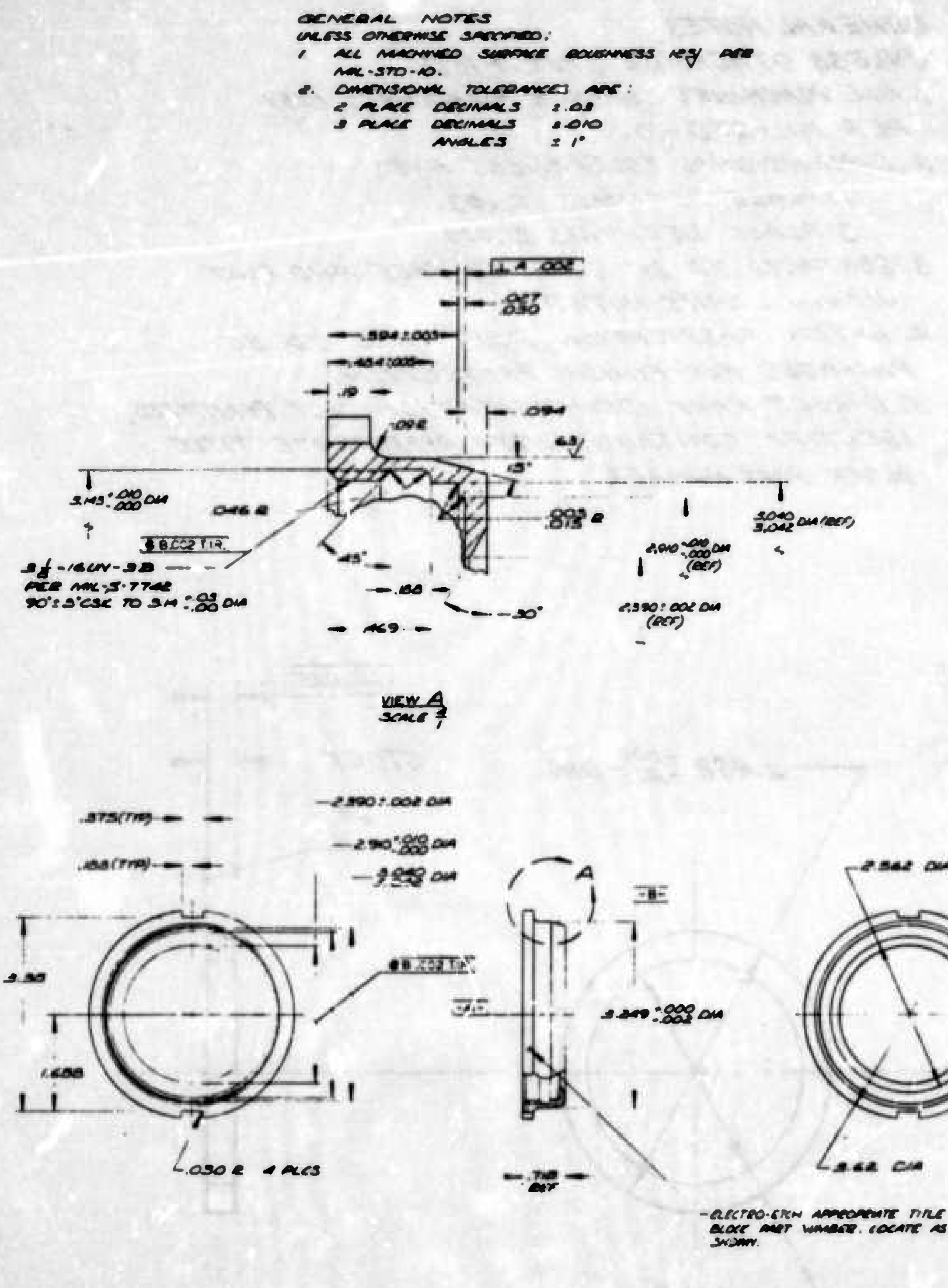


Figure XII-29. Retainer, Seal (1D00828)

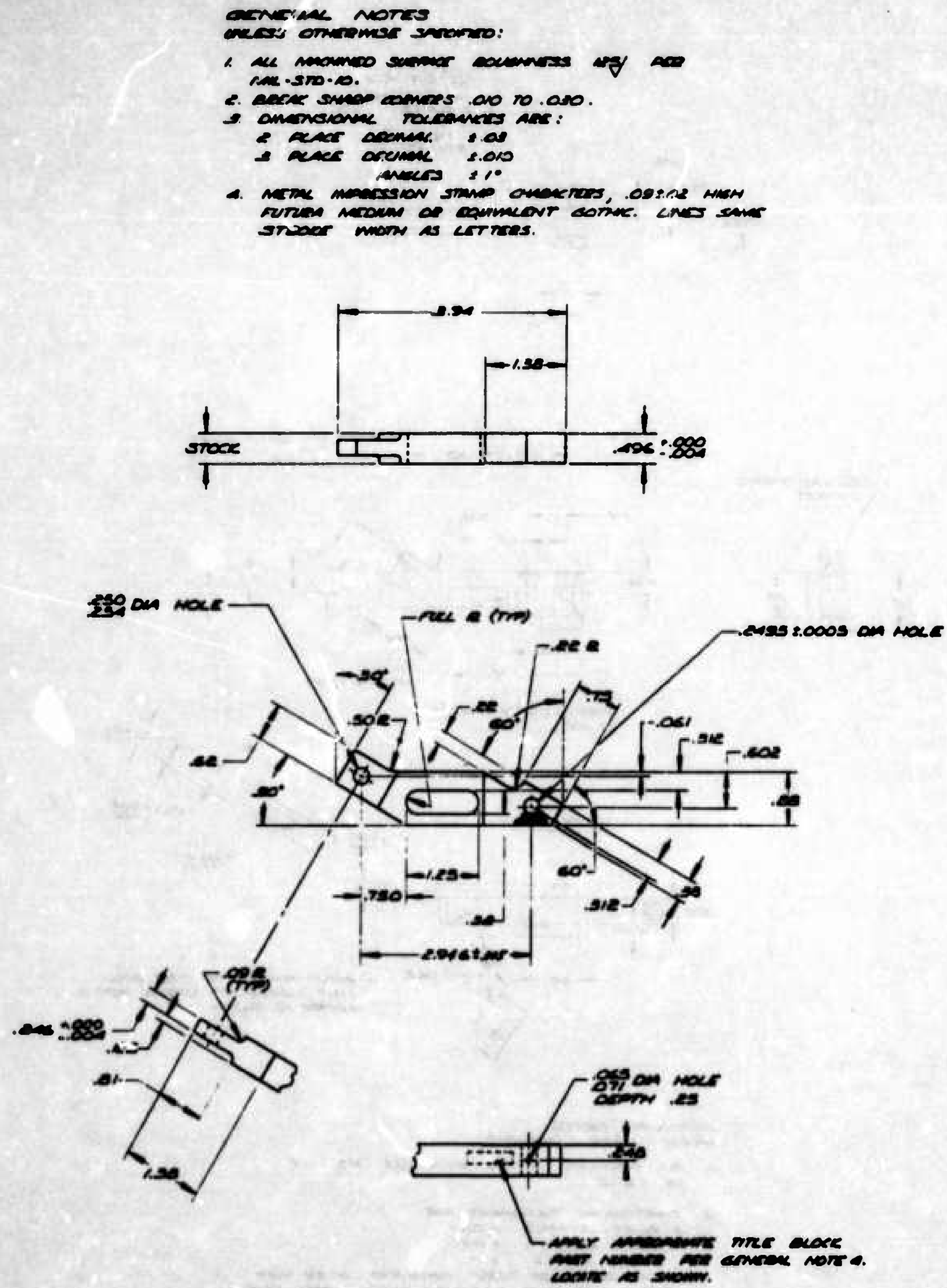


Figure XII-30. Link, Latch Retaining (1D00829)

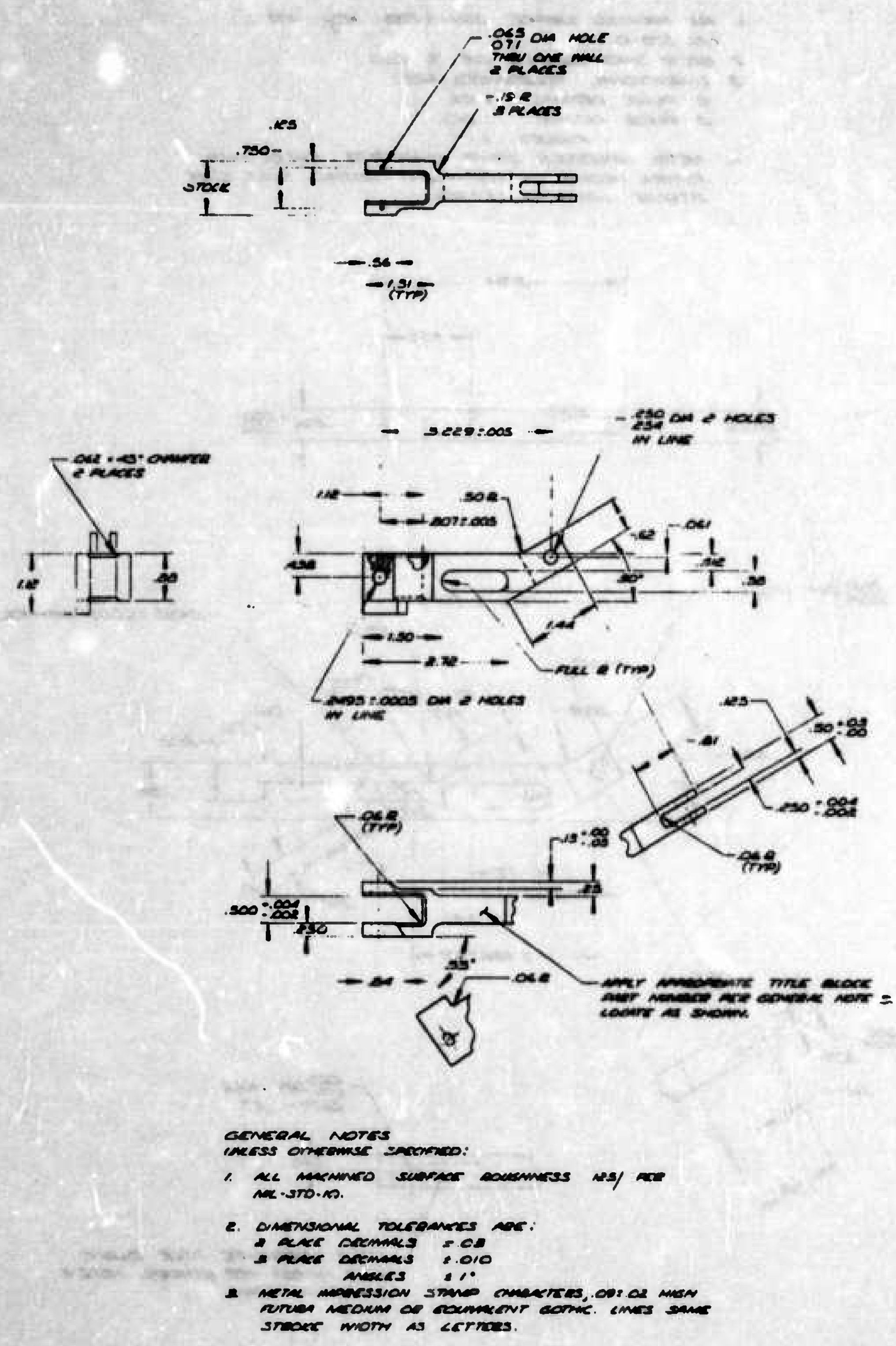
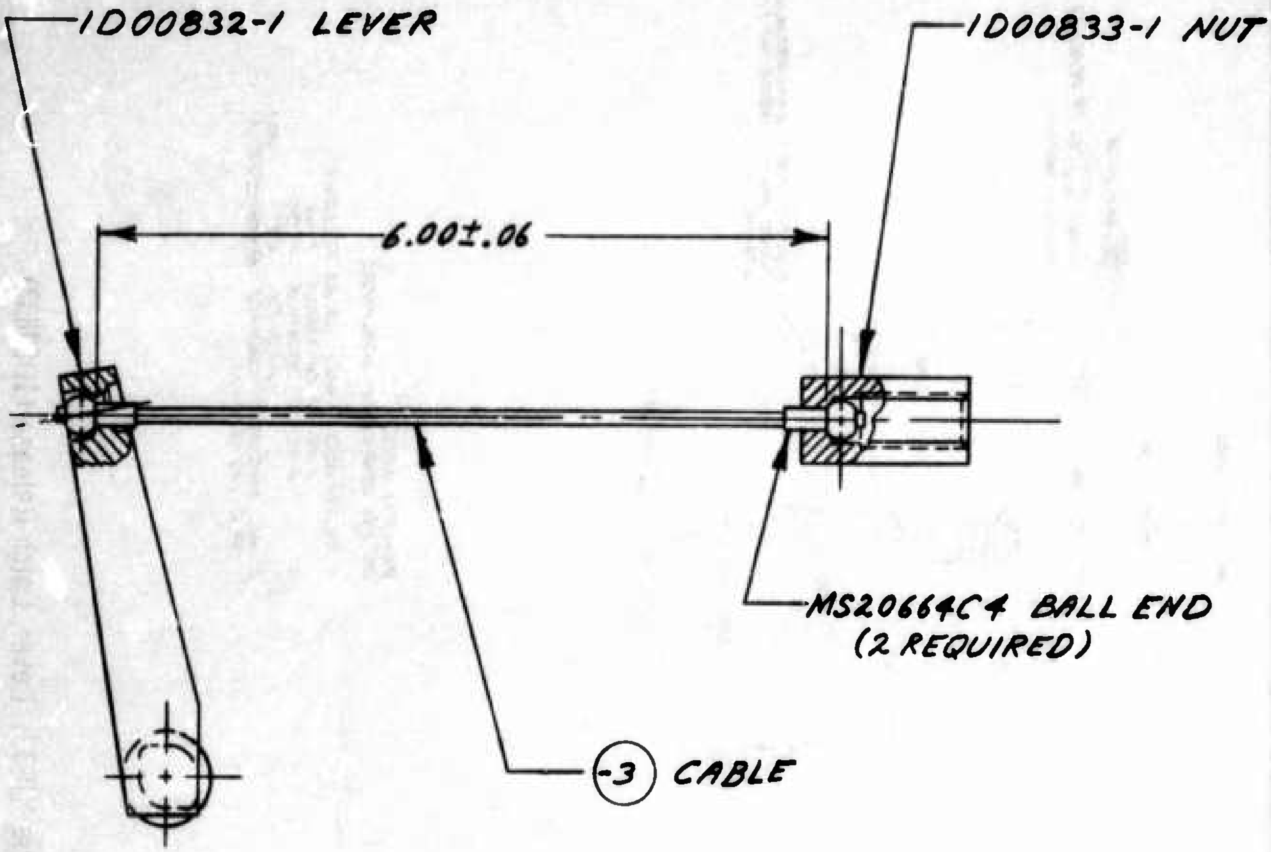


Figure XII-31. Link, Release Cam Retaining (1D00830)



GENERAL NOTES
UNLESS OTHERWISE NOTED:
1. SWAGE PER MIL-T-6117
2. PROOF TEST PER MIL-C-5688
3. DIRECT PART NUMBER IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.

Figure XII-32. Lever Assembly, Latch Release (1D00831)

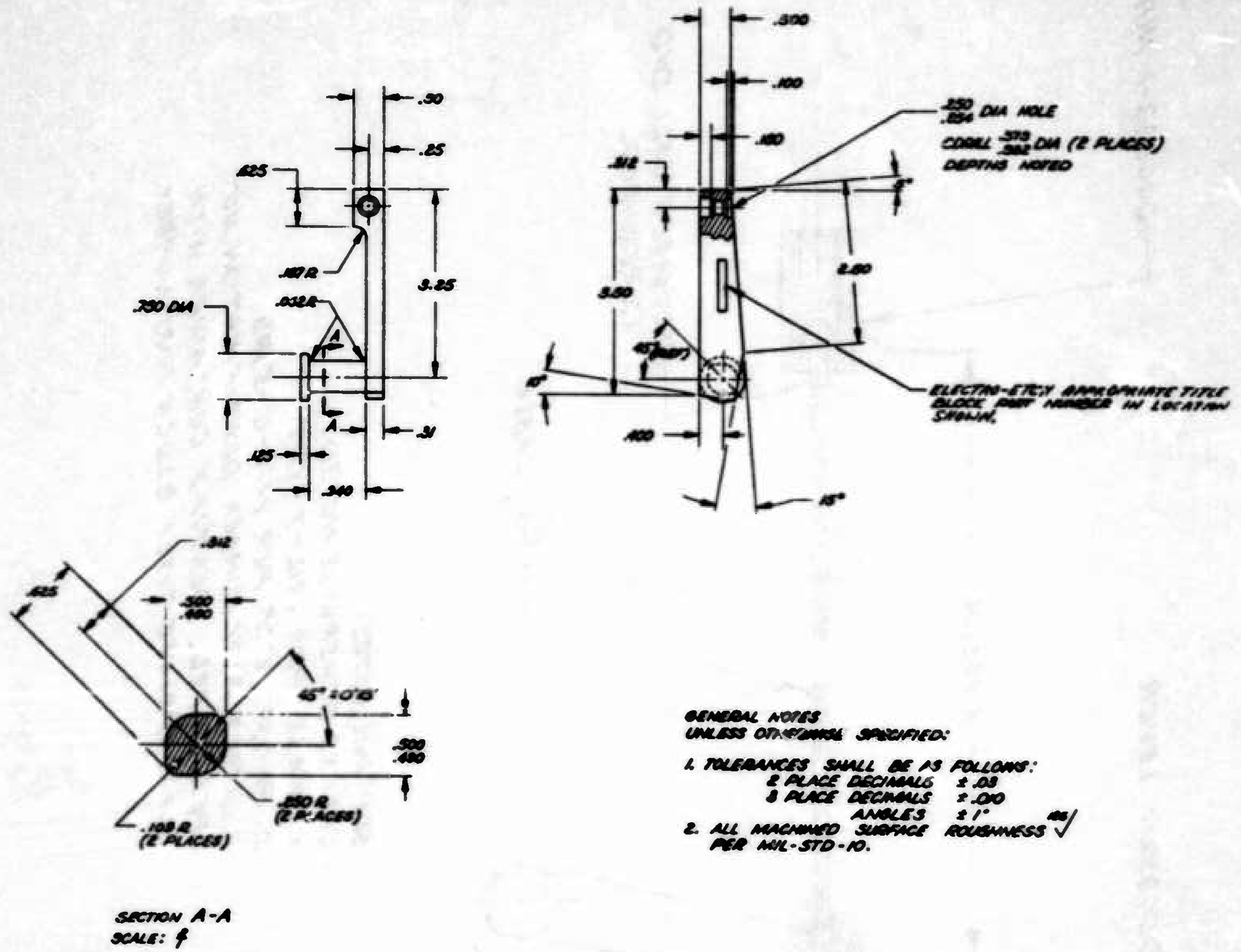


Figure XII-33. Lever, Latch Release (1D00832)

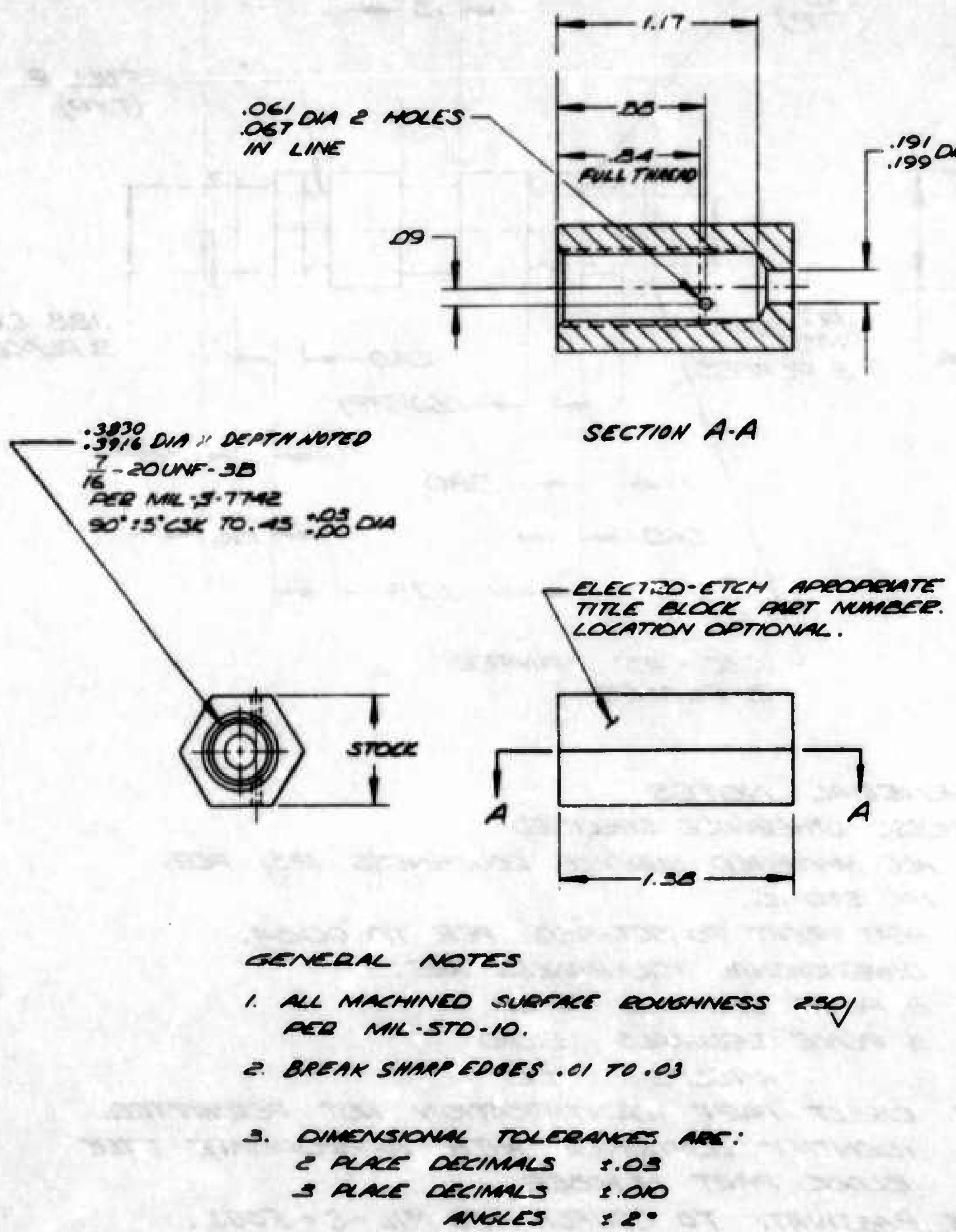
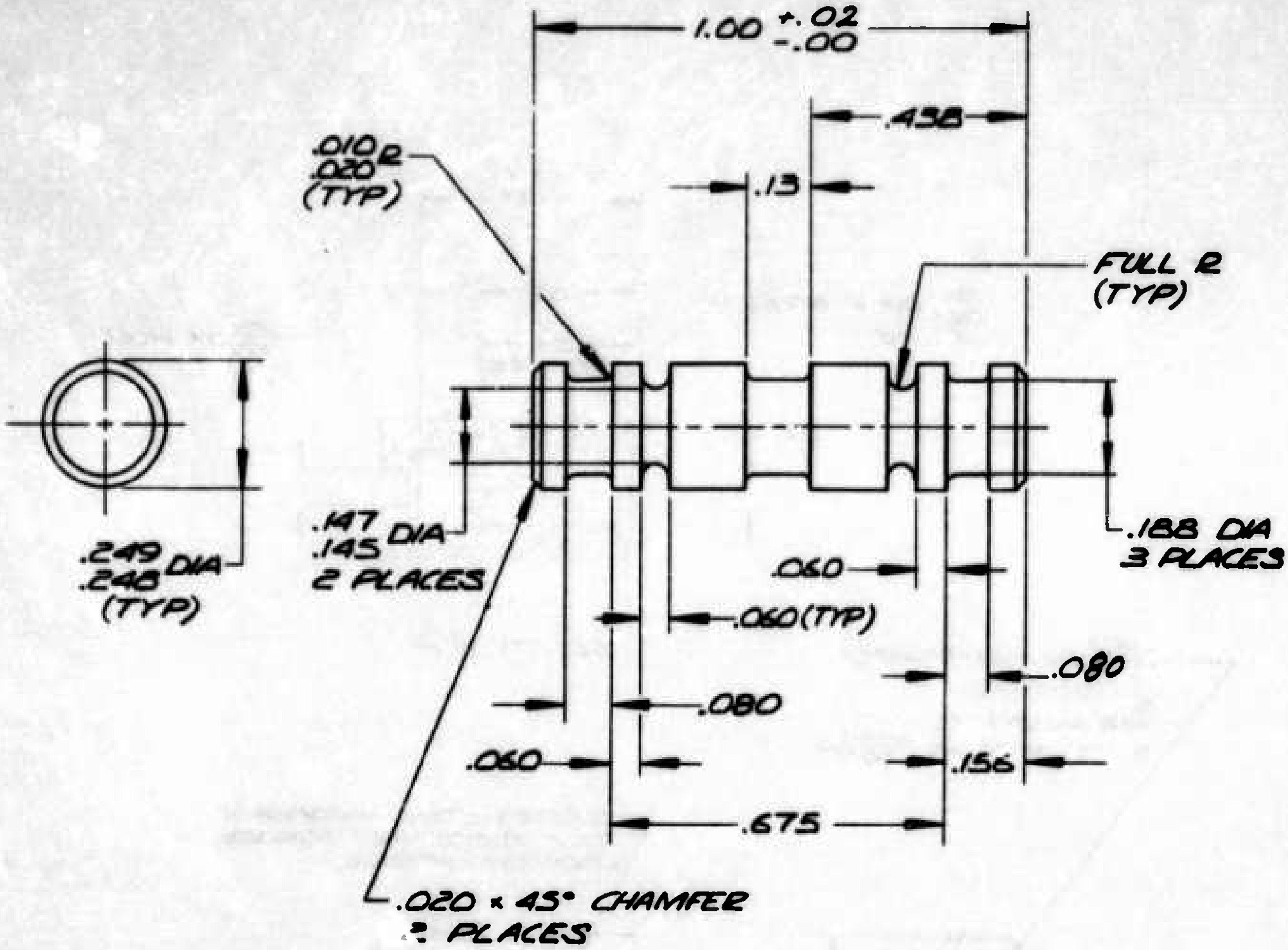


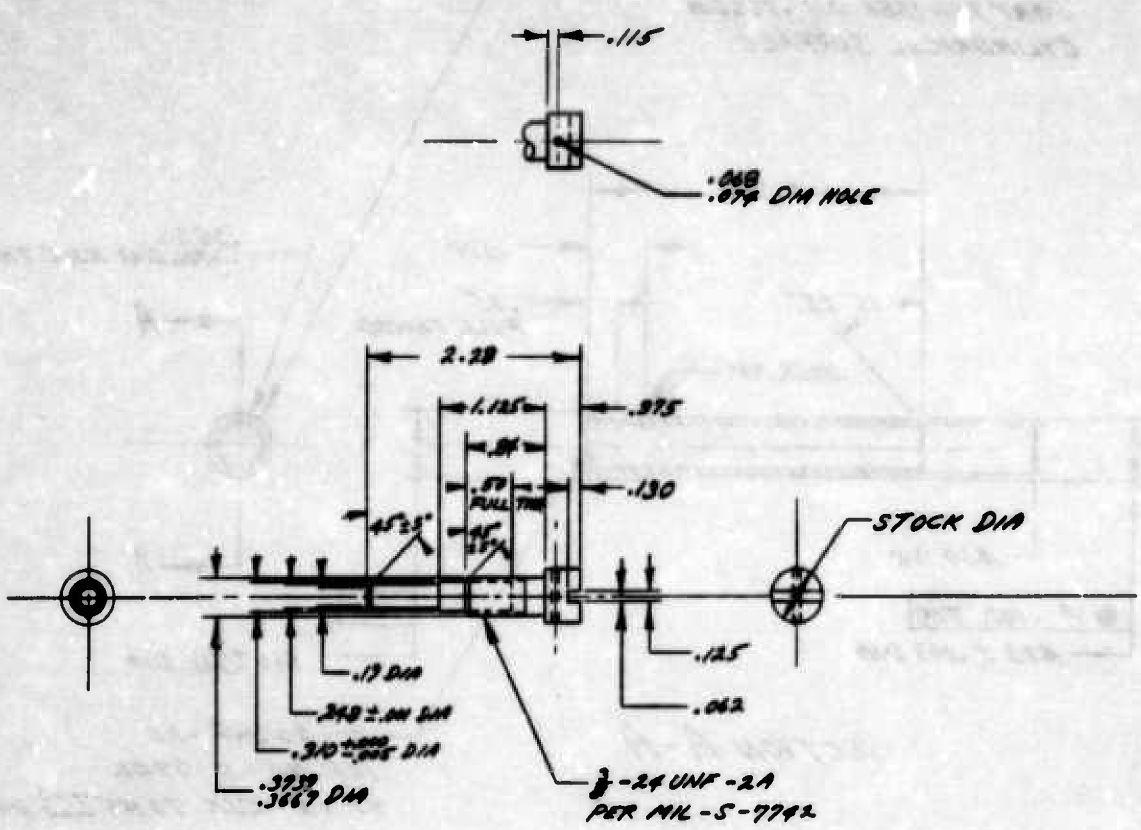
Figure XII-34. Nut, Coupling, Wire Rope (1D00833)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:

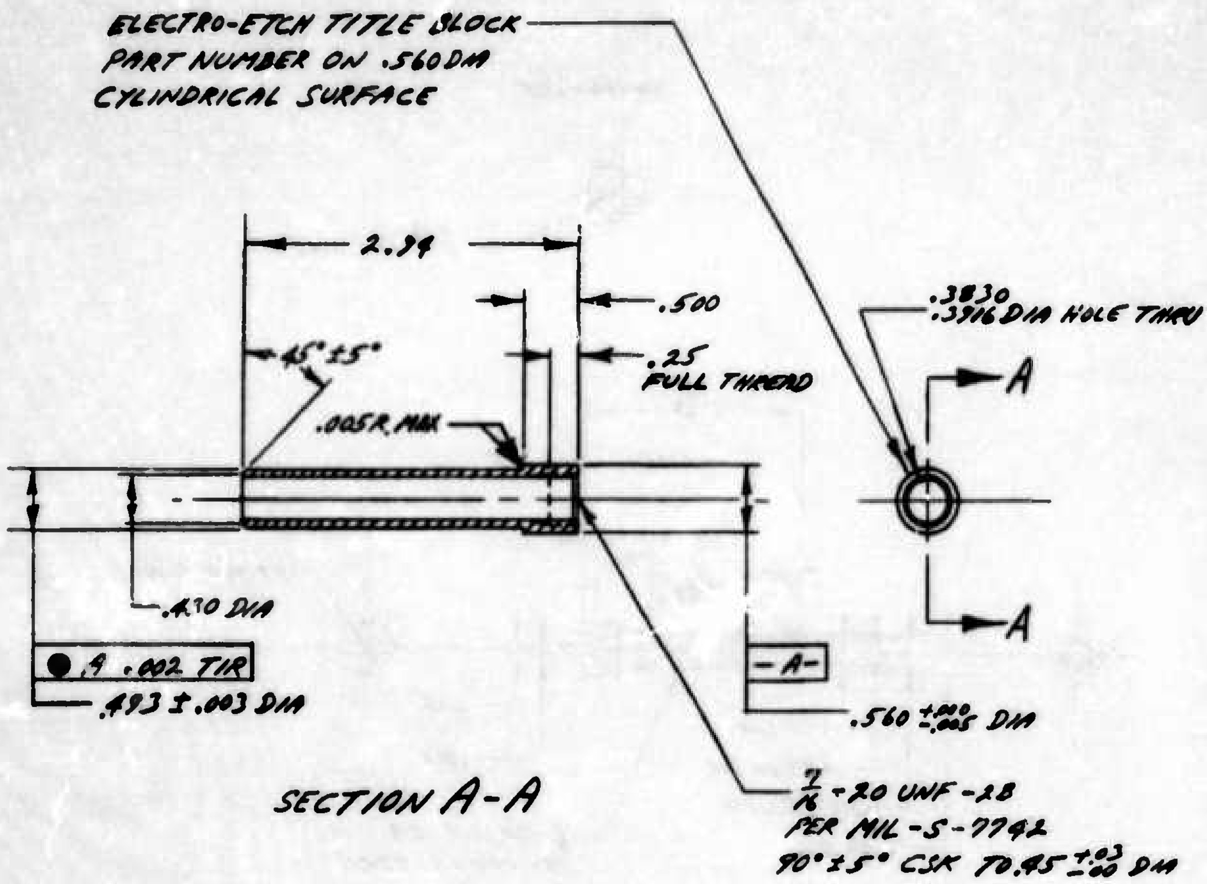
1. ALL MACHINED SURFACE ROUGHNESS 125 PER MIL-STD-10.
2. HEAT TREAT TO SCT-950 PER 1P00084.
3. DIMENSIONAL TOLERANCES ARE:
   - 2 PLACE DECIMALS ±.03
   - 3 PLACE DECIMALS ±.010
   - ANGLES ±2°
4. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.
5. PASSIVATE TO CONFORM TO MIL-S-5002.

Figure XII-35. Pin, Shear, Latch Release (1D00834)



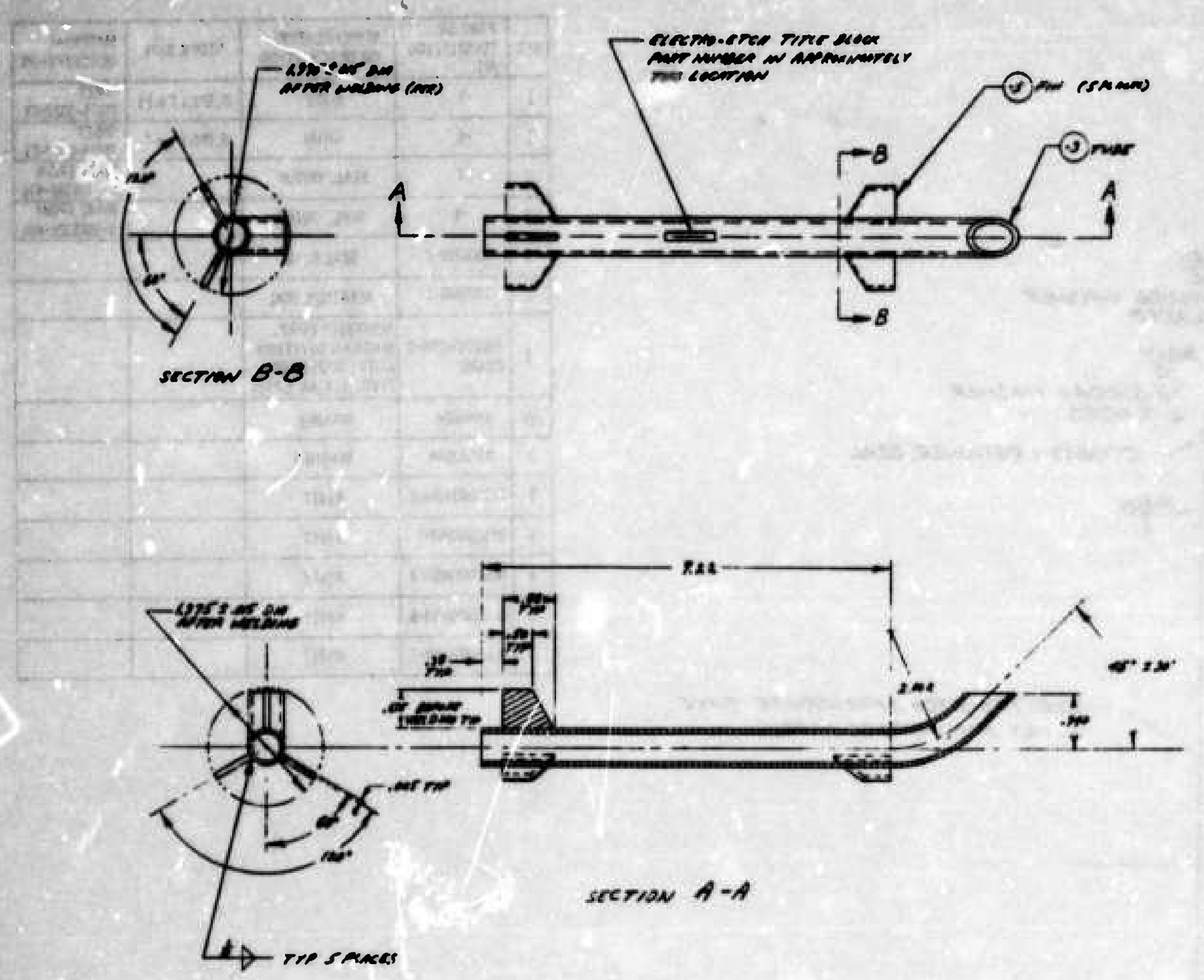
GENERAL NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL MACHINED SURFACE ROUGHNESS 125
PER MIL-STD-10.
2. ALL MACHINED FILLET RADII .005 .001
3. DIMENSIONAL TOLERANCES ARE:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ± 2°
4. BREAK SHARP EDGES .005 TO .015.
5. ELECTRO-ETCH PART NUMBER 1D00835-1 ON
CYLINDRICAL SURFACE OF SCREW HEAD.

Figure XII-36. Screw, Retaining, Cylinder Block (1D00835)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL MACHINED SURFACES 125 PER MIL-STD-10
2. DIMENSIONAL TOLERANCES ARE:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010

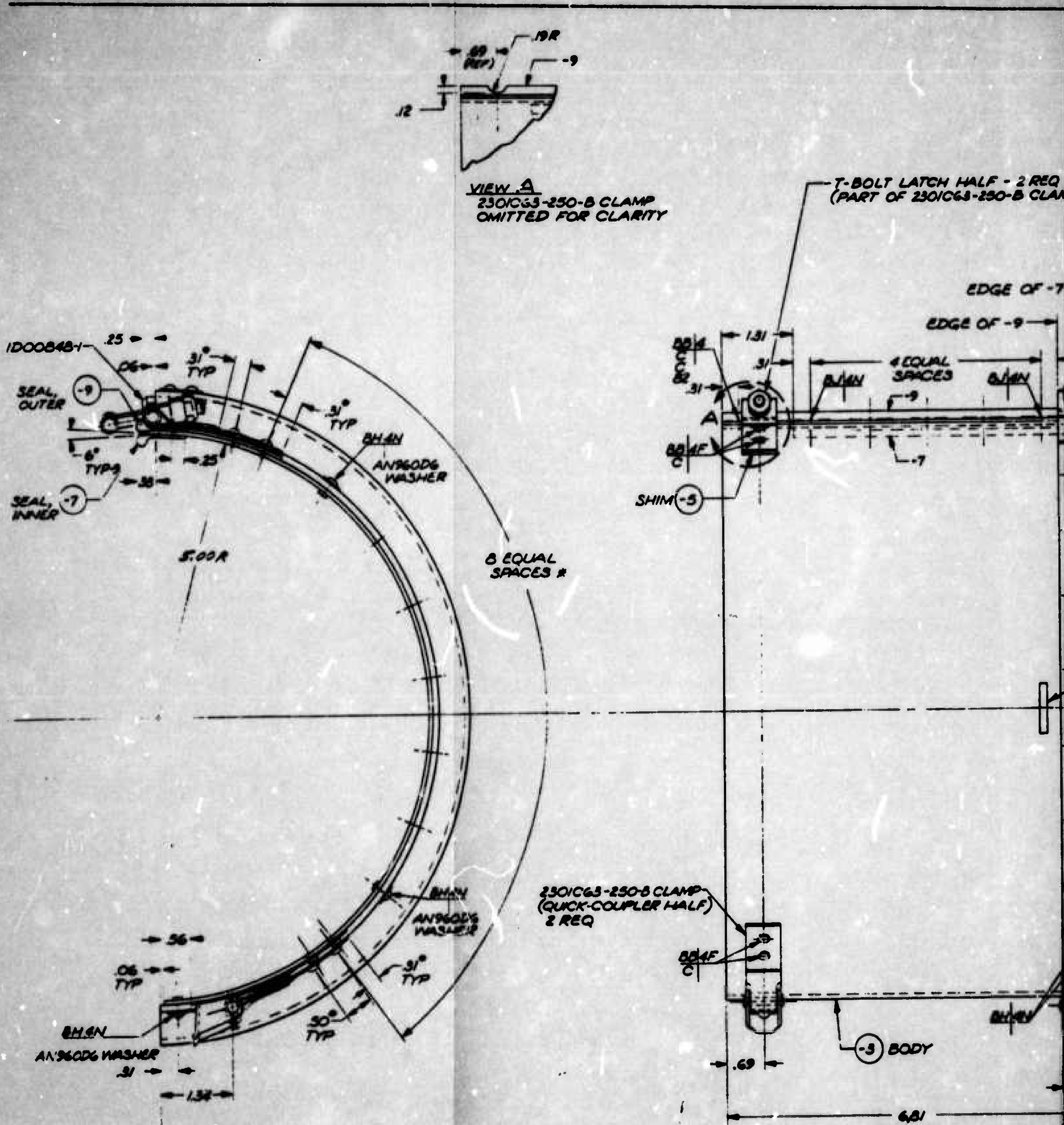
Figure XII-37. Retainer, Purge Line Nozzle (1D00836)

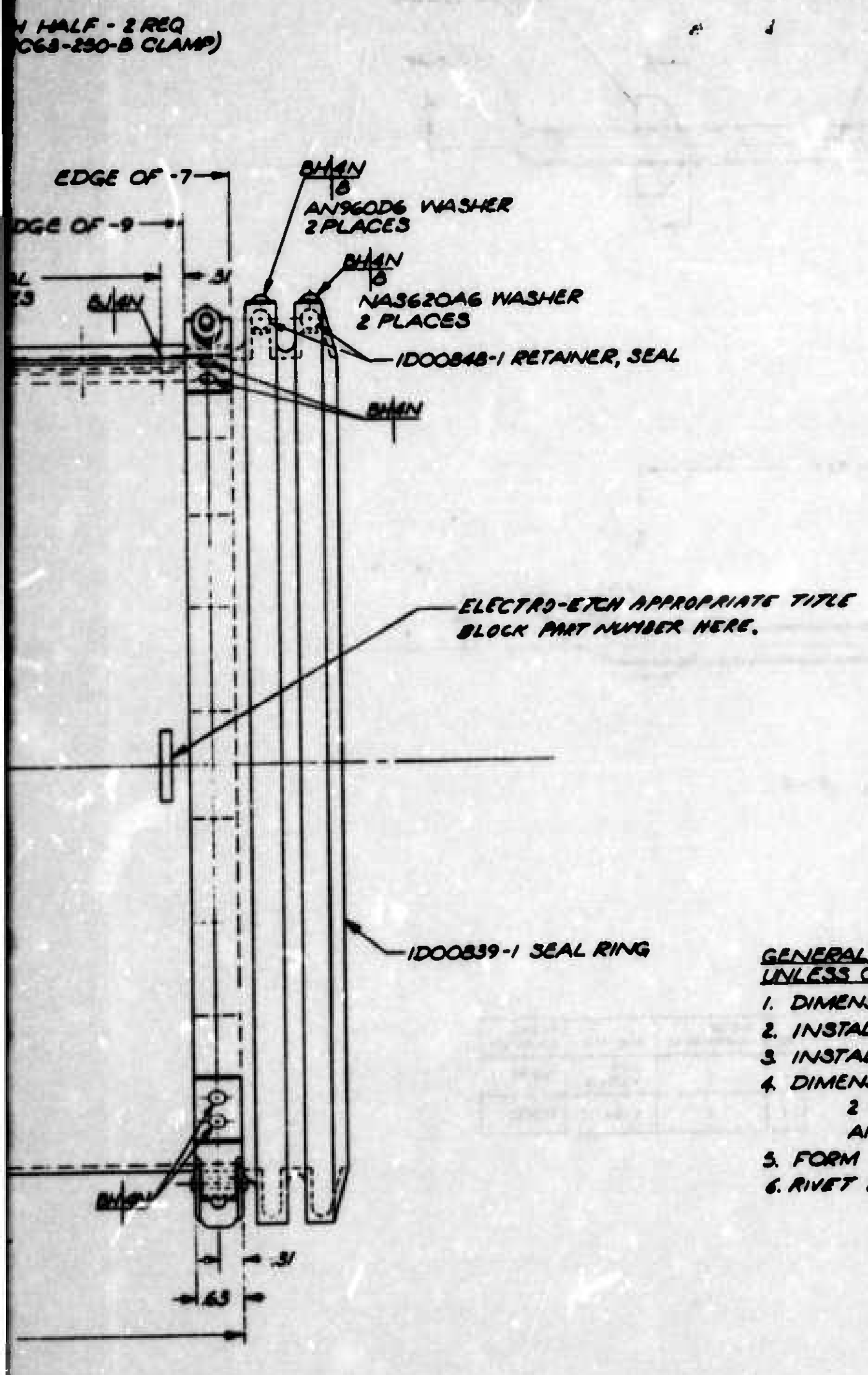


GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:
1. TOLERANCES ARE AS FOLLOWS:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ± 2°
2. FUSION WELD PER MIL-W-8611.
3. NO RADIOGRAPHIC INSPECTION OF WELD REQUIRED. HOWEVER NO SURFACE CRACKS OR VISIBLE INCLUSIONS ARE PERMISSIBLE IN WELD.

REQ	PART OR IDENTIFYING NO.	STOCK SIZE	MATERIAL DESCRIPTION
1	-3	5/8 O.D. x 0.50 x 14	TUBE 347 1
5	-5	0.090 x 1 x1	SHEET 321

Figure XII-38. Nozzle Assembly, Purge Line (1D00837)


VIEW A
2301C63-250-B CLAMP
OMITTED FOR CLARITY
T-BOLT LATCH HALF - 2 REQ
(PART OF 2301C63-250-B CLAM
EDGE OF -7
EDGE OF -9
4 EQUAL SPACES
SHIM -5
SEAL, OUTER
SEAL, INNER
AN960D6 WASHER
5.00R
8 EQUAL SPACES
2301C63-250-B CLAMP
(QUICK-COUPLER HALF)
2 REQ
-3 BODY
6.81



REQ	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	STOCK SIZE	MATERIAL DESCRIPTION
1	-3	BODY	0.071 x 7 x 16	SHEET 2024-T3
1	-5	SHIM	0.050 x 1 x 2	SHEET 2024-T3
1	-7	SEAL, OUTER		MAKE FROM S-2505326-516
1	-9	SEAL, OUTER		MAKE FROM S-2505326-606
1	1D00839-1	SEAL RING		
2	1D00848-1	RETAINER SEAL		
2	2301C63-230-B CLAMP	AEROQUIP CORP. MARMAN DIVISION 11214 EXPOSITION BLVD., L.A. 64, CALIF.		
10	AN960D6	WASHER		
2	NAS620A6	WASHER		
5	MS20426AD4-5	RIVET		
8	MS20470A4-7	RIVET		
4	MS20470AD4-8	RIVET		
5	MS20470AD4-6	RIVET		
4	MS20470AD4-7	RIVET		

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS MARKED THUS * ARE ON SURFACE OF PART.
2. INSTALL MS20470 RIVETS PER MIL-STD-403.
3. INSTALL MS20426 RIVETS PER MIL-STD-403.
4. DIMENSIONAL TOLERANCES ARE AS FOLLOWS:
   2 PLACE DECIMALS ±.03
   ANGLES ±0°30'
5. FORM OR STRAIGHTEN -3, -5, -7 AND -9 PER 1P00011.
6. RIVET DESIGNATION
   MS20470AD4 AD4
   MS20426AD4 BB4
   MS20470A4 BH4

Figure XII-39. Shroud, Anti-Icing (1D00838)

2

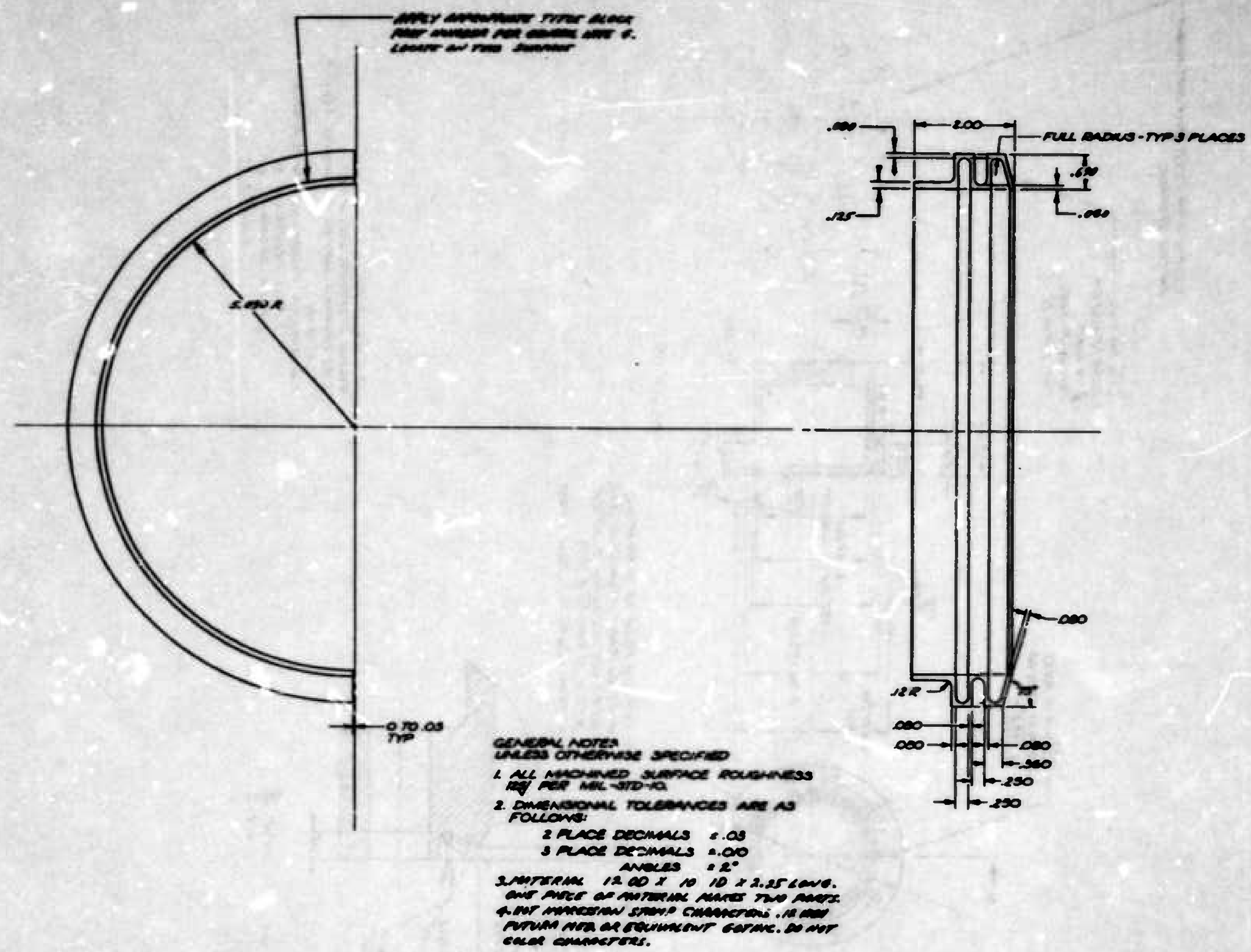


Figure XII-40. Seal Ring, Anti-Icing Shroud (1D00839)

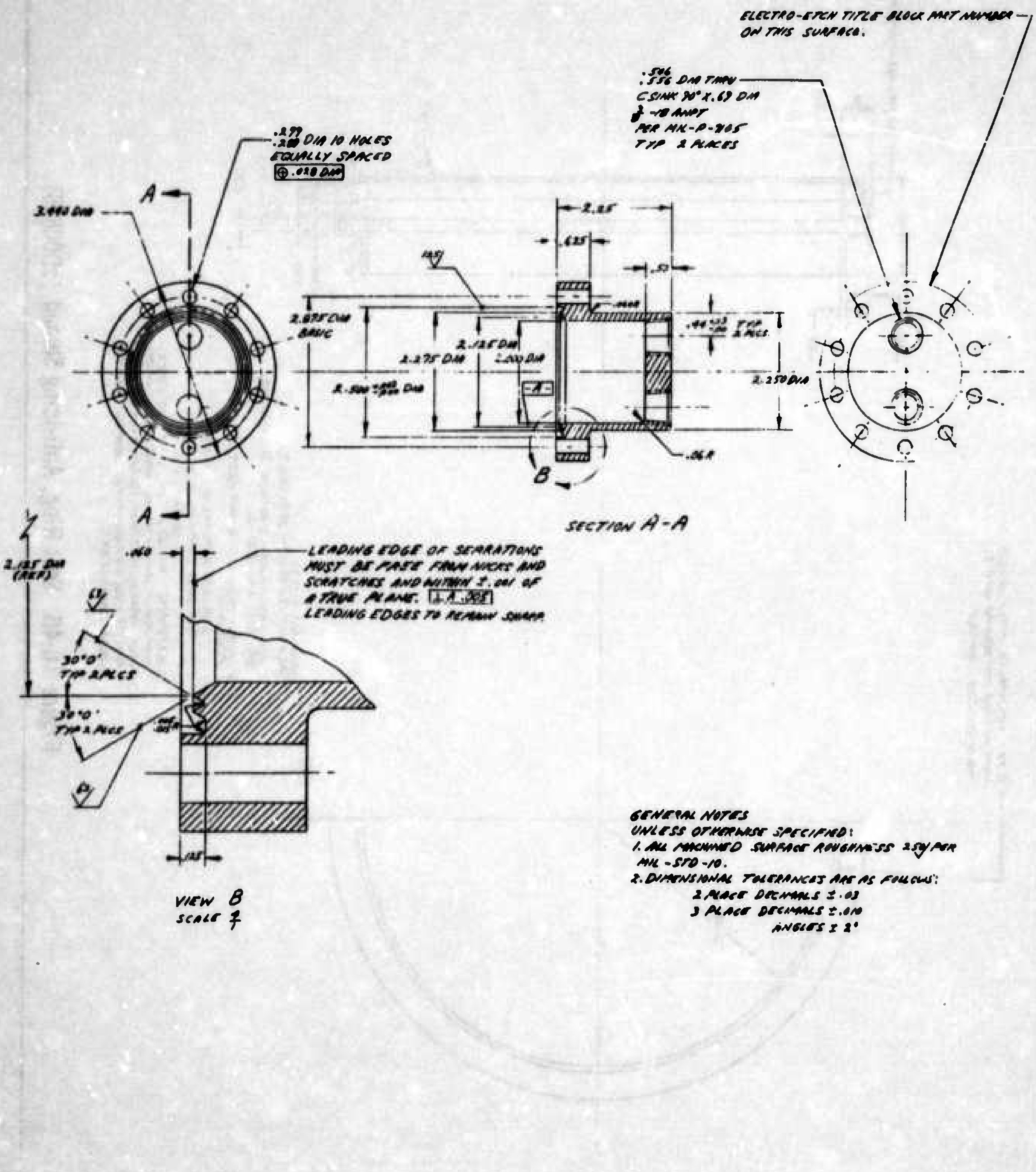
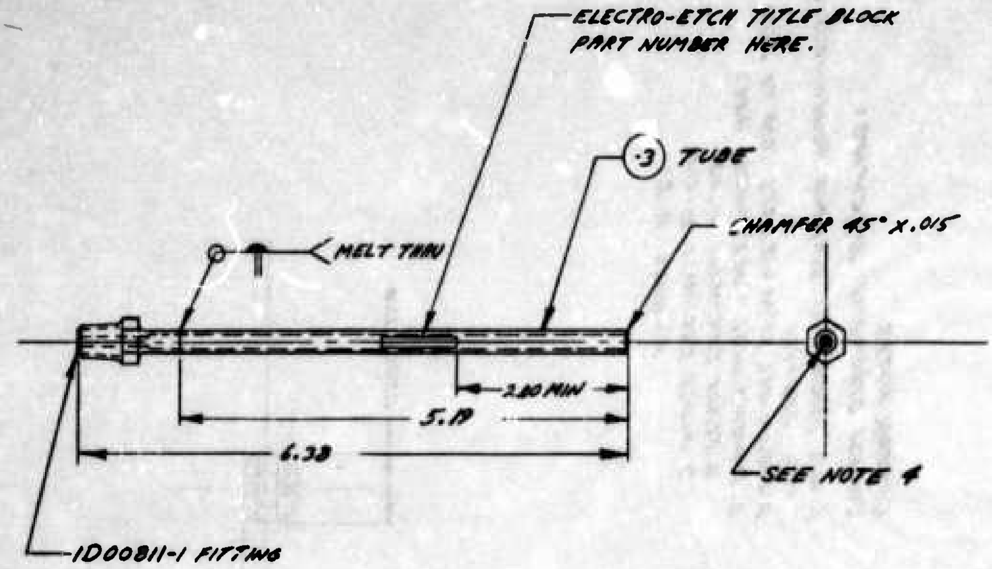


Figure XII-41. Flange, Pipe Adapter (1D00842)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:
1. DIMENSIONAL TOLERANCES ARE:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ± 2°
2. WELD PER MIL-W-8611.
3. NO RADIOGRAPHIC INSPECTION OF WELD REQUIRED. HOWEVER WELD MUST BE FREE OF ANY VISIBLE CRACKS OR INCLUSIONS.
4. .099 DIA MIN OPENING THRU TUBE ASSEMBLY AFTER WELDING.
5. .015 MAX MISMATCH BETWEEN OD'S OF -3 AND 1D00811-1 AFTER WELDING.

REQ	PART OR IDENTIFYING NO.	STOCK SIZE	MATERIAL DESCRIPTION	MATERIAL SPECIFICATION
1	1D00843-3	1/4 O.D. x 0.049 x 5.50	CRES TUBE TYPE 304L	AMS5647
1	1D00811-1			

Figure XII-42. Tube Assembly, Metal – Seal Cavity Purge (1D00843)

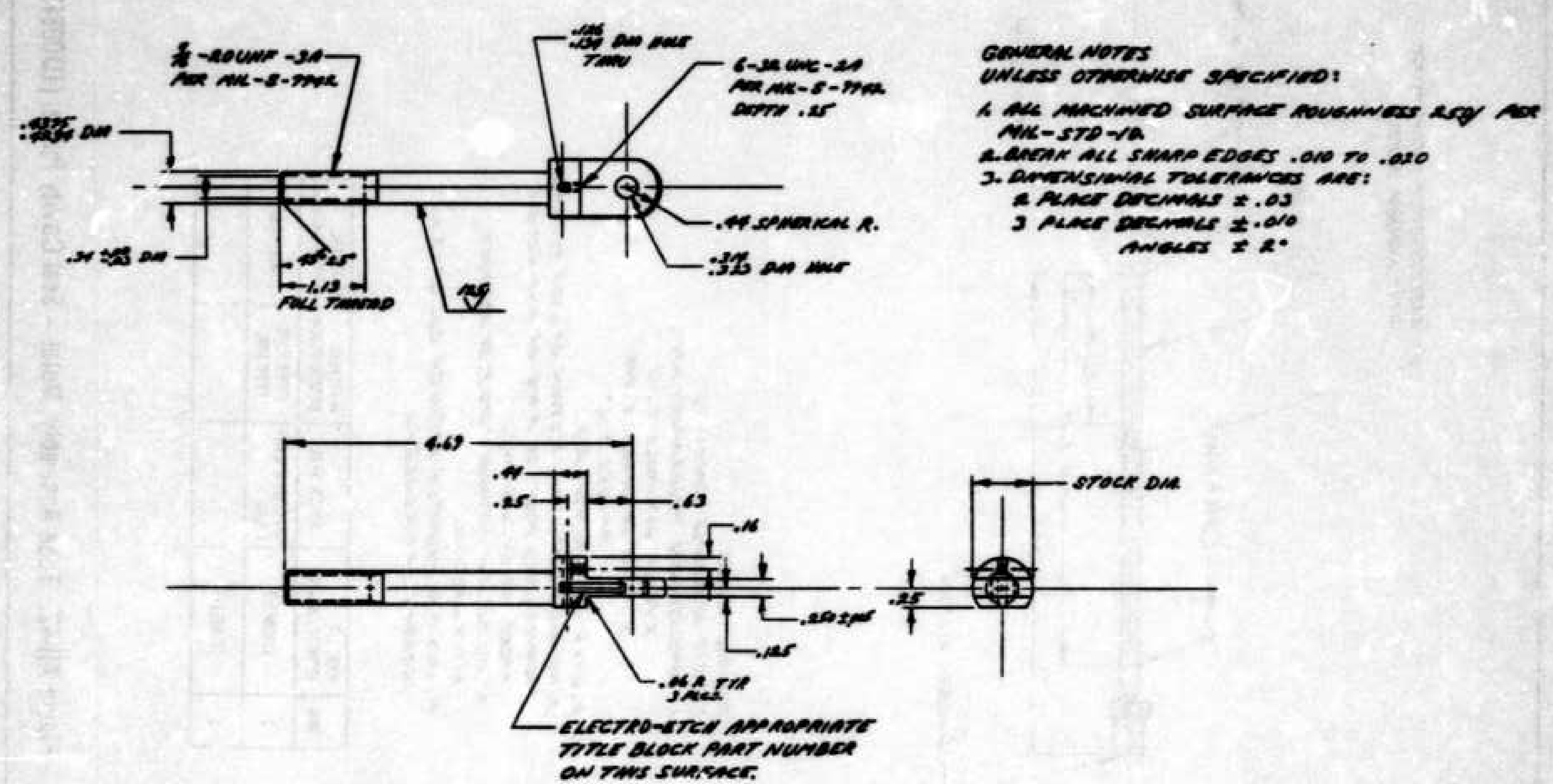
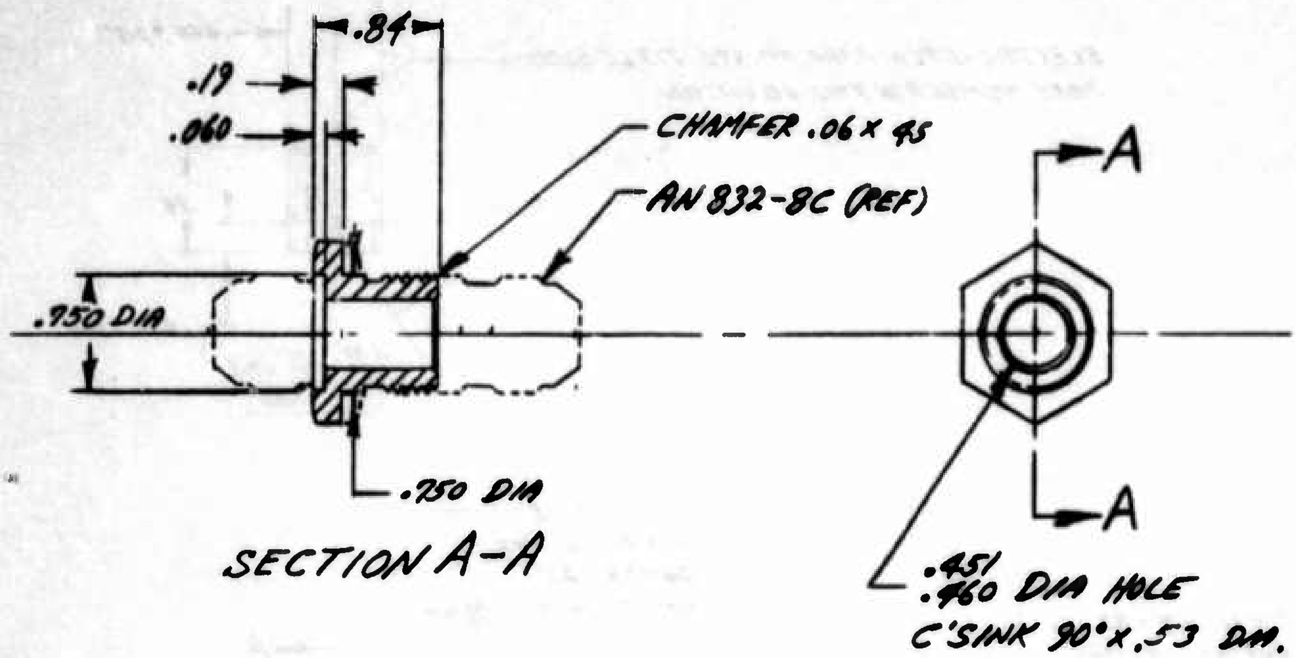
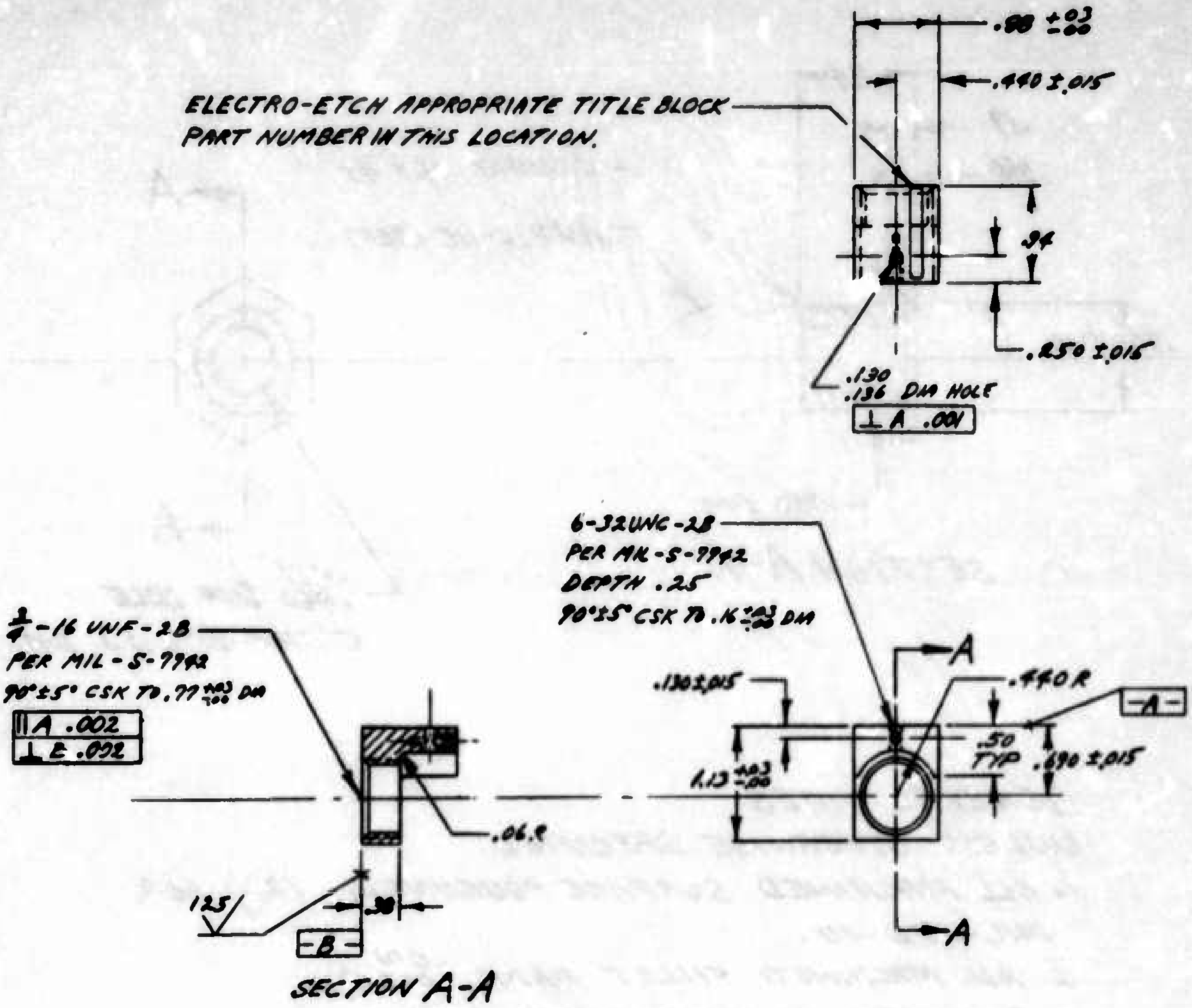


Figure XII-43. Link, Separation Mechanism (1D00844)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED:
1. ALL MACHINED SURFACE ROUGHNESS 125 PER MIL-STD-10.
2. ALL MACHINED FILLET RADII .010/.020 R.
3. DIMENSIONAL TOLERANCES ARE:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ± 2°

Figure XII-44. Sleeve, Separation Mechanism (1D00845)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED
1. ALL MACHINED SURFACE ROUGHNESS 250
PER MIL-STD-10
2. DIMENSIONAL TOLERANCES ARE AS FOLLOWS:
2 PLACE DECIMALS ±.03
3 PLACE DECIMALS ±.010
ANGLES ± 1°

Figure XII-45. Nut, Separation Mechanism (1D00846)

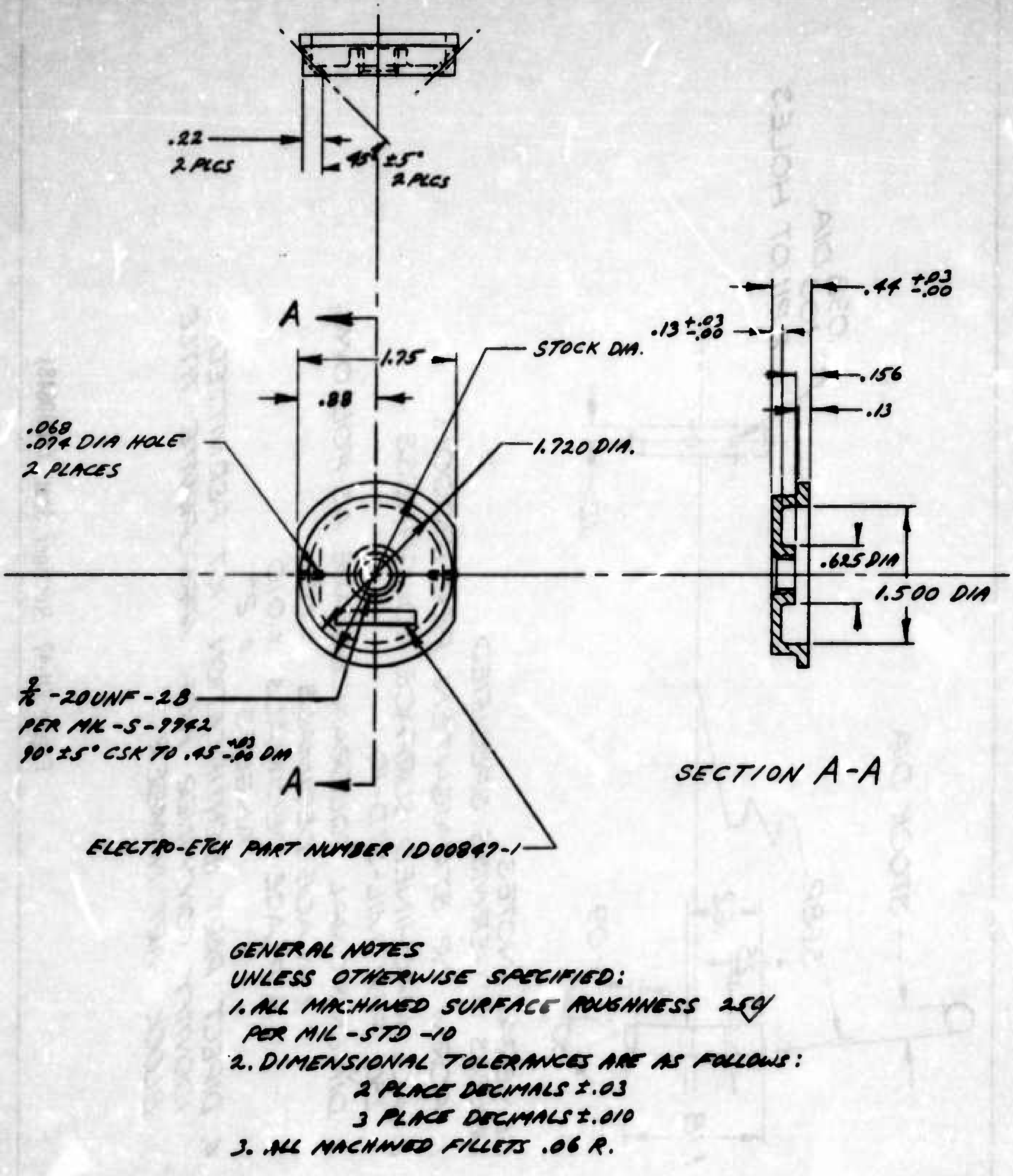
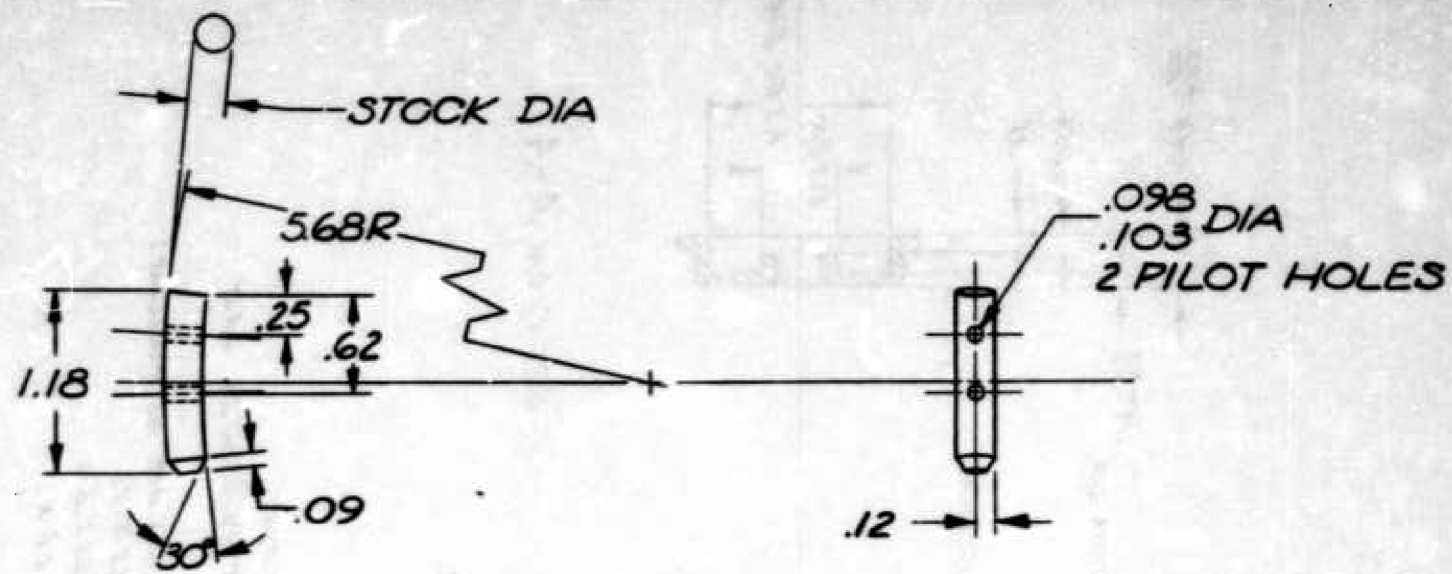


Figure XII-46. Stop, Separation Mechanism (1D00847)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED

1. FORM OR STRAIGHTEN PER 1P00011.
2. ALL MACHINED SURFACE ROUGHNESS 250√ PER MIL-STD-10.
3. DIMENSIONAL TOLERANCES ARE AS FOLLOWS:
   - 2 PLACE DECIMALS ±.03
   - 3 PLACE DECIMALS ±.010
   - ANGLES ± 2°
4. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.

Figure XII-47. Retainer, Seal (1D00848)

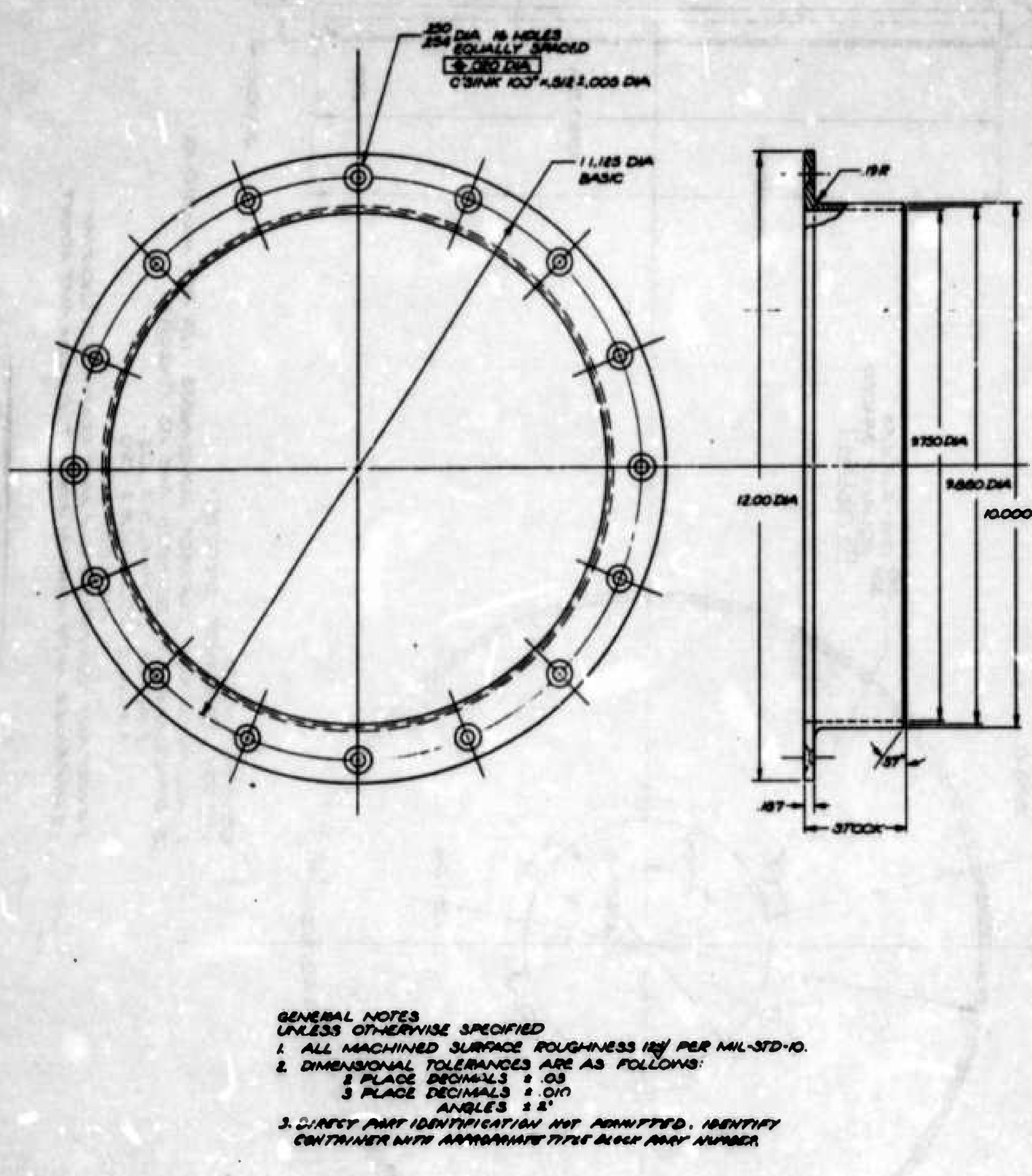
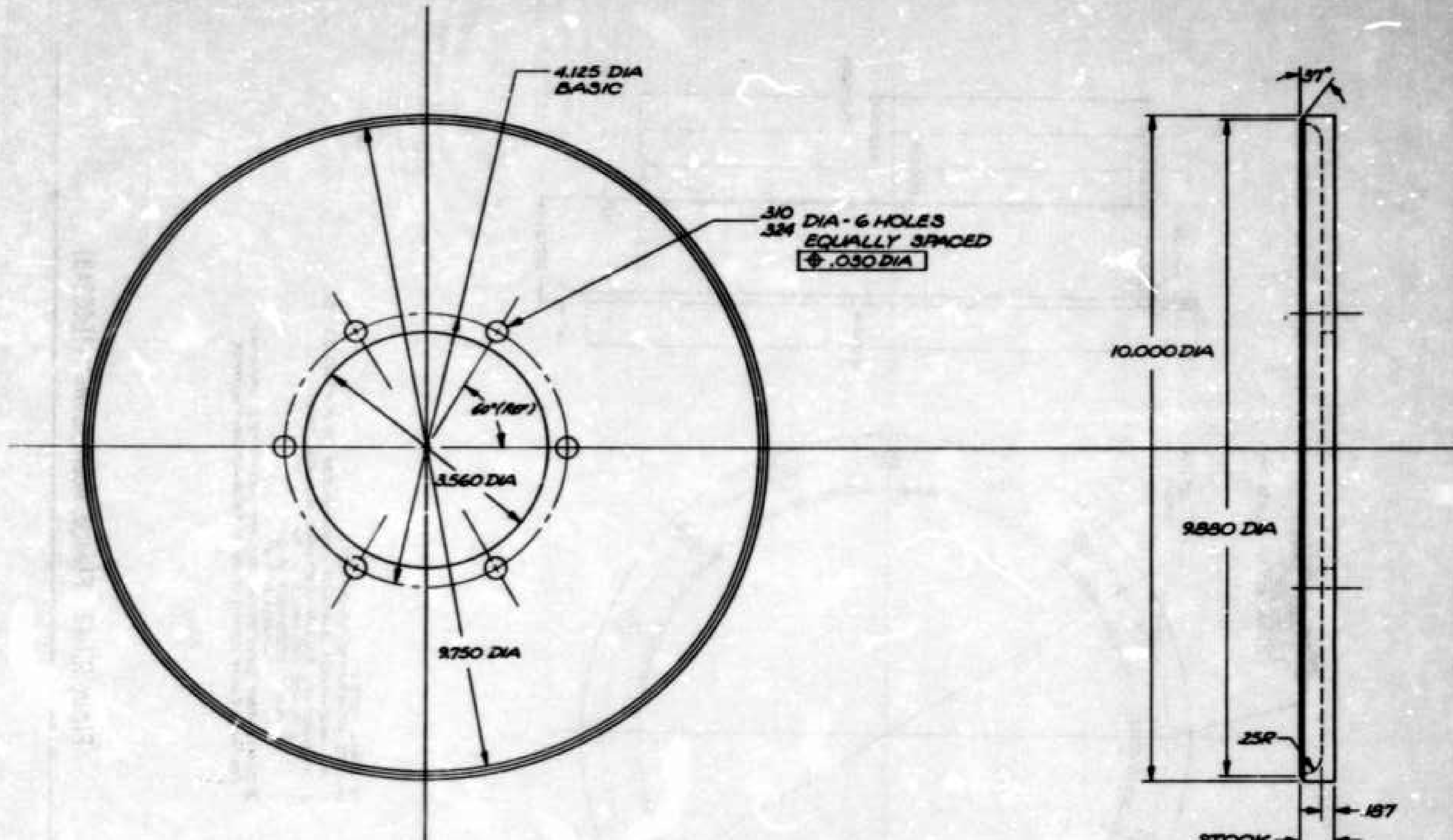


Figure XII-48. Flange, Mount, Lower (1D00849)



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED

1. ALL MACHINED SURFACE ROUGHNESS 125 PER MIL-STD-10.
2. DIMENSIONAL TOLERANCES ARE AS FOLLOWS:
   2 PLACE DECIMALS ± .03
   3 PLACE DECIMALS ± .010
   ANGLES ± 2°
3. DIRECT PART IDENTIFICATION NOT PERMITTED. IDENTIFY CONTAINER WITH APPROPRIATE TITLE BLOCK PART NUMBER.

Figure XII-49. Flange, Mount, Upper (1D00850)

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13. ABSTRACT

This report documents the results of a study conducted to define criteria for quick disconnect (QD) couplings for use with fluorine and fluorine containing oxidizers. For this study a number of vehicle systems were examined to determine the fundamental requirements for couplings. Identified are the requirements imposed on a typical upper stage oxidizer fill-and-drain QD by vehicle and AGE considerations, and disconnect technology capabilities. It was determined that the coupling should remain connected until vehicle launch is committed, and that the coupling should not provide oxidizer flow control or fluid shutoff provisions.

Design development and criteria demonstration tests were conducted using both liquid nitrogen and liquid fluorine on two test model QD's during the Phase II portion of this study. Specifically studied were the parameters influencing leakage, connect/disconnect, the draining and purging of fluorine, and compatibility. A detail specification was prepared along with detail drawings for a prototype QD coupling based on the criteria of Phase I and the test results of Phase II. One prototype QD was fabricated and acceptance tested prior to delivery as a part of this contract. The criteria established has been demonstrated by design, fabrication, and testing of a fluorine QD.

The primary conclusion resulting from this program is that the design criteria established have provided a quick disconnect that is capable of servicing vehicles utilizing liquid fluorine.

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Security Classification

14. KEY WORDS		LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
Engagement	Contamination						
Fluorine	Cleaning						
Chlorine trifluoride	Failure Modes						
FLOX	Purging						
Compound A	Testing						
Quick Disconnect Coupling	Specification						
Seals	Design						
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