CR 183969

FAIRCHILD
SPACE

# AUTOMATED FLUID INTERFACE SYSTEM (AFIS)
# FINAL REPORT DOCUMENT

Prepared for:

**National Aeronautics and Space Administration**
**George C. Marshall Space Flight Center**
Marshall Space Flight Center, AL 35812

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**NAS8-37457**

## FOREWORD

NASA has identified the need to develop a facility to conduct the on-orbit transfer of fluids either Situ via the OMV or while attached to the STS or Space Station Freedom. In response to that need, Fairchild Space has developed the Automated Fluid Interface System (AFIS) flight concept and demonstration unit. This report describes the Fairchild design in response to the AFIS contract requirements, contract number NAS8-37457.

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# 1.0 INTRODUCTION

## 1.1 BACKGROUND

Automated remote fluid servicing will be necessary for future space missions, as future satellites will be designed for on-orbit consumable replenishment. In order to develop an on-orbit remote servicing capability, a standard interface between a tanker and the receiving satellite is needed.

The objective of the Automated Fluid Interface System (AFIS) program is to design, fabricate, and functionally demonstrate compliance with all design requirements for an automated fluid interface system. This effort was done for the Marshall Space Flight Center, contract NAS8-37457.

This report provides a description and documentation of the Fairchild AFIS design. The Fairchild requirements are documented in the "AFIS Requirements Document", Fairchild, Nov 1989, NAS8-37457, and the test plan is documented in the "Test Plan and Operational Procedures", Fairchild, April 1989, NAS8-37457.

## 1.2 SUMMARY DESCRIPTION

The Automated Fluid Interface System (AFIS) is an automated system that provides the capability for remote satellite refueling. It is designed to be compatible with the space servicing infrastructure which includes the Space Transportation System (STS), the Space Station, the Orbital Spacecraft Consumables Resupply System (OSCRS), and the Orbital Maneuvering Vehicle (OMV).

AFIS is designed to be a flexible, completely redundant, reconfigurable system capable of resupplying either cryogens or bi-propellants and monopropellants. It can accommodate up to 8 fluid type couplers, 4 gas couplers and 8 C&DH electrical connectors on a single mission. The number and location of the coupler and connectors can be arranged as dictated by the mission requirements. It is designed to be compatible with the three Point Docking Mechanism (TPDM) and the Remote Grapple Docking Mechanism (RGDM) on the OMV and can be reused for 40 missions. The design meets all of the safety requirements of the STS. The AFIS is 5 feet in diameter and 17.5 inches high without the legs. The legs shown in **Figure 1-1** are 19 inches high in order to be compatible with the OMV, however, they could be shorter depending on the particular mission requirement. The total system, AFIS and legs, weighs between 325 to 450 pounds depending on the number of fluid couplers and electrical connectors required.

The AFIS can be left on orbit for an extended period of time since it does not require refurbishment between missions and contamination covers are provided to prevent debris from getting into the couplers and connectors.

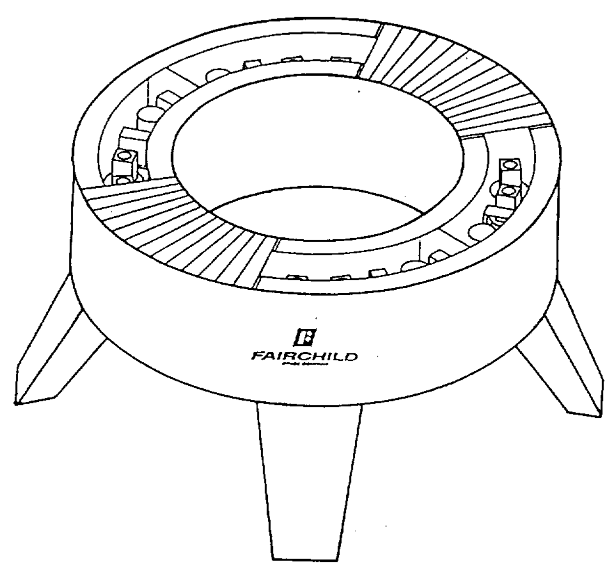


**Figure 1-1 AFIS Configuration**

# 2.0 SYSTEM TRADE STUDIES

## 2.1 DESIGN DRIVERS

The principal design requirement of AFIS is to transfer cryogens, propellants, liquids and high pressure gasses from one spacecraft to another. It is required to be compatible with Orbiting Maneuvering Vehicle (OMV) and OSCRS. Further, it must be compatible with the Three Point Docking Mechanism (TPDM) and the Remote Grapple Docking Mechanism (RGDM). One of the requirements of OMV is that a 15° docking clearance cone be provided. This requirement tends to drive the AFIS location toward the OMV centerline for maximum envelope usage and minimum connector travel.

AFIS is also required to provide redundancy. Providing redundant couplers and connectors consumes much of the available AFIS surface area. The number and sizes of the couplers and connectors for two AFIS configurations, including redundancy, is shown below:

Cryogen Transfer Configuration
- o 2 to 4 Cryogenic Couplers (6 inch Dia)
- o 4 to 8 Electrical Connectors (2 inch Dia)
- o 2 to 4 Gas Couplers (3 inch Dia)

Propellant Transfer Configuration
- o 4 to 8 Liquid Couplers (4 inch Dia)
- o 4 to 8 Electrical Connectors
- o 2 to 4 Gas Couplings

It is required that AFIS accommodate couplers/connectors as long as 15 inches on the AFIS side and 12 inches on the spacecraft side. This requirement drives the AFIS height.

The 2000 lbs pressure transfer force requirement is the design driver for the latch design. Other drivers include safety requirements and the need for contamination covers to keep the couplers/connectors free of debris. One safety requirement is the need to keep the fuel and oxidizer at safe distances. **Figure 2-1** summarizes the AFIS design drivers. Further detail on these requirements is provided in the "AFIS Requirements Document", Fairchild Space, November 1989, NAS8-37457.

## 2.2 TRADE STUDIES

Two basic concepts were considered for AFIS. The baseline is the present configuration which houses all the couplers, connectors, latches, motors, etc in one unit. The second concept considered was a distributed system of two or more smaller units.

The baseline AFIS has approximately a 61 inch outer diameter and is 17.5 inches tall with legs 19 inches long. Since the baseline is one unit, it can straddle the TPDM with a 36 inch annular opening. The maximum distance from the spacecraft to the AFIS is 4 inches.

Since the alternate configuration is distributed into smaller units, it cannot straddle the TDPM and thus must be placed further away from the center of the OMV. **Figure 2-2** shows the maximum available space outside of the TPDM to be about 24 by 24 inches. This is a result of the 15° docking clearance cone and the TPDM diameter. This arrangement has a 16 inch distance to the spacecraft interface. **Figure 2-3** shows a similar arrangement with the OMV and the RGDM. A minimum of two distributed units are required if each have a diameter of 24 inches. Since the height of the RGDM is greater than the TPDM, the separation distance between the AFIS and the spacecraft would be 23 inches. This means that the AFIS would have to extend 23 inches in order for the fluid couplers and electrical connectors to mate with the spacecraft. This will accommodate the worst case bipropellant configuration. The baseline AFIS's interfaces with the RGDM and TPDM are discussed in Section 4.2 Mechanical Design.

**Figure 2-4** shows a typical arrangement of one of the distributed units with the liquid couplers (4"Dia), Electrical connectors (2"Dia), and Gas couplers (3"Dia).

**Figure 2-5** shows the baseline AFIS configuration layout. With this arrangement the MMH and NTO are kept 30 inches apart compared with 10 inches for the alternate configuration. Moreover, angular misalignment is reduced since the interface centerline is 48 inches compared with 70 inches for the alternate. **Figure 2-6** summarizes the pros and cons of the two options. The drawback of the single large unit baseline is the increased difficulty in ground handling because of its larger physical size.

- MISSION REQUIREMENTS
  - Cryogenics, Bipropellants, Monopropellants, Water, Gas
  - Maximum delivery pressure: 500 psi (Liquid), 6000 psi (Gas)

- DESIGN CONSTRAINTS
  - Configuration: Attachment to OMV front face
    Compatibility with RGDM/TPDM
    Minimal contact w/ Spacecraft during docking ($15^o$ Misalignment)
  - Mass, C.G.
  - Construction
    - Materials/Processes: MSFC-STD-506, MSFC-SPEC-522, MSFC-HDBK-527, MIL-STD-889B
    - Safety: NSTS 1700.7B,NHB 1700.1, NHB 8060.1B
    - Reliability (Provide redundancy to match OMV reliability)
    - Number and Size of Couplings/Connectors
    - Alignment Tolerances: Axial Overtravel of 0.25 inches
      Lateral Offset of +/- 0.10 inches
      Angular Misalignment of +/- $0.1^o$
    - Lubrication: MSFC-STD-509 (Flight unit only)
    - Finish: MSFC-SPEC-250A (Flight Unit only)
    - Fastener Locking: MSFC-STD-561 (Flight unit only)

- THERMAL PERFORMANCE REQUIREMENTS
  - Not applicable to Prototype Fabrication
  - STS versus ELV versus Space Station
  - Temperature Limits
  - Orbital Flight Thermal Environment
    - Maximum solar radiation of 443.7 Btu/hr/sq. ft.
    - Maximum earth emitted radiation of 77 Btu/hr/sq. ft.
    - Space sink temperature of 3 degrees Kelvin
  - Passive Design: Heaters, Isolators, MLI Blankets, Paints
  - AFIS/OMV Isolation
  - AFIS/Couplers Isolation

- OTHER NATURAL AND INDUCED ENVIRONMENTS
  - NASA-TM-82473, NASA-TM-82478, NASA-TM-86460
  - Meteoroid Impact
  - Space Radiation

- MECHANICAL PERFORMANCE REQUIREMENTS
  - STS versus ELV (Atlas, Delta II, Titan III)
  - Ground Handling & Transportation Loads: FED-STD-101B, MIL-STD-810C (including Fabrication, Testing and Shock Loads)
  - S/M Flight Loads: Quasi-static, Random Vibration, Acoustic Pressure, Shock, Crew-Applied Loads
  - Operational Loads: Fluid Transfer 2000 lbs total (may be all at one coupler)
    Mate/Demate: 10 lbs/gas coupling
    30 lbs/liquid coupling
    100 lbs/electrical connector
  - Emergency Rapid Demate Loads (Water Hammer)
    (not applicable to prototype)
  - Load path: Non-latching couplings
    AFIS operational loads must be borne by Mechanism
  - Factors of Safety: MSFC-HDBK-505A
  - Minimum Natural Frequency: 40 Hz (for mass > 50 lbs)
  - S/M Analyses: Strength/Margins of Safety
    Rigidity/Minimum Natural Frequency
    Deflections
    Fatigue/Fracture Mechanics: MSFC-HDBK-1453

- ELECTRICAL PERFORMANCE REQUIREMENTS
  - MSFC-SPEC-521
  - OMV/AFIS Interface:
    - OMV front face elecrical connector panel
    - TBD electrical connectors
    - Voltage range 22 VDC to 35 VDC
    - Power (5 KWHrs, 1 KW maximum)
    - Command data (256 words max, 1000 bps max)
    - Telemetry data (256 words max at OMV video data rate, serial data, discreet events, analog voltage)
    - Mechanism Control Device
  - Pyrotechnic/Ordinance Control Device: MIL-STD-1512
  - AFIS/Spacecraft Interface:
    - 8 G&H Technology Connectors per GSFC Spec 700-42 (882-700-002 Plug, 882-800-002 Receptacle)
    - Function?
  - Safety:
    - three independent electrical inhibits
  - Redundancy
    - Motors, Commutation devices electrically redundant
    - Limit switches redundant
  - Electrostatic Discharge
  - EMC

**Figure 2-1 AFIS Mission Requirements Summary**

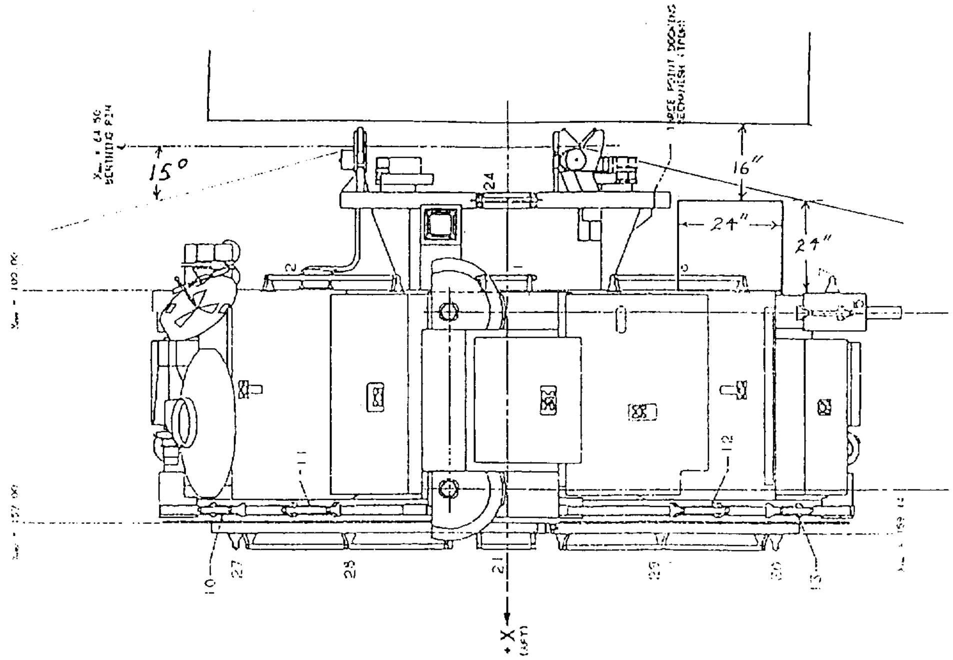


**Figure 2-2 Outside clearance on OMV With TPDM Docking System**

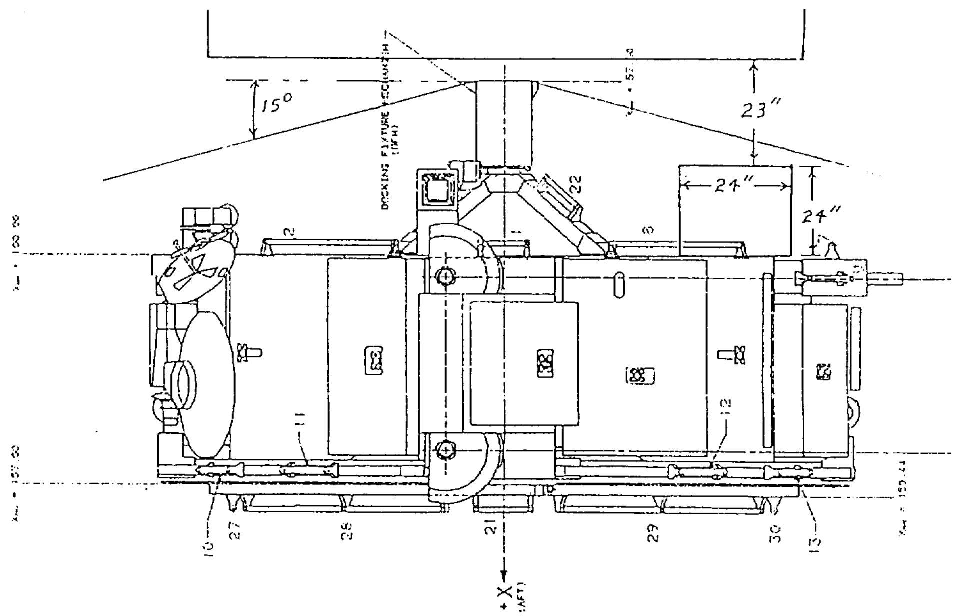


**Figure 2-3 Outside clearance on OMV With RGDM Docking System**

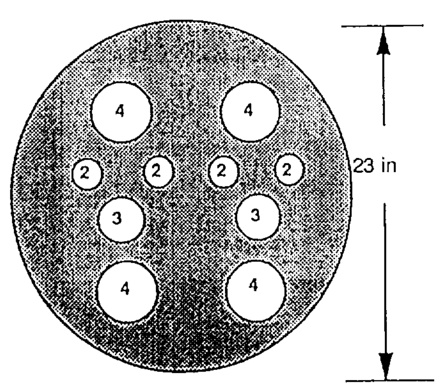


**Figure 2-4 AFIS Multi-Case Option**

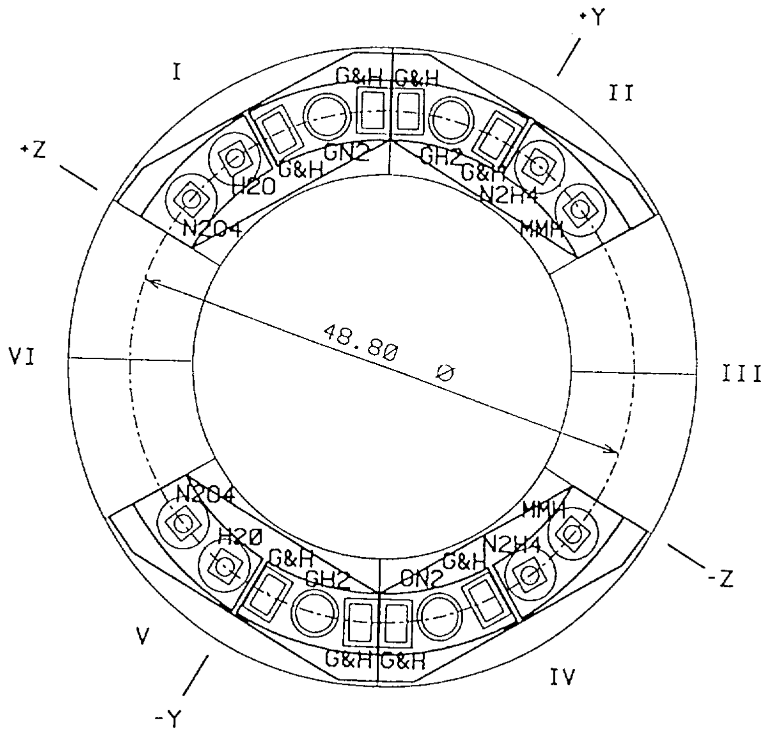


**Figure 2-5 Baseline AFIS Bi-Propellant Fluid Transfer Arrangement**

| | Multiple Small Units | Single Large Unit |
|---|---|---|
| Units Required | 2-4 | 1 |
| Diameter of Unit | 17-23 inches | 61 inches |
| Separation of Fuel & Oxidizer | 10 inches | +30 inches |
| Weight | 200-400 lbs | 300-400 lbs |
| Redundancy | yes | yes |
| Distance From AFIS to SC | 16-23 inches | 4 inches |
| Attachment to OMV | 8-12 places | 4 places |
| Interface to OSCRS | Spread Out | Centralize |
| Alignment to SC | More Difficult | - |
| Integration | More Complex | - |
| Cable Runs | Long | Short |
| Propellent Lines Run | Long | Short |
| Flexible Reconfiguration | yes | yes |
| Controls Electronics | Multiple | Single |
| Handling | - | More Difficult |

**Figure 2-6 Pros & Cons of Single Vs. Multiple Units**

## 3.0 AFIS APPLICATIONS

AFIS's compatibility with either OMV or OSCRS makes it suitable for a variety of freeflying spacecraft or manned based resupply operations. The resupply operation can be set up with either the RGDM or the TPDM in conjunction with OMV, OSCRS, Space Station, or the Space Shuttle.

The resupply of expendables to a spacecraft can either be done from OSCRS or from the OMV itself. **Figure 3-1** shows the AFIS resupplying a spacecraft from the OSCRS tanker. In this setup one RGDM is used to dock with the spacecraft and a second RGDM to fix the OSCRS to the OMV. By using OSCRS in unison with OMV, many spacecraft can be resupplied in one mission.

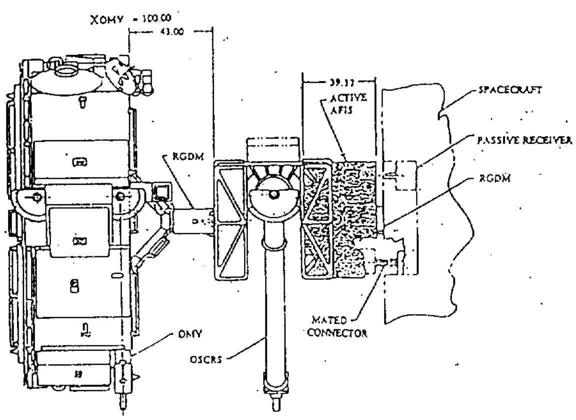


**Figure 3-1 AFIS Resupplying Spacecraft With OSCRS and OMV**

If only one spacecraft needs resupply, then the OMV itself can be used as a tanker. **Figure 3-2** shows the OMV docked to a spacecraft with AFIS providing the fluid, propellant, gas, and electrical interface. This interface works in both directions in the case that the OMV is itself being resupplied from a tanker. **Figure 3-3** shows the OMV being resupplied from OSCRS with a TPDM docking interface. In this type of operation the OSCRS could be attached to the Space Shuttle as shown in **Figure 3-4**.

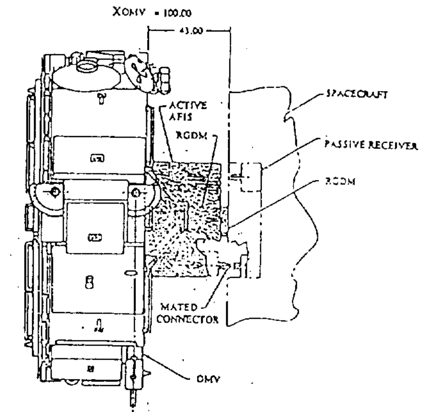


**Figure 3-2 AFIS Resupplying Spacecraft Using RGDM**

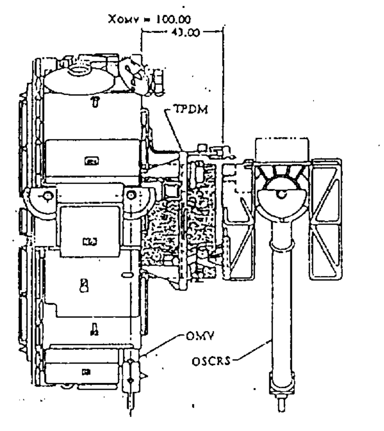


**Figure 3-3 AFIS Resupplying OMV From OSCRS Using a TPDM**

**Figure 3-5** shows, AFIS can be incorporated into Space Station operations. This operation shows two AFIS units attached to an OSCRS and the two AFIS's attached to the Space Station and a spacecraft that could be an OMV. This arrangement allows resupply of the Space Station, or resupply of the freeflying spacecraft.

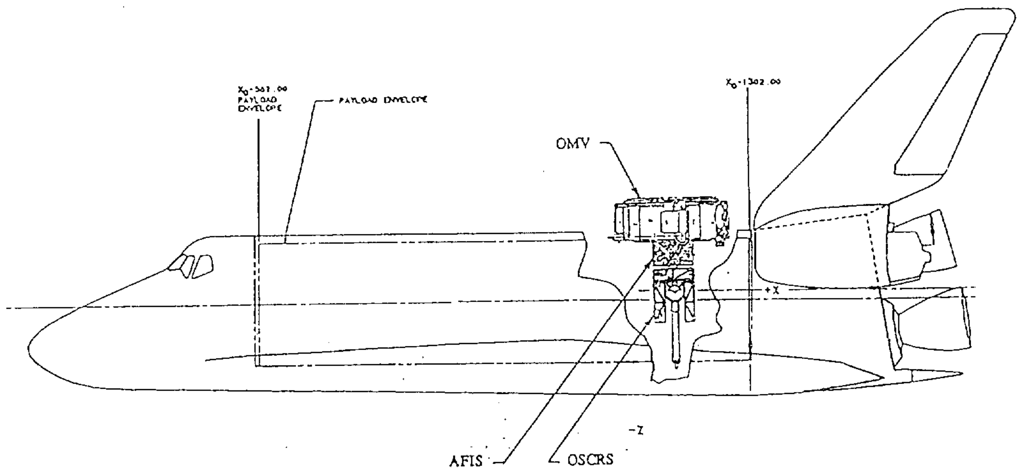


**Figure 3-4 AFIS Inside the Shuttle Bay with OMV and OSCRS**

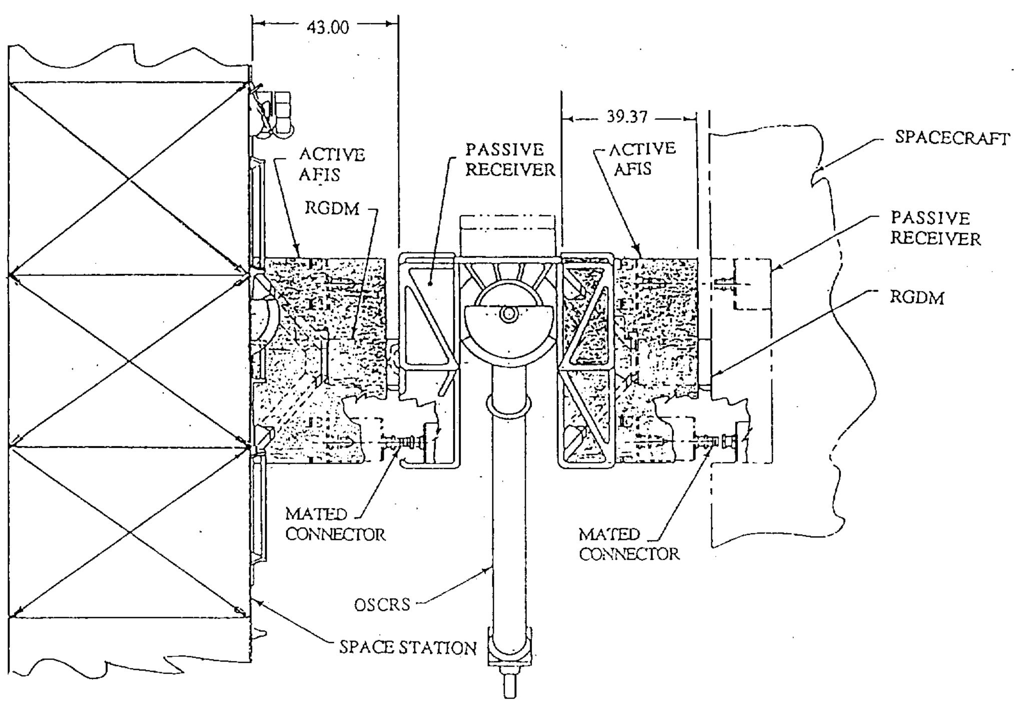


**Figure 3-5 TWO AFISs Supporting Space Station Operations**

## 4.0 SUBSYSTEM DESCRIPTION

### 4.1 FUNCTIONAL DESCRIPTION

The operation of the AFIS can be accomplished remotely (i.e. from the ground, shuttle, or Space Station). Once the AFIS is docked with a satellite, the AFIS, upon command opens the contamination covers, raises and engages the latches, then raises the couplers and connectors up to mate with the coupler half on the spacecraft. The couplers automatically open when the two halves are mated. Another command opens the propellant valves (which are not part of AFIS) to allow transfer of the propellant. The AFIS latching mechanism is connected to prevent any of the propellant transfer loads to be induced into either the satellite or the tanker. The covers are closed after the system demates upon command.

### 4.2 MECHANICAL DESIGN

#### 4.2.1 Interfaces

The AFIS is currently planned to be used on the OMV as a mechanism to engage fluid couplers between the tanker and a receiving spacecraft. As such, the AFIS must be compatible with the docking mechanisms and the docking envelope of the OMV. The current design of the OMV has two docking mechanisms available for use, the RGDM (Remote Grapple Docking Mechanism) and the TPDM (Three Point Docking Mechanism). **Figure 4-1** shows the AFIS/RGDM compatibility. The AFIS was designed to fit inside the structural ring of the TPDM. The AFIS was designed to fit around the RGDM and not interfere with the camera and lights. The camera and lights can still be mounted in an allowable position on the TPDM with the AFIS mounted inside the docking ring. **Figure 4-2** shows how the AFIS fits when mounted with the TPDM. Additionally, the AFIS needed to avoid interfering with the $15^{o}$ docking misalignment requirement of the OMV. **Figure 4-3** is an illustration of the clearance available in a $15^{o}$ misaligned position.

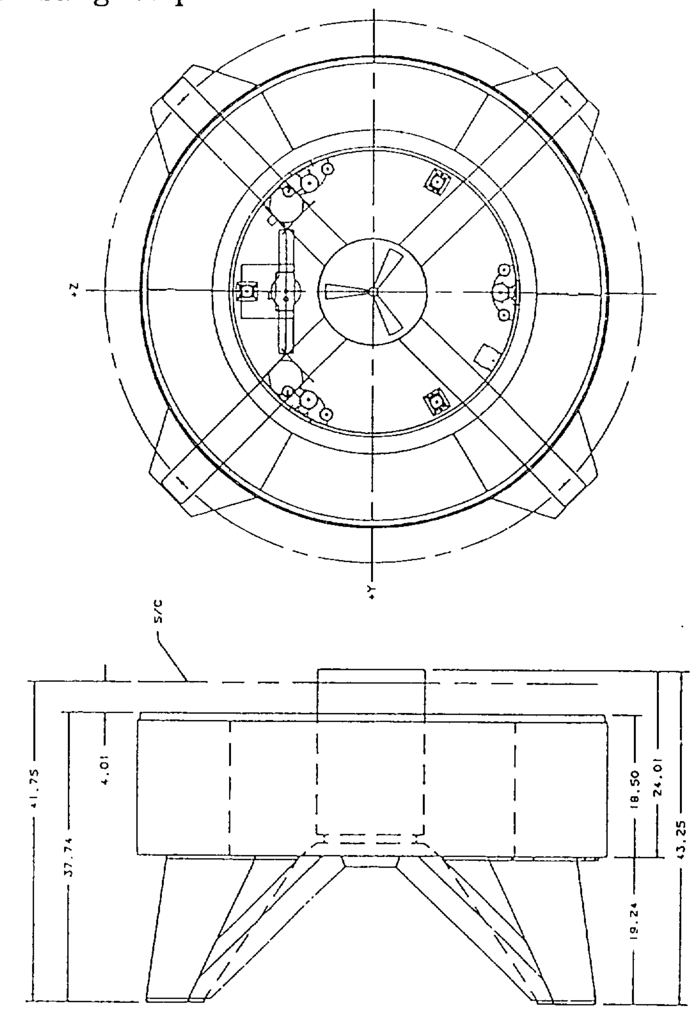


**Figure 4-1 AFIS/RGDM Compatibility**

The structural mounting of the AFIS to the OMV is accomplished by mounting the AFIS and a docking mechanism to the OMV through a common bolt. The AFIS has legs mounted to the structural housing of the mechanism which would extend to the bolt locations. This design was intended to minimize the impact in changing the docking mechanism design. At a future time and date, a study can be done to determine the feasibility of integrating the AFIS and the docking mechanism onto a single structure.

The interface between the AFIS and the serviced spacecraft is designed to accommodate some misalignment between the spacecraft couplers and the AFIS couplers. As noted in the SOW for the AFIS design, the mechanism must be capable of functioning with a 0.1" lateral misalignment and a 0.25" axial misalignment. The lateral misalignment is accommodated at each individual coupler by a mechanism that allows the coupler to "float" within that envelope. The couplers on the serviced spacecraft are fixed to the interface plate and the couplers on the AFIS mechanism are allowed to "float." The axial misalignment requirement is met by designing the AFIS so that the couplers can extend the additional distance required to mate with the spacecraft.

One additional design requirement imposed on the AFIS was that "all fluid transfer loads must be borne by the interface mechanism." To accomplish this, a load path must be established between the AFIS and the spacecraft interface and a load path must be removed from between either the AFIS and the OMV or the spacecraft interface and the serviced spacecraft. The AFIS design accomplishes this by decoupling the spacecraft interface and allowing it to translate within a limited envelope and installing a latch mechanism. Given the latch mechanism, a load path is directly established between the AFIS and the spacecraft interface. Since the spacecraft interface is decoupled from the spacecraft, no load path exists between the AFIS and the spacecraft or the OMV for fluid transfer loads. Even if the load path requirement didn't exist, the latch mechanism would still be required for the AFIS. The RGDM is only capable of handling a 750 pound axial load and the AFIS design requirements states that the design load for fluid transfer is 2000 pounds.

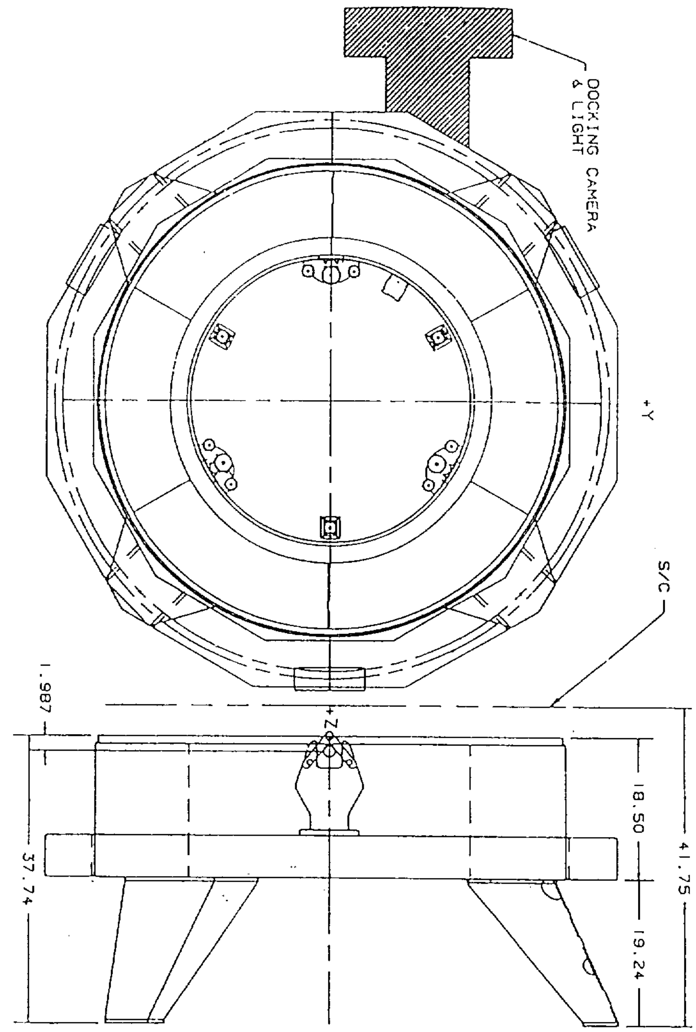


**Figure 4-2 AFIS/RGDM Compatibility**

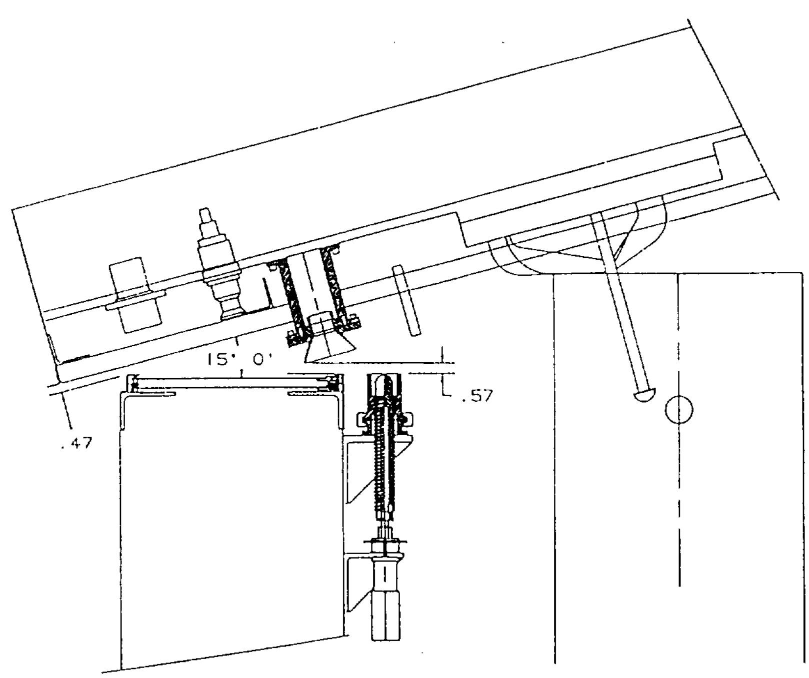


**Figure 4-3 OMV 15° Alignment Requirement**

### 4.2.2 Structure

The AFIS is a rigid toroidal structure that is supported by four legs. The main structure consists of a one piece machined base, to which six radial ribs are attached. The ribs are tied together at the top of the toroid by two machined rings. A sheet metal skin is attached to the base ring, ribs, and top rings on the inside and outside diameters of the toroid. For the flight unit, the ribs and the support legs would be made of aluminum honeycomb to minimize weight. All other machined structural components and the skins would be made of aluminum. The structure is designed to be riveted and bolted in order to allow for easy maintenance and reconfiguring. **Figure 4-4** is an illustration of some of the internal structural details of the AFIS.

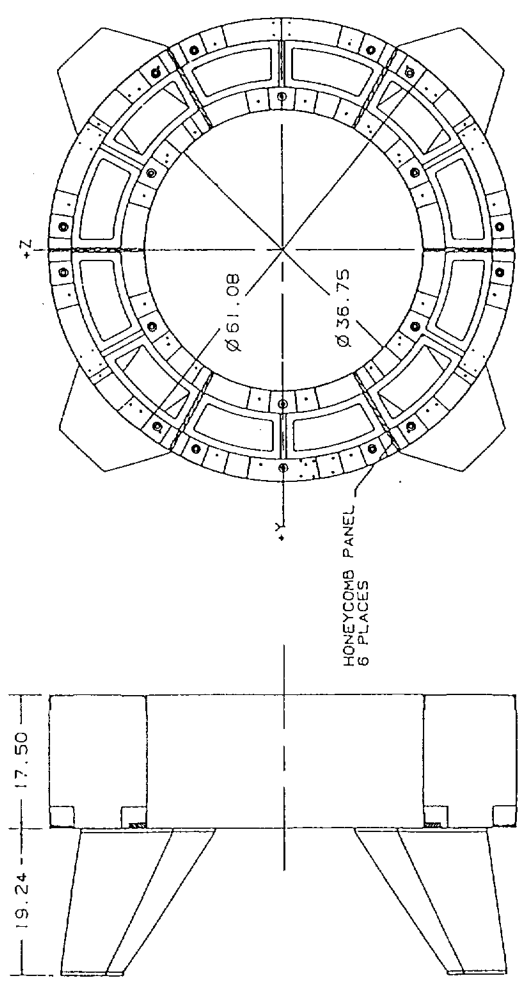


Figure 4-4 AFIS Structural Inboard Profile

### 4.2.3 Latch Mechanism

The Latch Mechanism is designed to serve as the structural load path between the AFIS and the spacecraft interface. As such, it must be capable of handling the 2000 pound fluid transfer load. Additionally, the Latch Mechanism must be capable of functioning given lateral misalignments. The basic principle of the latch is based on the MMS spacecraft module nut and acme screw. The spacecraft interface has three acme nuts attached to it. These nuts have a "floating" mechanism, similar to the fluid couplers. The AFIS has three acme screws which extend to engage the nuts on the spacecraft interface.

The latch screws are extended by rotating them through an acme nut attached to the AFIS. The operation of the latch screws is synchronized through the use of a chain and sprocket system. A hexagonal bushing is attached at the base of each latch screw. A hexagonal rod fits inside of the bushing. The rotation of this rod turns the acme screw and extends the latch screw toward the latch nut on the spacecraft interface. The sprockets are attached to the hexagonal rods and provide for the synchronization of the latch screws. The drive motor for the Latch Mechanism is attached to one of the latch screw drive sprockets. **Figure 4-5** is a section view of one Latch Mechanism engaged with the spacecraft to be serviced.

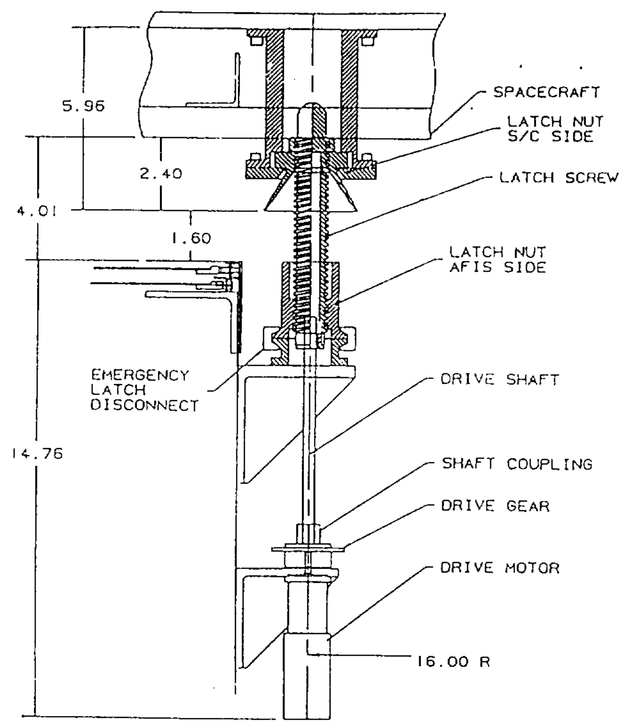


**Figure 4-5 AFIS Latch Mechanism**

The chain drive system for the Latch Mechanism provides for a chain tension adjustment in order to prevent any slippage in the chain-sprocket interface. The chain tensioning system has two types of chain tensioners. The first is spring loaded tensioner that provides some compliance in the system to allow for any situations where slack may develop. It also maintains sprocket-chain contact if the chain tension should increase. The second type are screw adjustable tensioners used to set the nominal tension of the system.

The Latch Mechanism is designed to demate if the mechanism fails after engaging to the spacecraft interface. The acme nut and the latch screw on the AFIS unit are designed to separate from the AFIS when a pyro device is fired. This allows the tanker and the serviced spacecraft to separate after the refueling operation is complete in the event of a failure.

4.2.3 Coupler Shelf Drive System

The Coupler Shelf Drive Mechanism performs the mating and demating of the connectors for the refueling mission. The system consists of a chain drive that synchronously operates some ball screws that raise a shelf. Attached to the shelf is a spacer and the individual fluid couplers. This mechanism is also capable of an emergency demate of all of the couplers. The design is intended to be reconfigurable in any generic form. The choice of coupler location is left to the user of the AFIS. **Figure 4-6** illustrates the main components of the Coupler Shelf Drive Mechanism.

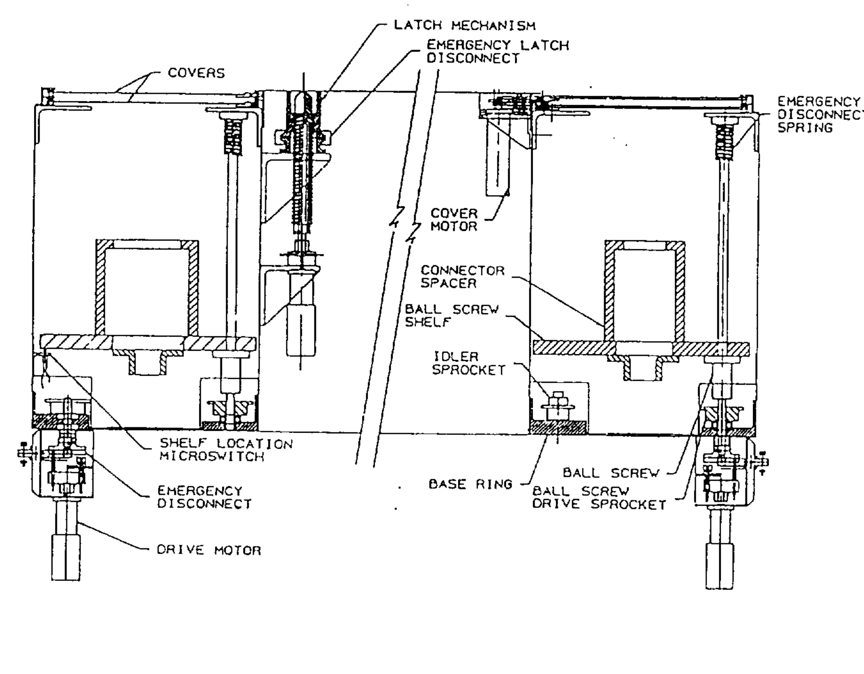


**Figure 4-6 AFIS Internal Mechanism**

The drive system is driven by a single motor that rotates the main drive sprocket. The chain in turn rotate the driven sprockets that are attached to the ball screws. As the ball screws rotates, the ball nuts that are attached to the shelves move up or down, depending on the direction of rotation. Each shelf has three ball screws attached to it. The spacer that is attached to the shelf is used to extend the couplers through the space between the AFIS and the spacecraft interface to the mating position.

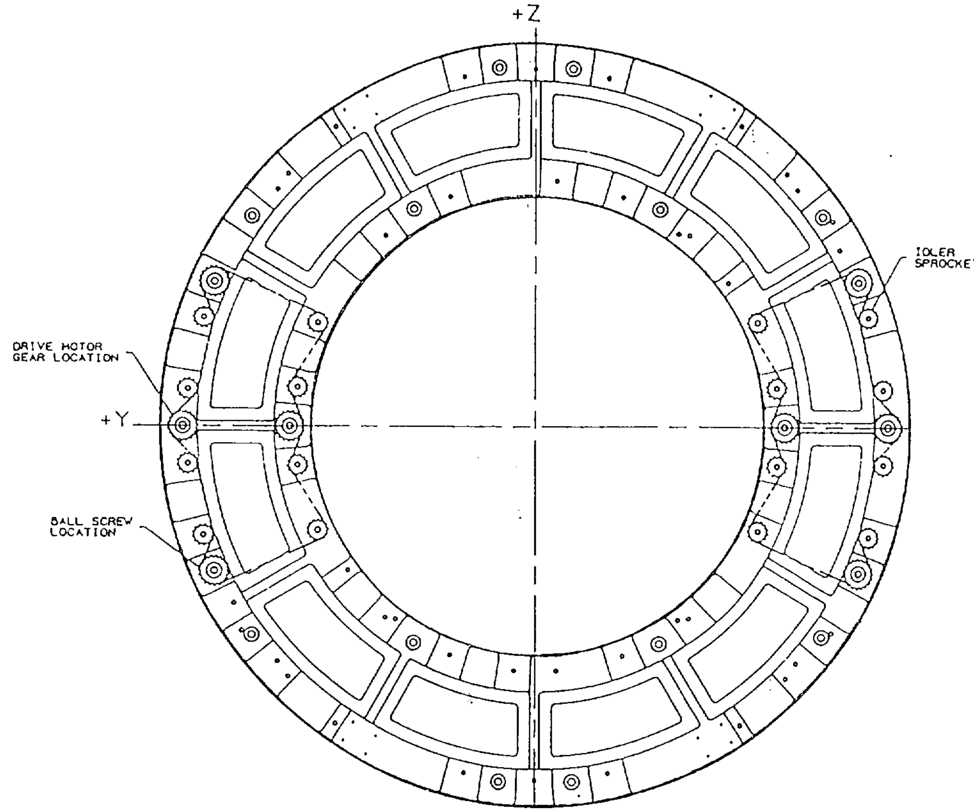


**Figure 4-7 AFIS 1 Shelf Configuration**

The Coupler Shelf Drive System is designed to be reconfigurable. The drive motor can operate one to three shelves. This capability allows the user to optimize the AFIS to suit his requirements and reduce the weight of the mechanism if the entire mechanism is not necessary. **Figures 4-7, -8, and -9** are illustrations of typical one, two, and three shelf chain drive configurations, respectively, for the AFIS. The AFIS can carry the full complement of six shelves, either fully populated with couplers or a combination thereof. The AFIS has two separate drive systems to allow for redundancy. This enables the AFIS to accomplish its refueling mission if the primary drive system fails. This design imposes no penalties to the serviced spacecraft, as the AFIS design requirements dictate that the AFIS and the serviced spacecraft must have redundant couplers.

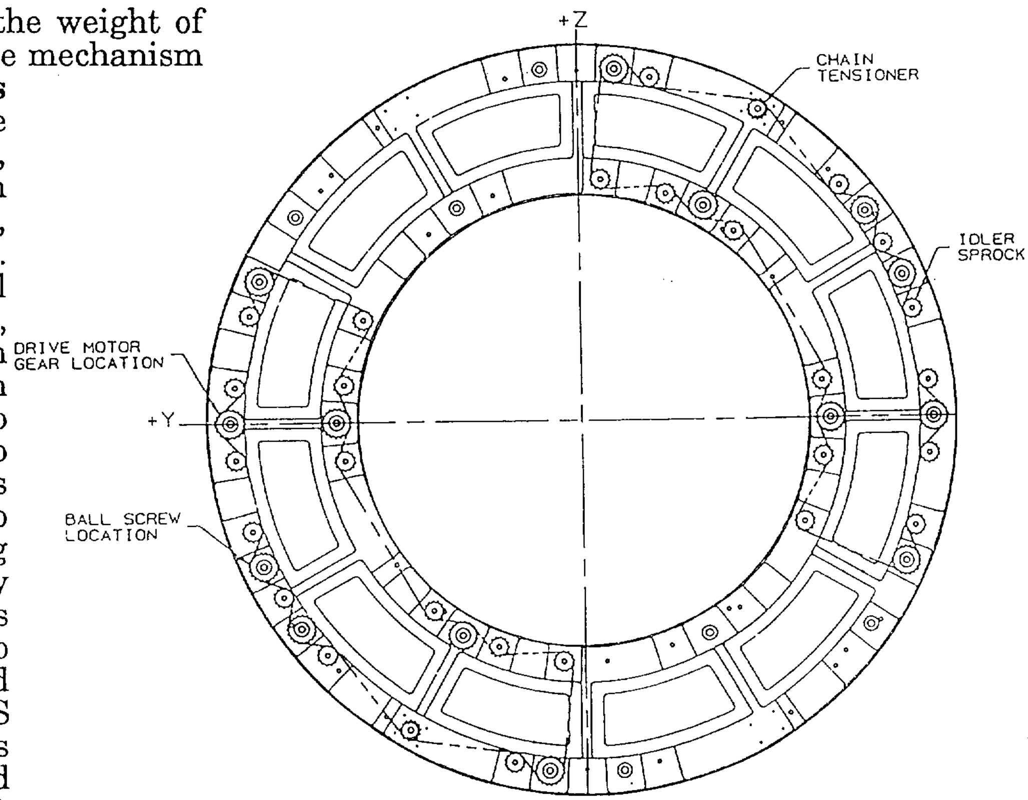


**Figure 4-8 AFIS 2 Shelf Configuration**

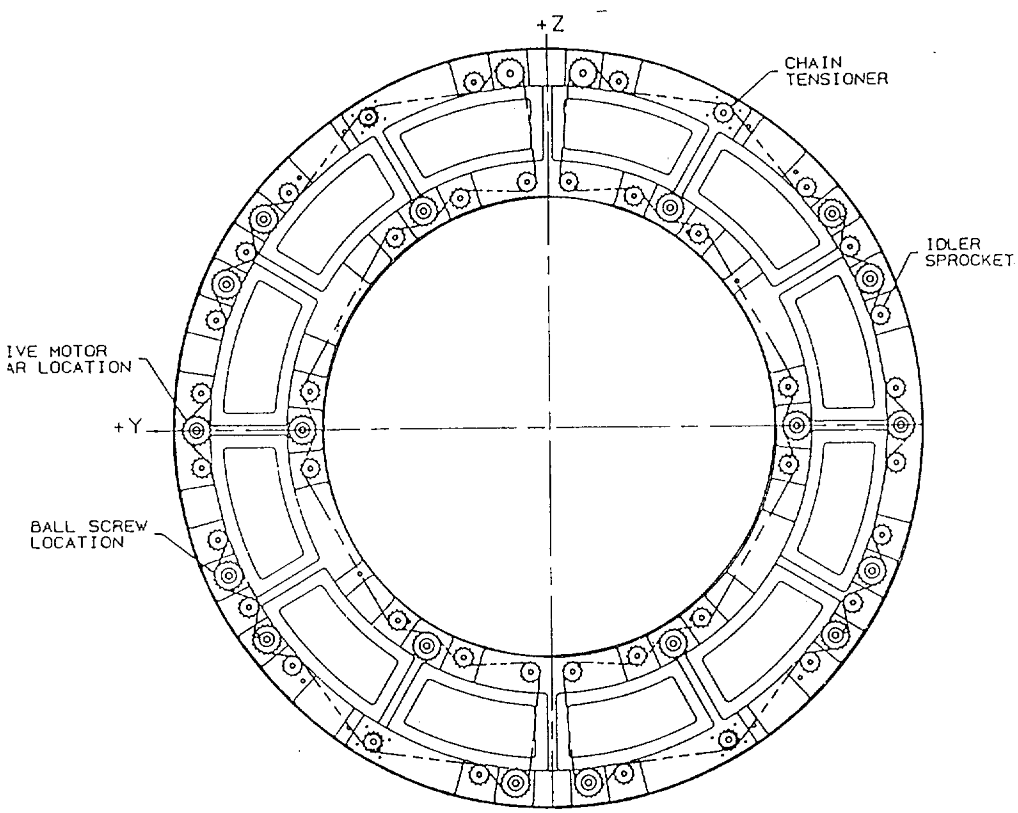


**Figure 4-9 AFIS 3 Shelf Configuration**

If an emergency situation arises during the refueling operation, then the couplers will need to be demated as quickly as possible to prevent damage to either spacecraft. Each Coupler Shelf Drive System has an emergency demate capability. The Emergency Demate Mechanism requires two components to operate. First, some stored energy must be available to move the shelves down and demate the couplers. Next, this stored energy must be released.

Stored energy is provided by three springs that compress when the coupler shelves reach their end of travel. This stored energy is maintained by preventing the ball screws from being backdriven and lowering the shelves. This is accomplished through the backdriving resistance of the drive motor. If the backdriving resistance of the motor is removed, then the spring energy is released, moving the shelves down and demating the couplers.

The backdriving resistance of the motor is removed through a shaft coupling that connects the motor to the main drive sprocket. The main drive sprocket is attached to a coupling that has a tab which fits into a movable coupling. The movable coupling is attached to the output shaft of the drive motor. The movable coupling has springs installed to maintain engagement to the drive sprocket coupling. If an emergency arises, then a solenoid would be triggered to operate a lever and separate the two coupler halves. This would remove the backdriving resistance of the motor and the stored energy would be released to demate the fluid couplers. **Figure 4-10** is a section view of the emergency disconnect drive motor coupler. It is shown as a split view, to illustrate the engaged and disengaged positions.

A unique feature of the Emergency Demate Mechanism is that the fluid couplers can be mated again if the emergency is corrected. This would require triggering the solenoid to release the lever and allowing the shaft couplings to mate. Then the Coupler Shelf Drive Motor can be used to move the shelves up and mate the fluid couplers again and complete the servicing mission.

The Coupler Shelf Drive System also has a chain tensioning system that is similar to the Latch Mechanism. This system is intended to prevent any chain slippage during the emergency demate. This system will be installed and operational regardless of the shelf configuration.

### 4.2.5 Cover Mechanism

The baseline AFIS Cover Mechanism consists of two rings that are driven in separate tracks. Attached to each ring are two *fan* shaped covers, set on opposite sides of the ring. The rings rotate from an active section of the AFIS to an unused section. The cover rings are driven at a 2:1 ratio so that four sections of the AFIS are exposed when the covers are opened leaving two sections covered. The baseline mission types only require a two shelf arrangement for each Coupler Shelf Drive System. **See Figure 4-11** for an illustration of the cover mechanism.

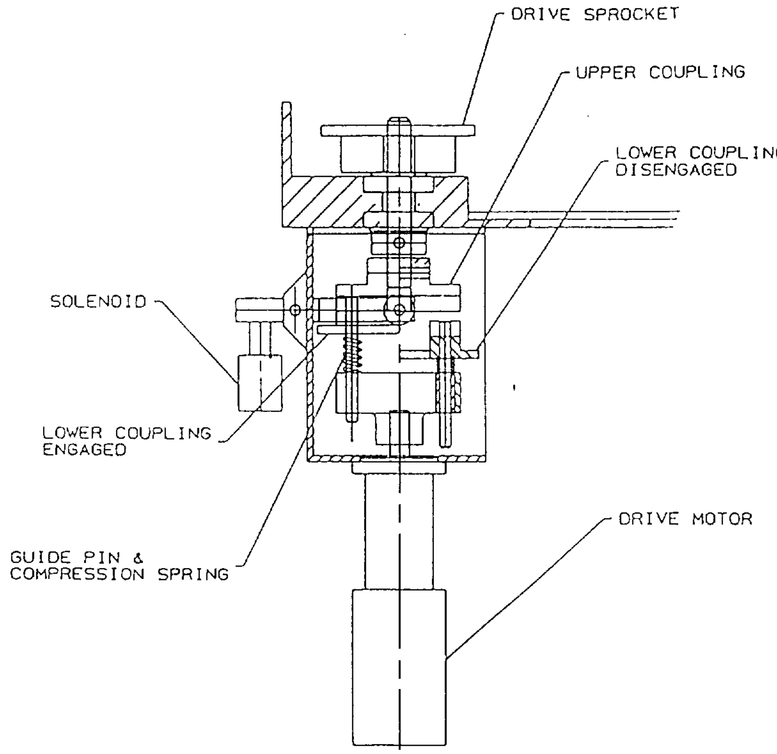


**Figure 4-10 AFIS Emergency Disconnect**

The cover rings are driven by a single motor that has a gearbox to provide two output sprockets. The output sprockets engage a chain that is imbedded in the cover rings. The output speeds of the sprockets are set at a 2:1 ratio so that the cover rings move at different speeds. The Upper Cover rotates 120° while the Lower Cover rotates 60°. This allows the two covers to rotate from adjacent sections of the AFIS and overlap over an unused section of the AFIS.

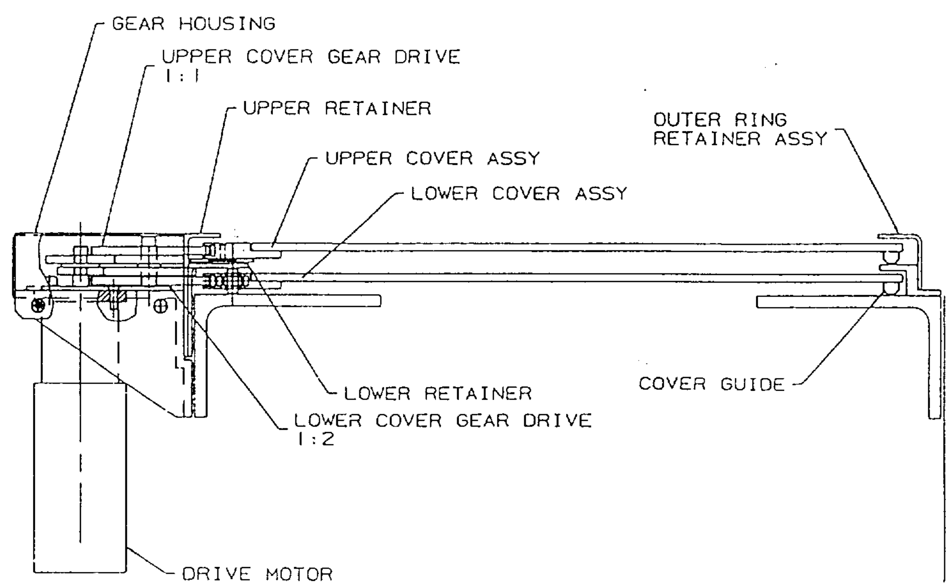


**Figure 4-11 Cover Mechanism**

The covers are reconfigurable to allow for any combination of one or two shelves to operate. This is enabled by removing the *fans* from the cover rings and bolting the *fans* to a new location on the cover rings. **Figures 4-12 and -13** show the two baseline cover configurations for a fluid and cryogenic transfer mission, respectively.

If the Cover Drive Motor should fail, then a backup mechanism can be operated to open the covers. First a pyro device would be fired to release the cover motor. A spring would rotate the motor away from the cover rings and disengage the drive sprockets from the embedded chain. A negator spring would then provide the necessary force to move the cover *fans* to the open position. **Figures 4-14 and -15** show the working parts of the cover release mechanism before and after operating the release mechanism, respectively. The servicing mission can then be accomplished without any difficulties.

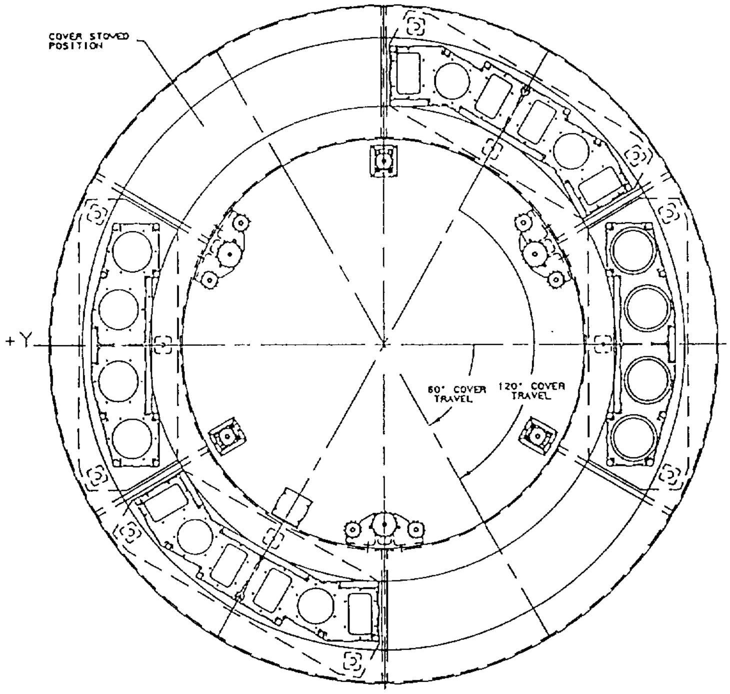


**Figure 4-12 Fluid Transfer Cover Arrangement**

If all three shelves are required for a servicing mission, then an alternate cover mechanism can be installed. This mechanism consists of two lids that cover half of the AFIS and would rotate outward to expose all three shelves for operation. **Figure 4-16** illustrates the alternate covers in the open position. These covers would not interfere with the docking mechanisms or cameras. However, the covers would need to be stiff, due to the size of the lid. For this type of cover, the covers would need to be open prior to docking of the spacecraft and the OMV.

4.2.6 Coupler "Floating" Mount

Each of the couplers and connectors that is mounted in the AFIS is mounted in a "floating" mechanism to accommodate the lateral and angular misalignment requirements of the AFIS.

The nominal position of the coupler is maintained through the use of two springs, one to hold the axial position and one to hold the lateral position. The housing for each coupler is designed to hold the coupler within the envelope specified by the angular and lateral misalignment. **Figure 4-17** illustrates a typical coupler floating mount.

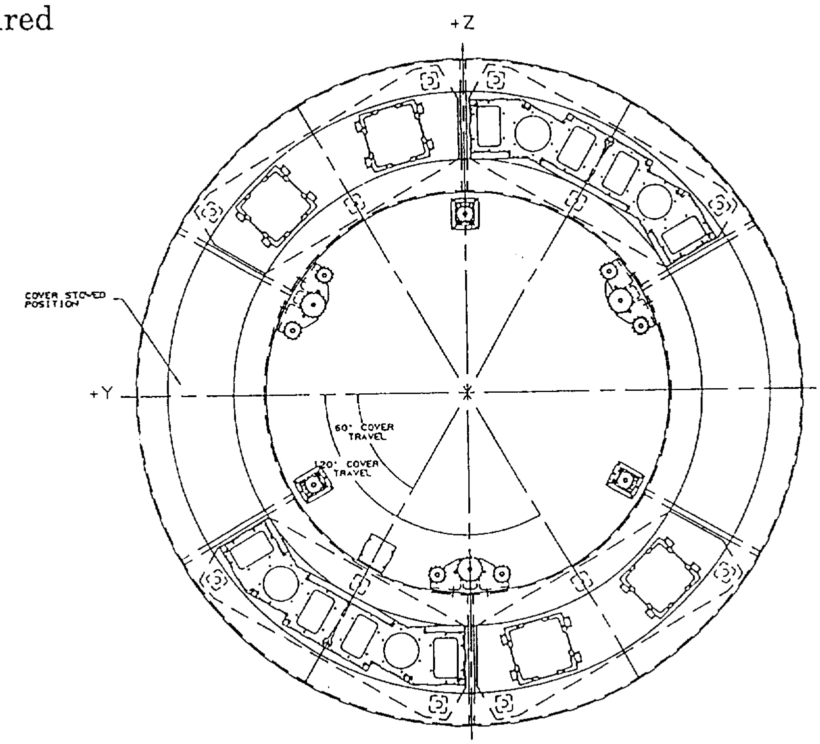


**Figure 4-13 Cryo Transfer Cover Arrangement**

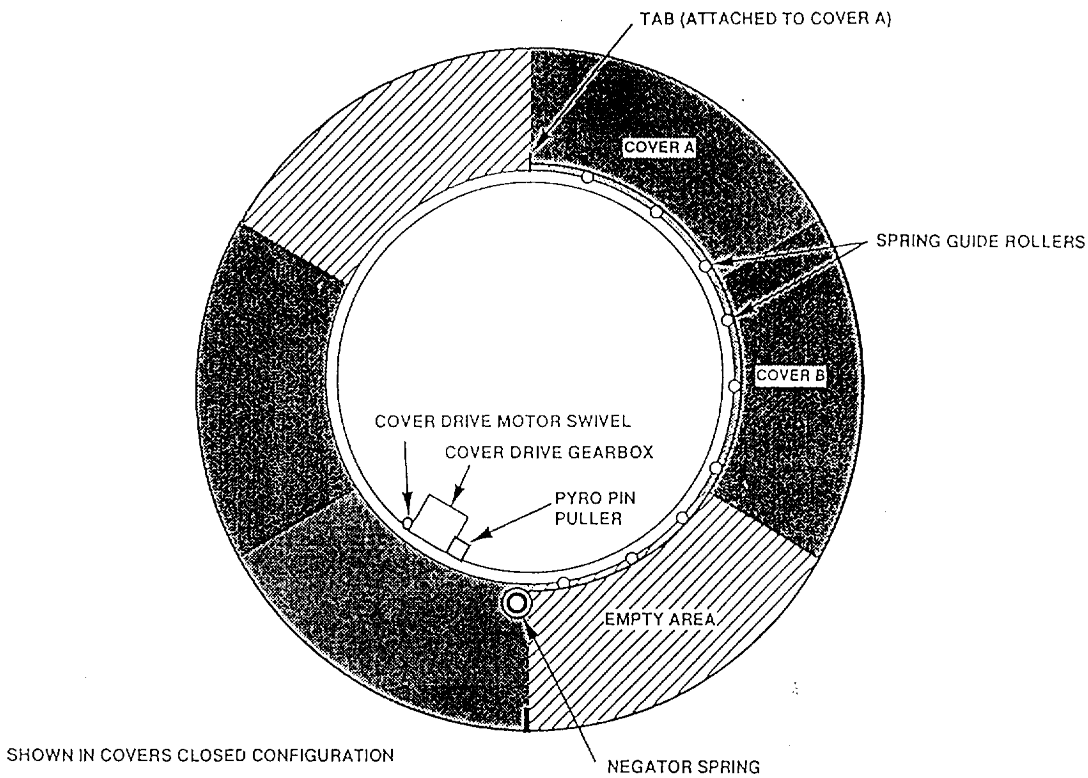


**Figure 4-14 Backup Mechanism Backup Release**

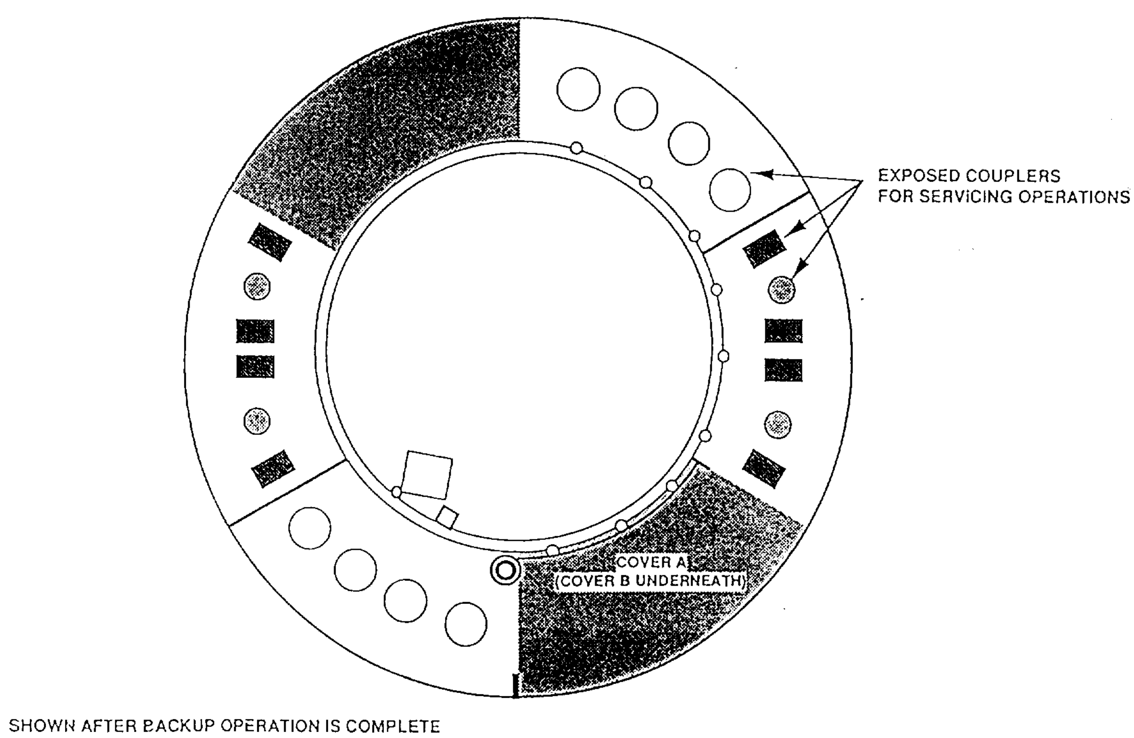


**Figure 4-15 Backup Mechanism Backup Release After Operation is Complete**

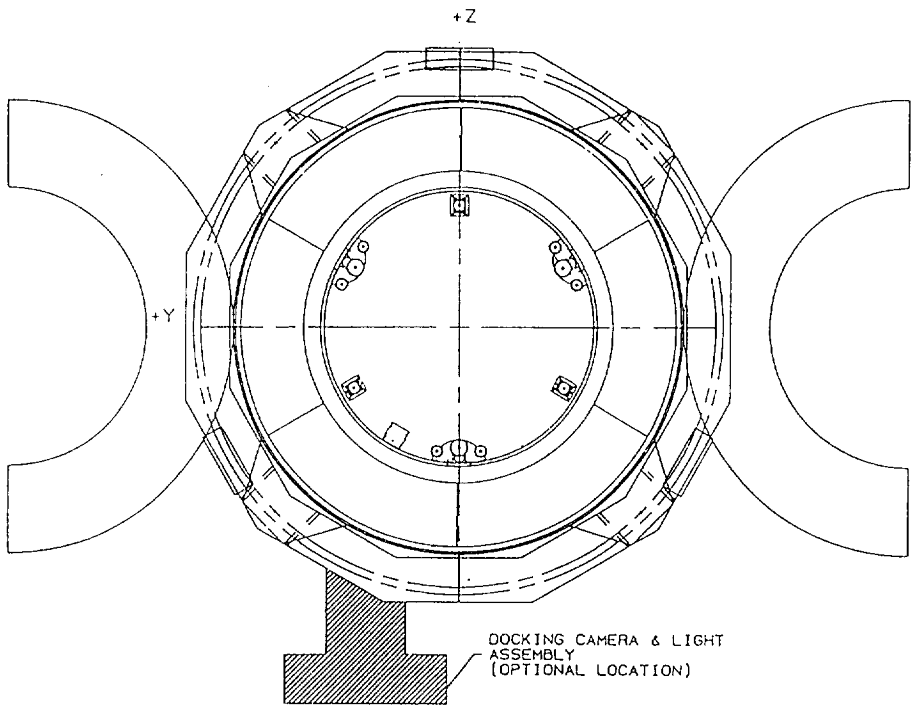


**Figure 4-16 AFIS Alternate Cover Configuration**

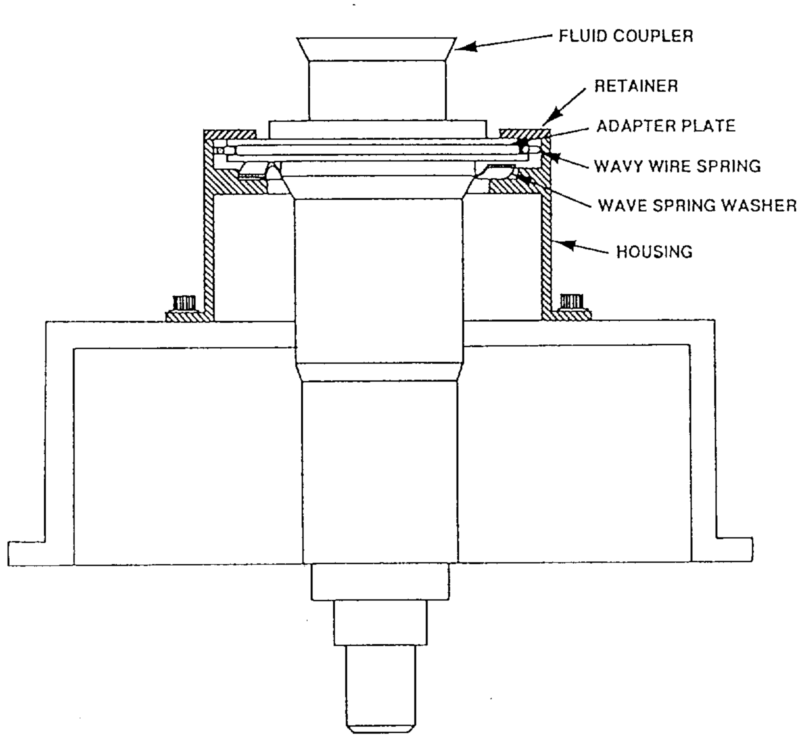


**Figure 4-17 Fluid and Cryogenic Coupler Floating Feature**

## 4.3 AFIS STRUCTURAL ANALYSIS

The AFIS structural analysis was performed on the AFIS system as a whole and on stress critical detailed structural components.

The AFIS system level structural analysis comprised a static analysis of the gravity loads induced during the launch and landing phases of the AFIS mission, and a static analysis of the fluid transfer loads. The gravity loads were studied for both the STS and the Titan, Atlas, and Delta ELV's. An eigenvalue analysis was done to determine the first natural frequency of the AFIS Mechanism. The safety factors used for all analyses were 1.25 for yield strength and 2.0 for ultimate strength.

The worst case gravity loads occurred during the STS launch and emergency landing cases. The gravity loads were based on the STS documentation and included an equivalent random input on one axis as specified in the MSFC stress analysis document. All possible load combinations were run with the worst case being X=-10.1 g, Y=-18.36 g, Z=-4.0 g. The analysis shows a maximum stress of 14,366 PSI, giving a margin of safety of 0.95 on yield strength and 0.46 on ultimate strength. **Figure 4-18** is a stress contour plot of the worst case liftoff/landing loads.

The operational loads of the AFIS unit were determined through the use of a detailed model of the ball screws, coupler shelf, and the spacer. Static forces were applied to this detail model to simulate the mating forces (including the emergency disconnect springs) and the fluid transfer forces. The reaction forces at the ends of the ball screws were then applied to the structure. The mating forces for the couplers/connectors were based on the AFIS SOW and are as follows:

100 lbs. per electrical connector (per GSFC-700-42)
30 lbs. per fluid coupler
10 lbs. per gas coupler

The fluid transfer load was 2000 lbs., in accordance with the SOW. This load was applied at a single coupler station. The fluid transfer load case was analyzed at every fluid coupler station, and the highest stress was 4,938 PSI. This stress gives a margin of safety of 4.67 for yield strength and 3.25 on ultimate strength. **Figure 4-19** is a stress contour plot of the worst case operational loads of the AFIS.

The eigenvalue analysis indicates that the first natural frequency of the AFIS occurs at 54.6 Hz. This exceeds the minimum requirement of 40 Hz for the AFIS system. **Figure 4-20** shows the mode shape of the AFIS mechanism at its first natural frequency.

The detail structural analysis was focused on the operational parts of the AFIS. Each of the Coupler Floating Mechanisms was analyzed for the coupler engagement and fluid transfer forces. The highest stress was 10,804 PSI, giving margins of 1.96 for yield strength and 1.08 on ultimate strength. The ball screws, coupler shelves, and spacers were analyzed as an assembly to study the engagement and fluid transfer loads. The highest stress was 8,554 PSI, giving margins of 2.74 for yield strength and 1.63 on ultimate strength.

In summation, the AFIS design is capable of handling all of the operational and environmental loads imposed upon it.

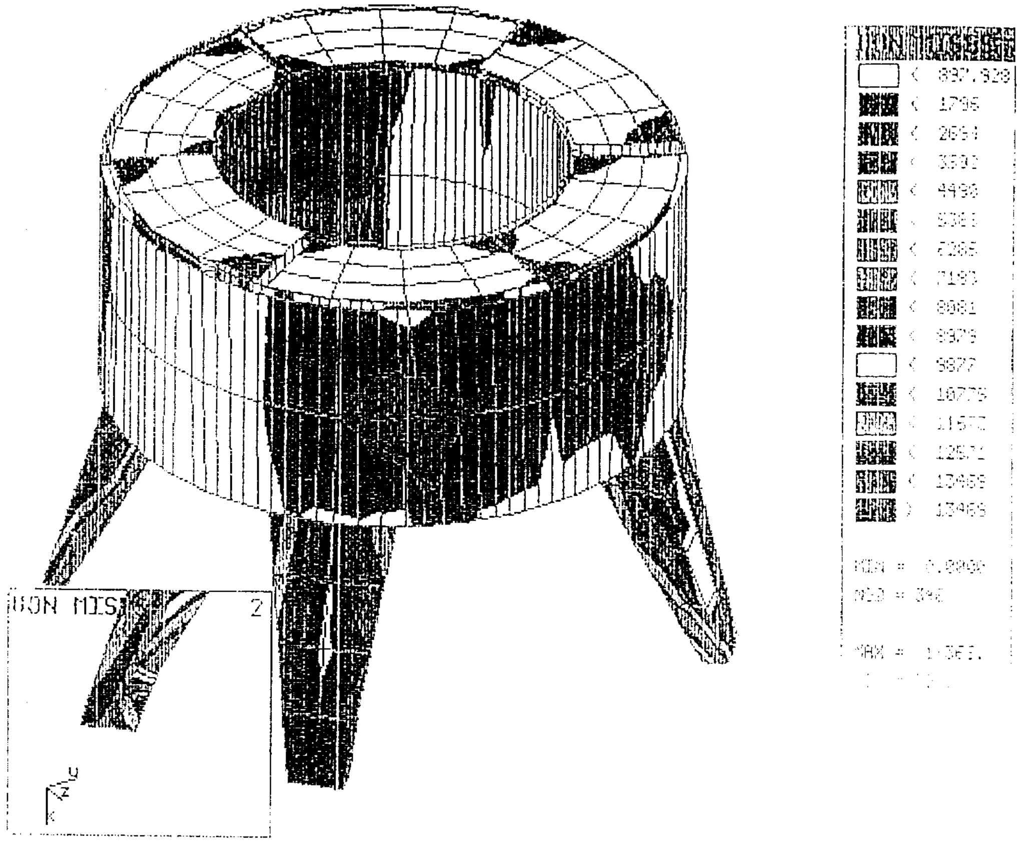


**Figure 4-18 Von Mises Stress Plot of AFIS Showing Results For Worst Case Liftoff/Landing Loads**

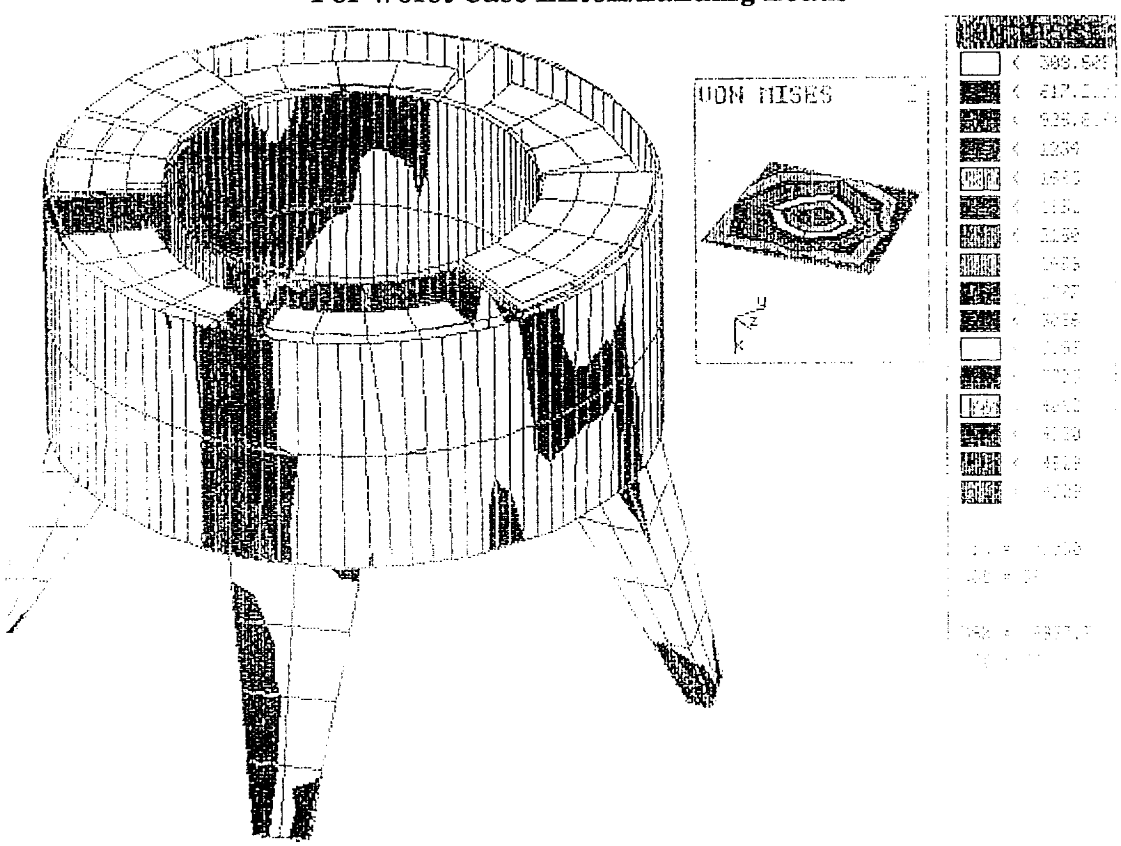


**Figure 4-19 Von Mises Stress Plot of AFIS Showing Results For Worst Case Fluid Transfer Loads**

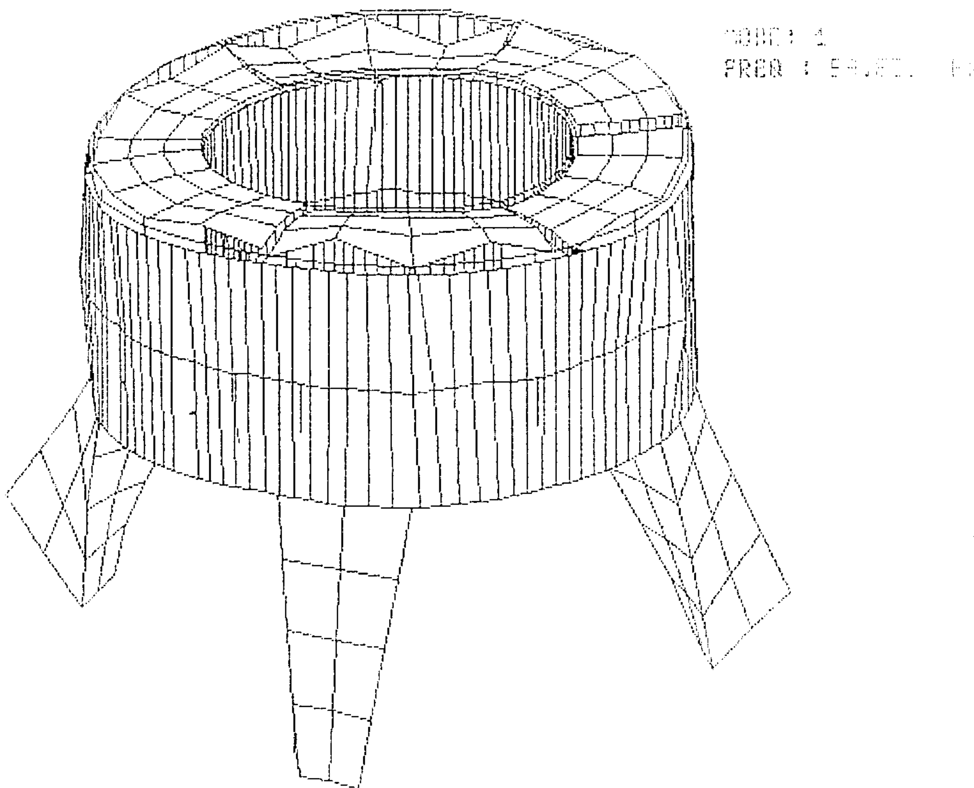


Figure 4-20 First Natural Frequency and Corresponding Mode Shape In Stowed Configuration

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## 4.4 ELECTRICAL SYSTEM

The AFIS flight unit incorporates the required electrical design to interface remotely with and be compatible with the power, command and telemetry systems presently proposed for the NASA OMV, STS, or Space Station. Tables 1 and 2 list the electrical interfaces and hardware considerations for the AFIS flight unit.

There are three motor control systems on the AFIS: Latch, Cover, and Shelf control systems. These three systems along with the emergency de-mate and temperature measurement are routed through the Remote Interface Unit (RIU). The RIU is supplied by NASA and is compatible with the OMV's 1553 type bus. In effect, the AFIS RIU will look like another payload to the OMV. While the contract required one RIU, a second unit is recommended to provide for redundancy of the AFIS electrical control and telemetry systems.

The three AFIS motor control systems are similar. A schematic for each system is shown in **Figures 4-21, -22, and -23**. These systems take advantage of the multiplexing data bus provided by the OMV to drive the command decoder and telemetry multiplexer within the RIU to actuate and control the mechanisms and monitor the status.

The OMV will either issue a command or a status request to the RIU command decoder and the telemetry multiplexer responds with a reply. A typical sequence begins with the engage selection command of the latch then the latch on command is issued. Next, the priority select is tested. This command tests the decision logic, for instance in the case of the shelf drive, a decision logic test prior to driving the shelf motor would be "are the covers open?".

Each of the three motor control systems is equipped with a position end of travel limit switch as the primary method for stopping the motor. A motor timer is provided as a "time-out" backup to the limit switch.

The emergency disconnect and latch bolt pyro systems shown in **Figure 4-24** are two independent operating systems used under different scenarios. The latch bolt pyro is only used as a last resort in separating the AFIS from the spacecraft. This system is implemented in the event that the AFIS latches cannot be retracted from the spacecraft. As such, the bolt pyros are enabled, armed, and fired. Thus, cutting the AFIS acme screw bolts which results in the acme screws remaining with the spacecraft. On the other hand, the emergency disconnect system can be actuated repeatedly with no system degradation to the AFIS or the spacecraft. If for instance, the mating of the AFIS couplers/connectors was not successful, the emergency disconnect is enabled, thus removing the motor/gearbox resistances from the ball screws holding up the platform. Once this resistance is removed the emergency demate springs are free to move the platform down approximately 3/4 of an inch. This movement demates all couplers and/or connectors which ere mated.

**Figure 2-24** also shows the interface of the four thermistors to the telemetry multiplexer. These values are obtained when the OMV sends a status request.

**Table 1. Electrical Interfaces**

| Power | Commands | Telemetry |
|---|---|---|
| Coupler Shelf Drive Motor | Latch Operation | Heater Thermistor Readout |
| Cover Mechanism Motor | Cover Mechanism Operation | Cover Status |
| Heater Power | Coupler Shelf Mechanism | Coupler Shelf Status |
| Latch Motor | Latch Pyro Operation | Latch Status |
| Latch Pyro | Emergency Disconnect Operation | Emergency Disconnect Status |
| | | Latch Pyro Status |

**Table 2. Electrical Hardware**

| Name | Type |
|---|---|
| Coupler Shelf Drive Motor | Space Qualified Stepper Motor or Brushless DC Motor |
| Cover Mechanism Drive Motor | Space Qualified Stepper Motor or Brushless DC Motor |
| Latch Motor | Space Qualified Stepper Motor or Brushless DC Motor |
| Emergency Disconnect Solenoid | TBD |
| Heaters | TBD |
| Thermistors | TBD |
| Control Logic and Electronics | TBD |
| Latch Pyro Bolt Cutter | TBD |

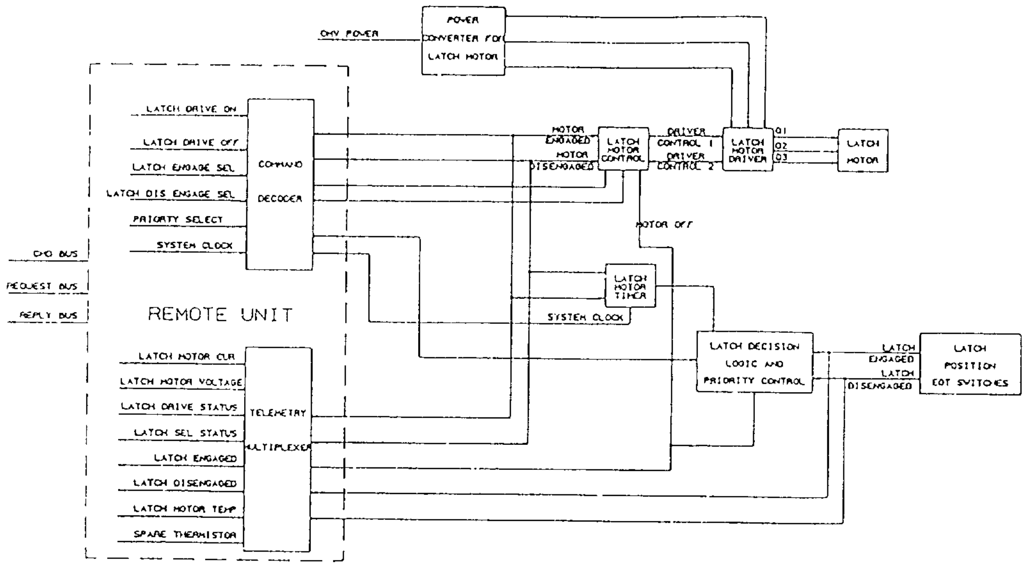


Figure 4-21 Latch Control and Telemetry Block Diagram

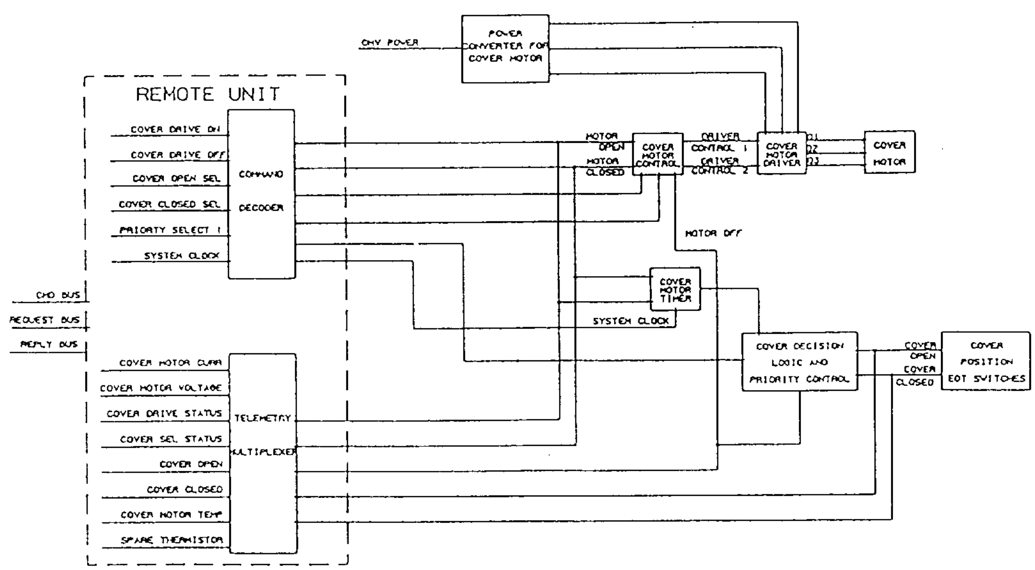


Figure 4-22 Cover Control and Telemetry Block Diagram

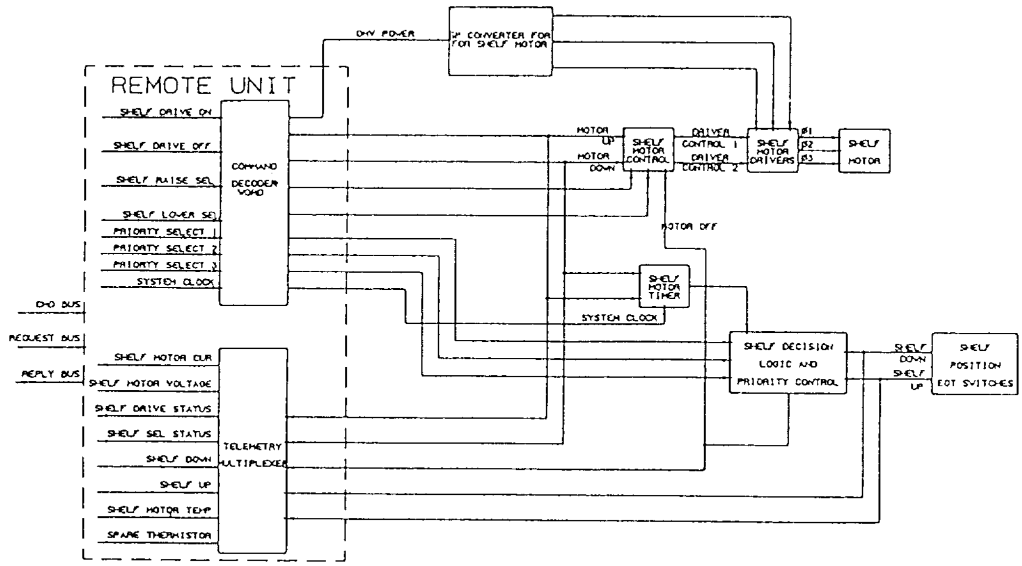


Figure 4-23 Shelf Control and Telemetry Block Diagram

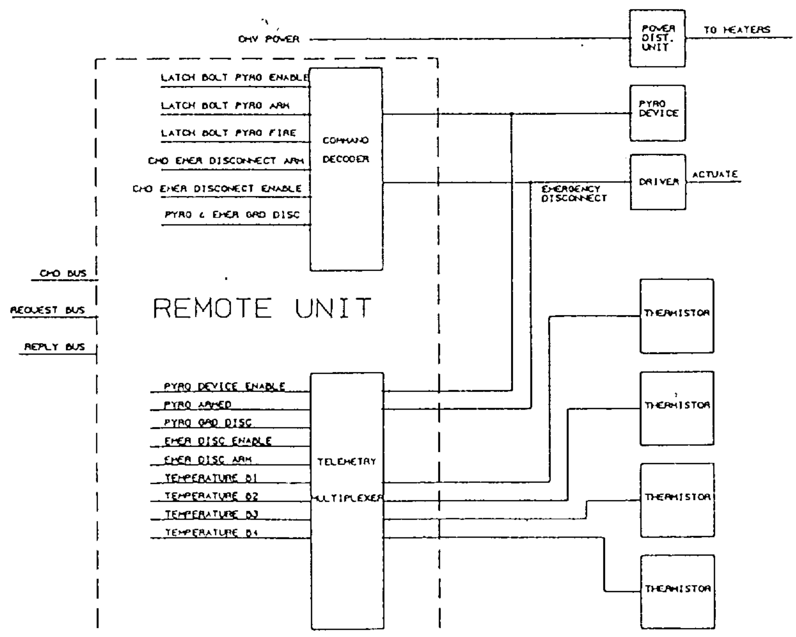


Figure 4-24 Latch Bolt Pyro, Emergency Disconnect and Temperature Measurement

## 4.5 WEIGHT BUDGETS

A mass budget was developed for each of the four flight configurations of the AFIS. The four configurations are as follows:

A. Fully laden version with three spacer assembly tables

B. Cryogen configuration with two tables

C. Fluid configuration with two tables

D. Demonstration

**Figure 4-25** shows a weight summary for each of the four options.

A detailed breakdown of each entry in **Figure 4-25** can be found in Appendices A through D. For example, the fully laden version (three table configuration) is detailed in Appendix A, the cryogen configuration is detailed in Appendix B, and so on. The drawing numbers of the components is shown in the comments column of each spreadsheet in the Appendices.

Each entry in **Figure 4-25** comprises both the predicted weight and an associated weight margin. The weight margins correspond to the confidence in each component. A 20% margin is assigned to any part that is estimated. A 10% margin is assigned to any part where the weight is calculated, and a 5% margin is assigned to existing parts. The total margin of each configuration is a weighted average of the individual component margins. For instance, the total AFIS weight of the fully laden (three table) configuration has 54.37 lbs of margin, or a 13.28% margin of the quantity weight as shown in Appendix A

| | THREE TABLES | (CRYO) TWO TABLES | (FLUID) TWO TABLES | SINGLE TABLE |
|---|---|---|---|---|
| MAIN STRUCTURE ASSY-7A1200 | 195 | 176 | 176 | 157 |
| FLUID SPACER ASSY.-7A1210 | 25 | N/A | 25 | N/A |
| GAS/ELEC SPACER ASSY.-7A1220 | 25 | 25 | 25 | 25 |
| CRYRO SPACER ASSY.-7A1230 | 24 | 24 | N/A | N/A |
| TENSIONER ASSY.-7A1240 | 3 | 3 | 3 | 3 |
| COVER MECHANISM ASSY.-7A1300 | 19 | 19 | 19 | 19 |
| COVER GEAR HOUSNIG ASSY.-7A1301 | 2 | 2 | 2 | 2 |
| DISCONNECT ASSY.-7A1400 | 4 | 4 | 4 | 4 |
| LATCH MECHANISM-7A1500 | 19 | 19 | 19 | 19 |
| THERMAL CONTROL HARDWARE | 21 | 21 | 21 | 21 |
| ELECTRONICS AND WIRING HARNESS | 49 | 49 | 49 | 49 |
| *AFIS Subtotal* | *386* | *342* | *343* | *299* |
| GFE COUPLERS AND CONNECTORS | 79 | 60 | 60 | 25 |
| *AFIS Total Weight and Margin* | *465* | *402* | *403* | *324* |

**Figure 4-25 AFIS Mass Budget Summary**

The difference in weights between the four configurations occurs in the main structure, the number of tables (spacer assembles), and the combination of couplers and connectors.

Listed below are six components within the main structure that have different quantities for the different configurations.

A. Ball Screws.

B. Thrust Bearing.

C. Drive Sprockets.

D. Idler Sprockets.

E. Idler Shafts.

F. Ball Screw Mtg Block

The quantity of these components for the single table configuration is typically a third as much as the three table option.

Each of the three types of spacer assemblies (tables) weigh approximately the same as shown in **Figure 4-25**.

The combination of couplers and connectors is dictated by the configuration requirements. The cryogen configuration, for example, has four cryogen couplers, four gas couplers, zero liquid couplers and eight electric connectors, as detailed in Appendix B.

## 4.6 THERMAL ASSESSMENT

An initial thermal design and performance assessment was performed for the AFIS. While the AFIS might be utilized in a variety of orbital applications and in combination with different carrier vehicles, the thermal assessment study focuses on a single generic thermal design which could subsequently be optimized for a given mission. In this study, extreme environments and steady-state solutions were combined to yield very conservative analytical results.

The basic requirements to be met by the AFIS thermal design are derived from vendor information and previous hardware studies, such as OSCRS and OMV, and are given in Table 3. The most restrictive temperature range will apply to fluid subsystem components containing monopropellant and bipropellant fluids, such as MMH, NTO and $N_2H_4$. In addition to maintaining an adequate thermal environment for propellants and the AFIS equipment components, other goals of the thermal design are to minimize temperature gradients within the AFIS structure and to minimize heater power requirements.

### 4.6.1 Thermal Configuration

The AFIS is conductively isolated from the carrier vehicle at the interfaces between the Base Ring and Strut Assemblies. Each electrical connector or fluid coupling is conductively isolated from the AFIS structure at its mounting flange. Thermal isolators of 0.5 inch G-10 are used.

The AFIS is insulated from the radiation environment by the use of Multi-Layer Insulation (MLI) on all external surfaces and other surfaces with a view of space. Beta cloth comprises the outer layer. Ten-layer MLI is used on the contamination covers with twenty-layer MLI in all other locations. The Base Ring is closed out with MLI and therefore has no view of space or of the carrier vehicle. The Strut Assemblies and fluid and electrical lines between the AFIS and the carrier vehicle are enclosed with MLI and also have no view of space. This tends to isothermalize those components, promoting better alignment and thermal control.

Flight heaters are located near critical components, such as drive motors, electronics, and fluid subsystem hardware. The features of the initial thermal design for the AFIS are shown in **Figures 4-26 and 4-27**. It is assumed that the AFIS contamination covers are open and that there is no internal power dissipation other than that required for thermal control.

### 4.6.2 Thermal Analysis

Steady-state solutions were obtained with a 15-node SINDA finite-difference model. Three cases were identified for analysis: the hot case, the propellant cold case, and the cryogen cold case. The assumed conditions for these cases are quite extreme and are noted in Table 4. In the hot case, the AFIS receives a full solar input from the forward direction and on all lateral external surfaces. In the cold cases, the AFIS receives no radiative input while viewing only space.

Certain assumptions have been made in order to perform this initial thermal assessment. These are related to MLI performance and expected environments. External environments were taken from the AFIS

Requirements Document. Carrier vehicle mounting surface temperatures were taken from OMV thermal analyses. The assumed properties are quite conservative in general and are given in Table 4.

### 4.6.3 Results and Recommendations

Results from the AFIS thermal assessment are shown in Table 5.; estimated heater power requirements for both the propellant servicing and cryogen servicing missions are given in Table 6. These results are very conservative, being based on extreme environmental conditions and derived by steady-state solution, demonstrating that the AFIS thermal design as proposed herein should meet all basic thermal requirements. The thermal design may be optimized for particular missions to provide increased performance.

The AFIS should be operated at temperatures somewhat colder for the cryogen servicing case than for the propellant servicing case in order to minimize cryogen losses. The cryogen transfer losses are incurred only during the period of cryogen fluid transfer. Propellant cold case power requirements may be reduced by operating at cryogen case temperature levels before propellant fluid transfer, but thermal pre-conditioning of the AFIS will be required before any propellant transfer may take place.

**Table 3. AFIS Temperature Requirements**

| | |
|---|---|
| PROPELLANTS | 50°F to 120°F |
| DRIVE MOTORS | -100°F to 250°F |
| ELECTRICAL CONNECTORS | -55°F to 250°F |
| BALL SCREWS | -60°F to 250°F |

**Table 4. AFIS Assumed Environmental Factors**

| | |
|---|---|
| SOLAR CONSTANT | 443.7 Btu/hr-ft$^2$ |
| SPACE SINK TEMPERATURE | 3K (-455°F) |
| HOT CASE | FULL SUN FROM ALL DIRECTIONS<br>MOUNTING SURFACE AT 25°F |
| PROPELLANT COLD CASE | NO RADIATIVE INPUTS<br>MOUNTING SURFACE AT -15°F |
| CRYOGEN COLD CASE | NO RADIATIVE INPUTS<br>MOUNTING SURFACE<br>AT -15°F |
| MLI | 10-LAYER EFFECTIVE EMISSIVITY = 0.05<br>20-LAYER EFFECTIVE EMISSIVITY = 0.03 |

## Table 5. Thermal Analysis Results

| | HOT CASE | PROPELLANT COLD CASE | CRYOGEN COLD CASE |
|---|---|---|---|
| RADIATIVE INPUTS | FULL SUN | NONE | NONE |
| MOUNTING SURFACE TEMPERATURE | 25°F | -15°F | -15°F |
| CONNECTOR FRAME TEMPERATURE | 40°C (104°F) | 10°C (50°F) | -38°C (-36°F) |
| ENVIRONMENTAL LOSS MAKEUP | - | 30W | 10W |
| CRYOGEN TRANSFER LOSS MAKEUP | - | - | 20W * |

## Table 6. Worst Case Heater Power Requirements

| | PROPELLANT CASE | CRYOGEN CASE |
|---|---|---|
| COLD CASE ENVIRONMENTAL LOSSES | 30W | 10W |
| CRYOGEN TRANSFER LOSSES | - | 20W* |
| CONTINGENCY | 10W | 10W |
| TOTAL AVERAGE POWE | 40W | 40W |
| PEAK POWER AT 50% DUTY CYCLE | 80W | 80W |

* REQUIRED DURING CRYOGEN TRANSFER ONLY.

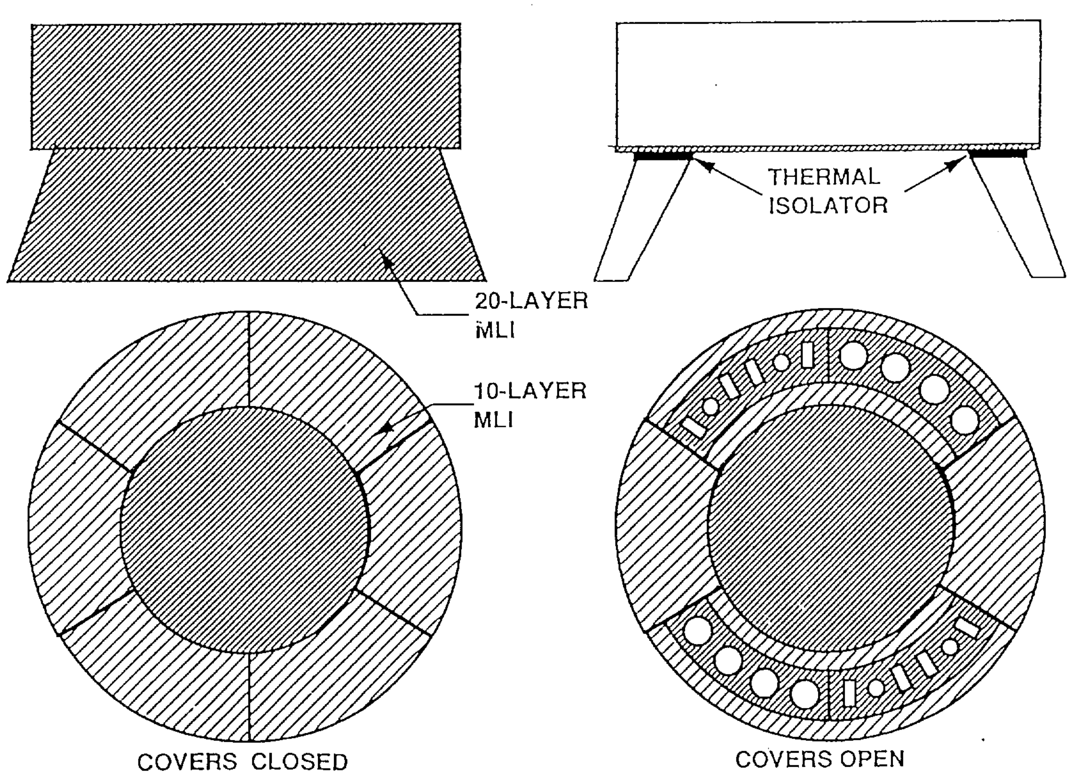


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Figure 4-26 AFIS Thermal Configuration

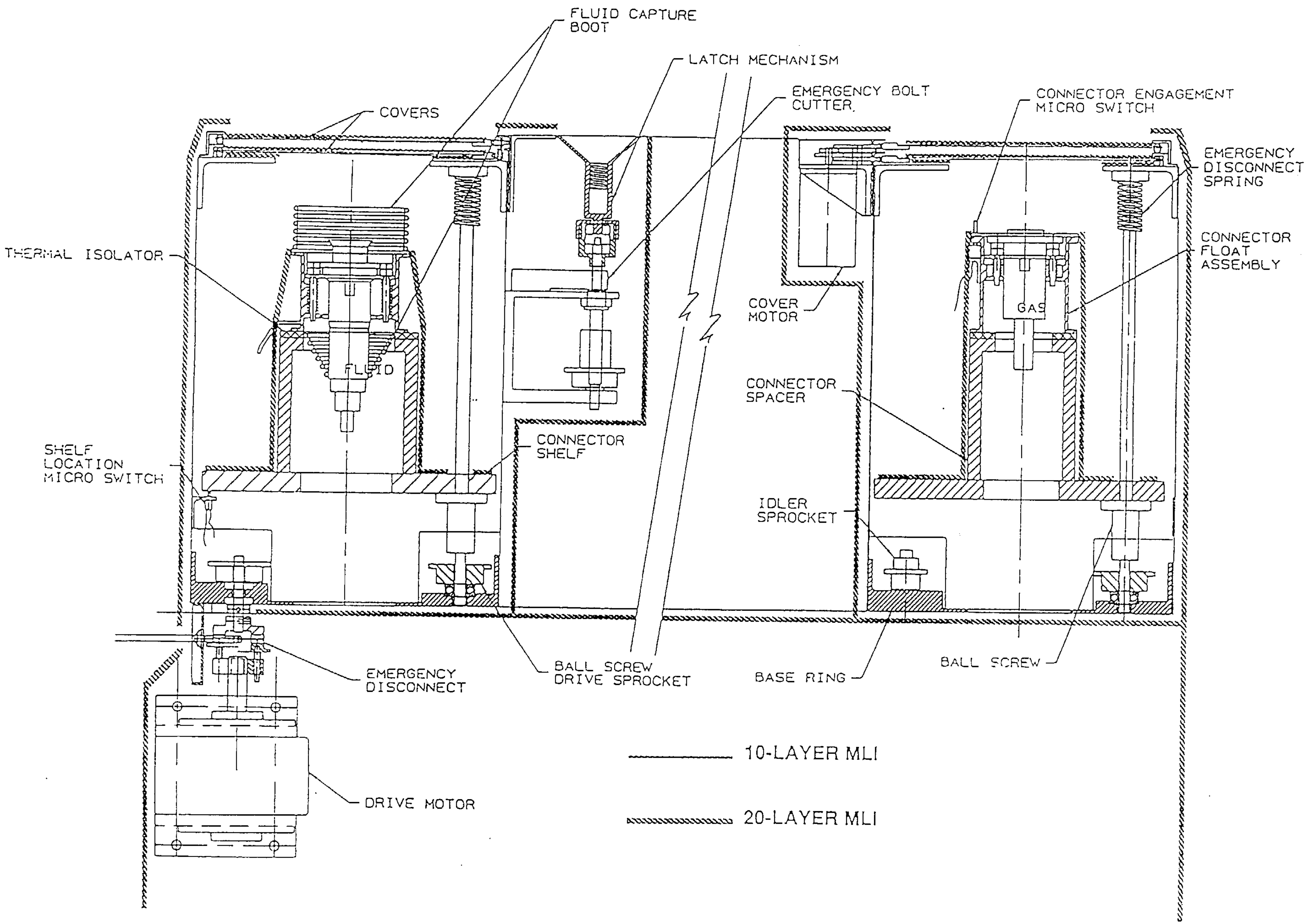


Figure 4-27 AFIS Thermal Configuration

## 4.7 SAFETY ASSESSMENT

### 4.7.1 Safety Requirements Matrix

A preliminary safety assessment has been performed for the AFIS system hardware and its operational aspects. Each element of the AFIS has been reviewed to establish how it relates to the specific requirements as defined in NHB 1700.7B. The review has made known those payload elements for which a hazard has been identified and for which a hazard must be controlled during the design, testing, and operation of the AFIS.

The AFIS Safety Requirements Matrix, shown in **Figure 4-28**, provides the relationship between individual AFIS subsystems and the requirements of specific sections of NSTS 1700.7B.

### 4.7.2 System Hazards

The hazards associated with the design and operation of the AFIS will be controlled by appropriate design, manufacturing, and operational measures taken to insure compliance with the requirements of NSTS 1700.7B and NHB 1700. **Figure 4-29** lists the major AFIS system hazards and indicates the type of activity or function which will be employed to control those hazards.

The AFIS structural elements and pressurized fluid components are made failure-tolerant by compliance with requirements in NSTS 1700.7B, Section 208. Injury to personnel and/or damage to STS equipment due to sharp edges, corners, protrusions, etc., are prevented by compliance with the requirements of NSTS 1700.7B, Section 217.

The incorporation of redundancy and inhibits in the AFIS design enhances the failure tolerance and safe operation of fluid couplings, fluid vent valves, fluid component heater circuits and the emergency demate mechanism. Explosion hazards are controlled by the separation and isolation of fluid components containing incompatible fluids, such as fuel and oxidizer. The requirements of NSTS 1700.7B, Sections 200-210, 213, and 219 apply to these AFIS components and associated hazards.

The ability to release the receiving spacecraft in the event of docking mechanism failure is insured by the use of EVA-releasable or EVA-operable docking components and non-latching fluid couplings in the AFIS design. The requirements of NSTS 1700.7B, Sections 200, 203-205, 216, and 217 are applicable.

### 4.7.3 Fluid Coupler/Electrical Connector Layout

The fluid coupler layout is designed to maximize safety by maximizing the distance between hazardous propellants and cryogens. The MMH fluid coupler will be located on the opposite side of the AFIS from the $N_2O_4$ fluid coupler and the LOX and $LH_2$ fluid couplers are similarly separated. The connectors utilized for data are separated 180° from the electrical power connectors to minimize EMI/EMC problems. **Figure 4-30** shows the proposed fluid coupling arrangement.

It is envisioned that the propellants will be transferred in a serial fashion. The fluid trapped in the lines after propellant transfer will be vented to space, either directly to space or through a catalysis bed.

## STS PAYLOAD SAFETY REQUIREMENTS APPLICABILITY MATRIX

| 1. PAYLOAD/SUBSYSTEM: AFIS | 2. DATE: | 3. PHASE: | 4. PAGE ___ OF ___ |
|---|---|---|---|

6. NHB 1700.7A REQUIREMENTS

| 5. PAYLOAD ELEMENT | 200 GENERAL | 201 FAILURE TOLERANCE | 201.1 CRITICAL HAZARDS | 201.2 CATASTROPHIC HAZARDS | 202.2A SOLID PROPELLANT | 202.2B LIQUID PROPELLANT | 202.2C DEPLOYMENT/SEPARATION | 202.2D BAY DOOR CLOSURE | 202.2E PAYLOAD RF XMTR | 203 RETRIEVAL OF PAYLOAD | 204 HAZARD DETECTION & SAFING | 205 P/L CONTINGENCY RETURN | 206 FAILURE PROPAGATION | 207 REDUNDANCY SEPARATION | 208.1, 2 & 3 STRUCTURAL | 208.4 & 5 PRESSURE SYSTEM | 208.6 DECOMPRESSION | 208.7 SEALED CONTAINERS | 209.1 HAZARDOUS MATERIALS | 209.2 CABIN MATERIALS | 209.3 FLAMMABLE MATERIALS | 209.4 OFFGASSING MATERIAL | 210 PYROTECHNICS | 211 DESTRUCT SYSTEMS | 212.1 IONIZING RADIATION | 212.2 NONIONIZING RADIATION | 213 ELECTRICAL SYSTEMS | 214 VERIFICATION REQMTS | 215 HAZARDOUS PROCEDURES | 216 REFLOWN HARDWARE | 217 EXTRAVEHICULAR ACTIVITY | 218 SERIES PAYLOAD | 219 FLAMMABLE ATMOSPHERE | 7. SAFETY ANALYSIS BY: (NAME, ORG, INITIAL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STRUCTURE | / | X | / | / | - | - | - | - | - | - | - | - | / | - | X | - | - | - | - | - | / | - | - | - | - | - | - | / | - | / | X | - | - | |
| MECHANISMS | / | X | / | / | - | - | - | - | - | - | - | - | - | / | X | - | - | - | - | - | / | - | / | - | - | - | - | / | - | / | / | - | - | |
| AVIONICS & ELEC. POWER | / | X | X | / | - | - | - | - | - | - | - | - | / | / | X | - | - | - | - | - | X | / | - | - | - | - | X | / | / | / | / | - | X | |
| THERMAL CONTROL | / | X | X | X | - | - | - | - | - | / | - | - | / | / | - | / | - | - | - | - | / | / | - | - | - | - | / | / | - | / | / | - | X | |
| MONO-PROPELLANTS | / | X | X | X | - | X | - | - | - | X | - | / | X | / | - | X | - | - | X | - | - | - | - | - | - | - | - | / | / | - | / | - | - | |
| BI-PROPELLANTS | / | X | X | X | - | X | - | - | - | X | - | / | X | / | - | X | - | - | X | - | - | - | - | - | - | - | - | / | / | - | / | - | - | |
| CRYOGENS | / | X | X | X | - | X | - | - | - | X | - | / | X | / | - | X | - | - | / | - | - | - | - | - | - | - | - | / | / | - | / | - | - | |
| PRESSURANT GASES | / | X | X | X | - | X | - | - | - | X | - | / | X | / | - | X | - | - | / | - | - | - | - | - | - | - | - | / | / | - | / | - | - | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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8. LEGEND:

| | |
|---|---|
| — NOT APPLICABLE | / APPLICABLE: NO HAZARD IDENTIFIED |
| X APPLICABLE: HAZARD IDENTIFIED | ■ WAIVER DEVIATION REQUIRED |

| 9. | IMPLEMENTATION PERSONNEL | DATE | PAYLOAD ORGANIZATION PERSONNEL | DATE |
|---|---|---|---|---|
| PREPARED BY: | | | | |
| REVIEWED BY: | | | | |
| APPROVED BY: | | | | |

JSC Form 1090 (APR 83)

**Figure 4-28 STS Payload Safety Requirements Applicability Matrix**

| AFIS SYSTEM HAZARDS | CONTROLLED BY: INHIBITS | DESIGN | MFG/TEST | OPN |
|---|---|---|---|---|
| • LEAKAGE OR RUPTURE IN FLUID SUBSYSTEM DUE TO STRUCTURAL FAILURE | | X | X | |
| • LEAKAGE OR RUPTURE IN FLUID SUBSYSTEM DUE TO FAILURE OF HEATER CIRCUIT | X | X | X | |
| • FAILURE OR INADVERTENT ACTUATION OF AFIS VENT VALVES | X | X | X | |
| • FAILURE OR IMPROPER MATING OF FLUID COUPLINGS | | X | X | |
| • INABILITY TO RELEASE RECEIVING SPACECRAFT AFTER SERVICING | | X | | X |
| • INADVERTENT ACTUATION OF THE EMERGENCY DEMATE MECHANISM | X | X | | |
| • INJURY OR DAMAGE RESULTING FROM SHARP EDGES, CORNERS, PROTRUSIONS, ETC. | | X | X | |
| • IGNITION OF FLAMMABLE ATMOSPHERES | X | X | | |
| • FAILURE OF PRIMARY STRUCTURE | | X | X | |
| • EXPLOSION DUE TO FUEL AND OXIDIZER IN CLOSE PROXIMITY | X | X | | X |

**Figure 4-29 AFIS Safety Assessment**

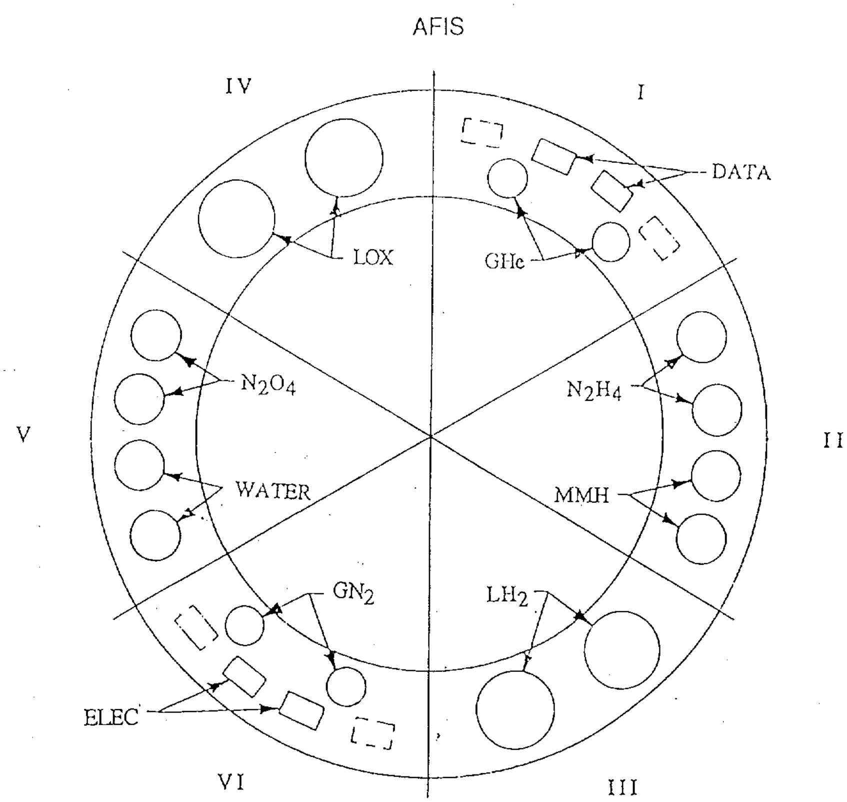


**Figure 4-30 Fluid Coupler and Electrical Connector Layout**

# 5.0 DEMONSTRATION UNIT

## 5.1 DEMONSTRATION OBJECTIVE

An Engineering working model of AFIS was constructed to demonstrate the proof of concept. All of the AFIS subsystems with the exception of the pyros were operated in a scenario representing a typical fluid transfer mission. A detailed description of the procedures can be found in "Test Plan and Operational Procedures", Fairchild Space, April 1990, NAS8-37457. In order to demonstrate a typical fluid transfer operation, a satellite simulator was designed and constructed. The simulator provided the interface needed for mounting the fluid coupler. It also provided the structural frame for simulating the 2,000 lbs fluid transfer force.

A summary of the functions and tests performed is provided below:

a) Raise and engage latches.
b) Open contamination covers.
c) Raise shelf assembly and engage fluid coupler.
d) Transfer fluid through coupler.
e) Apply 2,000# load to AFIS interface.
f) Break interface with emergency de-mate.
g) Raise shelf assembly again and re-mate coupler.
h) Lower shelf assembly.
i) Close contamination covers.
j) Disengage latches.

The 0.25 inch over-travel and 0.1 inch lateral misalignment requirements were demonstrated by repeating the same procedure described above for the nominal condition.

## 5.2 DEMO MECHANICAL CONFIGURATION

The AFIS demonstration unit mechanical design is similar to the flight design. The major changes involve lubricants and motor selection. The rationale for these changes was to reduce cost without sacrificing performance. Each of the major systems is listed below, along with the listed components that are not flight qualified.

### 5.2.1 Cover Mechanism

This mechanism is essentially the same as the flight unit. The only changes from the flight design involve the motor selection and the design of the cover fans. For the flight design, a flight qualified motor would need to be used. The cover fans would be made of aluminum honeycomb to reduce weight. The microswitches that control the travel of the covers would need to be flight qualified parts. The cover backup release was not incorporated on the demonstration unit because of the pyro device that is required for the release.

### 5.2.2 Latch Mechanism

The Latch Mechanism is essentially the same as the flight design, with only a few modifications. The motor would need to be a flight qualified unit, and the lubricants would need to be flight qualified. A carbon steel chain was used for the demo unit; a stainless steel chain would be used for flight. Additionally, carbon steel sprockets were used instead of stainless steel to reduce cost. The bearings that were used in the mechanism were not flight qualified since commercially available parts cost less. Non-flight qualified microswitches were used.

### 5.2.3 Shelf Drive Mechanism

The shelf drive mechanism is similar to the corresponding flight design, with only a few exceptions. The emergency disconnect is manually operated rather than operated by a solenoid. The chain drive components are commercially available carbon steel rather than stainless steel. No flight lubricants are used. Non-flight qualified microswitches were used.

### 5.2.4 Structure

The demo AFIS structure is essentially the same as the flight AFIS structure. Honeycomb panels would be installed in the flight unit for the radial ribs and for the legs to reduce weight. Appendix D itemizes the demo AFIS weights.

## 5.3 DEMO ELECTRICAL SYSTEM

The AFIS demonstration unit electrical system simulates the flight unit electrical system by using a series of remotely actuated relays to drive the melanisms. Tables 7 and 8 list the electrical interfaces and hardware considerations for the AFIS demo unit. The demo unit electrical system consists of the following three main elements: the remote controller, the remote relay chassis, and the sensors and motors mounted on the AFIS (see **Figure 5-1**)

The remote controller provides the control and 12 volt DC power necessary to control and drive the latch and cover mechanism motors. The coupler shelf drive, which is driven by an AC motor, is controlled remotely via 12 volt relays. The status of all mechanisms and their respective End of Travel (EOT) limits are provided by indicators on the remote control panel, as shown in **Figure 5-2**. The method of operation to be used with this panel is as follows: the operation decides which system is to be driven, selects the direction of travel and then activates the drive switch for that particular function. The demo unit design concept lends itself well to the remote operation needed for eventual flight application. The remote controller would be replaced with either an STS or ground based command and telemetry system to conduct on-orbit operations.

The remote control relay chassis, that provides the relay activation and status sensing of the mechanisms, is located on the AFIS unit. The remote unit contains the necessary relays and sensing resistors to carry out the functions necessary to drive and stop the mechanisms. This unit simulates the actual Remote Interface Unit (RIU) functions that would be provided in a flight version of the AFIS.

The sensors and motors are mounted on the AFIS mechanical system as required to perform the electrical to mechanical interface. For purposes of the demonstration unit, the EOT sensors selected are microswitches, but for flight several other proximity sensing techniques will be considered. The motors are also standard 12 volt DC brushless DC motors or stepper motors as required for the flight application.

**Table 7. Demo Electrical Interfaces**

| Power | Commands | Telemetry |
|---|---|---|
| Coupler Shelf Drive Motor | Latch Operation | Heater Thermistor Readout |
| Cover Mechanism Motor | Cover Mechanism Operation | Cover Status |
| Latch Motor | Coupler Shelf Mechanism | Coupler Shelf Status |

**Table 8. Demo Electrical Hardware**

| Name | Type |
|---|---|
| Coupler Shelf Drive Motor | 110 V AC Motor & Gear Reducer |
| Cover Mechanism Drive Motor | 12 V DC Motor & Gear Reducer |
| Latch Motor | TBD |
| Emergency Disconnect Solenoid | Manual Only |
| Heaters | None |
| Thermistors | None |
| AFIS Control Unit | GSE |
| Latch Motor | 12V DC Motor & Gear Reducer |

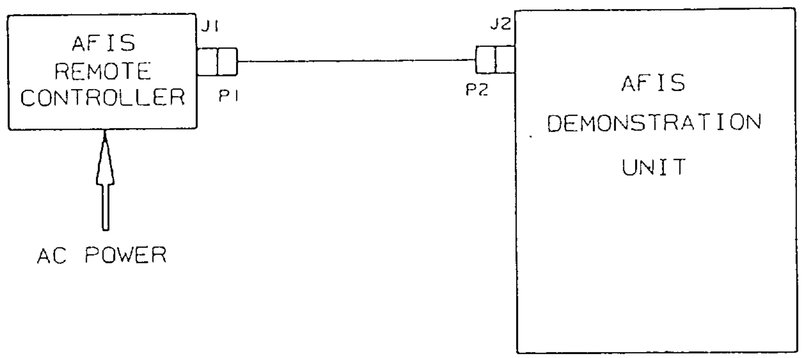


**Figure 5-1 AFIS/Controller Interconnect Diagram**

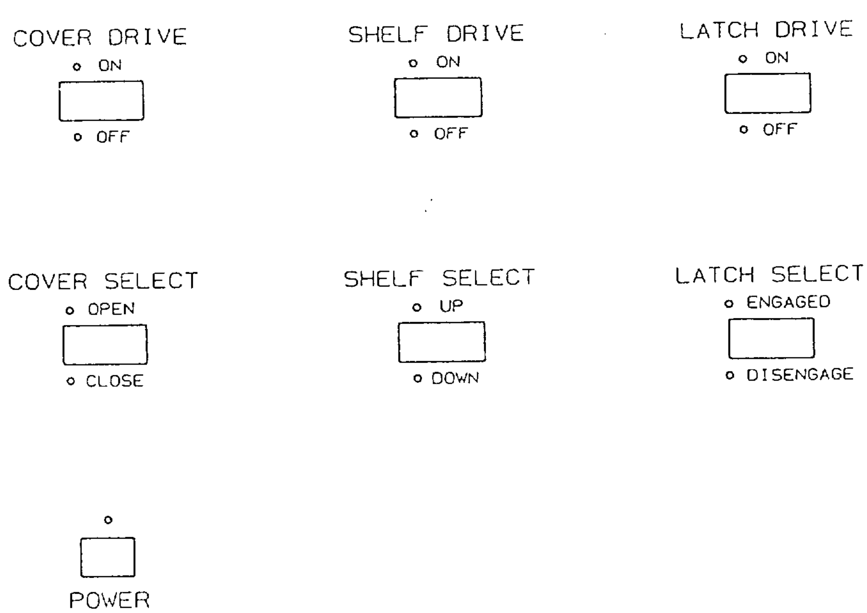


**Figure 5-2 AFIS Remote Controller**

# APPENDIX A WEIGHTS-FULLY LADEN (THREE TABLES)

| Assembly Level | Assembly Components | Subassembly Components | Unit Wt Pounds | QTY | Quantity Weight Pounds | % Breakdown of Current Weight | | | Weight Plus Margin (total) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Est'd 20% margin | Cal'd 10% margin | Actual 5% margin | | |
| | OUTER SKIN | | 9.580 | 1 | 9.580 | | 100 | | 10.538 | - |
| | INNER SKIN | | 5.770 | 1 | 5.770 | | 100 | | 6.347 | - |
| | MAIN DRIVE MOTORS | | 1.320 | 2 | 2.640 | 100 | | | 3.168 | - |
| | BASE RING ASSEMBLY | | 26.220 | 1 | 26.220 | | 100 | | 28.842 | 7A1201 |
| MAIN | RADIAL SUPPORT RIB | | 2.570 | 6 | 15.420 | | 100 | | 16.962 | 7A1202 |
| STRUCTURE | UPPER RING, OUTER | | 10.470 | 1 | 10.470 | | 100 | | 11.517 | 7A1203 |
| ASSEMBLY | RING, INNER | | 6.840 | 1 | 6.840 | | 100 | | 7.524 | 7A1204 |
| 7A1200 | BALL SCREWS | | 2.000 | 18 | 36.000 | | 100 | | 39.6 | 7A1205 |
| | THRUST BEARINGS | | 0.130 | 18 | 2.340 | | | 100 | 2.457 | AUBURN |
| | DRIVE SPROCKETS | | 0.160 | 20 | 3.200 | | | 100 | 3.36 | BROWNING |
| | CHAIN | | 2.610 | 1 | 2.610 | | 100 | | 2.871 | BERG |
| | IDLER SPROCKETS | | 0.140 | 36 | 5.040 | | | 100 | 5.292 | BROWNING |
| | IDLER SHAFTS | | 0.055 | 36 | 1.980 | | | 100 | 2.079 | BROWNING |
| | BALL SCREW MNTG. BLOCK | | 0.097 | 18 | 1.746 | | 100 | | 1.9206 | 7A1201 |
| | STIFFENER ANGLE (INNER) | | 0.277 | 12 | 3.324 | | 100 | | 3.6564 | 7A1201 |
| | STIFFENER ANGLE (OUTER) | | 0.126 | 12 | 1.512 | | 100 | | 1.6632 | 7A1201 |
| | SUPPORT LEG | | 10.690 | 4 | 42.760 | | 100 | | 47.036 | 7A1201 |
| | | *Subtotal* | | | *177.452* | *composite* | *margin=* | *9.79%* | *194.83* | |
| FLUID | FRAME, BALL SCREW-FLUID | | 6.090 | 2 | 12.180 | | 100 | | 13.398 | 7A1211 |
| SPACER ASSY. | SPACER ASSY.-FLUID | | 5.300 | 2 | 10.600 | | 100 | | 11.66 | 7A1212 |
| 7A1210 | | *Subtotal* | | | *22.780* | *composite* | *margin=* | *10.01%* | *25.06* | |
| GAS/ELEC | FRAME, BALL SCREW-GAS/ELEC | | 5.550 | 2 | 11.100 | | 100 | | 12.21 | 7A1221 |
| SPACER ASSY. | SPACER ASSY.-GAS/ELEC. | | 5.750 | 2 | 11.500 | | 100 | | 12.65 | 7A1222 |
| 7A1220 | | *Subtotal* | | | *22.600* | *composite* | *margin=* | *10.00%* | *24.86* | |
| CRYRO | FRAME BALL SCREW-CRYO | | 6.940 | 2 | 13.880 | | 100 | | 15.268 | 7A1231 |
| SPACER ASSY. | SPACER ASSY.-CRYRO | | 1.950 | 4 | 7.800 | | 100 | | 8.58 | 7A1232 |
| 7A1230 | | *Subtotal* | | | *21.680* | *composite* | *margin=* | *10.01%* | *23.85* | |
| | IDLER SPROCKET | | 0.120 | 7 | 0.840 | | 100 | | 0.924 | BROWNING |
| | IDLER SHAFT | | 0.055 | 7 | 0.385 | | 100 | | 0.4235 | BROWNING |
| TENSIONER | HOUSING | | 0.060 | 7 | 0.420 | | 100 | | 0.462 | 7A1241 |
| ASSEMBLY | GUIDE SHAFT | | 0.036 | 14 | 0.504 | | 100 | | 0.5544 | 7A1242 |
| 7A1240 | RETAINER | | 0.071 | 7 | 0.497 | | 100 | | 0.5467 | 7A1243 |
| | LEAD SCREW | | 0.010 | 3 | 0.030 | | 100 | | 0.033 | 7A1244 |
| | | *Subtotal* | | | *2.676* | *composite* | *margin=* | *9.87%* | *2.94* | |
| | RING, UPPER | | 1.190 | 1 | 1.190 | | 100 | | 1.309 | 7A1310 |
| | RING, LOWER | | 0.980 | 1 | 0.980 | | 100 | | 1.078 | 7A1311 |
| | | RING, LOWER FRAME | 2.960 | 1 | 2.960 | | 100 | | 3.256 | - |
| | LOWER FRAME | CHAIN | 0.082 | 1 | 0.082 | | 100 | | 0.0902 | BERG |
| | 7A11312 | ROLLER | 0.002 | 10 | 0.020 | | 100 | | 0.022 | 7A1304 |
| | | PIN | 0.001 | 10 | 0.010 | | 100 | | 0.011 | 7A1305 |
| | | SHAFT | 0.003 | 1 | 0.003 | | 100 | | 0.0033 | 7A1307 |
| | | RING, UPPER FRAME | 3.020 | 1 | 3.020 | | 100 | | 3.322 | - |
| COVER | | CHAIN | 0.140 | 1 | 0.140 | | 100 | | 0.154 | BERG |
| MECHANISM | UPPER FRAME | ROLLER | 0.002 | 8 | 0.016 | | 100 | | 0.0176 | 7A1304 |
| ASSEMBLY | 7A1313 | PIN | 0.001 | 8 | 0.008 | | 100 | | 0.0088 | 7A1305 |
| 7A1300 | | WHEEL | 0.002 | 3 | 0.006 | | 100 | | 0.0066 | 7A1306 |
| | | SHAFT | 0.003 | 3 | 0.009 | | 100 | | 0.0099 | 7A1307 |
| | | RETAINER | 0.002 | 3 | 0.006 | | 100 | | 0.0066 | 7A1308 |
| | COVER FAN | COVER | 0.636 | 4 | 2.544 | | 100 | | 2.7984 | 7A1316 |
| | 7A1316 | SLIDE, UPPER | 0.002 | 16 | 0.032 | | 100 | | 0.0352 | 7A1315 |
| | | SLIDE, LOWER | 0.002 | 16 | 0.032 | | 100 | | 0.0352 | 7A1317 |
| | OUTER RING, LOWER COVER | | 4.320 | 1 | 4.320 | | 100 | | 4.752 | 7A1318 |
| | OUTER RING, UPPER COVER | | 1.780 | 1 | 1.780 | | 100 | | 1.958 | 7A1319 |
| | | *Subtotal* | | | *17.158* | *composite* | *margin=* | *9.98%* | *18.87* | |
| | HOUSING SUB-ASSEMBLY | | 0.230 | 1 | 0.230 | | 100 | | 0.253 | 7A1302 |
| | COVER | | 0.073 | 1 | 0.073 | | 100 | | 0.0803 | 7A1303 |
| COVER GEAR | SHAFT, SPROCKET | | 0.008 | 1 | 0.008 | | 100 | | 0.0088 | 7A1309 |
| HOUSING | COVER DRIVE MOTOR | | 1.320 | 1 | 1.320 | | 100 | | 1.452 | 7A1314 |
| ASSEMBLY | PLATE, ADAPTER GEAR | | 0.029 | 1 | 0.029 | | 100 | | 0.0319 | 7A1320 |
| 7A1301 | DRIVE GEAR ASSY | | 0.052 | 1 | 0.052 | | 100 | | 0.0572 | 7A1323 |
| | SPROCKET ASSY | | 0.129 | 1 | 0.129 | | 100 | | 0.1419 | 7A1324 |
| | SPROCKET ASSY-LG PITCH DIA | | 0.153 | 1 | 0.153 | | 100 | | 0.1683 | 7A1325 |
| | | *Subtotal* | | | *1.994* | *composite* | *margin=* | *9.83%* | *2.19* | |

| Assembly Level | Assembly Components | Subassembly Components | Unit Wt Pounds | QTY | Quantity Weight Pounds | % Breakdown of Current Weight | | | Weight Plus Margin (total) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Est'd 20% margin | Cal'd 10% margin | Actual 5% margin | | |
| DISCONNECT ASSEMBLY 7A1400 | SHAFT | | 0.110 | 2 | 0.220 | | 100 | | 0.242 | 7A1401 |
| | UPPER COUPLING | | 0.106 | 2 | 0.212 | | 100 | | 0.2332 | 7A1402 |
| | LOWER COUPLING | | 0.185 | 2 | 0.370 | | 100 | | 0.407 | 7A1403 |
| | PIN,YOKE | | 0.004 | 4 | 0.016 | | 100 | | 0.0176 | 7A1404 |
| | YOKE | | 0.088 | 2 | 0.176 | | 100 | | 0.1936 | 7A1405 |
| | YOKE PIVOT PIN | | 0.012 | 2 | 0.024 | | 100 | | 0.0264 | 7A1406 |
| | MOTOR COUPLER | | 0.237 | 2 | 0.474 | | 100 | | 0.5214 | 7A1407 |
| | MOTOR HOUSING | | 0.482 | 2 | 0.964 | | 100 | | 1.0604 | 7A1408 |
| | HANDLE | | 0.431 | 2 | 0.862 | | 100 | | 0.9482 | 7A1409 |
| | | *Subtotal* | | | *3.318* | *composite* | *margin=* | *10.01%* | *3.65* | |
| LATCH MECHANISM 7A1500 | CHAIN | | 2.000 | 1 | 2.000 | 100 | | | 2.4 | |
| | MOTOR | | 4.000 | 1 | 4.000 | 100 | | | 4.8 | |
| | MISC. HARDWARE | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | | *Subtotal* | | | *16.000* | *composite* | *margin=* | *20.00%* | *19.20* | |
| THERMAL CONTROL HARDWARE | HEATERS | | 0.100 | 1 | 0.100 | 100 | | | 0.12 | |
| | BLANKETS | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | ISOLATORS | | 5.000 | 1 | 5.000 | 100 | | | 6 | |
| | SENSORS | | 2.000 | 1 | 2.000 | 100 | | | 2.4 | |
| | | *Subtotal* | | | *17.100* | *composite* | *margin=* | *20.00%* | *20.52* | |
| ELECTRONICS AND WIRING HARNESS | CONTROL ELECTRONICS | | 20.000 | 1 | 20.000 | 100 | | | 24 | |
| | REMOTE UNIT | | 10.800 | 1 | 10.800 | 100 | | | 12.96 | |
| | ELECTRICAL HARNESS | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | | *Subtotal* | | | *40.800* | *composite* | *margin=* | *20.00%* | *48.96* | |
| **AFIS SUBTOTAL** | | | | | 343.558 | *composite* | *margin=* | *12.04%* | 384.930 | |
| GFE COUPLERS AND CONNECTORS | Cryogen Coupler | | 4.000 | 4 | 16.000 | 100 | | | 19 | |
| | Gas Coupler | | 2.500 | 4 | 10.000 | 100 | | | 12 | |
| | Liquid Coupler | | 2.000 | 8 | 16.000 | 100 | | | 19 | |
| | Electrical Connector | | 3.000 | 8 | 24.000 | 100 | | | 29 | |
| | | *Subtotal* | | | *66.000* | *composite* | *margin=* | *19.70%* | *79* | |
| AFIS TOTAL | | | | | 409.558 | *composite* | *margin=* | *13.28%* | 463.93 | |

# APPENDIX B WEIGHTS-CRYOGEN CONFIGURATION (TWO TABLES)

| Assembly Level | Assembly Components | Subassembly Components | Unit Wt Pounds | QTY | Quantity Weight Pounds | % Breakdown of Current Weight: Est'd 20% margin | Cal'd 10% margin | Actual 5% margin | Weight Plus Margin (total) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| MAIN STRUCTURE ASSEMBLY 7A1200 | OUTER SKIN | | 9.580 | 1 | 9.580 | | 100 | | 10.538 | - |
| | INNER SKIN | | 5.770 | 1 | 5.770 | | 100 | | 6.347 | - |
| | MAIN DRIVE MOTORS | | 1.320 | 2 | 2.640 | 100 | | | 3.168 | - |
| | BASE RING ASSEMBLY | | 26.220 | 1 | 26.220 | | 100 | | 28.842 | 7A1201 |
| | RADIAL SUPPORT RIB | | 2.570 | 6 | 15.420 | | 100 | | 16.962 | 7A1202 |
| | UPPER RING, OUTER | | 10.470 | 1 | 10.470 | | 100 | | 11.517 | 7A1203 |
| | RING, INNER | | 6.840 | 1 | 6.840 | | 100 | | 7.524 | 7A1204 |
| | BALL SCREWS | | 2.000 | 12 | 24.000 | | 100 | | 26.4 | 7A1205 |
| | THRUST BEARINGS | | 0.130 | 12 | 1.560 | | | 100 | 1.638 | AUBURN |
| | DRIVE SPROCKETS | | 0.160 | 14 | 2.240 | | | 100 | 2.352 | BROWNING |
| | CHAIN | | 1.740 | 1 | 1.740 | | 100 | | 1.914 | BERG |
| | IDLER SPROCKETS | | 0.140 | 24 | 3.360 | | | 100 | 3.528 | BROWNING |
| | IDLER SHAFTS | | 0.055 | 24 | 1.320 | | | 100 | 1.386 | BROWNING |
| | BALL SCREW MNTG. BLOCK | | 0.097 | 12 | 1.164 | | 100 | | 1.2804 | 7A1201 |
| | STIFFENER ANGLE (INNER) | | 0.277 | 12 | 3.324 | | 100 | | 3.6564 | 7A1201 |
| | STIFFENER ANGLE (OUTER) | | 0.126 | 12 | 1.512 | | 100 | | 1.6632 | 7A1201 |
| | SUPPORT LEG | | 10.690 | 4 | 42.760 | | 100 | | 47.036 | 7A1201 |
| | | *Subtotal* | | | *159.920* | *composite* | *margin=* | *9.90%* | *175.75* | |
| CRYRO SPACER ASSY. 7A1230 | FRAME, BALL SCREW-CRYRO | | 6.940 | 2 | 13.880 | | 100 | | 15.268 | 7A1211 |
| | SPACER ASSY.-CRYRO | | 1.950 | 4 | 7.800 | | 100 | | 8.58 | 7A1212 |
| | | *Subtotal* | | | *21.680* | *composite* | *margin=* | *10.00%* | *23.85* | |
| GAS/ELEC SPACER ASSY. 7A1220 | FRAME, BALL SCREW-GAS/ELEC | | 5.550 | 2 | 11.100 | | 100 | | 12.21 | 7A1221 |
| | SPACER ASSY.-GAS/ELEC. | | 5.750 | 2 | 11.500 | | 100 | | 12.65 | 7A1222 |
| | | *Subtotal* | | | *22.600* | *composite* | *margin=* | *10.00%* | *24.86* | |
| TENSIONER ASSEMBLY 7A1240 | IDLER SPROCKET | | 0.120 | 7 | 0.840 | | 100 | | 0.924 | BROWNING |
| | IDLER SHAFT | | 0.055 | 7 | 0.385 | | 100 | | 0.4235 | BROWNING |
| | HOUSING | | 0.060 | 7 | 0.420 | | 100 | | 0.462 | 7A1241 |
| | GUIDE SHAFT | | 0.036 | 14 | 0.504 | | 100 | | 0.5544 | 7A1242 |
| | RETAINER | | 0.071 | 7 | 0.497 | | 100 | | 0.5467 | 7A1243 |
| | LEAD SCREW | | 0.010 | 3 | 0.030 | | 100 | | 0.033 | 7A1244 |
| | | *Subtotal* | | | *2.676* | *composite* | *margin=* | *10.00%* | *2.94* | |
| COVER MECHANISM ASSEMBLY 7A1300 | RING, UPPER | | 1.190 | 1 | 1.190 | | 100 | | 1.309 | 7A1310 |
| | RING, LOWER | | 0.980 | 1 | 0.980 | | 100 | | 1.078 | 7A1311 |
| | LOWER FRAME 7A11312 | RING, LOWER FRAME | 2.960 | 1 | 2.960 | | 100 | | 3.256 | - |
| | | CHAIN | 0.082 | 1 | 0.082 | | 100 | | 0.0902 | BERG |
| | | ROLLER | 0.002 | 10 | 0.020 | | 100 | | 0.022 | 7A1304 |
| | | PIN | 0.001 | 10 | 0.010 | | 100 | | 0.011 | 7A1305 |
| | | SHAFT | 0.003 | 1 | 0.003 | | 100 | | 0.0033 | 7A1307 |
| | UPPER FRAME 7A1313 | RING, UPPER FRAME | 3.020 | 1 | 3.020 | | 100 | | 3.322 | - |
| | | CHAIN | 0.140 | 1 | 0.140 | | 100 | | 0.154 | BERG |
| | | ROLLER | 0.002 | 8 | 0.016 | | 100 | | 0.0176 | 7A1304 |
| | | PIN | 0.001 | 8 | 0.008 | | 100 | | 0.0088 | 7A1305 |
| | | WHEEL | 0.002 | 3 | 0.006 | | 100 | | 0.0066 | 7A1306 |
| | | SHAFT | 0.003 | 3 | 0.009 | | 100 | | 0.0099 | 7A1307 |
| | COVER FAN 7A1316 | RETAINER | 0.002 | 3 | 0.006 | | 100 | | 0.0066 | 7A1308 |
| | | COVER | 0.636 | 4 | 2.544 | | 100 | | 2.7984 | 7A1316 |
| | | SLIDE, UPPER | 0.002 | 16 | 0.032 | | 100 | | 0.0352 | 7A1315 |
| | | SLIDE, LOWER | 0.002 | 16 | 0.032 | | 100 | | 0.0352 | 7A1317 |
| | OUTER RING, LOWER COVER | | 4.320 | 1 | 4.320 | | 100 | | 4.752 | 7A1318 |
| | OUTER RING, UPPER COVER | | 1.780 | 1 | 1.780 | | 100 | | 1.958 | 7A1319 |
| | | *Subtotal* | | | *17.158* | *composite* | *margin=* | *10.00%* | *18.87* | |
| COVER GEAR HOUSING ASSEMBLY 7A1301 | HOUSING SUB-ASSEMBLY | | 0.230 | 1 | 0.230 | | 100 | | 0.253 | 7A1302 |
| | COVER | | 0.073 | 1 | 0.073 | | 100 | | 0.0803 | 7A1303 |
| | SHAFT, SPROCKET | | 0.008 | 1 | 0.008 | | 100 | | 0.0088 | 7A1309 |
| | COVER DRIVE MOTOR | | 1.320 | 1 | 1.320 | | 100 | | 1.452 | 7A1314 |
| | PLATE, ADAPTER GEAR | | 0.029 | 1 | 0.029 | | 100 | | 0.0319 | 7A1320 |
| | DRIVE GEAR ASSY | | 0.052 | 1 | 0.052 | | 100 | | 0.0572 | 7A1323 |
| | SPROCKET ASSY | | 0.129 | 1 | 0.129 | | 100 | | 0.1419 | 7A1324 |
| | SPROCKET ASSY-LG PITCH DIA | | 0.153 | 1 | 0.153 | | 100 | | 0.1683 | 7A1325 |
| | | *Subtotal* | | | *1.994* | *composite* | *margin=* | *10.00%* | *2.19* | |
| DISCONNECT ASSEMBLY 7A1400 | SHAFT | | 0.110 | 2 | 0.220 | | 100 | | 0.242 | 7A1401 |
| | UPPER COUPLING | | 0.106 | 2 | 0.212 | | 100 | | 0.2332 | 7A1402 |
| | LOWER COUPLING | | 0.185 | 2 | 0.370 | | 100 | | 0.407 | 7A1403 |
| | PIN,YOKE | | 0.004 | 4 | 0.016 | | 100 | | 0.0176 | 7A1404 |
| | YOKE | | 0.088 | 2 | 0.176 | | 100 | | 0.1936 | 7A1405 |
| | YOKE PIVOT PIN | | 0.012 | 2 | 0.024 | | 100 | | 0.0264 | 7A1406 |
| | MOTOR COUPLER | | 0.237 | 2 | 0.474 | | 100 | | 0.5214 | 7A1407 |
| | MOTOR HOUSING | | 0.482 | 2 | 0.964 | | 100 | | 1.0604 | 7A1408 |
| | HANDLE | | 0.431 | 2 | 0.862 | | 100 | | 0.9482 | 7A1409 |
| | | *Subtotal* | | | *3.318* | *composite* | *margin=* | *10.00%* | *3.65* | |

| Assembly Level | Assembly Components | Subassembly Components | Unit Wt Pounds | QTY | Quantity Weight Pounds | % Breakdown of Current Weight | | | Weight Plus Margin (total) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Est'd 20% margin | Cal'd 10% margin | Actual 5% margin | | |
| LATCH MECHANISM 7A1500 | CHAIN | | 2.000 | 1 | 2.000 | 100 | | | 2.4 | |
| | MOTOR | | 4.000 | 1 | 4.000 | 100 | | | 4.8 | |
| | MISC. HARDWARE | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | | *Subtotal* | | | *16.000* | *composite* | *margin=* | *20.00%* | *19.20* | |
| THERMAL CONTROL HARDWARE | HEATERS | | 0.100 | 1 | 0.100 | 100 | | | 0.12 | |
| | BLANKETS | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | ISOLATORS | | 5.000 | 1 | 5.000 | 100 | | | 6 | |
| | SENSORS | | 2.000 | 1 | 2.000 | 100 | | | 2.4 | |
| | | *Subtotal* | | | *17.100* | *composite* | *margin=* | *20.00%* | *20.52* | |
| ELECTRONICS AND WIRING HARNESS | CONTROL ELECTRONICS | | 20.000 | 1 | 20.000 | 100 | | | 24 | |
| | REMOTE UNIT | | 10.800 | 1 | 10.800 | 100 | | | 12.96 | |
| | ELECTRICAL HARNESS | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | | *Subtotal* | | | *40.800* | *composite* | *margin=* | *20.00%* | *48.96* | |
| AFIS SUBTOTAL | | | | | 303.246 | *composite* | *margin=* | *12.38%* | 340.801 | |
| GFE COUPLERS AND CONNECTORS | Cryogen Coupler | | 4.000 | 4 | 16.000 | 100 | | | 19 | |
| | Gas Coupler | | 2.500 | 4 | 10.000 | 100 | | | 12 | |
| | Liquid Coupler | | 0.000 | 0 | 0.000 | 100 | | | 0 | |
| | Electrical Connector | | 3.000 | 8 | 24.000 | 100 | | | 29 | |
| | | *Subtotal* | | | *50.000* | *composite* | *margin=* | *20.00%* | *60* | |
| AFIS TOTAL | | | | | 353.246 | *composite* | *margin=* | *13.46%* | 400.801 | |

# APPENDIX C WEIGHTS-FLUID CONFIGURATION (TWO TABLES)

| Assembly Level | Assembly Components | Subassembly Components | Unit Wt Pounds | QTY | Quantity Weight Pounds | % Breakdown of Current Weight Est'd 20% margin | Cal'd 10% margin | Actual 5% margin | Weight Plus Margin (total) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| MAIN STRUCTURE ASSEMBLY 7A1200 | OUTER SKIN | | 9.580 | 1 | 9.580 | | 100 | | 10.538 | - |
| | INNER SKIN | | 5.770 | 1 | 5.770 | | 100 | | 6.347 | - |
| | MAIN DRIVE MOTORS | | 1.320 | 2 | 2.640 | 100 | | | 3.168 | - |
| | BASE RING ASSEMBLY | | 26.220 | 1 | 26.220 | | 100 | | 28.842 | 7A1201 |
| | RADIAL SUPPORT RIB | | 2.570 | 6 | 15.420 | | 100 | | 16.962 | 7A1202 |
| | UPPER RING, OUTER | | 10.470 | 1 | 10.470 | | 100 | | 11.517 | 7A1203 |
| | RING, INNER | | 6.840 | 1 | 6.840 | | 100 | | 7.524 | 7A1204 |
| | BALL SCREWS | | 2.000 | 12 | 24.000 | | 100 | | 26.4 | 7A1205 |
| | THRUST BEARINGS | | 0.130 | 12 | 1.560 | | | 100 | 1.638 | AUBURN |
| | DRIVE SPROCKETS | | 0.160 | 14 | 2.240 | | | 100 | 2.352 | BROWNING |
| | CHAIN | | 1.740 | 1 | 1.740 | | 100 | | 1.914 | BERG |
| | IDLER SPROCKETS | | 0.140 | 24 | 3.360 | | | 100 | 3.528 | BROWNING |
| | IDLER SHAFTS | | 0.055 | 24 | 1.320 | | | 100 | 1.386 | BROWNING |
| | BALL SCREW MNTG. BLOCK | | 0.097 | 12 | 1.164 | | 100 | | 1.2804 | 7A1201 . |
| | STIFFENER ANGLE (INNER) | | 0.277 | 12 | 3.324 | | 100 | | 3.6564 | 7A1201 |
| | STIFFENER ANGLE (OUTER) | | 0.126 | 12 | 1.512 | | 100 | | 1.6632 | 7A1201 |
| | SUPPORT LEG | | 10.690 | 4 | 42.760 | | 100 | | 47.036 | 7A1201 |
| | | *Subtotal* | | | *159.920* | *composite margin=* | | *9.90%* | *175.75* | |
| FLUID SPACER ASSY. 7A1210 | FRAME, BALL SCREW-FLUID | | 6.090 | 2 | 12.180 | | 100 | | 13.398 | 7A1211 |
| | SPACER ASSY.-FLUID | | 5.300 | 2 | 10.600 | | 100 | | 11.66 | 7A1212 |
| | | *Subtotal* | | | *22.780* | *composite margin=* | | *10.01%* | *25.06* | |
| GAS/ELEC SPACER ASSY. 7A1220 | FRAME, BALL SCREW-GAS/ELEC | | 5.550 | 2 | 11.100 | | 100 | | 12.21 | 7A1221 |
| | SPACER ASSY.-GAS/ELEC. | | 5.750 | 2 | 11.500 | | 100 | | 12.65 | 7A1222 |
| | | *Subtotal* | | | *22.600* | *composite margin=* | | *10.00%* | *24.86* | |
| TENSIONER ASSEMBLY 7A1240 | IDLER SPROCKET | | 0.120 | 7 | 0.840 | | 100 | | 0.924 | BROWNING |
| | IDLER SHAFT | | 0.055 | 7 | 0.385 | | 100 | | 0.4235 | BROWNING |
| | HOUSING | | 0.060 | 7 | 0.420 | | 100 | | 0.462 | 7A1241 |
| | GUIDE SHAFT | | 0.036 | 14 | 0.504 | | 100 | | 0.5544 | 7A1242 |
| | RETAINER | | 0.071 | 7 | 0.497 | | 100 | | 0.5467 | 7A1243 |
| | LEAD SCREW | | 0.010 | 3 | 0.030 | | 100 | | 0.033 | 7A1244 |
| | | *Subtotal* | | | *2.676* | *composite margin=* | | *9.87%* | *2.94* | |
| COVER MECHANISM ASSEMBLY 7A1300 | RING, UPPER | | 1.190 | 1 | 1.190 | | 100 | | 1.309 | 7A1310 |
| | RING, LOWER | | 0.980 | 1 | 0.980 | | 100 | | 1.078 | 7A1311 |
| | LOWER FRAME 7A11312 | RING, LOWER FRAME | 2.960 | 1 | 2.960 | | 100 | | 3.256 | - |
| | | CHAIN | 0.082 | 1 | 0.082 | | 100 | | 0.0902 | BERG |
| | | ROLLER | 0.002 | 10 | 0.020 | | 100 | | 0.022 | 7A1304 |
| | | PIN | 0.001 | 10 | 0.010 | | 100 | | 0.011 | 7A1305 |
| | | SHAFT | 0.003 | 1 | 0.003 | | 100 | | 0.0033 | 7A1307 |
| | UPPER FRAME 7A1313 | RING, UPPER FRAME | 3.020 | 1 | 3.020 | | 100 | | 3.322 | - |
| | | CHAIN | 0.140 | 1 | 0.140 | | 100 | | 0.154 | BERG |
| | | ROLLER | 0.002 | 8 | 0.016 | | 100 | | 0.0176 | 7A1304 |
| | | PIN | 0.001 | 8 | 0.008 | | 100 | | 0.0088 | 7A1305 |
| | | WHEEL | 0.002 | 3 | 0.006 | | 100 | | 0.0066 | 7A1306 |
| | | SHAFT | 0.003 | 3 | 0.009 | | 100 | | 0.0099 | 7A1307 |
| | COVER FAN 7A1316 | RETAINER | 0.002 | 3 | 0.006 | | 100 | | 0.0066 | 7A1308 |
| | | COVER | 0.636 | 4 | 2.544 | | 100 | | 2.7984 | 7A1316 |
| | | SLIDE, UPPER | 0.002 | 16 | 0.032 | | 100 | | 0.0352 | 7A1315 |
| | | SLIDE, LOWER | 0.002 | 16 | 0.032 | | 100 | | 0.0352 | 7A1317 |
| | OUTER RING, LOWER COVER | | 4.320 | 1 | 4.320 | | 100 | | 4.752 | 7A1318 |
| | OUTER RING, UPPER COVER | | 1.780 | 1 | 1.780 | | 100 | | 1.958 | 7A1319 |
| | | *Subtotal* | | | *17.158* | *composite margin=* | | *9.98%* | *18.87* | |
| COVER GEAR HOUSING ASSEMBLY 7A1301 | HOUSING SUB-ASSEMBLY | | 0.230 | 1 | 0.230 | | 100 | | 0.253 | 7A1302 |
| | COVER | | 0.073 | 1 | 0.073 | | 100 | | 0.0803 | 7A1303 |
| | SHAFT, SPROCKET | | 0.008 | 1 | 0.008 | | 100 | | 0.0088 | 7A1309 |
| | COVER DRIVE MOTOR | | 1.320 | 1 | 1.320 | | 100 | | 1.452 | 7A1314 |
| | PLATE, ADAPTER GEAR | | 0.029 | 1 | 0.029 | | 100 | | 0.0319 | 7A1320 |
| | DRIVE GEAR ASSY | | 0.052 | 1 | 0.052 | | 100 | | 0.0572 | 7A1323 |
| | SPROCKET ASSY | | 0.129 | 1 | 0.129 | | 100 | | 0.1419 | 7A1324 |
| | SPROCKET ASSY-LG PITCH DIA | | 0.153 | 1 | 0.153 | | 100 | | 0.1683 | 7A1325 |
| | | *Subtotal* | | | *1.994* | *composite margin=* | | *9.83%* | *2.19* | |
| DISCONNECT ASSEMBLY 7A1400 | SHAFT | | 0.110 | 2 | 0.220 | | 100 | | 0.242 | 7A1401 |
| | UPPER COUPLING | | 0.106 | 2 | 0.212 | | 100 | | 0.2332 | 7A1402 |
| | LOWER COUPLING | | 0.185 | 2 | 0.370 | | 100 | | 0.407 | 7A1403 |
| | PIN,YOKE | | 0.004 | 4 | 0.016 | | 100 | | 0.0176 | 7A1404 |
| | YOKE | | 0.088 | 2 | 0.176 | | 100 | | 0.1936 | 7A1405 |
| | YOKE PIVOT PIN | | 0.012 | 2 | 0.024 | | 100 | | 0.0264 | 7A1406 |
| | MOTOR COUPLER | | 0.237 | 2 | 0.474 | | 100 | | 0.5214 | 7A1407 |
| | MOTOR HOUSING | | 0.482 | 2 | 0.964 | | 100 | | 1.0604 | 7A1408 |
| | HANDLE | | 0.431 | 2 | 0.862 | | 100 | | 0.9482 | 7A1409 |
| | | *Subtotal* | | | *3.318* | *composite margin=* | | *10.01%* | *3.65* | |

| Assembly Level | Assembly Components | Subassembly Components | Unit Wt Pounds | QTY | Quantity Weight Pounds | % Breakdown of Current Weight | | | Weight Plus Margin (total) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Est'd 20% margin | Cal'd 10% margin | Actual 5% margin | | |
| LATCH MECHANISM 7A1500 | CHAIN | | 2.000 | 1 | 2.000 | 100 | | | 2.4 | |
| | MOTOR | | 4.000 | 1 | 4.000 | 100 | | | 4.8 | |
| | MISC. HARDWARE | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | | *Subtotal* | | | *16.000* | *composite margin=* | | *20.00%* | *19.20* | |
| THERMAL CONTROL HARDWARE | HEATERS | | 0.100 | 1 | 0.100 | 100 | | | 0.12 | |
| | BLANKETS | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | ISOLATORS | | 5.000 | 1 | 5.000 | 100 | | | 6 | |
| | SENSORS | | 2.000 | 1 | 2.000 | 100 | | | 2.4 | |
| | | *Subtotal* | | | *17.100* | *composite margin=* | | *20.00%* | *20.52* | |
| ELECTRONICS AND WIRING HARNESS | CONTROL ELECTRONICS | | 20.000 | 1 | 20.000 | 100 | | | 24 | |
| | REMOTE UNIT | | 10.800 | 1 | 10.800 | 100 | | | 12.96 | |
| | ELECTRICAL HARNESS | | 10.000 | 1 | 10.000 | 100 | | | 12 | |
| | | *Subtotal* | | | *40.800* | *composite margin=* | | *20.00%* | *48.96* | |
| AFIS SUBTOTAL | | | | | 304.346 | *composite margin=* | | *12.37%* | 342.000 | |
| GFE COUPLERS AND CONNECTORS | Cryogen Coupler | | 0.000 | 0 | 0.000 | 100 | | | 0 | |
| | Gas Coupler | | 2.500 | 4 | 10.000 | 100 | | | 12 | |
| | Liquid Coupler | | 2.000 | 8 | 16.000 | 100 | | | 19 | |
| | Electrical Connector | | 3.000 | 8 | 24.000 | 100 | | | 29 | |
| | | *Subtotal* | | | *50.000* | *composite margin=* | | *20.00%* | *60* | |
| AFIS TOTAL | | | | | 354.346 | *composite margin=* | | *13.45%* | 402 | |

# APPENDIX D DEMO WEIGHTS

| Assembly Components | Subassembly Components | Unit Weight Pounds | QTY | Current Item Weight Pounds (Total) | % Breakdown of Current Weight Est'd. | Cal'd. | Act. | Drawing Number |
|---|---|---|---|---|---|---|---|---|
| MAIN STRUCTURE ASSEMBLY 7A1200 | OUTER SKIN | 12.770 | 1 | 12.770 | 0 | 100 | 0 | - |
| | INNER SKIN | 7.690 | 1 | 7.690 | 0 | 100 | 0 | - |
| | MAIN DRIVE MOTORS AND DISCONNECT | 17.140 | 2 | 34.280 | 0 | 0 | 100 | 7A1401 |
| | BASE RING ASSEMBLY | 67.500 | 1 | 67.500 | 0 | 0 | 100 | 7A1201 |
| | RADIAL SUPPORT RIB ASSEMBLY | 4.342 | 6 | 26.052 | 0 | 0 | 100 | 7A1209 |
| | UPPER RING, OUTER | 18.000 | 1 | 18.000 | 0 | 0 | 100 | 7A1203 |
| | RING, INNER | 11.300 | 1 | 11.300 | 0 | 0 | 100 | 7A1204 |
| | BALL SCREWS | 2.038 | 18 | 36.684 | 0 | 0 | 100 | 7A1205 |
| | THRUST BEARINGS | 0.122 | 18 | 2.196 | 0 | 0 | 100 | T-100 |
| | DRIVE SPROCKETS (MODIFIED) | 0.338 | 20 | 6.760 | 0 | 0 | 100 | 7A1251 |
| | CHAIN | 2.610 | 1 | 2.610 | 0 | 100 | 0 | |
| | BALL SCREW MNTG. BLOCK | 0.087 | 18 | 1.566 | 0 | 0 | 100 | 7A1206 |
| | SUPPORT LEG | 15.400 | 4 | 61.600 | 0 | 100 | 0 | 7A1250 |
| | MANUAL TENSIONER | 0.230 | 2 | 0.460 | 0 | 0 | 100 | 7A1241 |
| | SPRING TENSIONER | 0.240 | 2 | 0.480 | 0 | 0 | 100 | 7A1242 |
| | STRUCTURE SUBTOTAL | | | 289.948 | | | | |
| FLUID SPACER ASSY. 7A1210 | FRAME, BALL SCREW - FLUID | 7.900 | 2 | 15.800 | 0 | 0 | 100 | 7A1211 |
| | SPACER ASSY. - FLUID | 6.300 | 2 | 12.600 | 0 | 0 | 100 | 7A1212 |
| | SUBTOTAL | | | 28.400 | | | | |
| GAS/ELEC SPACER ASSY. 7A1220 | FRAME,BALL SCREW - GAS/ELEC | 7.300 | 2 | 14.600 | 0 | 0 | 100 | 7A1221 |
| | SPACER ASSY. - GAS/ELEC. | 7.160 | 2 | 14.320 | 0 | 0 | 100 | 7A1222 |
| | SUBTOTAL | | | 28.920 | | | | |
| CRYO SPACER ASSY. 7A1230 | FRAME, BALL SCREW - CRYO | 8.800 | 2 | 17.600 | 0 | 0 | 100 | 7A1231 |
| | SPACER ASSY. - CRYO | 1.900 | 0 | 0.000 | 0 | 0 | 100 | 7A1232 |
| | SUBTOTAL | | | 17.600 | | | | |
| COVER MECHANISM ASSEMBLY | RING, UPPER | 2.310 | 1 | 2.310 | 0 | 100 | 0 | 7A1310 |
| | RING, LOWER | 1.900 | 1 | 1.900 | 0 | 100 | 0 | 7A1311 |
| | LOWER RING FRAME ASSY | 3.050 | 1 | 3.050 | 0 | 0 | 100 | 7A1312 |
| | UPPER RING FRAME ASSY | 3.100 | 1 | 3.100 | 0 | 0 | 100 | 7A1313 |
| | COVER FAN | 1.910 | 4 | 7.640 | 0 | 0 | 100 | 7A1316 |
| | OUTER RING, LOWER COVER | 3.150 | 1 | 3.150 | 0 | 0 | 100 | 7A1318 |
| | OUTER RING, UPPER COVER | 1.780 | 1 | 1.780 | 0 | 100 | 0 | 7A1319 |
| | COVER GEAR HOUSING ASSEMBLY | 1.760 | 1 | 1.760 | 0 | 0 | 100 | 7A1301 |
| | COVER MECHANISM SUBTOTAL | | | 24.690 | | | | |
| LATCH ASSEMBLY WITH MOTOR | | 8.140 | 1 | 8.140 | 0 | 0 | 100 | 7A1500 |
| LATCH ASSEMBLY WITHOUT MOTOR | | 7.110 | 2 | 14.220 | 0 | 0 | 100 | 7A1510 |
| LATCH TENSIONER ASSEMBLY | | 2.000 | 3 | 6.000 | 100 | 0 | 0 | 7A1520 |
| AFIS SYSTEM TOTAL | | | | 417.918 | | | | |