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MAINTENANCE EVALUATION FOR SPACE STATION LIQUID SYSTEMS

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Many of the thermal and environmental control life support subsystems as well as other subsystems of the Space Station utilize various liquids and contain components which are either expendables or are life-limited in some way. Since the Space Station has a 20-year minimum orbital lifetime requirement, there will also be random failures occurring within the various liquid-containing subsystems. These factors as well as the planned Space Station build-up sequence require that maintenance concepts be developed prior to the design phase. This applies to the equipment which needs maintenance as well as the equipment which may be required at a maintenance work station within the Space Station.

This paper presents several maintenance concepts for liquid-containing items and a flight experiment program which would allow for evaluation and improvement of these concepts so they can be incorporated in the Space Station designs at the outset of its design phase.

Introduction

The general goals for liquid-containing systems are to minimize liquid loss and gas ingestion as well as contaminant inclusion during all maintenance operations. Liquid loss should be prevented or minimized to preclude a recharge operation with the attendant need for replacement liquid and to minimize spillage which could induce other component failures, introduce possible contamination or crew safety problems, or require different, complex and time-consuming cleanup operations. Contaminant inclusion can adversely affect system operation by increasing system filter and contaminant toleration requirements. Gas ingestion should also be prevented or minimized, because it could significantly increase the requirements of gas separation equipment and could introduce the need for special evacuation or bleeding equipment.

These concerns are less significant when the liquid is water but become very significant if the liquid is hazardous, has a high vapor pressure, or if the liquid system is external to the pressurized volume of the Space Station. This paper mainly addresses the more significant cases requiring special maintenance features. The flight experiment should help determine which cases need special solutions as well as prove the acceptability of the solutions.

Background

Due to the difficulty of, and special equipment required for draining and later recharging an entire system in zero-g, the recommended safe method for system and individual component replacement is to isolate the item or small group of items to be replaced at each of its liquid interfaces prior to removal and replacement as shown in Figure 1.

GENERAL REPLACEMENT STEPS

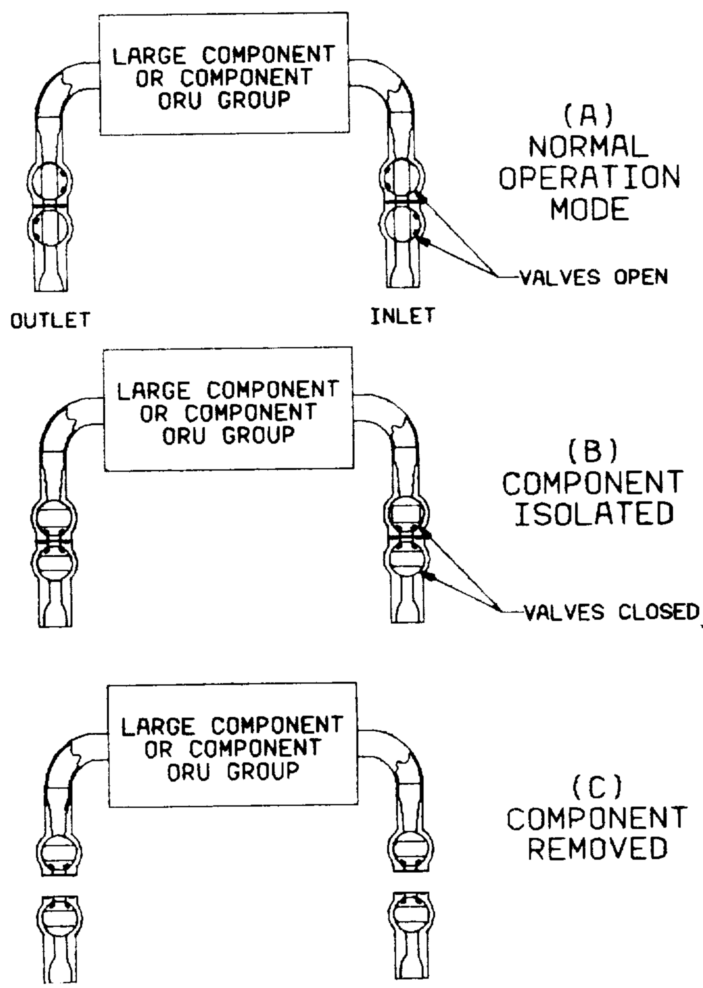


Figure 1

Because there will be at least hundreds and maybe thousands of maintenance isolation devices in the Space Station, they will have an impact on the total reliability and therefore they must themselves meet the maintenance requirements of the Space Station. Some of the basic considerations for the isolation devices are specified in Table 1.

DISCONNECT DESIGN CRITERIA

- Positive Isolation of the Fluid Loops

  Minimum liquid spillage
  Minimum air and contaminant inclusion

- Maintainable in Place (All Seals and Dynamic Parts)

  No drainage and recharge
  No depressurization required
  Minimum system interference

- Operable in Zero-g While Suited

- Low Impact

  Small
  Light weight
  Low pressure/power losses
  Allow for assembly tolerances
  Simple
  Inexpensive
  Reliable

- Common for All Applications

  Minimize non-recurring costs
  Minimize crew training
  Minimize spares

Table 1

Many approaches have been studied and developed by Hamilton Standard and others, which combine the functions of isolation valves and maintenance disconnects and meet many, but usually not all, of the above considerations. Several of the key basic concepts are shown in Figures 2A and 2B. Fittings are simple, small and inexpensive, but do not provide positive isolation; relying instead on the surface tension of the fluid to prevent spillage. The quick disconnect is complicated, has high pressure drop, is sensitive to contamination, and due to its many dynamic parts is somewhat unreliable. The contamination and reliability problems compound themselves due to the fact that it is not possible to maintain quick disconnects without draining the lines.

MAINTENANCE DISCONNECT CONCEPTS

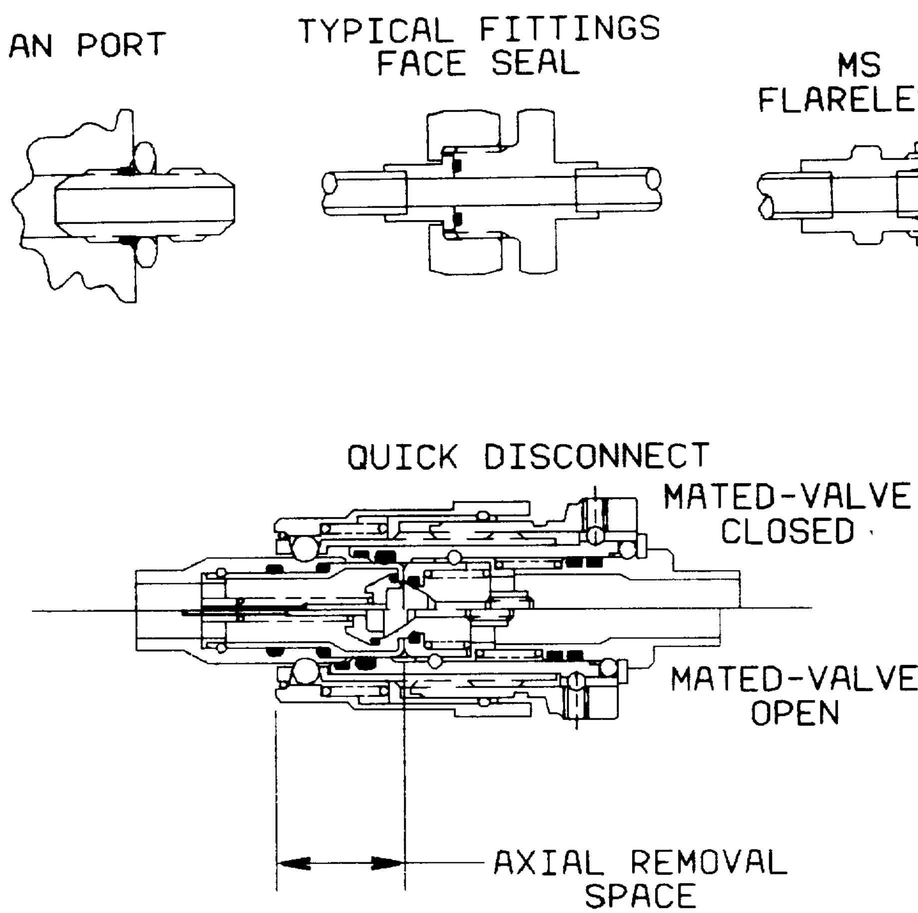


Figure 2A

The poppet and interlocking spheres positive isolation disconnects developed especially for zero-g maintenance are also not maintainable. The poppet concept has high pressure drop and the interlocking spheres concept requires accurate alignment tolerances and a significant axial separation motion. Neither is maintainable without line depressurization/drainage and both have many moving parts and stagnant fluid volumes in which contamination or precipitation can accumulate or bacteria can grow. The Maintainable Maintenance Disconnect Valve (MMDV) utilizes maintainable cylinders. This valve eliminates the problems of those above, but has a small potential spillage volume.

MAINTENANCE DISCONNECT CONCEPTS (Continued)

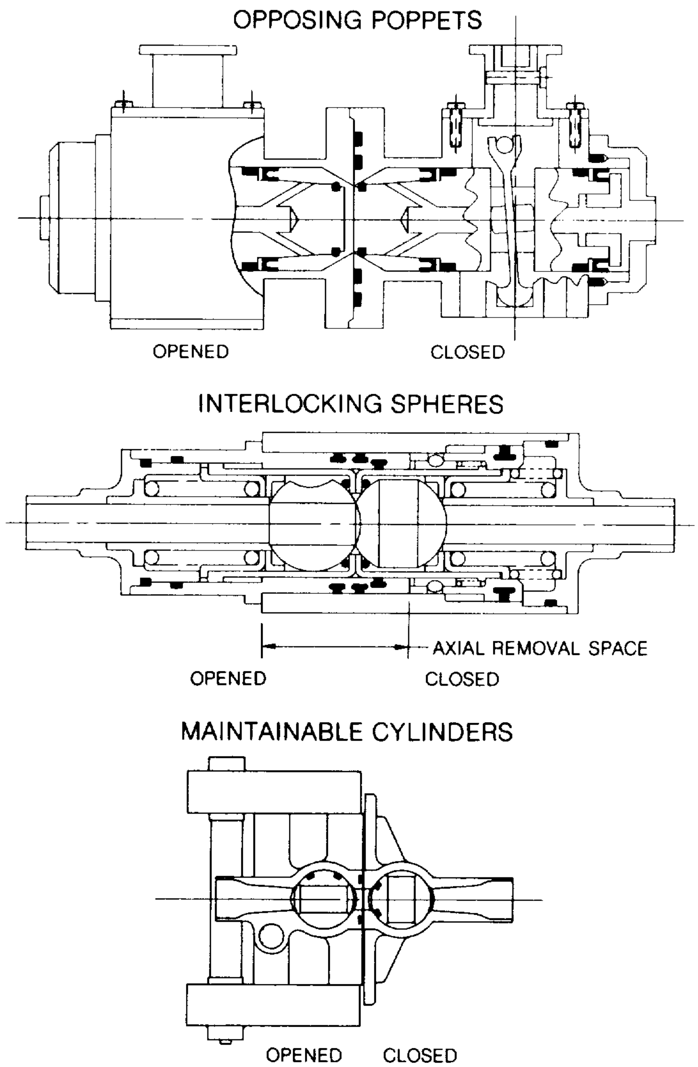


Figure 2B

Universal Applications

Various versions of the MMDV have been developed which address all of the considerations mentioned earlier. Other features such as alternate attachment techniques, ganging into multivalved manifolds, and the incorporation of various degrees of safety interlocks and redundant seals have been evaluated. Figure 3 shows an MMDV incorporating some of these features. All of these versions consist of two valves utilizing identical cylindrical cartridges and sleeves that permit servicing and replacement of all seals and moving parts with a minimum effect on system function, i.e., system pressure can be maintained and system flow will be only momentarily interrupted. As the separation plane is flat, the pair can be separated with any combination of axial or radial motion.

MAINTAINABLE MAINTENANCE DISCONNECT VALVE PAIR

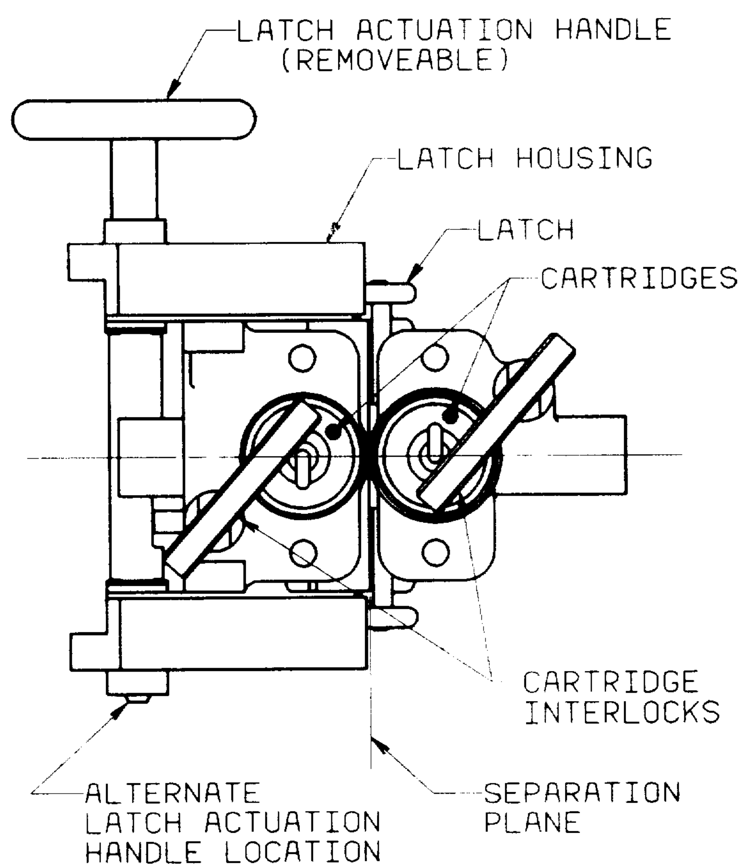
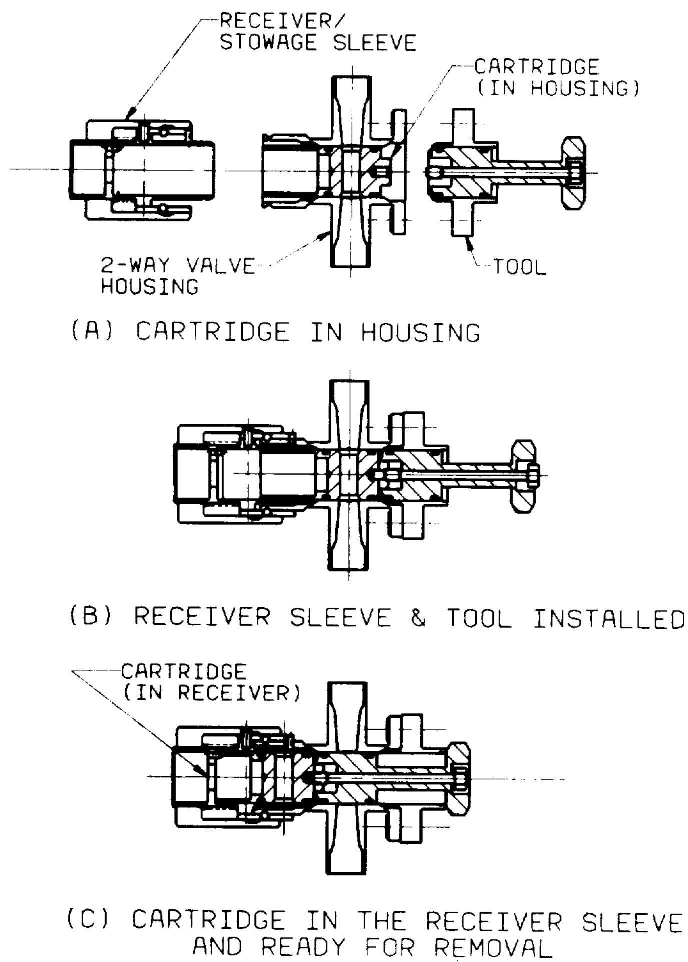


Figure 3

Figure 4 shows a 2-way application of this valve and illustrates cartridge removal. A push/pull tool and a receiver/stowage sleeve are mated to the valve housing. A central screw thread in the tool engages the cartridge. Actuation of the tool pushes the used cartridge into the receiver sleeve with no spillage of liquid. The sleeve with the used cartridge is then removed and replaced with a new sleeve containing a new precharged cartridge. The tool is now used to pull the new cartridge from the sleeve and position it in the valve housing. Removal of the tool and the sleeve completed the cartridge servicing. The cartridge concept was applied extensively to promote the maintainability of the Environmental Control and Life Support (ECLS) system developed by Hamilton Standard for the NASA Space Station Prototype (SSP), in 1972. Several improved versions of the valve have been produced since the basic concept was proven in SSP. These versions have reduced size and weight and have incorporated various degrees of seal redundancy and operational safety.

EASY CARTRIDGE REMOVAL



(A) CARTRIDGE IN HOUSING

(B) RECEIVER SLEEVE & TOOL INSTALLED

(C) CARTRIDGE IN THE RECEIVER SLEEVE AND READY FOR REMOVAL

Figure 4

The MMDV cartridge concept also has many other applications as a maintenance feature on valves and other components. Conventional valves are replaced by a single housing (see Figure 4) similar to a MMDV housing with the cartridge configured to act as a 2-way, 3-way, or proportional flow control valve, among others, or configured to house a check valve, relief valve, or any other small items which can fit within the cartridge. Figure 5 shows several of these applications. The accumulator version allows for shut-off of trapped fluid volumes. When in the shut-off mode, the accumulator comes on line and allows for thermal expansion of the trapped liquid without significant and potentially damaging pressure increases.

CARTRIDGE WITH MULTI-FUNCTIONS
(In addition to shut-off mode)

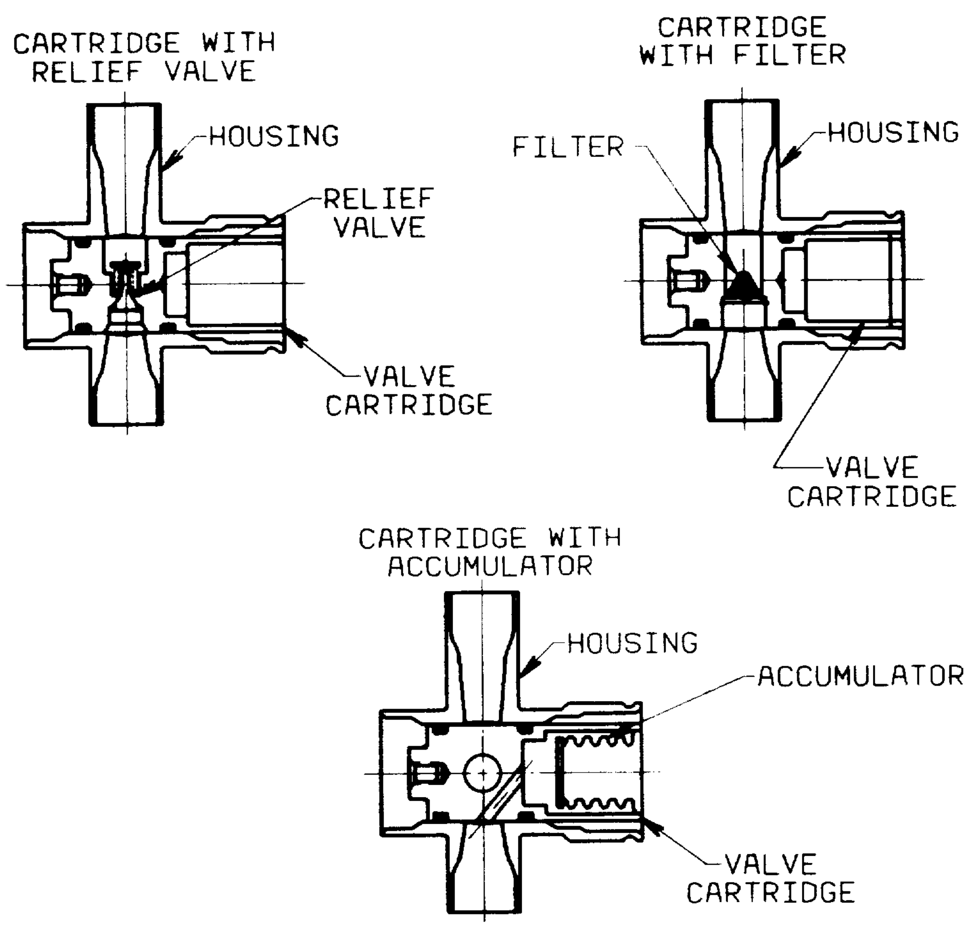


Figure 5

For components which are too large to fit within a cartridge, but too small to require a pair of MMDV's, a variation of the cartridge concept called a probe can be used. Two of the key probe configurations are shown in Figure 6. Short probes are utilized for sensors and other small components which require access on one end and have a diameter which is smaller than that of the cartridge. Long probes are typically used for small to medium sized components such as regulators, pumps, or accumulators whose diameter is larger than that of the cartridge or require access on more than one surface. The probes are replaced in the same way as a valve cartridge, the only difference being that the receiver sleeve is built onto the long probe.

KEY PROBE CONFIGURATIONS

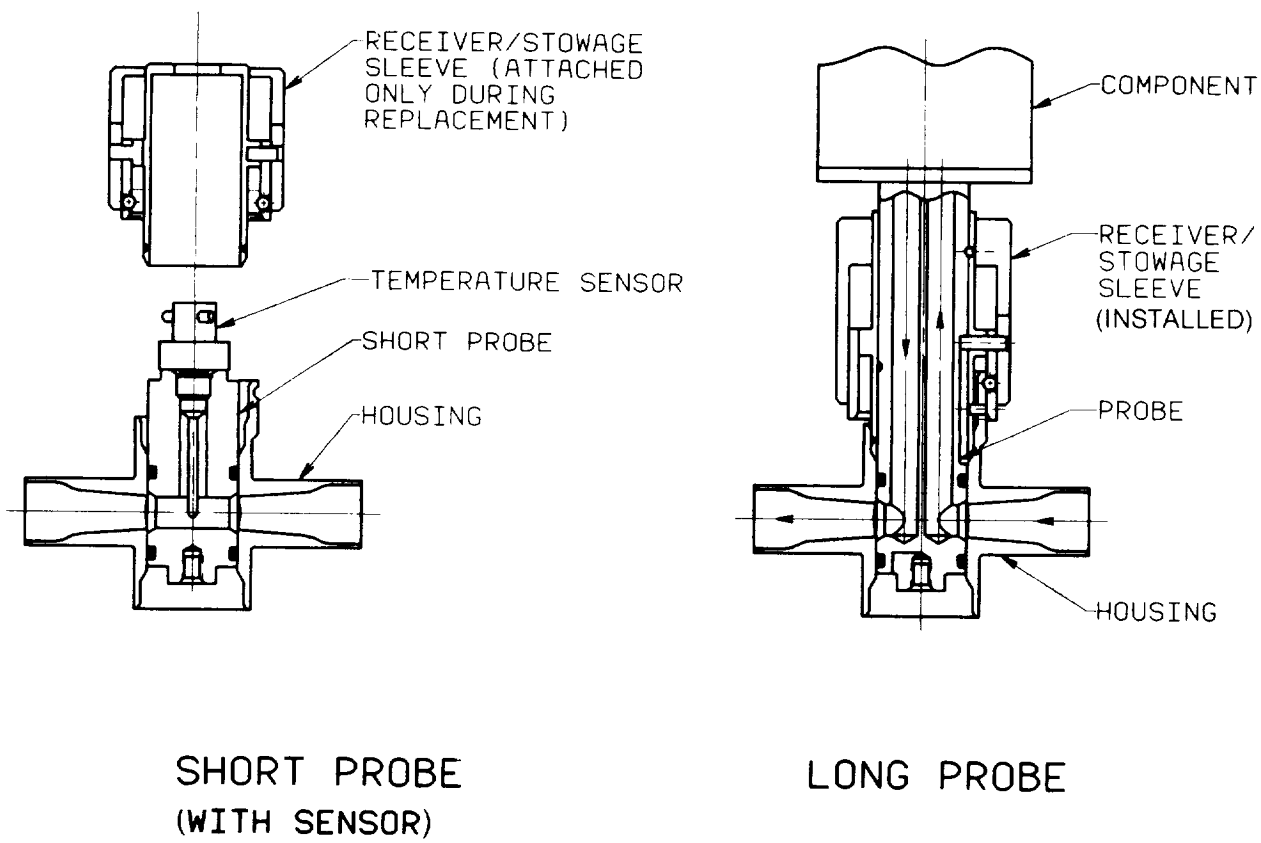


Figure 6

An additional use for probes was conceived that eliminates the need for additional valve porting and immediate line repair in the event that it becomes necessary to continue the operation of a system containing a failed line. A set of probes interconnected by a flex hose can be inserted in the appropriately located housings to bypass the failed line. One end of this bypass configuration is shown in Figure 7.

FAILED-LINE BYPASS PROBE

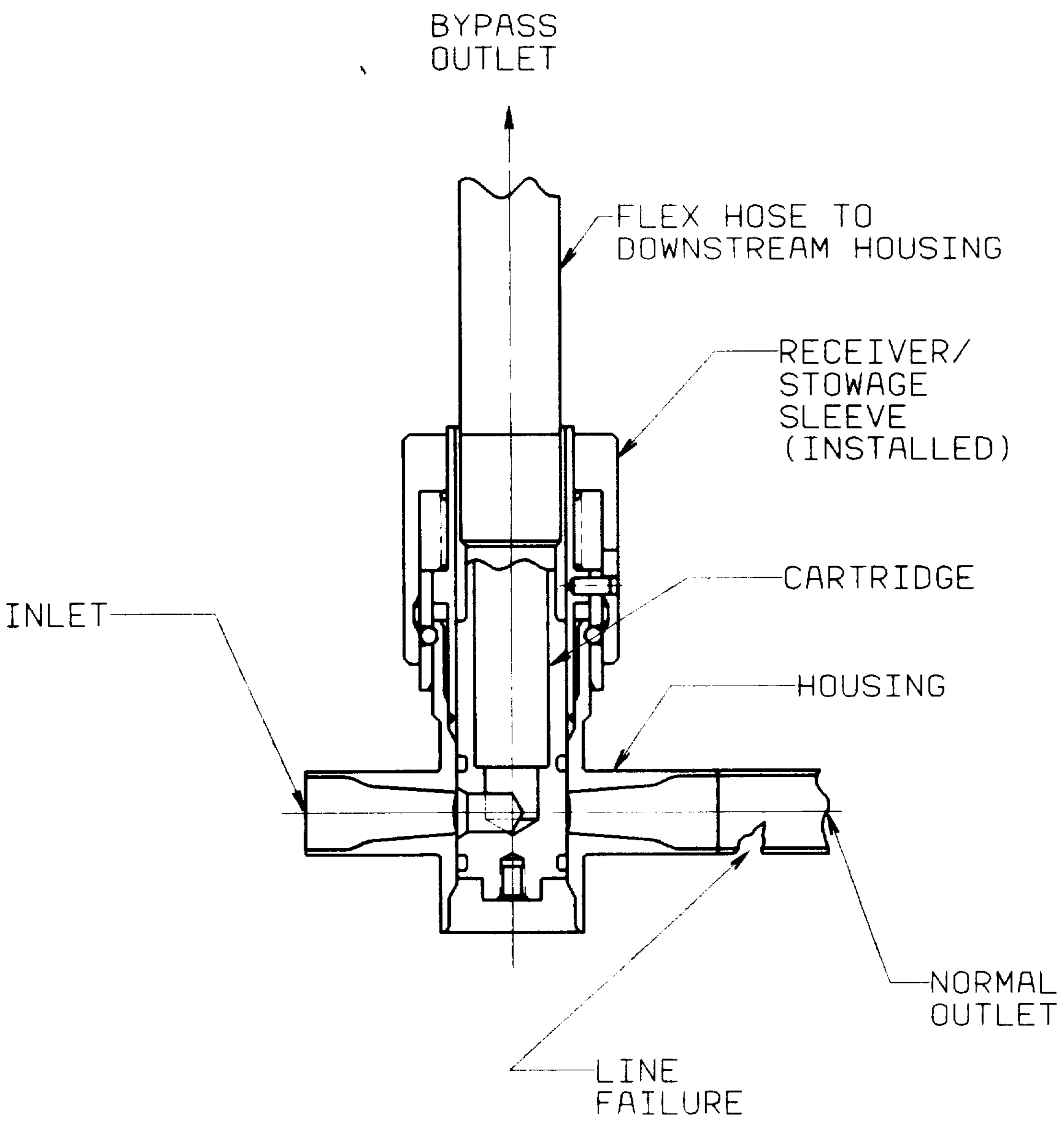


Figure 7

The cartridge/probe concept allows for a large variety of maintainable hardware. By selecting one version from each column shown in Table 2, one can create as many as 7680 different theoretically possible maintainable assemblies/components. In actuality the realistic number will be between 100 and 200.

All of these applications share the <u>identical</u> MMDV push-pull cartridge replacement concept with all seals and dynamic parts replaceable without liquid line drainage or even depressurization.

MULTIPLE ASSEMBLY COMBINATIONS

<table>
<tr><th>HOUSING</th><th colspan="2">CARTRIDGE OR PROBE</th><th>ACTUATOR</th><th>COMPONENT</th></tr>
<tr><td rowspan="3">1-WAY
2-WAY
3-WAY
4-WAY
L.S.MMDV
C.S.MMDV</td><td>2-WAY
3-WAY</td><td>(ALL WITH COMPONENT)
1-WAY
2-WAY
3-WAY
4-WAY
FLOATING
TELE-SCOPING</td><td rowspan="3">90°
180°
270°
360°
ADJUSTABLE
90°</td><td rowspan="4">AS REQD</td></tr>
<tr><td colspan="2">WITH OR W/O EXPANSION ACCUMULATOR</td></tr>
<tr><td>WITH OR W/O COMPONENT</td><td>SHORT OR LONG</td></tr>
<tr><td colspan="3">5/8" OR 1 1/4"</td><td>MANUAL OR ELECTRICAL</td></tr>
<tr><td>12</td><td colspan="2">64</td><td>10</td><td>TOTAL OPTIONS</td></tr>
</table>

L.S. = LINE SIDE
C.S. = COMPONENT SIDE

Table 2

To keep the impact (i.e., volume, weight, spillage, maintenance time, cost, etc.) at a minimum, Table 3 shows the preferred maintenance scheme for all applications requiring positive isolation.

ISOLATION TECHNIQUE PREFERENCE

Choice	Maintenance Concept	Main Application
1st	Cartridge	Small item which fits into the MMDV cartridge
2nd	Short Probe	Small or electrical items having a diameter smaller than the MMDV housing bore
3rd	Long Probe	Small-to medium-sized component or those requiring multi-sided access
Last	Maintenance Disconnect	Large, high flow rate components or subassemblies

Table 3

ORU Level

An on-orbit replaceable unit (ORU) is defined as an item or group of items that can be automatically fault isolated and safely replaced on-orbit. The selected ORU maintenance level can range from replacement of a piece/part (washers, springs, bearings, seals, etc.) through components or component groups, to a level where the entire subsystem or package is replaced. Each possible ORU level has various advantages and disadvantages.

Hamilton Standard has conducted studies on ECLSS subsystems to determine the optimum ORU level based on weight, volume, and cost considerations. The general results have followed a typical pattern which is illustrated by Figure 8A. The pattern is basically the same for both weight and volume and it indicates that a low level of component grouping or the component level itself is the preferred ORU level, based on a 20-year life cycle. Of course, individual limited life or expendable items should always be ORU's. In general, the installed weight and volume penalty to incorporate direct access to the piece part ORU level is so large as to be impractical and therefore was not considered in the studies.

As opposed to weight and volume, the cost analysis shown in Figure 8B indicates that the group level of maintenance is best but the component level additional impact is quite small. Yet, in order to allow for technology advances, the major functional or subsystem level should also be an ORU. Thus, it is felt that a combination of levels is appropriate for the final selection.

OPTIMUM ORU LEVELS

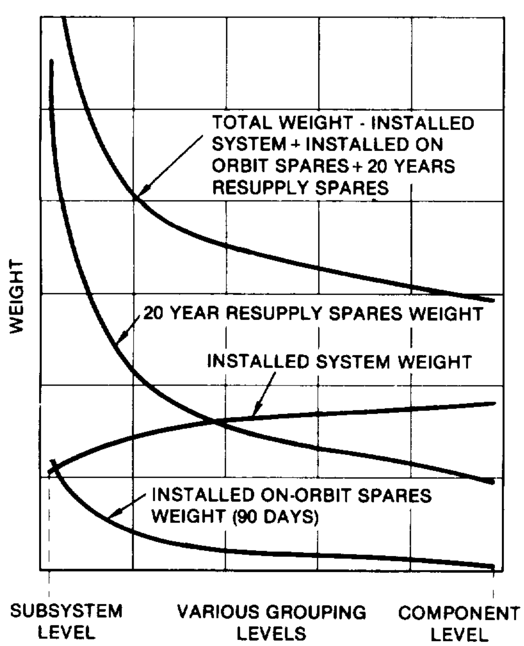


Figure 8A

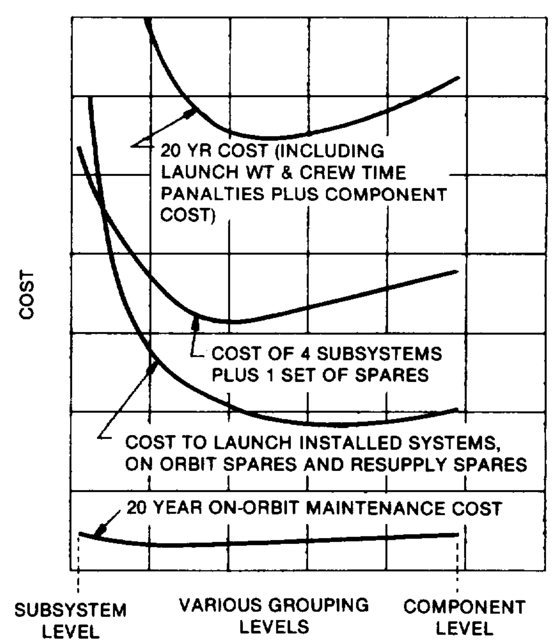


Figure 8B

Figure 8 assumes that we meet all of the present Space Station maintenance rules. The key ones being:

- o An automatic fault detection system must exist and be capable of determining the failed ORU requiring replacement.
- o The system must allow for safe direct access to the ORU requiring replacement.

As one goes to lower level ORU's these rules lead to the addition of many sensors and isolation valves in the system, increasing the weight, volume, and cost. These added items can also fail and thus require their own maintenance access. Therefore, the component level of ORU maintenance is not as advantageous as it could be if one would allow more crew intervention to help determine which ORU requires replacement and, when practical, accept the removal of some ORU's in order to get to other more reliable ORU's. It may also be possible to remove and "drain" non-hazardous liquids from the groups of ORU's prior to performing maintenance on the now readily accessible and drained, failed, lower level ORU's themselves. A unit similar to the urinal could be used for this purpose. With this approach, only the group level would possibly need positive isolation features; each lower level ORU within the group would not. These alternate ideas may add some crew time to specific maintenance operations but the reduction in system complexity, cost, weight, and volume, along with the increased reliability, may well prove to be an overall advantage.

Testing Recommendations

Without flight evaluation of the maintenance features, the determination of the conditions requiring positive liquid isolation, and the ability of man to aid in both the fault detection and performance of sub-ORU level maintenance in zero-g, it is very likely that the proper ORU level will not be selected in all cases. This could also result in the incorporation of too many unnecessary isolation features, adding excessive weight, volume, and cost. It is also quite likely that several necessary maintenance features will be missing, causing potential maintenance problems, delays, or even safety hazards.

We believe that the key maintenance issues need both neutral buoyancy and flight evaluation prior to the design of the Space Station itself. We must know and understand all of the issues so we will be able to make the best maintenance decisions for each use. We must know which actions are acceptable to the crew and which are not. Limits for IVA-versus-EVA maintenance must be determined. We must also use flight evaluations to determine the specific needs and requirements of the equipment to be maintained as well as the work station and tools required to perform the maintenance.

Underwater neutral buoyancy tests will allow for evaluation of many of the maintenance features such as slides, guides, latches, fasteners, and accessibility requirements; however, the evaluation of the various liquid isolation and control concepts must be performed in zero-g.

Potential flight application problems have been assessed and recommendations made for a zero-g flight experiment to evaluate key Space Station liquid maintenance issues, including liquid isolation, liquid filling and draining, liquid item replacement, and the repair of failed lines. Figure 9 illustrates the recommended schematic.

FLIGHT ASSESSMENT SCHEMATIC

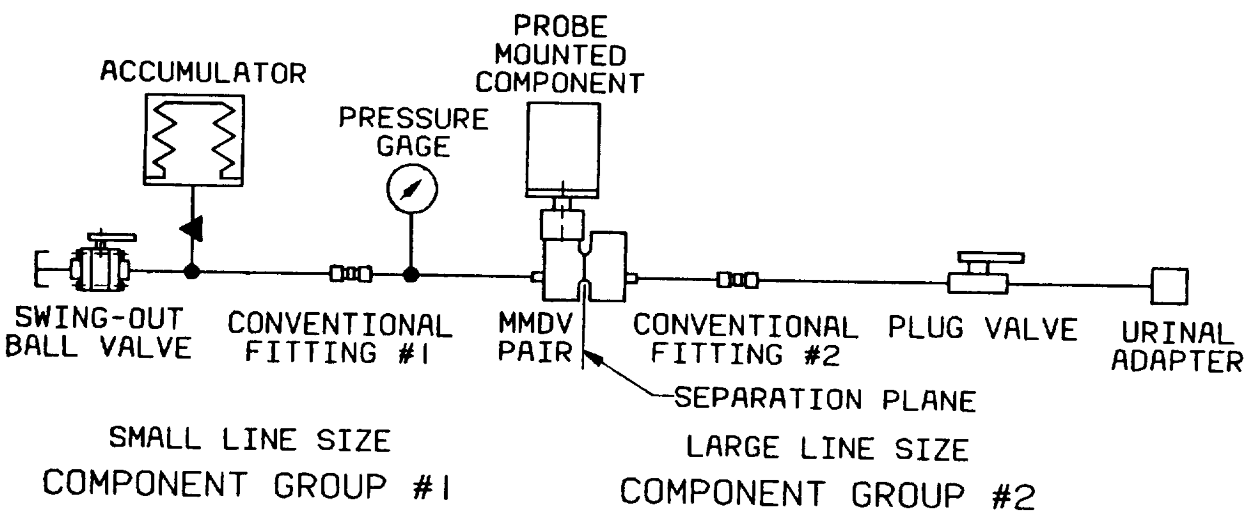


Figure 9

FLIGHT EXPERIMENT OBJECTIVES

- o Need for Positive Isolation - When is positive isolation required? What should be the selection criteria for the separation/isolation feature? Does the direction or speed of interface separation affect the surface tension containment of the liquid? Does the fitting style, line size, or surface coating make any significant difference? Are there any mechanical problems with assembly/disassembly of the fittings and disconnects in zero-g?

- o MMDV Evaluation - Of primary interest is the behavior of the trapped fluid between the MMDV pair. Surface tension in zero-g will tend to hold the majority of this fluid within the valve. Depending upon the test results, a surface tension device such as multiported insert or hydrophilic screen may be required at the valve interfaces. In addition, replacement of the valve cartridge is also recommended in order to assure the acceptability of this operation in zero-g.

- o Probe Evaluation - Insertion and removal of a probe is also recommended, and it is a necessary step for the tests below.

- o Fluid Draining and Charging - The capability of liquid drain and charge on-orbit would have a significant impact on the selected ORU levels and thus the hardware launch weight, volume, and cost. Significant reductions in these areas may be possible by reducing the required number of fluid isolation and thermal expansion features in a group of components and eliminating the need to launch precharged replacements as well as store and return charged items. Also, grouping the components allows for higher packaging densities but increases the requirements for the work station.

- o Permanent Repair of Failed Lines - Concepts, including local freezing, cutting, bonding, welding, brazing, addition of fittings, etc., need to be developed and evaluated.

Table 4

SUMMARY

- o There will be a need for assembly and maintenance of liquid-containing systems and items during the life of the Space Station.

- o Many line separation/isolation schemes exist but most are unproven in zero-g applications. Some may be inadequate for specific applications (hazardous or high pressure liquids) and others may cause excessive cost, weight, and volume impact for relatively for simple applications.

- o A flight experiment evaluation of the key separation/isolation and tubing repair concepts, the tools, work bench facility and access space as well as maintenance times required should be performed prior to the Space Station design phase so the resulting flight hardware will be properly maintainable.

References

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