TR-80-2-D
August 10, 1964

JOHN F. KENNEDY
SPACE CENTER

PROPOSAL

# APOLLO SPACECRAFT GASEOUS NITROGEN DELUGE SYSTEM

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LAUNCH SUPPORT EQUIPMENT BRANCH
LAUNCH SUPPORT EQUIPMENT ENGINEERING DIVISION


[redacted]

KSC FORM 16-12 (1/64)

August 10, 1964

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PROPOSAL

# APOLLO SPACECRAFT GASEOUS NITROGEN DELUGE SYSTEM

## ABSTRACT

One of the two gaseous nitrogen deluge systems examined in this report is proposed to inert a hazardous hydrogen atmospheric condition which may exist in the Command Module Cavity, Service Module Compartment, LEM Adapter Compartment, or Instrument Unit of the Apollo Spacecraft. This system will supply gaseous nitrogen of deluge proportions to the Apollo compartments to dilute and displace the oxygen content in the air creating an enert atmosphere which, for the purpose of this proposal, shall be considered 97% pure nitrogen or less than 4% hydrogen.

[redacted]

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## SYSTEM REQUIREMENTS

The function of this system is to inert the Apollo compartments with a gaseous nitrogen deluge in the event of an emergency such as free hydrogen within the spacecraft. This nitrogen deluge will be available on a "standby ready" basis at all times while hydrogen is on board the spacecraft. On demand, the gaseous nitrogen ($GN_2$) will replace the oxygen ($O_2$) in the spacecraft, nullifying a fire or potentially explosive atmosphere in the presence of gaseous hydrogen.

The system will utilize existing equipment, where feasible, with a limited number of modifications being made to the existing hardware. The existing flexible ducts for the Environmental Control System (E.C.S.) will deliver nitrogen to the compartments. The existing spacecraft openings or orifices will act as the purge vents.

There are critical pressure limitations which must be considered for this system design. The pressure within the Apollo spacecraft compartments must never exceed 1 psig above atmospheric pressure due to the structural limitations. A second pressure limitation is an 18 psig maximum pressure in the flexible ducts. However, this pressure is considerably higher than the required working pressure range.

Consideration is given to the fact that a mixture of air and hydrogen gas has a lower flammability limit of 4% hydrogen by volume. Inerting of the atmosphere to 97% nitrogen will leave 0.66% by volume oxygen which is well below the safe limit for support combustion.

## SECTION II
## SYSTEM DESIGN DATA

### 2-1. PURGE TIME

The time required to inert the compartment is a function of the nitrogen entering the spacecraft and the mixed gases leaving at a constant flow rate. There are two basic types of flow that will occur within the vehicle: 100% mixed or slug flow. If 100% mixing occurs, the gas leaving the spacecraft will be a combination of nitrogen gas entering and air within the spacecraft. With slug flow the gas leaving will be 100% air until the spacecraft is 100% gaseous nitrogen. The actual flow will be a combination of both with a greater degree of mixing than slug flow. To insure a safety factor, the time required for purging will be based on 100% mixing, which is the greater of the two.

### 2-2. COMPARTMENT VOLUMES

The free compartment volumes to be inerted with nitrogen are as follows:

| | |
|---|---|
| Command Module Cavity** .......... | 48.6 cu. ft. |
| Service Module Compartment ......... | 996.0 cu. ft. |
| LEM Adapter Compartment........... | 2,000.0 cu. ft. |
| Instrument Unit .................... | 1,104.0 cu. ft. |

The LEM Adapter compartment volume to be purged is assumed as 30% of the total volume. The remaining 70% is assumed occupied by the LEM.

### 2-3. E.C.S. Duct Sizes (Based on Saturn IB Vehicle).

| | |
|---|---|
| Command Module Cavity Line | - 2" diameter - 55 feet long |
| Service Module Compartment Line | - 8" diameter - 42 feet long |
| | - 4" diameter - 13 feet long |
| *Instrument Unit | - 6" diameter - 55 feet long |

---

** The term Command Module Cavity will be used to indicate the area exterior to the crew compartment.

2-4. Compartment E. C. S. Entrance and Exit Sizes, (Approximate).

| | Flow Areas in Sq. In. |
|---|---|
| Command Module Entrance ................. | 0.307 |
| Command Module Vent ..................... | 0.785 |
| Service Module Entrance .................. | 9.5 |
| Service Module Vent ....................... | 63.8 |
| (Vented to Spacecraft LEM Adapter) | |
| *Instrument Unit Entrance .................. | 28.275 |
| (Also vent from S/M & LEM Compartment) | |
| S-IVB Vent ................................ | 150.0 |
| (Unrestricted flow into S-IVB Stage) | |

(Based on information received at Propellants and Gases Subpanel Meeting 17-18 June 1964)

2-5. GASEOUS NITROGEN TEMPERATURE

The design ambient temperature range is assumed between 30° F and 100° F. For the purpose of pressure loss calculations in the flexible ducts, a mean temperature of 60° F is assumed. The nitrogen and air temperature within the Apollo compartments is assumed as 70° F, which is the assumed compartment temperature due to the E. C. S. conditioning.

For the purpose of calculating flow rates and required orifice diameters, the nitrogen temperature is assumed as 30° F entering and 70° F within and leaving the compartments. These assumptions create a safety factor against overpressurizing the compartments due to nitrogen expansion. The orifices and flow rates are sized for nitrogen at a temperature of 30°F. With full expansion to 70° F in the compartments, the compartment pressure will be within the allowable pressure using this assumption. If the nitrogen enters the system at a higher temperature, the flow rate and expansion within the compartments will be less. The minimum flow rate and compartment pressure will occur when the nitrogen supply is 100° F. The maximum and minimum flow rates for the system are listed for 30° F and 100° F in this report.

*Employed in system "B" only. (See Sect. 3-2, System B)

## SECTION III
## SYSTEM DESCRIPTION

### 3-1. GENERAL

The fuel cells are pressurized between T-9 and T-5 hours for Saturn IB; T-12 and T-8 for Saturn V. Manned Spacecraft Center (MSC) proposes that the Deluge Purge System be placed on a "standby ready" basis by T-13 to T-18 hours maximum. In the event of free hydrogen within the upper compartments of the Apollo spacecraft, a detecting device will activate a series of alarms. The immediate area will be evacuated of all personnel. After assurance that personnel are clear, the emergency gaseous nitrogen deluge system will be activated manually from one of several approved locations; the umbilical tower control panel or service structure platform, tower base, or blockhouse.

Upon activation of the $GN_2$ deluge, flow from the E. C. S. is terminated; solenoid valves within the Deluge Control Panel open, allowing controlled flow of nitrogen through the panel and E. C. S. ducts, deluging the compartments. The deluge will continue at a fixed rate until the compartments are inerted with nitrogen. At this time, the Service Module Compartment, Spacecraft LEM Adapter Compartment, and Instrument Unit deluge will be reduced to a purge of approximately 50 lbs/min for nitrogen economy. This does not compromise the deluge effectiveness in any manner. The Command Module Cavity deluge will remain unchanged due to its negligible nitrogen consumption. The low rate of flow would make it possible for the high pressure nitrogen battery to provide the entire deluge supply.

The $GN_2$ purge will continue to operate until all hydrogen aboard the spacecraft has been removed or a condition of safety prevails.

Pressure relief valves will be included in the lines to protect the Apollo compartments against overpressurization by the nitrogen deluge.

A flow verification system could be installed as a check on the required deluge. In the event of a plugged orifice or malfunctioning solenoid valve, the flow verification system would indicate the problem and a redundant flow path could be opened. This redundant line is proposed to increase system reliability.

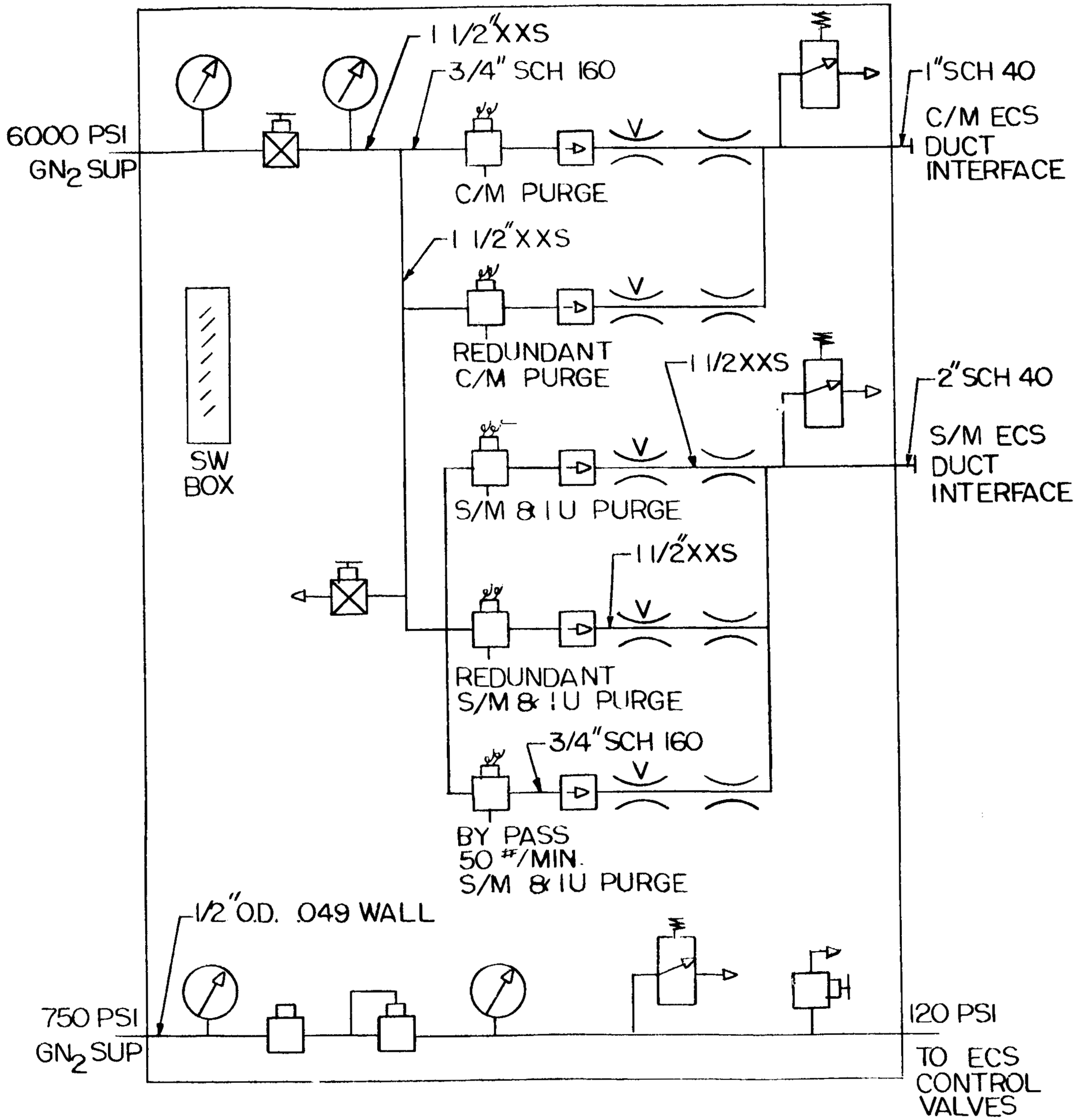


Figure 3-1. System "A"

3-2. System "A." (For consideration through Command Module Cavity and Service Module Compartment connect points.)

This system (figure 3-1) employs two flexible E.C.S. ducts for delivering the emergency nitrogen deluge to the Apollo compartments. One duct is connected to the Command Module Cavity and the second to the Service Module Compartment.

Nitrogen enters the system through two lines from the Deluge Valve Panel which is supplied from a 6,000-psi nitrogen source. Flowing through the valve panel, the nitrogen in each line passes through a variable orifice and a sharp edged orifice, which reduce the pressure and control the flow. From the valve panel, the two lines interface with the E.C.S. ducts on the umbilical tower.

Nitrogen for the Command Module Cavity deluge is vented to the atmosphere. The nitrogen deluge for the Service Module Compartment also purges Spacecraft LEM Adapter Compartment and Instrument Unit. The Command Module Cavity deluge flow rate is 4.75 to 5.08 lbs/min. The Service Module Compartment flow rate is 365 to 390 lbs/min. The total nitrogen deluge flow rate for this system is 370 to 395 lbs/min. These flow rates are at nitrogen temperatures of $100^{\circ}F$ and $30^{\circ}F$, respectively. The Service Module Compartment deluge is vented to the atmosphere through the S-IVB Stage.

A bypass line is included around the flow control orifice in the Service Module deluge line. This bypass line is opened as the deluge line is closed with a solenoid valve. It contains an orifice to provide the reduced nitrogen flow of approximately 50 lbs/min to conserve nitrogen until the Environmental Control System can be activated.

The time required to inert the Apollo compartments with this system's flow rate is as follows:

1. Command Module Cavity.......... 2.56 to 2.72 minutes

2. Service Module Compartment, Spacecraft LEM Adapter Compartment, and Instrument Unit .... 2.85 to 3.0 minutes

This system should be allowed to deluge the compartments for a full 3 minutes. The nitrogen consumption in this period will be 1,524 to 1,623 pounds.

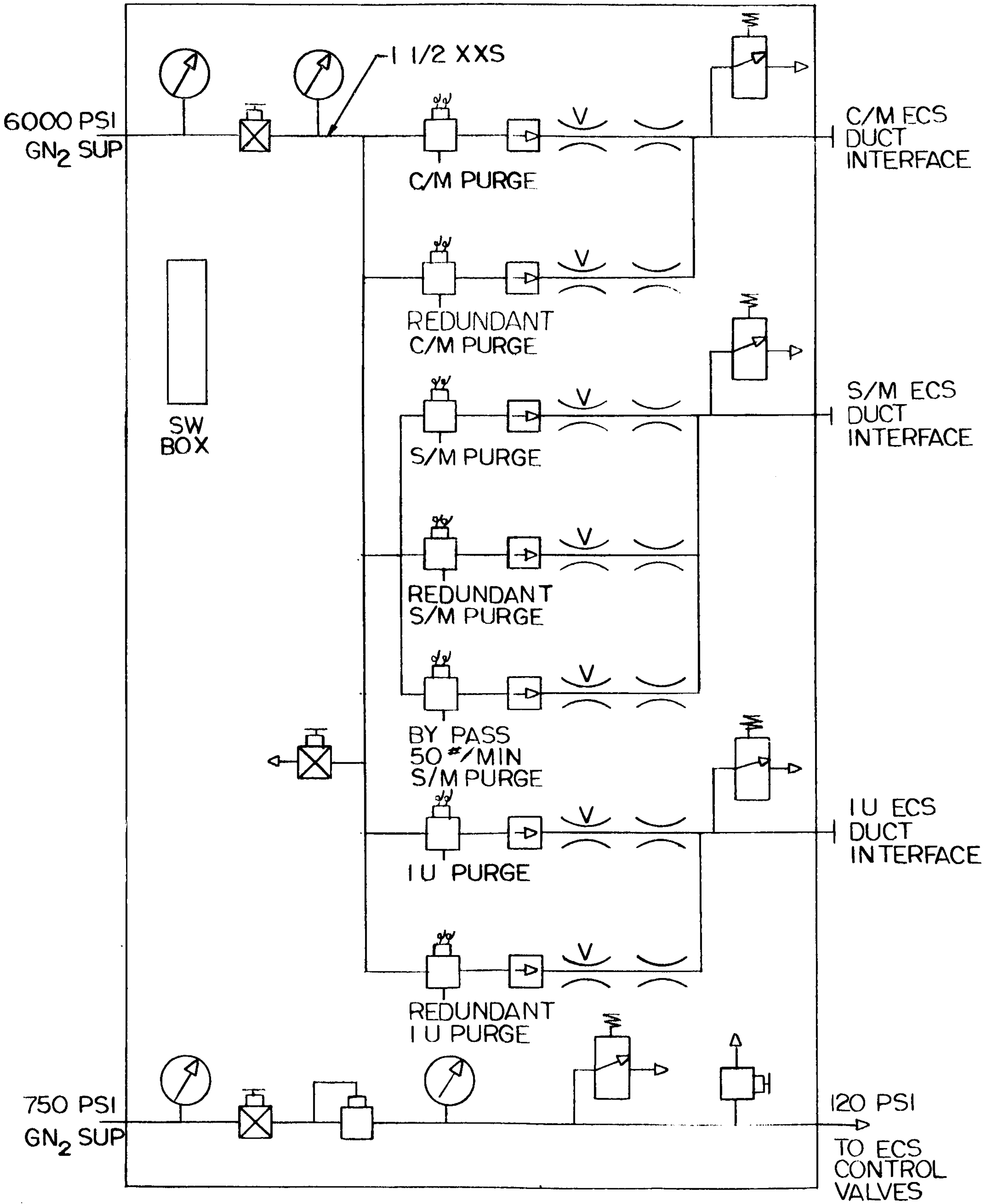


Figure 3-2. System "B"

3-3. <u>System "B."</u> (For consideration through Command Module Cavity. Service Module Compartment, and Instrument Unit Compartments connect points.)

This system (figure 3-2) employs three E.C.S. ducts for delivering the $GN_2$ deluge to the Apollo compartments. The basic system is similar to System "A." The major differences are the flow rates due to the different internal pressure characteristics of the vehicle as a result of the third duct. The allowable flow rates for this system are 226 to 242 lbs/min to the Service Module Compartment, 503 to 536 lbs/min to the Instrument Unit, and 4.75 to 5.08 lbs/min to the Command Module Cavity. The total deluge flow rate with this system is 734 to 783 lbs/min.

This system also employs a reduced flow operation similar to System "A." The method employed to reduce the deluge to a 50 lbs/min purge is to terminate flow through the E.C.S. duct to the Instrument Unit, and route the Service Module Compartment flow through a bypass line similar to System "A."

The time required to inert the Apollo compartments with this system's permissible flow rate is as follows:

1. Command Module Cavity........ 2.56 to 2.72 minutes
2. Service Module Compartment & Spacecraft LEM Adapter Compartment ................. 3.31 to 4.38 minutes
3. Instrument Unit ............... 0.56 to 0.59 minutes.

This system should be allowed to deluge the compartments for approximately 4.5 minutes. The nitrogen consumption in this period will be 3,303 to 3,524 pounds.

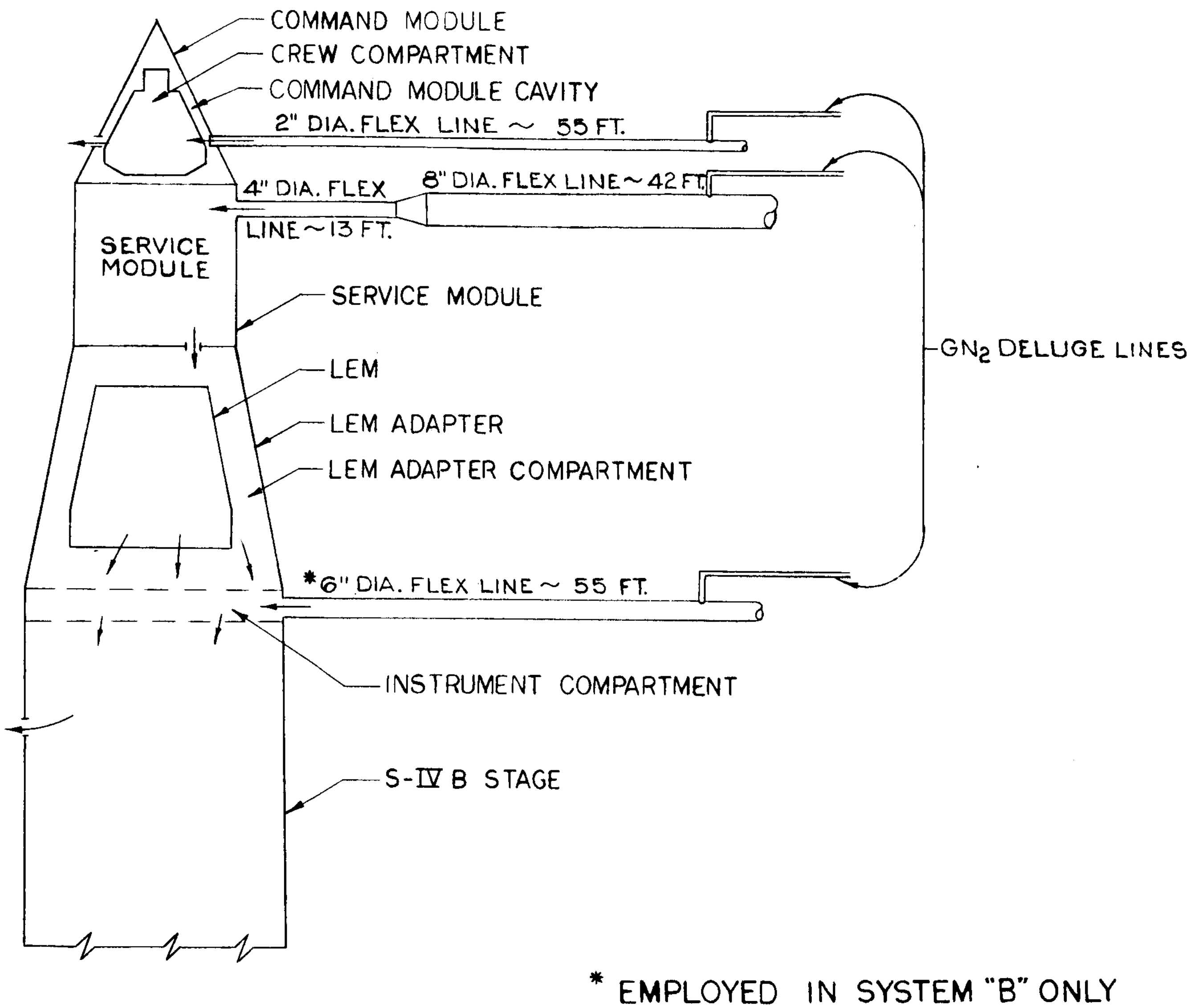


Figure 3-3. Apollo Compartment Purge Schematic

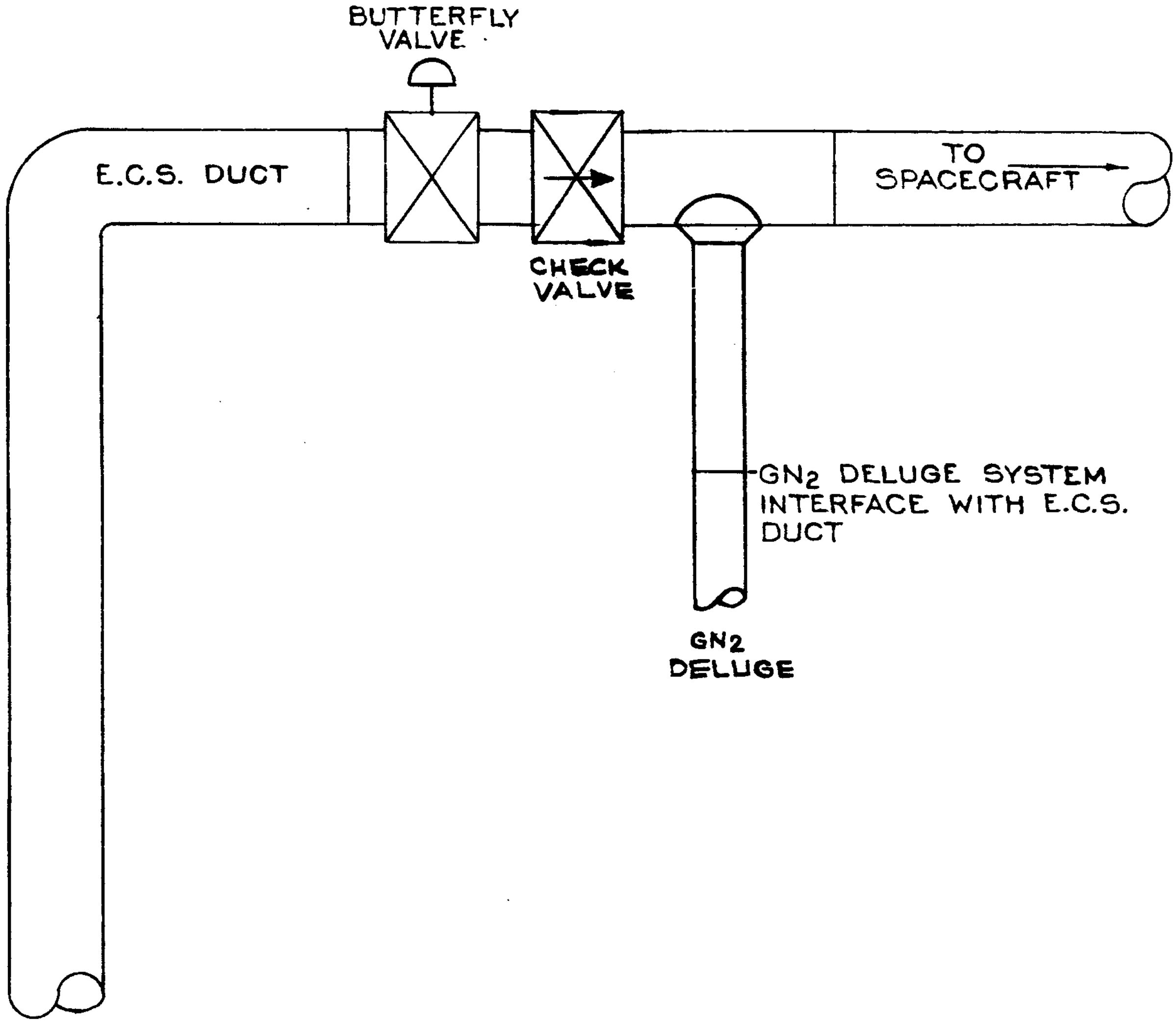


Figure 3-4. $GN_2$ Deluge System Typical Interface with Environmental Control System

## SECTION IV
## COST ESTIMATES

### 4-1. COST BREAKDOWN

| | SATURN IB | | SATURN V | |
|---|---|---|---|---|
| | "A" | "B" | "A" | "B" |
| DELUGE PANEL ONLY | | | | |
| Design & Engineering | 8,000 | 9,000 | 8,000 | 9,000* |
| Material & Components | 13,000 | 17,000 | 13,000 | 17,000 |
| Fabrication | 4,000 | 4,500 | 4,000 | 4,500 |
| Test & Checkout | 4,000 | 4,000 | 4,000 | 4,000 |
| TOTAL/Unit (1st Unit) | 29,000 | 34,500 | 29,000 | 34,500 |
| TOTAL/Unit (Each Subseq. Unit) | 21,000 | 25,500 | 21,000 | 25,500 |
| E.C.S. (Deluge Interface Req.) | | | | |
| Design & Engineering | 8,000 | 8,000 | 9,000 | 9,000 |
| Material & Components | 7,000 | 7,000 | 10,500 | 10,500 |
| Fabrication | 3,000 | 3,000 | 4,500 | 4,500 |
| Test & Checkout | 4,000 | 4,000 | 6,000 | 6,000 |
| TOTAL/Unit** | 22,000 | 22,000 | 30,000 | 30,000 |
| INSTALLATION (Panel & E.C.S.) | | | | |
| Material & Components | 2,500 | 2,700 | 2,750 | 2,950 |
| Labor | 4,000 | 4,600 | 5,000 | 5,600 |
| TOTAL/Unit | 6,500 | 7,300 | 7,750 | 8,550 |
| TOTAL COST/Unit (1st Unit) | 57,500 | 63,800 | 66,750 | 73,050 |
| TOTAL COST/Unit (Each Subseq. Unit) | 49,500 | 54,800 | 58,750 | 64,050 |

| TOTAL COST | "A" | "B" |
|---|---|---|
| SATURN IB (LC 34 & LC 37B) | 85,000 | 95,600 |
| SATURN V (LC 39 LUTS 1,2, & 3) | 124,250 | 141,150 |
| | $209,250 | $236,750 |

*Cost is split equally for SATURN IB & SATURN V.
**Total cost includes LC 34 & LC 37 B for SATURN IB and LUTS 1,2, & 3 for LC 39.

## SECTION V
## CONCLUSIONS AND RECOMMENDATIONS

### 5-1. CONCLUSIONS

Both systems "A" and "B" proposed in this report have advantages, one over the other. The following are the advantages of System "A."

1. Less Complex System: Two purge lines and related equipment are required rather than three. Cost savings are from a smaller size valve panel, fewer controls, and equipment.

2. Reliability: This system is more reliable than System "B" by virtue of fewer components necessary to operate the system.

3. Time for Inerting: This system has the advantage of inerting the Apollo compartments in 3 minutes as compared to the 4.5 minutes required for System "B."

4. A smaller quantity of nitrogen is required to inert the compartments. System "A" requires a maximum of 1,623 pounds as compared to 3,524 pounds required for System "B."

System "A" has the disadvantage of a longer time requirement to inert the Instrument Unit.

### 5-2. RECOMMENDATIONS

1. It is the recommendation of this report that System "A" be considered for delivering a gaseous nitrogen deluge to the Apollo Spacecraft.

2. Upon acceptance by MSC, K-D will establish a simulated test to determine fixed and variable orifice equivalents prior to final panel design.

3. Design flexibility shall be inherent with the mechanical capabilities of the system so that upon a completed installation at KSC the system can be tested and properly calibrated for actual existing conditions.

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