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PRELIMINARY RESULTS OF SPACE SHUTTLE EC/LSS STUDIES

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INTRODUCTION

The purpose of this paper is to indicate overall status of the Langley Research Center program on space shuttle environmental control/ life support systems (EC/LSS), present preliminary results of studies being conducted, and provide a current assessment of technology advancements required.

LRC Program Status

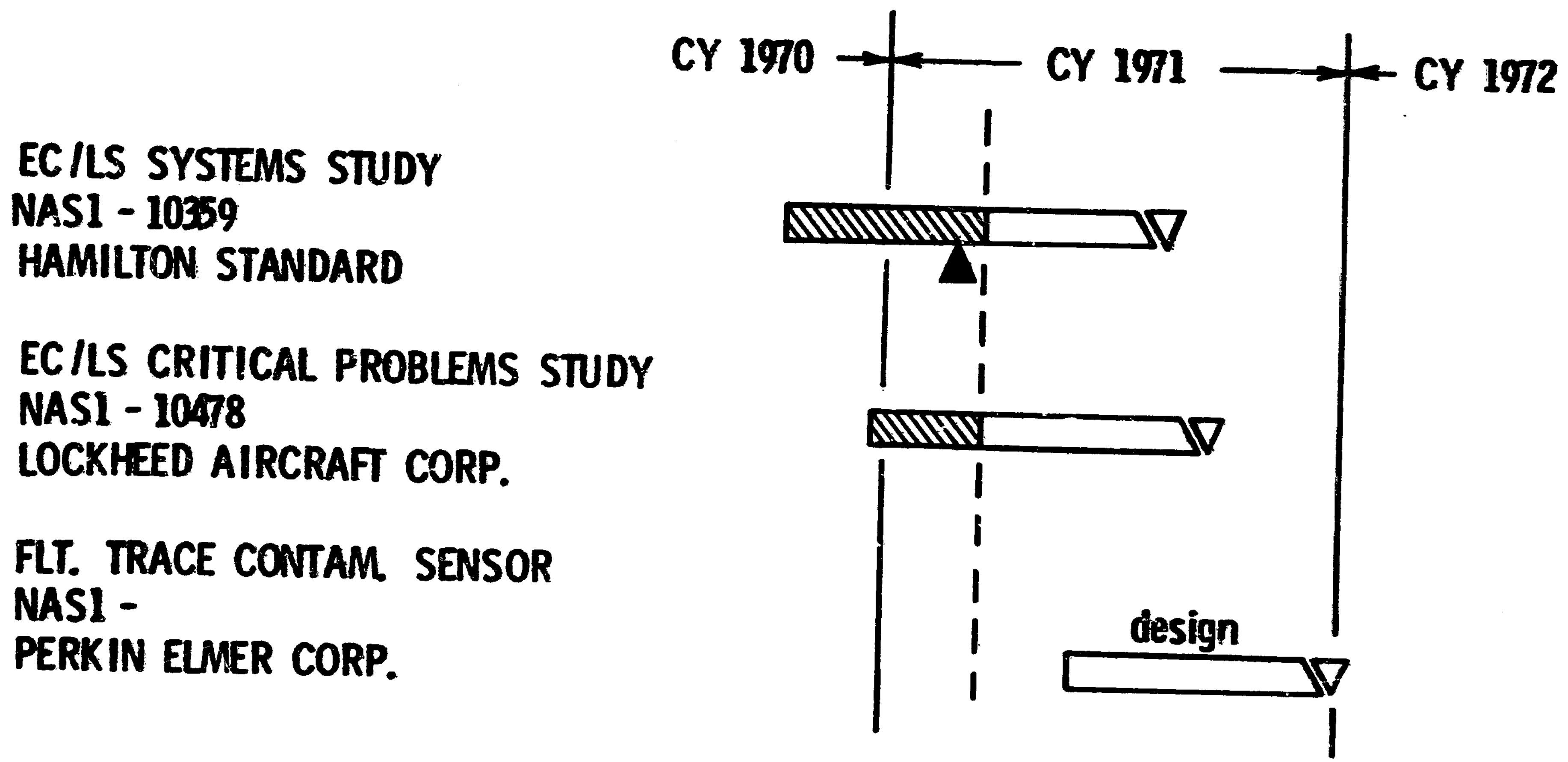
Primary elements of the program currently consist of two contracted EC/LS systems studies and design of a flight trace contaminant sensor system. Other Langley research activities not supported directly by shuttle funding also have application to shuttle life support problems and will be identified later.

The Hamilton Standard effort includes conducting subsystem trade-off studies, assembling a conceptual system, and identifying pacing technology for shuttle orbiter EC/LS. It is about 50 percent complete and, as noted by the recent milestone, a midterm progress report has been published.

Lockheed is concentrating on four orbiter EC/LSS problems: cargo module system concepts, shuttle/space station interfaces, integrated cabin thermal control for all mission phases, and subsystem reusability. This contract has been underway for only about three months and results are limited.

The design phase of the contractual effort to develop a multi-gas trace contaminant sensor system will be initiated shortly.

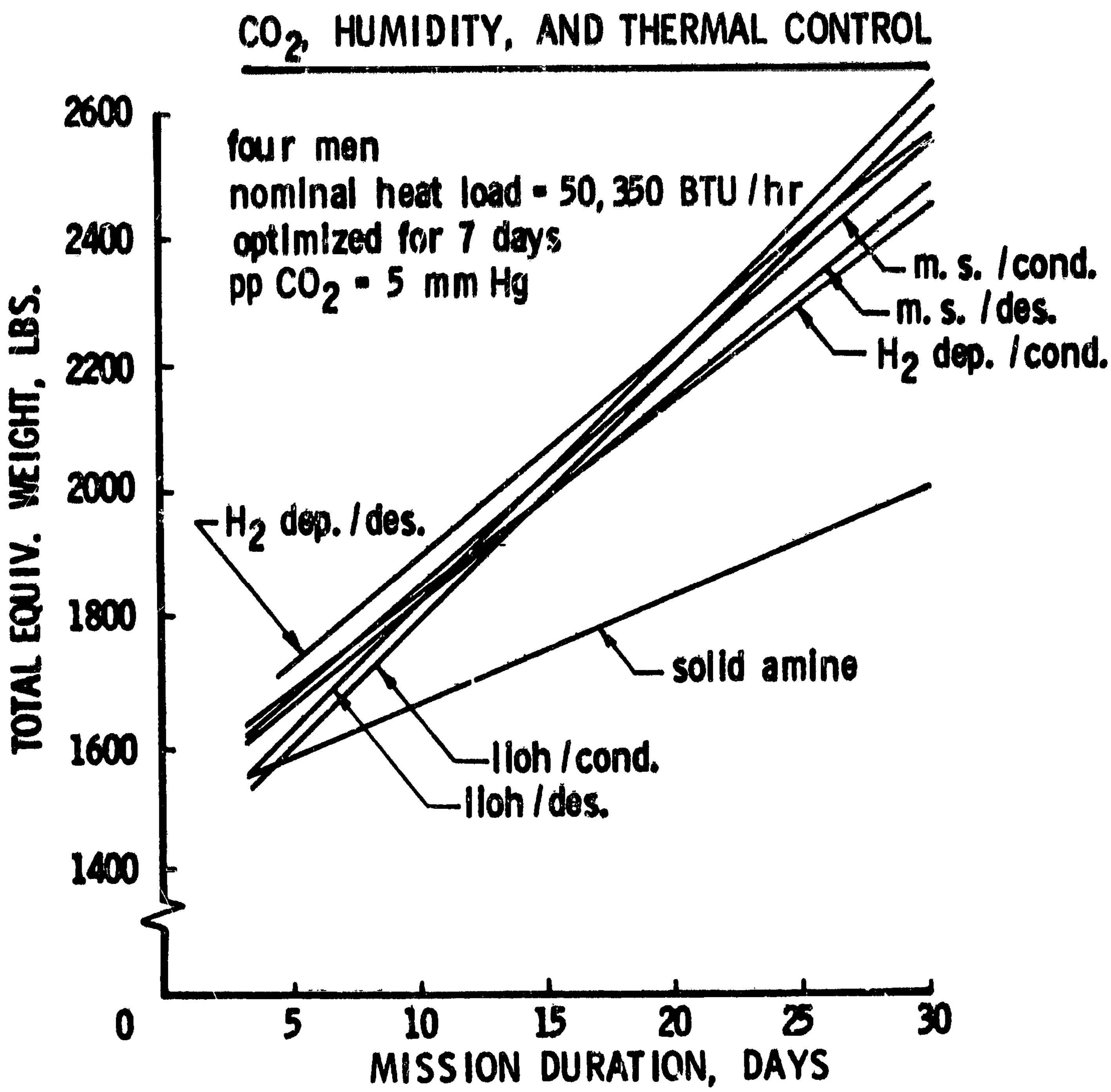
LRC PROGRAM STATUS



CO_2, Humidity, and Thermal Control

Much of Hamilton Standard's effort to date has involved subsystem trade-off studies. The most extensive of these studies is in the area of CO_2, humidity, and thermal control. In this case candidate concepts which include all of these EC/LS functions are being evaluated since most CO_2 removal methods also control or affect humidity and have an impact on the cabin temperature control system. One aspect of this evaluation is shown in the figure where the total equivalent weight (includes hardware weight, power and heat rejection penalties, expendables, etc.) of a number of concepts varies with mission duration. These calculations include consideration of a typical heat rejection system for a nominal heat load (includes metabolic, avionic, wall, and fuel cell loads). The increase in weight with time reflects ullage losses, bakeout requirements, and expendables although some additional penalty is incurred for operation beyond the 7-day design point for some of the concepts.

Systems considered include lithium hydroxide, molecular sieve, and H_2 depolarized concepts, each with either condensing heat exchangers or desiccants, and a solid amine concept which collects both CO_2 and water vapor and is regenerated by vacuum desorption. The figure indicates that the solid amine concept is the lightest system for missions longer than about 4 days. Other factors, however, ranging from safety to cost to maintainability must be considered in the selection process. For example, during the reentry and ferry mission phases, only the LiOH/condenser and the H_2 depolarized/condenser concepts actively control CO_2 and humidity, while the other concepts must rely on either cabin transients or auxiliary equipment. Additionally, the LiOH/condenser concept is developed and proven with the added advantage of fewer parts and lower initial cost. On a cost-through-first-flight basis, the expendable LiOH/condenser concept would be chosen; however, on a total-program (10 years) cost basis, the regenerable solid amine system would be chosen.


CO2, HUMIDITY, AND THERMAL CONTROL
four men
nominal heat load = 50,350 BTU/hr
optimized for 7 days
pp CO2 = 5 mm Hg
TOTAL EQUIV. WEIGHT, LBS.
2600
2400
2200
2000
1800
1600
1400
m. s. /cond.
m. s. /des.
H2 dep. /cond.
H2 dep. /des.
solid amine
lioh /cond.
lioh /des.
0
5
10
15
20
25
30
MISSION DURATION, DAYS

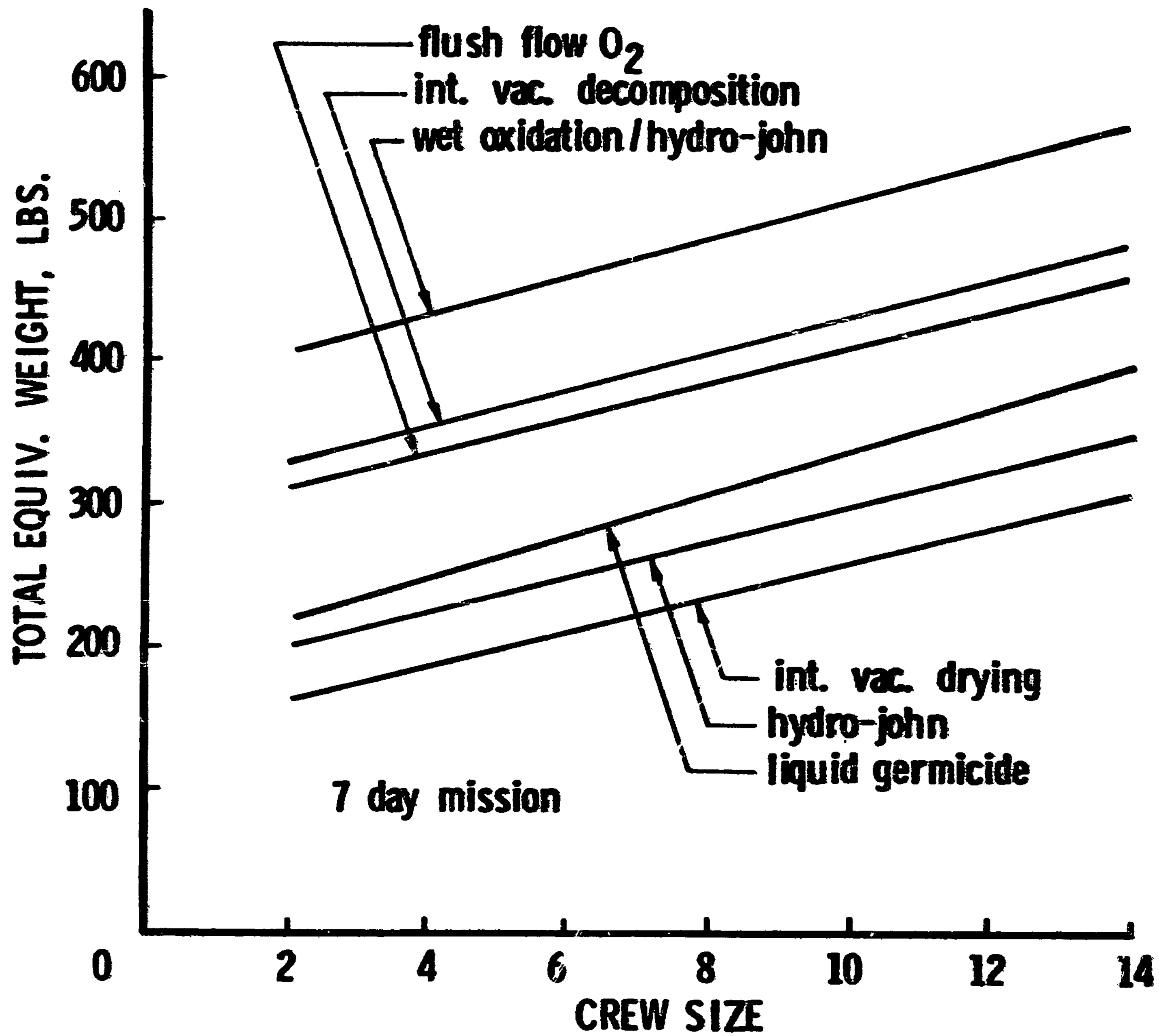
Waste Management

Another example of the subsystem trade-off studies being conducted by Hamilton Standard involves the selection of a shuttle waste management system. In this case the use of a conventional sitdown commode is considered as the only practical feces collection system. Such a system would involve no manual handling of fecal material and thereby should be highly acceptable to crew and passengers both practically and aesthetically.

The figure shows the weight penalty of six candidate concepts as a function of crew/passenger size for a 7-day mission. An integrated vacuum drying concept in which waste material is collected, processed, and stored in a single unit has the lowest weight followed by the Hydro-John and liquid germicide concepts. All of the other concepts involve high-temperature processing and use a high rate of expendables and/or power. They also require two collectors for processing in order that the waste decomposition process can take place and cool down before reuse.

The vacuum drying concept using tissue wipes is the selected system not only because of its low weight and volume, but also because it is a relatively simple system with good reliability and mission flexibility. The number of waste management units required will depend upon not only the number of crew or passengers, but on their location in the shuttle vehicle.

WASTE MANAGEMENT



Technology Recommendations

As noted previously, one of the primary objectives of the Hamilton Standard EC/LS systems study is to identify pacing technology items. The figure indicates a technology forecast of items that have been identified as warranting further development in order to provide improved flexibility for achieving a low-cost, technically optimized shuttle EC/LSS. Subsystem trade-off studies have been conducted in five areas and some 14 pacing technology items identified. These conclusions are, however, tentative and are subject to change as the study progresses and the total EC/LSS is defined and optimized. One change has already been made in that the selected humidity control water separator is now an elbow separator configuration instead of the wick separator indicated.

One item of special interest is the need for a realistic shuttle orbiter contaminant model. Current models are based on space station technology and do not generally consider the great variety of possible shuttle missions with the attendant variety of passengers, cargoes, and experiments. The reasons why other specific items are listed are too lengthy to be discussed here, but are found in the interim progress report previously mentioned and will be covered in detail in the final report due to be published in September of this year. It is interesting to note that most, if not all, of these items are presently being pursued to some degree. NASA Langley, as a part of its advanced technology program, is conducting and sponsoring applicable research and development in a number of these areas. For example, the trace contaminant absorption capability of "Purafil," a potentially useful material, is being conducted under contract NAS1-9506 with Texas Tech University, and in the water management area, breadboard water quality monitoring equipment is being produced under Contract NAS1-10382 with Aerojet General.

TECHNOLOGY RECOMMENDATIONS (NAS1 - 10359)

CO_2, Humidity and Thermal Control

- Solid Amine
- H_2 Depolarized Cell
- Face Wick Separator

Atmospheric Contamination Control

- Purafil
- Model Definition

Water and Waste Management

- Urinal - Male
- Commode - Male/Female
- Zero "G" Tanks
- Quantity Sensor
- Quality Monitor

Atmospheric Storage and Pressure and Composition Control

- Composite Material Tanks
- Partial Pressure Sensors - O_2 and CO_2

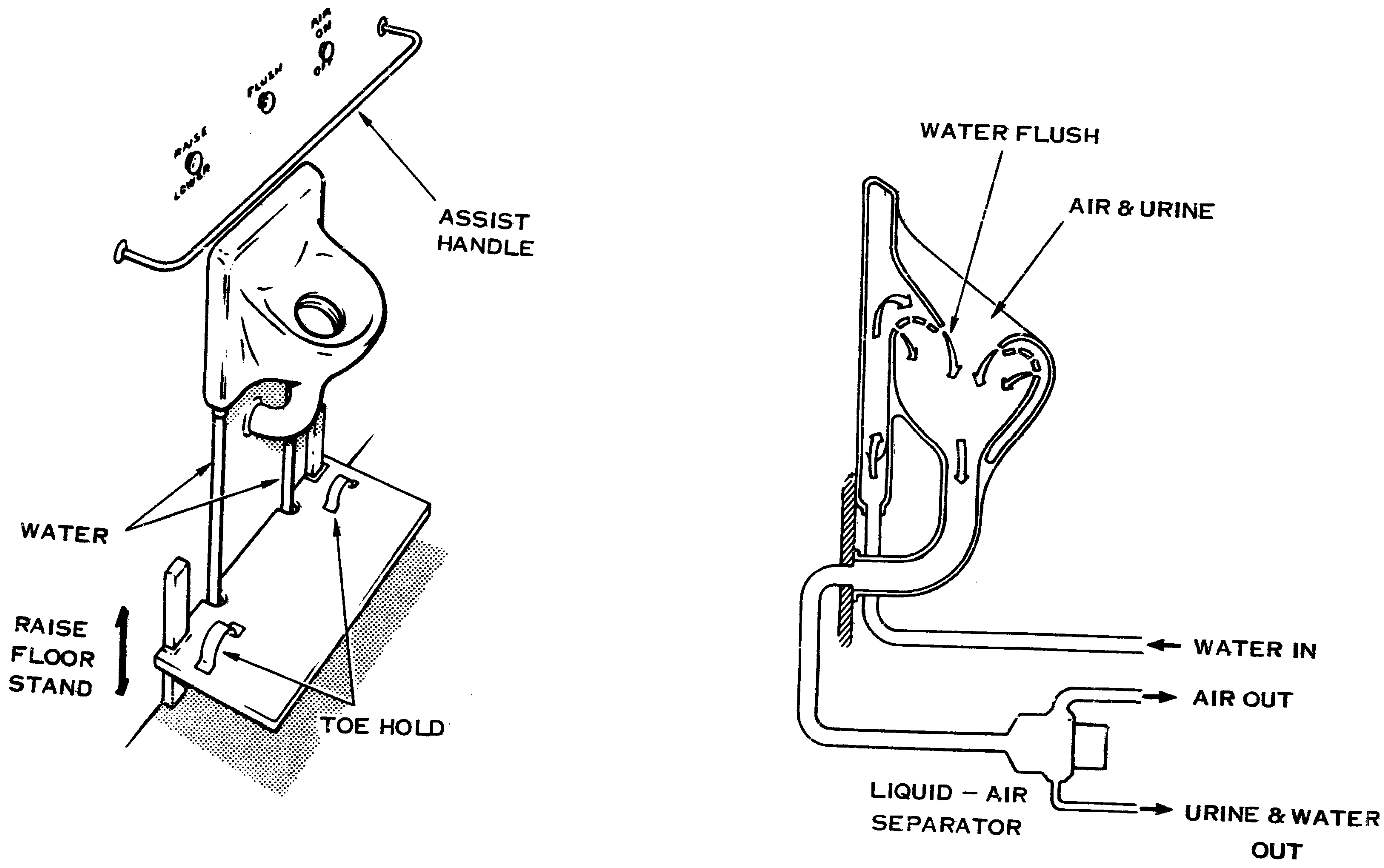
Heat Rejection

- Cryogenic Heat Exchangers
- Evaporators

Air Flow Urinal Concept

The waste management subsystem for the shuttle requires a number of technological advances to improve crew/passenger acceptability. The Hamilton Standard artist's concept shown illustrates a new, more conventional, height adjustable, wall-mounted urinal which eliminates body contact with the urine collection device. An air stream within the collector facilitates urine collection and delivery to the separation system. Appropriate filters are used for odor and bacteria control of the air and a water flush is incorporated within the urinal. The requirement for urine collection tanks will depend upon overboard dumping limitations.

AIR FLOW URINAL CONCEPT

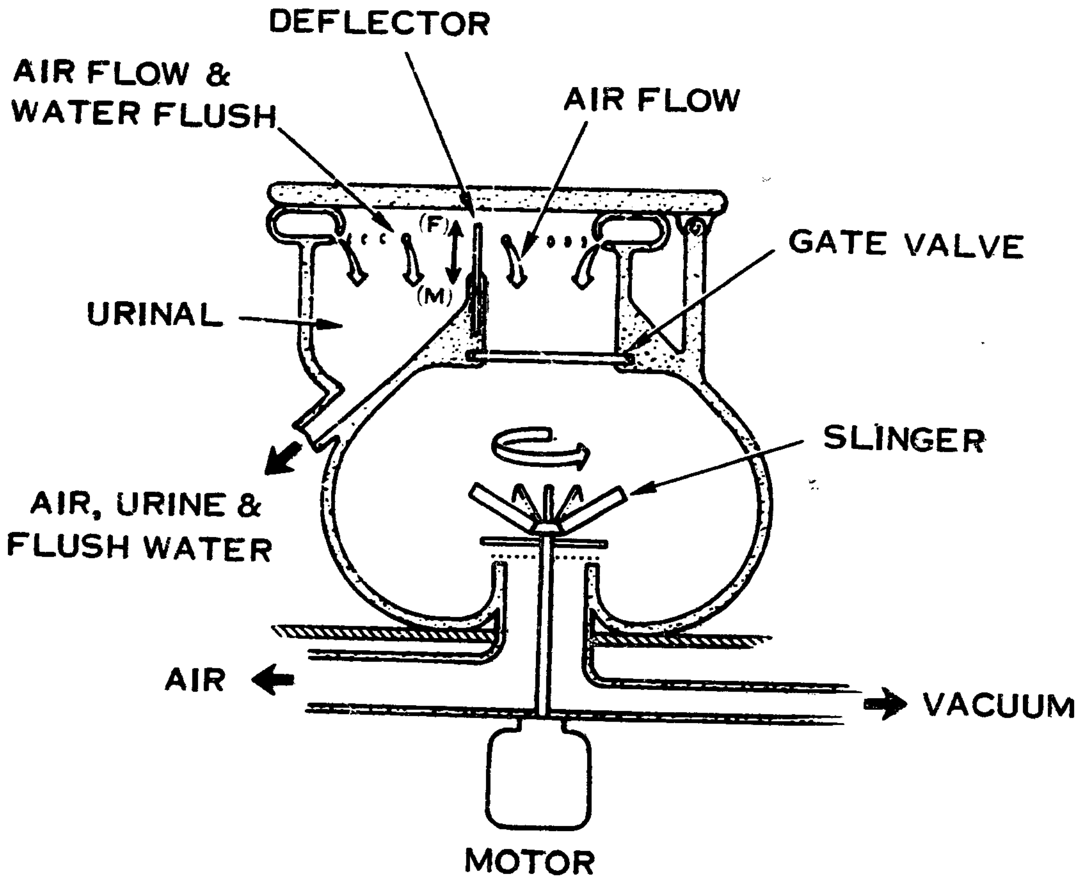


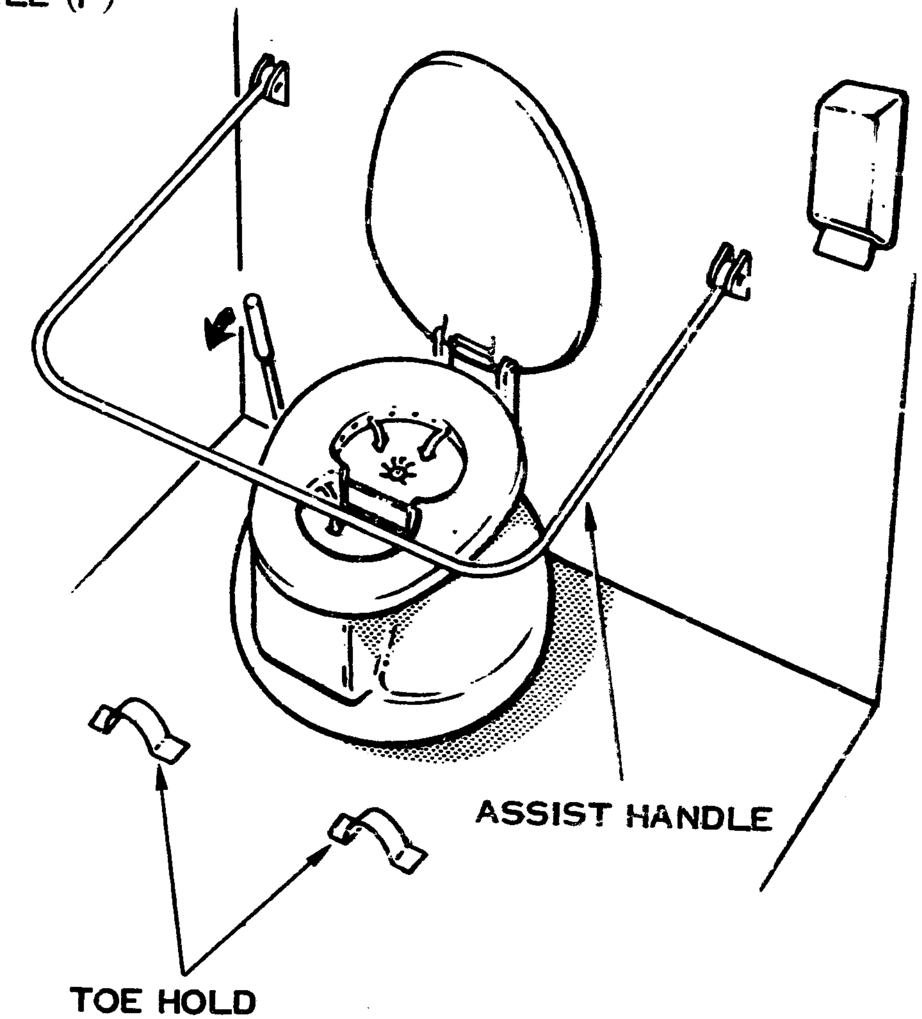
Split-Flow Commode Concept

The waste management subsystem for the shuttle should accommodate both males and females and be as conventional and earthlike as possible for crew/passenger acceptance and convenience. The Hamilton Standard artist's concept shown illustrates a zero "g" commode concept for meeting shuttle requirements. Basically, the unit consists of an air flow urine collector (similar to that previously illustrated) integrated with a feces collector. The two collectors are separated by a deflector which is positioned down for male use and up for female use. Separate collection of urine is desirable since it can be readily stored and/or disposed of to vacuum. Fecal collection is aided by air flow into the unit where the feces are shredded by a motor-driven slinger and then vacuum dried. As with the urinal, appropriate filters are used for odor and bacteria control.

SPLIT-FLOW COMMODE CONCEPT

MALE (M) & FEMALE (F)





Cargo Module EC/LSS

Initially, Lockheed has used system cost as a basis for selecting the best type of EC/LSS for the shuttle payload or cargo module. The study was based on an assumed 13-year traffic model recently generated by the NASA Space Station Task Force. As shown, the model includes 93 flights wherein passengers are located within the module. Another assumption was that a four-man, 7-day EC/LS would be used for the forward crew compartment of the orbiter, and that development costs for that unit are covered in the basic shuttle development cost.

Customized 2-, 6-, and 12-man systems were considered and compared in various combinations with single or multiple four-man units to fulfill requirements for individual flights. Results of this cost-effectiveness study show that the basic four-man EC/LSS modularized for payload application is the optimum approach. Other parameters such as flight frequency and scheduling, mission length, and system weight and volume will be considered later during the course of the contract in order to provide a complete analysis.

CARGO MODULE EC/LSS

- Objective - optimize design for 13 year mission traffic model*
- Results - use basic four-man units modularized for payload application

* Traffic Model

20	12-passenger transfer flights
24	6-passenger transfer flights
49	2-passenger cargo/experiment flights
93	flights

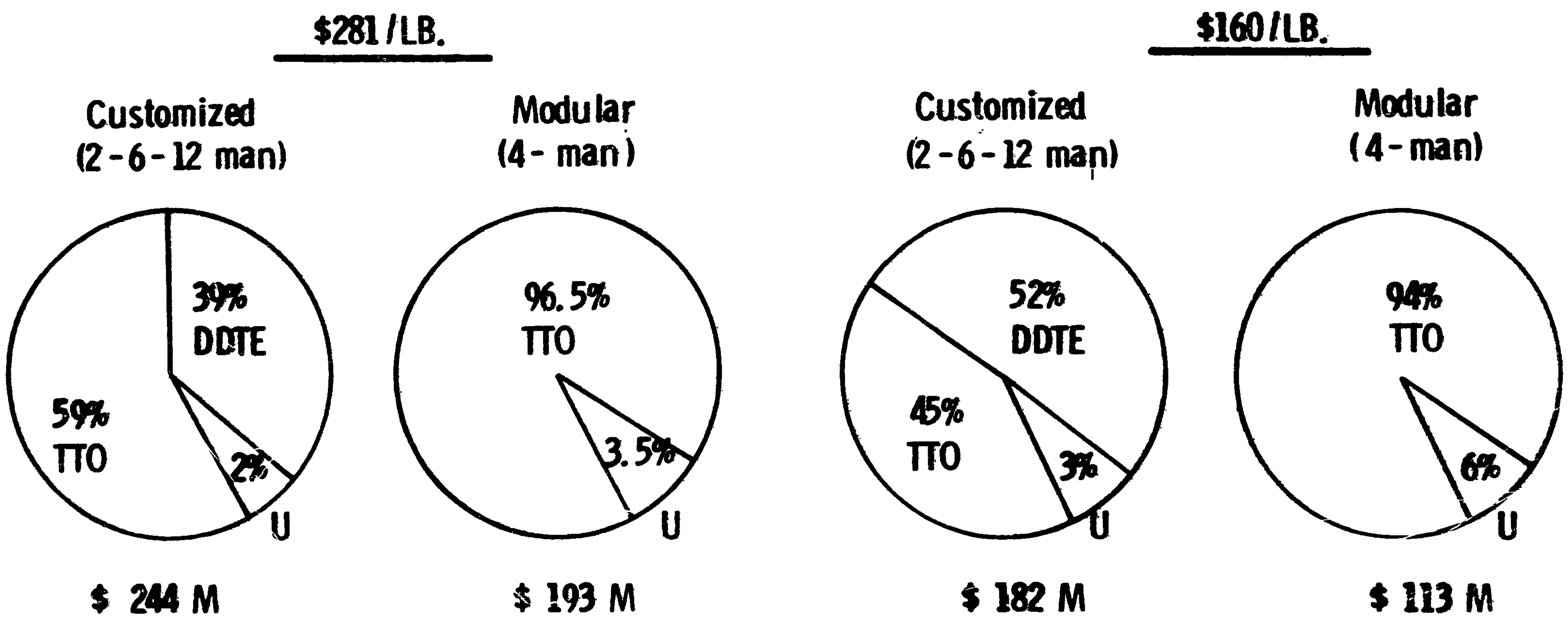
Cargo Module EC/LSS Cost Comparison

The cost comparison for the customized and modular approaches to cargo module EC/LSS for the total of 93 flights is presented graphically for two different values of cost per pound for transportation to orbit. These values of $281/pound and $160/pound represent a range currently under consideration by shuttle system planners.

In both comparisons, estimated launch weight and unit costs are lower for the customized systems. However, the large added cost of design, development, test, and evaluation results in the total estimated cost of these systems being substantially greater than for the modular units. It should be noted that significance should be attached only to the differences in cost. Absolute costs could be altered about equally in all cases when one considers costs of system integration and maintenance, for example. It is also significant that the cost of DDT and E estimated for the customized systems could be reduced as much as 50 percent without altering the conclusions reached.

CARGO MODULE

EC/LSS COST COMPARISON



$\left.\begin{array}{ll} \text{DDTE} & \text{— Design, Development, Test, Evaluation} \\ \text{U} & \text{— Unit} \\ \text{TTO} & \text{— Transportation To Orbit} \end{array}\right\}$ Costs

Shuttle/Space Station EC/LSS Interfaces

Work by Lockheed in this area has been very limited to date. The chart makes only two points. First, early in the space station mission, if the station EC/LSS is designed for 12 men and only 6 are onboard, the station system can accommodate the shuttle orbiter relief crew of six men. However, after the station crew has grown to 12 men, presence of the six-man shuttle transfer crew will result in an 18-man load on the station EC/LSS for as long as 5 days. The problem will be even more severe for a 12-man transfer. The station EC/LSS will then require either support from the shuttle system or an overdesign capability from the station system itself. The other point is that, for reasons of crew safety, the shuttle must be maintained ready to leave the station under emergency conditions at any time while docked.

Integrated Thermal Control

Only a limited effort has been conducted to date to define a cabin or internal thermal control system for shuttle orbiter launch, on orbit, reentry, cruise, landing, and ferry mission phases. Early results indicate onboard fuels can be used as heat sinks and provide advantages for the reentry, cruise, and ferry phases.

It would also be desirable for several reasons (reentry heating and cargo door operations, for example) to offer an alternative to the customary practice of rejecting heat to space from a radiator located on the inside of the shuttle cargo doors. An attractive concept for this purpose is the cryhocycle system. The cryhocycle has been proposed by both Lockheed and Grumman and consists of collecting waste cabin heat and utilizing it in a turbine generator to produce electrical power. Hydrogen is used as the working fluid. Theoretically, such a system would eliminate the need for fuel cell power systems as well as radiators for heat rejection. A disadvantage would be losing the availability of fuel cell water to meet crew and passenger needs.

SHUTTLE/SPACE STATION EC/LSS INTERFACES

- **Objective** - determine system interdependence, crew activities
- **Results** - station crew growth requires (1) support from shuttle system; (2) station overdesign
  - docked shuttle "ready", but dormant

INTEGRATED THERMAL CONTROL

- **Objective** - determine best system for all mission phases
- **Results** - use H_2 as heat sink for reentry, ferry
  - "Cryhocycle" promising

EC/LSS Reusability

Lockheed has conducted a survey of maintenance practices of TWA, United, and Eastern Airlines to determine applications to shuttle EC/LSS quick turn-around and reusability. Onboard aircraft system monitoring methods used include AIDS (Aircraft Integrated Data System), ADAS (Automatic Data Acquisition System), and MADAR (Malfunction, Analysis, Detection, and Repair). This kind of data acquisition is recommended on the shuttle by including EC/LSS fault isolation data. Also, critical parameters such as those for aircraft engines are monitored continuously by the airlines and trend data are analyzed for corrective action by ground facilities. For the shuttle, EC/LSS parameter trend data should be included in the system.

The airlines schedule maintenance on a nonflight interference basis and will not delay flights to repair minor items. They also perform repairs and overhauls on the basis of failures rather than time in service. They have found that replacement on a time schedule does not preclude failures, especially since most difficulties occur near the beginning of the operational life of a component. Another practice is to remove and replace a failed unit rather than try to repair it on the aircraft. If a problem cannot be isolated, all suspected components are removed and replaced. All this maintenance philosophy is recommended for application to the shuttle.

In addition, airline experience has shown that actual operating hours of equipment such as that used for EC/LSS are high. In some cases, component life is of the same magnitude or greater than the operating life of the shuttle itself. This enhances the confidence level of reliability to be expected for the shuttle.

EC/LSS REUSABILITY

- **Objective** - quick turnaround, maximum reuse
- **Results** - based on airline practice survey

Airline	Shuttle
On-board monitoring (AIDS)	Include EC/LSS
Trend analysis	Analyze EC/LSS trends
Non-interference maintenance	Airline philosophy
Failure-basis maintenance	Airline philosophy
Replace instead of repair	Airline philosophy
High actual operating life	Enhances confidence level

Typical life:

Manual valves	indefinite
Heat exch.	30-40,000 hrs
Temp. controls	10,000
Compressors	3,000

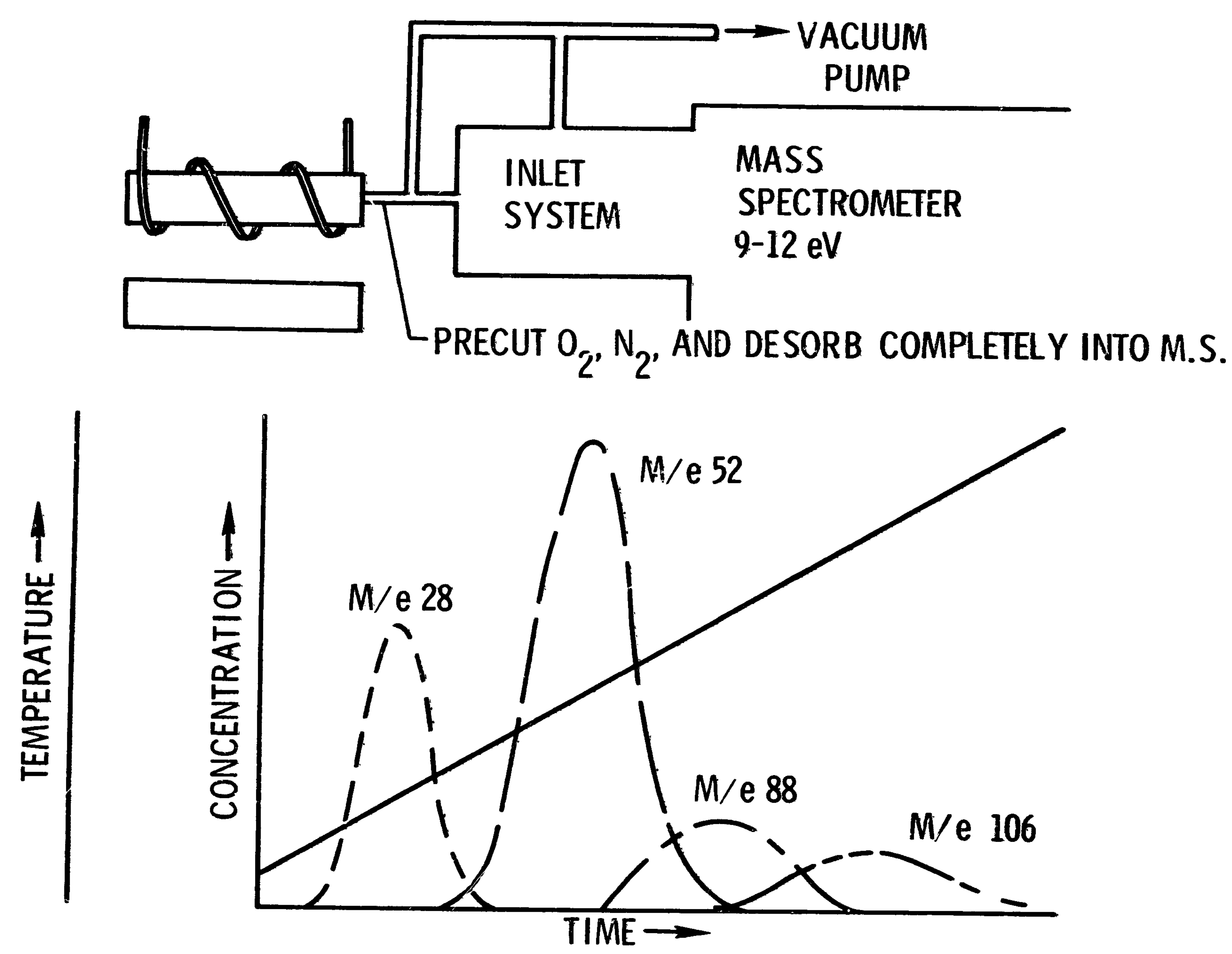
Flight Trace Contaminant Sensor System

This development program is intended to furnish a flight-qualifiable sensor which will be capable of identifying and quantifying contaminants present in a closed atmosphere. This essentially self-contained analytical system is applicable to the monitoring of a broad spectrum of gaseous organic and inorganic compounds having molecular weights of up to mass 140. The hybrid sensor consists of two main units: an accumulater cell inlet system and a mass spectrometer analyzer system.

The accumulator cell inlet system consists of from one to three gas/vapor sorption units. Each cell contains a given amount of a particular sorbent which is capable of quantitatively adsorbing the low level atmospheric contaminant(s) from an air stream passing through the cell. It effectively concentrates the adsorbed compound(s) to a level that permits quantitative evaluation. When the adsorption cycle is complete, the residual cabin atmosphere is removed from the cell and the contaminants are desorbed by the application of heat to the cells. The gases leave the cell and enter the mass spectrometer by means of the inlet leak between the cell and the mass spectrometer. The exact number of cells employed for a given operation will depend upon the degree of analytical monitoring desired.

The mass spectrometer anticipated for use is the Nier-Johnson double focusing mass spectrometer. This instrument uses a 90° electric and a 90° magnetic sector and is presently near optimum in terms of flight design.

FLIGHT TRACE CONTAMINANT SENSOR SYSTEM



Concluding Remarks

The shuttle mission is a relatively short one, normally 7 days, and generally an open-cycle or expendable environmental control/life support system can be used. The technology for such a system is available from a combination of Apollo spacecraft and aircraft hardware.

However, while such a system might be satisfactory for very early shuttle flights, certainly a more sophisticated system should be pursued for the large bulk of the routine operational flights. It is here that improvements in technology can result in reduced costs, reduced weight, simpler systems, and increased passenger acceptability.

A solid amine system for removal of carbon dioxide and humidity control, for example, can save weight and ultimately reduce costs as compared to the lithium hydroxide/condensing heat exchanger combination. The cryhocycle thermal control concept, if developed and utilized, could replace the troublesome heat rejection radiator as well as the fuel cells required for electric power and result in a simpler, more reliable, and possibly lighter weight system. And certainly the development of more earthlike male and female urine and feces collection devices would result in the increased passenger acceptability which will be necessary if the shuttle is to become part of a routine and widely utilized space transportation system.

CONCLUDING REMARKS

- EC/LSS TECHNOLOGY FOR THE SHUTTLE IS AVAILABLE

BUT - - -

- IMPROVEMENTS IN TECHNOLOGY CAN RESULT IN
  - REDUCED COSTS
  - REDUCED WEIGHT
  - SIMPLIER, MORE RELIABLE SYSTEM
  - INCREASED PASSENGER ACCEPTABILITY