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SATURN VEHICLE CRYOGENIC PROGRAMS

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1965 CRYOGENIC ENGINEERING CONFERENCE

RICE UNIVERSITY

HOUSTON, TEXAS

AUGUST 23 - 25, 1965

PAPER K-4

ABSTRACT

SATURN VEHICLE CRYOGENIC PROGRAMS

This paper covers the cryogenic propellant and gaseous application to the George C. Marshall Space Flight Center Saturn Programs. Emphasis is placed on the overall application and the resultant logistic considerations.

The planning of facilities, storage, and transportation required to ensure an adequate supply of cryogenic fluids when needed is traced from the engine and stage requirements. The entire cycle of technical requirements, estimating the quantities required from production and management of the program is developed.

Spacecraft application and other trends that affect cryogenic production are reviewed.

SATURN VEHICLE CRYOGENIC PROGRAMS

INTRODUCTION

Since many factors of cryogenic research have been reported by previous cryogenic engineering conferences, a paper describing how MSFC uses and manages the cryogenic propellant program for Saturn applications is appropriate.

Descriptions of the Saturn vehicles are available in the literature and elaboration on either the vehicles or their performance is not pertinent to this paper; however, a short summary illustrating the magnitude of cryogenic applications is in order. For convenience this is shown in tabular form in Figure 1.

Let us look then to what part cryogenic fluids play in the Saturn vehicle programs. The selection of liquid hydrogen-liquid oxygen engines for the second and third stage, based on their higher performance, has created demands for large quantities of these products. The selection of large liquid oxygen-RP-1 engines for the first stage has generated the need for unprecedented quantities of liquid oxygen. It is fair to state that without the benefit of cryogenic research, which has resulted in an improved engine capability, that the Manned Lunar Landing Program would be much more difficult to achieve.

It is estimated that 40,000,000 pounds of liquid hydrogen, 130,000 tons of liquid nitrogen and 378,000 tons of liquid oxygen will be required to support the Saturn test effort in CY 1965. This test effort is spread throughout the United States and results in an annual expenditure on the cryogenic fluids alone in excess of 50 million dollars per year. This is illustrated by the tabulation of major test stands as shown in Figure 2.

Let us now review the Saturn vehicle cryogenic program in some detail by analyzing the planning, implementation, and management that has been established at MSFC.

PLANNING FOR THE SATURN CRYOGENIC FLUID REQUIREMENTS

The planning problem is one of estimating and providing the quantities of the correct products required at each test location at the proper time. This involves three major steps:

a. Determining the quality and quantitative requirement at the interface with the engine or stage.

b. Determining the quality required in the storage vessels and the storage capacity required.

c. Determining the best method of meeting these requirements.

The end result of these determinations is a translation of the test requirements of major locations into a production plant capacity. Remember this has to be done when engine or vehicle hardware design has hardly begun. Fortunately, the cryogenic production techniques have been, in all major applications, available prior to the need, requiring only the lead time then to construct plants.

Obviously there are many "trade-offs" concerning storage capacity and transportation to be considered in making these determinations. The advantages of each of the "trade-offs" are never very clear and each must be considered on its own merit, based on the data available at the time. Many situations have been reviewed and the present quantities of storage capacity and modes of transporting have resulted. These are tabulated for the major facility locations in Figure 3.

To plan for an orderly acquisition of the necessary cryogenic facilities, an accurate estimate of the quantity required must be known. An important consideration is "What is the accuracy needed in estimating requirements so that the effective capability of all the test facilities can be provided?" There are several factors involved, some of which can be measured in dollars and cents and some of which can only be measured in terms of achievement of program goals. Of these factors there are three major parameters which basically determine the accuracy required. These are:

a. The increased cost in providing more production capacity than needed if the estimate is too high or, conversely, the adverse effect of inadequate test capability if the estimate is too low.

b. The amount by which cost of the product could be reduced by increased accuracy of forecast.

c. The accuracy required for obtaining and obligating program dollars.

There are two significant factors that place an upper limit on the accuracy of estimating requirements. These are:

a. Program schedules.

b. Maturity of the state of development of the particular engine, stage, or component.

Let us review the accuracy of the estimate of requirements compared to usage data which are now available. This is illustrated by the comparison of the estimate made at six month intervals of requirements with actual usage as shown in Figure 4.

Liquid oxygen was chosen for the example, however, the same general trends are noted for liquid hydrogen and liquid nitrogen. What then should be the criteria for accuracy in estimating cryogenic requirements for programs such as the Saturn? Are the present methods adequate? If not, are more elaborate procedures required? What is the break-even point on money spent in estimating requirements? The answers to these questions are not clear at present, although they are of considerable concern.

The limitations on the accuracy of estimating requirements are so broad that it is difficult to justify expenditure of money to investigate extremely accurate forecasting methods. Simplified methods of estimating requirements, based on test experience, are used by the Saturn test facilities.

The following is a method which is presently used by Rocketdyne and approved by MSFC in the engine programs. The development and production schedule for each engine program determines the allocation of engines to each test stand. Also, the schedule of component testing which is required to support the total development and production program is obtained. Over a period of time statistical data have been obtained on the actual losses from the receipt of product to the completion of test. The losses are shown on the schematic of Figure 5. It should be noted that these data reflect the engine or component maturity. These data are revised periodically and the revised data are used in subsequent estimates of quantity requirements. Having these data for each engine test stand combination leaves only the test seconds times pounds per second quantity to be determined. The test seconds scheduled are obtained from a program plan which reflects the best judgment of the contractor and MSFC as to the testing required and the capability of the engine to meet the testing required. Thus this factor also reflects a judgment on the maturity of the engine.

When historical data are not available, as is the case at new locations such as the Mississippi Test Facility, calculated values for the various losses are required. Obviously an assumed value must be used for the hold time, i.e., the time from filling tanks to completion of tests. This judgment factor will be used until actual data are obtained.

A tabulation showing the major factors by engine, stage, and location which must be considered in estimating requirements is shown in Figure 6.

SPECIFICATIONS

A complete review of the specification requirements for Saturn programs has been made by an ad hoc committee with representatives from the laboratories who are experts in their field and who are knowledgeable in future program needs as well as present needs.

The ad hoc committee has provided MSFC Procurement Specifications for liquid hydrogen, liquid and gaseous oxygen, liquid and gaseous nitrogen -- one called Space Vehicle Grade is for general purging, pressurizing and pneumatic requirements -- the other called Instrument Grade, and having more stringent requirements, is for guidance instrumentation and gyro gas bearings. The technical requirements of each specification were coordinated through MSFC laboratories, project office~, contractor manufacturing and test engineers, the liquid and gas producing industry, NASA Headquarters and other NASA Centers. The capabilities of the Government-owned air separation plants were discussed with the Air Force.

Some of the special requirements considered in developing the MSFC specifications were oxygen for breathing and fuel cells, hydrogen for fuel cells and nitrogen for gyro gas bearings. Examples where the above criteria exposed problems are:

a. The aging Government-owned air separation plants were not designed to produce nitrogen to meet MSFC specification purity at 99.99%. There are 15 units that produce 75 tons per day each supporting NASA which are producing a military specification grade of only 99.5% purity. Prudent implementation of the MSFC specification consistent with program requirements should minimize this potential problem.

b. Small quantities of super clean nitrogen gas (Instrument Grade) are required for the Instrument Unit of Saturn IB and Saturn V at Cape Kennedy. If the special clean up components in the Instrument Unit transfer system can upgrade the Space Vehicle Grade Nitrogen to meet the Instrument Unit requirements, it can be supplied from the same liquid storage tanks, converters, compressors, and transfer lines as the larger quantities of nitrogen gas used in all other components of the vehicles. Tests are being conducted to determine if the Instrument Unit can accept the Space Vehicle Grade Nitrogen.

A comparison of the military specification and MSFC specification requirements for liquid nitrogen is shown in Figure 7.

In conclusion, it should be noted that even with the latest MSFC specifications, 17,000 pounds of impurities are allowed in the cryogenic fluids on board a Saturn V launch vehicle.

PROPELLANT MANAGEMENT

Since cryogenic requirements for the Saturn vehicle development and production programs cut across many organizational lines, MSFC has established a propellant management function with the responsibility of insuring an adequate supply of propellants to support all MSFC programs. This function is assigned to the Project Logistics Office, Industrial Operations. It is a staff planning function with each laboratory or project office having the implementing function.

At present most of the major planning has been completed and contracts have been consummated. Many of the MSFC test sites are supplied by the Air Force under a NASA-Air Force Agreement.

Even after all major supply contracts are consummated, the management problems are not over. Let us not lose sight that the Saturn programs are still development programs; therefore, many unanticipated test requirements may appear. Sometimes this results in a complete move of a large test program. This has a great impact on the logistics involved in supplying the program needs. Based on total delivery by trailer, the present programs require in one day the quantities shown below.

	LH_2	LOX	LN_2
Trailer Loads	22	76	26

Any change in this pattern requires a reanalysis in a manner similar to the original analysis previously described.

TRENDS FOR THE FUTURE

Although the Saturn programs are moving rapidly along, a great amount of testing remains to be done. Since indications are that the Saturn vehicle will continue to be a prime carrier of payloads, trends are developing in regard to cryogenic needs. Some of interest to the cryogenic industry are given below. It should be noted that these are based on personal opinion of the writers and does not necessarily reflect NASA-wide opinion.

a. A modular designed air separation plant that could be readily moved could fit the needs of increased requirements for short periods of time, or could supply interim requirements such as unscheduled component testing.

b. MSFC specification requirements for liquid nitrogen and liquid oxygen will ultimately be required for the manned space program.

c. More storage capacity that can be readily moved is highly desirable.

d. Development of better materials and methods for decreasing boil-off and transfer losses should continue to be an industry objective.

e. Inexpensive measuring devices that can readily provide accurate readings of quantities used per test would assist in estimating requirements.

f. Test activity will not drop as suddenly as would be indicated by current programs.

CONCLUSIONS

Conclusions derived are:

a. Improved accuracy in estimating the quantities of products needed is belately but properly being emphasized by contractors and MSFC.

b. The Saturn vehicle programs have resulted in a need for cryogenic fluids that are shown in the table below. The requirements will be of this order of magnitude for the next two or three years.

Product	Quantity	Total Estimated Cost
Liquid Hydrogen	40,000,000 Lbs.	$29,000,000
Liquid Oxygen	378,000 Tons	16,300,000
Liquid Nitrogen	139,000 Tons	5,800,000
		$51,100,000

SATURN LAUNCH VEHICLE
CRYOGENIC REQUIREMENTS

VEHICLES	STAGE	ENGINES	APPROXIMATE ON - BOARD CAPACITY LBS (1)	
			LOX POUNDS	LH_2 POUNDS
SATURN I			(710,000)	(17,000)
	S-I	(8) H-I'S	626,000	
	S-IV	(6) RL-10'S	84,000	17,000
SATURN IB			(821,000)	(43,000)
	S-IB	(8) H-I'S	628,000	
	S-IVB	(1) J-2	193,000	43,000
SATURN V			(4,308,000)	(202,000)
	S-IC	(5) F-I'S	3,294,000	
	S-II	(5) J-2'S	821,000	159,000
	S-IVB	(1) J-2	193,000	43,000

TOTAL WEIGHT OF ON BOARD CRYOGENIC FLUIDS

SATURN I	727,000 POUNDS
SATURN IB	864,000 POUNDS
SATURN V	4,510,000 POUNDS

1. ACTUAL QUANTITIES VARY WITH MISSION.
2. LARGE QUANTITIES OF GASEOUS NITROGEN ARE REQUIRED FOR LAUNCH BUT ONLY SMALL QUANTITIES ARE "ON-BOARD."

Figure 1

MAJOR SATURN PROGRAM TEST STANDS

TEST STAND	SINGLE POSITION	2 POSITION	CENTER/ CONTRACTOR	LOCATION	PROGRAM
S-I STAGE		1	MSFC	HUNTSVILLE, ALA	SAT I
RL-10 ENGINE	1		MSFC	HUNTSVILLE, ALA	SAT I
RL-10 ENGINE[a]	6	1	P&WA	WESTPALM BEACH, FLA	SAT I
S-IV STAGE	2		DAC	SACRAMENTO, CALF	SAT I
H-I ENGINE	3		RKT	SANTA SUSANA, CALIF	SAT I, SAT IB
H-I ENGINE	1	2	RKT	NEOSHO, MISSOURI	SAT I, SAT IB
S-IB STAGE		S-I STAND MODIFIED	MSFC	HUNTSVILLE, ALA	SAT IB
S-IVB STAGE	2		DAC	HUNTSVILLE, ALA-	SAT IB, SAT V
J-2 ENGINE	1	2	RKT	SANTA SUSANA, CALIF	SAT IB, SAT V
J-2 ENGINE	1		MSFC	HUNTSVILLE, ALA	SAT IB, SAT V
S-IC STAGE	1		MSFC	HUNTSVILLE , ALA	SAT V
S-IC STAGE [b]		1	MSFC	MTF, MISS	SAT V
S-II STAGE [b]	2		MSFC	MTF, MISS	SAT V
S-II STAGE	1		S&ID	SANTA SUSANA, CALIF	SAT V
F-I ENGINE	4	1	RKT	EAFB, CALIF	SAT V
F-I ENGINE	1	(d)	MSFC	HUNTSVILLE , ALA	SAT V
COMPONENTS [c]					

TOTAL NUMBER OF STANDS 34
TOTAL NUMBER POSITIONS 42

MSFC - GEO. C. MARSHALL SPACE FLIGHT CENTER
P&WA - PRATT & WHITNEY AIRCRAFT DIV OF UNITED AIRCRAFT , CORP.
DAC - DOUGLAS AIRCRAFT CO.
RKT - ROCKETDYNE DIV. OF NORTH AMERICAN AVIATION, INC.
S&ID - SPACE & INFORMATION DIV., NORTH AMERICAN AVIATION

(a) ONE 2 POSITION STAND CENTAUR, 2 SINGLE POSITION STANDS NOW FOR CENTAUR/SAT, 4 SINGLE POSITION FOR SAT.

(b) UNDER CONSTRUCTION

(c) 5 MAJOR COMPONENT TEST LABORATORIES AT RKT, SANTA SUSANA, SEVERAL MAJOR POSITIONS AT MSFC HUNTSVILLE AND DAC AT SACRAMENTO AND AT SANTA MONICA.

(d) ONE POSITION OF THE S-I STAND WAS MODIFIED FOR F-I ENGINE TESTING

Figure 2

SATURN VEHICLE CRYOGENIC STORAGE, AND TRANSPORT MODES

LOCATION	STORAGE (TONS)			TRANSPORT
	LOX	LN2	LH2	MODE
SANTA SUSANA CALIF	3280	570	501	TRAILER
MISSISSIPPI TEST FACILITY	5000 (1)	2150	16	TRAILER, RAILCAR AND BARGE
MSFC HUNTSVILLE ALA	3470	348	79	TRAILER, RAILCAR
SACRAMENTO CALIF	600	40	223	TRAILER, RAILCAR
EDWARDS AF BASE	6000 (2)	1000	–	TRAILER AND RAILCAR
WEST PALM BEACH FLA.	200	120	28	TRAILER, RAILCAR

NOTES: 1. THE 5000 TON LOX STORAGE IS AT THE LH_2 PLANT IN EAST NEW ORLEANS. ADDITIONAL PRODUCT WILL BE IN THE (4) 450 TON LOX BARGES.
2. 2500 TON STILL UNDER CONSTRUCTION.
3. LARGE QUANTITIES OF LH_2 AND LOX PLANT STORAGE ARE NOT SHOWN.

Figure 3

COMPARISON OF ESTIMATED SATURN LOX REQUIREMENT WITH ACTUAL USAGE

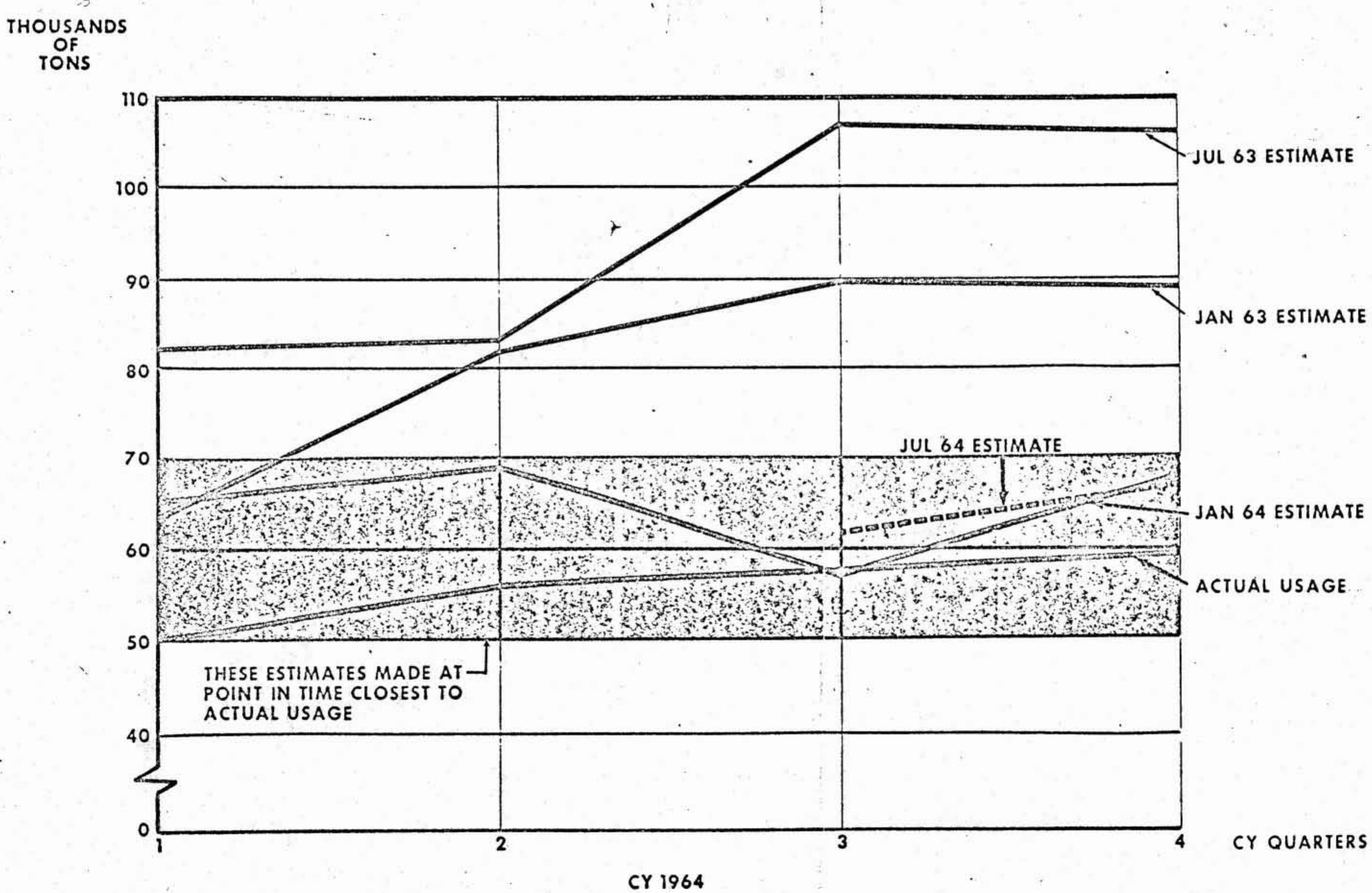

Figure 4

LOSSES THAT OCCUR IN A TYPICAL TEST

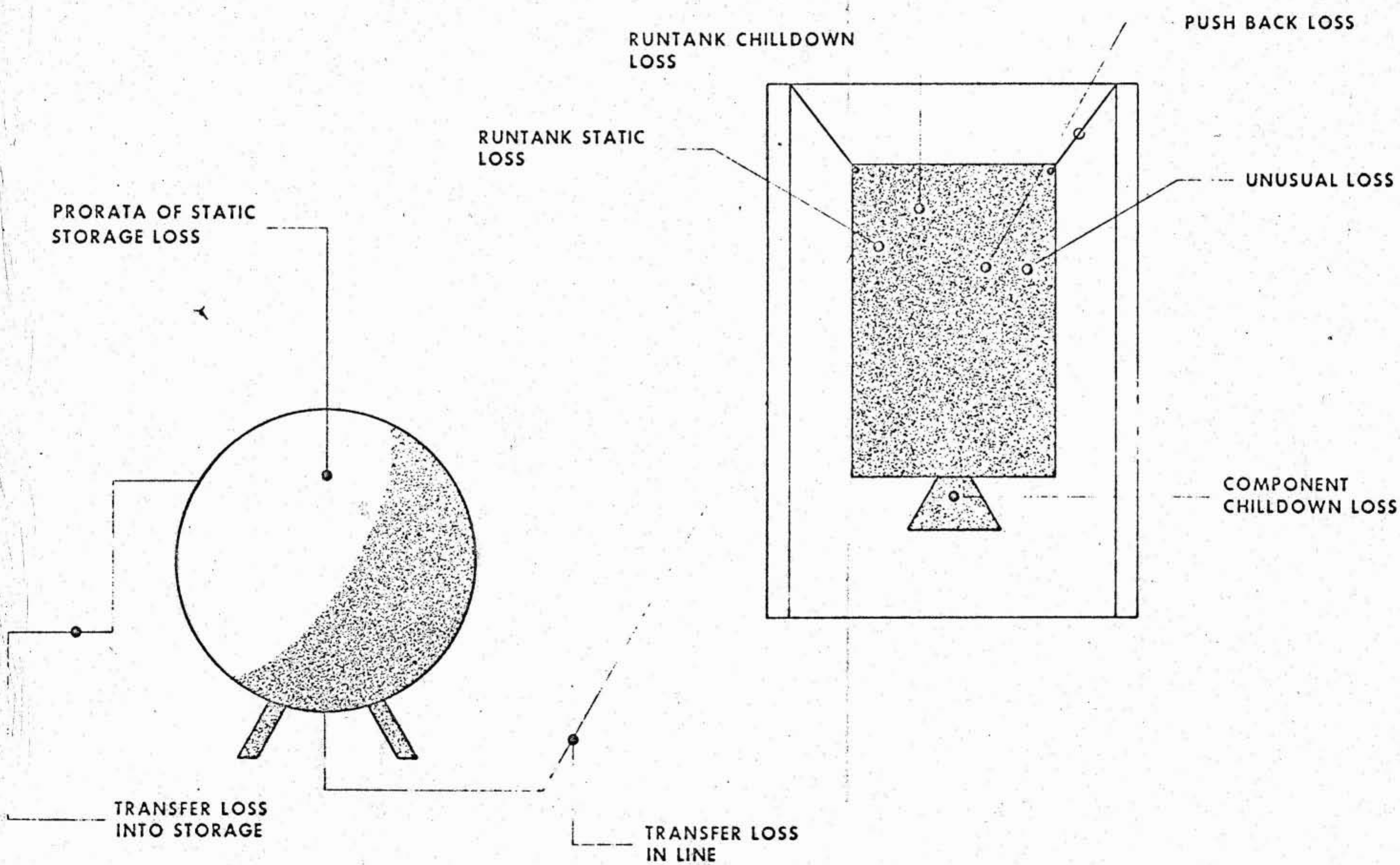

Figure 5

FACTORS CONSIDERED IN ESTIMATING SATURN CRYOGENIC REQUIREMENTS

FACTORS CONSIDERED	CONTRACTOR/ CENTER	ROCKETDYNE	ROCKETDYNE	DAC	MSFC	MSFC	PRATT & WHITNEY
	LOCATION	SANTA SUSANA	EDWARDS	SACRAMENTO	HUNTSVILLE	MTF	WEST PALM BEACH
	ENGINE/STAGE	FI-HI-J2-SII	F-1	SIV/SIVB	RL 10, SI-FI-J2-SIC H-I	S IC S II	RL 10
	PROGRAM	SAT I, IB, V	SAT V	SAT I, IB, V	SAT I, IB, V	SAT V	SAT I
	COMPONENTS	X		X	X		X
1. FACILITY CHECKOUT (INDICATES PRESENT STATUS-OTHERS COMPLETE)		S II	NEW STORAGE		J-2 F-1	BARGE, SII, S-IC	
2. STATIC STORAGE TANK LOSSES		X	X	X	X	X	X
3. LATEST DEVELOPMENT PROGRAM TEST PLAN		ENGINE, COMPONENTS, AND SII BATTLESHIP	ENGINE	COMPONENTS, BATTLESHIP AND ALL SYSTEMS	ENGINE, COMPONENTS, AND BATTLESHIP	SII ALL SYSTEMS	ENGINE AND COMPONENTS
4. LATEST PRODUCTION SCHEDULE		COMPONENTS AND ENGINES	ENGINE	FLIGHT STAGE		FLIGHT STAGE	ENGINE AND COMPONENTS
5. APPROVED TEST SEQUENCE				FLIGHT STAGE		FLIGHT STAGE	
6. TEST OPERATION LOSSES							
A. HISTORICAL DATA		X	X	X			X
B. CALCULATED					X	X	
7. LEVEL OF EFFORT (SPECIAL COMPONENTS)		X		X (ALSO SANTA MONICA)	X		X
8. QUANTITY BURNED (t_b r_b)		X	X	X	X	X	X
9. CONFIGURATION/TEST STAND		X	X				X

DAC - DOUGLAS AIRCRAFT CO.
MSFC - GEORGE C. MARSHALL SPACE FLIGHT CENTER
MTF - MISSISSIPPI TEST FACILITY

BATTLESHIP TEST - DEVELOPMENT STAGE FOR REPETITIVE TESTING
ALL SYSTEMS TEST - STAGE IS COMPARABLE TO FLIGHT STAGE

Figure 6