SPACE SHUTTLE EXTERNAL TANK PROJECT STATUS

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ABSTRACT

This is an update on the status of the Space Shuttle External Tank Project. It covers the DDT&E and Production phases as well as the new light weight tank development. The DDT&E phase is progressing well with the structural and ground vibration test article programs complete, the propulsion test article program progressing well, and the component qualification and verification testing 92% complete. The first flight ET has been delivered to KSC, the second flight ET is in final assembly, the third and fourth ET's are undergoing TPS application, and the fifth, sixth and seventh ET's are in structural buildup. New tools and facilities are being brought on line to support the increased build rate for the production phase.

The light weight tank, which will provide additional payload in orbit, is progressing to schedule with first delivery in early 1982. A brief discussion is presented of future changes under study, including the Liquid Boost Module and a futher reduction in the External Tank inert weight

GENERAL DESCRIPTION

The Space Shuttle External Tank Project, Figure 1, consists of the basic DDT&E phase, the Production phase and the development of a light weight tank. I will address the status of these and then look to future developments in the Space Shuttle Program that affect the External Tank.

The Space Shuttle provides a low cost delivery system for Earth-orbiting payloads. The External Tank (ET), Figure 2, serves dual functions as the structural backbone for the attachment of the Orbiter and Solid Rocket Boosters (SRB) and as the cryogenic propellant tanks for the Orbiter main engines.

The ET remains attached to the Orbiter after Solid Rocket Booster separation, providing propellants to the Orbiter main engines until ET/Orbiter separation occurs just prior to orbital insertion. The ET is then intentionally tumbled for re-entry footprint control and thereafter descends to a point of structural breakup and ocean impact.

As the structural backbone of the Space Shuttle, the ET must accommodate loads as high as 1,654,310 pounds at each SRB forward attachment and up to 1,426,000 pounds from the Orbiter. The SRB loads are imposed in the intertank area while Orbiter loads are imposed on the aft of the ET, requiring complex load paths to be accommodated in the pressure structure. The ET must also survive vibroacoustic levels up to 172 db and heating rates up to 42 BTU/ft^2/sec as well as cryogenic temperatures as low as -423^{o}F. This complex set of environments posed interesting design and demanding qualification challenges that have been successfully met.

As the cryogenic propellant tank for the Orbiter main engines, the ET contains 227,600 pounds of liquid hydrogen (LH_2) and 1,362,000 pounds of liquid oxygen (LO_2) and provides these to the Orbiter at a rate of 2,944 pounds per second with the proper interface temperatures and pressures. Thermal Protection Systems (TPS) are utilized to minimize heat leakage to the cryogenic propellants (LH_2 at -423^{o}F and LO_2 at -297^{o}F) and prevent formation of ice on the tank surfaces that would reduce orbital payload or potentially damage the Orbiter surface thermal protection tiles.

For DDT&E, the ET must also provide capability for obtaining thermal, acoustic and pressure flight data during ascent.

STRUCTURAL SYSTEM

Three primary elements comprise the External

Tank structural system: the LO_2 Tank, the Intertank and the LH_2 Tank.

The basic design philosophy has been to keep the tank simple - namely, minimize active functions and moving parts. All power and purges are received from the Orbiter or from the ground. The only active components on the operational ET's are the vent/relief valves. All operational instrumentation is hardwired to the Orbiter. Separation, tumbling and propellant dispersion systems are pyrotechnically actuated.

Maintainability and weight considerations led to externally mounting the propulsion lines and electrical cable trays, with the external environments, especially thermal, accommodated by added Thermal Protection System (TPS) materials.

LO_2 TANK

The liquid oxygen (LO_2) tank is a thin-wall monocoque shell structure, 655.5 inches long with a diameter of 331 inches, a volume of 19,500 cubic feet and an empty weight of 12,500 pounds. The pressure vessel is a fusion-welded assembly of preformed, chem-milled gores and panels, machined fittings and ring chords. The major 2219 aluminum alloy welded subassemblies consist of a 0.75 height-to-radius ratio ellipsoidal aft dome, a 98.2 inch long cylindrical barrel and a 612 inch radius forward ogive and a cover plate, a conical nose cap, an anti-slosh baffle and an anti-vortex baffle.

INTERTANK

The Intertank is a semi-monocoque cylindrical structure with flanges on each end for mechanically joining to the LO_2 and LH_2 Tanks. The Intertank cylindrical structure consists of eight 45 degree mechanically joined panels, a main ring frame, four smaller intermediate stability frames, and an SRB beam assembly with two forged thrust fittings. Aluminum alloys (2024, 2219 and 7075) are used exclusively in the fabrication and assembly of the Intertank.

LH_2 TANK

The liquid hydrogen (LH_2) tank is a 2219 aluminum alloy structure 1,160.25 inches long with a diameter of 331 inches, a total volume of 55,552 cubic feet, and an empty weight of 31,860 pounds. The tank is a fusion-welded assembly of forward and aft 0.75 ellipsoidal domes and four cylindrical barrel sections joined by five main ring frames. Thirteen intermediate ring frames stabilize the barrel skins. Two longerons are welded into the aft barrel section to introduce Orbiter thrust loads.

THERMAL PROTECTION SYSTEM

Thermal Protection System (TPS) materials are applied to the external surfaces, Figure 3, to maintain the cryogenic propellant quality, to protect the structure from ascent heating and to prevent ice from forming after cryogenic propellant loading. It is applied to over 1,500 detail parts, 16,750 square feet of surface and accounts for 7,000 pounds or about 10% of the ET inert weight.

Only two primary TPS materials are used on the ET. CPR-488 Spray-On Foam Insulation (SOFI) is the primary cryogenic insulation; and Super Light Ablator (SLA) 561 is the primary ablator. Minor quantities of BX 250 and PDL foams are used for closeouts and MA25S ablator is used for four highly heated local areas.

The SLA 561 is a highly filled silicone with an applied density of 15 pounds per cubic foot (PCF) and can withstand heating rates of 25 $BTU/ft^2/sec$. It is applied in two forms - spray and molded. The primary design driver is cryogenic strain compatibility at LH_2 temperatures and high substrate stresses.

The CPR-488 SOFI is a rigid, closed cell isocyanurate foam with an applied density of 2.6 PCF and a heating rate capability of 10 $BTU/ft^2/$ sec. It is applied with automated spray equipment in a barber-pole fashion. The primary design driver for SOFI is to prevent ice from forming on the cold surfaces. This requires one inch of SOFI which is more than adequate for propellant conditioning.

MAJOR TEST ARTICLES

Three major test articles were built across the production tools and facilities. These were the Structural Test Article (STA), the Ground Vibration Test Article (GVTA) and the Main Propulsion Test Article (MPTA).

The STA was tested at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama, in individual elements to verify the structural integrity at the critical design conditions. The LO_2 STA Tank, Figure 4, was tested at room temperature with loads applied by filling with liquids of varying density in combination with concentrated loads applied at frames and on 2,600 tension pads bonded to the surface. Approximately 1,800 channels of strain gage and deflection data were monitored. The Intertank STA was tested similarly, at room temperature but with liquid nitrogen (LN_2) simulators at the LO_2 and LH_2 interfaces. Approximately 2,500 channels of data were monitored.

The LH_2 STA tank testing was performed at both room temperature and at cryogenic temperature by filling the tank with LH_2. Concentrated loads were applied to simulate the Orbiter and SRB attachment loads in combination with internal pressure loads. Approximately 4,000 channels of data were monitored. The use of liquid hydrogen created special safety and fluid handling considerations for these hazardous tests which were taken to ultimate load conditions without incident.

The highly successful STA test program is complete and has provided an excellent data base for the weight reduction design which will be discussed later.

The GVTA successfully completed the scheduled vibration testing at Marshall Space Flight Center (MSFC) in Huntsville, Alabama, in early 1979. Two major test programs were conducted representing the lift off configuration (Orbiter, ET and SRB's) and the post SRB flight configuration (Orbiter and ET).

Following this series of successful tests the GVTA was utilized as a Facility Verification Vehicle, Figure 5, at KSC to checkout the major physical interfaces with the assembly and launch facilities. The GVTA ET is now at the Michoud Assembly Facility and will be used for production facility/tooling verification prior to refurbishment

The MPTA, Figure 6, a flight configured ET with all propulsion components and an aft section Orbiter with flight configuration propulsion components including three Space Shuttle Main Engines (SSME), is installed in the hot firing test stand at the National Space Technology Laboratories (NSTL) in Mississippi. Major ET objectives of the MPTA test program are to gain experience and confidence with the flight hardware and to verify the propellant loading operations and accuracy, pressurization system operations and performance, fluid interface performance, and the thermal performance of the ET.

Approximately 80% of the test objectives have been met with several full duration firings yet to be accomplished. The ET will remain in support of the MPTA program at NSTL through certification for STS-1 launch and for testing of the main engine uprating to 109% RPL for later Space Shuttle flights.

QUALIFICATION/VERIFICATION TESTING

The components qualification and verification program for STS-1 is progressing well as shown below and testing will be complete this summer.

Class	Scheduled	Complete
Structural	23	21
Propulsion	49	46
Electrical	44	39
TPS	14	13

ET FABRICATION

The ET assembly sequence shown in Figure 7, consists of flowing the three major elements (LO_2 tank, intertank, LH_2 tank) through major tools and facilities in four phases - structural, TPS, final assenbly, and chechout. The elements are built up individually and the LO_2 and LH_2 tanks proof tested in the structural phase. The SLA and SOFI materials are applied to the main acreage and the elements mated in the TPS phase. In the final assembly phase, approximately 1,500 components that have had SLA and SOFI individually applied are assembled to form the interface structure which supports the Orbiter, the externally mounted feedlines, pressurization lines and the cable trays. Installation of flight cabling completes the final assembly phase. The propulsion system lines are leak checked, wiring and instrumentation system integrity is verified, vent valves and feed line disconnects are actuated, sensors stimulated and TPS closeouts completed in the checkout phase.

The ET is then prepared for shipment and transported to a barge for the five day trip to KSC.

The first flight tank, ET-1, was delivered to KSC in July 1979 and is currently in the Vertical Assembly Building (VAB) undergoing the application of additional ice prevention TPS and final checkout prior to mate with the SRB's and Orbiter. At delivery the ET-1 was about 870 pounds underweight.

ET-2 has completed the structural and TPS phases of fabrication and is now in the final assembly position, Figure 8, with delivery scheduled late this summer.

ET-3, Figure 9, and ET-4 have completed the structural phase and are in the TPS application phase with delivery scheduled in 1981.

ET-5 is nearing the end of the structural buildup phase and ET-6 is well into the structural buildup phase with both tanks scheduled for delivery in 1981.

ET-7 is just starting into the structural buildup phase with delivery scheduled in 1982.

As evidenced by the above fabrication status, the external tank production line is in complete support of the Space Shuttle DDT&E flights and, with the new tools and facilities, Figures 10 and 11, being brought on line, is proceeding toward the production capability required in the operational phase of the Space Shuttle program.

LIGHT WEIGHT TANK DEVELOPMENT

Recognizing the need for additional orbital payload capability and that a pound decrease in ET inert weight results in almost a pound increase in orbital payload, we began studies in 1977 to determine the feasibility of reducing the inert weight of the External Tank. Data from the highly successful structural test program (STA) in the form of confirmation of our analytical models, determination of specific load path distributions and measured margins greater than required at ultimate load, formed the basis for our current confidence in being able to reduce the inert weight of the tank by 6,000 pounds.

The fundamental techniques utilized in obtaining the weight reduction consist of (1) reducing the excess margins, (2) design optimization (which includes reconfiguring for greater structural efficiency, incorporating the latest thermal environments which are reduced over the earlier more conservative values and material changes), and (3) reduction of the safety factors on well defined loads (such as SRB thrust, Orbiter thrust, and inertial loads). Each of these techniques contributes approximately one third of the weight reduction with the distribution between the LO_2 tank, intertank and the LH_2 tank as shown in Figure 12.

At the present time we have about 35% of our drawings released and about 55% of our procurement on contract with 24 barrel panels already delivered to the Michoud Assembly Facility (MAF). The only major impact on our tooling is to the structural assembly/welding tools. Modification designs are underway and conversion of the tools will follow immediately as ET-7 clears each tool. The first LWT dome subassemblies will start through the modified tools in October of this year. There are no major facilities impacts.

We currently have a calculated weight margin comfortably above the 6,000 pound requirement and will be well prepared for the Critical Design Review in August of this year. We are in complete support of the schedule shown in Figure 1, which will deliver the first LWT in early 1982.

FUTURE CHANGES IN THE EXTERNAL TANK

Looking ahead in the near term there are two activities which deserve special mention: the Liquid Boost Module (LBM) and a second generation light weight tank. Although the two items are very much interrelated, let me focus on the LBM first.

West coast shuttle launches from Vandenberg Air Force Base (VAFB) require up to a 32,000 pound delivery capability to 150 N. Mi. orbit. The payload capability of the Shuttle, which takes into consideration a weight reduction in the Orbiter and SRB's, the Light Weight External Tank and the 109% SSME's, is about 24,000 pounds.

The NASA initiated a study activity about two years ago to determine the best solution to meet the West coast launch requirement. Several concepts were considered, i.e., adding a third SRB, enlarging the SRB (diameter or length), subcooled propellants, strapping solid rocket motors on the side of the SRB's, strapping solid rocket motors under the ET and finally, strapping the LBM under the ET. This latter approach was selected last fall as the preferred method.

The Aerojet engines and boat tail are identical to that of the Titan III (TIII) first stage which has flown successfully 119 times since 1964. The engines deliver ≈500,000 pounds of thrust. Four short 10 foot diameter tanks (two fuel and two oxidizer), supply the same propellants as those used in the TIII, i.e., Nitrogen Tetroxide and Aerozine 50. A skirt extension will be added to the 27 foot diameter LH_2 tank to carry the flight/thrust loads into the aft end of the ET, and a new thrust structure will be provided which integrates the propulsion module with the ET skirt.

Launch facility changes are minimized by delaying ignition of the LBM until the Shuttle is five seconds off the pad. With the baseline design loading of 350,000 pounds of propellant, the LBM will burn for 200 seconds before being separated from the Shuttle. The separation plane will be in the ET attachment skirt to minimize the "scar weight" that must be carried for the remainder of the flight. The LBM will increase the delivery capability of the shuttle for West coast launches to ≈40,000 pounds with first launch planned for 1985.

Martin Marietta and Aerojet are currently under contract for detailed studies and definition of the LBM program with hardware development scheduled to be initiated in the fall of 1981. More details, on LBM can be found in a paper being presented at this Space Congress by Mr. Art Inman of Martin Marietta.

Next, I will address what I refer to as the "second generation light weight tank". In view of the tight schedule for the light weight tank (first flight article delivery in early 1982) there are several potential weight saving items that could not be incorporated. These include flexible LO_2 slosh baffles, eliminating external cable trays by routing wiring internal to the tanks and relocating other hardware currently in the cable trays, alternatives to the current corrugated intertank structure, etc.

In addition, we are continuing to explore other design and manufacturing changes that could result in production schedule improvements and cost reductions. One could also forecast that some ET design changes may be desired as a result of flight data and experience from the early Shuttle flights.

The most cost effective time to incorporate major changes to the External Tank, for whatever reason, will be during the re-engineering to accept the LBM. It is therefore my opinion that there will be a "second generation light weight ET" that will accommodate standard as well as LBM shuttle launches.

In summary, the ET status totally supports the Space Shuttle DDT&E flights, is progressing well towards the LWT design that will significantly increase orbital payload capability and has the inherent capability to accommodate future payload improvement programs.

*Work sponsored by the NASA, Marshall Space Flight Center under contract NAS8-30300

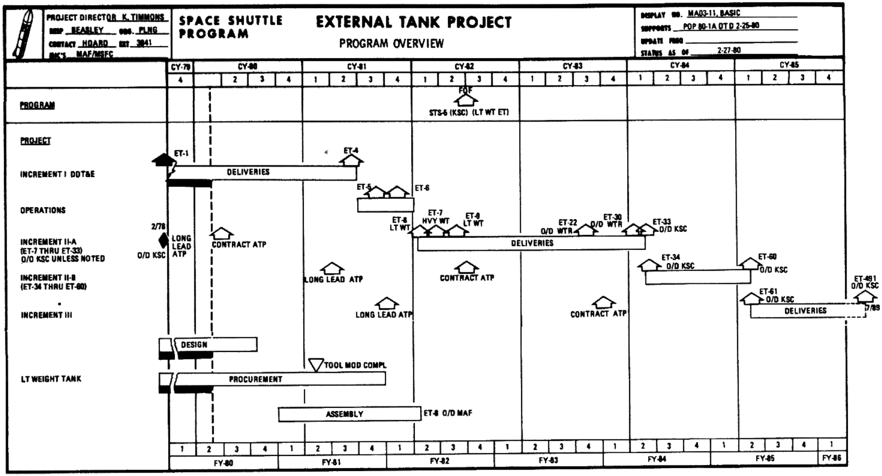

PROJECT DIRECTOR K. TIMMONS
BEASLEY PLNG
CONTACT HOARD 3841
MAF/MSFC
SPACE SHUTTLE PROGRAM
EXTERNAL TANK PROJECT
PROGRAM OVERVIEW
MA03-11, BASIC
POP 80-1A DTD 2-25-80
2-27-80
CY-79
CY-80
CY-81
CY-82
CY-83
CY-84
CY-85
PROGRAM
FOF
STS-6 (KSC) (LT WT ET)
PROJECT
ET-1
ET-4
INCREMENT I DDT&E
DELIVERIES
ET-5
ET-6
OPERATIONS
2/78
LONG LEAD ATP
CONTRACT ATP
ET-8 LT WT
ET-7 HVY WT
ET-9 LT WT
ET-22 O/D WTR
ET-30 O/D WTR
ET-33 O/D KSC
INCREMENT II-A (ET-7 THRU ET-33) O/D KSC UNLESS NOTED
O/D KSC
DELIVERIES
ET-34 O/D KSC
ET-60 O/D KSC
INCREMENT II-B (ET-34 THRU ET-60)
LONG LEAD ATP
CONTRACT ATP
ET-491 O/D KSC
ET-61 O/D KSC
INCREMENT III
LONG LEAD ATP
CONTRACT ATP
DELIVERIES
DESIGN
TOOL MOD COMPL
LT WEIGHT TANK
PROCUREMENT
ASSEMBLY
ET-8 O/D MAF
FY-80
FY-81
FY-82
FY-83
FY-84
FY-85
FY-86

Figure 1

EXTERNAL TANK — A Highly Efficient Element

GENERAL SPECIFICATIONS

LENGTH:	154.2 FT	LO_2 CAPACITY:	1,361,900 LB
DIAMETER:	27.6 FT	LH_2 CAPACITY:	227,600 LB
DRY WEIGHT:	76,000 LB	MASS FRACTION:	0.951
MECO WEIGHT:	81,200 LB		

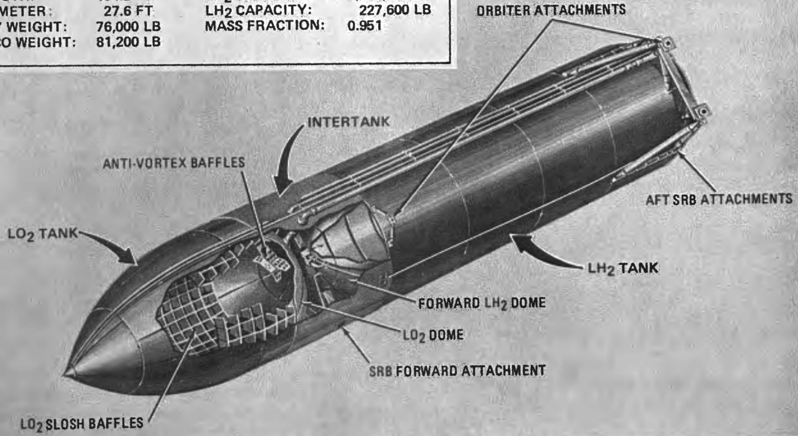
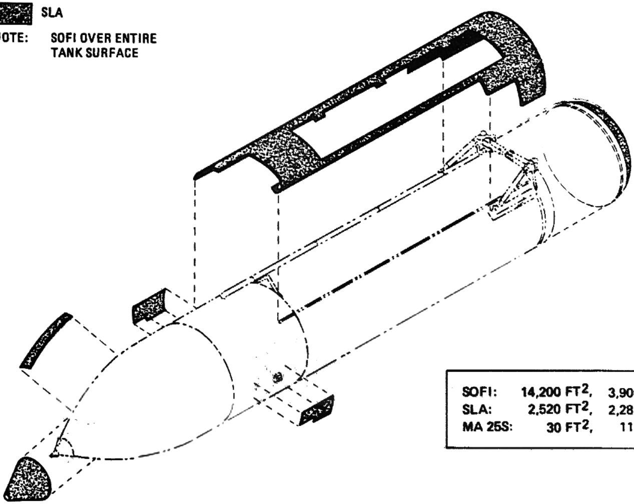


Figure 2

TPS — Key to Production Readiness

SLA

NOTE: SOFI OVER ENTIRE TANK SURFACE



SOFI:	14,200 FT^2,	3,900 LBS
SLA:	2,520 FT^2,	2,280 LBS
MA 25S:	30 FT^2,	115 LBS

Figure 3

LO_2/INTERTANK STRUCTURAL TEST ARTICLES

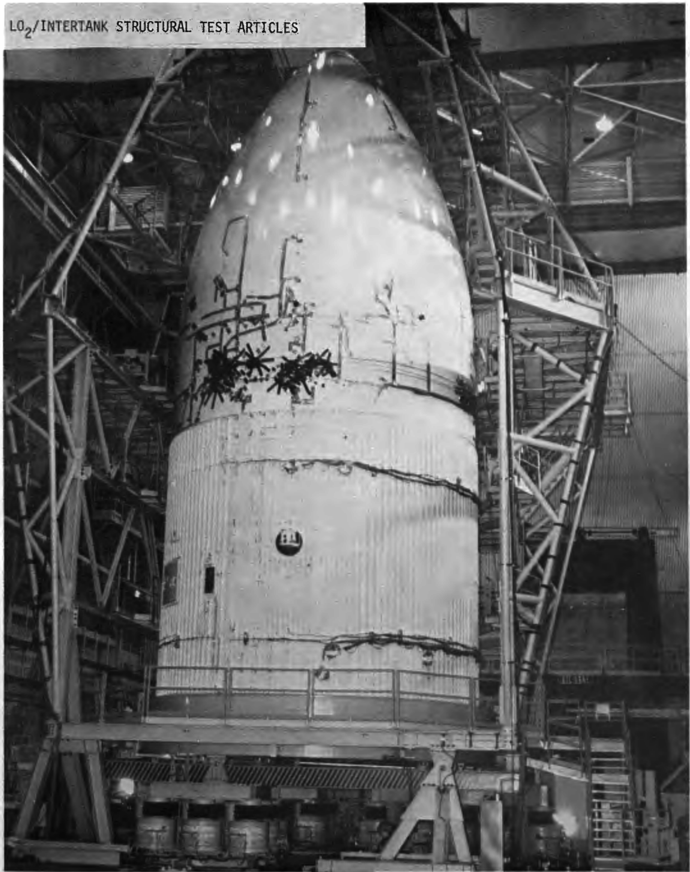


Figure 4

GVTA FACILITY VERIFICATION VEHICLE

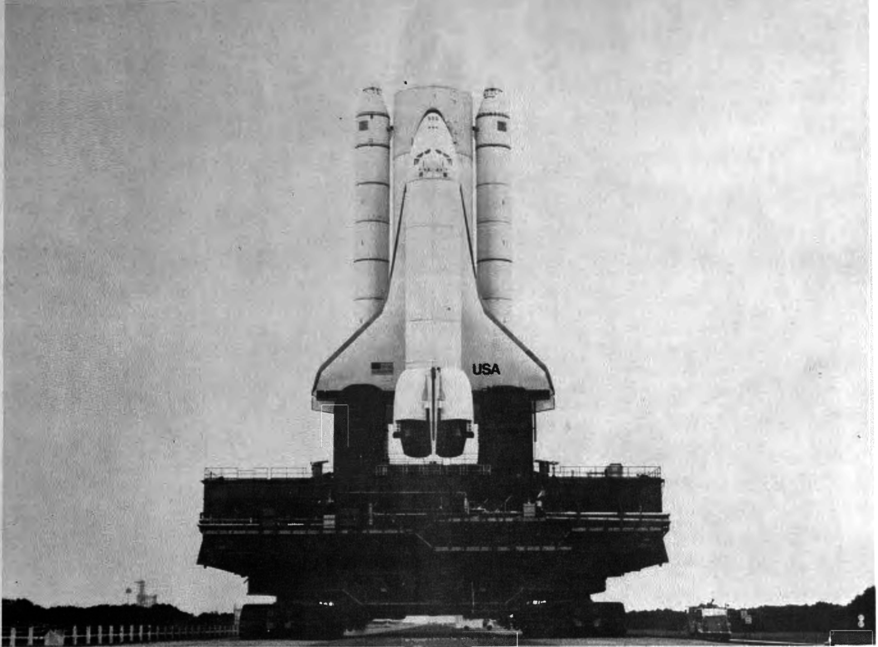


Figure 5

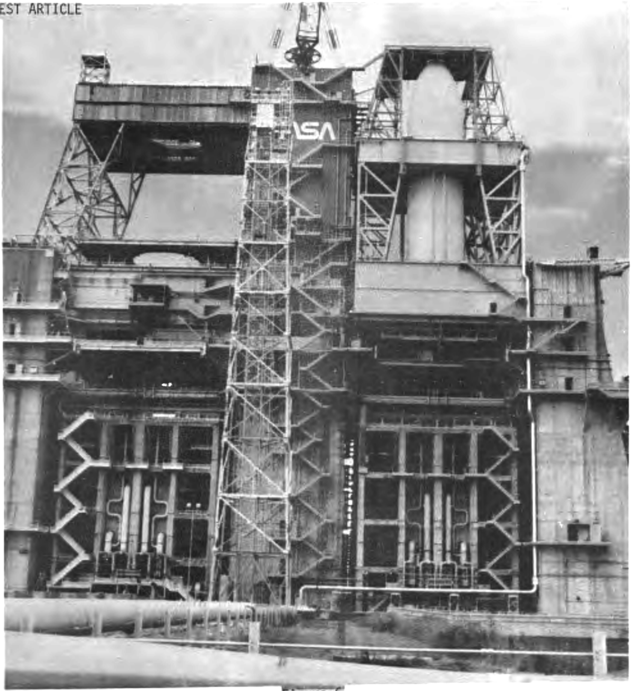


Figure 6

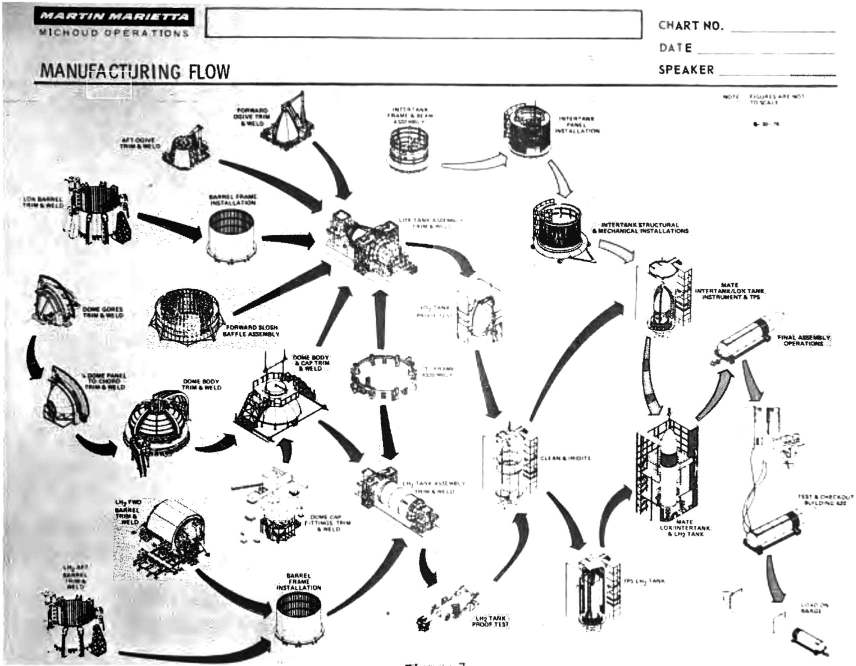

MARTIN MARIETTA
MICHOUD OPERATIONS
CHART NO.
DATE
SPEAKER
MANUFACTURING FLOW
FORWARD OGIVE TRIM & WELD
AFT OGIVE TRIM & WELD
LOX BARREL TRIM & WELD
BARREL FRAME INSTALLATION
INTERTANK PANEL INSTALLATION
INTERTANK STRUCTURAL & MECHANICAL INSTALLATIONS
DOME GORES TRIM & WELD
FORWARD SLOSH BAFFLE ASSEMBLY
MATE INTERTANK/LOX TANK, INSTRUMENT & TPS
FINAL ASSEMBLY OPERATIONS
DOME BODY & CAP TRIM & WELD
DOME BODY TRIM & WELD
CLEAN & IRIDITE
LH2 FWD BARREL TRIM & WELD
DOME CAP FITTINGS TRIM & WELD
LH2 TANK ASSEMBLY TRIM & WELD
MATE LOX/INTERTANK, & LH2 TANK
TEST & CHECKOUT BUILDING 420
LH2 AFT BARREL TRIM & WELD
BARREL FRAME INSTALLATION
LH2 TANK PROOF TEST
TPS LH2 TANK
LOAD ON BARGE

Figure 7

ET-2 IN FINAL ASSEMBLY

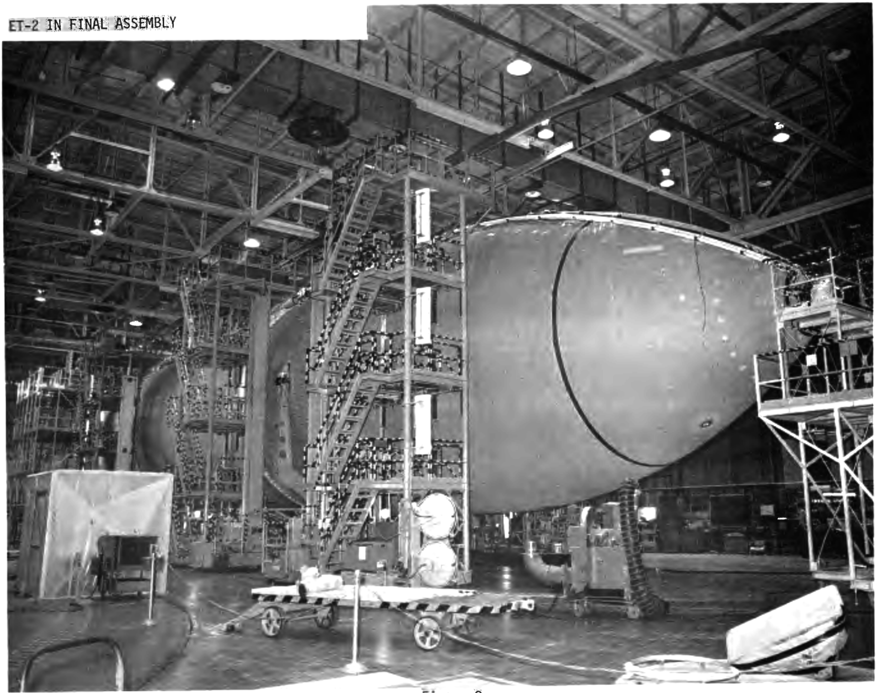


Figure 8

ET-3 IN TPS APPLICATION

Figure 9

VERTICAL CELLS (G, H, J)

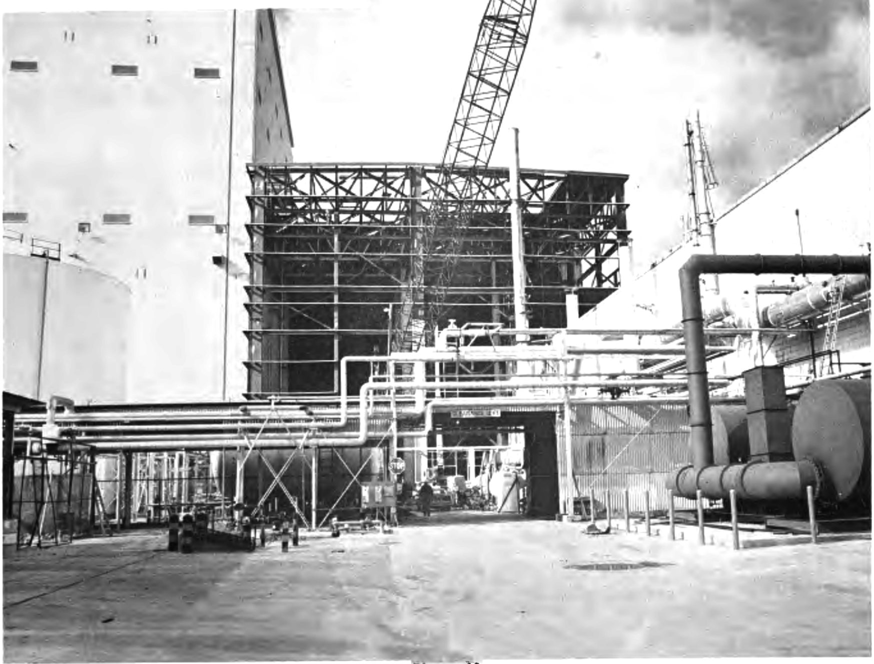


Figure 10

HORIZONTAL CELLS (M, N)

Figure 11

VERTICAL CELLS (G, H, J)

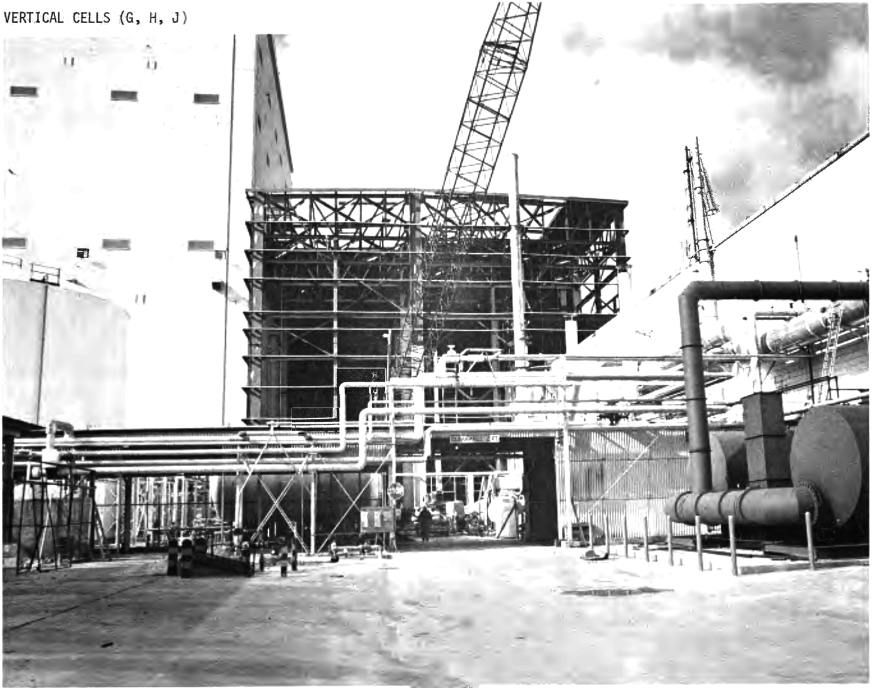


Figure 10

HORIZONTAL CELLS (M, N)

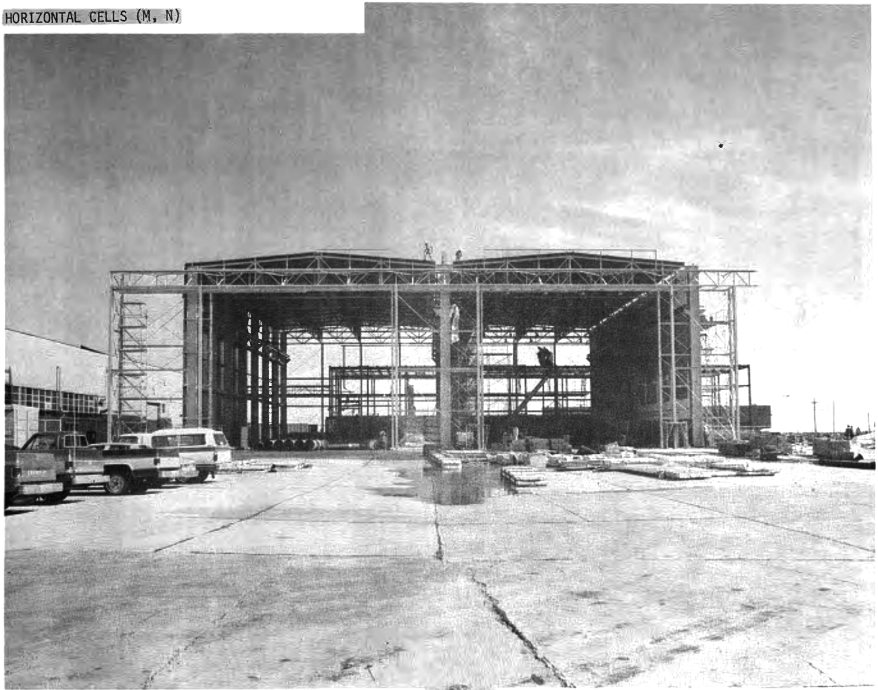


Figure 11

LWT - WEIGHT SUMMARY

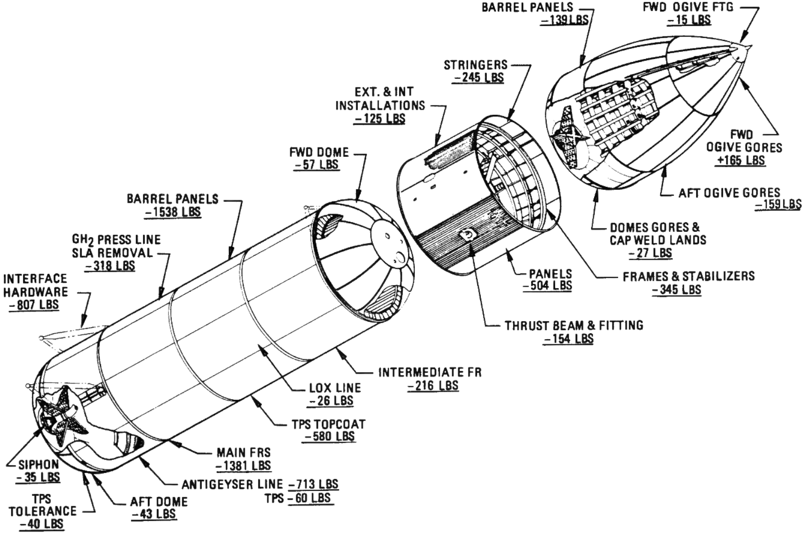


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Figure 12