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DESIGN
OF A
SPACE SHUTTLE
STRUCTURAL DYNAMICS MODEL

Prepared Under Contract NAS 1-10635-11 by

Grumman Aerospace Corporation

Bethpage, N.Y.

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

ABSTRACT

A 1/8th scale Structural Dynamics model of a parallel burn Space Shuttle has been designed. Basic objectives were to represent the significant low frequency structural dynamic characteristics while keeping the fabrication costs low.

The model was derived from the proposed Grumman Design 619 Space Shuttle. The design includes an Orbiter, two Solid Rocket Motors (SRM) and an External Tank (ET). The ET consists of a monocoque LO_2 tank (.02" walls and .016" lower dome), an intertank skirt (.05" skins) with three frames to accept SRM attachment members, an LH_2 tank (.025" and .016" skins) with 10 frames of which 3 provide for orbiter attachment members, and an aft skirt with one frame to provide for aft SRM attachment members. The frames designed for the SRM attachments are fitted with transverse struts to take symmetric loads. The SRM consists of a monocoque (0.2" skins) cylinder representing the propellant carrying structure, a simplified forward skirt with two frames and longerons for interstage attachments, and an aft conical skirt with one frame for interstage attachments and 4 longerons representing the on-pad support structure. The orbiter consists of an aft section representing simplified version of the major load paths between engines and the aft interstage attachment, a midsection formed from U shaped frames spaced about 10" apart covered by a .02" skin, provisions for 3 different payload lengths, wings designed as 6 spars covered by .02" skins, a simple torque box representing the fin out to the c.g., and a tapered non-circular shell representing the cabin.

The model design details are presented in 41 drawings which have been filed with the Dynamic Loads Branch of the Loads Division at the NASA/Langley Research Center.

FOREWORD

The work described in this report was performed by Grumman Aerospace Corporation, Bethpage, New York, under NASA Contract NAS1-10635-11 and administered by the Dynamic Loads Branch, Loads Division, NASA/Langley Research Center, Hampton, Virginia. The reported work was carried out between June and October 1972.

The design work was performed by A. P. LaValle, P. W. Tracy, F. L. Halfen, C. M. Cacho-Negrete, P. J. Cartensen and S. Rosenstein. The stress analysis was conducted by W. P. Bierds. The suspension system frequency analysis was performed by L. Mitchell.

This project was directed by M. Bernstein as one of the Master Agreement Tasks Program managed by E. F. Baird.

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SUMMARY

The basic objectives of the 1/8th scale Preliminary Structural Dynamics model are to:

- o Provide early verification of analytical modeling procedures on a Shuttle-like structure.
- o Demonstrate important vehicle dynamic characteristics of a typical Shuttle design
- o Disclose any previously unanticipated dynamics problems
- o Demonstrate optimum configuration changes for eliminating critical problem areas
- o Provide for development and demonstration of cost-effective and efficient prototype testing procedures

The design objective for this task was to represent important structural dynamic characteristics (discussed in CR 112196) while keeping the fabrication costs low. The basis for the model was the Grumman proposed Design 619 Space Shuttle which was a 4.8M lb. GLOW 182 ft. long parallel burn configuration. Simplifications included extensive use of constant thickness unstiffened skins in place of variable thickness skin-stringer-frame construction, frames designed as back-to-back channel with elements formed from cut flat plates fastened between them to act as fittings in place of machined frames, and simple tubular struts with standard AN end fittings for interstage members in place of more elaborately formed members. These and other simplifications in the design resulted in locally stiffer and heavier areas than would occur in a full replica model, however, they were necessary to keep the fabrication costs within target. Structural joints in the model were designed to be simpler and stiffer than the

prototype in an effort to avoid the extra flexibility which has occurred in replica scaling down to thin gages.

The model consists of 4 elements. An Orbiter, and External Tank and two Solid Rocket Motors. Since investigation of hydroelastic effects was an important objective in the test program, and since the ET flexibility and weight was expected to be the most significant factor in the low frequency modes, the ET was the first element to be designed.

The ET is 39.5" in diameter and 237.8" long and consists of a forward LO_2 tank, an intertank skirt with provisions for attaching the SRMs, an aft LH_2 tank with internal frames to support the Orbiter attachments, and an aft skirt providing the aft SRM attachment. In order to avoid buckling of the LH_2 tank during vertical suspension of the model, it was designed to be supported from the intertank skirt. The LO_2 tank is of welded monocoque constant thickness design 78.3" long. The forward portion is conical while the aft is cylindrical. Both regions have .02" thick walls. The bottom consists of an .016" thick lower dome. The intertank skirt is 29" long cylinder of .050" wall thickness. There are 3 frames to accept the SRM and the model suspension system attachments. The LH_2 tank is a 144" long cylinder with 10 frames, 3 of which take the orbiter attachments and the remainder required to prevent buckling. The skin thickness is .025" in the upper regions of higher load and .016" for the remainder. The aft skirt is a simple .020" thick cylinder 13" long with a single frame to take the SRM attachments.

The SRM consists of a forward skirt with ET attachment provisions, a propellant cylinder, and an aft skirt with both ET attachment and hold-down support provisions. The propellant cylinders are 147.3" long, 19.5" in diameter with 0.2" thick walls.

The propellant simulation proposed is inert PBAN which has an inert salt in place of the oxidizer used in the active material. Six cylinders are proposed, two each to represent full, maximum $q\alpha$, and burnout conditions. The forward skirt is a 23.6" long .05" thick cylinder with a forward and aft frame to provide for ET attachment. The aft skirt consists of a cylindrical and conical section. The 5" long by .062" thick cylindrical section contains the SRB to ET attachment frame. The 22" long .062" thick conical section progresses from 19-½" diameter to 30.2". Four tapered longerons attached to this cone represent the hold-down supports.

When the ET and SRM designs were almost completed, manufacturing cost estimates were made to determine the fabrication cost target for the Orbiter. The Orbiter representation which met this requirement consisted of a forward non-circular shell representing the cabin, a midsection payload and wing area, and an aft section providing a representative engine and fin support structure. The fuselage external lines are simplified to minimize curved sections, the sides and bottom are flat as are the surfaces of the wings and fin stub. The forward .020" thick shell is 17.25" long and varies from 19" to 26.4" deep. Longerons are extended along the sides and slightly forward to constitute the forward hoist point when lifting the Orbiter separately from the remainder of the model. The midsection is 102.5" long and consists of a series of U shaped frames spaced every 10" running up to shoulder longerons along each side. These frames are covered by .020" thick skin. Payload attachment provisions are made at 4 locations along the length. The payload door is a semi-cylinder .016" thick divided into 7 segments along its length by V shaped angles which permit the door to carry torsion but not bending. The wings consist of 6 spars 2.5" deep at the tip and 6" deep at the root extending 49" from the fuselage and covered by .02" skins. The aft section of the orbiter is 20" long and is designed to represent the basic load carrying structure between the orbiter engines and the ET thrust load attachment. At the aft end is an open frame which supports the aft fin beam. Forward of this is the engine bulkhead containing provisions for mounting representations of one upper and two lower engines. A sloping deck between the engine bulkhead and the aft payload bulkhead provides a load path from the upper engine to the shoulder longerons. Two struts provide a path of proper stiffness between the lower engines and the ET thrust attachment. Stability of the sloping deck and the strut attachment points is provided by vertical channels attached to the engine bulkhead.

MODEL DESCRIPTION

Basically the design is a simplified 1/8th scale model of a parallel-burn Shuttle, which full scale is represented by the Grumman Design 619 (or GIII) shown in Figure 1. A summary weight statement for this prototype is listed in Table 1.

In simplifying the design, a major objective was to keep the fabrication costs within target while retaining as many of the significant structural characteristics important for dynamics as possible. The guide lines used are outlined in Section 1 of CR112196 prepared under NAS 1-10635-4.

External Tank

The prototype design used as the basis for the model is shown in Figure 2. The principal parts of the external tank are the oxygen (LO_2) tank, the intertank skirt, the hydrogen (LH_2) tank, and the aft skirt.

Initially, in designing the model external tank, an effort was made to adhere to the scaled down cross-sectional area and the moment of inertia in bending for both the major structural elements and the interconnecting members. This proved to be difficult in the LH_2 tank when an effort was made to provide for a test condition where the configurations without the SRM's were supported by the orbiter engine base. Buckling occurred if scaled down thicknesses were used even with the addition of rings at less than 2" spacing. Suspending the model from the intertank skirt at the interstage connection and thereby putting the LH_2 tank in tension eliminated this problem below the suspension point but buckling was still present above the suspension point in the intertank skirt. Therefore, after discussion and a NASA review, the change of support point to the intertank skirt was made and the intertank skirt thickness was increased in gage until buckling was no longer a problem. This approach also minimizes fabrication costs. The comparison in areas and inertias between the prototype direct scaling and the model design is shown on Figures 3 and 4. It was felt that the resulting configuration would still provide a good check of analytical methods, and that the major structural dynamic interactions between the model SRM, external tank, and orbiter would still demonstrate the type of behavior anticipated on the prototype.

The prototype LO_2 tank was monocoque construction with variable tapered skin thicknesses as shown on Figure 5. The model tank is also monocoque. The lower dome is formed of 3 spherical segments to save the tooling required for an elliptical shape. The thickness which varied in the prototype, is kept constant in the model at .016". A thicker section is retained adjacent to the Y ring to permit welding. The model Y ring is considerably larger than the scaled down prototype dimensions and is made in simple tapered shape to expedite analysis. The cylindrical section of the model LO_2 tank which if scaled directly, would require variable-thickness (.023 to .016") is kept constant at .020". The conical section (scaled prototype design .016" to .012") is kept constant at .020" to avoid welding difficulties. The upper dome which, if scaled directly, would have been .0065" is .025" in the model in order to limit welding and handling difficulties. The upper dome is a single spherical section. A removable upper cover is added to permit inspection and cleaning of the model. The dimensions of the LO_2 tank are adjusted to provide proper scaled LO_2 weight using H_2O.

The Intertank Skirt in the prototype was a ring-frame stiffened cylinder with one very large frame stiffened by internal struts (Section B-B, Fig. 2) to carry the SRM symmetric lateral (Y direction) load. These strut cross-sectional areas would be .16 to .19 sq. in. if directly scaled, but in order to achieve commonality of members throughout the model they are increased to .26 sq. in. Back-to-back channels are used in place of tubes. The skin gages required in the prototype varied from a minimum of .070" to a maximum of .2". Scaling these values down to .009" to .025" for the model would result in buckling in this area under handling and vibration test induced loads. Therefore, to avoid the complexity of many rings at close spacing, and chem milling to various thicknesses, it was decided to select a .050" aluminum skin which is the minimum for a uniform thickness. There are, therefore, only 3 frames required in this area of the model. The SRM axial loads are applied to two fittings on each side. One of these fittings is shown in detail in Section B-B on Figure 2. In the model, this fitting is also used to suspend the configuration. Therefore, the model is heavier than a scaled-down version of the prototype would be. In simplifying the design to reduce machining costs, still more weight and stiffness is unavoidably added.

The LH_2 tank prototype, as shown in Figure 2, was a ring-frame stiffened cylinder with 3 major frames and fittings to accept the orbiter induced loads. The skin thickness if scaled directly, would vary from .026" to .015". To simplify construction of the model, the skin is either left at .025" or chem milled to .016". The total number of ring frames and ring stiffeners is limited to 10, about half the number in the prototype. This is feasible because the buckling loads were low. All three ring frames are back-to-back channels having the same channel section in order to save tooling costs. The I (area moment of inertia) selected for each of the frames is 0.45 $in.^4$ which is approximately representative of the scaled prototype value of 0.49 $in.^4$ for the forward interstage frame. The end domes in the model are .020" in place of the .009" scaled from the prototype in order to avoid welding and handling problems. They are formed with the same tooling as the LO_2 tank dome and, therefore, unlike the prototype, they have the same geometry. The internal struts in the frames which distribute the aft orbiter loads are of the same geometry as the prototype but made from back-to-back sections in place of tubes in order to save tooling costs. The cross-sectional area of the model internal struts is larger than the scaled prototype value (.26 $in.^2$ in place of .23 or .19 $in.^2$). The prototype orbiter drag fitting was as shown in Detail P of Figure 2. In the model, the drag fitting has the same effective line of action but is made of a single machined straight sided element which is stiffer and weighs more than the scaled prototype value.

The aft skirt in the model is simpler than the prototype since there is no beading of panels or ventral fins and only one ring frame which distributes the aft SRM loads. This is stiffened by lateral struts which would be .19 to .22 $in.^2$ if scaled from the prototype, but which are .26 $in.^2$ in the model to save the cost of additional tooling. There is no full bulkhead installed in the model as there was in the prototype since the bulkhead was not considered significant for the structural dynamic characteristics.

SRM

The prototype design used as the basis for the model is shown in Figure 6. The central cylindrical section which in the prototype is made of 6 segments of .57" thickness steel is modeled by a single 0.2" thick walled aluminum cylinder. The propellant is modeled by an inert propellant in which the oxidizer replaced by an inert salt. No structure was considered necessary to represent the upper dome of the prototype. The lower dome is represented by a conical section for simplicity.

The forward skirt in the prototype SRM was designed as an orthogonally stiffened steel cylinder with closely spaced longerons, and with 5 ring frames spaced about 26" apart. Skin thickness varied from .2" to .06". In the model, this is represented by an unstiffened .050" thick uniform aluminum cylinder which represents average thickness, and because this thickness will prevent buckling under any of the model loading conditions. The forward skirt of the model has frames consisting of back-to-back channels located at the forward and aft intersections of the interstage struts with the skirt in order to take the SRM-to-external-tank loads. In the prototype, the forward frame had an area which varied from about 4 $in.^2$ to 10 $in.^2$, with a corresponding variation in I from 125 $in.^4$ to 490 $in.^4$. The aft frame area varied from 1.8 $in.^2$ to 6.2 $in.^2$, and the I from 18 $in.^4$ to 106 $in.^4$. On the model, both are represented by the same frame with an area of .27 $in.^2$ and an inertia of .28 $in.^4$ which, when scaled up to prototype size and material, would represent a 5.7 $in.^2$ area and a 430 $in.^4$ inertia. This is considered within the proper range for the forward frame.

The prototype geometry of the interstage strut fittings is retained but the model fittings are simplified. The interstage strut attachment lugs are fabricated from plate to save machining costs. This makes the model elements heavier than scaled down prototype design. The SRM recovery system is represented by lumped weight attached to the forward ring.

The aft skirt of the prototype which contains the hold-down fittings and SRM-to-external-tank fittings, was designed as an orthogonally stiffened conical frustrum with stringers every 4 degrees and ring frames approximately every 24". The prototype material was steel. Skin thicknesses varies from 0.3" to .075". This structure is simulated in the model by a conical .062" unstiffened uniform aluminum skin. The prototype had 4 major tapered longerons extending from the hold-down fittings to the SRM cylinder each with a maximum area of 10 $in.^2$ and an inertia of 389 $in.^4$. These are represented in the model by back-to-back channels which when scaled up to prototype material and dimensions have an area of 8.6 $in.^2$ and an inertia of 280 $in.^4$. Above the conical section of the aft SRM skirt, the prototype had a short cylindrical section containing the fittings for the struts linking the SRM to the external tank and containing the ring which fastens to the aft portion of the SRM propellant cylinder. On the prototype, this ring was a double U shaped section about 10-$\frac{1}{2}$" deep by 4-$\frac{1}{2}$" wide with an area of about 20 $in.^2$ and an inertia of about 290 $in.^4$. A simpler single U section is used in the model having an area equivalent to 13 $in.^2$ and an inertia of 95 $in.^4$ when scaled to prototype dimensions and material. The short cylindrical section of the model forward of the U ring has the same skin thickness (.062") as the conical section, and is terminated in a ring for attaching to the model SRM cylinder. This area, while not representative of the prototype, is designed to have stiffness compatible with the upper portion of the conical skirt.

Orbiter

The prototype structural arrangement used as a basis for the orbiter model is shown on Figure 7.

The aft portion of the model fuselage has similar geometry as the prototype but is designed with only two full bulkheads, one aft frame and two intermediate frames in place of the larger number on the prototype. The upper cutouts in the prototype which provided for the OMS and abort SRM's are not modeled, instead full frames are used. The external lines of the model are simplified and straightened compared to the prototype to reduce fabrication costs. The cross-sectional areas of the struts between the lower engines and the aft interstage fitting are scaled directly from the prototype as were the side longeron areas. A simple fin structure which extends up to the location of the fin c.g. is also included in the model. The skin gages in the bulkheads (.032" aft and .040" forward) are adequate for fabricating, thick enough to avoid buckling, and heavy enough to simulate some of the non-structural weight in the prototype. The in-plane areas of the prototype bulkheads are not scaled for the model in order to avoid structural complexities and because it is not considered significant in establishing the primary structural dynamic characteristics of the model. All side skins of the model fuselage are .020" thick, which is adequate to avoid buckling. The scaled down prototype dimension for the fuselage side skins is .012" but this would require intermediate rings and longerons in the model and increase the cost of the fabrication. The deck of the model which distributes the upper engine loads to the longerons is .016" thick and correctly scales the prototype stiffness (area/length).

The prototype fuselage mid-section consisted of closely spaced frames covered by corrugated outer skin carrying TPS tiles. The model has similar but simplified geometry and structural arrangement. The model consists of series of more widely spread U shaped frames spaced every 10" covered by a .020" side skin and .025" bottom skin. This skin thickness is enough to prevent buckling under static load but it results in a larger area and inertia than the scaled prototype values as shown in Figures 8 and 9. Payload support provisions are made at 4 different stations to permit variations to be tested. The longerons of the model are designed to furnish the proper scaled area for the aft end of the orbiter. It is kept at a constant area for the entire length of the fuselage to limit fabrication costs. In order to simulate the prototype weight, about 0.8 lbs/inch, including the structure, would be required on the model. This is accomplished by increasing the thickness of the frame webs where stiffness is not significantly affected.

The wing of the model consists of 6 beams covered top and bottom by flat plates. Wing root connections are made by bolts in shear through the webs of the beams and machine screws connecting the top and bottom wing skins to the fuselage. This method of attachment simulates the prototype. The prototype had a corrugated double skin with an average thickness of .16" to 14". This structure is simulated in the model by a .020" sheet. Since the wing depth of the model is properly scaled, the prototype inertia at the wing root is properly represented on the model. A constant skin thickness is used over the entire model wing to control costs and this does give the proper order of magnitude for inertia since the beam depth decreases toward the model wing tip. The proper weight for the wing including the TPS panels is simulated on the model by adding thickness to the webs of the spars. The model wing does not have chordwise trusses or beams (typical of the prototype) so that loads applied away from the outer periphery are not distributed properly between spars, but loads applied at the outer edges are properly transmitted by the top and bottom covers. Therefore, realistic modes are anticipated if shakers are kept at the periphery of the wing. The RCS wing tip pods of the prototype are simulated by lumped weights on the model.

The orbiter interstage fittings duplicate the prototype geometry using simplified components.

The orbiter model payload bay door consists of a removable 7 segmented semi-cylindrical cover skin which can take loads in torsion but not in tension and compression, thereby simulating the structural properties of the prototype door in a closed and locked position. The minimum skin gage which could be used for the door in order to prevent buckling is .016", which is quite thick compared to the scaled prototype value of .00325".

The forward fuselage in the model consists of a tapered non-circular stiffened shell extending through the cabin location. The two side longerons of the fuselage mid-section are extended through this area in order to provide a forward orbiter model hoist point. There are provisions for attaching weights simulating the forward equipment. Additional stabilizing stiffeners are added to the model to prevent buckling. Local stiffnesses are not considered significant for vehicle structural dynamic characteristics and are, therefore, not scaled.

Complete design drawings of the 1/8th scale dynamic model are available at the Dynamics Loads Branch, Loads Division, NASA/Langley Research Center. An assembly drawing of the model showing the major components and overall dimensions is presented in Figure 10.

SUSPENSION SYSTEM FOR MODEL

Suspension System For Model

The objectives of this system are to provide support which does not interfere with measurements of the unrestrained structural dynamic characterstics, such as mode shapes modal frequencies and damping during tests, while keeping the support induced buckling and handling loads to a minimum. The system should also permit the ready disassembly and changes in the model elements required by the test program. The system must be compatible with the current support structure (Backstop) in the NASA Langley Dynamics Research Laboratory, and should be relatively inexpensive to implement.

Suspension Concepts

Various support concepts were considered for use on the model. These included the systems analyzed by R. W. Herr and H. D. Carden in USAF RTD-TDR-63-4197 (Sept. 1963). Vertical suspension of the launch configuration is necessary to obtain the proper hydroelastic interactions in the LO_2 tank. Successful use of air springs for large vehicles at Grumman prompted the adoption of 0.5 hz units remaining from the LM program to provide vertical isolation. Horizontal isolation is complicated because unlike previous axisymmetric models, the Shuttle center of gravity shifts laterally with reduction in fuel so that the attitude changes for most practical vertical suspensions. Base support springs as used on the full scale Saturn V Dynamic Test Vehicle were considered too expensive and a cable system was therefore adopted. A single cable was impractical because no adequately strong suspension point was available. Therefore the system described below was adopted and designed.

Recommended Suspension Scheme

A modified two cable suspension system shown schematically in Figure 11 was selected. The modification consists of a bridle positioned between each suspension cable and the model. The bridle is routed thru a sheave on the suspension cable and each end is attached to an SRM interstage fitting on the same side of the HO tank. This arrangement offers the advantage of supporting the model at the same four points at which the SRM thrust is introduced on the full size vehicle, minimizing the effect of the suspension loads on the model and permitting the model to assume its eqilibrium attitude at any level of propellant loading.

Within the restraints shown on Dwg AD 383-500, the primary suspension system may be routed in any number of ways thru a system of sheaves mounted on the upper backstop structure. One such routing is presented on Figure 11 .

Provision for changing the SRM propellant level between tests was an important consideration in the design of the overall system. Discussion with NASA concluded that changing propellant cylinders, (relatively long and heavy masses,)on both SRM's with the model suspended was not desirable, and, that the approach should be to first lower the model and to support it vertically on the floor prior to replacing the cylinders. Since the suspended model can be in any of three possible attitudes this requires that it be oriented vertically prior to lowering. Also shown in Figure 11 is a proposed routing of the model leveling cable system. It should be noted that this routing is proposed to run parallel to that of the suspension system in order to maintain the attitude attained by use of the leveling system while the model is being raised or lowered.

Both cable systems are interconnected by a hydraulic ram and sheave arrangement, also shown in Figure 11 . The hydraulic ram is proposed, permitting remote operation and selection of rate, however, any mechanical device of adequate capacity, such as a chain hoist, could be used instead . The ram changes the model orientation by varying the distance between the two sheaves, one being held fixed by the cable to the actuator on the floor by a winch or ram or any other satisfactory device, the other connected to the orbiter and free to move. During tests the leveling ram is fully extended permitting the model to assume its equalibrium attitude. The slack leveling cables may be left attached to the orbiter or disconnected. The model may be raised or lowered in any attitude by means of the floor mounted actuator.

Drawing AD 383-500-1 showing the extreme positions anticipated for the range of weights to be tested with and without SRM is shown on Figure 12. Also shown is the clearance anticipated. The orbiter alone could be readily suspended from the forward attachment point, and an aft handling point at the top of the fin is available for support during any required movement.

Estimated Suspension System Frequencies

The fundamental model free resonant frequency is expected to be about 8 hz. Therefore suspension frequencies below .8 hz would be desirable for the support system. The LM airsprings will furnish a .5 hz vertical suspension which should be adequate. Laterally the combination of rocking and pendulum motion is anticipated. To estimate the lateral frequencies, the model was analyzed in two planes separately assuming the vertical airspring was not effective.

In the plane where the vertically suspended model is viewed from directly in line with left wing, the right hand bridle attachments are directly behind those on the left hand side and the system acts like a simple physical pendulum with the center of gravity below the point of support, as described on page 250 of "Advanced Dynamics" by Timoshenko and Young. The two resonant frequencies were calculated for 5 weight conditions from full-up (9432 lbs.) to just prior to decoupling the external tank (675 lbs). The resonant frequencies for the lightest condition were 0.61 hz and 0.18 hz, while those for the heaviest were 0.37 hz and 0.19 hz.

In the plane at right angles to this, where the suspended vehicle is viewed from directly in line with the orbiter fin no adequate expression for the resonant frequencies was found. An approximate expression was developed using Lagrange's equations and assuming small motions and equivalence of small angles as shown in Apprendix B. The resonant frequency in this plane varied from .20 to .26 hz for the range of weights from full (9432 lbs.) to almost empty (675lbs). A more detailed analysis would include the effects of the vertical flexibility however the resonant frequencies for the idealized cases are considered sufficiently low to provide confidence that the isolation furnished by the suspension should be adequate.

Handling Procedures

The procedure recommended for the initial assembly of the model is listed on Figure 10. The weights and angles anticipated for various loading conditions are shown schematically in the Stress Report on page 22 "Flow Chart For Model Handling".

STRESS ANALYSIS

STRESS ANALYSIS

The Stress Analysis includes the following:

1. A discussion of ground rules concerning the handling of the model.
2. Presentation of the loads associated with these ground rules.
3. Documentation of model geometry at internal interfaces, and the determination of model loads for which the model structure was checked.
4. Analysis of a typical SRM drag strut.

The detailed analysis of the basic internal model is not presented herein. In designing a 1/8 scale model, true scaling results in margins of safety up to 8 times those on the prototype for the same accelerations. For this model, for cost control and design simplicity, many critical structural areas show even greater margins of safety. Each drawing was reviewed to assure adequate factors of safety and stability for all defined load conditions. It is not considered necessary to include all detailed calculations in this document.

Discussions of Ground Rules

Handling conditions are presented on Page 20.

All raising and lowering of the model shall be accomplished with the O_2 (water) tank of the external tank drained and empty; and with the model in a vertical orientation with the orbiter supported vertically from the nose fittings provided at Orbiter X Station 46. These stipulations are necessary to (1) prevent buckling of the intertank skirt between the pickup fittings and the O_2 tank Y ring and (2) to prevent compression bucking in the lower skin of the orbiter.

Loads Induced by Handling

The load factors acting on the dynamic model are tabulated on Page 20. These include mode survey as well as model ground handling conditions.

Flight configurations are designated by symbols "A" thru "G" as given on Page 21. Condition "A" is representative of the prelaunch configuration. Flight conditions progress until the last flight configuration condition "G" is achieved. The appropriate model weight for each flight condition is also listed on Page 21.

A "Flow Chart for Model Handling" is presented on Page 22. The chart lists the configuration sequences that the model sees in the test program. Configuration "A" may proceed to configuration "F" by means of 30 steps. Each step is designated by the step number encircled and an adjacent arrow. All 1 g support loads and the inertia loads on the model components for each step are given on Page 26. These support loads occur either at the base of the SRM or at interface points 1 & 4. The interface points are located on Page 24. Ultimate loads for design for these locations are shown on Page 26.

Orbiter Loads

The orbiter weight distribution & inertias are presented on Page 27 & 29. The loads induced on the orbiter during handling are presented on Page 28. Loads induced at the interface locations due to a unit load applied at both the center of gravity & the forward nose hoist location are shown. The shear axial load & bending moments for a 1 g axial and lateral applied force are then determined as shown on Pages 30 to 33. These form the basis to check the strength of the orbiter fuselage.

Orbiter to external tank interface loads are obtained by applying unit loads at the interface locations and calculating the strut member loads & the tank support point reaction forces as shown on Page 34. The loads at these interface locations due to critical handling conditions on the orbiter are obtained by multiplying the appropriate values on Page 26 by the unit factors on Page 28 & are listed on Page 35. These are then converted to the member & fitting loads in the lower table on Page 35.

SRM Loads

A similar procedure is followed in determining the SRM induced loads on the external tank interfaces. The geometry & distribution of forces to the interfaces is shown on Page 36. The loads at the tank reaction points & in the truss members for a unit axial (1 lb.) load applied at the point designated 5' is shown on Page 37. A similar distribution for lateral (Y & Z) loads applied at the SRM center & for lateral loads and moments applied at the center of the external (HO) tank are shown on Page 38 for the forward interface & Page 39 for the aft interface. The reaction forces have been translated into axial, radial, & tangential forces & strut loads & summarized on Page 40. The critical handling conditions from Page 26 are then multiplied by these factors to give the ultimate loads as listed on Page 41. The primarily axial handling loads are combined with the lateral handling loads to give the design values listed on Page 41. A similar calculation for the loads in the SRM at these interfaces gives the values shown on Page 42.

Analysis of a Typical SRM Drag Strut

A typical analysis is shown on Page 43. The loads applied are determined on Page 41. Two cross sectional areas are checked and the margin of safety is .27.

1/8 SCALE DYNAMIC MODEL

2. DISCUSSION OF LOAD FACTORS

$$\frac{\text{ULTIMATE}}{\text{LIMIT}} = 1.5$$

DURING MODE SURVEYS — $\eta_x = 1.2$ limit $\times 1.5 = 1.8$ g's ULT

THIS LIMIT AXIAL LOAD FACTOR WAS SELECTED TO PROVIDE A .20 ENVELOPE ON BODY BENDING, SHEARS AND LOCAL INTERFACE LOADS DUE TO DYNAMIC LOADING. SEE APPENDIX A FOR ESTIMATES OF DYNAMIC LOADS DUE TO OSCILLATING SHAKER APPLIED FORCES AT THE ORBITER ENGINE.

DURING RAISING AND LOWERING OF MODEL

$\eta_x = 1.5$ (limit) $\times 1.5 = 2.25$ g's ULT

THIS LIMIT AXIAL LOAD FACTOR WAS SELECTED AS AN ENVELOPE TO ACCOUNT FOR STARTING AND STOPPING OF HOIST SYSTEM

AT IMPACT DURING JOINING OR SETTING DOWN OF MODEL

$\eta_x = 2.0$ (limit) $\times 1.5 = 3.0$ g's ULT

ALL CABLE AND HOIST FITTING AND ATTACHMENTS

$\eta_x = 2.0$ (limit) $\times 1.5 = 3.0$ g's ULT

LATERAL FORCES DURING HANDLING

$\eta_y = \eta_z = .5$ (limit) $\times 1.5 = .75$ g's ULT

THIS VALUE FOR LATERAL LOAD FACTORS (ALONG THE Y AND Z AXES - SEE P. 23, AND 24) WAS SELECTED TO ACCOUNT FOR HANDLING FORCES

1/8 SCALE DYNAMIC MODEL

3. MODEL LOADING CONDITIONS

THE FOLLOWING MODE SURVEY TEST CONDITIONS HAVE BEEN CONSIDERED IN THIS ANALYSIS. ADDITIONAL INTERMEDIATE CONDITIONS ARE ALSO INVESTIGATED. (SEE p 22)

A - CANTILEVERED PRE LAUNCH
B - FREE-FREE POST LIFT OFF
C - FREE-FREE MID BOOST (MAX q)
D - FREE-FREE END BOOST (PRE SRM SEPARATION)
E - FREE FREE END BOOST (POST SRM SEPARATION)
F - FREE - FREE HO BURNOUT (PRE HO SEPARATION)
G - FREE FREE ORBITER (POST HO TANK SEPARATION)

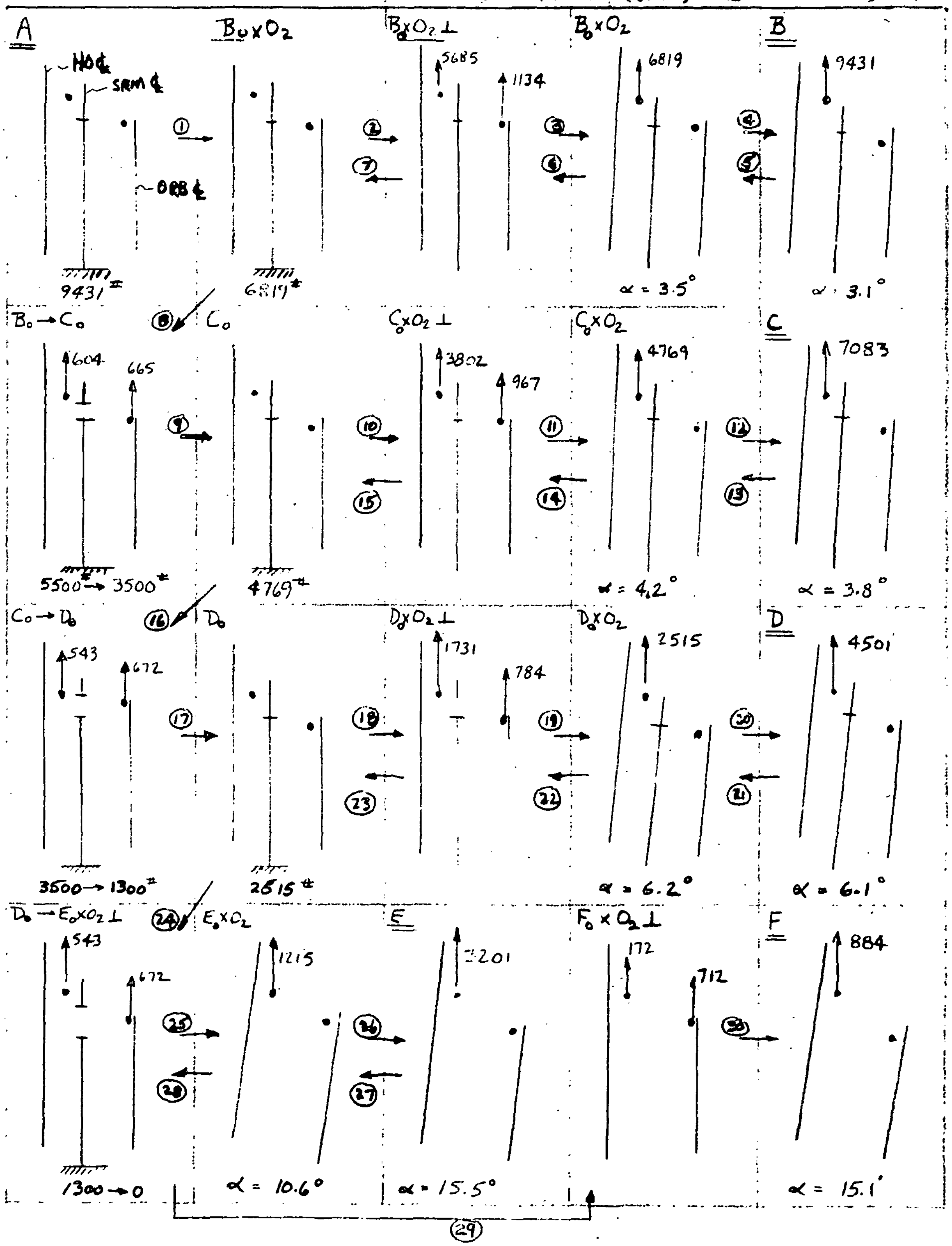
WEIGHT AND CENTER OF GRAVITY OF SIGNIFICANT MODEL MASSES ARE SHOWN IN THE FOLLOWING TABLE FOR EACH TEST CONDITION IN TERMS OF EXTERNAL TANK COORDINATES.

ITEM	COND	WEIGHT (LBS.)	EXT. TANK * COORD. IN. X	EXT. TANK * COORD. IN. Z
ORBITER	A→G	654	219.4	36.9
EXT. TANK LO_2	A,B	2612	74.	0
	C	2314	78	0
	D,E	1986	82	0
	F,G	0	–	–
EXT. TANK LH_2	A,B	435	190	0
	C	385	200	0
	D,E	331	209	0
	F,G	0	–	–
EXT. TANK STRUCT	A→F	230	150	0
	G	0	–	–
SRM PRO-PELLANT	A,B	5000	192.5	6.138
	C	3000	192.5	6.138
	D	800	192.5	6.138
	E→G	0	–	–
SRM STRUCT	A→D	500	192.5	6.138
	E→G	0	–	–

* FWD LO_2 TANK DOME IS STATION X 34.16

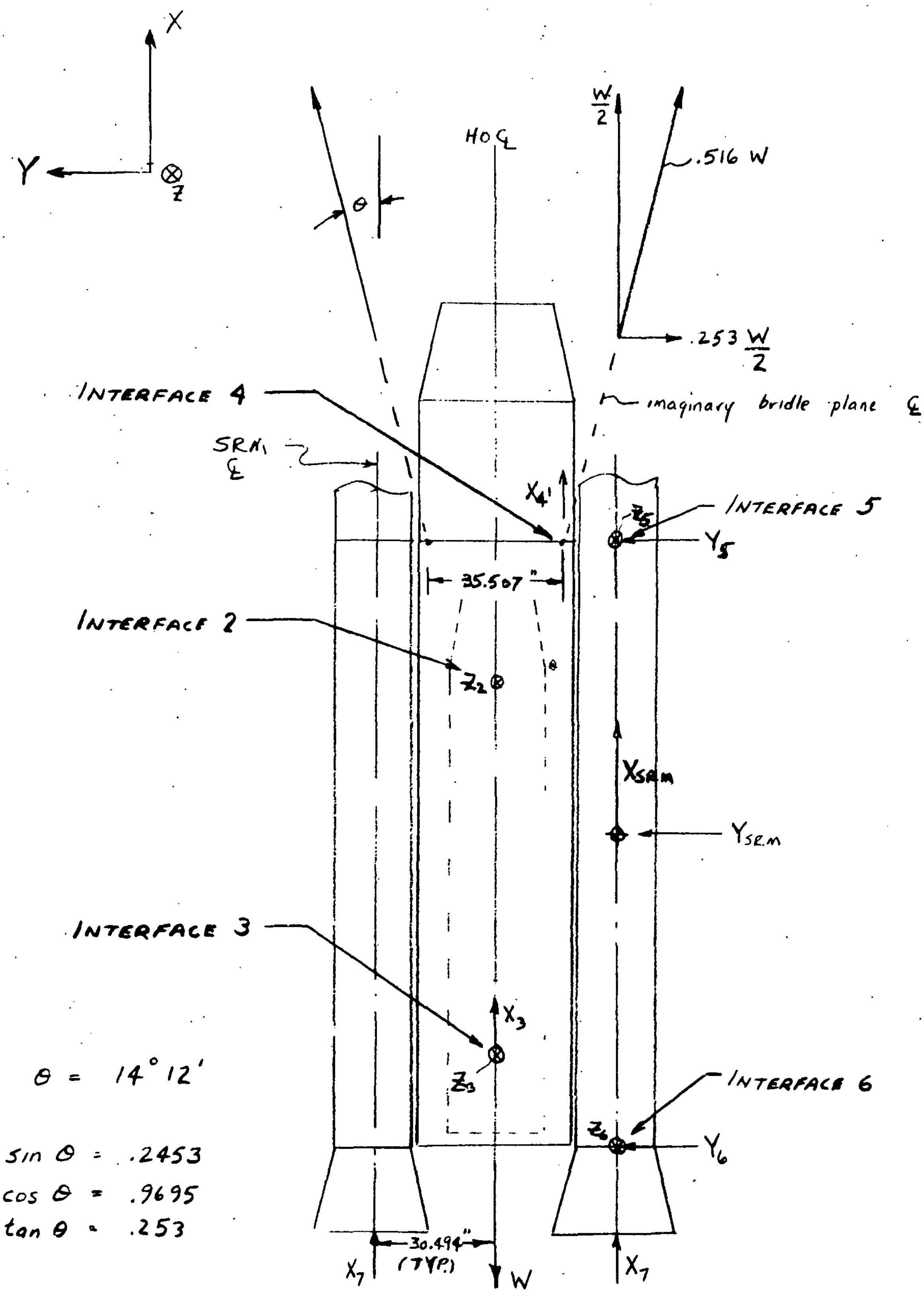
1/8 SCALE DYNAMIC Model - FLOW CHART FOR MODEL HANDLING

LEGEND: - A THRU E DENOTES TEST CONDITION, $\times O_2$ = O_2 DRAINED
⊥ = SUPPORTED AT ① AND ④ VERTICALLY, ╪ = DECOUPLE SRM PROPELLANT CYLINDER, o SUBSCRIPT DENOTES INTERMEDIATE CONDITION,
5500# → 3500# = CHANGE PROPELLANT (SRM) LOAD



1/8 SCALE DYNAMIC MODEL

BASIC MODEL CONFIGURATION AND GEOMETRY (XY PLANE)



$\theta = 14^\circ 12'$

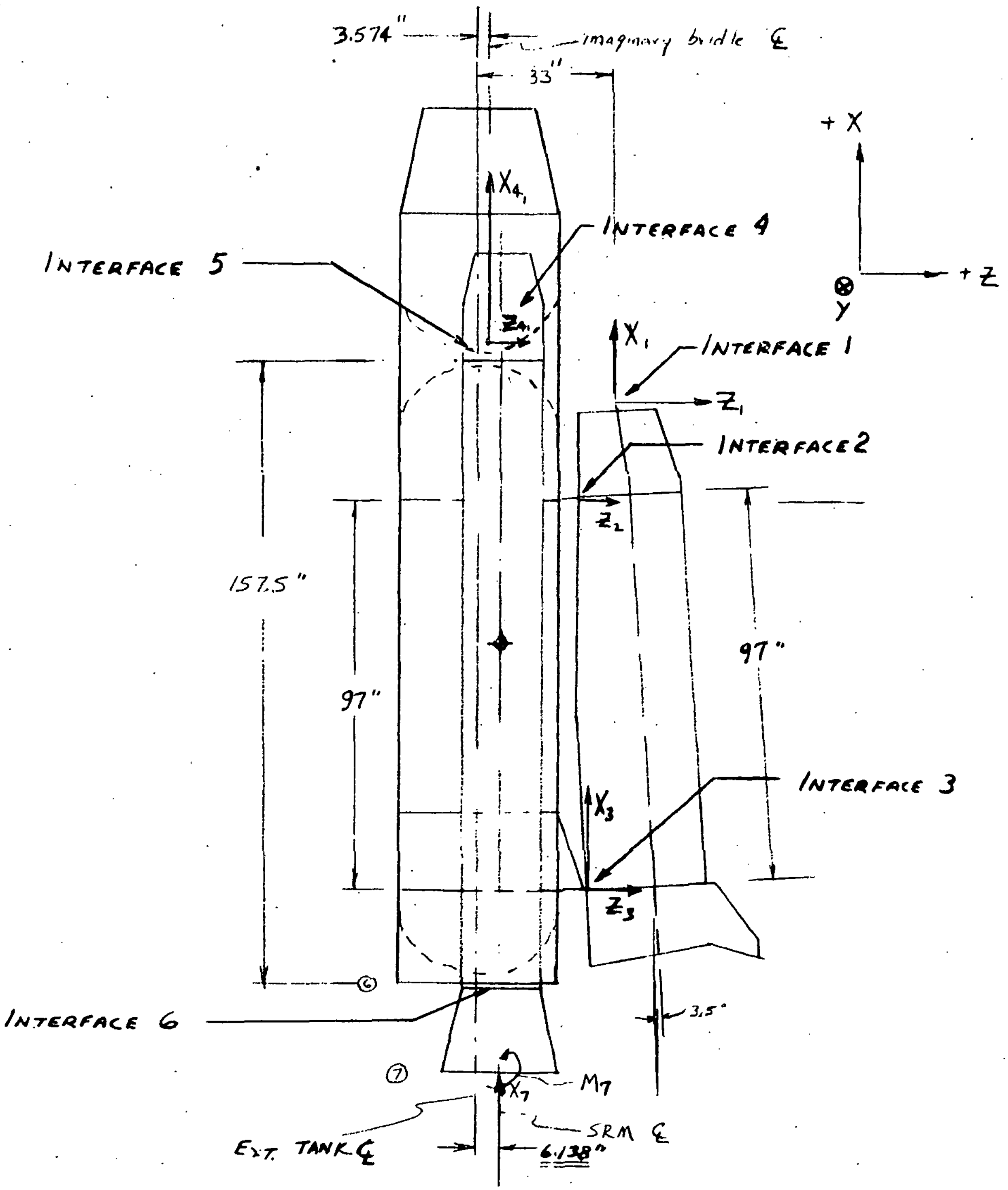
$\sin\theta = .2453$

$\cos\theta = .9695$

$\tan\theta = .253$

1/8 SCALE DYNAMIC MODEL

BASIC MODEL CONFIGURATION AND GEOMETRY (XZ PLANE)



1g LOADING CONDITIONS		X_1	Z_1	X_o	Z_o	$2X_4$	$\pm Y_4$	$2Z_4$	X_{HO}	Z_{HO}	$2X_{SRM}$	$2Z_{SRM}$	$2X_7$	$2M_7$
A		0	0	-654	0	0	0	0	-3277	0	-5500	0	+9431	0
B_o		0	0	-654	0	0	0	0	-665	0	-5500	0	+6819	16,031
$B_oXO_2\perp$		1134	0	-654	0	5685	-720	0	-665	0	-5500	0	0	0
B_oXO_2	(α = 3.50)	0	0	-653	+40	6806	-862	-417	-664	+41	-5489	+336	0	0
B	(α = 3.09)	0	0	-653	+35	9417	-1200	-509	-3272	+177	-5492	+297	0	0
$B_o\perp$		814	0	-654	0	8617	-1090	0	-3277	0	-5500	0	0	0
$C_o\perp$		665	0	-654	0	604	-76	0	-615	0	0	0	—	0
C_o		0	0	-654	0	0	0	0	-615	0	-3500	0	+4769	16,338
$C_oXO_2\perp$		967	0	-654	0	3802	-480	0	-615	0	-3500	0	0	0
C_oXC_1	(α = 4.2)	0	0	-652	+47	4756	-604	-348	-613	45	-3491	+256	0	0
C	(α = 3.77)	0	0	-653	+43	7068	-895	-466	-2923	+193	-3492	+230	0	0
$C_o\perp$		684	0	-654	0	6399	-810	0	-2929	0	-3500	0	0	0
$D_o\perp$		672	0	-654	0	543	-69	0	-561	0	0	0	0	0
D_o		0	0	-654	0	0	0	0	-561	0	-1300	0	2515	16,669
$D_oXO_2\perp$		784	0	-654	0	1731	-220	0	-561	0	-1300	0	0	0
D_oXO_2	(α = 6.2)	0	0	-651	+71	2498	-318	-272	-555	60	-1292	141	0	0
D	(α = 6.1)	0	0	-651	+70	4477	-571	-314	-2532	+178	-1294	139	0	0
$D_o\perp$		541	0	-654	0	3960	-500	0	-2541	0	-1300	0	0	0
$E_oXO_2\perp$		672	0	-654	0	543	-69	0	-561	0	0	0	0	0
E_oXC_2	(α = 10.56)	0	0	-642	+120	1195	-154	-223	-553	+103	0	0	0	0
E	(α = 15.47)	0	0	-629	+175	3120	-405	-325	-2491	+150	0	0	0	0
$E_o\perp$		429	0	-654	0	2772	-350	0	-2547	0	0	0	0	0
$F_o\perp$		172	0	-654	0	712	-90	0	-230	0	0	0	0	0
F	(α = 15.14)	0	0	-630	+171	852	-112.	-231	-222	+60	0	0	0	0
G	(α = 3.7°)	653	41	-653	-41	0	0	0	0	0	0	0	0	0

LOADS AT MODEL SUPPORT LOCATIONS & C.G OF ORBITER, TANK, AND SRM FOR 1g VERTICALLY

SEE p. 21 FOR DESCRIPTION OF LOAD CONDITIONS AND p. 22 FOR APPLIED LOADS AND p. 24 FOR GEOMETRY

ULT LOAD FACTOR	ULTIMATE APPLIED LOADS TO MODEL CONDITION	X_1	Z_1	X_{OFB}	Z_{OFB}	$2X_4$	$\pm Y_4$	$2Z_4$	X_{HO}	Z_{HO}	$2X_{SEM}$	$2Z_{SEM}$	[illegible]	$2M_7$
1.8	A	0	0	-1177.	0	0	0	0	-5999	0	-9900	0	[illegible]	0
3.0	A_0	0	0	-1962	0	0	0	0	-1995	0	-16500	0	[illegible]	48,093
2.25	$B_0XO_2 \perp$	2552	0	-1472	0	12791	-1620	0	-1496		-12775	0	0	0
1.5	B_0XO_2	0	0	-980	+60	10209	-1293	-676	-996	62	-8234	524		
1.8	B	0	0	-1175	+63	16951	-2160	-916	-5899	319	-9886	535	0	0
1.5	$B_0 \perp$	1272	0	-981	0	12926	-1635	0	-4916	0	-5250	0	0	0
2.25	$C_0 \perp$	1496	0	-1472	0	1357	-171	0	-1384	0	0	0	0	0
3.0	C_0	0	0	-1962	0	0	0	0	-1845	0	-10500	0	[illegible]	49,014
2.25	$C_0XO_2 \perp$	2176	0	-1472	0	8555	-1080	0	-1384	0	-7875	0	0	0
1.5	C_0XO_2	0	0	-975	71	7134	-906	-522	-920	68	-5237	384	0	0
1.8	C	0	0	-1175	77	12722	-1611	-839	-5261	347	-6286	[illegible]	0	0
1.5	$C_0 \perp$	1026	0	-981	0	9599	-1215	0	-4371	0	-5250	0	0	0
2.25	$D_0 \perp$	1512	0	-1472	0	+1727	155	0	-1262	0	0	0	0	0
3.0	D_0	0	0	-1962	0	0	0	0	-1683		-7700	0	[illegible]	50,007
2.25	$D_0XO_2 \perp$	1764	0	-1472	0	3895	-495		-561	0	-2925	0	0	0
1.5	D_0XO_2	0	0	-977	107	3747	-477	-408	-833	90	-1938	212		
1.8	D	0	0	-1172	126	5059	-1028	-565	-4558	320	-2329	250	0	0
1.5	$D_0 \perp$	812	0	-981	0	5940	-750	0	-3820	0	-1750	0	0	0
2.25	$E_0XO_2 \perp$	1512	0	-1472	0	1222	-155	0	-1262	0	0	0	0	0
1.5	$E\ XO_2$	0	0	-963	180	1793	-231	-335	-830	154	0	0	0	0
1.8	E	0	0	-1132	315	5616	-729	-585	-4484	270	0	0	0	0
1.5	$E_0 \perp$	644		-981	0	4158	-525	0	-3820	0	0	0	0	0
2.25	$F_0 \perp$	387	0	-1472	0	1602	-203	0	-517	0	0	0	0	0
1.8	F	0	0	-1134	308	1534	-202	-416	-400	108	0	0	0	0
2.25	G	1490	92	-1490	-92	0	0	0	0	0	0	0	0	0

ULTIMATE MODEL SUPPORT & C.G LOADS

THESE VALUES OBTAINED BY MULTIPLYING THOSE ON P.25 BY ULTIMATE FACTORS

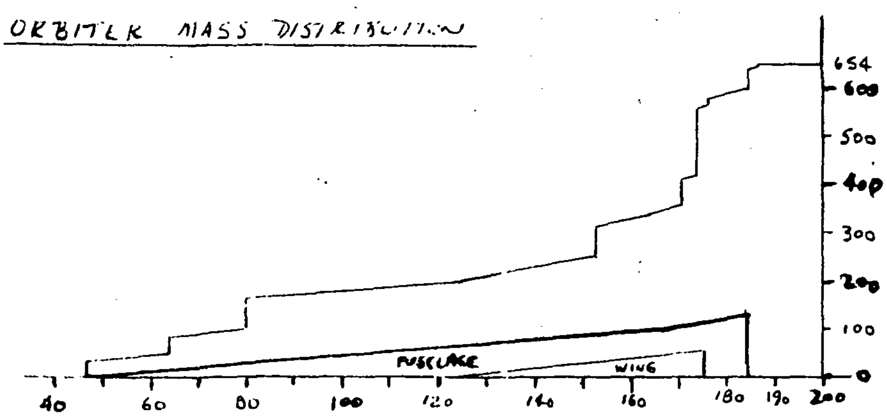
1/8 SCALE DYNAMIC MODEL

ORBITER MASS DISTRIBUTION

AREA	METHOD OF SIMULATION	WT. (LBS.)	ESTIMATED CG ORBITER STA. (IN.)	Z_{ORB} *
ORB. STA. 47 TO 165	FRAME BALLAST	95	108	6
CABIN	BALLAST	22 35	47 64	10 10
PAYLOAD	BEAM WITH BALLAST	130	114	16
WING	RIB + SPAR BALLAST	61	150	2
OMS + FUEL	BALLAST	50	170	24
ORB. STA. 166-185	STRUCTURE	40	176	11
ENGINES	BALLAST	44	184	14
ABORT SRM	BALLAST	136	173	16
TAIL	BALLAST	11	186	42
ACS (NOSE)	BALLAST	14	47	8
ACS (WINGS)	BALLAST AT TIPS	16	175	3
PAYLOAD (FWD)	BEAM WITH BALLAST	(130)	(96)	16
ORBITER WITH NOMINAL PAYLOAD		654	137.9	12.8
ORBITER WITH MOST FWD PAYLOAD		654	134.3	12.8
ORBITER (LESS ABORT SRM) NOM. PAYLOAD		518	128.7	12.0
ORBITER (LESS ABORT SRM) MOST FWD. PAY.		518	124.2	12.0

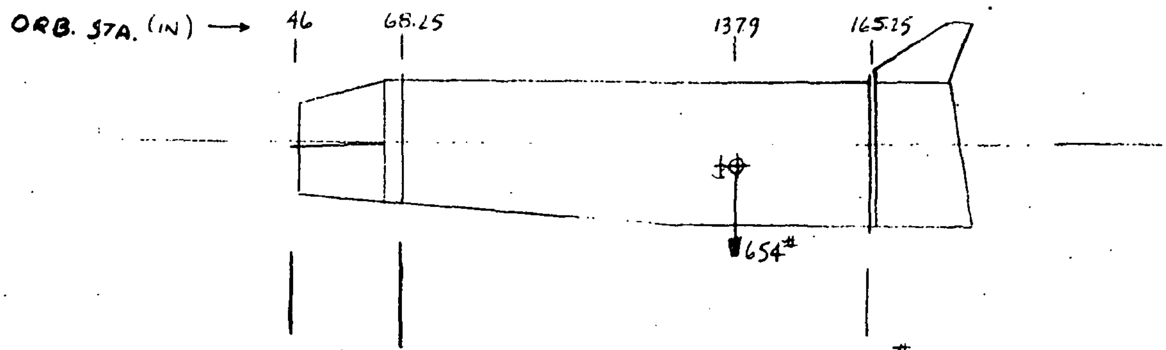
* INCHES ABOVE AFT INTERSTAGE ORBITER INTERFACE

ORBITER MASS DISTRIBUTION



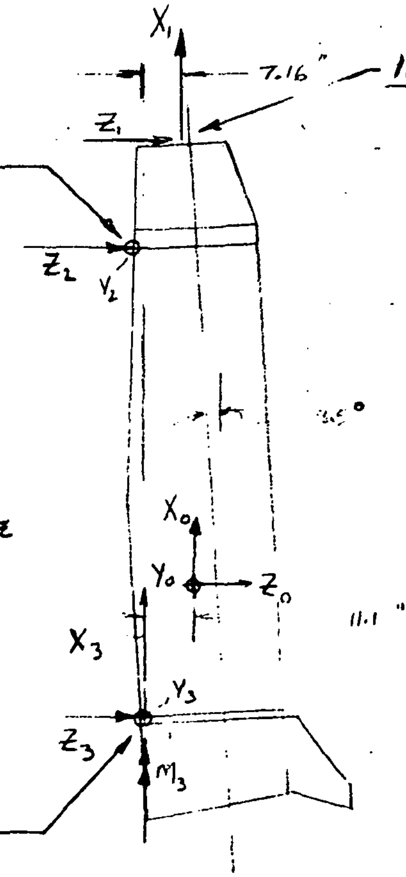
1/8 SCALE DYNAMIC MODEL

ORBITER HANDLING CONDITIONS



NOSE/AFT INTSTG	155#	–	499#	PAYLOAD NOMINAL
"	173#	–	481#	PAYLOAD FWD
FWD/AFT INTSTG	–	189#	465#	PAYLOAD NOMINAL
"	–	213#	441#	PAYLOAD FWD

ORBITER SUPPORTED AT H2O TANK INTERSTAGES



FOR X_1 = 1 LB FORCE

$X_3 = -1$ LB

$Z_2 = +.074$ LB

$Z_3 = +.074$ LB

FOR Z_1 = 1 LB FORCE

$X_3 = 0$ LB

$Z_2 = -1.23$ LB

$Z_3 = +.23$ LB

FOR X_0 = 1 LB FORCE

$X_3 = -1$ LB.

$Z_2 = +.115$ LB.

$Z_3 = -.115$ LB

FOR Y_0 = 1 LB FORCE

$Y_2 = .29$ LB

$Y_3 = .71$ LB

$M_3 = 11.1$ IN. LB

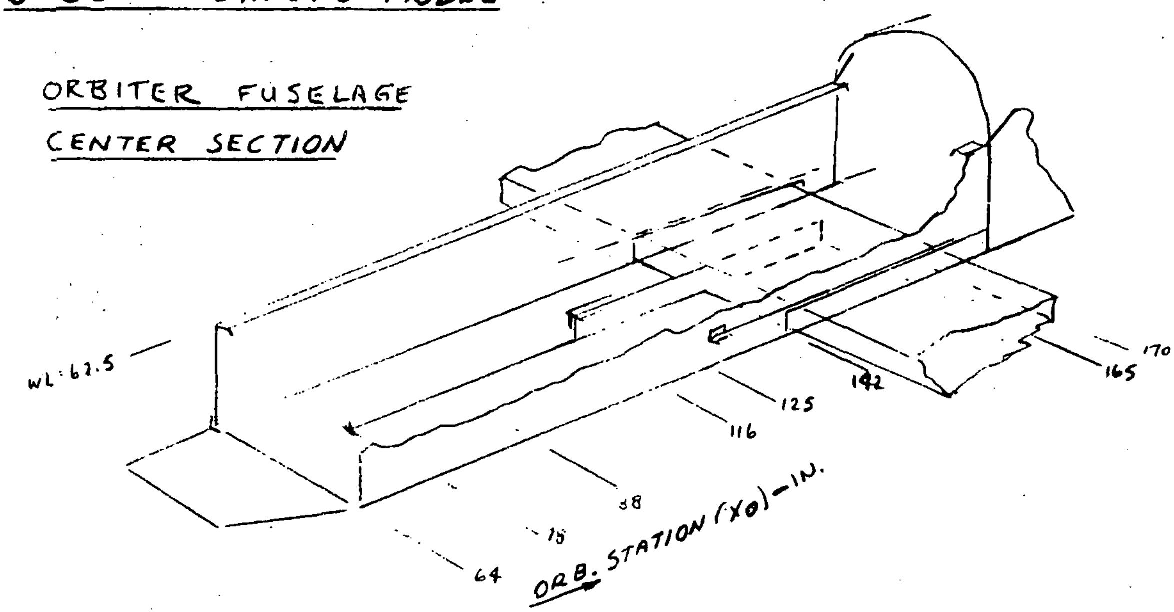
FOR Z_0 = 1 LB. FORCE

$Z_2 = -.29$ LB

$Z_3 = -.71$ LB

1/8 SCALE DYNAMIC MODEL

ORBITER FUSELAGE CENTER SECTION



SUMMARY of ORBITER SECTION PROPERTIES

$X_O = 64$ (WL = 53.07)

$A = 1.46 \text{ in}^2$, $I_{yy} = 43.95 \text{ in}^4$ $\frac{c}{I}$(LOWER) = .101 in^{-3} $\frac{c}{I}$(UPPER) = .192 in^{-3}

$X_O = 88$ (WL = 51.9)

$A = 1.65$ $I_{yy} = 56.12$ $\frac{c}{I}L = .082$ $\frac{c}{I}up = .206$

$X_O = 116$ (WL = 50.82)

$A = 1.715$ $I_{yy} = 72.4$ $\frac{c}{I}L = .074$ $\frac{c}{I}up = .161$

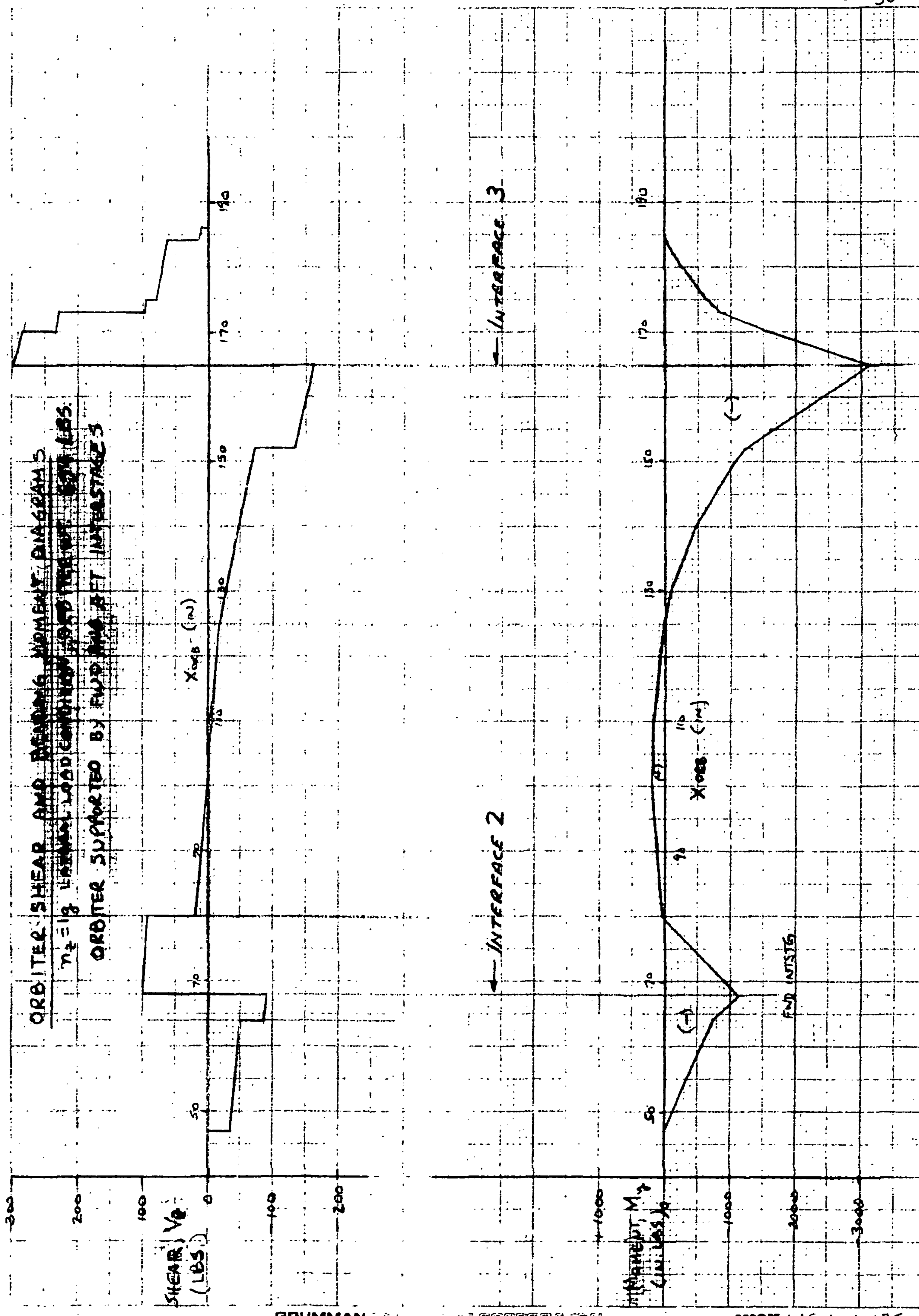
$X_O = 125 \rightarrow 142$ (WL = 50.528)

$A = 2.21$ $I_{yy} = 76.75$ $\frac{c}{I}L = .0656$ $\frac{c}{I}up = .156$

$X_O = 154 \rightarrow 165$ (WL = 50.508)

$A = 2.99$ $I_{yy} = 82.8$ $\frac{c}{I}L = .0612$ $\frac{c}{I}up = .145$

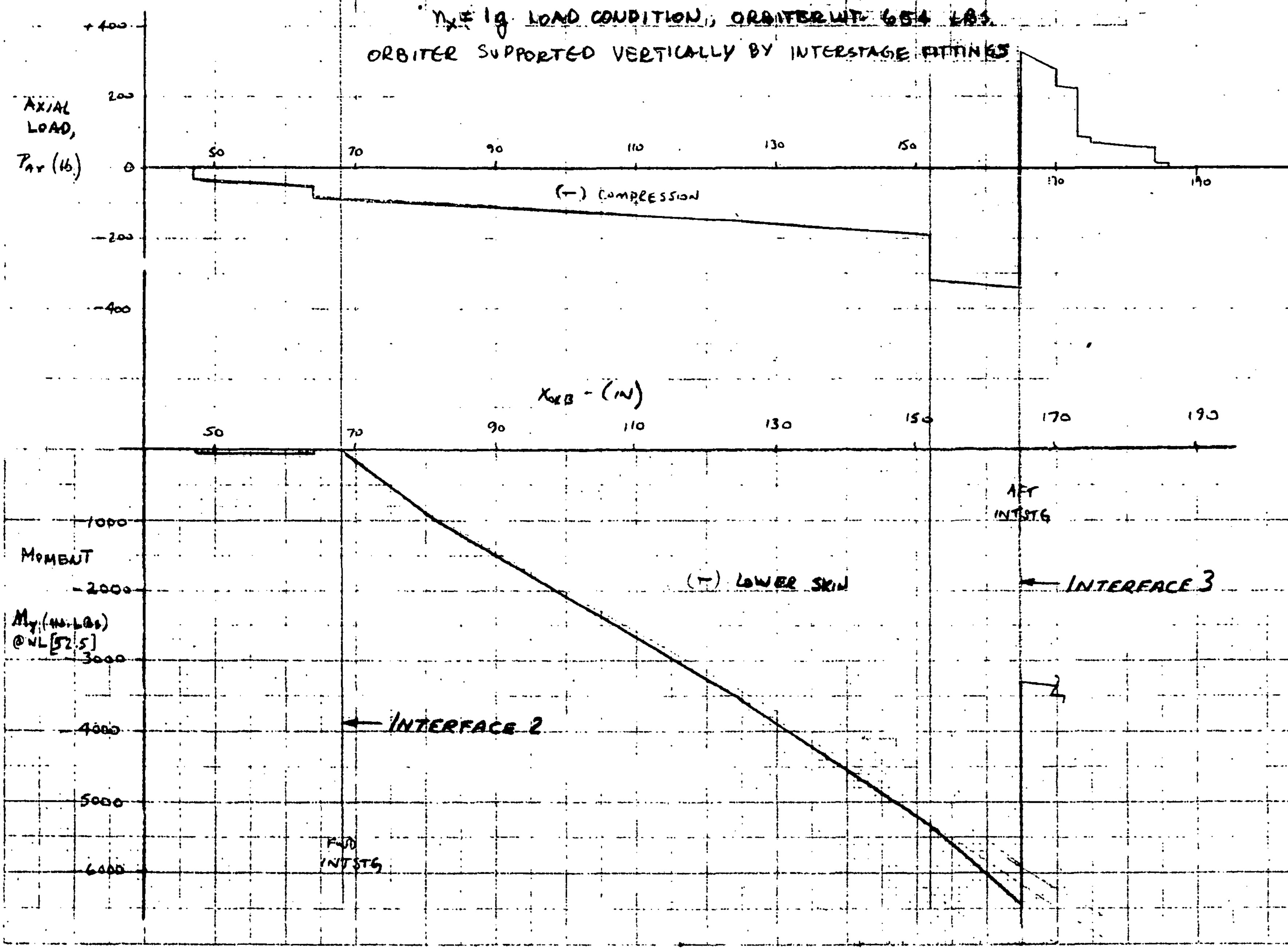
THESE VALUES CHECK THE APPROXIMATE DISTRIBUTIONS SHOWN ON FIGS. 8 AND 9.


ORBITER SHEAR AND BENDING MOMENT DIAGRAMS
n_z=1g LATERAL LOAD CONDITION
ORBITER SUPPORTED BY FWD AND AFT INTERSTAGES
SHEAR, V_y (LBS.)
300
200
100
0
-100
-200
X_{ORB} - (IN)
50
70
90
110
130
150
170
190
← INTERFACE 2
← INTERFACE 3
MOMENT, M_y (IN. LBS.)
+1000
-1000
-2000
-3000
(−)
(+)
FWD INTSTG

ORBITER AXIAL LOAD AND BENDING MOMENT DIAGRAMS

$n_x = 1g$ LOAD CONDITION, ORBITER WT. 654 LBS.

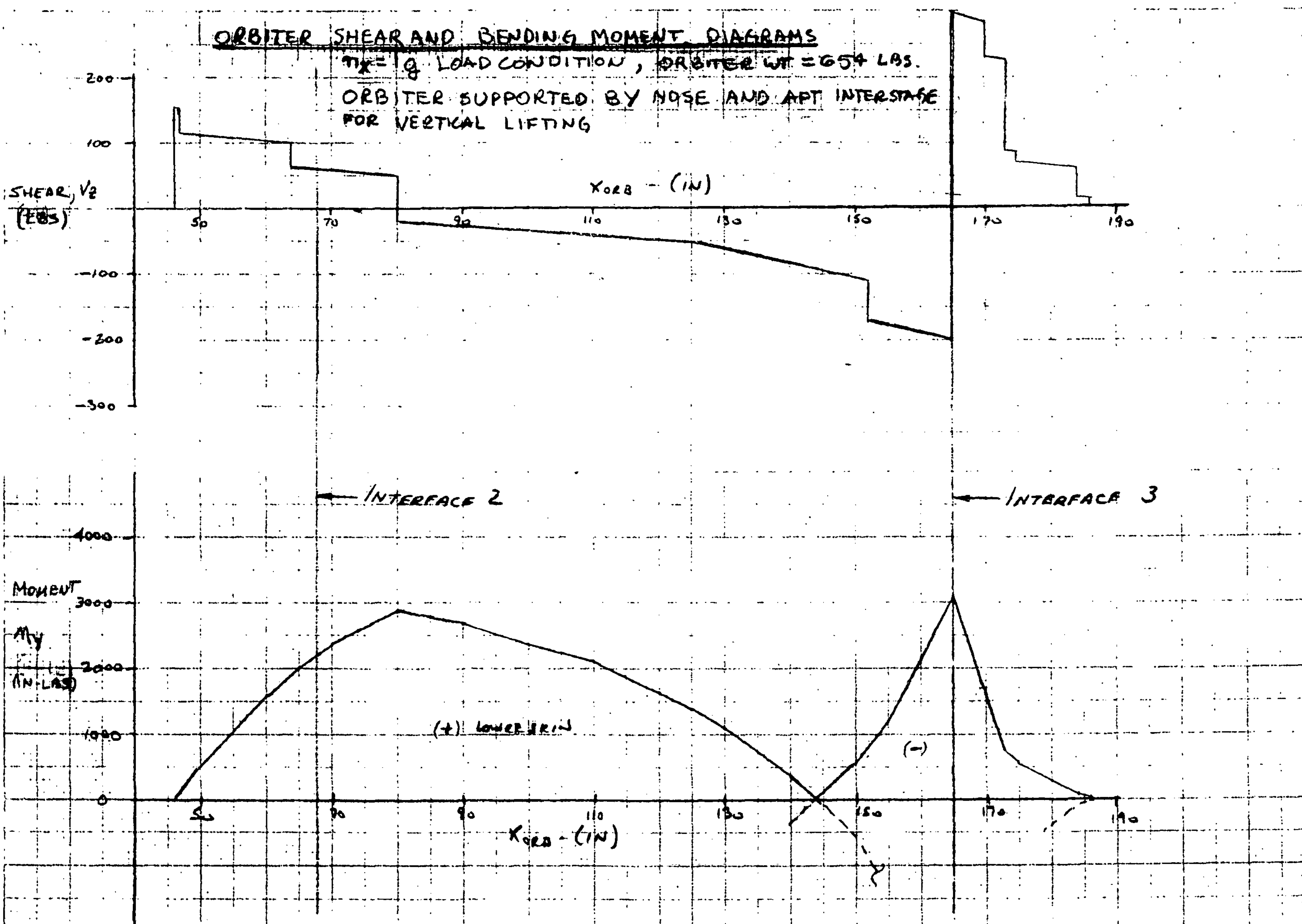
ORBITER SUPPORTED VERTICALLY BY INTERSTAGE FITTINGS



ORBITER SHEAR AND BENDING MOMENT DIAGRAMS

$n_x = 1g$ LOAD CONDITION, ORBITER WT = 654 LBS.

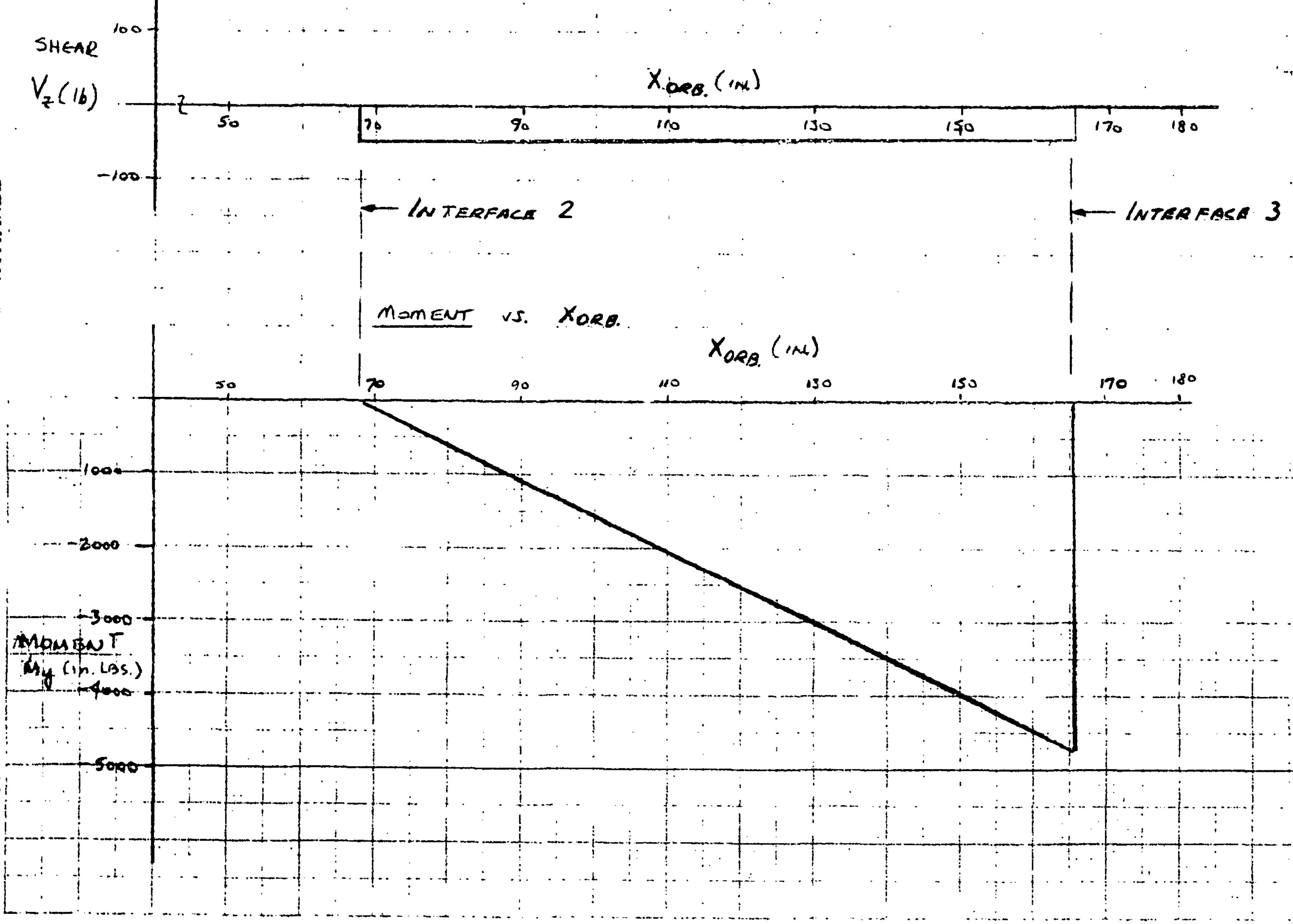
ORBITER SUPPORTED BY NOSE AND APT INTERSTAGE FOR VERTICAL LIFTING



ORBITER SHEAR AND BENDING MOMENT DIAGRAMS

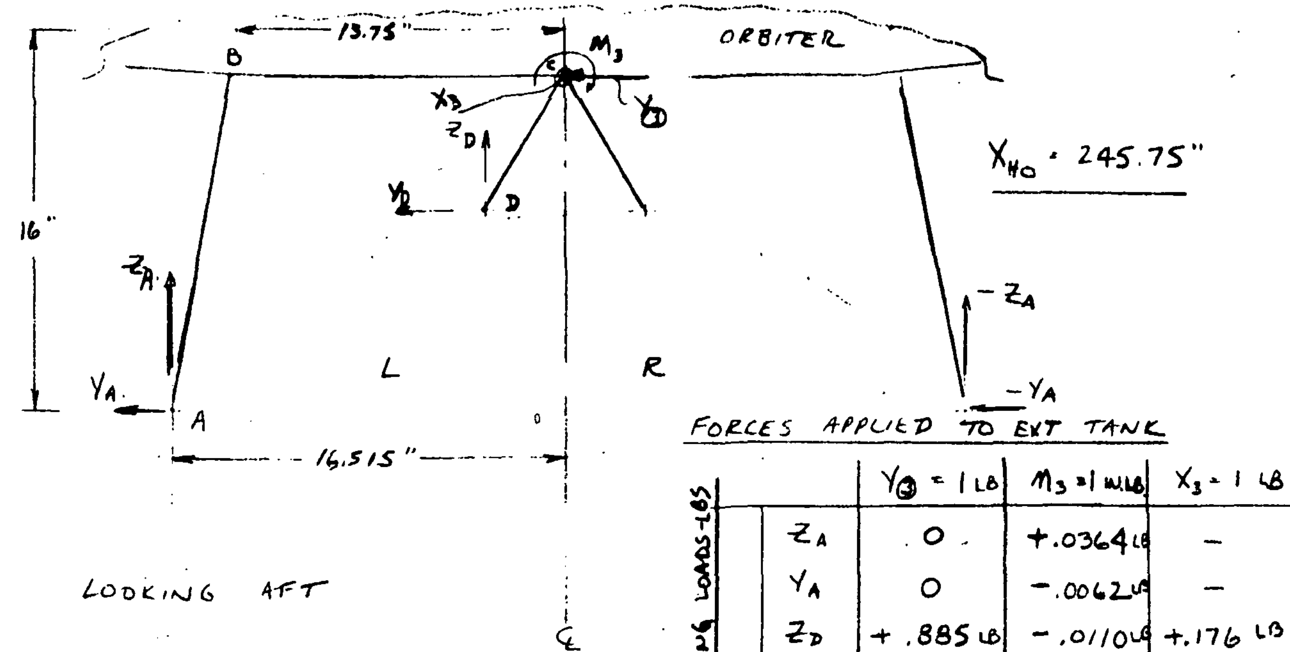
$n_x = 1g$ LOAD CONDITION, ORBITER WT = 654 LBS.

ORBITER SUPPORTED BY NOSE FITTING FOR VERTICAL LIFT



1/8 SCALE DYNAMIC MODEL

INTERFACE 3 – (TANK/ORBITER) GEOMETRY (SCHEMATIC) AFT INTERSTAGE



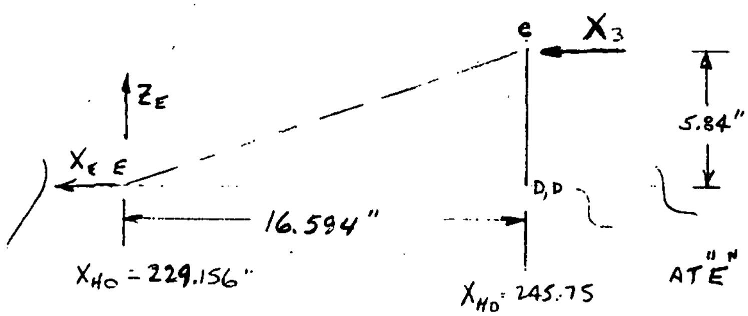
FORCES APPLIED TO EXT TANK

RESULTING LOADS-LBS	Y_3 = 1 LB	M_3 = 1 IN LB	X_3 = 1 LB
Z_A	0	+.0364 LB	–
Y_A	0	–.0062 LB	–
Z_D	+ .885 LB	–.0110 LB	+.176 LB
Y_D	+ .5 LB	+.0062 LB	–.099 LB
AB	0	+.037 LB	–
CD	–1.016 LB	–.0126 LB	+.202 LB

INTERFACE 3

(AFT INTERSTAGE) GEOMETRY (EXT TANK)

FORCES APPLIED TO HO TANK



FOR X_3 = 1 LB

$\overline{CE}$ = – 1.060 LB

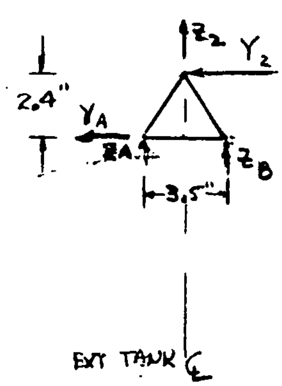
$\overline{CD}$ = + .352 LB

AT "E" $\begin{cases} X_E = 1.000 \text{ LB} \\ Z_E = -.352 \text{ LB} \end{cases}$

INTERFACE 2

(FWD. INTERSTAGE) GEOMETRY (X_{Ho} = 148.756") LOOKING AFT

FORCES APPLIED TO EXT TANK



RESULTING LOADS-LBS	Z_2 = 1 LB	Y_2 = 1 LB
Z_A	.5 LB	–.685 LB
Y_A	–	1.000 LB
Z_B	.5 LB	+ .685 LB

1/8 SCALE DYNAMIC MODEL

ULT. ORBITER - HO TANK INTERSTAGE TRUSS MEMBER LOADS

LOADS AT INTERFACE DUE TO EXT TANK LOAD CONDITIONS

[ALL LOADS IN LBS, MOMENTS IN IN.-LBS]

		HANDLING APPLIED LOADS FROM P. 26			LATERAL APPLIED LOADS	
		B_0	$B \times O_2 \perp$	E	$Y_0 = \pm 491$ (1)	$Z_0 = \pm 491$ (1)
INTER FACE 2	Y_2	—	—	—	$\pm$ 142	—
	Z_2	+ 226	− 20	+ 222	—	$\pm$ 142
INTER FACE 3	X_3	− 1962	+ 1080	− 1132	—	—
	Y_3	—	—	—	$\pm$ 349	—
	Z_3	− 226	+ 20	+ 93	—	$\pm$ 349
	M_y	—	—	—	$\mp$ 5892	—

(1) ULTIMATE LATERAL LOAD $= (0.5)(1.5)(654 \text{ LBS.}) = 491$ LBS

ULTIMATE LOADS (2) IN SUPPORT TRUSSES AND AT TANK SUPPORT POINTS DETERMINED FROM TABLE ABOVE AND UNIT LOAD DISTRIBUTION ON P. 34

LOCATION OF RESULTING FORCES		HANDLING LOAD CONDITIONS			LATERAL CONDITIONS		DESIGN ULTIMATE *	
		B_0	$B \times O_2 \perp$	E	$Y_0 = \pm 491$	$Z_0 = \pm 491$	MAX +	MAX −
INTER FACE 2	Y_A	—	—	—	$\pm$ 142	—	+ 142	− 142
	Z_A	+ 113	− 10	+ 111	$\mp$ 98	$\pm$ 71	+ 211	− 108
	Z_B	+ 113	− 10	+ 111	$\mp$ 98	$\pm$ 71	+ 211	− 108
INTER FACE 3	AB (1)	− 113	+ 10	+ 47	$\mp$ 218	$\pm$ 175	+ 265	− 331
	CD	− 396	+ 218	− 229	$\mp$ 280	—	+ 498	− 676
	CE	+ 2080	− 1145	+ 1200	—	—	+ 2080	− 1145
	Y_A	+ 19	− 2	− 8	$\pm$ 37	$\mp$ 30	+ 56	− 45
	Z_A	− 113	+ 10	+ 47	$\mp$ 214	$\pm$ 175	− 327	+ 261
	Y_D	+ 194	− 107	+ 112	$\pm$ 211	—	+ 405	− 318
	Z_D	− 345	+ 190	− 199	$\pm$ 373	—	− 718	+ 563
	X_E	− 1962	+ 1080	− 1132	—	—	+ 1080	− 1962
	Z_E	691	− 380	+ 399	—	—	− 380	+ 691

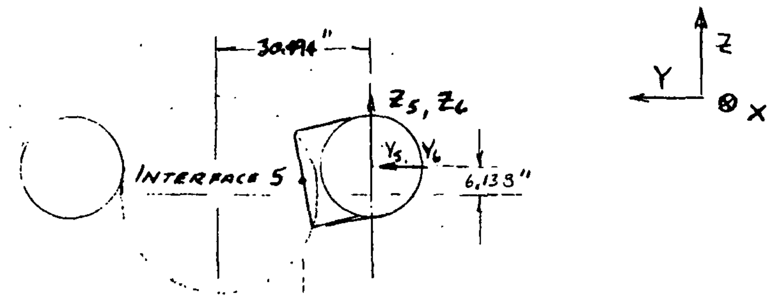
* COMBINATION OF HIGHEST HANDLING AND LATERAL CONDITION

(1) FOR TRUSSES (+) DENOTES TENSION (−) DENOTES COMPRESSION

(2) ALL LOADS IN LBS.

1/8 SCALE DYNAMIC MODEL

SRM LOADING AND REACTIONS AT HO TANK



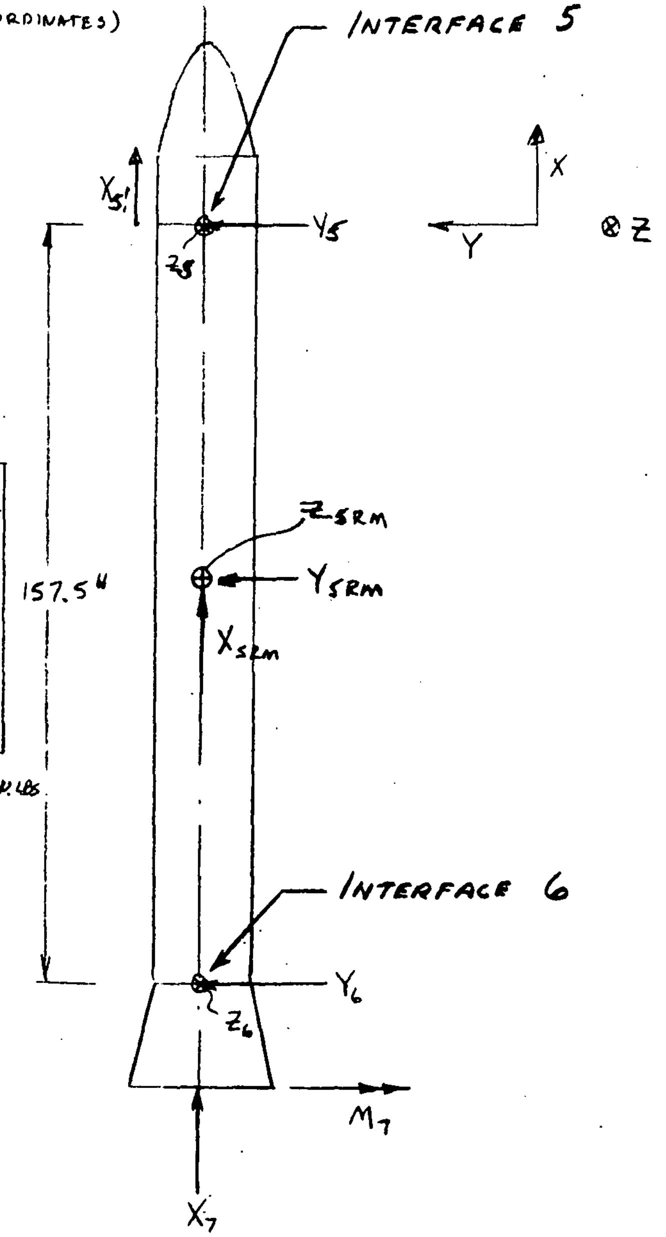
COORDINATES OF INTERSTAGE 5 (EXT TANK COORDINATES)

$Z = 12.887 - \frac{12.887 + 5.74}{2} = 3.574''$

$Y = \frac{19.628 + 15.879}{2} = 17.753''$

$X_{5'} = 113.488''$

$X_6 = 271''$



UNIT APPLIED LOADS TO SRM

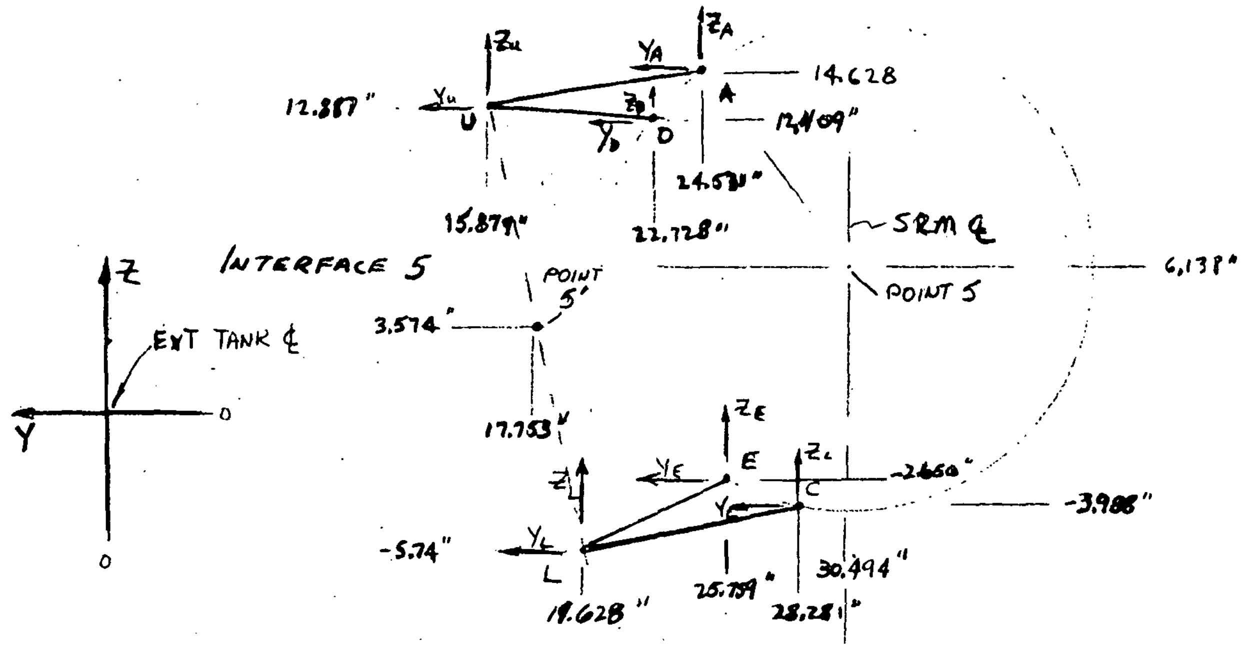
RESULTING FORCES ON EXT TANK.

	$X_7 = 1$ $X_{SRM} = 1$	$Y_{SRM} = 1$	$Z_{SRM} = 1$	$M_7 = 1$
$X_{5'}$	1	—	—	—
Y_5	+.081	.5	—	—
Z_5	-.016	—	.5	-.0064
Y_6	-.081	.5	—	—
Z_6	+.016	—	.5	+.0064

ALL LOADS IN LBS, MOMENTS IN IN.LBS

1/8 SCALE DYNAMIC MODEL

INTERFACE 5 EXT TANK ATTACHMENT (DRAG TRUSS)



DISTANCES IN INCHES FOR STRUTS SHOWN ABOVE

X_{STA} (SRM)	PTS
22.5	U,A,C,L
38.5	DE

	ΔX	ΔY	ΔZ	ℓ	X/ℓ	Y/ℓ	Z/ℓ
AU	0	8.652	1.741	8.825	—	.980	.197
UD	16.25	6.849	-.473	17.641	.921	.388	-.027
CL	0	8.653	1.742	8.827	—	.980	.197
LE	16.25	6.131	3.090	17.641	.921	.348	.175

FOR $X_{5'} = 1 LB$; THEN $X_U = .5 LB$ & $X_L = .5 LB$,

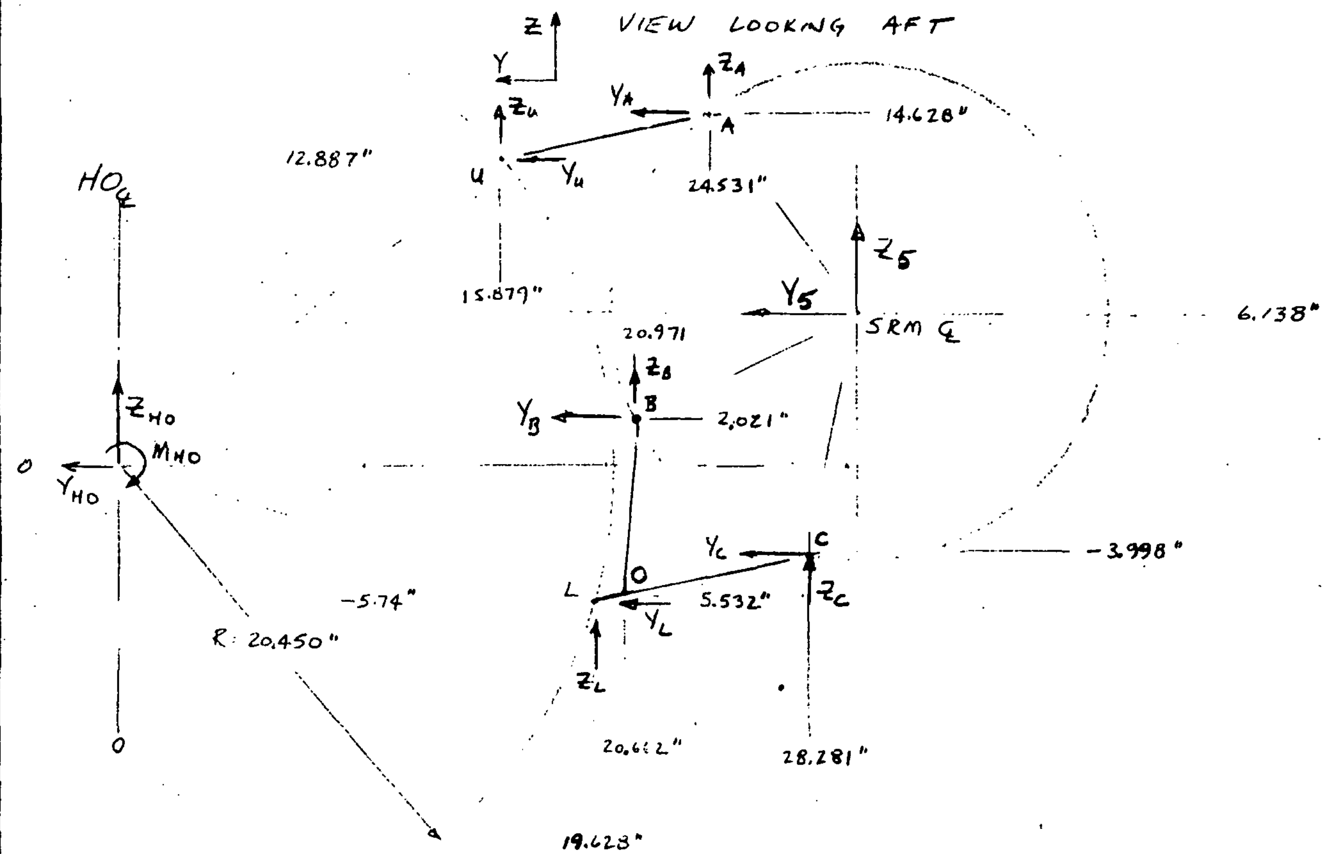
FORCE @		$X_U = .5$
EXT TANK	Z_U	-.055
	Y_U	-.011
TRUSS	AU	.204
	UD	-.543
SRM	Z_A	-.040
	Y_A	+.200
	Z_D	-.014
	Y_D	-.211
	X_D	+.500

FORCE @		$X_L = .5$
EXT TANK	Z_L	+.055
	Y_L	+.011
TRUSS	CL	.204
	LE	-.543
SRM	Z_C	-.040
	Y_C	+.200
	Z_E	+.095
	Y_E	-.189
	X_E	+.500

(ALL FORCES IN LBS.)

1/8 SCALE DYNAMIC MODEL

INTERFACE 5 - HO TANK ATTACHMENT GEOMETRY (IN PLANE YZ)

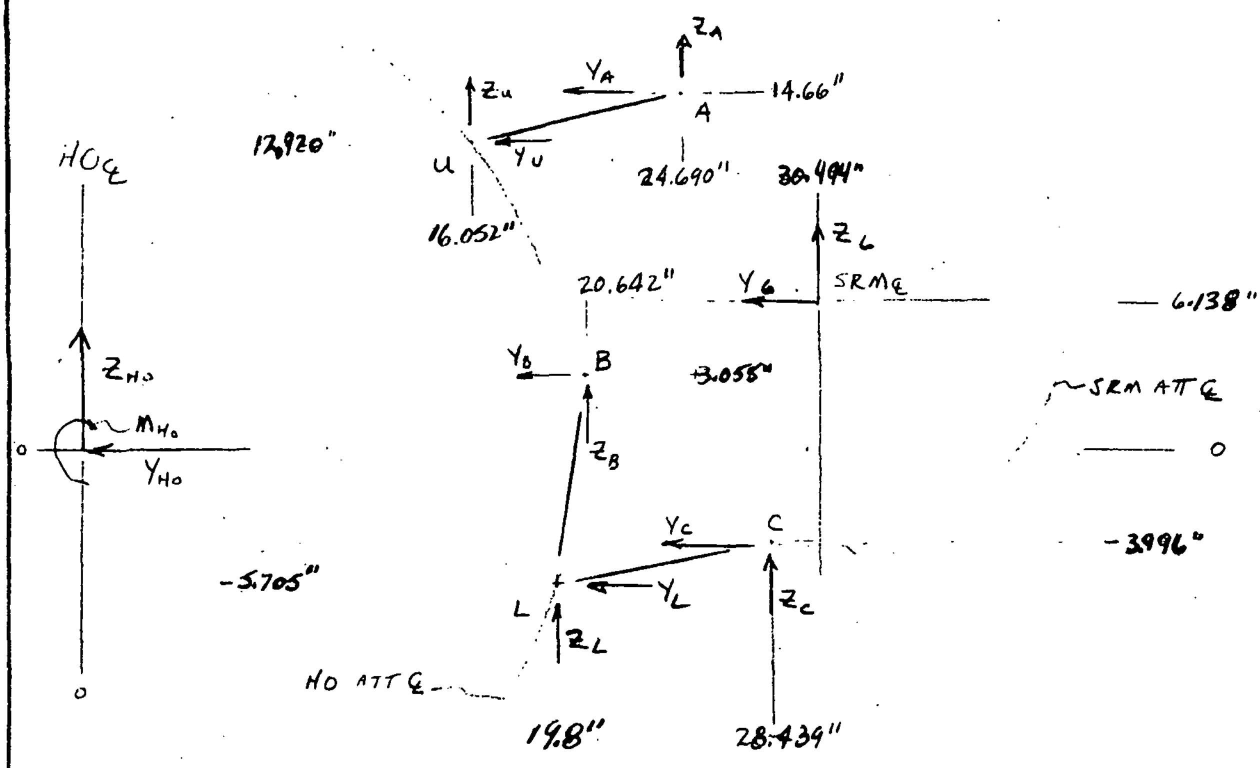


FORCES DUE TO LOADS & MOMENTS APPLIED TO SRM AND EXT TANK (HO) -

	FORCE AT	Z_5 = 1 LB	Y_5 = 1 LB	Z_{HO} = 1 LB	Y_{HO} = 1 LB	M_{HO} = 1 IN LB
HO	Z_u	-.113	-.123	-.204	+.060	-.0104
	Y_u	+.561	+.613	+1.013	-.296	+.0516
	Z_L	+1.113	+.123	-.796	-.060	+.0104
	Y_L	-.561	+.387	-1.013	-.704	-.0516
TRUSS	AU	-.572	-.625	-1.033	.302	-.0526
	BO	+1.108	+.223	-1.108	-.223	0
	LOC	+.507	-.368	+1.098	+.731	+.0526
	LC at C SHEAR	.096	.177	.102	.020	0
SRM	Z_A	+.113	+.123	+.204	-.060	+.0104
	Y_A	-.561	-.613	-1.013	+.296	-.0516
	Z_B	-1.107	-.223	1.107	+.223	0
	Y_B	+.045	+.009	-.045	-.009	0
	Z_C	-.006	+.100	-.311	-.163	-.0104
	Y_C	+.516	-.396	+1.058	+.713	+.0516

$1/8$ SCALE DYNAMIC MODEL

INTERFACE 6 - HO TANK ATTACHMENT GEOMETRY



	FORCE AT	$Z_6 = 1$	$Y_6 = 1$	$Z_{HO} = 1$	$Y_{HO} = 1$	$M_{HO} = 1$
HO	Z_u	-.111	-.123	-.206	+.059	-.0104
	Y_u	+.552	+.611	1.022	-.294	+.0516
	Z_L	+1.111	+.123	-.794	-.059	+.0104
	Y_L	-.552	+.389	-1.022	-.706	-.0516
TRUSS (+TENSION)	AU	-.563	-.623	-1.042	+.300	-.0526
	BL	+1.024	+.206	-1.024	-.206	0
	CL	+.463	-.417	+1.143	+.741	+.0526
SRM	Z_A	+.111	+.123	+.206	-.059	+.0104
	Y_A	-.552	-.611	-1.022	+.294	-.0516
	Z_B	-1.020	-.205	+1.019	+.205	0
	Y_B	+.098	+.020	-.098	-.020	0
	Z_C	-.091	+.082	-.225	-.146	-.0104
	Y_C	+.454	-.409	+1.120	+.726	+.0516

FORCES TABULATED ARE APPLIED TO HO, SRM

1/8 SCALE DYNAMIC MODEL

SUMMARY OF INTERFACE INFLUENCE COEFFICIENTS

R = RADIAL, + OUTWARD
T = TANGENTIAL, + CLOCKWISE

AT INTERFACE 5 – $X_{STA\,HO}$ = 113488 $X_{STA\,SEM}$ = 38.5

	FORCE AT	$X_T + Y_{sem} = 1$	$Y_{sem} = 1$	$Z_{sem} = 1$	$M_y = 1$
HO TANK	X_U	+.5	0	0	0
	R_U	-.063	-.277	-.253	+.003
	T_U	+.030	-.145	-.133	+.002
	X_L	+.5	0	0	0
	R_L	-.063	-.203	+.113	-.001
	T_L	-.031	-.005	-.613	+.008
STRUTS	AU	-.246	-.313	-.286	+.004
	UD	+.543	–	–	–
	$LOC_{A,T}$	-.242	-.184	+.254	-.003
	LOC_V	–	+.089	+.048	-.001
	BO	0	+.112	+.554	-.007
	LE	+.543	–	–	–
SRM	R_A	-.099	-.126	-.115	+.002
	T_A	+.225	+.286	+.262	- 003
	R_B	+ 0	+.048	+.240	-.003
	T_B	- 0	-.101	-.499	+.006
	R_C	-.098	-.091	+.058	-.001
	T_C	-.225	-.183	+.251	-.003
	X_D*	-.5			
	R_D*	+.173			
	T_D*	-.122			
	X_E*	-.5			
	R_E*	+.173			
	T_E*	+.122			

* LOADS AT X STATION SEM 22

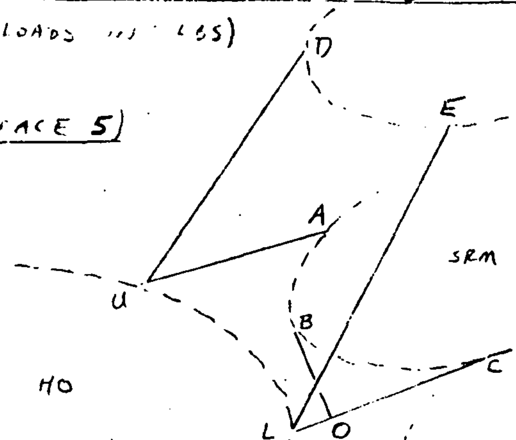
AT INTERFACE 6 – $X_{STA\,SEM}$ = 196., $X_{STA\,HO}$ = 271.

		$X_{SRM} + X_T = 1$	$Y_{SRM} = 1$	$Z_{SRM} = 1$	$M_Y = 1$
HO TANK	R_U	+.037	-.277	-.245	-.003
	T_U	-.019	-.144	-.130	-.002
	R_L	+.037	-.204	+.111	+.001
	T_L	-.019	-.005	-.610	-.008
STRUTS	AU	+.041	-.312	-.282	-.004
	BL	-.000	+.103	+.512	+.007
	CL	+.041	-.209	+.232	+.003
SRM	R_A	+.016	-.121	-.110	-.001
	T_A	-.038	+.287	+.260	+.003
	R_B	0	+.040	+.199	+.003
	T_C	+.0	-.095	-.472	-.006
	R_C	+.016	-.081	+.067	+.001
	T_C	+.038	-.209	+.213	+.003

1/8 SCALE DYNAMIC MODEL

ULTIMATE SRM SUPPORT TRUSS MEMBER LOADS
(ALL LOADS IN LBS)

AT FWD (INTERFACE 5)

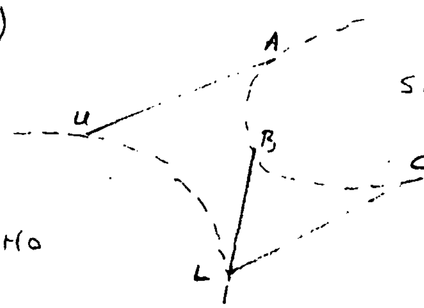


$.75(2750) = 2060^{*}$

	HANDLING APPLIED LOADS FROM P. 26 & P. 40				LATERAL APPLIED LOADS		DESIGN ULTIMATE*	
	A	B_o	$B \times O_2 \perp$	B	$Y_{SRM} = \pm 2060$	Z_{SRM} ±2060	MAX +	MAX −
AU	−869	−399	+1519	+1137	∓ 65	∓ 590	+2109	−1459
UD	+1921	+1074	−3360	−2684	−	−	+1921	−3360
LOC AX	−856	−555	+1497	+1264	∓ 380	± 523	+2020	−1379
LOC VC	−	−14	−	+13	± 183	± 99	+196	−197
BO	+1	−170	−2	+147	± 230	± 1143	+1270	−1313
LE	+1921	+1074	−3360	−2684	−	−	+1921	−3360

* COMBINATION OF HIGHEST HANDLING AND LATERAL CONDITION

AFT (INTERFACE 6)



	HANDLING APPLIED LOADS (P. 26 & P. 40)				LATERAL APPLIED LOADS		DESIGN ULTIMATE*	
	A	B_o	$B \times O_2 \perp$	B	Y_{SRM} ±2060	Z_{SRM} ±2060	MAX +	MAX −
AU	+146	−5	−256	−280	∓ 642	∓ 581	+808	−898
BL	−1	+156	+2	+138	± 212	± 1056	+1212	−900
CL	+146	+151	−255	−142	∓ 430	± 497	+648	−752

1/8 SCALE DYNAMIC MODEL

ULTIMATE SRM RING LOADINGS

[ALL LOADS IN LBS, +X IS FWD, +R IS RADIAL OUTWARD, +T IS TANGENTIAL CLOCKWISE]

AT STA. 22.5

	HANDLING LOADS				LATERAL LOADS		DESIGN ULTIMATE (1)	
	A	B_o	$B \times O_2 \perp$	B	$Y_{SRM} = \pm 2060$	$Z_{SRM} = 2060$	MAX +	MAX −
X_D*	− 1769	− 989	+ 3094	+ 2472	—	—	+ 3094	− 1769
R_D	+ 612	+ 342	− 1074	− 855	—	—	+ 612	− 1074
T_D	− 430	− 241	+ 752	+ 601	—	—	− 430	+ 752
X_E	− 1769	− 989	+ 3094	+ 2472	—	—	+ 3094	− 1769
R_E	+ 610	+ 341	− 1066	− 852	—	—	+ 610	− 1066
T_E	+ 431	+ 241	− 753	− 602	—	—	+ 431	− 753

* LOADS (X, RADIAL, TANGENTIAL APPLY TO LOCATION D ON PAGE 37)

AT STA. 38.5

	A	B_o	$B \times O_2 \perp$	B	$Y_{SRM} = \pm 2060$	$Z_{SRM} = \pm 2060$	DESIGN ULTIMATE (1) MAX +	MAX −
R_A	− 350	− 160	+ 613	+ 459	∓ 260	∓ 237	+ 873	− 610
T_A	+ 794	+ 375	− 1389	− 1040	± 590	± 540	− 1979	+ 1384
R_B	0	− 74	− 1	+ 64	± 100	± 496	+ 560*	− 570*
T_B	− 1	+ 153	+ 2	− 132	∓ 212	∓ 1030	+ 1183*	− 1162*
R_C	− 348	− 212	+ 609	+ 502	∓ 188	± 120	+ 797	− 536
T_C	− 794	− 521	+ 1389	+ 1177	∓ 377	± 519	+ 1908	− 1313

AT STA. 196.0

	A	B_o	$B \times O_2 \perp$	B	$Y_{SRM} = \pm 2060$	$Z_{SRM} = \pm 2060$	DESIGN ULTIMATE (1) MAX +	MAX −
R_A	+ 57	− 2	− 100	− 109	∓ 260	∓ 237	+ 317	− 369
T_A	− 135	+ 4	+ 236	+ 258	± 590	± 540	− 725	+ 848
R_B	0	+ 60	0	+ 53	± 100	± 496	+ 556*	− 496*
T_B	+ 1	− 144	− 2	− 128	∓ 212	∓ 1030	+ 1031*	− 1274*
R_C	+ 56	+ 60	− 98	− 61	∓ 188	± 120	+ 248	− 286
T_C	+ 134	+ 140	− 235	− 130	∓ 377	± 519	+ 659*	− 754*

* MAXIMUM LOADS BUT NOT TO BE CONSIDERED SIMULTANEOUSLY FOR COMBINING RADIAL AND TANGENTIAL VALUES

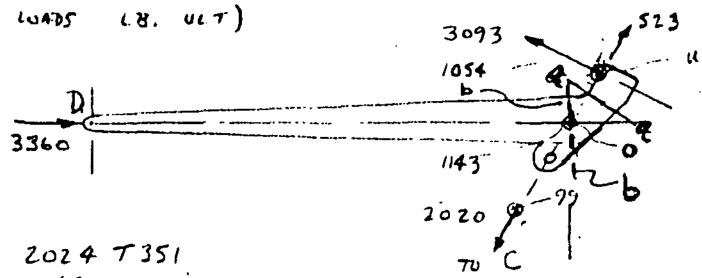
(1) COMBINATION OF HIGHEST LATERAL AND HANDLING CONDITION

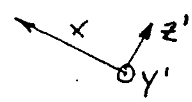
1/8 SCALE DYNAMIC MODEL

ANALYSIS OF TYPICAL SRM DRAG STRUT (REF AD383-521-13,15)

(ALL LOADS LB. ULT)

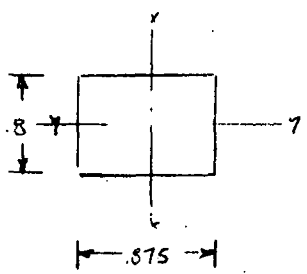
LOADS [REF p.41]





MAT'L: 2024 T351
F_{TU} : 62,000 psi

AT [a - a] (.62" FROM "U")



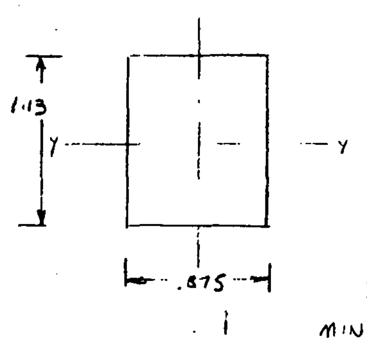
$$M_{xx} = 653 \text{ in lb} \quad , M_{yy} - 1915 \text{ in lb} , \quad P_A = 523 \text{ lb}$$

$$f_t = \frac{6(653)}{(.8)(.875)^2} + \frac{6(1915)}{(.875)(.8)^2} + \frac{523}{(.875)(.8)} = 750$$

$$= 6400 + 20600 + 750 = 27750 \text{ psi}$$

$$MS = \frac{62000}{27{,}750} - 1 = \underline{1.24}$$

AT [b - b] (1.1" FROM U)



$$M_{yy} = 3360\,(1.1) = 3700 \text{ in lb} \qquad P_{Ax} - 3360 \text{ lb.}$$

$$f_t : \frac{3700(6)}{(1.13)^2(.875)} + \frac{3360}{1.13(.875)} = 19950 + 3400 = 23350 \text{ psi}$$

CONSIDER COLUMN DO (CONSERVATIVE)

MINIMUM SECTION .65 x .875

$$F_c = \frac{\pi^2 E}{(L/\rho)^2} = 14{,}300 \text{ psi}$$

$$f_c \cdot \frac{3360}{(.65)(.875)} = 5920 \text{ psi}$$

$$\frac{f_c}{F_c} = .41 \quad \therefore \text{ NO MOMENT MAGNIFICATION}$$

$$MS = \frac{1}{.41 + \frac{23{,}350}{62{,}000}} - 1 = +\underline{0.27}$$

TABLES AND FIGURES

TABLE I

WEIGHT STATEMENT					PAGE 1 OF 1
CONFIGURATION	619				
CODE	SYSTEM	STACK ELEMENT ORB.	SRM	TANK	
1	WING GROUP	18017			
2	TAIL GROUP	3186			
3	BODY GROUP	38146	290312	50199	
4	INDUCED ENVIR. PROTECTION	29145		5999	
5	LANDING, RECOVERY, DOCKING	9613	5860		
6	PROPULSION-ASCENT	21816	27900	2350	
7	PROPULSION-CRUISE	217			
8	PROPULSION-AUXILIARY	5738			
9	PRIME POWER	3674			
10	ELECT CONVER. & DISTR.	2975			
11	HYDRA CONVER. & DISTR.	1546			
12	SURFACE CONTROLS	1538			
13	AVIONICS	6615	1720	469	
14	ENVIRONMENTAL CONTROL	4418			
15	PERSONNEL PROVISIONS	1068			
16	RANGE SAFETY & ABORT		500		
17	BALLAST				
18	GROWTH/UNCERTAINTY	13068	14340	1300	
	NOSE CONE			1134	
	SEPARATION & DEORBIT	100	1200	4854	
	SUBTOTAL (DRY WEIGHT)	160880	341832	66305	
20	PERSONNEL	1420			
21	CARGO (LANDED)	40000			
22	ORDNANCE (IGNITER)		1028		
23	RESIDUAL FLUIDS	1803		8186	
25	RESERVE FLUIDS (LANDED)	897		7333	
	SUBTOTAL (LANDED WEIGHT)	205000	342860	N. A.	
21	△ CARGO UP	25000			
2	FINS/SKIRT (STAGED)			10396	
5	RECOVERY SYS. (EXPENDED)		21220		
22	IGNITER (EXPENDED)		900		
25	RESERVE FLUIDS				
26	IN FLIGHT LOSSES	6432			
27	PROPELLANT-ASCENT		2452932	1560052	
28	PROPELLANT-CRUISE				
29	PROPELLANT-MANEUV./ACS	27396			
	SEP. SYS./NOSE CONE		5600		
	INSULATION/LINER		21200		
	ELEMENT GROSS WEIGHT	263828	2844712	1652272	
	ABORT SRM		68500		
	GLOW		4829312		

TABLE II

DRAWINGS OF 1/8 SCALE MODEL

DRAWING NUMBER	DESCRIPTION
AD383-500	Model Assembly Suspended (3 Sheets)
-501	Shuttle Model Assembly
-502	External Tank Assembly
-503	SRM Assembly
-504	Orbiter Assembly
-505	LO_2 Tank Assembly (2 sheets)
-506	Intertank Skirt Assembly
-507	LH_2 Tank Assembly (2 sheets)
-508	Aft Skirt Assembly
-510	SRM Forward Skirt Assembly
-511	SRM Propellant Cylinder Assembly
-512	SRM Aft Skirt Assembly
-514	LH_2 Tank Fitting Installation
-515	Rings for External Tank
-516	Intertank Skirt Frame Assembly
-517	LH_2 Tank Frame Assembly
-518	External Tank Aft Skirt Frame Assembly
-520	SRM Rings
-521	SRM-to-External Tank Thrust Fittings
-522	External Tank-to-Orbiter Thrust Fitting
-525	Orbiter Forward Section Assembly & Installation
-526	Orbiter Payload Bay Cover Assembly & Installation
-527	Orbiter Payload Module Installation
-528	Orbiter Aft Section Assembly
-529	Orbiter Wing Installation
-530	Orbiter Fuselage Side & Bottom Skin Panel Assembly and Installation
-531	Orbiter Keel Assembly and Installation
-532	Orbiter Wing Beam Carry-Through Assembly
-533	Orbiter Aft Interstage Fitting Assembly

TABLE II (continued)

DRAWING NUMBER	DESCRIPTION
-534	Orbiter Engine Support Bulkhead Assembly (2 sheets)
-535	Orbiter Fin Stub Installation
-536	Orbiter Fuselage Forward Frame Assembly
-537	Orbiter Abort SRM Installation
-538	Model Cosmetic Lines (2 sheets)
-539	Orbiter Engine Bulkhead (Station 180.009) Fittings

Note:

1. Two (or more) copies of each of the above drawings have been submitted separately to NASA/Langley for review.

2. These drawings are available from the Dynamic Loads Branch, Loads Division, NASA/Langley Research Center, Hampton, Virgina 23365

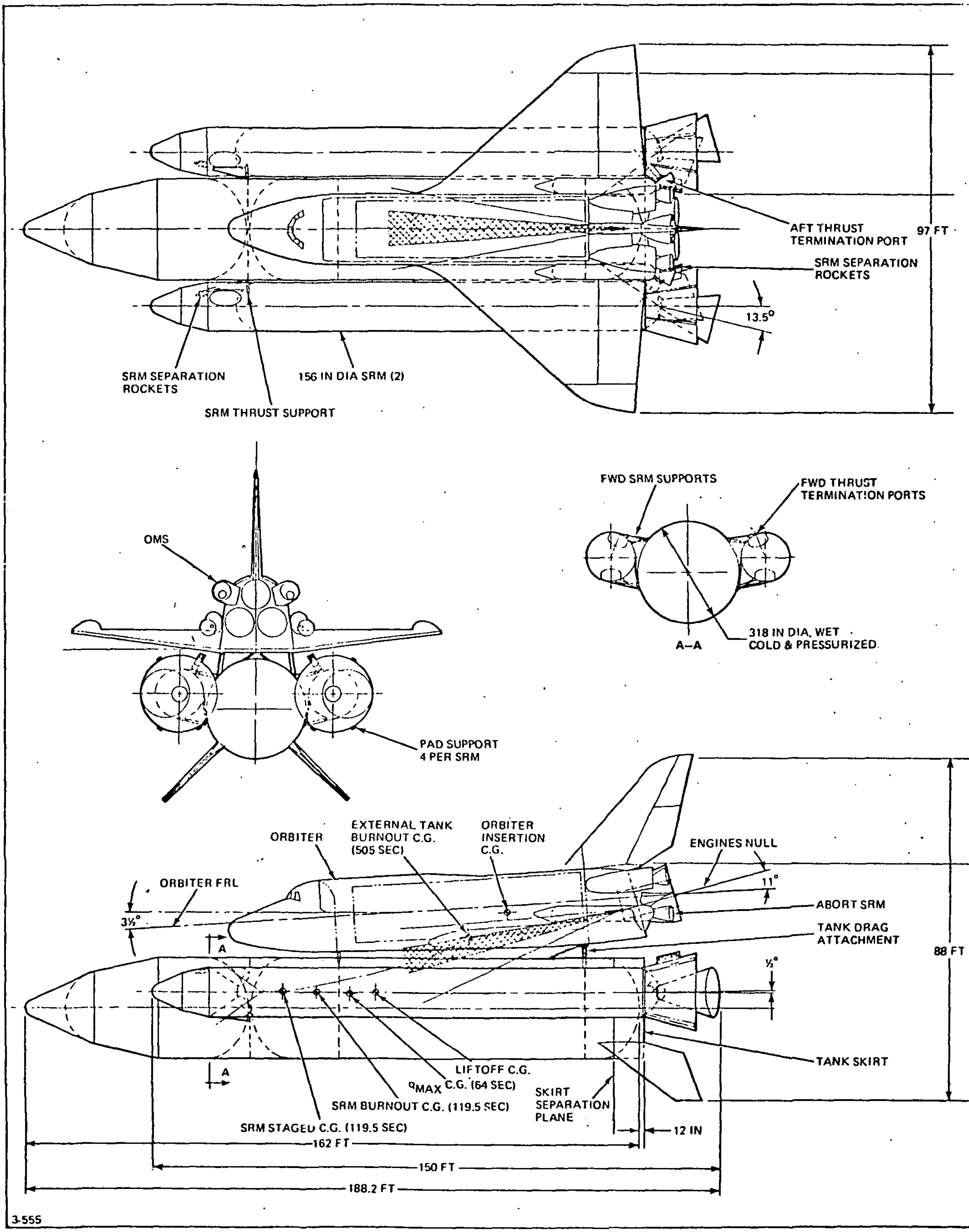


Fig. 1 Mated Flight System

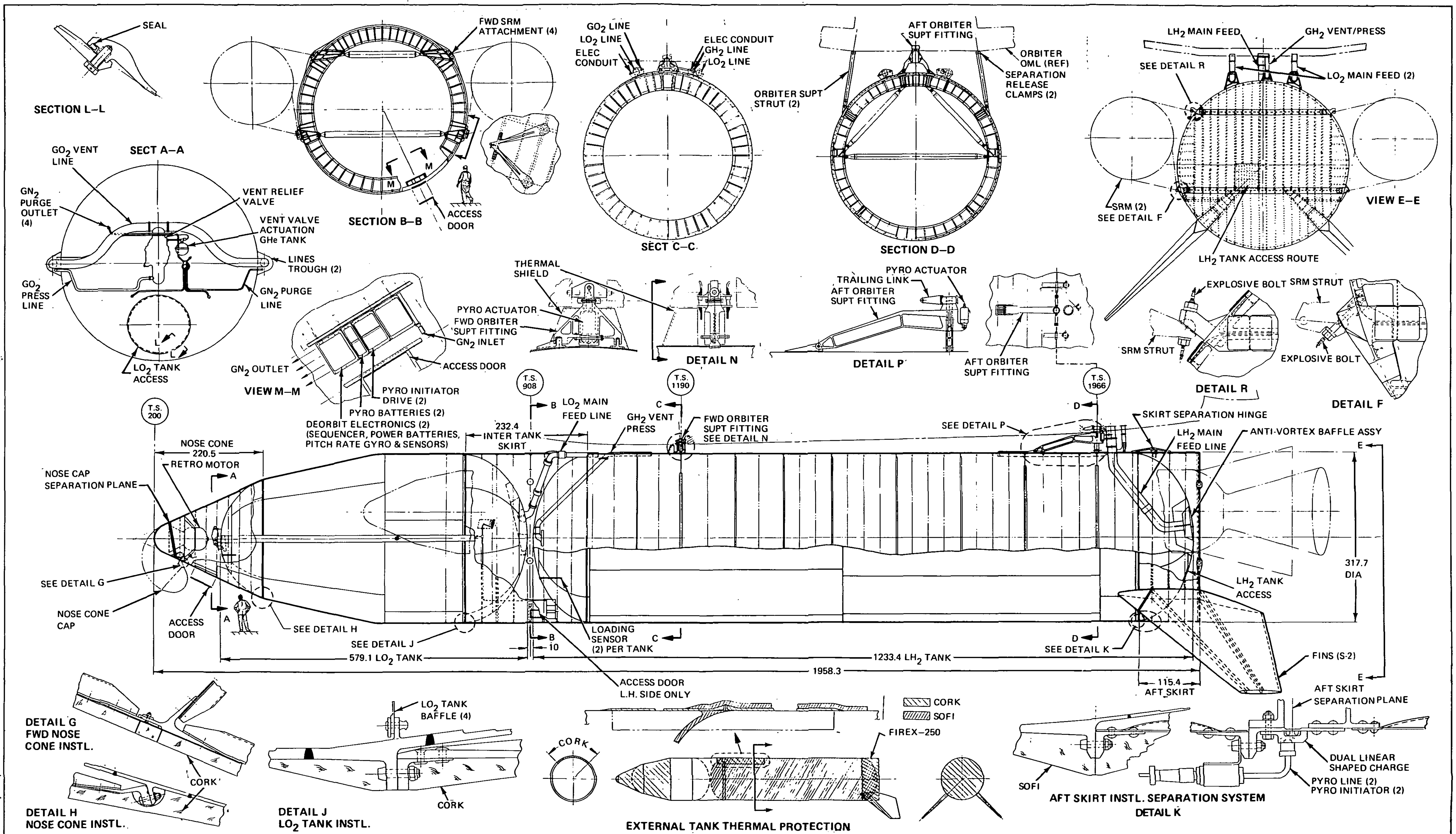


Fig. 2 External Tank Inboard Profile

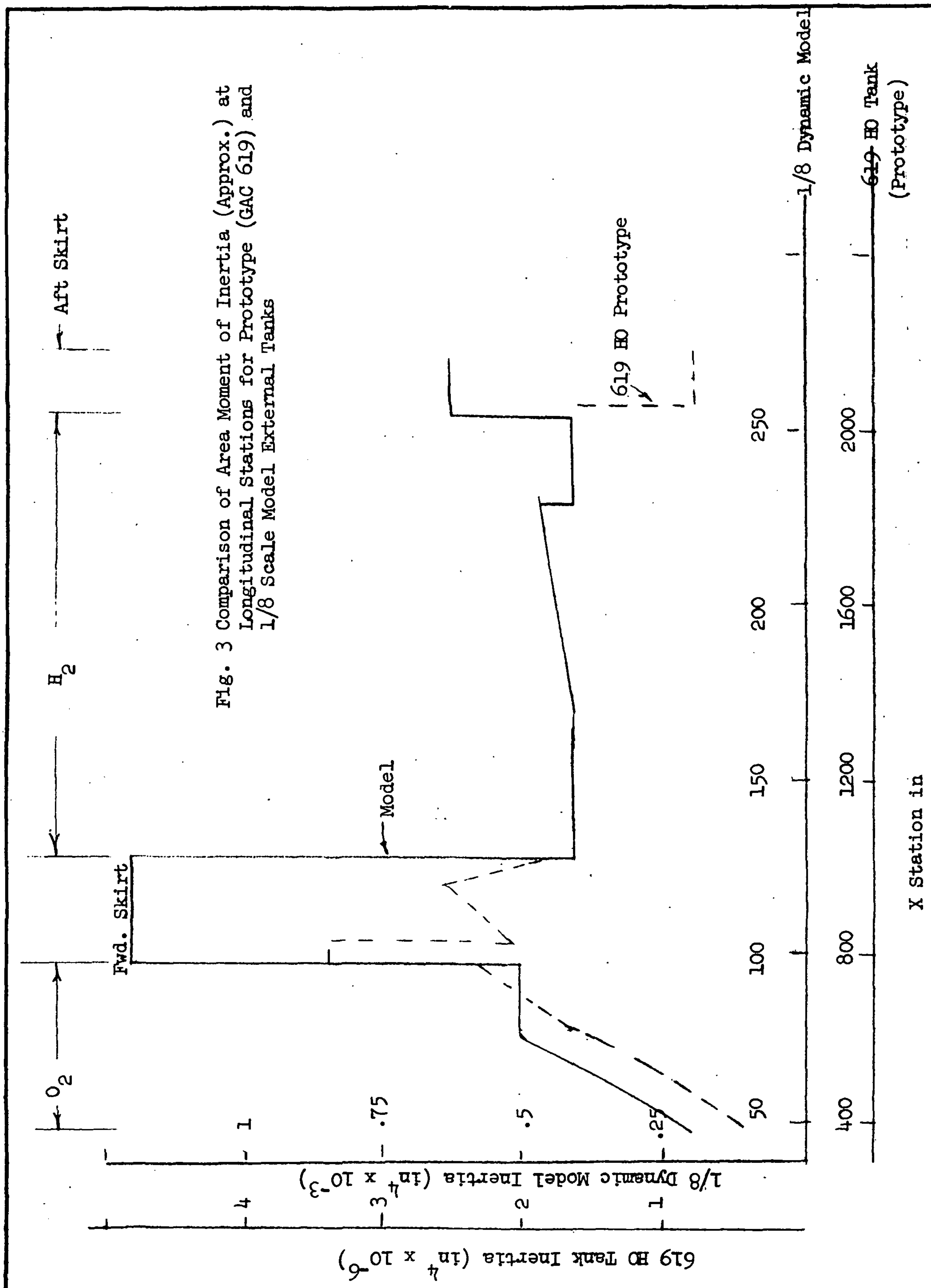
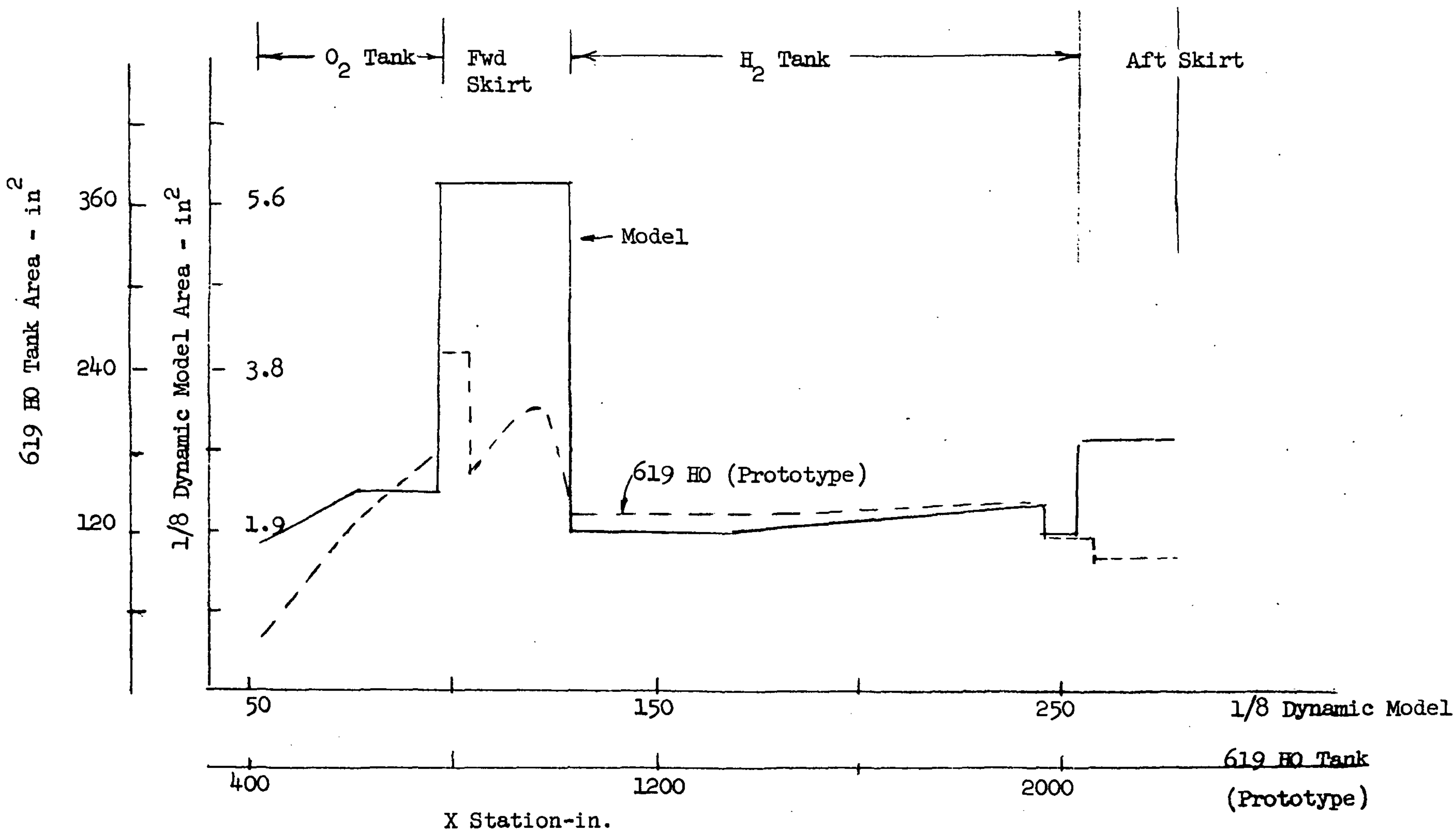
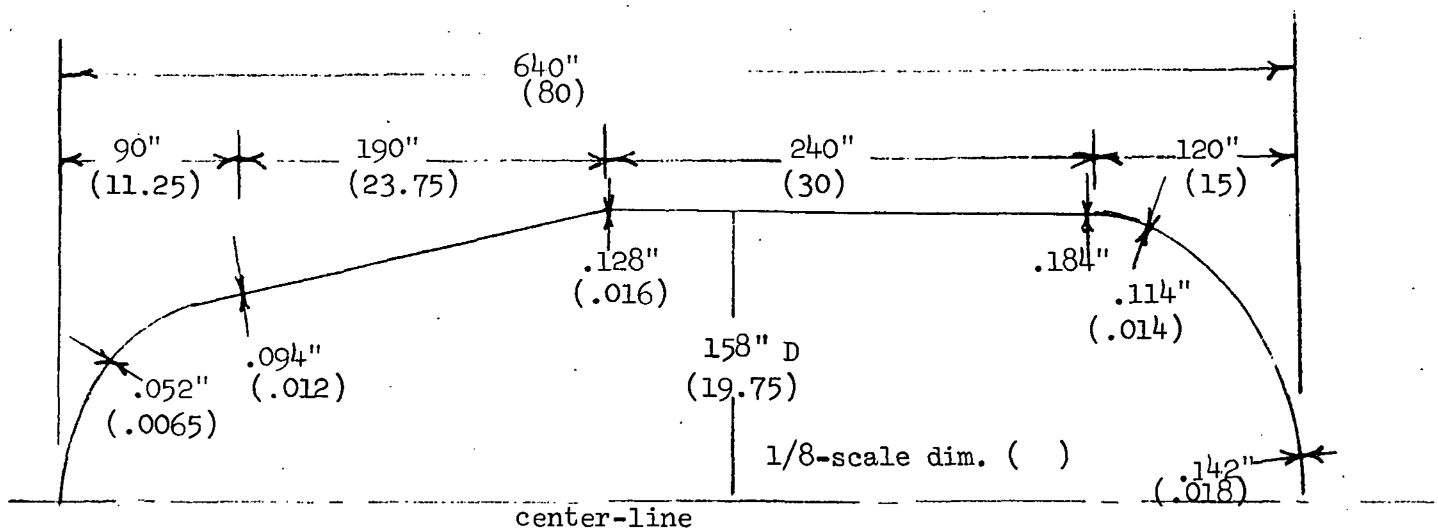


Fig. 3 Comparison of Area Moment of Inertia (Approx.) at Longitudinal Stations for Prototype (GAC 619) and 1/8 Scale Model External Tanks

Fig. 4 Comparison of Cross Sectional Areas (Approx) at Longitudinal Stations for Prototype (GAC 619) and 1/8 Scale Model External Tanks





APPROXIMATE PROTOTYPE LO_2 TANK DIMENSIONS

Figure 5

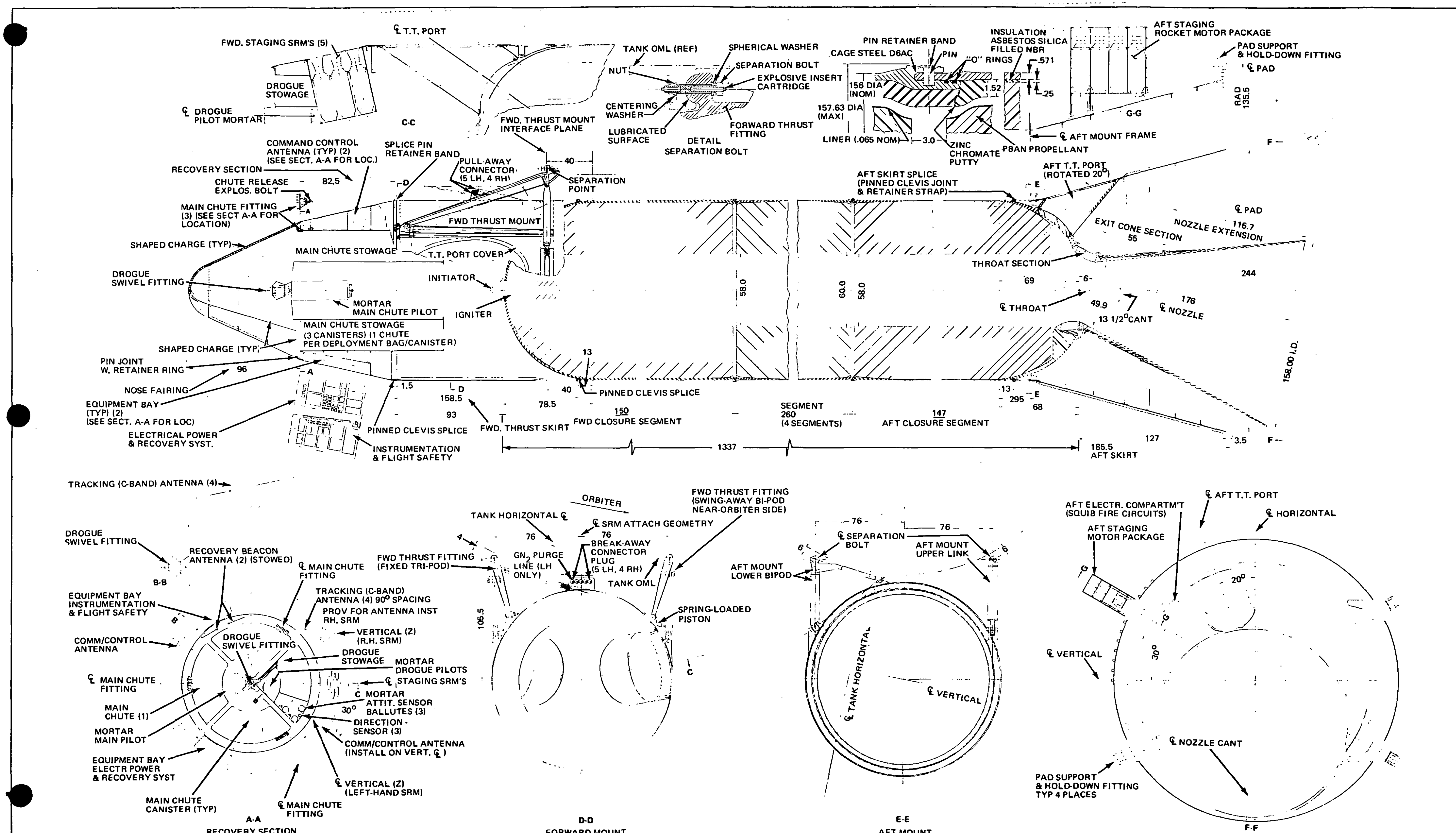


Fig. 6 SRM Inboard Profile

Structural Weight Summary

Component	Aluminum	Titanium	Non-Metallic	Total *
Fuselage				(38,146)
Nose	212		11	223
Crew Compartment	8203		2845	11048
Mid Fuselage	3871		613	4484
Side Panels	2348		326	2674
Payload Doors	3600		650	4250
Fwd Wing Carry-Thru	2497		287	2784
Aft Wing Carry-Thru	3660		343	4003
Aft Fuselage	3283	3611	644	7538
OMS Pods	742			742
RCS Pods	400			400
Wing				(18,017)
Fwd Exposed Wing	5343		675	6018
Aft Exposed Wing	7824		475	8299
Elevon	3700			3700
Tail				(3,186)
Fin	2226			2226
Upper Rudder	540			540
Lower Rudder	420			420
Total	48,869	3611	6869	59,349 LBS

* 10% growth not included

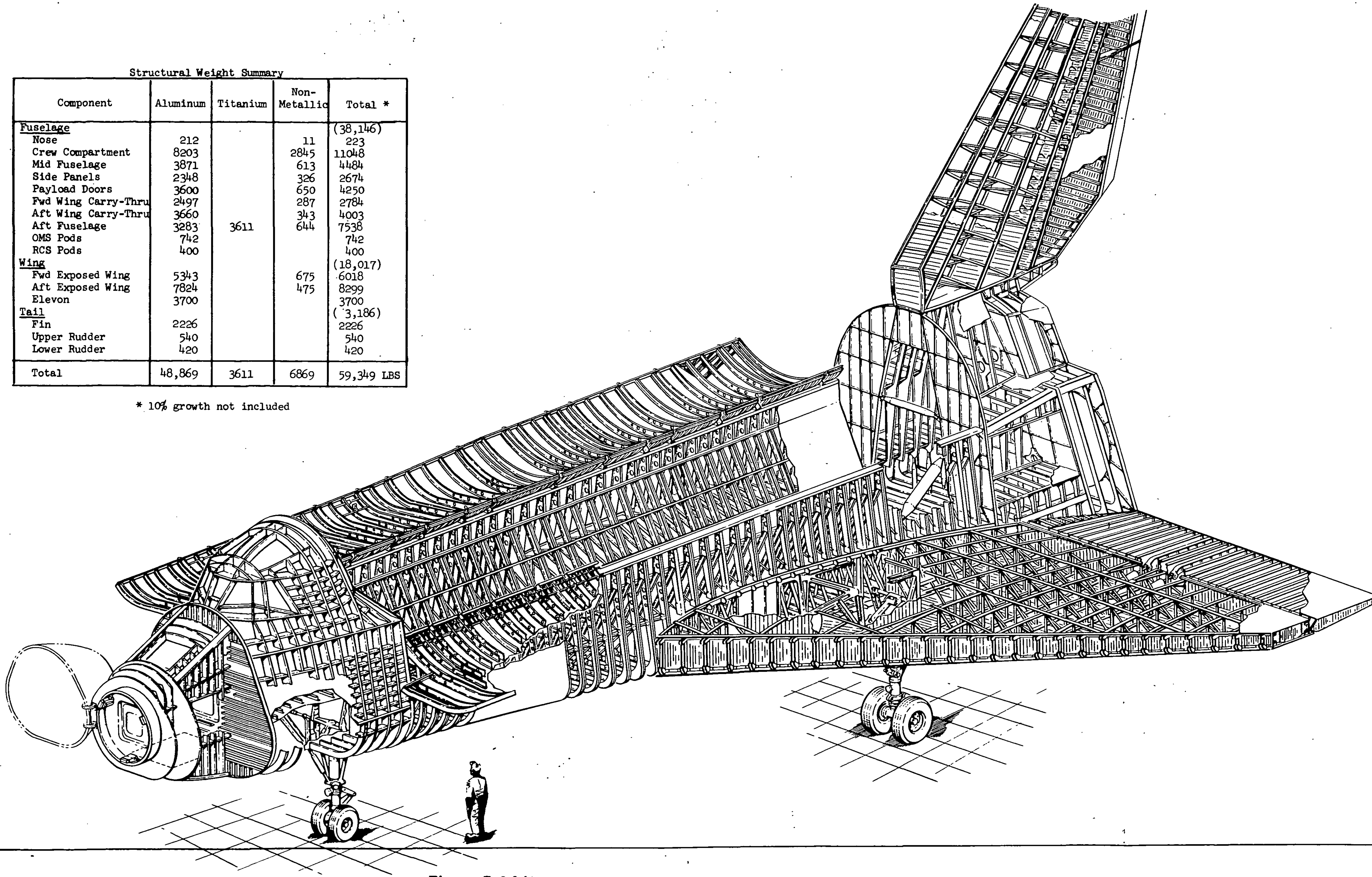


Figure 7 Orbiter Structural Arrangement

Fig. 8 - Comparison of Cross-Sectional Areas (Approx.) at Longitudinal Stations for Prototype (GAC 040S) and 1/8 Scale Model Orbiters

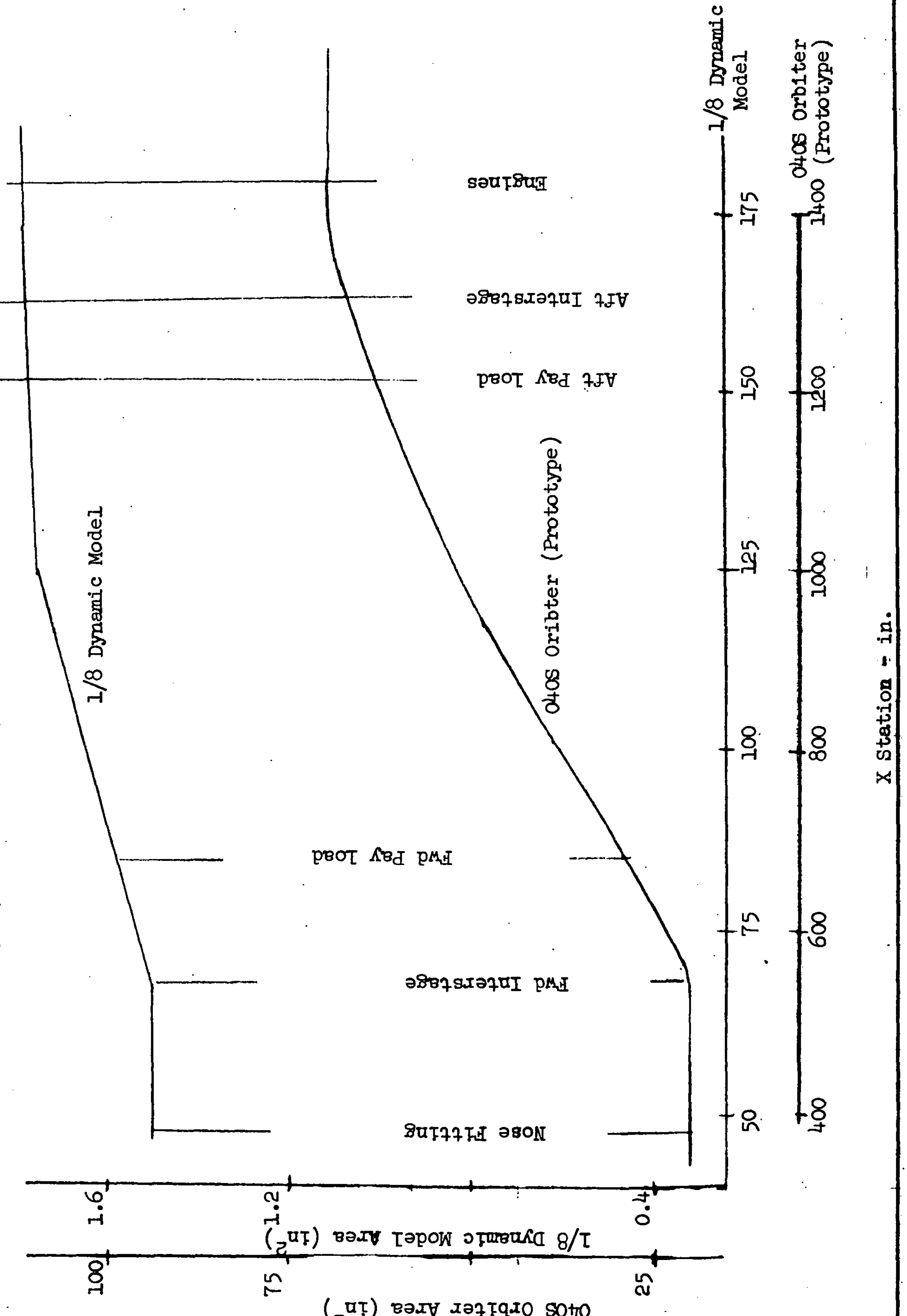
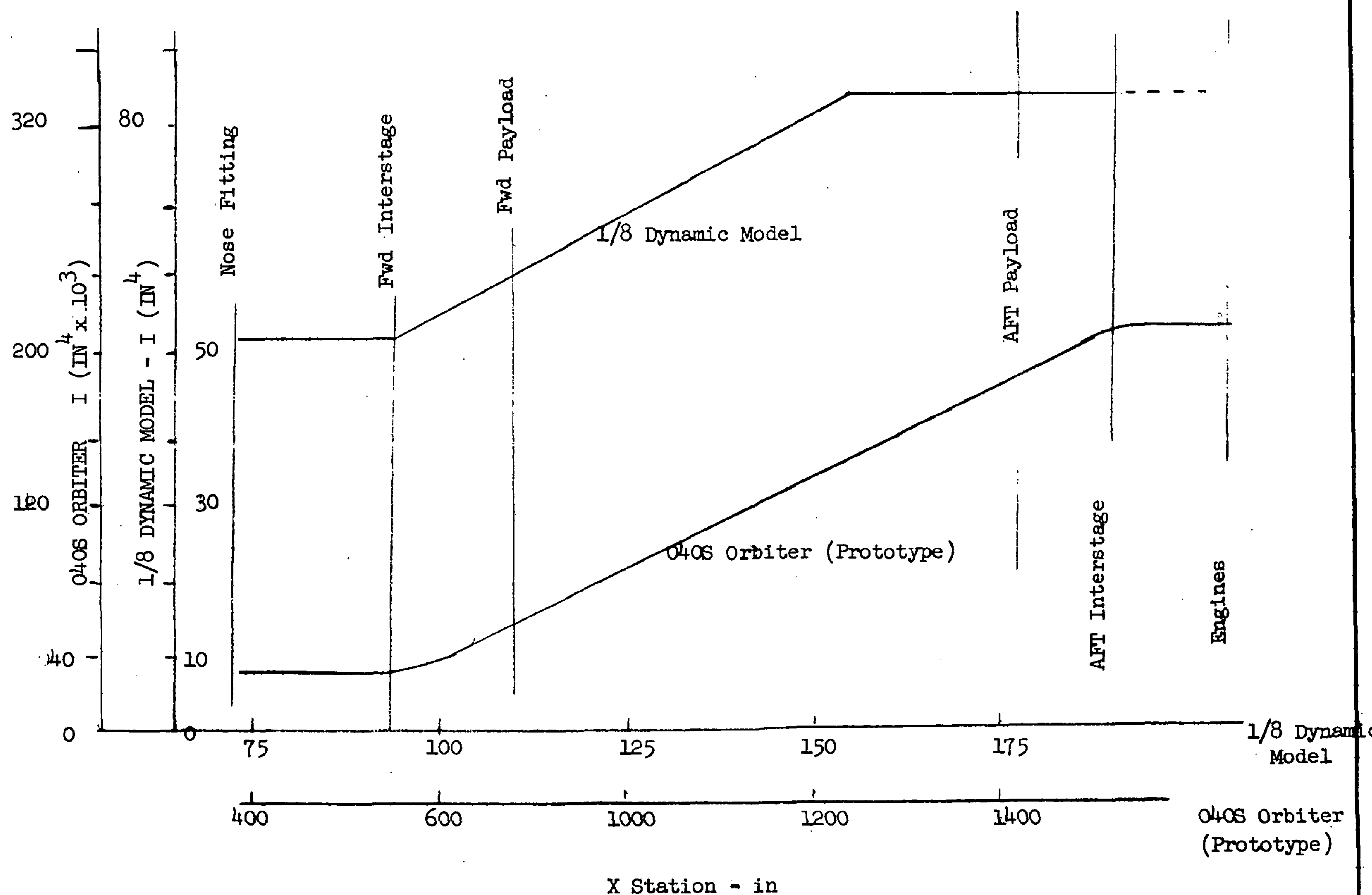
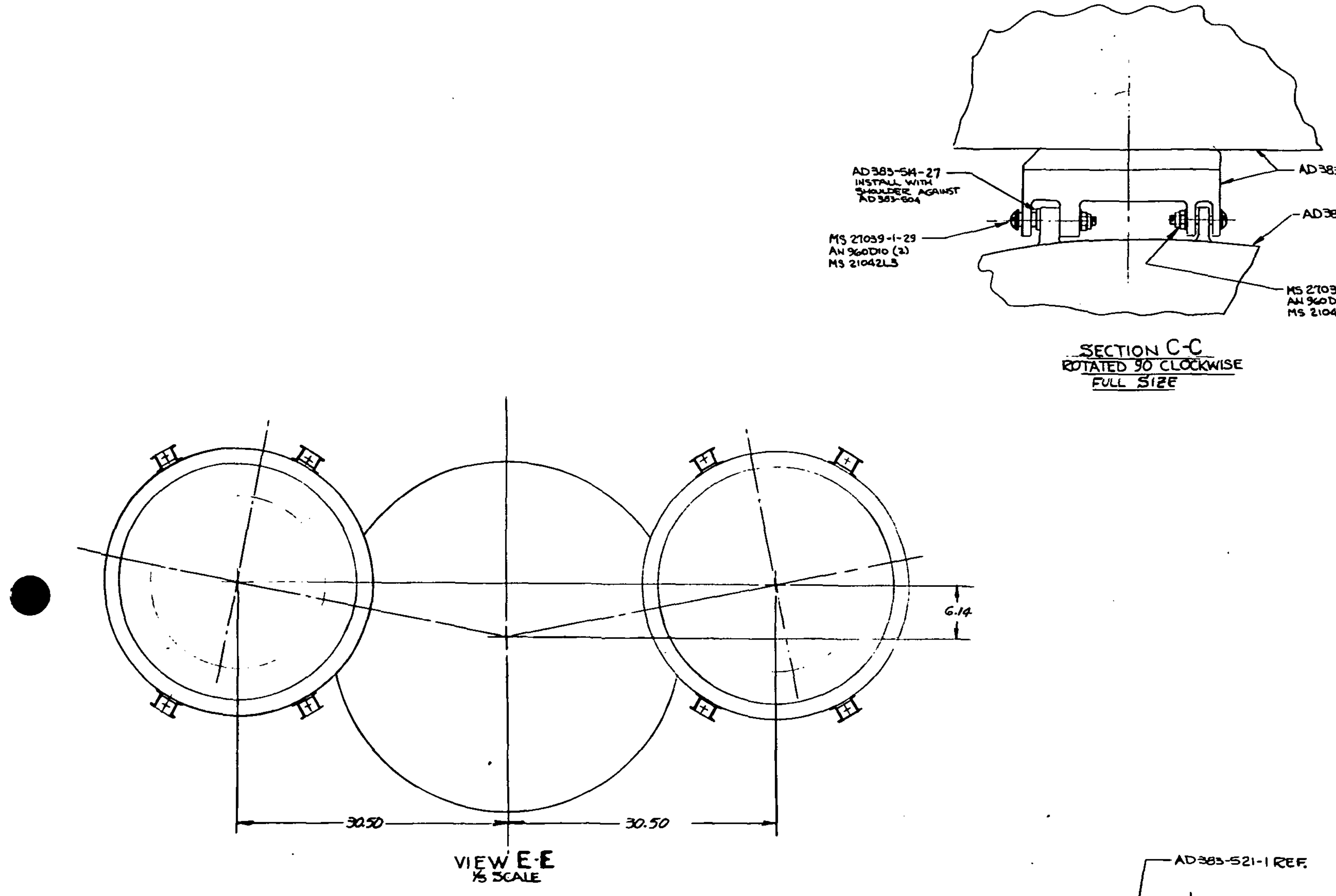


Fig. 9 - Comparison of Area Moment of Inertia at Longitudinal Stations for Prototype (GAC 040S) and 1/8 Scale Model Orbiters





INITIAL ERECTION PROCEDURE:~

1- STAND L.H & R.H SRM ASSYS ON LEVEL FLOOR AS SHN IN VIEW E-E. SRM ℄'S TO BE PARALLEL WITHIN ±.030.

2- LOWER INTERTANK (I/T) SKIRT ASSY BETWEEN PRE-POSITIONED SRM'S.

3- INSTALL LINK INSTALLATIONS AD383-521-1 & -2 AND WITH AD383-522-17 SPACERS IN PLACE INSERT BOLTS AS SHN IN DETAIL "D". DO NOT TIGHTEN NUTS.

4- POSITION & ASSEMBLE LO TANK ON UPPER FLANGE OF I/T SKIRT. CONNECT FLEXIBLE DRAIN LINE TO FITTINGS ON LO TANK AND I/T SKIRT. (REF DWGS AD383-502 & AD383-506 FOR HARDWARE.

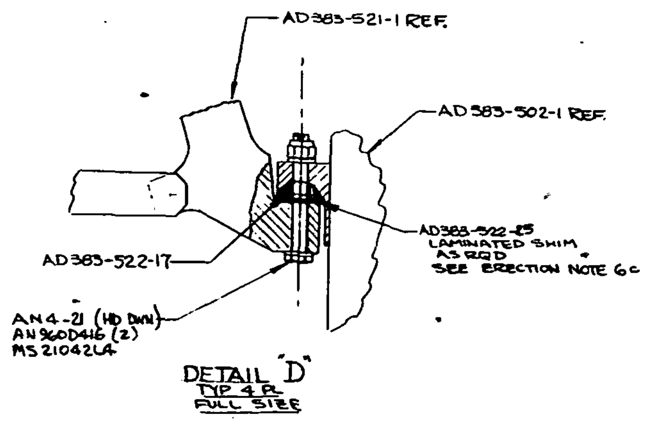
5- POSITION & ASSEMBLE LH TANK (WITH AFT SKIRT PRE-ASSEMBLED) ON LOWER FLANGE OF I/T SKIRT. (REF DWG AD383-506 FOR HARDWARE.

6- ALIGN ℄ OF HO TANK TO ℄ OF SRM'S AS FOLLOWS:~
   a/ WITH ONE JOINT AT HO TANK STA 113.49 BOTTOMED SPACER AD383-522-17 ALIGN ℄ OF HO TANK PARALLEL TO ℄ OF SRM'S
   b/ MEASURE GAPS AT OTHER THREE POINTS AT SPACERS ON HO STA 38.75
   c/ PEEL LAMINATED SHIM AD383-522-25 AS RQD & SLIP INTO GAP AT JOINT. TIE WITH SAFETY WIRE THRU HOLES PROVIDED.

7- WITH HO TANK ALIGNED, POSITION & INSTALL LWR LINK INST. AD383-518-1 ADJUST LGTH OF STRUTS, AS RQD & TIGHTEN LOCK NUTS

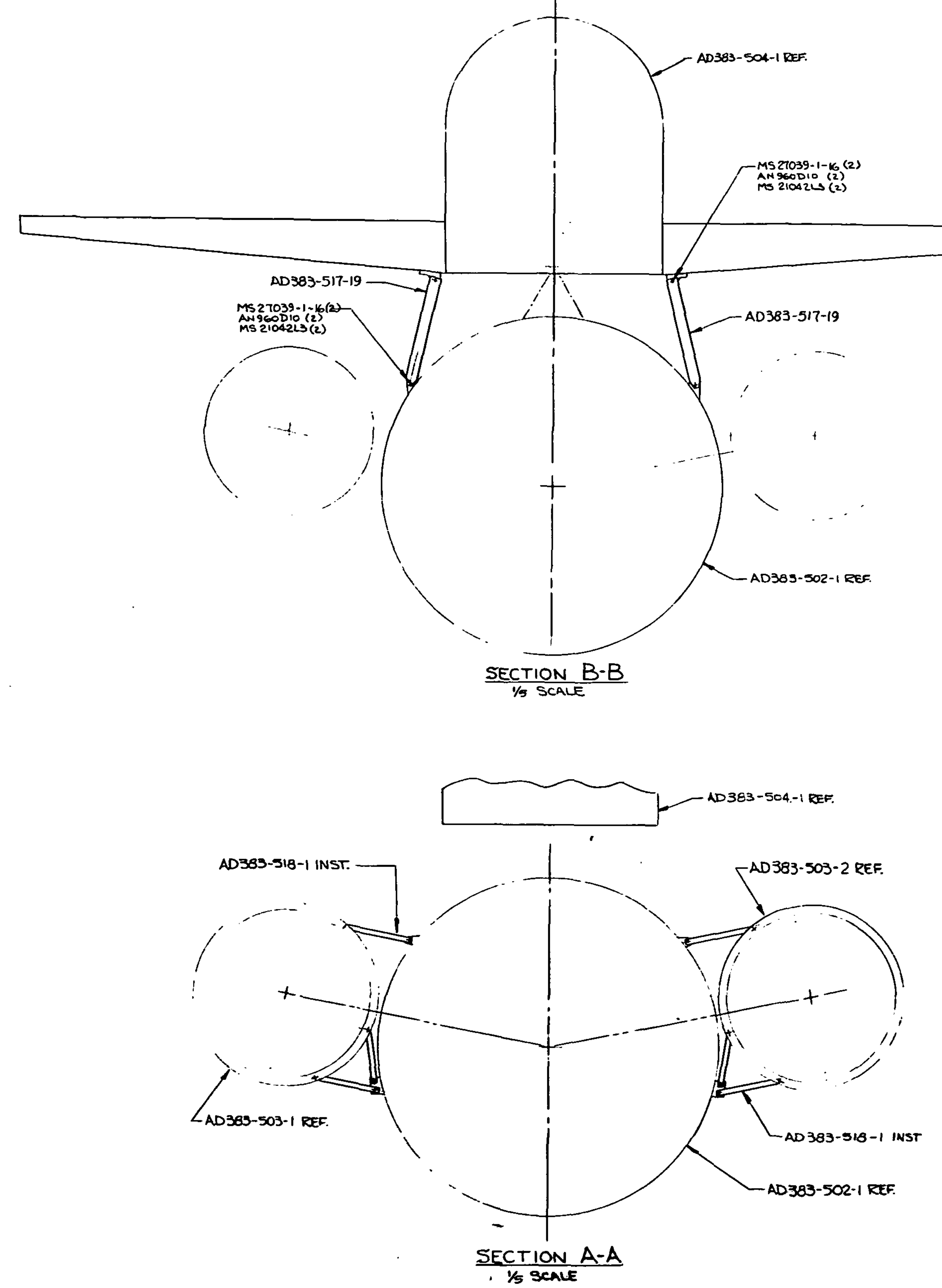
8- TIGHTEN ALL BOLTS AT HO TANK STAS. 113.49 & 270.99

(CONTINUED) →



INITIAL ERECTION PROCEDURE (CONTINUED)

9- POSITION & INSTALL ORBITER AS FOLLOWS:~
   a/ ORIENT ORBITER IN VERTICAL POSITION
   b/ ENGAGE BEARING ON HO TANK IN SOCKET ON ORBITER & AT ORBITER STA 165.25 & INSTALL STRUTS AD383-517-19 (SEE SECTION B-B)
   c/ JOIN ORBITER TO HO TANK AT TANK STA 148.75 (SEE SECTION C-C)



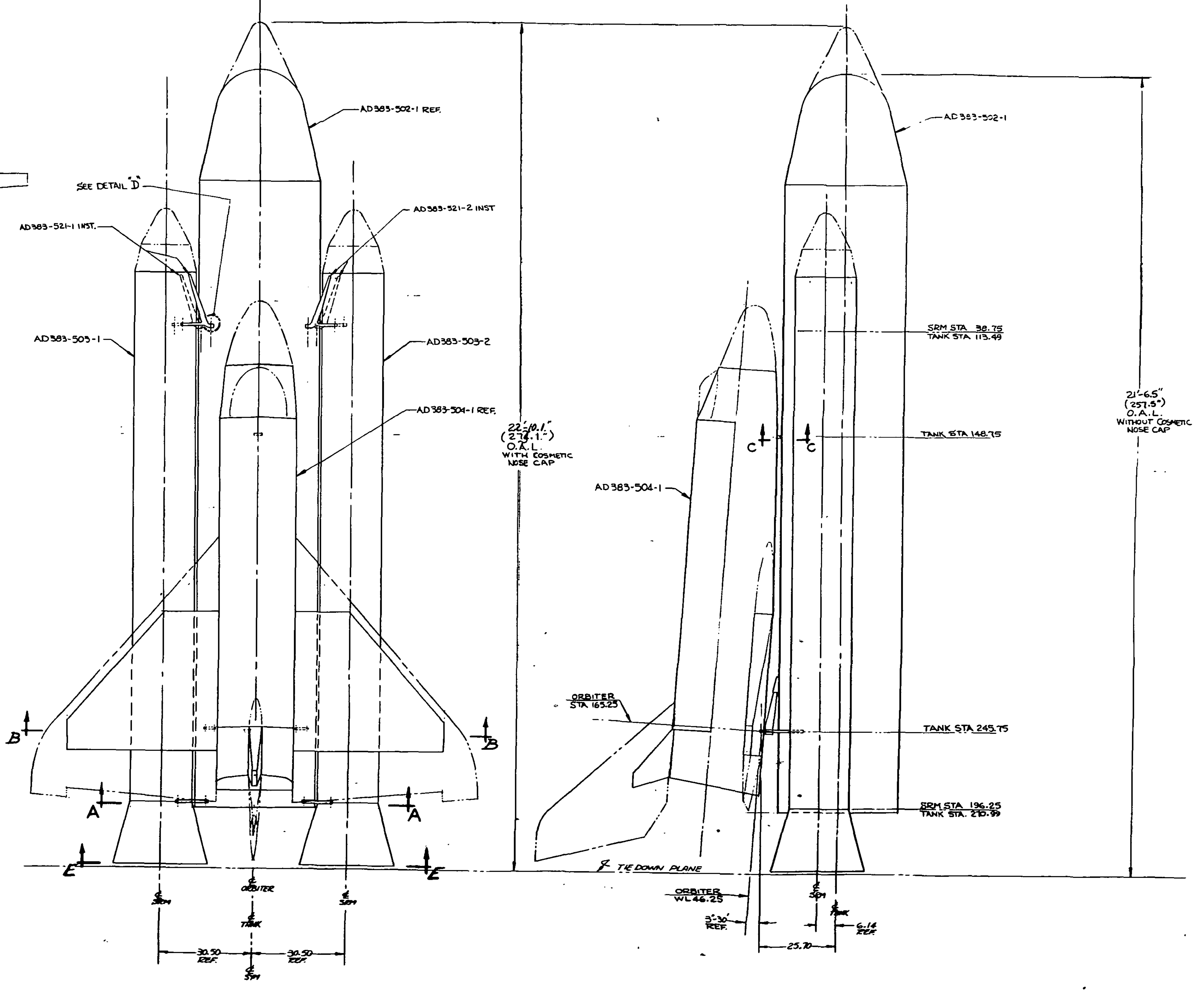


Fig. 10 Assembly Drawing (AD 383-501) of 1/8 Scale Shuttle Structural Dynamics Model

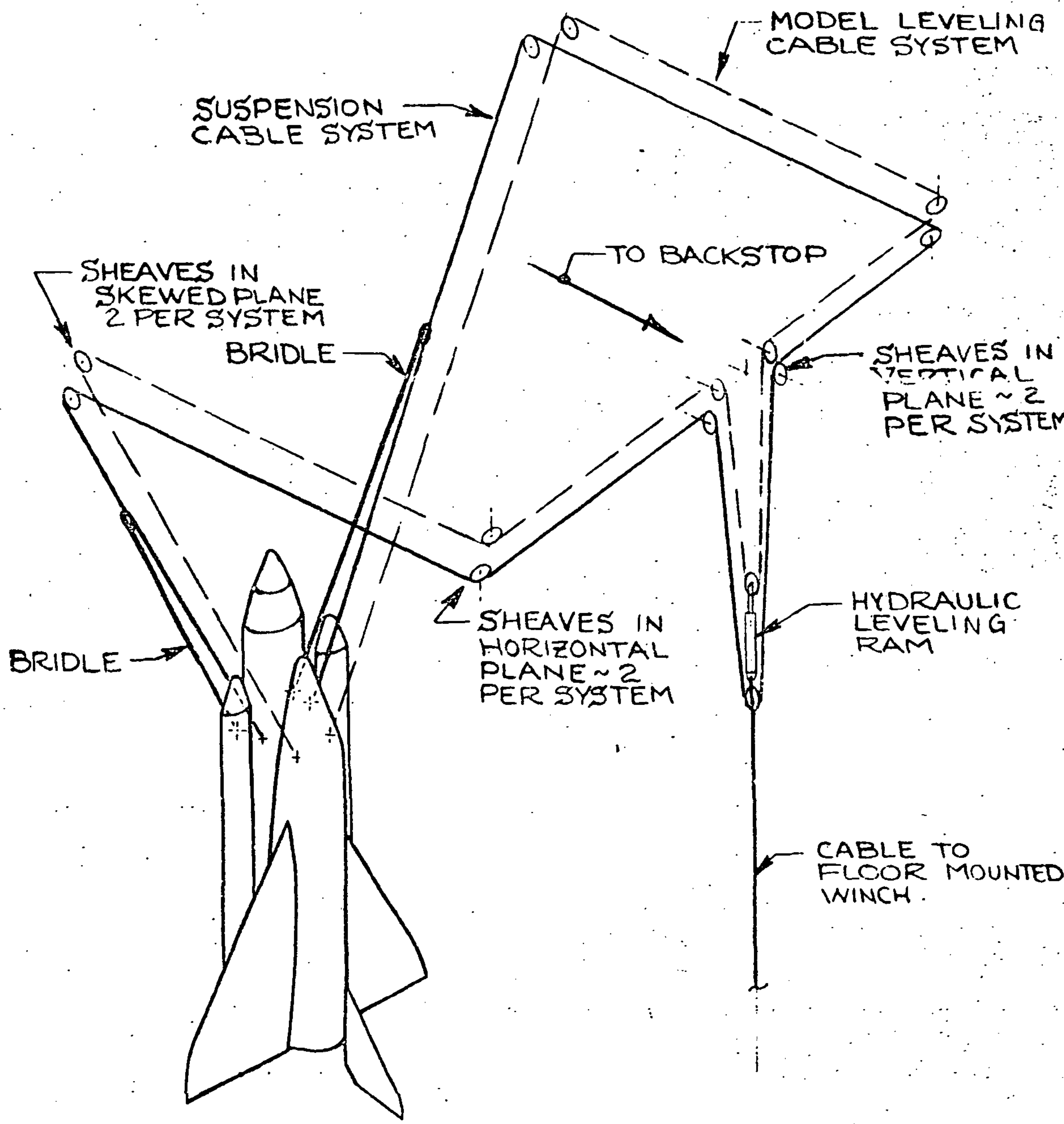


FIGURE 11
SCHEMATIC OF MODEL SUSPENSION AND LEVELING SYSTEMS.

Fig. 12 Drawing (AD 383-500-1) of Shuttle Model Suspended

APPENDIX A

SUMMARY OF INTERSTAGE FORCES FOR 1 LB. OSCILLATING FORCE APPLIED AT ORBITER ENGINE

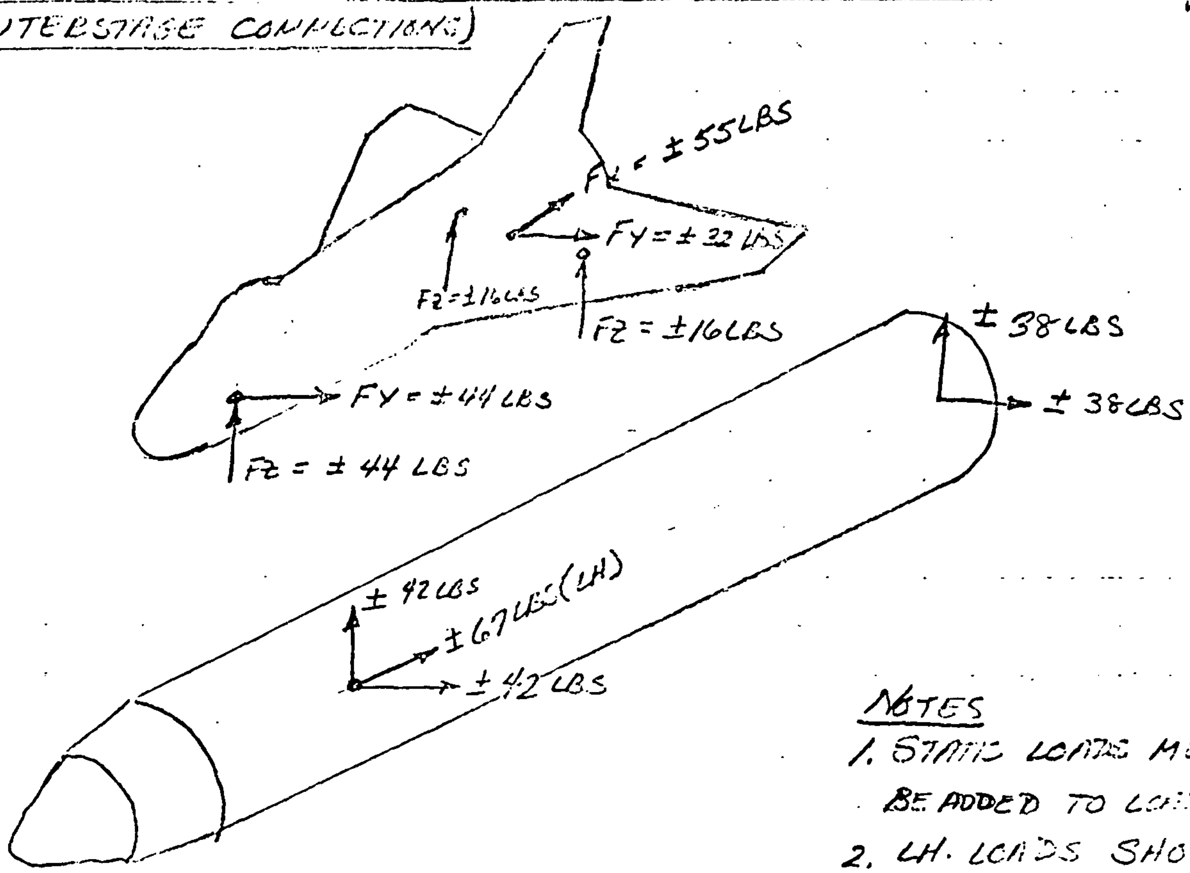
Appendix A 1/8 Scale Model – Summary of Interstage Forces with 1 LB oscillating force Applied at Orbiter Engine

(Forces are in LBS)

	ORB/HO TANK INSIDE			HO TANK/SRM INTERSTAGE				
	FWD	AFT		FORWARD			AFT	
	Fz	Fx	Fz	Fx	Fy	Fz	Fy	Fz
LIFTOFF	±13.9	±20.6	±16.1	±22.1	5.1	±21.2	±10.6	±19.0
MAX Q	±13.8	±17.9	±16.0	±33.7	±1.3	±19.1	±9.5	±12.3
SRM B/O	±21.8	±27.5	±11.8	±4.7	±2.7	±12.3	4.90	±15.8
POST SEP	±18.9	±24.2	±8.9	—	—	—	—	—
SSME B/O	±2.6	±10.5	±3.6	—	—	—	—	—

SSME B/O – SPACE SHUTTLE MAIN ENGINE BURN OUT.

Recommended Values for Model Design (ie 2 LB input)
(Interstage Connections)



Notes
1. Static loads must be added to loads shown
2. LH. loads shown RH loads opp. for tank to SRM connections

FORCES AND BENDING MOMENTS (LIFTOFF)
1/8 SCALE MODEL WITH 1st INPUT FORCE APPLIED
AT CENTER ENGINE

FULL SCALE FORCES IN KIPS & MOMENTS IN IN-KIPS

	ORB. STA. FULL SCALE	ORB. STA. MODEL	Px F.S	Px MOD	Vz F.S	Vz MOD	BM F.S	BM MOD
ORBITER	NOSE = 200 318	NOSE = 25 39.75	2.7	2	4.3	3.2	167	15.
	444	55.5	5.4	4	6.7	5.0	705	65.
	500	62.5	18.0	13.3	15.3	11.3	1356	125.
	570	71.25	20.5	15.2	9.8	7.3	2426	224.
	704	88.0	22.1	16.4	7.33	5.4	2345	217
	837.5	104.06	22.5	17.	6.90	5.1	2524	233
	979.5	122.44	23.3	17.2	6.53	4.8	2657	246
	1006	125.75	23.6	17.5	5.56	4.1	2956	273
	1162	145.25	20.27	15.6	7.24	5.4	4052	375
	1237	154.62	26.34	19.5	7.42	5.5	4500	416
	TANK STA FULL SCALE	25.44						
H_2O TANK	NOSE = 0 203.5	25.44	.13	.1	5.2	3.8	122	11
	298.6	37.32	.19	.14	10.1	7.5	620	57
	393.7	49.21	.23	.18	15.8	11.7	1511	140
	515.5	64.44	.27	.2	19.7	14.6	3407	315
	637.3	79.66	.32	.24	21.0	15.5	5802	537
	762.3 -	95.29 -	.32	.24	21.0	15.5	8429	780
	762.3 +	95.29 +	33.4	24.7	23.1	17.1	8575	793
	873.3	109.16	33.4	24.7	21.7	16.1	8243	762.
	1078 -	134.75 -	33.4	24.7	21.7	16.1	9167	848
	1078 +	134.75 +	33.3	24.7	13.4	9.9	9167	848
	1302	162.75	33.3	24.7	11.9	8.8	10774	997
	1562	195.25	33.2	24.7	9.4	7.0	11749	1080
	1822 -	227.75 -	33.2	24.7	9.4	7.0	11567	1070
	1822 +	227.75 +	30.6	22.7	25.6	19.0	10039	920
	2077.1	259.64	2.8	2.1	27.3	20.2	3513	320
	2206.3	275.79	2.8	2.1	27.3	20.2	5.81	.5

FORCES AND BENDING MOMENTS (LIFTOFF)
1/8 SCALE MODEL WITH 1# INPUT FORCE APPLIED
AT ORBITER ENGINE

FULL SCALE, FORCES IN KIPS, MOMENT IN IN.KIPS — MODEL, F = LBS, BM = IN.-LBS.

TANK STA FS	TANK STA MOD	Px FS	Px MOD.	Vy FS	Vy MOD	Vz FS	Vz MOD	My FS	My MOD	Mz FS	Mz MOD
762.3	95.29	25.8	22.	7.4	5.5	26.8	19.8	608	56.2	3009	278.
1002.97	125.37	24.8	18.4	5.3	3.9	17.4	17.9	6212	575	2892	268
1243.64	155.46	19.7	14.6	4.6	3.4	6.2	4.6	10407	962	2333	215.8
1484.3	185.38	14.1	10.4	4.75	3.5	7.2	5.3	11883	1099	2720	251.6
1724.98	215.62	8.8	6.5	3.9	2.9	17.4	12.9	10239	947	2522	233
1965.65	245.71	3.4	2.5	7.3	5.4	25.2	18.7	6041	559	1657	153
2206.3	275.79	3.4	2.5	7.3	5.4	25.2	18.7	141	13.	97.2	9

INTERSTAGE LOADS (KIPS)

	Fz FWD FS	Fz FWD MOD	Fx AFT FS	Fx AFT MOD	Fz AFT FS	Fz AFT MOD				
ORBITER TO HO TANK	18.8	13.9	27.8	20.5	21.7	16.1				
	Fx FWD FS	Fx FWD MOD	Fy FWD FS	Fy FWD MOD	Fz FWD FS	Fz FWD MOD	Fy AFT FS	Fy AFT MOD	Fz AFT FS	Fz AFT MOD
SRM TO HO TANK	25.8	22.1	6.52	6.1	28.7	21.2	14.3	10.4	25.7	19.0

FORCES AND BENDING MOMENTS (SRM BURNOUT)

1/8 SCALE MODEL WITH 1# INPUT FORCE APPLIED AT [illegible] ENGINE -

F.S. FORCES IN KIPS, MOMENTS IN-KIPS

MODEL FORCES IN LBS, " IN-LBS

	ORB. STA FULL SCALE	ORB. STA MODEL	P_x FS	P_x MOD	V_z FS	V_z MOD	B.M. F.S	B.M. MOD
ORBITER	318	39.75	2.8	2.1	2.8	2.1	125	11.5
	444	55.5	5.6	4.1	3.5	2.6	482	44.6
	500	62.5	18.9	14.0	9.5	7.0	709	65.6
	570	71.25	21.5	15.9	15.1	11.2	1287	119.
	704	80.0	23.1	17.1	10.1	7.5	1688	156
	832.5	104.06	24.	17.8	9.0	6.7	2279	211
	929.5	116.19	24.4	18.1	8.0	5.9	2956	273
	1006	125.75	24.7	18.3	5.6	4.1	3606	334
	1162	145.25	21.1	15.6	7.5	5.6	4772	441
	1237	154.62	27.4	20.3	7.7	5.7	5017	464
	TANK STA FULL SCALE							
HO TANK	203.5	25.44	.14	.10	.9	.67	111.7	10.3
	298.6	37.33	.20	.15	5.2	3.8	193.	17.9
	393.7	49.21	.23	.17	20.2	14.9	686	63.5
	515.5	64.44	.28	.21	28.8	21.3	3149	291
	637.3	79.66	.33	.24	28.5	21.1	6653	615
	762.3-	95.29-	.33	.24	28.5	21.1	10215	945
	762.3+	95.29+	35.2	26.0	23.2	17.2	10466	968
	873.3	109.16	35.2	26.0	23.1	17.1	13048	1207
	1078-	134.75-	35.2	26.0	23.1	17.1	17767	1643
	1078+	134.75+	35.3	26.1	7.8	5.8	17769	1644
	1302	162.75	35.4	26.2	10.9	8.1	16014	1481
	1562	195.12	35.5	26.3	14.1	10.4	13167	1218
	1822-	227.5-	35.5	26.3	14.1	10.4	9498	879
	1822+	227.5+	7.5	5.6	22.2	16.4	8549	791
	2077.1	259.44	2.9	2.1	21.8	16.1	2897	268
	22[illegible].3	275.79	2.9	2.1	21.8	16.1	85.1	8.2

FORCES AND BENDING MOMENTS (SRM BURNOUT)
1/8 SCALE MODEL WITH 1# INPUT FORCE AT CENTER ENGINE
F.S. FORCES IN KIPS, MOMENTS IN-KIPS
MOD. FORCES IN LBS, " IN-LBS

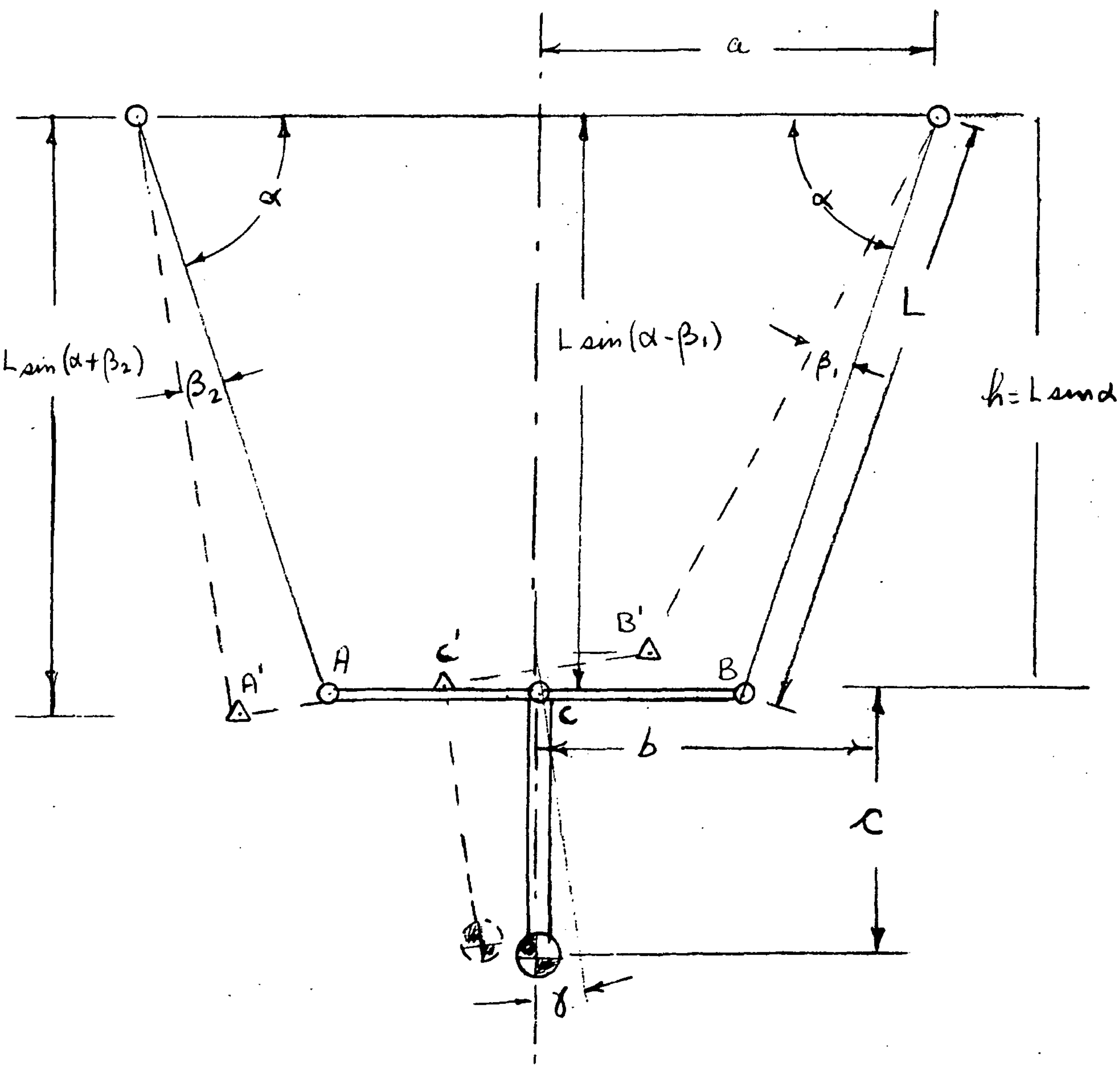
HO TANK STA F.S.	HO TANK STA. - MODEL	P_x FS	P_x MOD	V_y F.S.	V_y MOD	V_z FS	V_z MOD	M_y FS	M_y MOD	M_z FS	M_z MOD
762.3	95.29	27.5	22.1	7.4	5.5	26.8	19.8	608	56.2	[illegible]	[illegible]
1002.57	125.37	24.8	18.4	5.5	3.9	17.5	13.0	6212	575	[illegible]	265
1243.61	155.455	19.7	14.6	4.6	3.4	6.2	4.6	10407	962	[illegible]	216
1484.3	185.56	14.1	10.4	4.7	3.5	7.2	5.3	[illegible]	1099	2720	252
1724.98	215.62	8.7	6.4	3.9	2.9	17.4	12.9	10239	947	[illegible]	[illegible]
1965.65	245.71	3.4	2.5	7.3	5.4	25.2	18.6	6041	559	1657	153
2206.3	275.79	3.4	2.5	7.3	5.4	25.2	18.6	141	13	97	9

APPENDIX B

RESONANT FREQUENCY OF BODY SUSPENDED FROM THE TWO ANGLED WIRES

APPENDIX B

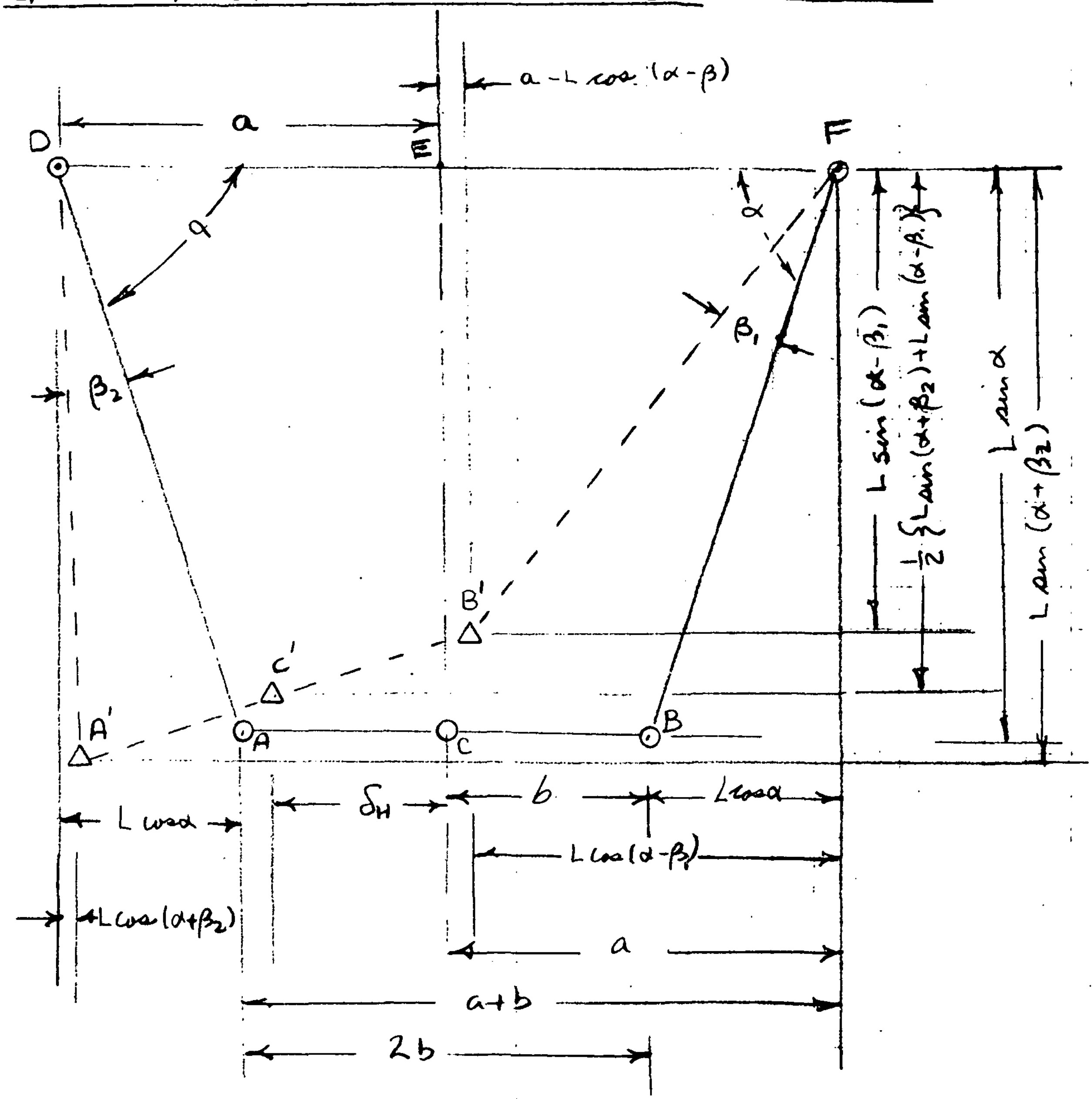
RESONANT FREQUENCY OF BODY SUSPENDED FROM TWO ANGLED WIRES



IDEALIZED MODEL SUSPENSION SYSTEM

FIG. B-1

GEOMETRY OF SUSPENSION SYSTEM FIG. B-2



The analysis uses Lagrange's equations to derive the equations of motion. The potential energy is calculated from the vertical displacement of the center of gravity due to translation and rotation. The kinetic energy is determined by adding the components due to linear and rotational velocities. Assumptions of small motions and equality of small angles are used to simplify the analysis. The longitudinal flexibility due to the air springs and the cable elasticity are also omitted as further simplifying assumptions.

DEFLECTION δ, FROM FIG. B-2

HORIZ. DISTANCE FROM A' TO F $= (a+b)+(a-b)-L\cos(\alpha+\beta_2)$

HORIZ. DISTANCE FROM B' TO F $= L\cos(\alpha-\beta_1)$

HORIZ. DISTANCE FROM C' TO F IS THE AVERAGE OF POINTS A' AND B'

THEREFOR:

$$\delta_H = \frac{1}{2}\left\{a+b+a-b-L\cos(\alpha+\beta_2)+L\cos(\alpha-\beta_1)\right\} - a$$

USING TRIGONOMETRIC SUBSTITUTIONS

$$\delta_H = \frac{1}{2}\left\{2a + L\cos\alpha(\cos\beta_1-\cos\beta_2)+L\sin\alpha(\sin\beta_1+\sin\beta_2\right\} - a$$

ASSUME $\beta_1=\beta_2$ THEN

$$\delta_H = L\sin\alpha\sin\beta$$

VERTICAL DISTANCE OF B' FROM LINE DF $= L\sin(\alpha-\beta_1)$

VERTICAL DISTANCE OF A' FROM LINE DF $= L\sin(\alpha+\beta_2)$

VERTICAL DISTANCE OF C' IS THE AVERAGE OF POINTS A' AND B', THEREFOR:

$$\delta_V = L\sin\alpha - \frac{1}{2}\left\{L\sin(\alpha+\beta_2)+L\sin(\alpha-\beta_1)\right\}$$

USING TRIGONOMETRIC SUBSTITUTIONS

$$\delta_V = L\sin\alpha - \frac{1}{2}\left\{L\sin\alpha(\cos\beta_1+\cos\beta_2)-L\cos\alpha(\sin\beta_1-\sin\beta_2)\right\}$$

ASSUME $\beta_1=\beta_2$ THEN

$$\delta_V = L\sin\alpha\left\{1-\cos\beta\right\}$$

$$\begin{aligned}\delta &= (\delta_V^2+\delta_H^2)^{1/2}\\ &= \left\{(L\sin\alpha - L\sin\alpha\cos\beta)^2 + L^2\sin^2\alpha\sin^2\beta\right\}^{1/2}\\ &= \left\{L^2\sin^2\alpha - 2L^2\sin^2\alpha\cos\beta + L^2\sin^2\alpha(\cos^2\beta+\sin^2\beta)\right\}^{1/2}\\ &= \left\{2L^2\sin^2\alpha - 2L^2\sin^2\alpha\cos\beta\right\}^{1/2}\\ \delta &= 2L\sin\alpha\left(\frac{1-\cos\beta}{2}\right)^{1/2} = 2L\sin\alpha\sin\frac{\beta}{2}\end{aligned}$$

ROTATION γ, FROM FIG. B-1 AND FIG B-2

$$\begin{aligned}\sin\gamma &= \text{DIFFERENCE IN VERTICAL DEFLECTIONS OF A' AND B'} \div 2b\\ &= \frac{L}{2b}\left(\sin(\alpha+\beta_2)-\sin(\alpha-\beta_1)\right)\end{aligned}$$

ASSUME $\beta_1=\beta_2$

$$\sin\gamma = \frac{L}{b}\cos\alpha\sin\beta$$

ASSUME γ AND β ARE SMALL ANGLES

THEN $\gamma = \left(\frac{L}{b}\cos\alpha\right)\beta$

POTENTIAL ENERGY

$$V = mgL\sin\alpha\{1-\cos\beta\} + mgc\,(1-\cos\gamma)$$

WHERE mg IS THE WEIGHT OF THE SUSPENDED BODY

ASSUME $\cos\beta \approx 1 - \frac{1}{2}\beta^2$, $\cos\gamma \approx 1 - \frac{1}{2}\gamma^2 \approx 1 - \frac{1}{2}\left(\frac{L^2}{b^2}\cos^2\alpha\right)\beta^2$

$$V = mgL\frac{\beta^2}{2}\sin\alpha + mgc\frac{L^2}{b^2}\frac{\beta^2}{2}\cos^2\alpha$$

NOTE AT $\alpha = \frac{\pi}{2}$ THIS IS EQUAL TO V FOR SIMPLE PENDULUM

KINETIC ENERGY

$$T = \frac{m}{2}\dot{\delta}^2 + \frac{I_o}{2}\dot{\gamma}^2$$

WHERE I_o IS THE MASS MOMENT OF INERTIA OF THE SUSPENDED BODY $= \frac{m}{2}\left[c^2+k^2\right]$ ABOUT POINT C.

k IS THE RADIUS OF GYRATION $= \left(I_{cg}/m\right)^{1/2}$

$$T = \frac{m}{2}\left(L^2\sin^2\alpha\right)\dot{\beta}^2 + \frac{m}{2}\left[c^2+k^2\right]\left[\frac{L^2}{b^2}\cos^2\alpha\right]\dot{\beta}^2$$

LAGRANGE'S EQUATION $\frac{d}{dt}\left(\frac{\partial T}{\partial\dot{\beta}}\right) + \frac{\partial V}{\partial\beta} = 0$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial\dot{\beta}}\right) = m\left(L^2\sin^2\alpha\right)\ddot{\beta} + m\left[c^2+k^2\right]\left[\frac{L^2}{b^2}\cos^2\alpha\right]\ddot{\beta}$$

$$\frac{\partial V}{\partial\beta} = \left(mgL\sin\alpha\right)\beta + \left(mgc\frac{L^2}{b^2}\cos^2\alpha\right)\beta$$

COMBINING INTO THE PROPER FORM

$$L^2\left(\sin^2\alpha + \frac{c^2+k^2}{b^2}\cos^2\alpha\right)\ddot{\beta} + gL\left(\sin\alpha + \frac{cL}{b^2}\cos^2\alpha\right)\beta = 0$$

THEREFORE $f = \frac{1}{2\pi}\left(\frac{g}{L}\,\frac{\sin\alpha + \frac{cL}{b^2}\cos^2\alpha}{\sin^2\alpha + \left(\frac{c^2+k^2}{b^2}\right)\cos^2\alpha}\right)^{1/2}$, THE RESONANT FREQUENCY IN HZ.

NOTE: WHEN $\alpha = \frac{\pi}{2}$ (VERTICAL SUSPENSION) THIS REDUCES TO A SIMPLE PENDULUM, OR $f = \frac{1}{2\pi}\left(\frac{g}{L}\right)^{1/2}$

WHEN $\alpha = 0$ (HORIZONTAL SUSPENSION) THIS REDUCES TO A COMPOUND PENDULUM, OR $f = \frac{1}{2\pi}\left(\frac{gc}{c^2+k^2}\right)^{1/2}$

CALCULATION OF RESONANT FREQUENCIES FOR 5 WEIGHT CONDITIONS

COND	c (IN.)	W (lbs)	I_{xx} (lb-in^2)	I_{yy} (lb-in^2)	I_{zz} (lb-in^2)	k_{xx}^2 (in^2)	k_{yy}^2 (in^2)
a	48.9	9432	6912900	44617600	49413300	733	4730
b	40.6	7103	4867200	34028700	37048000	685	4791
c	26.9	3734	1877600	18463300	18803100	503	4945
d	12.5	2992	1105000	12480600	12166200	369	4171
e	89.9	675	379300	2412300	2400100	562	3574

COND	k_{zz}^2 (in^2)	$c^2+k_{zz}^2$	$\frac{c^2+k_{zz}^2}{b^2}$	$\frac{cL}{b^2}$	A *	B **	$\left(\frac{g}{L}\frac{A}{B}\right)^{1/2}$	f (Hz)
a	5239	7630	24.15	33.41	2.9798	2.3930	1.49208	.24
b	5216	6864	21.72	27.74	2.6386	2.2468	1.44903	.23
c	5036	5760	18.23	18.38	2.0754	2.0368	1.34974	.21
d	4066	4222	13.36	8.54	1.4834	1.7438	1.23325	.20
e	3556	11638	36.83	61.42	4.6651	3.1560	1.62520	.26

$*\ A = \sin\alpha + \frac{cL}{b^2}\cos^2\alpha$

$**\ B = \sin^2\alpha + \left(\frac{c^2+k^2}{b^2}\right)\cos^2\alpha$

$a = 70.73$ in., $b = 17.76$ in. $L = 215.89$ in., $k = 204.3$ in.

$\sin\alpha = .9695$, $\cos^2\alpha = .2453$