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Launch Vehicle Integration Options for a Large Earth Sciences Geostationary Platform Concept

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Abstract

Concepts are derived for the packaging of the components of a large Earth sciences geostationary platform to be launched in either the Space Shuttle or the Titan IV Complementary Expendable Launch Vehicle. Geometric data from a proposed conceptual design for the spacecraft, antenna sizing results from thermal and structural finite element analyses, and independent mass and volume estimates are used to determine sizes, shapes, and masses of the major platform components and support equipment. Solid modelling software is used to evaluate proposed launch vehicle integration concepts in terms of meeting volume and mass constraints, checking for interference between components, verifying that center-of-gravity locations are within vehicle specifications, and designing suitable interface structures that do not violate any of these constraints. Construction at Space Station *Freedom* is assumed, and a space-based orbital transfer vehicle is determined to be necessary for inserting the spacecraft, once assembled, into geostationary orbit.

Introduction

Global changes in our environment are a documented reality, and new efforts are being undertaken to monitor the important variables reflecting changes in our oceans, atmosphere, land, and living species. Some variables will need to be monitored on a nearly continuous basis so that regional events can be observed at a frequency sufficient for understanding, modelling and, eventually, forecasting. For this reason, Earth science sensors will have to be flown on geostationary platforms in order to meet these temporal resolution requirements. The size and performance requirements for these platforms are unprecedented for geosynchronous orbit, and thus the development of new enabling technologies for science sensors, spacecraft systems, and data and information systems may be required.

Researchers at Langley Research Center have conducted a systems study of a large "second-generation" Earth sciences geostationary platform that would accommodate the large optical instruments and microwave antennas needed to meet the scientific requirements beyond the year 2000. The straw-man platform design that was used in the overall study is based on the conceptual design (fig. 1) developed by Ford Aerospace Corp. (study entitled "Geostationary Platform Bus Study—For Earth Observation Sciences, Volume II—Comprehensive Report," WDL-TR 11066, Dec. 1987). This spacecraft concept is recognized as being too large to be launched fully assembled. The extremely stringent surface tolerance requirement of the solid microwave radiometer reflector dictates on-orbit construction. Thus, this configuration requires on-orbit assembly and an orbital transfer vehicle (OTV) to place the erected spacecraft into geostationary orbit.

The objectives of the overall study are (1) to quantify performance issues and feasibility of flying very large platforms at geostationary orbit, (2) to identify needed technology developments to enable or enhance the mission, and (3) to identify infrastructure and support equipment requirements. This report, one of several produced during the study, addresses the launch packaging and vehicle integration issues. It draws upon other reports for the configuration details (ref. 1) and antenna structural design (refs. 2 and 3).

With the baseline platform concept as outlined in the Ford study and the assumption of an erectable solid surface 7.5-m antenna and a deployable 15-m membrane antenna for the passive microwave radiometers, this study was conducted to determine possible methods of integrating the spacecraft components into the launch vehicle for transport to low Earth orbit (LEO). Components consistent with the specifications of the baseline design are assumed, except for specific changes arising from subsystem design of individual components of the platform.

Only two existing U.S. launch vehicles have the weight and volume capacity to launch all the platform components into LEO. These are the Space Shuttle and the Titan IV Complementary Expendable Launch Vehicle (CELV). This report limits consideration to these two launch vehicles with their present operational capacities and performance.

Only the state-of-the-art Titan IV is considered, and far-term Space Shuttle enhancements such as the aft cargo carrier (ACC) are not employed. However, it is assumed that a space-based orbital transfer vehicle (SBOTV) will be available. This decision results because all existing or near-term upper stages have insufficient weight capacity and structural requirements of the assembled spacecraft make a low-thrust orbital transfer necessary. Additionally, several scenarios proposed assume that an orbital maneuvering vehicle (OMV) will be available based at Space Station *Freedom*.

To verify launch feasibility, proposed packaging concepts are checked for violation of launch vehicle payload envelopes, interference between packaged components, compatibility of payload with vehicle support hardware, and acceptability of payload center-of-gravity (c.g.) location. Required interface and support hardware is conceptually designed and included in the payload, along with the spacecraft components, for evaluation of all the aforementioned criteria.

Component Mass and Volume Estimation

A complete listing of the spacecraft components with their mass and volume estimates is given in table 1. The net dry platform mass is 6681 kg, and the net packaged volume of the spacecraft is 89 m^3. These components are modelled with the GEOMOD solid modelling program (ref. 4). Unless further specified, mass estimates are obtained directly from the Ford study and volume estimates are derived from GEOMOD solid models created from the geometric data in that study. A redesign of the two antennas in references 2 and 3 produced revised estimates of the masses and volumes for all components associated with the passive microwave radiometers. The purpose of this section is to summarize additional work that was performed to estimate masses and volumes that could not be explicitly obtained from the Ford study or the other geostationary platform design reports (refs. 1 to 3).

Instruments and Support Subsystems

According to the baseline platform design (fig. 1), instruments with fine pointing requirements are placed within an instrument module located on the spacecraft truss structure near the 15-m antenna. Underneath the instrument module is the housekeeping module, where most of the spacecraft support systems are located. Instruments and support components not included within these two modules are distributed along the platform truss structure. Estimates are made in the Ford study of the masses of the instrument module, housekeeping module, distributed instruments, and spacecraft support systems.

The Ford study gives the instrument module a mass estimate of 3008 kg and the housekeeping module an estimate of 500 kg. For the purposes of this study, these two large mass contributions have to be further divided so that many of the individual components or subsystems can be treated as discrete objects. A mass estimate of 20 kg for the high-gain antenna is taken from an instrument mass breakdown for the baseline platform and is subtracted from the total mass of the instrument module and charged to the command and data handling mass budget. An estimate of 45 kg is obtained for the lower central cylinder by assuming that areal density is constant on all panels of the structural model of the modules shown in figure 2. This mass is subtracted from that of the housekeeping module. Finally, the mass of the two solar array booms, estimated to be 13 kg, is included with that of the housekeeping module.

Both the housekeeping and instrument modules are combined into a single entity with a net mass of 3456 kg and a center of gravity located 4.09 m above the interface between the housekeeping module and the lower central cylinder. A division of platform mass based on subsystem function is also included in the Ford study.

The net mass of the housekeeping and instrument modules is broken down according to subsystem category as follows:

Science instruments (payloads), kg	1043
Command and data handling, kg	87
Spacecraft controls, kg	81
Attitude and orbit control, kg	425
Propulsion, kg	173
Thermal control, kg	272
Electrical power, kg	397
Structure (both modules), kg	639
Integration, kg	339
Housekeeping and instrument modules, total, kg	3456

Station-keeping propellant, estimated at 1435 kg, will be loaded into the housekeeping module following assembly at Space Station *Freedom*. Therefore, this mass is not included as part of the housekeeping module for launch packaging but is added to the payload manifest as part of the OTV propellant.

Other component masses not obtained directly from the Ford study include the 10 kg of the solar sail, 4 kg for the sail itself and 6 kg for its boom. The package for the solar sail is a cylinder 0.53 m in diameter and 1.50 m in height. North and south solar array panels are given mass estimates of 76 and 73 kg, respectively. These masses include the active cavity radiometer (28 kg) on the south panel and the X-ray imager (31 kg) on the north panel.

Passive Microwave Radiometers

Two large passive microwave radiometers, 7.5 and 15.0 m in diameter, are mounted on the platform truss. These provide measurements of atmospheric temperature and moisture profiles at frequencies of 60, 90, 118, 160, and 183 GHz by the 7.5-m radiometer and at 6, 10, 18, 22, and 37 GHz by the 15-m radiometer according to specifications in the Geostationary Platform Study performed by Lockheed Missiles & Space Co., Inc. (Final Report, Contract NAS8-36103, Modification No. 13, DR-9, Nov. 1988). Both microwave radiometers are of the offset-fed Cassegrain design, with the 7.5-m antenna having an erectable structure with a solid surface made up of hexagonal elements and the 15-m antenna having a deployable structure with a membrane surface.

For the purpose of making mass and volume estimates, the antennas are broken down into five parts: (1) strongback truss, (2) reflecting surface, (3) feed array, (4) subreflector, and (5) mast boom to support the subreflector. Development and evaluation of these designs are covered in more detail in reference 3 for the 7.5-m antenna and in reference 4 for the 15-m antenna.

The design of the 7.5-m passive microwave radiometer is based on the precision segmented reflector (PSR) concept of reference 5. The 15-m radiometer design is based on the geo-truss concept (ref. 6).

Strongback truss structure. Estimations of the shape, volume, and mass of support structures are obtained from structural models of the antennas generated by the Large Advanced Space Systems (LASS) antenna sizing software (ref. 7). These models are shown in figure 3. The packaged size of the 7.5-m-antenna strongback is estimated to be 0.82 m in diameter by 2.38 m long. Its mass is determined from LASS to be 131 kg. For the 15-m antenna, this package has a diameter of 1.97 m, a length of 1.30 m, and a mass of 250 kg.

Within LASS, the package sizing is based on either of two schemes for folding truss elements. One option involves folding them inward, while the other folds them outward. For the 7.5-m erectable antenna, either option is acceptable. An inward folding scheme is chosen because it has the shortest length and is the most compact. Because the larger antenna is deployed with its thin membrane surface attached to points on the truss backing, the packaging scheme that folds the elements inward must be used so that they do not puncture the surface upon deployment.

Reflecting surface. The surface of the 7.5-m antenna is divided into 18 hexagonal segments (2.0 m between edges) in accordance with specifications from the antenna design work of reference 2. These segments are small enough to be packaged side by side in sets of two within the Space Shuttle or Titan IV payload envelopes. Mass of the solid surface is computed from an areal density of 10 kg/m^2. This value is an antenna sizing approximation that includes the additional mass of hardware fittings and control system components (ref. 5) and produces a surface mass estimate of 441 kg. The mass of the surface membrane, assumed to be constructed of aluminized type-H polyimide film, is estimated to be 4 kg.

The volume of the membrane is found by scaling the packaged surface of the 5-m, three-bay geo-truss proof-of-concept model (ref. 8) by antenna surface area. In this model, the surface mesh fits within a cylinder 0.67 m in diameter and 0.70 m in height (i.e., 0.25 m^3). A package volume of 2 m^3 is obtained for the antenna by scaling up to 15 m.

Because the membrane must remain attached to the support truss when in the undeployed state, the package shape is a cylinder with the same diameter as that of the folded strongback (1.97 m) and attached to the front of the strongback. This requires a membrane package height of 0.72 m.

Feed arrays. Feed arrays for microwave radiometers as large and complex as those considered in this study contribute a significant amount of mass and volume. While the need to include contributions of the feed arrays in the mass and volume estimates is recognized, little information on their design for the geostationary platform exists. In order to roughly estimate their masses and volumes, reference feed array designs are scaled by wavelength for each of the 10 frequencies for which microwave radiometry data are sought. The reasoning behind this sizing technique is that the waveguides and other microwave components must be shaped based on the wavelength of the radiation that they are carrying, and these parts contribute the most to the mass and volume of the feed assemblies. Effects of electronic components in the feed arrays that cannot be scaled directly with wavelength are approximated by applying a rough multiplicative factor to these mass estimates. A factor of 1.5 (ref. 3) is assumed for the feed array of the 15-m antenna and a factor of 2.0 (ref. 2) is assumed for that of the 7.5-m antenna.

The reference feed array design for mass estimates consists of 33 horns operating at 1.5 GHz with an approximate total mass of 500 kg. This feed array is described in reference 9. This mass is scaled linearly from the reference wavelength of 0.20 m to that corresponding to the operating frequency of each antenna. The net masses of the two feed arrays are found by summing these individual feed masses. These calculations produce an estimate of 443 kg for the feed array of the 15-m antenna and 72 kg for the feed array of the 7.5-m antenna.

Volume and shape of the feed arrays are estimated by a similar method. Reference 9 does not give sufficient data on the geometry of the feed array, so dimensions are scaled from measurements taken on a single horn from the feed array of a 15-m hoop-column antenna test article. This horn has an overall length of 0.46 m and operates at a frequency of 11.6 GHz. It is a circular horn with a frontal area of 0.02 m^2. To maintain compatibility with the baseline feed array design and with the mass estimate above, 33 horns are assumed to be used for each operating frequency. The actual number of horns required is based on the number of beams needed and whether or not electronic steering of the radiometer is implemented. These factors cannot be assessed at the present time, so the 33-horn feed array is considered to be a representative design and is used as the working baseline.

With the assumption that the additional electronic components that cannot be scaled simply with wavelength are located behind the feed horns, the multiplication factors of 1.5 and 2.0 are included in the length estimates of the feed arrays for the 15- and 7.5-m antennas, respectively. These length estimates come from the length of the longest feed horn in each array as scaled by wavelength (0.09 and 0.89 m for the 7.5- and 15-m antennas, respectively). A factor of 1.103 is included in the frontal area estimate because circular horns cannot fit together perfectly without some amount of wasted space between them. The geometry of this arrangement is shown in figure 4. Scaling length and cross-sectional area by wavelength and applying the aforementioned multiplicative factors results in the feed array of the 7.5-m antenna being sized at 0.64 by 0.64 by 0.18 m and the feed array of the 15-m antenna being sized at 2.69 by 1.26 by 1.33 m.

Subreflector. The masses of the two subreflector assemblies are taken from estimates used in structural models of the radiometer assemblies in references 2 and 3. Mass estimates for the subreflectors of the 7.5- and 15-m antennas are 13 and 52 kg, respectively. GEOMOD models of these components, based on drawings and data in the Ford study, are modified to represent stowed configurations.

Mast booms. A point of departure from the baseline design of the Ford study is the use of deployable boom structures based on the minimast test article (ref. 10) to extend the subreflectors out to the proper distance for high-resolution scanning. Masses and volumes of these booms are found by scaling those of the minimast test article by boom length (10- and 20-m booms are used for the 7.5- and 15-m antennas, respectively). Stowed boom lengths of 0.35 and 0.70 m and corresponding masses of 48 and 95 kg are predicted for the 7.5- and 15-m antennas, respectively. The deployment mechanism required for these booms is a large structure, a significant factor in the mass and volume totals of the packaged system. This mechanism and other support hardware are described subsequently.

Truss Structure Package

The main section of the geostationary platform is constructed of seven 3-m cubic bays with beam elements similar to those proposed for Space Station *Freedom.* Support for the antennas is estimated from drawings of the platform to be the equivalent of approximately two more bays. This estimate is based on the length by which the main truss structure would have to be extended to attach directly to the antennas. At the present time the exact structural design of the interface between the main structure and the antennas is not defined.

Each of the nine bays (seven on the spacecraft bus and two assumed for attachment of the antennas) contains four longerons, four battens, and four diagonals, with an additional four battens included in the last bay. Longerons and battens are 3.0 m in length and diagonals are determined from basic geometry to be 4.24 m in length. In total, the platform requires seventy-six 3.0-m elements and thirty-six 4.24-m elements.

The 3.0-m elements are small enough to be stacked in 3.0-m-wide rectangular containers that can be placed transversely in either the Space Shuttle or the Titan IV. The 4.24-m elements, almost as long as the diameter of the Space Shuttle or Titan IV payload envelopes, are packaged in another container, which is oriented longitudinally.

Estimation of the volume required for this packaging is based on an assumption that these elements, which are 0.05 m in diameter, would be spaced at least one diameter away from each other. A multiplicative factor of 2.0 is included to allow for the contribution of other components such as wiring harnesses, joints, assembly hardware, and a packaging structure to hold each of the 112 truss elements in place during launch and assembly.

Packaging volumes required for the structure and related hardware are accommodated by two containers 3.00 by 1.50 by 0.60 m for the 3.0-m elements and one container 4.24 by 0.60 by 0.25 m for the 4.24-m elements. The 3.0-m elements are packaged into two containers to allow placement on both sides of the housekeeping module base and to facilitate easy access for assembly as well as to distribute the component mass about the payload centerline.

The breakdown of structural mass (377 kg from the Ford study) between the three truss element packages is based on volume so as to give a constant density to each package. A multiplying factor of 1.5 is used to roughly account for the launch integration structure and miscellaneous assembly hardware packaged with the structural components. A smaller multiplicative factor is chosen for the mass estimates than that for the volume estimates because of the wasted space between packaged elements implicit in the assumption that these elements are placed one diameter apart. This empty space contributes to the volume of the package but not to its mass.

The net mass of each of the two 3.0-m packages is estimated to be 253 kg, and mass of the 4.24-m element package is estimated to be 60 kg. The 50-percent mass contribution for launch integration structure is included as part of the launch support hardware and not as part of the payload. This contributes a total of 377 kg to payload mass and 189 kg to launch support. A volume of 4 m^3 is contributed to payload, and 2 m^3 is contributed to launch support.

Vehicle Considerations

Two launch vehicles are considered in this study, the Space Shuttle and the Titan IV expendable booster. These two are chosen because they are the only near-term vehicles that possess sufficient mass and volume capacity to launch the proposed geostationary platform. In some scenarios, an OMV based at Space Station *Freedom* is assumed for transfer of payloads to *Freedom* from lower orbits. All options considered in this study depend on a reusable SBOTV to transfer the assembled platform to geosynchronous orbit.

Space Shuttle

Payload mass properties. Present Space Shuttle payload weight capacity is 24 297 kg (53 500 lb) for launch into a low Earth orbit of 28.5° inclination and 204-km (110 n.mi.) altitude. For launch to the 407-km (220 n.mi.) altitude of the proposed Space Station *Freedom* the capacity is predicted to be 17 690 kg (39 000 lb). The advanced solid rocket motor (ASRM), a future enhancement to the Space Shuttle, will increase these respective payload capacities to 30 164 kg (66 500 lb) and 23 133 kg (51 000 lb) by the middle 1990's (ref. 11).

The center of gravity (c.g.) of the entire payload, including any shuttle integration hardware, must remain within the acceptable envelopes specified in the Space Shuttle manuals (ref. 12). Modifications to the c.g. specifications made as of September 1989 (private communication from Steve Gaylor, Rockwell Space Operations Company, Johnson Space Center, Houston, Texas) were taken into account in this study.

Payload volume constraints. Any payload within the Space Shuttle cargo bay must be confined within the payload envelope. This envelope, shown in figure 5, is a cylinder 4.57 m (180 in.) in diameter by 18.29 m (720 in.) in length with an enclosed volume of 300 m^3. An interference check within the solid modelling software is used to verify that none of the components of the packaged system (except the attachment pins of the support cradles) penetrate the orbiter payload envelope, and it also verifies that none of the packaged components unexpectedly touch each other or occupy the same space.

To fully verify that the payload dynamic envelope is not violated during any stage of flight, deflection of the payload structure under the flight loading conditions and vibration environment must be checked. Such an analysis is beyond the scope of this study, so the assumption is made that the Space Shuttle integrated payload is stiff enough and that a large enough margin is left between the payload and the envelope boundaries that this kind of interference will not occur.

Payload integration. Each payload pallet mounted in the Space Shuttle cargo bay is supported in a statically determinate manner by three pinned longeron fittings, one stabilizing longeron fitting, and one keel pin. Pin attachment points are customarily measured in inches in the standard orbiter-referenced coordinate system from reference 12. The origin and axis orientation of this coordinate system are shown in figure 5.

Location of these attachment points is limited to those listed in reference 12. There are two kinds of attachment points: active, for payloads that are removable, and passive, for payloads that are not. In all scenarios considered in this study, the pallets have to be removable; therefore, they all require attachment at active pin locations.

Cradles were designed to attach several individual payload elements onto pallets and to provide for attachment of the pallet longeron and keel pins. The volume contribution of the cradles is determined from solid models of them, and mass is computed from an estimated average density. This density is found from the assumption that these support structures are approximately 20 percent solid and constructed mostly of aluminum. Aluminum has a density of 2800 kg/m^3, so 560 kg/m^3 is used as an approximate support hardware average density.

For more detailed sizing, a structural analysis of the response of these cradles to typical launch accelerations is required. Such an analysis is beyond the scope of this study. Only geometrical considerations are used in the arrangement of components into the three pallets and the design of launch support cradles. These considerations include providing hard points for support of the major spacecraft components, attaching to allowable keel and trunnion pin locations, preventing components from interfering with each other, and not violating the Space Shuttle cargo bay payload envelope. Therefore, the design of the support cradles represents a very preliminary concept for these structures. It is developed primarily to estimate the contribution to the mass and volume of the launch support hardware.

Remote manipulator system (RMS). Use of the remote manipulator system (RMS) to remove the pallets from the Space Shuttle puts important constraints on their placement. Reference 12 requires a 0.61-m (24-in.) clearance between a payload item being removed with the RMS and any other cargo or support hardware in the shuttle bay and a 1.22-m (48-in.) clearance between the forward-most pallet and the forward bulkhead of the cargo bay. The latter specification can be waived, however, if the pallets are removable, as they are in all concepts considered in this study.

Another consideration in using the RMS is the placement of grapple fixtures on each of the three payload modules. Figure 6 shows envelopes containing areas that are within reach of the RMS arm as specified in reference 13. Positions in these plots are measured with respect to the base of the RMS arm, located at coordinates 17.26 m, −2.74 m, 11.30 m (679.5 in., −108.0 in., 444.8 in.) in the standard orbiter-referenced coordinate system of reference 12.

Reference 12 also specifies that the total distance from the grapple fixture base to the center of gravity of a payload attached to its end effector must be less than 3.96 m (13.0 ft) and that the perpendicular distance from the grapple fixture centerline must pass within 3.35 m (11.0 ft) of the pallet center of gravity.

The range of movements allowable at the three joints of the RMS places further limitation on its use. These limits are as follows:

Shoulder yaw:	−180° to 180°
Shoulder pitch:	−145° to 2°
Elbow pitch:	−2° to 160°
Wrist pitch:	−120° to 120°
Wrist yaw:	−120° to 120°
Wrist roll:	−447° to 447°

Another constraint on placement of RMS grapple fixtures is that no surrounding structure can violate an envelope that surrounds the fixture. The dimensions of this envelope are defined in reference 12. A contribution of 13 kg to the total package mass must be included for each grapple fixture.

Launch loads. In this study, no calculations involving the inertial loads imposed on the payload components because of the Space Shuttle ascent accelerations were made. Further refinement of the concepts proposed in this study will require this information to evaluate reaction forces at the keel and trunnion pin attachments and to size the support structure cradles in each of the pallets. For this reason, quasi-static launch loads for three flight regimes of the Space Shuttle ascent trajectory are reproduced below from reference 12. The load factors are given in g units in the same orbiter-referenced coordinate system used for specifying locations within the cargo bay.

Flight event	Load factor, g units, in—		
	X-direction	Y-direction	Z-direction
High-dynamic-pressure boost	−1.9	±0.40	0.25 −.50
Integrated vehicle boost (maximum X-direction load)	−2.9 −2.6	±0.06 ±.02	−0.15 −.20
Orbiter boost (maximum X-direction load)	−3.17 −3.05	0 0	−0.60 .80

Transient launch accelerations are specified in reference 12 to be −3.2, 1.4, and 2.5g in the X-, Y-, and Z-directions for the Space Shuttle ascent trajectory.

Titan IV

Payload mass properties. The payload capacity for the Titan IV in the no-upper-stage (NUS) configuration is 11 793 kg (26 000 lb) to 444 km (240 n.mi.) LEO. Unlike the Space Shuttle, there are no detailed published criteria for c.g. position for the Titan IV in the NUS configuration. As long as the payload c.g. is not offset much from the centerline of the vehicle, it will not be considered as a factor in this packaging study.

Payload volume constraints. Platform components are packaged into the 23.16-m (76-ft) payload shroud of a Titan IV NUS configuration. This offers a payload envelope with a volume of 296 m^3 (10 453 ft^3).

Interference between the platform components is checked using solid modelling software in a method similar to that used for the shuttle model. The Titan IV shroud payload envelope from the Titan IV User's Handbook (Martin Marietta Denver Aerospace, MCR-88-2541, Contract F04701-85-C-0019, June 1987) is checked to ensure that no part of the payload, except for the interface ring on the bottom of the support structure, extends outside of it.

Payload integration. The Titan IV CELV is intended to launch either assembled or deployable satellites and, as such, does not provide for attachment of many smaller payloads in a way that the orbiter longeron and keel pins do. Integration of the individual geostationary platform components into this launch vehicle requires conceptually designing a support structure that will, during launch and OMV transfer, retain three payload modules similar to those proposed for use on the Space Shuttle. A simplified design of this structure is conceived for the purpose of estimating its mass contribution.

Launch loads. Load factors used to size the launch support structure are taken from those representative of Titan III launch performance, because published values are not readily available for the Titan IV. The Titan III static accelerations assumed in this analysis are based on those in reference 14. Three sets of loads are selected that represent the worst cases. The load factors for these cases are as follows:

1. 4.0g longitudinal (compressive), 1.8g lateral
2. 1.0g longitudinal (tensile), 1.8g lateral
3. 4.6g longitudinal (compressive), 1.1g lateral

From these load factors and a minimum allowable factor of safety of 2.0, the column supports are sized based on buckling load and Von Mises stresses, and the thrust tube is sized for buckling from thin-walled-tube theory.

Orbital Maneuvering Vehicle

Using the orbital maneuvering vehicle (OMV) to return each cargo pallet to Space Station *Freedom*, from either the Space Shuttle or the Titan IV, for assembly is based on the OMV design reference mission (DRM) number 10. In this DRM, the OMV is capable of retrieving a 22 680-kg (50 000-lb) payload module from a Space Shuttle in LEO, boosting it to Space Station *Freedom* 204 km (110 n.mi.) above, and returning with another 22 680-kg module. This operation uses 4371 kg (9636 lb) of expendables, which include 3855 kg (8489 lb) of bipropellant fuel, 444 kg (979 lb) of hydrazine, and 72 kg (159 lb) of cold gas.

Estimates of the expendables that will be used for retrieval of pallets in the scenarios presented in this study are based on the assumption that the values obtained for the DRM can be scaled according to the total mass of the OMV payload, the OMV, and its fuel. This assumption implies a constant expenditure of propellant per unit mass for the same altitude and plane change. Calculated from the DRM, these ratios are as follows: bipropellant, 0.062 kg/kg net mass; hydrazine, 0.007 kg/kg net mass; and cold gas, 0.0001 kg/kg net mass.

These calculations assume the same change of altitude as used in DRM number 10, namely, 204 km (110 n.mi.) from a Space Shuttle orbit of 204 km to a Space Station *Freedom* orbital altitude of 407 km (220 n.mi.). As such, they represent a conservative scenario in that the pallets have to be transferred to the highest orbit proposed for Space Station *Freedom*.

Note that another DRM, number 12, may also be applicable. This mission involves moving a 34 019-kg (75 000-lb) payload and OTV combination 1 km from Space Station *Freedom* in the same orbit and returning only the OMV. It is derived for the movement of an assembled spacecraft and OTV combination away from *Freedom* Station for ignition of the OTV. Because the target is closer and does not require an altitude or plane change, only cold gas is used as a propellant. In this study the retrieval of pallets from a co-orbiting Space Shuttle is not considered, and DRM number 10 is chosen as the baseline because its operation is closest to the planned retrieval scenario.

Orbital Transfer Vehicle Considerations

A proposed beginning-of-life (BOL) platform mass of 8116 kg (6681-kg platform and 1435-kg station-keeping propellant) is too large for any existing upper stage system. In addition, the Ford study specifies that the geostationary platform truss structure is designed based on assumed orbital transfer accelerations of $0.1g$.

The decision to use an SBOTV in this study is the only significant deviation from a basic constraint on using only existing or near-term systems. An SBOTV is deemed necessary because of the limited weight capacities of all existing upper stages and the need to provide a low-thrust transfer to geosynchronous orbit. Also, a reusable SBOTV eliminates the need to include this upper stage in the payload manifest.

From figure 7 (ref. 15), the OTV delivery propellant requirement is 25 850 kg. From reference 16, the average density of the O_2 and H_2 (taking into account the proper mixture ratios) is 260 kg/m^3; therefore, the required fuel volume is 99 m^3. Station-keeping propellant required for the platform on orbit is estimated in the Ford study to be 1435 kg of nitrogen tetroxide and monomethyl hydrazine. Reference 16 gives the density of this propellant, averaged by mixture ratio, as 1210 kg/m^3. This requires an extra 1 m^3 of fuel volume for station-keeping propellant. Therefore, a total of 27 285 kg (101 m^3) of propellant must be transported to LEO in addition to the 6681 kg of platform hardware.

Space Shuttle Pallet Design

In all the scenarios using the Space Shuttle, the platform components are packaged into three pallets. This arrangement of components is identical for every Space Shuttle scenario, so a brief explanation of the packaging within the pallets is given here before presentation of the specific scenarios.

The first pallet, designated "A," is illustrated in figure 8(a). It contains the following components: instrument and housekeeping modules, solar panel arrays, truss structure, infrared interferometer spectrometer, lower central cylinder and OTV interface, geodynamic laser ranging experiment, high-gain antenna, multichannel microwave radiometer, and the global positioning system (GPS) antenna. The net mass of this pallet is 5486 kg.

The second pallet, designated "B," is illustrated in figure 8(b). It contains the 15-m passive microwave radiometer feed array, strongback, surface membrane, and mast boom and the 7.5-m passive microwave radiometer boom. This pallet has a net mass of 1851 kg.

The third pallet, designated "C," is illustrated in figure 8(c). It contains the following payload components: subreflectors for both antennas, solar sail, and 7.5-m passive microwave radiometer truss structure, surface segments, and feed array. Its net mass is 978 kg.

Separation of the platform components into three pallets is done according to the three main structural areas of the platform: the housekeeping and instrument modules and truss structure, the 7.5-m passive microwave radiometer, and the 15-m passive microwave radiometer. Assembly considerations are also taken into account in the arrangement of platform components into the three pallets described above.

The housekeeping and instrument modules are assumed to be the first components used in the assembly sequence. They are placed on pallet A. The lower central cylinder and OTV interface are packaged for launch perpendicular to their on-orbit deployed positions to prevent them from violating the Space Shuttle payload envelope and to allow for the proper clearances for use of the RMS arm.

Once the lower central cylinder is properly connected, the housekeeping and instrument modules are removed from the temporary attachment location on the structure of Space Station *Freedom* and taken to a dummy OTV port located elsewhere on the station. This dummy port provides electricity, data communications, and fueling for the reaction control jets. Communications through this port are used for checkout of the instruments and onboard systems inside the housekeeping module. This may be done in addition to, or as a substitute for, moving individual instruments to a separate integration and checkout facility on the space station.

Construction of the truss structure is assumed to begin at the base of the housekeeping module and move outward. Structural elements are stowed in three packages attached to the bottom of the housekeeping module to permit easy access to them during the assembly sequence.

Once the platform truss structure is assembled, the packaged 15-m antenna strongback and mesh are removed from pallet B. This antenna is deployed and attached to hard points on the spacecraft truss.

The minimast boom deployment mechanism forms the second half of pallet B. This mechanism is attached to points along Space Station *Freedom* and then operated automatically to open the minimast booms stowed inside of it.

Placement of the grapple fixture for pallet B on the base of the minimast deployment mechanism can present future problems from the standpoint of visual cues for the RMS operator because it cannot be seen except by a camera on the RMS end effector. Alternatives include placement of the grapple fixture on the top of the pallet or orientation of the entire pallet 90° in pitch (private communication from Laura S. Mann, Johnson Space Center, Houston, Texas). To place the grapple fixture on top of the pallet will require additional integration structure because the packaged antenna components are very delicate and cannot serve as load-bearing points as the deployment mechanism structure does. For these reasons, placement of the grapple fixture on the aft side of this pallet is recommended.

The surface and structural elements of the 7.5-m antenna form the basis of pallet C. The strongback truss is erected from this set first. Solid surface elements are attached to the assembled tetrahedral truss, and then the entire antenna is connected to the hard points on the spacecraft structure. Launch support structure and the used deployment mechanism will have to be returned to the ground on a future Space Shuttle flight.

To determine the mass and volume properties of the complete packaged system in the Space Shuttle orbiter cargo bay, the contribution of launch support hardware must be estimated. This hardware is separated into four areas for sizing: the support cradles for attachment of the pallets, the RMS grapple fixtures, the mechanism required to deploy minimast booms, and the integration structure to hold disassembled truss components.

The three sets of Space Shuttle integration hardware for pallets A, B, and C are estimated to have masses of 162, 277, and 246 kg and volumes of 0.29, 0.48, and 0.44 m^3, according to the assumptions made previously in this section. Three RMS grapple fixtures are required, one for each pallet, with a mass of 13 kg each.

The minimast boom deployment mechanism, included in pallet B, is considered as part of the support hardware, rather than as part of the payload, because it does not remain on the assembled platform. Folded booms loaded into it are included as payload. The design for this mechanism is based on that of a test article constructed as a boilerplate model. Volume is computed to be 1 m^3 from this solid boilerplate model of the mechanism. Mass, however, is taken from estimates of the flight model version to be 721 kg from "Preliminary System Requirements Review: Mass Properties Status Report #8, DRD SE-28, Harris Corp., Sept. 18, 1987.

From the section entitled "Truss Structure Package," integration hardware for the truss structure, which is included in pallet A, is estimated to contribute 189 kg and 2 m^3 to the launch support mass and volume, respectively.

Scenarios

Four different scenarios are considered for launch of the geostationary platform components to Space Station *Freedom*. One involves a single Space Shuttle launch, one uses the Titan IV expendable booster, and two involve dual Space Shuttle launches. All four assume that the assembled platform will be transferred to geosynchronous orbit by an SBOTV.

Scenario Number 1: Shuttle Launch and OMV Retrieval to Space Station *Freedom*

Description of scenario. This scenario involves launch of the platform to LEO as three specialized pallets in the Space Shuttle cargo bay. One at a time, these pallets are removed with the Space Shuttle RMS and retrieved with an OMV for transfer to Space Station *Freedom*.

At *Freedom* Station, the pallets are broken down and those instruments that require checkout before assembly are taken to the appropriate facility. The platform is then assembled by the crew at *Freedom* using a combination of extravehicular activity (EVA) and telerobotics. Propellant for the OMV and OTV will be allocated to another shuttle launch.

Placement of components. The proposed arrangement of geostationary platform components into three pallets inside the Space Shuttle cargo bay is shown in figure 9. Figure 10 gives the specific locations of trunnion pins that support the pallets.

Pallet A is attached to the longeron support pins at the 25.35-m (998.20-in.) station and to the keel and longeron pins at the 29.85-m (1175.20-in.) station. Pallet B is attached to the longeron supports at the 19.96-m (785.80-in.) station and to the keel and longeron supports at the 21.46-m (844.80-in.) station. Pallet C is attached to the longeron supports at the 16.56-m (652.07-in.) station and to the keel and longeron supports at the 18.06-m (711.07-in.) station.

The interference check in GEOMOD confirms that none of the components of the packaged system unexpectedly touch each other or violate the Space Shuttle cargo bay dynamic envelope.

Mass properties. Net mass of the packaged system is 8315 kg and net volume is 93 m^3. Support mass includes the three cradle assemblies, RMS grapple fixtures, minimast boom deployment mechanism, and truss structure integration hardware. Together these contribute 1634 kg of mass and 4 m^3 of volume to launch support hardware. Center of gravity for the Space Shuttle integrated payload is located at coordinates 24.26 m, -0.003 m, 10.12 m (955.1 in., -0.1 in., 398.3 in.) in the orbiter-referenced coordinate system defined in figure 5. As plotted in figure 11, this c.g. position is within the acceptable envelopes, although little clearance from the maximum forward position is found. A more detailed summary of mass properties of the system and each of the three pallets is given in table 2.

Remote manipulator system considerations. Spacing between each of the three pallets and the cargo bay bulkheads is shown in figure 10. Clearance between the payload and the forward bulkhead in this scenario is 0.94 m (37.2 in.). These spacings are within the specifications given earlier.

These clearance requirements do not provide enough space in the payload bay for a space station docking adapter to be included. Therefore, the orbiter is incapable of attaching directly to Space Station *Freedom*. The use of the OMV to retrieve each of the payload pallets one at a time and return them to Space Station *Freedom* is proposed to rectify this problem.

Numerical data used in evaluating the constraints on use of the RMS arm are given in table 3. Drawings of the RMS arm configuration used in removing each of the pallets are shown in figure 12. The RMS grapple fixture envelopes are shown for each of the three pallets in figure 13.

The RMS arm is modelled to reach each of the three grapple points and is included in the GEOMOD interference checks used to search for violation of the payload dynamic envelope. From this information, the arm is verified as not touching any other parts of the cargo as it retrieves each of the pallets.

In terms of payload clearance, reach envelopes, attached payload mass properties, allowable joint movement, and grapple fixture clearance envelopes, this analysis shows the feasibility of using the RMS in the present Space Shuttle packaged configuration.

OMV retrieval considerations. A summary of the fuel expenditure estimates for each of the six segments of the OMV retrieval operation is given in table 4. From these computations, net expendables consumed are 3380 kg of bipropellant, 389 kg of hydrazine, and 63 kg of cold gas. These represent 83, 73, and 84 percent, respectively, of the OMV capacities.

Assembly considerations. As illustrated in figure 12, the order of pallet removal is first A, then B, and then C. Operational difficulties could arise in the future because of this order of removal. Pallets are arranged from heaviest to lightest in moving from the aft to the forward position in order to force the launch payload center of gravity aftward and to keep it within an allowable range.

Placement of the grapple fixture on the aft side of pallet B requires that pallet A be removed first. This order of deployment moves the payload center of gravity forward as each pallet is removed. If a contingency is allowed for immediate return of the orbiter in an emergency, then having partially removed the cargo could cause a violation of the center-of-gravity envelope and result in aerodynamic return problems. These concerns were pointed out in the previously mentioned private communication from Laura S. Mann. Full consideration of the operational consequences of this proposed scenario is beyond the scope of this study.

Scenario Number 2: Titan IV Launch and OMV Retrieval to Space Station *Freedom*

Description of scenario. A scenario for placing the platform in orbit using the Titan IV begins with a launch to LEO. The platform components are retained inside the launch support structure, which was conceptually designed previously. Once in orbit, this package is separated from the final stage of the Titan IV, and an OMV based at Space Station *Freedom* mates with a docking port on the top of this structure. The OMV then transfers the complete system to *Freedom* Station.

The payload then docks with the dummy OTV port on Space Station *Freedom* using the OTV adapter on the lower central cylinder. Then the OMV separates from the payload forward end. The launch support structure is disassembled, and platform components are removed by telerobotic operators at Space Station *Freedom*. Because the Titan IV is unmanned and is not intended to reach Space Station *Freedom* altitudes, an OMV is needed to move the entire payload, once on orbit, to Space Station *Freedom* for removal of the platform component modules.

Placement of components. The arrangement of payload components on the launch support structure inside the Titan IV 23.16-m (76-ft) payload shroud is shown in figure 14. The locations of payload groups within the Titan IV shroud are shown in figure 15. The three modules are arranged with the housekeeping module at the bottom, as mentioned previously, to allow its OTV docking module to be attached to the dummy port on Space Station *Freedom*. The 15-m antenna assembly, with the minimast deployment mechanism, is placed on a platform located at the −7.43-m (−292.5-in.) station in the Titan IV coordinate system defined in the Titan IV User's Handbook. Surface segments and the strongback truss structure for the 7.5-m antenna are placed on a platform at the −11.24-m (−442.5-in.) station, and the OMV interface is located above them at the −15.48-m (−609.5-in.) station. The individual payload modules are illustrated in figure 16.

An interference check with GEOMOD determined that none of the packaged components, or the launch support structure, unexpectedly touch each other or violate the Titan IV payload envelope.

Launch loads and structural design of support equipment. Inertial loads from the payload sets at the −11.24-m (−442.5-in.) and −7.43-m (−292.5-in.) stations are transferred through four column supports to a conical thrust tube, which also transfers the loads from the 5311-kg module. A drawing of this simplified support structure is shown in figure 17.

This payload support structure is designed from the static launch loads given previously in order to estimate its contribution to the packaged system mass and volume. Aluminum is chosen as the structural material. Adequate strength is provided by 0.10-m-diameter columns with thicknesses of 0.008 m. The thrust tube has a top radius of 2.29 m, a bottom radius of 1.57 m, and a height of 1.29 m to attach properly between the forward support structure and the Titan IV payload interface ring. The thickness of this thrust tube is 0.006 m to provide adequate support for the launch loads.

With a density of 2800 kg/m^3 for aluminum, this support structure has a mass of 801 kg. A 30-percent contingency in this estimate is added to account for attachment hardware and non-loadbearing structural elements to bring its contribution to support mass to 1041 kg. Volume of this structure is 3 m^3.

Mass properties. The net mass of the packaged system is 8645 kg, and net volume is 95 m^3. This mass breakdown is summarized in table 5. Location of the center of gravity is −5.37 m, 0.06 m, 0.04 m (−211.5 in., 2.5 in., 1.6 in.) in the Titan IV coordinate system. As mentioned previously, there are no detailed published criteria for the payload c.g. location for the Titan IV. The c.g. offset only 0.08 m (3.2 in.) from the vehicle centerline is not expected to present a problem.

The platform components included as payload remain unchanged from the Space Shuttle launch design. Support mass includes the 1041 kg determined above, the OMV retrieval grapple fixture (assumed to be the same as those on the shuttle, with a mass of 13 kg), the minimast boom deployment mechanism, and the truss structure package. Total support structure contribution to mass is 1964 kg and contribution to volume is 6 m^3.

OMV retrieval considerations. With the same assumptions for use of the OMV as is done in scenario number 1, it is estimated that the OMV uses 1883 kg of expendables in retrieving the Titan IV payload module from a 204-km (110-n.mi.) orbit. This expenditure is broken down as follows: transfer of empty OMV from Space Station *Freedom* to LEO (bipropellant, 587 kg; hydrazine, 66 kg; and cold gas, 9 kg) and retrieval of Titan IV payload module (bipropellant, 1082 kg; hydrazine, 122 kg; and cold gas, 17 kg). Net expendables required are 1669 kg of bipropellant, 188 kg of hydrazine, and 26 kg of cold gas. These amount to 41, 36, and 35 percent, respectively, of the OMV capacities.

Assembly considerations. The platform components are arranged into three sets, as with the Space Shuttle configurations. Special considerations for use of the Titan IV include extension of the OTV docking adapter on the lower central cylinder to the base of the Titan IV interface ring. This allows the complete packaged system, once retrieved by the OMV, to be docked to the dummy OTV port on Space Station *Freedom*. Once docked securely to *Freedom* Station, the launch support structure is disassembled and platform components are removed for checkout and assembly.

Scenario Number 3: Shuttle Launch Direct to Space Station *Freedom*

Description of scenario. This scenario involves direct launch of the platform to Space Station *Freedom* in two Space Shuttle flights. Three pallets, identical to those used in scenario number 1, are divided between the two flights. Pallet A is placed on the first launch, and pallets B and C are included on the second launch. Both flights can accommodate a Space Station *Freedom* docking adapter.

Each orbiter docks at Space Station *Freedom* using the standard interface. The pallets are removed from each flight at *Freedom*. After the second flight, the platform is assembled. Assembly operations are assumed to be similar to those used in scenario number 1.

Placement of components. The proposed arrangement of the pallets for the two Space Shuttle launches is shown in figure 18. Figure 19 gives the locations of trunnion pin attachment points for the first launch, and figure 20 gives this information for the second launch. These positions are measured in inches in the standard orbiter-referenced coordinate system.

Pallet A is launched on the first flight attached to the longeron support pins at the 22.56-m (888.07-in.) station and to the keel and longeron pins at the 27.05-m (1065.07-in.) station. Pallets B and C are launched on the second Space Shuttle flight. Pallet C attaches to the longeron supports at the 19.46-m (766.13-in.) station and to the keel and longeron supports at the 20.96-m (825.13-in.) station. Pallet B is attached to the longeron supports at the 23.80-m (939.20-in.) station and to the keel and longeron supports at the 25.35-m (998.20-in.) station. The docking adapter is located in the standard position, with its centerline at the 15.72-m (619-in.) station.

Support hardware included within each of the three pallets is identical to that proposed for scenario number 1.

An interference check, similar to that used on the single launch configuration, is performed within GEOMOD to verify that none of the packaged components unexpectedly touch each other or occupy the same space. The GEOMOD interference check also verifies that the Space Shuttle payload envelope and the grapple fixture clearance envelopes are not violated.

Mass properties. Net mass of the packaged system on the first launch is 6189 kg and net volume is 82 m^3. On the second launch, net mass is 3532 kg and net volume is 28 m^3. Launch support contributes a total of 1067 kg and 11 m^3 on the first launch and 1973 kg and 11 m^3 on the second launch. This includes the docking adapter, which adds 703 kg of mass and 9 m^3 of volume to each flight. The c.g. for this flight is located at coordinates 23.18 m, −0.01 m, 10.07 m (912.3 in., −0.42 in., 396.3 in.) in the standard orbiter coordinate system. For the second flight, c.g. position is located at 20.21 m, 0.003 m, 10.06 m (795.5 in., 0.1 in., 395.7 in.). Centers of gravity on both flights are within the acceptable envelopes, as shown in figure 21.

As in scenario number 1, this c.g. is very close to the maximum forward position allowed. However, as discussed in the next scenario, this arrangement provides the option of dividing the OTV propellant between these two flights instead of requiring a dedicated launch, as would be the case in scenario number 1. If this propellant is included, it moves the c.g. for both flights aft a significant distance. To provide some flexibility and a factor of safety in integrating OTV propellant containers on these two launches, if that is desired, a movement of the dry payload c.g. as far forward as possible may be advantageous. A more detailed summary of mass properties for each launch is given in table 6.

Space Station** Freedom **RMS considerations. When the Space Shuttle is docked at Space Station *Freedom*, the space-station-based RMS arm is assumed to be used to remove the pallets from the cargo bay. If a space-station-based RMS arm is unavailable, the arm inside the Space Shuttle can also be used. Requirements for payload clearances, mass properties, and grapple fixture envelopes are assumed to be the same as, or more liberal than, those specified for the orbiter-based RMS.

Spacing between each of the pallets and cargo bay bulkheads for both launches is shown in figure 19 for the first launch and in figure 20 for the second launch. All these clearances are greater than the 0.61-m (24-in.) minimum specified for the orbiter-based RMS.

Since the three pallets are identical to those used in the previous single launch configuration, the c.g. offsets from the grapple fixtures are equal to those for that configuration. Refer to table 3 for the pallet mass properties in relation to use of the RMS. As shown previously, these offsets are within the allowable limits, and no interference exists with the grapple fixture envelopes.

Scenario Number 4: Two Shuttle Launches, Including OTV Propellant

One important factor to consider in packaging the geostationary platform components is the large amount of propellant required for the OTV transfer. This is computed to contribute 27 285 kg of mass and 101 m^3 of volume. In any concept proposed, this supplemental mass will require at least one additional launch of either the Space Shuttle or an expendable vehicle. Scenario number 3, in which the payload is divided between two launches, provides a sufficient amount of unused volume in which to include this propellant.

In this scenario, the OTV propellant is packaged into the excess volume on each of the two launches. The three pallets will be located in the same positions within the cargo bay. Each Space Shuttle launch will thus contain some platform components as well as some OTV propellant.

In figure 22, available areas where the propellant can be located are indicated. On the first flight there will be 46 m^3 of volume between the 29.65-m (1167.44-in.) and 33.07-m (1302-in.) stations (allowing the 0.61-m (24.00-in.) margin for the RMS arm to remove the propellant containers). On the second flight, 117 m^3 of volume will be available between the 25.35-m (998.2-in.) and 33.07-m (1302-in.) stations.

To evaluate the option of dividing this additional payload between the two Space Shuttle flights in this scenario, the contribution to mass and volume of the tankage and support structure is assumed to be 30 percent of the propellant alone. No further assumptions are made as to the exact nature of this support. Net mass and volume contributions incurred by including OTV and station-keeping propellant on the two Space Shuttle flights are 35 470 kg and 131 m^3. This estimate of propellant and support equipment mass significantly exceeds the projected capacity of the Space Shuttle with the ASRM to LEO (204 km) of 30 164 kg. Therefore, the option of using a second Space Shuttle launch for the propellant alone will not be feasible under present shuttle capabilities.

If 10 612 kg (39 m^3) are included in the first flight, the c.g. is moved aft to the 28.34-m (1115.86-in.) station and the payload mass is increased to 16 801 kg. If 24 859 kg (92 m^3) are included in the second flight, the c.g. is moved aft to the 28.09-m (1105.98-in.) station and the net mass is increased to 28 392 kg. These new c.g. locations are indicated in figure 23.

By including this propellant with the payload manifest, dividing platform components between two launches becomes more desirable. Note that although the first flight is below the projected Space Shuttle capacity (17 690 kg) to attain the lowest orbit proposed for Space Station *Freedom* (407 km), the second flight will slightly exceed the 204-km altitude capability, so this option is dependent on future Space Shuttle capability upgrades such as the ASRM.

With such a large payload, the second launch will probably require OMV retrieval to Space Station *Freedom.* Therefore, the docking adapter will not be necessary and can be removed, slightly lowering the predicted payload weight but not enough to change the conclusions about the feasibility of this scenario. Another possibility will be to remove the OTV propellant using OMV sorties first, and then change orbits and dock with Space Station *Freedom* using the docking module to then unload the pallets. Space Shuttle operations such as that have not been investigated any further.

Summary of Payload Integration Concepts (Scenarios)

A summary of the three geostationary platform payload integration concepts considered in this study is given in table 7. The breakdowns in net mass and volume among platform components, launch integration hardware, and OTV propellant are shown graphically in figure 24 for scenario number 1, in figure 25 for scenario number 2, in figure 26 for scenario number 3, and in figure 27 for scenario number 4.

Scenario number 1, a single Space Shuttle launch with OMV retrieval, has the advantage of packaging all the platform into one flight using only present Space Shuttle capabilities. This advantage would be offset by the need for a second mission to launch OTV propellant, although separating the spacecraft and the propellant could be advantageous. Its primary disadvantage is the reliance on many separate aspects of future space architecture, including the OMV, OTV, and Space Station *Freedom*, as well as the need for two separate crews, one at *Freedom* and one on the orbiting Space Shuttle. This complexity is compounded by the fact that, with all three pallets in one flight, direct docking with Space Station *Freedom* is impossible. Also, using a dedicated OTV and station-keeping propellant launch after the platform is assembled may not be practical because the payload mass of such a launch exceeds projected Space Shuttle with ASRM capabilities for LEO.

Use of the Titan IV, as in scenario number 2, has the advantage of not being dependent on Space Shuttle launch schedules. It also does not require a second crew. The disadvantage of this scenario is the need to provide nonstandard launch support hardware. This concern could give rise to problems unforeseen at the present time if this design option is pursued further. Other than the nonstandard launch support structure, the only special hardware required is an OMV based at Space Station *Freedom.*

Separating the geostationary platform package into two Space Shuttle flights, as in scenario number 3, allows docking at Space Station *Freedom.* However, this scenario presents the disadvantages of having to store the components launched on the first flight in either a disassembled or a partially assembled form. Also, scheduling an additional launch into the Space Shuttle manifest could be difficult. A final disadvantage is that there will still be the need for another mission to get the OTV propellant up.

Requiring two flights for the payload may still be attractive as a means of launching the platform if the OTV propellant is included in the flights. By separating the payload between two flights it is conceivable that the OTV propellant could be accommodated within the excess volume and mass on both flights, if the advanced solid rocket motor (ASRM) is available. However, having the platform assembled and checked out before the OTV propellant is launched is an advantage of using a dedicated payload flight and a dedicated propellant flight. If this propellant is included, then the second launch will require retrieval by an OMV because its payload will exceed Space Shuttle performance limits to Space Station *Freedom* altitudes.

Recommendations and Options

Packaging and integration concepts for launch of the components of a large Earth sciences geostationary platform in either the Space Shuttle or the Titan IV Complementary Expendable Launch Vehicle have been derived. On a conceptual level, all these concepts meet launch vehicle requirements and do not exceed projected performance specifications. The comparison of the four can be based primarily on mission complexity, amount of nonstandard hardware and operations required, and level of space technology infrastructure assumed.

All four scenarios considered in this study require Space Station *Freedom* and an SBOTV. Dependence on either of these pieces of future space infrastructure can put the schedule of the geostationary platform in question. However, the only scenarios that do not require Space Station *Freedom* or an SBOTV entail either significant modifications to the basic geostationary platform design or utilization of far-term technology.

Future options might include the following: assembly of the platform on an orbiting Space Shuttle, launch of the 7.5-m microwave radiometer assembled in the ACC of the Space Shuttle, use of proposed upgrades to the Titan IV, or application of existing upper stages. Consideration can also be given to launching individual components packaged on Spacelab payload accommodation pallets. Studies of this option show that sufficient payload volume is difficult to obtain because of the space taken up by the pallets themselves. Also, removal of the individual platform components is difficult without a heavy reliance on EVA.

If the dependence on existing launch vehicle technology is relaxed, the heavy lift launch vehicle (HLLV), the Advanced Launch System (ALS), or Shuttle-C could be considered as future options. Further evaluation of these options and their impact on utilization of launch vehicle capabilities is beyond the scope of this study.

Recommendations to improve the basic platform concept for the next design iteration include reducing its mass below 4535 kg (10 000 lb) and strengthening the truss structure to allow use of a Centaur upper stage for transfer to geosynchronous orbit. Reducing the amount of assembly required in LEO is also desirable because this could eliminate the dependence on Space Station *Freedom*. A deployable design below 4535 kg is optimum because this could be launched directly to geosynchronous orbit on a Titan IV/Centaur. Options for a partially deployable platform include launch of the main bus and the Centaur upper stage into LEO by a Titan IV and then assembly of the remainder of the spacecraft by a Space Shuttle crew.

Concluding Remarks

This paper has demonstrated, on a very preliminary basis, several options for placing the components of a large Earth sciences geostationary platform at Space Station *Freedom*. The four scenarios considered, three using the Space Shuttle and one using the Titan IV, were all shown to be viable mission choices, dependent on near-term hardware only.

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Table 1. Platform Mass and Volume Estimates

Platform component	Mass, kg	Volume, m^3
15-m passive microwave radiometer:		
Strongback truss	250	4
Membrane surface	4	2
Feed array	443	4
Mast boom	95	1
Subreflector	52	0
7.5-m passive microwave radiometer:		
Strongback truss	131	1
Surface panels	441	4
Feed array	72	0
Mast boom	48	1
Subreflector	13	0
Instrument and housekeeping modules	3456	54
Infrared interferometer spectrometer	860	4
Lower central cylinder and OTV interface	45	2
Main structure	377	4
Geodynamic laser ranging experiment	100	1
Multichannel microwave radiometer	100	1
High-gain antenna	20	0
Solar arrays (includes active cavity radiometer and X-ray imager)	149	5
GPS antenna	15	0
Solar sail	10	0
Contribution from smaller components[a]		1
Total platform	6681	89

[a]Contribution of components with volumes listed as 0.

Table 2. Mass Properties for Scenario Number 1

Component	Mass, kg	Center of gravity, m, in orbiter-referenced coordinate system		
		x	y	z
Pallet A	5486	26.92	-0.01	10.11
Pallet B	1851	20.14	0	10.08
Pallet C	978	17.15	0.01	10.24
Total packaged system	8315	24.26	0	10.12

Table 3. Remote Manipulator System (RMS) Reach Analysis for Scenario Number 1

	Pallet A	Pallet B	Pallet C
Module c.g. in orbiter-referenced coordinate system, in.:			
x	1055.8	793.0	675.3
y	−.2	0	.5
z	398.0	396.9	403.0
Grapple fixture location in orbiter-referenced coordinate system, in.:			
x	1113.7	851.9	681.5
y	0	0	60.7
z	460.1	364.2	438.7
Grapple fixture location unit vector:			
x	0	1.0	0
y	0	0	0.5
z	1.0	0	0.9
Total distance from grapple to module c.g., in. . . .	84.9	67.3	70.3
Perpendicular distance from grapple to module c.g., in. . . .	57.9	58.9	34.8
RMS arm joint orientation, deg:			
Shoulder pitch	-43.3	-46.2	-88.6
Shoulder yaw	14.0	23.8	89.6
Elbow pitch	61.1	116.6	133.0
Wrist pitch	-72.2	-109.0	-75.5
Wrist yaw	0	-23.8	-.3

Table 4. OMV Estimated Propellant Expenditure

[All values in kilograms]

Operations segments	Payload	Net fuel			Fuel expenditure		
		Bipropellant	Hydrazine	Cold gas	Bipropellant	Hydrazine	Cold gas
1. First OMV transfer to Space Shuttle	0	4082	535	75	588	68	11
2. Retrieval of pallet A	5486	3494	467	64	888	102	17
3. Second OMV transfer to Space Shuttle	0	2606	365	47	484	56	9
4. Retrieval of pallet B	1851	2122	309	38	566	65	10
5. Third OMV transfer to Space Shuttle	0	1556	244	28	411	47	8
6. Retrieval of pallet C	978	1145	197	20	443	51	8
Total expenditure					3380	389	63

Table 5. Mass Properties for Scenario Number 2

Component	Mass, kg	Center of gravity, m, in Titan IV coordinate system		
		x	y	z
Payload set at 4.14-m (163.0-in.) station	5311	-2.95	-0.01	-0.07
Payload set at -7.43-m (-292.5-in.) station	1708	-8.90	.35	.41
Payload set at -11.24-m (-442.5-in.) station	572	-12.13	.01	-.01
Launch support structure and grapple fixture	1054	-8.18	0	0
Total packaged system	8645	-5.37	0.06	0.04

Table 6. Mass Properties for Scenario Number 3

Component	Mass, kg	Center of gravity, m, in orbiter-referenced coordinate system		
		x	y	z
First flight: pallet A	5486	24.14	-0.01	10.11
First flight: Space Station *Freedom* docking adapter	703	15.72	0	9.74
Total packaged system, first flight	6189	23.18	-0.01	10.07
Second flight: pallet B	978	24.50	0.01	10.24
Second flight: pallet C	1851	19.64	0	10.08
Second flight: Space Station *Freedom* docking adapter	703	15.72	0	9.74
Total packaged system, second flight	3532	20.20	0	10.06

Table 7. Summary of Mass and Volume for Four Scenarios

Scenario	Launch vehicle weight capacity, kg	Payload mass, kg	Support hardware mass, kg	OTV fuel mass, kg	Total packaged system mass, kg	Launch vehicle envelope volume, m^3	Payload volume, m^3	Support hardware volume, m^3	OTV fuel volume, m^3	Total package system volume, m^3
Number 1	24 267	6681	1634		8 315	300	89	4		93
Number 2	11 793	6681	1964		8 645	296[a]	89	6		95
Number 3, first launch	17 690	5122	1067		6 189	300	71	11		82
Number 3, second launch	17 690	1559	1973		3 532	300	18	10		28
Number 4, first launch	17 690	5122	3330	7 542	15 994	300	71	19	39.1	130
Number 4, second launch	30 164[b]	1559	7881	19 692	29 132	300	18	32	91.7	142

[a] With 23.16-m (76-ft) shroud.
[b] Projected mid-1990's capacity to 204 km (110 n.mi.) with ASRM.

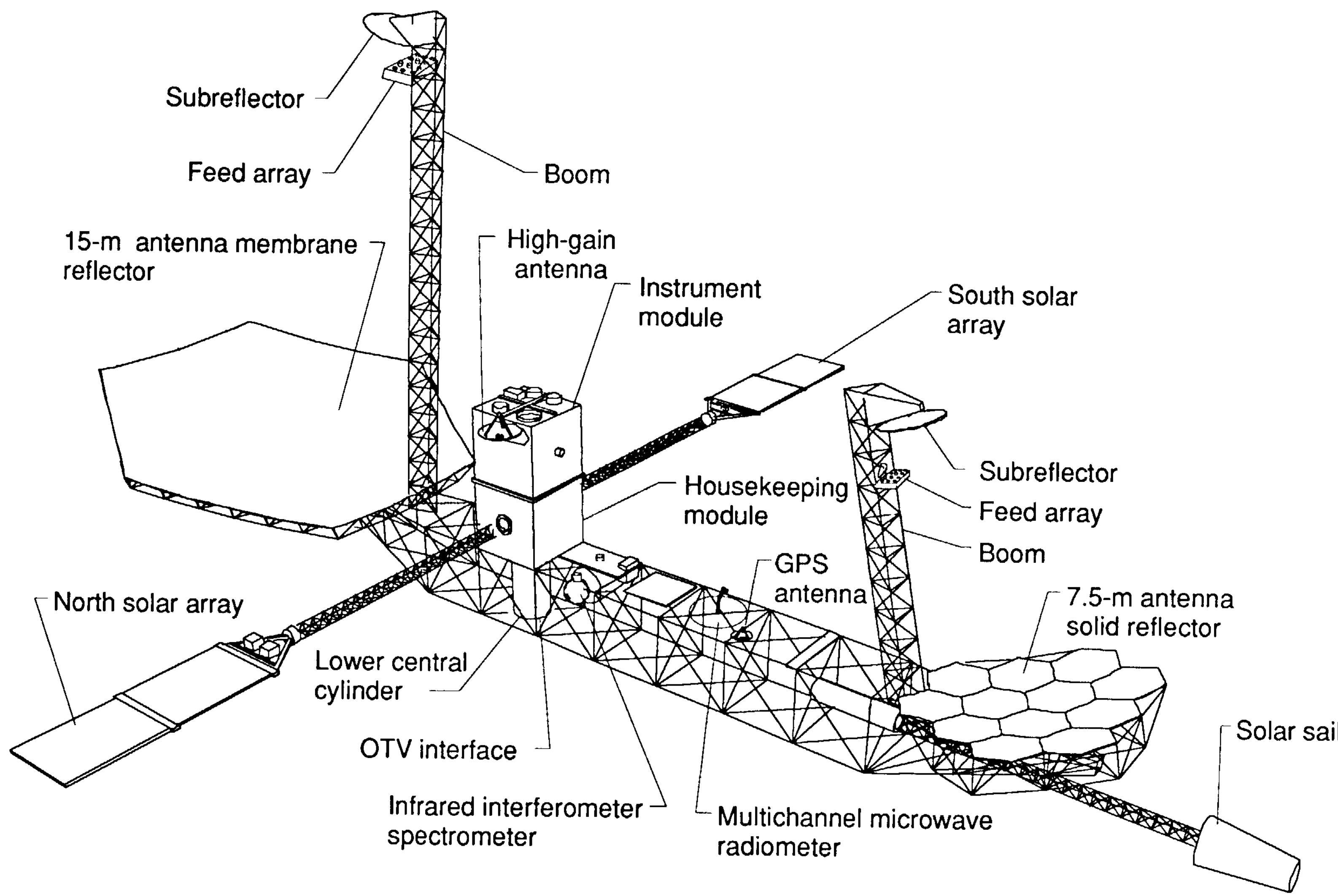


Figure 1. Earth sciences geostationary platform conceptual design.

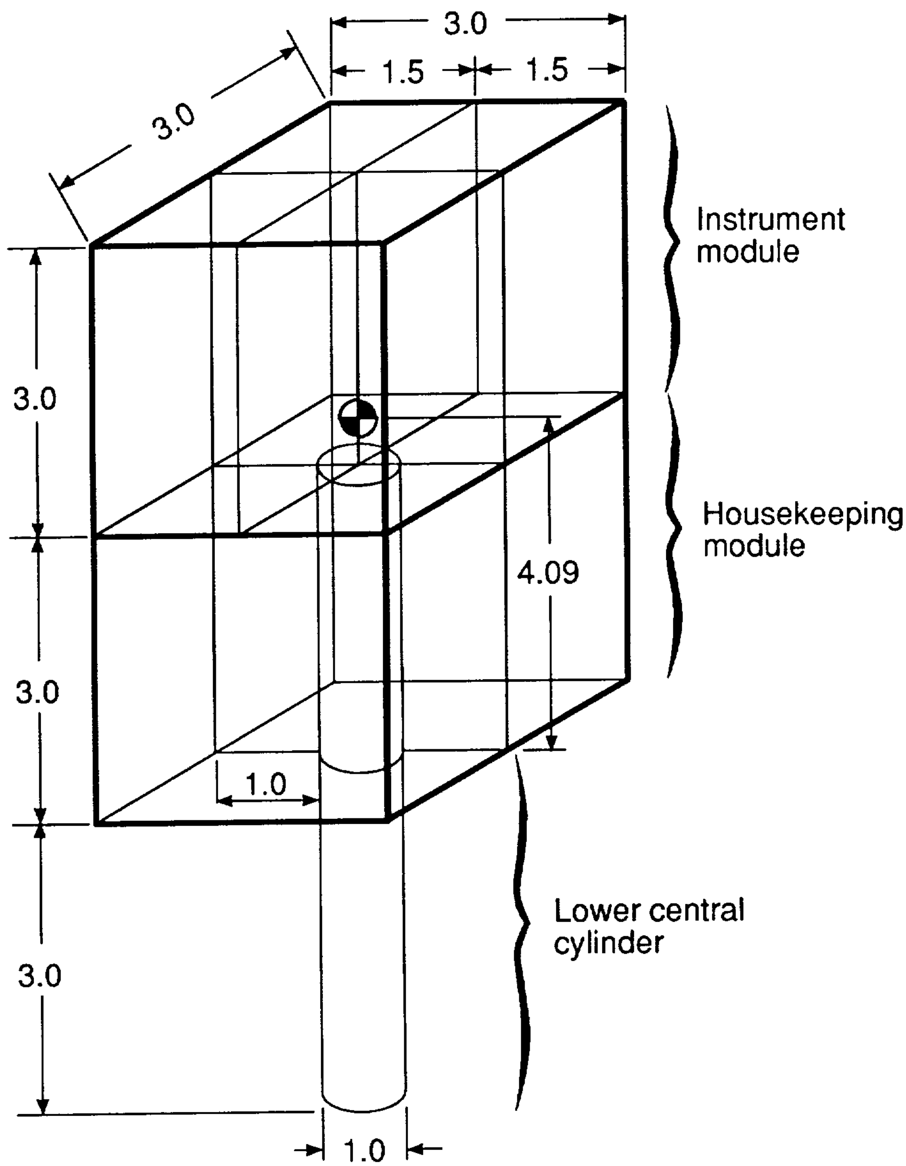


Figure 2. Internal structure of instrument and housekeeping modules. All dimensions are in meters.

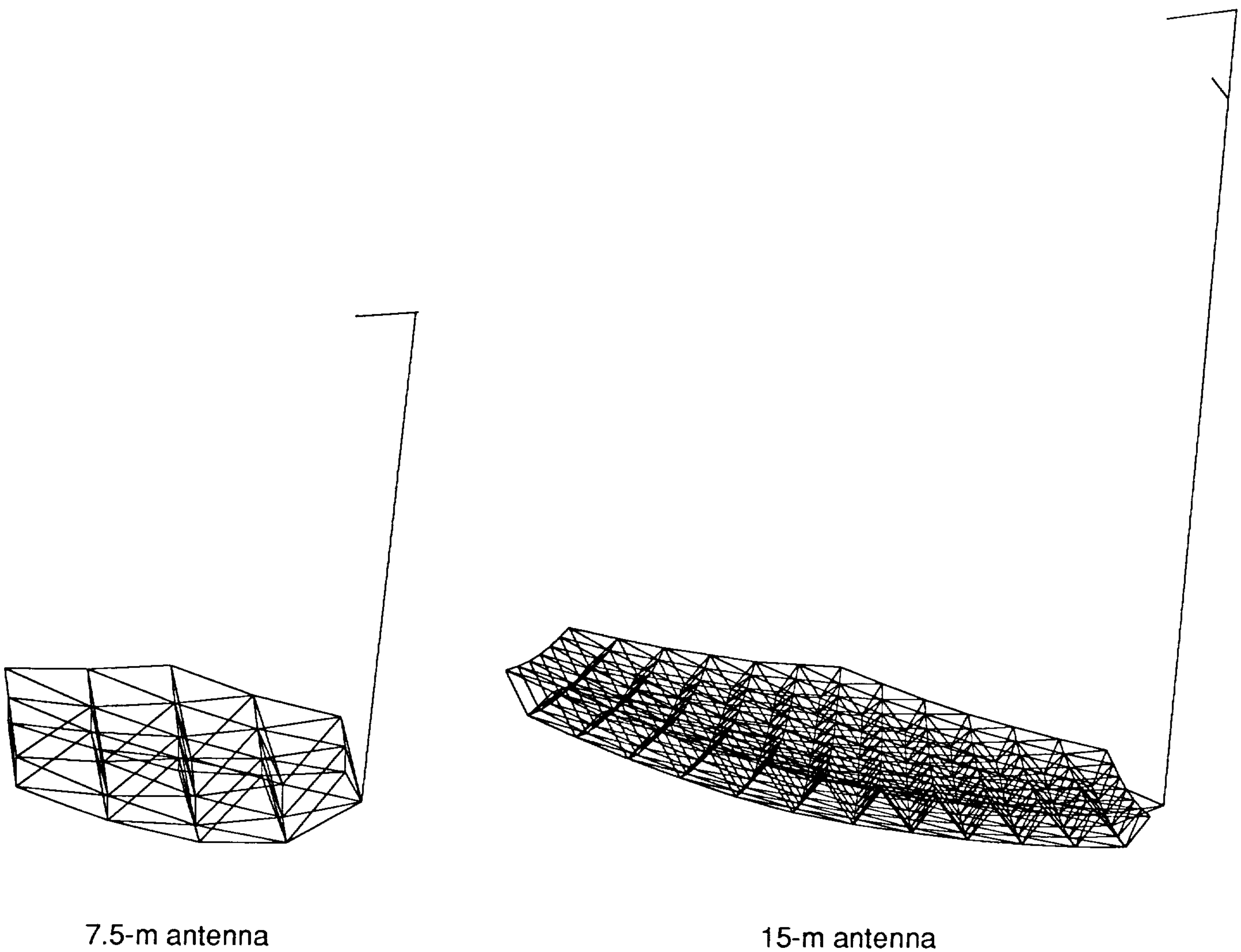
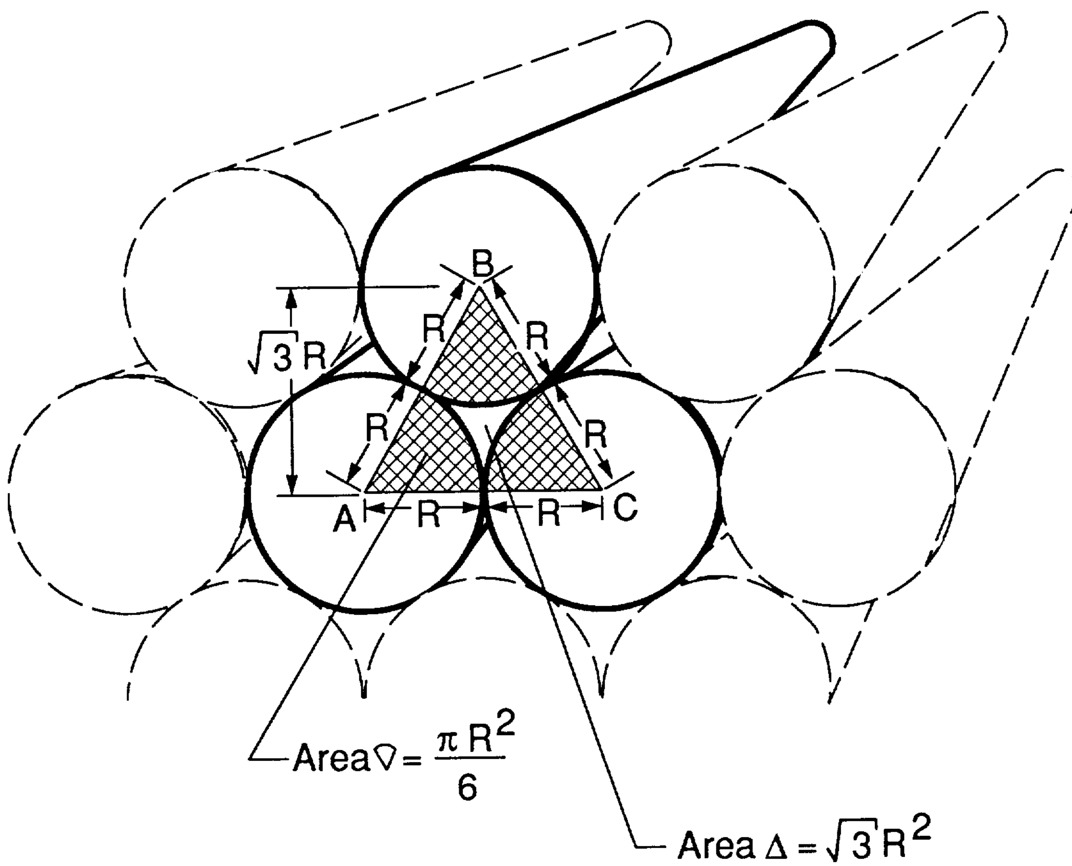


Figure 3. Finite element models of passive microwave radiometer structures.



Within the triangle ABC

$$\frac{\text{Total area of feed array}}{\Sigma \text{ Area of individual feeds}} = \frac{\sqrt{3}R^2}{3\,\frac{\pi R^2}{6}} = 1.103$$

Figure 4. Wasted area in fitting circular feed horns into array.

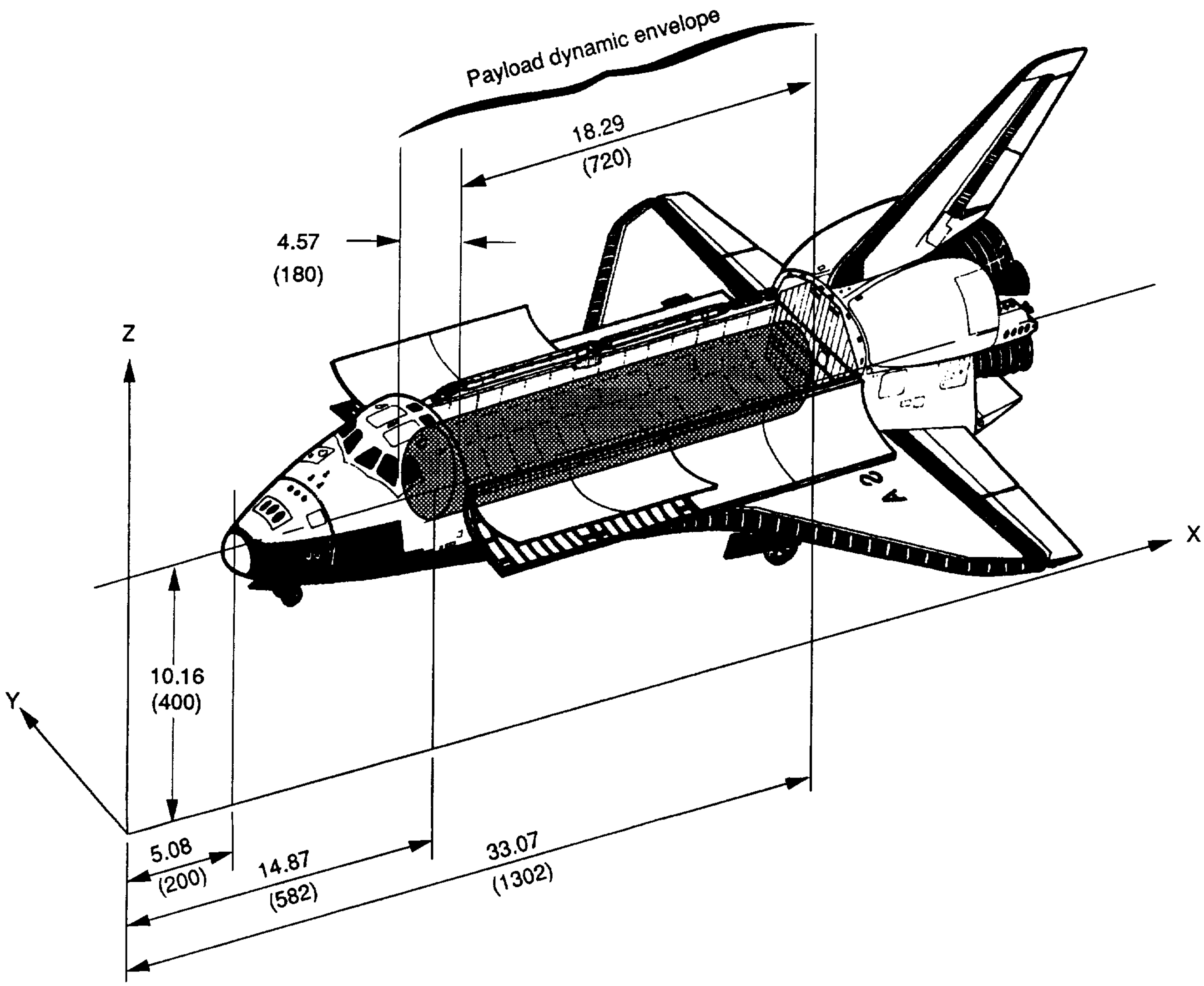


Figure 5. Space Shuttle orbiter-referenced coordinate system. Dimensions are in meters (inches).

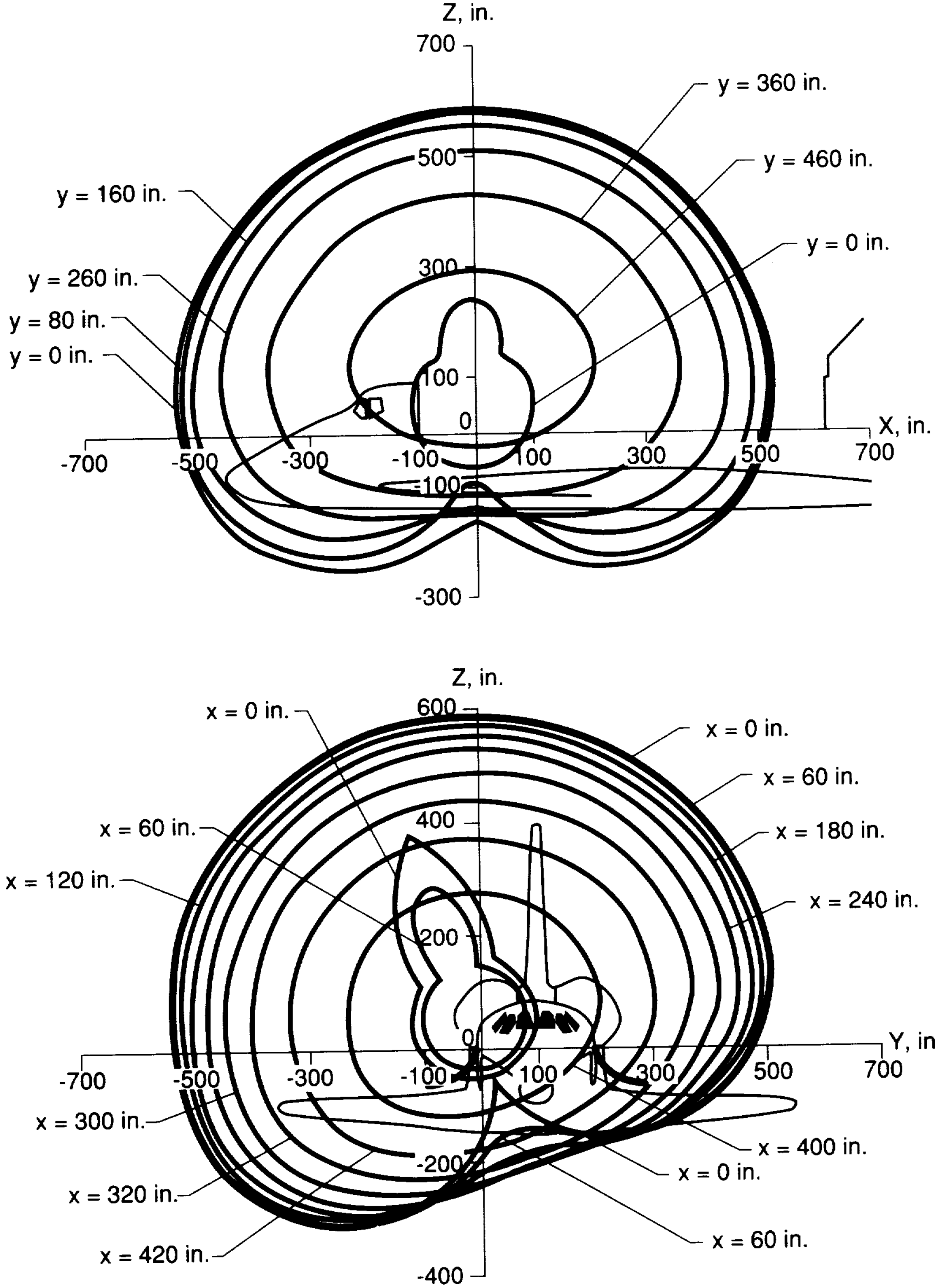


Figure 6. Reach envelope of shuttle RMS (measured in RMS-centered coordinate system).

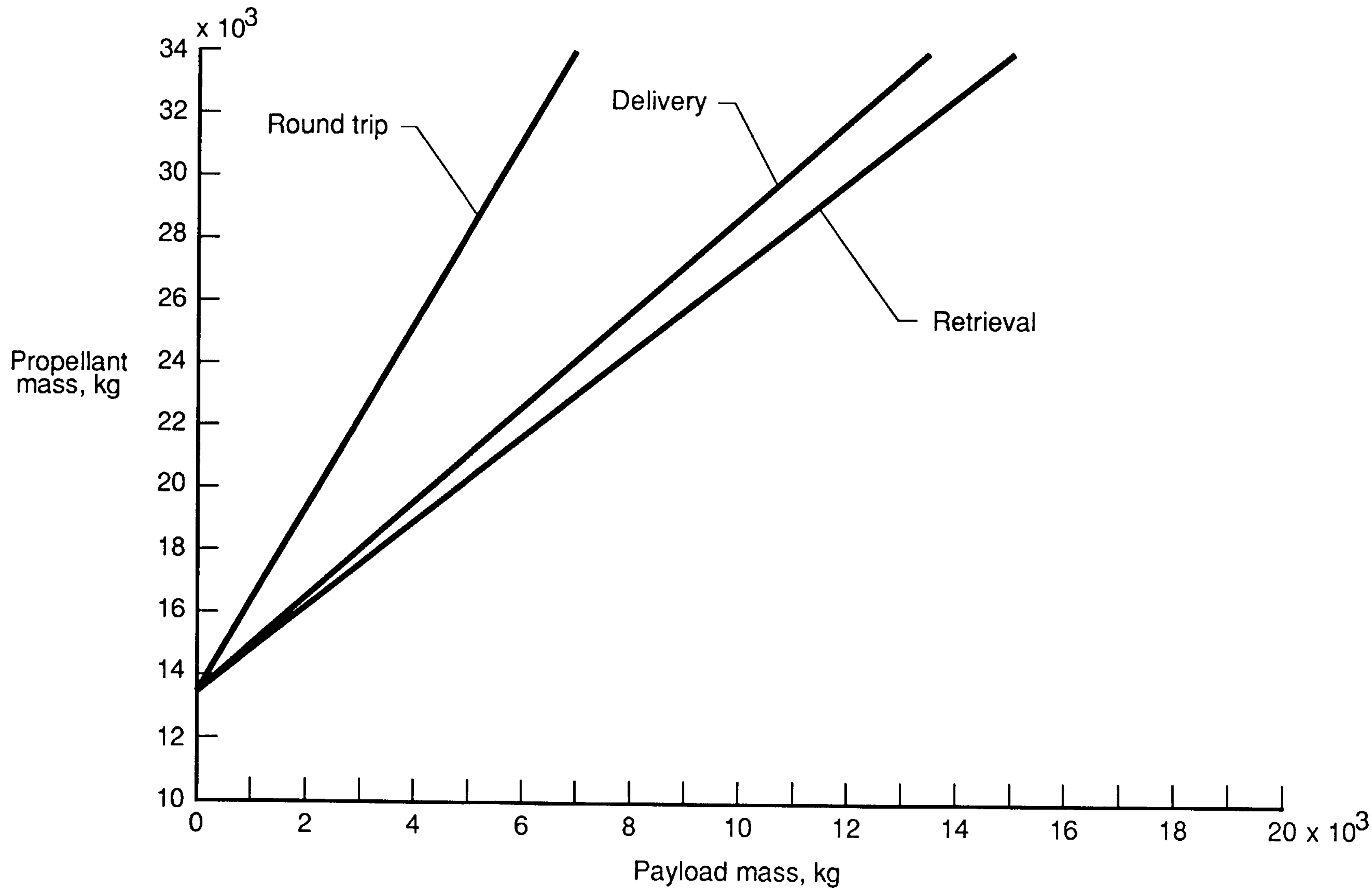
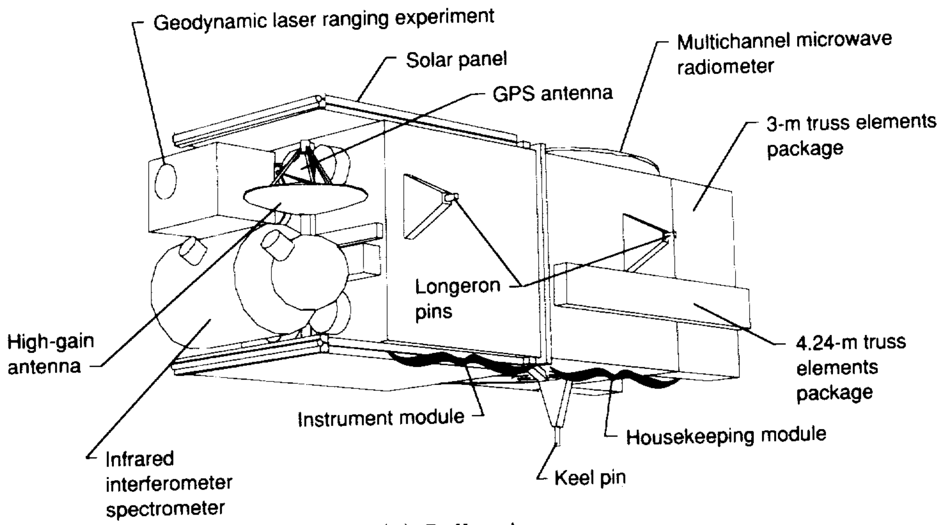
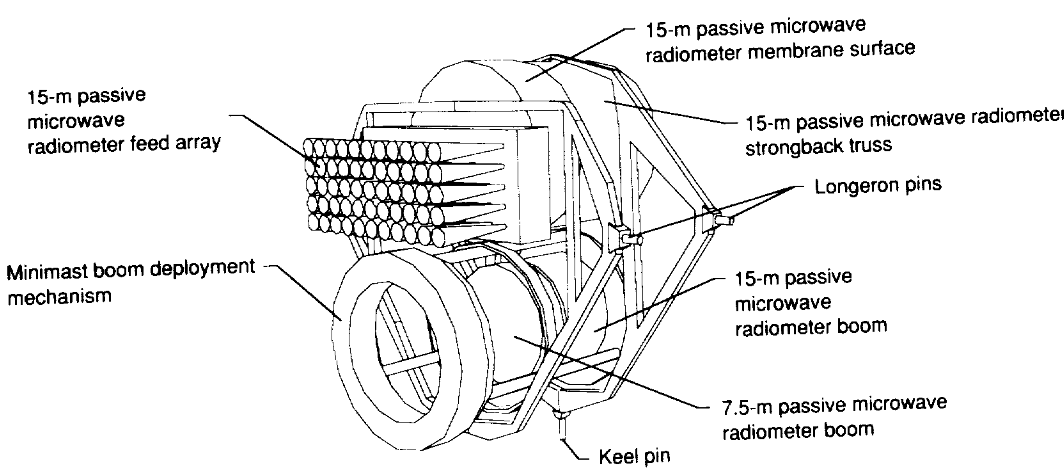


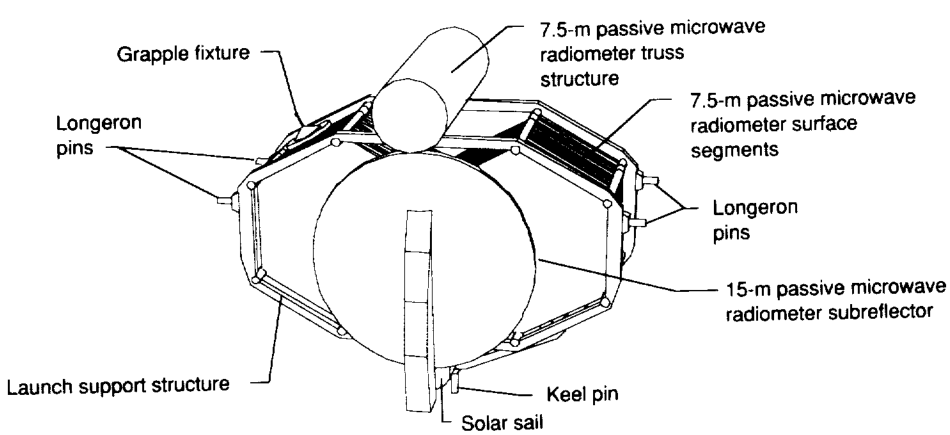
Figure 7. Space-based OTV performance. (Based on ref. 19.)



(a) Pallet A.



(b) Pallet B.



(c) Pallet C.

Figure 8. Space Shuttle orbiter cargo pallets.

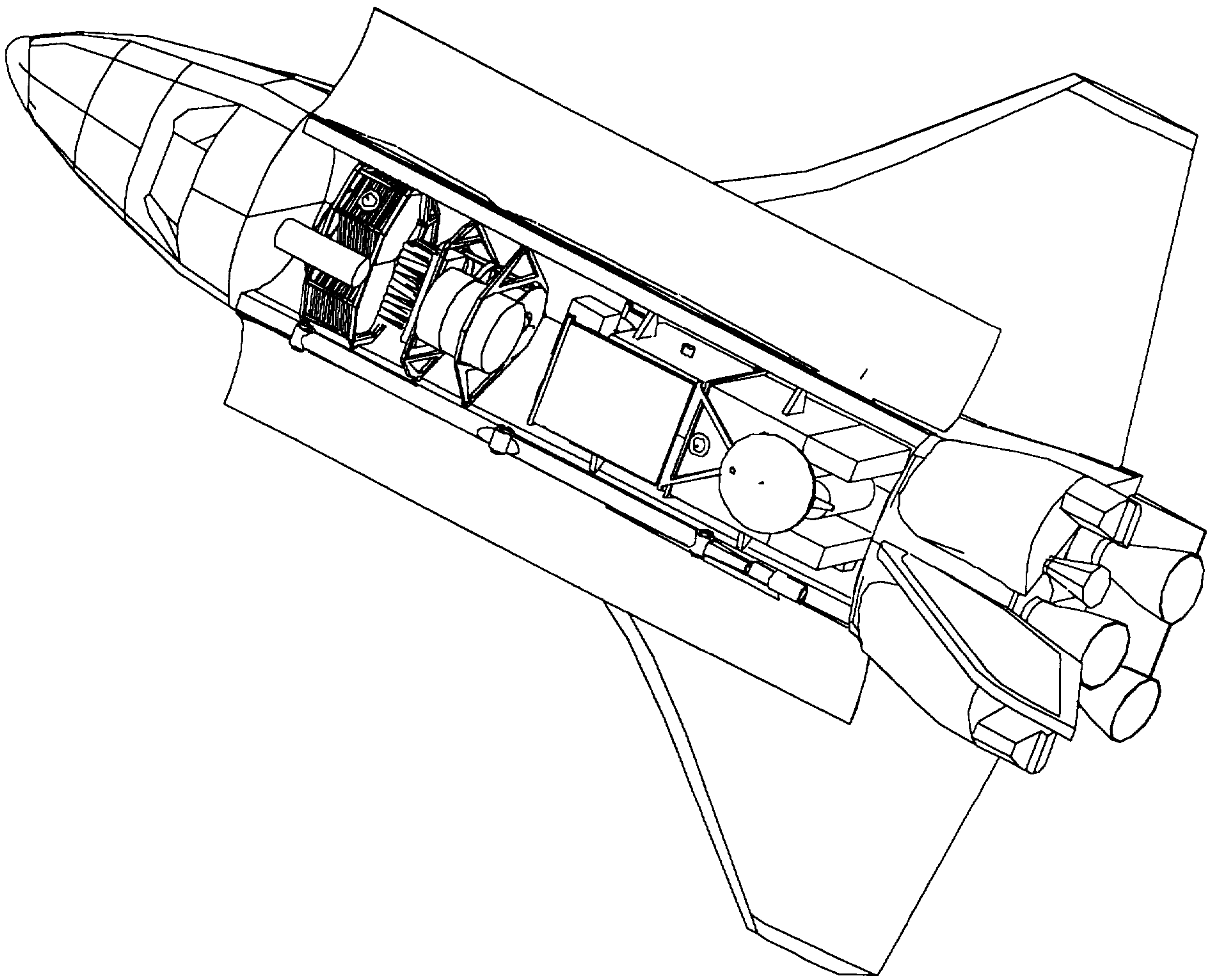
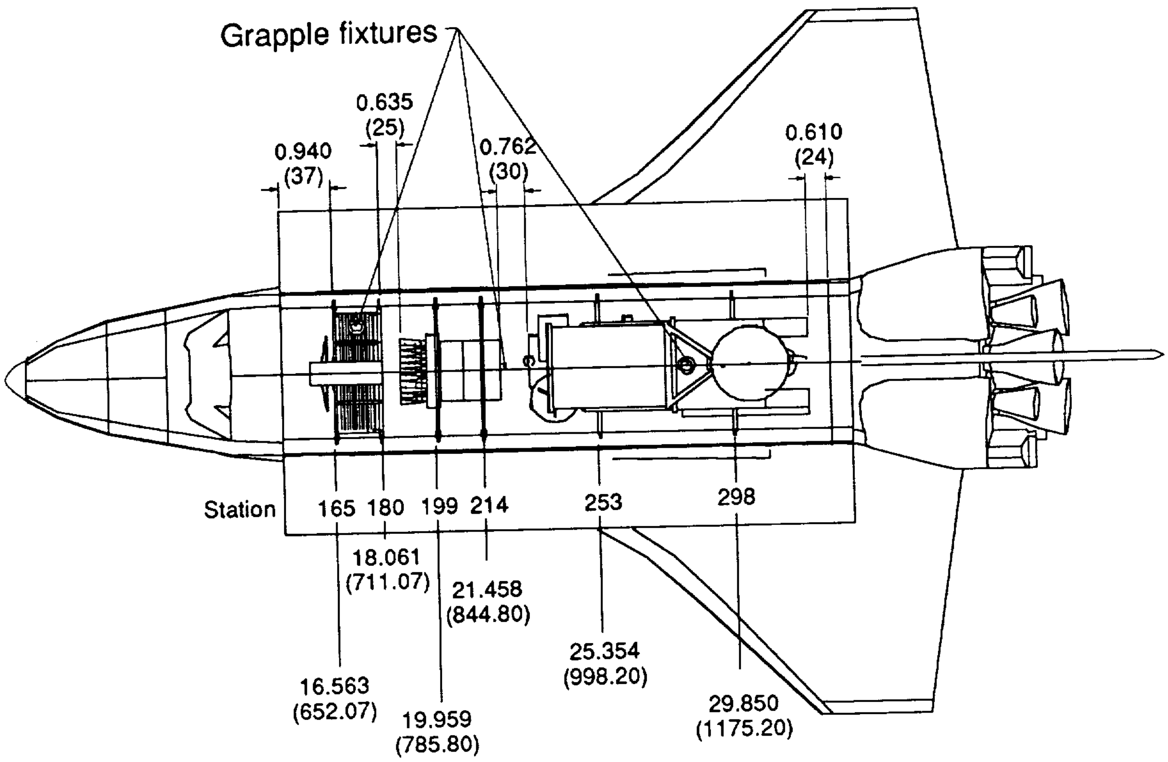
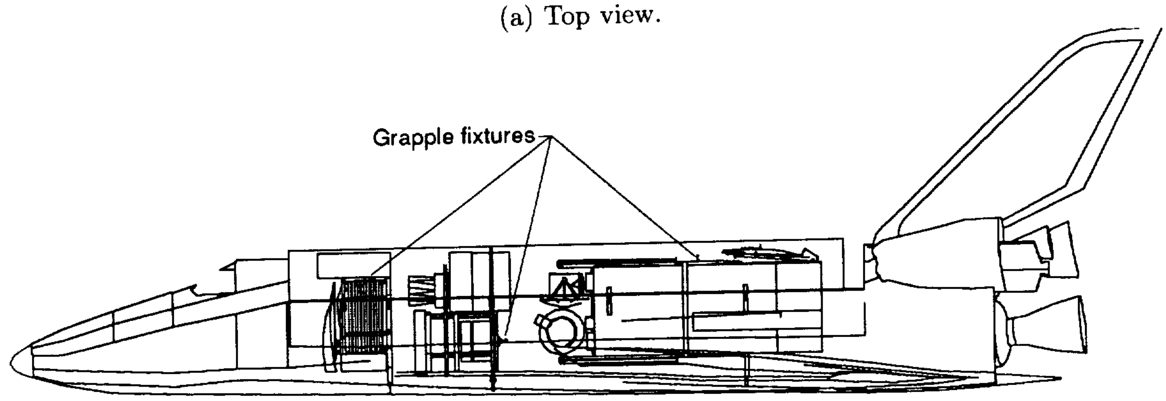


Figure 9. Space Shuttle arrangement of pallets for scenario number 1.

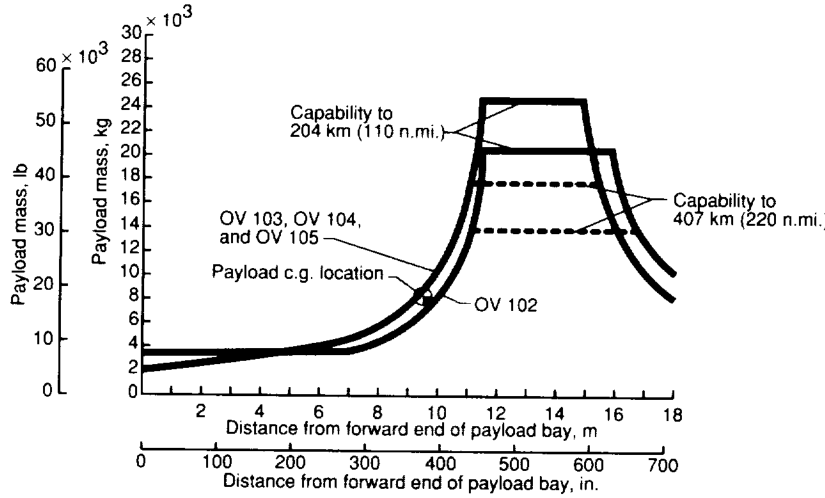


(a) Top view.

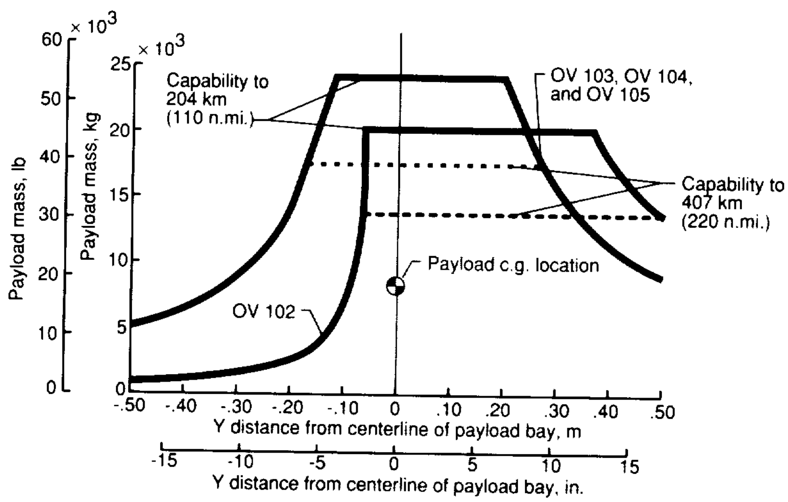


(b) Side view.

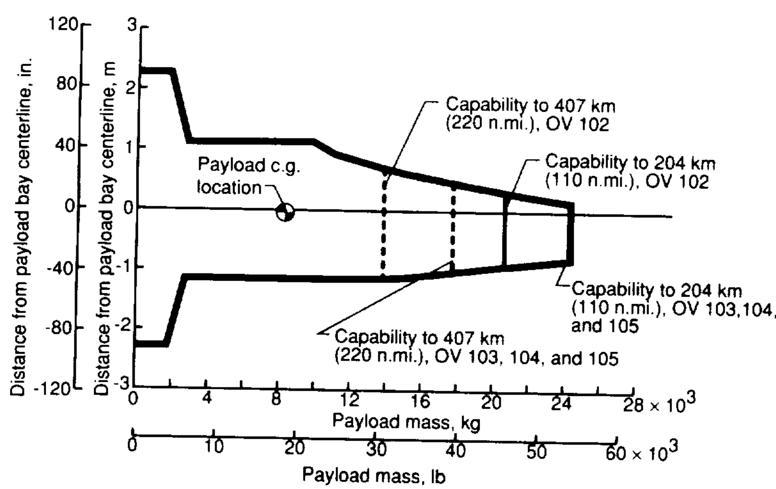
Figure 10. Top and side views of Space Shuttle orbiter packaged configuration for scenario number 1. All dimensions are in meters (inches).



(a) X-direction.

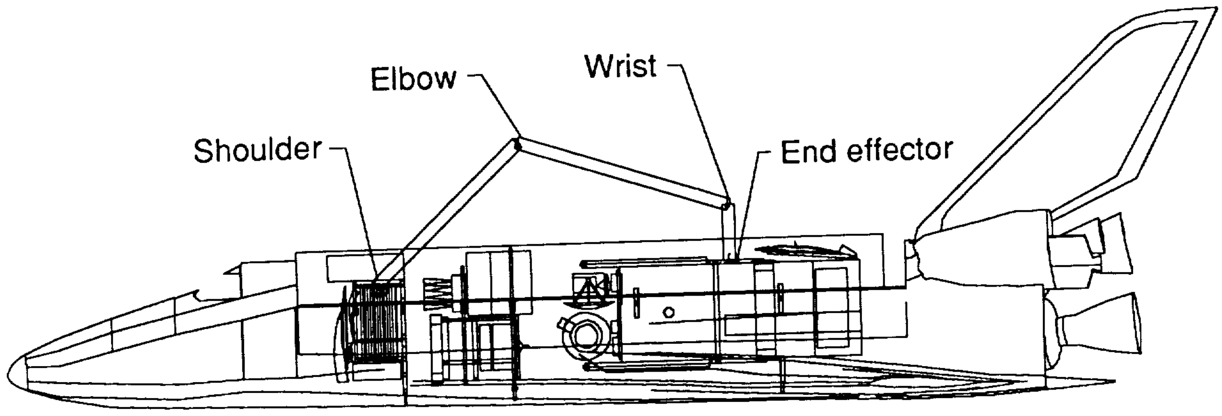


(b) Y-direction.

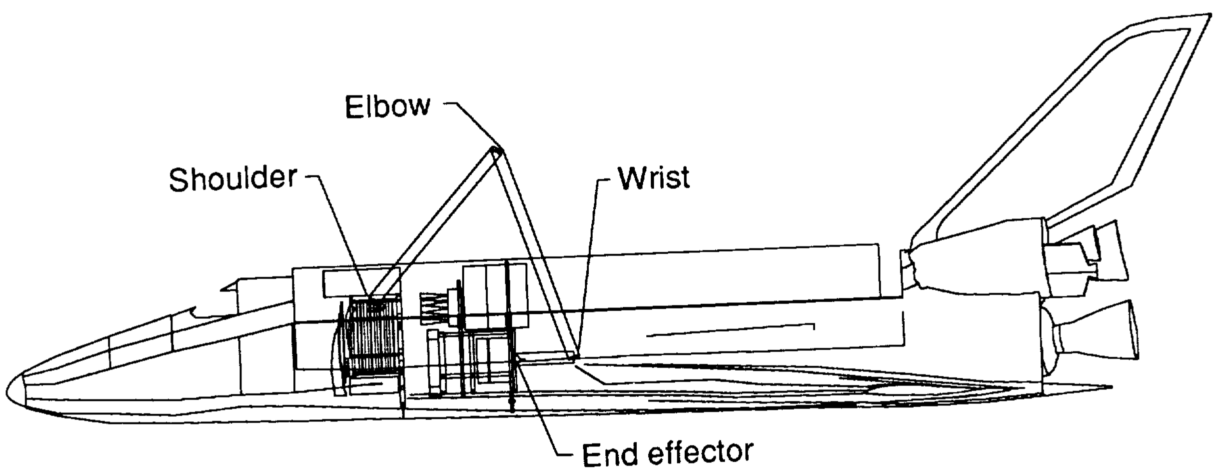


(c) Z-direction.

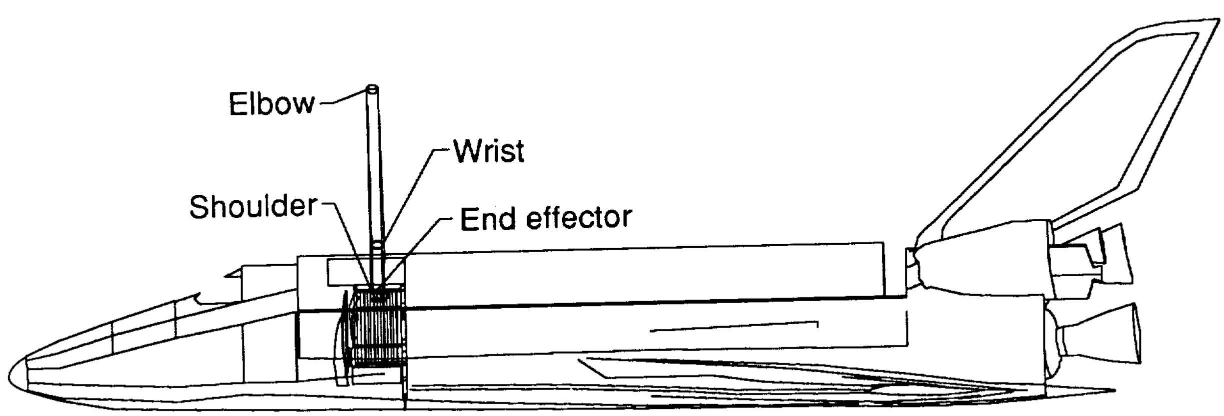
Figure 11. Space Shuttle payload c.g. locations for scenario number 1.



(a) Pallet A first.

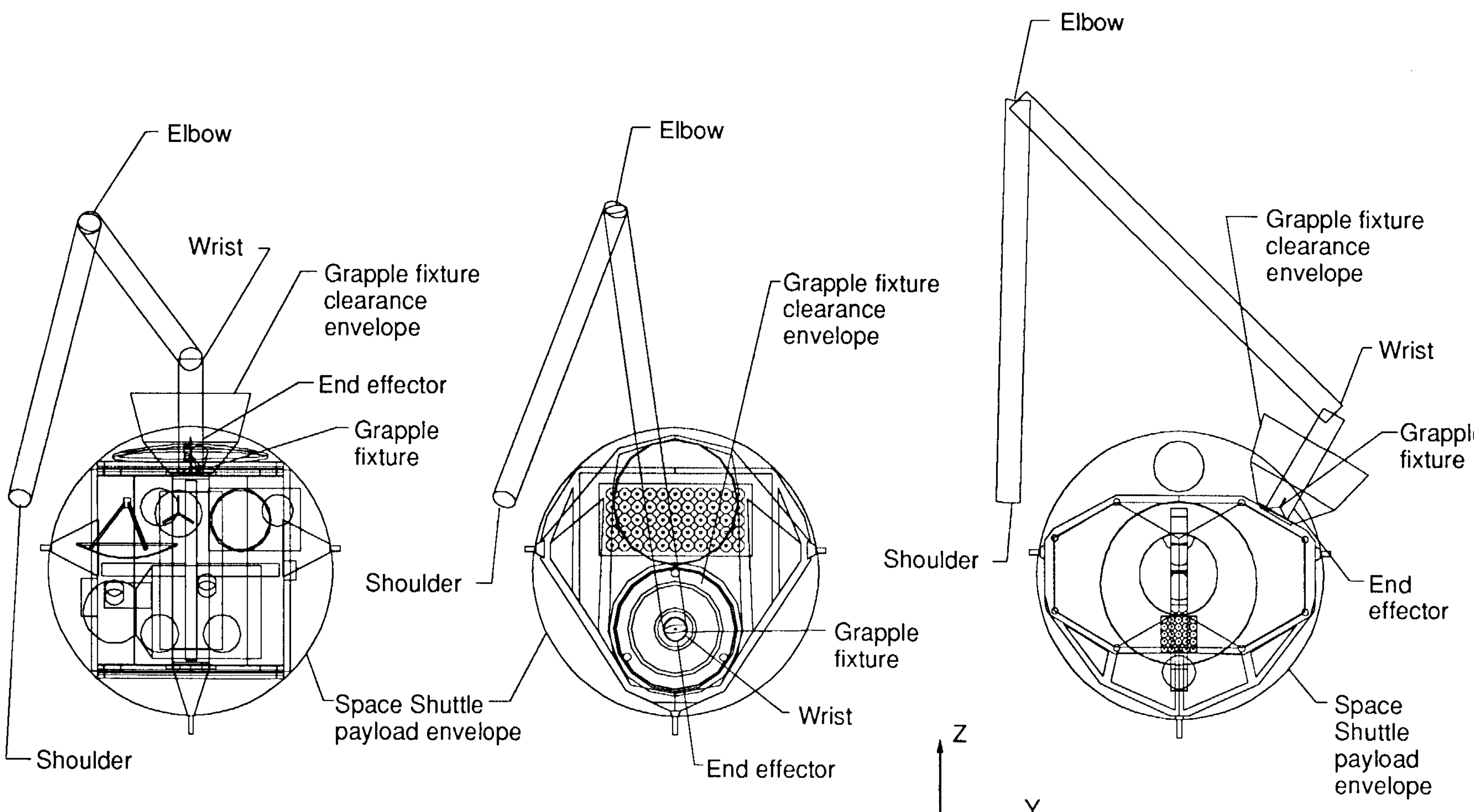


(b) Pallet B second.



(c) Pallet C third.

Figure 12. Removal of pallets with RMS for scenario number 1.



(a) Pallet A first.

(b) Pallet B second.

(c) Pallet C third.

Figure 13. Grapple fixture clearance during RMS removal of pallets for scenario number 1.

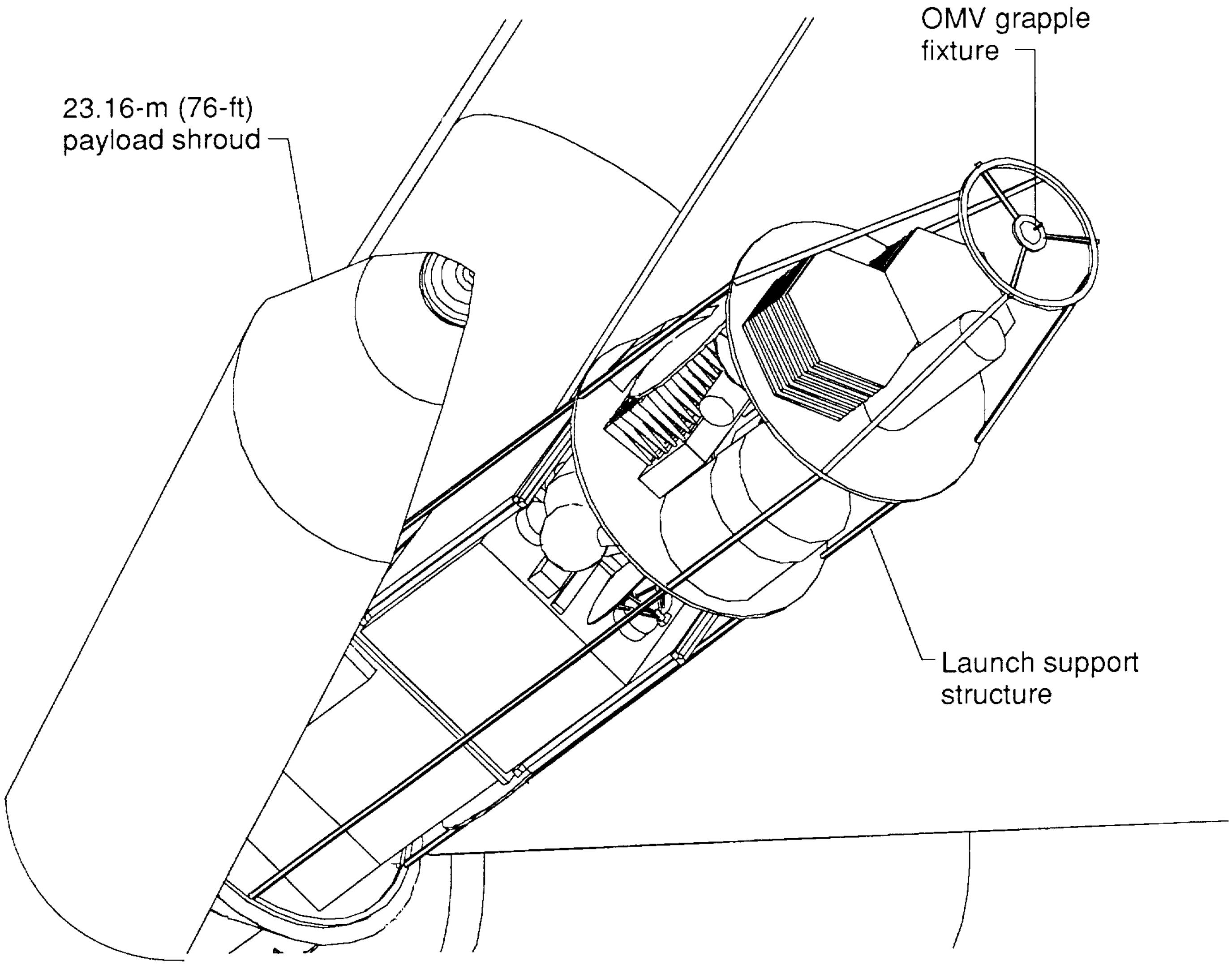


Figure 14. Titan IV launch packaging for scenario number 2.

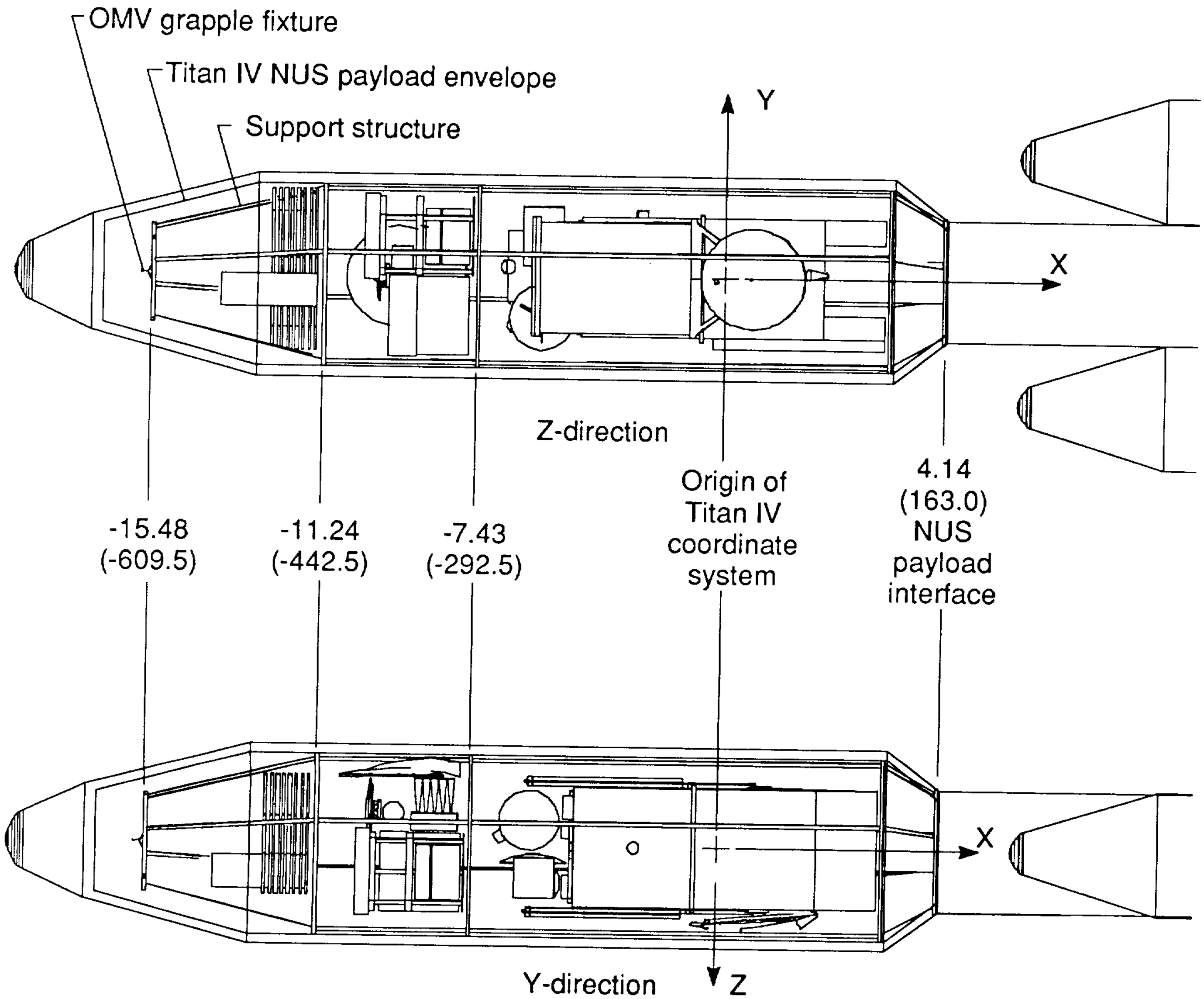
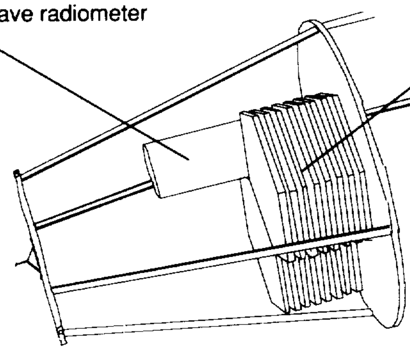
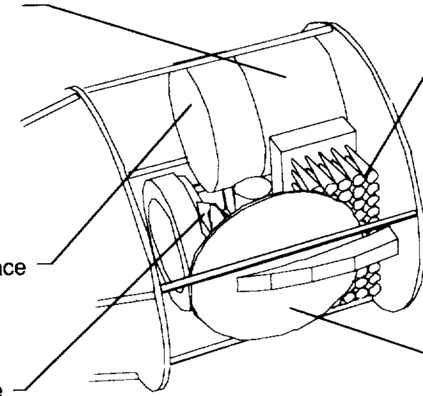


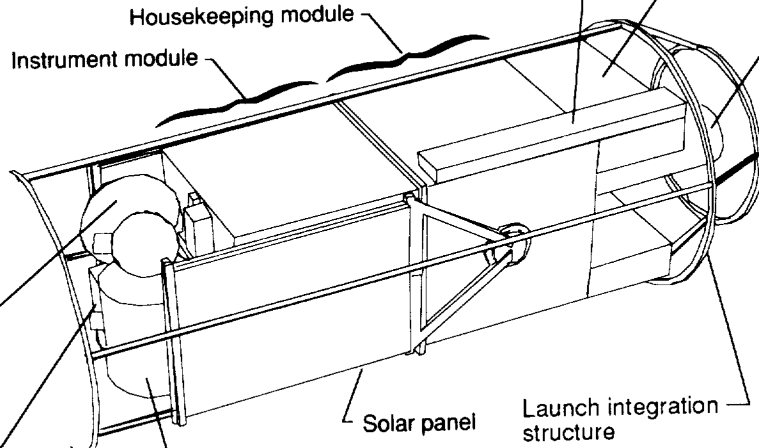
Figure 15. Titan IV NUS packaged configuration for scenario number 2. All dimensions are in meters (inches).



(a) 572-kg module.



(b) 1708-kg module.



(c) 5311-kg module.

Figure 16. Titan IV NUS payload modules for scenario number 2.

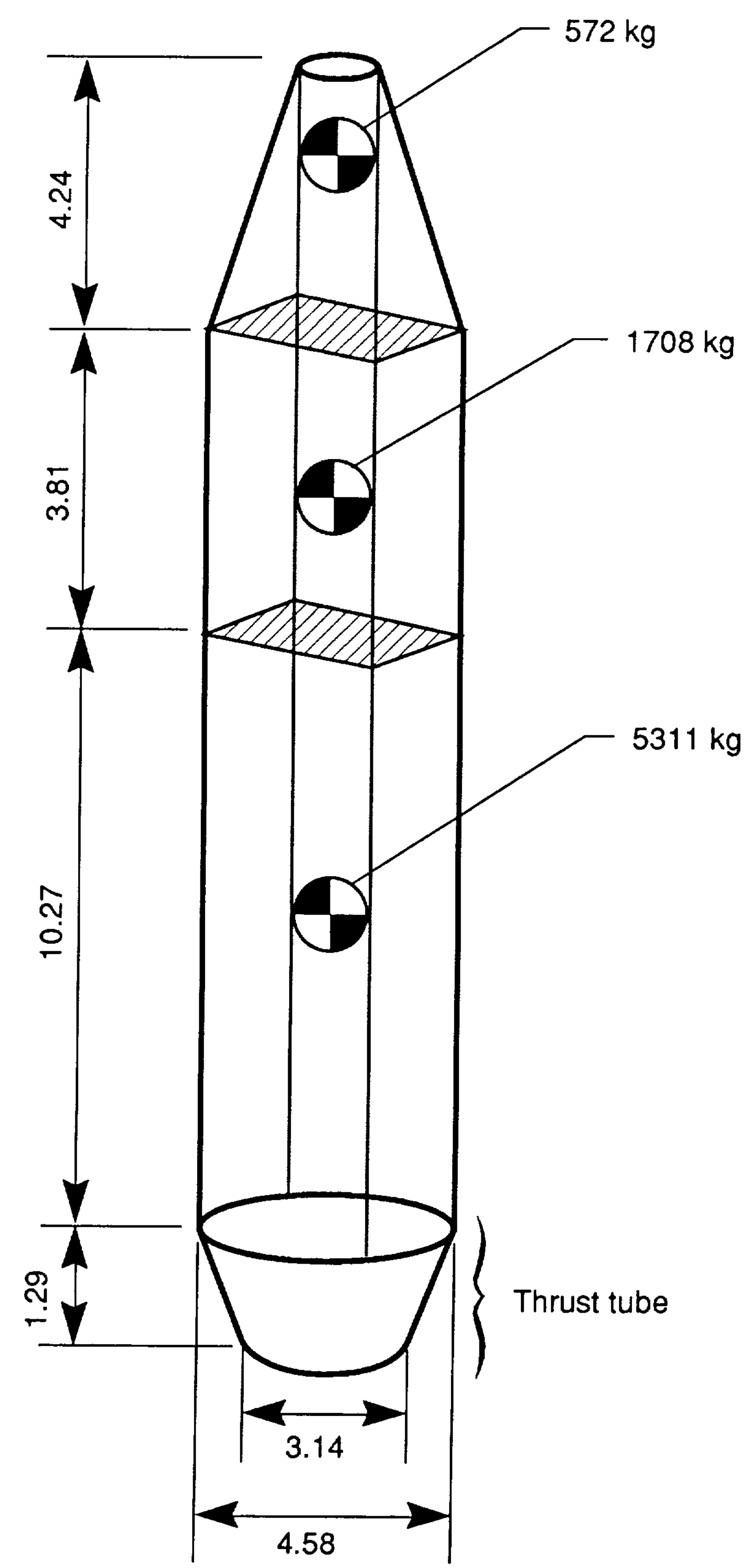


Figure 17. Simplified Titan IV launch support structure model. All dimensions are in meters unless otherwise indicated.

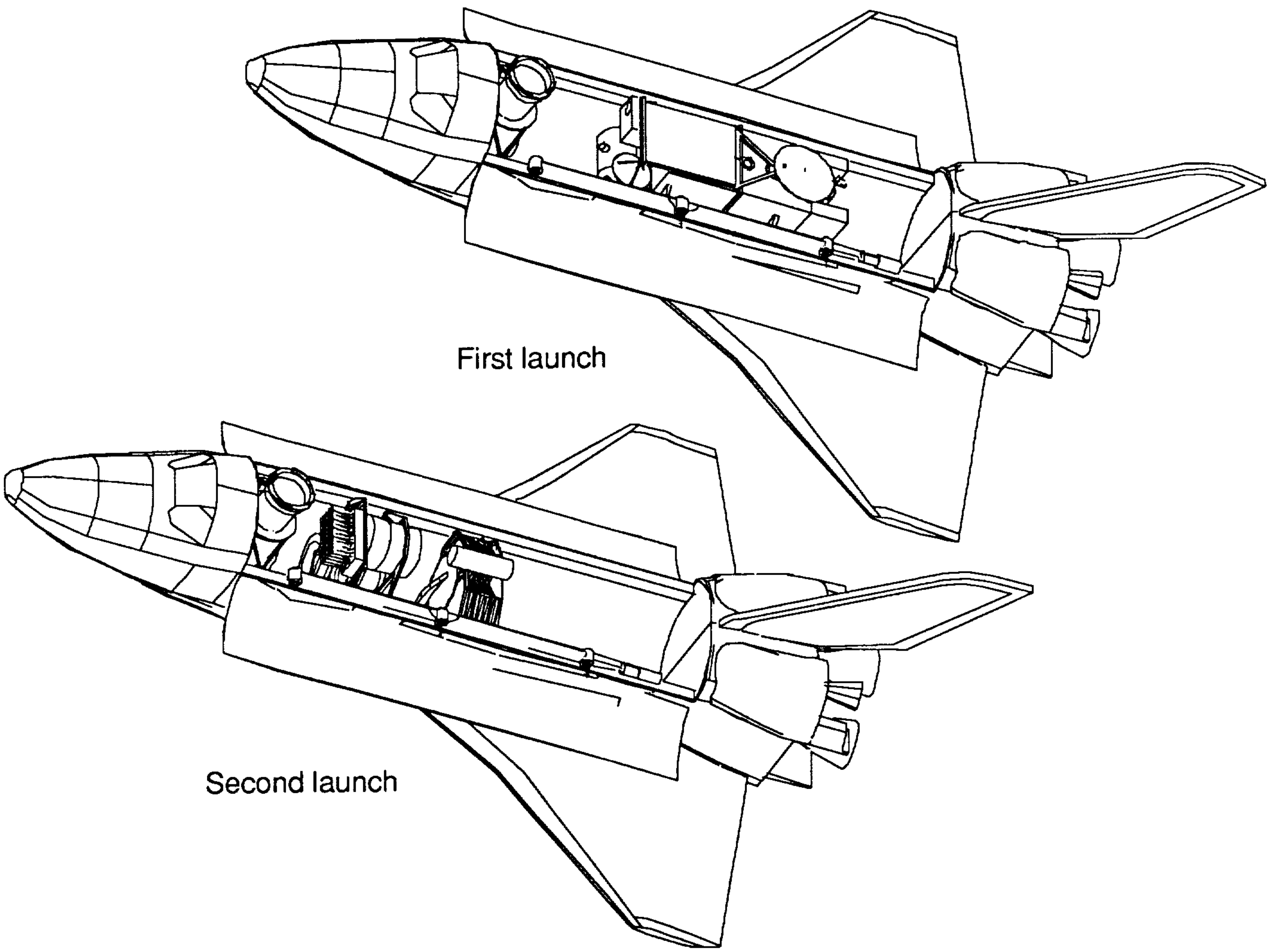
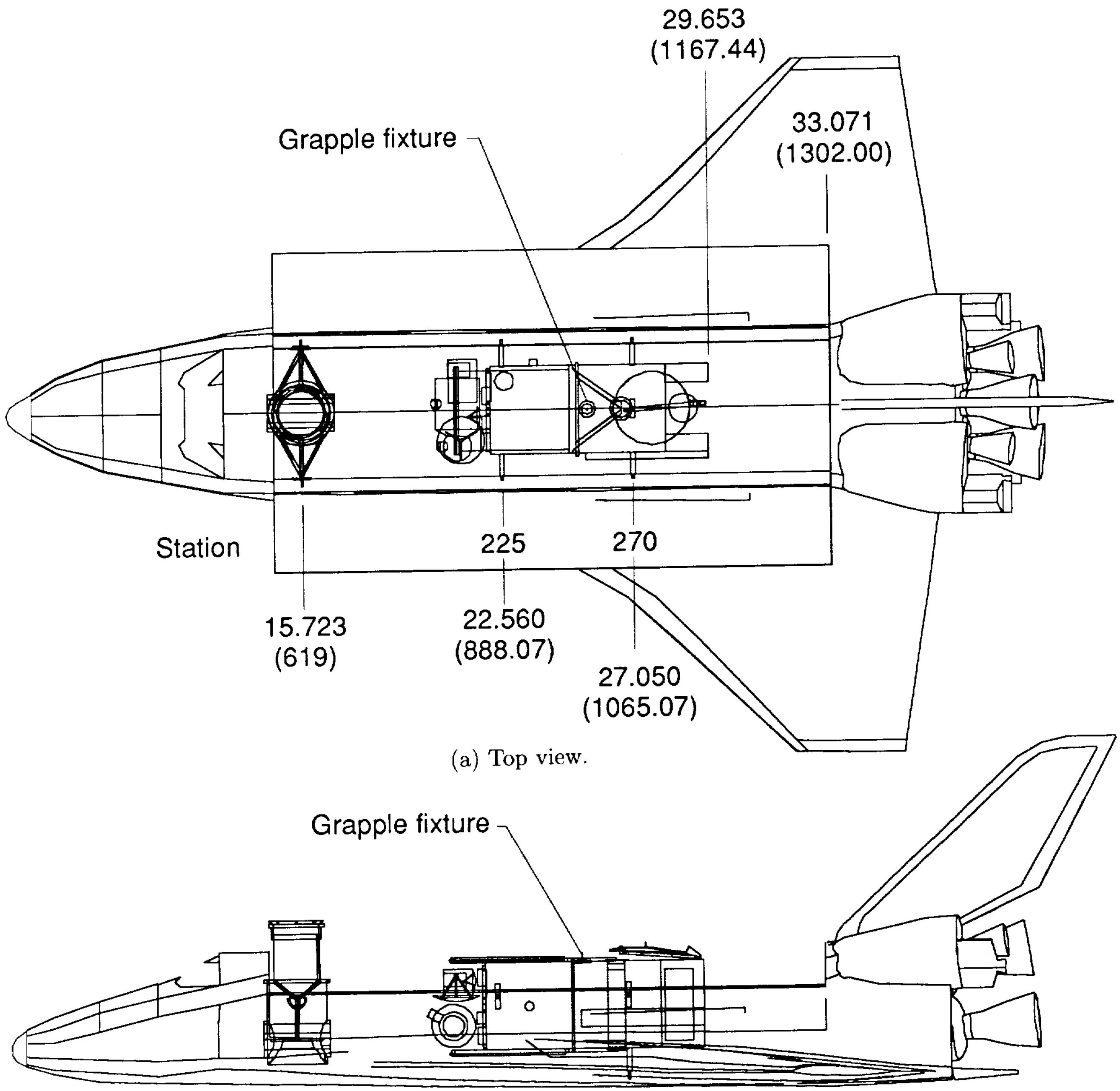


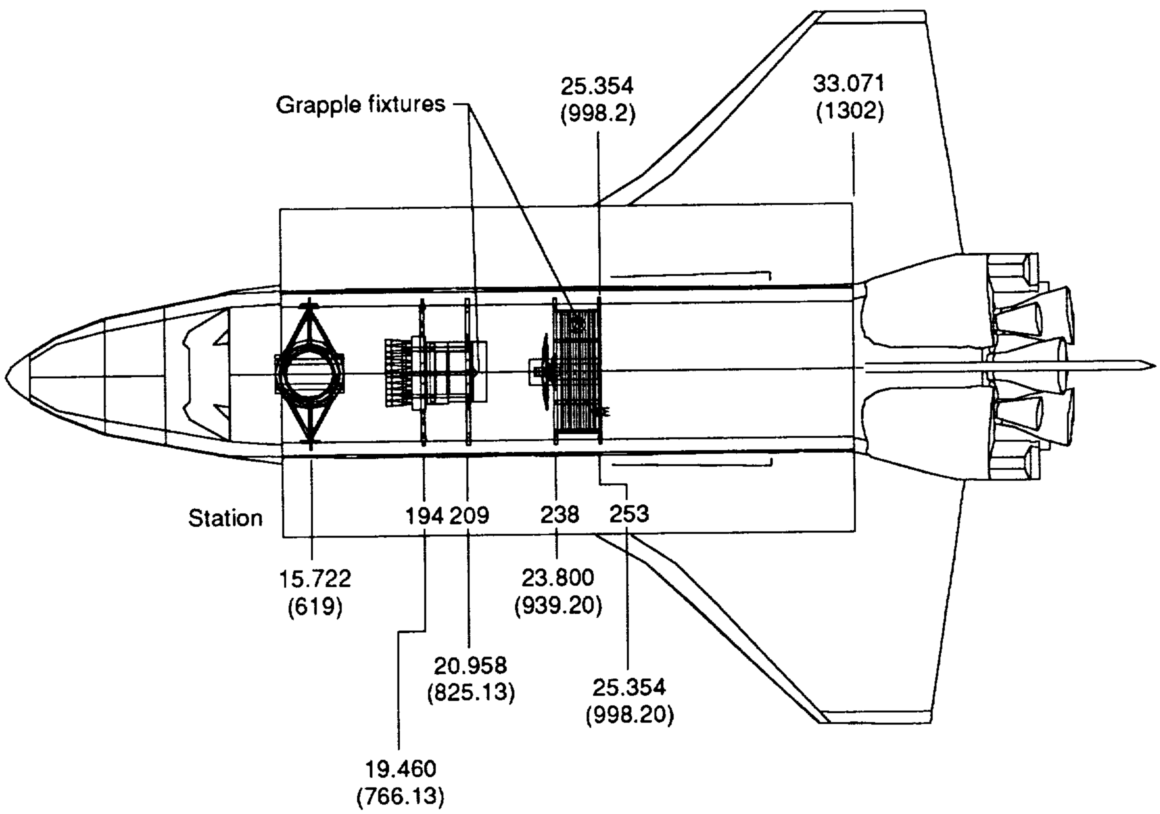
Figure 18. Space Shuttle packaging for scenario number 3.



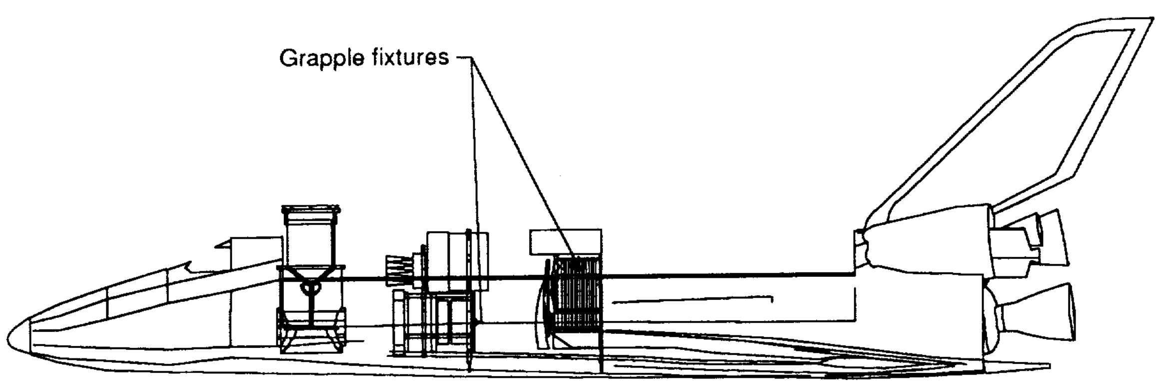
(a) Top view.

(b) Side view.

Figure 19. Top and side views of Space Shuttle packaged configurations (first flight) for scenario number 3. All dimensions are in meters (inches).

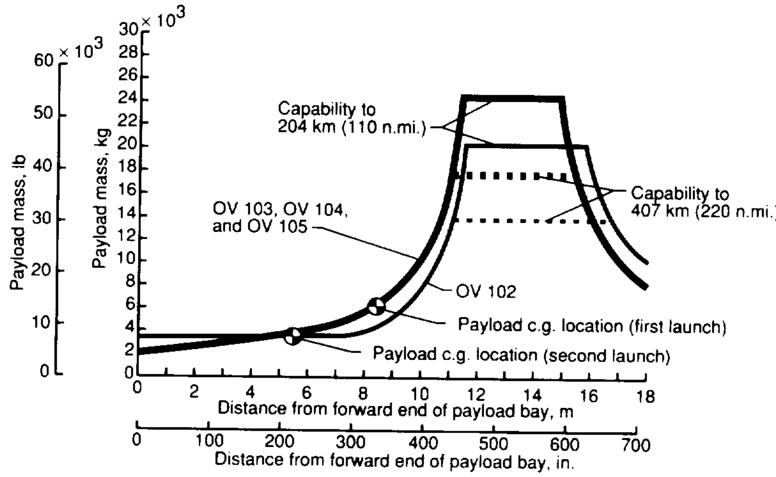


(a) Top view.

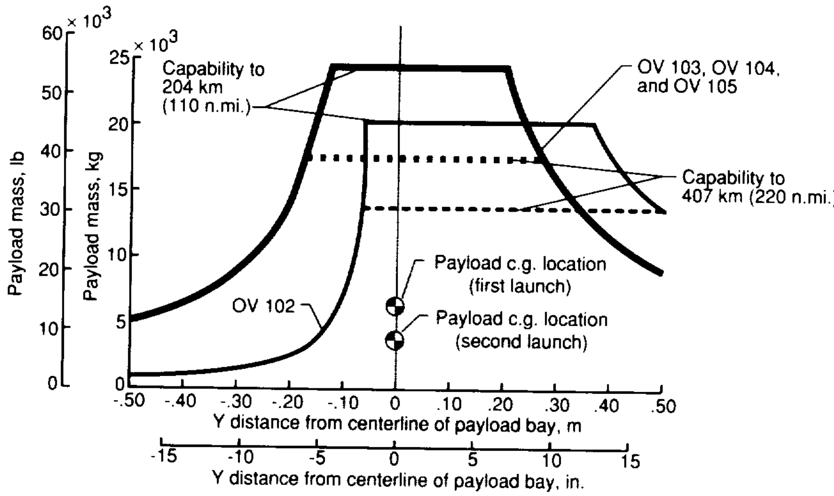


(b) Side view.

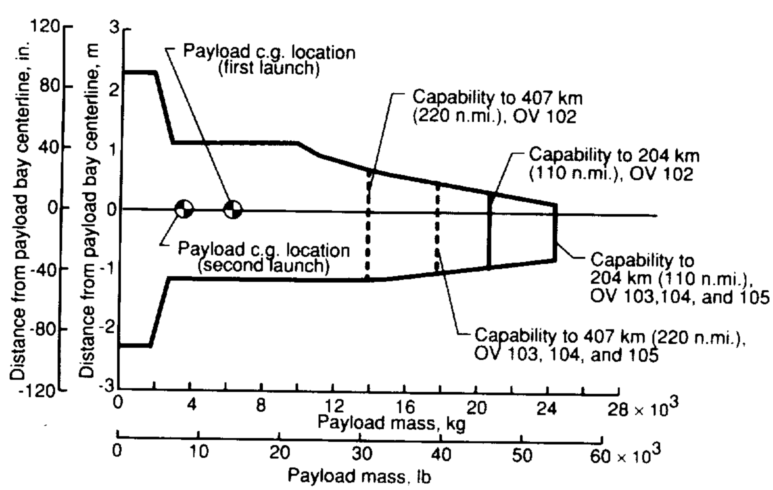
Figure 20. Top and side views of Space Shuttle packaged configurations (second flight) for scenario number 3. All dimensions are in meters (inches).



(a) X-direction.

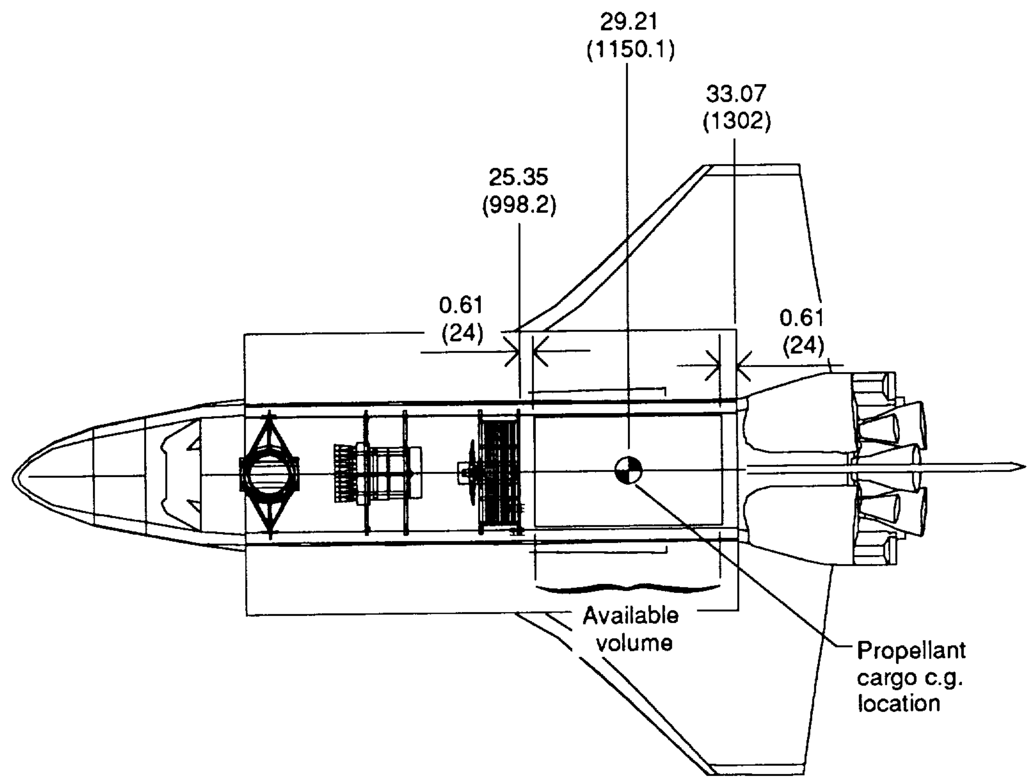


(b) Y-direction.



(c) Z-direction.

Figure 21. Space Shuttle payload c.g. locations for scenario number 3.



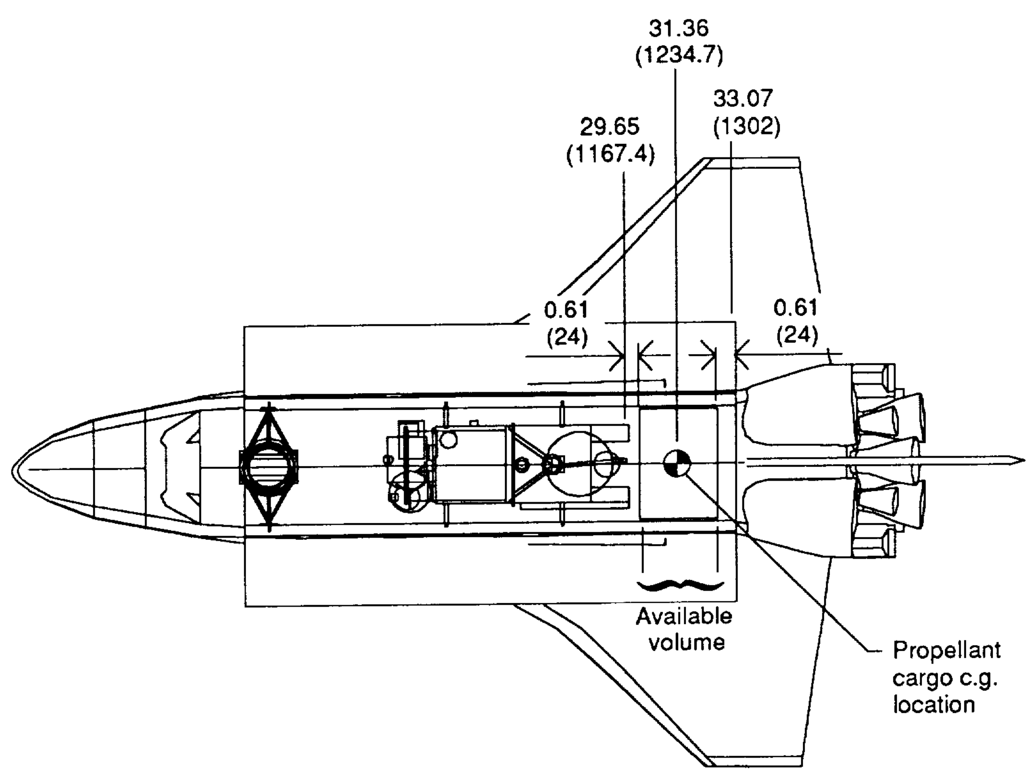


Figure 22. Volume available on Space Shuttle launches for OTV propellant for scenario number 4. All dimensions are in meters (inches).

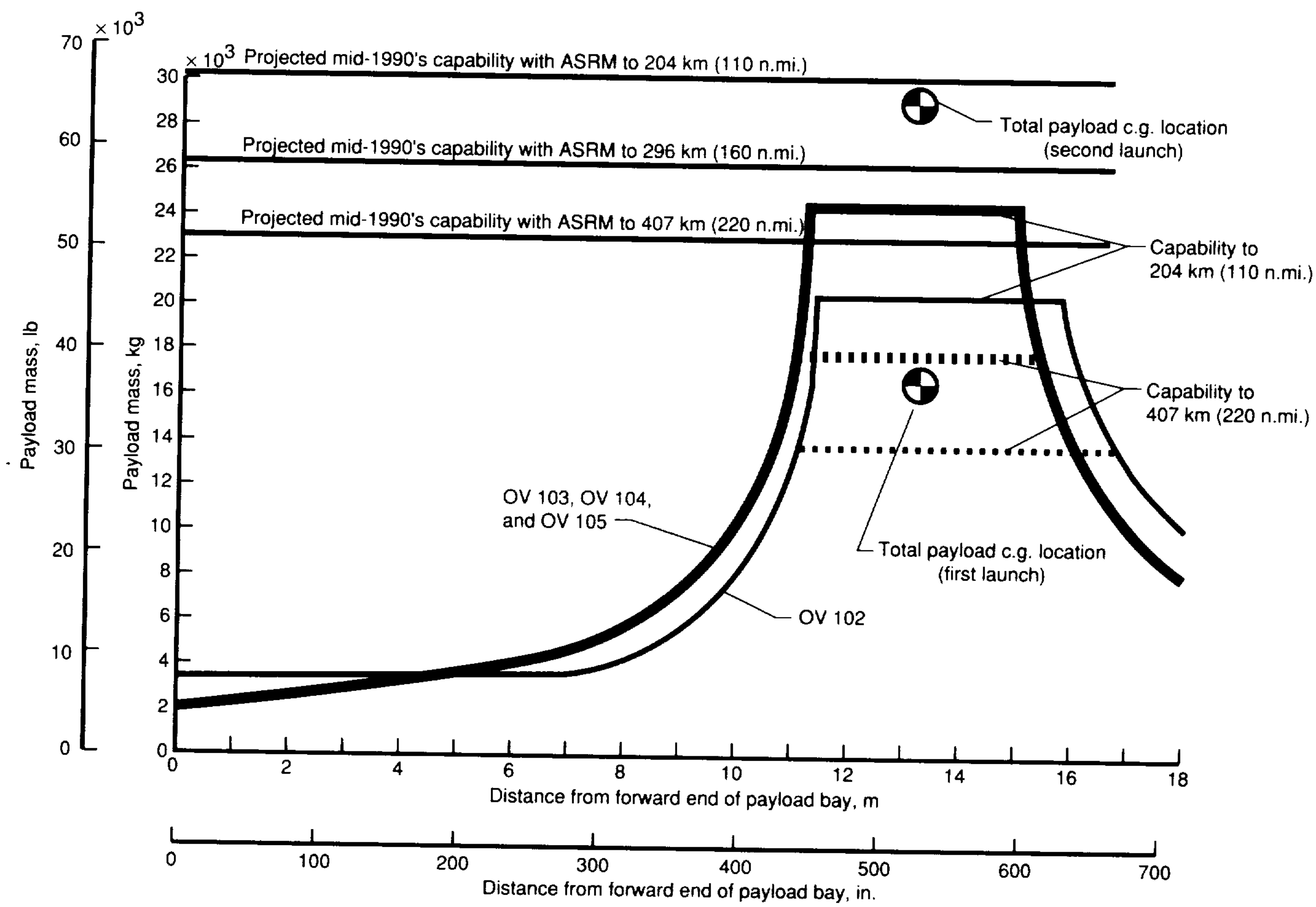
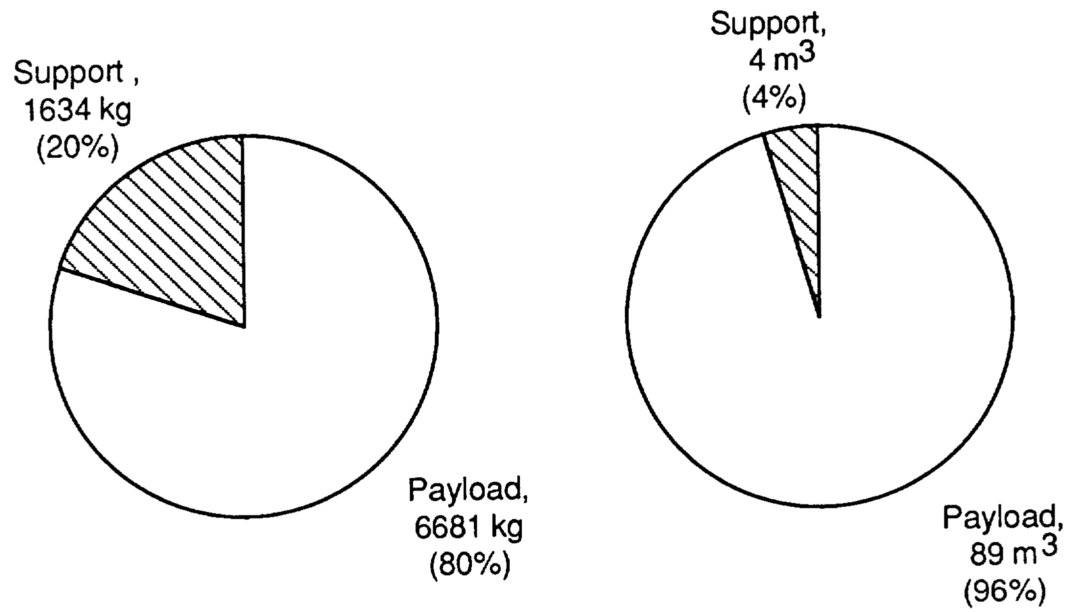
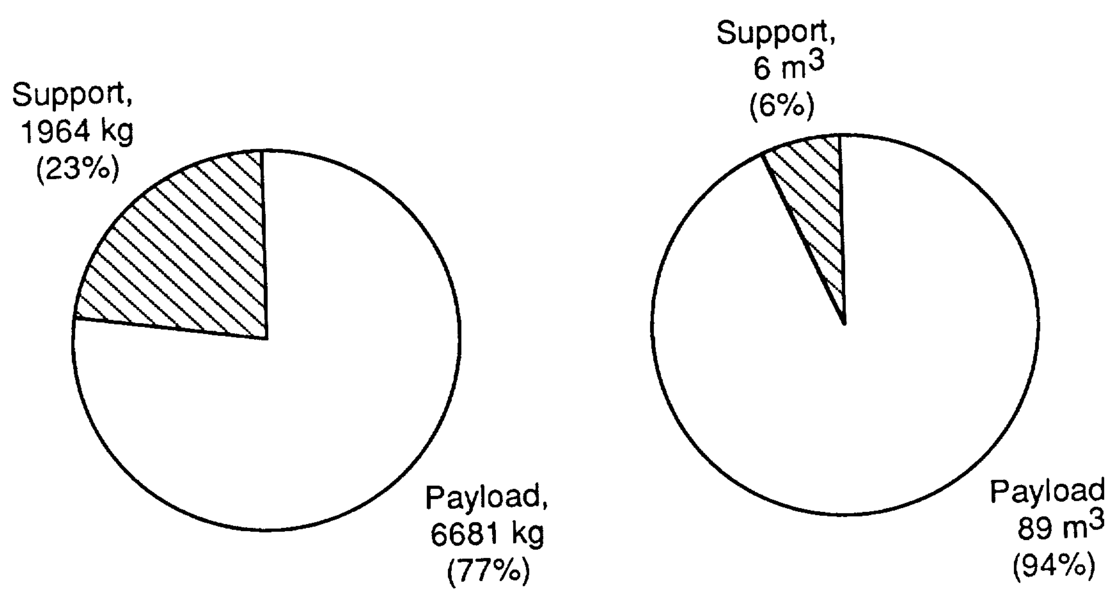


Figure 23. Space Shuttle payload c.g. locations for scenario number 4.



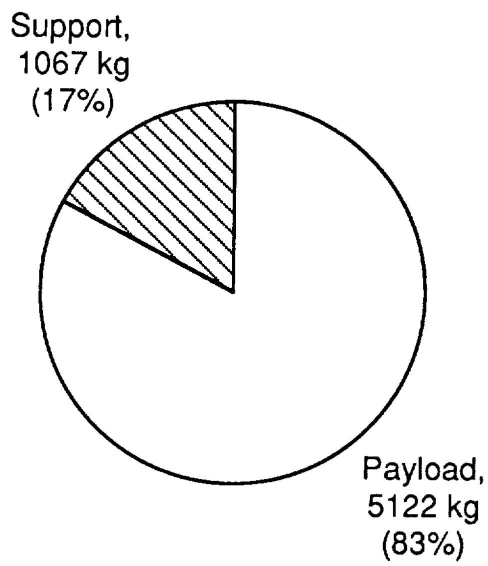
(a) Mass breakdown. (b) Volume breakdown.

Figure 24. Mass and volume breakdowns for scenario number 1.

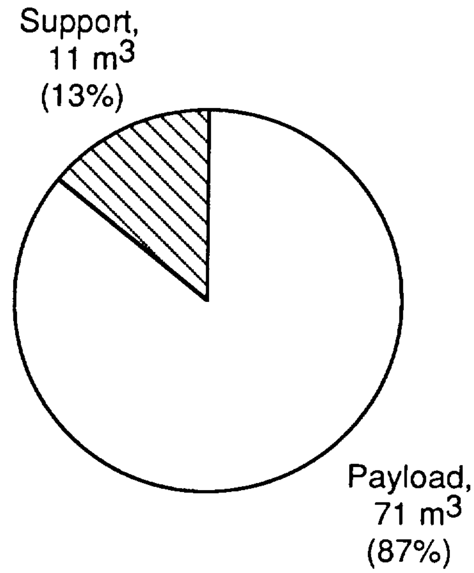


(a) Mass breakdown. (b) Volume breakdown.

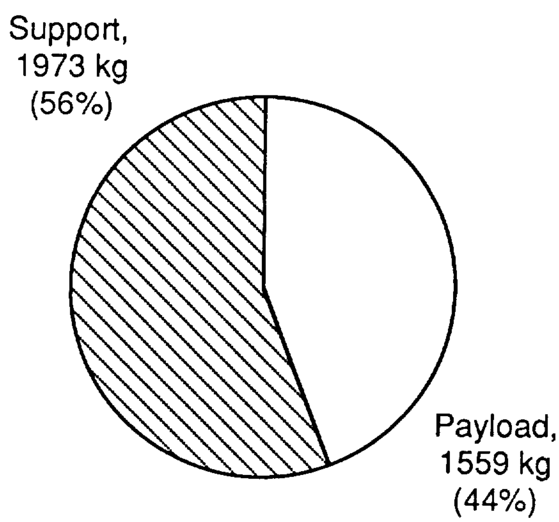
Figure 25. Mass and volume breakdowns for scenario number 2.



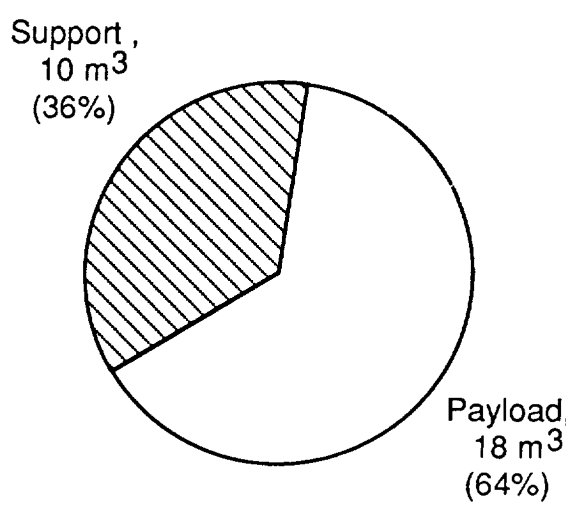
(a) Mass breakdown, first launch.



(b) Volume breakdown, first launch.

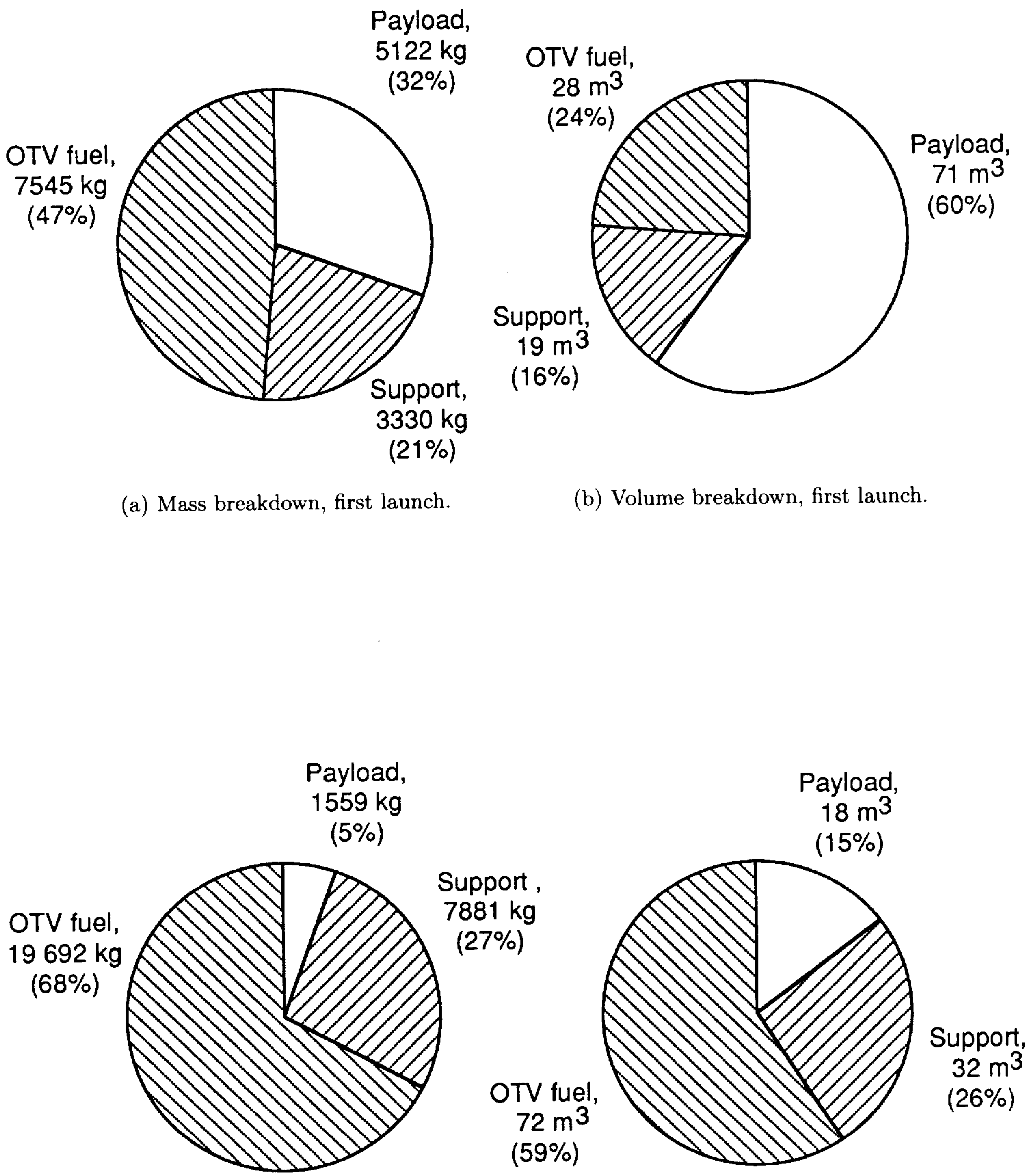


(c) Mass breakdown, second launch.



(d) Volume breakdown, second launch.

Figure 26. Mass and volume breakdowns for scenario number 3.



(a) Mass breakdown, first launch.

(b) Volume breakdown, first launch.

(c) Mass breakdown, second launch.

(d) Volume breakdown, second launch.

Figure 27. Mass and volume breakdowns for scenario number 4.

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15. Supplementary Notes

16. Abstract

Concepts are derived for the packaging of the components of a large Earth sciences geostationary platform to be launched in either the Space Shuttle or the Titan IV Complementary Expendable Launch Vehicle. Geometric data from a proposed conceptual design for the spacecraft, antenna sizing results from thermal and structural finite element analyses, and independent mass and volume estimates are used to determine sizes, shapes, and masses of the major platform components and support equipment. Solid modelling software is used to evaluate proposed launch vehicle integration concepts in terms of meeting volume and mass constraints, checking for interference between components, verifying that center-of-gravity locations fall within vehicle specifications, and designing suitable interface structures that do not violate any of these constraints. Construction at Space Station *Freedom* is assumed, and a space-based orbital transfer vehicle is determined to be necessary for inserting the spacecraft, once assembled, into geostationary orbit.

17. Key Words (Suggested by Author(s)) Geostationary platform; Launch packaging; Launch vehicles; Launch compatibility	18. Distribution Statement Unclassified - Unlimited. Subject Category 16

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