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COMPARATIVE EVALUATION OF EXISTING EXPENDABLE UPPER STAGES FOR SPACE SHUTTLE

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ABSTRACT

The use of existing expendable upper stages in the Space Shuttle during its early years of operation is evaluated. The Burner II, Scout, Delta, Agena, Transtage and Centaur were each studied under contract by their respective manufacturers to determine the extent and cost of the minimum modifications necessary to integrate the stage with the Shuttle Orbiter. A comparative economic analysis of thirty-five different families of these stages is discussed. The results show that the overall transportation system cost differences between many of the families are quite small. However, by considering several factors in addition to cost, it is possible to select one family as being representative of the capability of the minimum modification existing stage approach. The selected family meets all of the specified mission requirements during the early years of Shuttle operation.

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SUMMARY

One alternative for providing an interim Shuttle upper stage capability is to use one or more of the existing launch vehicle upper stages in an expendable mode. For this alternative, the existing stages would be modified only as required for compatibility with the Space Shuttle. This approach has been the subject of a detailed investigation over the past three years at the Lewis Research Center (LeRC). The activity included two contracted studies to establish the feasibility of the existing upper stage alternative, six additional contracted studies by the manufacturers of the Burner II, Scout, Delta, Agena, Transtage and Centaur stages to define in detail the modifications required for Shuttle compatibility, and a comprehensive in-house evaluation.

To provide the widest possible participation in the evaluation, a coordinating committee was formed with representatives from four NASA Headquarters offices, six NASA field centers and the Air Force (SAMSO).

The evaluation activity included: (1) a review of the contracted study results, (2) selection of specific guidelines and groundrules concerning the Shuttle, upper stages, mission models and operational and programmatic considerations, and (3) a cost and capture analysis. The ability of about 35 different families of expendable upper stages to perform the selected mission model and the associated cost for each of three unique combinations of low cost spacecraft designs and multiple launch options was assessed. The cost differences between several of the top families were quite small. By considering a number of factors in addition to cost, it was possible to select one family as being representative of the most attractive combination of existing expendable upper stages for Shuttle for an interim period. The selected minimum modification family consists of the cryogenic Centaur, the storable Transtage and the small Burner IIA solid. A Burner II type kickstage is also used on both the Transtage and Centaur.

The selected family is not intended to be a final choice of expendable stages for Shuttle since factors which were beyond the scope of this evaluation will have to be considered in making that decision. The selected Centaur, Transtage, Burner II family does, however, combine a high degree of flexibility and cost-effectiveness as an interim Shuttle upper stage system, and its use is [illegible] this upper stage [illegible] and activities.

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INTRODUCTION

When the Space Shuttle becomes operational, it will be used to deliver automated earth orbital, geostationary and planetary spacecraft as well as manned sortie laboratories. The required final destination of many of the automated missions is beyond the capability of the Shuttle orbiter by itself. A Shuttle upper stage is required for these missions if continued use of existing expendable launch vehicles is to be avoided. Eventually a highly versatile and fully reusable Space Tug is to be developed for this application. This full capability Tug is not expected to be operational, however, until several years after the initial operating capability (IOC) of the Shuttle. (All symbols and abbreviations are defined in Appendix A.) For this evaluation the reusable Tug IOC is assumed to be January 1, 1984, and the Shuttle IOC January 1, 1980. During the four year period between Shuttle IOC and Tug IOC, an interim Shuttle upper stage capability is needed. Possible alternatives for providing this early Shuttle upper stage capability include:

1. Existing expendable upper stages incorporating only those modifications necessary for Shuttle compatibility,
2. Improved versions of existing upper stages modified for reusability and/or increased performance capability, and
3. An interim phase-developed reusable space Tug which would eventually be evolved into the full capability Tug.

Because of the large number of existing stages and the many possible combinations of these stages, there are many variations within the first alternative. At the request of NASA Headquarters' Office of Space Science (OSS), a comprehensive analysis of the existing upper stage alternative was initiated in calendar year 1971 at the Lewis Research Center (LeRC). Subsequent to this activity, the NASA's Office of Manned Space Flight (OMSF) undertook the task of assessing all three of the interim upper stage alternatives when it became evident that the full capability Tug could not (because of budget constraints) be developed in time to match the Shuttle IOC. To avoid the necessity for duplication of the LeRC evaluation activities in the broader OMSF assessment which was being conducted at the Marshall Space Flight Center (MSFC), a concerted effort was made to assure that all of the basic groundrules and assumptions in the two activities were consistent. The results of the LeRC evaluation were to be fed into the MSFC assessment for comparison with the other alternatives. As a result, many of the groundrules for the LeRC evaluation as well as the scheduled milestones were strongly influenced (and occasionally dictated) by the requirements of the MSFC assessment. This report documents the LeRC evaluation of the existing upper stage for Shuttle alternative.

As a first step in determining the feasibility of integrating an existing stage with Shuttle, the Centaur (cryogenic) and Agena (storable) stages were studied under contract by their respective manufacturers. The results established the feasibility of this approach (references 1 and 2). Six sole-source contracts were then awarded to the manufacturers of the Burner II, Scout, Delta, Agena, Transtage and Centaur stages for the purpose of defining in detail the extent and cost of all modifications necessary to adapt their stages for use with the Shuttle. The results are documented in references 3 through 8.

At the outset of the study of the existing upper stage approach it was planned that this alternative would be used with the Space Shuttle for only an interim period of time until a reusable Tug became available. This would permit deferring the high development cost of a new reusable Tug past the period of peak Shuttle development funding. With this objective in mind, primary emphasis in the contracted studies and in the subsequent evaluation is on the existing upper stage configurations modified only as necessary for Shuttle compatibility. No upgrading solely for increasing performance is included. The incentive is to provide a baseline Shuttle upper stage alternative for the interim period at low development cost and program risk. The resulting configurations are referred to as the baseline minimum modification existing stages. (Actually, the configurations in existence at the time of go-ahead for Shuttle modification should be used as the baseline stages. In this study, the current stage configurations including only firm, already-approved changes were used.)

In addition to the minimum modification baseline version, each manufacturer proposed and briefly investigated improved non-baseline configurations of his stage, but in much less detail. Also, since the completion of these studies, other upgraded configurations have been identified in recent studies. These newer upgraded configurations are not included in the following evaluation.

The results obtained through all eight of the contracted studies were evaluated in-house at the Lewis Research Center to determine the most effective family of existing expendable upper stages for Shuttle. A chart showing the schedule for each of the contracted studies and the in-house evaluation is included as figure 1.

To provide wider participation in the evaluation, a coordinating committee was set up with representatives of four NASA Headquarters' offices (OSS, OMSF, OA and OAST), five other NASA field centers (GSFC, JSC, KSC, LaRC and MSFC) and the Air Force (SAMSO). The stated function of the coordinating committee was to: (1) provide liaison for timely exchange of pertinent information, (2) review, critique and approve guidelines and assumptions, (3) recommend specific variations and options to be exercised, and (4) assess the validity and implications of the results. These functions were accomplished through review of the Study Plan and Data Documentation Package by the Coordinating Committee members and the status review and committee meetings as indicated in figure 1. The individual committee members are listed in figure 2.

During the evaluation, thirty-five different groupings or "families" of baseline and non-baseline stages were investigated. A cost and capture analysis was completed for each of the families for each of three different combinations of assumptions or "options". The first of the three options (option I) limits consideration to conventional spacecraft designs. The second option (option II) allows use of a combination of conventional and low cost spacecraft designs (low cost designs are typically larger and heavier but less expensive than the corresponding conventional or current design model). In options I and II only a single spacecraft is allowed on each Shuttle flight which includes an upper stage. Those missions which do not require an upper stage are packaged together to more fully utilize the Shuttle capability. These "Shuttle-only" multiple launch assignments are the same for options I and II and also for each family considered. Option III includes the same combination of current and low-cost spacecraft as option II. In addition, maximum multiple packaging of spacecraft on a single stage and in a single Shuttle is permitted. Both NASA and DOD missions are included in the capture analysis. The families are compared on the basis of transportation system cost or, where appropriate, "equivalent" transportation cost which accounts for savings due to low cost payload design.

The pertinent groundrules and assumptions are discussed in the next section. The results of the evaluation for each of the three options (I, II, and III) for both minimum-modification baseline and non-baseline families are discussed in the "DISCUSSION OF RESULTS" section. The effects of several "special case" variations are also discussed. Based on these results, one family is selected as being representative of the capability of the existing expendable upper stage alternative to satisfy the interim Shuttle upper stage requirements. Additional information is provided for the selected family. The conclusions reached during this evaluation are summarized in the "CONCLUDING REMARKS" section.

GROUNDRULES AND ASSUMPTIONS

The task of assessing the various options in the use of existing expendable Shuttle upper stages is quite complex and requires that a clear, comprehensive set of groundrules be established to guide the analysis. For this reason, a substantial portion of this report is devoted to describing the various elements which served as input to this study as well as the assumptions which were made to facilitate the analysis.

Such items as the mission model, Shuttle definition, and program schedules change frequently as new information is developed. It is impractical to respond to all such changes which occur during the course of a study such as this. Therefore, the groundrules to be followed were "frozen" at the last practical point and remained unchanged throughout the remainder of the analysis. They are discussed below.

The sensitivity of the results to some of the groundrules which include uncertainties was also determined as will be discussed in later sections of this report.

SPACE SHUTTLE

IOC and Availability

The Space Shuttle is assumed operational at ETR beginning January 1, 1980. The Shuttle buildup rate given in reference 9 is assumed. The Shuttle launches available at each launch site under the assumed buildup rate are as follows:

YEAR	ETR	WTR
1980	13	0
1981	34	0
1982	46 total launches split as required	
1983 and later	as required	as required

During the period of Shuttle buildup, those missions in excess of the available Shuttle launches are assigned to expendable launch vehicles. All available Shuttle launches in a given year are used before expendable vehicles are assigned. The missions are considered for assignment to Shuttle in the following order:

1) NASA missions within the capability of Shuttle without an upper stage.

2) DOD missions within the capability of Shuttle without an upper stage.

3) NASA Shuttle-plus-upper-stage missions.

4) DOD Shuttle-plus-upper-stage missions.

When insufficient Shuttle flights are available to complete a particular category, other factors are considered to determine which missions within that category should be flown on Shuttle and which on expendable launch vehicles. Two such factors are:

1) The Shuttle should be used to replace the most expensive launch vehicles for maximum cost effectiveness.

2) New programs should be assigned to Shuttle before a continuing program which has previously (before 1980) been integrated with an expendable launch vehicle.

Performance

Space Shuttle performance characteristics used in this study are taken from the Space Shuttle Payload Accommodations document (reference 10). Space Shuttle delivery capability from ETR is shown in figure 3 as a function of circular orbit altitude for various orbit inclinations. Figure 4 shows similar data for Shuttle launches from WTR. This performance was derived assuming the external tank is jettisoned prior to reaching a 50 by 100 nautical mile transfer orbit, and the final orbit is achieved by using the Shuttle's orbit maneuvering system (OMS).

It is possible that the Shuttle will also be able to deliver payloads to elliptic orbits, which would be advantageous for some missions. However, no Shuttle performance data for this mode of operation were available at the time of this analysis.

Maximum Shuttle performance, based on figures 3 and 4 is used in this study. It is assumed that cargo bay OMS tankage kits could be used with the expendable Shuttle upper stages. For missions beyond Shuttle-only capability, the Shuttle delivers the spacecraft and expendable upper stage to a circular orbit. The altitude and inclination of the circular Shuttle orbit are selected to maximize expendable upper stage performance.

When the Shuttle performance with integral OMS tanks is adequate, the Shuttle cargo space available for Shuttle payloads is 15 feet in diameter by 60 feet long. The expendable stage, when one is required, is part of the Shuttle payload. If cargo bay OMS kits are required, the 60-foot available cargo bay length is reduced by 12.3 feet. Multiple OMS kits can be nested so that the available cargo bay length is 47.7 feet whether 1, 2, or 3 cargo bay OMS kits are needed (reference 10).

Figure 5 illustrates the Shuttle launch azimuth constraints for launch sites at ETR and WTR. The allowable launch azimuth range for ETR is defined as 35 degrees to 120 degrees. This azimuth range gives an inclination range of 28.5 degrees to 57 degrees. The allowable azimuth range at WTR is 140 degrees to 201 degrees. This azimuth range gives an inclination range of 56 degrees to 104 degrees. All missions requiring Shuttle orbit inclinations less than 57 degrees are launched from ETR. Missions requiring higher Shuttle orbit inclinations are launched from WTR.

Center-of-Gravity and Landing Weight Constraints

The maximum design landed payload weight and the allowable payload, longitudinal center-of-gravity (c.g.) envelope for the Space Shuttle are shown in figure 6. The landing weight limit of 32,000 pounds is applied, in this study, to planned operations only. Planned operations include the return of sortie spacecraft and/or upper stage/Shuttle interface equipment. The landing weight is not constrained for mission abort situations (unplanned operations). For abort landings, therefore, the margins of safety could be below the nominal.

The longitudinal c.g. constraint is applied to all landed weight either for planned or abort operations. Dumping of upper stage liquid propellants is assumed in case of abort; therefore, the landed Shuttle payload weight in abort situations consists of all spacecraft on the flight plus the empty weight of any liquid stages, the full weight of any solid stages, and all upper stage/Shuttle interface equipment. Detailed c.g. information was not available for the individual spacecraft. The c.g.'s of all spacecraft (including sortie modules) are assumed to coincide with the center of the cylindrical payload envelope.

In those cases where a single sortie spacecraft apparently violates the landing weight constraint and/or the longitudinal c.g. constraint, the mission is flown but no other spacecraft is packaged with it for multiple launches.

Costs

Development costs for the Space Shuttle are not included in this study. The direct operating cost per launch, as supplied by OMSF (reference 9), is held constant at $9.8M per launch.

UPPER STAGES

The baseline Shuttle upper stages considered in this study are versions of existing propulsive stages modified only as required to make them compatible with the Space Shuttle. Those configurations considered as baseline stages are:

- Agena
- Burner II
- Burner IIA
- Scout (Castor II/X259)
- Scout (Castor II/X259/FW-4S)
- Centaur
- Delta
- Transtage

The characteristics of these stage configurations are discussed in the section entitled "Baseline Stages."

In addition to the baseline stage configurations, several other configurations, proposed by the stage contractors are considered. These involve further modifications to the existing stages in order to enhance their performance capability as Shuttle upper stages. These stage configurations are described in the section called "Non-Baseline Stages."

Baseline Stages

The characteristics of the baseline Shuttle-compatible expendable upper stages are given in table 1. The information shown was, in general, taken from the final reports (references 1 through 8) of the recently completed NASA-funded Shuttle Integration Studies. The comparative sizes of the baseline stage configurations may be seen in figure 7 which shows the stages drawn schematically to a common scale. Each of the baseline stages is discussed briefly later in this section.

In order to facilitate performance calculations, total expended weight and effective specific impulse are used and are included in table 1. Total expended weight includes all weight expended between the upper stage's first ignition and final burnout. This includes items such as main impulse propellant, attitude control propellant, engine shutdown and restart losses, boil-off, solid rocket motor expended inerts, etc. The effective specific impulse is determined by multiplying the engine specific impulse by the ratio of usable propellant weight to total expended weight. Using total expended weight and effective specific impulse (rather than usable propellant weight and engine specific impulse) in performance calculations simplifies the accounting for the non-impulse expendables while maintaining a high degree of accuracy.

Also, shown in table 1 is the longitudinal center-of-gravity location for the stages plus their interface equipment. The value given is for an abort landing, and hence for liquid propellant stages assumes the propellant has been dumped. The dimension given is the distance from the aft end of the Shuttle 15' x 60' cargo bay assuming the stage is installed in its aft-most position in the cargo bay.

For options I and II, no more than one upper stage is carried on each Shuttle flight. The groundrules for option III permit multiple similar stages on a single Shuttle flight. In most instances, weight and volume constraints preclude multiple stages in the cargo bay so that, even in option III, the single stage per Shuttle arrangement is most prevalent. The possibilities for multiple stage arrangements are discussed along with the main characteristics of each individual stage in the following paragraphs. Figures 8 through 15 which will be referred to in this section are taken from the final contractor reports (references 2 through 8) and do not all include the same amount of detail and information.

Agena. - The Shuttle-compatible Agena baseline stage is shown in figure 8. The Agena uses a single Bell Model 8096 engine capable of multiple restarts. Its 5-foot diameter allows side-by-side mounting in the cargo bay for small spacecraft. This type of mounting would require design of a special cradle or pallet. Such a design was not undertaken for this study, however, for the option III capture analysis it is assumed that such a cradle is available. The Agena's 21-foot length will accommodate spacecraft packages up to 39 feet long with integral Shuttle OMS tankage and up to 27 feet long when cargo bay OMS kits are required.

Burner II and Burner IIA. - The Burner II characteristics shown in table 1 are based on the use of the flight-proven TE-M-364-4 solid rocket motor, as shown in figure 9, which carries 2290 pounds of composite solid propellants. While this Burner II configurations has not flown, substitution of the larger motor in place of the 1440-pound TE-M-364-2 rocket motor presently used has been studied and is considered to be "existing" in the context of this study.

Restartable motors are not considered in this study, hence, the Burner II single burn capability severely limits its ability to capture missions starting from circular Shuttle orbits. Therefore, the single stage Burner II is not considered as an independent stage in the capture analysis. However, it is representative of small solid propellant kickstages which can be used to increase the performance capability of the liquid propellant stages. Because of the availability of technical and cost data for a Shuttle-compatible Burner II, it was used for all kickstage applications in this evaluation. It is recognized that a variety of kickstage configurations could be used. For example, as indicated in table 1, the Burner II is a 3-axis stabilized stage. For those missions which require a kickstage, and for which a spin-stabilized kickstage is adequate, the TE-M-364-4 motor in a spin stabilized mode offers comparable ΔV capability (slightly higher) at a cost savings of approximately $0.5M per flight. However, the mission requirements are not known well enough to determine the type of stabilization required in all cases.

The adapter weight used between the lower stage and the Burner II kickstage is given in table 1 under the respective liquid propellant stages.

The c.g. location given in table 1 for the Burner II is measured from the forward end of the lower stage.

The 2-stage Burner IIA configuration shown in figure 10 is used independently to fly missions from the Space Shuttle. The Burner IIA retains the TE-M-364-2 rocket motor in the lower stage and uses the TE-M-422-1 motor in the second stage. The 2-stage concept significantly increases the flexibility over the single-stage Burner II.

The stage contractor (reference 3) looked at two options for mounting the Burner IIA in the Shuttle cargo bay. For this study, mounting with the Burner IIA centerline parallel to the Shuttle cargo bay centerline was selected rather than the perpendicular mode.

Scout Stages. - The upper three stages of the present 4-stage Scout B which are considered as candidate Shuttle upper stages are shown in figure 11. A two-stage and a three-stage configuration are included in the evaluation. The two stage version, composed of the Castor II and the X-259, is controlled by a 3-axis stabilized guidance system on the X-259 stage. The lower two stages of the three-stage version are controlled by the same guidance system in the X-259, while the third stage, the FW-4S, is spin-stabilized.

The 38-foot length of the 3-stage configuration limits the spacecraft length which it can carry to 22 feet with integral Shuttle OMS tanks, and under 10 feet with cargo bay OMS kits. The 2-stage configuration can carry spacecraft up to about 6 feet longer in each case. The small diameter of the Scout stages permits side-by-side packaging with small spacecraft. A pallet for this purpose was proposed by the stage contractor in reference 4.

Centaur. - The Centaur D-1S, shown in figure 12 is the largest of the baseline stages studied, and offers the highest performance. The Centaur D-1S is a modification of the present Centaur D-IT which is currently being flown on the Titan booster. Two pump-fed hydrogen-oxygen RL10A-3-3A engines with multiple restart capability provide the propulsion for Centaur. The length of Centaur limits its capability to spacecraft less than 28 feet long with integral OMS tankage. For the mission model used in this study, the performance capability of Centaur is adequate to perform all missions without cargo bay OMS kits.

Delta. - The Shuttle-compatible Delta stage is shown in figure 13. This configuration is based on the second stage of the current expendable TAT/Delta launch vehicle. It carries the Delta Inertial Guidance System and uses a single pressure-fed LM descent engine capable of multiple restarts.

The Delta stage is the smallest of the liquid propellant stages studied, and carries about 10,000 pounds of propellant. Its 5-foot diameter allows side-by-side mounting in the cargo bay, assuming an appropriate cradle or pallet could be designed. Spacecraft up to 40 feet long can be accommodated with integral OMS tankage and up to 28 feet long with cargo bay OMS kits.

Transtage. - The C-26 Transtage, which served as the basis for the Shuttle-compatible Transtage (figure 14) considered in this study, is the final stage of the Titan IIIC expendable launch vehicle. Propulsion is provided by two AJ-10-138 pressure fed engines which are capable of multiple restarts. Transtage carries the most propellant of the Earth storable stages and it is the shortest of all the liquid propellant stages considered. Its total length is 15 feet. While the Transtage's 10-foot diameter precludes side-by-side installation in the cargo bay, it is possible to take advantage of its shortness by mounting two Transtage/spacecraft packages end-to-end in the cargo bay.

Non-Baseline Stages

As discussed in the *INTRODUCTION*, the expendable upper stages are intended to be an interim system planned for use with the Space Shuttle for only a few years until a reusable Tug becomes available. Consequently, the primary emphasis in the contracted studies (references 1-8) and in this evaluation is on existing stages modified only to provide Shuttle compatibility. The resulting minimum-modification baseline stage versions discussed in the previous section, received about 90 percent of the contracted study resources. There are, of course, improvements that can be incorporated into the existing stages which enhance their performance for the Shuttle application. The improved "non-baseline" configurations proposed by the contractors were studied under about 10 percent of the contracted activity and are discussed in this section. Various other improved versions of the baseline stages have been identified since the completion of the contracted studies but could not be included in this evaluation.

The non-baseline stages considered in the contracted studies and included in this evaluation are:

Tandem Agena
Tandem Delta
Tandem Transtage
Large Tank Agena

The characteristics of these configurations are given in table 2. As a special case, a new advanced Scout configuration is also considered.

A non-baseline version of Centaur, the large tank Centaur, was also proposed by the Centaur contractor (reference 1). However, because the baseline Centaur with a kickstage can perform all of the missions in the model, the large tank Centaur is not needed and, hence, is not considered in this evaluation.

The three tandem-stage configurations are very similar in concept. The upper stage of each stack is essentially the same as the respective baseline stage described in the previous section. A new interstage adapter is provided between the two stages. The lower stage is a baseline stage stripped of most of its avionics systems and converted to a propulsion module. Such functions as guidance, navigation control, and sequencing of events are provided for both stages by the systems carried on the upper stage.

The specific system designs and functional details varied among the three tandem configurations. Additional information may be found in references 5, 6, and 7.

The Large Tank Agena (LTA) configuration which is included in this study is the evolutionary Agena configuration proposed by the contractor in the initial Shuttle/Agena Compatibility Study (reference 2). The configuration is shown in figure 15. This stage represents a major change in systems over the present Agena and as such is considered to be a higher risk development than the other non-baseline stages considered. The significant increase in Isp over the present Agena and the low jettison weight give this stage a very good performance capability.

The final non-baseline configuration, the Advanced Scout, differed from the others in that the stage configurations considered are not designed for the expressed purpose of increasing performance in the Space Shuttle. The Scout Project Office, in anticipation of a requirement for increased performance from the Scout expendable launch vehicle, funded a study with the Scout prime contractor to design an improved Scout launch vehicle (see reference 11). If the Advanced Scout vehicle proposed by that study were to become a reality in the near future, the stages of that configuration, rather than the current Scout, would be considered for use in the Shuttle. Thus, the second (Short Algol III), third (Antares IIB), and fourth (Short Antares IIB) stages of the proposed Advanced Scout launch vehicle are considered as Shuttle upper stages. The stages are designated "SA", "AB" and "SB", respectively. This concept is considered to be a special case because the use of these stage configurations in the Shuttle would rely on the previous development of the Advanced Scout launch vehicle.

Performance and cost data for all of the non-baseline stage configurations are presented later in this report.

Performance

In order to perform the capture analysis required in this study, the performance capability of the Shuttle and/or the Shuttle plus upper stages had to be determined for each of the various missions in the model. The capability of the Shuttle without upper stage is discussed in the earlier section on "SPACE SHUTTLE" in the subsection entitled "Performance". For missions requiring energies beyond Shuttle capability, an expendable upper stage (or stages) and the spacecraft are injected into an initial orbit by the Shuttle. At the proper time the upper stage is ignited and performs the desired mission. The performance capabilities of the expendable upper stages considered, and the groundrules followed in the computation of Shuttle plus upper stage performance are discussed in this section.

In computing Shuttle upper stage performance, the upper stage/Shuttle adaptation equipment weights are charged to Shuttle payload. These adaptation equipment weights are presented in tables 1 and 2 for all expendable upper stages.

For liquid propellant stages, a one percent FPR is included by reducing the effective stage specific impulse one percent. Since the expendable solid stages considered are not restartable and once ignited they must burn to propellant depletion, there was no attempt to include any flight performance reserves.

Performance characteristics of expendable upper stages are given in tables 1 and 2. Using the basic stage performance data and the Shuttle performance maps described in the "SPACE SHUTTLE" section above, the delivered payload is maximized for each mission in the mission model. There are two parameters free for optimization, the circular orbit altitude to which the Shuttle can inject a spacecraft and expendable upper stage, and the Shuttle orbit inclination. These two parameters are chosen to maximize payload with the constraint that spacecraft plus expendable stage plus support equipment weights are less than or equal to Shuttle capability. For orbit-to-orbit transfer, the liquid stages and the two-stage solid vehicles use a two impulse Hohmann transfer. The amount of perigee inclination change is selected to give a maximum payload for the given total inclination change. The 3-stage solid vehicles use a three impulse transfer mode. The three impulse transfer is accomplished in either of two ways. In the first transfer mode the first stage burns into an intermediate transfer orbit making an optimal inclination change. The second stage then coasts to the apogee where it ignites and puts the third stage into another transfer orbit with an apogee equal to the apogee of the desired final orbit. The second stage also makes an optimal inclination change. At the apogee of the second transfer orbit the third stage ignites, making the remaining inclination change and raising the perigee to coincide with the desired final perigee. The second three impulse transfer mode is similar to the two-impulse transfer in that the first and second stages are burned at perigee of the initial orbit, making an optimal plane change and raising the initial apogee to the desired final apogee. The third stage then coasts to apogee where it makes the final inclination change and raises the perigee to the desired perigee altitude. For the three stage solid vehicles both three impulse transfer modes are evaluated, and the one giving the higher payload (generally the first mode) is selected.

Payload capability of all baseline and non-baseline stages to geosynchronous equatorial orbit are given in table 3 and table 4 respectively. For comparison, two sets of performance numbers are presented. The first set is obtained by optimizing Shuttle orbit altitude and inclination to give maximum payload. The second case assumes the Shuttle delivers the payload and upper stage to a 100 nautical mile circular orbit.

Planetary mission performance capability of the baseline stages without and with Burner II kickstage are presented as a function of incremental velocity on figures 16 and 17, respectively. The curves include a one percent flight performance reserve. These curves are used in determining planetary mission performance for each stage and mission. Again, the Shuttle orbit is selected to give maximum payload weight delivered. Similar performance curves are presented for the non-baseline stages on figures 18 and 19.

Cost Data

Cost estimates for the various stages (baseline and non-baseline) were provided under contract by the respective manufacturers (see refs. 2 through 8). A common set of groundrules was imposed on all six contractors and all costs were reported to a common work breakdown structure (WBS). In spite of these attempts to achieve comparability among all elements of the cost estimates, a number of apparent discrepancies and variations in the method of bookkeeping specific cost items were noted in the published results. In an attempt to put all of them on an equal basis, a number of adjustments were made to some of the cost estimates. No attempt was made to modify the contractor's estimates of individual cost elements. Rather, certain elements were deleted or added in an effort to insure that the same items were included in each of the overall stage cost estimates.

The major groundrules imposed on the cost estimates include:

1. Costs are for planning purposes only,
2. All costs are expressed in constant 1972 dollars,
3. Prime contractor fees are not included,
4. No flight tests are included in the development program,
5. Government Furnished Equipment (GFE) costs are included,
6. Government administrative costs are not included,
7. Cost estimates assume that all launches are from a single pad at ETR,
8. Costs for all launch operations, facilities and GSE required to support the Shuttle upper stage (but not the Shuttle itself) are included,
9. Costs associated solely with the spacecraft and/or Space Shuttle are not included,
10. Typical mission peculiar and software costs are included.

A number of adjustments were made to the individual stage cost estimates in the area of mission peculiar costs. This topic is discussed in the first part of this section. Following this, the nonrecurring and recurring costs for the baseline stages are treated separately. A discussion of the costs used for the non-baseline stages completes the section.

Mission peculiar costs. - Very large variations were noted in the contractor's estimates of "first-of-a-kind" and "repeat" mission peculiar or spacecraft integration costs. Some elements of the mission peculiar costs are specifically related to the individual stage characteristics. Other portions of these costs are related to the particular spacecraft and mission requirements. Planetary missions, for example, require very extensive launch window analyses and trajectory optimization activities. Multiple spacecraft delivery missions could require extensive software.

Historically, the larger upper stages have been used to launch heavier, more complicated and more expensive spacecraft than the smaller stages. As a result, the mission peculiar cost estimates tended to be much higher for the larger stages since the estimates were necessarily based on the individual contractor's experience. In the Shuttle upper stage application the smaller stages are capable of accomplishing (and may be assigned to) more sophisticated missions. In that event, the mission peculiar costs for these stages will be more comparable to those of the larger stages.

It is also quite possible that some of the mission planning and spacecraft integration tasks that are traditionally included as mission peculiars would be accomplished by NASA or by a separate contractor in the Shuttle era and not charged to the individual stages.

Because of all these various [illegible], the decision was made to include only those mission peculiar costs which would be required to supply a stage identical in all respects (hardware and software) to a previous unit. These items are included in the stage costs used in this evaluation. All other mission peculiar costs were eliminated.

Baseline stage non-recurring costs. - The contractor estimates, the adjustments that were made to them, and the resulting non-recurring costs as used in the evaluation are summarized in table 5 for each of the baseline stages. The mission peculiar costs that were removed from the Scout and Transtage estimates are those associated specifically with particular spacecraft and are in addition to the stage-related costs. The service console and safety equipment costs added to the Agena estimate are for equipment and capability equivalent to that already included in the other stage estimates. The contingency is removed from the Centaur estimate for consistency with all of the other stages.

Baseline stage recurring costs. - A summary of the baseline stage recurring costs is given in table 6. The contractor estimates, all adjustments thereto, and the resulting cost at a launch rate of six per year are included. The Burner II stage studied as a baseline case by the contractor utilizes the 1440-pound solid propellant TE-M-364-2 motor. For use as a kickstage it is desirable to substitute the 2290-pound TE-M-364-4 motor. The contractor cost estimates for the Scout are based on the assumption that there would be five expendable Scout launch vehicle flights per year in addition to the six per year used in the Shuttle. When the decision was made to eliminate the concurrent Scout vehicle program in the baseline case, it was necessary to adjust the recurring cost as indicated in table 6. Mission peculiar costs are deducted from the contractor's estimates for the Scout, Delta and Centaur. The items deducted are specifically related to the spacecraft. Costs which are necessary to provide stages identical to the previous one are not deducted. The safety equipment cost added to the Agena is the contractor's estimate for equipment necessary to provide safety provisions comparable to those included for the other stages. The cost of each stage at a rate of six per year is shown in the bottom row of table 6.

In addition to a detailed breakdown at a rate of six per year, each contractor was required to provide an estimate of the stage recurring cost as a function of launch rate for rates between two and twenty per year. These estimates were adjusted consistent with table 6. The resulting recurring costs as a function of launch rate are shown in figure 20. The launch rate dependent costs as shown in figure 20 are used throughout the evaluation. For rates above 20/year, the costs at 20/year are assigned.

Non-baseline stage costs. - The cost estimates provided under contract for the non-baseline stage configurations are, in general, much less detailed and were studied to a lesser degree than those for the baseline versions. They should consequently be treated with less confidence. The non-recurring and recurring costs (at a reate of six per year) of non-baseline and special cases are summarized in table 7. The non-recurring costs for the Advanced Scout are those required for adaptation to the Shuttle assuming that the Advanced Scout launch vehicle is already in existence. As with the baseline stages, launch rate dependent costs are used throughout the evaluation.

EXPENDABLE LAUNCH VEHICLES

During the gradual buildup of available Shuttle flights, as indicated in the section "IOC and Availability", it is necessary to assign all WTR missions in 1980 and 1981 plus some of the ETR missions in 1980 and 1981 to expendable launch vehicles. Only expendable launch vehicles presently available in the NASA and/or DOD inventories are used and they are flown only out of the launch sites at which they are presently operational. The launch vehicles considered are listed below under the launch site(s) at which they are considered operational:

ETR	WTR
Scout (Wallops)	Scout
TAT/Delta	TAT/Delta
Atlas/Centaur	Titan IIIB/Agena
Titan IIIC	Titan IIID
Titan IIIE/Centaur	

The performance of these vehicles, assuming launch from ETR, was taken from reference 12 and is shown in figure 21 for purposes of comparison. When vehicles are assigned to WTR missions, performance corrections are made to account for the decreased capability.

The TAT/Delta vehicles with 3, 6, and 9 Castor strap-on solid motors are used in the study, however, only the performance of the largest version is shown on figure 21 to indicate the upper limit of the TAT/Delta vehicle capability.

The Titan IIIE/Centaur is the largest expendable launch vehicle required to perform the missions assigned to expendable vehicles in this study. However, the performance capability of the Titan IIIE/Centaur/Burner II configuration is also shown in figure 21 to illustrate the maximum expendable launch vehicle capability presently available outside of the Saturn class of vehicles.

Recurring costs for the expendable launch vehicles are based on the information in the January 5, 1973 draft of the OSS Economic Data Document. The recurring costs are varied with launch rate. In those families where a stage is part of an expendable launch vehicle and is also used as a Shuttle upper stage, the combined use rate is considered in determining the recurring costs for both the expendable vehicle and the Shuttle upper stage.

MISSION MODEL

To project funding requirements for space exploration and evaluate transportation system needs of the future; it is of primary importance to define and collate all mission objectives. From these objectives a mission model can be derived which defines spacecraft weight and orbit characteristics needed for space transportation system analysis. Since the objectives change as new knowledge is acquired and technological advances are made, and expected budget levels also change, both NASA and DOD are continuously updating their mission models. Since the mission models are in a constant state of flux, the models used in this study were frozen at what were considered to be the best versions available at the time. The DOD mission model is classified, therefore, most of the discussion on mission models will center about the NASA (non-DOD) model.

NASA

The mission model used in the analysis is given in table 8. The table contains an abbreviated mission name, mission characteristics and launch schedule including the number of spacecraft launched. The mission model was obtained from MSFC who is responsible for the continued updating of the model. Two spacecraft options are shown in table 8 for each mission, a current design expendable (CDE) spacecraft, and a low cost expendable (LCE) design. The current design designation refers to spacecraft designs based on current design philosophy.

This philosophy is characterized by high density miniaturized systems designed with high reliability. High reliability tends to increase spacecraft costs. Low cost design philosophy on the other hand relies more on modularization and commonality between spacecraft and less on miniaturization. A number of NASA contracted studies (references 13 and 14) indicate substantial spacecraft cost savings can be achieved through low cost design. Estimated cost savings associated with the given low cost spacecraft designs of table 8 were obtained from MSFC for most missions requiring upper stages. Table 9 gives the cost savings for a selected sample of missions.

Transportation costs were evaluated using: current design spacecraft and multiple launches only for non-upper stage missions (Option I); best-mix of current design and low cost spacecraft with multiple launches restricted as in Option I (Option II); and the best-mix of CDE and LCE spacecraft with maximum multiple launches (Option III). A "best-mix" mission model was derived for each family of expendable stages. Starting with all CDE spacecraft, each mission was checked to see if the potential cost savings attributed to the LCE design was greater than the increase (if any) in transportation system cost due to the heavier weight and larger volume of the LCE spacecraft. Only the two CDE and LCE spacecraft point designs were available, so there was no opportunity to parametrically trade spacecraft savings against transportation cost. The same best-mix model was used in Options II and III for each family. The maximum multiple launches groundrules and restrictions will be discussed in a later section entitled "MULTIPLE LAUNCH GROUNDRULES".

Based on destination, the missions can be classified into four categories; namely geostationary, planetary, high inclination and a fourth group which includes all missions that do not fall into the first three categories. Table 10 summarizes this breakdown for the baseline four year period. In addition there is a breakdown of missions by year and by launch site of Shuttle-only missions and those that require an expendable Shuttle upper stage. Roughly 44 percent of the missions (85 out of 193) require a Shuttle upper stage. Of these, 53 percent are geostationary, 15 percent planetary, 24 percent high inclination and 8 percent fall into the "other" category. The high inclination missions have relatively low energy requirements and will not pose significant problems to any of the expendable third stage families considered. It is of interest, however, to discuss in more detail the geostationary (because of the high traffic rate) and planetary (because of their high energy requirements) missions in terms of expendable third stage capabilities.

On figure 22 the distribution of geostationary spacecraft is plotted as a function of the number of spacecraft for both current design expendable and low cost expendable designs as defined in table 8. The specific weights used were the current NASA estimates at the time of this study. Future detailed design studies will undoubtedly lead to revised estimates especially for the low cost designs which have received limited study. There is a substantial increase in weight in going from current design expendable to low cost expendable spacecraft. This is consistent with low cost design philosophy as discussed previously.

Expendable Shuttle baseline third stage performance is also indicated on the figure. Baseline stages are defined as Shuttle compatible minimum modification existing expendable stages. The Centaur has the capability of delivering the weight of all current design and low cost design geostationary spacecraft. Transtage plus Burner II can fly all current design geostationary spacecraft but cannot deliver the weight of four of the low cost designs. None of the stages considered can accommodate the length of the low cost version of mission number 14, although several can carry the required weight.

Planetary missions fall into two categories; inner planet missions (relatively low energy missions) and outer planet missions (high energy). Since the outer planet missions are the most demanding in terms of performance requirements, they are also referred to as the Driver Planetary Missions in this report. On figure 23 the planetary spacecraft weights are plotted as a function of Delta velocity. Payload vs. Delta velocity curves are also plotted for the baseline stages with a Burner II kickstage. The inner planet missions do not pose significant performance problems. The Driver Planetary missions, however, have very stringent performance requirements. None of the baseline stage configurations can deliver the low cost outer planetary spacecraft (missions #30, #31, #33, #35) and only Centaur with Burner II kickstage can deliver the weight of the current design versions of all these spacecraft. The Centaur/Burner II does, however, violate the 60 foot length constraint for mission #35. Since Centaur/Burner II is the only baseline configuration that can deliver the weight of mission #35, it was assumed that the spacecraft could be reconfigured from the specified 24.5 foot by 9 foot configuration specified to the 20.6 foot by 15 foot available volume.

On figure 24 payload capability of the best performing (baseline or non-baseline) configurations of each Shuttle upper stage studied is given along with the planetary traffic for the baseline four year period. Again none of the configurations can deliver the low cost versions of the Driver Planetary Mission spacecraft. Of the non-baseline configurations only Large Tank Agena/Burner II can deliver all current design versions. Since Large Tank Agena/Burner II is substantially shorter than Centaur/Burner II it can accommodate mission #35 without violating the Shuttle cargo bay length constraint.

It should be pointed out, that all planetary missions, except mission #31 (Encke rendezvous) are flown ballistically. The Encke rendezvous mission incorporates a solar electric propulsion stage. Spacecraft weight given in table 8 for this mission includes the solar electric stage. The characteristic velocity does not include the velocity increment supplied by the solar electric stage.

DOD

The DOD mission model used in the evaluation is classified and it is not presented. Based on Delta velocity and spacecraft weight, NASA and outside user transportation requirements are more stringent than those of DOD. A selected family of expendable stages which satisfies NASA performance needs will satisfy those of DOD as well. However, the indicated spacecraft length requirements of DOD exceed those of NASA, which may lead to a requirement for a short stage like Transtage to be included in the stable of expendable stages as will be discussed later.

All DOD missions are included in the evaluation with the appropriate groundrules, but detailed results are not presented to keep the results unclassified. Basic groundrules and assumptions were supplied by DOD.

MULTIPLE LAUNCH GROUNDRULES

A major benefit attributed to the Space Shuttle is the capability to deliver several spacecraft to their respective mission destinations with a single Shuttle launch and thereby reduce transportation costs. The task of grouping the various spacecraft so as to make optimum use of the Shuttle and Shuttle upper stages under this multiple launch philosophy is a very complex one. There are many obvious constraints which must be imposed on the packaging, such as volume limitations, c.g. location constraints, compatible destinations, etc., which will be described in the list of groundrules presented below.

In addition there are many other considerations which cannot be readily quantified especially for missions 6 to 10 years in the future. For example, program priorities, scheduling, transportation cost distribution, and systems compatibility are among those items which must be considered in the actual packaging of Shuttle payloads, but are beyond the scope of the present analysis. While these items may have a strong effect on the absolute level of savings achievable with multiple launch capability, it is felt that the analysis presented in this report is valid for purposes of comparing expendable Shuttle upper stage families.

The packaging of spacecraft and Shuttle upper stages for multiple launches in the Shuttle is based on the following groundrules and assumptions:

1. All Shuttle loads must fit within the 15' x 60' clear volume of the Shuttle cargo bay.

2. When cargo bay OMS kits are required for adequate performance capability, the available volume in the cargo bay is reduced to 15' by 47.7'.

3. The 32,000 lb. landing weight limit is observed for all planned operations with multiple spacecraft. In any case where a single sortie spacecraft weighs more than 32,000 pounds the mission is flown, but no other spacecraft of any kind are packaged with it.

4. The Shuttle longitudinal c.g. constraints are satisfied by all multiple launch Shuttle loads. Only in the case of single sortie spacecraft which apparently violate the c.g. constraints are the limits shown in figure 6 exceeded. In such cases no other spacecraft are packaged in the same Shuttle. As is indicated in the earlier section of this report where Shuttle c.g. constraints are discussed, this constraint is applied only to reentry and landing. Since the expendable upper stages are returned only in an abort situation, the liquid propellants are assumed to be dumped before the c.g. constraint is applied.

5. Up to 3 spacecraft are permitted on a single Shuttle upper stage.

6. Up to 5 spacecraft are permitted on a single Shuttle launch.

7. Up to 3 identical spacecraft for the same mission are permitted on the same Shuttle launch.

8. Both side-by-side (parallel) and end-to-end (tandem) packaging of spacecraft are allowed on Shuttle upper stages and in the Shuttle cargo bay. The longitudinal axis of each stage and spacecraft is oriented parallel to the longitudinal axis of the cargo bay.

9. Packaging of spacecraft alongside the Centaur and Transtage upper stages is not allowed.

10. Only spacecraft with launches scheduled in the same year are packaged together.

11. Only spacecraft requiring the same Shuttle inclination may be launched together. The missions are separated into four groups by Shuttle orbit inclination. The first includes those missions requiring a nearly due East launch from ETR ($i \leq 30^\circ$). This group includes the geostationary orbit missions, planetary missions, and low inclination Earth orbit missions. Included in the second group of missions ($i = 55^\circ - 57^\circ$) are several sortie missions and mission number 54. The third group consists of polar Earth orbit missions with inclinations of 90°. The final grouping was made up of sun-synchronous and other high inclination missions at 98° to 105° inclination.

12. Only one type of upper stage is permitted in the Shuttle cargo bay at a time, with the exception of Burner IIA. Because of the interfaces and dump provisions required for each liquid propellant stage, it is not likely that the Shuttle orbiter could support the operations required for two different liquid stages on the same flight. The relatively small size and simple interfaces associated with the Burner IIA were felt to justify allowing it in the cargo bay with other stages. Two or more stages are also permitted in the cargo bay simultaneously when both stages are the same.

(As an illustration of this groundrule, a Transtage and a Delta could not be carried in the Shuttle at the same time. However, two Transtages or a Transtage and a Burner IIA could be carried simultaneously.)

13. No more than one planetary spacecraft is permitted per Shuttle launch.

14. No other spacecraft is flown on the same Shuttle upper stage with a planetary spacecraft.

15. DOD spacecraft are not launched with non-DOD spacecraft. This is a DOD constraint.

16. Spacecraft for different DOD missions are not launched together. Up to 3 of the same spacecraft for a given DOD mission may be launched together. These are DOD constraints.

17. Spacecraft are delivered to the destinations indicated in the mission model as shown in table 8 with one exception. The Space Processing Sortie missions listed as missions number 102 and 103 in the table are actually a single mission with a launch schedule equal to the sum of the launch schedules shown for missions 102 and 103.

An inclination of 28.5° is given for the mission #102 and 103 destination. However, the objectives of this mission are such that the inclination of its orbit is not important. Because of its relatively light weight and compact size, this spacecraft can be conveniently packaged with many other spacecraft. But because of the large number of launches required, if the inclination of its orbit were restricted to 28.5°, several Shuttle launches would have to be dedicated to this mission alone. For these reasons it was decided to allow these spacecraft to be launched to any inclination where they can be fitted into a Shuttle flight.

18. No multiple launches are permitted on expendable launch vehicles.

The above groundrules are applied to all cases where maximum multiple launch packaging is considered. In those cases, where only Shuttle-only multiple launches are considered, the same groundrules, except those which refer to Shuttle upper stages, apply.

DISCUSSION OF RESULTS

Results of the cost and capture analysis are presented and discussed in this section. The minimum-modification baseline family results are presented first. Those non-baseline options that were investigated are then discussed. Tandem configurations and the Large Tank Agena are included in the non-baseline category. Finally, results of several special investigations (variable Tug IOC, concurrent Scout launches and Advanced Scout) are included.

BASELINE STAGE FAMILIES

Minimum modification versions of the Centaur (CT), Transtage (TR), Agena (AG), Delta (DL), Scout (SC), and Burner-IIA (B2) were grouped into 16 distinct baseline families. Since Centaur is the only baseline stage capable of meeting the requirements of the Driver Planetary Missions as shown in figure 23, it is necessarily included in all 16 families. A kickstage of some type must be added to the Centaur for the most demanding planetary missions. The growth (2290 pound propellant) Burner-II (K) is used. The same Burner II configuration is also assumed to be available for use as a solid kickstage on all of the liquid propellant baseline stages.

For comparison purposes in this evaluation each family is classified according to the number of stages in the family. The two configurations consisting of a liquid stage and that same liquid stage with a solid propellant kickstage are counted as only 1.0 stages. The two Scout configurations are always assumed to be included in a family together and together are counted as 1.0 stages. The Burner IIA is simpler and easier to integrate with Shuttle than the larger configurations and, accordingly, is counted as only 0.5 stages for classification purposes. The 16 baseline families are listed in table 11. The third column shows the classification number of stages in the family. The stage and configuration nomenclature of table 11 is used throughout this section.

Current Design Spacecraft, Shuttle-only Multiple Launches (Option I)

The 16 baseline families are shown in order of increasing transporation system cost for the current design spacecraft, Shuttle-only multiple launches (option I) case in table 12. The total number of flights for each configuration in each family is shown in the center portion of the table. The Shuttle-only (SS) missions require 71 Shuttle flights and are the same for every family. The expendable launch vehicle assignments are also the same for each family. There are 62 expendable launch vehicle flights in option I during the four year period. In addition to the Shuttle-only and expendable launch vehicle flights, there are 76 Shuttle plus upper stage launches. The number of flights that are within the capability of any particular stage is the same as the number assigned to that stage when it is the smallest configuration in the family. As indicated in table 12, there are 7 flights within the capability of the Burner-IIA. The two-stage

Scout picks up 34 missions and the three-stage configuration captures an additional 3 missions. The Delta can accomplish 42 launches by itself and 14 additional ones with a kickstage. Similarly, the Agena captures 60 plus 2 with kickstage, Transtage flies 67 plus 2 with kickstage, and Centaur captures 72 missions by itself and the four remaining ones with a kickstage added. When the Transtage is included in the family, only the 7 Driver Planetary Mission launches are assigned to the Centaur.

The cost breakdown is given in the right side of the table. There are 147 Shuttle flights (71 by itself and 76 with an upper stage). At $9.8M per flight, the Shuttle cost is $1441M for every family. The 62 expendable launch vehicles cost from $868M to $890M, depending on which stages are in the Shuttle upper stage family. The variation in expendable launch vehicle cost is a function only of the individual upper stage use rate, since the expendable launch vehicle assignments are the same for all families. Non-recurring and recurring Shuttle upper stage costs are shown separately. The total transportation cost is the sum of the Shuttle, expendable launch vehicle and Shuttle upper stage (non-recurring and recurring) costs.

The 2.5-stage (CT, DL, B2) family has the lowest transportation cost for option I at $2589M. The 2.0-stage (CT, DL) family is a close second at $2594M. Examination of table 12 reveals that each of the 2.0-stage families is just slightly more expensive than the corresponding 2.5-stage family which includes the same 2 basic stages and the Burner IIA. This would indicate that when there are two main stages in the family, the Burner IIA can be either included or excluded without having a substantial effect on the transportation cost. The 3.0-stage families are not attractive for option I since there is usually a corresponding 2.5- or 2.0-stage family (with two of the same stages) having a lower cost. The single stage Centaur family is the most expensive candidate, costing nearly $150M more than the lowest cost family. This indicates that 2.0- or 2.5-stage families are the most desirable for option I. Centaur is required, Delta is the first choice and Transtage is the second choice as a second stage in the family. It should be noted that only the Transtage can accommodate both the length and weight of the longest DOD spacecraft. Consequently, all of the non-Transtage families violate the Shuttle length constraint for this mission.

Best Mix Spacecraft, Shuttle-only Multiple Launches (Option II)

The flight summary and transportation cost breakdown for the 16 baseline families for the best-mix spacecraft, Shuttle-only multiple launches (option II) case is shown in table 13. The number of expendable launch vehicle flights, number of Shuttle flights and the Shuttle cost is the same as for option I (table 12). The intermediate stages (Scout, Delta, Agena and Transtage) capture fewer missions in option II than in option I since the low-cost spacecraft included in the best mix mission models are heavier than the corresponding CDE spacecraft of option I. The Centaur is required for 10 of the best-mix missions as compared to 7 of the CDE spacecraft. The expendable launch vehicle costs are slightly different for most families in option II than in option I due to the different upper stage use rates. As in option I, there are 62 expendable launch vehicle flights.

The total transportation cost is slightly higher for option II than for option I since in some cases larger stages are required for the heavier LCE payloads. The savings in payload costs (payload effects) for the best-mix spacecraft model is $446M for each of the 16 baseline families of table 13. For the four year period considered, the best mix of current and low-cost designs is the same for all families which include the Centaur. Only the 7 Driver Planetary Missions and mission number 14 are forced to be current design versions. For all other missions for which low-cost design spacecraft data were available, it was best (on a cost basis) to use the low-cost versions. Since the payload effects savings are the same for all of the families in table 13, the families can be compared on the basis of total transportation cost.

The 2.5-stage (CT, TR, B2) family is top-ranked in option II. The 3.0-stage (CT, TR, DL) family is second, followed by the 2.5-stage (CT, DL, B2) which was the lowest cost family for option I. The cost differences between any of the top six families are quite small. The 1.0-stage family is the most expensive as it was in option I, costing $115M more than the lowest cost family. The relatively high performing Transtage shows up better in option II than in option I while the Agena, Delta and Scout families are further down the list in option II. This is a direct result of the heavier LCE spacecraft in the best-mix mission model.

Best-Mix Spacecraft, Maximum Multiple Launches (Option III)

The flight summary and transportation cost breakdown for the 16 baseline families are shown in table 14 for the option III case (best-mix spacecraft, maximum multiple launches). The best-mix mission model derived in option II for each family is used in option III as well. The same best-mix model applies to each of the families, the cost savings due to payload effects are $446M for each family in table 14, and therefore the families can be compared on the basis of total transportation cost. There are 4 columns in the flight summary portion of table 14 which did not appear in the previous tables. They are designated $\begin{pmatrix}2X\\B2\end{pmatrix}$, $\begin{pmatrix}2X\\DL/K\end{pmatrix}$, $\begin{pmatrix}2X\\AG\end{pmatrix}$, and $\begin{pmatrix}2X\\TR\end{pmatrix}$ and represent the number of flights on which 2 Burner IIA's, 2 Delta/Kick's, 2 Agena's or 2 Transtage's respectively, are carried to orbit in the same Shuttle. Although not restricted, no more than 2 stages were ever assigned to the same Shuttle flight.

The expendable launch vehicle cost is lower in option III than it was for options I and II. In option III there are 58 expendable launch vehicle flights compared to 62 in the previous options. The reduction is due to the increased number of spacecraft which can be carried on the available Shuttle flights because of the maximum multiple launch packaging.

The 2.5-stage (CT, TR, B2) family which ranked first in option II is also top-ranked in option III. The 2.0-stage (CT, TR) family ranks second. The third ranked family is actually identical to the second one. The zero's representing the number of AG, AG/K and $\genfrac{}{}{0pt}{}{2X}{AG}$ flights indicate that although these configurations were available, they were not assigned to a single mission The Agena non-recurring cost is therefore not included in the cost summary for the third-ranked family and it becomes identical to the second-ranked family.

The transportation cost for the top-ranked families in option III is about $340M less than for the top-ranked families in option II. This is a result of the reduction in the number of Shuttle/upper stage and Shuttle-only flights required because of the maximum multiple launches packaging. The number of flights and the Shuttle cost are a function of how efficiently the individual spacecraft and their delivery stages can be packaged and therefore differ for the various families. As mentioned previously, the same best-mix mission model that was derived for each family in option II is used for that family in option III. Since the best-mix model was the same for each of the 16 baseline families in option II, the $446M savings due to low-cost payload effects also apply in option III. Total savings for each of the top families in option III over the same families in option I is therefore about $340M plus $450M, or nearly $800M.

Summary of Baseline Stage Results

The relative rankings of all 16 of the baseline families are summarized in table 15 for options I, II and III. In this section, those baseline families which do not appear to be cost effective choices are eliminated. The remaining families will be compared with the non-baseline and special cases in the following sections. The 1.0- and 1.5-stage families rank near the bottom for all three options and are not considered to be reasonable alternatives on this basis. Of the 2.0-stage families, the (CT, DL) and (CT, TR) both rank as high as second for one of the three options and are therefore considered reasonable alternatives. This conclusion is indicated by the check in the rightmost "candidates" column of table 15. The (CT, SC) and (CT, AG) families do not rank higher than ninth for any of the three options and are therefore not considered candidates. Of the 2.5-stage alternates, the (CT, DL, B2) and (CT, TR, B2) families both rank first in at least one option and are therefore attractive candidates. The (CT, AG, B2) ranks as high as eighth in option III and, since the Agena is not included in any of the previous candidate families, it is listed as a candidate. The (CT, SC, B2) ranks very low in all 3 options and is not considered a reasonable alternate. Of the 3.0-stage families, the (CT, TR, DL) is a candidate by virtue of its very high ranking in all 3 options. The (CT, TR, SC) alternate is also listed as a candidate since it appears to be the most attractive family which includes the Scout. The other 3.0-stage families are not attractive candidates.

Each of the stages is included in at least one of the seven candidate families. The top 3 families in each option are also included. These seven families are used as a point of comparison for the non-baseline and special cases of the following sections.

Special Case: Non-Centaur Baseline Families

All of the results presented thus far are for baseline stage families having the Centaur as the largest stage. The Centaur, as previously discussed, is required for the Driver Planetary Missions. In this section the seven candidate baseline Centaur families are compared with baseline families that do not include Centaur to see if significant cost savings would result. The Transtage, which is the next best performing baseline stage would then be the largest stage in the family. A transportation cost comparison of the seven candidate Centaur-based families and various Transtage-based families is shown in table 16. The Transtage (with kick) falls far short of meeting the requirements of the Driver Planetary Missions. In fact, most of these missions could not be accomplished at all with the Transtage (see figure 23). For comparison purposes, however, these missions must be included in the traffic schedule so the Transtage/Kick is assigned to each of them and its cost is included in the totals of table 16. In option I, the lowest cost (TR, DL) family is \$52M less expensive than the best Centaur-based family (CT, DL, B2). In options II and III, heavier LCE spacecraft are included. With Centaur in the family, the estimated spacecraft savings due to payload effects is \$446M. When Centaur is not in the family, fewer of the LCE spacecraft can be included and the estimated savings are only \$378M. The spacecraft savings must be subtracted from the transportation cost in order to obtain the "equivalent transportation cost" on which legitimate comparisons can be made. The payload effects (P.E.) columns in table 16 indicate the expected spacecraft savings and the "equivalent transportation cost" is given in the columns headed "EQUIV". In option II the cost advantage of the best non-Centaur family over the best Centaur-based family is only \$5M and in option III this drops to an insignificant \$1M. If only baseline stages are considered, the effect of eliminating the Centaur would be to sacrifice the outer planet programs in return for little or no reduction in total program cost.

NON-BASELINE STAGE FAMILIES

In addition to the minimum-modification baseline stage families, a number of non-baseline options were considered. These are compared to the seven candidate baseline families described in the previous section.

Centaur-based Tandem Stage Families

Tandem Delta, Agena and Transtage configurations were investigated briefly in the contracted studies by the respective stage manufacturers. None of the investigated tandems is capable of capturing all of the Driver Planetary Missions (see figure 24). Therefore, if the requirements for these missions are firm, then the Centaur must be included in the families along with the tandems. A comparison of the transportation costs of the Centaur plus tandem Delta (TD), Centaur plus Tandem Agena (TA), and Centaur plus tandem Transtage (TT) families with the 7 candidate baseline families for options I, II and III is shown in table 17. It is assumed in each case that when a Tandem configuration of a particular stage is included in a family, then the single stage versions (with and without a kickstage) of that same stage are also available.

The (CT, TD) family ranks second in option I. It would not be selected, however, since the top-ranked (CT, DL, B2) has fewer configurations. Also, there is practically no cost advantage over the 2.0 baseline stage (CT, DL) family. The (CT, TD) is ranked first in option II. It is doubtful that it would be selected over the second-ranked (CT, TR, B2) baseline family since the cost advantage of only $14M probably would not warrant development of the non-baseline Tandem Delta configuration. In option III the (CT, TT) family ranks third, but here again the simpler and more cost-effective baseline families which rank first and second are preferred alternates. In options I and II the (CT, TT) family has exactly the same cost as the (CT, TR) since the TT is not assigned to any missions. All but the Driver Planetary Missions can be done by the TR/K. The Driver Planetary Missions are beyond the TT capability and are assigned to Centaur.

The results of table 17 lead to the conclusion that if the Centaur is included in the family, then it does not seem reasonable to develop any of the tandem configurations.

Tandem Transtage-based Families

The performance capability of the Tandem Transtage is insufficient to meet the requirements of the 7 Driver Planetary Missions as defined for this evaluation (see figure 24). It might be possible to decrease the requirements of these missions to match the Tandem Transtage performance, although as indicated in figure 24, the decrease would be significant for all 7 Driver Planetary Missions. The performance of the Tandem Transtage (with kick) is roughly comparable to that of the largest existing unmanned expendable launch vehicle, the Titan IIIE/Centaur/TE364-4. Use of the Tandem Transtage as the largest stage in the Shuttle would therefore restrict the planetary program of the 80's to requirements no greater than those of the 70's. A comparison of the transportation costs of the 7 candidate baseline families and 5 tandem Transtage-based families is shown in table 18. The Tandem Transtage-based families occupy the top 4 or 5 spots for each of the three options. The cost difference between the best Tandem Transtage-based and the best Centaur-based family ranges from $34M to $77M for the three options. This potential cost savings would have to be traded off against the impact of limiting the delivery capability to that of the Tandem Transtage rather than Centaur. Also, the Tandem Transtage with a planetary payload utilizes very close to the maximum specified Shuttle payload capability. The Centaur, on the other hand, utilizes considerably less than the maximum Shuttle capability and would allow a relaxation of Shuttle requirements during the early years of its use.

Large Tank Agena (LTA) Families

A large tank growth version of the Agena was investigated briefly as a non-baseline configuration in the first Agena upper stage study (see reference 2). The performance capability of the LTA is comparable to that of the Centaur (see figure 24). Because the LTA is nearly 10 feet shorter than Centaur, it can accomplish all of the CDE versions of the Driver Planetary Missions without violating any of the stated length constraints.

A comparison of the transportation cost of six LTA-based families with the seven candidate baseline families is given in table 19. In options I and II, baseline families are top-ranked. In option III, three of the LTA families are ranked first, second and third. The cost difference between the best baseline family and the lowest cost (LTA, DL) family is less than $30M. The technical and cost risks associated with a major development such as the LTA do not seem to be advisable for an interim period in view of the modest potential cost savings.

SPECIAL CASES

In addition to the baseline and non-baseline stage families discussed above, a number of special cases were evaluated. These included the effect of: (1) varying the initial operational capability of the Space Tug; (2) expendable Scout vehicle launches concurrent with the Shuttle launches; and (3) the possibility that an advanced version of the expendable Scout launch vehicle could be flying by 1980. The special case results are discussed in this section.

Variable Tug IOC

All of the results presented thus far are for the 1980-1983 four year period. The full capability Tug is assumed to be available by January 1, 1984. It is possible, however, that technical or budget difficulties could delay the Tug IOC. In this event it would be necessary to utilize the interim expendable upper stages for five or six years. The effect of variations in Tug IOC were investigated.

The transportation costs of the 16 baseline families for all three options and for two, four and six-year periods (1980 through 1981, 1983 and 1985, respectively) are shown in table 20. There is very little difference in the relative rankings of any of the families between the four-year and six-year cases. Potential slips in planned Tug IOC need not impact the choice of expendable stages for the interim period. In the two-year case, families having less than 3.0 stages tend to rank better than they do for longer periods. As indicated by the footnotes in table 20, a number of the 3.0 stage families revert to being identical to 2.0 stage families since one of the stages in the family is not assigned to any of the launches in the two-year mission model. The most reasonable choices of families for each option in the four-year case is therefore a good basis on which to select a representative family.

It should be recognized that if it were planned to use the expendable stages for more than about 4 years, then it would be important to consider incorporating additional modifications initially. The cost of the improvements could be amortized over the extended time period and greater utility in the Shuttle application could be achieved.

Concurrent Scout Launches

During the course of the evaluation the Scout Project Office representative on the Coordinating Committee suggested that the mission model being used did not properly account for the type of international programs which currently utilize expendable Scout launch vehicles. As a special case, the effect of an expendable Scout launch rate of 5 per year, concurrent with the Shuttle program, was investigated. The transportation cost of each of the 16 baseline families for all three options is presented in table 21. A comparison of the results of table 21 with the previous results (see table 15) shows that the families including Scout stages rank higher, in general, than they did when concurrent Scout expendable launch vehicles were not included. In all three options the highest ranking Scout family is a 3.0-stage grouping including Centaur and either Delta or Transtage. And in all three cases there is a less expensive, lower stage number family involving the same two other stages. The Scout families are not the best choices on the basis of transportation cost for any of the three options, even when the effect of an expendable launch vehicle launch rate of five per year is included.

Advanced Scout

An improved version of the expendable Scout launch vehicle has been studied under contract (see reference 11). This Advanced Scout would incorporate a second stage (short Algol III) which is a modification of the current first stage, a modified third stage (Antares IIB in lieu of the current X-259), and a fourth stage which is a shortened version of the new third stage. New and modified guidance and control systems are also incorporated. An analysis was completed which shows how the existence of the Advanced Scout (AS) would impact the selection of a family of expendable upper stages for Space Shuttle. Since development of the Advanced Scout would not be undertaken without the anticipation of a substantial launch rate, it was assumed that if the Advanced Scout were available, there would be 5 expendable Advanced Scout launches per year in addition to the Shuttle program. The transportation costs of 16 upper stage families for options I, II and III are shown in table 22. The (CT, DL, AS) 3.0-stage family ranks first in options I and II. In option I, the savings over the 2.5-stage (CT, DL, B2) family is only $3M. In option II, the Advanced Scout makes its best showing, occupying the first 5 rankings. The cost savings of the second-ranked 2.5-stage (CT, AS, B2) family over the sixth ranked (CT, TR, B2) (also 2.5 stages) is $27M. In option III the top ranked 2.5-stage (CT, TR B2) and 2.0-stage (CT, TR) families are lower in cost than the best AS family. If the Advanced Scout is operational at the time of Shuttle IOC, then it is a potential contender among the expendable Shuttle upper stage candidates.

SELECTED FAMILY

The primary objective of this study was to evaluate the various possible alternatives of minimum modification existing expendable upper stages for Shuttle, on a cost effectiveness basis. The results were to be used in the planned NASA/MSFC assessment of various Shuttle upper stage program options. In one of the MSFC options the expendable upper stage family would provide an interim capability until the full capability reusable Space Tug became available. The benefits of this option were to be compared to those of other options such as the phase-developed Tug. The MSFC assessment ground-rules closely resemble those of option III (best-mix of CDE and LCE spacecraft, maximum multiple launches). The option III results of this evaluation were therefore given more weight than those of options I and II.

On the basis of all of the results presented, a 2.0- or 2.5-stage baseline family consisting of the Centaur, an intermediate stage, and perhaps the Burner IIA should be selected. None of the non-baseline cases investigated offered potential cost savings sufficient to justify the additional risk associated with the required development effort or the resulting impact on the planetary missions. The baseline stage results summarized in table 15 indicate that the 1.0- and 1.5-stage families are not cost competitive. Furthermore, the 3.0-stage families offer no advantage over the simpler 2.0- and 2.5-stage groupings.

The rankings of the candidate 2.0- and 2.5-stage families consisting of Centaur and an intermediate stage both without (2.0) and with (2.5) the Burner IIA are shown in table 23. Several interesting trends are visible. As the potential payloads become heavier (because of low cost designs and multiple packaging) in moving from option I to option II to option III, the families which include the relatively small Scout and Delta stages move further down in the rankings. The families which include the larger Agena and Transtage vehicles improve their standing from option I to II to III. The Scout and Agena families rank well below the Delta and Transtage groupings. The choice is between Delta and Transtage for the intermediate stage role.

On the basis of all available information the family consisting of the Centaur, the Transtage and the Burner IIA (CT, TR, B2) is selected. This family ranked first of the baseline families in the prime option III case. It also ranked first in option II and was only $26M more expensive than the best family in option I. The selected family showed up well against all of the non-baseline and special cases, particularly in the prime option III results.

The Centaur provides an excellent planetary program capability as well as the opportunity to deliver multiple spacecraft to geostationary orbit. The Transtage is the only stage that can meet both the performance and length requirements of one of the DOD missions. The Burner IIA is not a strong cost driver and could be eliminated without significantly changing either the capability or the cost of the selected family. On the other hand, a Burner-type kickstage is required for some of the planetary missions and the use of the Burner IIA by itself does result in a slight cost advantage. The combination of a large cryogenic stage, a relatively large but short intermediate stage and a small solid stage, all of which are minimum-modification versions of existing stages, combines a high degree of flexibility, margin for spacecraft weight increases (or accommodation of low cost spacecraft) and cost effectiveness.

A computer printout of the mission model showing the vehicle assigned to each launch for the selected family for Option I is included as table 24. The first column gives the mission number. This is followed by the mission code and name. The "WT" column is the weight in pounds of the CDE spacecraft design. The next two columns show the apogee and perigee altitudes, respectively, in nautical miles. The required orbit inclination for earth orbit missions appears in the "INC" column. The "VC" column shows the required characteristic velocity for planetary and escape type missions in feet per second. The TL number is the total number of launches in the four year period. The launch schedule by year is also shown. The vehicle assigned to each mission is given in the column entitled, "VEHICLE". For a number of missions there is an additional code shown at the far right. A KITS" code indicates that cargo bay OMS kits are required. The "O" code means that the vehicle was assigned external to the computer. In the vehicle assignments, EOS stands for Earth-Orbit-Shuttle, TRANS represents the Transtage and CENTR is the Centaur. The kickstage is represented by the designation "B-II". The Burner-IIA has a "B-II" first stage and a "B-IIA2" second stage. Option I includes multiple launches for missions not requiring an upper stage. For each multiple shuttle-only mission, one of the included spacecraft has the Shuttle (EOS) as the assigned vehicle, and all of the other spacecraft are specified as being "MULT". In this way the correct number of Shuttle launches are always included in the cost totals. The expendable launch vehicle missions appear at the bottom of table 24 starting with mission 111. Missions 91 through 96 are simulated missions representing the actual DOD mission model that was used. The vehicle assignments and total number of launches are the same as would be required for the actual model. However, the launch schedules and mission weights shown in table 24 for the DOD missions are simulations. A complete schematic showing which spacecraft are included in each of the Shuttle-only flights is included as table 25. The cylindrical envelope of each spacecraft is shown to scale in the Shuttle cargo bay. When cargo bay OMS kits are required, they are also shown to scale at the aft end of the bay.

The option II mission descriptions and vehicle assignments are shown in table 26. The Shuttle-only mission assignments are the same as for option I (table 25). A complete cargo bay manifest for the selected family for the option III case is shown in table 27. A total of 165 non-DOD and 26 DOD missions are flown on the 119 Shuttle flights for an average of 1.6 spacecraft per flight. The structural attachments between stages and spacecraft are indicated on the sketches.

CONCLUDING REMARKS

The use of existing expendable upper stages is a feasible approach for providing an interim Shuttle upper stage capability. All of the candidate stages are adaptable to the Shuttle with relatively minor modifications and low technical and cost risk. Since the expendable upper stages would be used for only several years with the Shuttle, primary emphasis in this evaluation has been on minimum modification versions of existing stages. In order to minimize program cost and development risk the stages were modified only as required for compatibility with the Shuttle and not explicitly to increase their performance. Additional modifications can increase the capabilities of each of the stages and enhance their ability to capture missions when flown in the Shuttle but at a correspondingly higher development cost. Each of the contractors proposed and briefly studied one or more uprated configurations under contract and these were included in this evaluation. Other configurations, including new expendable upper stages have been proposed since that time but they have not been evaluated.

The Centaur is the only existing minimum modification upper stage which can capture all of the high energy planetary missions as defined for this study. Use of the Centaur in Shuttle provides an increase in capability over the existing unmanned expendable launch vehicles and also would permit a relaxation in Shuttle performance requirements during its initial years of operation. When Centaur is included in the family, there is no reason to include tandem configurations. If Centaur is not included, the Tandem Transtage-based families provide the best capability and are also cost-effective, but the outer planet performance capability is marginal.

The Transtage is attractive as a second stage in the family because of its short length and relatively high geostationary orbit delivery capability. It is the only stage capable of capturing all of the DOD missions without violating the stated length constraints. It is the most cost-effective intermediate stage for the option II and option III cases.

The Delta is also a cost effective intermediate stage. Families including both Centaur and Delta have the lowest transportation cost for option I. Because of its lower capability and longer length, however, Delta is not as attractive as the Transtage for the other options.

The Scout is not attractive as a Shuttle upper stage system for several reasons. Its long length is a distinct disadvantage for the multiple launch application. When used as an intermediate stage in a Centaur-based family, a large number of Centaur flights are required when compared to families having Delta, Agena or Transtage as the intermediate stage, and the cost is higher. Also, the Scout's guidance accuracy and flexibility is not as good as that of the liquid propellant stages. As a small stage in a family including Centaur and a larger intermediate stage, Scout is less cost effective than the Burner IIA. When the Advanced Scout and concurrent expendable launch vehicle flights are considered, Scout becomes more cost effective, but the other disadvantages remain.

The Agena is more expensive, longer and has lower performance capability than Transtage and therefore is not as attractive as a Shuttle upper stage.

The Burner IIA has potential application as a small third member of a Shuttle upper stage family. Its inclusion in a family having two larger stages does not have a substantial impact on the overall transportation system cost. A solid kickstage, such as the growth Burner II is a cost effective addition to any of the families considered in this evaluation and is required for the most difficult planetary missions.

The Centaur, Transtage, Burner IIA (CT, TR, B2) family is selected as being representative of the capability of minimum modification existing expendable upper stages for the interim Shuttle upper stage application. The selected family is not intended to be a final choice of stages for integration with the Shuttle. Differences in transportation system cost were relatively small between the various families indicating that the final choice will be based on other factors which could not be included in this evaluation. Other factors which could influence the final selection include the effect on cost of future changes in the level of business of the various stage manufacturers at the time the selection is made, the type of reusable Tug which will follow the interim expendable system, the need for a concurrent expendable launch vehicle program for either supplemental or back-up purposes and further definition of the mission model including the extent of payload effects benefits and the feasibility of multiple spacecraft launches.

APPENDIX A

ABBREVIATIONS AND ACRONYMS

AB	-	Antares IIB
ACS	-	Attitude Control System
AG	-	Agena
Apo. Alt.	-	Apogee altitude
AS	-	Advanced Scout
B_2	-	Burner-IIA
B-II	-	Burner II kickstage or lower stage of Burner-IIA
B-IIA2	-	Upper stage of Burner-IIA
CDE	-	Current design expendable
Cent.	-	Centaur
CENTR	-	Centaur
c.g.	-	Center-of-gravity
CT	-	Centaur
DDT&E	-	Design, development, test and evaluation
DL	-	Delta
DOD	-	Department of Defense
EOS	-	Earth Orbit Shuttle
ETR	-	Eastern Test Range
Exp.	-	Expendable
FPR	-	Flight performance reserve
fps.	-	Feet per second
FWD	-	Forward
GFE	-	Government furnished equipment
GSE	-	Ground support equipment
GSFC	-	Goddard Space Flight Center
H-AP	-	Apogee altitude
HDA	-	High density acid
H-PR	-	Perigee altitude
i	-	Inclination
INC	-	Inclination
Incl.	-	Inclination
IOC	-	Initial operational capability
I_{sp}	-	Specific impulse
JSC	-	Johnson Space Center
K	-	Kickstage
KITS	-	Flag to indicate use of cargo bay OMS kits
KSC	-	Kennedy Space Center
LaRC	-	Langley Research Center
LCE	-	Low cost expendable
LeRC	-	Lewis Research Center
LEO	-	Low earth orbit
LM	-	Lunar module
LTA	-	Large Tank Agena
LV	-	Launch vehicle

MSFC - Marshall Space Flight Center
MULT - Flag to indicate flight as part of multiple launch with no additional SS cost
N.A. - Not applicable
NASA - National Aeronautics and Space Administration
NM - Nautical Miles
N.Mi. - Nautical Miles
NR - Non-recurring
N-Rec. - Non-recurring
OA - Office of Applications
OAST - Office of Aeronautics and Space Technology
OMS - Orbital Maneuvering System
OMSF - Office of Manned Space Flight
OSS - Office of Space Science
P.E. - Payload effects
Per. Alt. - Perigee Altitude
Rec. - Recurring
SA - Short Algol III
SAMSO - Space and Missile Systems Organization
SB - Short Antares IIB
SC - Scout
S/C - Spacecraft
SC(2) - Two-stage Scout
SC(3) - Three-stage Scout
SRB - Solid Rocket Booster
SS - Space Shuttle
TA - Tandem Agena
TAT - Thrust Augmented Thor
TIIIB - Titan IIIB Booster
TIIID - Titan IIID Booster
TD - Tandem Delta
TL - Total launches for 4-year period
TR - Transtage
TRANS - Transtage
Trans. - Transportation
TT - Tandem Transtage
UDMH - Unsymmetrical-dimethyl Hydrazine
USO - UDMH + Silicone Oil
V - Velocity
V_c - Characteristic Velocity
WBS - Work breakdown structure
WTR - Western Test Range
XLV - Expendable launch vehicle
ΔV - Delta velocity

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TABLE 1. CHARACTERISTICS OF BASELINE SHUTTLE-COMPATIBLE EXPENDABLE UPPER STAGES

		Burner II	Burner IIA	Castor II/X-259	Castor II/X-259/FW-4S	Delta	Agena	Transtage	Centaur
Usable Propellant Wt., lb		2290	1440/524	8212/2575	8212/2575/606	10,047	13,596	23,032	30,020
Propellant	Fuel	Solid*	Solid*/Solid*	Solid*/Solid**	Solid*/Solid**/Solid*	UDMH-N_2H_4	UDMH	UDMH-N_2H_4	H_2
	Oxid.					N_2O_4	HDA	N_2O_4	O_2
Mixture Ratio, O/F		N.A.	N.A.	N.A.	N.A.	1.6	2.7	2.0	5.0
Prop. Feed System		N.A.	N.A.	N.A.	N.A.	Press. Fed	Pump Fed	Press. Fed	Pump Fed
Engine I_{sp}, sec.		285.0	290.4/272.4	281.9/281.4	281.9/281.4/284.1	304	295	302	444
Thrust, lb.		16,500	10,200/8,700	61,839/20,931	61,839/20,931/5,856	9850	16,500	16,000	30,000
Total Expended Wt., lb		2332	1463/542	8,324/2,597	8,324/2,597/610	10,097	13,720	23,130	30,164
Effective I_{sp}, sec.		280.6	285.8/263.3	278.1/279.1	278.1/279.1/282.7	302.5	292.3	300.8	441.9
Jettison Weight, lb		498	224/341	2091/769	2124/804/118	2018	1418	3675	4371
Length, ft		7.1	8.3	31.9	37.5	19.1	20.7	14.75	32.3
Diameter, ft		5.6	5.6	2.6	2.6	5.0	5.0	10.0	10.0
Guidance		Strapped down pre-programmed	Strapped down pre-programmed	Strapped down pre-programmed	Strapped down Pre-programmed/SPIN	Strapped down Closed Loop	Strapped down Closed Loop	Platform Closed Loop	Platform Closed Loop
ACS Propellant		H_2O_2 & N_2	H_2O_2 & N_2	H_2O_2/H_2O_2	H_2O_2/H_2O_2/N.A.	N_2	N_2	N_2H_4	H_2O_2
Shuttle Adapt. Equip. Weight, lb		925	925	4823	4823	1517	1470	2763	2810
Kickstage Adapter Weight, lb.		N.A.	N.A.	N.A.	N.A.	125	130	130	135
Longitudinal cg location for abort, ft from aft end		3.31	4.04	20.40	21.08	13.08	11.96	9.50	18.13

* composite solid propellant ** modified double-base solid propellant

TABLE 2. CHARACTERISTICS OF NON-BASELINE EXPENDABLE UPPER STAGES

	Tandem Agena		Tandem Delta		Tandem Transtage		Large Tank Agena
	Lower	Upper	Lower	Upper	Lower	Upper	
Propellant Weight, lb.	13,596	13,596	10,047	10,047	22,802	23,032	48,412
Propellant — Fuel	UDMH	UDMH	UDMH-N_2H_4	UDMH-N_2H_4	UDMH-N_2H_4	UDMH-N_2H_4	USO
Propellant — Oxid.	HDA	HDA	N_2O_4	N_2O_4	N_2O_4	N_2O_4	HDA
Mixture Ratio, O/F	2.7	2.7	1.6	1.6	1.96	1.99	2.7
Prop. Feed System	Pump Fed	Pump Fed	Press Fed	Press Fed	Press Fed	Press Fed	Pump Fed
Engine Isp, sec	295	295	304	304	303.5	302.6	310
Thrust, lb.	16,500	16,500	9850	9850	16,000	16,000	17,620
Total Expended Weight, lb	13,720	13,720	10,097	10,097	22,842	23,136	48,633
Effective I_{sp}, sec.	292.3	292.3	302.5	302.5	303.0	301.2	308.8
Jettison Weight, lb	1180	1425	1768	2018	3477	3572	2054
Length, ft	42.2		37.6		30.0		22.8
Diameter, ft	5.0		6.7		10.0		10.0
Guidance	Strapped down closed loop in upper stage		Strapped down closed loop in upper stage		Platform closed loop in upper stage		Strapped down Closed loop
ACS Propellant	N_2	N_2	N_2	N_2	---	N_2H_4	N_2
Shuttle Adapt. Equip. Wt., lb.	3068		2631		3770		796
Kickstage Adapter Wt., lb.	130		125		155		150
Longitudinal cg location for abort, ft from aft end	24.1		24.0		18.4		16.0

TABLE 3. BASELINE SHUTTLE UPPER STAGE GEOSTATIONARY ORBIT PERFORMANCE

		Optimum Performance			
		Inclination Change (Deg)			
Vehicle Name	Initial Circular Orbit Altitude (NM)	Perigee	Apogee	Payload (LBS)	Payload (LBS) from 100 x 100 (NM) Orbit
CASTOR/X-259/FW-4S	617	*	*	1526	1065
DELTA	644	2.47	26.03	1555	1057
AGENA	632	2.47	26.03	3021	2494
TRANSTAGE	485	2.38	26.12	4096	3295
CENTAUR	324	2.30	26.20	13480	12500
DELTA/BURNER II	630	2.46	26.04	2737	2226
AGENA/BURNER II	598	2.45	26.05	3739	3205
TRANSTAGE/BURNER II	445	2.36	26.14	5285	4602
CENTAUR/BURNER II	290	2.28	26.22	13630	12790

* Inclination change made by the Castor, X-259 and FW-4S stages are 1.60, 10.50 and 16.40 degrees respectively.

TABLE 4. NON-BASELINE SHUTTLE UPPER STAGE GEOSTATIONARY ORBIT PERFORMANCE

		Optimum Performance			
Vehicle Name	Initial Circular Orbit Altitude (NM)	Inclination Change (Deg) Perigee	Inclination Change (Deg) Apogee	Payload (LBS)	Payload (LBS) from 100 x 100 (NM) Orbit
SA/AB	475	13.33	15.17	2755	2610
SA/AB/SB	450	*	*	2963	2253
DELTA/DELTA	497	2.39	26.11	4528	3825
AGENA/AGENA	429	2.35	26.15	6960	6193
TRANSTAGE/TRANSTAGE	210	2.26	26.24	9527	9175
LARGE TANK AGENA	210	2.26	26.24	13760	13417
DELTA/DELTA/BURNER II	461	2.37	26.13	5106	4727
AGENA/AGENA/BURNER II	396	2.33	26.17	7463	6736
TRANS/TRANS/BURNER II	210	2.26	26.24	9589	9208
LARGE TANK AGENA/BURNER II	210	2.26	26.24	13250	12880

* Inclination change made by the Short Algol III (SA), Antares IIB (AB) and Short Antares IIB (SB) stages are .40, 9.10 and 19.00 degrees respectively.

TABLE 5. BASELINE STAGE NON-RECURRING COSTS

Cost Item	Stage							
	B-II KICK	B-IIA	SCOUT 2-Stage	SCOUT 3-Stage	DELTA	AGENA	TRANS	CENTAUR
Contractor estimate, 10^6 $	6.3	1.4[1]	12.8	1.4[2]	15.8	20.1	14.9	37.4
Remove mission peculiars			-0.1				-1.6	
Add service console costs						+0.9		
Add safety equipment						+0.5		
Remove contingency								-3.4
Non-recurring cost used in evaluation, 10^6 $	6.3	1.4[1]	12.7	1.4[2]	15.8	21.5	13.3	34.0

(1) The $1.4M is the incremental cost assuming that the basic B-II (KICK) has already been adapted to Shuttle.

(2) The $1.4M is the incremental cost for the 3-stage configuration assuming that the 2-stage configuration has already been adapted to Shuttle.

TABLE 6. BASELINE STAGE RECURRING COSTS AT A LAUNCH RATE OF SIX PER YEAR

Cost Item	Stage							
	B-II KICK	B-IIA	SCOUT 2-Stage	SCOUT 3-Stage	DELTA	AGENA	TRANS	CENTAUR
Contractor estimate, 10^6\$	0.59	0.64	1.70	1.73	2.55	4.23	3.71	6.41
Substitute larger solid motor	+.05							
Remove effect of concurrent SCOUT expendable launch vehicles			+.47	+.47				
Remove mission peculiars			-.07	-.07	-.20			-.22
Add safety equipment						.12		
Recurring cost used in evaluation @ 6 yr, 10^6\$	0.64	0.64	2.10	2.13	2.35	4.35	3.71	6.19

TABLE 7. NON-BASELINE CONFIGURATIONS COST SUMMARY

Configuration	Non Recurring Cost 10^6\$	Recurring Cost (@ 6/year) 10^6\$
Tandem Delta	4.6 [1]	3.30
Tandem Agena	5.3 [1]	5.94
Tandem Transtage	6.9 [1]	5.20
Large Tank Agena	50.0	5.00
Advanced Scout		
2-Stage	13.4	2.25
3-Stage	1.4 [2]	2.35

[1] Incremental amount assuming the single stage configuration is also adapted to Shuttle.

[2] Incremental amount assuming the 2-stage configuration is also adapted to Shuttle.

TABLE 8. PRELIMINARY 1973 NASA MISSION MODEL

Miss. No.	Miss. Code	Mission Name	Mission Description			CDE S/C Desc.			LCE S/C Desc.			Launch Schedule											
			Per. Alt. (N. MI.)	APO. Alt. (N. MI.)	Incl. (Deg.)	Weight (LB)	Lgth. (FT)	Dia. (FT)	Weight (LB)	Lgth. (FT)	Dia. (FT)	80	81	82	83	84	85	86	87	88	89	90	91
1	NE3-047	Small Appl. Tech. Sat (Synch.)	19,323	19,323	0.0	387	10.5	3.0	695	9.8	4.8	1	0	0	0	0	0	0	0	0	0	0	0
2	NE3-393	Small Appl. Tech. Sat. Follow-on	19,323	19,323	0.0	387	10.5	3.0	695	9.8	4.8	0	0	0	1	0	0	1	0	0	1	0	0
3	NE3-041	Synch. Meteorological Sat.	19,323	19,323	0.0	596	8.0	6.0	1,100	10.9	7.2	0	0	0	0	1	0	0	0	0	0	0	0
4	CE3-111	Earth Resources - Synch.	19,323	19,323	0.0	1,061	8.0	6.0	1,680	10.8	7.0	0	0	0	0	0	0	0	2	0	2	0	0
5	CE3-315	Foreign Synch. Meteor. Sat.	19,323	19,323	0.0	1,072	10.5	5.0	2,117	11.2	7.8	0	2	1	1	1	1	1	1	1	1	1	1
6	CE3-115	Synch. Operational Meteor. Sat.	19,323	19,323	0.0	1,072	10.5	5.0	2,117	11.2	7.8	0	1	1	1	1	1	0	1	0	1	0	1
7	CC3-109	Foreign Comm. Sat.	19,323	19,323	0.0	1,081	15.0	4.0	1,700	10.9	7.1	1	2	2	1	2	2	1	2	2	2	2	2
8	NC3-049	Tracking and Data Relay Sat.	19,323	19,323	0.0	1,795	17.5	10.0	3,262	15.1	14.6	0	0	0	3	0	0	0	0	0	0	0	0
9	CC3-050	Disaster Warning Sat.	19,323	19,323	0.0	1,795	17.5	10.0	2,870	14.5	14.0	1	1	0	0	0	1	0	0	0	0	1	0
10	CC3-113	Traffic Management Sat.	19,323	19,323	0.0	2,042	16.0	12.0	3,487	17.6	14.7	2	2	1	1	1	0	1	0	1	0	1	0
11	CC3-105	Intelsat	19,323	19,323	0.0	2,346	17.5	10.0	4,022	14.8	14.3	3	0	0	2	3	2	2	0	0	2	3	2
12	CC3-051	Prototype Operational Sat.	19,323	19,323	0.0	2,917	16.0	12.0	3,936	14.8	14.3	1	1	1	1	0	1	0	1	1	0	1	1
13	CC3-046	Communications R&D	19,323	19,323	0.0	3,060	25.5	9.0	5,689	18.0	14.7	1	1	0	0	0	1	1	0	0	0	1	1
14	CC3-108	U.S. Domestic Comm. Sat.	19,323	19,323	0.0	3,545	27.5	15.0	5,172	39.2	14.7	1	2	2	1	1	1	2	2	3	2	2	1
15	NE3-039	Synch. Earth. Obs. Sat.	19,323	19,323	0.0	5,262	13.0	8.0	6,798	15.9	14.7	0	1	0	1	0	0	0	0	0	0	0	0
16	NE3-043	Synch. Earth. Obs. - Oper.	19,323	19,323	0.0	5,262	13.0	8.0	6,798	15.9	14.7	0	0	0	0	0	0	0	2	0	2	0	2
17	NU3-037	Asteroid Rendezvous	V_c = 36,488 fps			3,713	20.5	10.0	5,521	14.9	14.4	0	0	0	0	0	0	2	0	0	0	0	0
18	NL3-381	Automated Lunar Orbiter	V_c = 36,668 fps			1,472	6.3	7.5	2,556	11.3	7.9	0	0	0	0	1	0	1	0	0	0	0	0
19	NL3-382	Automated Lunar Rover	V_c = 36,670 fps			8,874	27.3	10.0	8,874	27.3	10.0	0	0	0	0	0	0	0	1	1	0	0	0
20	NL3-383	Halo Sat.	V_c = 36,670 fps			2,254	24.5	9.0	4,696	19.3	14.7	0	0	0	0	0	0	0	0	0	1	0	0
21	NL3-384	Lunar Sample Return	V_c = 36,670 fps			11,730	27.3	10.0	11,730	27.3	10.0	0	0	0	0	0	0	0	0	0	0	1	1
22	NU3-378	Mars Surf. Sample Return/Lander	V_c = 37,888 fps			8,353	17.5	14.0	10,779	31.1	14.7	0	0	0	0	1	0	0	0	0	0	0	0
23	NU3-379	Mars Surf. Sample Return/Orbiter	V_c = 37,888 fps			8,921	12.0	10.0	17,236	14.1	13.5	0	0	0	0	1	0	0	0	0	0	0	0
24	NU3-389	Mars Satellite Sample Return	V_c = 37,890 fps			7,231	27.0	12.0	9,120	23.0	14.7	0	0	0	0	0	0	0	0	0	0	1	1
25	NU3-324	Inner Planetary Follow-on	V_c = 38,588 fps			897	15.5	10.0	1,631	14.5	14.0	1	2	0	1	0	0	1	0	0	0	0	0
26	NU3-025	Venus Radar Mapper	V_c = 38,588 fps			2,123	12.5	10.0	3,153	13.4	12.2	0	0	0	2	0	0	0	0	0	0	0	0
27	NU3-386	Venus Buoyant Station	V_c = 38,588 fps			2,244	12.5	10.0	4,174	14.0	13.2	0	0	0	0	0	2	0	0	0	0	0	0
28	NU3-026	Venus Large Lander	V_c = 38,590 fps			1,192	10.5	10.0	2,008	13.2	11.8	0	0	0	0	0	0	0	0	0	2	0	0
29	NU3-027	Mercury Orbiter	V_c = 42,288 fps			5,269	26.0	12.0	7,456	24.4	14.7	0	0	0	0	0	0	0	2	0	0	0	0
30	NU3-035	Comet "X" Slow Flyby	V_c = 47,488 fps			3,222	18.0	12.0	4,254	15.6	14.7	1	0	0	0	0	0	0	0	0	0	0	0
31	NU3-036	Encke Rendezvous	V_c = 47,488 fps			3,257	20.5	10.0	4,196	14.2	13.7	0	0	2	0	0	0	0	0	0	0	0	0
32	NU3-030	Pioneer Jupiter Probe	V_c = 49,888 fps			813	17.5	10.0	1,346	14.6	14.1	0	0	0	0	2	0	0	0	0	0	0	0
33	NU3-032	Mariner Jupiter Orbiter	V_c = 49,388 fps			2,550	17.0	12.0	3,523	15.4	14.7	0	1	1	0	0	0	0	0	0	0	0	0
34	NU3-387	Jupiter Saturn Orbiter/Lander	V_c = 50,790 fps			22,440	27.0	12.0	37,446	47.6	14.7	0	0	0	0	0	0	0	0	0	0	1	1
35	NU3-328	Pioneer Saturn/Uranus Flyby	V_c = 50,788 fps			2,050	24.5	9.0	3,336	15.2	14.7	2	0	0	0	0	0	0	0	0	0	0	0
36	NU3-034	Mariner Saturn Orbiter	V_c = 50,788 fps			2,415	18.0	12.0	4,307	21.0	14.7	0	0	0	0	0	2	0	0	0	0	0	0
37	NU3-033	Mariner Uranus Probe/Nept. Flyby	V_c = 57,388 fps			5,090	18.0	12.0	6,310	15.0	14.5	0	0	0	0	0	0	2	0	0	0	0	0
38	NU3-388	Halley Comet Flyby	V_c = 57,388 fps			6,222	35.5	10.0	12,289	32.8	14.7	0	0	0	0	0	1	0	0	0	0	0	0
39	NP3-015	Explorer - High Alt.	V_c = 39,988 fps			721	9.0	3.0	1,252	10.4	6.2	1	0	1	1	0	1	1	1	0	0	0	0
40	NP3-017	Gravity/Relativity Sat. - Solar	V_c = 47,790 fps			797	7.6	8.5	1,400	12.0	9.3	0	0	0	0	0	0	1	0	0	0	0	1

TABLE 8. (Continued)

Miss. No.	Miss. Code	Mission Name	Mission Description			CDE S/C Desc.			LCE S/C Desc.			Launch Schedule											
			Per. Alt. (N. MI.)	APO Alt (N. MI.)	Incl. (Deg)	Weight (LB)	Lgth. (FT)	Dia. (FT)	Weight (LB)	Lgth. (FT)	Dia. (FT)	80	81	82	83	84	85	86	87	88	89	90	91
41	NP3-020	Heliocentric/Interstellar	V_c =	54,490 fps		635	10.5	10.0	954	12.9	11.2	0	0	0	0	0	0	0	0	1	0	0	0
42	NE3-038	Earth Observation Sat. - R&D	500	500	98.0	2,448	12.0	10.0	3,735	13.4	12.1	1	0	0	0	0	0	0	0	0	0	0	0
43	NE3-338	Earth. Obs. Sat. - System Demo.	500	500	98.0	6,678	47.3	10.0	6,678	47.3	10.0	0	1	2	1	2	1	2	1	2	1	2	1
44	CE3-116	Earth Resources - LEO	500	500	100.0	2,561	14.0	6.0	4,071	13.0	11.3	1	1	1	1	1	1	1	1	1	1	1	1
45	NP3-013	Explorer - Upper Atmos.	180	1,800	90.0	1,241	11.0	4.0	2,678	11.7	8.8	0	1	0	0	1	0	0	0	1	1	1	1
46	NE3-048	Small Appl. Tech. Sat. (Polar)	300	3,000	90.0	387	10.5	3.0	695	9.8	4.8	1	0	0	0	0	0	0	0	0	0	0	0
47	NE3-340	TIROS N-P	906	906	103.0	1,415	13.0	8.0	1,956	12.4	10.1	0	0	1	0	0	0	0	1	0	0	0	0
48	CE3-040	TIROS Oper. Sat.	906	906	103.0	1,415	13.0	8.0	1,956	12.4	10.1	0	1	1	1	0	1	0	1	0	1	0	1
49	CE3-360	Environment Monitor	600	600	105.0	1,642	12.0	10.0	2,426	13.3	11.9	1	1	1	0	0	1	1	1	1	0	1	1
50	NP3-014	Explorer - Med. Alt.	1,000	20,000	90.0	642	10.5	2.5	932	10.5	6.4	0	1	0	0	1	0	0	0	1	1	1	1
51	NA3-002	Explorer - Synch.	19,323	19,323	28.5	463	9.9	2.6	546	14.1	3.5	1	0	0	1	0	1	0	1	0	0	0	0
52	NE3-397	Magnetic Monitor	800	800	28.5	524	9.3	3.5	1,122	10.3	5.9	0	1	0	0	0	0	1	0	0	0	1	0
53	NA3-011	Radio Astronomy Observatory	38,646	38,646	28.5	2,433	25.5	10.0	4,223	31.4	12.0	0	0	0	0	0	1	0	1	0	1	0	1
54	NP3-018	Environment Perturbation Sat.	6,900	6,900	55.0	4,437	13.5	7.0	8,335	21.9	14.7	0	1	0	0	1	0	0	0	0	0	0	0
55	NP3-019	Environment Perturbation Sat.	6,900	6,900	55.0	8,874	15.5	10.0	16,763	49.1	14.7	0	0	0	0	0	0	0	1	0	0	1	0
56	NA3-001	Explorer - LEO	297	297	28.5	463	9.9	2.6	546	14.1	3.5	1	1	1	1	1	1	1	1	1	1	1	1
57	NA3-215	Solar Max. Sat.	350	350	28.5	1,980	10.0	7.0	4,270	15.5	10.0	1	0	1	0	1	0	1	0	1	0	1	0
58	NP3-016	Gravity/Relativity Sat.	500	500	90.0	1,061	13.2	7.6	2,572	13.7	12.6	1	0	0	1	0	0	0	0	0	0	0	0
59	NE3-391	Small Appl. Tech. Sat.	280	280	90.0	387	10.5	3.0	695	9.8	4.8	0	2	0	0	1	0	0	1	0	0	1	0
60	NE3-392	Small Appl. Tech. Sat.	400	400	90.0	387	10.5	3.0	695	9.8	4.8	0	0	1	0	0	1	0	0	1	0	0	1
61	NE3-395	Gravity Gradiometer Sat.	110	110	90.0	6,732	16.5	13.0	11,329	33.3	14.7	1	0	0	0	0	0	0	0	0	0	0	0
62	NE3-045	Geopause	270	270	90.0	782	11.5	5.0	1,100	16.3	14.7	0	0	1	0	0	0	0	0	0	0	0	0
63	NE3-396	Mini-Lageos	350	350	28.5	1,554	8.1	10.0	1,554	8.1	10.0	1	0	0	0	0	1	0	0	0	0	0	0
64	NE3-380	Magnetometer Sat.	215	215	28.5	414	9.3	3.5	895	10.0	5.4	0	3	0	0	0	0	3	0	0	0	3	0
65	NE3-349	Seasat-B	380	380	90.0	734	7.5	5.0	1,240	10.4	6.2	0	0	1	0	0	0	0	0	0	0	0	0
66	NB3-055	Bio-Research Module	300	300	28.5	491	10.7	2.2	491	10.7	2.2	2	0	0	0	0	0	0	0	0	0	0	0
67	CE3-371	Global Earth and Ocean Monitor	200	200	98.0	2,561	14.0	6.0	4,986	13.6	12.6	0	0	0	0	0	0	3	0	3	0	3	0
68	NA3-003	High Energy Astronomical Obs.	250	250	28.5	19,085	47.6	9.2	19,085	47.6	9.2	0	0	1	0	0	0	0	1	0	0	0	0
69	NA3-004	HEAO-Revisit	250	250	28.5	3,500	5.0	15.0	3,500	5.0	15.0	0	0	0	1	1	1	0	0	1	1	1	1
70	NA3-005	Large Space Telescope	330	330	28.5	21,038	44.1	12.8	21,038	44.1	12.8	1	0	0	1	0	0	0	0	1	0	0	0
71	NA3-006	LST-Revisit	330	330	28.5	3,500	5.0	15.0	3,500	5.0	15.0	0	1	1	0	1	1	1	1	0	1	1	1
72	NA3-007	Large Solar Obs.	270	270	28.5	36,799	56.5	14.5	36,799	56.5	14.5	0	0	0	0	0	1	0	0	0	0	0	0
73	NA3-008	LSO-Revisit	270	270	28.5	3,500	5.0	15.0	3,500	5.0	15.0	0	0	0	0	0	0	1	1	1	1	1	1
74	NA3-009	Large High Energy Telescope	400	400	28.5	17,903	35.4	10.4	17,903	35.4	10.4	0	0	0	0	0	0	0	1	0	0	0	0
75	NA3-010	LHET-Revisit	400	400	28.5	3,500	5.0	15.0	3,500	5.0	15.0	0	0	0	0	0	0	0	0	1	1	1	1
76	NP3-321	Cosmic Ray Lab.	200	200	28.5	46,758	43.5	14.0	46,758	43.5	14.0	0	0	0	0	0	0	0	1	0	0	0	0
77	NP3-322	CRL-Revisit	200	200	28.5	3,500	5.0	15.0	3,500	5.0	15.0	0	0	0	0	0	0	0	0	1	1	1	1
78	NA3-301	Stellar Ast. Sortie	150	150	28.5	45,400	55.5	14.0	45,400	55.5	14.0	0	1	1	2	3	4	1	1	2	1	1	2
79	NA3-302	Stellar Ast. Sortie (30-day)	150	150	28.5	56,400	55.0	14.0	56,400	55.0	14.0	0	0	0	0	0	0	2	2	2	2	2	2
80	NA3-304	Solar Physics Sortie	167	167	28.5	43.500	55.0	14.0	43.500	55.0	14.0	1	1	1	3	4	4	2	2	2	2	2	2

TABLE 8. (Concluded)

Miss. No.	Miss. Code	Mission Name	Mission Description			CDE S/C Desc.			LCE S/C Desc.			Launch Schedule											
			Per. Alt. (N. MI.)	APO Alt. (N. MI.)	Incl. (Deg)	Weight (LB)	Lgth. (FT)	Dia. (FT)	Weight (LB)	Lgth. (FT)	Dia. (FT)	80	81	82	83	84	85	86	87	88	89	90	91
81	NA3-305	Solar Physics Sortie (30-day)	167	167	28.5	54,500	55.0	14.0	54,500	55.0	14.0	0	0	0	0	0	0	2	2	2	2	2	2
82	NA3-312	Space Physics Sortie	200	200	28.5	33,200	56.5	14.0	33,200	56.5	14.0	0	0	1	1	2	0	2	0	2	0	2	0
83	NA3-313	Space Physics Sortie	200	200	55.0	33,200	56.5	14.0	33,200	56.5	14.0	0	0	0	0	2	0	2	0	2	0	2	0
84	NA3-314	Space Physics Sortie	100	100	90.0	33,200	56.5	14.0	33,200	56.5	14.0	0	0	0	0	0	4	0	4	0	4	0	4
85	NB3-057	Life Science Lab. Sortie	200	200	28.5	30,300	25.5	14.0	30,300	25.5	14.0	1	1	1	0	0	0	0	0	0	0	0	0
86	NB3-058	Life Science Lab. Sortie	200	200	28.5	41,300	25.5	14.0	41,300	25.5	14.0	0	0	0	1	2	2	2	2	4	4	4	4
87	NE3-044	Earth Obs. Sortie	150	150	55.0	24,000	56.5	14.0	24,000	56.5	14.0	1	1	0	0	0	0	0	0	0	0	0	0
88	NE3-344	Earth Obs. Sortie	150	150	90.0	24,000	56.5	14.0	24,000	56.5	14.0	0	0	1	1	1	1	1	1	1	1	1	1
89	NE3-306	Earth Obs. Sortie	150	150	28.5	19,300	25.5	14.0	19,300	25.5	14.0	1	1	1	1	1	1	1	1	1	1	1	1
90	NE3-307	EOPAP Comm.Nav. Sortie	150	150	57.0	18,514	55.0	14.0	18,514	55.0	14.0	1	2	2	2	2	2	2	2	2	2	2	2
91-100		DOD Simulated Missions																					
101	NM3-062	Space Processing Sortie	150	150	28.5	22,850	30.5	14.0	22,850	30.5	14.0	1	1	1	1	1	1	1	1	1	1	1	1
102	NM3-365	Space Processing Sortie	160	160	28.5	7,650	5.0	14.0	7,650	5.0	14.0	0	3	10	9	10	9	10	9	10	9	10	9
103	NM3-365	Space Processing Sortie	160	160	28.5	7,650	5.0	14.0	7,650	5.0	14.0	0	1	2	3	2	3	2	3	2	3	2	3
104	NT3-063	Adv. Tech. Lab. Sortie	200	200	57.0	27,380	51.5	14.0	27,380	51.5	14.0	2	4	4	4	4	4	4	4	4	4	4	4
105	CP3-375	Foreign Sci./Phys. Sortie	200	200	28.5	33,200	56.5	14.0	33,200	56.5	14.0	0	0	1	1	0	0	1	0	0	1	0	0
106	CP3-376	Foreign Sci./Phys. Sortie	200	200	55.0	33,200	56.5	14.0	33,200	56.5	14.0	0	0	0	0	1	0	0	1	0	0	1	0
107	CP3-377	Foreign Sci/Phys. Sortie	100	100	90.0	33,200	56.5	14.0	33,200	56.5	14.0	0	0	0	0	0	1	0	0	1	0	0	1
108	CP3-374	Foreign Sci./Ast. Sortie	150	150	28.5	45,400	55.5	14.0	45,400	55.5	14.0	0	1	0	1	1	1	1	1	1	1	1	1
109	CP3-372	Space Processing Sortie	160	160	28.5	7,650	5.0	14.0	7,650	5.0	14.0	0	0	0	0	0	4	8	4	8	4	8	4
110	NT3-061	Long Duration Exposure Facility	270	270	28.5	10,200	35.5	14.0	10,200	35.5	14.0	1	0	1	0	1	0	1	0	1	0	1	0

TABLE 9. EXAMPLES OF SPACECRAFT COST SAVINGS DUE TO PAYLOAD EFFECTS

SPACECRAFT	COSTS, 10^6 $					
	Current Design		Low Cost Design		No. of Launches (4 years)	Total S/C Savings
	R&D	Unit	R&D	Unit		
Foreign Synch. Meteor. Sat.	80.4	19.7	62.2	15.6	4	34.6
INTELSAT	46.8	12.0	37.6	11.0	2	11.2
Inner Planetary Follow-on	74.9	18.5	64.4	16.6	3	16.2
Earth Resources Sat.	78.2	19.8	61.6	16.9	2	22.4
TIROS Operational Sat.	75.1	20.7	60.7	18.3	2	19.2

TABLE 10. MISSION MODEL SUMMARY
4-YEAR PERIOD (NO DOD)

By Year	1980	1981	1982	1983	Total
Missions within Shuttle Capability	17	23	34	34	108
Missions beyond Shuttle Capability	21	25	18	21	85
	38	48	52	55	193

By Launch Site	ETR	WTR
Missions within Shuttle Capability	98	10
Missions beyond Shuttle Capability	66	19
	164	29

By Mission Destination	Geostationary	Planetary	High Incl.	Other
Missions beyond Shuttle Capability	45	13	20	7

TABLE 11. BASELINE FAMILY DESCRIPTIONS

Family No.	Stages	Designation	No. of Stages	Configurations
1	Centaur	CT	1.0	CT,CT/K
2	Centaur, Burner-IIA	CT,B2	1.5	CT,CT/K,B2
3	Centaur, Scout	CT,SC	2.0	CT,CT/K,SC(2),SC(3)
4	Centaur, Delta	CT,DL	2.0	CT,CT/K,DL,DL/K
5	Centaur, Agena	CT,AG	2.0	CT,CT/K,AG,AG/K
6	Centaur, Transtage	CT,TR	2.0	CT,CT/K,TR,TR/K
7	Centaur, Scout, Burner-IIA	CT,SC,B2	2.5	CT,CT/K,SC(2),SC(3),B2
8	Centaur, Delta, Burner-IIA	CT,DL,B2	2.5	CT,CT/K,DL,DL/K,B2
9	Centaur, Agena, Burner-IIA	CT,AG,B2	2.5	CT,CT/K,AG,AG/K,B2
10	Centaur, Transtage, Burner-IIA	CT,TR,B2	2.5	CT,CT/K,TR,TR/K,B2
11	Centaur, Delta, Scout	CT,DL,SC	3.0	CT,CT/K,DL,DL/K,SC(2),SC(3)
12	Centaur, Agena, Scout	CT,AG,SC	3.0	CT,CT/K,AG,AG/K,SC(2),SC(3)
13	Centaur, Transtage, Scout	CT,TR,SC	3.0	CT,CT/K,TR,TR/K,SC(2),SC(3)
14	Centaur, Agena, Delta	CT,AG,DL	3.0	CT,CT/K,AG,AG/K,DL,DL/K
15	Centaur, Transtage, Delta	CT,TR,DL	3.0	CT,CT/K,TR,TR/K,DL,DL/K
16	Centaur, Transtage, Agena	CT,TR,AG	3.0	CT,CT/K,TR,TR/K,AG,AG/K

TABLE 12. FLIGHT SUMMARY AND TRANSPORTATION COST BREAKDOWN FOR BASELINE FAMILIES FOR OPTION I. CURRENT DESIGN EXPENDABLE SPACECRAFT. SHUTTLE ONLY MULTIPLE LAUNCHES. FOUR YEAR PERIOD.

		Number of Flights by Stage												Transportation Costs, 10^6\$				
				Scout		Delta		Agena		Trans		Cent				Upper Stage		
Rank	Family	SS	B2	(2)	(3)	DL	DL/K	AG	AG/K	TR	TR/K	CT	CT/K	Shuttle	Exp. LV	N-Rec	Rec	Total
1	CT,DL,B2	71	7			35	14					16	4	1441	872	57	218	2589
2	CT,DL	71				42	14					16	4		872	56	226	2594
3	CT,TR,DL	71				42	14			11	2	3	4		888	69	206	2604
4	CT,DL,SC	71		34	3	8	11					16	4		871	70	232	2614
5	CT,AG,DL	71				42	14	4	2			10	4		875	78	221	2614
6	CT,TR,B2	71	7							60	2	3	4		890	55	231	2617
7	CT,TR,SC	71		34	3					30	2	3	4		889	68	220	2617
8	CT,TR	71								67	2	3	4		890	54	244	2628
9	CT,AG,SC	71		34	3			23	2			10	4		871	76	249	2637
10	CT,SC,B2	71	7	27	3							35	4		872	56	272	2640
11	CT,SC	71		34	3							35	4		872	54	276	2643
12	CT,AG,B2	71	7					53	2			10	4		869	63	278	2650
13	CT,AG	71						60	2			10	4		868	62	295	2665
14	CT,TR,AG	71						60	0	7	2	3	4		883	75	285	2684
15	CT,B2	71	7									65	4		874	42	353	2709
16	CT	71										72	4		874	40	383	2737

TABLE 13. FLIGHT SUMMARY AND TRANSPORTATION COST BREAKDOWN FOR BASELINE FAMILIES FOR OPTION II.
BEST-MIX OF CURRENT DESIGN EXPENDABLE AND LOW COST EXPENDABLE SPACECRAFT DESIGNS FOR EACH FAMILY.
SHUTTLE ONLY MULTIPLE LAUNCHES. FOUR YEAR PERIOD.

		Number of Flights by Stage												Transportation Costs, 10^6 $				
				Scout		Delta		Agena		Trans		Cent				Upper Stage		
Rank	Family	SS	B2	(2)	(3)	DL	DL/K	AG	AG/K	TR	TR/K	CT	CT/K	Shuttle	Exp. LV	N-Rec	Rec	Total
1	CT,TR,B2	71	7							59	0	6	4	1441	887	55	240	2622
2	CT,TR,DL	71				28	15			23	0	6	4		882	69	232	2624
3	CT,DL,B2	71	7			21	15					29	4		869	57	263	2630
4	CT,TR	71								66	0	6	4		886	54	252	2632
5	CT,TR,SC	71		22	0					44	0	6	4		884	66	244	2635
6	CT,DL	71				28	15					29	4		868	56	270	2635
7	CT,AG,DL	71				28	15	3	9			17	4		869	78	265	2652
8	CT,DL,SC	71		22	0	8	13					29	4		867	69	279	2656
9	CT,AG,B2	71	7					39	9			17	4		866	63	297	2667
10	CT,AG,SC	71		22	0			24	9			17	4		866	74	294	2675
11	CT,AG	71						46	9			17	4		865	62	314	2681
12	CT,SC,B2	71	7	15	0							50	4		871	54	318	2684
13	CT,TR,AG	71						46	0	20	0	6	4		877	75	293	2686
14	CT,SC	71		22	0							50	4		870	53	323	2686
15	CT,B2	71	7									65	4		874	42	353	2709
16	CT	71										72	4		874	40	383	2737

TABLE 14. FLIGHT SUMMARY AND TRANSPORTATION COST BREAKDOWN FOR BASELINE FAMILIES FOR OPTION III. BEST-MIX OF CURRENT DESIGN EXPENDABLE AND LOW COST EXPENDABLE SPACECRAFT DESIGNS FOR EACH FAMILY. MAXIMUM MULTIPLE LAUNCHES. FOUR YEAR PERIOD.

Rank	Family	Number of Flights by Stage																Transportation Costs, $10^6$$				
					Scout		Delta			Agena			Trans			Cent				Upper Stage		
		SS	B2	2X B2	(2)	(3)	DL	DL/K	2X DL/K	AG	AG/K	2X AG	TR	TR/K	2X TR	CT	CT/K	SS	XLV	NR	REC	Total
1	CT,TR,B2	64	2	2									31	5	4	7	4	1166	844	55	216	2281
2	CT,TR	65											33	4	5	8	4	1166	842	54	224	2286
3	CT,TR,(AG)	65								0	0	0	33	4	5	8	4	1166	842	54	224	2286
4	CT,TR,DL	66					16	4	1				14	3	3	9	4	1176	839	69	216	2300
5	CT,DL,B2	64	2	2			10	7	1							30	4	1176	829	57	239	2302
6	CT,TR,SC	65			9	0							24	4	5	8	4	1166	842	66	228	2302
7	CT,DL	65					14	7	1							30	4	1186	829	56	243	2313
8	CT,AG,B2	64	2	2						19	7	2				20	4	1176	827	63	260	2326
9	CT,AG	65								21	7	2				21	4	1176	826	62	268	2331
10	CT,DL,SC	65			7	0	12	2								31	4	1186	829	69	249	2333
11	CT,AG,DL	65					12	9	1	2	7					21	4	1186	829	78	241	2333
12	CT,SC,B2	64	2	2	9	0										40	4	1186	832	54	266	2338
13	CT,AG,SC	65			7	0				14	7	2				21	4	1176	827	74	268	2346
14	CT,B2	65	2	2												49	4	1196	833	42	280	2350
15	CT,SC	66			14	0										40	4	1215	830	53	269	2368
16	CT	65														56	4	1225	832	40	307	2404

TABLE 15. SUMMARY OF BASELINE FAMILY RANKINGS FOR OPTIONS I, II, AND III.

No. of Stages	FAMILY	OPTION I	OPTION II	OPTION III	CANDIDATES
1.0	CT	16	16	16	
1.5	CT,B2	15	15	14	
2.0	CT,SC	11	14	15	
	CT,DL	2	6	7	✓
	CT,AG	13	11	9	
	CT,TR	8	4	2	✓
2.5	CT,SC,B2	10	12	12	
	CT,DL,B2	1	3	5	✓
	CT,AG,B2	12	9	8	✓
	CT,TR,B2	6	1	1	✓
3.0	CT,DL,SC	4	8	10	
	CT,AG,SC	9	10	13	
	CT,TR,SC	7	5	6	✓
	CT,AG,DL	5	7	11	
	CT,TR,DL	3	2	4	✓
	CT,TR,AG	14	13	-	

TABLE 16. COST COMPARISON OF NON-CENTAUR BASELINE FAMILIES WITH SEVEN CANDIDATE BASELINE FAMILIES

Option	I				II				III			
Spacecraft	CDE				Best-Mix				Best-Mix			
Multiple Launches	Shuttle-only				Shuttle-only				Maximum			
	Cost, 10^6\$			Rank	Cost, 10^6\$			Rank	Cost, 10^6\$			Rank
Family	Trans.	P.E.	Equiv.		Trans.	P.E.	Equiv.		Trans.	P.E.	Equiv.	
CT,DL	2594	0	2594	7	2635	-446	2189	10	2313	-446	1867	11
CT,TR	2628	0	2628	11	2632	-446	2186	9	2286	-446	1840	3
CT,DL,B2	2589	0	2589	6	2630	-446	2184	6	2302	-446	1856	7
CT,AG,B2	2650	0	2650	12	2667	-446	2221	12	2326	-446	1880	12
CT,TR,B2	2617	0	2617	9	2622	-446	2176	3	2281	-446	1835	2
CT,TR,SC	2617	0	2617	10	2635	-446	2189	11	2302	-446	1856	8
CT,TR,DL	2604	0	2604	8	2624	-446	2178	4	2300	-446	1854	6
TR	2563	0	2563	4	2563	-378	2185	7	2227	-378	1849	4
TR,B2	2549	0	2549	2	2549	-378	2171	1	2212	-378	1834	1
TR,SC	2549	0	2549	3	2561	-378	2183	5	2242	-378	1864	10
TR,DL	2537	0	2537	1	2552	-378	2174	2	2237	-378	1859	9
TR,AG	2563	0	2563	5	2563	-378	2185	8	2227	-378	1849	5

TABLE 17. TRANSPORTATION COST COMPARISON OF CENTAUR-BASED TANDEM STAGE FAMILIES WITH SEVEN CANDIDATE BASELINE FAMILIES

Option	I		II		III	
Spacecraft	CDE		Best-Mix		Best-Mix	
Multiple Launches	Shuttle-only		Shuttle-only		Maximum	
Family	Cost, 10^6\$	Rank	Cost, 10^6\$	Rank	Cost, 10^6\$	Rank
<u>Baseline Families</u>						
CT,DL	2594	3	2635	6	2313	8
CT,TR	2628	7	2632	5	2286	2
CT,DL,B2	2589	1	2630	4	2302	5
CT,AG,B2	2650	9	2667	9	2326	9
CT,TR,B2	2617	5	2622	2	2281	1
CT,TR,SC	2617	6	2635	7	2302	6
CT,TR,DL	2604	4	2624	3	2300	4
<u>Tandem Stage Families</u>						
CT,TD	2592	2	2608	1	2307	7
CT,TA	2672	10	2687	10	2345	10
CT,TT	2628	8	2639	8	2296	3

Note: The savings due to payload effects are \$446M for each family in options II and III.

TABLE 18. TRANSPORTATION COST COMPARISON OF TANDEM TRANSTAGE-BASED FAMILIES WITH SEVEN CANDIDATE BASELINE FAMILIES

Option	I		II		III	
Spacecraft	CDE		Best-Mix		Best-Mix	
Multiple Launches	Shuttle-only		Shuttle-only		Maximum	
Family	Cost, 10^6\$	Rank	Cost, 10^6\$	Rank	Cost, 10^6\$	Rank
<u>Baseline Families</u>						
CT,DL	2594	6	2635	10	2313	11
CT,TR	2628	10	2632	9	2286	7
CT,DL,B2	2589	5	2630	8	2302	9
CT,AG,B2	2650	12	2667	12	2326	12
CT,TR,B2	2617	8	2622	6	2281	6
CT,TR,SC	2617	9	2635	11	2302	10
CT,TR,DL	2604	7	2624	7	2300	8
<u>Tandem Transtage-based Families</u>						
TT	2583	4	2587	4	2221	2
TT,B2	2569	3	2573	2	2204	1
TT, SC	2565	2	2580	3	2236	5
TT,DL	2555	1	2571	1	2221	4
TT,AG	2638	11	2587	5	2221	3

Note: The savings due to payload effects are \$446M for each family in Options II and III.

TABLE 19. TRANSPORTATION COST COMPARISON OF LARGE TANK AGENA FAMILIES WITH SEVEN CANDIDATE BASELINE FAMILIES

Option	I		II		III	
Spacecraft	CDE		Best-Mix		Best-Mix	
Multiple Launches	Shuttle-only		Shuttle-only		Maximum	
Family	Cost, $10^6$$	Rank	Cost, $10^6$$	Rank	Cost, $10^6$$	Rank
Baseline Families						
CT,DL	2594	2	2635	6	2313	12
CT,TR	2628	7	2632	4	2286	5
CT,DL,B2	2589	1	2630	3	2302	10
CT,AG,B2	2650	10	2667	9	2326	13
CT,TR,B2	2617	5	2622	1	2281	4
CT,TR,SC	2617	6	2635	7	2302	11
CT,TR,DL	2604	4	2624	2	2300	9
Large Tank Agena Families						
LTA	2689	13	2689	12	2291	7
LTA,B2	2672	11	2672	11	2261	2
LTA,SC	2638	9	2668	10	2288	6
LTA,DL	2601	3	2634	5	2252	1
LTA,AG	2674	12	2689	13	2291	8
LTA,TR	2634	8	2641	8	2263	3

Note: The savings due to payload effects are $446M for each family in Options II and III.

TABLE 20. EFFECT OF VARIABLE TUG IOC

Period	2-Years						4-Years						6-Years					
Option	I		II		III		I		II		III		I		II		III	
Spacecraft	CDE		Best-Mix				CDE		Best-Mix				CDE		Best-Mix			
Mult. Lchs.	Shuttle-only				Maximum		Shuttle-only				Maximum		Shuttle-only				Maximum	
Family	Cost	Rank	Cost	Rank	Cost	Rank	Cost	Rank	Cost	Rank	Cost	Rank	Cost	Rank	Cost	Rank	Cost	Rank
CT	1398	14	1398	10	1320	12	2737	16	2737	16	2404	16	4273	16	4273	16	3639	16
CT,B2	1396	13	1396	8	1308	6	2709	15	2709	15	2350	14	4223	15	4223	15	3555	14
CT,SC	1392	7	1408	16	1331	15	2643	11	2686	14	2368	15	4081	11	4158	12	3568	15
CT,DL	1376	1	1388	5	1307	5	2594	2	2635	6	2313	7	4006	2	4076	6	3491	7
CT,AG	1395	12	1402	12	1319	9	2665	13	2681	11	2331	9	4137	13	4164	14	3526	12
CT,TR	1382	5	1386	1	1296	2	2628	8	2632	4	2286	2	4068	9	4073	5	3442	2
CT,SC,B2	1393	8	1407	14	1320	11	2640	10	2684	12	2338	12	4076	10	4153	11	3525	11
CT,DL,B2	1377	3	1389	7	1298	4	2589	1	2630	3	2302	5	3995	1	4067	4	3477	6
CT,AG,B2	1394	10	1401	11	1319	10	2650	12	2667	9	2326	8	4105	12	4139	10	3515	9
CT,TR,B2	1381	4	1386	4	1294	1	2617	6	2622	1	2281	1	4044	7	4050	2	3433	1
CT,DL,SC	(1376)[1]	(2)	(1388)[1]	(6)	1325	13	2614	4	2656	8	2333	10	4026	4	4101	8	3517	10
CT,AG,SC	1404	15	(1402)[1]	(13)	1334	16	2637	9	2675	10	2346	13	4066	8	4137	9	3542	13
CT,TR,SC	1394	9	(1386)[1]	(2)	(1296)[1]	(3)	2617	7	2635	5	2302	6	4028	5	4058	3	3459	4
CT,AG,DL	1395	11	1407	15	1328	14	2614	5	2652	7	2333	11	4033	6	4101	7	3511	8
CT,TR,DL	1387	6	1396	9	1316	7	2604	3	2624	2	2300	4	4014	3	4047	1	3445	3
CT,TR,AG	1410	16	(1386)[2]	(3)	1316	8	2684	14	2686	13	(2286)[2]	(3)	4160	14	4159	13	3467	5

[1] Although available, the Scout was not assigned to any missions.

[2] Although available, the Agena was not assigned to any missions.

TABLE 21. EFFECT OF CONCURRENT SCOUT LAUNCHES

Option	I		II		III	
Spacecraft	CDE		Best-Mix		Best-Mix	
Multiple Launches	Shuttle-only		Shuttle-only		Maximum	
Family	Cost, $10^6$$	Rank	Cost, $10^6$$	Rank	Cost, 10^6	Rank
CT	2785	16	2785	16	2452	16
CT,B2	2756	15	2756	15	2398	14
CT,SC	2677	11	2722	12	2403	15
CT,DL	2642	2	2683	6	2361	7
CT,AG	2713	13	2729	13	2379	11
CT,TR	2676	10	2680	5	2334	2
CT,SC,B2	2675	9	2720	11	2373	9
CT,DL,B2	2636	1	2678	4	2350	5
CT,AG,B2	2698	12	2715	10	2373	10
CT,TR,B2	2665	7	2669	1	2328	1
CT,DL,SC	2648	3	2692	7	2368	8
CT,AG,SC	2671	8	2711	9	2381	13
CT,TR,SC	2651	4	2670	2	2337	3
CT,AG,DL	2662	6	2699	8	2381	12
CT,TR,DL	2651	5	2672	3	2348	4
CT,TR,AG	2732	14	2734	14	2361	6

TABLE 22. TRANSPORTATION COST COMPARISON OF SIXTEEN BASELINE FAMILIES WITH ADVANCED SCOUT (AS) SUBSTITUTED FOR SCOUT

Option	I		II		III	
Spacecraft	CDE		Best-Mix		Best-Mix	
Multiple Launches	Shuttle-only		Shuttle-only		Maximum	
Family	Cost, 10^6\$	Rank	Cost, 10^6\$	Rank	Cost, 10^6\$	Rank
CT	2789	16	2789	16	2456	16
CT,B2	2761	15	2761	15	2403	15
CT,AS	2646	5	2650	4	2393	14
CT,DL	2646	6	2687	10	2366	7
CT,AG	2717	13	2734	13	2384	12
CT,TR	2681	11	2684	9	2339	2
CT,AS,B2	2643	3	2647	2	2378	9
CT,DL,B2	2641	2	2683	8	2354	5
CT,AG,B2	2702	12	2720	12	2378	10
CT,TR,B2	2669	10	2674	6	2333	1
CT,DL,AS	2638	1	2642	1	2368	8
CT,AG,AS	2658	8	2663	5	2382	11
CT,TR,AS	2644	4	2650	3	2342	3
CT,AG,DL	2667	9	2704	11	2385	13
CT,TR,DL	2656	7	2676	7	2353	4
CT,TR,AG	2737	14	2738	14	2366	6

Note: The savings due to payload effects are \$446M for each family in Options II and III.

TABLE 23. COMPARATIVE RANKINGS OF 2.0- AND 2.5-STAGE BASELINE FAMILIES

Stage	SCOUT			DELTA			AGENA			TRANSTAGE		
Option	I	II	III	I	II	III	I	II	III	I	II	III
Rank												
1				2.5							2.5	2.5
2				2.0								2.0
3					2.5							
4											2.0	
5						2.5						
6					2.0					2.5		
7						2.0						
8									2.5	2.0		
9								2.5	2.0			
10	2.5											
11	2.0							2.0				
12		2.5	2.5				2.5					
13							2.0					
14		2.0										
15			2.0									
16												

Note: Each family includes the Centaur and the intermediate stage indicated. The 2.0 and 2.5 entries indicate the relative ranking without and with the Burner IIA also included in the family, respectively.

TABLE 24. VEHICLE ASSIGNMENTS FOR SELECTED FAMILY - OPTION I

CDF SPACECRAFT

NO.	MISSION	WT	H-AP	H-PR	INC	VC	TL	80	81	82	83	84	85	86	87	88	89	90	VEHICLE	
2	NF3-393.SMALL APPL TECH	367.	19323.	19323.	0.	-0.	1	0	0	0	1	0	0	1	0	0	1	0	EOS /TRANS / /	
5	CF3-315.FOREIGN SYNCH ME	1072.	19323.	19323.	0.	-0.	4	0	2	1	1	1	1	1	1	1	1	1	EOS /TRANS / /	
6	CF3-115.SYNCH OPER METEO	1072.	19323.	19323.	0.	-0.	3	0	1	1	1	1	1	0	1	0	1	0	EOS /TRANS / /	
7	CC3-109.FOREIGN COMM SAT	1081.	19323.	19323.	0.	-0.	5	0	2	2	1	2	2	1	2	2	2	2	EOS /TRANS / /	
8	NC3-045.TRACKING AND DAT	1795.	19323.	19323.	0.	-0.	3	0	0	0	3	0	0	0	0	0	0	0	EOS /TRANS / /	
9	CC3-050.DISASTER WARNING	1795.	19323.	19323.	0.	-0.	1	0	1	0	0	0	1	0	0	0	0	1	EOS /TRANS / /	
10	CC3-113.TRAFFIC MANAGEME	2042.	19323.	19323.	0.	-0.	4	0	2	1	1	1	0	1	0	1	0	1	EOS /TRANS / /	
11	CC3-135.INTELSAT	2346.	19323.	19323.	0.	-0.	2	0	0	0	2	3	2	2	0	0	2	3	EOS /TRANS / /	
12	CC3-051.PROTOTYPE OPER	2917.	19323.	19323.	0.	-0.	3	0	1	1	1	0	1	0	1	1	0	1	EOS /TRANS / /	
13	CC3-046.COMM R AND D	3060.	19323.	19323.	0.	-0.	1	0	1	0	0	0	1	1	0	0	0	1	EOS /TRANS / /	
14	CC3-108.U S DOMESTIC COM	3545.	19323.	19323.	0.	-0.	5	0	2	2	1	1	1	2	2	3	2	2	EOS /TRANS / /	
15	NE3-034.SYNCH EARTH OBS	5262.	19323.	19323.	0.	-0.	2	0	1	0	1	0	0	0	0	0	0	0	EOS /TRANS /B-II /	KITS
25	NU3-324.INNER PLANETARY	857.	-0.	-0.	-0.	38588.	3	0	2	0	1	0	0	1	0	0	0	0	EOS /TRANS / /	
26	NU3-025.VENUS RADAR MAPP	2123.	-0.	-0.	-0.	38588.	2	0	0	0	2	0	0	0	0	0	0	0	EOS /TRANS / /	
30	NU3-035.COMET -X- SLOW F	3222.	-0.	-0.	-0.	47488.	1	1	0	0	0	0	0	0	0	0	0	0	EOS /CENTR / /	
31	NU3-036.ENCKE RENDEZVOUS	3257.	-0.	-0.	-0.	47488.	2	0	0	2	0	0	0	0	0	0	0	0	EOS /CENTR / /	
33	NU3-032.MARINER-JUPITER	2550.	-0.	-0.	-0.	49388.	2	0	1	1	0	0	0	0	0	0	0	0	EOS /CENTR /B-II /	
35	NU3-328.PIONEER SATURN/U	2050.	-0.	-0.	-0.	50788.	2	2	0	0	0	0	0	0	0	0	0	0	EOS /CENTR /B-II /	
39	NP3-015.EXPLORER-HIGH AL	721.	-0.	-0.	-0.	39988.	2	0	0	1	1	0	1	1	1	0	0	0	EOS /TRANS / /	
43	NE3-338.EARTH OBS SAT -	6678.	500.	500.	98.0	-0.	3	0	0	2	1	2	1	2	1	2	1	2	EOS / / /	0
44	CF3-116.EARTH RESOURCES-	2561.	500.	500.	100.0	-0.	2	0	0	1	1	1	1	1	1	1	1	1	EOS /B-II /B-IIA2/	
47	NF3-340.TIROS N-P	1415.	906.	906.	103.0	-0.	1	0	0	1	0	0	0	0	1	0	0	0	EOS /B-II /B-IIA2/	
48	CE3-040.TIROS OPER SAT	1415.	906.	906.	103.0	-0.	2	0	0	1	1	0	1	0	1	0	1	0	EOS /B-II /B-IIA2/	
49	CF3-360.ENVIRONMENT MONI	1642.	600.	600.	105.0	-0.	1	0	0	1	0	0	1	1	1	1	0	1	EOS /B-II /B-IIA2/	
51	NA3-002.EXPLORER-SYNCH	463.	19323.	19323.	28.5	-0.	1	0	0	0	1	0	1	0	1	0	0	0	EOS /TRANS / /	
52	NF3-397.MAGNETIC MONITOR	524.	800.	800.	28.5	-0.	1	0	1	0	0	0	0	1	0	0	0	1	EOS /B-II /B-IIA2/	
54	NP3-018.ENVIRONMENT PERT	4437.	6900.	6900.	55.0	-0.	1	0	1	0	0	1	0	0	0	0	0	0	EOS /TRANS / /	
56	NA3-001.EXPLORER-LEO	463.	297.	297.	28.5	-0.	4	1	1	1	1	1	1	1	1	1	1	1	MULT / / /	0
57	NA3-215.SOLAR MAX SAT	1580.	350.	350.	26.5	-0.	2	1	0	1	0	1	0	1	0	1	0	1	MULT / / /	0
58	NP3-016.GRAVITY/RELATIVI	1061.	500.	500.	90.0	-0.	1	0	0	0	1	0	0	0	0	0	0	0	EOS / / /	0
60	NF3-392.SMALL APPL TECH	387.	400.	400.	90.0	-0.	1	0	0	1	0	0	1	0	0	1	0	0	EOS / / /	0
62	NF3-045.GEOPAUSE	782.	270.	270.	90.0	-0.	1	0	0	1	0	0	0	0	0	0	0	0	MULT / / /	0
63	NE3-396.MINI-LAGEOS	1554.	350.	350.	26.5	-0.	1	1	0	0	0	0	1	0	0	0	0	0	MULT / / /	0
64	NF3-380.MAGNETOMETER SAT	414.	215.	215.	26.5	-0.	3	0	3	0	0	0	0	3	0	0	0	3	MULT / / /	0
65	NF3-349.SEASAT-B	734.	380.	380.	90.0	-0.	1	0	0	1	0	0	0	0	0	0	0	0	MULT / / /	0
66	NB3-055.BIO-RESEARCH MOD	491.	300.	300.	28.5	-0.	2	2	0	0	0	0	0	0	0	0	0	0	MULT / / /	0
68	NA3-003.HIGH ENERGY AST	19065.	250.	250.	28.5	-0.	1	0	0	1	0	0	0	0	1	0	0	0	EOS / / /	0
69	NA3-004.HEAO-REVISIT	3500.	250.	250.	28.5	-0.	1	0	0	0	1	1	1	0	0	1	1	1	MULT / / /	0
70	NA3-005.LARGE SPACE TELE	21038.	330.	330.	28.5	-0.	2	1	0	0	1	0	0	0	0	1	0	0	EOS / / /	0
71	NA3-006.LST-REVISIT	3500.	330.	330.	28.5	-0.	2	0	1	1	0	1	1	1	1	0	1	1	MULT / / /	0
78	NA3-301.STELLAR AST SORT	45400.	150.	150.	28.5	-0.	4	0	1	1	2	3	4	1	1	2	1	1	EOS / / /	0
80	NA3-304.SOLAR PHYS SORTI	43500.	167.	167.	28.5	-0.	6	1	1	1	3	4	4	2	2	2	2	2	EOS / / /	0
82	NA3-312.SPACE PHYS SORTI	33200.	200.	200.	28.5	-0.	2	0	0	1	1	2	0	2	0	2	0	2	EOS / / /	0
85	NB3-057.LIFE SCI LAB SOR	30300.	200.	200.	28.5	-0.	3	1	1	1	0	0	0	0	0	0	0	0	EOS / / /	0
86	NB3-058.LIFE SCI LAB SOR	41300.	200.	200.	28.5	-0.	1	0	0	0	1	2	2	2	2	4	4	4	EOS / / /	0
87	NF3-044.EARTH OBS SORTIE	24000.	150.	150.	55.0	-0.	2	1	1	0	0	0	0	0	0	0	0	0	EOS / / /	0
88	NF3-344.EARTH OBS SORTIE	24000.	150.	150.	90.0	-0.	2	0	0	1	1	1	1	1	1	1	1	1	EOS / / /	0
89	NF3-306.EARTH OBS SORTIE	19300.	150.	150.	28.5	-0.	4	1	1	1	1	1	1	1	1	1	1	1	EOS / / /	0
90	NF3-307.ECPAP COMP/NAV S	18514.	150.	150.	57.0	-0.	7	1	2	2	2	2	2	2	2	2	2	2	EOS / / /	0
91	CCD-I (SIMULATED)	5.	0.	0.	0.	0.	8	0	0	0	8	0	9	0	0	0	0	0	EOS /TRANS / /	
92	CCD-II (SIMULATED)	10.	0.	0.	0.	0.	8	0	2	0	6	0	5	0	0	0	0	0	EOS /TRANS / /	
93	CCD-III (SIMULATED)	15.	0.	0.	0.	0.	1	0	0	0	1	0	2	0	0	0	0	0	EOS /TRANS / /	
94	CCD-IV (SIMULATED)	25.	0.	0.	0.	0.	1	0	0	0	1	0	2	0	0	0	0	0	EOS /TRANS / /	
95	CCD-V (SIMULATED)	25.	0.	0.	0.	0.	1	0	0	0	1	0	1	0	0	0	0	0	EOS /TRANS / /	
96	CCD-VI (SIMULATED)	2.	0.	0.	0.	0.	2	0	0	0	2	0	4	0	0	0	0	0	EOS / / /	
101	NA3-062.SP PROC SORTIE(7	22850.	150.	150.	28.5	-0.	4	1	1	1	1	1	1	1	1	1	1	1	EOS / / /	0

TABLE 24. VEHICLE ASSIGNMENTS FOR SELECTED FAMILY - OPTION I, CONCLUDED

102	NM3-365.SP PREC SORTIE(7	7650.	160.	160.	28.5	-0.	22	0	3	10	9	10	9	9	9	9	9	9	MULT / / / 0
103	NM3-365.SP PREC SORTIE(7	7650.	160.	160.	28.5	-0.	6	0	1	2	3	2	3	3	3	3	3	3	EOS / / / 0
104	NT3-063.ADV TECH LAB SOR	27380.	200.	200.	57.0	-0.	14	2	4	4	4	4	4	4	4	4	4	4	EOS / / / 0
105	CP3-375.FOR SCI/PHYS SOR	33200.	200.	200.	28.5	-0.	2	0	0	1	1	0	0	1	0	0	1	0	EOS / / / 0
108	CP3-374.FOR SCI/AST SORT	45400.	150.	150.	28.5	-0.	2	0	1	0	1	1	1	1	1	1	1	1	EOS / / / 0
110	NT3-061.LONG DURATION EX	10200.	270.	270.	28.5	-0.	2	1	0	1	0	1	0	1	0	1	0	1	EOS / / / 0
111	NE3-047.SMALL APPL TECH	387.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
112	CC3-051.PROTOTYPE OPER	2917.	19323.	19323.	0.	0.	1	1	0	0	0	0	0	0	0	0	0	0	T IIID/TRANS / / 0
113	CC3-109.FOREIGN COMM SAT	1081.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	0	0	0	0	0	ATLAS /CENTR / / 0
114	CC3-053.DISASTER WARNING	1795.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	0	0	0	0	0	ATLAS /CENTR / / 0
115	CC3-113.TRAFFIC MANAGEME	2042.	19323.	19323.	0.	-0.	2	2	0	0	0	0	0	0	0	0	0	0	T IIID/TRANS / / 0
116	CC3-105.INTELSAT	2346.	19323.	19323.	0.	-0.	3	3	0	0	0	0	0	0	0	0	0	0	T IIID/TRANS / / 0
117	CC3-046.COMM R AND D	3060.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	0	0	0	0	0	T IIID/TRANS / / 0
118	CC3-108.U S DOMESTIC COM	3545.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	0	0	0	0	0	T IIID/CENTR / / 0
119	NU3-324.INNER PLANETARY	897.	-0.	-0.	-0.	38588.	1	1	0	0	0	0	0	0	0	0	0	0	ATLAS /CENTR / / 0
120	NP3-015.EXPLORER-HIGH AL	721.	-0.	-0.	-0.	39988.	1	1	0	0	0	0	0	0	0	0	0	0	ATLAS /CENTR / / 0
121	NE3-038.EARTH OBS SAT -	2448.	500.	500.	98.0	-0.	1	1	0	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
122	NE3-338.EARTH OBS SAT -	6678.	500.	500.	98.0	-0.	1	0	1	0	0	0	0	0	0	0	0	0	T IIIB/AGENA / / 0
123	CE3-116.EARTH RESOURCES-	2561.	500.	500.	100.0	-0.	2	1	1	0	0	0	0	0	0	0	0	0	T IIIB/AGENA / / 0
124	NP3-013.EXPLORER-UPPER A	1241.	1800.	180.	90.0	-0.	1	0	1	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
125	NE3-048.SMALL APPL TECH	387.	3000.	300.	90.0	-0.	1	1	0	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
126	CE3-040.TIROS OPER SAT	1415.	906.	906.	133.0	-0.	1	0	1	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
127	CE3-360.ENVIRONMENT MONI	1642.	600.	600.	105.0	-0.	2	1	1	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
128	NP3-014.EXPLORER-MED ALT	642.	20000.	1000.	90.0	-0.	1	0	1	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
129	NA3-002.EXPLORER-SYNCH	463.	19323.	19323.	28.5	-0.	1	1	0	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
130	NP3-016.GRAVITY/RELATIVI	1061.	500.	500.	90.0	-0.	1	1	0	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
131	NE3-391.SMALL APPL TECH	387.	280.	280.	90.0	-0.	2	0	2	0	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
132	NE3-395.GRAV-GRADIOMETER	6732.	110.	110.	90.0	-0.	1	1	0	0	0	0	0	0	0	0	0	0	T IIIB/AGENA / / 0
133	DOD SCOUT MISSIONS	0.	0.	0.	0.	0.	3	1	0	0	2	0	1	0	0	0	0	0	ALGOL /CASTR2/X-259 /FW-4S 0
134	DOD TAT/DELTA MISSIONS	0.	0.	0.	0.	0.	3	0	2	1	0	0	0	0	0	0	0	0	TAT /DELTA / / 0
135	DOD TITAN IIIB/AGENA MIS	0.	0.	0.	0.	0.	16	4	8	4	0	0	0	0	0	0	0	0	T IIIB/AGENA / / 0
136	DOD ATLAS/CENTAUR MISSIO	0.	0.	0.	0.	0.	8	4	4	0	0	0	0	0	0	0	0	0	ATLAS /CENTR / / 0
137	DOD TITAN IIIC MISSIONS	0.	0.	0.	0.	0.	4	4	0	0	0	0	0	0	0	0	0	0	T IIID/TRANS / / 0

TABLE 25. SHUTTLE-ONLY MULTIPLE LAUNCHES FLIGHT ASSIGNMENTS FOR OPTIONS I AND II

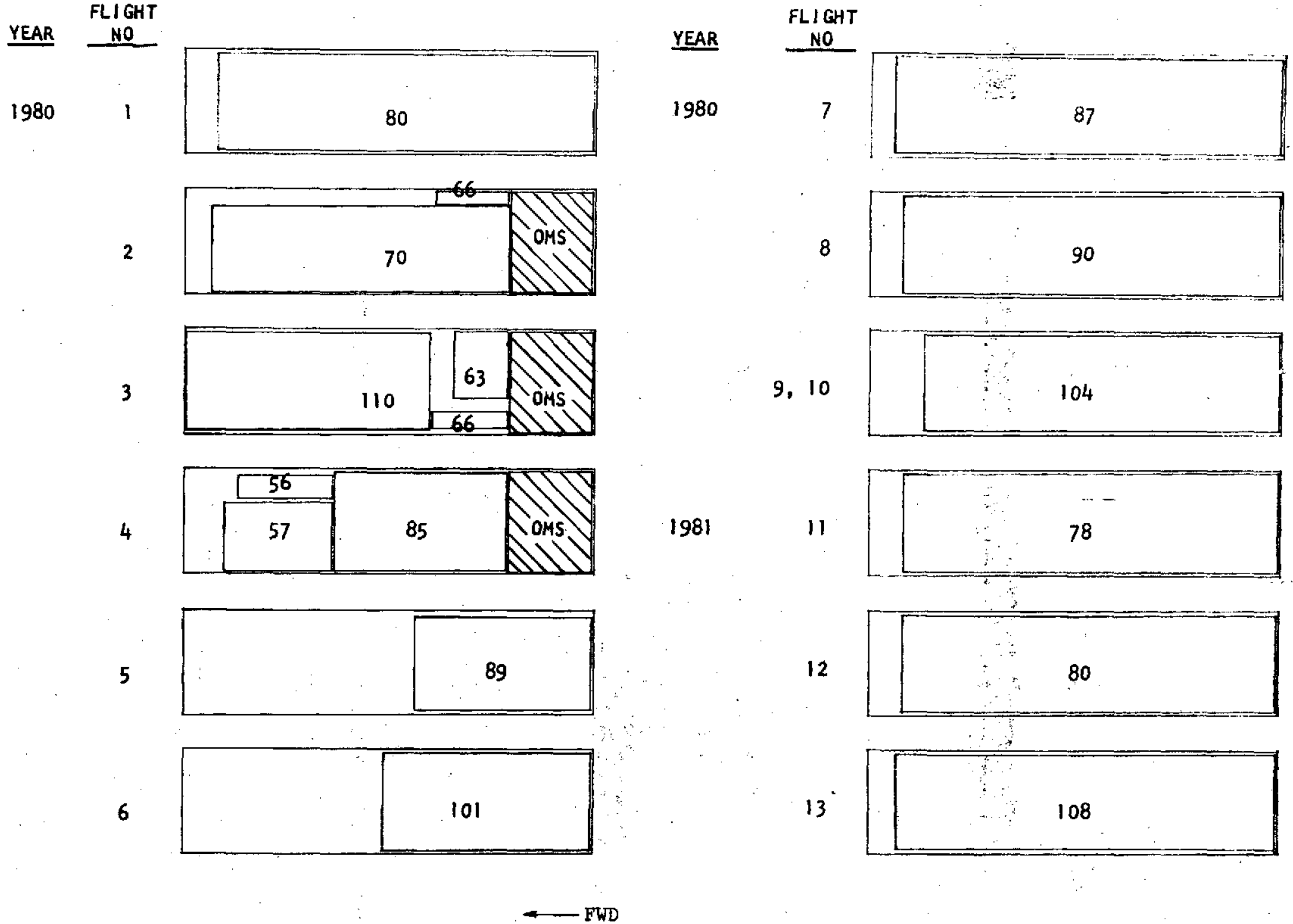


TABLE 25. CONTINUED

YEAR	FLIGHT NO	Layout
1981	14	104
	15	104
	16	104
	17	64, 85, 64, 64
	18	56, 101, OMS
	19	89, 102, 71, OMS
1981	20	87
	21	104
	22, 23	90, 102
	24	102
1982	25	78
	26	80

← FWD

TABLE 25. CONTINUED

YEAR	FLIGHT NO	
1982	27	82
	28	105
	29	56, 68, OMS
	30	57, 85, OMS
	31	101, 71, OMS
	32	102, 89
1982	33-36	104
	37, 38	90, 102
	39	88
	40	102, 65, 62, 60, OMS
	41, 42	43, OMS
	43	110, 02, 102, 102

← FWD

TABLE 25. CONTINUED

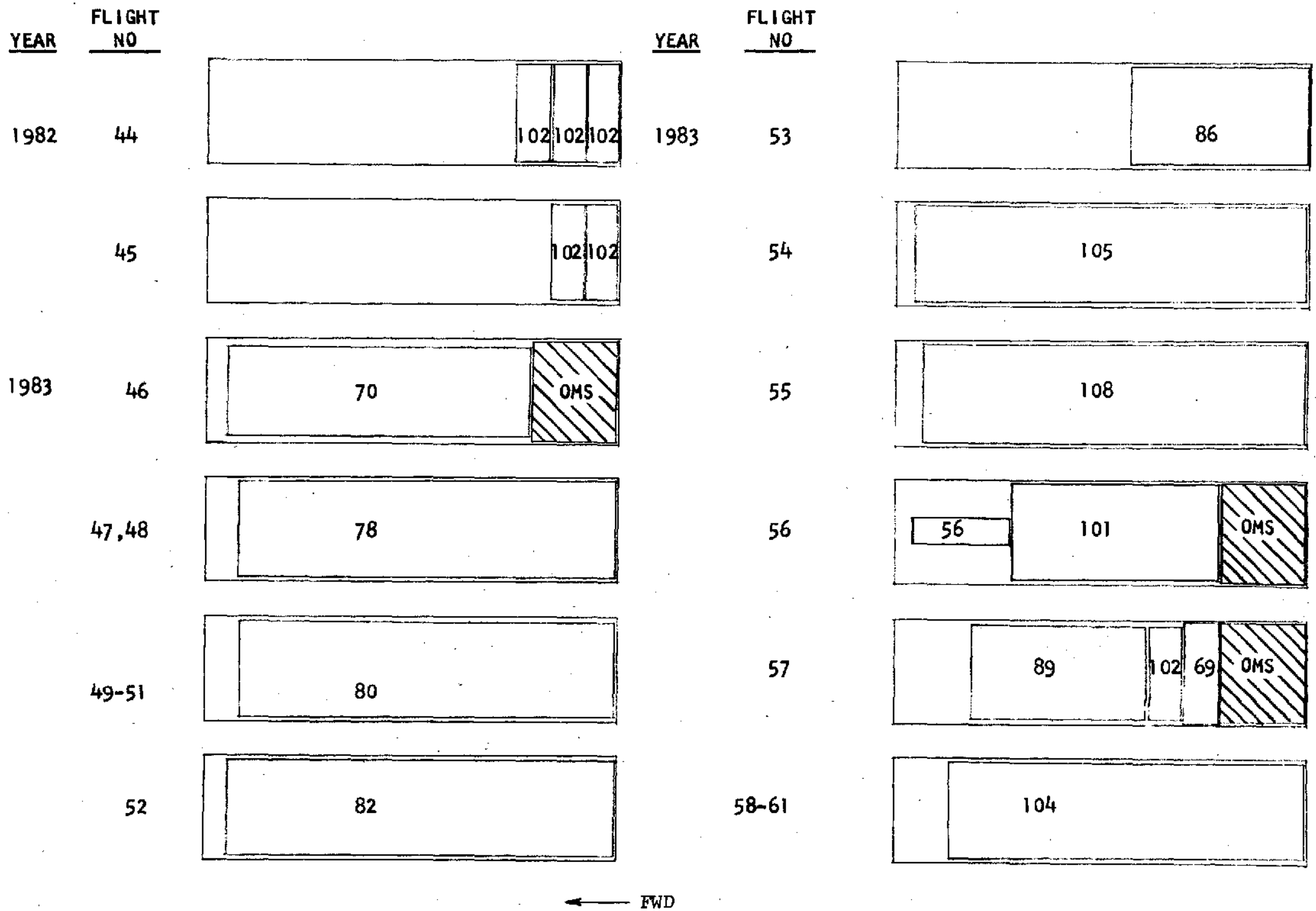


TABLE 25. CONCLUDED

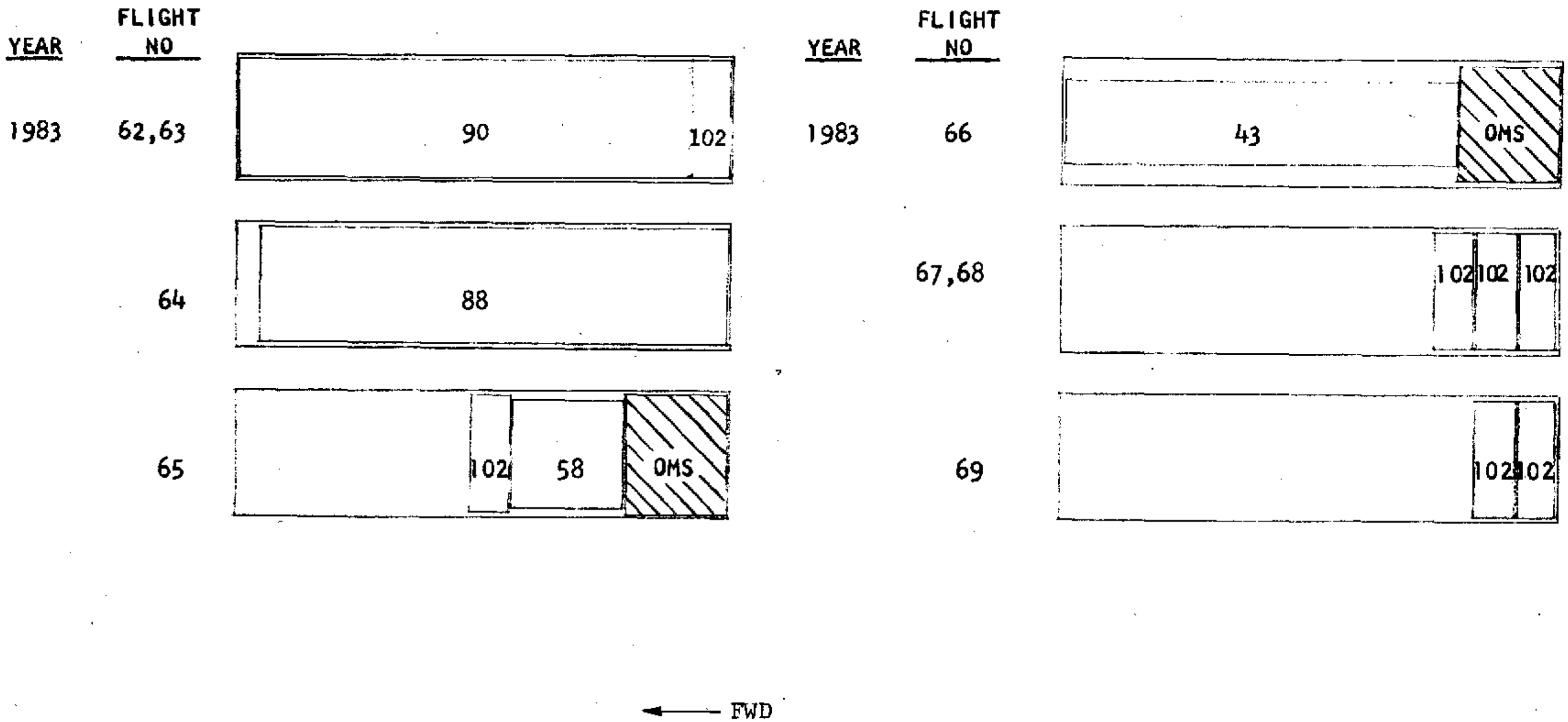


TABLE 26. VEHICLE ASSIGNMENTS FOR SELECTED FAMILY - OPTION II

BEST-MIX OF CCE AND LCE SPACECRAFT FOR CENTAUR W/ TRANSTAGE

NO.	MISSION	WT	H-AP	H-PR	INC	VC	TL	80	81	82	83	84	85	86	87	88	89	90	VEHICLE	
2	NE3-393,SMALL APPL TECH	695.	19323.	19323.	0.	-0.	1	0	0	0	1	0	0	1	0	0	1	0	EOS /TRANS / /	
5	CE3-315,FOREIGN SYNCH ME	2117.	19323.	19323.	0.	-0.	4	0	2	1	1	1	1	1	1	1	1	1	EOS /TRANS / /	
6	CE3-115,SYNCH OPER METEO	2117.	19323.	19323.	0.	-0.	3	0	1	1	1	1	1	0	1	0	1	0	EOS /TRANS / /	
7	CC3-109,FOREIGN COMM SAT	1700.	19323.	19323.	0.	-0.	5	0	2	2	1	2	2	1	2	2	2	2	EOS /TRANS / /	
8	NC3-049,TRACKING AND DAT	3262.	19323.	19323.	0.	-0.	3	0	0	0	3	0	0	0	0	0	0	0	EOS /TRANS / /	
9	CC3-050,DISASTER WARNING	2870.	19323.	19323.	0.	-0.	1	0	1	0	0	0	1	0	0	0	0	1	EOS /TRANS / /	
10	CC3-113,TRAFFIC MANAGEME	3487.	19323.	19323.	0.	-0.	4	0	2	1	1	1	0	1	0	1	0	1	EOS /TRANS / /	
11	CC3-105,INTELSAT	4022.	19323.	19323.	0.	-0.	2	0	0	0	2	3	2	2	0	0	2	3	EOS /TRANS / /	KITS
12	CC3-051,PROTOTYPE OPER	3936.	19323.	19323.	0.	-0.	3	0	1	1	1	0	1	0	1	1	0	1	EOS /TRANS / /	KITS
13	CC3-046,COMM R AND D	5689.	19323.	19323.	0.	-0.	1	0	1	0	0	0	1	1	0	0	0	1	EOS /CENTR / /	
14	CC3-108,U S DOMESTIC COM	3545.	19323.	19323.	0.	-0.	5	0	2	2	1	1	1	2	2	3	2	2	EOS /TRANS / /	
15	NE3-039,SYNCH EARTH OBS	6758.	19323.	19323.	0.	-0.	2	0	1	0	1	0	0	0	0	0	0	0	EOS /CENTR / /	
25	NU3-324,INNER PLANETARY	1631.	-0.	-0.	-0.	38588.	3	0	2	0	1	0	0	1	0	0	0	0	EOS /TRANS / /	
26	NU3-025,VENUS RADAR MAPP	3153.	-0.	-0.	-0.	38588.	2	0	0	0	2	0	0	0	0	0	0	0	EOS /TRANS / /	
30	NU3-035,COMET -X- SLOW F	3222.	-0.	-0.	-0.	47488.	1	1	0	0	0	0	0	0	0	0	0	0	EOS /CENTR / /	
31	NU3-336,ENCKE RENDEZVOUS	3257.	-0.	-0.	-0.	47488.	2	0	0	2	0	0	0	0	0	0	0	0	EOS /CENTR / /	
33	NU3-032,MARINER-JUPITER	2550.	-0.	-0.	-0.	49388.	2	0	1	1	0	0	0	0	0	0	0	0	EOS /CENTR /B-II /	
35	NU3-328,PIONEER SATURN/U	2050.	-0.	-0.	-0.	50788.	2	2	0	0	0	0	0	0	0	0	0	0	EOS /CENTR /B-II /	
39	NP3-015,EXPLORER-HIGH AL	1252.	-0.	-0.	-0.	39988.	2	0	0	1	1	0	1	1	1	0	0	0	EOS /TRANS / /	
43	NE3-338,EARTH OBS SAT -	6678.	500.	500.	98.0	-0.	3	0	0	2	1	2	1	2	1	2	1	2	EOS / / /	0
44	CE3-116,EARTH RESOURCES-	4071.	500.	500.	100.0	-0.	2	0	0	1	1	1	1	1	1	1	1	1	EOS /B-II /B-IIA2/	
47	NE3-340,TIROS N-P	1956.	906.	906.	103.0	-0.	1	0	0	1	0	0	0	0	1	0	0	0	EOS /B-II /B-IIA2/	
48	CE3-040,TIROS OPER SAT	1956.	906.	906.	103.0	-0.	2	0	0	1	1	0	1	0	1	0	1	0	EOS /B-II /B-IIA2/	
49	CE3-360,ENVIRONMENT MONI	2426.	600.	600.	105.0	-0.	1	0	0	1	0	0	1	1	1	1	0	1	EOS /B-II /B-IIA2/	
51	NA3-002,EXPLORER-SYNCH	546.	19323.	19323.	28.5	-0.	1	0	0	0	1	0	1	0	1	0	0	0	EOS /TRANS / /	
52	NE3-357,MAGNETIC MONITOR	1122.	800.	800.	28.5	-0.	1	0	1	0	0	0	0	1	0	0	0	1	EOS /B-II /B-IIA2/	
54	NP3-018,ENVIRONMENT PERT	8335.	6900.	6900.	55.0	-0.	1	0	1	0	0	1	0	0	0	0	0	0	EOS /TRANS / /	
56	NA3-001,EXPLORER-LEO	546.	297.	297.	28.5	-0.	4	1	1	1	1	1	1	1	1	1	1	1	MULT / / /	0
57	NA3-215,SOLAR MAX SAT	4270.	350.	350.	28.5	-0.	2	1	0	1	0	1	0	1	0	1	0	1	MULT / / /	0
58	NP3-016,GRAVITY/RELATIVI	2572.	500.	500.	90.0	-0.	1	0	0	0	1	0	0	0	0	0	0	0	EOS / / /	0
60	NE3-392,SMALL APPL TECH	695.	400.	400.	90.0	-0.	1	0	0	1	0	0	1	0	0	1	0	0	EOS / / /	0
62	NE3-045,GEOPAUSE	782.	270.	270.	90.0	-0.	1	0	0	1	0	0	0	0	0	0	0	0	MULT / / /	0
63	NE3-396,MINI-LAGEOS	1554.	350.	350.	28.5	-0.	1	1	0	0	0	0	1	0	0	0	0	0	MULT / / /	0
64	NE3-380,MAGNETOMETER SAT	414.	215.	215.	28.5	-0.	3	0	3	0	0	0	0	3	0	0	0	3	MULT / / /	0
65	NE3-349,SEASAT-B	734.	380.	380.	90.0	-0.	1	0	0	1	0	0	0	0	0	0	0	0	MULT / / /	0
66	NB3-055,BIO-RESEARCH MOD	491.	300.	300.	28.5	-0.	2	2	0	0	0	0	0	0	0	0	0	0	MULT / / /	0
68	NA3-003,HIGH ENERGY AST	19085.	250.	250.	28.5	-0.	1	0	0	1	0	0	0	0	1	0	0	0	EOS / / /	0
69	NA3-004,HEAO-REVISIT	3500.	250.	250.	28.5	-0.	1	0	0	0	1	1	1	0	0	1	1	1	MULT / / /	0
70	NA3-005,LARGE SPACE TELE	21038.	330.	330.	28.5	-0.	2	1	0	0	1	0	0	0	0	1	0	0	EOS / / /	0
71	NA3-006,LST-REVISIT	3500.	330.	330.	28.5	-0.	2	0	1	1	0	1	1	1	1	0	1	1	MULT / / /	0
78	NA3-301,STELLAR AST SORT	45400.	150.	150.	28.5	-0.	4	0	1	1	2	3	4	1	1	2	1	1	EOS / / /	0
80	NA3-304,SOLAR PHYS SORTI	43500.	167.	167.	28.5	-0.	6	1	1	1	3	4	4	2	2	2	2	2	EOS / / /	0
82	NA3-312,SPACE PHYS SORTI	33200.	200.	200.	28.5	-0.	2	0	0	1	1	2	0	2	0	2	0	2	EOS / / /	0
85	NB3-057,LIFE SCI LAB SOR	30300.	200.	200.	28.5	-0.	3	1	1	1	0	0	0	0	0	0	0	0	EOS / / /	0
86	NB3-058,LIFE SCI LAB SOR	41300.	200.	200.	28.5	-0.	1	0	0	0	1	2	2	2	2	4	4	4	EOS / / /	0
87	NE3-044,EARTH OBS SORTIE	24000.	150.	150.	55.0	-0.	2	1	1	0	0	0	0	0	0	0	0	0	EOS / / /	0
88	NE3-344,EARTH OBS SORTIE	24000.	150.	150.	90.0	-0.	2	0	0	1	1	1	1	1	1	1	1	1	EOS / / /	0
89	NE3-306,EARTH OBS SORTIE	19300.	150.	150.	28.5	-0.	4	1	1	1	1	1	1	1	1	1	1	1	EOS / / /	0
90	NE3-307,EOPAP COMM/NAV S	18514.	150.	150.	57.0	-0.	7	1	2	2	2	2	2	2	2	2	2	2	EOS / / /	0
91	COD-I (SIMULATED)	5.	0.	0.	0.	0.	8	0	0	0	8	0	9	0	0	0	0	0	EOS /TRANS / /	
92	COD-II (SIMULATED)	10.	0.	0.	0.	0.	8	0	2	0	6	0	5	0	0	0	0	0	EOS /TRANS / /	
93	COD-III (SIMULATED)	15.	0.	0.	0.	0.	1	0	0	0	1	0	2	0	0	0	0	0	EOS /TRANS / /	
94	COD-IV (SIMULATED)	25.	0.	0.	0.	0.	1	0	0	0	1	0	2	0	0	0	0	0	EOS /TRANS / /	
95	COD-V (SIMULATED)	25.	0.	0.	0.	0.	1	0	0	0	1	0	1	0	0	0	0	0	EOS /TRANS / /	
96	COD-VI (SIMULATED)	2.	0.	0.	0.	0.	2	0	0	0	2	0	4	0	0	0	0	0	EOS / / /	
101	NM3-062,SP PROC SORTIE(7	22850.	150.	150.	28.5	-0.	4	1	1	1	1	1	1	1	1	1	1	1	EOS / / /	0

TABLE 26. VEHICLE ASSIGNMENTS FOR SELECTED FAMILY - OPTION II, CONCLUDED

2

102	NM3-365,SP PROC SORTIE(7	765C.	160.	160.	28.5	-0.	22	0	3	10	9	10	9	9	9	9	9	9	MULT	/	/	/	0
103	NM3-365,SP PROC SORTIE(7	7650.	160.	160.	28.5	-0.	6	0	1	2	3	2	3	3	3	3	3	3	EOS	/	/	/	0
104	NT3-063,ACV TECH LAB SOR	27380.	200.	200.	57.0	-0.	14	2	4	4	4	4	4	4	4	4	4	4	EOS	/	/	/	0
105	CP3-375,FOR SCI/PHYS SOR	3320C.	200.	200.	28.5	-0.	2	0	0	1	1	C	0	1	0	C	1	0	EOS	/	/	/	0
108	CP3-374,FOR SCI/AST SORT	4540C.	150.	150.	28.5	-0.	2	0	1	C	1	1	1	1	1	1	1	1	EOS	/	/	/	0
110	NT3-061,LONG DURATION EX	1020C.	270.	270.	28.5	-0.	2	1	0	1	0	1	0	1	C	1	0	1	EOS	/	/	/	0
111	NE3-047,SMALL APPL TECH	387.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	C	C	C	0	0	TAT	/DELTA	/	/	0
112	CC3-051,PROTOTYPE OPER	2917.	19323.	19323.	0.	0.	1	1	0	0	0	0	0	C	0	0	0	C	T IIID	/TRANS	/	/	0
113	CC3-1C9,FOREIGN COMM SAT	1C81.	19323.	19323.	0.	-0.	1	1	0	0	0	C	C	C	C	0	0	0	ATLAS	/CENTR	/	/	0
114	CC3-050,CISASTER WARNING	1795.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	0	0	C	0	0	ATLAS	/CENTR	/	/	0
115	CC3-113,TRAFFIC MANAGEME	2042.	19323.	19323.	0.	-0.	2	2	0	C	0	0	0	C	C	C	0	0	T IIID	/TRANS	/	/	0
116	CC3-105,INTELSAT	2346.	19323.	19323.	0.	-0.	3	3	0	0	0	C	C	C	C	C	0	C	T IIID	/TRANS	/	/	0
117	CC3-046,COMM R AND D	3060.	19323.	19323.	0.	-0.	1	1	0	0	0	0	0	C	0	C	0	C	T IIID	/TRANS	/	/	0
118	CC3-10B,U S DOMESTIC COM	3545.	19323.	19323.	0.	-0.	1	1	0	C	0	0	0	C	C	C	0	0	T IIID	/CENTR	/	/	0
119	NU3-324,INNER PLANETARY	897.	-0.	-0.	-0.	38588.	1	1	0	0	0	0	0	C	C	C	0	0	ATLAS	/CENTR	/	/	0
120	NP3-015,EXPLORER-HIGH AL	721.	-C.	-0.	-0.	39988.	1	1	0	0	0	0	0	C	C	0	0	0	ATLAS	/CENTR	/	/	0
121	NE3-038,EARTH OBS SAT -	2448.	500.	500.	98.0	-0.	1	1	0	C	0	C	0	C	C	C	0	0	TAT	/DELTA	/	/	0
122	NE3-338,EARTH OBS SAT -	6678.	500.	500.	98.0	-0.	1	0	1	C	0	C	0	C	C	C	0	0	T IIIB	/AGENA	/	/	0
123	CE3-116,EARTH RESOURCES-	2561.	500.	500.	100.0	-0.	2	1	1	0	0	0	0	C	C	0	0	0	T IIIB	/AGENA	/	/	0
124	NP3-013,EXPLORER-UPPER A	1241.	1800.	180.	90.0	-0.	1	0	1	C	0	C	0	0	C	C	0	0	TAT	/DELTA	/	/	0
125	NE3-048,SMALL APPL TECH	387.	3000.	300.	90.0	-0.	1	1	0	C	0	C	0	C	0	C	0	0	TAT	/DELTA	/	/	0
126	CE3-040,TIROS OPER SAT	1415.	906.	906.	103.0	-0.	1	0	1	C	0	0	0	C	C	0	0	0	TAT	/DELTA	/	/	0
127	CE3-360,ENVIRONMENT MONI	1642.	600.	600.	105.0	-0.	2	1	1	C	0	C	0	C	C	C	0	0	TAT	/DELTA	/	/	0
128	NP3-014,EXPLORER-MED ALT	642.	20000.	1000.	90.0	-0.	1	0	1	C	0	C	0	C	0	C	0	0	TAT	/DELTA	/	/	0
129	NA3-002,EXPLORER-SYNCH	463.	19323.	19323.	28.5	-0.	1	1	0	C	0	C	0	0	C	0	0	0	TAT	/DELTA	/	/	0
130	NP3-016,GRAVITY/RELATIVI	1061.	500.	500.	90.0	-0.	1	1	0	C	0	0	0	C	0	C	0	0	TAT	/DELTA	/	/	0
131	NE3-391,SMALL APPL TECH	387.	280.	280.	90.0	-0.	2	0	2	C	0	C	0	C	0	C	0	0	TAT	/DELTA	/	/	0
132	NE3-395,GRAV-GRADIOMETER	6732.	110.	110.	90.0	-0.	1	1	0	0	0	C	0	C	C	C	0	C	T IIIB	/AGENA	/	/	0
133	COD SCOUT MISSIONS	0.	0.	0.	0.	0.	3	1	0	0	2	C	1	C	0	C	0	C	ALGOL	/CASTR2	/X-259	/FH-4S	0
134	COD TAT/DELTA MISSIONS	0.	0.	0.	0.	0.	3	0	2	1	0	C	0	C	C	0	0	0	TAT	/DELTA	/	/	0
135	COD TITAN IIIB/AGENA MIS	0.	0.	0.	0.	0.	16	4	8	4	0	C	0	C	0	C	0	C	T IIIB	/AGENA	/	/	0
136	COD ATLAS/CENTAUR MISSIO	C.	0.	0.	0.	0.	8	4	4	C	0	C	0	C	0	C	0	0	ATLAS	/CENTR	/	/	0
137	COD TITAN IIIC MISSIONS	C.	0.	0.	0.	0.	4	4	0	0	0	0	0	C	C	C	0	0	T IIID	/TRANS	/	/	0

TABLE 27. SHUTTLE CARGO BAY MANIFEST FOR SELECTED FAMILY, OPTION III.

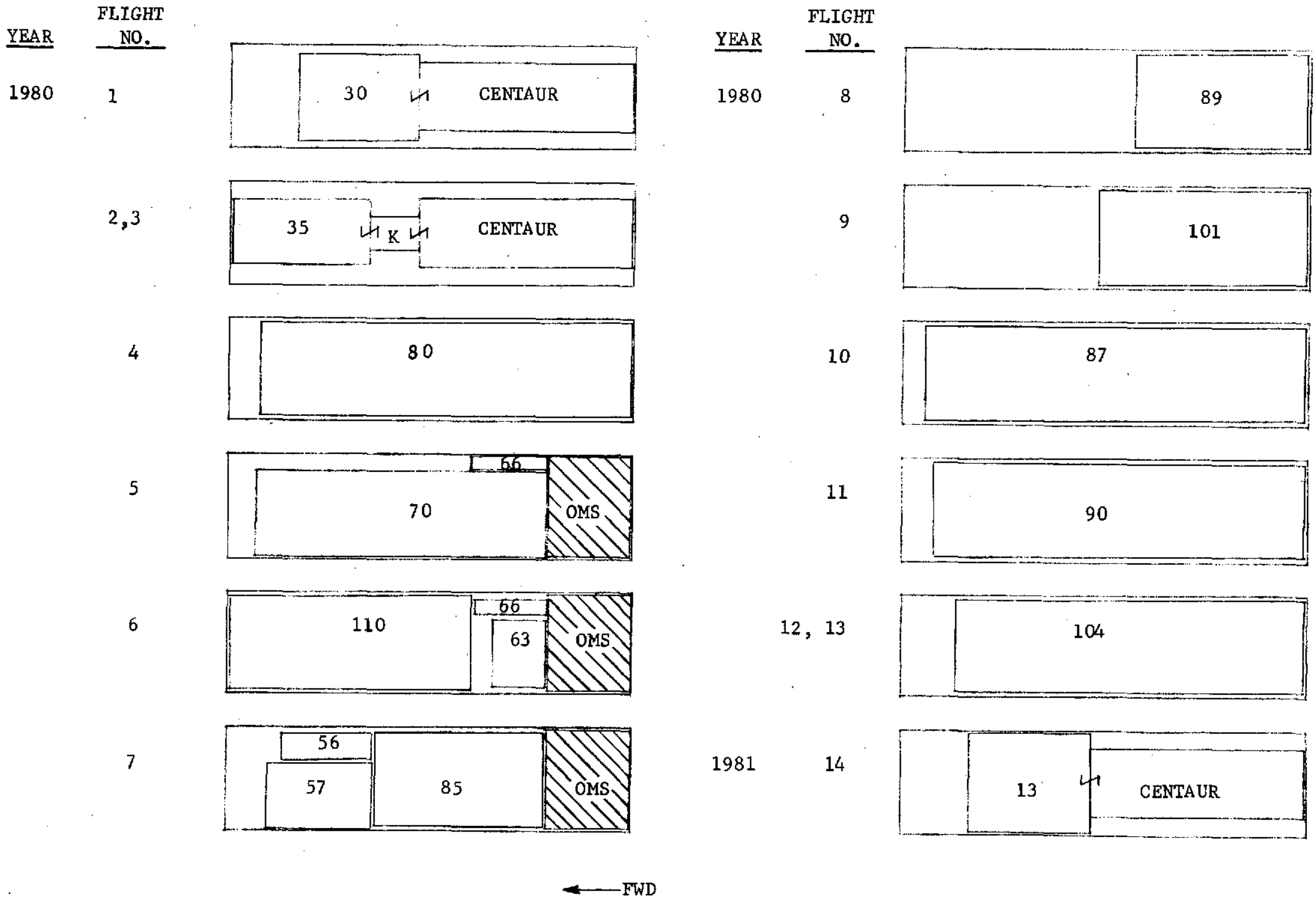
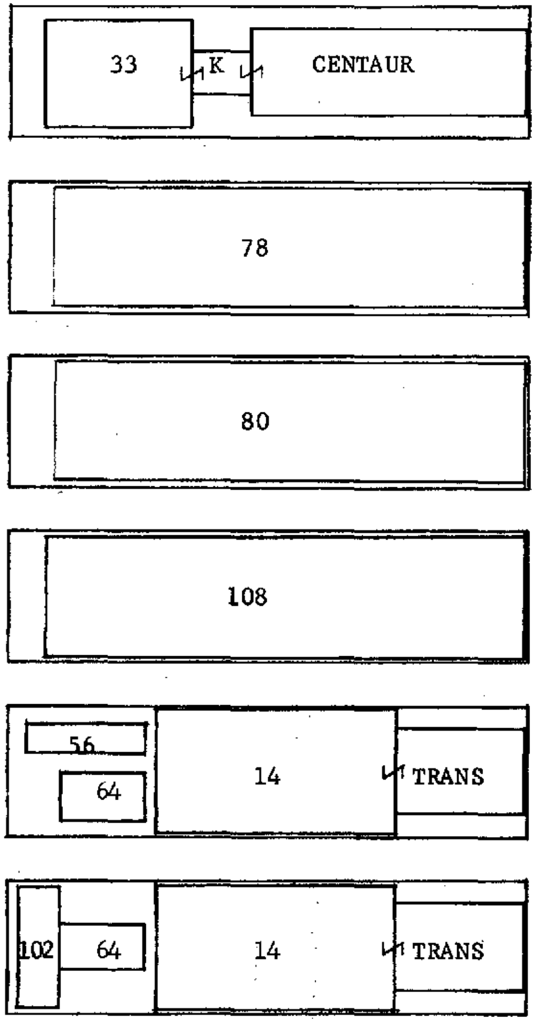
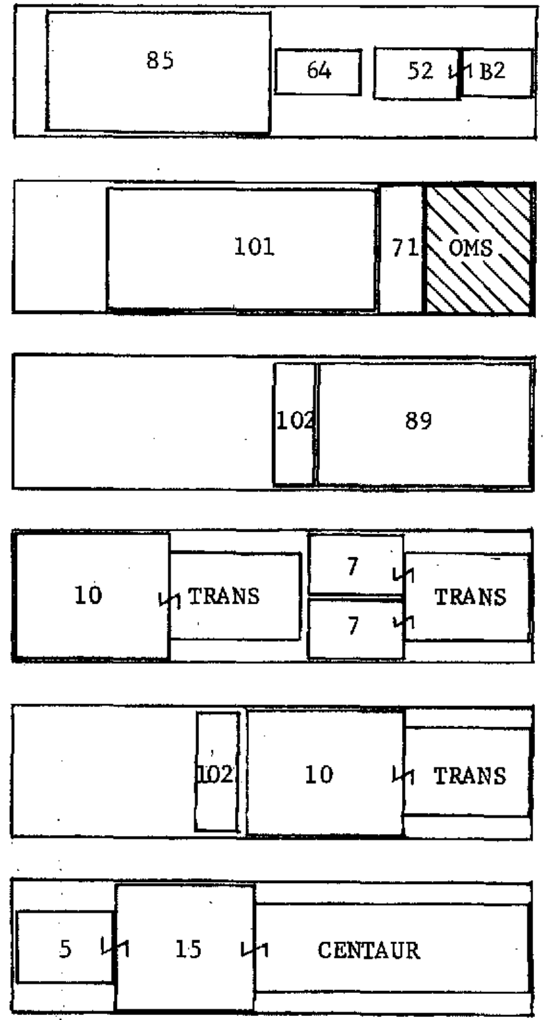


TABLE 27. CONTINUED

YEAR	FLIGHT NO.
1981	15
	16
	17
	18
	19
	20



YEAR	FLIGHT NO.
1981	21
	22
	23
	24
	25
	26



← FWD

TABLE 27. CONTINUED

YEAR	FLIGHT NO.	
1981	27	102 / 25 / TRANS
	28	25 / TRANS / 6 / TRANS
	29	5 / 9 / K / TRANS / OMS
	30	12 / TRANS / OMS
	31	54 / TRANS
	32	87
1981	33-34	90
	35-38	104
1982	39, 40	31 / CENTAUR
	41	33 / K / CENTAUR
	42	78
	43	80

← FWD

TABLE 27. CONTINUED

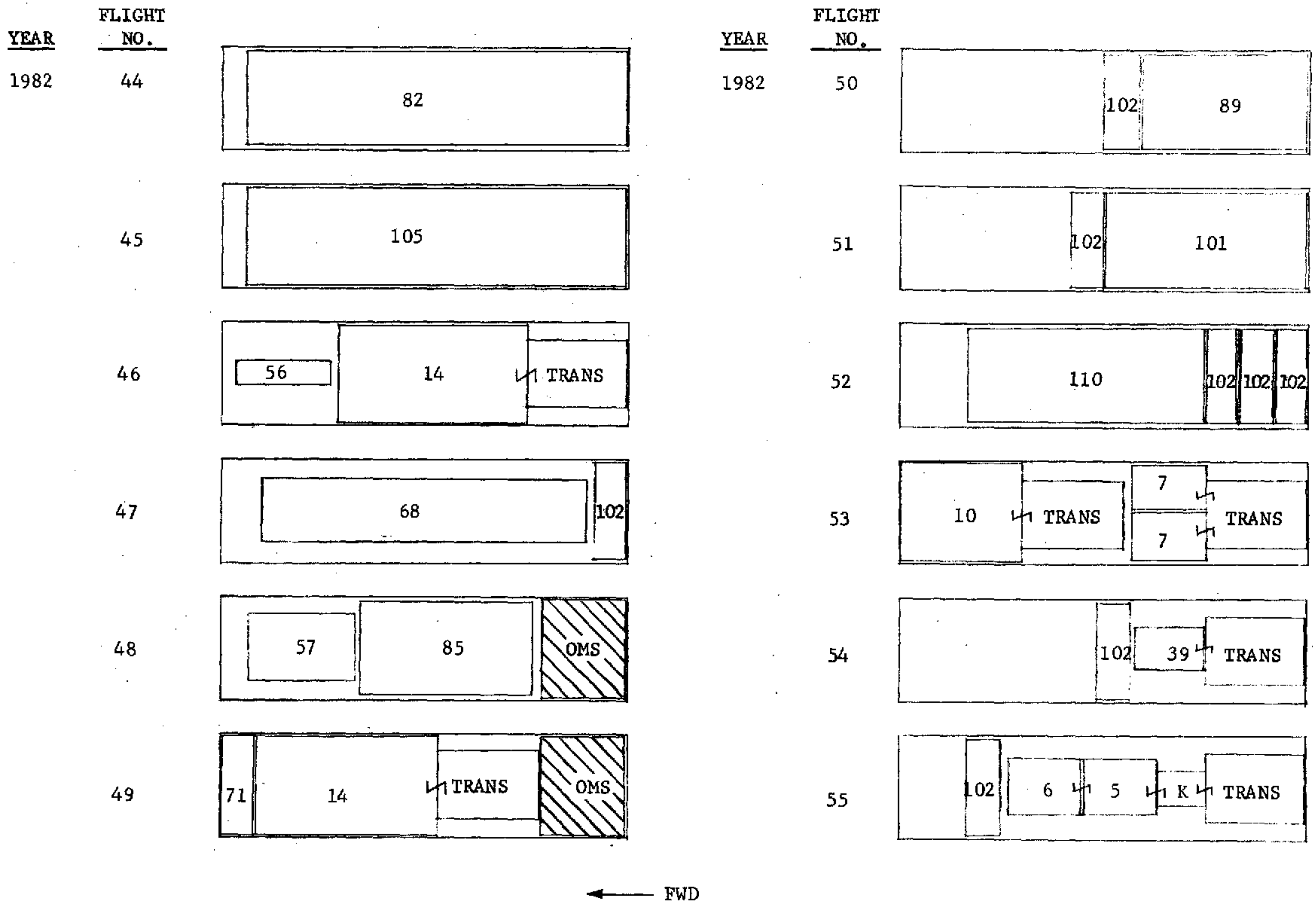


TABLE 27. CONTINUED

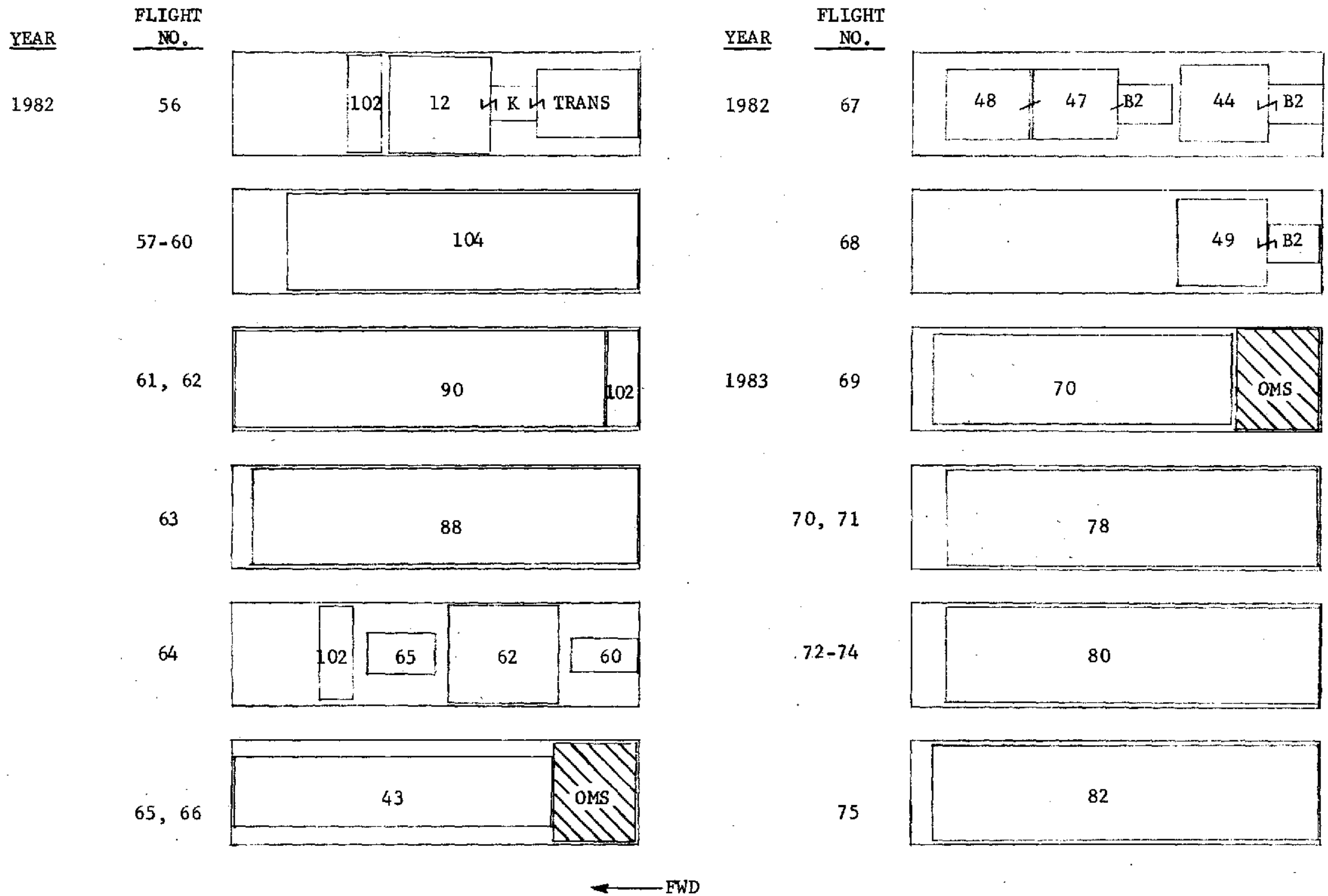


TABLE 27. CONTINUED

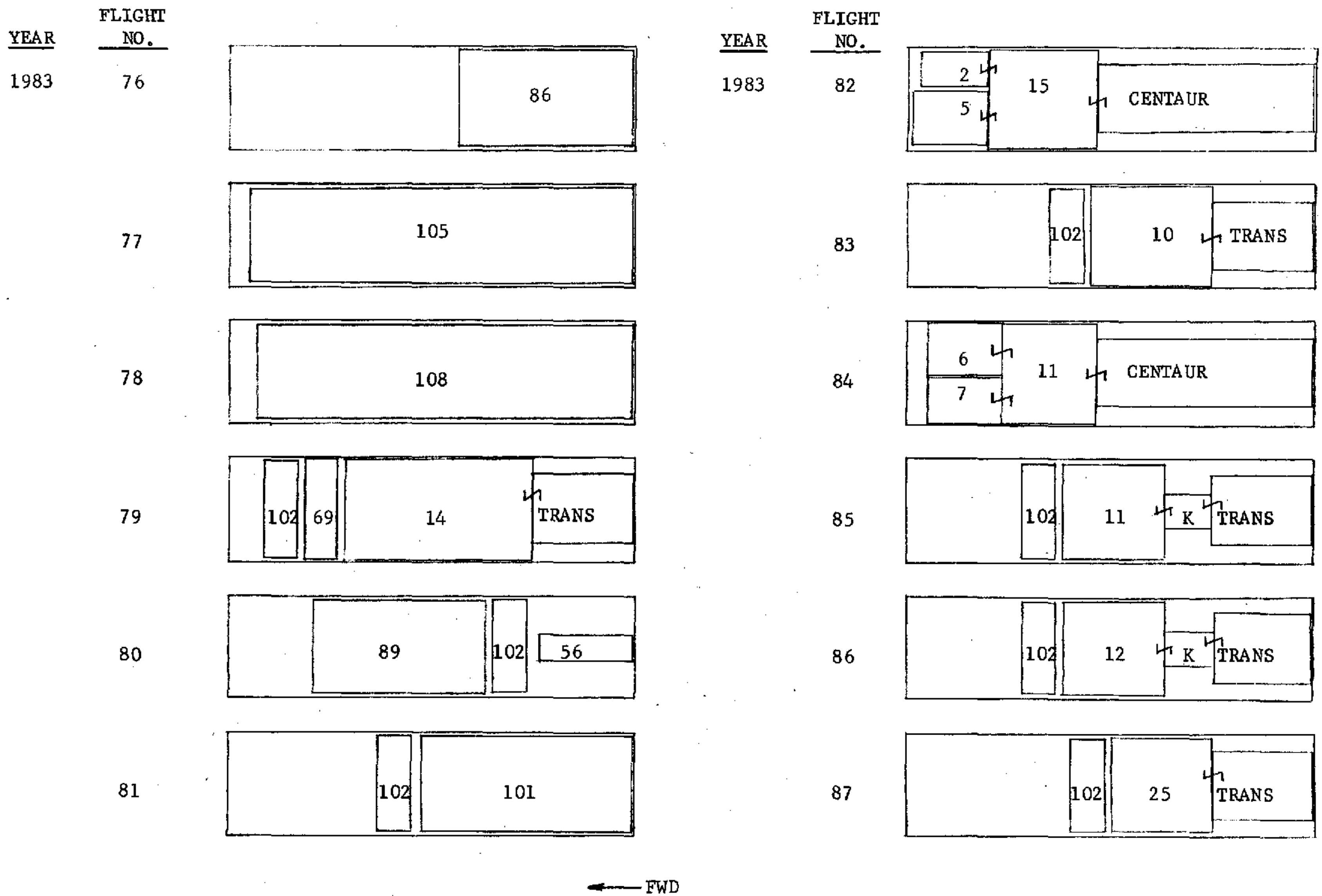
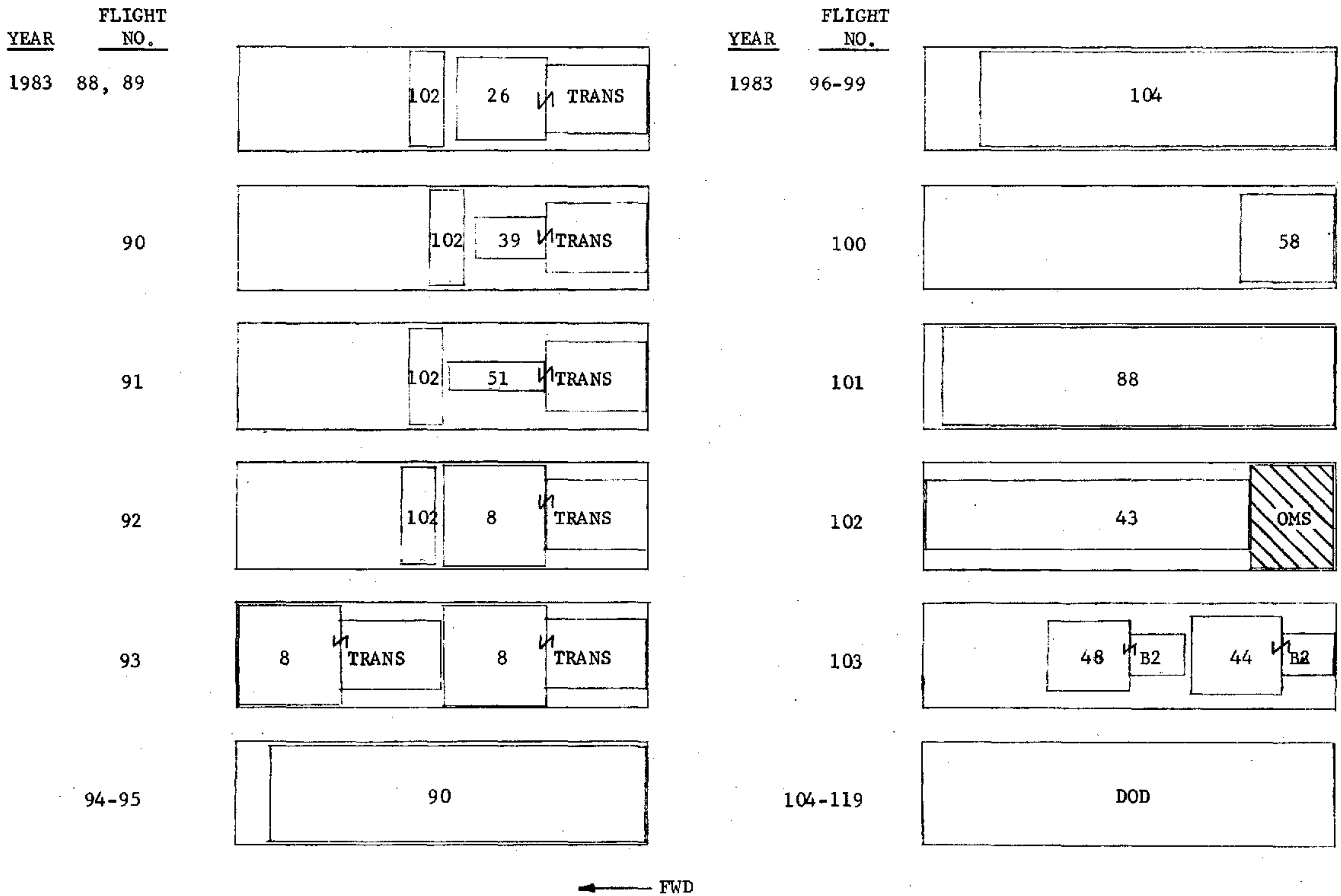


TABLE 27. CONCLUDED



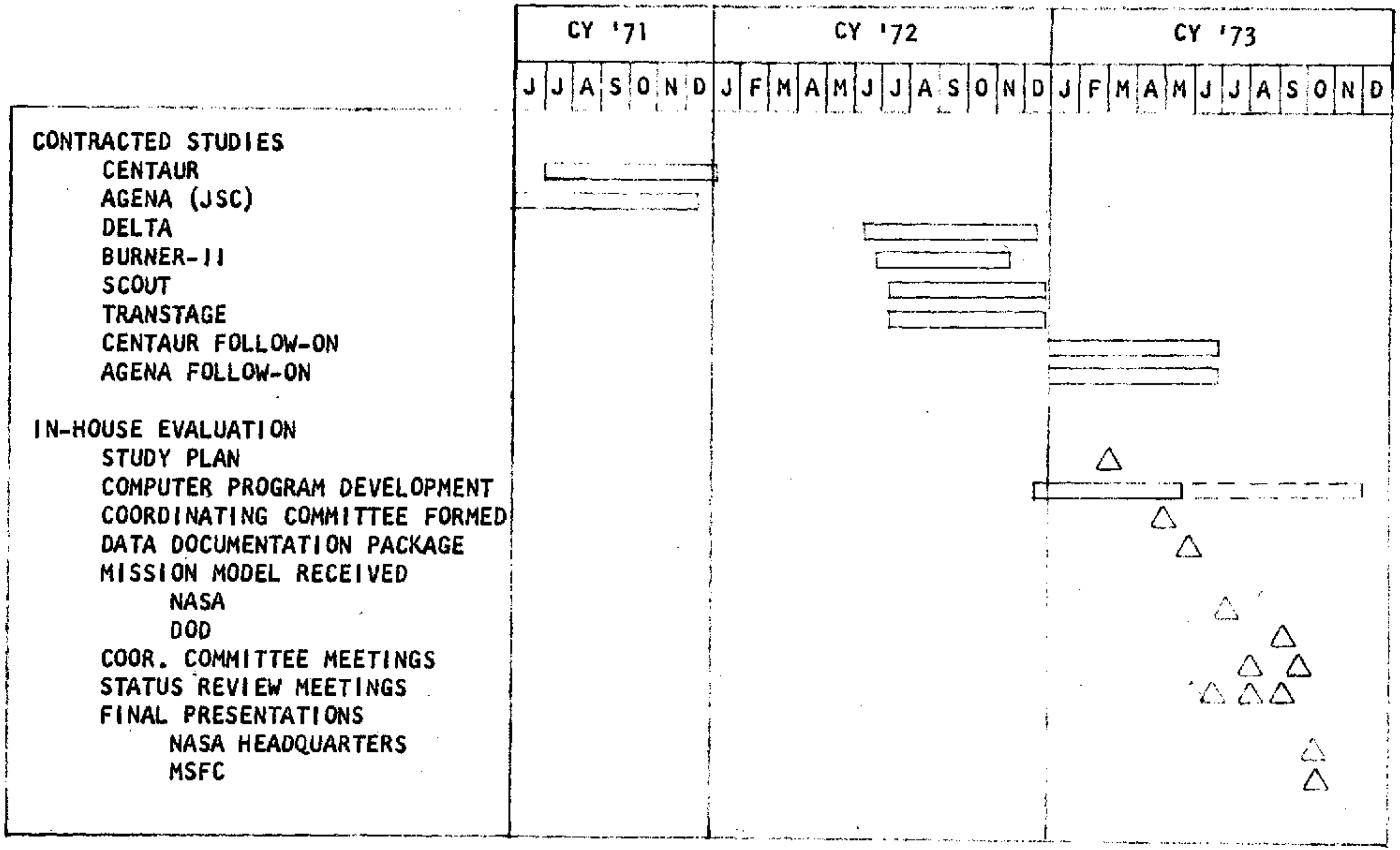


Figure 1. - Schedule of evaluation activity

COORDINATING COMMITTEE MEMBERS

LeRC	-	R. J. Lubick, Chairman
OSS	-	B. C. Lam
OMSF	-	M. Kitchens
OA	-	C. Catoe
OAST	-	P. Wetzel
GSFC	-	P. Eaton
JSC	-	H. Davis
KSC	-	W. Brosier
LaRC	-	A. Leiss
MSFC	-	R. Davies (J. Brewer)
SAMSO	-	Capt. T. May

Figure 2. - Coordinating Committee members

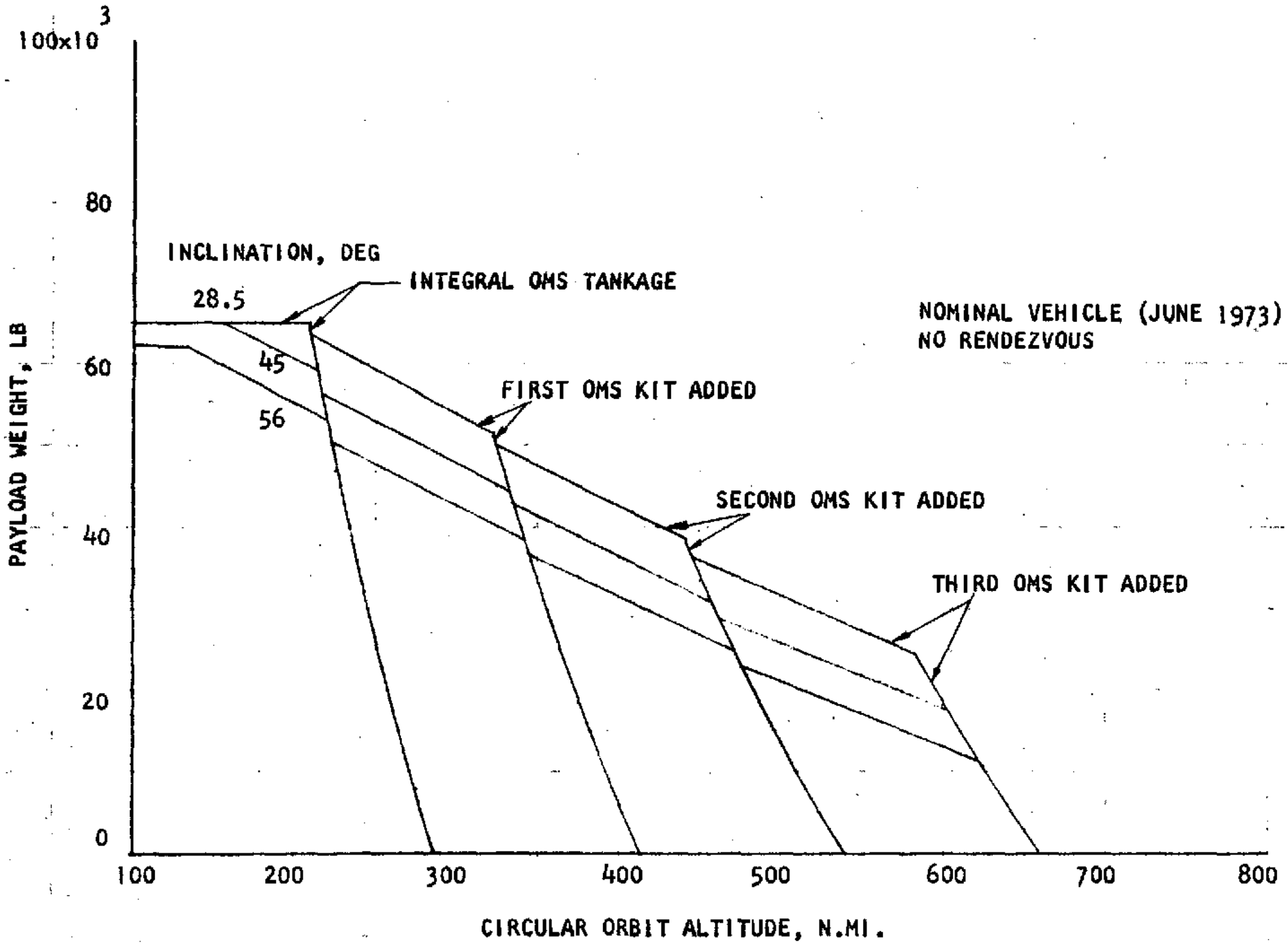


Figure 3. - Shuttle payload weight vs. circular orbit altitude for ETR launch and delivery only.

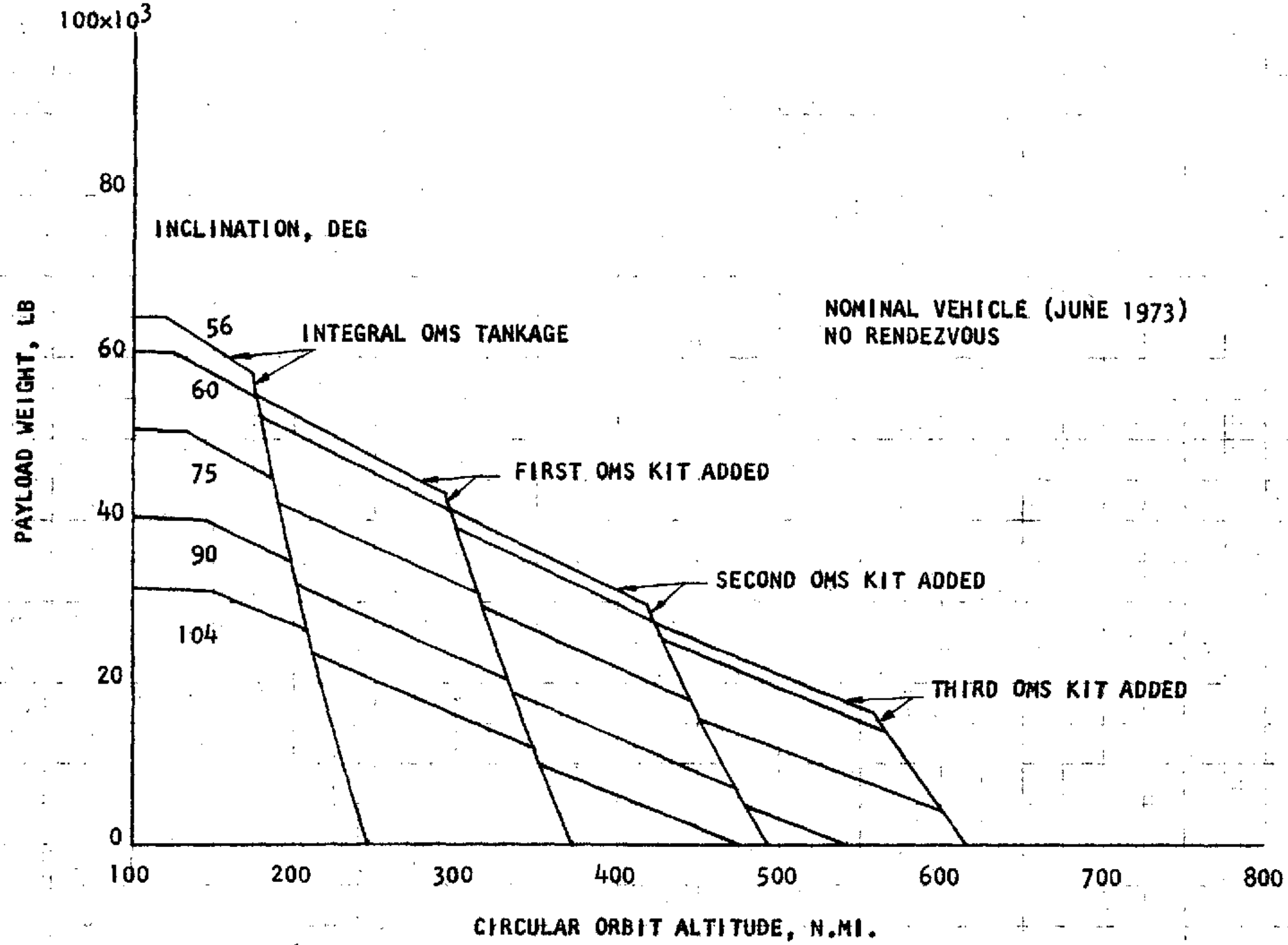


Figure 4. - Shuttle payload weight vs. circular orbit altitude for WTR launch and delivery only

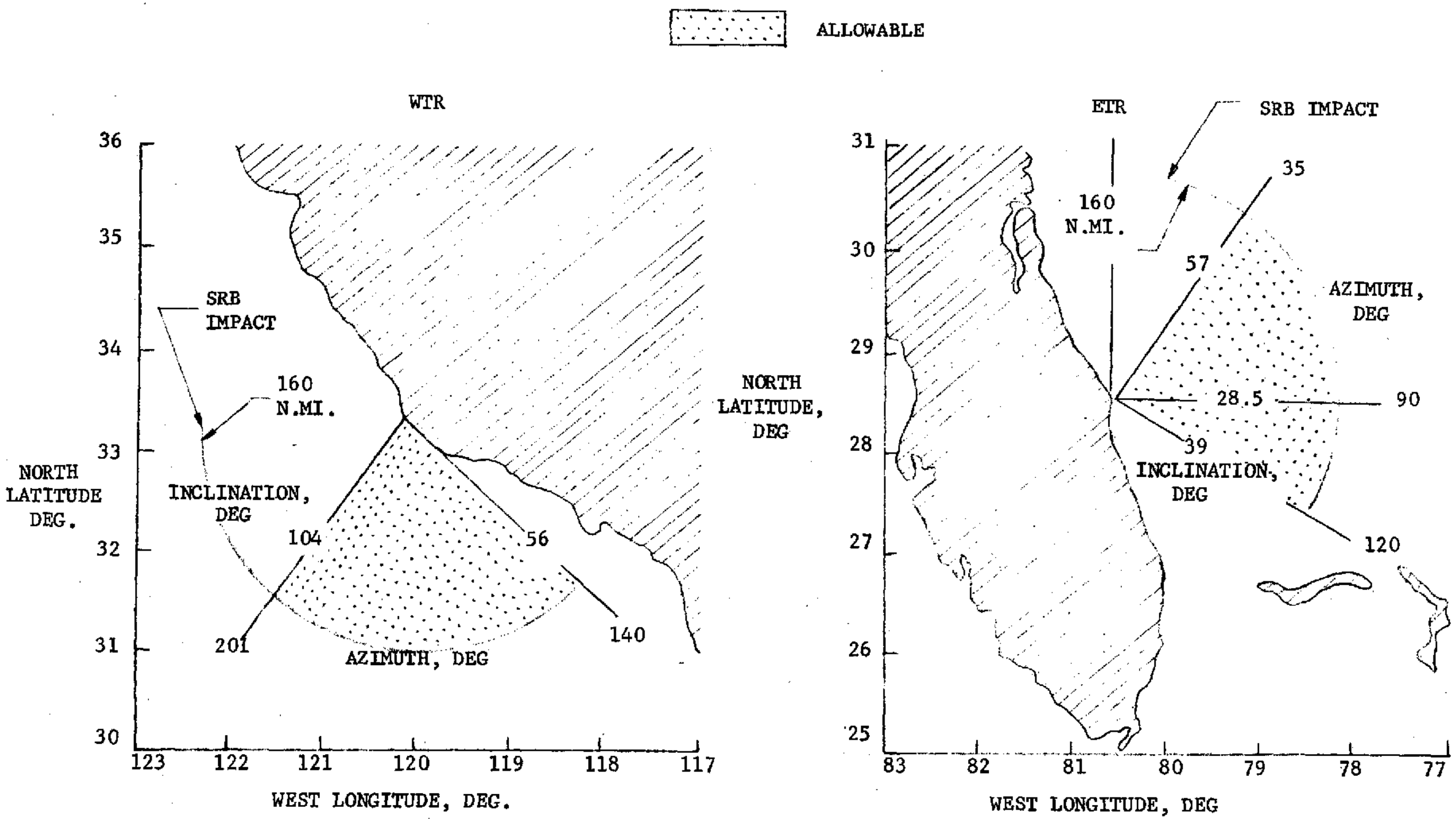


Figure 5-Launch azimuth and inclination limits from WTR and ETR

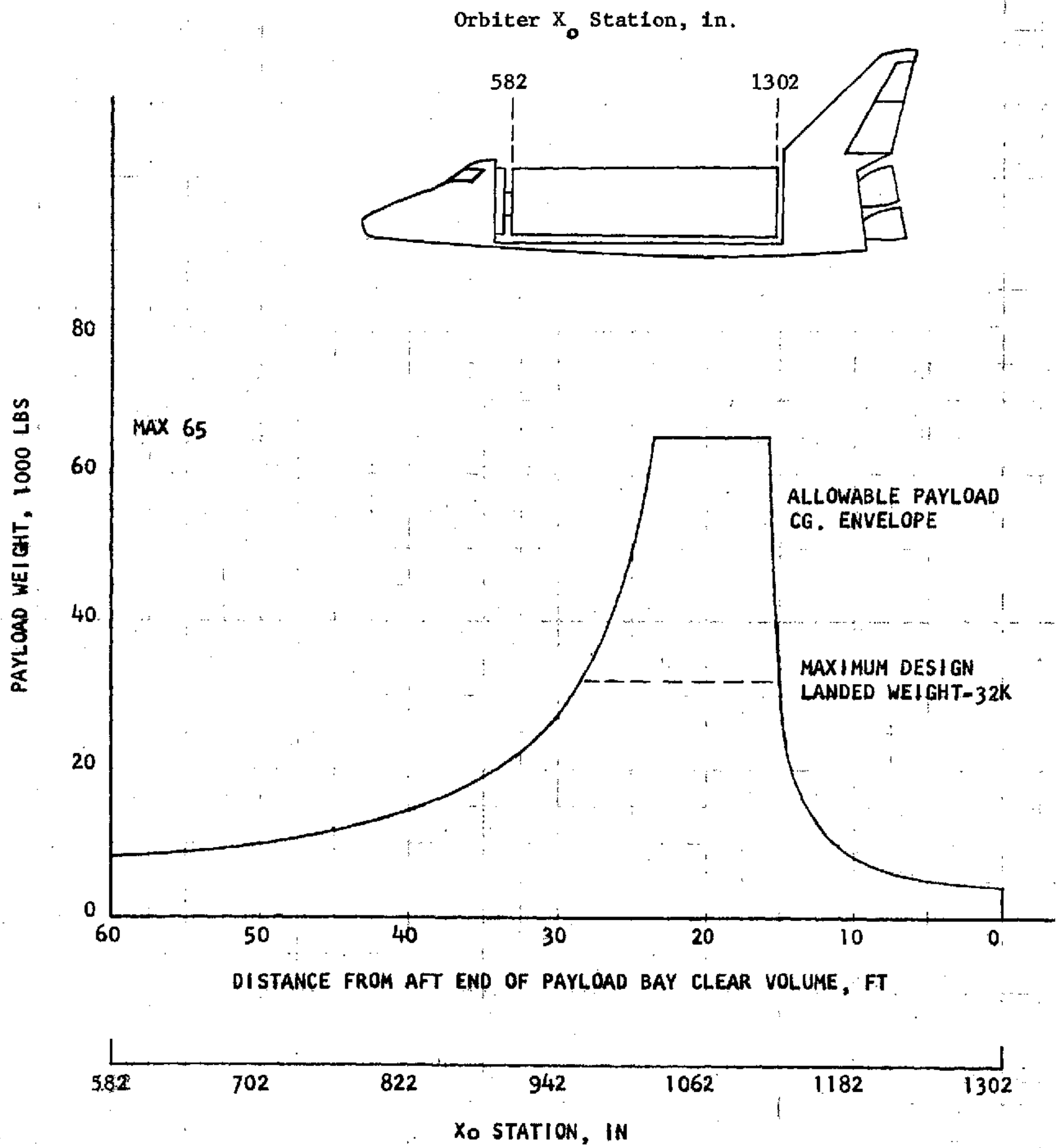


Figure 6. - Payload longitudinal cg envelope (design specification)

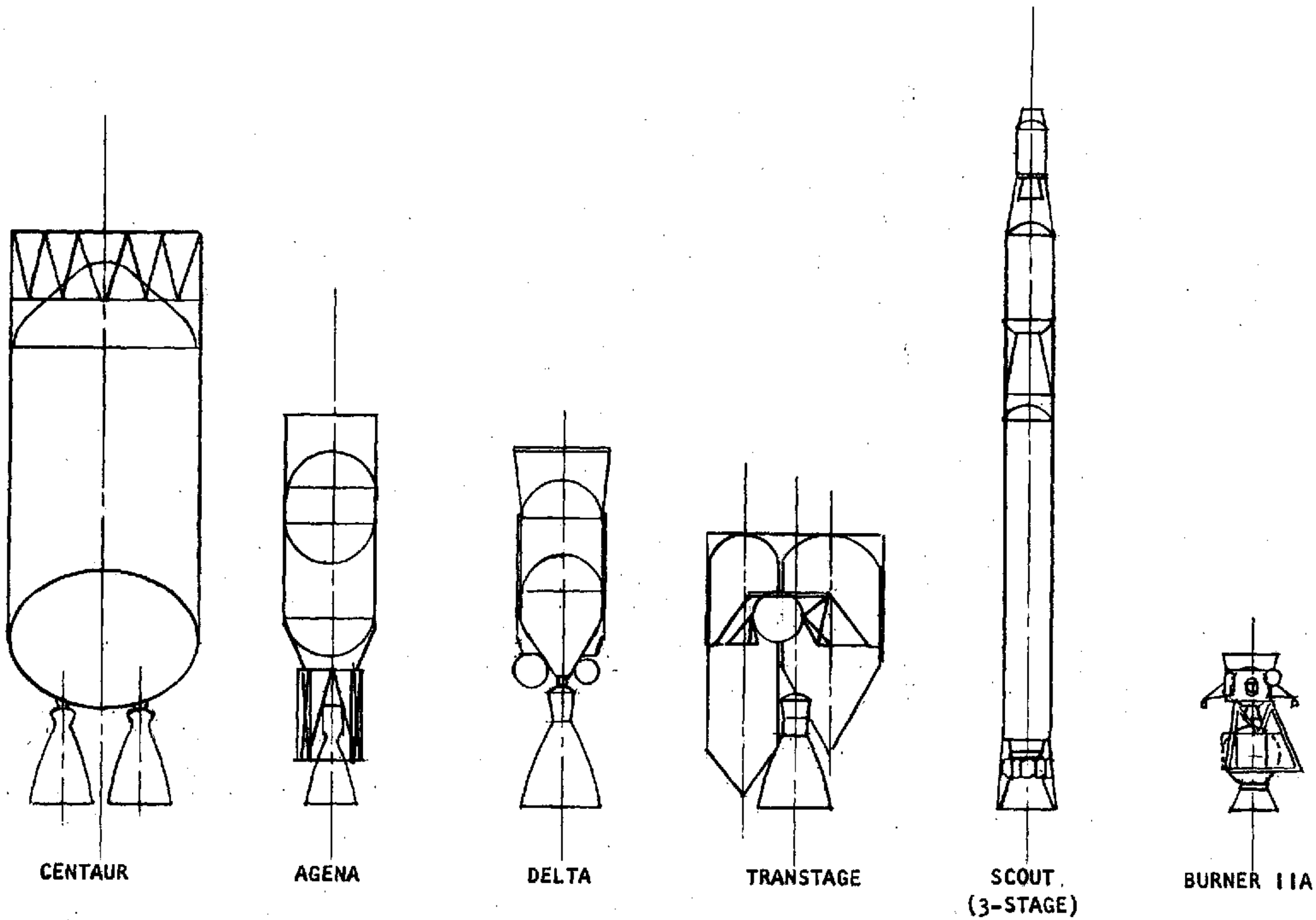


Figure 7. - Baseline expendable shuttle upper stage configurations

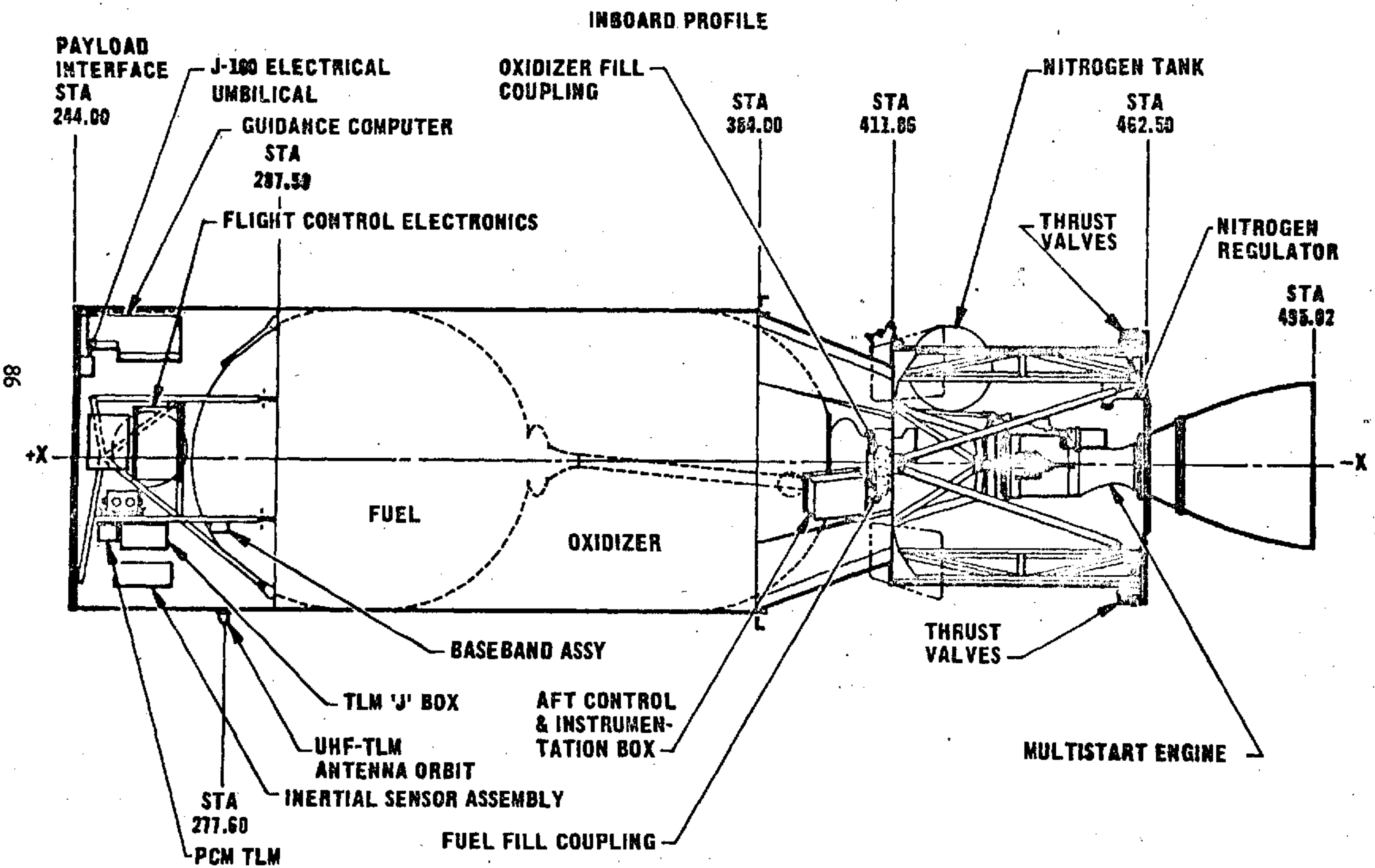


Figure 8. - Shuttle-compatible Agena baseline stage

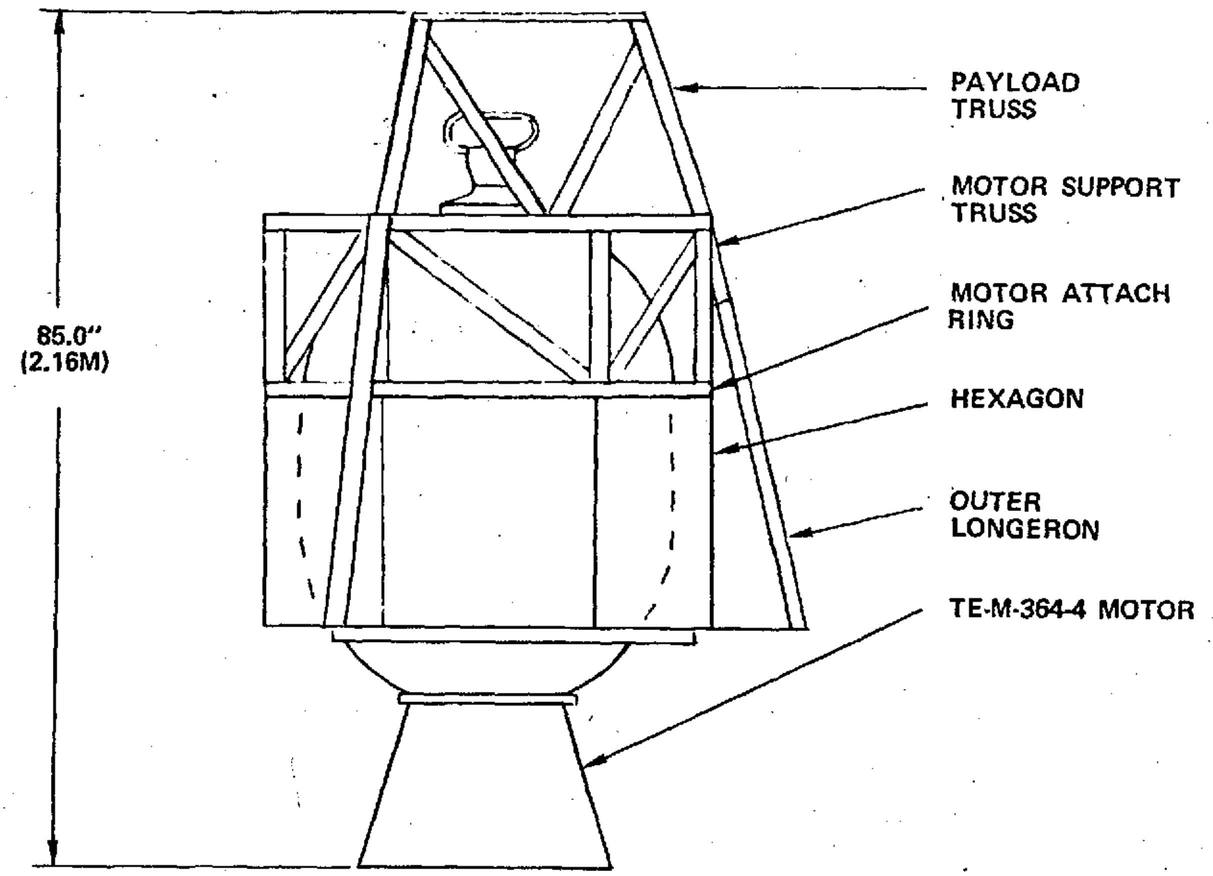


Figure 9. - Burner II (kick stage)(TE-M-364-4 motor)

LENGTH = 100 IN.

DIAMETER = 67 IN.

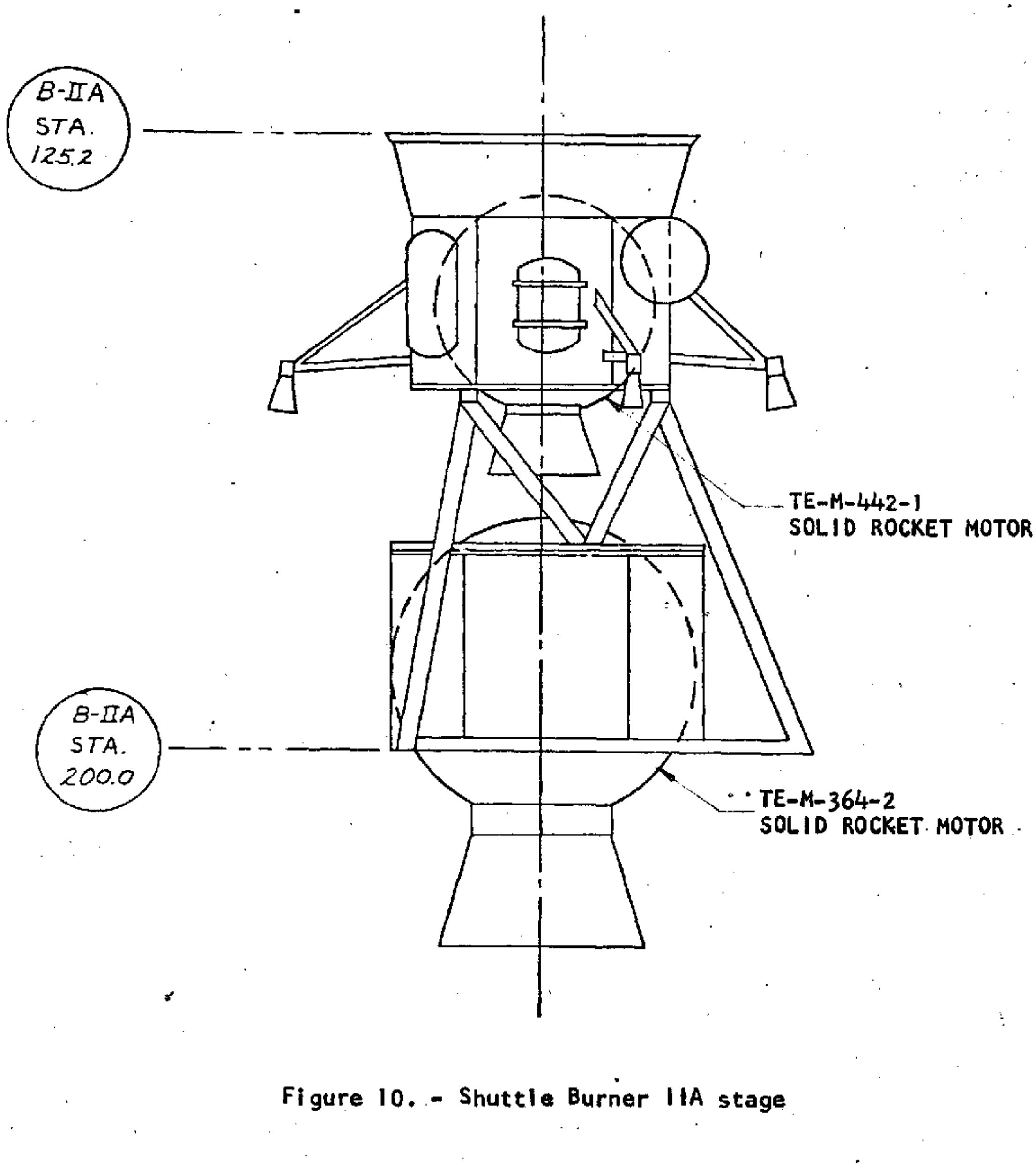


Figure 10. - Shuttle Burner IIA stage

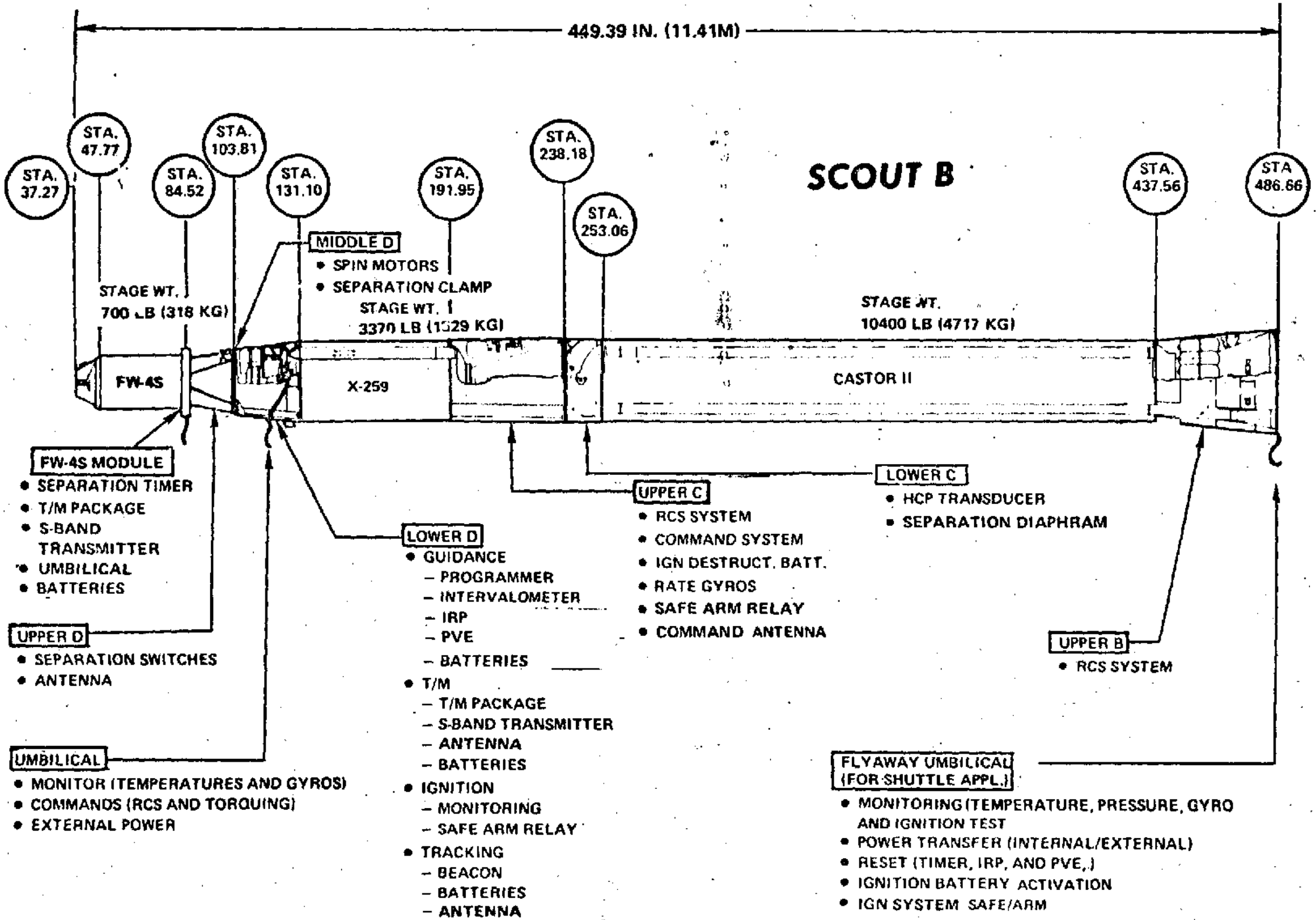


Figure 11. - Upper three stages of Scout B launch vehicle

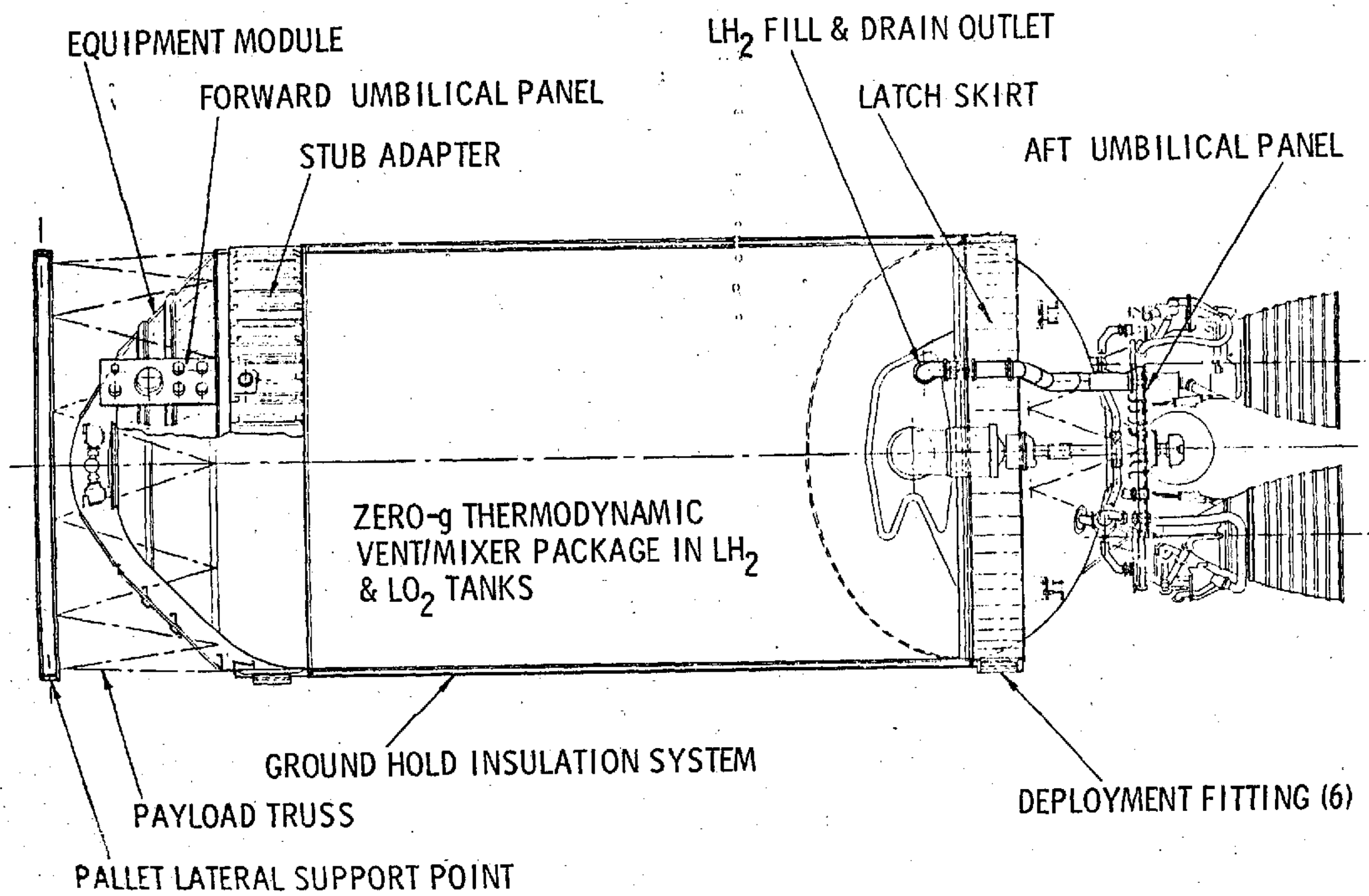
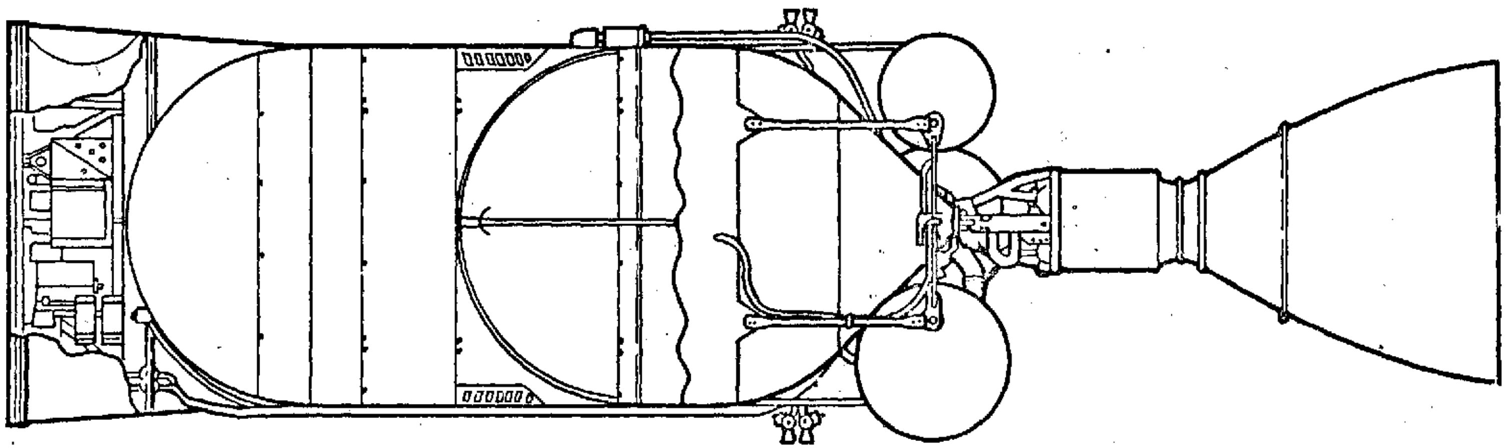


Figure 12. Centaur D-1S vehicle configuration



- ENGINE - LM DESCENT (PRESSURE FED)
- PROPELLANTS - N_2O_4/AEROZINE-50
- THRUST - 9,850 LB
- I_{SP} - 304 SECONDS
- PROPELLANT WT - 10,120 LB
- MULTIPLE RESTART
- GUIDANCE - DELTA INERTIAL GUIDANCE SYSTEM
- DRY WGT - 1,667 LB

Figure 13. - Delta baseline stage

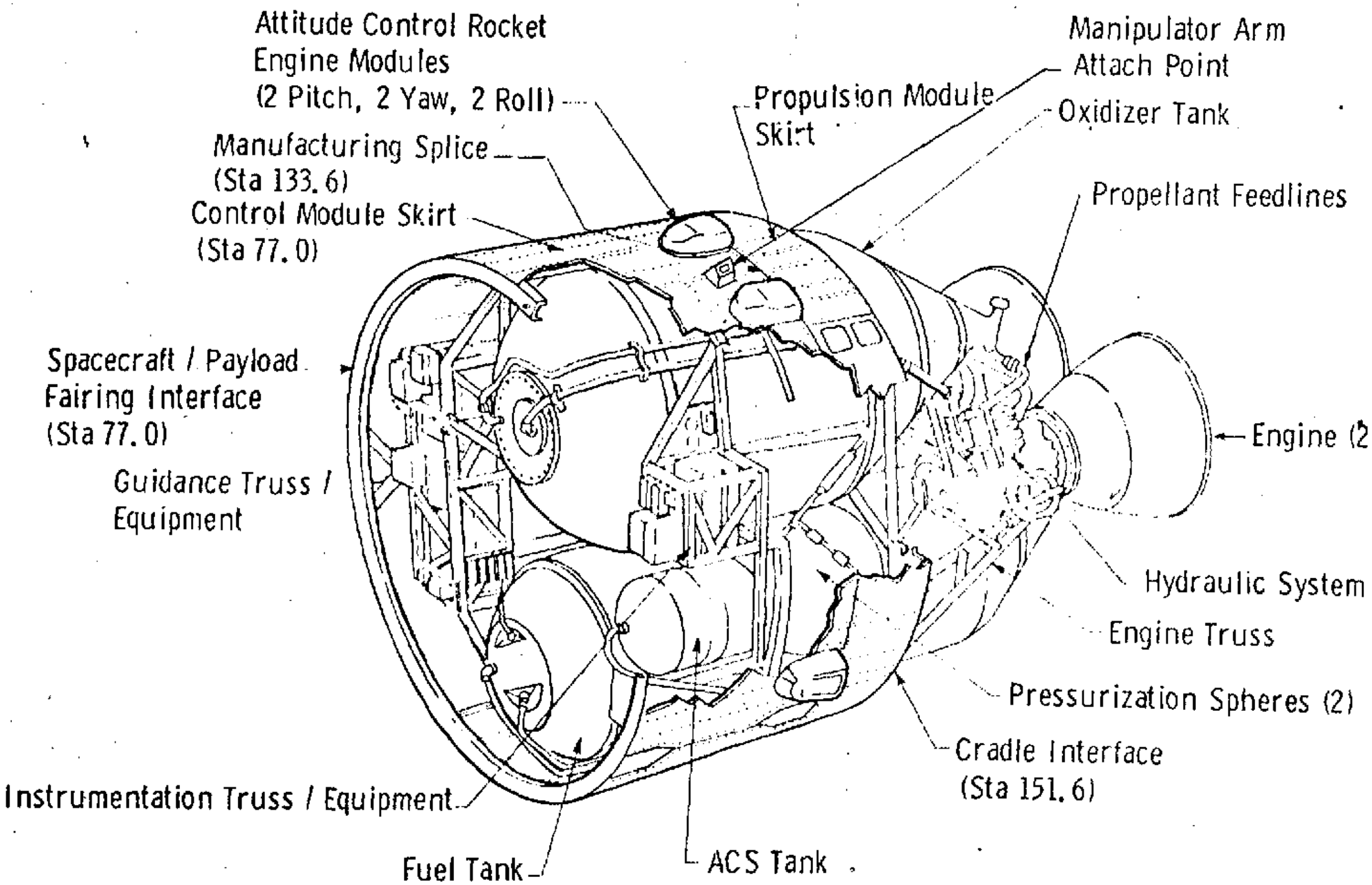


Figure 14. - Transtage Pictorial

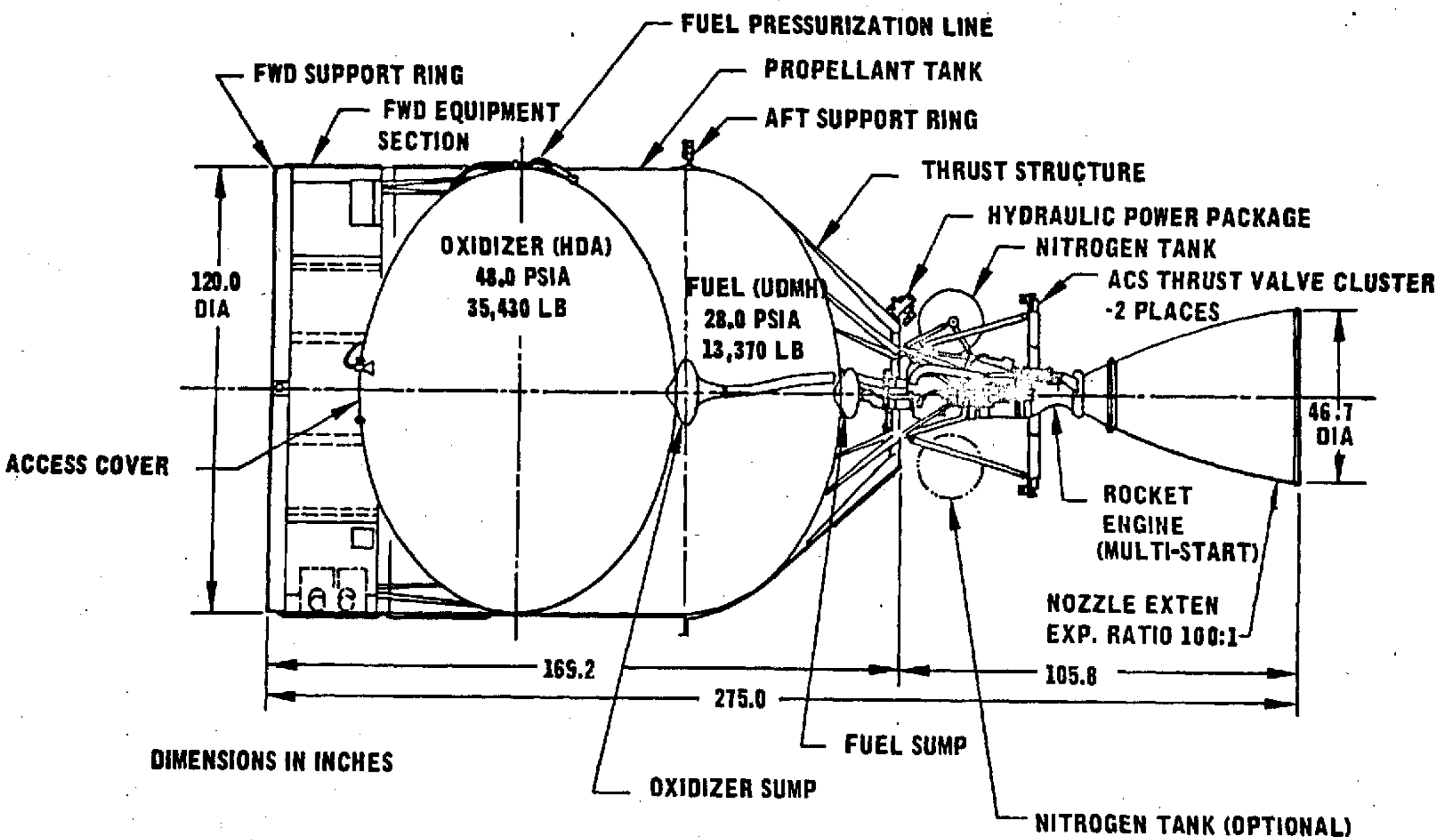


Figure 15. Large Tank Agena Configuration

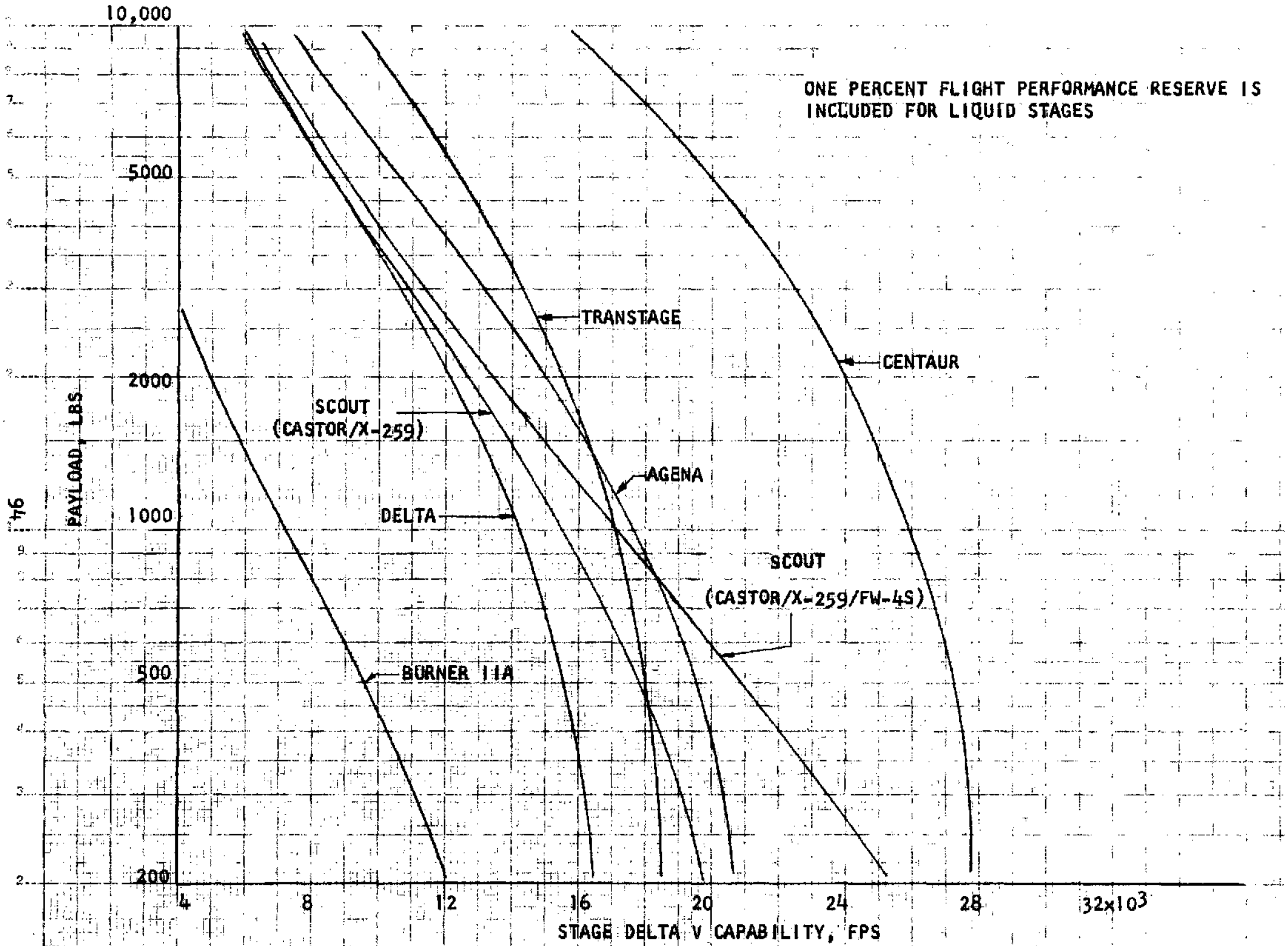


Figure 16. - Baseline expendable upper stage performance

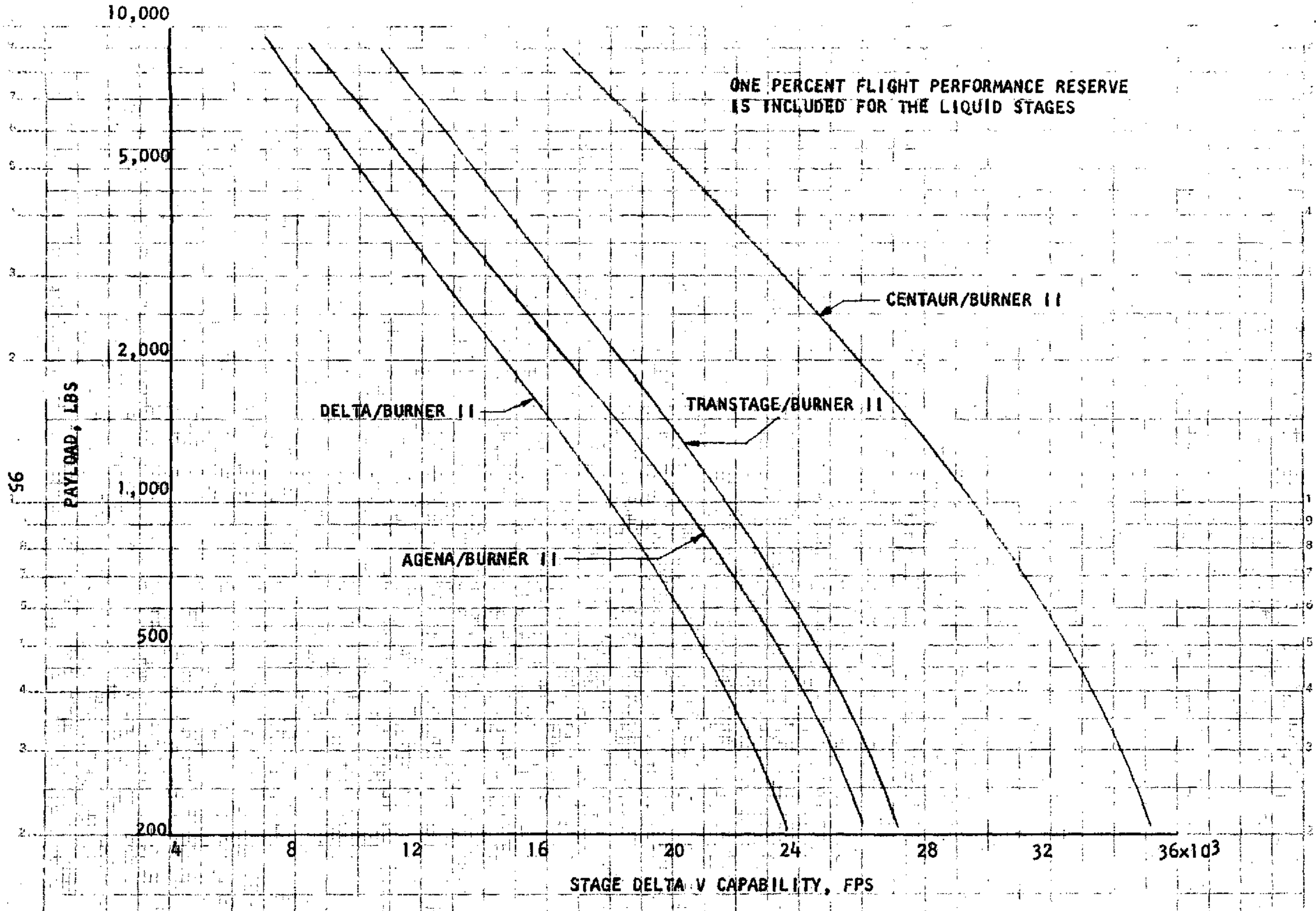


Figure 17. - Baseline expendable upper stage performance with BII kickstage

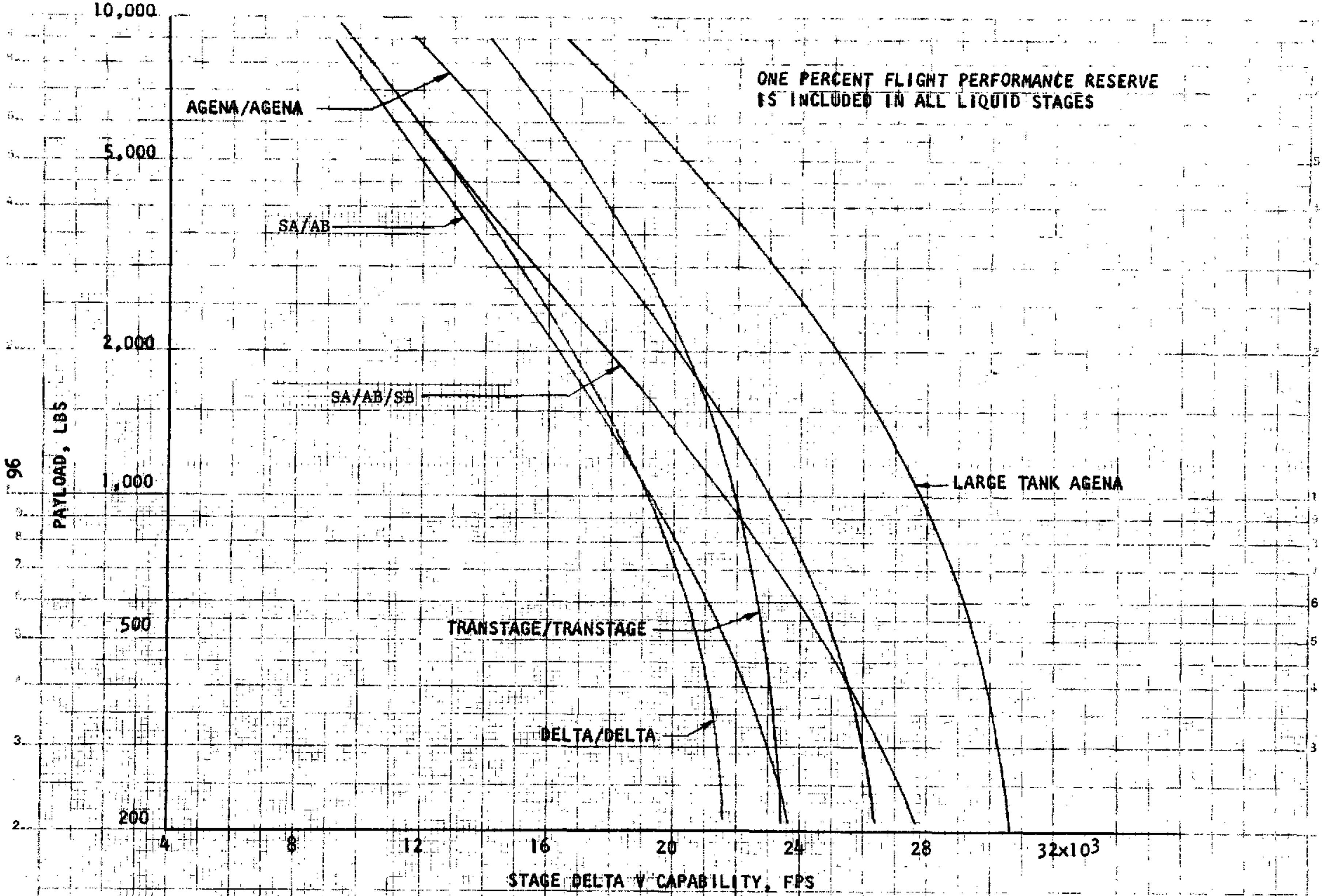


Figure 18. - Non-baseline expendable upper stage performance

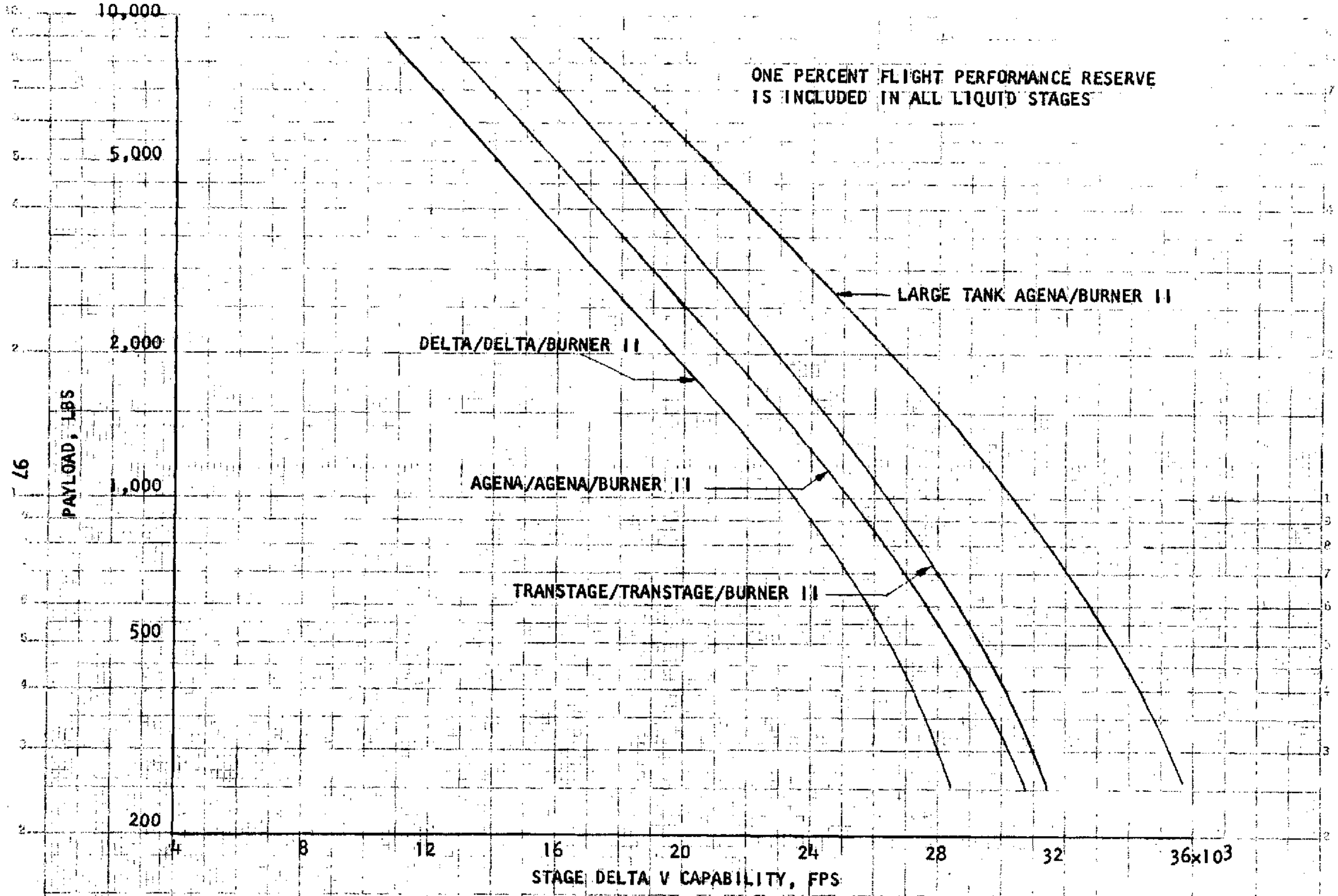


Figure 19. - Non-baseline expendable upper stage performance with Burner II kickstage

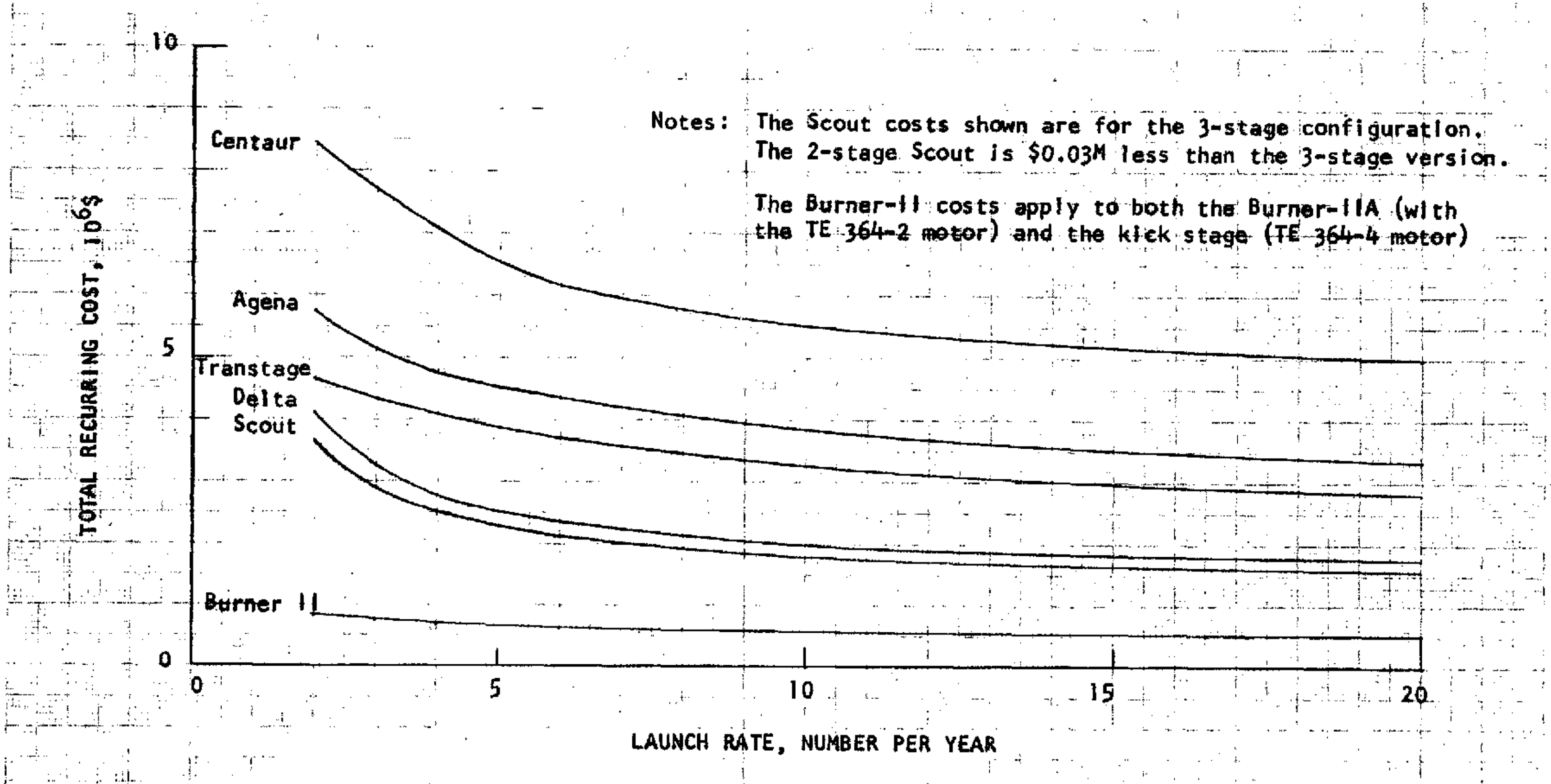


Figure 20. - Baseline stage recurring costs as a function of launch rate

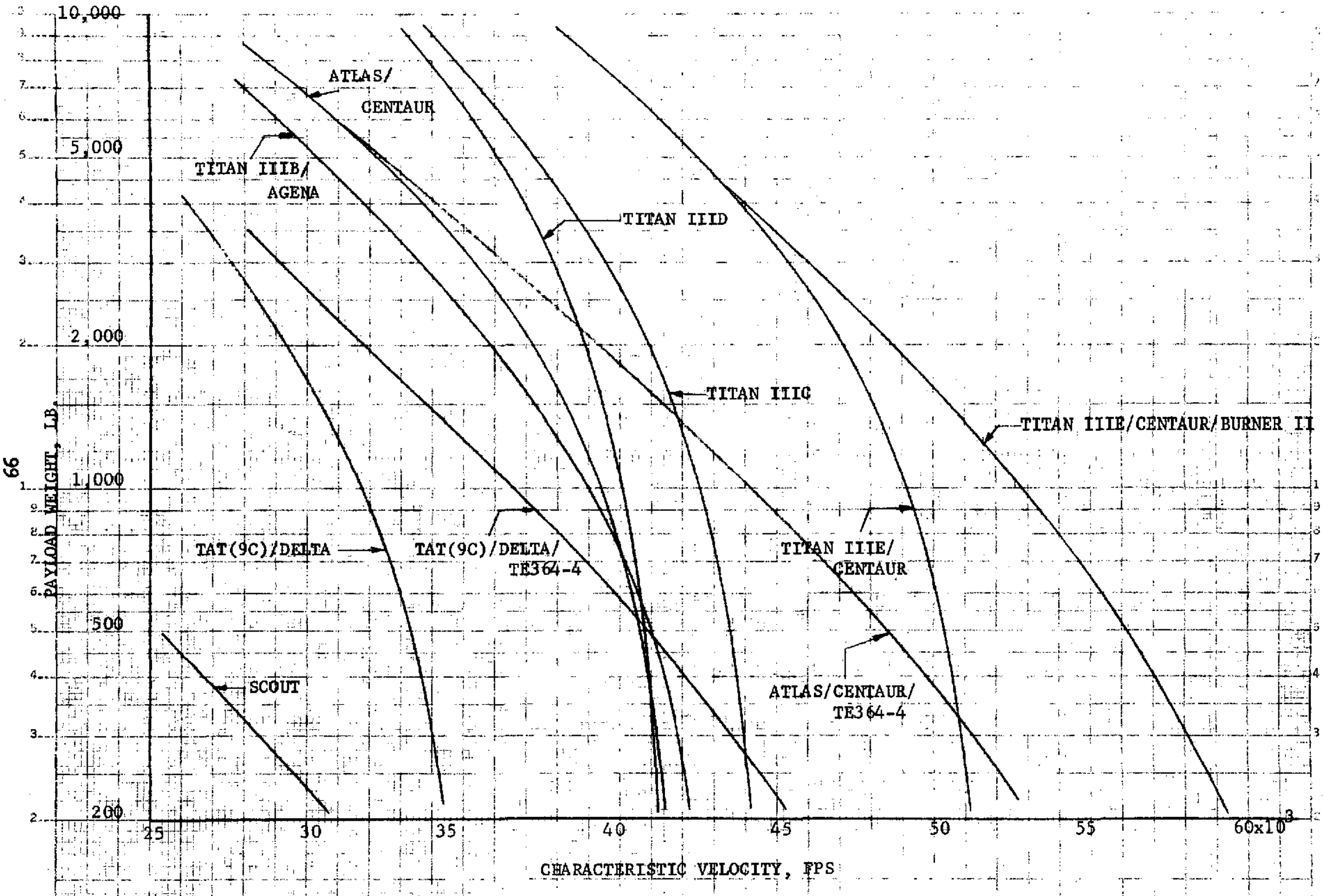


Figure 21. - Expendable launch vehicle performance

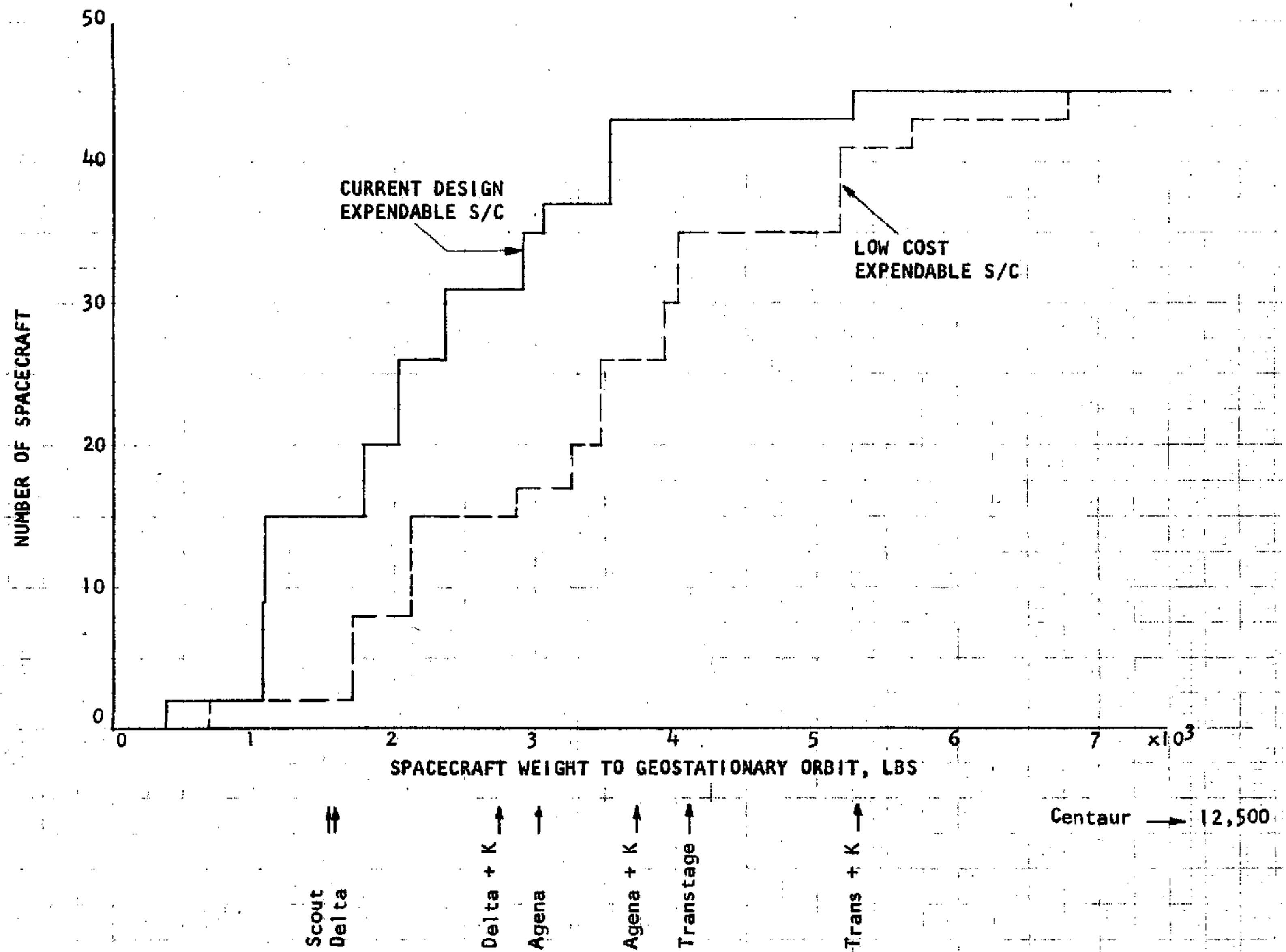


Figure 22. - Geostationary traffic for the base four year period. DOD spacecraft are not included.

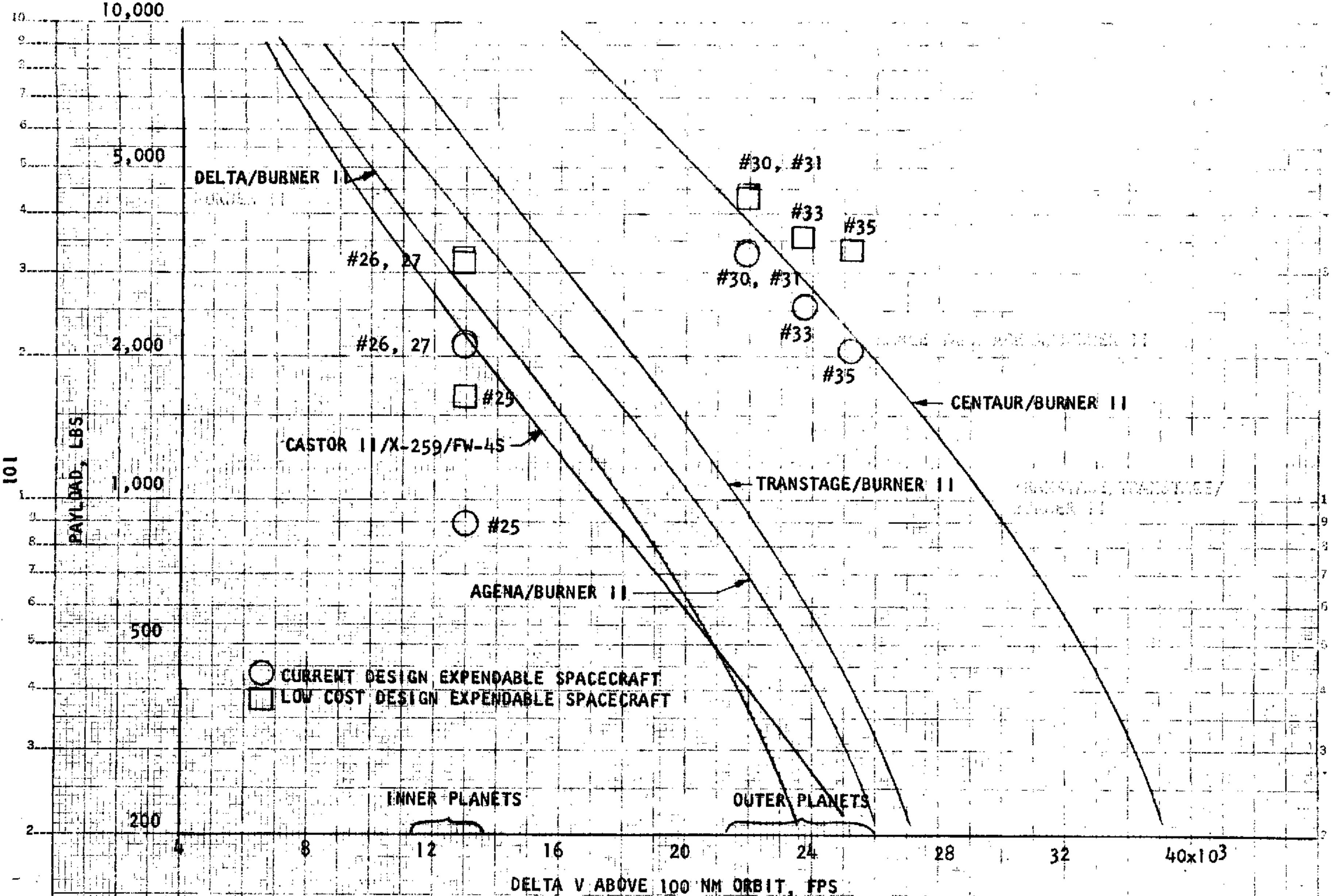


Figure 23. - Planetary traffic for the base four year period and baseline stage performance

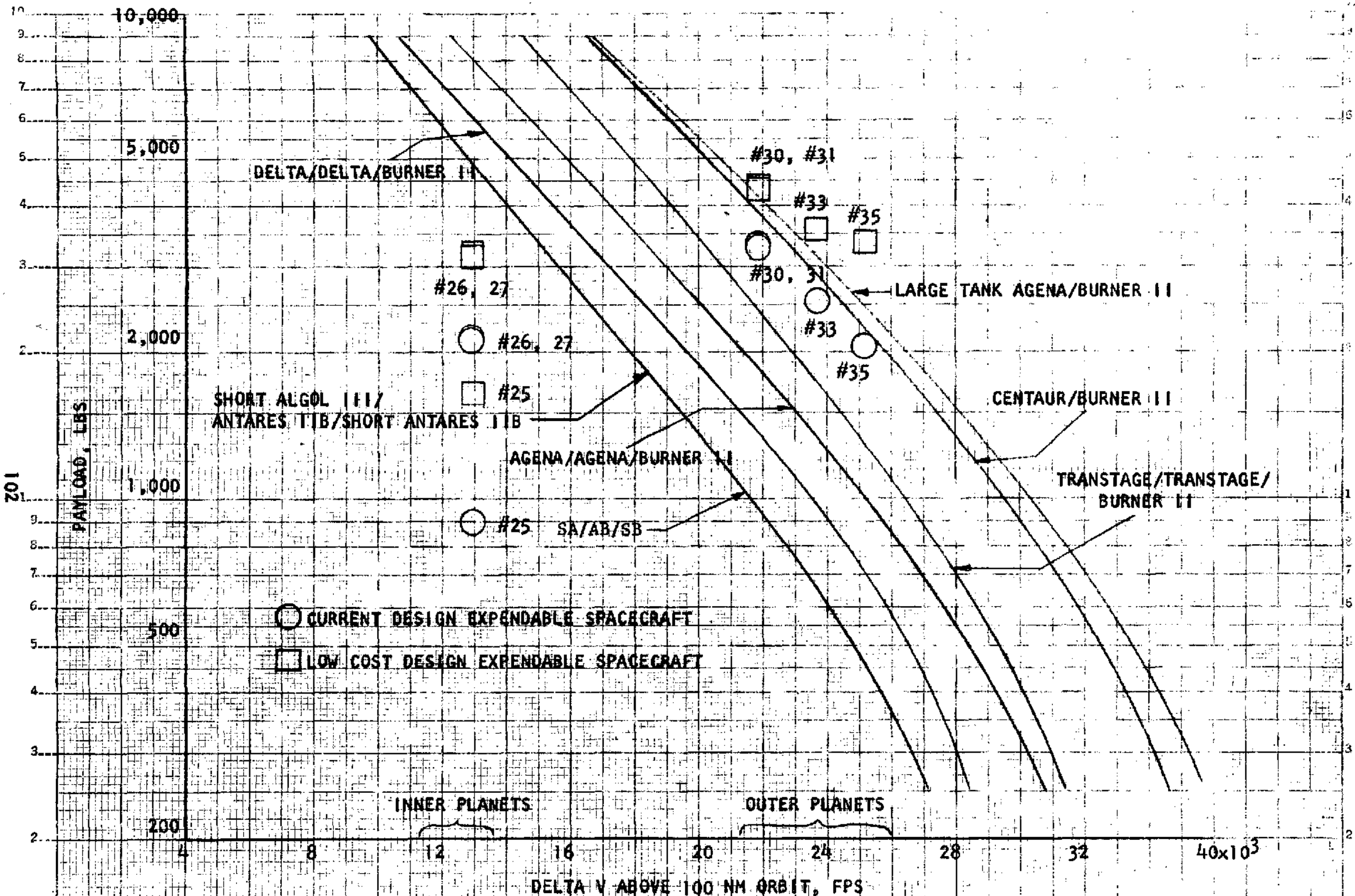


Figure 24. - Planetary traffic for the base four year period and non-baseline stage performance