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THE DEVELOPMENT OF A COMPLEMENTARY EXPENDABLE LAUNCH VEHICLE INTERFACE FOR AN STS DEPLOYABLE PAYLOAD

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ABSTRACT

This paper describes the development of a unique interface, the Titan Payload Adapter (TPA), between a Space Transportation System (STS) deployable payload and an expendable launch vehicle (ELV). Separate ascent and separation constraint systems allow a payload with integral trunnions to retain its originally designed, boost-phase load structure, yet also allow the expendable booster vehicle to separate from the payload via retro-rockets. We discuss design requirements as well as development problems and their resolutions.

INTRODUCTION

The Challenger accident and the subsequent STS redesign and upgrade period created an immediate need for an ELV capable of boosting a shuttle-class payload into orbit, with a minimum of design changes to the payload. Lockheed Missiles and Space Co. (LMSC) developed an interface to address this need which adapts such a payload to the Titan IV booster (Fig. 1).

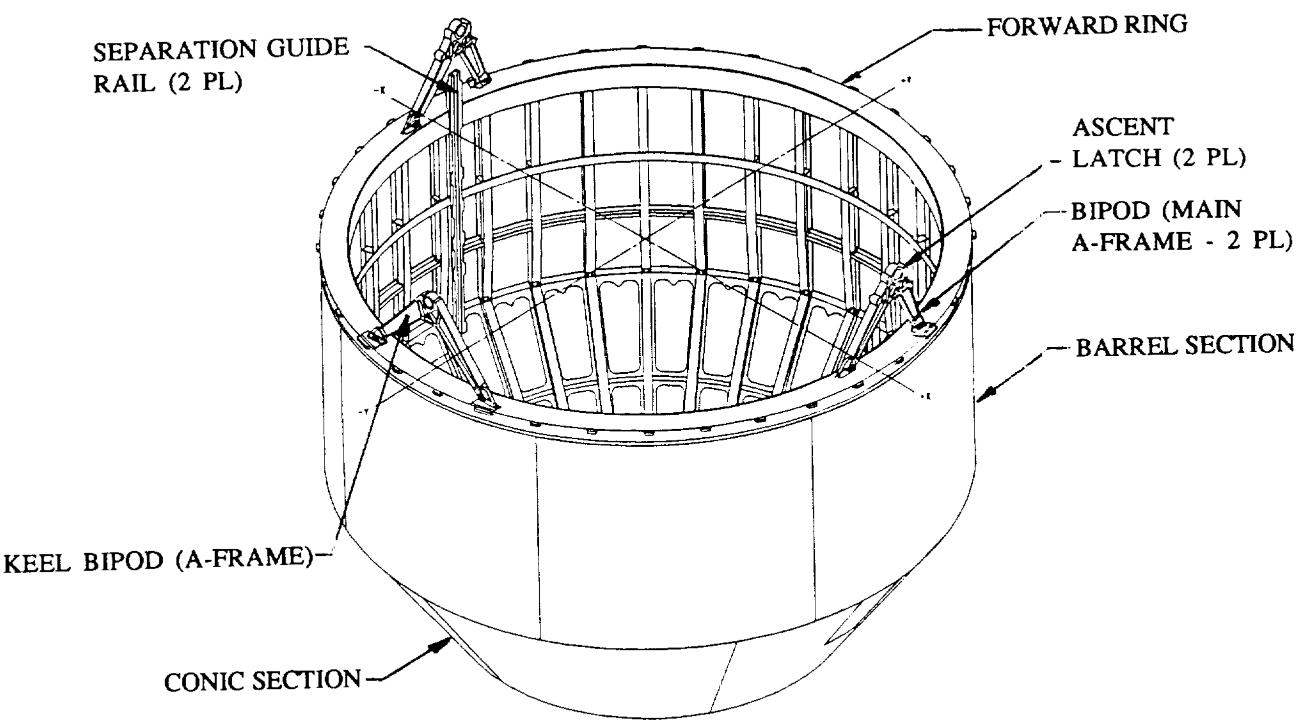

FIGURE 1: Titan Payload Adapter

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REQUIREMENTS

Several groundrules directly influenced TPA design. Specific requirements for the adapter design were that the interface must:

1) Cause no significant structural change to the payload (i.e., retain four-point payload trunnion system);

2) Attach to the ELV mounting interface (Titan IV, Stage II);

3) Accommodate dynamic and thermal distortion during ascent and residual distortion during separation;

4) Separate from the payload via existing booster retro-rockets;

5) Prevent contact between the booster and payload structure during separation;

6) Meet the above separation requirements with only three out of four retro-rockets functioning (this is actually a goal, not a requirement).

Additional derived requirements also affect mechanism design for the adapter. These requirements address concerns of redundancy, reliability, flexibility, manufacturability, and weight minimization. All mechanisms are required to have redundant activation paths for reliability. We found that the separation mechanisms must be flexible enough to minimize impact loads, yet stiff enough to prevent undue motion leading to Booster Vehicle/Satellite Vehicle (BV/SV) contact. This somewhat unique flexibility requirement is a direct consequence of the separation guidance system deadband, which results in impact loading during separation. Weight minimization of components is a goal, but no specific requirements exist.

DESIGN EVOLUTION

The TPA engineering team faced a challenging design task. This problem, reduced to its essential kinematic description, was to provide a six-degree-of-freedom (DOF) constraint between the BV and the SV during ascent, and five-DOF constraint during separation (Fig. 2). The TPA engineering team, a small group consisting of a broad range of disciplines, worked together to produce a system which meets all requirements.

The predominant TPA structural design problem is the absence of a planar boundary typically existing between the spacecraft and the booster. Preliminary work done by the engineering team, using the booster and payload structural interface requirements as constraints, indicated that the most efficient TPA structural design would consist of a cylindrical "barrel" mated to a diameter-reducing conical section. The adapter barrel envelopes the aft two meters of the payload, while the conic section attaches to the booster. Hardpoints on the barrel are required to transfer high trunnion loads into a ring-longeron system, eventually leading to an evenly stressed skin at the conic portion. The engineering team desired that the adapter fit within a standard "hammerhead" 5-meter-diameter payload fairing (PLF) for structural weight efficiency. However, the space available for the adapter structure between the payload and the PLF is insufficient when dynamic deflections are accounted for. The solution of this problem resulted in a 5-meter-diameter barrel structure with a modified PLF attached to the forward end of the barrel. The aft portion of the PLF (the hammerhead conic) is removed and the

TPA doubles as a fairing for the payload in this region, carrying both payload inertia and aerodynamic loads.

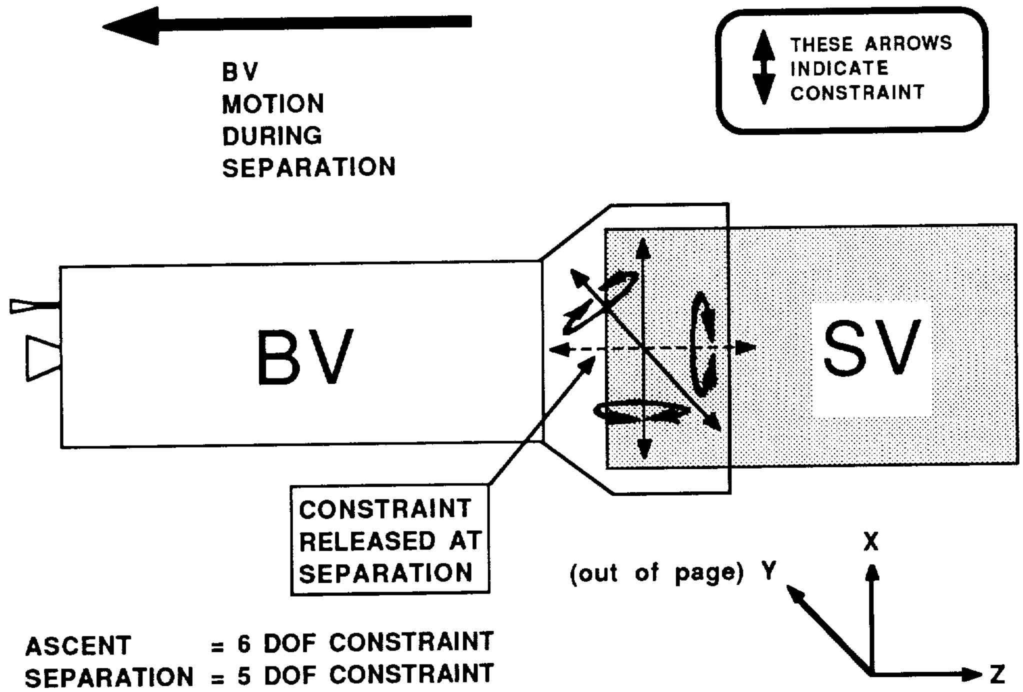


FIGURE 2: Ascent and Separation Constraints

The TPA's designers decided to divide the ascent and separation constraint tasks after developing the preliminary structural design. We believed that separating the tasks would produce a more optimal solution than one system designed to constrain the payload during both ascent and separation. The ascent constraint design task, then, was to react loads kinematically, as is done with the shuttle trunnion system, and then release this constraint at separation.

Ascent Constraint System

TPA designers produced numerous iterations of the BV/SV ascent constraint system in the course of developing the final configuration. We considered one early system using three latch mechanisms bolted to a forward ring structure on the TPA cylinder, one latch at each main trunnion and one at the keel trunnion. This design did not receive serious consideration because of high predicted loads and the requirement to preclude structural redesign of the payload, which virtually mandates retention of the four-trunnion concept. Additionally, stress analysts predicted large bending moments in the TPA forward ring due to the distance between the latch points and the skin of the adapter (0.25 m). Large ring bending moments were also predicted for the earliest four-trunnion constraint concept. This concept used two latches at the main trunnions and slotted bearing plates at the keel and aft trunnion locations to react loads in a similar fashion to the original shuttle latch system. Other proposed designs allowed the ring to support high moments, but were ultimately eliminated due to a payload access requirement which forced the payload adapter forward ring to be about 0.5 meters aft of the plane containing the main and keel trunnions.

To accommodate the aft placement of the ring, TPA designers considered a four-trunnion configuration wherein the supports mating with the main and keel trunnions increased in height, but remained bolted to the forward ring. The stress engineers once again predicted excessive bending moments applied to the ring. The design team eliminated the moments by adding bipod supports between the forward ring and the trunnion latches and keel bearing plate with spherical bearings at each ring attachment point. Likewise, the aft slotted bearing plate was attached to the TPA structure with a bipod, but lesser loads (and consequent distortion) allowed using a pin joint attachment. The spherical bearings and pin joints are incapable of transferring moments to the TPA structure (except as may develop as a result of friction in either a bearing or pin). The legs of the main and keel trunnion support bipods are designed to establish a path that brings the trunnion loads into the barrel main longerons and forward ring as close as possible to the skin at two points for each trunnion. This halves the point loads applied to the longerons and greatly minimizes the moment applied to the ring.

Ascent Latch

TPA engineering considered many concepts during latch development, with the aim of achieving a configuration satisfying several requirements. These include rapid unlatching, redundancy, the capability to withstand loads up to 220 kN, using an existing flight-qualified initiating device, and compatibility with the kinematic ascent support system. The rapid unlatching requirement led us to eliminate the STS trunnion latch mechanism from consideration. The concepts we did consider further used either pin pullers, explosive bolts or separation nuts for quick initiation. We studied several latch configurations gaining mechanical advantage through links or levers to minimize loading on the initiating device. Yet we also wanted both simplicity of design and minimal components for high reliability. Because of concerns about high latch loads, pinpullers were eliminated from consideration. The pinpuller-actuated designs required numerous linkages designed to reduce the load at the actuator, which resulted in uncertainty about reliability and stiffness due to the number of components. After much consideration, the design team proposed a final concept of actuation by a separation nut without a bolt ejector (Fig. 3). The

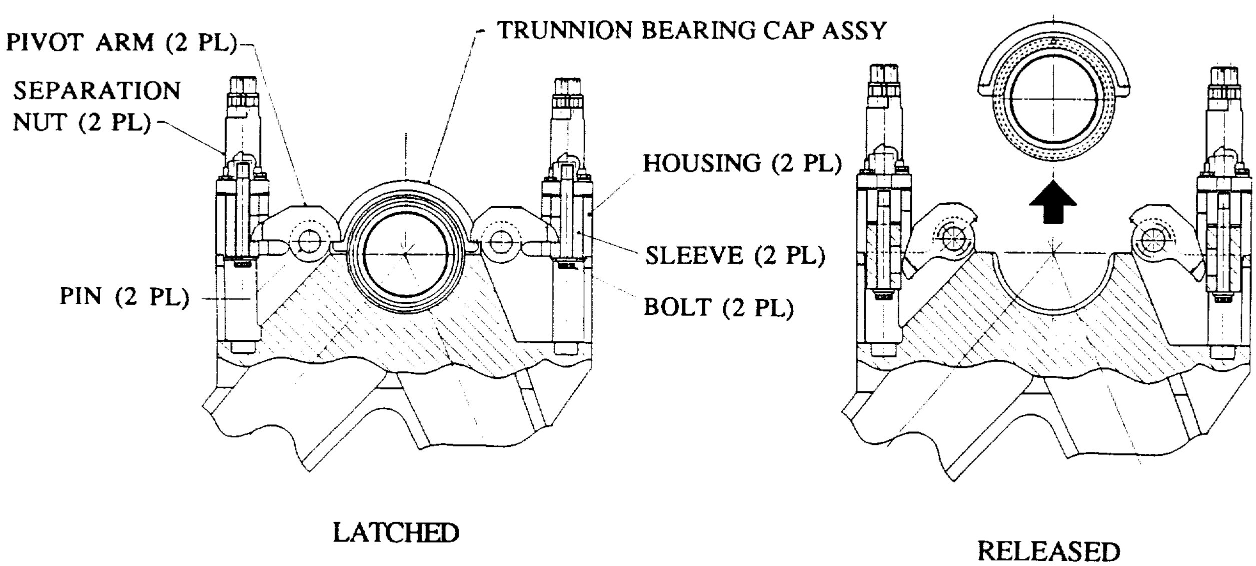


FIGURE 3: Ascent Latch

principal advantages of this design are simplicity, strength, and reduced shock, due to the elimination of the bolt ejector. Development testing proved that the latch's stored strain energy was sufficient to rapidly eject the bolt without assistance.

Separation Guide System

Preliminary studies by the separation analysis group showed that avoiding contact between the adapter and the spacecraft required a guidance system; an unguided system resulted in contact, even under nominal conditions. This conclusion was fairly obvious given the two-meter overlap of the two structures and the minimal clearances between them. The engineering team proposed several guidance concepts, based on rails and rollers.

The rail/roller separation guidance concept was previously used by the Lockheed Agena spacecraft and its adapter. The Agena system originally used three rails with two planes of rollers (Fig. 4). A fourth rail was added to the Standard Agena to reduce loads. The rollers acted upon the rails in compression only for both of these systems. Furthermore, the nominal rail/roller clearance was one-eighth of a millimeter, and rail/roller loads were likely induced by dynamic and thermal distortion during ascent (distortion predictions were beyond the state of the art at this time).

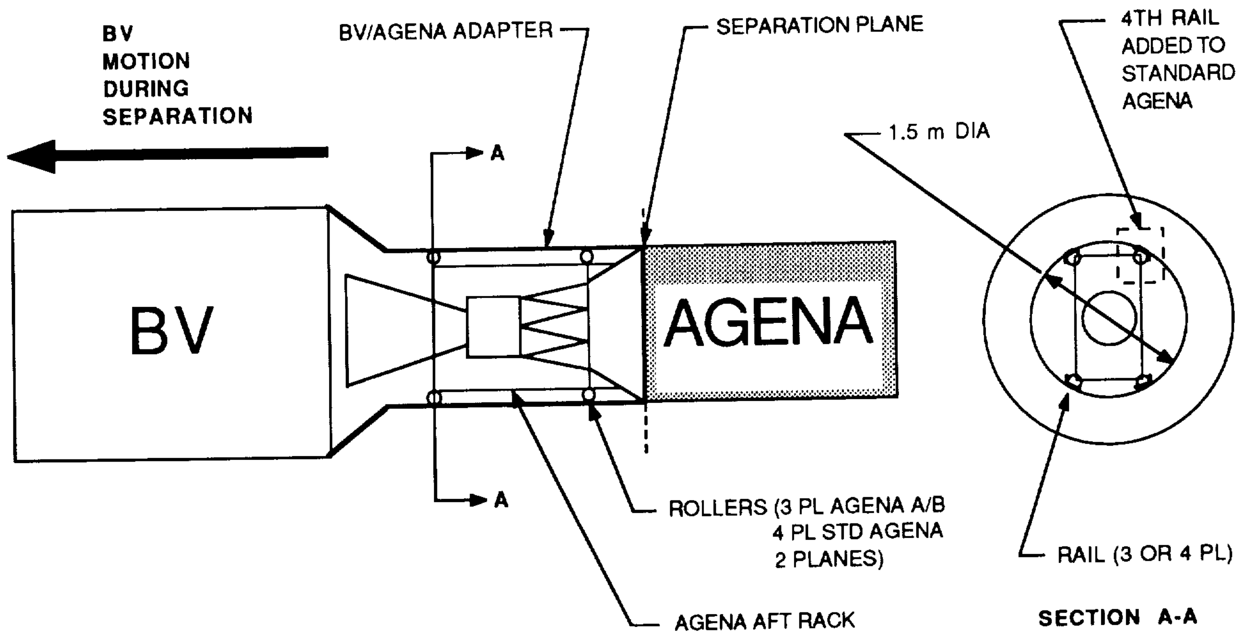


FIGURE 4: Agena Rail/Roller System

Initially, the design team proposed a three-rail system mounted to either the adapter for the payload, with two planes of compressively loaded guide rollers, similar to the original Agena but on a larger scale. The rail/roller interfaces between the payload and booster adapter are approximately at a 1.5-meter diameter for the Agena system, and this is increased by 230% to 5 meters on the Titan Payload Adapter. However, the payload's design precluded a three-rail system, and, moreover, kinematics prevented mounting the rails on the payload (relative pitch or yaw increases effective rail diameter, causing high compressive loads). Faced with these limitations, the design team proposed a two-rail system with rollers attached to the payload and rails affixed to the adapter. The designers realized that in addition to radial loads (as in the Agena), tangential loads would also be reacted with a two-rail system. Several rail/roller concepts were examined to address this problem. We chose a C-shaped rail cross section because it has low local distortion under load and it encloses the rollers, preventing jamming or mislocation caused by ascent distortions.

Ascent Distortion

The most unusual and difficult problem the engineering team faced was accommodating BV/SV dynamic and thermal ascent distortions in the separation system to prevent it from becoming a secondary load path. Structural dynamic analysis predicted relative motion of plus or minus three centimeters between rails and roller locations on the payload. We knew a separation system similar to the Agena's, with its minimal rail/roller clearance, would undoubtedly react high loads during ascent at these distortion levels. The design team suggested expanding the rail/roller deadband to accommodate the dynamic motion, but analysis showed that this would result in large impact loads during the separation phase. Increasing the rail/roller freeplay locally, at the ascent positions of the rollers, was next considered (Fig. 5). Analysis of this concept, dubbed the "rail pocket" design, determined that it also could produce unacceptably high loads for most separation cases. This design is analogous to a bicycle hitting a pothole. The design team proposed using three planes of rollers, staggering the pockets so that two rollers remained on the rail when one was over a pocket. Unfortunately, manufacturing tolerances, residual ascent distortions, or rail flexibility could always permit a roller to contact a pocket.

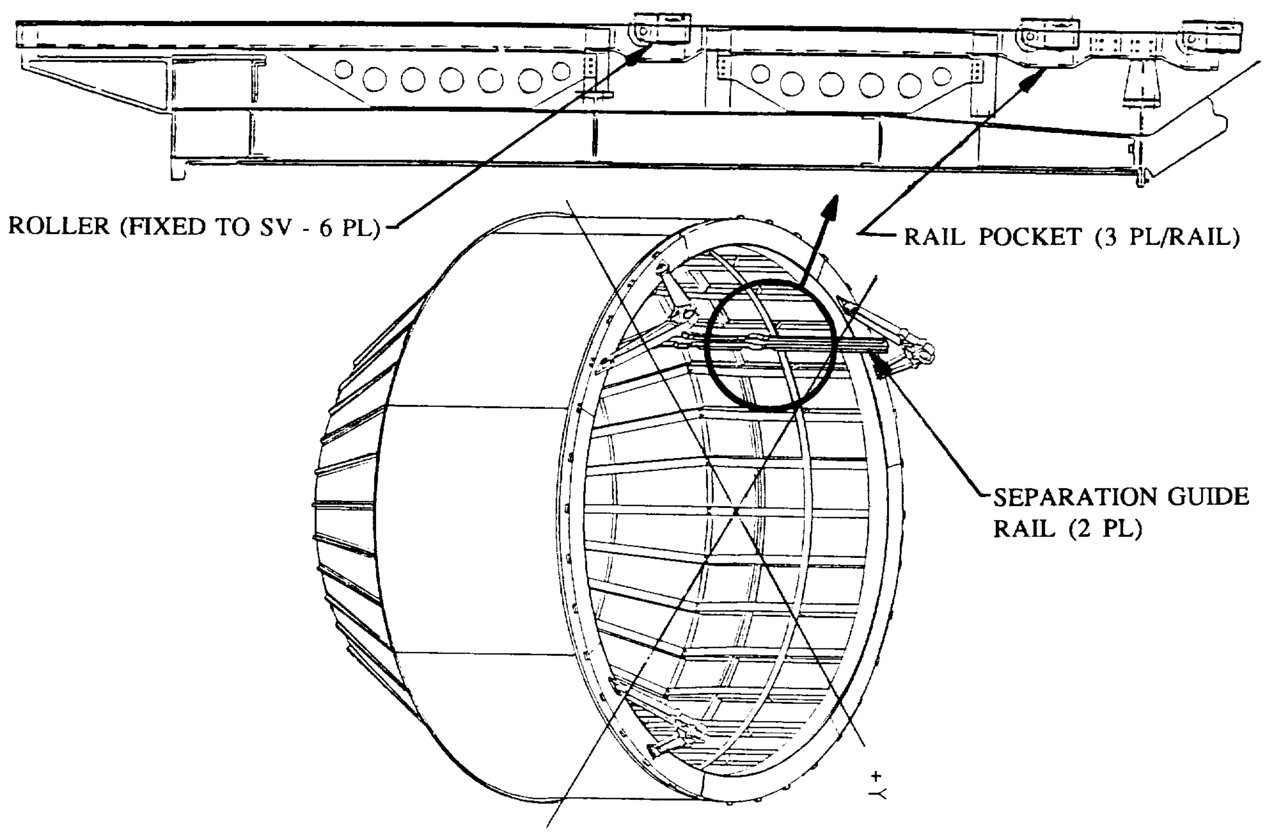


FIGURE 5: Rail Pocket Concept

TPA engineering began investigation of active solutions to the ascent motion problem after analysis of the rail pocket design failed to produce acceptable loads. Two basic concepts were proposed, rail "trap doors" and "active rollers." The trap door concept was based on the guide rail having a movable portion which accommodated rail/roller ascent motion. At separation, the movable portion of the rail would lock into place, giving the effect of a continuous rail. We became concerned about a roller becoming jammed when the trap door was open during ascent, and also about a trap door failing to close against a residually displaced roller at separation. These concerns caused us to focus on the active roller concept.

Residual Distortion

The active roller concept allowed the rollers to be free to move during ascent and locked them into position during separation (Fig. 6). The separation analysts determined that this concept could produce acceptable loads if proper control of the rail/roller deadband and total system flexibility was maintained. Additionally, we used kinematic analysis to determine that three roller locations on the payload would be sufficient for guidance. All three rollers are required to take tangential loads, but only two are required to react radial loads for a kinematic separation constraint system (Fig. 7). Thus constrained in five DOF, the payload is unaffected by residual distortions of the TPA. Residual distortions can result from thermal strain, PLF (aero) loads during ascent, and inertial ascent loads. A three-roller separation system is also unaffected by manufacturing tolerances of the TPA or payload.

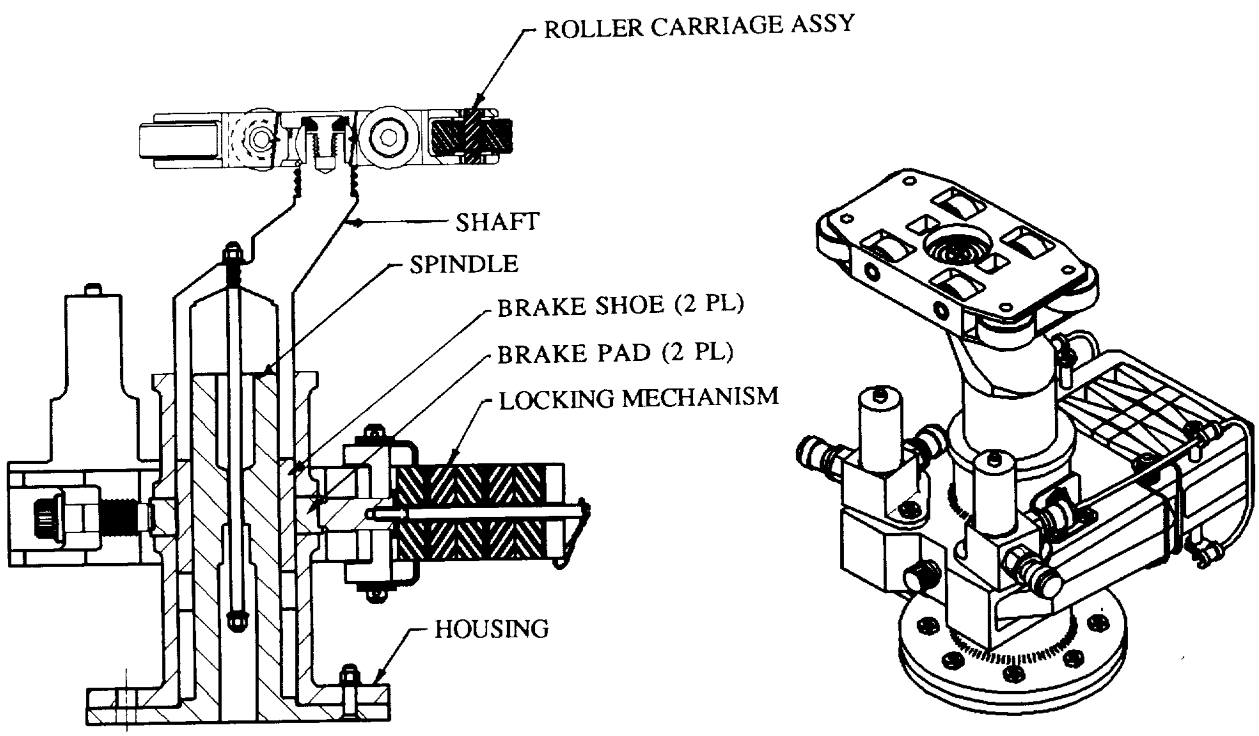


FIGURE 6: Active Roller Mechanism

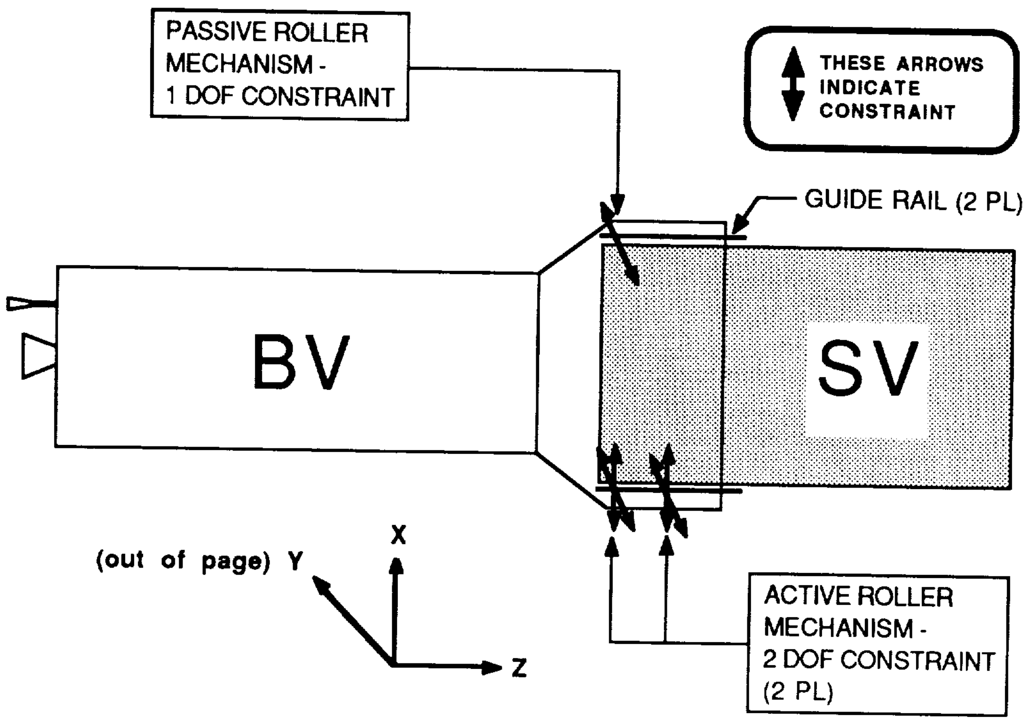


FIGURE 7: Three Roller Separation Constraint System

The engineering team decided to make the rollers reacting both radial and tangential loads active mechanisms (with lock-up). However, a requirement to limit the number of pyrotechnic circuits led us to design the roller taking only tangential loads as a passive mechanism (no lock-up). The separation analysts showed that a plus or minus three centimeter tangential deadband at the passive roller location exclusively would produce acceptable loads with anticipated flexibilities. Predicted flexibility values were later verified by testing end-item hardware.

Active Roller Mechanism

The primary requirements for the active separation guidance mechanism are that it accommodate relative rail/roller deflections of up to plus or minus three centimeters in both the radial and tangential directions during ascent, and that it support loads predicted to be as high as 20 kN and 9 kN in the radial and tangential directions, respectively, once activated at separation. The engineering team created a mechanism comprising a cylindrical housing with an inner telescoping shaft to accommodate the radial deflections (Fig. 6). We felt that a device based on a linkage arrangement could have allowed the required deflections but would have had unacceptably high deflections under the predicted loads. The inner shaft has an integral offset arm ("dogleg") at the outboard end near the rail. This dogleg accommodates tangential deflections as the inner shaft rotates in its housing. The dogleg offset is sized so that it is longer than the greatest tangential deflection. We accounted for friction effects to ensure that shaft rotation can never hang up in a fully deflected condition.

The TPA team next needed to solve the problem of locking the inner shaft to the housing with sufficient force to withstand the predicted separation loads. We preferred pinpuller activation to meet redundancy and rapid actuation requirements. We studied one design that used spring-loaded levers to engage splined locking surfaces, but eliminated it due to concerns over immediate engagement of the splines. Up to two millimeters of motion might have been required to lock the splined shafts, and analysis showed that this had undesirable effects on separation. A design that provided for immediate positive lock-up was required. TPA designers revised the spline mechanism, replacing the coarse mechanical spline grip with a friction grip (Fig. 8). An inner spindle was also added to the outer housing to provide additional friction braking surface for the lock-up brake pads. The two pads, when clamped by the lock-up springs, provide four friction surfaces (inner and outer) to react separation loads from the telescoping/rotating shaft to the cylindrical housing. The lock-up springs are a stack of five high-rate leaf springs, which can be applied by either of two pinpullers. TPA engineering gave high priority to a development program to investigate high-coefficient-of-friction materials for braking surfaces, which is discussed in a subsequent section.

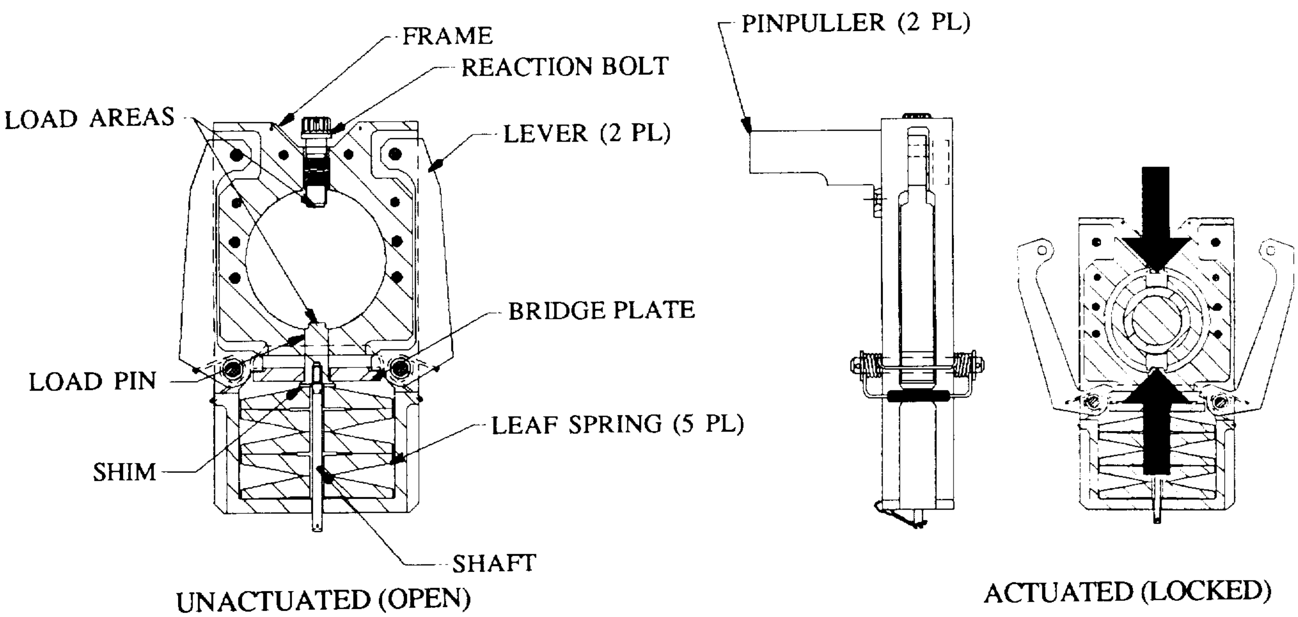
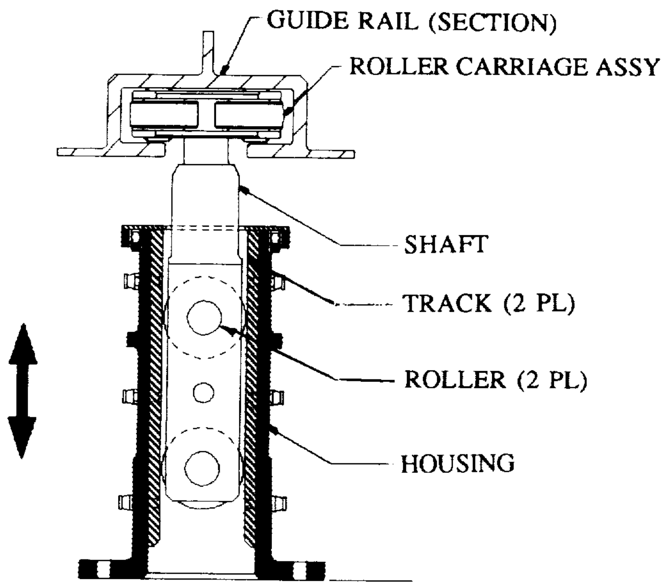


FIGURE 8: Active Lock-up Mechanism

<u>Passive Roller Mechanism</u>

The two primary requirements for the passive roller mechanism are to accommodate plus or minus three centimeters of relative tangential rail/roller deflection during ascent and to withstand loads of up to 9 kN in the same direction during separation. The implied design requirement, of course, is to allow unrestricted radial motion during both ascent and separation. The TPA designers were easily able to meet the relative ascent motion requirement by increasing rail/roller freeplay to plus or minus three centimeters, thanks to the separation sensitivity study proving acceptable loads. We decided to account for radial motion with a telescoping device similar to the active roller mechanism. An outer housing mounts to the payload, and the inner shaft, attached to the roller, is free to move radially relative to the payload. Initially, the design team proposed coating the sliding surfaces of the mechanism with a teflon-impregnated anodic finish. However, analysis proved that binding of the telescoping action could result if the mechanism was under tangential load, since the coefficient of friction of the coating was not sufficiently low enough. To rectify the potential problem, the inner shaft was redesigned with rollers which transfer tangential loads to track surfaces attached to the outer housing (Fig. 9). The rollers provide an effective friction coefficient an order of magnitude below the teflon-anodic coating.



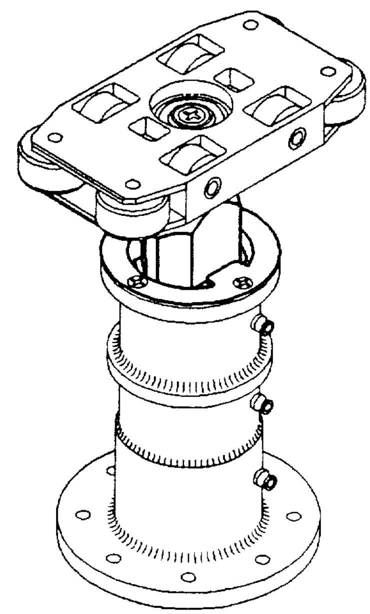


FIGURE 9: Passive Roller Mechanism

Roller Carriage Assembly

The TPA designers, in the early stages of the separation system design process, planned on using rollers to react loads against the rails. This concept was proven in the Agena program to cause minimal loss of separation impulse due to friction. Later, however, for simplicity in the TPA separation system, the design team proposed using low-friction sliders. Additionally, sliders are advantageous for reducing contact bearing stresses, which initially were high for the roller systems considered. Testing later proved sliders to be unworkable, although initially promising.

The engineering team revisited the roller concept and proposed some modifications to reduce bearing stresses, such as increasing the crown radius of the rollers and increasing the number of rollers in contact with the rail. We used an aggressive development test program to identify the most promising bearing method and validate the predictions of the stress group regarding load capability. The final design of the separation roller system is based on an eight-roller "carriage" (Fig. 6). A monoball pivot at the center of the carriage prevents the transmission of moment at each guide constraint, to allow a kinematic system. The rollers have low-friction teflon bushing inserts. The bearing shafts are also mounted in teflon bushings in the carriage structure. Thus, redundant bearing paths are provided. Snap rings retain the bearing shafts in the carriage.

TEST PROGRAM

The TPA engineering team used extensive development testing early in the design phase to assist the decision-making process, as well as to refine design details. The most critical testing involved friction surfaces, in an effort to find both low and high friction combinations for the rail/roller and active lock-up mechanisms, respectively. Unfortunately, the results of early coupon (sample) testing did not always correlate to later component-level testing.

Rail/Slider Testing

The rail/roller coefficient of friction greatly influenced separation performance, as shown by analysis. Failure to achieve separation could be caused by friction dissipation of retro-rocket impulse, especially in the One Retro Misfire (ORM) cases, which had 25% less impulse combined with high guide loads due to retro imbalance. Early separation analysis assumed the effective Coulomb friction coefficient to be 0.048, from previous Agena experience. Later parametric study showed that coefficients as high as 0.15 were tolerable, which, in combination with other factors, caused design to investigate sliders in place of rollers.

We used coupon testing of various materials, both lubricated and unlubricated, to select a candidate slider/rail material combination with suitable characteristics. All tests were done at ambient temperature and pressure. Low-load static tests (inclined plane) identified Anatef I, Anatef II, and Kahrlon as promising coatings for aluminum surfaces. Anatef (either type I or II) was selected after high-load testing with vendor-supplied samples of these coatings.

Unfortunately, trouble developed during a dynamic simulated system test of two sliders in a rail fixture some time later. We recorded coefficients of friction of up to 0.4 as well as visible and audible evidence of gouging and scuffing. TPA management directed the design team to reinvestigate roller concepts while the cause of the high slider friction was determined, to provide a back-up precluding schedule impact. Engineering found that the Anatef coating's friction coefficient was very sensitive to surface finish, and the production finish on the rails and sliders was not smooth enough. The coupon samples were buffed to a finish at least four times smoother than production rail/slider hardware by the vendor. Manufacturing of rails with the required surface finish would have been both difficult and expensive, so TPA management decided to return to rollers when full-scale development testing showed good results.

Rail/Roller Testing

The rail/roller development test program to evaluate materials and bearings for strength and effective coefficient of friction looked at two roller bearing and two journal bushing configurations. The first roller design had a 7075 aluminum outer sleeve ("tire") press fit on the outer bearing race, and the second used a stainless steel tire. The tires were machined with a 0.25 meter crown to minimize bearing stresses in the rail and roller. Some amount of crown is desirable to preclude tire edge contact (with resulting high stresses) caused by distortion. Under load, the aluminum tire yielded and loosened on the bearing. The steel-tire bearing test resulted in inconsistent (spiked) drag loads attributed to high compressive loads on the bearing due to the interference fit of the tire and bearing and the high tire/rail contact stress. The journal bushing rollers were built using a solid 7075 aluminum wheel and a solid stainless steel wheel. The wheels were machined with the same crown radius as the roller bearing tires, and the journal bearings were press fit into the wheels. The steel wheels exhibited a coefficient of friction of less than 0.05 under a maximum load of 8 kN, but left permanent indentations in the rail. The aluminum wheel test also found that the coefficient of friction was less than 0.05, but with no observed anomalies.

Design selected the aluminum-wheeled journal bearing to incorporate into the roller carriage breadboard test, based on the results of the bearing and materials test. An eight-tired prototype roller carriage was built, with four tires capable of reacting radial loads (in both directions) and four tires capable of reacting tangential loads (two in each direction, see Fig. 6). The carriage was placed in a production rail section and attached to a load application and measurement test apparatus. We measured carriage drag force while applying radial loads up to 16 kN and tangential loads up to 11 kN simultaneously (resultant 19 kN), in increments of 1 kN. All measured coefficients of friction were less than or equal to 0.05, including parasitic test apparatus forces.

Lock-up Device Friction Testing

Design conducted a development test program to evaluate material combinations with the object of finding a high friction coefficient to be used in the active roller mechanism lock-up device. Prototype lock-up mechanism components were created from four candidate materials, corrosion resistant steel (CRES), 6061 and 7075 aluminum, and titanium. The components built included the inner braking surface (spindle), the brake shoes, and the outer friction reaction surface, termed brake pads. The various spindle-shoe-pad combinations were tested for their effective coefficient of friction, with the titanium spindle, 6061 aluminum shoes, and titanium pads exhibiting consistently higher values than the other combinations for applied loads ranging between 4 kN to 22 kN.

ANALYSIS PROGRAM

The engineering team used analysis throughout the TPA mechanism design and development process, greatly influencing the design of the separation system.

Constraint Analysis

The separation engineering group used analysis to prove that the ascent constraint system was kinematic and to investigate potential "binding" (axial drag) of the payload in the adapter caused by transition from the ascent to the separation constraint system. Redundant constraint exists for the first two centimeters of separation (axial) motion, until the trunnions clear their respective latches and guide plates sufficiently. TPA management originally proposed a full-scale test program to evaluate binding effects. When difficulties in designing a zero gravity test apparatus which would provide meaningful results arose, the separation analysts were directed to look at the problem to determine what could be done. An Automatic Dynamic Analysis of Mechanical Systems (ADAMS) model of the ascent constraint system was built and used to confirm that it was kinematic by displacing the payload relative to the adapter and observing the resulting loads. Next, we investigated binding by adding separation constraint locations to the kinematic ADAMS model. By moving ascent/separation constraint locations relative to one another and assuming friction values at each interface, the worst-case separation drag force was found to be 220 N. The separation analysts found that this force had negligible effect on overall BV/SV separation behavior when it was included in the detailed dynamic model.

Mechanism Analysis

Throughout the course of TPA design, analysis groups (i.e., stress, structural dynamics, thermal, and separation) worked in conjunction with design, materials and processes, and manufacturing engineers on mechanism development. The most significant recommendations analytical engineers made were regarding stress, friction requirements and loads. Stress analysts helped determine material choices and dimensions of each mechanism. Friction criteria were developed from binding analyses and lock-up margin analysis (in the case of the active roller mechanism) done by the separation engineers. The separation group also determined dynamic loads on the separation mechanisms. Finally, the analysts served an engineering audit function within the TPA design team itself.

Separation Analysis

The separation analysts modeled the BV/SV system with a digital computer simulation program called SEParation STudY (SEPSTY). The equations of motion used by this code assume the BV and the SV are rigid bodies, each with six DOF. These bodies interact with one another through a flexible rail/roller separation guide system. Figure 10 shows a schematic representation of the separation model.

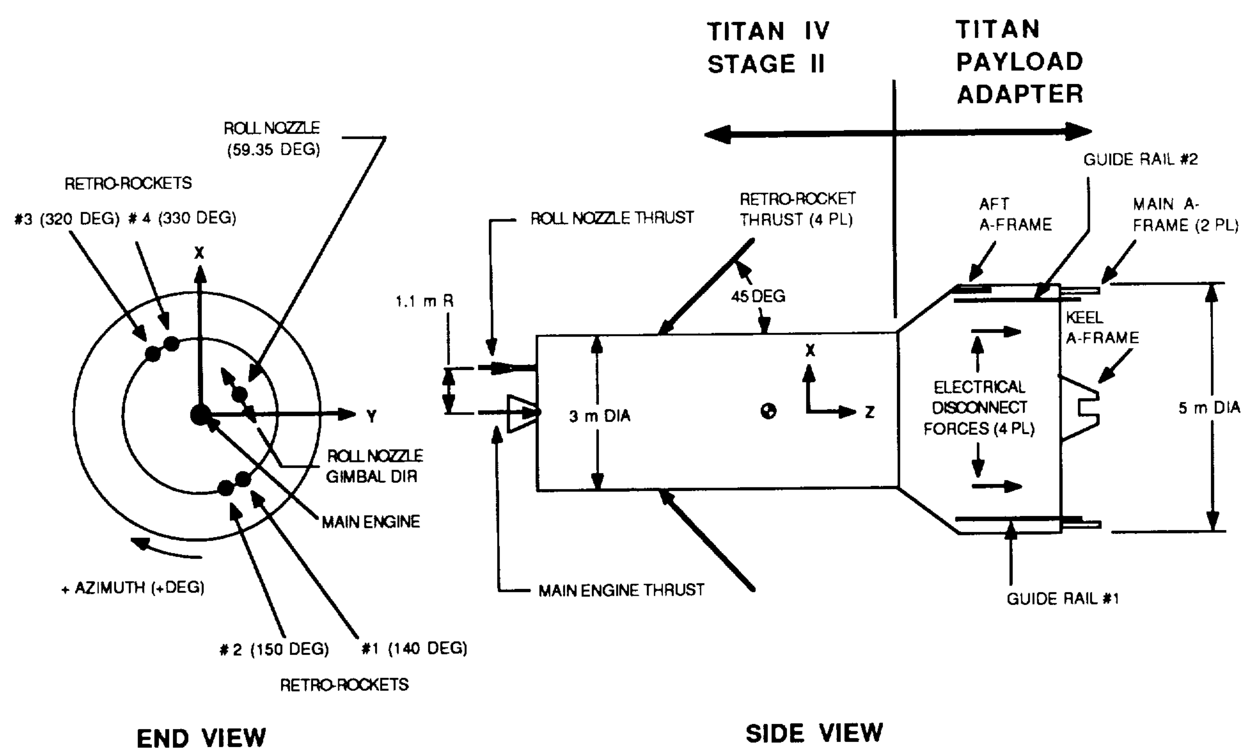


FIGURE 10: Separation Model Schematic

The SEPSTY TPA model has over 100 input parameters which all can be varied. The analysts determined that separation system performance was greatly influenced by three of these variables using a parametric study technique. The most significant parameters are friction coefficient and deadband (between rail and roller or slider), and flexibility of the overall rail/roller/mechanism structure. High friction and deadband values increase guide loads, as does low flexibility (high stiffness).

Table 1 lists the results of the separation analysis for nominal All Retros Firing (ARF) and One Retro Misfired (ORM) conditions. An ORM condition occurs if one of the four retro rockets fails to fire. In reality, an ORM condition is rare, but the condition is modeled to demonstrate separation system capability. The table shows the separation system performance over the evolution of the design. The most notable result is the decline in rail/roller guidance load as the separation system evolves from rail pockets to active mechanisms, and then from sliders to rollers.

		DESIGN					
PARAMETER	UNITS	Rail	Pockets	Active	Sliders	Active	Rollers
Retro State		ARF	ORM	ARF	ORM	ARF	ORM
SV Tipoff Rate	°/s	0.4	4.5	0.4	4.5	0.3	4.5
BV/SV Sep. Vel.	m/s	2.3	0.6	2.3	1.3	2.4	1.3
BV/SV Clearance	cm	4.3	2.3	4.3	3.0	4.3	3.6
Guide Loads -	kN						
Drag		5.0	17	0.4	1.9	0.2	1.2
Tangential		12	49	0.9	4.4	0.2	4.4
Radial		21	65	1.8	8.0	1.3	7.0

TABLE 1: Separation Analysis Results

SYSTEM OPERATION

Ascent Constraint System

The TPA ascent constraint system reacts loads in the same manner and direction, relative to the payload, as the four-point Shuttle latch system. Loads are transferred from the payload trunnion locations to the TPA structure via bipods in a kinematic arrangement which prevents moment transfer, allowing a lighter, more efficient TPA structure. Slotted bearing plates at the keel and aft trunnion locations react loads in the appropriate directions, but do not constrain separation motion. Latch mechanisms at the main trunnion locations are necessary to react loads along the separation axis during ascent and then to release this constraint at separation.

Each latch mechanism is attached to a main bipod structure (Fig. 1). The latch mechanism is composed of two identical subassemblies to provide redundancy. A subassembly comprises one separation nut, a sleeve, a bolt, and a pinned pivot arm with a two-to-one mechanical advantage (Fig. 3). Adequate load margin to use a thirteen-millimeter (half-inch) separation nut is ensured by this pivot ratio. The shorter leg of the pivot arm bears against a surface on a cap assembly. The assembly is mated to the payload trunnion and consists of a spherical bearing (which can also slide on the trunnion) fixed to a bearing cap. The pivot arm's longer leg bears against a cutout in the sleeve. A bolt passes through the sleeve into the separation nut, which is fixed to the latch structure.

Redundant pyrotechnic devices activate the separation nut, initiated by primary and secondary electrical command signals. Prior to actuation, three 120-degree split nut segments (collets) are supported radially by a ring within the separation nut. The ring is driven away from the collets by gas pressure when the pyrotechnic devices fire, allowing the collets to translate radially, releasing the separation bolt. This action frees the sleeve, and thus the pivot arm, which rotates away from the bearing cap. The payload is no longer constrained to the TPA in the separation axis when both latch mechanisms have completed actuation. Redundant operation of each latch is provided by the two subassemblies. In the event that one subassembly fails to function, the bearing cap assembly rotates away from the unreleased subassembly's pivot arm. The designers provided for rotational redundancy in the cap assembly by allowing the cap to rotate relative to the bearing's outer race.

Separation Guidance System

Separation of the payload from the TPA is enabled when the ascent constraint system is released and the separation guidance system is locked-up. The active roller mechanisms are activated at virtually the same time as the ascent latches are released. Until lock-up of the active mechanisms, the separation guidance rollers are incapable of transferring loads from the payload to the TPA. The passive roller mechanism cannot react loads prior to separation because sufficient freeplay has been built into the rail/roller interface to accommodate ascent distortion. The active roller mechanisms accommodate ascent distortion due to their kinematic layout.

The active roller mechanism consists of a tubular housing, a spindle, a doglegged shaft, an external locking mechanism, and a roller carriage assembly (Fig. 6). The housing and spindle are fastened to the payload. The shaft, supporting the roller carriage, is mounted within the housing, but enveloping the spindle. Prior to the lock-up mechanism activation, the shaft is free to telescope and rotate, which in combination with the dogleg, accommodates large dynamic ascent motions of the payload relative to the TPA. The locking mechanism mounts to the housing and applies force to frictionally lock the shaft to the housing and spindle when activated. This force is applied through two openings in the housing, which contain load-reacting brake shoes. In turn, these shoes apply load to brake pads constrained by two similar openings in the shaft. The brake pads also react against the spindle, thereby providing a total of four lock-up friction surfaces. The centers of the windows, shoes, and pads are nominally coincident, and we chose dimensions and tolerances to allow lock-up over the predicted range of residual displacement.

The locking mechanism is made up of a frame, five leaf springs, a bridge plate, a load pin, a reaction bolt, two levers, and two pinpullers (Fig. 8). In the unactuated state, the preloaded spring stack is retained between the bridge plate and the frame, attached to the active roller mechanism housing. Preload is transferred via one lever arm to each pinpuller. When either pinpuller actuates, its corresponding lever rotates, allowing the bridge plate to apply spring force to the load pin. The bridge plate can rotate about an unactuated lever surface, providing redundancy. Locking force is thus applied to the brake shoe-pad-spindle combination of the active roller mechanism. This force is reacted against the bolt on the opposite side of the frame, which "floats" on the housing much like a single-acting brake caliper on a bicycle. The bolt allows adjustment of the lock-up force and provides tolerance compensation.

One passive roller mechanism completes the separation guidance system. This mechanism has a telescoping shaft within a housing fixed to the payload (Fig. 9). Telescoping friction is reduced by rollers pinned to the shaft and running on tracks in the housing, which maintains the kinematic nature of the separation system. The roller carriage, running within the TPA rail, is bolted to the shaft.

Activation of the separation guidance system is also accomplished by primary and secondary electrical command signals, issued within milliseconds of the ascent latch activation signals. Redundant pyrotechnic devices are used for each lock-up mechanism pinpuller. When lock-up is achieved, by either one or both pinpullers actuating, each active roller mechanism provides constraint in two DOF. The passive roller mechanism provides one-DOF constraint outside of its deadband, for a total of five DOF (Fig. 7). The remaining, unconstrained DOF, is in the separation direction, which enables the TPA to retro away from the payload.

CONCLUSION

The TPA engineering team created an adapter which allows a payload, designed to launch on the STS shuttle, to be launched on an ELV with minimal changes to the payload. This adapter has mechanisms which allow retention of the four-trunnion payload mounting system (trunnion latches). Additionally, a separation guidance system consisting of active and passive mechanisms accommodates large dynamic and thermal ascent distortions between the payload and the adapter, as well as residual distortions at separation. Prior to actuation, the mechanisms constrain the payload to the adapter for ascent. When pyrotechnically activated, the mechanisms allow separation from the adapter using the existing booster retro-rockets.

The engineering team realized several lessons during the development of the TPA. One lesson is that design simplicity cannot always be pursued successfully. The early rail pocket concept is the most straightforward solution to the problem of large dynamic ascent deflections, but produces unacceptable impact loads. Similarly, sliders are certainly less complex than rollers, but materials and manufacturing problems forced transition to rollers. The slider problem illustrates the second and third lessons: the value of early development testing, and to be especially aware of surface finish when using low-friction coatings. However, perhaps the most important lesson provided by the TPA engineering effort is not strictly a design issue. The TPA program proved that a small, motivated team of designers and analysts, working in conjunction with manufacturing engineers, could operate in the bureaucratic environment of a large company and efficiently create a product in less than half the time typically required, within budget.

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