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MECHANISMS TO DEPLOY THE TWO-STAGE IUS FROM THE SHUTTLE CARGO BAY[1]

H. Theron Haynie, PE
Boeing Aerospace Company

SUMMARY

The Inertial Upper Stage (IUS) is a two-stage or three-stage booster used to transport spacecraft from the space shuttle orbit to synchronous orbit or on an interplanetary trajectory. The mechanisms discussed in this paper were designed specifically to perform the two-stage IUS required functions while contained within the cargo bay of the space shuttle during the boost phase and while in a low Earth orbit. This paper describes the requirements, configuration, and operation of the mechanisms with particular emphasis on the tilt actuator and the mechanism for decoupling the actuators during boost to eliminate redundant load paths.

INTRODUCTION

The mechanisms required to function during the space shuttle orbiter boost and IUS separation sequence were designed and selected to meet the challenge of remote deployment. The environment is hostile and exceeds the capabilities of many of the materials considered standard in the aircraft industry.

The IUS cradle assembly is the airborne support equipment (ASE), which interfaces between the IUS flight vehicle and the space shuttle orbiter cargo bay. The cradle structure consists of (1) an aft support frame that provides support structure for IUS X, Y, Z, Mx and Mz loads and (2) a forward support frame that provides support for IUS Y and Z loads during boost. A keel pin between the forward frame and the IUS carries the Y loads and may be loaded at deployment due to thermal distortions of the orbiter. The aft frame pivots during deployment to elevate the IUS out of the shuttle cargo bay. All mechanisms are a part of these two major structural elements. Figure 1 shows the space shuttle and its relationship to the IUS cradle assembly.

After orbit has been achieved, the forward frame latches are opened to allow the aft frame tilt actuators (AFTA) to erect the IUS and its payload to a checkout position and, finally, the separation position. The Super*Zip[2] linear explosive fractures the support structure, allowing self-deployment spring assemblies to eject the IUS and its payload at a velocity that is adequate to obtain a safe separation distance before firing the IUS first-stage boost motor.

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[1] Work performed on contract F04701-78-C-0040, HQ. Space Division (AFSC).
[2] Lockheed Missiles and Space Company.

DESIGN REQUIREMENTS

All mechanisms share certain general requirements relative to the space environment, such as the following:

a. Complete 100 flights and last for 10 years.

b. Operate in zero gravity.

c. Survive temperatures as low as -84°C (-120°F).

d. Have an operating temperature range of -23°C to +52°C (-10°F to +125°F).

e. Provide redundancy for any operating mechanism.

f. Be contained within the allowable payload dynamic envelope.

g. Use materials and finishes that will not outgas.

Tilt system specific design requirements are:

a. Rotate the aft frame at an angular rate of 12 ± 6 degrees per minute.

b. Elevate the IUS to 29° for checkout and to 58° for separation.

c. Provide the capability to elevate the IUS to 90°.

d. Retract the aft frame to the stowed position with the IUS attached.

e. Retract the aft frame to the landing lock position (-[illegible]) without the IUS attached.

f. Provide redundant drive systems.

g. No intentional load paths during boost.

h. Decouple a failed drive system.

AFT FRAME TILT ACTUATOR

Rotation of the IUS about the trunnion in the aft support frame is powered by the aft frame tilt actuator (AFTA), an electrically driven jack screw. The design is similar to the thrust vector control actuator described in reference 1. The power is provided by a reversible rare-Earth dc torque motor and tachometer mounted directly to a recirculating ball nut. The controller electronics are mounted on the aft support frame. The operation performance characteristics and the actuator assembly are shown in figure 2.

The lower curve of the performance diagram describes the worst case resistance torques. These include trunnion friction, electrical cable bending between the shuttle and the aft frame, IUS keel pin friction and two umbilical plug lanyards. The curve shows a margin in excess of 1 as required by specification DOD-A-83577A(USAF). Cable bending loads and umbilical plug forces have been verified in full scale development tests. Keel pin friction test results are shown in table 1 and cable bending loads are shown in table 2.

The AFTA system consists of the jackscrew, motor, tachometer, potentiometer, and electronic control assembly. The hollow machined screw is 98.8 cm (38.9 in) long and is supported on both ends by guide bushings. The ball nut is supported to the housing by a combination radial and thrust ball bearings. Position control for power off mission functions is provided by two meshing lock gears that mesh with a gear integral with the ball nut. With solenoids unpowered, return springs inside the solenoids hold the lock gears in mesh with the ball nut gear. When energized, the solenoids withdraw two gears from the ball nut gear, allowing the torque motor to drive. The locking gears operate independently and will perform their lock-unlock function even if one solenoid fails to operate.

The lead of the ball screw is .254 cm (0.10 in) and the normal rotational rate of the ball nut is 18 r/min. A linear potentiometer and wiper provide position information and switch signals to the controller. A tachometer provides the rate data to the controller. The rod end of the actuator connects to a slip-ring assembly mounted on the aft frame.

SLIP RING

The slip ring shown coupled to the AFTA in figure 3 provides the means to decouple the AFTA during boost. The requirement results from the two-stage aft frame mounting to the shuttle cargo bay longerons. A 1.83 m (6 ft) long spreader spring supports each end of the aft frame. Deflections of the spring would create a load path through the AFTA if coupled during boost or landing.

An engage pin mounted within the aft frame structure is spring loaded and offset from the mating hole in the slip ring. As the spreader spring deflects under IUS oscillations in boost, the engage pin moves along the slip ring approaching but never entering the engage hole. A redundant load path through the tilt actuator is avoided.

Engagement of the actuator and slip ring to the aft frame to erect for launch of the IUS is accomplished when the actuator is extended until the mating hole is aligned with the engage pin. A signal at the crew station confirms engagement.

The tilt actuator and slip-ring system is completely redundant. The primary AFTA is located on the right-hand side of the shuttle with the alternate system located on the left side on the opposite end of the aft support frame. During operation of the primary actuator, the alternate system engage pin slides along the alternate slip ring, never aligning with the engage hole. A failure of the primary actuator system stops the erection cycle and will require the astronaut to remotely extend the alternate actuator until the alternate engage pin enters the slip ring hole. At that time, the pin puller of the primary system is fired, using two NSI cartridges to release the primary actuator from the aft frame. A spring cartridge rotates the primary actuator out of engagement to prevent any physical interference as the aft frame rotates back to lock for landing.

KEEL PIN EXTRACTOR SPRING

During the erection cycle of the IUS from the shuttle, the keel pin at the forward frame to IUS interface must be withdrawn. This is normally a simple matter unless the shuttle has assumed a distorted shape because of differential heating of the two sides of the cargo bay. The resulting Y loads on the keel pin could overload the tilt actuator since this friction is applied at a moment arm of about 3.35 m (11 ft) from the aft frame pivot.

The keel pin is shown in figure 3. The pin is machined from 4330M steel and chrome plated. The IUS keel pin socket is machined from 6Al-4V titanium anc coated with Vitrolube[2] dry film lubricant. Selection of this material combination was made after completion of a simulated keel pin friction test summarized on table 1. The test objective was to find materials with a consistent coefficient of friction of less than 0.1 at very low loads. The objective was not met which resulted in a decision to design a spring assist system to ensure successful keel pin extraction under the worst expected keel pin side loads. The spring has 4 coils rated at 445 N each (100 lbf). In terms of aft frame rotation moment applied at an arm of 3.35 m, we have 5330 N·m (47174 lbf·in). This moment will overcome a keel pin initial side load of 4450 N (1000 lbf) with a margin of 1 if the coefficient of friction is 0.2 or less. The keel pin is disengaged after 2.3 cm (0.90 in) of travel. The spring leaves the IUS after about 3 cm of travel and is not reactivated throughout the remainder of the mission.

DEPLOYMENT SYSTEM DESCRIPTION

The block diagram and time line of figure 4 is a schematic description of the system. The power control panel is mounted in the shuttle crew station and contains all control switching except the payload retention latch actuator (PRLA) which remains on the shuttle A6 panel. The power control unit and the two AFTA controllers are located on the ASE cradle aft support frame.

In a typical mission after the space shuttle is in orbit, the flight crew orients the shuttle and opens the cargo bay doors. The primary AFTA is extended until the slip ring engage pin enters its mating hole and signals engagement. The latches on the forward support frame are opened and the IUS spacecraft is elevated to an angle of 29 degrees for completion of the spacecraft electrical

[2] National Process Industries

checkout through the IUS-to-shuttle umbilical cables. After verification of spacecraft flight readiness, the crew disconnects the umbilical plugs and the umbilical cable tray moves away from the IUS for deployment clearance.

The AFTA is again extended to an IUS-spacecraft angle of 58 degrees with the space shuttle center, the Super*Zip is fired, the IUS separates structurally from the aft support frame, and the separation springs provide the impulse to separate the IUS from the space shuttle.

Once separated, the AFTA is retracted to return the aft support frame to its original position plus 6 degrees to engage landing locking pins and to capture the umbilical boom to a latch located on the forward support frame. The pin puller is fired to disengage the AFTA and eliminate a redundant load path. The payload bay doors are closed for reentry or repositioning of the space shuttle for operation with other payloads.

The tilt mechanism system contains built-in redundancy by providing two actuators, two controllers, two power supplies, two switching systems, and two slip ring mechanisms.

CONCLUDING REMARKS

The AFTA and slip ring mechanisms meet the established design requirements for operation in a near Earth orbit.

A test program is planned to gain confidence that the system will successfully perform as required. The IUS and aft support frame will be statically balanced about a single tree and sling support. A counterweight will exactly balance the test article. During the rotation test, measurements will be made to verify that the required drive margins are present.

REFERENCES

1. G. E. Conner: IUS Thrust Vector Control (TVC) Servo System, 13th Aerospace Mechanisms Symposium, NASA CP-2081, 1979.

TABLE 1.- KEEL PIN FRICTION TEST

MATERIAL/FINISH (TEST CONDUCTED AT ROOM TEMPERATURE)	LOAD, N	DYNAMIC* FRICTION COEFFICIENT
TITANIUM/CANADIZE AGAINST 4130 STL/CHROME	1333	.29
	2000	.31
	2667	—
TITANIUM/VITROLUBE AGAINST 15-5 PH/VITROLUBE	1300	.16
	2000	.15
	2667	.17
TITANIUM/VITROLUBE AGAINST 4130 STL/CHROME (SELECTED)	1300	.14
	2000	.14
	2667	.15
TITANIUM/EVERLUBE 620 AGAINST 4130 STL/CHROME	1300	.22
	2000	.24
	2667	[illegible]
TITANIUM/PLASMA SPRAYED Cr_2O_2 AND ~~EVERLUBE 620~~ AGAINST 4130 STL/CHROME	1300	[illegible]
	2000	.23
	2667	.23

* CONSTANT VELOCITY OF .38 cm/sec.

TABLE 2.- ELECTRICAL CABLE TORQUE TESTS

	UMBILICAL CABLE IN BENDING (90° TO 0°)		UMBILICAL CABLE IN TORSION	
ANGLE	*TORQUE (21°C), N·m	TORQUE (-51°C), N·m	TORQUE (21°C), N·m	TORQUE (-51°C), N·m
22.5°	1.7	4.1	1.4	3.8
45°	1.4	3.6	1.4	5.0
67.5°	2.6	3.3	3.1	6.2
90°	1.9	3.3	3.1	6.2
POWER AND CONTROL CABLE BENDING				
ANGLE	TORQUE (21°C)●, N·m	TORQUE (-51°C)●, N·m	TORQUE (21°C)▲, N·m	TORQUE (-51°C)▲, N·m
0°	-6.8	-1.4	17.6	15.6
30°	1.4	19.0	7.5	5.4
60°	3.4	20.3	4.2	3.4
90°	12.9	29.8	12.9	1.4

● ERECT CYCLE 0° TO 90° ▲ RESTOW CYCLE 90° - 0° *1 N·m = .73756 lbf·ft

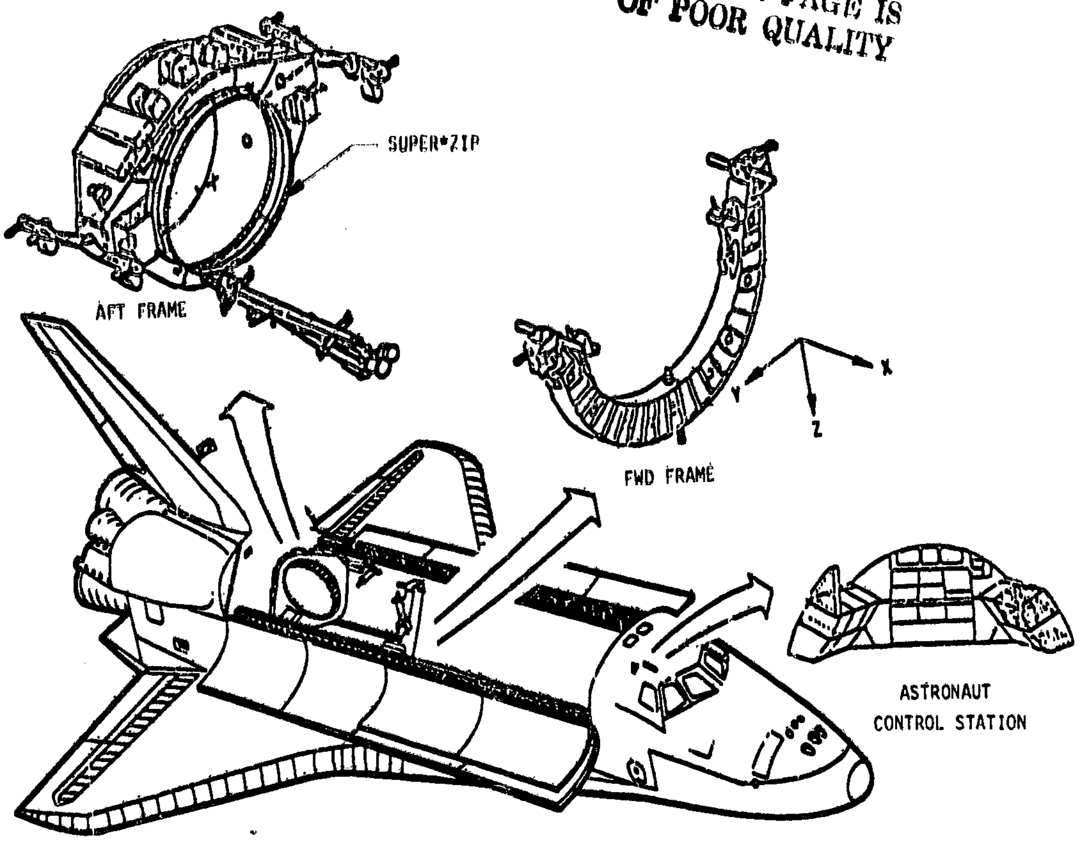

Figure 1.- IUS airborne support equipment.

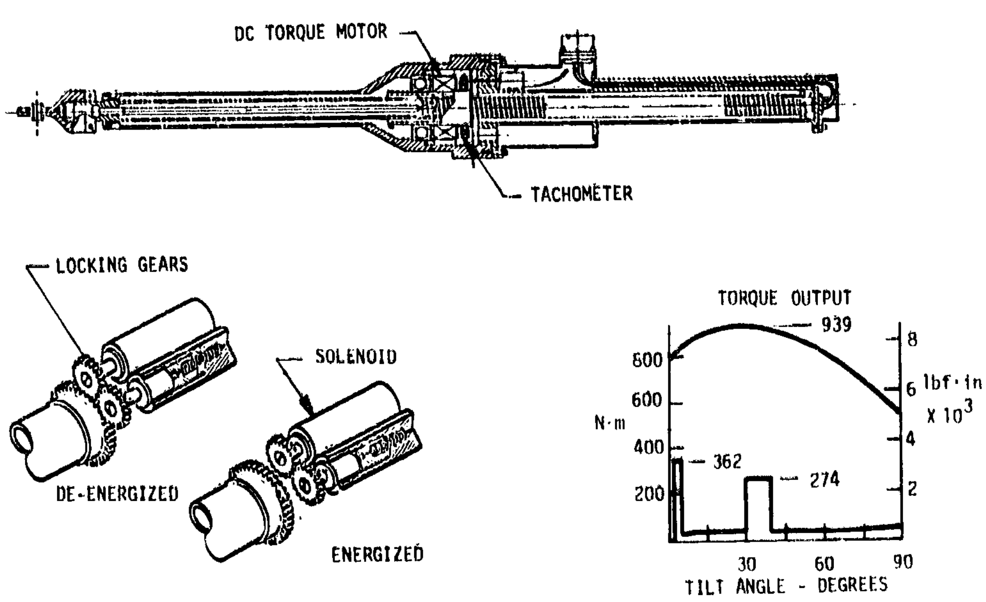

Figure 2.- Tilt actuator and performance characteristics.

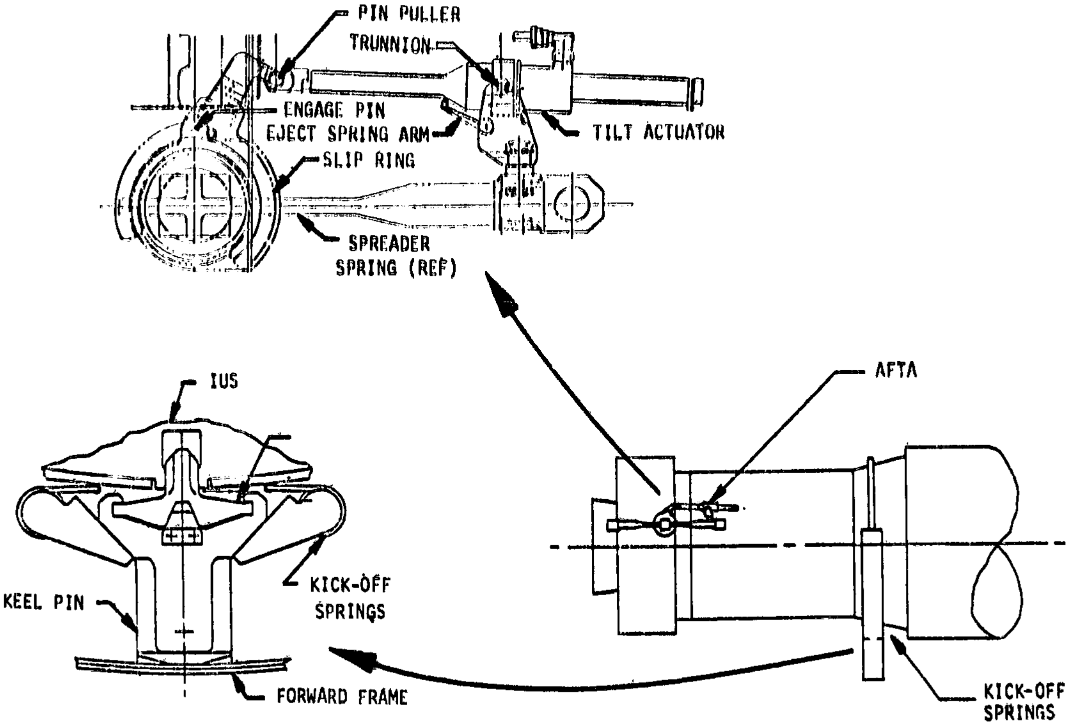

Figure 3.- Tilt mechanisms.

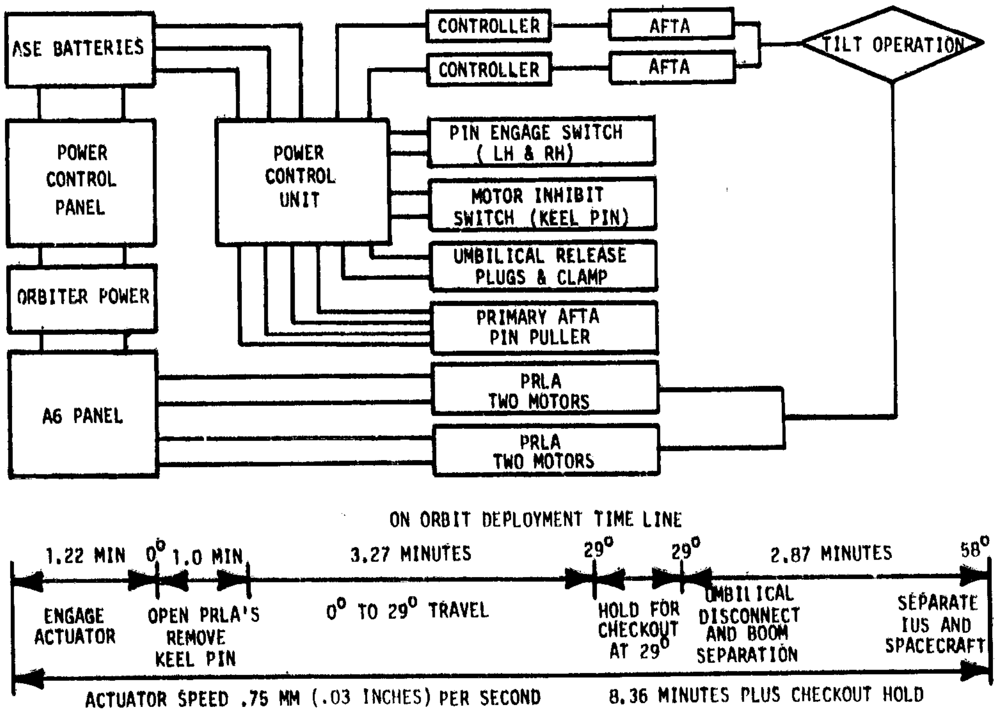

Figure 4.- Block diagram and time line description of deployment system.