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A DUAL, FAULT-TOLERANT AEROSPACE ACTUATOR

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ABSTRACT

The requirements for mechanisms used in the Space Transportation System (STS) are to provide dual fault tolerance, and if the payload equipment violates the Shuttle bay door envelope, these deployment/restow mechanisms must have independent primary and backup features. This paper describes the research and development of an electromechanical actuator that meets these requirements and will be used on the Transfer Orbit Stage (TOS) program.

INTRODUCTION

This deployment/restow mechanism will be used to perform three separate functions on the TOS program:

- Provide power to latch and unlatch the upper half of the forward Airborne Support Equipment (ASE) cradle.
- Provide power to open and close the upper half of the forward ASE cradle.
- Tilt the TOS/spacecraft (TOS/SC) combination for separation from the Shuttle and restow the aft ASE cradle for landing.

The Shuttle/TOS on-orbit configuration is illustrated in Figure 1.

REQUIREMENTS

The requirements imposed on the actuator mechanism to perform the required functions are summarized as follows:

Safety Requirements (in accordance with NHB 1700.7A)

- Independent primary and backup actuator functions are mandatory.
- Combination of primary and backup methods must be two-failure tolerant.

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Operational Requirements

- Provide power to latch and unlatch the forward cradle halves.

- Provide power to open and close the upper half of the forward cradle 112° ±5°.

- Erect the TOS/SC combination 45° ±5° for separation.

- Provide erection capability under active Vernier Reaction Control System (VRCS) or free-drift conditions the Primary Reaction Control System, (PRCS) and Orbiter Maneuvering System (OMS) are inhibited during rotation.

- Provide capability to react VRCS and PRCS when TOS/SC is in the erected position.

- Provide multiple erection/restow cycle capability for each mission; restow capability for an abortive mission is mandatory.

- Provide performance for 80 orbiter missions over 10 years.

System Requirments

- Unlatch or latch forward cradle in less than 4 minutes.

- Raise or lower forward cradle half 112° in less than 2 minutes.

- Erect or restow TOS/SC 45° in less than 2 minutes.

- Withstand all deployment and landing loads (each actuator). These loads to be reacted through the actuator structure and lock gears.

- Not to exceed 310 N (70 lb) per actuator.

- Operate at temperatures from -28°C to +59°C (-15°F to +140°F).

- Provide redundant limit switches, solenoids, DC power and avionics.

- Provide (one motor/clutch combination) sufficient torque under worst-case conditions to perform required function.

- Provide force margins of 100% at worst-case conditions for all actuators.

CONCEPT DEVELOPMENT

During the design trade-off phase, several priorities were established as design goals. These were

- o Satisfy all safety requirements of NHB 1700-7A without any waiver requests.
- o Use minimal design complexity and manufacturing simplicity.
- o Use previously qualified space hardware and components.
- o Provide a common design capable of a broad range of torque output forces with minimal configuration changes.
- o Combine additional mechanism functions within the actuator to eliminate additional separate mechanisms.

HARDWARE CONFIGURATION

Each actuator, as illustrated in Figure 2 consists of the following major components:

- o Structural housing containing the ball screw and nut assembly, reduction gear train, and attachment clevis ends.
- o Redundant DC gearhead motors.
- o Redundant DC solenoid-type, positive-engagement clutches.
- o Spring-loaded drive-engagement pin and pyrotechnic disengage.
- o Redundant position-indication potentiometers.
- o Redundant solenoid-powered lock gears.
- o Redundant microswitches for lock-gear and actuator-engagement-pin indication.

ACTUATOR FEATURES

Most actuator systems presently being used on the STS are physically separated from the structure in the event of primary actuator failure, thus allowing the backup actuator to be used. These systems require separate swingaway, catch, and latch mechanisms. The Martin Marietta actuator is self-contained in the event of primary actuator disengagement. This is possible since the actuator selector drive pin with its pyro release is contained within the actuator. The disengaged primary actuator simply becomes a free-sliding, telescoping tube assembly.

Additionally, the actuator has been designed to withstand the orbiter launch and landing loads, the TOS/SC deployment loads, and the orbiter maneuvering loads. This design feature eliminated the requirement for a separate landing lock mechanism and a deployment lock mechanism.

Rate control is normally used with actuators to control the output speed and prevent excessive slew rates to the payload being raised for deployment. This closed-loop, complex electronic control is required on rotary actuator systems and some existing screw-drive systems to prevent a possible runaway condition.

In the Martin Marietta actuator, this rate controller can be eliminated because drive motor gearhead reduction limits the maximum RPM. Maximum screw extension/retraction rates cannot exceed the free running speed of the drive motor as reduced through the reduction gear train and drive nut.

The maximum impact force when erecting the TOS/SC is less than 33.9 N-m (25 lb ft.). This low impact force allows the use of a simple structural hard stop, rather than a viscous damper.

The actuator motor shutoff is accomplished by use of a redundant motor current limiting circuit. The structure being deployed, or stowed, contacts a structural hard stop, thus increasing motor current demand, and motor shutoff occurs.

This method allows the required 100% force margin at worst-case conditions, while preventing structural overloads under best-case conditions. Additionally, the clutch assembly can be adjusted to slip at a predetermined torque, also preventing an accidental overload condition. Position indication to the crew is accomplished by the use of redundant rotary potentiometers that provide actuator extension/retraction data.

Since the actuator mechanism is a back-driveable device, a locking mechanism must be incorporated. A redundant, solenoid-operated, dual-gear, mesh lock has been selected for this design. A similar design has previously been used on the Inertial Upper Stage (IUS) program.

DISCUSSION

This actuator mechanism meets all the STS safety requirements as defined in NHB 1700.7A, and also meets the structural, life, and TOS mission requirements for the following reasons:

- The orbiter crew can use the Standard Switch Panel (SSP) at any point in the actuation cycle to stop, restart, and disengage the primary actuator, and engage the backup actuator. This allows for complete restow of the TOS/SC in case of a mission abort.

- Force margins are at least 100% greater than the required torques at worst-case conditions (Figures 3A, B and C).

- Each pair of actuators, primary and backup, has triple electrical redundancy and complete mechanical redundancy.

- All rolling-element bearings are sized to exceed the L10 life by a minimum factor of 17.

- Each actuator is capable of greater than 1000 duty cycles during its operating life, which far exceeds the 80 mission requirement.

- Clutches are designed for positive power-off disengagement using redundant, captive compression springs.

- The structural ultimate factor of safety is 1.4 minimum. Gear stress levels are less than one-fourth of the material ultimate stresses.

- Lubrication is a combination of wet and dry lubricants. All sliding surfaces are treated with space-qualified dry lubricants; however, they are designed to function without lubrication. All bearings, gears, and ball screw are lubricated with Bray Oil 3L-38RP, a qualified vacuum-stable grease.

- The static load capability of the actuator is 8000 lb.

- The actuator design can be easily modified to meet a variety of force and extension/retraction rate requirements (Table 1).

CONCLUSION

The actuator design selected for use on the TOS program meets the requirements for STS safety requirements. This design has successfully passed the NASA Phase I Safety Review without receiving any mechanical Review Item Discrepancies, nor were any safety waivers required. The design studies and tradeoff analysis resulted in a multifunction, simple mechanism that is easily adaptable to various output torque requirements and extension/retraction cycle times.

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SHUTTLE/TOS CONFIGURATION

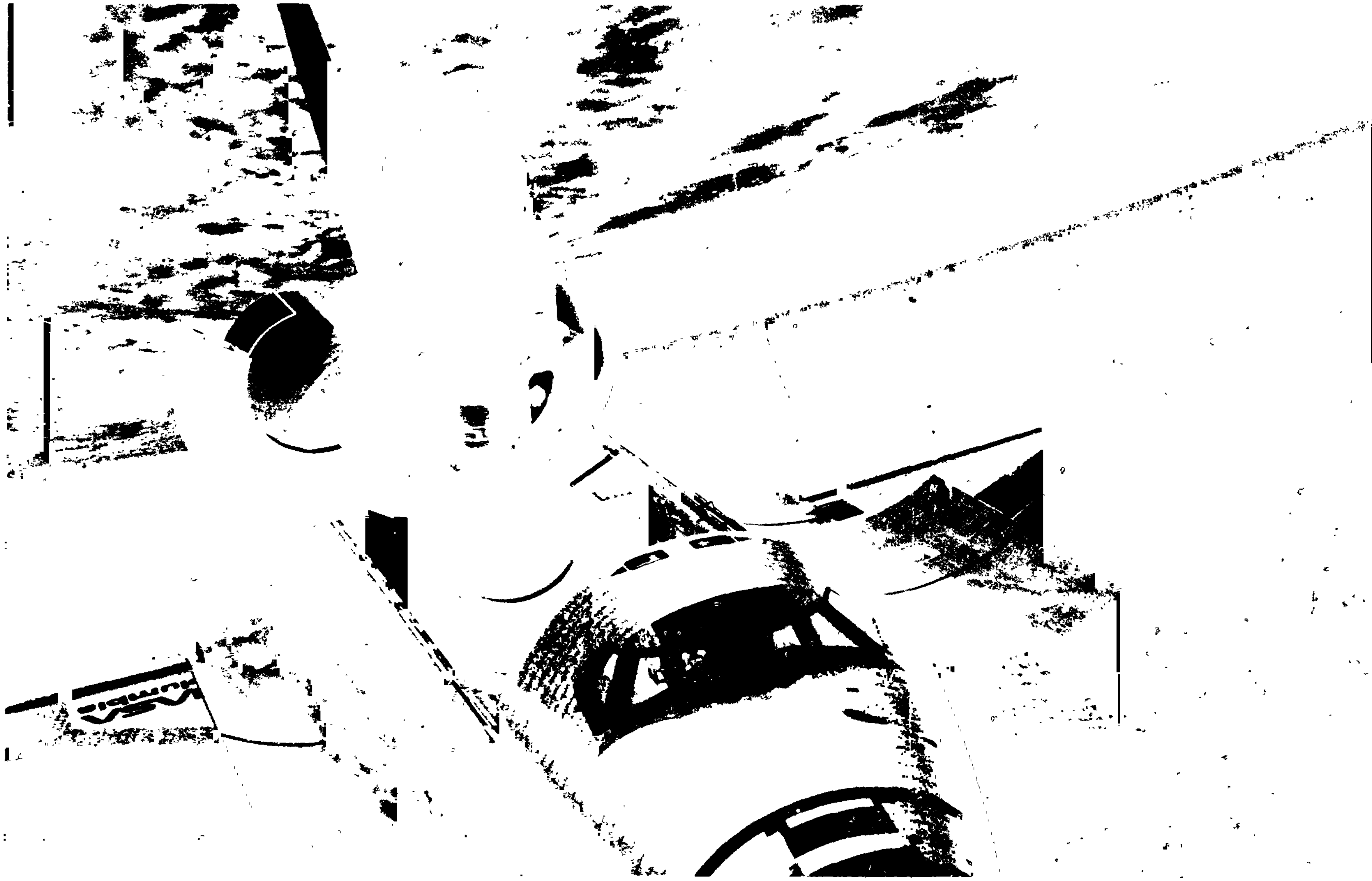

FIGURE 1

ELECTROMECHANICAL DRIVE ACTUATOR

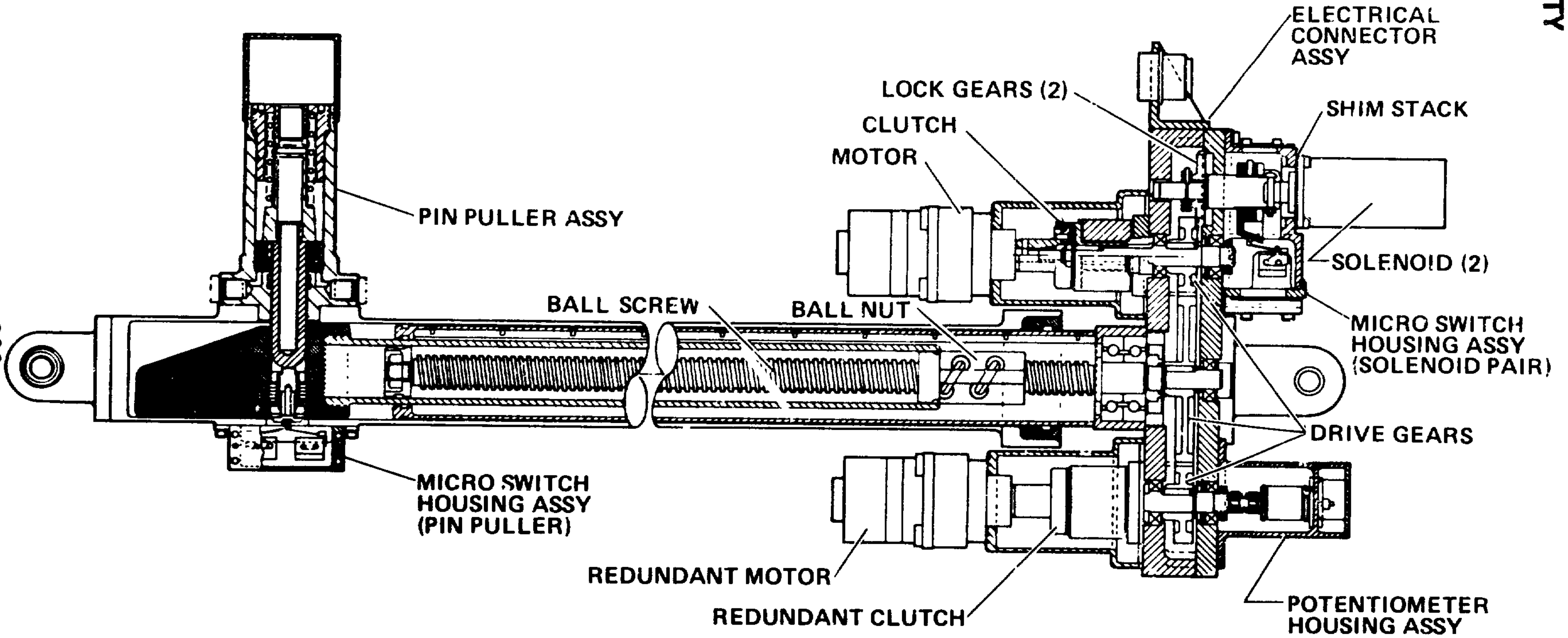

FIGURE 2

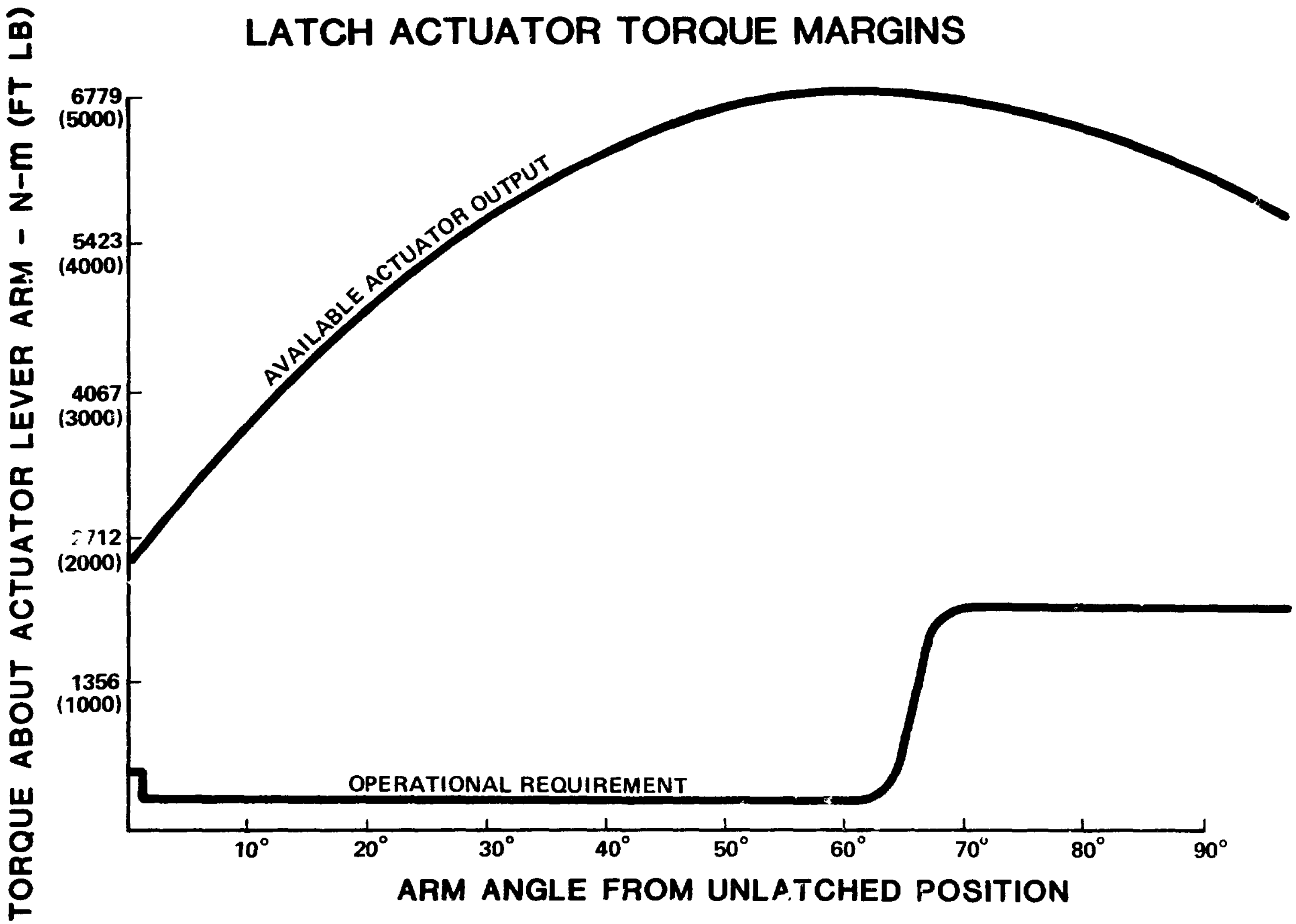
LATCH ACTUATOR TORQUE MARGINS
TORQUE ABOUT ACTUATOR LEVER ARM - N-m (FT LB)
6779 (5000)
5423 (4000)
4067 (3000)
2712 (2000)
1356 (1000)
AVAILABLE ACTUATOR OUTPUT
OPERATIONAL REQUIREMENT
10° 20° 30° 40° 50° 60° 70° 80° 90°
ARM ANGLE FROM UNLATCHED POSITION

FIGURE 3A

UPPER FORWARD CRADLE HINGE TORQUE MARGINS

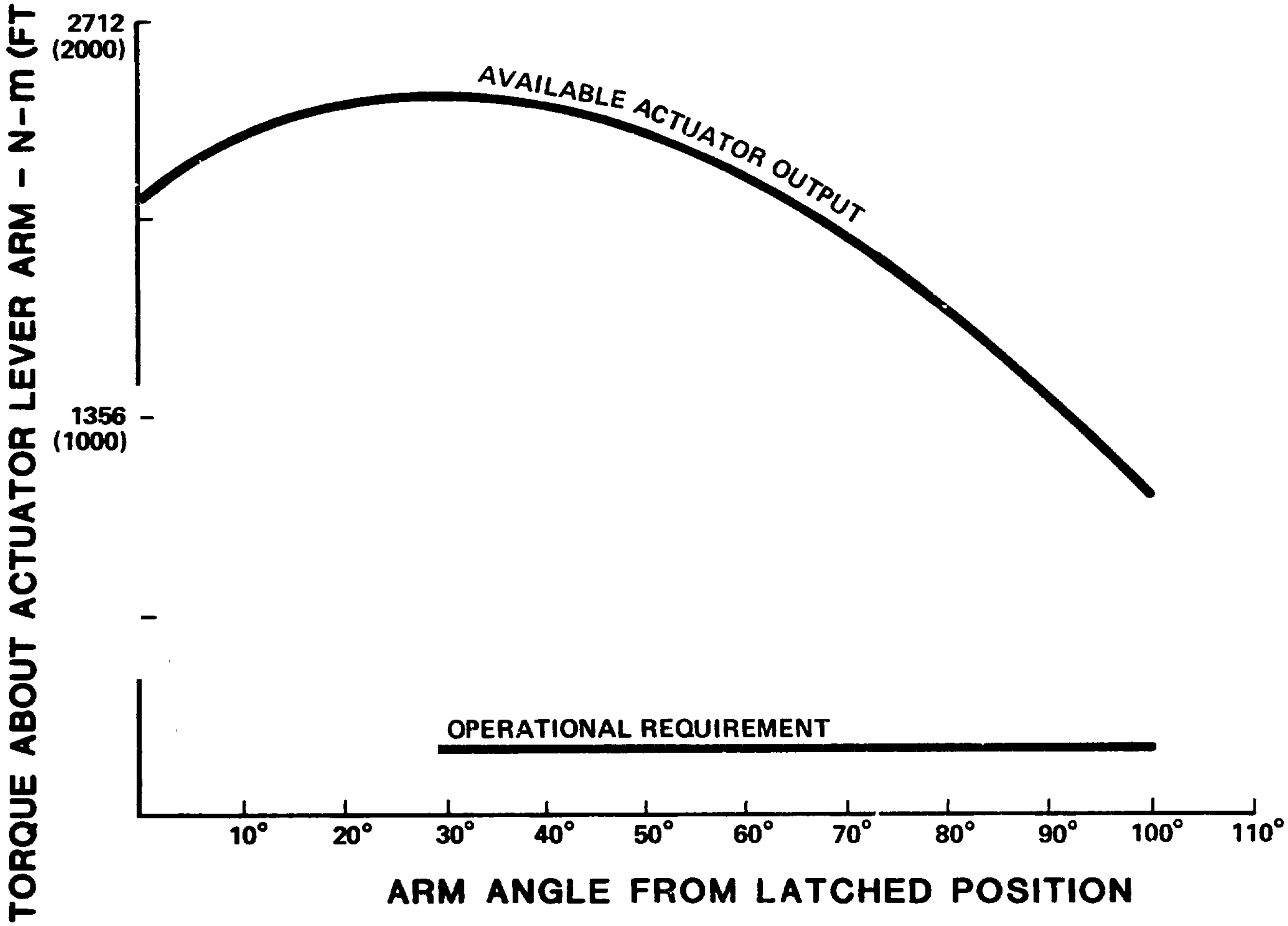

FIGURE 3B

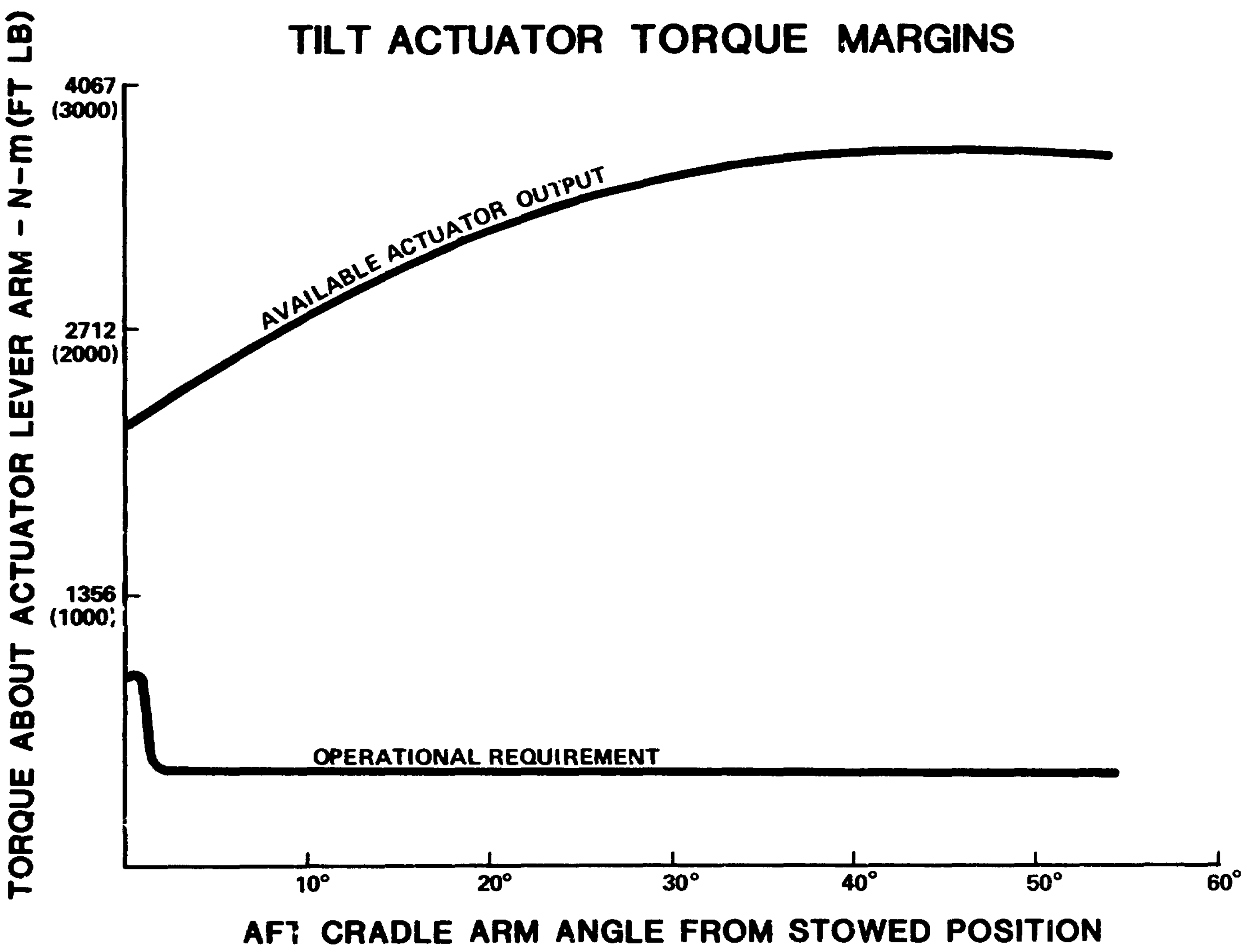
TILT ACTUATOR TORQUE MARGINS
TORQUE ABOUT ACTUATOR LEVER ARM - N-m (FT LB)
4067 (3000)
2712 (2000)
1356 (1000)
AVAILABLE ACTUATOR OUTPUT
OPERATIONAL REQUIREMENT
10°
20°
30°
40°
50°
60°
AFT CRADLE ARM ANGLE FROM STOWED POSITION

FIGURE 3C

TABLE 1

ACTUATOR CAPABILITIES

	LATCH ACTUATOR	TILT ACTUATORS
MAXIMUM FORCE BEFORE STALL	48930 N (11,000 LBF)	15569 N (3,500 LBF)
AVAILABLE FORCE (CURRENT LIMITED)	17793 N (4,000 LBF)	10053 N (2,262 LBF)
MAXIMUM EXTENSION/RETRACTION RATE. NO LOAD	2.54 mm/SEC (0.10 IN./SEC)	3.8 mm/SEC (0.15 IN.SEC)
AVAILABLE STROKE	432 mm (17 IN.)	432 mm (17 IN.)
STATIC LOAD CAPABILITY	35586 N (8,000 LBS)	35586 N (8,000 LBS)