ELECTROMECHANICAL ACTUATION FOR LAUNCH VECHICLES

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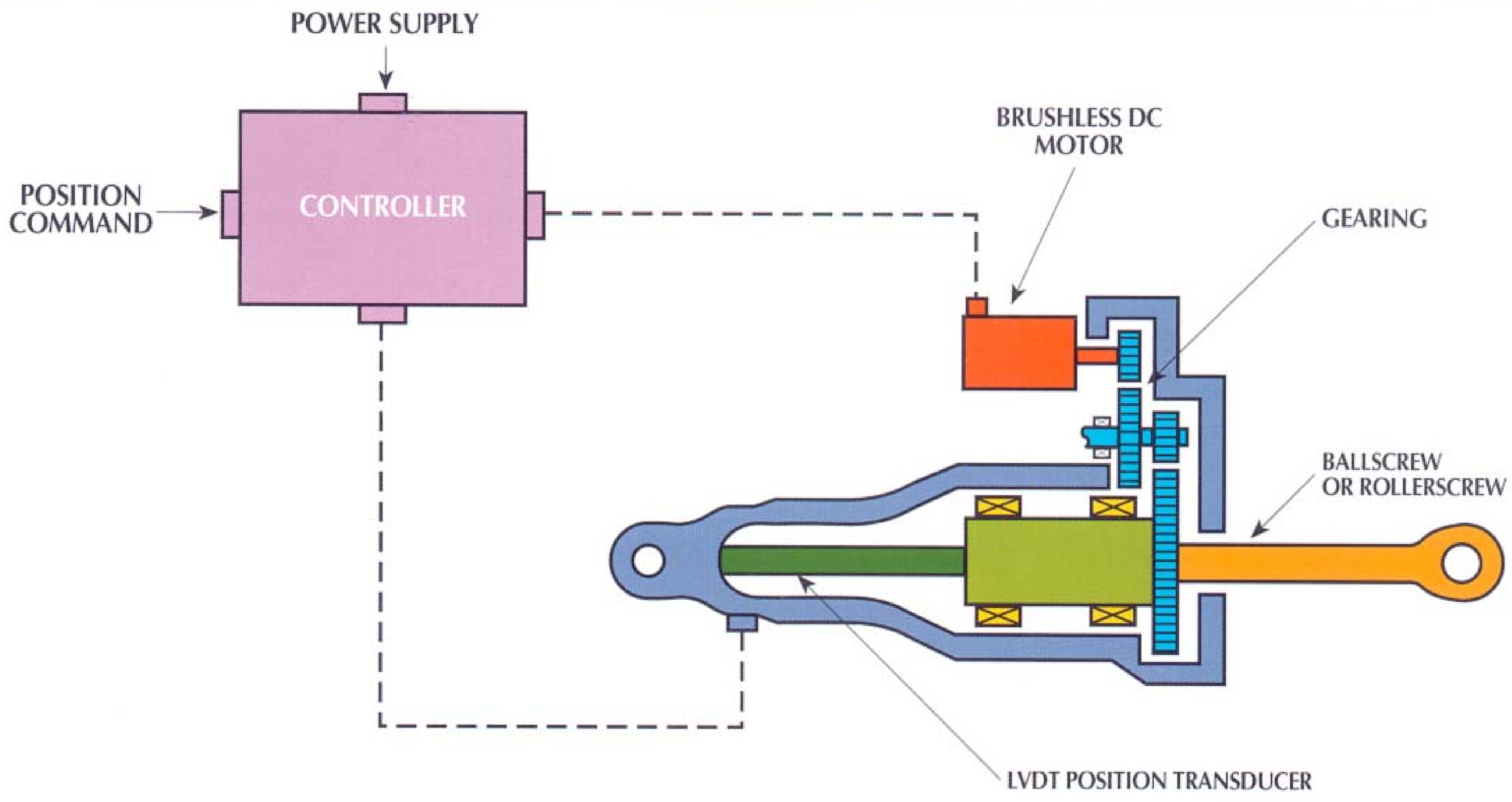
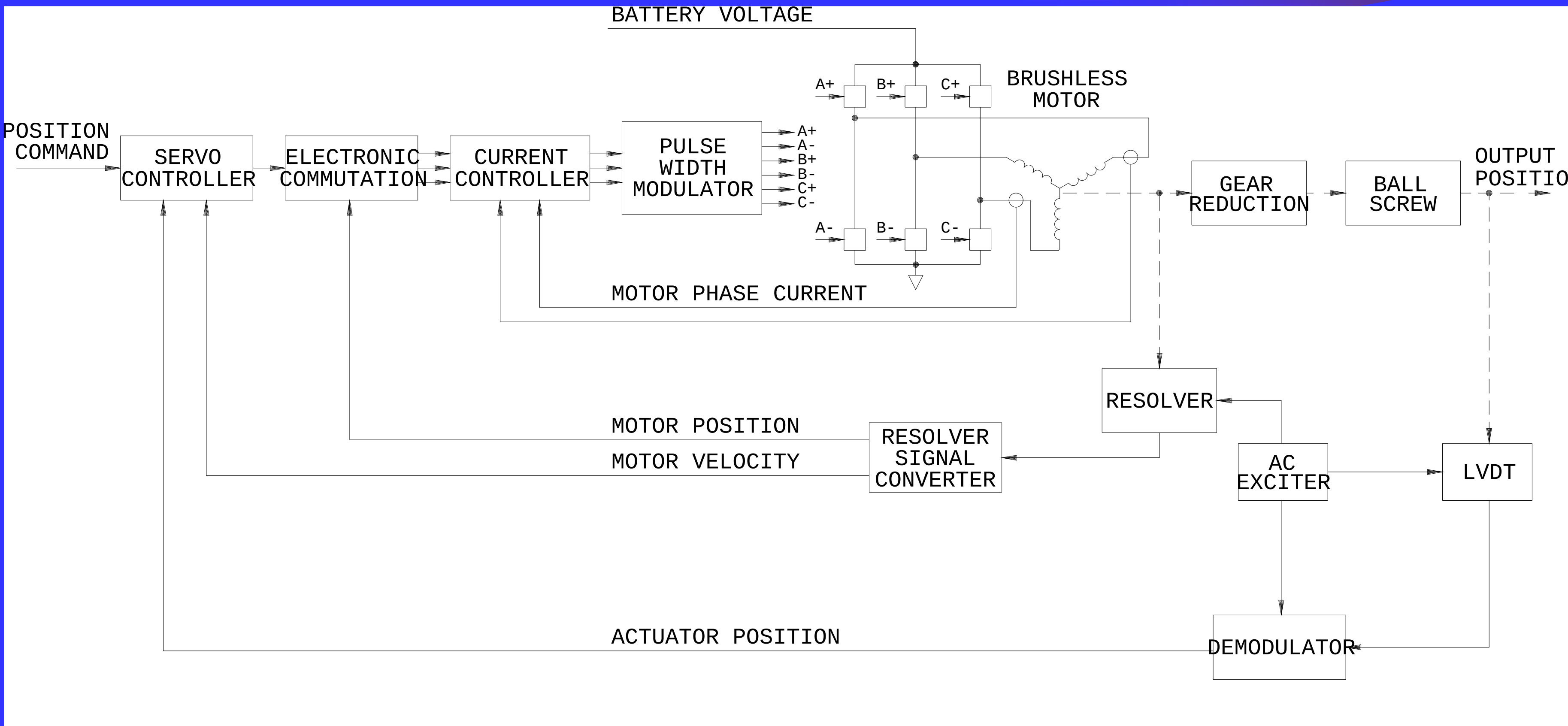
Introduction

- This paper describes recent developments in Electromechanical Actuation applied to Launch Vehicles. The following topics are discussed:
  - Electromechanical (EM) Actuation System Design
  - Comparison of Electromechanical and Electrohydraulic Actuation Systems
  - High Power EM Thrust Vector Control (TVC) Systems
  - Redundant EM TVC Systems
  - Propellant Valve Electromechanical Actuation

Electromechanical TVC Actuation System



Electromechanical Servoactuator System



Permanent Magnet Brushless Motor

Sinusoidal Motor Drive

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Comparison of EM and EH Actuation Systems

- **Advantages of Conventional Electrohydraulic Systems**
  - Mature Technology
  - High Reliability
  - Can Use Relief Valves to Limit Piston Force
    - Effective to Handle Impulse Load
  - Continuous Stall Torque Capability
  - High Acceleration Capability
  - No EMI Generation
  - Simple, Low Power Electronics
  - Mature Redundancy Implementation

Comparison of EM and EH Actuation Systems

- **Advantages of Electromechanical Systems**
  - Excellent Long-Term Storability
  - Easy Checkout
  - Easy Installation
  - Low Maintenance
  - Minimal Operations Cost
  - Low Quiescent Power
  - No Fluid Leakage
  - No Concern for Fluid Contamination
  - High Reliability
  - Lower Weight than Hydraulic Blowdown TVC Systems

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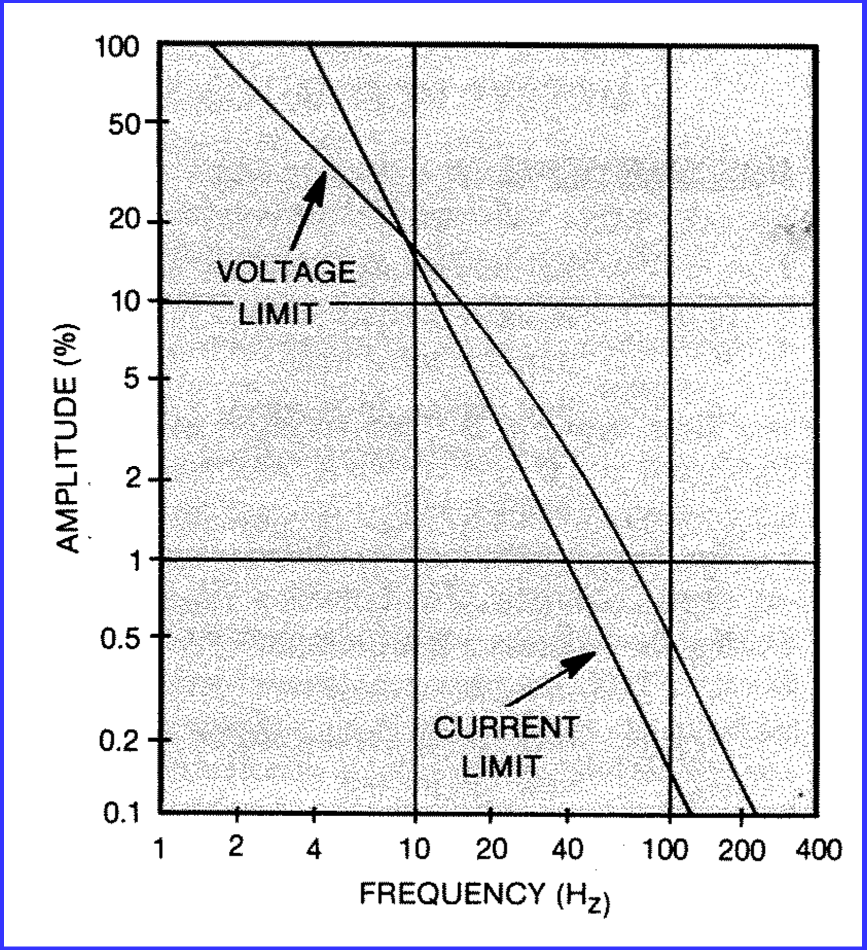
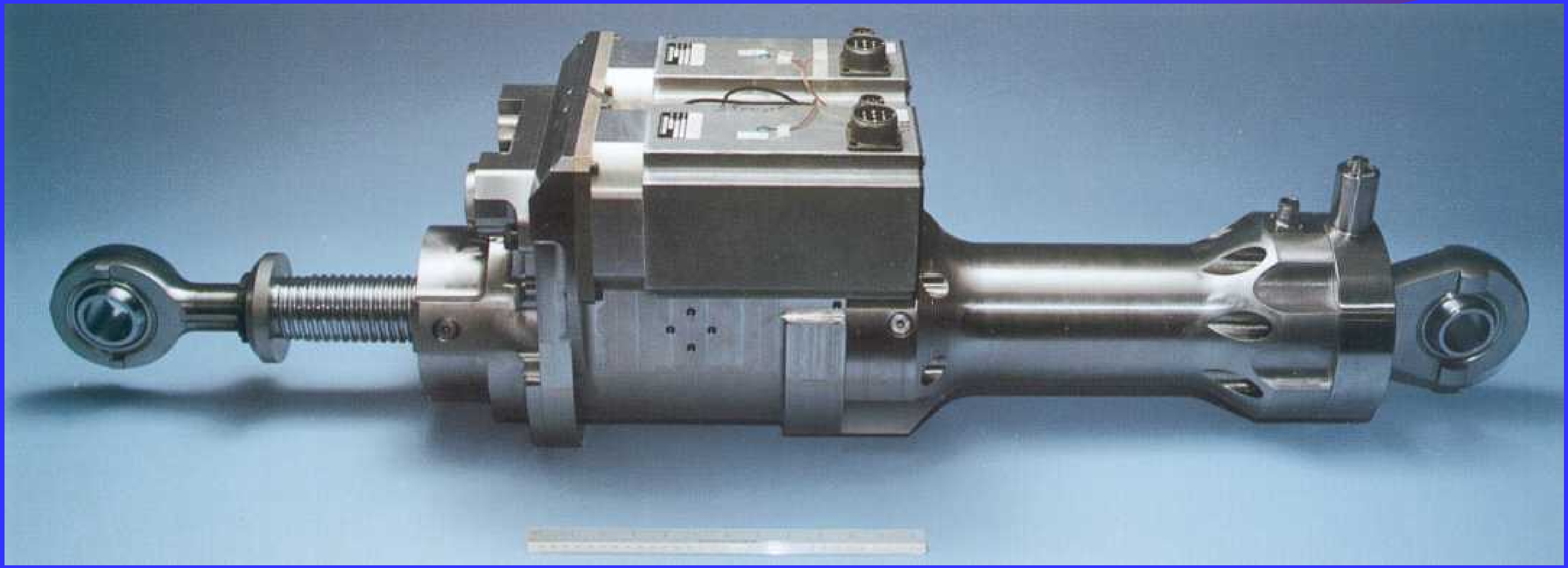
Limitation of EM Actuation Systems

Typical EM System Frequency Response Limits



38 HP EM TVC ACTUATOR Dual Torque-Summed Motors



Output Travel…….+/- 5.5 in

Stall Force …………55,000 lb

Rated Power………..38 HP

Output Force……..48,000 lb

Output Velocity…..5.2 in/sec

Impulse Load ….. 100,000 lb

Acceleration……..60 in/sec^2

Duty Cycle………10 min

Average Load…15,000 lb

Supply Voltage….270 VDC

Full Performance with one motor

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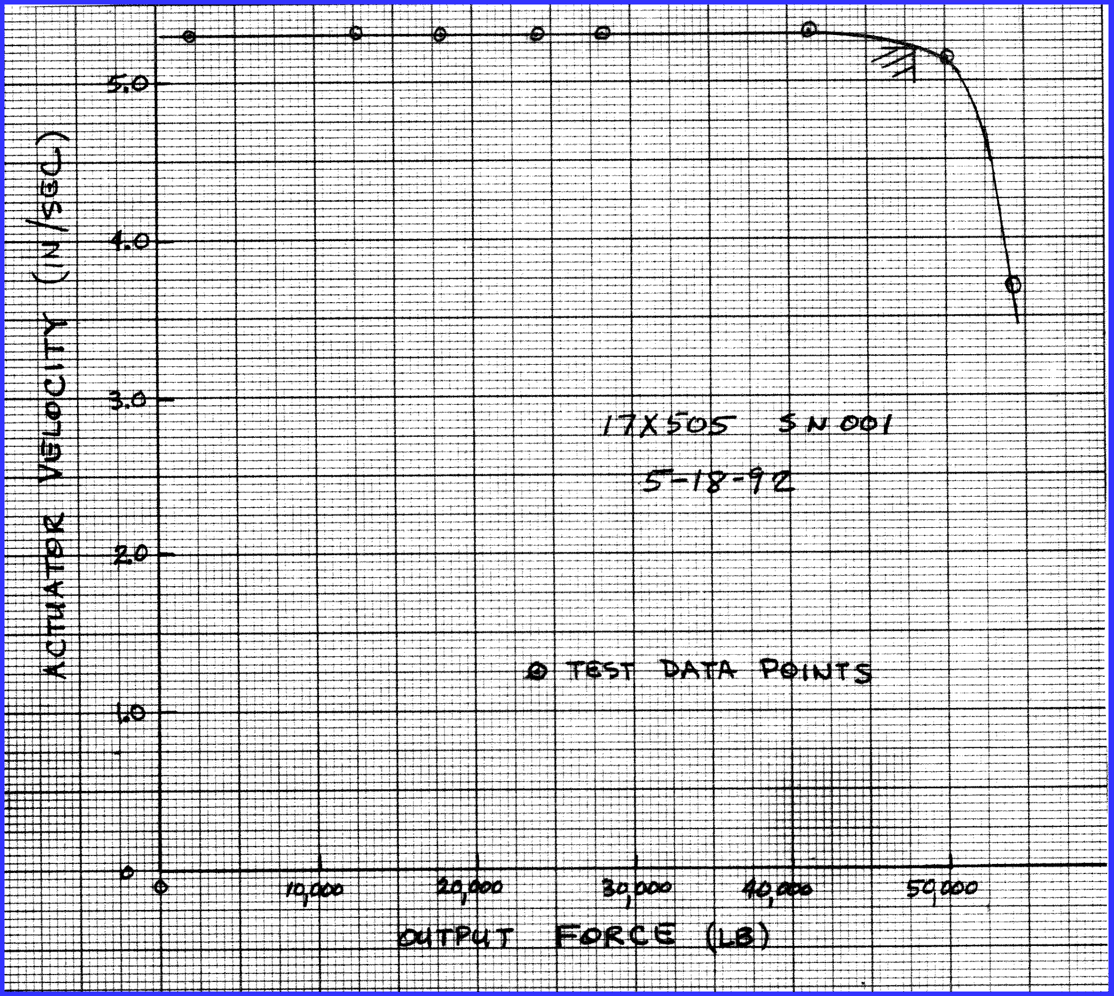
38 HP EM Actuation System

Force-Velocity Test Data On SSME Test Fixture



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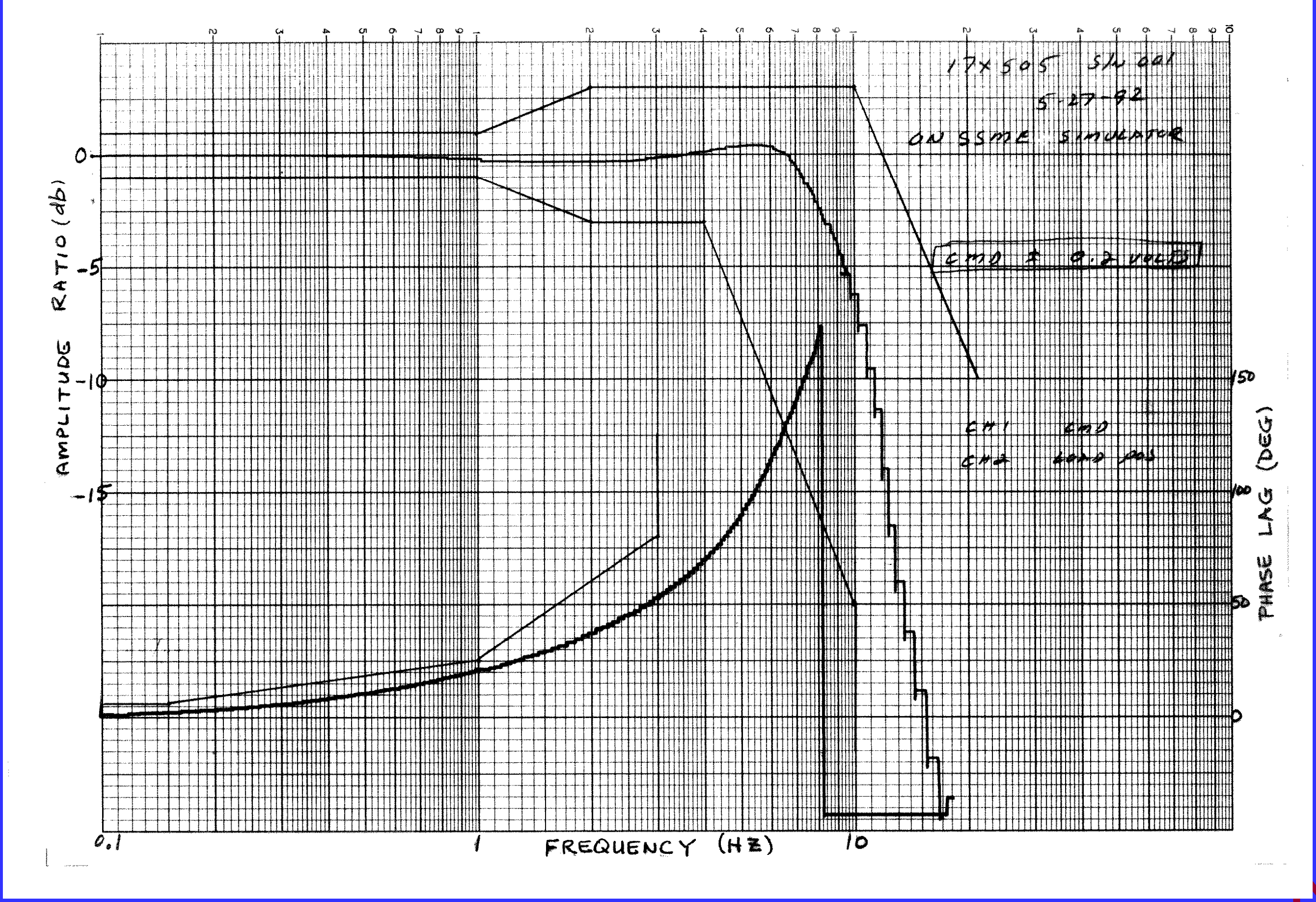
38 HP EM Actuation System

Frequency Response Test Data On SSME Simulator

Load Position Response (+/- 2 % COMMAND)



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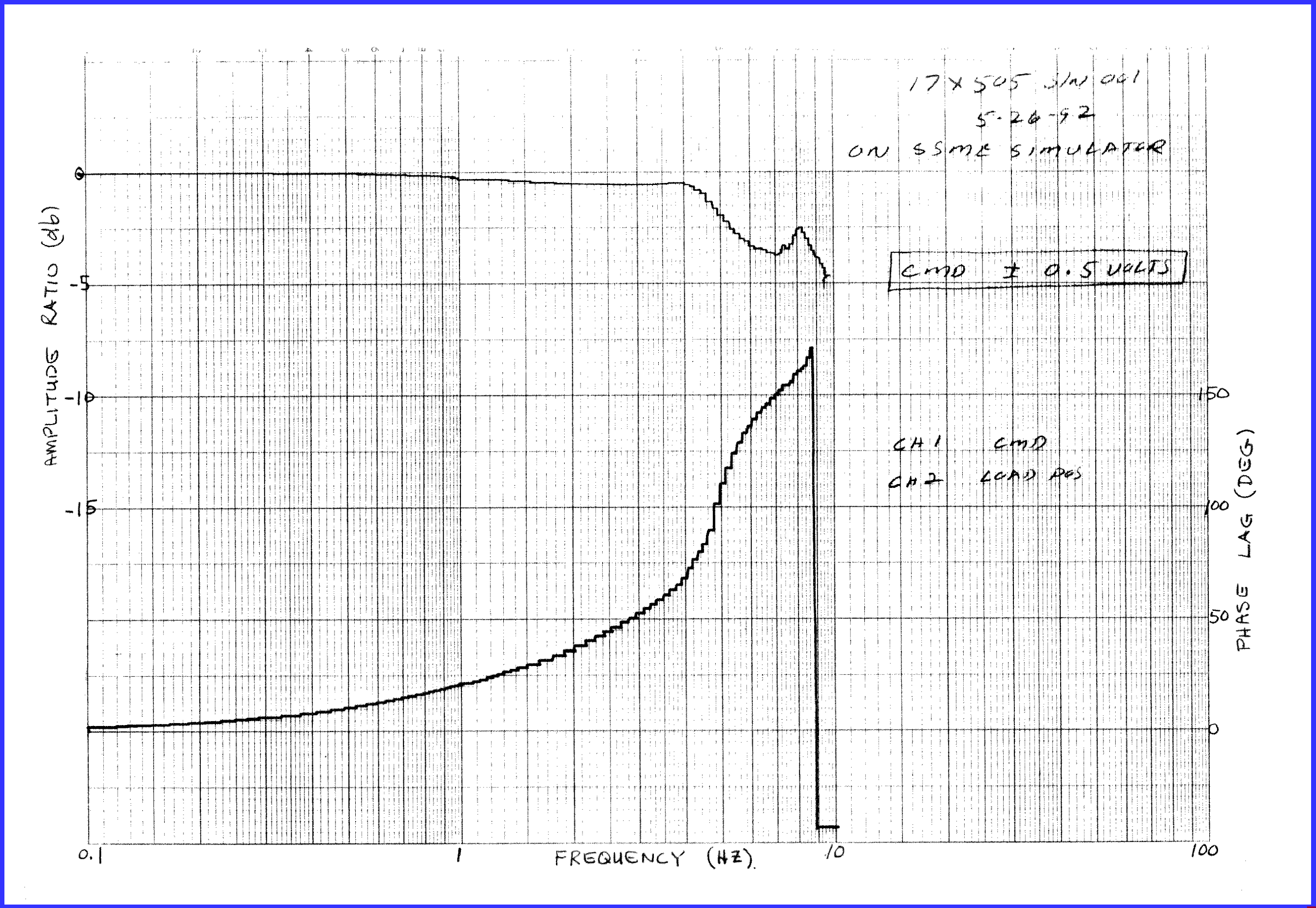
38 HP EM Actuation System

Frequency Response Test Data On SSME Simulator

Load Position Response (+/- 5 % Command)



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Controller

- Controller Critical to Performance of EM Systems
- Breadboard Controller Used to Demonstrate 38 HP EM TVC System
- Development of Flight Worthy High Power EM Controller

Moog DSP-Based Digital Controller

- Digital Loop Closure
- IGBT Power Stage
- 320 VDC Maximum Supply Voltage
- 200 Amps Peak Motor Phase Current
- Vector Control / Sinusoidal Motor Drive
- **Demonstrated with a 20 HP EM TVC Actuator**

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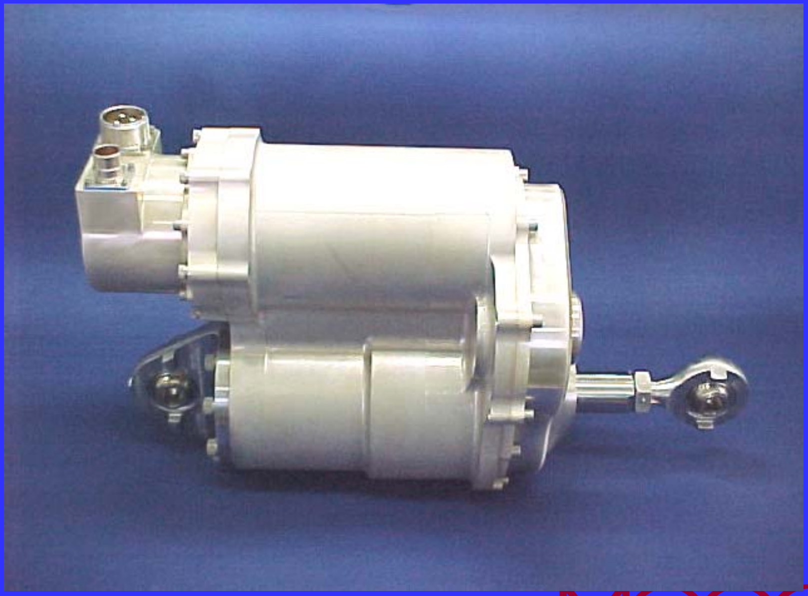
EM TVC Actuators For Large Solid Rocket Motors

Two TVC Actuators Have Been Demonstrated

	12 HP	21 HP
Stall Force (lb)	4600	31,000
Stroke (in)	+/- 1.92	+/- 1.5
Length (in)	15.5	17.0
Power Point		
Velocity (in/sec)	20	5.85
Force (lb)	4000	24,000
Weight (lb)	16	75
Voltage (VDC)	280	280

--- Brushless PM Motor
--- Ballscrew
--- LVDT



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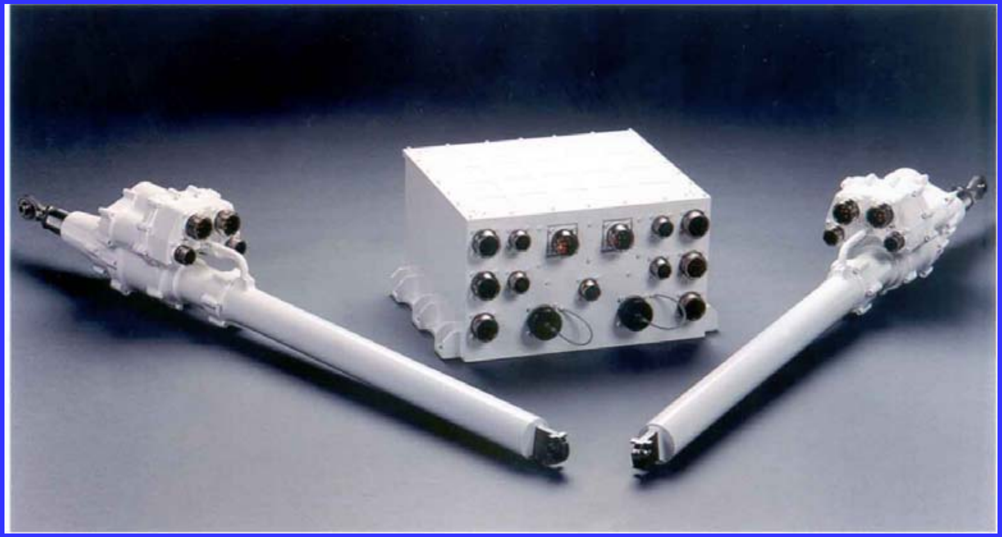
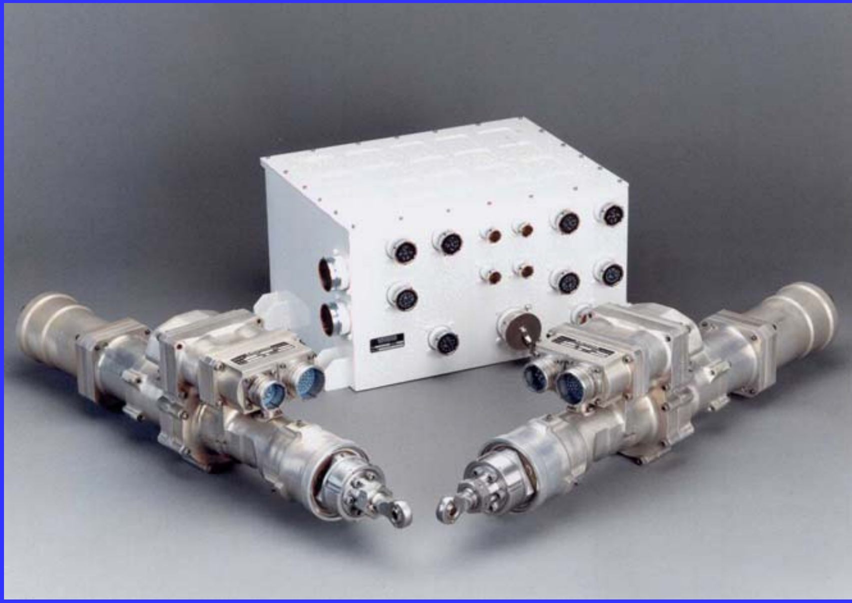
Upper Stage Redundant EM TVC Systems

- **Flight Proven**
- Active-Standby Redundancy
- Full Performance with one motor operating
- Six-Step Motor Drive





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Upper Stage Redundant EM TVC Systems

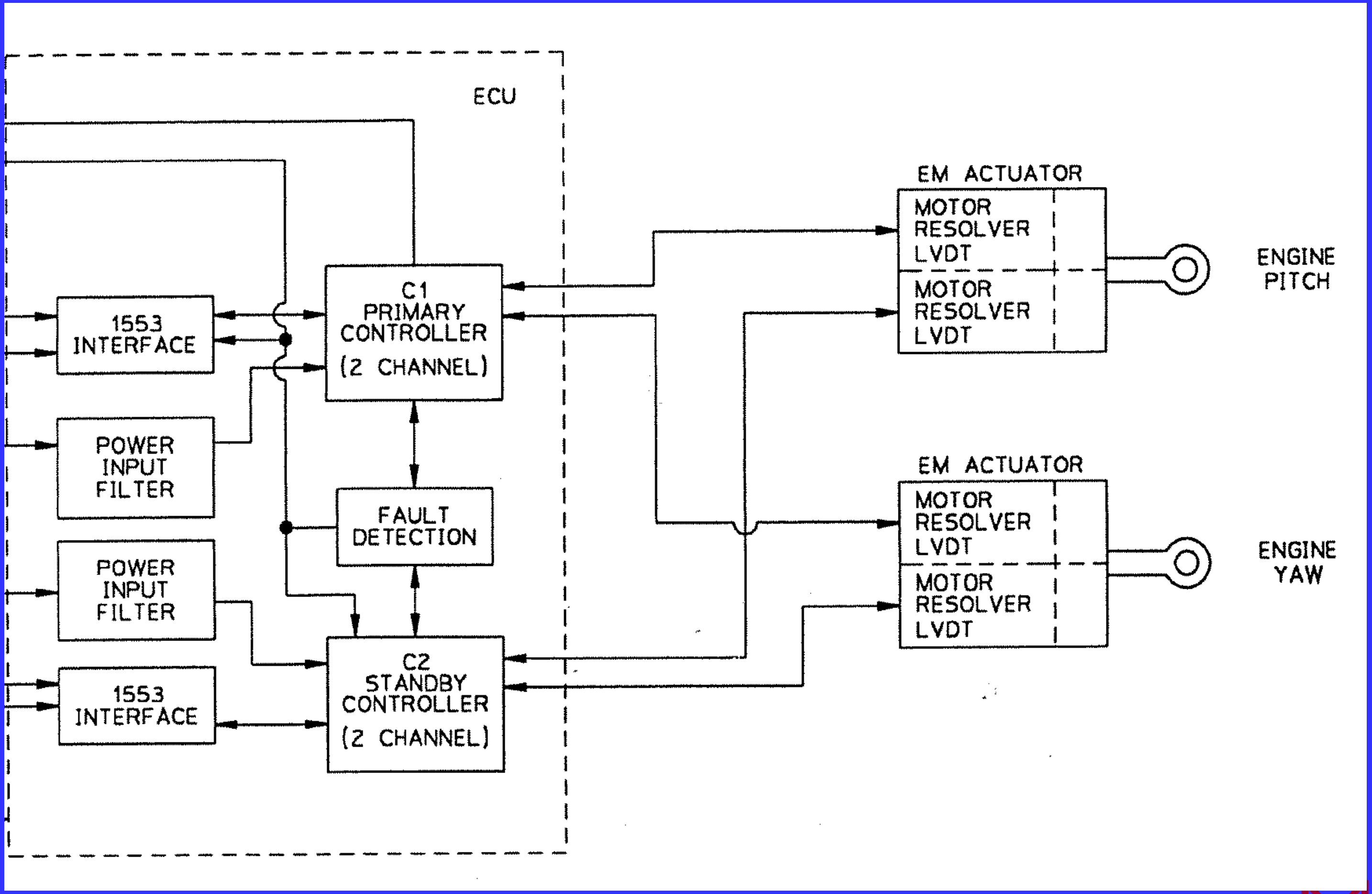
Typical Performance Summary

Stroke	+/- 0.75 in
Stall Force	2000 lb
No-load Velocity	3.0 in/sec
Output Power	0.4 HP
Frequency Response	90 deg phase @ 4.3 Hz
Actuator Length	23.25 in
Supply Voltage	28 VDC
Electrical Interface	MIL-STD-1553
Actuator Weight	17 lb each
Controller Weight	27 lb

Upper Stage TVC System Block Diagram

Active-Standby Redundancy

Full Performance With One Motor Operating



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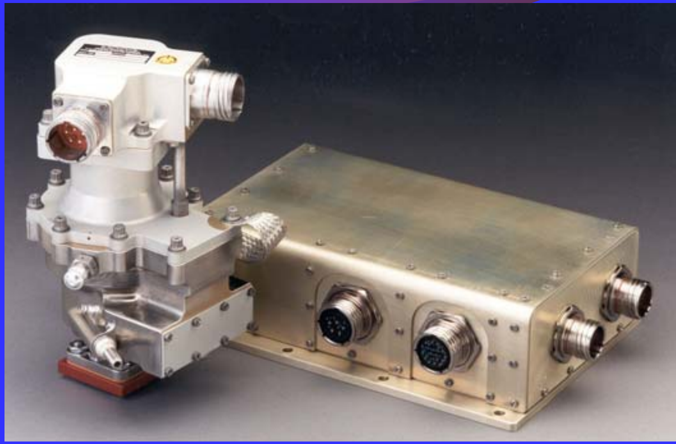
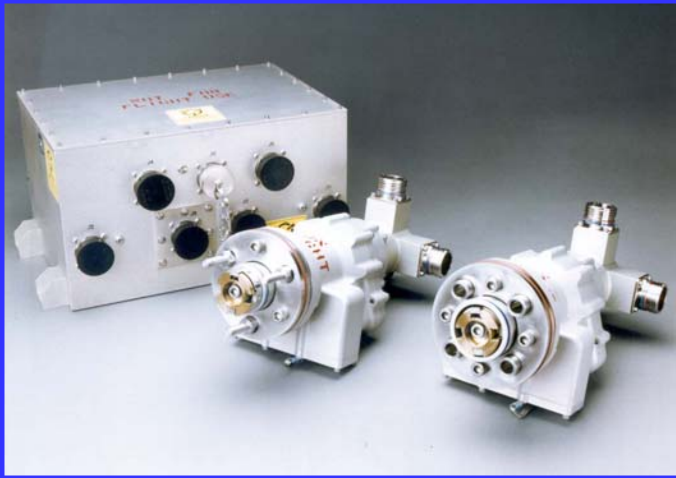
Propellant Valve EM Actuation Systems

- Dual Redundant Brushless Motors
- Harmonic Drive Provides Rotary Output
- Redundant Controller





Typical Performance

Stroke………………...+/- 70 deg
Output Power………..0.05 HP
Velocity………..340 deg/sec
Torque…………..60 in-lb
Actuator Weight…….8.2 lb
Controller Weight….21.3 lb
Voltage ……………..28 VDC

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Summary

- Electromechanical Actuation is a Reality for Launch Vehicles
  - **Flight Proven** EM TVC Systems on Upper Stages
- High Power Applications (Booster TVC Systems)
  - EM Actuation is a Viable Alternative to Electrohydraulic Actuation
  - High Power EM TVC Systems are **Flight Ready**
  - EM TVC Systems Offer the Potential of:
    - Lower Life Cycle Cost
    - Lower Weight