N87-22736

SPACE STATION

CONTROL SESSION 3B
HENRY WAITES, CHAIRMAN

SSS86-0047

PRELIMINARY EVALUATION OF A REACTION CONTROL SYSTEM FOR THE SPACE STATION

APRIL 22 - 24, 1986,
WORKSHOP ON STRUCTURAL DYNAMICS AND CONTROL, INTERACTION OF FLEXIBLE STRUCTURES, OAST AND MSFC

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Space Station Systems Division

INTRODUCTION

A new configuration called the "Dual-Keel" has been selected by NASA to accommodate the great number of payloads and experiments. The requirements and goals of a Space Station reaction control system (RCS) have been partially defined for this station.

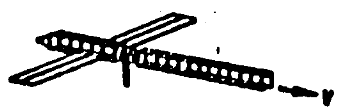
This briefing presents the challenges, the groundrules and criteria, some of the RCS concepts, classical and modern design analysis, and simulation results which are applicable to the Space Station. The objective is to present a preliminary Space Station RCS concept supported by analytical results which meets the given goals and requirements.

BUILDUP PHASES DICTATES GN&C ADAPTABILITY

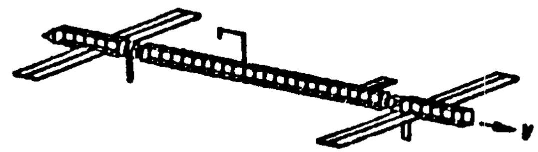
The buildup phases and the continuously changing configuration dictates adaptability in RCS design. The RCS software must be switched to account for the relocation of the propulsion system during assembly. The gains and filter coefficients need to be updated to improve performance and stability with each new configuration.

Buildup Phases Dictates GN&C Adaptability

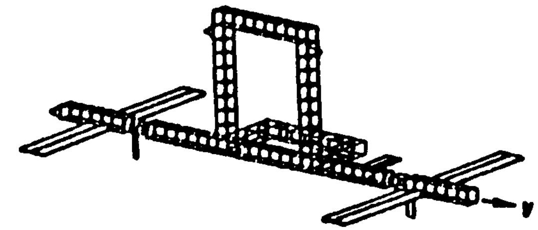
FACILITATE OPERATION AND USERS



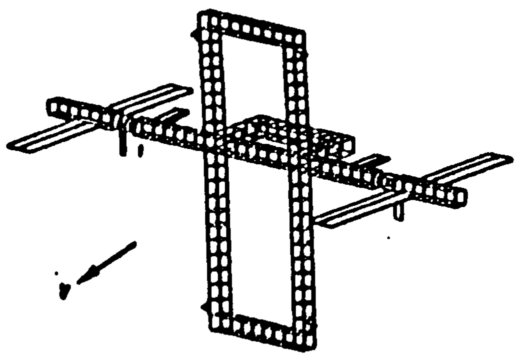
FLIGHT 1



FLIGHT 2

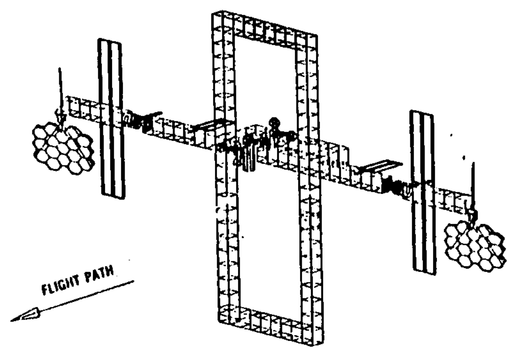


FLIGHT 3



FLIGHT 4

- Relocation of RCS



IOC

- Quiet Zone for Users
- USA / International
- Coarse Pointing Subsystem
- Dual Keel for Payload Service and Growth
- Hybrid Power
- Permanently Manned

CONSIDERATIONS:

- Establish Basic GN&C Capability on Flight 1
- Complete 3 Axis CMG and RCS Backup Control
- Place Thrusters for Reboost (Min. Altitude of 180 nmi)
- Allow Larger Angle and Rate for Momentum Dumping for Early Flights
- Add Traffic Control Later
- Add Payload Coarse Pointing as Needed.

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SCOPE AND METHOD OF APPROACH

The RCS design approach emphasizes groundrules for RCS thruster sizing. Concurrently, the appropriate criteria are determined. The RCS control concept is to develop compensation techniques by employing both modern and classical control methods for stability design and performance analysis with simulations. A non-real time simulation incorporating detailed dynamical models and many subsystem models is used to simulate the overall Space Station response to an RCS design during reboost, maneuvers, and Station disturbances.

RCS design parameters are chosen to meet structural and operational constraints as well as controllability and stability requirements. RCS thrust level, for instance, is chosen to meet the constraints of maximum allowable structural loads, reasonable time for reboost, and minimum structural/RCS interaction.

The thrust level may also have to be chosen so that it lies within a range applicable to a blowdown propulsion system. Overall Station performance requirements drive other RCS parameters such as thrust accuracy, minimum impulse bit, RCS loop gains, and jet select logic.

Scope and Method of Approach

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- EMPHASIZE GROUNDRULES FOR RCS THRUSTER SIZING
- DETERMINE APPROPRIATE CRITERIA FOR RCS THRUSTER SIZE
- DEVELOP COMPENSATION TECHNIQUE IN RCS CONTROL CONCEPT
- PERFORM STABILITY AND SIMULATION ANALYSIS

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SIZING RCS THRUSTER EMPHASIZES GROUNDRULES

Both the groundrules and criteria for RCS thrust sizing are emphasized by the technical community. The type of propellant feed system (centralized interconnected vs. decentralized) and thruster performance (regulated vs. blowdown) will require the appropriate compensation in RCS design.

Sizing RCS Thrusters Emphasizes Groundrules

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BLOWDOWN DESIGN OPTIONS:

- CENTRALIZED INTERCONNECTED FUEL FEED
- DECENTRALIZED FUEL FEED

RCS PROPULSION WILL PROVIDE FOR:

- STATION TRANSLATION AND REBOOST
- BACKUP ATTITUDE CONTROL
- MOMENTUM DUMPING WHEN NECESSARY
- DAMPING TRANSIENTS
- ATTITUDE MANEUVERS

RCS PROPULSION DESIGN DRIVERS IDENTIFY:

- MAXIMUM ALLOWABLE THRUST FOR REBOOST WITHOUT RCS / FLEX COUPLING
- SUFFICIENT THRUST TO SATISFY CONTROL AUTHORITY AND STABILITY REQUIREMENTS

RCS ATTITUDE AND STABILITY RATE GOALS ARE:

- STABILITY RATE OF 0.02 DEG / SEC / AXIS
- ATTITUDE OF +/- 1.0 DEG ABOUT ANY DESIRED ATTITUDE

ATTITUDE AND STABILITY RATE GOALS MAY BE RELAXED DURING:

- REBOOST
- BACKUP TO CMG'S
- MANEUVERS
- ORBITER, OMV, OTV BERTHING / DOCKING
- COLLISION AVOIDANCE
- STATION DISPOSAL
- OTHER CONTINGENCY OPERATIONS

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CRITERIA HELPS TO DETERMINE RCS THRUSTER SIZE

The functional and performance requirements must be reviewed critically so as to formulate appropriate criteria. The performance of reboost, for example, must be traded off with stability requirements. Due to the flexibility of the structure, the maximum thrust level must be limited as well. Also the jet cycling frequencies must be separated from structural modes. The minimum thrust level is driven by adequate control authority to handle disturbances and by performance during different operations.

Criteria Helps to Determine RCS Thruster Size

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- MINIMIZE REBOOST TIME -- (ONE CREW SHIFT - 9 HOURS)
- MINIMUM STRUCTURAL / CONTROL INTERACTION -- (STABILITY GAIN MARGIN OF 10 DB AND PHASE MARGIN OF 40 DEG)
- STRUCTURAL LOADS LIMITS AND DEFLECTIONS -- (LIMIT BENDING MOMENT TO 102,000 INCH - POUNDS FOR 16.4 FT / 0.04 INCH TRUSS)
- ADEQUATE CONTROL AUTHORITY WITH REASONABLE DISTURBANCE SETTLING TIME FOR DYNAMIC OPERATIONS -- (LESS THAN 15 MIN)
  - -- ORBITER PLUME IMPINGEMENT (10,000 TO 30,000 FT - POUNDS)
  - -- ORBITER DOCKING / BERTHING (500 POUNDS FOR 1 SEC)
  - -- CREW DISTURBANCE (25 POUNDS FOR 1 SECOND)
- LIMITING OF BENDING AMPLITUDES
  - -- FLEX RATE AT ISA LESS THAN 0.01 DEG / SEC
  - -- FLEX DEFLECTION AT SOLAR ARRAY LESS THAN 1.0 DEG
  - -- FLEX DEFLECTION AT PAYLOAD MOUND LESS THAN 1.0 DEG
  - -- FLEX RATE AT SOLAR DYNAMIC RECEIVER LESS THAN 0.1 DEG / SEC

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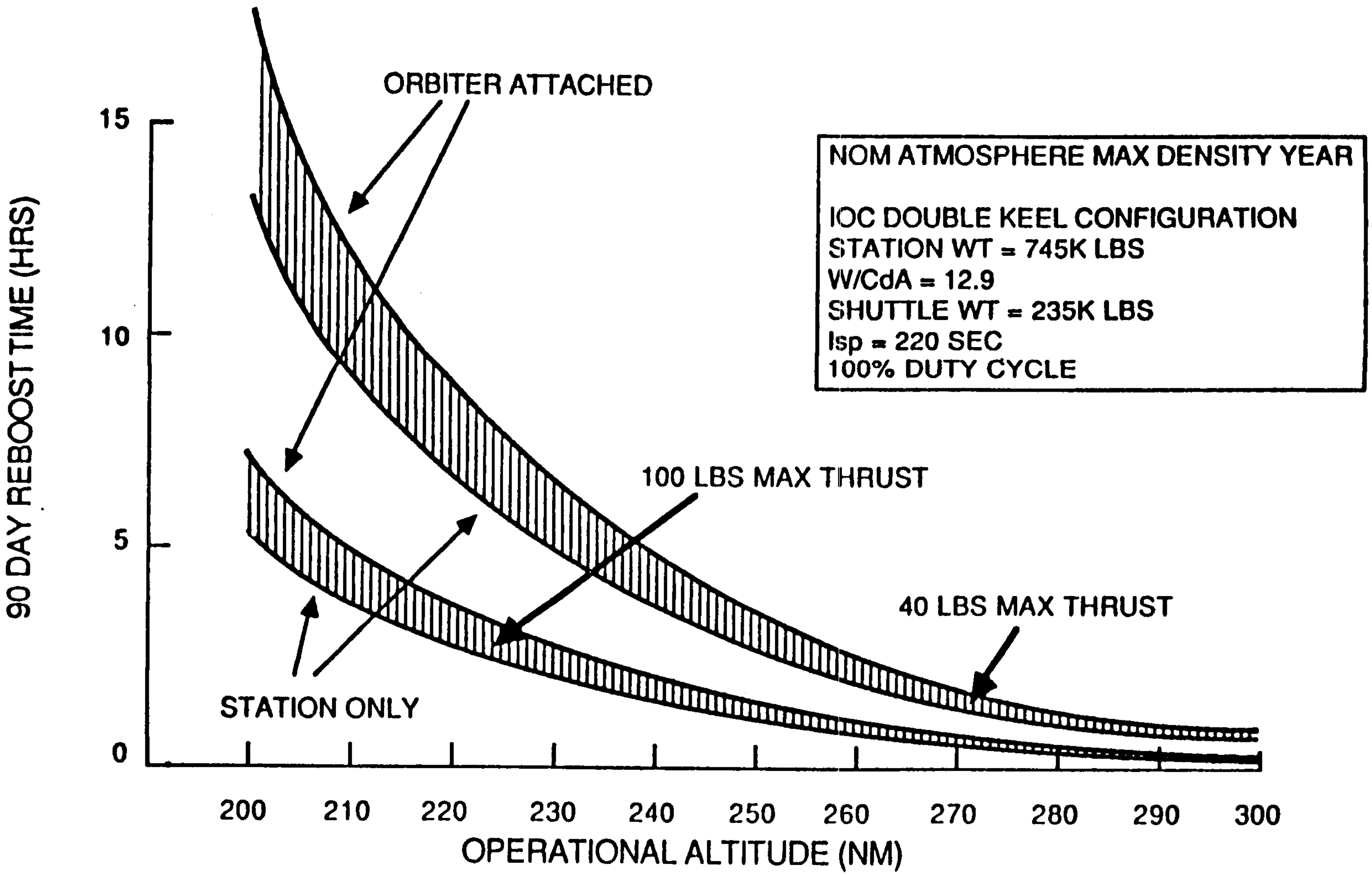
TIME TO REBOOST IS DRIVEN BY THRUST LEVEL

For the operational altitude range of 250 to 270 nmi, the reboost time is about two to four hours for high and low thrust levels (100 and 40 pounds maximum) respectively. During the assembly phase, the reboost time needs to be limited to one crew shift (9 hours) with the application of the appropriate thrust level. The case with the orbiter attached is comparable to a growth station.

TIME TO REBOOST IS DRIVEN BY THRUST LEVEL



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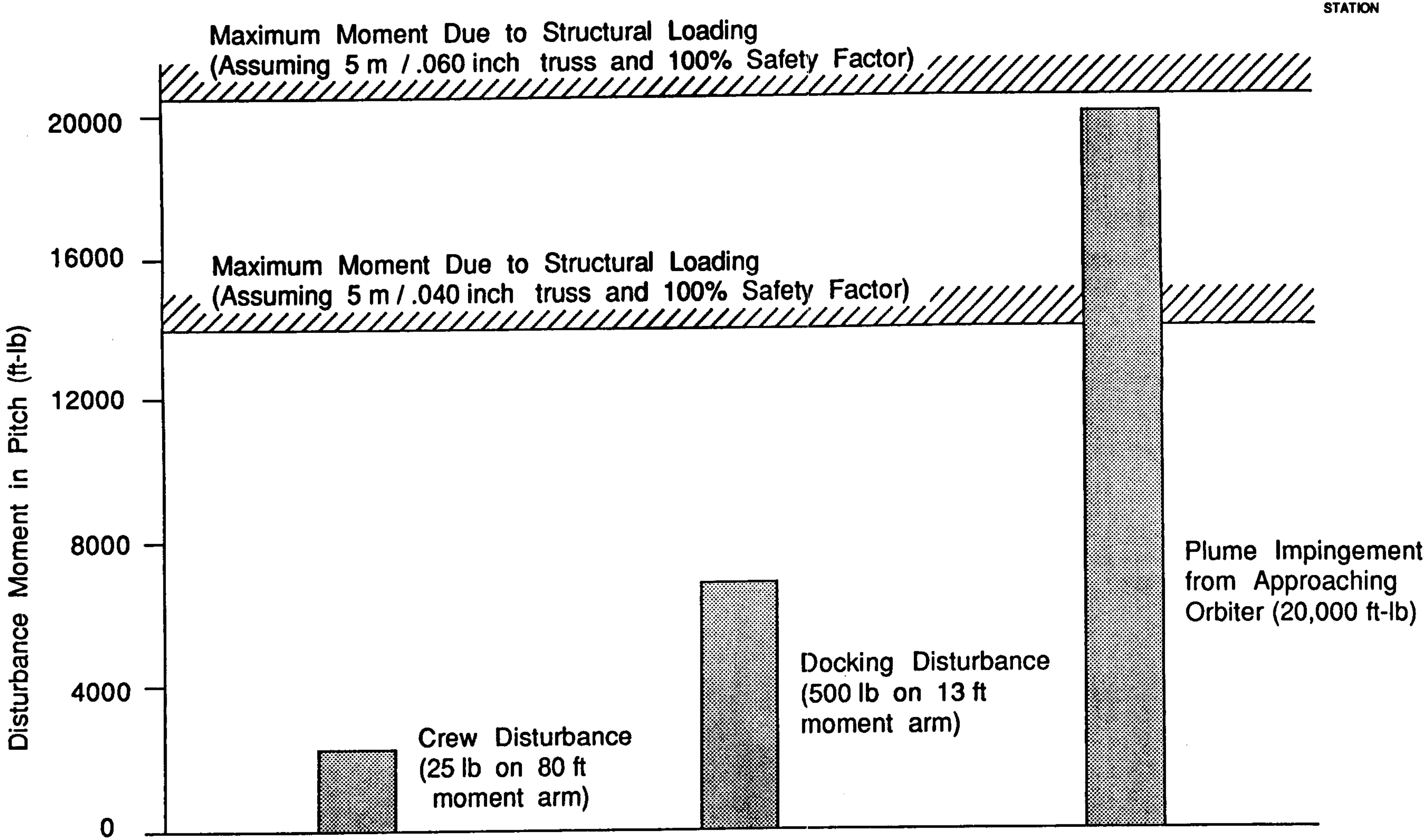
DISTURBANCE ACCELERATIONS DEFINE THE DESIRED CONTROL ACCELERATION

The RCS/propulsion system must accommodate disturbances which exceed the CMG momentum management capability. These major disturbances include docking, mission service center (MSC) motion, and orbiter plume impingement effects.

The maximum control acceleration, however, must be selected according to structural loads capability.

Disturbance Moments Define the Desired Control Moments



* Assuming IOC Station

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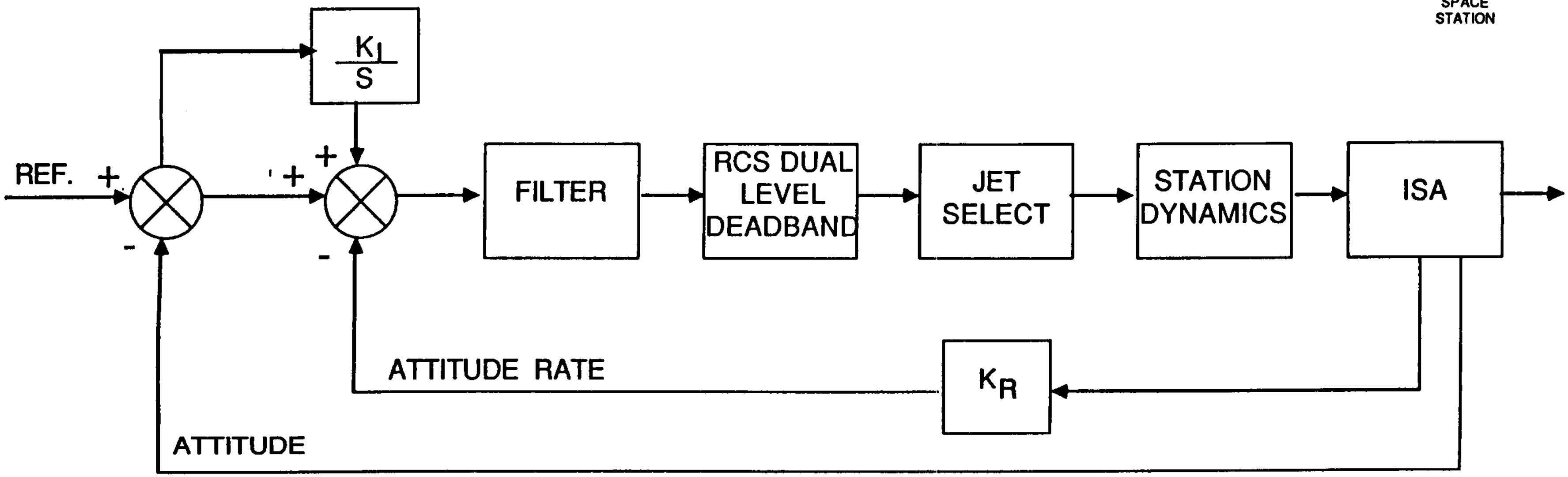
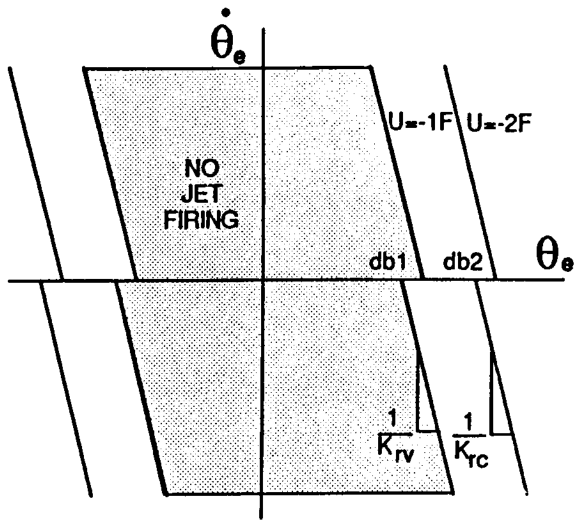
RCS CONTROL CONCEPTS COMPENSATE FOR PROPULSION SYSTEM VARIATIONS

The proposed RCS control concepts employ modern design techniques for wide notch filter design to attenuate closely spaced dominant structural modes. The rate gain is increased but bounded as the thrust level is reduced. A dual torque control level is practical for control of large and small disturbances. Steady state error due to mistrim moment can be integrated out.

RCS Control Concept Compensates for Propulsion System Variations





- USES WIDE BAND NOTCH FILTER FOR COMPENSATION
- SCHEDULES RATE GAIN AS FUNCTION OF THRUST
- PROVIDES VERNIER AND COARSE CONTROL LEVEL
- PROVIDES INTEGRAL LOOP FOR MISTRIM MOMENT

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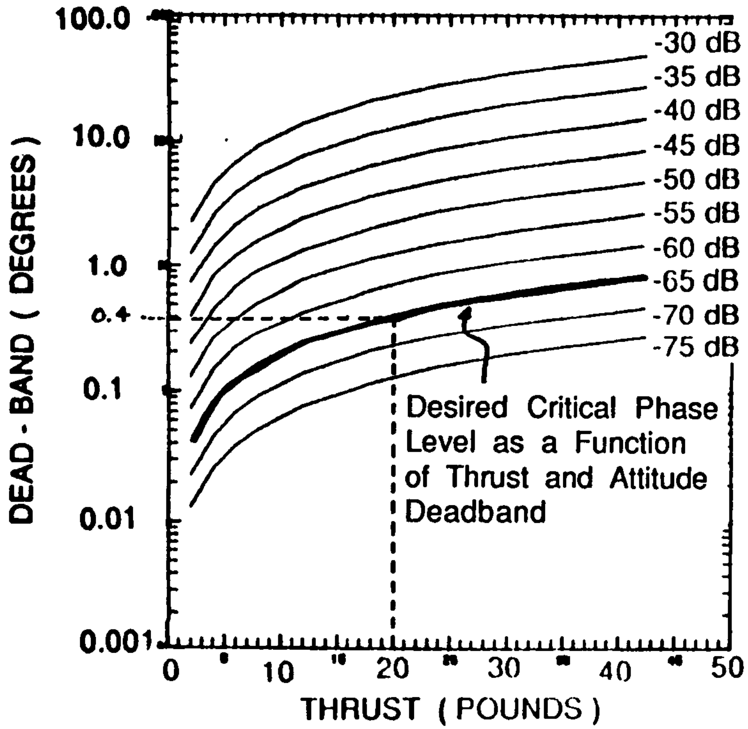
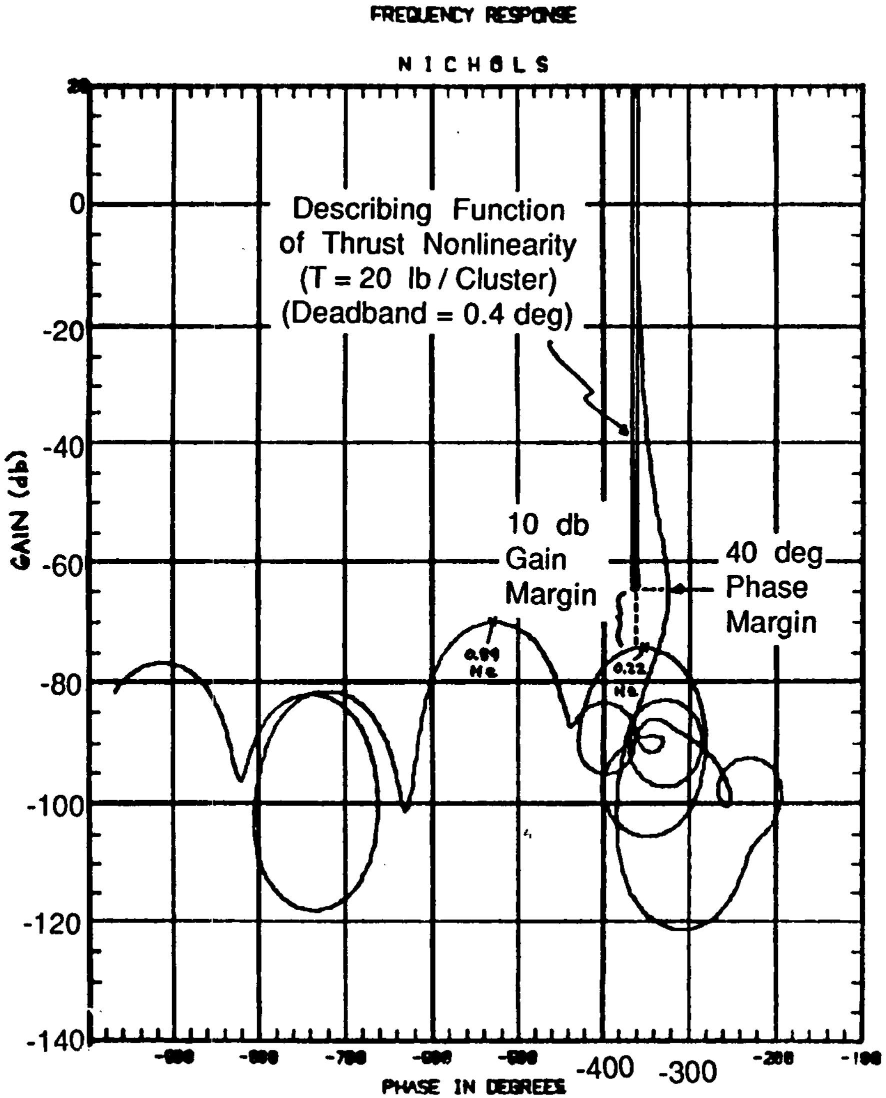
THRUST LEVEL OF 20 LB/CLUSTER PROVIDES ADEQUATE GAIN AND PHASE MARGIN FOR COMPENSATED SYSTEM

Adequate gain and phase margin must be achieved for stability while meeting controllability requirements. Describing function analysis is used to model the RCS thrust function as it interacts with a flexible structure. The relationship between attitude deadband, thrust level, and gain and phase margins provides a method necessary to prevent the RCS from interacting with the structure.

Thrust Level of 20 lb / Cluster Provides Adequate Gain and Phase Margin for Compensated System



- Phase Margin of 40 deg and Gain Margin of 10 db are Achievable with Thrust Level of 20 lb / Cluster and 4 Clusters Firing in Pitch



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PEAK DEFLECTION INDICATES ACCEPTABLE DESIGN

Since payload pointing is an important Space Station function, the RCS must be designed so as not to vibrate the structure to a great degree.

Sensitivity data derived from simulation indicates reasonable performance at remote locations on the structure for different configurations.

Peak Deflections Indicate Acceptable Design

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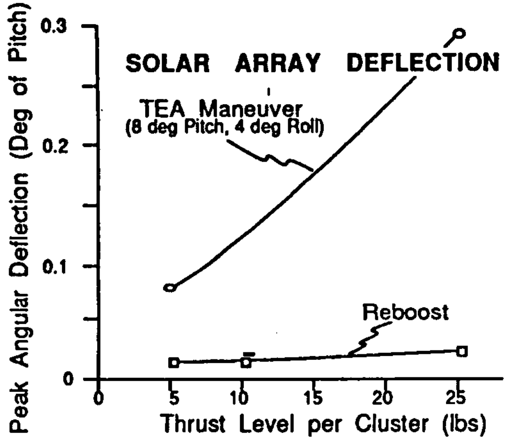
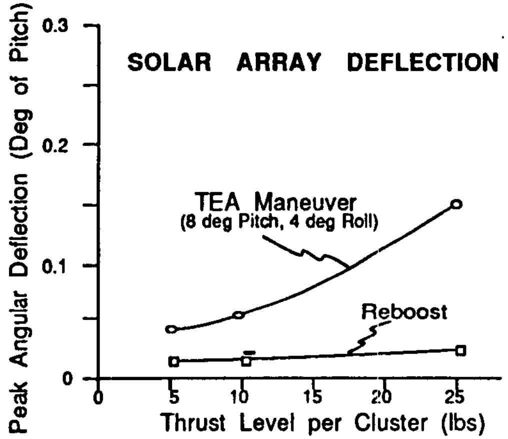
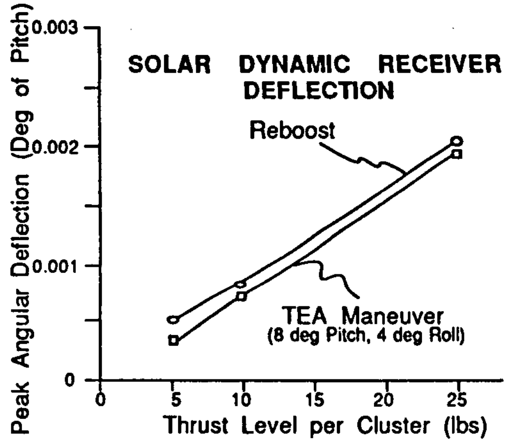
EARLY FLIGHTS

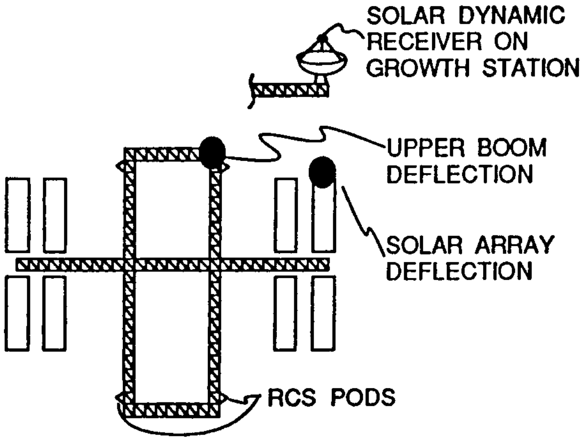


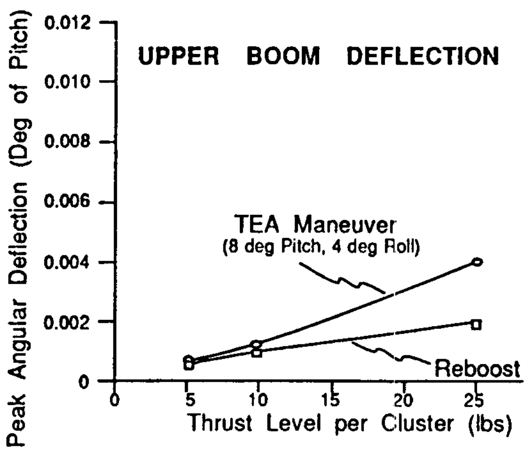
IOC

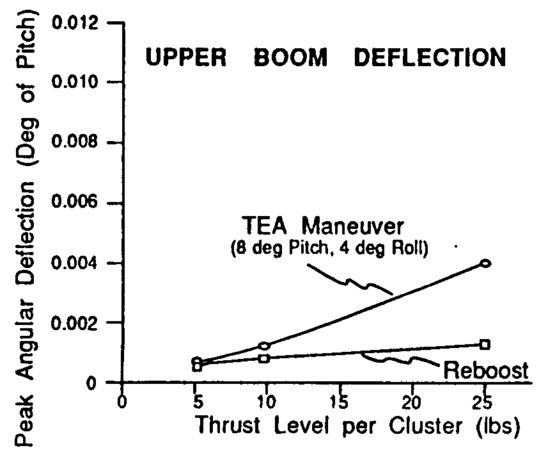


GROWTH









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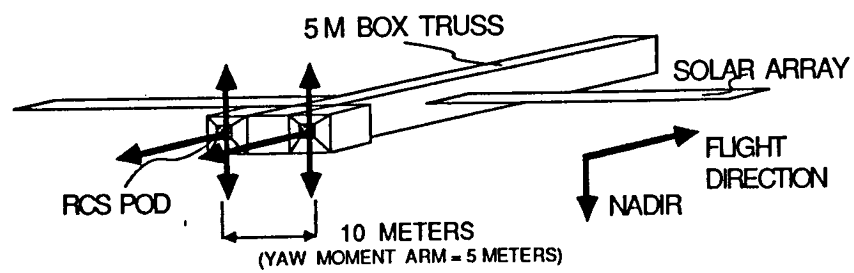
RCS PROVIDES ADEQUATE ATTITUDE ERROR CONTROL ASSEMBLY FLIGHT 1

Simulation results indicate that the location of the RCS thrusters provides adequate three-axis control authority and reboost capability.

RCS Provides Adequate Rate Error Control for Assembly Flight 1

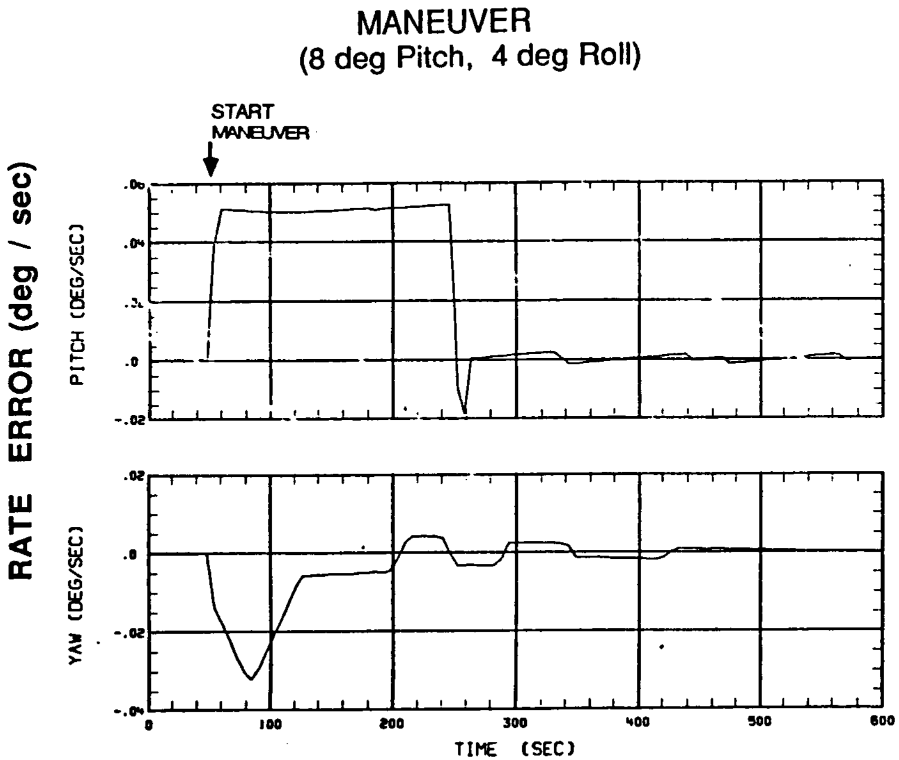


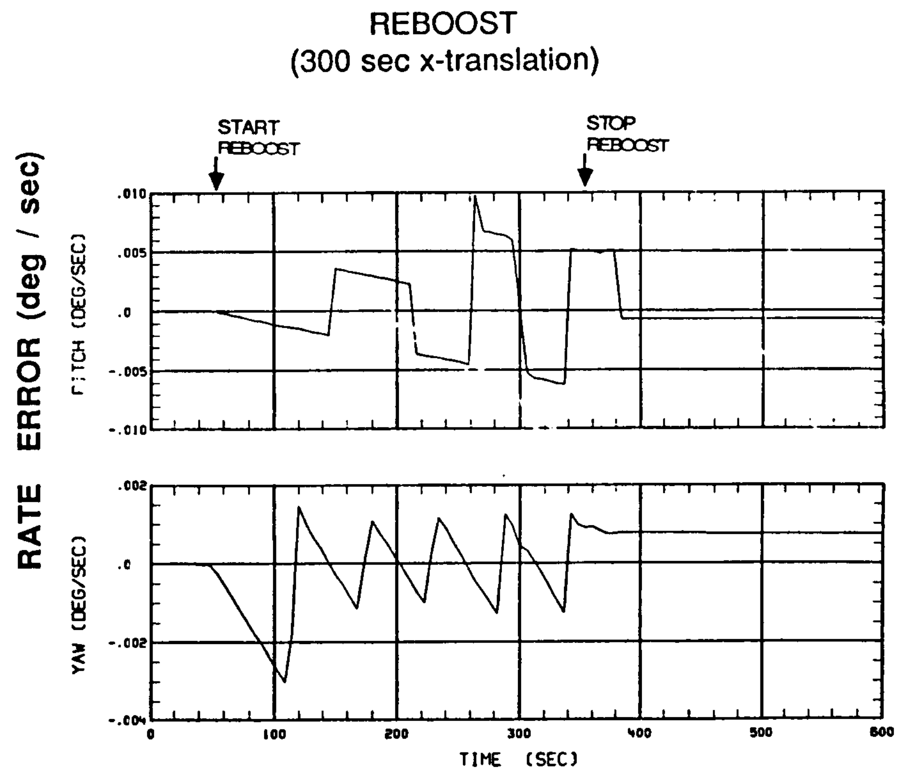
$\alpha^{*}_{(roll)} = 6 * 10^{-3} * \text{Jet Force}$

$\alpha_{(pitch)} = 1 * 10^{-3} * \text{Jet Force}$

$\alpha_{(yaw)} = 7 * 10^{-5} * \text{Jet Force}$

* Units in deg/sec/sec





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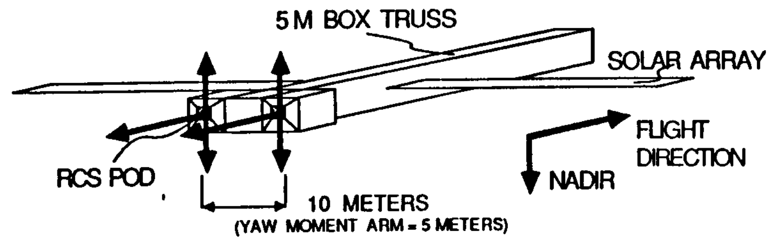
RCS PROVIDES ADEQUATE RATE CONTROL FOR ASSEMBLY FLIGHT 1

Simulation results indicates that the location of the RCS thrusters provides adequate three-axis control authority and reboost capability.

RCS Provides Adequate Attitude Error Control for Assembly Flight 1



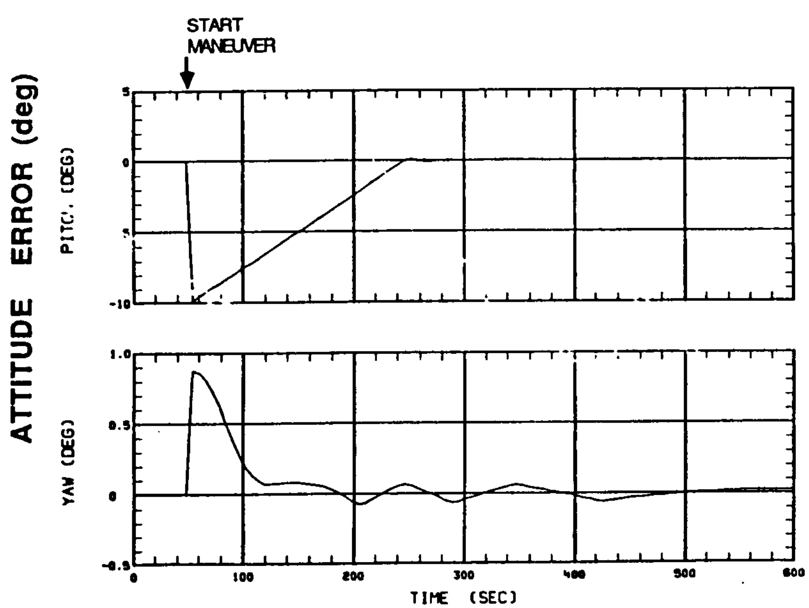
$\alpha^{*}_{(roll)} = 6 * 10^{-3}$ * Jet Force

$\alpha_{(pitch)} = 1 * 10^{-3}$ * Jet Force

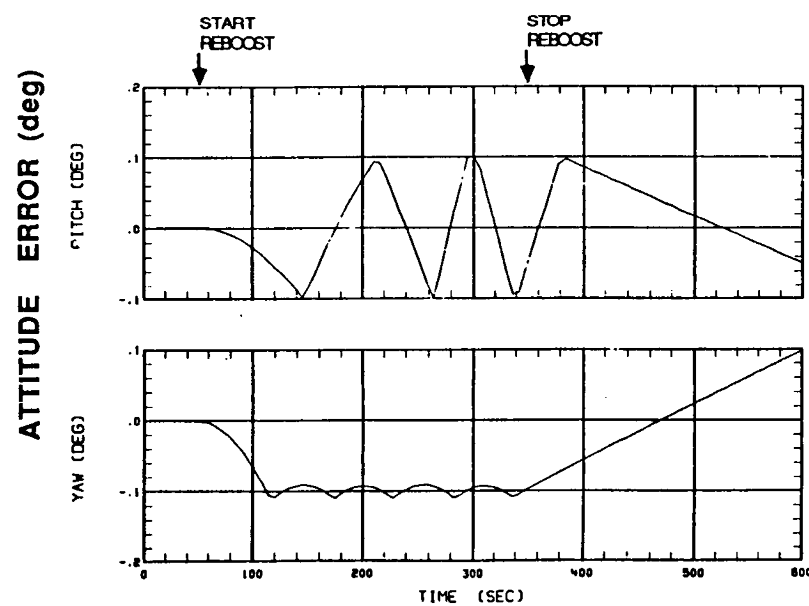
$\alpha_{(yaw)} = 7 * 10^{-5}$ * Jet Force

* Units in deg/sec/sec

MANEUVER
(8 deg Pitch, 4 deg Roll)



REBOOST
(300 sec x-translation)



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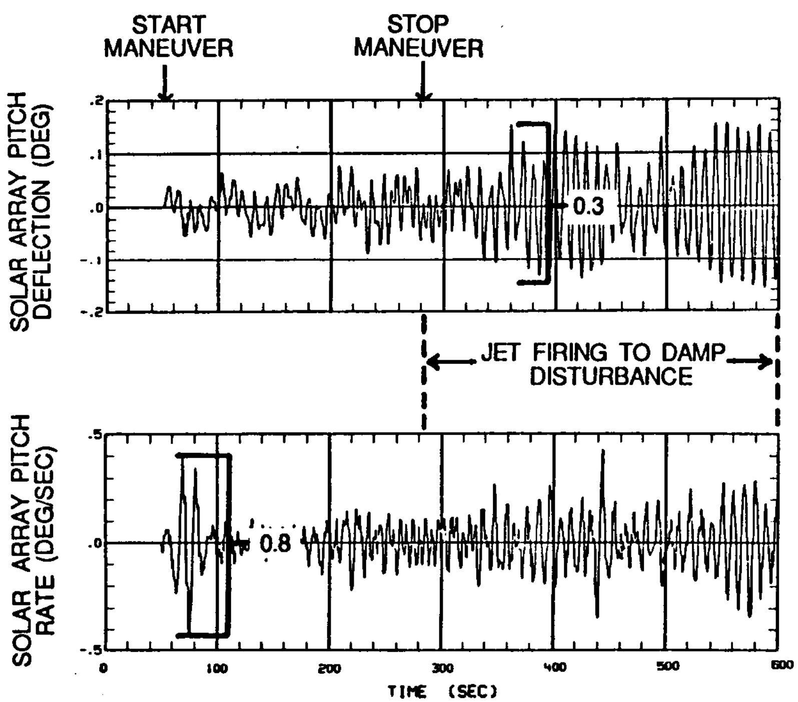
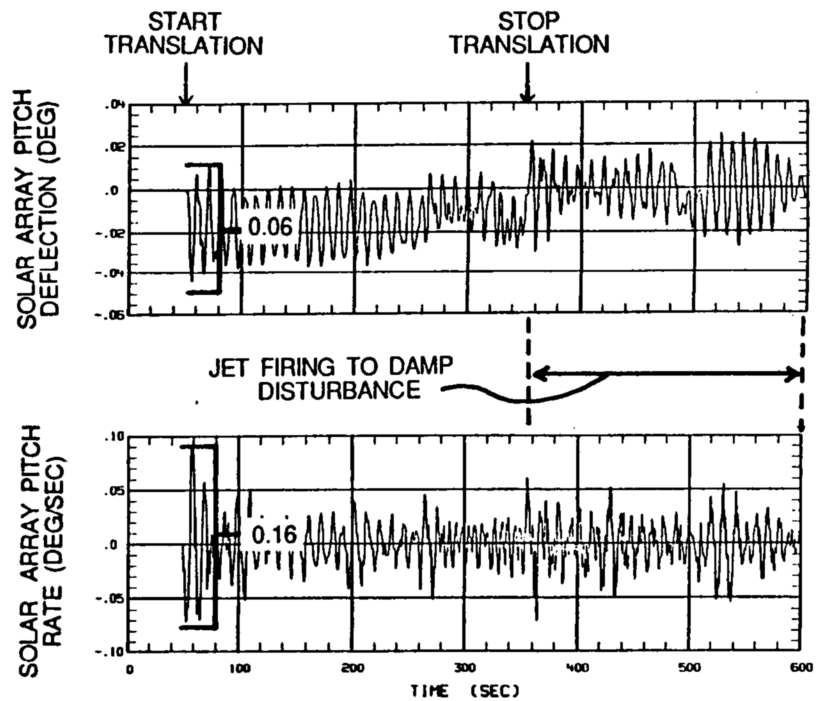
REBOOST AND ATTITUDE MANEUVERING PRODUCE ACCEPTABLE SOLAR ARRAY DEFLECTIONS AND RATES

Solar array deflection is acceptable during reboost and maneuver operations.

Reboost and Attitude Maneuvering Produce Acceptable Solar Array Deflections and Rates *





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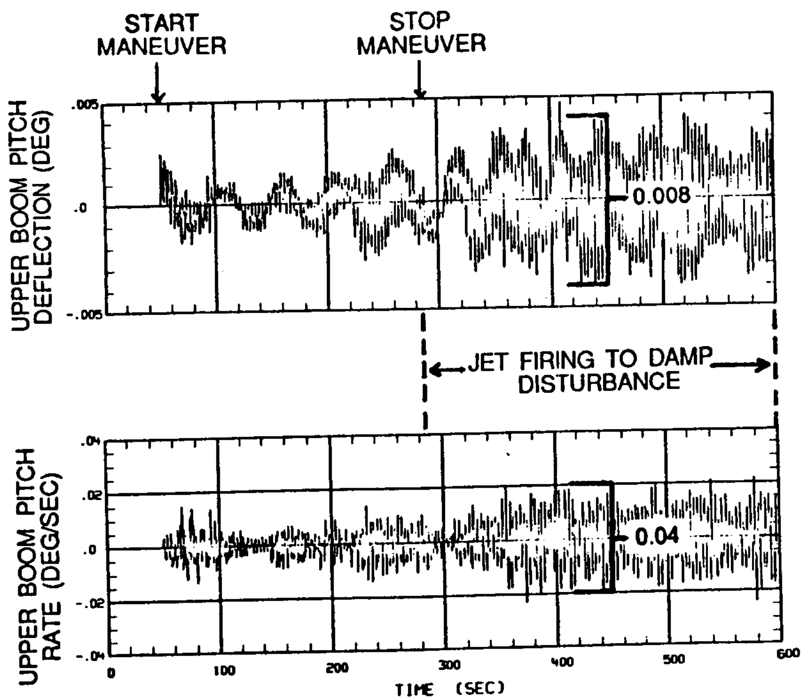
* 25 lb / Cluster Thrust Level

<u>REBOOST AND ATTITUDE MANEUVERING PRODUCE ACCEPTABLE UPPER BOOM DEFLECTIONS AND RATES</u>

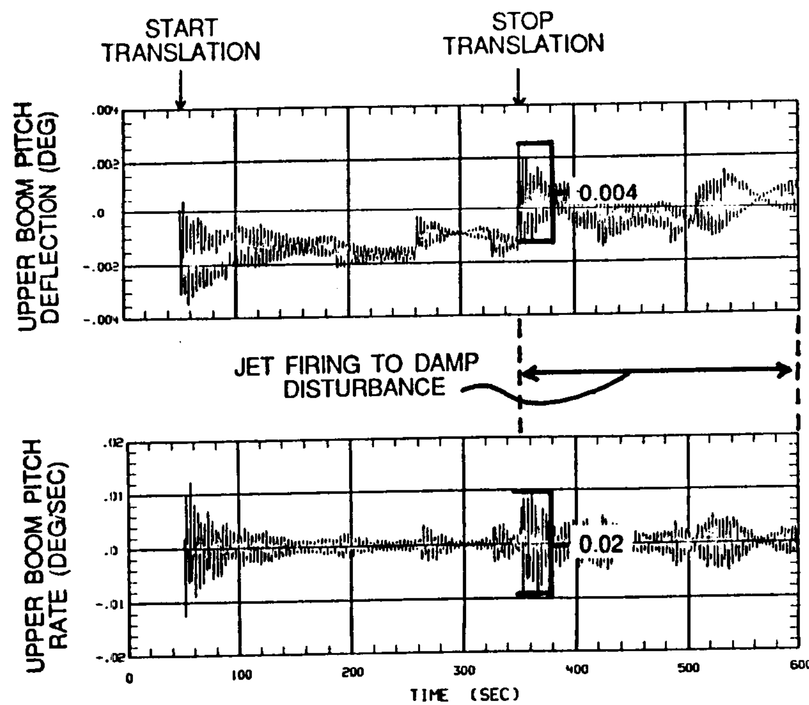
A remote location on the upper boom exhibits reasonable deflection during reboost and attitude maneuver operations.

Reboost and Attitude Maneuvering Produce Acceptable Upper Boom Deflections and Rates *

ATTITUDE MANEUVER (8 DEG PITCH, 4 DEG ROLL)



REBOOST -- 300 SECOND TRANSLATION



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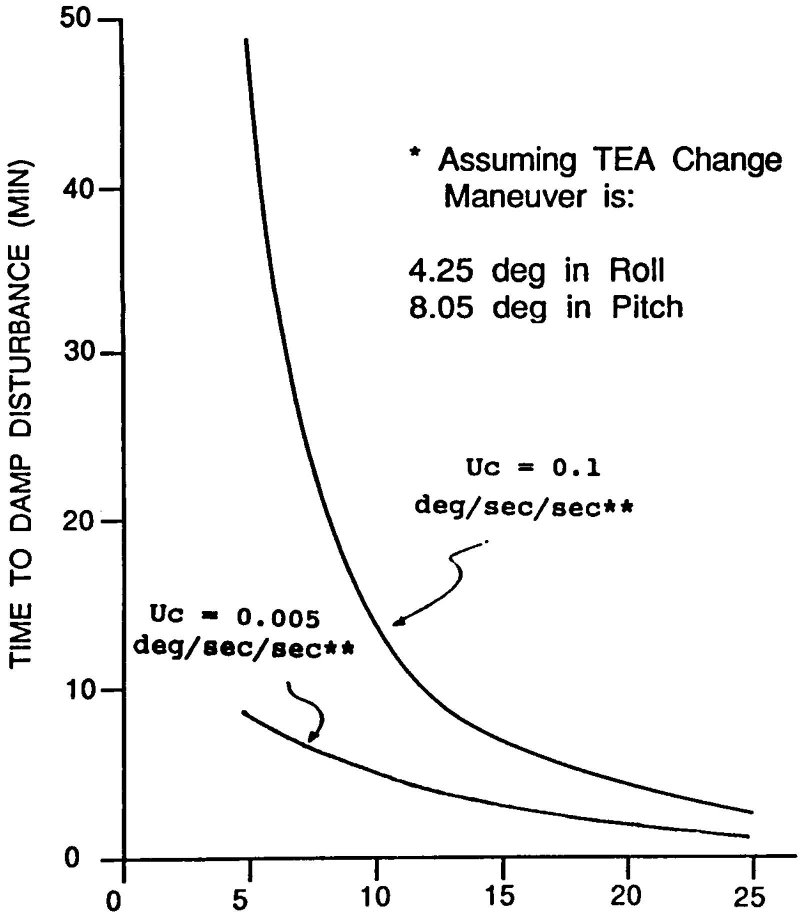
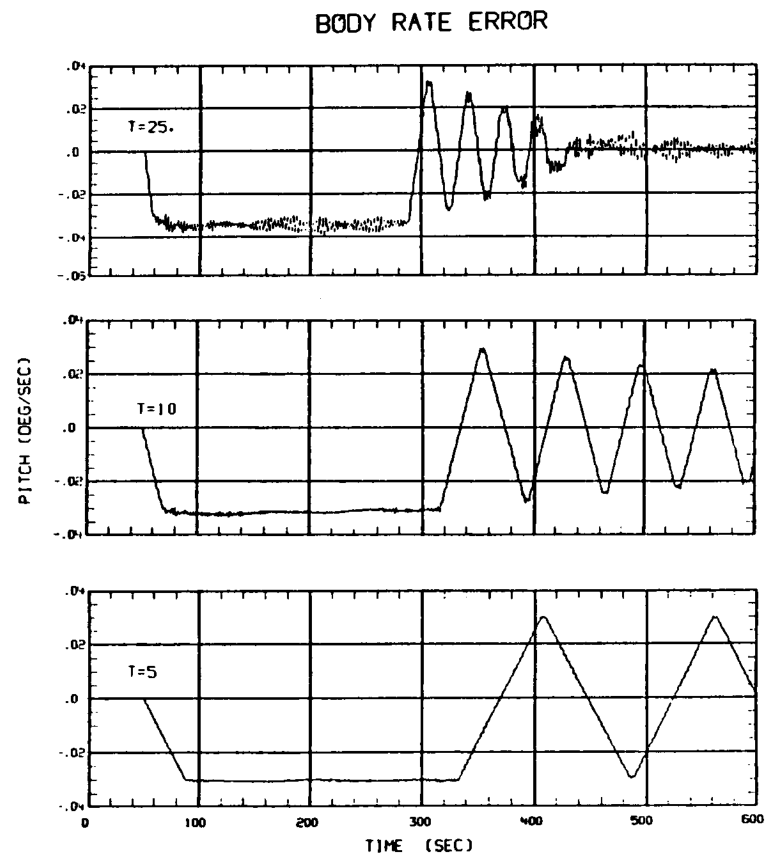
* 25 lb / Cluster Thrust Level

THRUST LEVEL OF 10 LB/CLUSTER PROVIDES ACCEPTABLE CONTROL AUTHORITY

The ability of a reaction control system to damp disturbances quickly is of interest as a measure of control authority. The settling-time-versus-thrust-level indicates the sensitivity of performance during the damping of a maneuver-related disturbance.

Thrust Level of 10 lb / Cluster Provides Acceptable Control Authority





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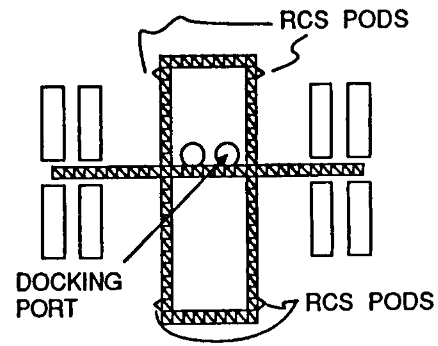
RCS PROVIDES ADEQUATE RATE ERROR AND ATTITUDE ERROR CONTROL FOR PLUME IMPINGEMENT DAMPING

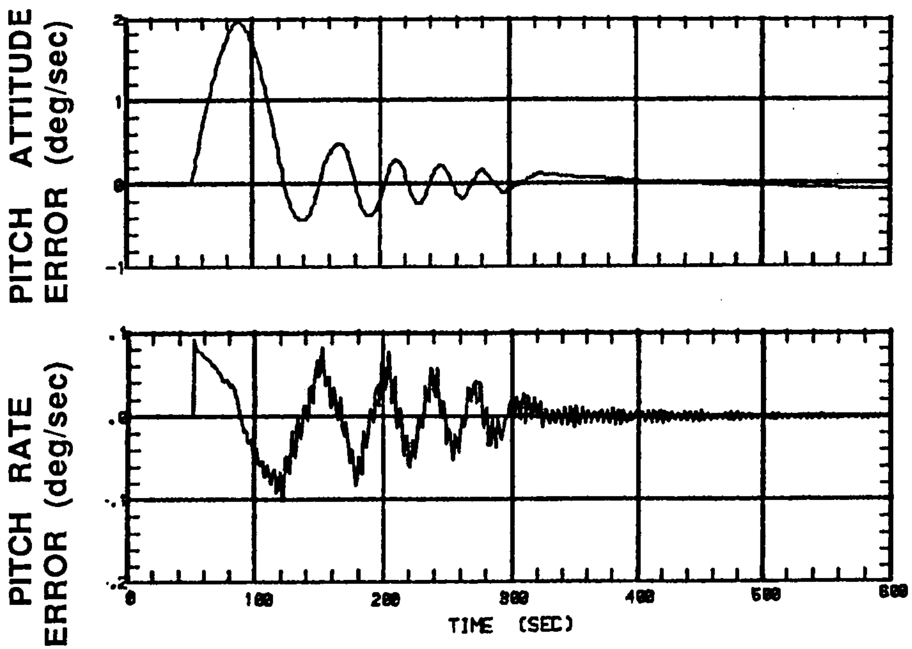
The effect of orbiter plume impingement disturbance was evaluated in terms of control authority, attitude excursion, and settling time. Worst case study of HIGH Z orbiter primary RCS firing indicates significant disturbance torque impulse of at least 161,000 ft-lb in pitch axis. Thrust level/cluster greater than 5 lb/jet is preferred to minimize attitude excursion and settling time. A more realistic case of LOW Z orbiter jet firing indicates less severe torque impulse of 26,188 ft-lbs at close range.

RCS Provides Adequate Rate Error and Attitude Error Control for Plume Impingement Damping

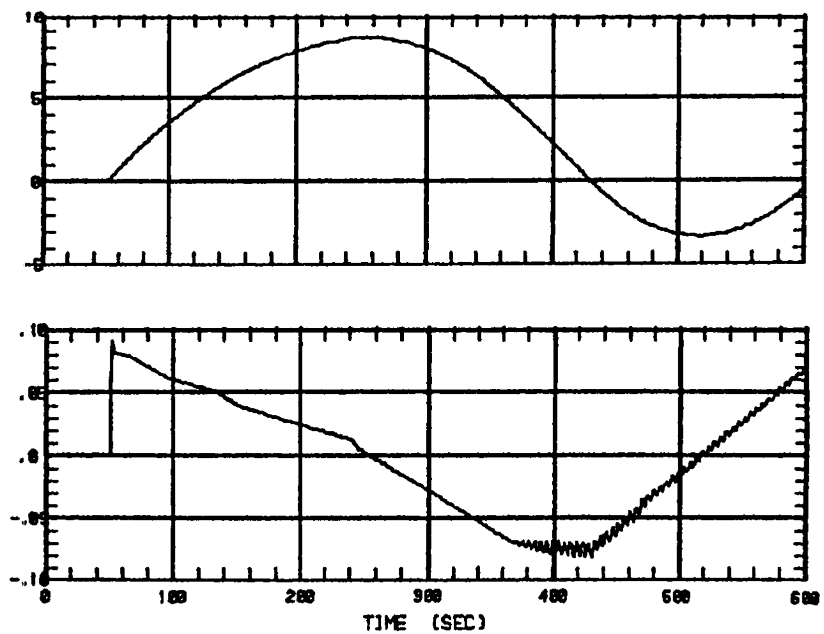
CONDITIONS:
- HIGH Z ORBITER BURN AT DOCKING PORT FOR 1 SECOND
- (-19,000 ft-lb in roll)
- (161,000 ft-lb in pitch)
- (-61,000 ft-lb in yaw)



THRUST LEVEL = 25 LB / JET



THRUST LEVEL = 5 LB / JET



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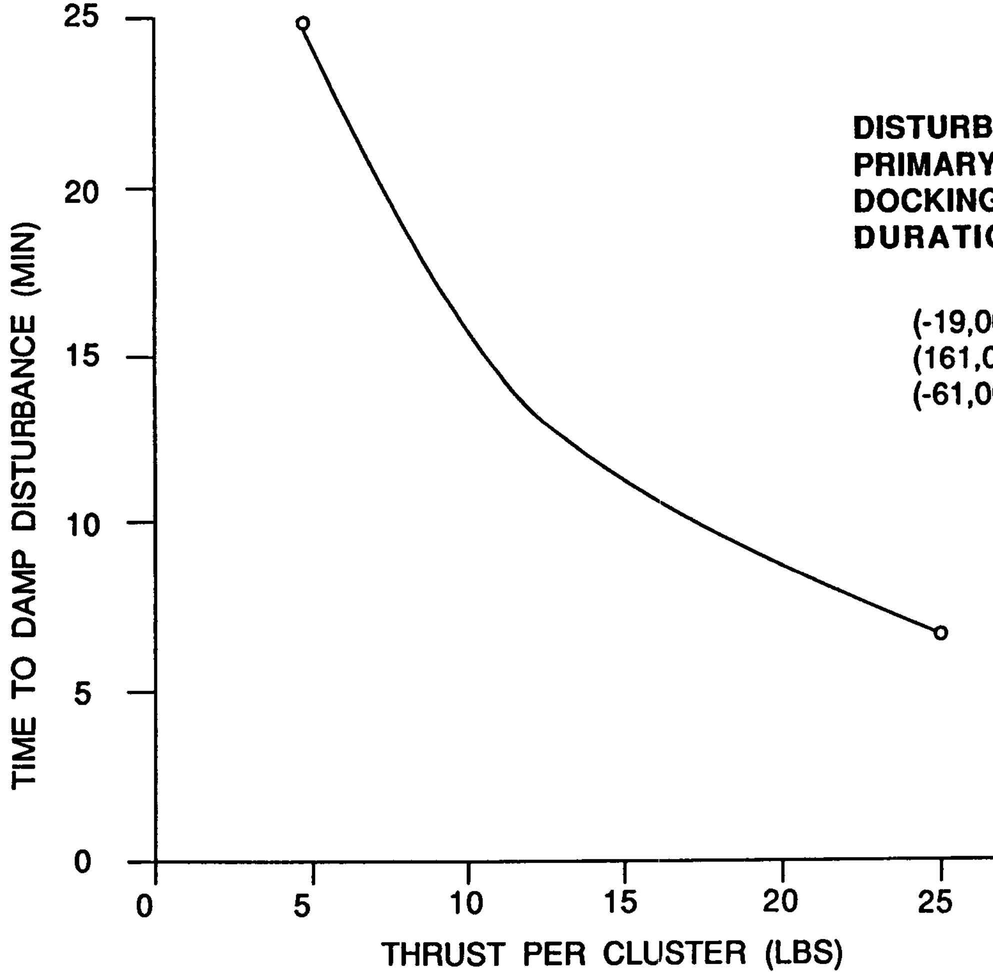
CONTINGENCY OPERATION DISTURBANCES HANDLED WITHIN REASONABLE SETTLING TIME

The HIGH Z RCS mode of the orbiter may be applied during a contingency braking condition. It is reasonable to allow settling time to be longer than it would be for a nominal operation, as long as the attitude excursion of the Station does not reduce the clearance between the orbiter and the Station.

Contingency Disturbances Controlled Within Reasonable Settling Time



DISTURBANCE IS HIGH Z PRIMARY JET FIRING AT DOCKING PORT FOR 1 SECOND DURATION

(-19,000 FT-LB IN ROLL)
(161,000 FT-LB IN PITCH)
(-61,000 FT-LB IN YAW)

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RCS CONTROL/STABILITY ACHIEVED BY COMPENSATION TECHNIQUE

A compensated RCS controller can provide adequate stability and performance. These techniques include wide notch filter, rate gain scheduling, dual control level, and integral loop.

A two-level RCS utilizing three engines per direction is applicable to the Space Station. A pressure regulated thrust level of 10 lb / engine or a blowdown thrust range of 15-7.5 lb / engine provides adequate control authority without unnecessary loading of the structure. Results also indicate that with proper choice of loop gains and phase plane parameters, system constraints and performance requirements can be met during reboost, maneuvers, and disturbance conditions.

RCS Control / Stability Achieved by Compensation Techniques

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- A COMPENSATED RCS CONTROLLER CAN PROVIDE A PHASE MARGIN OF 40 DEGREES AND A GAIN MARGIN OF 10 db.
- THOUGH THE YAW MOMENT ARM IS SMALL FOR ASSEMBLY FLIGHT 1, THREE AXIS CONTROL CAN BE MAINTAINED DURING MANEUVERS AND REBOOST
- MAXIMUM RATES AND DEFLECTIONS EXPERIENCED OVER THE RANGE OF ACCEPTABLE THRUST VALUES ARE:

	Upper Boom	Solar Array
Deflection (deg)	< 0.004 peak	< 0.15 peak
Rate (deg / sec)	< 0.02 peak	< 0.40 peak

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DESIGN ANALYSIS ESTABLISHES GN&C REQUIREMENTS FOR THRUST MAGNITUDE

By following the design criteria and performing the design analysis, we can achieve the design goals, fall within structural truss load limits, meet stability requirements, satisfy reasonable reboost time, assure adequate control authority, and cover the range of center of gravity variation.

Design Analysis Establishes GN&C Requirements for Thrust Magnitude

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DESIGN GOALS:
- Can be met with 10 lbf Minimum Thrust / Cluster

STRUCTURAL TRUSS LOAD LIMITS:
- Satisfied with Thrust Less Than 25 lbf / Cluster

ADEQUATE STABILITY GAIN MARGIN:
- Satisfied with Thrust Less Than 20 lbf / Cluster

REBOOST TIME:
- Reboost Time Less Than One Crew Shift with Thrust at 20 lbf / Cluster

ADEQUATE CONTROL AUTHORITY:
- Met with 10 lbf Minimum Thrust / Cluster

CLUSTER LOCATIONS FOR DUAL - KEEL
- Provide Large Control Moment Arm and Cover Range of CG Variations
- Need Further Study on CGx Offset

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CONCLUSION/RECOMMENDATIONS FOR GN&C THRUST MAGNITUDE REQUIREMENTS

Complying with loads and deflection constraints, the thrust range is limited to 20 pounds per cluster. If a pressure regulated system is chosen, 10 pounds thrust per thruster is required. If a blowdown system is chosen, a 15 to 7.5 thrust range/thruster is required.

A pressure regulated system is preferred in light of control logic simplicity, less cost for software development and verification, and straightforward performance verification.

Conclusions / Recommendations for GN&C Thrust Magnitude Requirements

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CONCLUSIONS:

- Limit Thrust Range to 20 lb / Cluster Maximum
- If a Pressure Regulated System is Chosen, 10 lb Thrust / Thruster is Required
- If A Blowdown System is Chosen, a 15 to 7.5 lb Thrust Range / Thruster is Required
- Require 3 Thrusters / Cluster, 9 Thrusters / Module (3 in +x, 3 in +y, 3 in -x)

RECOMMENDATIONS:

- Baseline Pressure Regulated System
  - 3 Jets / Cluster, 9 Thrusters / Module (3 in +x, 3 in +y, 3 in -x)
  - 10 Pound Thrust / Thruster

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April 23, 1986

SESSION 4

Integrated Session 4A - Don Skoumal, Chairman

Dual Keel Space Station Control/ Structures Interaction Study	J. W. Young, F. J. Lallman, P. A. Cooper, LaRC
High Speed Simulation of Flexible Multibody Dynamics	A. D. Jacot, R. E. Jones, C. Juengst, Boeing
On the Application of Lanczos Modes to the Control of Flexible Structures	R. R. Craig, Jr. U. of Texas
Modal Testing and Slewing Control Experiment for Flexible Structures	J. N. Juang, LaRC
MEOP Control Design Synthesis: Optimal Qualification of the Big Four Tradeoffs	David C. Hyland and Dennis Bernstein, Harris Corp.

Integrated Session 4B - Harry J. Buchanan, Chairman

Vibration Isolation for Line of Sight Performance Improvement	J. J. Rodden, H. Dougherty, W. Haile, LMSC
A New Semi-Passive Approach for Vibration Control in Large Space Structures	K. Kumar and J. E. Cochran, Jr. Auburn Univ.
Crew Motion Forcing Functions from Skylab Flight Experiment and Applicable to Space Station	B. Rochon, JSC
Modeling of Controlled Structures with Impulsive Loads	M. Zak, JPL