CSI-Star: A Low-Cost CSI Orbital Testbed

Flight Experiments Technical Interchange Meeting

5 October 1992

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MCDONNELL DOUGLAS
SPACE SYSTEMS COMPANY

RATIONALE FOR AN ON-ORBIT CSI TEST FACILITY

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ON-ORBIT OPEN- AND CLOSED-LOOP TESTING OF A CONTROLLED STRUCTURE TESTBED IS REQUIRED

- SPACECRAFT QUAL TESTS WILL USUALLY OCCUR ON THE GROUND WHERE GRAVITY AND SUSPENSION EFFECTS WILL CAUSE THE 1-G AND 0-G DYNAMICS TO DIFFER
- DIFFERENCES BETWEEN GROUND AND ON-ORBIT ENVIRONMENTS CAN SIGNIFICANTLY ALTER THE OPEN- AND CLOSED-LOOP BEHAVIOR, BOTH IN THE SHORT- AND LONG-TERM - UARS JITTER, HST DYNAMICS
- CONTROLLER STABILITY AND PERFORMANCE ROBUSTNESS REQUIRE MODEL FIDELITY THAT IS INTIMATELY RELATED TO THE LEVEL OF APPLIED CONTROL AUTHORITY - THE REQUIRED LEVEL OF 1-G AND 0-G CONTROL AUTHORITY WILL DIFFER

CSI FLIGHT EXPERIMENT OBJECTIVES

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OVERALL OBJECTIVE: PROVIDE ON-ORBIT TESTBED NECESSARY TO DEVELOP & VERIFY CSI TECHNOLOGY TOOLS

ON-ORBIT DEMONSTRATION / VALIDATION OF CSI TECHNOLOGY FOR:

- HEALTH MONITORING AND SYSTEM IDENTIFICATION OF CHANGING ON-ORBIT CONFIGURATION (ENVIRONMENTAL EFFECTS AND DEPLOYMENT DYNAMICS)
- GLOBAL VIBRATION SUPPRESSION WITH FIXED GEOMETRY USING SEVERALTYPES OF ACTUATORS
- MICRO-AMPLITUDE VIBRATION SUPPRESSION DURING PRECISION PAYLOAD POINTING
- GLOBAL VIBRATION SUPPRESSION DURING PRECISION POINTING OF MULTIPLE INSTRUMENTS/PAYLOADS
- GLOBAL VIBRATION SUPPRESSION DURING LARGE ANGLE REORIENTATION SLEWING OF WHOLE TEST ARTICLE
- GLOBAL VIBRATION SUPPRESSION DURING LARGE ANGLE ARTICULATION OF PAYLOAD WITH FLEXIBLE APPENDAGES

FEASIBILITY STUDY OBJECTIVES

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- OVERALL OBJECTIVE: DEFINE A LOW-COST CSI ORBITAL FACILITY USING THE QUICKSTAR SPACECRAFT BUS LAUNCHED AS A DELTA II SECONDARY PAYLOAD
- DEFINE EXPERIMENT PACKAGES THAT ARE COMPLEMENTARY TO EXISTING FLIGHT PROGRAMS
- ALL DEFINED CONCEPTS SHALL HAVE THE FOLLOWING:
  - ON-ORBIT LIFE OF AT LEAST 1 YEAR
  - FIRST FLEX MODE BELOW 1 Hz
  - CLOSELY-SPACED/COUPLED FLEX MODES
  - SUFFICIENT SENSORS FOR QUALITY SYSTEM ID
  - REPROGRAMABLE CONTROL ALGORITHMS VIA UPLINK
- AT LEAST ONE DEFINED CONCEPT SHALL HAVE ALL THE FOLLOWING:
  - MULTIPLE, INTERACTING CONTROL SYSTEMS
  - OPTICAL PATH LENGTH OR LINE-OF-SIGHT CONTROL
  - AUTOMATED ALIGNMENT/CALIBRATION OF SENSORS/ACTUATORS
  - SUB-ARC-MINUTE PAYLOAD OR SPACECRAFT POINTING
- PRESENT NASA WITH REALISTIC COST AND RISK ESTIMATES

CSI FREE-FLYER SOLUTION

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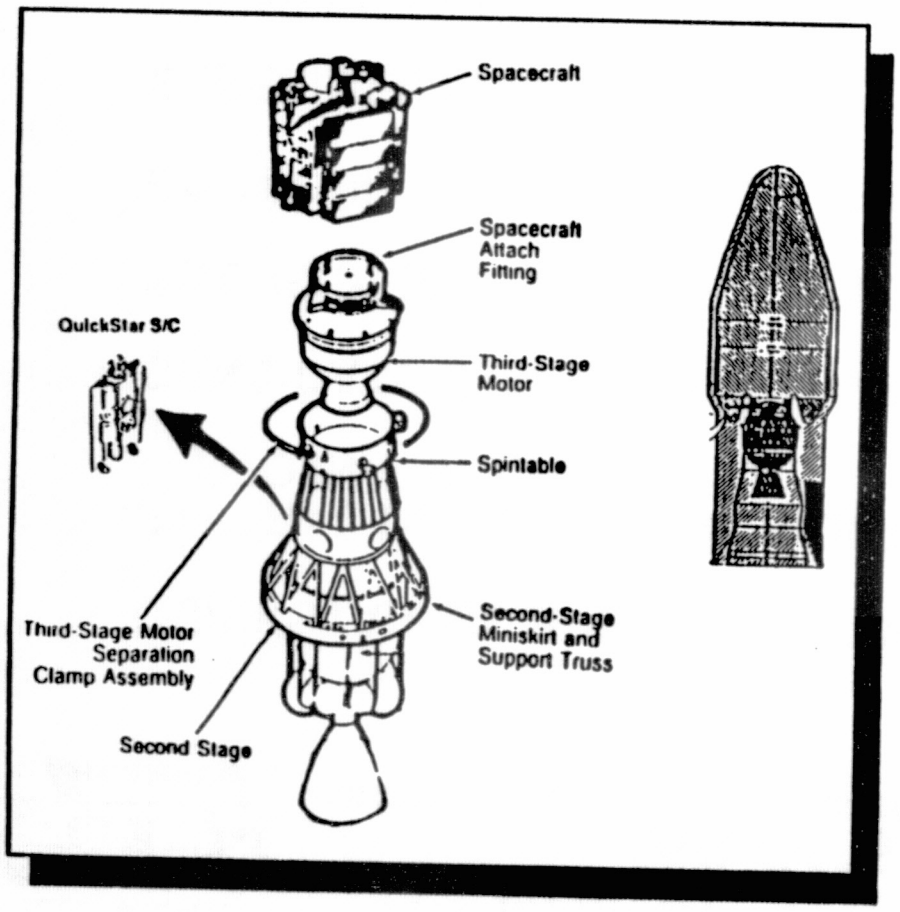
QUICKSTAR SPACECRAFT BUS AS DELTA II SECONDARY PAYLOAD



- MAJOR PRIMARY PAYLOAD IMPACT ISSUES RESOLVED (LOSAT-X)
- QUICKSTAR CAPABILITIES GREATER THAN TYPICAL SMALLSATS
- MANY LAUNCH OPPORTUNITIES EXIST
- LOW BUS COST ~ $10M - $15M
- LOW LAUNCH COSTS ~ $2M - $3M
- CURRENTLY THE ONLY FLOWN, SECONDARY S/C BUS AVAILABLE

FEASIBILITY STUDY
TECHNICAL STATUS SUMMARY
(AS OF 6-30-92)

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- QUICKSTAR S/C BUS REQUIREMENTS DEVELOPED
- SEVERAL DELTA II LAUNCH OPPORTUNITIES IDENTIFIED
  - TWO IN 1997 BASELINED
- CANDIDATE EXPERIMENT COMPONENTS IDENTIFIED
- TWO EXPERIMENT PACKAGES CONCEPTUALLY DESIGNED
- COMPONENT SIZING COMPLETED (FIRST PASS)
- EXPERIMENT ROM COST ESTIMATES (FIRST PASS) COMPLETED
- S/C BUS INTEGRATION DESIGN (FIRST PASS) ACTIVITIES COMPLETED
- S/C BUS REQUIRED CONTROL FUNCTIONS VERIFIED (FIRST PASS)
- EVALUATIONS OF CONCEPTS IN PROGRESS

CSI-Star
A LOW-COST CSI FREE FLYER

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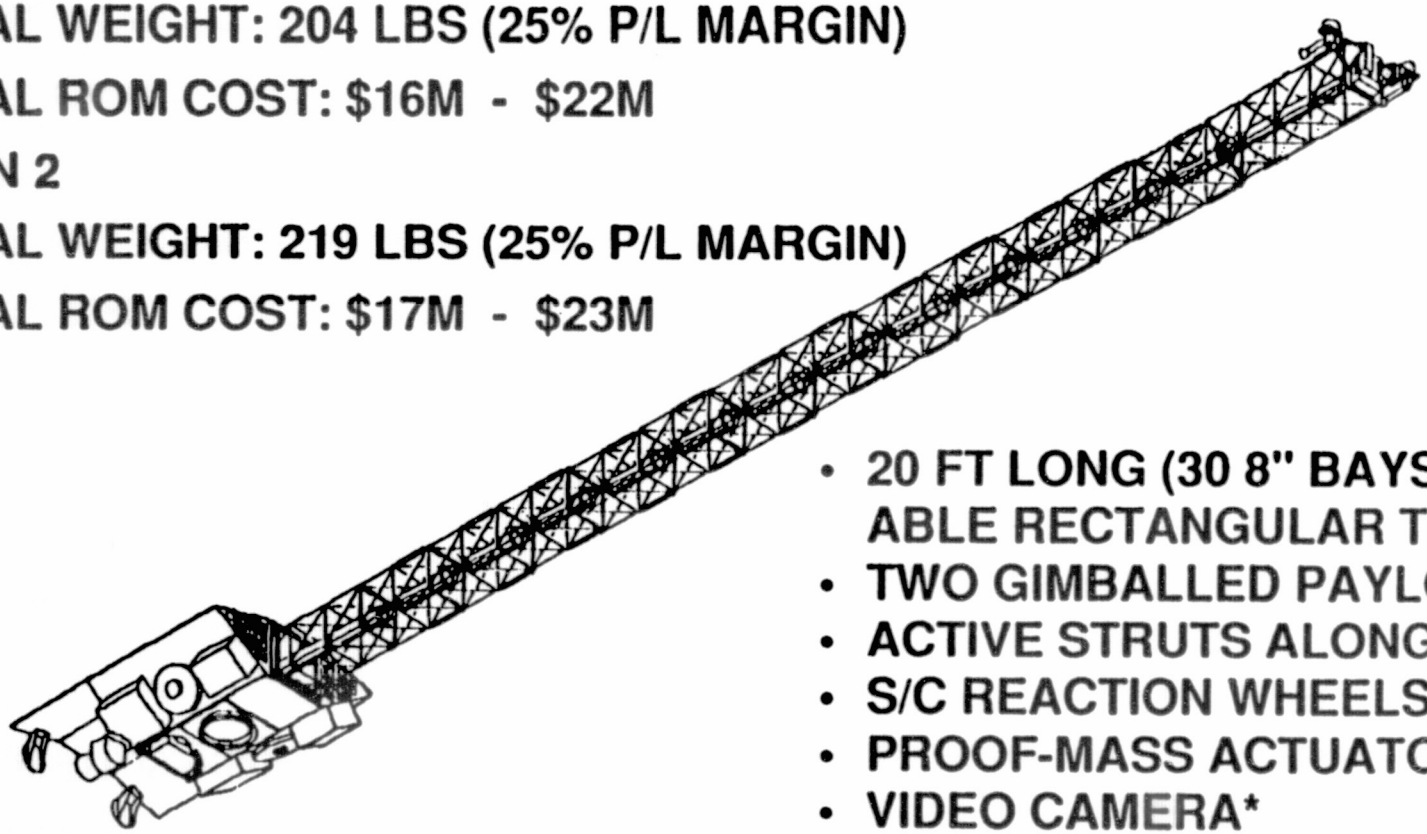
- TWO EXPERIMENT PACKAGE OPTIONS - WEIGHT DRIVEN
- BASELINE (OPTION 1)
  - TOTAL WEIGHT: 204 LBS (25% P/L MARGIN)
  - TOTAL ROM COST: $16M - $22M
- OPTION 2
  - TOTAL WEIGHT: 219 LBS (25% P/L MARGIN)
  - TOTAL ROM COST: $17M - $23M



- 20 FT LONG (30 8" BAYS) DEPLOYABLE RECTANGULAR TRUSS
- TWO GIMBALLED PAYLOADS
- ACTIVE STRUTS ALONG TRUSS
- S/C REACTION WHEELS
- PROOF-MASS ACTUATORS*
- VIDEO CAMERA*
- PZT PAYLOAD ISOLATOR TRIPOD*

* OPTION 2 ADDITIONS

CONCEPTUAL EXPERIMENT DESIGN
OPTION 2 CONFIGURATION

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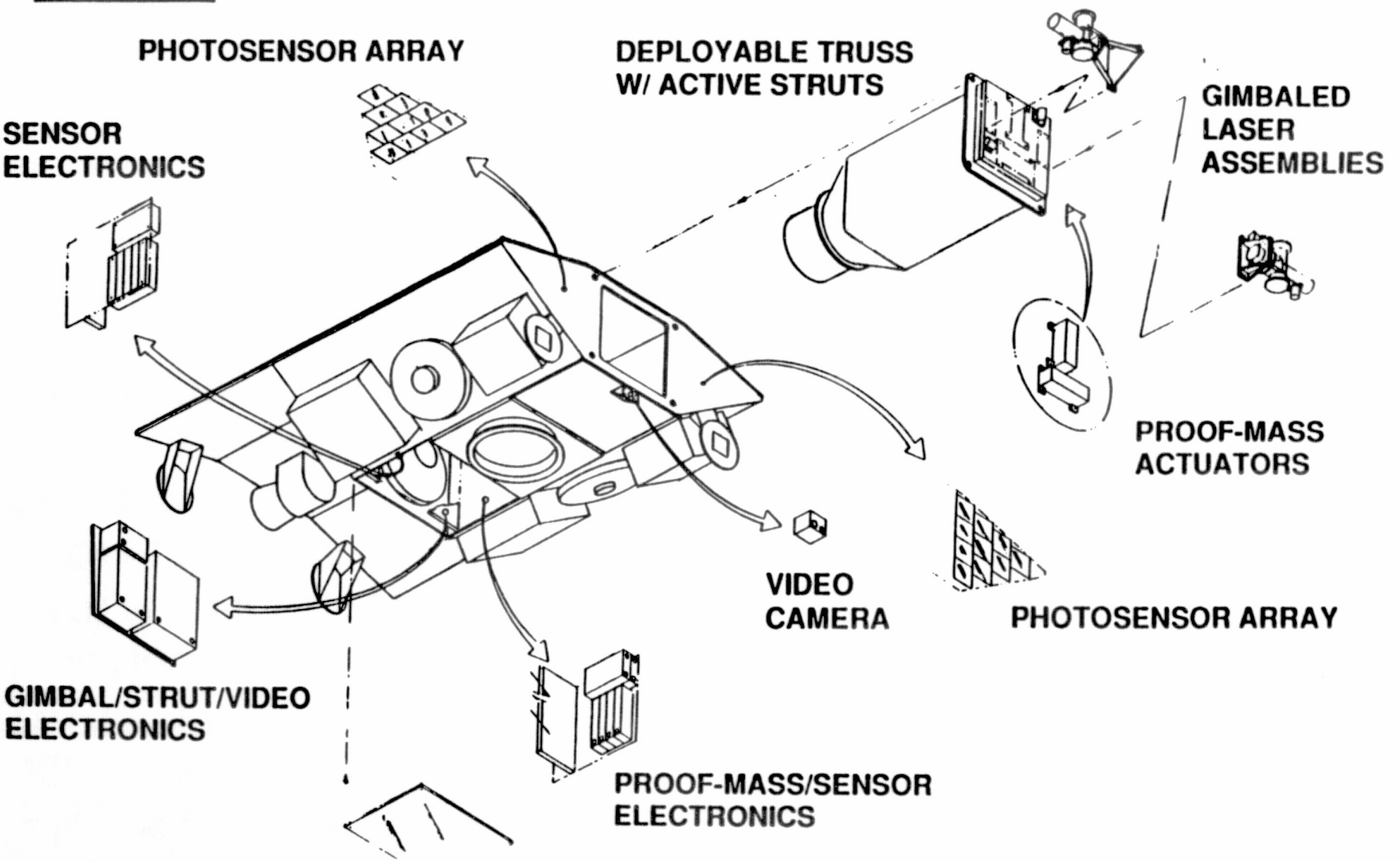

EXPERIMENT DESIGN DEPENDS ON PRIMARY MISSION & BUS CAPABILITIES AND COST CONSTRAINTS

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- PRIMARY MISSION
  - WEIGHT MARGIN
  - ORBIT
  - LAUNCH VEHICLE CAPABILITIES
    - CLAMPBAND LIMITS
    - C.G. LIMITS

- S/C BUS CAPABILITIES
  - DELTA-V (IF NEEDED)
  - CPU THROUGHPUT
  - PAYLOAD VOLUME
  - POWER

- COST CONSTRAINTS
  - "OFF-THE-SHELF" H/W
  - MINIMAL H/W DEVELOPMENT

DELTA II - QUICKSTAR INTERFACE
CLAMPBAND CAPABILITY

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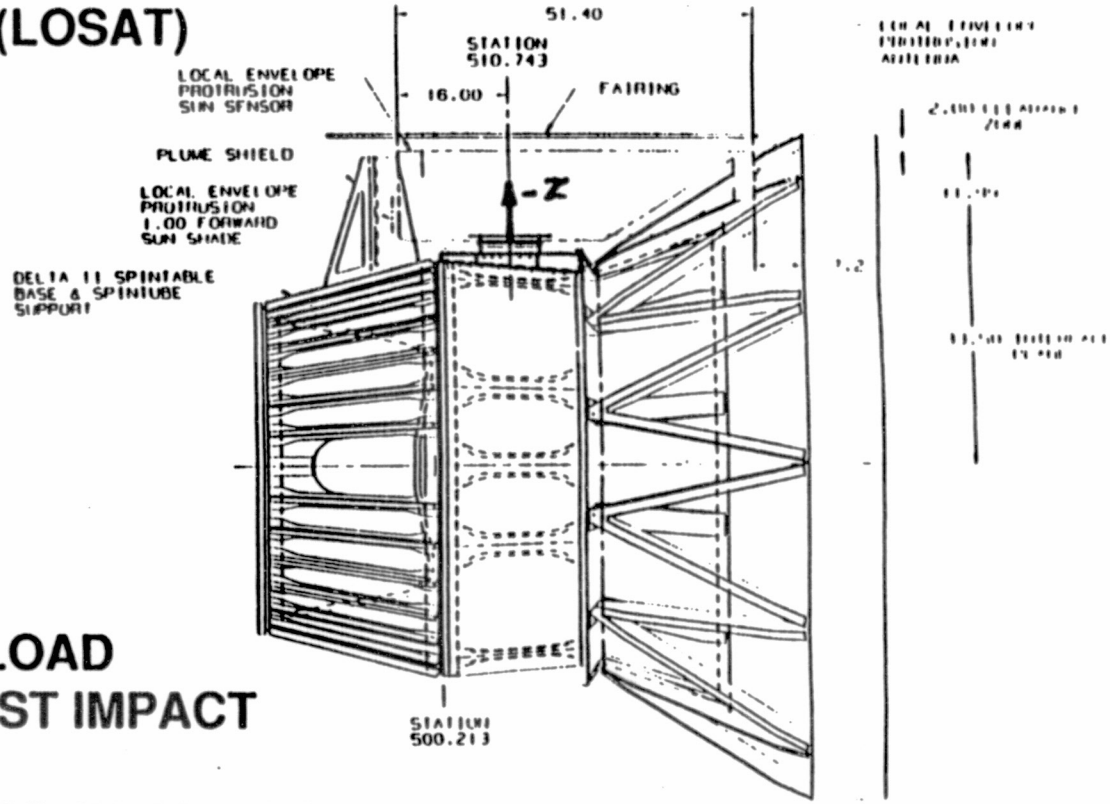
- CLAMPBAND CAPABILITY DETERMINES MAX PAYLOAD WEIGHT

- CURRENT CLAMPBAND DESIGN (LOSAT)
  - 200 LBS PAYLOAD
  - ±1.0", ±1.0", -6.0" PAYLOAD C.G. ENVELOPE
  - STATIC LOAD TEST REQUIRED
    - MINIMAL COST IMPACT



- REDESIGNED CLAMPBAND
  - 220 LBS PAYLOAD
  - ±1.0", ±1.0", -6.0" PAYLOAD C.G. ENVELOPE
  - REDESIGN EFFORT & STATIC LOAD TEST REQUIRED - MINIMAL COST IMPACT

- GREATER THAN 220 LBS PAYLOAD REQUIRES GUIDANCE SECTION IMPACT TO BE CONSIDERED - SIGNIFICANT COSTS POSSIBLE

1997 BASELINE
DELTA LAUNCH OPPORTUNITIES

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- **ACE MISSION**
  - LAUNCH DATE: JULY 1997
  - ORBIT ALTITUDE: 167 KM (100 MI) X L1 POINT
  - ORBIT INCLINATION: 28.7 DEG
  - WEIGHT MARGIN: 1415 LBS

- **ATMOS MISSION**
  - LAUNCH DATE: OCTOBER 1997
  - ORBIT ALTITUDE: 792 KM (475 MI) CIRCULAR
  - ORBIT INCLINATION: 98.5 DEG (SUN SYNCHRONOUS)
  - WEIGHT MARGIN: 400 LBS

CSI-Star CAN ACHIEVE ORBITAL LIFETIME OF MORE THAN 1 YEAR

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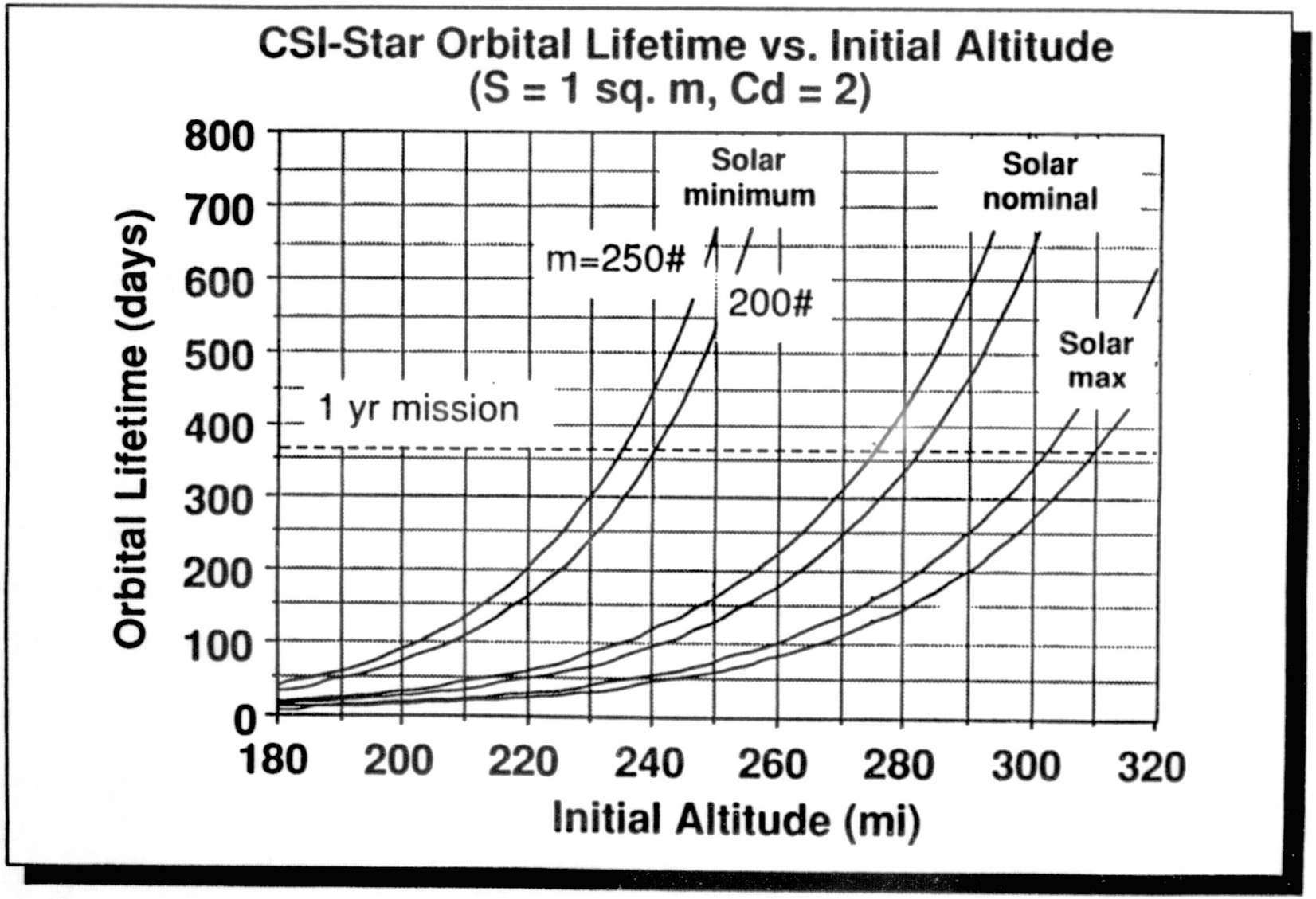
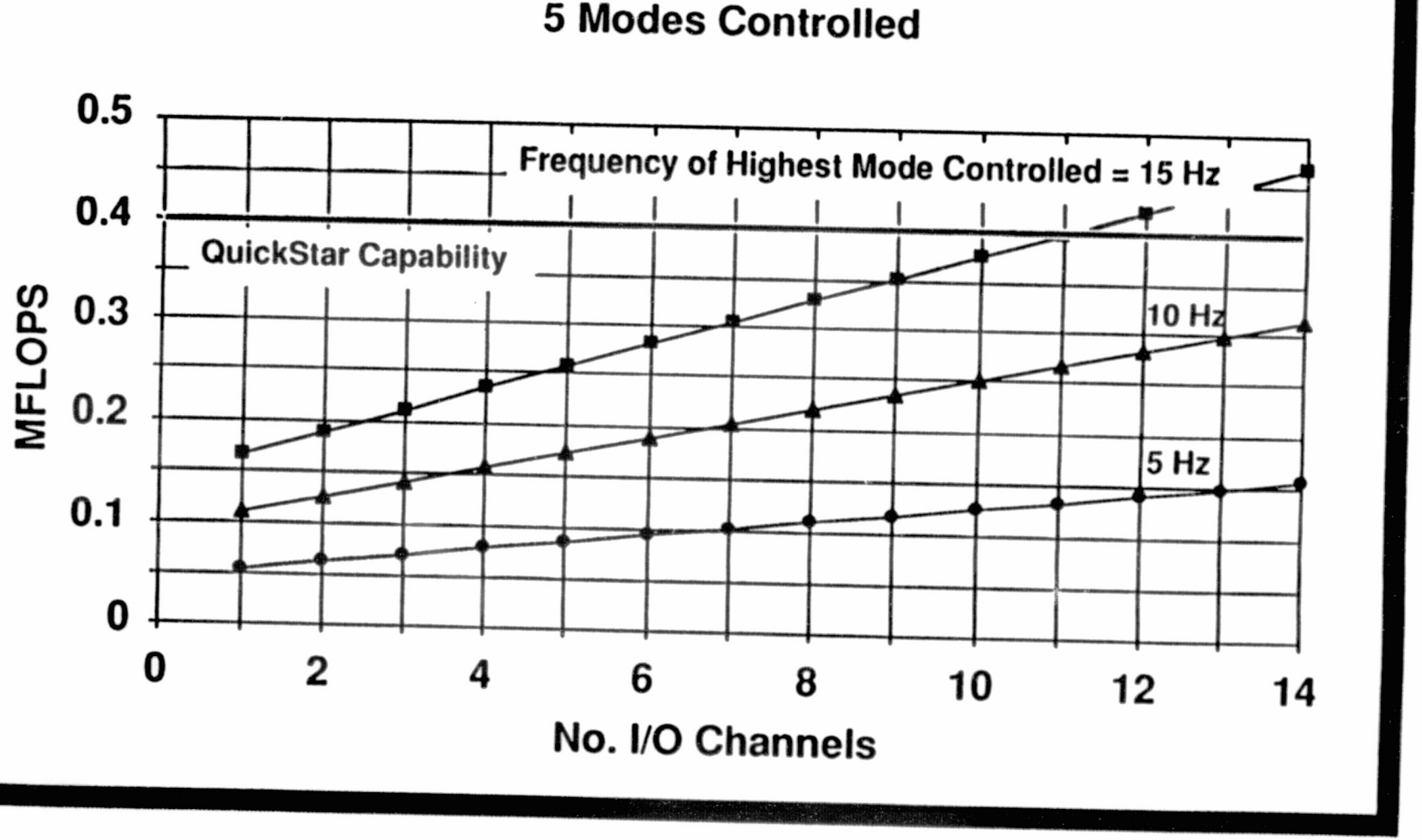


QUICKSTAR BUS CPU CAN PROVIDE THE REQUIRED THROUGHPUT



OPEN & CLOSED LOOP RESPONSE OF BASELINED TRUSS WITH ACTIVE STRUTS

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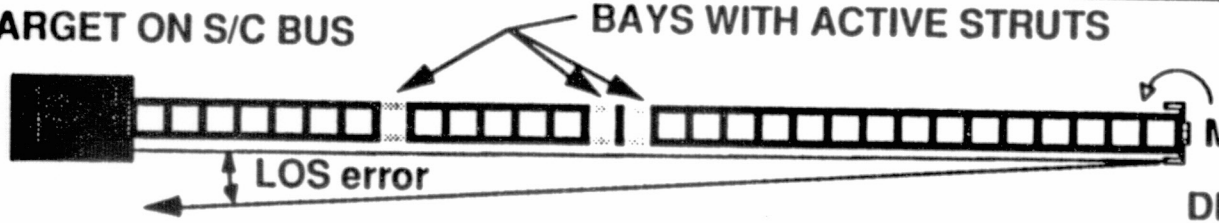

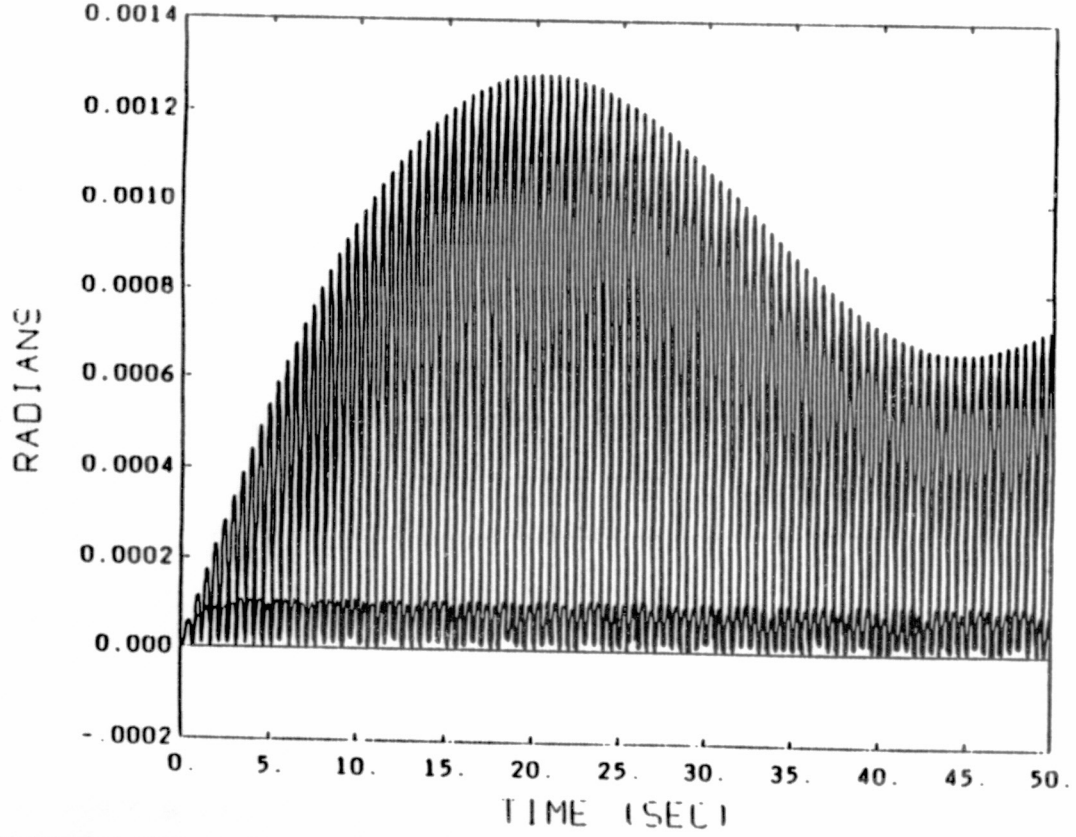

DISTURBANCE APPLIED BY SLEWING PAYLOAD WITH

M_o = 1 in-lb
$\omega = 2\pi$ s^{-1} (f = 1 Hz)

STRUT SIZING REQUIREMENTS

- REDUCE RESPONSE BY 10X
- SUB ARC-MINUTE POINTING
- LAC CONTROLLER
- 28 V MAX

STRUT CHARACTERISTICS

- 6 ACTIVE STRUT PAIRS
- 23 V MAX VOLTAGE
- 0.6 lb MAX FORCE
- SEVERAL LOW V, F OPTIONS

EXPERIMENT WEIGHT
BASELINE (OPTION 1) CONFIGURATION

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DESCRIPTION	SIZE	UNIT WEIGHT* (LBS)	QUANTITY REQUIRED	TOTALWEIGHT (LBS)
ACCELEROMETER	.625 HEX,.38 HI	0.01	20	0.20
STRAIN GAGE	small	0.01	20	0.20
ACTIVE STRUT, ASTROMAST	.5DIA X 6.0	0.25	12	3.00
TEMP SENSORS	small	0.05	6	0.30
ASTROMAST	9.2 X 9.2 X 16.8	21.00	1	21.00
PHOTO SENSOR	2.8 X 2.8 X 0.4	0.18	10	1.80
STRUT ELECTRONICS	6.5 X 4.0 X 2.5	2.25	1	2.25
SENSOR ELECTRONICS	5.5 X 1.2 X 0.9	0.20	9	1.80
DISTURB PAYLOAD	1.5 DIA X 4.0	2.00	1	2.00
LASER	1.5 DIA X 4.0	2.10	1	2.10
GIMBAL ASSY, 2 AXIS	BALL ESTIMATE	3.70	1	3.70
GIMBAL ASSY, 1 AXIS	BALL ESTIMATE	1.90	1	1.90
GIMBAL DR. ELECTRONICS	6.0 X 8.0 X 1.0	2.00	2	4.00
LASER ELECTRONICS	3.0 X 5.0 X 1.0	0.50	1	0.50
STRUCTURE	ENG. ESTIMATE	0.88	3	0.88
MISC.	ENG. ESTIMATE	0.38	A/R	0.38
MLI	PAST EXPERIENCE	.084 #/Ft2	3.75 Ft2	0.32
HARNESS	15 X.125#/ CONN	1.4#/1000FT	3112 Ft	6.23
TOTAL				52.56

* WEIGHTS ESTIMATED WITH A MINIMUM 25% MARGIN

EXPERIMENT WEIGHT
OPTION 2 CONFIGURATION

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DESCRIPTION	SIZE	UNIT WEIGHT (LBS)	QUANTITY REQUIRED	TOTALWEIGHT (LBS)
ACCELEROMETER	.625 HEX,.38 HI	0.01	20	0.20
LOAD CELL	.67DIA X 1.23	0.10	2	0.20
STRAIN GAGE	small	0.01	20	0.20
PROOF MASS ACT.	5.0 X 1.5 X 1.5	3.00	2	6.00
ACTIVE STRUT, ASTROMAST	.5DIA X 6.0	0.25	12	3.00
VIDEO CAMERA	2.0 X 2.0 X 2.3	1.00	1	1.00
TEMP SENSORS	small	0.05	6	0.30
ASTROMAST	8.6 X 8.6 X 27	21.00	1	21.00
PHOTO SENSOR	2.8 X 2.8 X 0.4	0.18	20	3.60
STRUT ELECTRONICS	6.5 X 4.0 X 2.5	2.25	1	2.25
SENSOR ELECTRONICS	5.5 X 1.2 X 0.9	0.20	9	1.80
PROOF MASS ELECTRONICS	3.0 x 5.0 x 1.0	0.50	2	1.00
TRIPOD, ACTIVE LASER	.38DIA X 2.5	1.00	1	1.00
LASER	1.5 DIA X 4.0	2.10	2	4.20
GIMBAL ASSY, 2 AXIS	BALL ESTIMATE	3.70	1	3.70
GIMBAL ASSY, 1 AXIS	BALL ESTIMATE	1.90	1	1.90
GIMBAL DR. ELECTRONICS	6.0 X 8.0 X 3.0	2.00	2	4.00
VIDEO ELECTRONICS	4.0 X 2.6 X 2.6	4.00	1	4.00
LASER ELECTRONICS	3.0 X 5.0 X 1.0	0.50	1	0.50
STRUCTURE	ENG. ESTIMATE	0.88	3	0.88
MISC.	ENG. ESTIMATE	0.38	A/R	0.38
MLI	PAST EXPERIENCE	.084 #/Ft2	3.75 Ft2	0.32
HARNESS	20 X.125#/ CONN	1.4#/1000FT	3512 Ft	7.40
TOTAL				68.83

* WEIGHTS ESTIMATED WITH A MINIMUM 25% MARGIN

EXPERIMENT POWER
BASELINE (OPTION 1) CONFIGURATION

CSI

NASA

DESCRIPTION	POWER (W)	QUANTITY REQUIRED	TOTAL POWER (W)
ACCELEROMETER	0.06	20	1.12
ACTIVE STRUT, ASTROMAST	0.15	12	1.86
ASTROMAST DRIVE ELECT.	20.00	1	20.00
GIMBAL DRIVE ELECTRONICS	2.00	1	2.00
GIMBAL DRIVE MOTOR	2.00	3	6.00
INSTRUMENT HEATING	10.00	1	10.00
LASER POWER	0.90	1	0.90
LASER ELECTRONICS	3.00	1	3.00
PHOTO SENSOR	0.03	10	0.25
SENSOR ELECTRONICS	0.00	9	0.01
STRAIN GAGES	0.13	20	2.50
STRUT ELECTRONICS	0.13	1	0.13
TEMP SENSORS	0.00	6	0.00
TOTAL			47.77

EXPERIMENT POWER
OPTION 2 CONFIGURARATION

NASA

DESCRIPTION	POWER (W)	QUANTITY REQUIRED	TOTAL POWER (W)
ACCELEROMETER	0.06	20	1.12
ACTIVE STRUT, ASTROMAST	0.15	12	1.86
ASTROMAST DRIVE ELECT.	20.00	1	20.00
GIMBAL DRIVE ELECTRONICS	2.00	3	6.00
GIMBAL DRIVE MOTOR	2.00	3	6.00
INSTRUMENT HEATING	10.00	1	10.00
LASER POWER	0.90	2	1.80
LASER ELECTRONICS	3.00	1	3.00
LOAD CELL	0.90	2	1.80
PHOTO SENSOR	0.03	20	0.50
PROOF MASS ACTUATOR	9.04	2	18.08
PROOF MASS ELECTRONICS	0.08	1	0.08
SENSOR ELECTRONICS	0.00	9	0.01
STRAIN GAGES	0.13	20	2.50
STRUT ELECTRONICS	0.25	1	0.25
TEMP SENSORS	0.00	6	0.00
VIDEO CAMERA	5.00	1	5.00
VIDEO ELECTRONICS	15.00	1	15.00
TOTAL			93.00

CSI QuickStar Capabilities/Requirements

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QuickStar Characteristic	QuickStar Capability	Payload Requirement
• Payload Weight	70 lbm	52.66 lbm (option 1) 67.11 lbm (option 2)
• Onboard processing	2 MIPS	0.9 MIPS
• Data storage	500 Mbits	80 - 400 Mbits
• D/L data rate	1 Mbps	0.83 Mbps
• Payload power	75 W Peak 40 W orbit ave	28 W (option 1) 58 W (option 2)

Configuraton Requirements

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• Use Quickstar bus	Meets reqt
• Fit in space between Guidance section and fairing	Needs work
• Package CSI experiment	Meets reqt
• Incorporate longer torque rods	Meets reqt
• Option 1 weight $\leq$ 200 lbs	204 lbs
• Option 2 weight $\leq$ 220 lbs	219 lbs
• C.G. at Z $\leq$ 6.0 inches	5.9 inches

Attitude Determination and Control

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- Moments of inertia vs boom length and tip mass
- Disturbance torques
- Management of disturbance torques
- Maneuverability of deployed system
- Control performance
- System stability

Torque Management Results

- Moment of inertia ~500 kg • m^2 with 25 lb tip mass and 20 ft boom
- Disturbance torques managed with 30 Amp • m^2 control magents
- Wheel capacity of 1.0 N • m • s is adequate
- System is maneuverable at 60° in ~10 minutes

Baseline Control Parameters

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- 0.05 Hz effective bandwidth (low)
- 10 Hz gyro sampling rate
- 20 msec gyro sampling (transport) delay
- 3 arcsec (15 microrad) rate quantization
- 10 Hz wheel torque commanding rate
- 6 oz-in (0.042 N • m) max wheel torque
- 1 Hz first boom free-free mode

System is highly stable and contributes to boom damping.

CSI QuickStar Bus ROM Costs

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Based on our current understanding of the mission and payload requirements, the cost of a Ball QuickStar spacecraft for the CSI vehicle would range from

$9.6 to $12.2 M*.

*** Note:**
- **Does not include launch vehicle integration , launch vehicle, or operations costs.**
- **A more refined estimate can be provided as the specifications and interfaces are more fully defined.**

WORK REMAINING

NASA

- RECHECK WEIGHT & POWER ESTIMATES
- IMPROVE COST ESTIMATES
- RISK ASSESSMENT
- EVALUATION OF EXPERIMENT OPTIONS
  - DATA POTENTIAL FOR TYPICAL CSI TESTS
  - BENEFITS STUDY
- FINAL BRIEFING & REPORT

SUMMARY

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- OUR PRIMARY OBJECTIVE IS TO DEFINE A FREE-FLYING CONCEPT THAT SATISFIES MOST CSI OBJECTIVES FOR THE LOWEST COST
- CSI-Star IS A TECHNOLOGY DEMONSTRATION NOT A TECHNOLOGY DEVELOPMENT PROGRAM, I.E., ALL H/W USED WILL HAVE BEEN PREVIOUSLY DEVELOPED
- QUICKSTAR'S FLIGHT-TESTED CAPABILITIES OFFER THE BEST POTENTIAL FOR A LOW-COST CSI FLIGHT EXPERIMENT
- LOSAT-X DEMONSTRATED NO ADVERSE IMPACT TO DELTA LAUNCH VEHICLE OR THE PRIMARY PAYLOAD, WHICH INCREASES CSI-STAR'S CHANCES OF FINDING A RIDE
- OUR STUDY END PRODUCT WILL BE 2 OR 3 LOW-COST CONCEPTS FOR AN ORBITAL CSI FACILITY THAT INCLUDES REALISTIC COST AND RISK ESTIMATES THAT WILL ALLOW NASA TO DETERMINE IF THE POTENTIAL DATA RETURN JUSTIFIES THE COST AND THAT THE RISK IS ACCEPTABLE