Final Report

LSS Systems
Planning and Performance Program

Contract NAS8-36670

Prepared for:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Authors:

Victoria Jones McKenna
Michael J. Dendy
Charles B. Naumann
Sally A. Rice
John M. Weathers

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1.0 Introduction

The LSS Systems Planning and Performance Program involved the development, integration and operation of the Control-Structures Interaction/Controls, Astrophysics, and Structures Experiment in Space (CSI/CASES) Advanced Development Facility; enhancement and operation of the Active Control of Systems (ACES) Ground Test Facility and participation in the CSI Guest Investigator Program. Accomplishments included the overall systems engineering responsibility associated with laboratory development, including specification, fabrication, testing, integration, and operation of the laboratory systems consisting of the test articles, sensors, actuators, RTCS, data acquisition systems, optics, power and electronics, Logicon Control Dynamics supported the day to day maintenance and operation of the facility, including both control and dynamic testing as well as simulation, structural modeling, control methodology design and implementation, and facility computer software.

This report addresses the ACES facility, CSI/CASES facility and the Guest Investigator program on the ACES facility. The accomplishments made in several areas for each facility are discussed, the current status of each facility is detailed, and recommendations for future work are prescribed.

Included in this report is Appendix A that lists all documents, drawings, blueprints, manuals, schematics, reports, papers, publications and other information that have been provided over the course of the contract. These items are located in the LSS Control Room in Building 4619.
LSS Program Team

Program Definition & Management
CDy, ED-12, ED-73

Facility Components
CDy, ED-73

System Integration
CDy, ED-73, EH-53, VerVal

Modal Testing & System ID
ED-73, CDy, GIs

Power Systems
CDy, EB-12

Computers
CDy, ED-73, AP Labs, EB-24

Electronics
CDy, EB-24, EB-22

Simulation & Modeling
CDy

Sensors & Actuators
CDy, EB-22, ED-73, Ball, MSI

LOGICON

Control Dynamics
General Activities

- Contract Management
  Bi-Weekly/Monthly Meetings & Minutes
  Monthly Status Reviews to NASA and CDy; Bi-weekly Financial Status Updates (CDy)

- Demonstrations

- Materials

- Facility Integration & Verification (CSI/CASES)

- Facility Operation & Maintenance (ACES & CSI/CASES)

- Computer System Administration (CSI/CASES)

- Training Session for NASA
General Activities

- Documentation

Prepare facility overview doc'n for control room (4 drawers +)

Prepare & Deliver final reports:

ACES: ACES System Overview doc't, ACES Software Description doc't,
ACES operator's manual
ACES Finite Element report

CASES: Operator's Manual,
Finite Element report, Simulation doc't,
SMS report, Auto-Cutoff/Sync Gen report,
Mux/Demux manual, PC Board Interface report,
Signal Processing doc't,
Test log notebook,
Test plot notebooks (DS, AMED, BLT, System, etc...)

Preparing final reports:
CASES System Doc'n, CASES System Testing Report
RTCC manual, AMED & Debug reports
2.0 ACES Facility

This section discusses the activities involving the ACES facility. This includes Guest Investigator Testing, structure maintenance, and documentation. Also listed are recommendations for facility upgrades.
SSC Activities

- Testing

Ohio University – further investigation of pendulum mode: identification and control.

  9/92: On-site open and closed loop testing, unsuccessful at dampening pendulum mode.

  1/93: OU provided custom noise disturbances for AGS. LCD performed open loop tests and shipped resulting data to OU.

- Facility

Instrumentation amplifier that serves Y-axis BET LVDT repaired by Data Tape.

HP 9000 computer replaced by NASA (Kissel) due to failure in I/O function.

Sine sweep code in control program corrected to produce proper sweep function.

Elliptic filter boards installed in COSMEC (GI testing had previously prohibited).
SSC Activities

• Documentation

SSC Facility Operator's Manual 11/92
SSC Facility Software Description 12/92
SSC Transfer Functions Packet 2/93
SSC Laboratory Overview 3/93
# ACES Facility: Future Recommendations

<table>
<thead>
<tr>
<th><strong>Recommended Upgrades</strong></th>
<th><strong>Benefits</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Update HP 9000/COSMEC/AP with MMVC computer</td>
<td>Increased sampling rate, controller order, expandability</td>
</tr>
<tr>
<td>Utilize present ACES computer for an SMS</td>
<td>Expand safety monitoring capability</td>
</tr>
<tr>
<td>Increase speed &amp; accuracy of LaMOD</td>
<td>Increased control performance and evaluation</td>
</tr>
<tr>
<td>Investigate intermittent COSMEC I/O failure</td>
<td>Eliminate COSMEC problems</td>
</tr>
<tr>
<td>ACES-IV: Add tip roll motor</td>
<td>Increased control authority at tip</td>
</tr>
<tr>
<td>Improve simulation model of BET</td>
<td>Add 8 Hz mode to simulation</td>
</tr>
</tbody>
</table>

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**ACES**  Active Control Evaluation of Spacecraft  
**AP**  Array Processor  
**BET**  Base Excitation Table  
**LaMOD**  Laser Motion Optical Detector  
**MMVC**  Multibody Modeling, Verification and Control  

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**LOGICON**

Control Dynamics
3.0 CSI/CASES Facility

An extensive amount of work has been performed relating to the CSI/CASES facility. The structure has been assembled, complete with sensors and actuators and a disturbance system. The computer system, and its corresponding software, has been developed and integrated with the hardware. A simulation tool and finite element model have been developed and tested. Documents have been written which discuss each component, as well as overview documents and users manuals. The next several sections break out in more detail the work performed relating to the CSI/CASES facility.
3.1 Facility Overview

This section describes the actual CSI/CASES facility and its objectives. There are breakdowns of sensor and actuator locations as well as pictures of the hardware. Also provided are recommendations for future hardware upgrades.
CSI/CASES  GTF  (Ground Test Facility)

- Objectives:
  Investigate CSI (Control-Structures Interaction)
  Conduct CSI Guest Investigator studies
  Investigate deployment dynamics
  Support ground testing of potential Flight Exp't

- Facility:  NASA/MSFC Bldg. 4619
  Main Platform at 132 ft.

- Test Article:  Vertically Suspended
  105 ft deployable boom (15 " D)
  Simulated MPRESS
  Simulated Occulter Plate (6'x6')
CASES GTF (Ground Test Facility)

Sensors:

2 gyros at mid-point, 2 at tip
3 accels at tip, 3 at MPESS
4 disp sensors at tip plate

Boom Motion Tracker
DS sensors (force, accel, pos'n, air gap, press, flow)

Actuators:

2 reaction wheels at mid-point, 3 at tip
2 thrusters at tip

2 DS shakers

Computer: 64 I, 64 O, 100 order ctlr at 250 Hz

Sun Host plus Real-Time CPU
with 3 Array Processors

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Control Dynamics
Facility Progress

- Finish curtain enclosure system
- Add MPESS access platform (unmotorized)
  Deliver motor & starter
- Add facility lighting system, garage door windows & doors, AC unit
- Finalize MPESS (- CW's, + Simulated Detector)

AC  Air Conditioner
CW  Counterweight
DS  Disturbance System
MPESS Mission Peculiar Experiment Support Structure
CSI ADF Test Articles

- MPESS
- Boom Canister
- Thruster Hose Supply
- Power Cables
- Signal Cables
- Bungee Cords
- Boom Tip
- Mask
- Tip Plate
- TDS Target

Boom (Horizontal Deployment)
## Facility: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add raised platform (&amp; stairs) on floor near tip for visitor's viewing</td>
<td>Easy access to tip components by facility workers</td>
</tr>
<tr>
<td></td>
<td>Convenient viewing of tip components by visitors</td>
</tr>
<tr>
<td>Add motor/starter to MPESS access platform</td>
<td>Motorized platform</td>
</tr>
<tr>
<td>Extend AMED access platform</td>
<td>Easy access to mid-boom instrumentation</td>
</tr>
<tr>
<td>Replace rails on access platforms</td>
<td>Increased safety</td>
</tr>
<tr>
<td>Add small hoist system for access platforms</td>
<td>Small loads (tools &amp; test equipment) won't have to be hand carried up ladders</td>
</tr>
<tr>
<td>Improve tip suspension system</td>
<td>Less dynamic interaction than bungees</td>
</tr>
</tbody>
</table>

**AMED** Angular Momentum Exchange Device  
**MPESS** Mission Peculiar Experiment Support Structure
3.2 Disturbance System

This section discusses the work performed on the CSI/CASES disturbance system, along with a description of the disturbance system.
Disturbance System

- Applies 2DOF disturbances to base of exp't
  Located at top of platform

- Components: Ring Bearing, Leveling Mechanism, Tripod, Air Pads, EM Shakers, Linear Motion System, Alignment System

- Air Pads provide "frictionless" surface
  Air Pad "spring constant" set above freq range of interest

- Tripod is attached to simulated MPESS, which supports experiment

AS  Alignment System
LMS  Linear Motion System
MPESS  Mission Peculiar Experiment Support Structure
Disturbance System
Disturbance System Progress

- Interface DS command from RTCC to shaker electronics; Add shaker current meas't to Mux

- Add signal conditioners for force transducers; Add gain to accelerometers

- Add shaker enable/disable relay (MSI, CDy); Interface with Auto-Cutoff system

- Repair/Replace force transducer joints

- Preliminary functionality testing & characterization testing

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Control Dynamics
3.3 Signal Processing & Electronics

The first topic discussed in this section is the Mux/Demux system for the CSI/CASES facility, its development, and current status. The second topic is the debug system developed for the facility. This system is extremely useful for locating the source of problems involved with the electronics. The third topic is the power system for the facility. Many components of this system are located on the MPRESS. Its components are described and progress listed. The final topic in this section is facility signal processing. Flow charts are provided to show signal flow paths for the sensors and actuators. Tests were performed on the system and the results are provided along with recommendations for future work.
Multiplexer System

- Designed by CDy & EB-22, Implemented by CDy
- Samples 24 channels at rates to 950 Hz
- Differential amplifier (of sensors) reduces common-mode noise
- Gains from 1 to 1000 are easily changeable (resistor modification)
- 2nd order Butterworth anti-aliasing filters with 4 selectable cutoff frequencies
- Fault indicator circuit on Mux/Demux
- Mux I/V & Demux V/I converters are used to transmit signals
- Remotely selectable: sync frequency, filter cutoff frequency
Multiplexer System

- Mux/Demux used for sensors and actuators

Actuator Mux/Demux:

Sensor Mux/Demux:

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Control Dynamics
Cases Electronic Multiplexer System

Differential to Single Ended Converter/Amplifier
Anti-Aliasing Filter
Multiplexer
Demultiplexer

Mounted on Experiment

Mounted in Control Room

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Control Dynamics
Mux/Demux: Sync Generator

- Designed & Implemented by ED-73 & CDy
- Generates the synchronization signals for M/D
- Sync frequency is selectable (100, 250, 500, 950 Hz) from CR
- RTCC Sync detector allows RTCC to generate sync during runs
- Resides in CR on Auto-Cutoff/Sync panel
Mux/Demux: Sync Generator

- Generates syncs for Actuator Mux's & Sensor Mux's

Minimizes time delays in system: Delayed & Undelayed Sync's

- Sensor Mux sync is filtered to prevent cross-talk between other M/D signals (di/dt is limited)

Actuator Sync Signal

Sensor Sync Signal

- M/D will not work without correct sync signal: Always verify Sync

Common Sync: All M/D's will not work if one M/D fails
Mux/Demux: Troubleshooting Signal

- Demux Comb signal is available for troubleshooting: very useful signal
- Demux Comb is the Mux'd signal in the CR prior to Demux'ing
- Provides observation of all 24 sensor signals on one signal

Sync tips 13V

Sync Duration 16 micro-sec
Data Duration 24 micro-sec
Total Data Frame 960 micro-sec
Debug System

- Designed & Implemented by CDy
- Provides access to boom signals (S & A's) from the CR
- Allows continuous (unmultiplexed) monitoring of selected signal
- Extremely useful
  
  locating source of problem (power, Mux, cable, sensor, actuator, etc...)
  
  comparing processed signals (Mux'ed & filtered) with raw signals
- Can also be used to provide remote signal injection into a Mux for in-place calibration
Debug System

- Microprocessor based system with LCD displays in CR
- Two component systems: Transmitter & Receiver
- Debug transmitter located at each M/D location (2 Boom, 2 Tripod, MPRESS)
- Debug receivers (5) in CR
- Each Debug system provides access to 1 of 48 signals
Debug System Progress

- Develop software for prototype debug system
- Design & Fabricate debug panel & mounting sys
- Populate & Test 5 debug transmitter PC boards
- Layout & Fabricate debug receiver PC boards
- Populate & Test 5 debug receiver boards
- Integrate revrs, Xmitters, rack, power, cables, etc.
- Test & calibrate debug system
- System presently operational

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Control Dynamics
Debug System: Application

- Problem: Gyro natural frequencies were aliasing thru the 125 Hz filter
- Solution: Modify 125 Hz to 25 Hz filter for added attenuation for all gyro channels
- Debug Test: Observe gyro signal during BLT sweep

Compare unmux'd, unfiltered gyro O/P via Debug with Mux'd, filtered gyro O/P

Transfer Function:
Mux'd gyro/Unmux'd gyro

TF shows effect of 25 Hz filter

Gain of TF = -3 dB from DC at 24 Hz

Note: Debug gain = 2 at time of test (Prior to installation of Amp)

Control Dynamics
Power System (MPESS)

- Five 60V/5A supplies for AMED reaction wheel motor supplies
- Two 28V/4A supplies for motor controllers & Power regulator primary
- One \( \pm 15V, 5V \) supply for Mux power
- Line power for BMT/TDS electronics
- Power Connector Panel to route power from supplies to boom cables

Note: Drawing Not to Scale

**Control Dynamics**

<table>
<thead>
<tr>
<th>AMED</th>
<th>BMT/TDS</th>
<th>MPESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular Momentum Exchange Device</td>
<td>Boom Motion Tracker/Tip Displacement Sensor</td>
<td>Mission Peculiar Experiment Support Structure</td>
</tr>
</tbody>
</table>
Power Regulation System

- Supplies power to boom-mounted electronics & sensors & actuators at mid-boom & boom tip
- Converts +28 V (from MPESS supply) to ±15 V, +7.5 V, and +5 V for boom electronics
- Sequences the ±15 V and + 7.5 V for the gyro power-on
- Designed by EB-12 and Fabricated & Integrated by CDy

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Control Dynamics
Power System Progress

- Add 28 V supply for tripod sensors
- Integrate 2 power regulation systems with boom electronics
- Add tip Jones strip to tip power reg system & recable
- Send 7 supplies to Lambda for repair
- Implement temporary 60 V supply system on MPESS
- Reintegrate Lambda supplies with MPESS
- Add remote switches for surge suppressors on tripod & MPESS; Allows remote power-on from CR

Control Dynamics
Signal Processing Overview

- Components:
  Mux/Demux Systems (7):
  Debug Systems (5)
  Auto-Cutoff System/Sync Gen
  Real Time Control Computer
  SMS Computer & DAS
  Dell Computer & DAS
  Power System

- Electronic Rack provides signal access & signal routing to/from components

- Locations: Control Room, Tripod, MPESS, Mid-Boom, Boom Tip

- Longest communication distance = 350 feet
Signal Processing: RTCC

- RTCC Inputs from Demux outputs (Sensor Mux's)

- RTCC Outputs to Mux inputs (Actuator Mux's)
Signal Processing: Electronic Rack

- Rack serves as patch panel between RTCC, SMS, Mux's, Demux's, Debug, Auto-Cutoff
CASES GTF Signal Processing: Actuators

Tip Actuators:
RW Motors, BLTs, Motor Enable/Disables

Mid Actuators:
RW Motors, Enable/Disables

GTF Shakers

Real-Time Control Computer

Mux = D/S → Filter → Mux → V/I
Demux = I/V → Demux → S/I

Control Dynamics
CASES GTF Signal Processing: Sensors

Tip Sensors:
Gyros, RW Speed, Motor Current, Fault, BLT Press, Flow

Mid Sensors:
Gyros, RW Speed, Motor Current, Fault

MPESS Base Sensors:
TDS, Accels, Fault

GTF Sensors:
Force, Pos'n, Accels, Air Gap, Press, Flow

Real-Time Control Computer

Control Dynamics
Cases Sensor Signal Processing

- Air Gap Measurement
- Flowmeter
- Pressure Transducer
- Accelerometers
- Demultiplexer
- Electronics Rack
- Safety Monitor System
- Control Computer

Locations:
- Tripod
- Control Room
Multiplexer Tests: Noise Comparison

- Perform Preliminary Mux/Demux testing: Compare noise levels from various M/D's

- Quiescent test in Volts (Compare accelerometer noise at MPESS & Tip)

- Discover tip Mux is noisier than other Mux's
Multiplexer Tests: Noise Comparison

- Modify shields, Change capacitor in Demux board, Add di/dt limiter to sync generator

- Examine thruster test point signals to evaluate effect of changes

Note improvement of noise by factor of 5 or 10

Quiescent Test (TPA1)

Before

After

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Control Dynamics
Signal Processing Summary

- Implementation, Integration & Testing by: CDy, ED-73
  Designs by: CDy, EB-22, EB-12, ED-73

- Signals routed to & from RTCC, SMS, M/D's, Auto-Cutoff, Debug systems
  Signals, Wires, Cables, Connectors prepared, labeled, installed & verified

  SMS: 34 inputs & 1 output  Auto-Cutoff: 6 inputs/6 outputs
  RTCC: 46 inputs & 9 outputs  Debug System: 82 inputs/5 outputs
  M/D's: 82 inputs/outputs

- Debug System developed, integrated & tested

- Auto-Cutoff System developed, integrated & tested

- Mux/Demux Systems (7) tested & operational
  Mux/Demux power systems operational

- Power Regulation System (3) operational
## Signal Processing: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refine Mux/Demux system (Add sync detector ckt)</td>
<td>M/D failure can cause large actuator commands</td>
</tr>
<tr>
<td>Replace Lambda 60 V supplies</td>
<td>Eliminate power supply failures</td>
</tr>
<tr>
<td>Miniaturize Mux/Demux &amp; Filtering system</td>
<td>Decrease weight of electronics on boom</td>
</tr>
<tr>
<td></td>
<td>More flight-like hardware</td>
</tr>
<tr>
<td>Investigate possibility of deployable &amp; retractable PC board fixtures</td>
<td>Ability to deploy &amp; retract boom electronics</td>
</tr>
</tbody>
</table>
3.4 Sensors & Actuators

This section discusses all the sensors and actuators located on the CSI/CASES facility: the disturbance system, the AMEDs, the BLTs, the BMT/TDS, and other associated sensors. Each sensor and actuator is depicted and the respective location on the facility explained. Sensor and actuator characteristics are also provided. Recommended upgrades are listed at the end of the section.
DS Sensors & Actuators

- Dynamic Sensors: Force, Accel, Position
- Air Bearing Sensors: Gap, Press, Flow
- Actuators: Shakers

Note: Each air bearing pad has an associated pressure transducer, flowmeter, and air gap measurement.

Tower Log

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Control Dynamics

Note: Drawing not to Scale
CASES Control Sensors

TDS Detector

Accelerometers

Conex Gyro
CSI Actuators

Angular Momentum Exchange Devices

Bidirectional Linear Thrusters

Inches

Inches

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Control Dynamics
Sensors: Accelerometers (PCB)

- 3 orthogonal 1-axis seismic accelerometers
  
  Located at: 
  Tripod
  MPESS
  Tip Plate

- Frequency Range: 0.025 - 800 Hz
- Weight: 2.2 Lbs each

Activities:

- Accels aligned & mounted onto MPESS, Tripod & DS
- Accel power units interfaced with power regulation system
- Accelerometer gain (50) incorporated (via DtoS boards)

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Control Dynamics
AMED Sensors: Gyros (Kearfott)

- 2 orthogonal dual-axis gyros in each AMED
  Located at: Mid-Boom & Boom Tip
- Bandwidth: 100 Hz
- Weight: 0.3 Lb

Activities:
- Gyros interfaced w/ Mux & Power Reg Sys
- Modified Gyro Preamps (gain: 150 to 30)
- Modified LPF cutoff for gyro channels
- Replaced one tip gyro (failure)
- Functionality testing: verified signs
- Utilized gyros in system ID testing

LOGICON

Control Dynamics
AMED Actuators: Motors (Inland)

- 2 orthogonal DC brushless motors per AMED
  Located at: Mid-Boom & Boom Tip
- Bandwidth: 1000 Hz
- Weight: 0.8 Lb
- Torque: $\pm 135$ oz-in

Activities:
- Attempt to improve wheel/shaft interface
- Interfaced w/ Demux & Power Reg Sys
- Perform sanity checks on wheel torque command, speed, current
- Replaced one motor speed board (failure)
- Utilized motors in system ID testing

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Control Dynamics
Angular Momentum Exchange Devices (AMEDs)

- Each AMED package includes:
  2 DC brushless Inland motors
  2 dual axis Kearfott Conex gyros (with electronics)
- Located at: Mid-Boom & Boom Tip
- Weight: 13 Lbs
- AMED package is retractable; Present motor, power, M/D electronics are not retractable

Activities:
- AMED Testing in-place: Functionality & System ID Tests
- Interfaced w/ Mux/Demux (M/D) & Power Regulation System

ID M/D Identification Multiplexer/Demultiplexer

Control Dynamics
Mid-Boom AMEDs

Note: Drawing not to Scale

LOGICON

Control Dynamics
Bidirectional Linear Thrusters (BLTs)

- 2 Orthogonal Boeing Thrusters located at Tip
- Force Range: ± 2 lbs-f (Linear)
- Weight: 4 lbs
- Bandwidth: 70 Hz (Boeing Freq Response) Phase lag is -120 deg at 70 Hz

Activities:
- Add pressure transducer to tip
- Add flow straightener to tip
- Replace defective chip on BLT elec PC board
- Interface BLT Test Points with Mux
- Perform BLT characterization tests
- Perform system ID tests with BLTs

logicon

Control Dynamics
Boom Tip (AMEDs & BLTs)

Note: Drawing not to Scale

- Thruster Electronics
- Thrusters
- Motor & Reaction Wheel
- AMED Chassis
  (2 reaction wheels, 2 gyros, & gyro electronics)
- Motor Controllers
- Power Regulation System
- Tip Plate
- Accelerometers

LOGICON
Control Dynamics
Tip Displacement Sensor (TDS)
Ball Aerospace

- Closed Loop Sensor: Control Sensor
- Open Loop Sensor: Augments BMT data for System ID
- Measures disp of tip targets
- Two CCD detectors (X,Y) mounted on MPESS
- Four LED targets on tip plate
- Processes 4 targets at up to 500 Hz
- Travel Range: (-15, +15) inches
- Accuracy 0.01 inch

BMT  Room Motion Tracker
CCD  Charge Coupled Device
LED  Light Emitting Diode
MPESS Mission Peculiar Experiment Support Structure

LOGICON

Control Dynamics
Boom Motion Tracker (BMT)
Ball Aerospace

- Optical system for measuring boom displacements
- Open Loop Sensor: System ID/Modeshape Meas't
- Measures angular disp of boom targets
- Three CCD detectors (X,Y,Z) mounted on MPESS
- LEDs on MPESS to illuminate targets
- Passive Targets made from reflective tape
- Processes 37 targets at 100 Hz
- Travel Range: (-10", +10") at boom tip
  (-4", +4") at boom base
- Accuracy 0.01 inch
BMT/TDS Interfaces

Note: Drawing Not to Scale

LOGICON

Control Dynamics
BMT/TDS Interfaces

MPESS (Bottom View)

3 BMT detectors (w/Illuminators), 2 TDS Detectors
(Accelerometers)

Reflective tape on Reflector mount
(Tape replaced with new Tape & Mask)

Control Dynamics
## Sensor & Actuator: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redesign motor shaft/RW interface</td>
<td>Reaction wheels will be safe</td>
</tr>
<tr>
<td></td>
<td>Extend allowable Torque &amp; Speed range</td>
</tr>
<tr>
<td>Develop TDS spike removal filter</td>
<td>Filter spikes prior to RTCC</td>
</tr>
<tr>
<td>Develop software to use BMT</td>
<td>Obtain useful EU data</td>
</tr>
<tr>
<td>Test &amp; Evaluate BMT System</td>
<td>Determine BMT limitations, difficulties, ranges of operation, etc...</td>
</tr>
<tr>
<td>Develop software to display &quot;animated&quot; run-time displacements (BMT)</td>
<td>Visual display of boom motion</td>
</tr>
<tr>
<td>Perform modal test to compare conventional accel modal test with BMT</td>
<td>Dynamic verification of BMT</td>
</tr>
<tr>
<td>Fabricate extra AMED system (working RWs) for demonstrations in lab</td>
<td>Provide active AMED demo to visitors</td>
</tr>
<tr>
<td></td>
<td>Extra available for replacement</td>
</tr>
</tbody>
</table>

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**Legend**

- AMED: Angular Momentum Exchange Device
- RW: Reaction Wheel
- BMT: Boom Motion Tracker
- TDS: Tip Displacement Sensor

**Control Dynamics**
3.5 Computer System

This section discusses the development of various components of the CSI/CASES computer system. These components include: the BMT data acquisition computer, the real-time control computer, the safety monitor system, the auto-cutoff system, and the video monitor system. The capabilities of each of the above is described along with their progress. Recommendations are listed on how the computer system could be upgraded in the future.
BMT Data Acquisition System

- Developed by CDy based on Ball Design
- Acquires data from BMT system
  Reduces peak transfer rate required (4 MB/sec)
  Transfer data at avg O/P rate of the BMT (45 kB/s)
  Transmit data 240 feet (BMT elec to CR)
- Verifies data received from BMT
- Displays statistical info for BMT data & error conditions
Real Time Control Computer (RTCC)

- 64 Inputs, 64 Outputs
- 100th order Linear controller at 250 Hz
- Sun Host (on VMEbus running Unix)
- AP Labs Real-Time System (on VMEbus running IOS) with 3 Sky Warrior APs

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Control Dynamics
RTCC Activities

- Extensive software modifications (CDy)
- Expand software to command actuators in Lab Frame in EUs (Engineering Units)
- Incorporate scale factor definition file
- Modify software to plot selected sensors & actuators in EUs
- Define scale factors, transformation matrices, biases for sensors & actuators
- Develop software for post-processing data (CDy)

Imperative to have good post-pro SW (Software) due to LARGE amounts of data
(1 minute run produces 3.8 MB of data)

C Program: RNR
M-file: GETNAMR
C Program: AVGDAT
M-file: WRITEM
M-file: EUBIGP

- Backup RTCC SW & Backup all test data files

LOGICON

Control Dynamics
Safety Monitor System
Description

- Dedicated PC-based data acquisition system
- Monitors and graphically displays GTF safety-critical signals:
  Tripod position, air bearing and thruster pressures and flows, facility temperature and humidity, AMED motor and demux fault indicators, AMED heat sink temps.
- Checks safety limits; can signal RT computer for system shutdown.
- Currently monitors 46 signals (64 is max) at 50 Hz. Graphics updated at 5 Hz.

Components:
- Gateway 386 SX computer,
- National Instruments 8 differential channel A/D
- National Instruments 32 differential channel MUX (2)
- National Instruments DOS labdriver software (C-based)
- Quinn-Curtis real-time graphics software (C-based)
SMS Activities

- Added scale factors to display in EUs (Engineering Units)
- Added DS Force variables & display
- Expanded cutoff capability: Motor Fault, Motor Speed, Bearing Gap, DS Force
Auto-Cutoff System

- Designed, Developed & Integrated by ED-73 and CDy (this year)

- Auto-Cutoff System disables Motors & Shakers in emergency situation

- Allows manual enable/disable of motors & shakers (from panel in CR)

- Interfaced with SMS which notifies of emergency conditions
Video Monitor System

- Concept, Design & Implementation by CDy (this year)
- Useful for Safety & Demonstrations
- Allows observation of 4 locations from CR Dist System, Mid-AMED, Boom, Tip Plate
- Components: TV Monitor, Quad-splitter, VCR, 1 Color Video Camera, 3 B/W Cameras
- DS Camera mounted on remote-control Pan/Tilt system
- DS Camera modified to allow remote zoom

LOGICON
Control Dynamics
## Computer System: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorporate Digital I/O Capability</td>
<td>Allow subset of BMT targets to be used as a control sensor</td>
</tr>
<tr>
<td>Investigate adding parallel processing capability</td>
<td>Allow dynamic update of lab-to-body transformation matrices</td>
</tr>
<tr>
<td>Change operation procedure to shut-down RTCC</td>
<td>Eliminate need for operator to use root</td>
</tr>
</tbody>
</table>

**Abbreviations:**
- **BMT**: Boom Motion Tracker
- **I/O**: Input/Output
- **RTCC**: Real Time Control Computer
3.6 CSI Model/Simulation

This section discusses the Treetops simulation developed to use in modeling the CSI/CASES facility and provides results generated using a preliminary finite element model. The remainder of the section discusses the development and tuning of the actual NASTRAN finite element model. Results (frequencies and mass properties) are provided from the final model along with modeshape comparisons with the actual modal test results. Recommended upgrades and additions to the model and simulation are listed at the end of the section.
CSI GTF Simulation

- Based upon Treetops Software, Version 9

- Flexible body model, MSC NASTRAN Version 65C2
  Includes: Boom, MPESS, Tripod, and Tip plate

- Full Sensor/Actuator Set

- Documented in Report
CSI GTF Simulation, Continued

DISTURBANCES
- X, Y force profiles via shakers

ACTUATORS
- Reaction wheels
- Thrusters

DISTURBANCE DYNAMICS

ACTUATOR DYNAMICS

PLANT
- Tuned FE model
- Rigid and flex effects
- Rolling carts on tripod
- Air pads

SENSORS
- Accelerometers
- Rate gyroscopes
- TDS system

CONTROLS

SENSOR DYNAMICS

LOGICON

Control Dynamics
CSI GTF Simulation, Continued

• Flexible Nastran Body
  • 2 Rigid Body Shakers - Translated in XY Plane wrt Flexible Body
  • 3 Rigid Air Pad Bodies - Translate in Z wrt Flexible Body

• Full Sensor and Actuator Set

• Disturbances applied at Shakers and BLTs
CSI GTF Simulation, Continued

- Good First Cut Simulation Tool

- Recommendations
  - Include Latest Finite Element Model Results
  - Include more than 20 Flexible Body Modes
  - Have Tip Plate be a separate Flexible Body
  - Measure LMS Rail Stiffness Characteristics
  - Compare Gravity Options between NASTRAN and Treetops Simulation
CSI GTF Finite Element Model

- Flexible Body Model includes:
  Boom, MPESS, Tripod, and Tip Plate

- Incorporated Tip Extender Package

- Lumped Mass Components
  LMS, AMEDs, Cabling and Hose, etc.

- Metric Model

- Added Grids at all Sensor/Actuator Locations

- 2 Stage Solution
  - Nonlinear Static to incorporate Gravity Effects
  - Eigensolution
CSI GTF Finite Element Model, Continued

• Convergence Problems
  • Static Nonlinear Solution - Gravity Effects
    Undergoes Large Angular Motion

• Remedies Tried
  • Adjusting Bungee Stiffness Values
  • Modifying Constraints
  • Adjusting Number of Load Steps and Iterations/Step
  • Re-oriented Gravity Vector to go through Boom Tip
  • Vertical Weight Loading of Boom, with Light Tip Plate
CSI GTF Finite Element Model, Continued

Resulting Configuration

- **Static Solution 66**
  - Base is Constrained
  - Bungee Springs have X, Y, and Z Values, Previously just Z
  - Tip Plate made essentially Massless with very light Bungee Springs
  - Concentrated Mass and Inertia Values were added to Tip Extender

- **Eigensolution 63**
  - Base is Freed-up in X and Y
  - Bungee Springs have X, Y, and Z Values, Previously just Z
  - Tip Plate Mass Restored
  - Bungee Stiffness Restored
  - Concentrated Mass and Inertias Removed from Tip Extender
  - ASET with 425 Degrees of Freedom
CSI GTF Finite Element Model, Continued

Model Facts:

- 777 Grid Points
- 244 Beam Elements
- 11 Springs
- 555 Quad Plate Elements
- 131 Tria Plate Elements

- Mass = 2235.766 Kg

- CG = (-0.6593183, -9.725136E-5, -1.4865) meters

- Inertia about CG

\[
\begin{bmatrix}
9.639672E+4 & -7.02168E-2 & 1.383586E+3 \\
-7.02168E-2 & 9.630034E+4 & -8.218950E-2 \\
1.383586E+3 & -8.218950E-2 & 2.048537E+3
\end{bmatrix}
\]
## CSI GTF Finite Element Model, Continued
### Analytical Results

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Modeshape Description</th>
<th>Frequency (Hz)</th>
<th>Modeshape Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0E-5, 1.0E-5</td>
<td>rigid body motion</td>
<td>10.18</td>
<td>torsion</td>
</tr>
<tr>
<td>0.08</td>
<td>Y 1st bending</td>
<td>10.42</td>
<td>tip plate bending</td>
</tr>
<tr>
<td>0.09</td>
<td>X 1st bending</td>
<td>11.00</td>
<td>X bending</td>
</tr>
<tr>
<td>0.16</td>
<td>torsion</td>
<td>11.32</td>
<td>Y bending w/ tip plate</td>
</tr>
<tr>
<td>0.56</td>
<td>X 2nd bending</td>
<td>14.18</td>
<td>torsion</td>
</tr>
<tr>
<td>0.58</td>
<td>Y 2nd bending</td>
<td>14.24</td>
<td>torsion</td>
</tr>
<tr>
<td>1.23</td>
<td>X 3rd bending w/ tip plate</td>
<td>14.99</td>
<td>tip plate bending</td>
</tr>
<tr>
<td>1.82</td>
<td>Y 3rd bending w/ tip plate</td>
<td>15.43</td>
<td>X bending</td>
</tr>
<tr>
<td>1.98</td>
<td>X bending w/ tip plate</td>
<td>15.47</td>
<td>Y bending w/ tip plate</td>
</tr>
<tr>
<td>2.73</td>
<td>Y 4th bending w/ tip plate</td>
<td>17.01</td>
<td>torsion</td>
</tr>
<tr>
<td>3.07</td>
<td>Y bending w/ tip plate, mpress</td>
<td>17.50</td>
<td>tip plate w/ Y bending</td>
</tr>
<tr>
<td>3.28</td>
<td>X 4th bending w/ tip plate</td>
<td>19.09</td>
<td>X bending w/ tip plate</td>
</tr>
<tr>
<td>3.38</td>
<td>torsion</td>
<td>19.38</td>
<td>Y bending w/ tip plate</td>
</tr>
<tr>
<td>3.61</td>
<td>Y bending w/ tip plate</td>
<td>21.10</td>
<td>torsion w/ Y bending</td>
</tr>
<tr>
<td>3.71</td>
<td>X bending w/ mpress</td>
<td>21.21</td>
<td>tip plate bending</td>
</tr>
<tr>
<td>5.39</td>
<td>X bending w/ tip plate</td>
<td>21.50</td>
<td>torsion</td>
</tr>
<tr>
<td>5.63</td>
<td>Y bending w/ tip plate</td>
<td>23.28</td>
<td>tip plate bending</td>
</tr>
<tr>
<td>6.70</td>
<td>X bending w/ mpress &amp; tip plate</td>
<td>23.75</td>
<td>X bending</td>
</tr>
<tr>
<td>7.11</td>
<td>torsion</td>
<td>23.80</td>
<td>Y bending</td>
</tr>
<tr>
<td>8.22</td>
<td>tip plate w/ Y bending</td>
<td>23.99</td>
<td>torsion</td>
</tr>
<tr>
<td>8.35</td>
<td>X bending</td>
<td>24.74</td>
<td>mpress w/ Y bending</td>
</tr>
<tr>
<td>8.97</td>
<td>tip plate w/ bending X &amp; Y</td>
<td>25.63</td>
<td>tip plate bending</td>
</tr>
<tr>
<td>9.09</td>
<td>tip plate</td>
<td>28.40</td>
<td>torsion</td>
</tr>
<tr>
<td>9.91</td>
<td>tip plate bending</td>
<td>29.50</td>
<td>mpress w/ X bending</td>
</tr>
</tbody>
</table>
CSI GTF Finite Element Model, Continued
Frequency Comparison

<table>
<thead>
<tr>
<th>Experimental Frequency (Hz)</th>
<th>Analytical Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.112</td>
<td>0.08</td>
</tr>
<tr>
<td>0.120</td>
<td>0.09</td>
</tr>
<tr>
<td>0.210</td>
<td>0.16</td>
</tr>
<tr>
<td>0.520</td>
<td>0.56</td>
</tr>
<tr>
<td>0.530</td>
<td>0.58</td>
</tr>
<tr>
<td>1.391</td>
<td>1.23</td>
</tr>
<tr>
<td>1.868</td>
<td>1.82</td>
</tr>
<tr>
<td>2.802</td>
<td>2.73</td>
</tr>
<tr>
<td>2.995</td>
<td>3.28</td>
</tr>
<tr>
<td>3.133</td>
<td>3.38</td>
</tr>
<tr>
<td>4.215</td>
<td>3.71</td>
</tr>
<tr>
<td>4.598</td>
<td>3.61</td>
</tr>
<tr>
<td>4.974</td>
<td>5.63</td>
</tr>
<tr>
<td>6.027</td>
<td>6.70</td>
</tr>
<tr>
<td>6.565</td>
<td>8.35</td>
</tr>
<tr>
<td>6.703</td>
<td>7.11</td>
</tr>
<tr>
<td>8.182</td>
<td>8.22</td>
</tr>
<tr>
<td>9.864</td>
<td>9.91</td>
</tr>
<tr>
<td>10.864</td>
<td>10.18</td>
</tr>
<tr>
<td>12.312</td>
<td>11.00</td>
</tr>
</tbody>
</table>
CSI GTF Finite Element Model
Modeshape Comparisons
CSI GTF Finite Element Model, Continued

- Documented in Report

- Recommendations
  - Incorporate every Boom Bay as a Beam Element
  - Add BMT and TDS Systems
  - Update AMED Packages
Closing Remarks

• Work in Systematic Manner
  • Model and Test Components
    (MPESS, Tip Plate, etc.)
  • Combine Components Mathematically and Physically
    Test and Tune
    (CSI GTF)

• Perform Modal Tests on Operational Configuration
  Lesson Learned from ACES
## Model/Simulation: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorporate latest tuned FE model into new simulation</td>
<td>Higher fidelity model</td>
</tr>
<tr>
<td>Add damping values from modal test to simulation</td>
<td>More accurate damping values</td>
</tr>
<tr>
<td>Perform wider bandwidth system ID tests (Transfer Functions)</td>
<td>Better identify very low modes &amp; also higher modes</td>
</tr>
<tr>
<td>Perform further comparison of analytical/experimental TFs</td>
<td>Allow further tuning of model/sim</td>
</tr>
<tr>
<td>Incorporate better model of DS characteristics from further DS testing</td>
<td>Better model/sim of shaker springs, friction, air pad springs, shaft bending, etc.</td>
</tr>
<tr>
<td>Perform modal test on present configuration</td>
<td>Configuration today slightly different from 1/92 configuration</td>
</tr>
<tr>
<td>Model each bay as beam element</td>
<td>Allow addition of BMT as sensor</td>
</tr>
</tbody>
</table>

**LOGICON**

Control Dynamics

**BMT** Boom Motion Tracker  
**FE** Finite Element
4.0 CSI/CASES Testing

This last section discusses the testing performed on several of the components to verify their capabilities. The results from these tests are provided. The systems tested include the disturbance system, the thrusters, the AMEDs, and system closed loop testing. Recommendations are included for each system.
DS: Preliminary Verification Testing (Volts)

- Preliminary testing indicated significant non-linearities at low frequencies

Pctest03: Shaker 1 Sine (0.5 Hz)

Pctest04: Shaker 1 Sine (0.05 Hz)

Control Dynamics
Disturbance System Testing

- Testing performed by CDy
- Last Year: DS Manual push, observe Position, Pressure (Volts)
- This Year: DS Shaker Excitation from RTCC; Observe all DS sensors in EUs
- Functionality Tests: Compare expected pressure, flow, gap of air bearing system

**Results:** Given Load = 5500 lbs & 190 psi

<table>
<thead>
<tr>
<th></th>
<th>Prediction</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Gap</td>
<td>0.0027&quot;</td>
<td>0.0020 - 0.0024&quot;</td>
</tr>
<tr>
<td>Flow</td>
<td>2.3 ACFM</td>
<td>3.3 - 4.3 ACFM</td>
</tr>
</tbody>
</table>

Pressure drop of 5% between air panel and air pads

As expected, air pad 2 has a higher variance in gap (less constrained in Z)

- Further investigation of flow:
  - recalibrate flowmeters with present electronics & range settings
  - examine flowmeter linearity over this region
  - investigate if flow straighteners might help
**DS: Scale Factor Calculation**

- **Scale Factor Testing:** Determine rough scale factor for shaker force command Pctest26 & Pctest27
- **Test Setup:** Air off, Force command (3 sine frequencies)  
  Measure actual force via calibrated force transducer (0.1031 V/lbf)  
  Double check via shaker current scale factor (0.010 V/lbf)

**Pctest26:** Shaker 1 Sine (0.05, 0.5, 5 Hz)

**Force Transducer**  

**Shaker Current**

- **Scale Factor:** Command = 2 Vpp  
  SF = 46 lbf/Cmd Volt  
  SF = 52 lbf/Cmd Volt  
  Actual = 9.44 Vpp = 91.2 lbf  
  (Force Transducer)  
  Current = 104 lbf  
  (Current)

**Control Dynamics**
DS Testing: Sign, Phase, Magnitude Relations (EUs)

- Given Force sine wave: Freq=1 Hz, M =5500 lbs, Fpp = 650 N
  Analytical Prediction: App = 0.26 m/s^2  Xpp = 6.6 e-3 m
  Experimental Results: App = 0.30 m/s^2  Xpp = 7 e-3 m
- Testing confirms DS & DSF are in phase, DS & DSA are in phase, DS & DSP are out of phase
- Testing shows DS command = 300 N results in DSF = 325 N  (Fairly close)

"Pctest52: DS Acceleration"

"PCtest52: DS Position"

LOGICON

Control Dynamics
DS Testing: Transfer Functions (EUs)

- Test: Five Log Sine Sweeps from 1 - 20 Hz in 20 sec followed by 13 sec of zero command

PcTest66: DS Command

PcTest66: DS Force

Control Dynamics
DS Testing: Transfer Functions (EUs)

- Test: Five Log Sine Sweeps from 1 - 20 Hz in 20 sec followed by 13 sec of zero command
- DSF/DS shows: force follows the command thru 20 Hz (test range) (i.e. mag=0db) phase delay of 90 deg at 20 Hz (M/D, LPF, RTCC, S & A Dynamics)
- DSA/DS shows: accel = force/mass (but, can see system modes 4 & 6 Hz)

Pctest66: DS Force/DC Command

Pctest66: DS Accel/DS Command

Control Dynamics
DS Testing: Transfer Functions (EUs)

- Test: Five Log Sine Sweeps from 1 - 20 Hz in 20 sec followed by 13 sec of zero command
- TAZ/DSX: Good deal of system dynamics in Z: 4.2 5th B-X, 6.0 & 8.2 Tip plate modes
  Also see some higher modes 15 & 22 Hz
- TDSAX/DSX: Basically see pend X mode (0.12 Hz) (Need lower freq sys ID test)

Pctest66: TAZ/DSX

Pctest66: TDSAX/DSX

LOGICON

Control Dynamics
## Disturbance System: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthen stinger/force transducer mechanical interface</td>
<td>Extend allowable force magnitude capability</td>
</tr>
<tr>
<td>Further testing &amp; characterization of DS</td>
<td>Better understanding of lower frequency non-linearities, friction/stiction, mechanical spring</td>
</tr>
<tr>
<td>Further testing of scale factor of DS</td>
<td>More accurate DS command scale factor</td>
</tr>
<tr>
<td>Additional shaft support structure (from tower leg to bearing shafts near LMS)</td>
<td>Constrain torsional motion</td>
</tr>
<tr>
<td>Investigate adding servo system to DS</td>
<td>Better force or position following capability</td>
</tr>
<tr>
<td>Add LMS baffles</td>
<td>Less debris will accumulate on shafts</td>
</tr>
<tr>
<td>Carefully measure mass of experiment</td>
<td>Know exact mass of experiment</td>
</tr>
</tbody>
</table>

---

**DS** Disturbance System  
**LMS** Linear Motion System

**LOGICON**

Control Dynamics
BLT: Preliminary Verification Testing (Volts)

- Preliminary testing indicated need to adjust BLT electronics bias adjustment

Pctest01: BLT 2 Sine (0.05 Hz)  Pctest19: BLT 2 Sine (0.05 Hz)

TPA = BLT Test Point A = Command/2

TPB = BLT Differential Pressure = Actual Force

LOGICON

Control Dynamics
BLT: Preliminary Verification Testing (Volts)

- Test demonstrates: repeatability (2 wks) & TDS "X" response & Linear TDS (= waveforms)

Pctest00: BLT 1 Sine (0.05 Hz)

Pctest18: BLT 1 Sine (0.05 Hz)
BLT: Preliminary Verification Testing (Volts)

- Test demonstrates: nonlinearity for larger magnitude commands (Command, TPA & TPB)

Pctest00: BLT1 1 V Sine (0.05 Hz)

Pctest18: BLT1 2 V Sine (0.05 Hz)

LOGICON

Control Dynamics
**BLT: Characterization Testing (Volts)**

- **Test:** BLT1 Sine Sweep: 1 - 50 Hz (0.5 V pk)
- Examine Transfer Function (TPB/TPA = Actual/Cmd) at different tip pressure
  Expect Actual = Cmd (0 dB, 180 deg out of phase)
- Test shows: 7.5 Hz Bandwidth
  B1A2B2: Pressure = 133 psi
  17 Hz Bandwidth
  BLT1A2B: Pressure = 162 psi
BLT: Characterization Testing (Volts)

- Test: BLT1 Sine Sweep: 1 - 50 Hz (150 psi at tip)
- Examine Transfer Function (TPB/TPA = Actual/Cmd) at different Max command voltages
  Expect Actual = Cmd (0 dB, 180 deg out of phase)
- Test shows: 13 Hz Bandwidth

B1A2B6: Cmd Volt = 1 V Pk

?? Hz Bandwidth (Flat: -6dB at 1 Hz)

B1A2B5: Cmd Volt = 2 V Pk
BLT: Sign Testing (EUs)

- Test: Positive Thruster Pulse in Y -> Tip Plate Rot'n -> Dissimilar TDS waveforms

Pctest45: TDS X & Y

Tip Displacement Sensor Targets

---

LOGICON

Control Dynamics
BLT: Sign Testing (EUs)

- Test: Thruster Pulse in +Y -> Tip Plate Rot'n +Z
- Test Shows: Gyro response (+Z), Amp & Unamp Magnitude agree, X & X redundant agree

Pctest45: Tip Gyros (Amp)

Pctest45: Tip Gyros (Unamp)
BLT: System ID Testing (EUs)

- BLTY Test: 5 Log Sine Sweeps (1 - 20 Hz) in 20 sec, 13 sec zero command

Pctest63: Power Spectrums

Input BLTY (Sine Sweep)

Tip Accel Y
8 modes: 1T, 2T, 2BY, 3 BXY, 5BY

Tip Gyro X
Sees mostly same modes as TAY

TDSDY
Sees only pendulum mode Y 0.11 Hz

LOGICON

Control Dynamics
## Thruster System: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrade</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigate possibility of adding pressure regulator at tip</td>
<td>Allow higher bandwidth &amp; performance</td>
</tr>
<tr>
<td>Investigate higher pressure air supply hose to tip</td>
<td>Allow higher bandwidth</td>
</tr>
<tr>
<td>Investigate possibility of individual thruster supply hoses</td>
<td>Reduce dependency of thrusters on same hose</td>
</tr>
<tr>
<td>Incorporate permanent TPB signal to SMS to warn when Command is not equal to actual thrust</td>
<td>Warning when actual thrust is not following command</td>
</tr>
</tbody>
</table>

**BLT**  
Bidirectional Linear Thruster

**SMS**  
Safety Monitor System

**TPB**  
Test Point B (on thruster)
AMED: Preliminary Testing (Volts)

- Test: AMED 5 (Tip Z) Sine wave 0.05 Hz Torque command
- Pctest39 Shows: Torque follows Cmd, Speed is noisy & drifts, TDS shows Rot'n about Z
AMED: Transfer Function (EUs)

- Test: AMED 3 (Tip X) Torque: 5 Log Sweeps (1-20 Hz) in 20 sec, 13 sec decay time
- Pctest69 Shows: Torque follows Cmd, Avgs are repeatable, MS occasional spikes near 0

Motor Command

Motor Torque (Sensed)

Motor Speed
**AMED: Transfer Function (EUs)**

- Test: AMED 3 (Tip X) Torque: 5 Log Sweeps (1-20 Hz) in 20 sec, 13 sec decay time
- Pctest69 Results: Transfer Fcns: MT3/MC3

Torque follows Cmd -> thru test range

MS3/MC3

Speed is a low BW meas't & Noisy Speed phase -90 deg & Mag -20 dB/dec Coherence only good to near 3 Hz

---

**LOGICON**

Control Dynamics
# AMED System: Future Recommendations

<table>
<thead>
<tr>
<th>Recommended Upgrades</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redesign Reaction Wheel/shaft mount</td>
<td>Reaction wheels will be safe</td>
</tr>
<tr>
<td></td>
<td>Extend allowable Torque &amp; Speed range</td>
</tr>
<tr>
<td>Redesign RW speed Measurement</td>
<td>Increase bandwidth of speed mea't</td>
</tr>
<tr>
<td></td>
<td>Reduce noise &amp; spikes near zero</td>
</tr>
<tr>
<td>Recalibrate gyros with new preamp</td>
<td>More accurate gyro scale factors</td>
</tr>
<tr>
<td>gains</td>
<td></td>
</tr>
<tr>
<td>Characterize gyros in AMED chassis</td>
<td>Account for misalignment between gyros and chassis</td>
</tr>
<tr>
<td>Fabricate working motor/RW demo for</td>
<td>PR plus Backup AMED system</td>
</tr>
<tr>
<td>visitors</td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- AMED: Angular Momentum Exchange Device
- RW: Reaction Wheel

---

**LOGICON**

Control Dynamics
Closed Loop Testing

- First Closed Loop Test (Aug 92): Harris Guest Investigator
- Pctest113/121: Disturbance X & Y Pulses Response: TGX & TGY

Control Dynamics
CSI GTF Status

- Disturbance System Integrated
  (Tripod, Air Pads, Shakers, Shaker Elec, LMS/AS, Sensors, Power, Mux's)

- MPRESS, Boom, Tip Plate, Sim Detector Integrated

- AMEDs, BLTs, 5th RW, Accels, BMT/TDS Integrated
  (Only preliminary testing done on BMT)

- Mux/Demux, Power, Cables, Rack Complete & Integrated

- RTCC, SMS, & BMT DAS Operational

- MPRESS Access Platform Operational (Manual)
  Facility Enclosure System completed

- Integration completed & Functionality and System ID Testing Performed

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<table>
<thead>
<tr>
<th>AMEDs</th>
<th>Angular Momentum Exchange Devices</th>
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<tbody>
<tr>
<td>BMT</td>
<td>Boom Motion Tracker</td>
</tr>
<tr>
<td>DAS</td>
<td>Data Acquisition System</td>
</tr>
<tr>
<td>LMS/AS</td>
<td>Linear Motion System/Alignment System</td>
</tr>
<tr>
<td>RTCC</td>
<td>Real Time Control Computer</td>
</tr>
<tr>
<td>SMS</td>
<td>Safety Monitor System</td>
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<tr>
<td>B/Ts</td>
<td>Bidirectional Linear Thrusters</td>
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<tr>
<td>CSI</td>
<td>Control Structures Interaction</td>
</tr>
<tr>
<td>GTF</td>
<td>Ground Test Facility</td>
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<tr>
<td>MPRESS</td>
<td>Mission Peculiar Experiment Support Structure</td>
</tr>
<tr>
<td>RW</td>
<td>Reaction Wheel</td>
</tr>
<tr>
<td>TDS</td>
<td>Tip Displacement Sensor</td>
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</tbody>
</table>

LOGICON

Control Dynamics
Conclusions

- ACES Laboratory operational: Demos & GIs

- CSI/CASES GTF operational
  Integrated facility: DS, AMEDs, BLTs, RTCC, SMS, M/D, BMT/TDS, Power MPESS, Boom, Tip Plate, VMS
  Performed Modal Testing (NASA)
  Developed Preliminary Model & Simulation
  Performed Validation, Testing & Characterization
  Performed Open and Closed Loop Testing

- LSS Team: Significant Progress

THE END

LOGICON

Control Dynamics
Appendix A. Control Room Documentation

ACES Documents in File Cabinet

SUBJECT:
ACES/SSC Lab General
General Info: Facility Blueprints, Scale Factors, Blueprints
Operator's Manual
ACES Final Report (6/88) & ACES Interim Presentation (4/87)
Guest Investigator Program Phase I (Apr 91)
Guest Investigator Overview
ACES System Documentation

AUTHOR:
(LCD)
(LCD)
(LaRC)
(BDM)
(ECD)

ACES General: Papers & Technical Memos (TM)
Report: Definition of Ground Test for LSS Control Verification (11/84)
Definition of Ground Test for LSS Control Verification (11/84) TM-86495
MSFC Ground Exp't for LSS Control Verification (12/84) NASA TM-86496
Ground Test Experiment for LSS (11/86) NASA TM-86489
NASA-VCOS Dynamic Test Facility (2/85) NASA TM-86491
Active Control of LSS: An Intro & Overview (2/85) NASA TM-86491
Ground Facility for LSS Dynamics & Control Verification NASA TM-86558
LSS Testing (2/87) AAS 87-036
LSS Testing (6/87) NASA TM-100306
Schemes for Improving ... Freq-Domain Models of LSS AAS-87-453
ACES Program: Lessons Learned (6/87) ACC Paper
An Application of High Authority/Low Authority & Positivity (6/88)
Presentation: Control Design for ACES (5/92)

Sensors
Optical Sensor (TRW):
Test Plan (VCOS) (1/86) & Mechanical Blueprints (10/86) TRW
Report (Sections): Optical Pos'n Sensor, Linear Actuators, Electronics, Mirrors TRW
Final Report: 3/84-3/86 (LMEDs & Optical System) TRW
Optical Sensor Testing Report LCD
IMC Laser/Mirror: Mirror Drawings, 4-quadrant detector info MSFC
IMC analog servo electronics & schematics MSFC
Manuals: Laser Power Supply, Pointing Gimbal Power Supply

ATM Gyros: Overview, ATM Gyro Processor System Description Report MSFC/LCD
Base Gyro Transfer Functions (11/90)
KARS: Overview, Tip Gyro transformations
US Army RPV ARA Interface Definition (4/79)
Kearfott Attitude Reference System Manual (2/80)
LaMOD User's Manual (7/91)
Base Accelerometers Overview (Digital)
Tip Accelerometer Info
Tip Mounting Plate Drawing

Actuators
AGS: Overview, Electronics Schematics (1/83)
Thrusters Report (7/87)
LMEDs:
  Electronics Schematics, Mechanical Blueprints, Test Report, Motor Specs
  LMED Accelerometer Calibration Sheet
  (TRW) Memo (11/85) & Test Plan (1/86)
  Characterization & Hardware Modification of LMEDs (2/87)
  Characterization & Hardware Modification of LMEDs (2/87) NASA TM-86594
  Distributed Control using LMEDs (10/87) NASA TM-100308

Computer
AP500 Information
ACES Software Description: HP Basic, COSMEC, AP descriptions & listings, etc...
Dell Computer (DAS Panel - Analog Devices)
Anti-Aliasing Filter Report (7/90)
COSMEC (3/82)
  Electronics Schematics, Software Listing
  Hardware/Software: Original System (Software Listing)
  Hardware Math for 6502: Original System (7/85) NASA TM-86517

Wavetek Software

Test Article
Antenna/Arms Blueprints (2/85)
BET X-Y Table Blueprints (9/83)
BET Analysis Informal Report (6/84)
Roll Tip Motor Design
Lab Information

Power Supply Manuals: Lambda, Topward, Sorenson
Video Monitor System Manuals: Panasonic TV, VCR, Quad System, Camera
Lab Supply Manuals (DMM, Scope, Solder Station, etc....)

CASES Documents in File Cabinet

System Information
General Info
- CASES GTF AAS-92-024 (LCD)
- Scale Factors (LCD)
- CASES System Test Plan (LCD)
- GTF Scale drawings (LCD)
- CSI/CASES System Documentation (LCD)
- CSI/CASES Operator's Manual (LCD)
- VMS User's Manual (LCD)

Facility Information
- GTF Platform Design Blueprints (5/88) (Williams-Russel & Johnson)
- CASES Lift Crane Document (3/90)
- Air Panel Blueprints (Valley Steel/MSFC)
- MPESS Access platform materials & Blueprints (10/91) (Sverdrup/MSFC)

Test Articles
SAFE/CASES Boom:
- SAFE Experiment Blueprints (Lockheed)
- SAFE/Dynamic Augmentation Experiment (87) NASA TP-2690 (MSFC)
- SAFE Final Report (4/86) (Lockheed)
- Re-verification Test Report for the SAFE Mast Assembly (3/83) (Able)
- CASES Boom Report: Final ... SAFE Mast Mod for CASES Pgm (2/90) (Able)
- Tip Plate: Experimental & Analytical Studies (6/90) (U of Alabama)
- CASES Tip Plate Assy: Prelim Designs & Fabrication Procedures (12/89) (U of Alabama)
- MPESS Blueprints (Campbell)
- AMED Blueprints (MSFC)
- Tip Plate/PMS Blueprints (MSFC)

Actuators
AMEDs:
- Inland Motor User's Manual, Operating Instructions for Motor Controller (Inland)
- AMED Motor Speed Board & AMED Testing Report (LCD)
- AMED Test Results (integrated with facility) (LCD)
- BLT Development & Test Report (2/90) (Boeing)
BLT Test Results (integrated with facility) (LCD)

Disturbance System
Disturbance System for CASES CDR Report (7/88) (LCD)
Rotary Table Blueprints (Troyke)
Linear Motion System Guide (Thomson)
Model 6 Shaker Manual (Unholz-Dickie)
Tripod Finite Element Model Report (12/89) (LCD)
Ring Finite Element Model Report (10/89) (LCD)
Flowmeter Manual & Calibration Sheets (Sponsler)
Pressure Transducer & String Pot Specification Sheets (Celecso)
Force Transducer Manual (PCB)
Optic Probe User's Manual (LCD)
Air Gap Capacitance Meter Report & Testing (1/92) (LCD)
Air Bearing Manual & Testing Report (12/89) (LCD)
Ring Epoxy Pour Plan (2/89) (LCD)

Sensors
Conex Gyros:
Kearfott Gyro Test Results (6/87) (Kearfott)
MSFC Gyro Test Results (9/91) (MSFC)
Gyro Preamp Report (1/92) (LCD)
CONEX Gyro Manual + correspondence (Kearfott)
BMT/TDS:
PCB Accelerometers: Manual & Calibration sheets & Power Unit Manual (PCB)
General Guide to ICP Instrumentation (PCB)
TRW Optical Sensor (Also see ACES Sensors):
VCROSS Technical Memo & VCOSS-II MSFC Test Plan (1/86) (TRW)
TRW Optical System Testing (1/92) (LCD)

Signal Processing/Computer
Signal Processing Document (LCD)
Differential/Single Ended Converter/Amplifier Report (1/92) (LCD)
Anti-Aliasing Filter Report (1/92) (LCD)
Mux/Demux Report (5/92) (LCD)
Debug Electronics Report (LCD)
Auto-Cutoff/Sync Generator Report (10/92) (LCD/MSFC)
Safety Monitor System Report & Software (1/92) (LCD)
Control Computer Report & Software (LCD)
RTCC User's Manual (Part of CSI/CASES operator's manual) (LCD)
IOS Overview Presentation Viewgraphs (AP Labs)
CASES Sensors

BMT/TDS:  
- Paper, Final Design Review Viewgraphs, Proposal (Ball)
- BMT overlap analysis (LCD)
- Structural Control Sensors for CASES AAS-90-044 (Ball/MSFC)
- Operation & Maintenance Manual (BMT & TDS) (Ball)
- Technical Documentation for TDS & BMT Report (Ball)
- Blueprints & Electronic Schematics (Ball)
- BMT FIFO test software (LCD)
- BMT FIFO Report (HW/SW & Schematics) (LCD)

CASES Testing/Model/Simulation

- CASES Ring Modal Survey Test Report (8/89) (MSFC)
- Ring Finite Element Model Report (10/89) (LCD)
- Tripod Finite Element Model Report (12/89) (LCD)
- MPESS Modal Test Report (5/90) (MSFC)
- Tip Plate Modal Test Data (11/91) (MSFC)
- CASES Expt Modal Test Report (1/92) (MSFC)
- CSI/CASES Finite Element Model Report (LCD)
- CSI/CASES Simulation Report (LCD)
- System Verification Test Results (LCD)
- System Characterization Test Results (LCD)

ACES Model/Simulation & Modal Testing

- Modal Tests of the LSS Ground Verif Test Facility (10/84) (MSFC)
- Modal Tests of the VCOSS-II Test Configuration (10/85) (MSFC)
- Modal Tests of ACES (9/86) (MSFC)
- Modal Survey Test Report for ACES (6/90) (MSFC)
- ACES Tip Structure Modeshapes (5/90) (MSFC)
- Modal Survey Testing of LSS Antenna, CWs & Mirror (5/90) (MSFC)
- ACES Simulation code (LCD)
- ACES Simulation Informal Report (8/84) (LCD)
- Evaluationa of Cruciform Model (6/86) (LCD)
- ACES Simulation User's Manual (LCD)
- ACES Finite Element Model Report (4/87) (LCD)

Guest Investigator

- CSI Phase I GI Program: 2nd Year Mid-Year Review (7/90)
- CSI Phase I GI Review: Year End Review (1/90)
- CSI Phase I GI Program: Final Review (4/91)
Bldg 4619 Blueprints

List of papers & publications

Assorted Papers

Extra Copies
- BLT Report (Boeing) 2/90
- ACES Final Report (LCD) 6/88
- ACES Modal Test Report (MSFC) 86
- ACES Modal Test Report (MSFC) 6/90
- Antenna/Counterweight/Mirror Modal Test Report (MSFC) 5/90
- CASES Flight Experiment Phase A Study (11/88)
- TDS/BMT Technical Proposal (Ball) 6/90

Contract Status Reviews 91
Contract Status Review 92

CASES Flight Experiment
- Pinhole/Occluter Facility Pre-Mission Def'n Study: Payload Concept Trade Studies (1/86) (TBE)
  - CASES Preliminary Definition Study (11/88) (MSFC)
  - Structural Control Sensors for CASES (2/90) AAS 90-044 (Ball/MSFC)

Other Deliverables in Control Room
- ACES Model & Simulation (386)
- CSI/CASES Model (Nastran Input Files)
- CSI/CASES Simulation (TREETOPS input files)
- Test Results (Floppy & Cartridge Tape) in Control Room
References in Control Room

Documentation Desk
- X Windows
- IOS Manuals AP Labs
- Sun Manuals
- Sky Warrior Manuals
- Data Translation Manual
- Qualstar Ministreamer

Bookshelves
- Analogic Manuals (AP 500)
- Borland C++
- Borland Turbo C & Turbo Assembler
- Central Point PC Tools
- Crosstalk Disk Optimizer 4.0
- Dell 310 MS DOS Manuals
- Dell MS DOS User's Guide
- Design CAD 3-D
- EXP Scientific Word Processor
- Gateway 2000 User's Guide MS DOS 5.0
- Graftool
- HP 3562A Manual
- HP 5423 Manual
- HP Manuals
- HP Manuals HP 9000 System (HP Basic OS)
- Lahey Fortran
- Logitech Mouse
- Mathematica
- Matlab for Sun Workstation
- MatrixX & System Build
- Metabyte Data Acquisition & Control
- Microsoft C Compiler Manuals
- Microsoft Excel
- Microsoft Fortran
- Microsoft Windows
- MSC PAL & MOD User's Manuals
- Norton Utilities
- PC NFS Manuals
- Printer Manuals
- Simulab User’s Guide
- Solution Systems Brief
- Word Perfect

Boxes on Bookshelves:
- 386 Related Unix Software & Manuals

Documentation in Computer Storage Cabinet:
- Sun OS Reference Manuals
Documentation in Wood Desk:
By Gateway 2000 (SMS):
By ACES Dell:
By HP 9000:

HP Manuals HP 9000 System (Unix OS)
Data Acquisition National Instrument
Quinn Curtis Real-Time Graphics
Matlab Manuals
IBM DOS 3.0
HP BASIC Reference Manuals (2)
This report describes the Marshall Space Flight Center's Large Space Structures Ground Test Facilities located in building 4619. Major topics include the Active Control Evaluation of Systems (ACES) Laboratory, the Control-Structures Interaction/Controls, Astrophysics, and Structures Experiment In Space (CSI/CASES), Advanced Development Facility and the ACES Guest Investigator Program.