James Webb Space Telescope Program

Mirror Manufacturing Status

Ben Gallagher

Technology Days in the Government 2007
July 31, 2007

Ball Aerospace
& Technologies Corp.

JWST Mirror Processing Flow

BRUSH
- Hip Blank

C1

AXSYS
- Machine Mirror Substrate

C1

TINSLEY
- Grind Mirror
- Initial Polish Operations

C1

BALL
- Clean Substrate
- Bond flexures
- Attach whiffles & surrogate delta frame
- Attach ROC and hexapod

C1 → C2 → C3

XRCF
- Measure mirror cryogenically

C3

BALL
- De-integrate actuation systems

C3 → C2

TINSLEY
- Final Polish

C2

BALL
- Critically Clean to Flight Requirements

C2

COATER
- Coat Mirror

C2

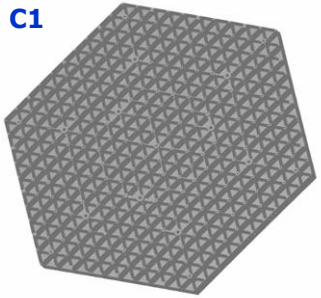
BALL
- Integrate actuation systems
- Hexapod characterization
- Acceptance Vibe

C2 → C3

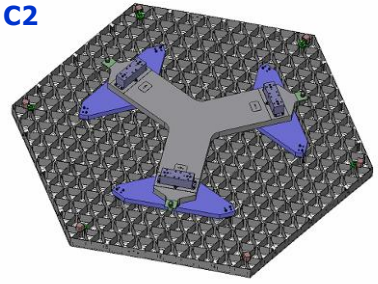
XRCF
- Final acceptance test at cryogenic temperature

C3

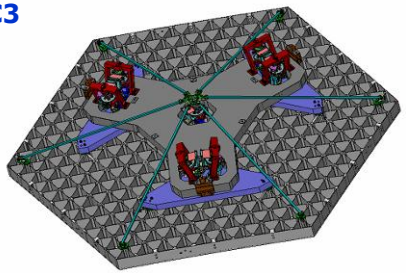
Deliver to NGST



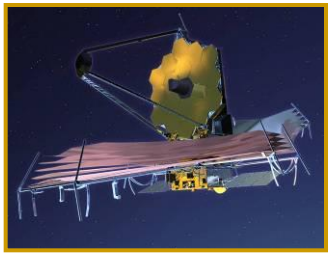
C1 Mirror Substrate Only



C2 Bonded Flexures and Whiffles Surrogate Delta Frame



C3 Fully Assembled PMSA



PM / SM Production Progress
(by Mirror SN and % Complete at that location)

NORTHROP GRUMMAN

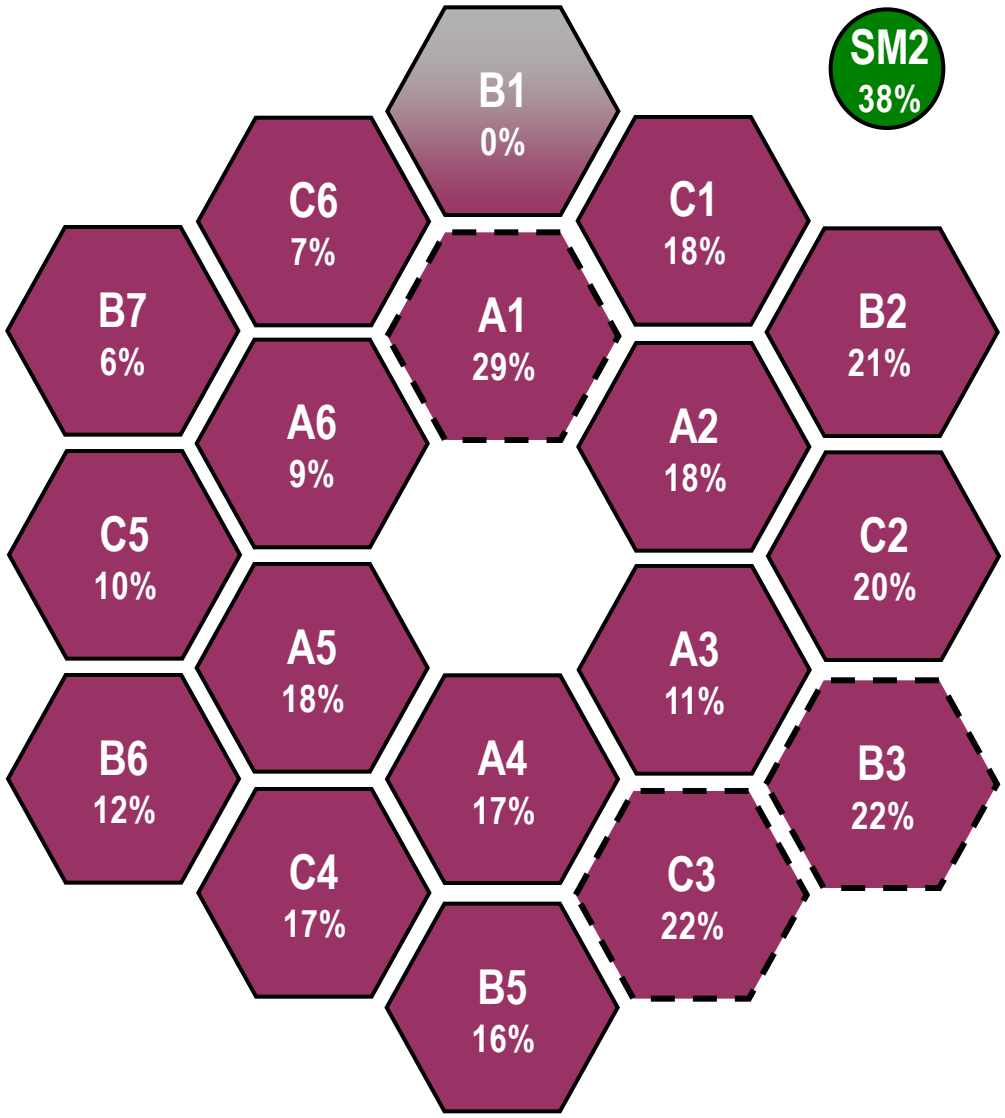
ITT

EDU

EDU-B 44%

SM1 1%

Flight



Flight Spares

B8 70%

C7 74%

LEGEND
Brush Wellman
Axsys Technologies
L-3 SSG-Tinsley
BATC
XRCF
Coating
Idle Time
– – – – – Pathfinders

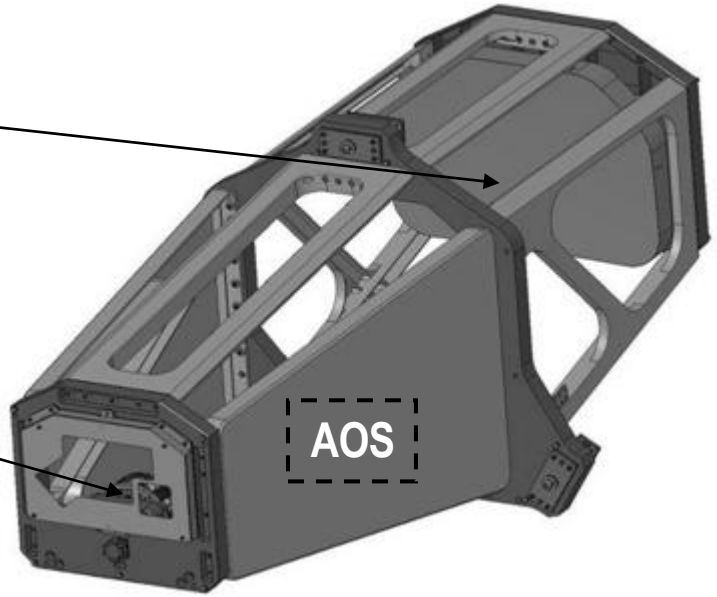
As of 5/14/07

TM / FSM Production Progress
(by Mirror SN and % Complete at that location)

Flight

TM1
29%

FSM
1%



LEGEND
Brush Wellman
Axsys Technologies
L-3 SSG-Tinsley
BATC
XRCF
Coating
Idle Time
----- Pathfinders

Flight Spares

TM2
100%

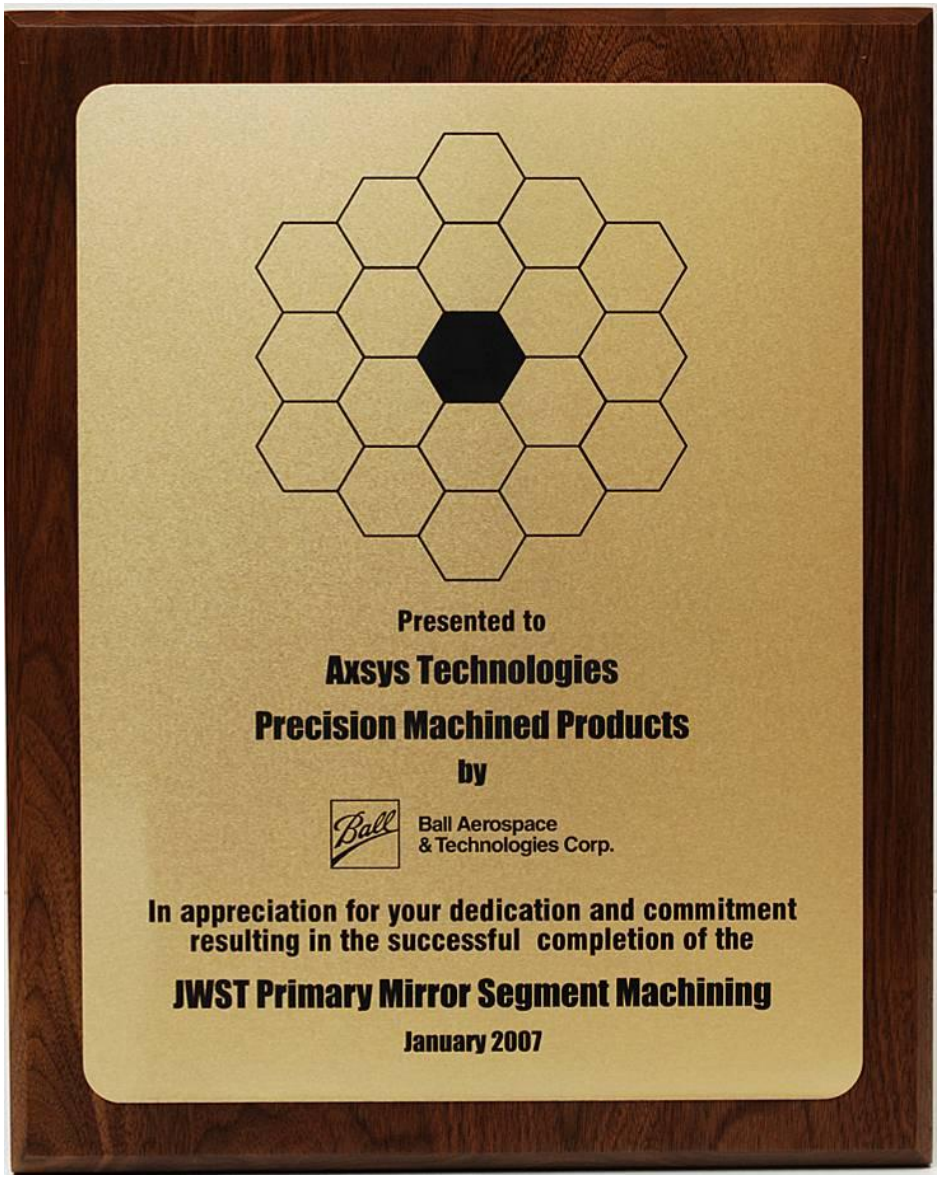
TM2 complete (Spare TM blank)

As of 5/14/07

Axsys Technologies - Status

- **Status as of 5/24/2007**
  - Primary Mirror Segments
    - EDU is Complete
    - All 18 flight Primary Mirror segments are complete
    - Spare B and C segments almost ¾ complete
    - Axsys is fabricating beryllium delta frames that attach to the back of each segment
      - 1 complete, 12 in work
  - Secondary Mirror
    - First Secondary Mirror is complete
    - Second Secondary Mirror ~ 30% complete
  - Tertiary Mirror
    - Tertiary Mirror is in work and ~ 30% complete

Flight Segment Machining is Complete



Ball Aerospace & Technologies Corp.
1600 Commerce Street, Boulder, CO 80301 (303)939-4000 FAX (303)939-6104
Reply to: P.O. Box 1062, Boulder, CO 80306-1062

12 January 2007

Axsys Technologies
Precision Machined Products
6717 Alabama Highway 157
Cullman, AL 35057

Attention: Martyn Acreman
General Manager
Axsys - Precision Machined Products

Subject: BATC Subcontractor Recognition

Reference: Subcontract 03JRL00010

Dear Mr. Acreman:

On behalf of Ball Aerospace & Technologies Corp. (BATC), I would like to take this opportunity to recognize Axsys Technologies' successful completion of the Primary Mirror Segment machining for the James Webb Space Telescope (JWST). This is a major milestone for Axsys Technologies, and one that has been critical to BATC and the continuing success of the entire JWST project.

JWST is the next great observatory being developed by NASA's Goddard Space Flight Center (GSFC). It is an infrared-optimized space telescope designed to study the earliest stars and galaxies formed after the Big Bang. Optics are the heart of any telescope and the quality of the large hexagonal mirrors being produced by the Beryllium Mirror Team is vital to the mission of the JWST observatory.

Axsys Technologies' completion of the beryllium blank machining shows the determination and dedication of the Axsys Technologies team. This team has demonstrated excellent problem solving skills, outstanding project management and upper management support to keep the program focused on success. We have benefited from the attention to detail and willingness to continually improve the manufacturing process at your Cullman, AL facility.

BATC is very pleased with the excellent working relationship that has developed with Axsys Technologies. Your willingness to do what it takes to get the job done has been greatly appreciated. We look forward to a long and prosperous working relationship in the future. Once again, congratulations on the successful completion of the Primary Mirror Segment machining.

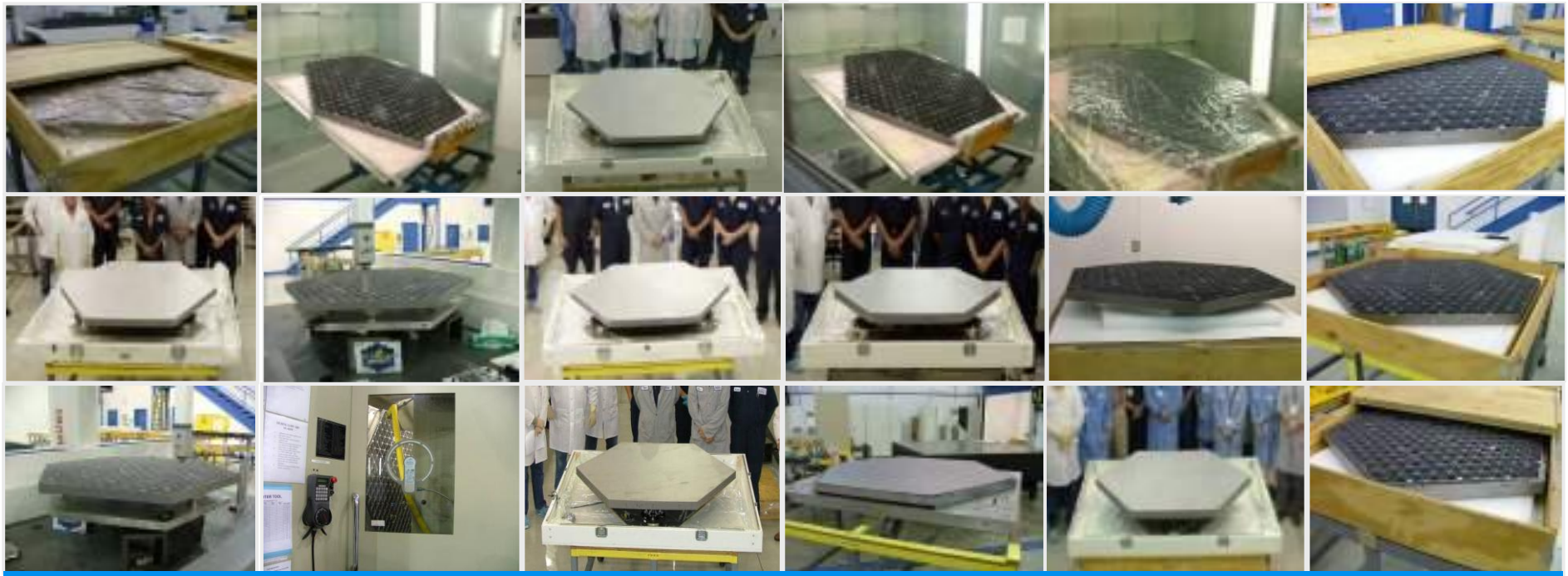
Sincerely,

David C. Taylor
President and Chief Executive Officer
Ball Aerospace & Technologies Corp.

cc: M. Acreman (Axsys)
J. Calvert (Axsys)
M. Stricklin (Axsys)
W. Townsend (BATC)
M. Bergeland (BATC)
M. Guidas (BATC)
J. Morris (BATC)
P. Volmer (BATC)
D. Neam (BATC)
S. Whitehill (BATC)
D. West (BATC)

A subsidiary of Ball Corporation

Axsys Technologies In-Process Photos

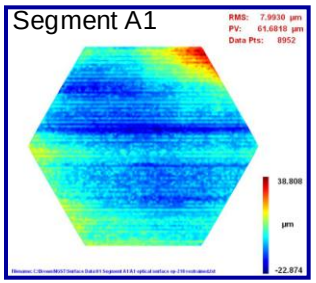


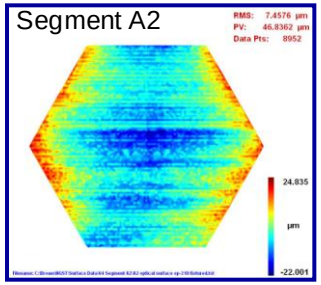
Machining of all 18 flight beryllium Primary Mirror blanks completed at Axsys Technologies

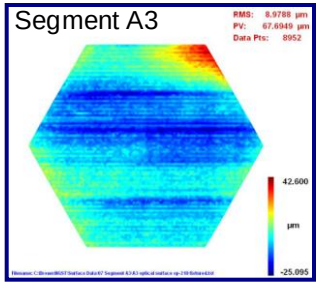
Machining of flight beryllium Secondary Mirror blanks at Axsys Technologies

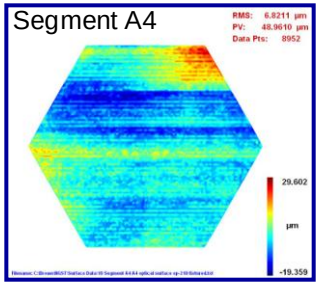
TM Setup Piece during pocket machining

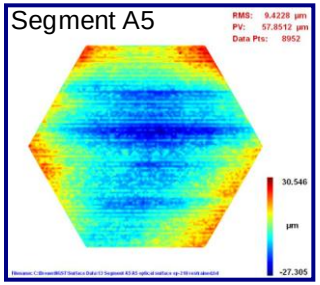
18 PM Segments - As-Machined Optical Surfaces (Post Op-210, Fixtured)

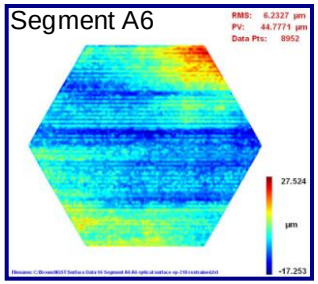


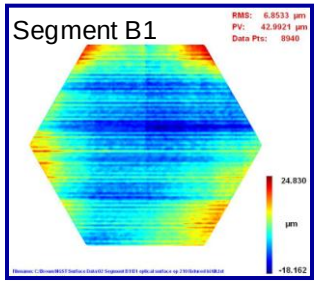


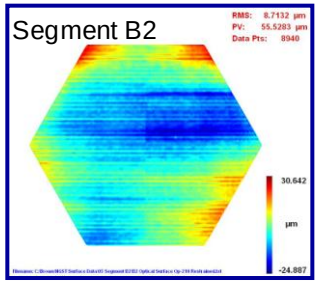


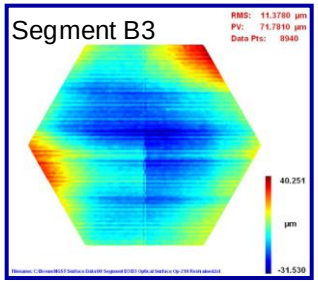


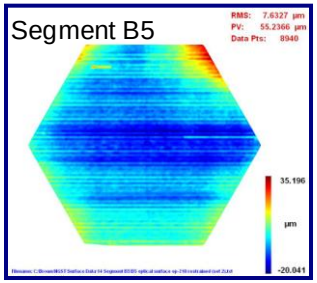


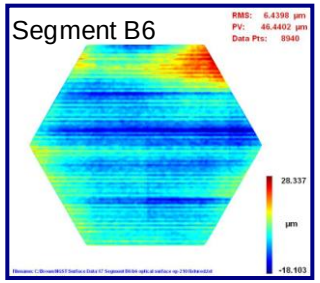


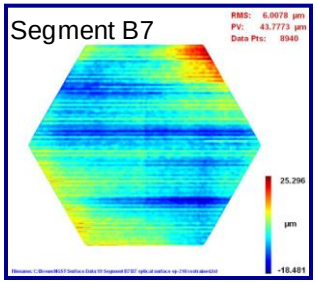


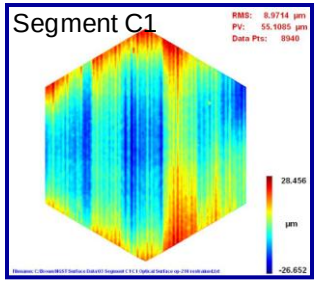


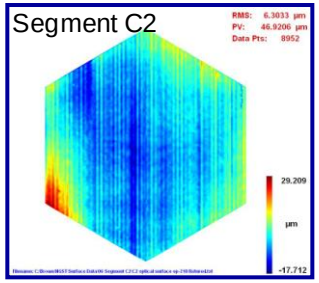


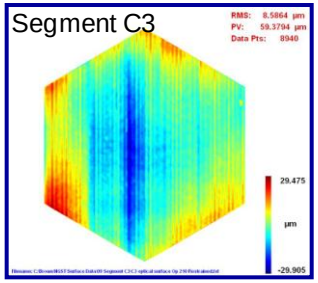


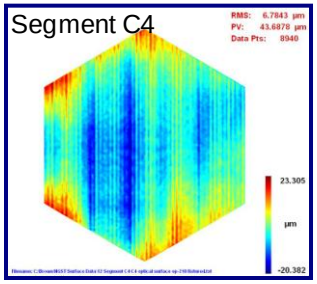


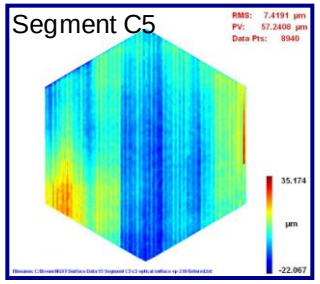


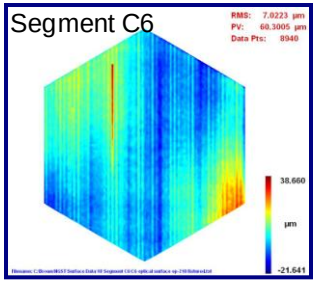




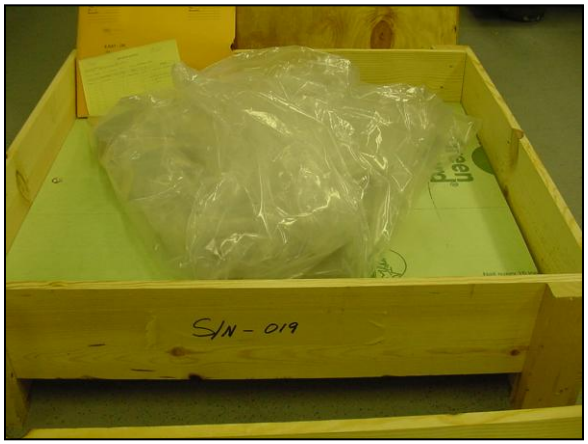


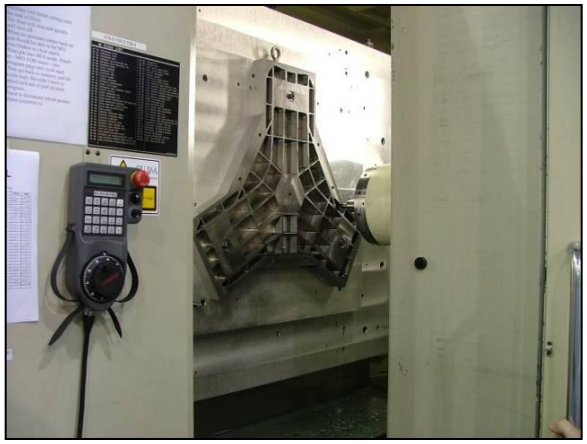






Delta Frame Production at Axsys Technologies





Delta Frame In-process Pictures at Axsys Technologies

Flight Delta Frame Complete

L3 – SSG - Tinsley Major Accomplishments

- Primary Mirror manufacturing hardware is on-line
- Metrology equipment development is nearing completion
- The EDU segment continues to path-find the process at Tinsley
- The receipt of 17 flight Primary Mirror segments
  - 14 segments have entered coarse grinding phase
  - 4 segments have completed coarse grind and are in Smooth Out Grind phase

- Secondary Mirror received at Tinsley and hardware needed for processing at Tinsley is nearing completion
- Completed significant investment to upgrade the Tinsley quality system to meet demanding needs of JWST mirror manufacturing

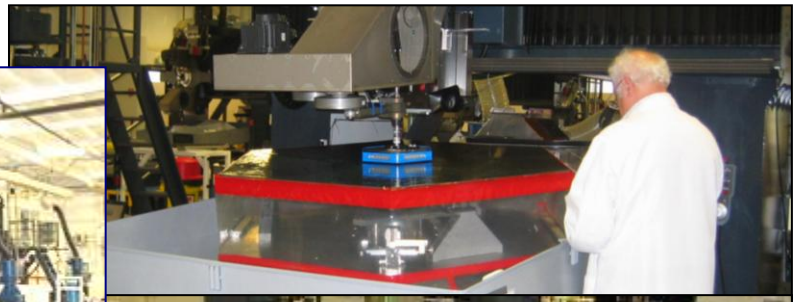
Ed Weiler's Q&A with Tinsley Team

"There will be only once for the First view of the First Light from Galaxies forming at the beginning of the Universe"

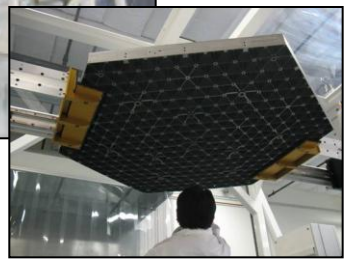
Lively Q&A with the Tinsley crew

and discussion of why JWST will not have HST situation with spherical aberration

PM Manufacturing Hardware is on-line



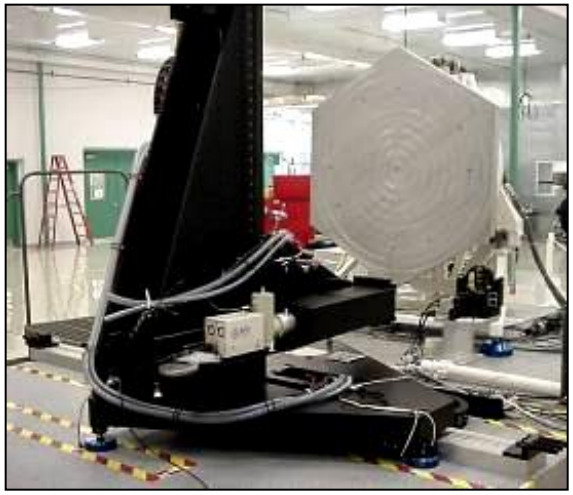
Computer-controlled Optical Surfacing Machines (8X)
8 qualified for production



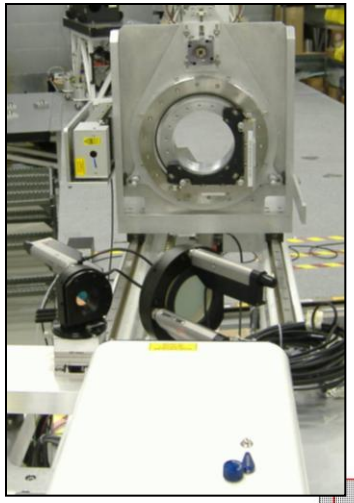
Fixture Transfer Station (1x)
1 qualified for production

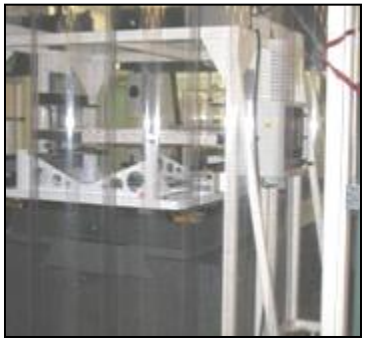
Thermal Processing Chambers (2x)
2 qualified for production

Metrology Equipment Integration Nearing Completion

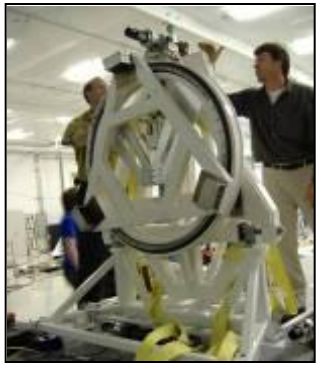


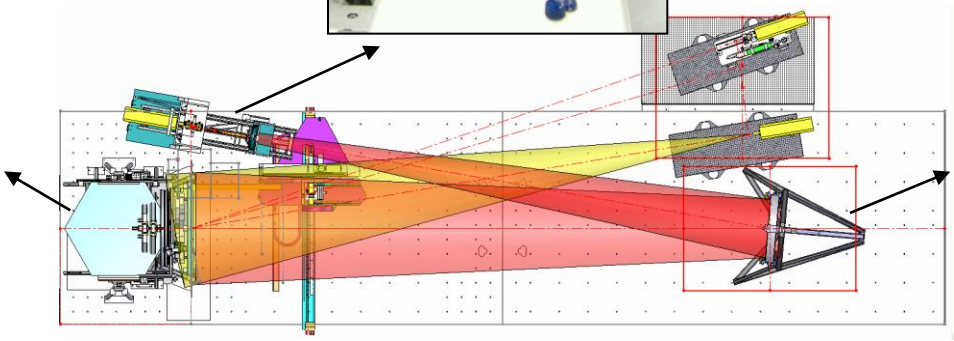
IR Scanning Shack-Hartmann Wavefront Sensor (2x)
1 qualified, 1 in qualification





CMM Profilometer (2x)
2 qualified for production





Visible Interferometric Test Station (2x)
2 in integration

PM / SM / TM Production Progress at L-3 SSG-Tinsley
(by Mirror SN and % Complete)

NORTHROP GRUMMAN

ITT

EDU

EDU-B
44%

SM1
1%

Flight

SM2
0%

TM1
0%

B1
0%

C6
7%

C1
18%

B7
6%

A1
29%

B2
21%

A6
9%

A2
18%

C5
10%

C2
20%

A5
18%

A3
11%

B6
12%

A4
17%

B3
22%

C4
17%

C3
22%

B5
16%

LEGEND
Not at Tinsley
In-House
Even Slice
Figure Grind Coarse >5um
Figure Grind Fine <5 um
Smooth Out
Polish
Complete
Pathfinders

As of 5/14/07

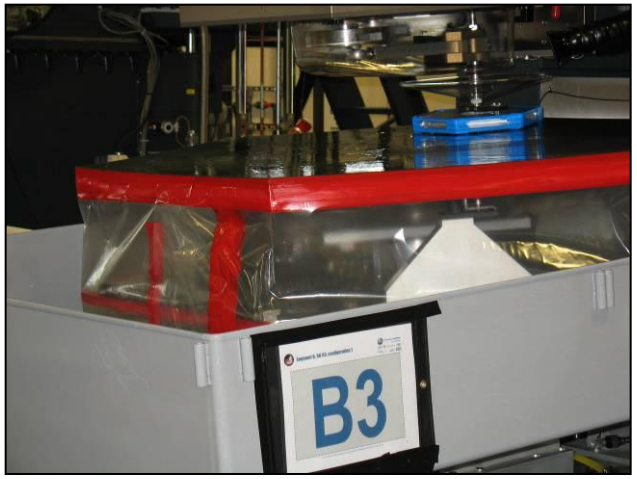
PMSA EDU (PM Segment SN EDU) Status

- EDU continues to be pathfinder for Tinsley process
- EDU is nearing the end of the smooth out grind process and will enter into the rough polishing phase next

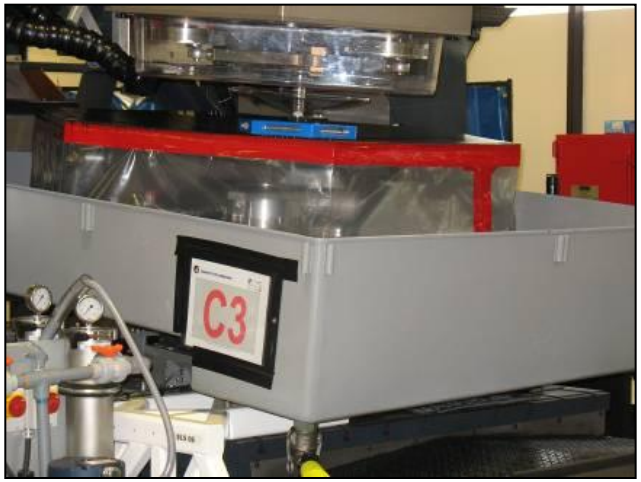
L-3 SSG-Tinsley In-Process Photographs

Batch #1 (Pathfinder) PM Segments

PMSA #1 (EDU-A / A1 / A1)



PMSA #5 (11 / B3 / B3)



PMSA #6 (12 / C3 / C3)

Batch #2 PM Segments

PMSA #4 (5 / A2 / A2)

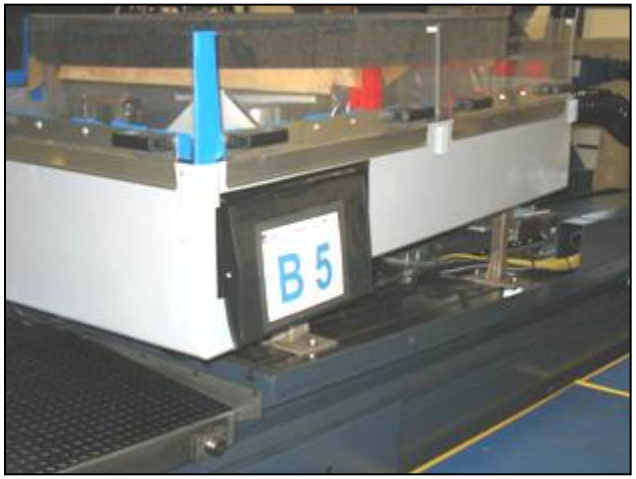
PMSA #2 (6 / B2 / B2)

PMSA #3 (7 / C2 / C2)

L-3 SSG-Tinsley In-Process Photographs

Batch #3 PM Segments

PMSA #7 (13 / A4 / A4)



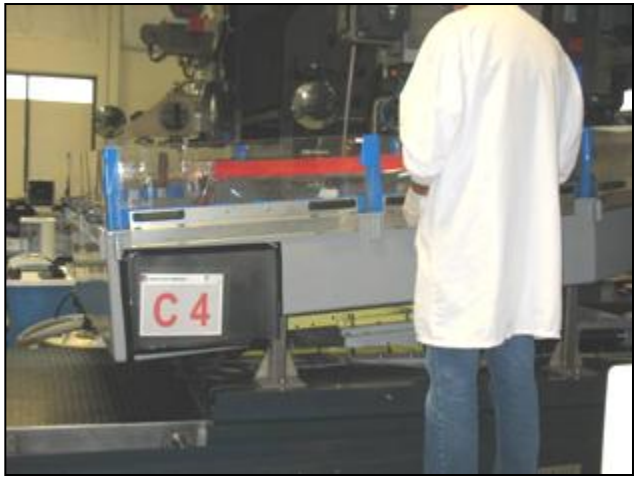
PMSA #8 (17 / B5 / B5)

PMSA #9 (4 / C1 / C1)

Batch #4 PM Segments

PMSA #10 (16 / A5 / A5)

PMSA #11 (20 / B6 / B6)



PMSA #12 (15 / C4 / C4)

L-3 SSG-Tinsley In-Process Photographs

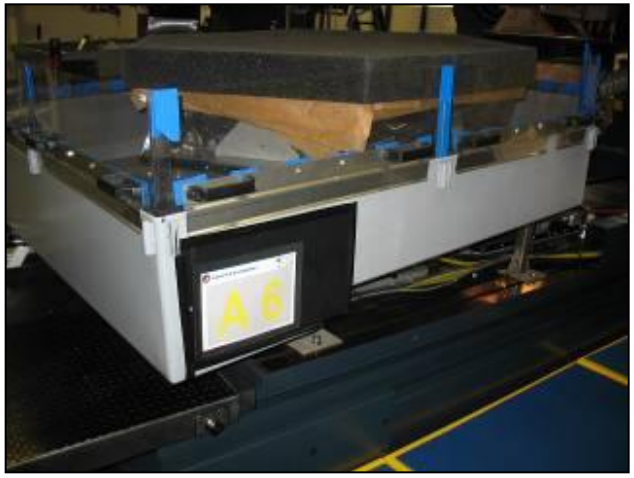
Batch #5 PM Segments

PMSA #13 (8 / A3 / A3)

PMSA #14 (22 / B7 / B7)

PMSA #15 (18 / C5 / C5)

Batch #6 PM Segments



PMSA #16 (19 / A6 / A6)

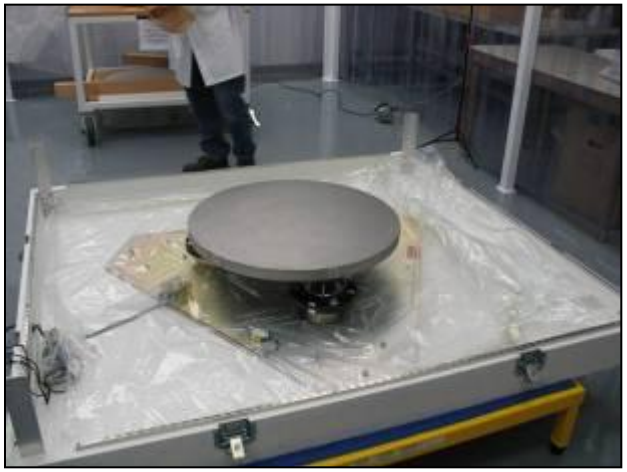
Machining complete at Axsys,
TRL-6 activities complete at Ball,
Model correlation at NGST complete.

PMSA #17 (6 / B1 / B1)

PMSA #18 (21 / C6 / C6)

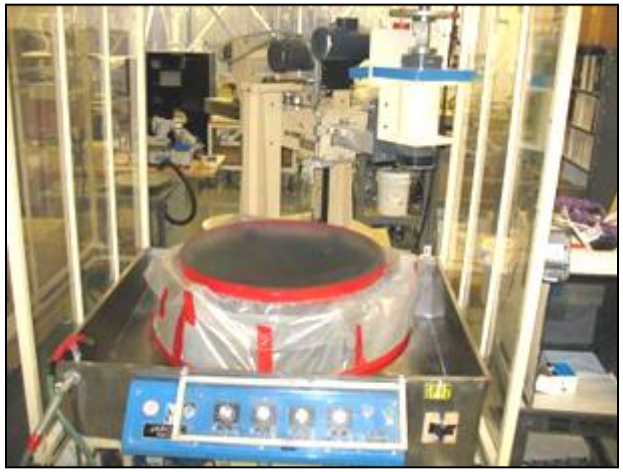
Secondary Mirror Processing at Tinsley

Secondary Mirror has been Received at Tinsley



Tinsley's SM hardware is nearing completion and SM processing at Tinsley should begin soon

CCOS machine being upgraded for SM



Hindle shell for Tinsley Test in work

SM surrogate used for GSE qualification

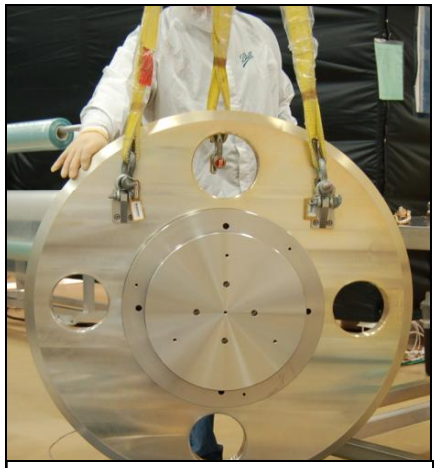
BATC Mirror Manufacturing Accomplishments

- **1st flight segment shipping container built and qualified**
  - Used to ship B1 from BATC to NGST for acoustic testing

- **SMA GSE nearing completion**
  - SMA GSE mounts and cryogenic test hardware nearing completion
  - SMA GSE lenses in polish phase at L3-SSG-Tinsley
- **Ball Optical Test Station (BOTS) plans / designs are in work**
- **Initial hexapod test / characterizations are complete**
- **PM cryogenic testing plans / designs are in work**
- **Coating requirements defined and vendor selection should happen this summer**

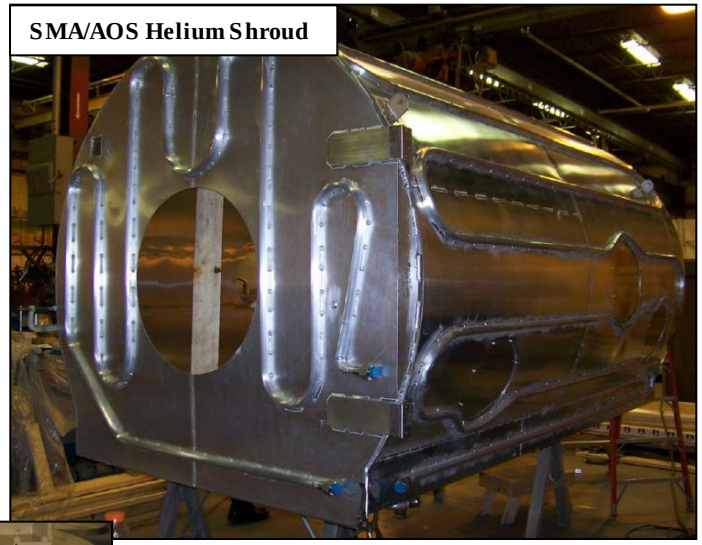
SMA GSE for Cryogenic Test Status: Mounts in Integration at BATC and Lenses in Polish at Tinsley

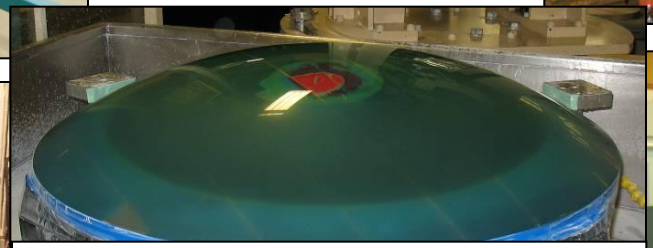
SMA Optical GSE Handling and Rotation Fixtures



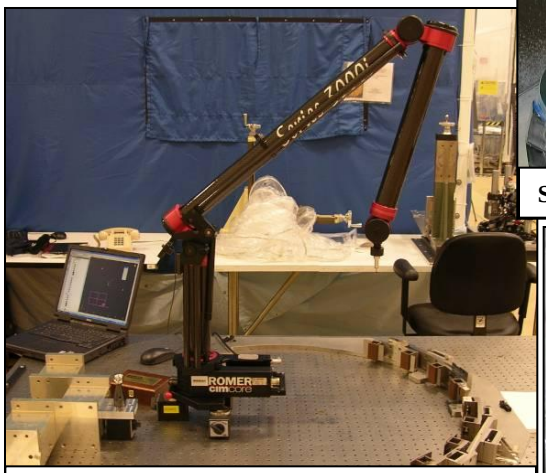
SMA Optical GSE Mass Simulators

SMA/AOS Helium Shroud

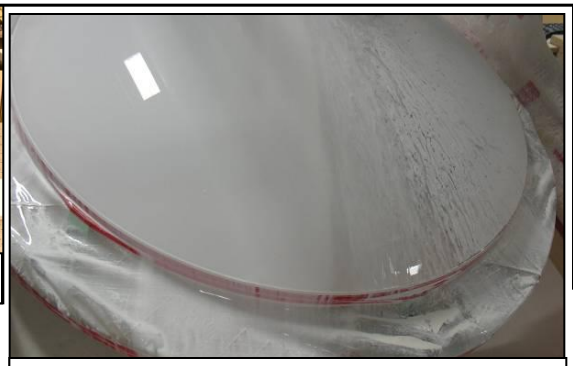




SMA Optical GSE – Aspheric Test Plate Lens in Polish



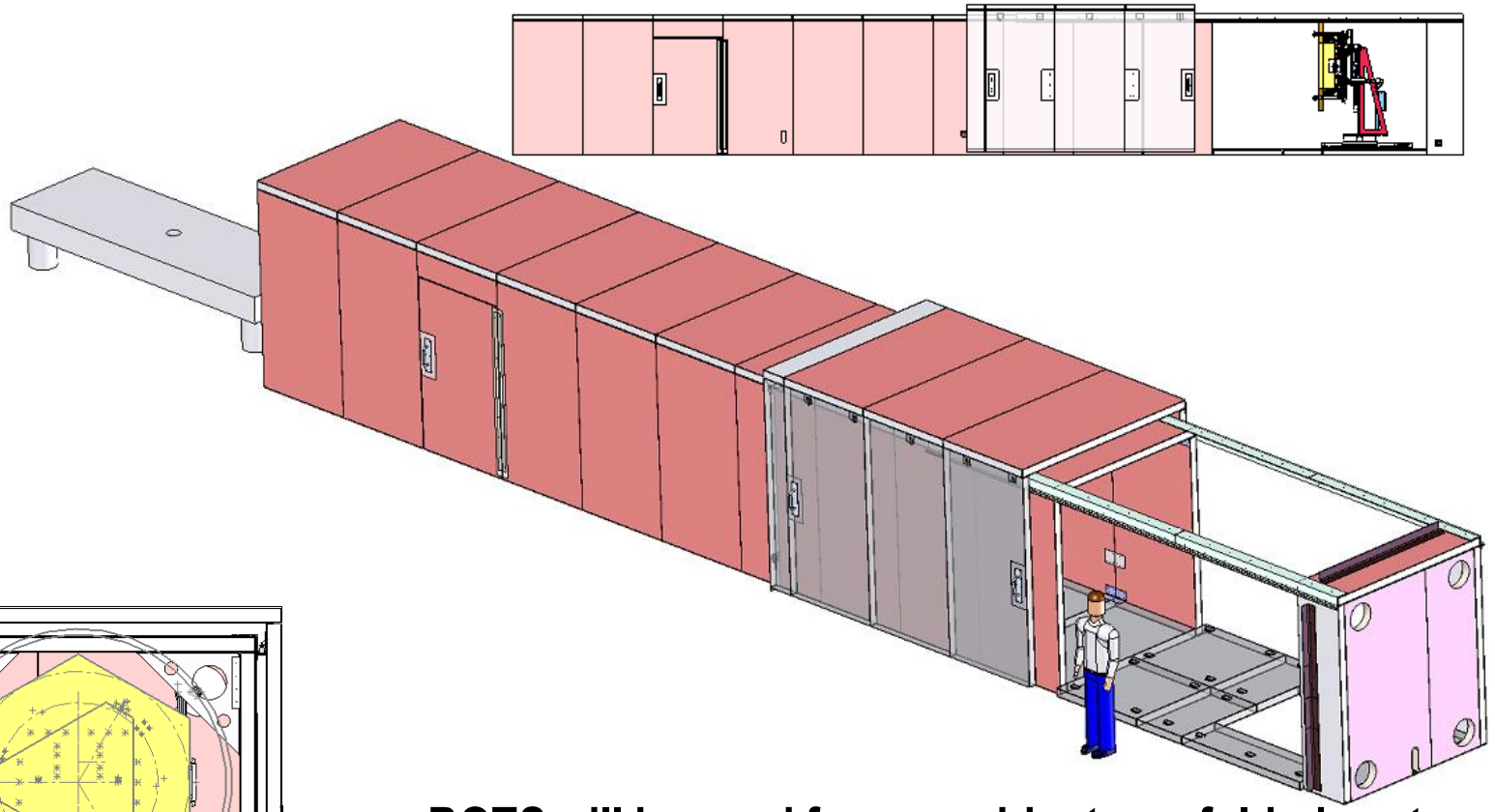
SMA Optical GSE Mount Alignment Station

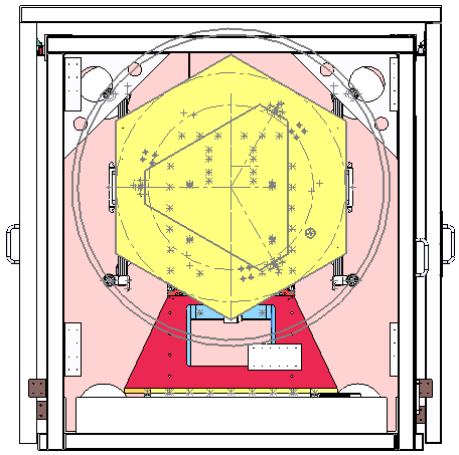


SMA Optical GSE – Illumination Lens in Polish

SMA Optical GSE Mount Base in Assembly

Ball Optical Test Station (BOTS) Status



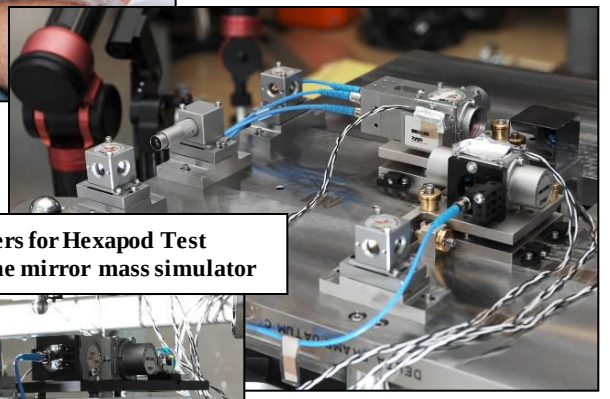


- **BOTS will be used for an ambient non folded center of curvature surface figure test inside the JWST clean room at BATC used for:**
  - Determining the surface figure affects of the C2 to C3 conversion
  - Create a gravity back-out file to be used at XRCF

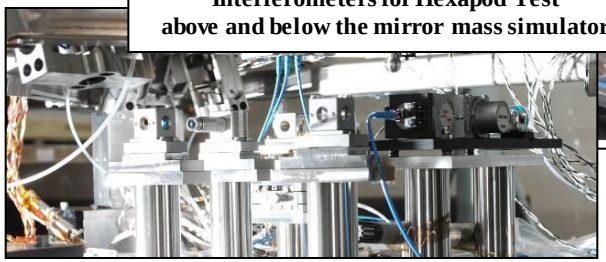
BATC Hexapod Assembly and Test

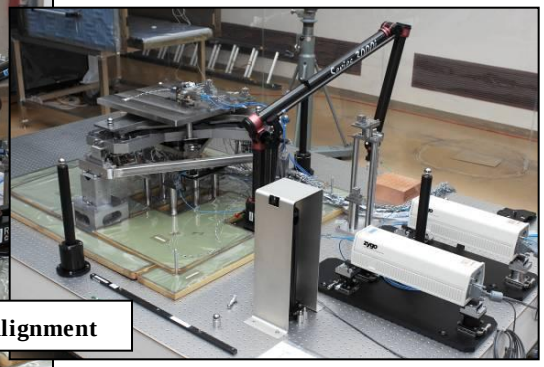
Hexapod Assembly

Bonding Hexapod Test Target Mirror

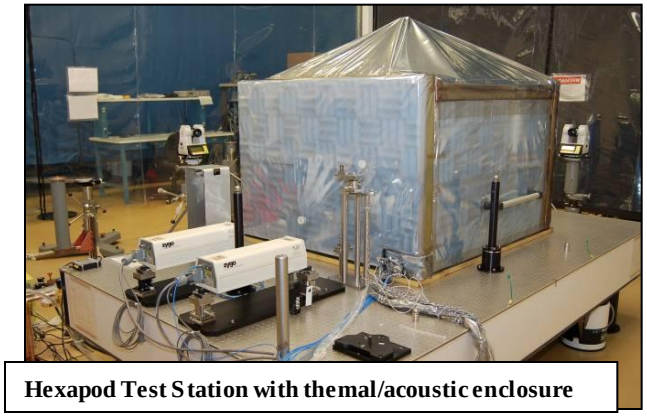


Interferometers for Hexapod Test
above and below the mirror mass simulator





Hexapod Test optical alignment

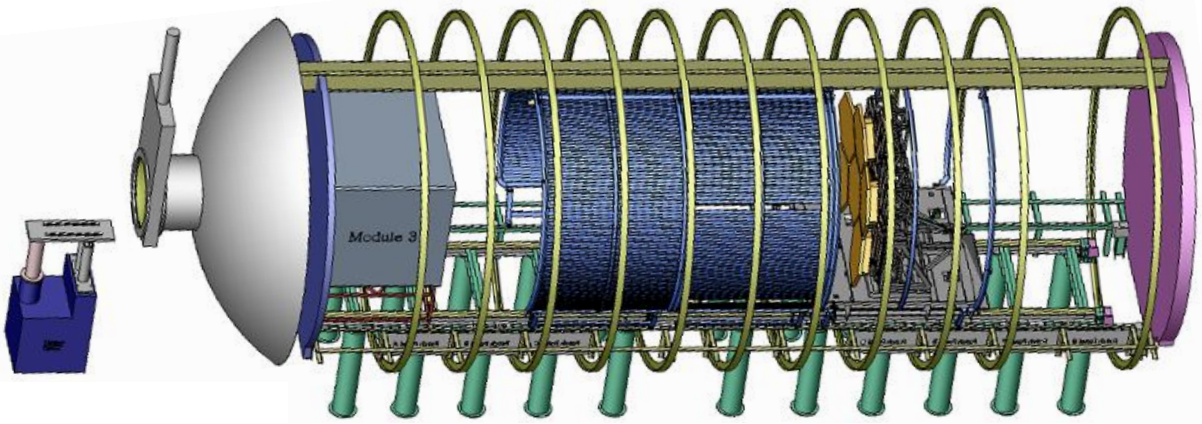


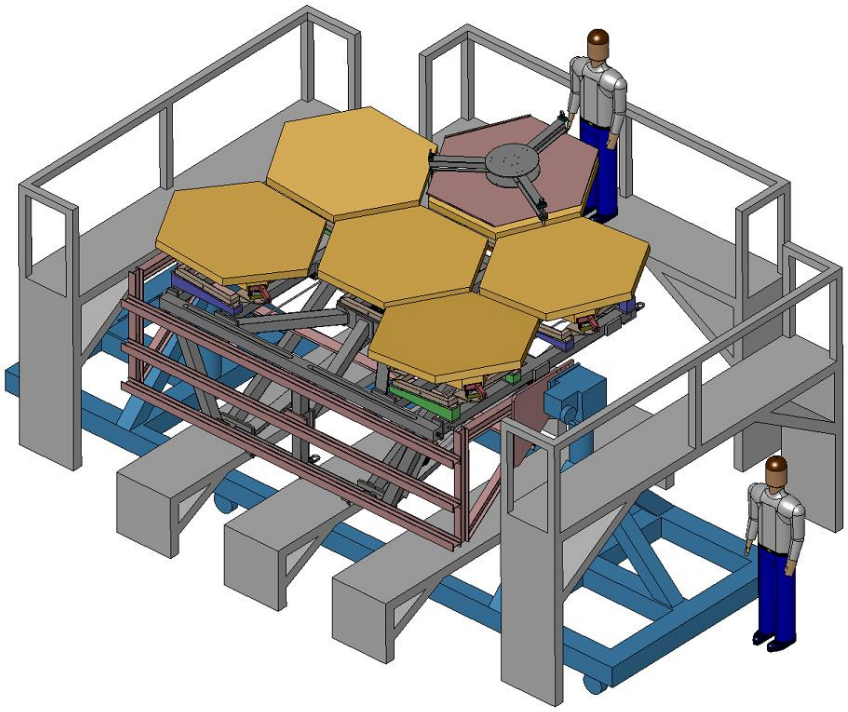
Hexapod Test Station with themal/acoustic enclosure

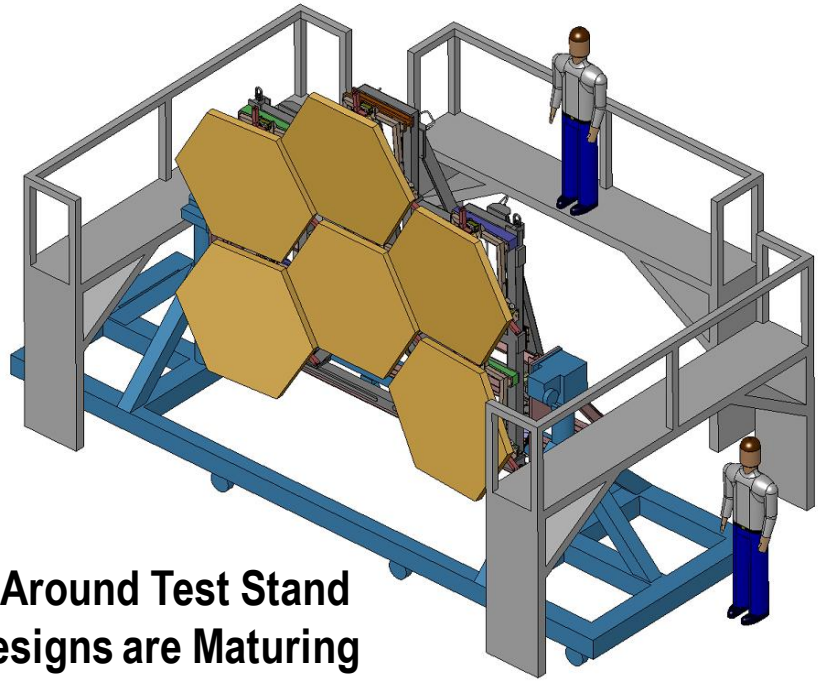
XRCF PMSA Integration Plans in Development

- **Each PM will be tested at cryogenic temperatures at the XRCF to:**
  - Create a cryogenic hit map
  - Demonstrate the segments pass final requirements

XRCF Chamber







5 Around Test Stand Designs are Maturing

JWST Mirror Manufacturing Summary

- **Ball Aerospace**
  - Cryogenic testing plans for the Primary Mirror segments and Secondary Mirror are well under way
  - Optical and mechanical GSE for the Secondary Mirror cryogenic test is nearing completion
    - Mounts are built and lenses are in polishing phase
- **Axsys Technologies**
  - All flight Primary Mirror segment blanks have been completed
  - First Secondary Mirror blank has been completed
  - Spare Secondary Mirror, flight Tertiary Mirror, and PM delta frames are in work
- **Tinsley Laboratories**
  - Primary Mirror manufacturing hardware is complete and metrology equipment integration is nearing completion
  - 18 Primary Mirror segments and 1 Secondary Mirror are at Tinsley for processing
  - 15 Primary Mirror segments have entered into the grinding phase of processing