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SOFIA Stratospheric Observatory for Infrared Astronomy

SOFIA

Stratospheric Observatory For Infrared Astronomy

Eric Becker, NASA Dryden Flight Research Center
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Outline

SOFIA Stratospheric Observatory for Infrared Astronomy

- Heritage & History
- Level 1 Requirements
- Top Level Overview of the Observatory
- Development Challenges
- Highlight Photos

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The Great Observatories

SOFIA Stratospheric Observatory for Infrared Astronomy

- Mt Wilson
- Mt Palomar
- Keck (Hawaii)

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Hubble

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Hubble Discoveries

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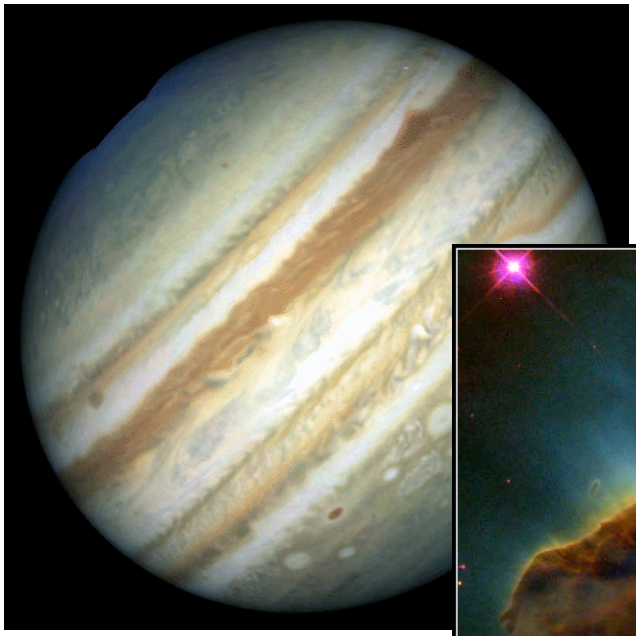

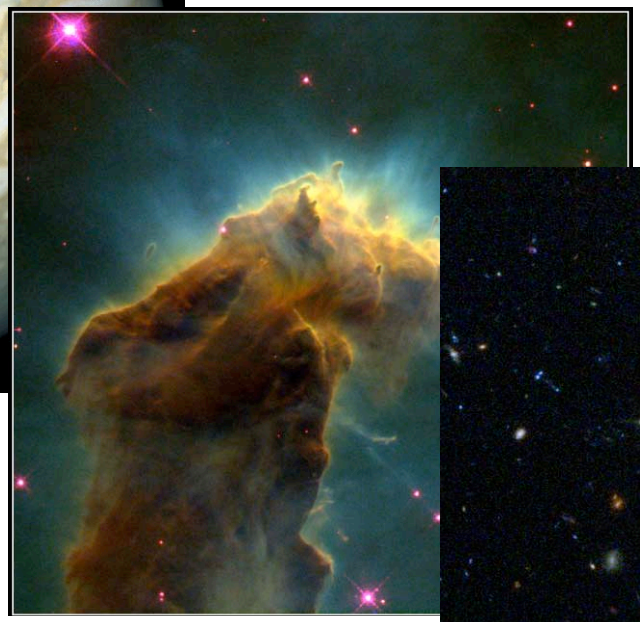

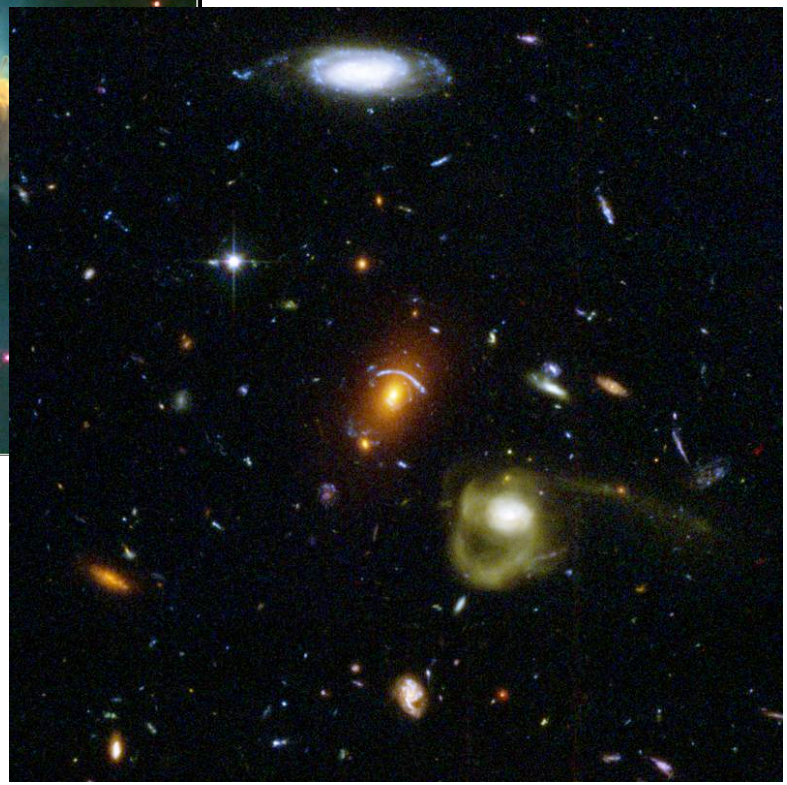

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SOFIA Stratospheric Observatory for Infrared Astronomy

The Org structure for majority of the development phase

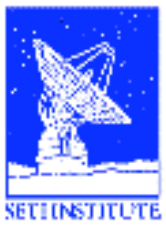
Project Sponsorship,
Fiscal Control
and Review

Project Co-Sponsorship,
Telescope Provider,
Oversight of German
Instrument and Subcontracts

US Instruments and
Subcontract
Science Support,
Operations

Telescope Assembly

Mission Control,
Software,
Network and
Web Support



Education & Public Outreach

Instruments, Mirror Cleaning,
Science Support

Aircraft Operation
and Maintenance

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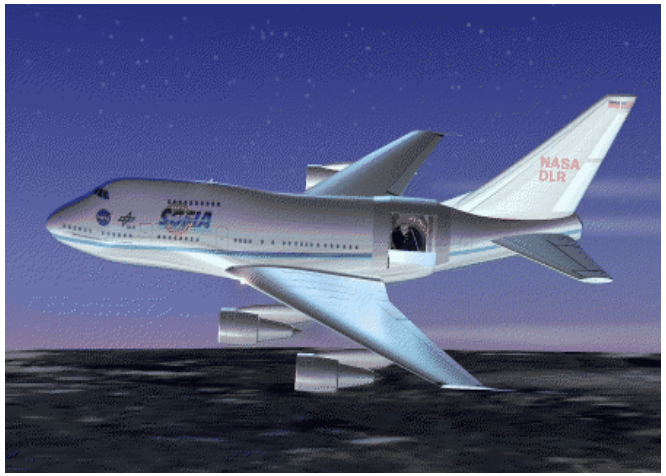
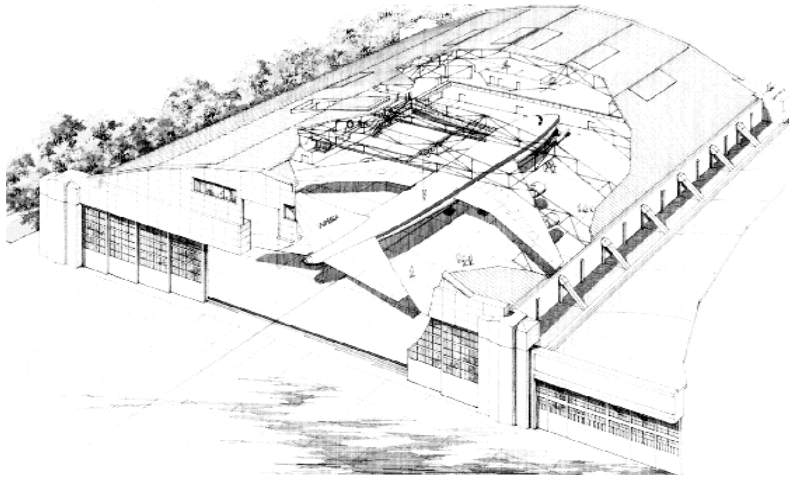
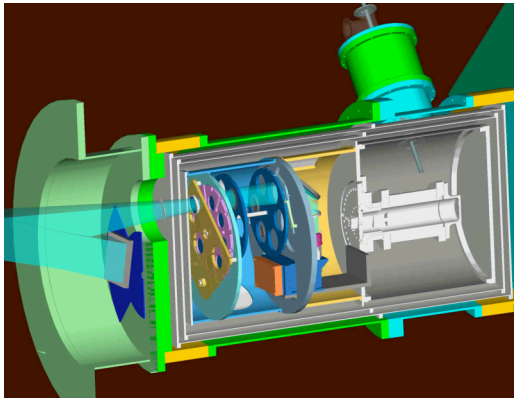
Major Components of SOFIA

SOFIA Stratospheric Observatory for Infrared Astronomy

Observatory







Science Instruments

Science and Mission Operations Center

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Heritage

SOFIA Stratospheric Observatory for Infrared Astronomy

- Kuiper Airborne Observatory is the direct Predecessor to SOFIA
  - Modified C-141 with 36” Diameter Telescope
  - Flew w/open port cavity 1974-1995
  - Cavity in forward fuselage
  - Porous fence was primary Shear Layer Control device
  - Aft Ramp augmentation based on SOFIA development wind tunnel test results was implemented in 1993
    - Flow attachment significantly improved
    - Internal Cabin noise significantly reduced for Open cavity flight
    - Cavity Environment significantly improved
    - Allowed fence position to be lowered from 30° to 10°
    - Reduced drag - improved flight performance

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Kuiper Airborne Observatory (KAO)

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1974-1995

Lockheed C-300
(Modified C-141)

36” Telescope

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KAO Aft Ramp - Passive Flow Fairing

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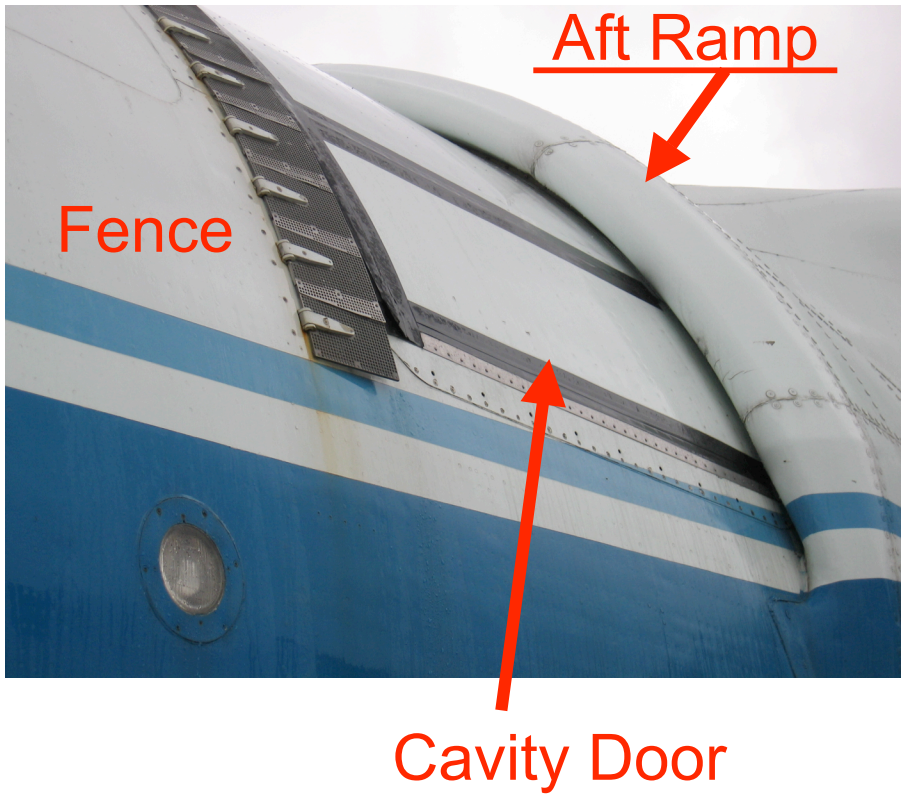

- Designed to stabilize the shear layer re-attachment downstream of the open cavity.
- Enabled KAO to fly with the cavity fence at 10° instead of 30°
- Reduced Shear layer thickness
- Significant improvements in "Seeing"
- Reduced cavity aero-acoustics
- Reduced structural fatigue in and around cavity
- Pilot noticed improvements in open door flight

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SOFIA - Airborne Astronomy Size Comparison

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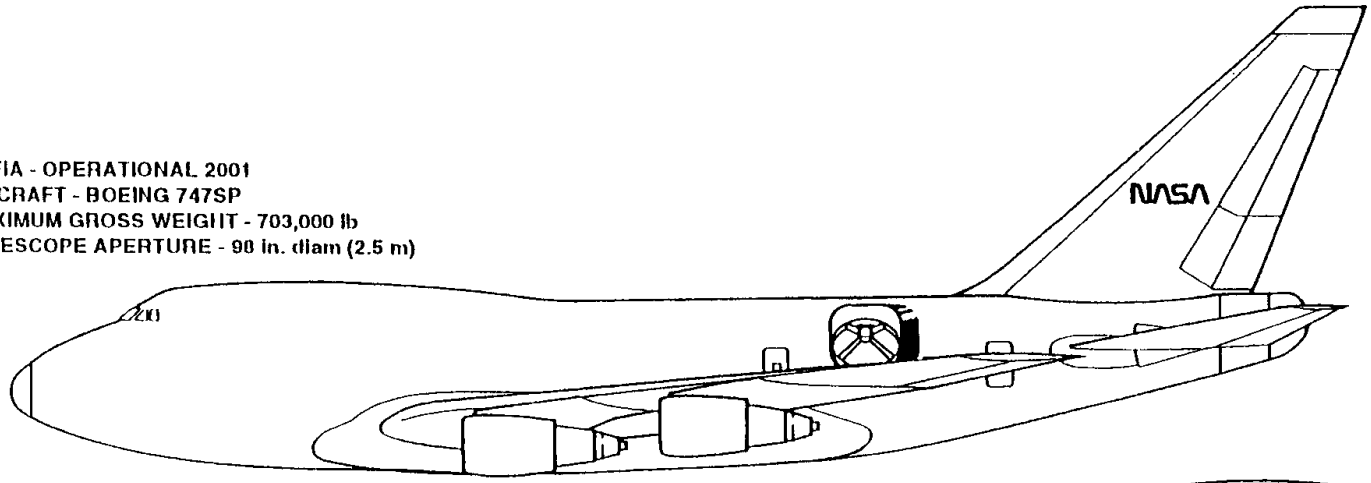
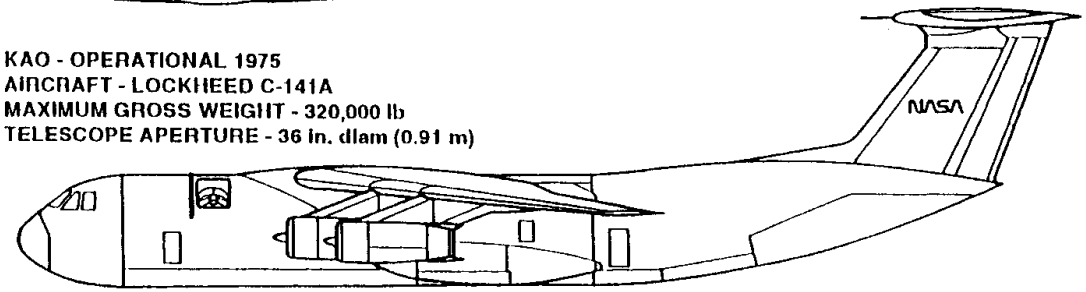
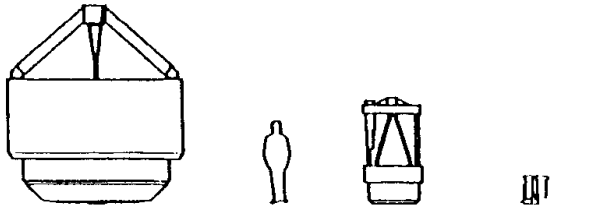
SOFIA - OPERATIONAL 2001
AIRCRAFT - BOEING 747SP
MAXIMUM GROSS WEIGHT - 703,000 lb
TELESCOPE APERTURE - 98 in. diam (2.5 m)

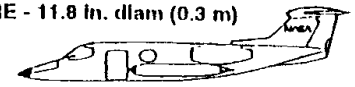


KAO - OPERATIONAL 1975
AIRCRAFT - LOCKHEED C-141A
MAXIMUM GROSS WEIGHT - 320,000 lb
TELESCOPE APERTURE - 36 in. diam (0.91 m)





LEARJET OBSERVATORY - OPERATIONAL 1965
AIRCRAFT - LEARJET, MODEL 24
MAXIMUM GROSS WEIGHT - 15,000 lb
TELESCOPE APERTURE - 11.8 in. diam (0.3 m)



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SOFIA - Requirements/Specifications

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- Wavelength Range 0.3 - 1600 microns
- Unvignetted elevation range 20° to 60° above the horizon
- Configuration: Instrument Access in Cabin
- Telescope effective Aperture Diameter 2.5 meters
- Time at ≥ 41,000 feet ≥ 6 hours
- Observing hours per year ≥ 960
- Lifetime≥ 20 years
- PI Teams per year capability ≥ 40
- Education Goals: NASA OSS Guidelines
- ~~Airworthiness: FAR FAA Certification~~
- IR functional capabilities: chopping, nodding, & scanning
- Image quality 80% encircled energy within 1.5 arcsec at visible wavelength
- Image stability at focal plane 0.2 arcsec rms

Combined to 80% encircled energy within 5.3 arcsec diameter image size at First Science Flight improving to 1.6 arcsec within 3 years.

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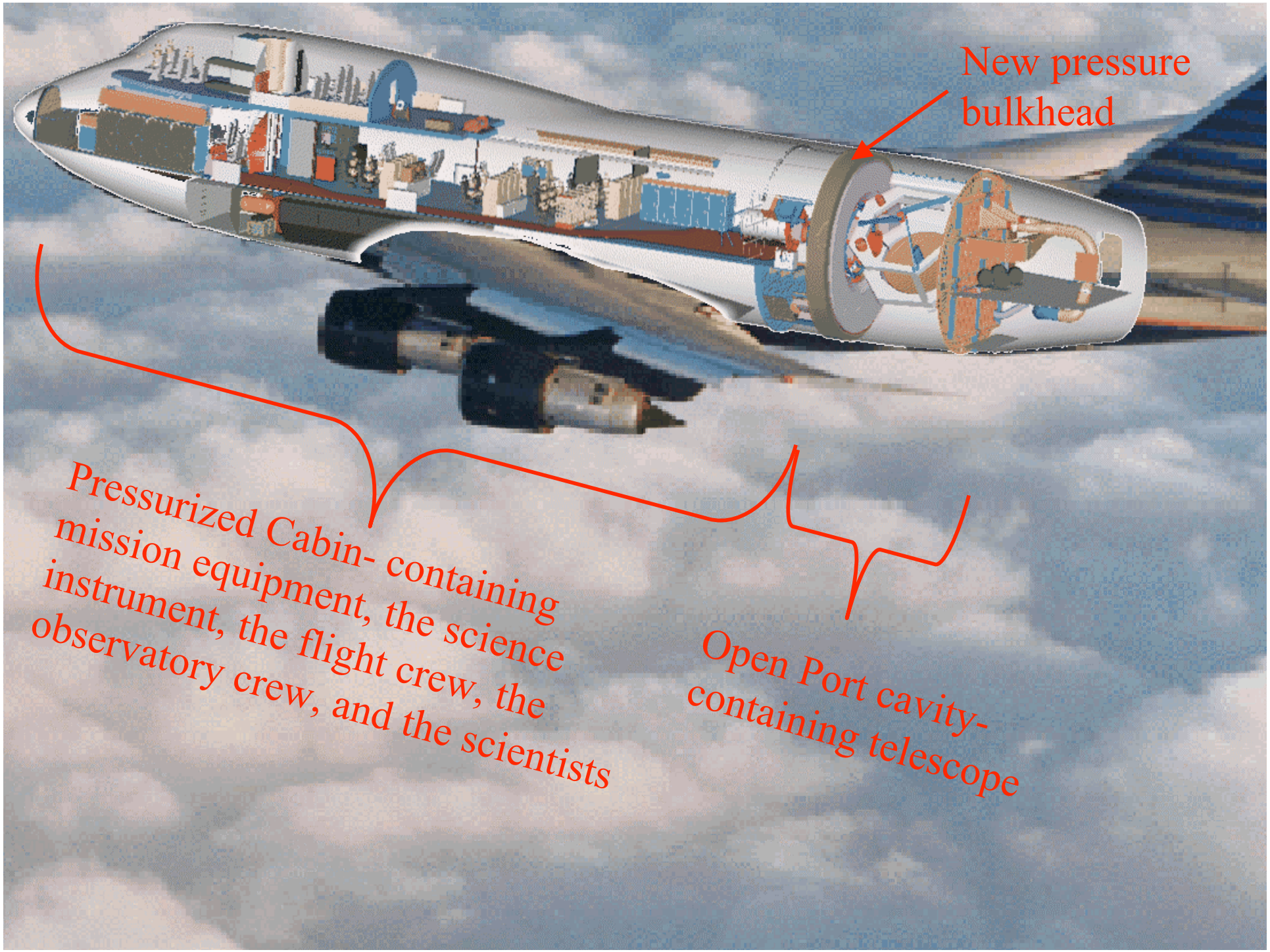
SOFIA
Location of future cavity opening


New pressure bulkhead
Pressurized Cabin- containing mission equipment, the science instrument, the flight crew, the observatory crew, and the scientists
Open Port cavity- containing telescope

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Airborne Observatory Layout

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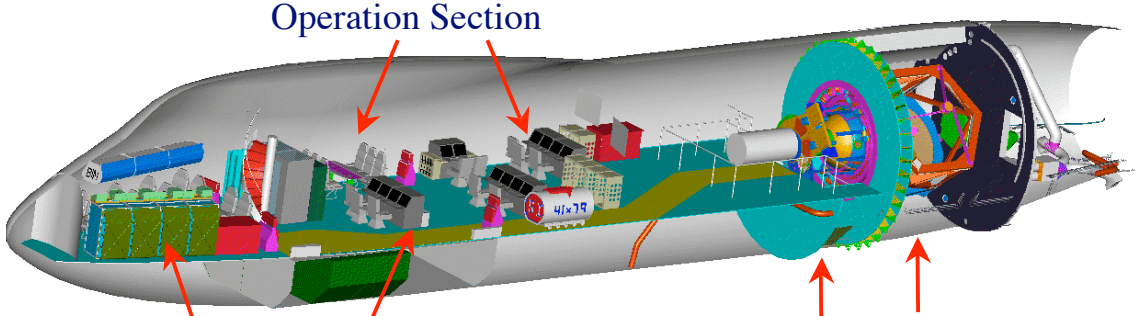

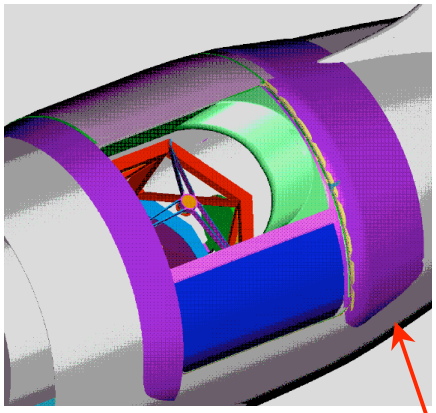

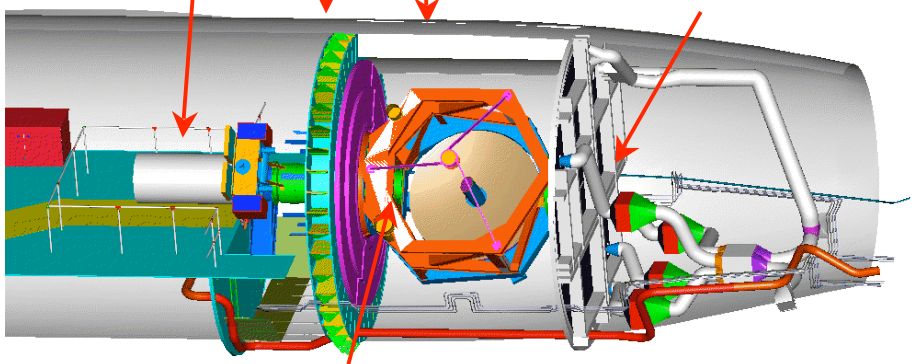

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2.5 Meter effective aperture

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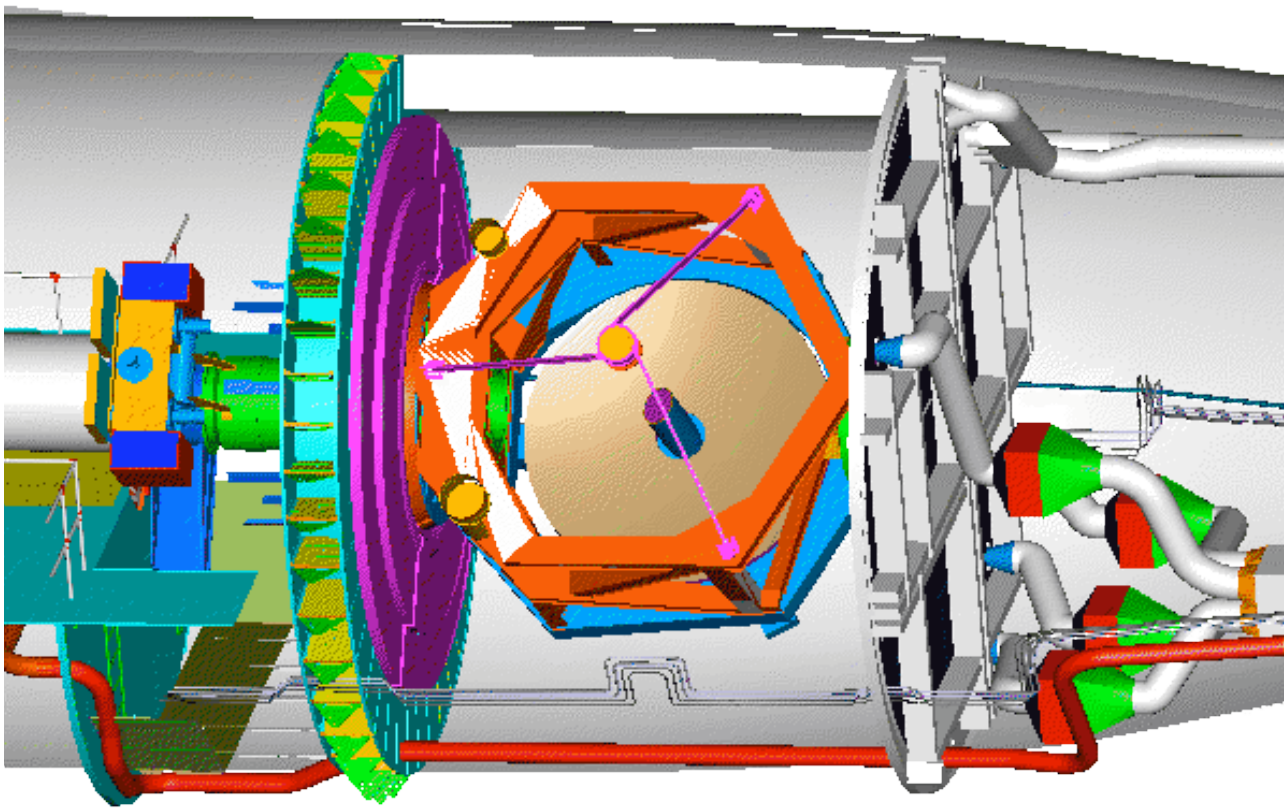
- Aircraft Size
- Large 2.7 Meter Primary Mirror
- "Fast" Mirror to fit within aircraft
  - Drives alignment/stiffness requirements



Telescope Size is Maximum that can fit Available Volume

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Telescope Optical Layout

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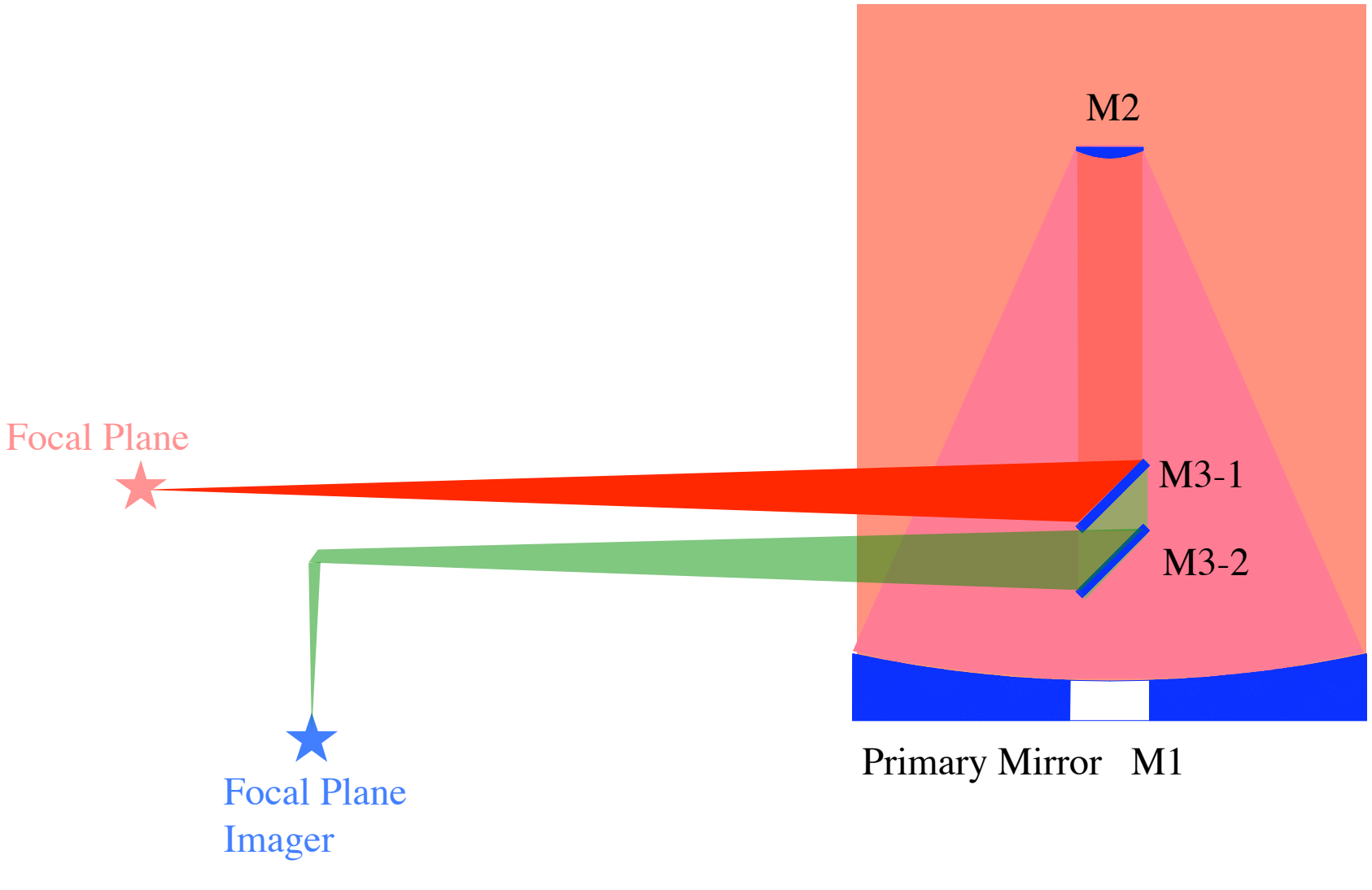

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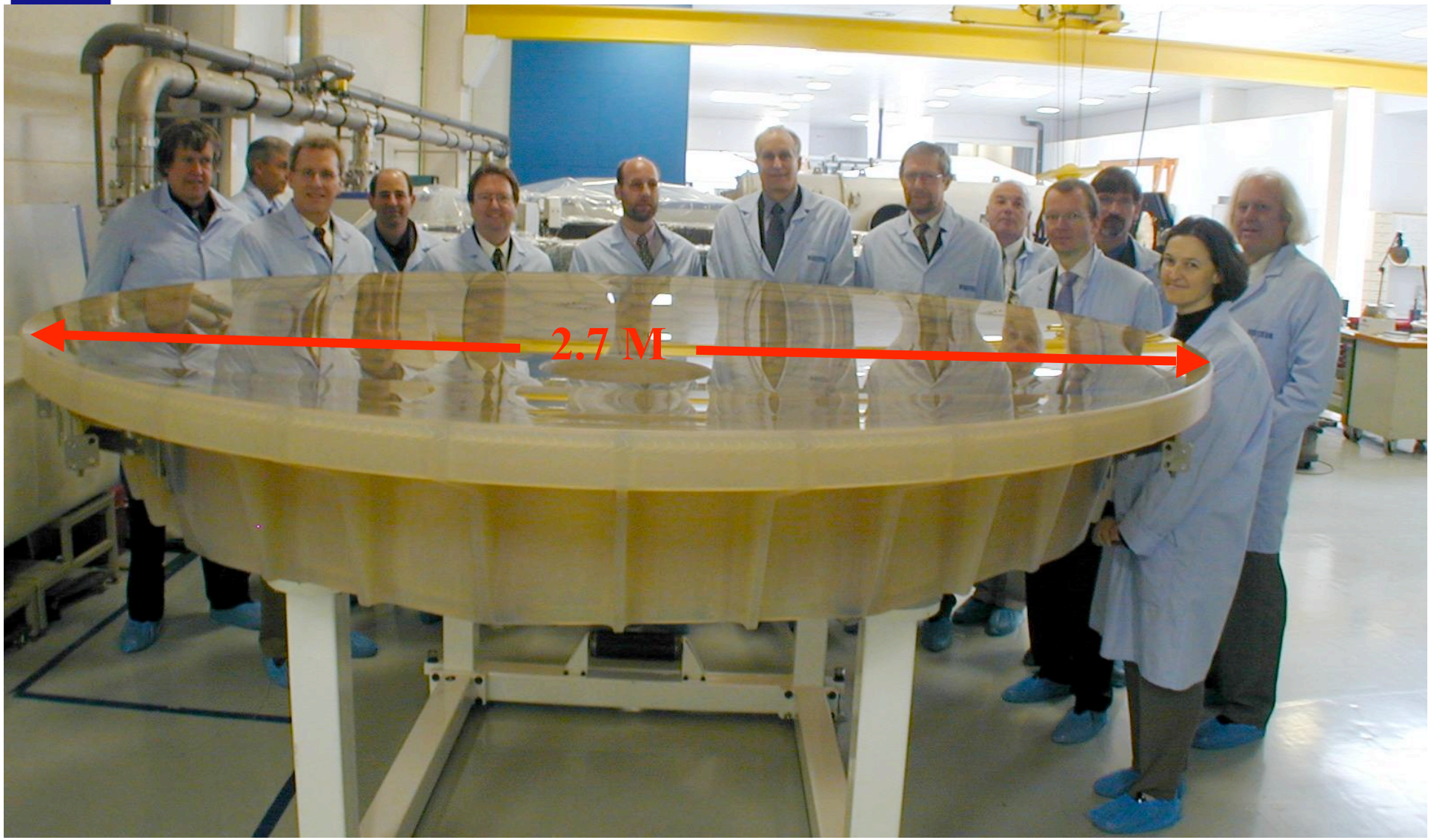
2.5 Meter effective aperture



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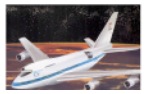
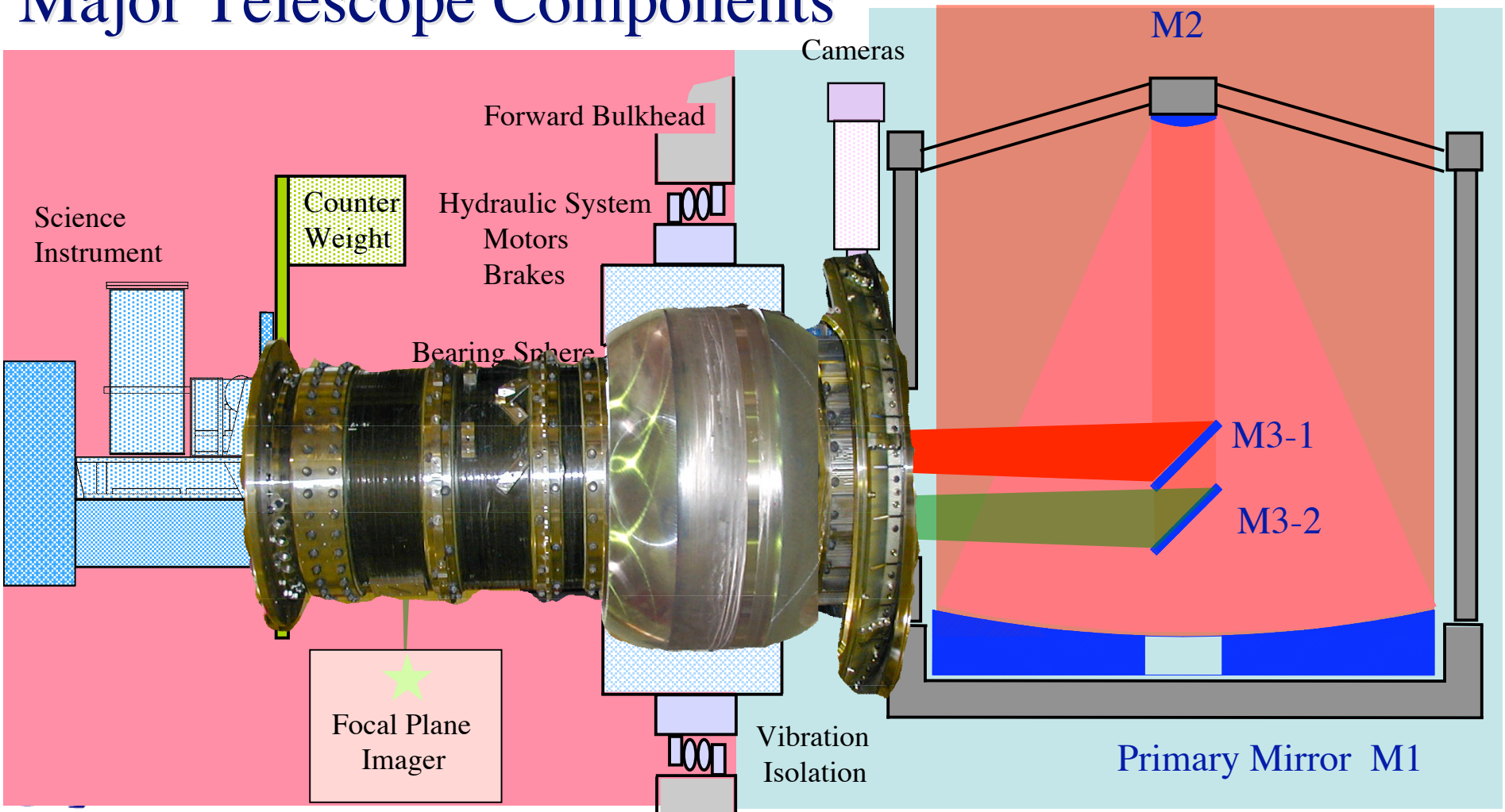
Major Telescope Components



Major Telescope Components



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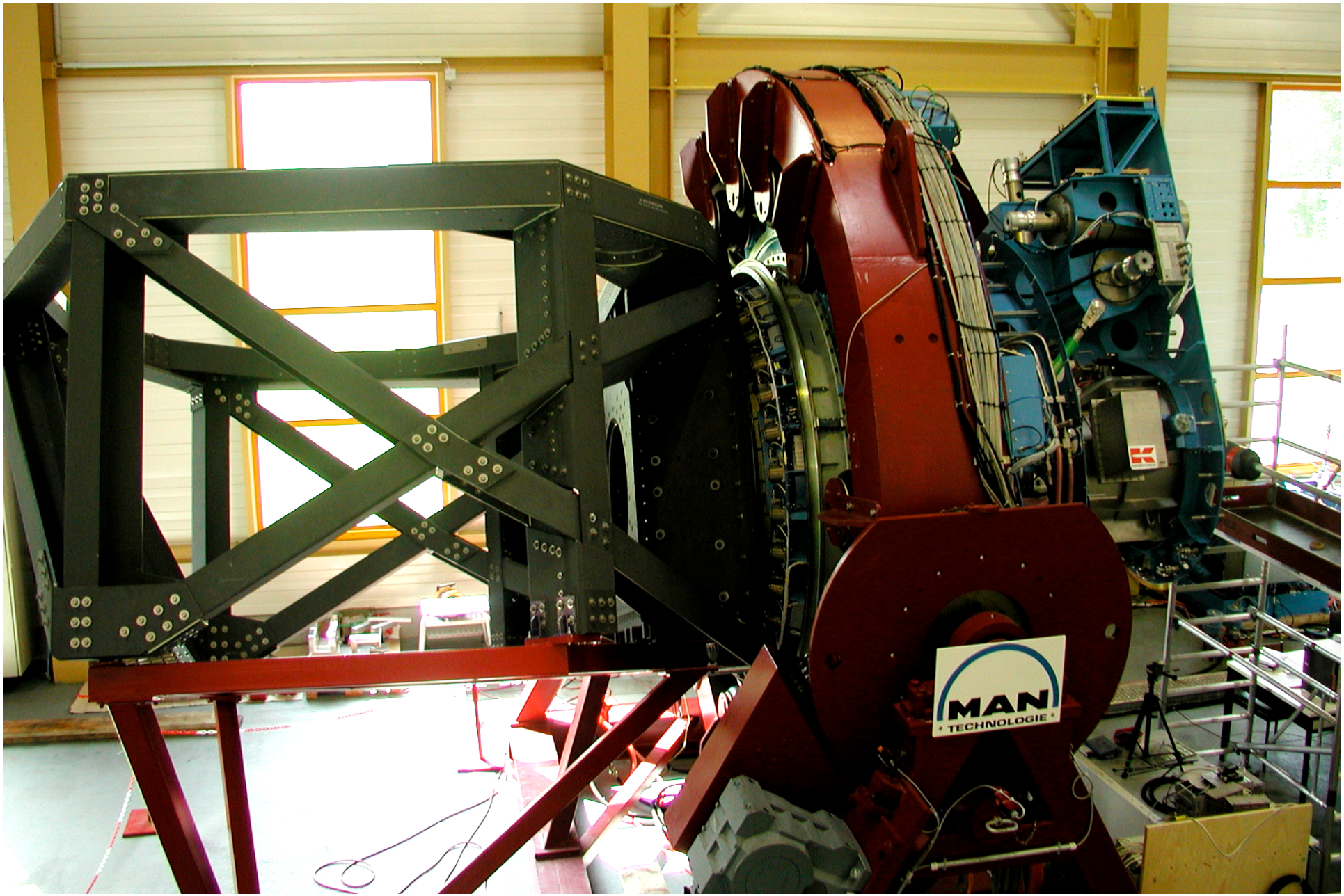
Telescope pre-ship integration



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Configuration: Instrument Access in Cabin

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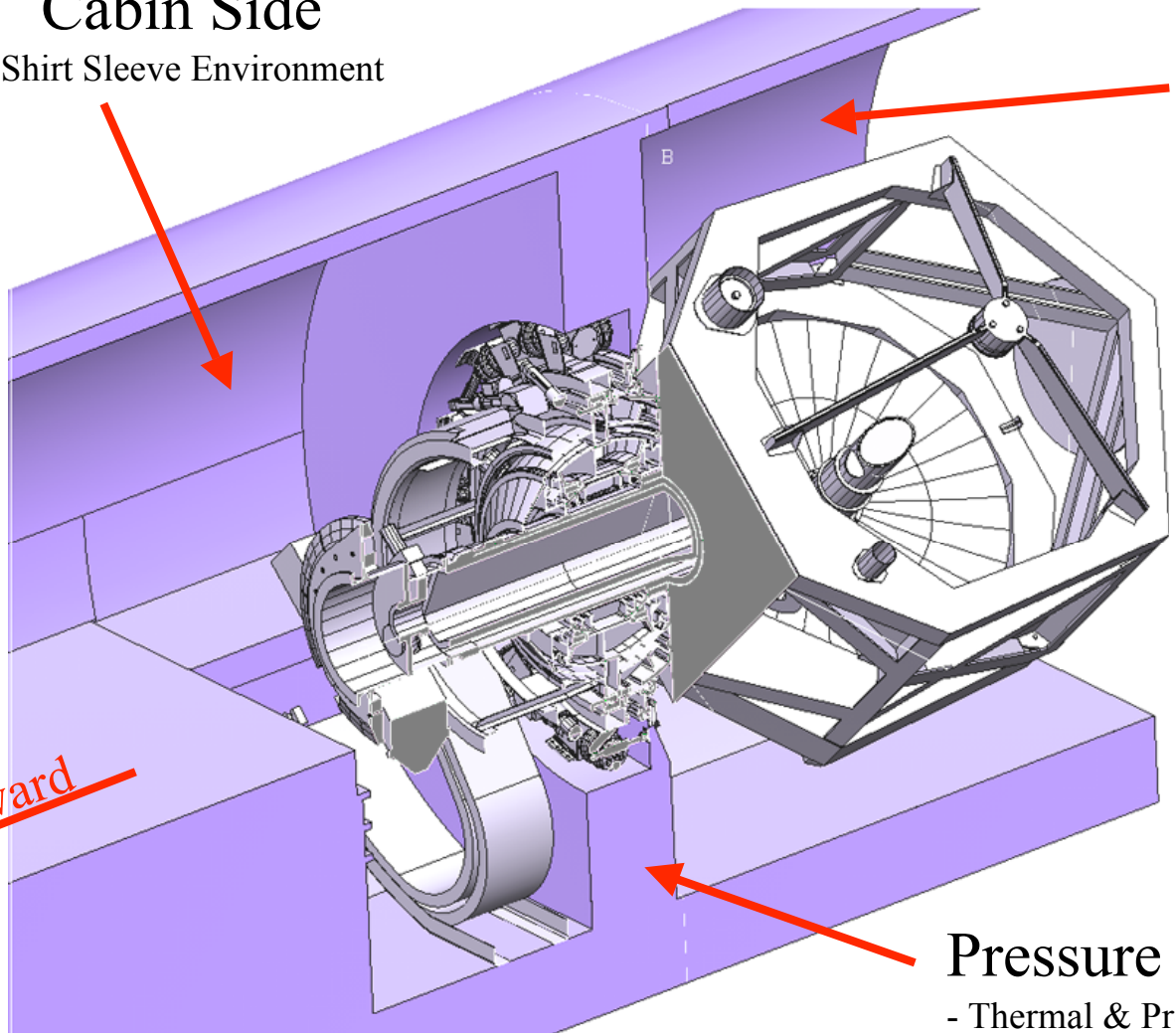
Cabin Side
- Shirt Sleeve Environment

Cavity Side
- Open to Atmosphere
(0.18 atm - -40°C)



Forward

Pressure Bulkhead
- Thermal & Pressure Boundary

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Bulkhead - Flight Hardware

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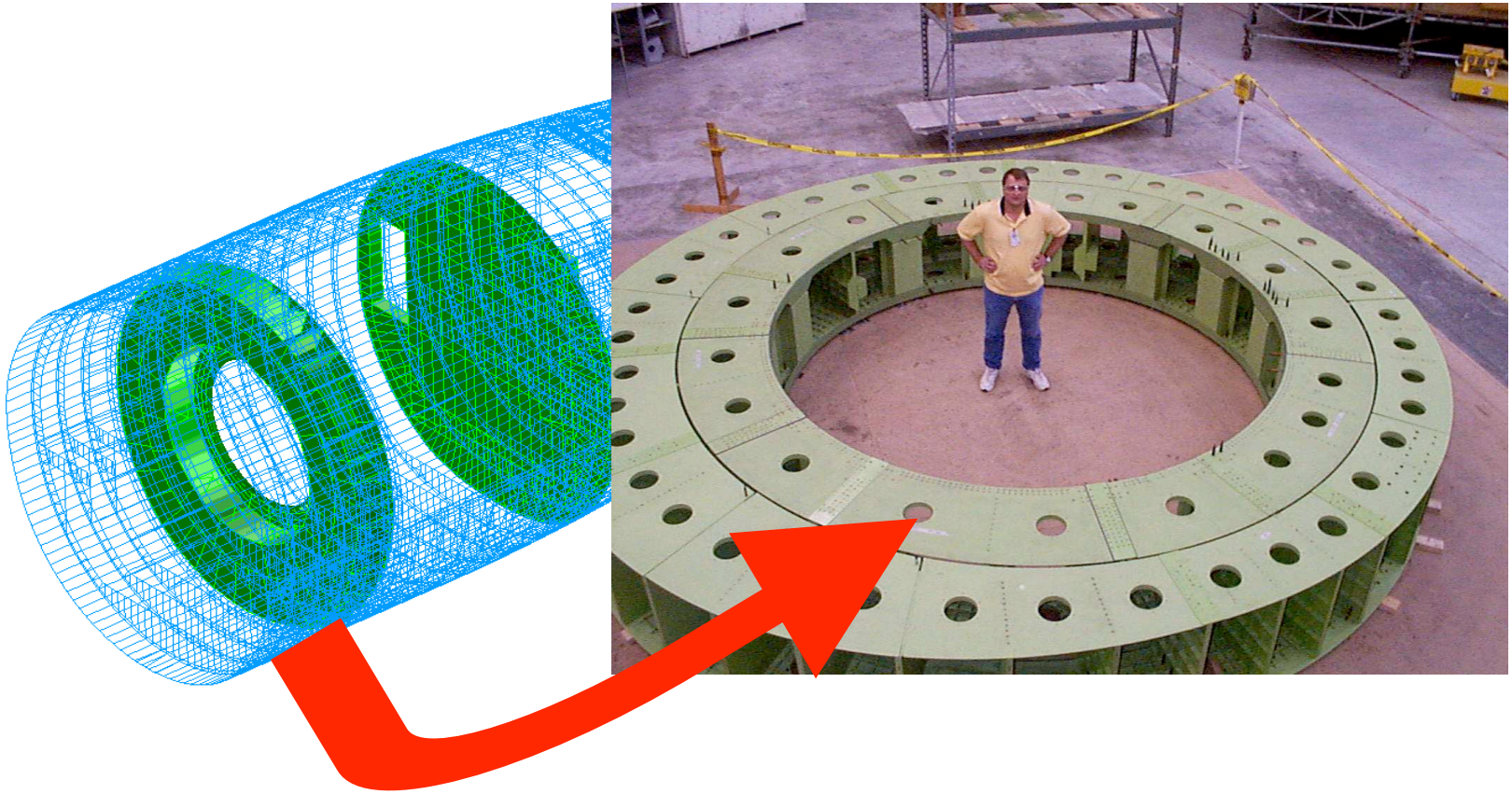
New Pressure Bulkhead



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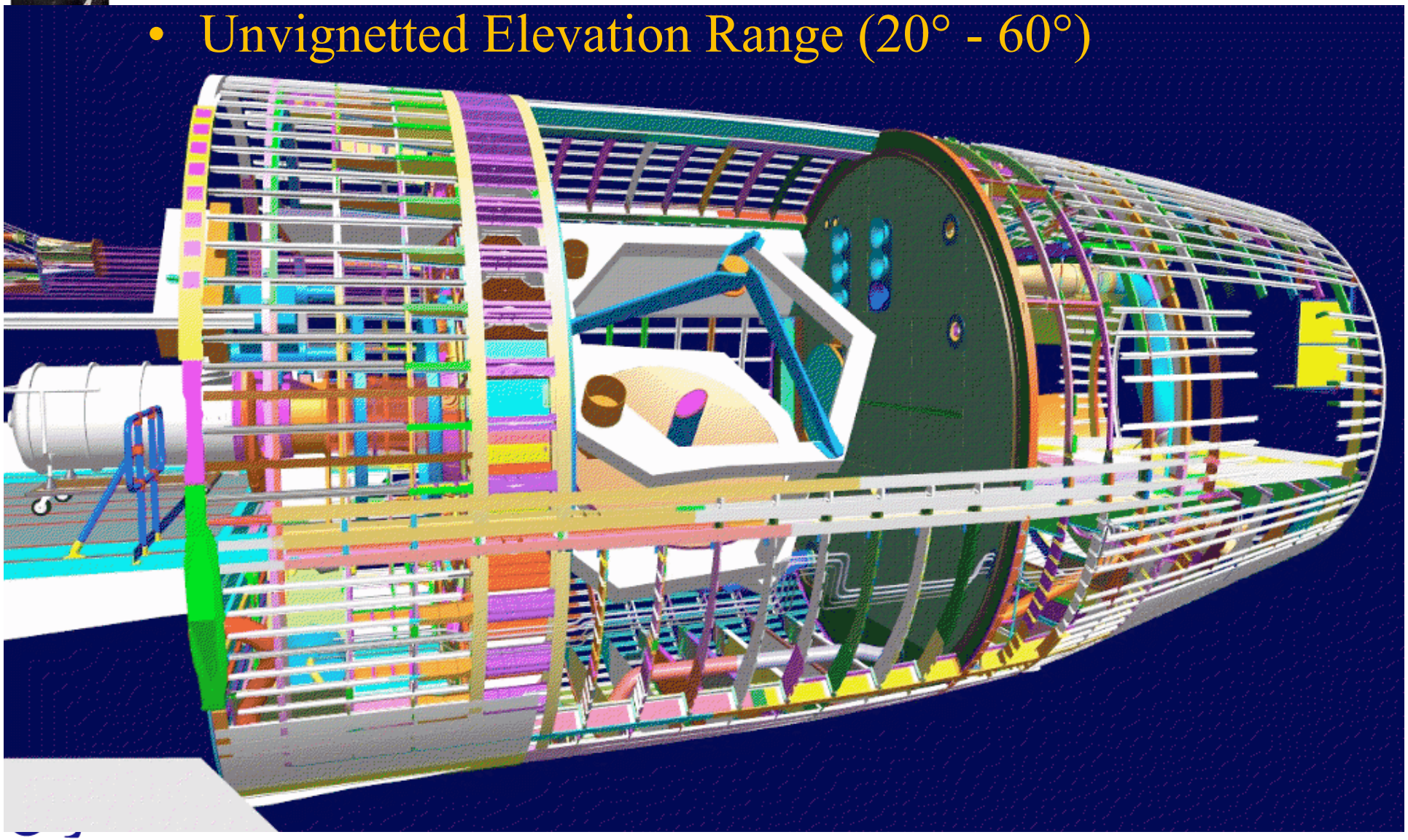
Large Structural Opening

- Unvignetted Elevation Range (20° - 60°)



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Technical Challenges

SOFIA Stratospheric Observatory for Infrared Astronomy

- Open Port cavity
- = Final Verification pending completion of Flight Tests
  - Influence on aircraft Stability & Control
  - Acoustic Issues
    - Resonance
    - Structural Fatigue
    - Environment for Telescope Performance
  - Drag (aircraft performance)
- Structural Modification
  - Strength
  - Stiffness
  - Transition to unmodified areas

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Technical Challenges

SOFIA Stratospheric Observatory for Infrared Astronomy

- Thermal Environment
  - Systems exposure
  - Science performance
- Cavity Door
  - Accommodate fuselage deformation
  - Track Telescope motion
  - Drive system safety
- Lightweight Primary Mirror
- Rotational Isolation System
  - KAO used air bearing but this technology does not scale well…

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SOFIA Wind Tunnel Testing Overview

SOFIA Stratospheric Observatory for Infrared Astronomy

7% Scale Tests

- SOFIA I - March 1990 to July 1990 - Forward Cavity configuration
- SOFIA II - June 1994 to August 1994 - Aft Cavity configuration
- SOFIA III - February 1995 -SP only -Aperture Geometry -TA loads
- SOFIA IV - Sept 1995 to Dec1995 Door design space evaluation
- SOFIA V - November 1997
  - Adjustment of Boundary Layer profile to match Baseline Flight tests
  - Verification of Final Partial External Door (PED) Design
  - Measurement of loads on Final Telescope design (pointing performance)
  - Measurement of loads for use in PED design

3% Scale Tests

Stability & Control - measure aero-coefficients between baseline 747-SP and SOFIA and provide substantiation for reduced flight test program

- Low Speed Tests - University of Washington Kirsten Wind Tunnel
  - Part 1 Sept 1998 to Oct 1998 & Part 2 Jan 1999 to Feb 1999
- High Speed Tests - Boeing Transonic Wind Tunnel
  - November 1998

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SOFIA 7% model in Ames 14ft Transonic Wind Tunnel

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Primarily used to development shear layer control design technology and to determine cavity acoustic environment and resultant loads on Telescope

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SOFIA CFD Predictions

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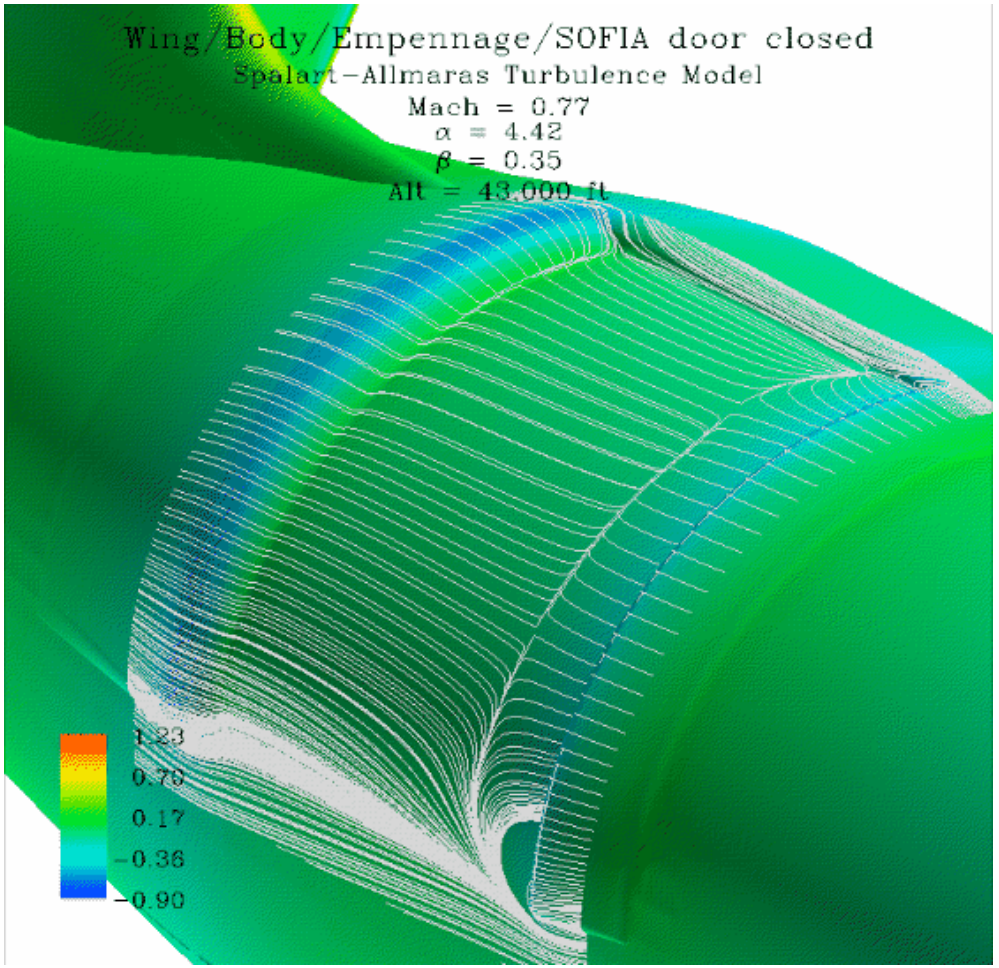
- Example of CFD flow over the mod



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SOFIA Wind Tunnel Data

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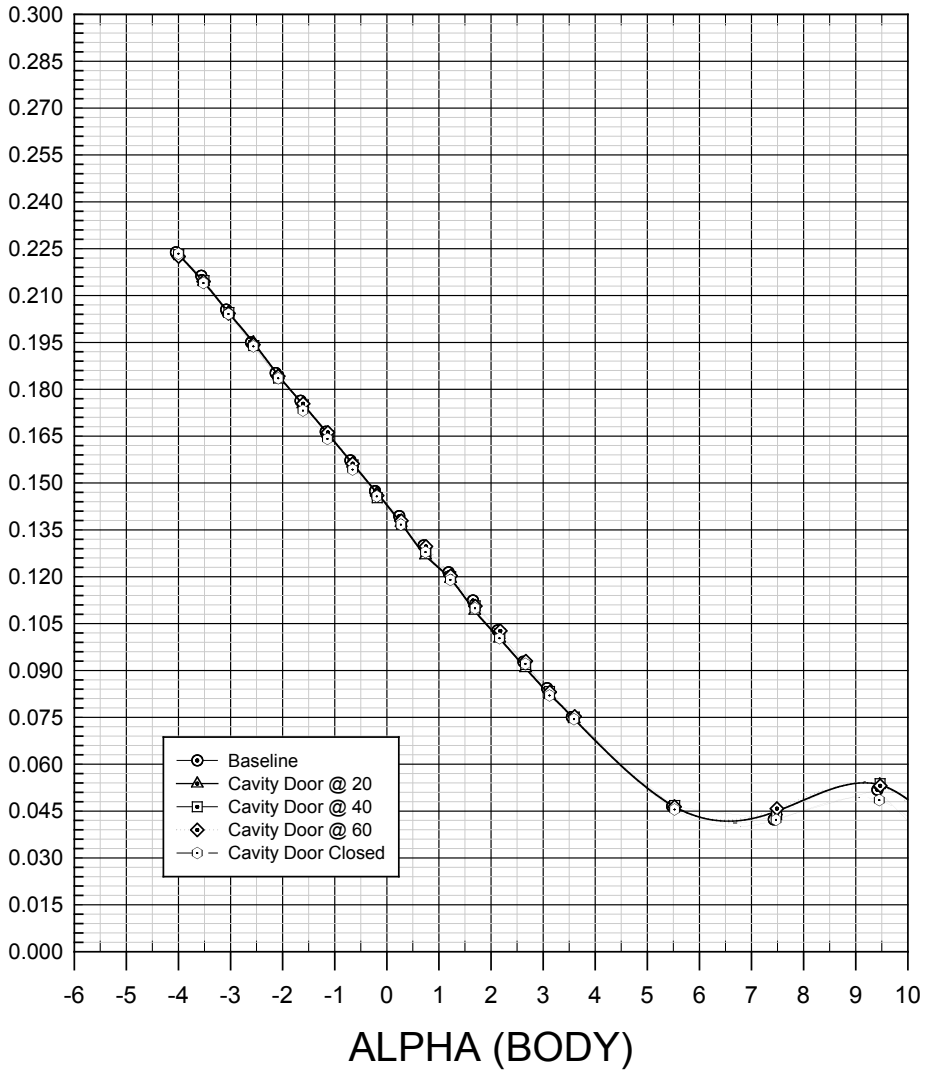
- Stab & Control
- Negligible change in drag and pitching moment
- No other F&Ms affected



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Objectives

SOFIA Stratospheric Observatory for Infrared Astronomy

- Per all Test and Analyses completed, data indicates Objectives will be met
  - Minimal impact on Stability & Control of Aircraft
  - Robust - Non resonating cavity (structural/safety)
  - "Quiet" cavity for optimum TA pointing performance
  - Minimize drag to maintain Aircraft performance
  - Optimize Aero-Optic performance "seeing" for short wave length image quality performance
- Flight Testing is remaining step to Verify

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Summary

SOFIA Stratospheric Observatory for Infrared Astronomy

- SOFIA SLC development began with KAO heritage
- Open port cavity/SLC issues identified early (1980's) as risk areas
  - Risk reduction activities were planned & completed accordingly
- Eight Separate Wind Tunnel Test Series Completed
  - Results Indicate:
    - Shear layer control implementation will provide quiet well behaved cavity acoustic environment
    - Stability & Control of aircraft will be essentially unaffected
- Multiple CFD and other analyses completed
  - Results concur with wind tunnel tests and provide additional data
- Multiple Independent Reviews Concur with approach
  - Latest NESC review extensively examined test and analysis data and planned program approach and recommend proceeding to flight test
- **All data indicates that SOFIA will fly like an unmodified 747-SP**

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Unloading Telescope Pieces

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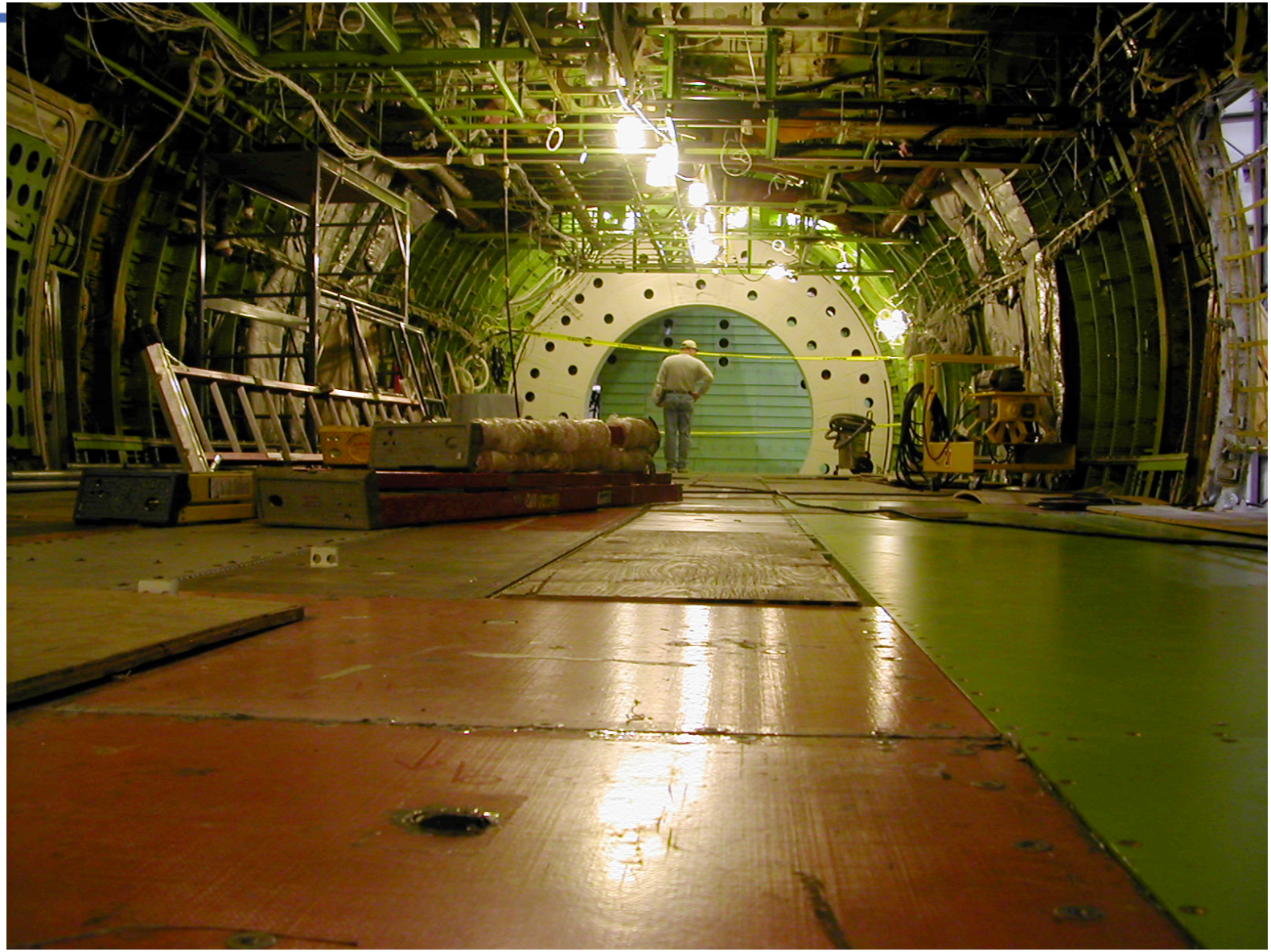

Inside aircraft just before SUA installation

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Lowering SUA into cavity

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SUA in place

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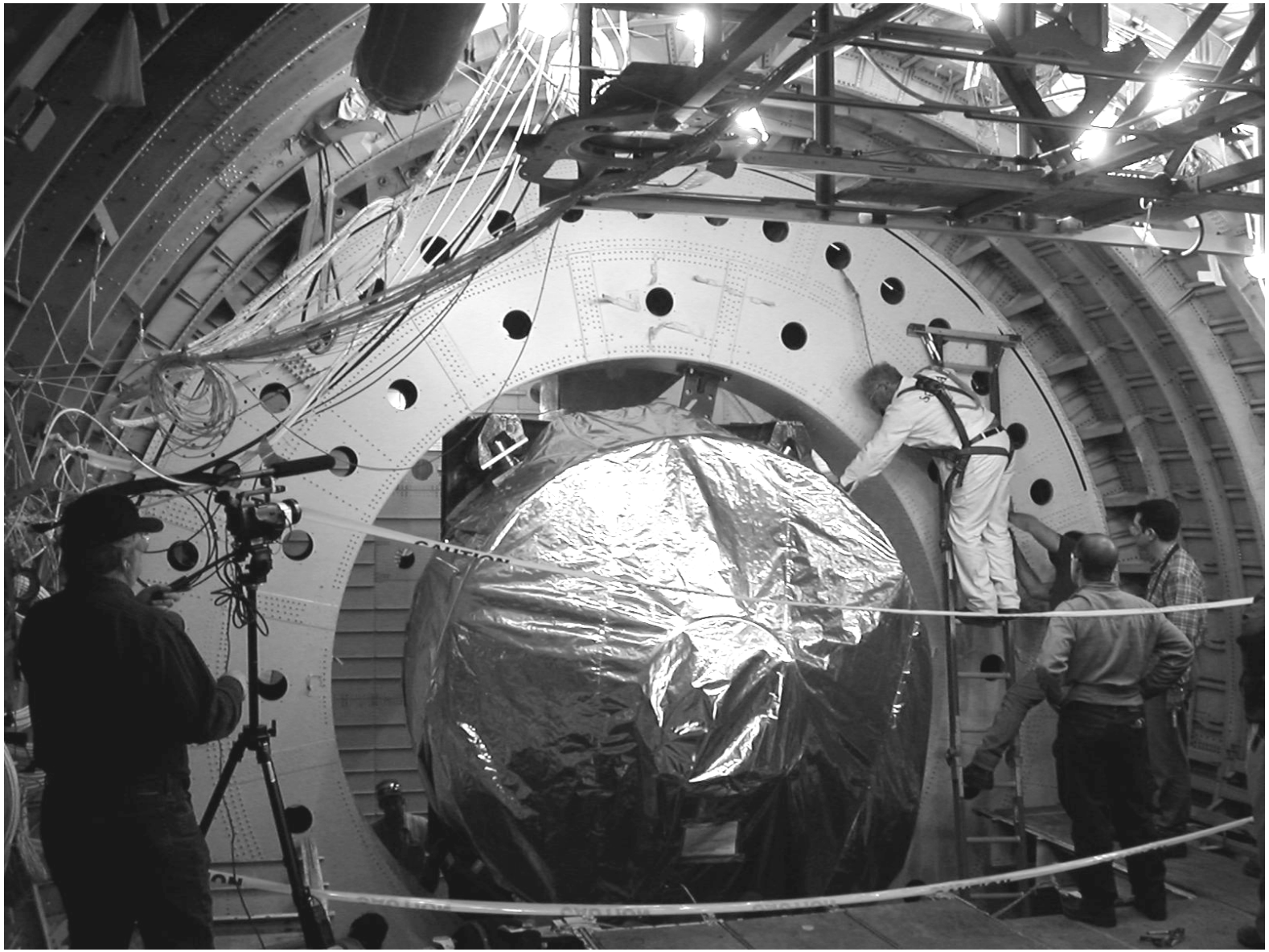

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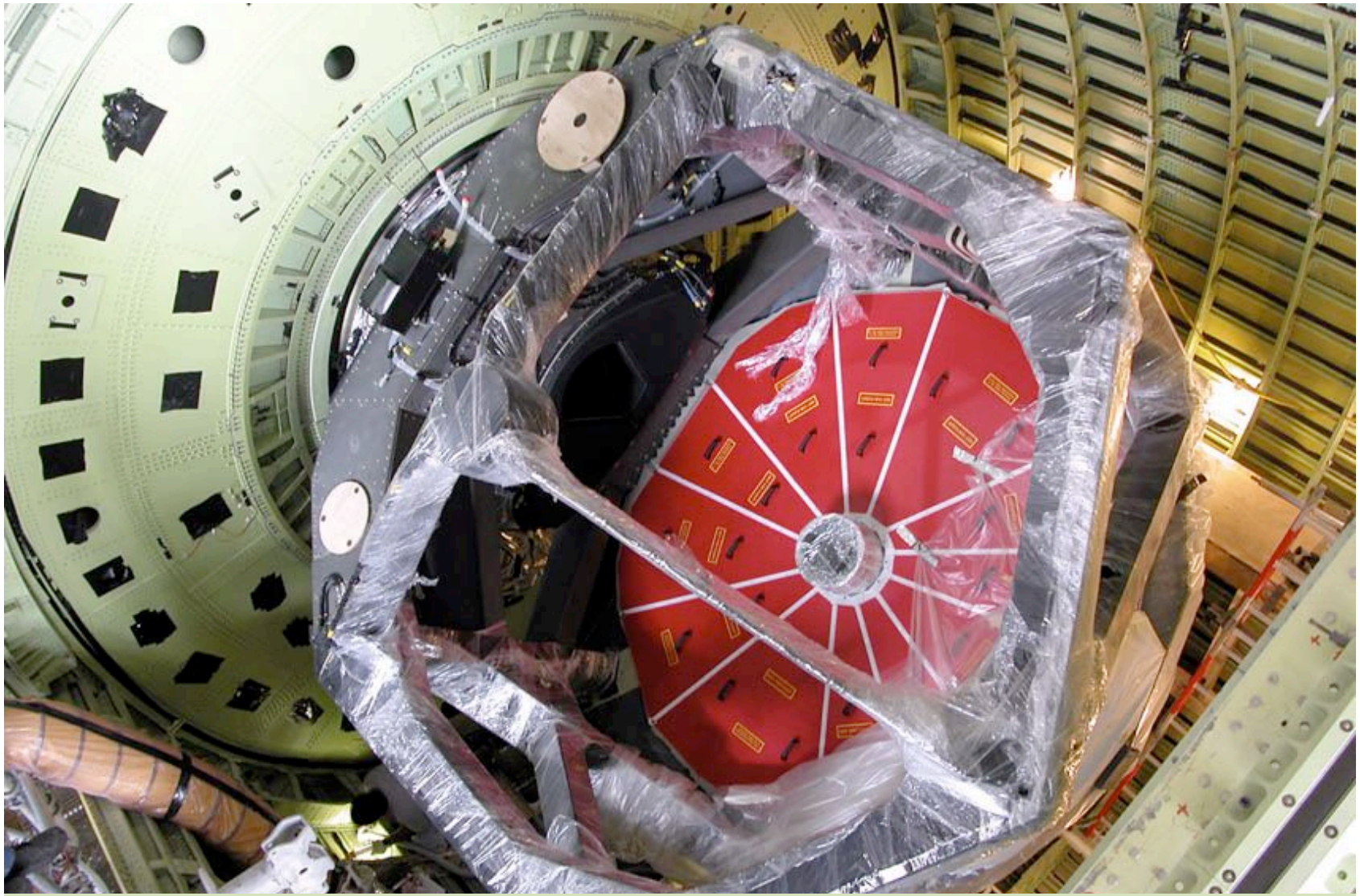
SOFIA Stratospheric Observatory for Infrared Astronomy



Telescope inside Aircraft Cavity

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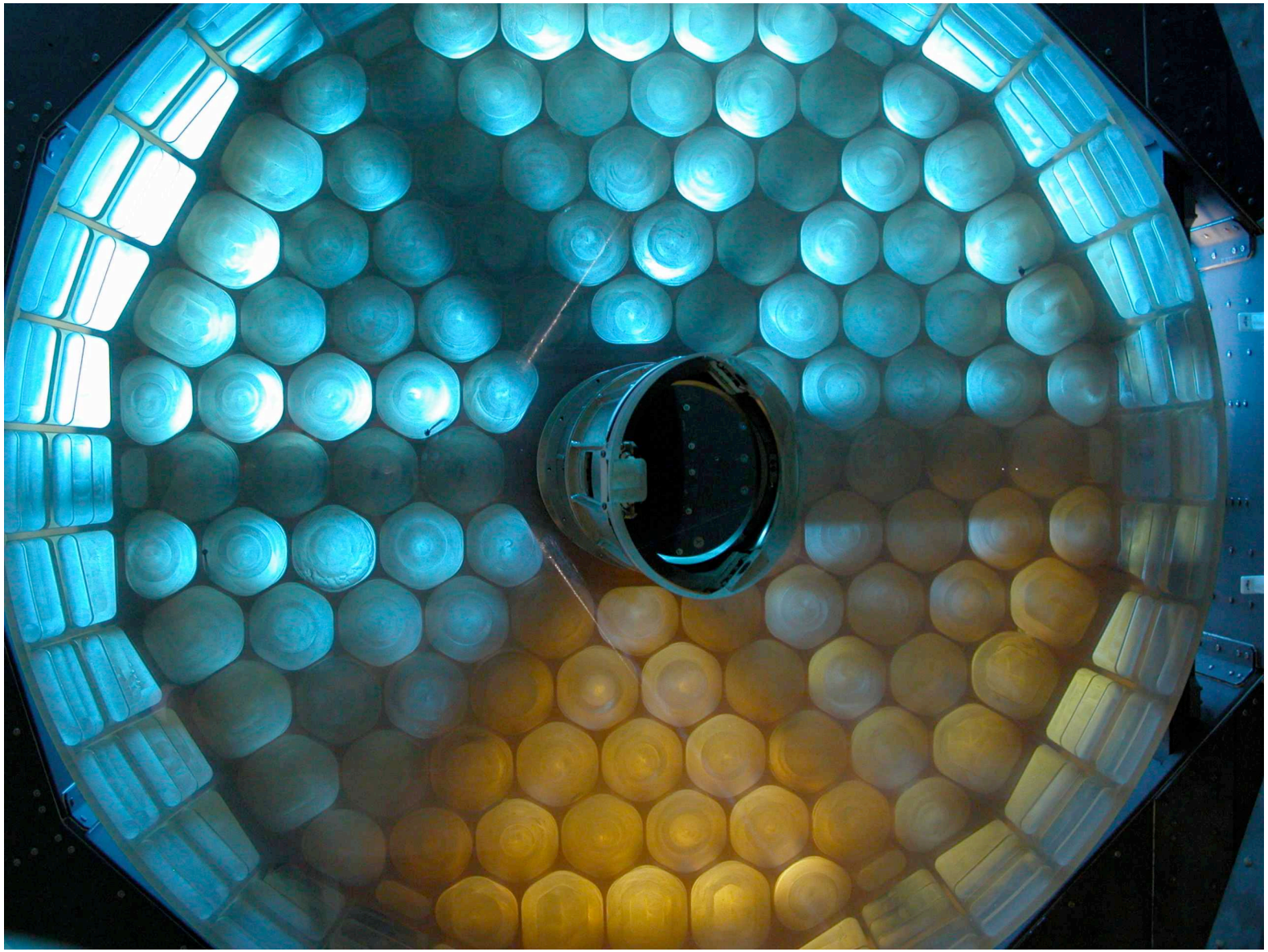

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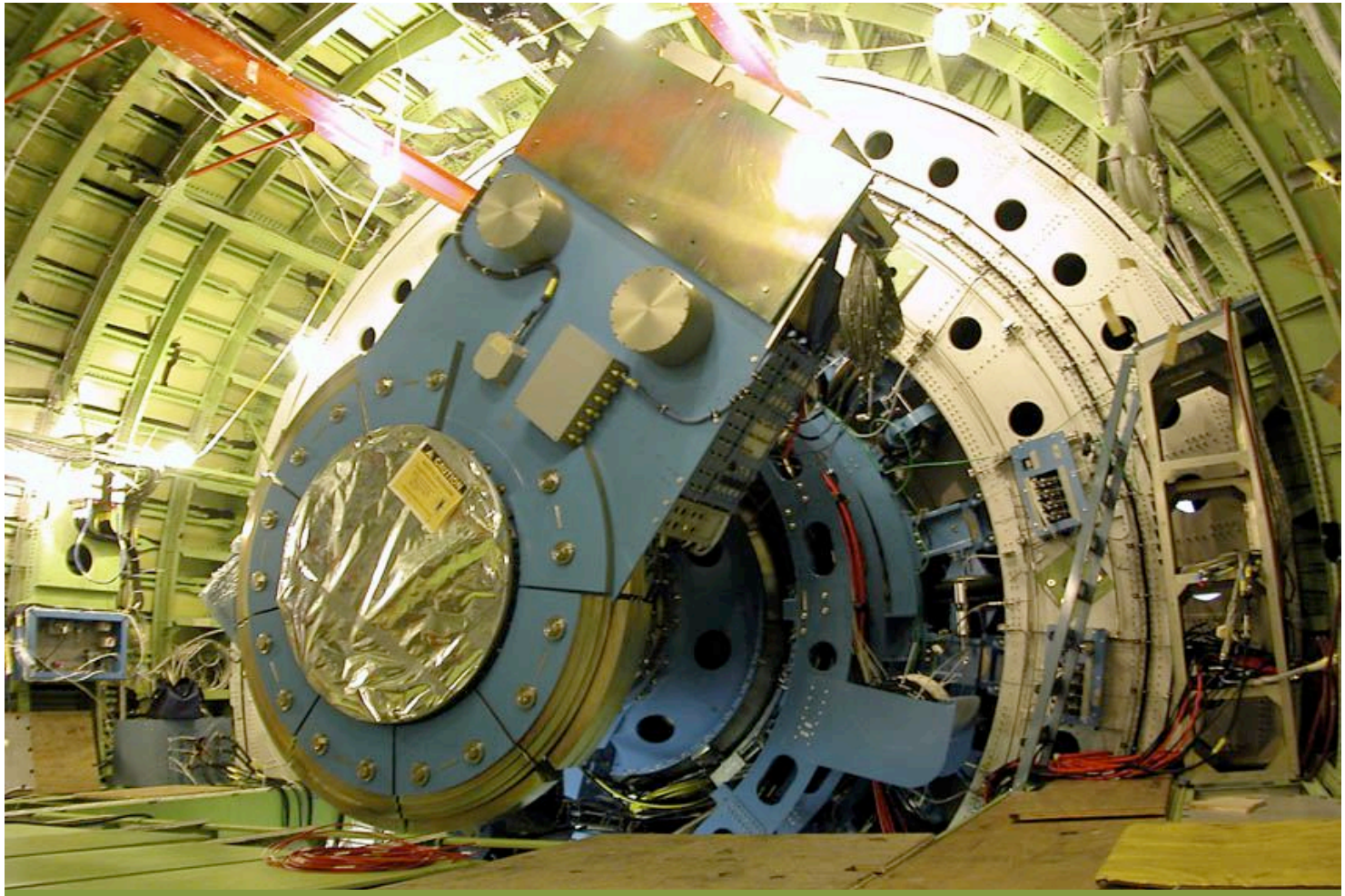

Inside the aircraft - Fall 2003

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First Light
August 2004

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Roll out from paint hangar September 2006

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First Flight

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Ferry to Dryden

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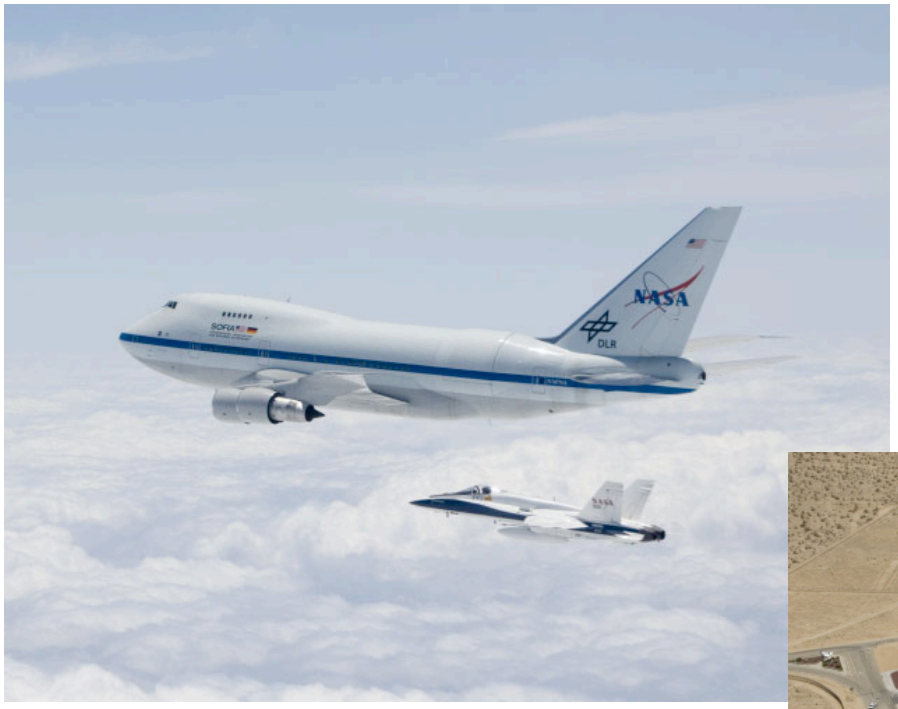

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Questions?

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