STOP Analysis for CLARREO IR Instrument Breadboard

Tory Scola

NASA Langley Research Center

08/18/2011

STOP Team

- Tory Scola (Team Lead, Thermal, CAD)
- Paul Manhart (Optics)
- Troy Mann (Structural)
- Charlie Boyer, Tim Shekoski (CAD)
- Nathan Akers (Comet Setup, CAD)
- JC Mahuet, Malcolm Panthaki (Comet Support)

Outline

- Introduction
- CLARREO IR Instrument/Breadboard
- Problem Definition
- Analysis Process and Goals
- Assumptions and Results From Each Analysis Discipline
- Structural Trade Study
- Design Summary
- Comet Statistics For This Project

Introduction

- **A Structural-Thermal-Optical (STOP) analysis was performed on a portion of the CLARREO IR Breadboard**
- **Comet software was used to link analyses**
  - *Allowed trade studies to be performed quickly*
- **Results indicate current design is acceptable**

CLARREO IR Instrument

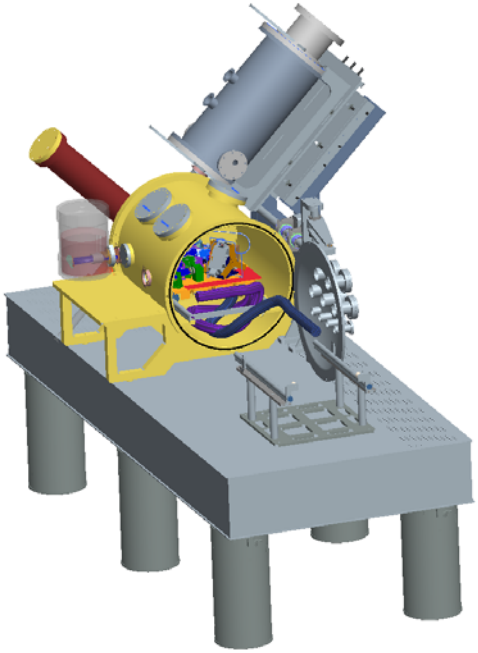
- **CLARREO is one of four Decadal Survey Tier 1 climate missions**
  - *Purpose: Make high accuracy, spectrally resolved reflected solar and emitted IR measurements of the Earth, tied to international standards*
  - *Two instruments: IR and Solar*
- **Langley responsible for design of the IR instrument**
  - *4 port Fourier Transform Spectrometer (FTS)*
  - *May require tight thermal control (< 0.1K / 15s stability)*
- **IR breadboard being built in order to:**
  - *Develop/verify radiometric requirements*
  - *Assess feasibility of thermal control system*
- **STOP analysis performed on optics in LHe Dewar before detector**

IR Breadboard

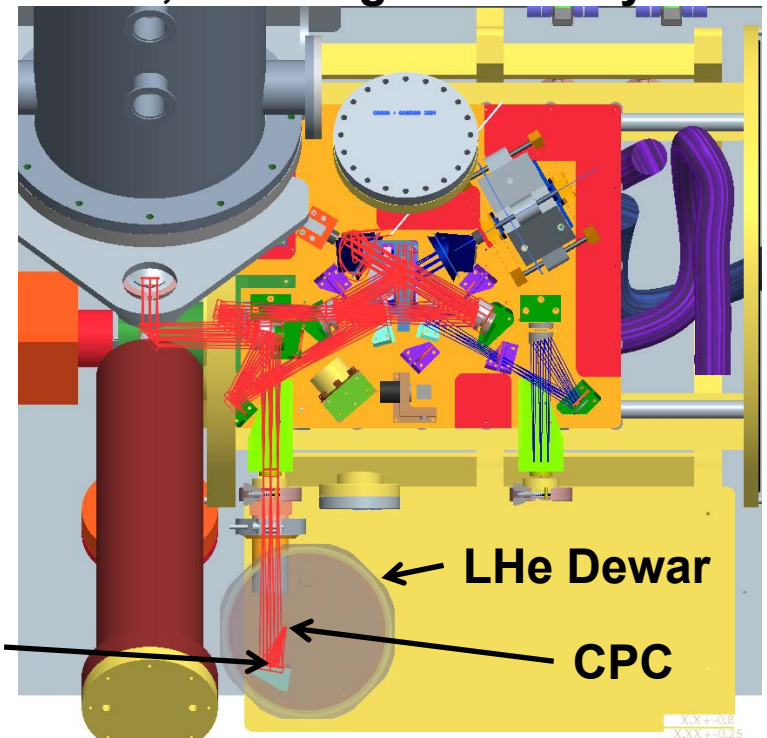
Problem Definition

- **Breadboard will utilize a silicon bolometer detector**
  - *Requires cooling to 4.2K (LHe boiling point at atmospheric pressure)*
- **LHe Dewar houses detector, spherical mirror, & Compound Parabolic Concentrator (CPC, or Winston Cone)**
- **Mirror and CPC will be assembled at room temperature**
  - *How does shrinking during cool-down to 4.2K affect optical performance?*

Breadboard System

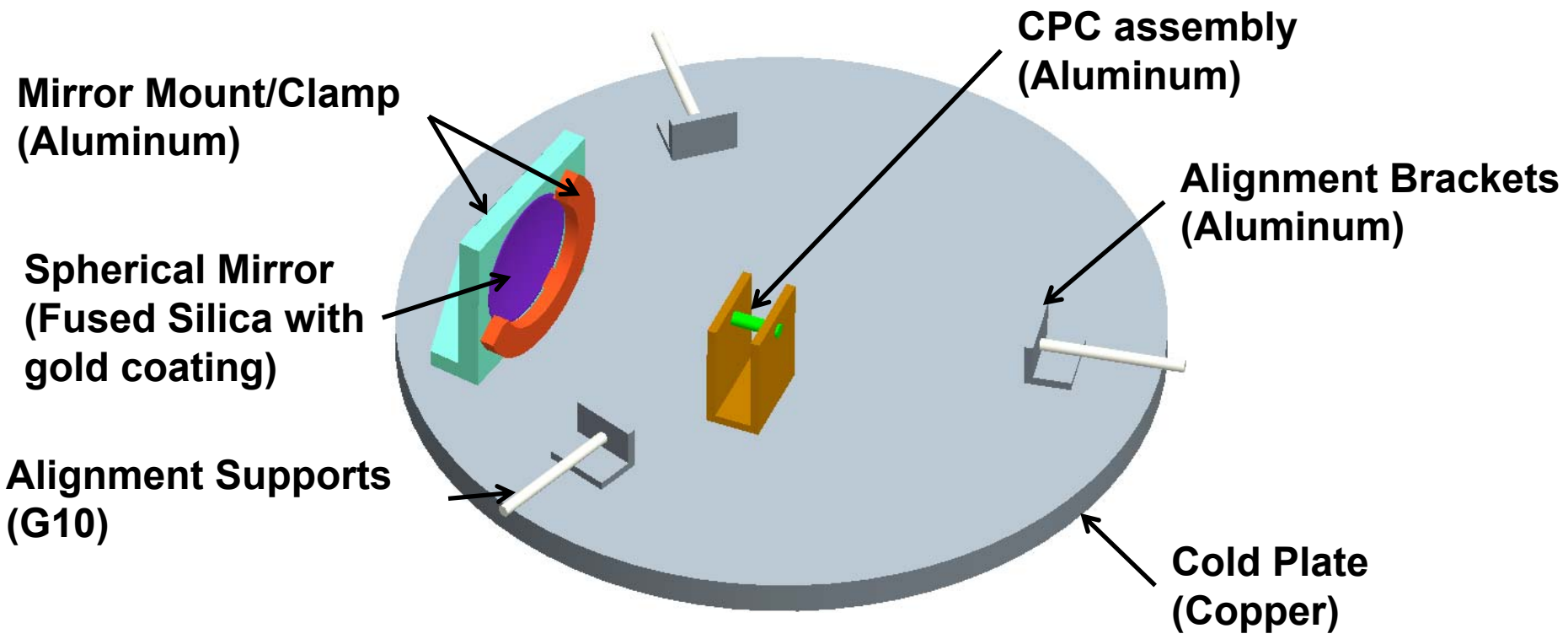


Top Down, Showing Dewar Ray Traces



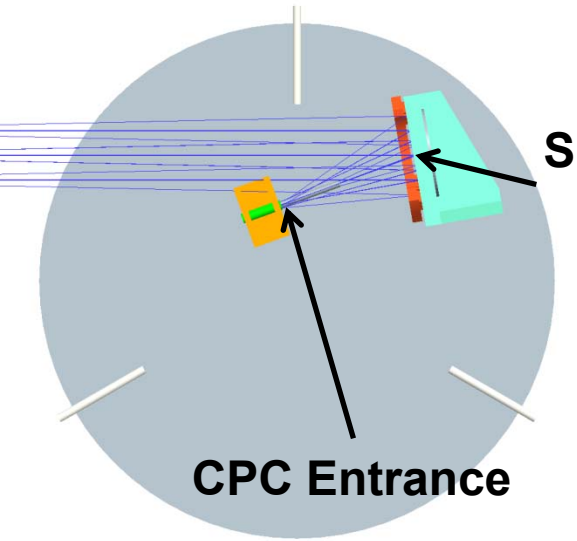
Dewar System

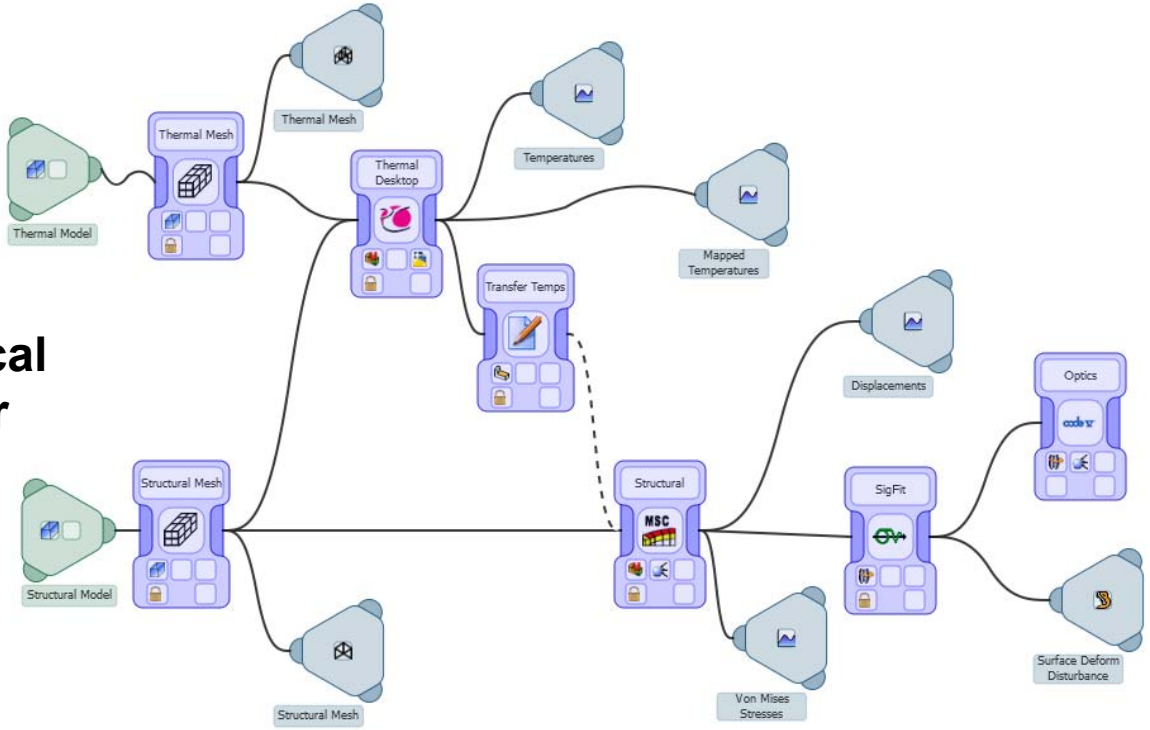
- **Mirror and CPC mounted to copper plate in dewar**
  - *Components assembled on plate at room temperature*
- **Back of copper plate in contact with LHe when dewar is filled**
- **Radiation Shield surrounds optics, filled with LN2 (77K)**



Analysis Goals and Process

- **Goals include:**
  - *How does deformation change footprint at CPC entrance*
  - *What adjustments during assembly can be made to minimize losses*
- **Comet process developed to determine effects of thermal expansion on the Dewar optical system**
  - *CAD → Mesh → Thermal → Structural → Optics*

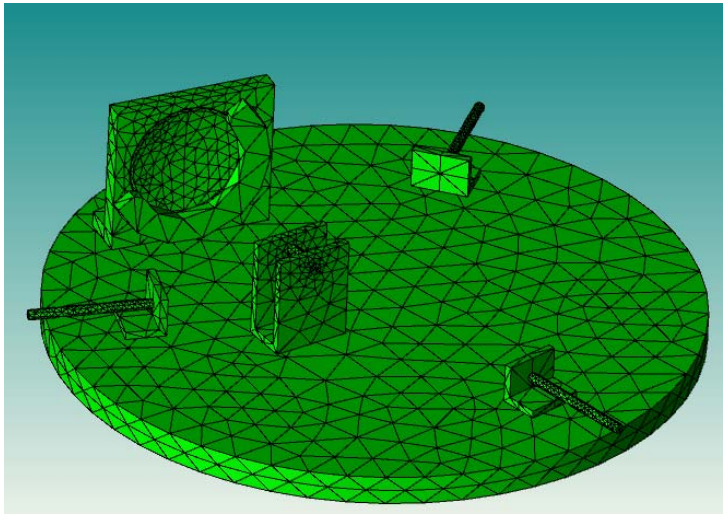




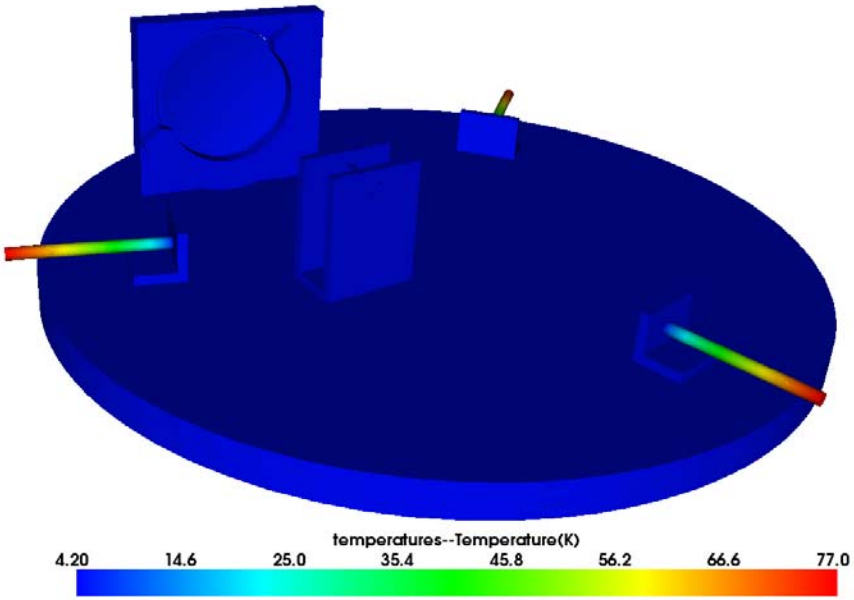
Thermal Assumptions and Results

- **TET4 mesh, unconnected**
  - *Thermal contactors used between components*
- **Back of cold plate fixed at 4.2K**
- **Ends of alignment supports fixed at 77K**
- **System radiates to 77K**
  - *Al/Copper ε=0.21, Mirror face ε=0.04, Glass Mirror/G10 ε=0.9*
- **Steady state thermal analysis**

Thermal Mesh



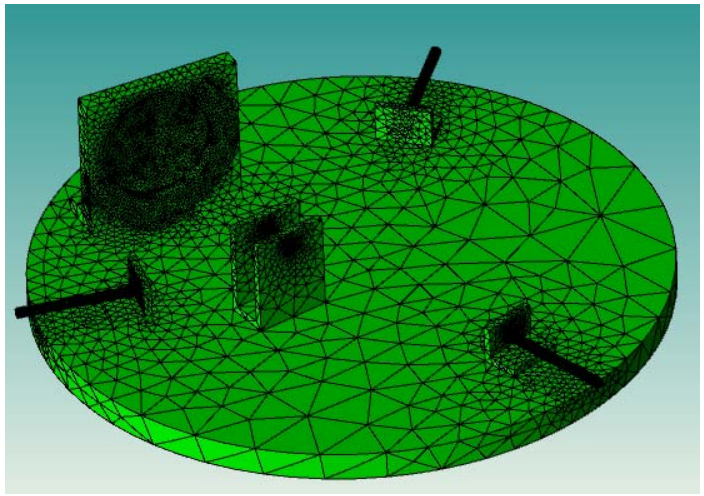
Thermal Analysis Results



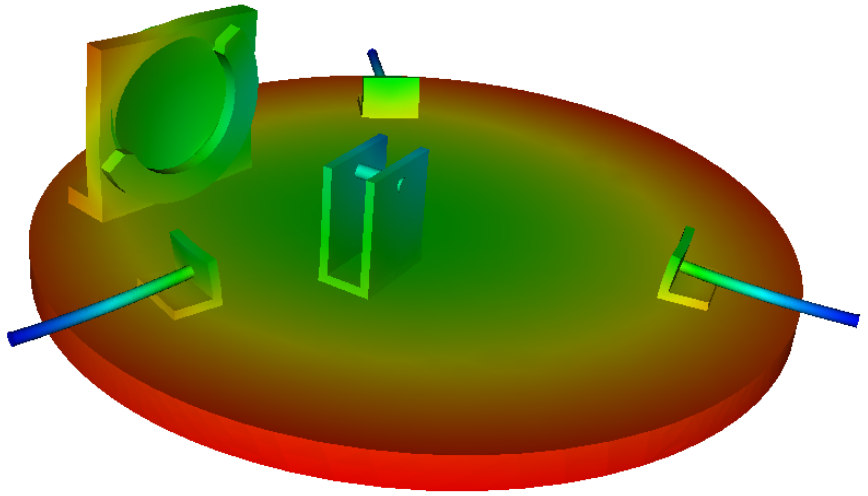
Structural Assumptions and Results

- **TET10 continuous mesh**
  - *Conservative, assumes mirror is rigidly fixed to mounting clamp*
- **Initial temperature of 20°C (293K)**
- **Final temperature: Thermal analysis results mapped to structural mesh**
- **Ends of alignment supports fixed in x,y,z**
- **Linear Static Analysis (NASTRAN Solution 101)**

Structural Mesh



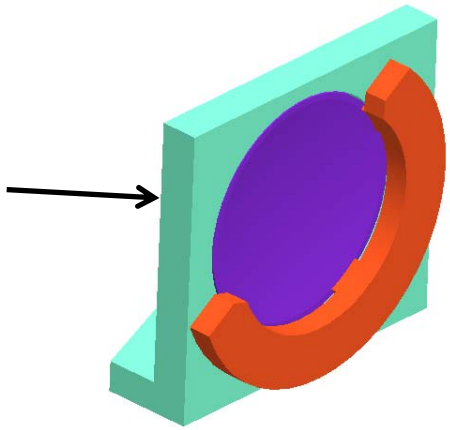
Structural Analysis Deformations



Optics Assumptions

- **Both the spherical mirror and CPC entrance included in CAD**
  - *CPC entrance is really the "image"*
  - *Fake mirror was used so that image position could be adjusted based on deformation*
- **Two types of optics input calculated from deformation results:**
  - *Translation/rotation of each optic component*
  - *Aberrations expressed in Zernike polynomials for each optic*
- **Rigid connection between clamp and spherical mirror is conservative**
  - *Aberrations likely not real, optical analysis performed with and without them*
  - *Contact analysis can be performed to remove rigid assumption*

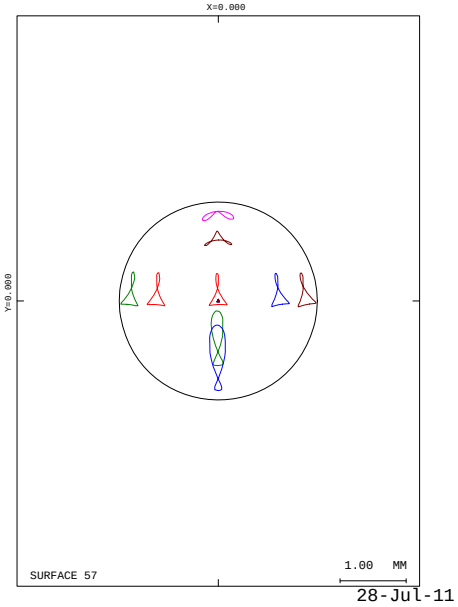
Mirror (purple) lightly pressed against clamp (orange) with a leaf spring mount on back surface



Optics Results

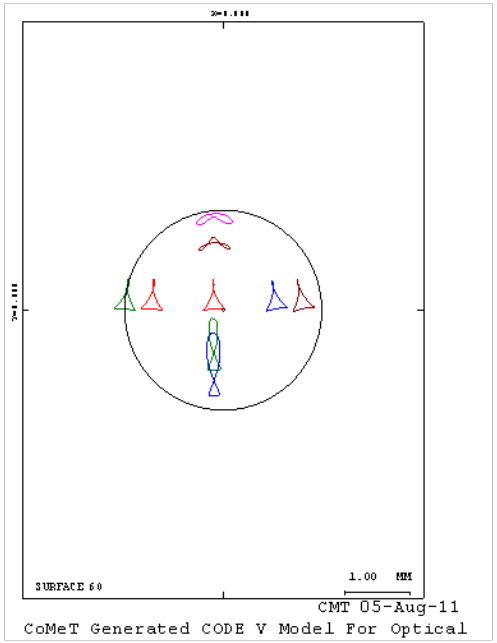
- **Image footprints show a slight shift and defocus from nominal**
  - *No aberration looses only 1.8% of light from nominal*
  - *Aberration has larger defocus*
- **Center footprint is likely more realistic than far right**
- **Shows minimal losses due to deformation**
  - *Minimal adjustment will be required for current design*

Nominal (73%)

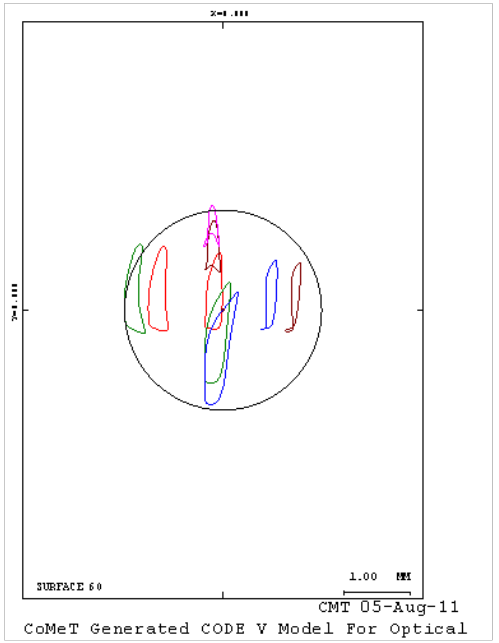


CLARREO TR FINAL DEWAR

Motion only, no aberration (71.8%)

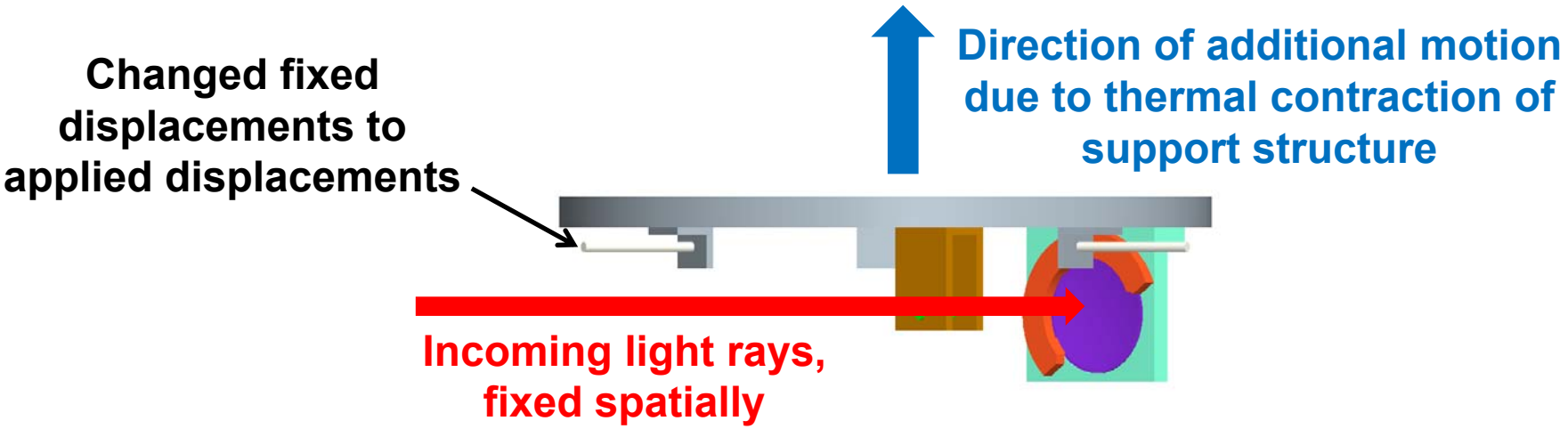


Motion and aberration



Structural Trade Studies

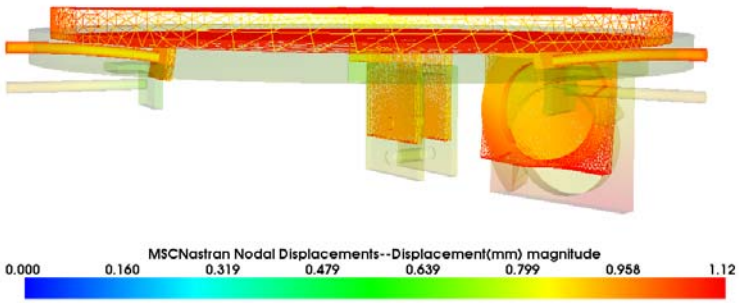
- Design of cold plate allows for motion normal to plate due to thermal contraction of support structure above
- Original analysis ignored this motion; avoided complicated geometric modeling
- Thermal expansion hand calc performed to estimate worst case deflection (Results: 0.9mm)
- Trade studies performed in Comet using applied displacements
  - *Look at 0.9mm and 1.8mm (double worst case estimate)*

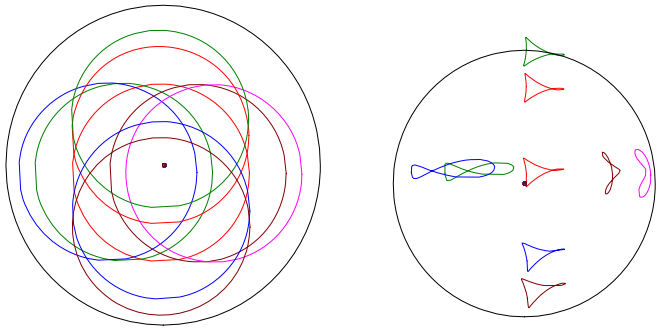


Trade Study Results

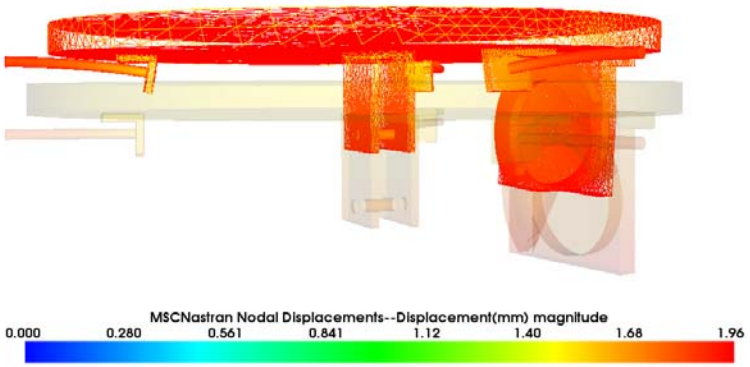
- Thermal analysis unchanged
- Structural BC's updated, and analysis rerun
- Optical analysis performed for updated displacements
- Less than 1 hour required from adjustments to optical results

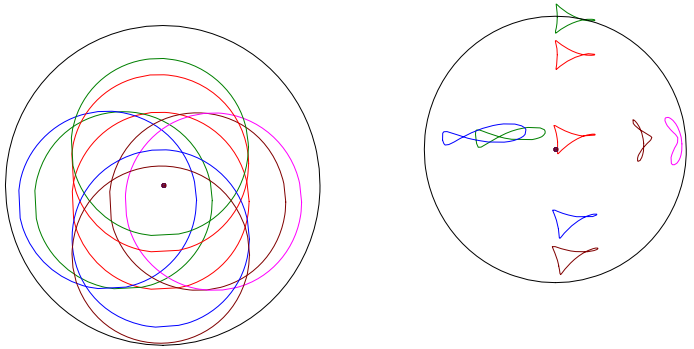
0.9mm case





1.8mm case





Design Summary

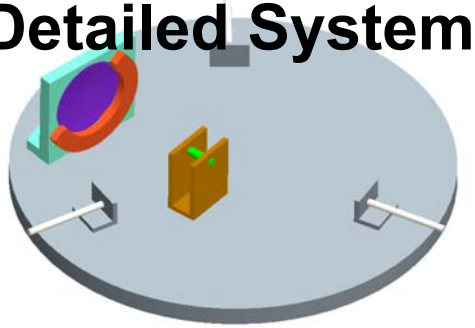
- **Design as is shows no significant changes are needed**
  - *Adjustments to mirror orientation during assembly should be minimal*
- **Forward work**
  - *Run contact analysis at lens/clamp interface and include aberrations (removes rigid interface assumption)*
  - *Would like to develop some way for correlation with this case to the assembled breadboard system*

Comet Statistics For This Project

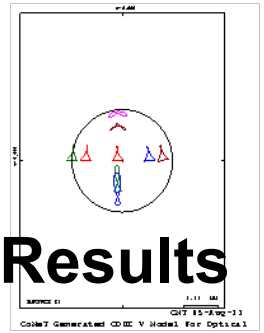
- **Analysis process set up by one engineer; run on one computer**
  - *Still requires input/review from discipline experts, doesn't eliminate this need*
- **Process and tagging take the most time to set up**
  - *< 1 week assuming dedicated team*
  - *Start out with simplified analysis assumptions to verify process*
  - *Iterate between CAD tagging and process until desired results obtained*
- **Full STOP analysis runs in ≈ 30 minutes**
- **Re-running analysis with new geometry dependent on how fast CAD and tagging can be completed**
  - *Example: Adding tie rods, adding CPC entrance geometry, updating sequence file and rerunning completed in ≈ 8 hours*

≈ 8 hours

Detailed System



Original System



Results