TPF-C Performance Modeling

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Feb 22, 2008

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Error Budget Models

Figure 3. Models used to calculate static and dynamic contrast.
**Static and Dynamic Terms**

\[
\text{Contrast} = I_s + \langle I_d \rangle \\
\text{Stability} = \sqrt{2I_s\langle I_d \rangle + \langle I_d^2 \rangle}
\]

<table>
<thead>
<tr>
<th>$I_s$ = Static Contrast</th>
<th>$I_d$ = Dynamic Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Front Sensing</td>
<td>Pointing Stability</td>
</tr>
<tr>
<td>Wave Front Control</td>
<td>Thermal and Jitter</td>
</tr>
<tr>
<td>Gravity Sag Prediction</td>
<td>Motion of optics</td>
</tr>
<tr>
<td>Print Through</td>
<td>Beam Walk</td>
</tr>
<tr>
<td>Coating Uniformity</td>
<td>Aberrations</td>
</tr>
<tr>
<td>Polarization</td>
<td>Bending of optics</td>
</tr>
<tr>
<td>Mask Transmission</td>
<td>Aberrations</td>
</tr>
<tr>
<td>Stray Light</td>
<td></td>
</tr>
<tr>
<td>Micrometeoroids</td>
<td></td>
</tr>
<tr>
<td>Contamination</td>
<td></td>
</tr>
</tbody>
</table>

Now we have

- Much better knowledge of:
  - Polarization
  - Mask Transmission
  - Stray Light
  - Micrometeoroids
  - Contamination

Now we have:

- Every item is unknown territory, new technology.
- Most are bandwidth-dependent

In 2005, we said:

- Solve with Design and Engineering, linear modeling.
- Bandwidth independent.
Aberration Sensitivity at 2 $\lambda/D$

- **COMA**
- **(3,1)**
- **BL4, VNC**
  - $4 \lambda/D$
- **PIAA, 4 $\lambda/D$**
- **PIAA, 2 $\lambda/D$**
- **Shaped Pupil, 4 $\lambda/D$**
- **Earth requirement (picometer)**
- **Jupiter requirement (Angstroms)**
- **BL8, 4 $\lambda/D$**

Increase sensitivity to aberration by > 2 orders of magnitude over 4 $\lambda/D$ design.
Executive Summary: Thermal Performance Models and Analysis

- Evaluated Thermal Tools:
  - TSS/SindaG, TMG, IMOS
- Thermal Model & Run Information is provided
- Performance evaluation: Dither angle from 195° to 225° is worst case
- Evaluated Temperature Control Heater Powers

- Conclusions:
  - Even with worst case conditions, appear to be meeting requirements from Error Budget

February 22, 2008
Blue = requirement due to finite star size

Black = requirement due to propagation effects

Green = requirement due to propagation effects

Fill = easier than state of the art
Executive Summary: Structural Performance Models and Analysis

- Currently, WFE’s & Rigid Body motions of optics are within the error budget
  - for thermal disturbance
- Toolsets work well so far, and are getting better
  - Looking forward to significant capability increase shortly
  - Lessons-learned: problems encountered & solved (or worked-around)
- We need to account for CTE variation in PM
  - Taking CTE variation into account generally results in higher WFEs than assuming uniform CTE
  - Initial calculations in work
- Primary Mirror front-to-back delta-temperature drives distortion
  - Focus & Astigmatism are biggest contributors to WFE
- Design feasibility looks good: no major road-blocks
  - Keep in mind the many idealizations made so far: more detail modeling to follow

February 22, 2008
Table 1. TPF-Coronagraph Contrast Error Budget Requirements.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Requirement</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Contrast</td>
<td>6.00E-11</td>
<td>Coherent Terms</td>
</tr>
<tr>
<td>Contrast Stability</td>
<td>2.00E-11</td>
<td>Thermal + Jitter</td>
</tr>
<tr>
<td>Instrument Stray Light</td>
<td>1.50E-11</td>
<td>Incoherent light</td>
</tr>
<tr>
<td>Inner Working Angle</td>
<td>4 ( \lambda/D_{\text{long}} )</td>
<td>57 mas at ( \lambda=550 \text{ nm} ), ( D_{\text{long}} = 8 \text{ m} )</td>
</tr>
<tr>
<td>Outer Working Angle</td>
<td>48 ( \lambda/D_{\text{short}} )</td>
<td>1.5 arcsec at ( \lambda=550 \text{ nm} ), ( D_{\text{short}} = 3.5 \text{ m} )</td>
</tr>
<tr>
<td>Bandpass</td>
<td>500-800 nm</td>
<td>Separate observ. in three 100 nm bands.</td>
</tr>
</tbody>
</table>
HCIT Demonstration of Planet Detection in Broadband Light

**The test:** Using a band-limited mask, form a dark hole using the Electric Field Conjugation algorithm. Then reset the DM to nominally flat, wait 8 days, and repeat.

**Parameters:**

- 3 filters, each band 2% wide
- Centered on 800, 816, and 832 nm.

- D-shaped dark hole:
  - IWA = 4 \( \lambda / D \)
  - OWA = 10 \( \lambda / D \)

- Add in simulated planet in second data set.
- Peak contrast = 1e-9

- Sum together the bands to form composite 6% bandwidth images.
Figure 1. Error Budget Structure. ‘C-matrix’ is a sensitivity matrix or equation. 
R1-R7 are multiplicative reserve factors.
Beam Walk Model

Contrast from Beam Walk

\[
C_{BW} = \left( \frac{D_x}{\delta_x} \right)^2 \square C_{psd}
\]

\[
D_x \quad C_{psd}
\]

Sensitivity/MACOS \quad PSD Function

Optical Motion Allocation rms

Figure 4. Beam walk calculation. \( C_{psd} \) is the contrast for a unit value of beam walk, \( \delta_x \) at a spatial frequency (image plane position) of \( k_x \). \( D_x \) is the beam walk calculated from linear sensitivity matrices applied to allocated translation and tilt motions.
Control Systems

• 3-tiered pointing control
  – Rigid body pointing using reaction wheels or Disturbance-Free Payload
  – Secondary mirror tip/tilt (~ 1 Hz)
  – Fine-guiding mirror (several Hz)

• PM-SM Laser Metrology and Hexapod
  – Measures and compensates for thermal motion of secondary relative to primary.
Figure 2. Pointing control. The CEB assumes a nested pointing control system. Reaction wheels and/or a Disturbance Reduction System control rigid body motions to 4 mas (1 sigma). The telescope secondary mirror tips and tilts to compensate the 4 mas motion but has a residual due to bandwidth limitation of 0.4 mas. A fine guiding mirror in the SSS likewise compensates for the 0.4 mas motion leaving 0.04 mas uncompensated.
Key Dynamics Requirements

Figure 5. We identify the major engineering requirements to meet the dynamic error budget. Thermally induced translations lead to beam walk that is partially compensated by the secondary mirror. Jitter is partially compensated by the fine guiding mirror.
Iterative Design/Analysis Cycle Process

Cycle "n"

Design Freeze
- Systems Eng'rg
- Baseline Design
- CAD model

4/1/05

Design Evolution
- Alternate Concepts
- Trade Study Results

5/6/05

Analysis Plan
- Results Goals
- Case Priorities

Changing Conditions
- Emerging Requirements
- Reprioritized Goals
- New Constraints

10/07/05

Design Refinement Decisions
- Updated Baseline Design
- Updated Req's for Cycle n+1
- Consolidated Alternate Design(s)

5/6/05

Model Creation
- Optical
- Structural FEMs
- Thermal
- Dynamics

7/12/05

Integrated Analyses
- Nominal Design & Conditions

Sensitivity Analyses & Design Perturbations

7/12/05

Prelim Analysis Results
- Review
- Plan Assessment

Cycle "n + 1"

Legend

Start
Done

Modeling path

Cycle 1 Target Dates