



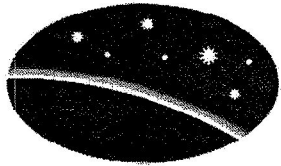
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# **Large Stroke, Picometer Resolution Hexapod for Dynamic Mirror Positioning**

Dr. Carl Blaurock  
Nightsky Systems, Inc.

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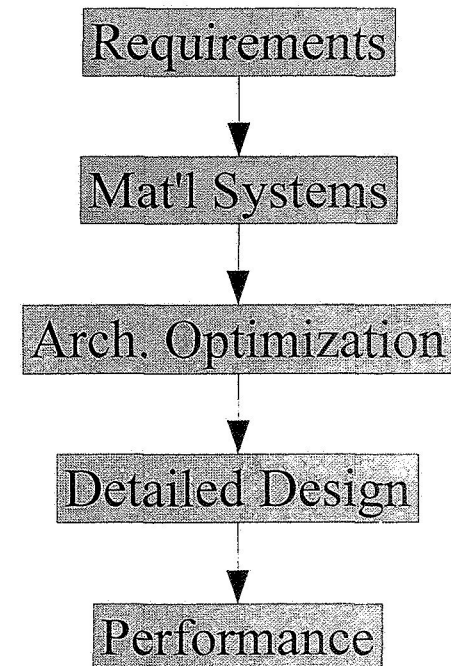
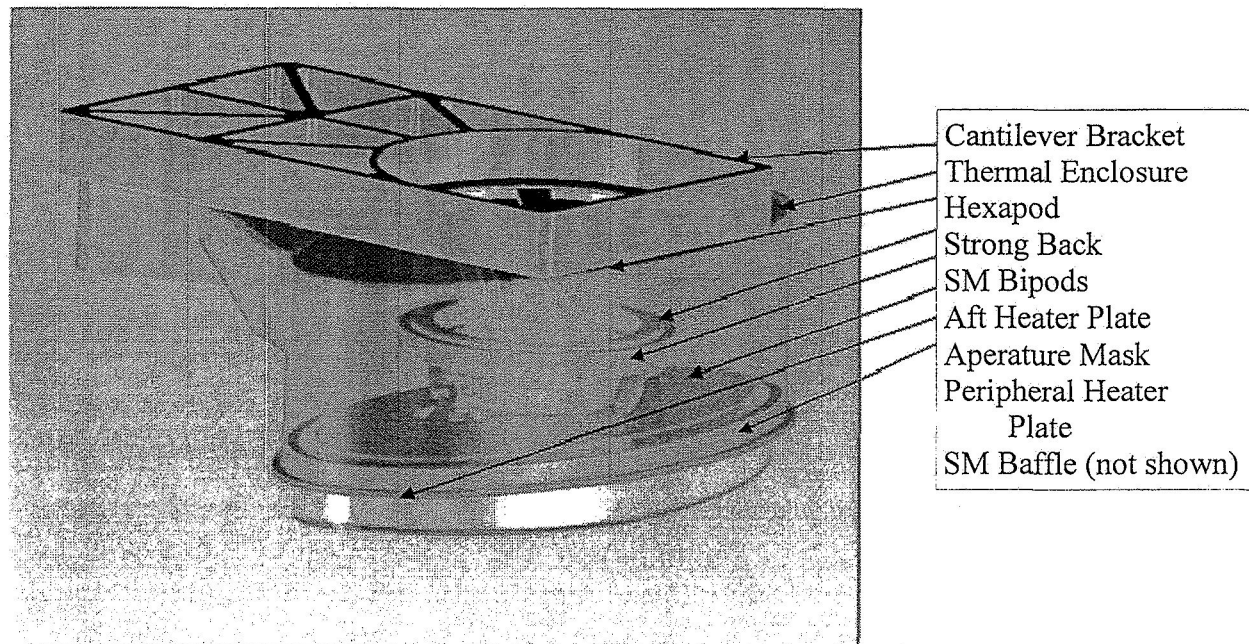
# Fast Picometer Mirror Mount

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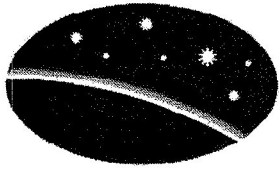
- ▶ SBIR program through GSFC
  - COTR: Raymond Ohl

Team members: Dr. John Rodgers, Alex Makarenko, Marco Serra

- ▶ Objective
  - Design (Phase I) and experimentally demonstrate (Phase II) a Secondary Mirror (SM) mount to enable Terrestrial Planet Finder Coronagraph (TPF-C)



Flight Baseline-1 SM Assembly (GSFC)



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# TPF-C Overview

Detect and characterize Earth-like planets

coronagraphic mask to suppress starlight to  $1e-11$

12-meter deployable secondary tower

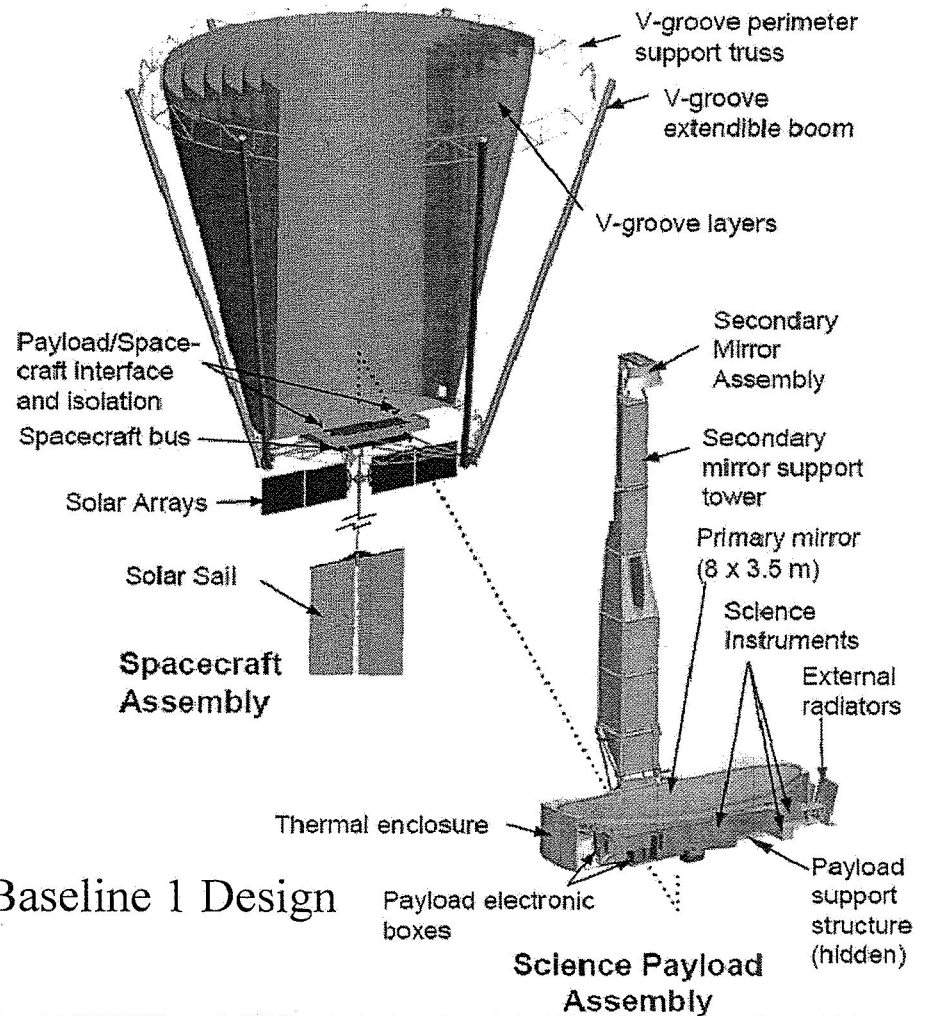
8-meter monolithic elliptical primary

SM/PM laser truss to 5-DOF hexapod SM mount

sunshield to maintain (room) temperature to milli-Kelvin stability

L2 orbit

## FB1 Observatory Design



TPF-C Flight Baseline 1 Design (courtesy JPL)



# FPMM Requirements

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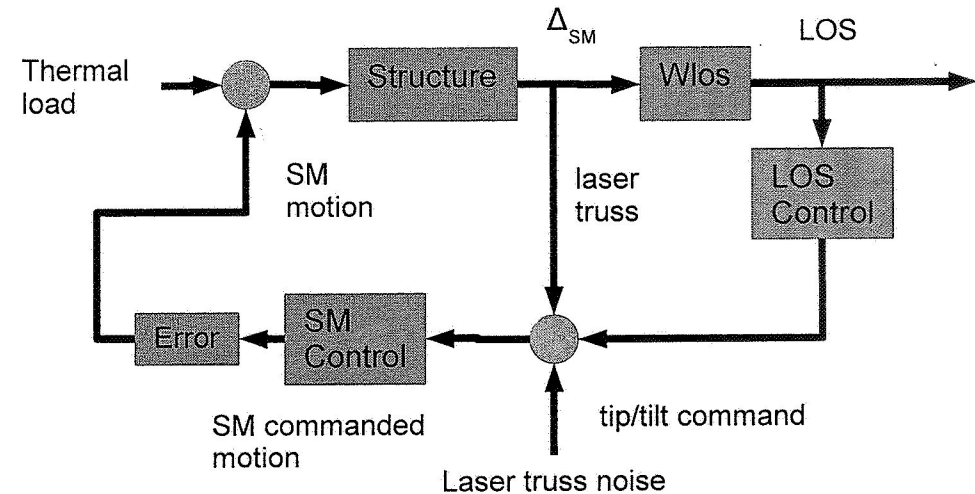
## ▶ TPF-C requirements defined in Contrast Error Budget (CEB)

- static contrast
- contrast stability (thermal and jitter)
- stray light

## ▶ SM and FGM controlled to reduce contrast

## ▶ Actuator error requirement set to contribute no more than 1/100<sup>th</sup> of total contrast

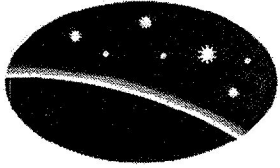
Shaklin et al, "The Terrestrial Planet Finder Coronagraph Dynamics Error Budget", SPIE 5905-13, Aug 2005.



### Summary of SMM requirements

- 65 kg load (mirror and thermal control system)
- coarse stroke > 1 inch at 0.3 mm/sec
- fine move of +/-500 nm up to 1 Hz, with 0.2 nm resolution
- first mode > 100 Hz
- footprint within 0.9 by 0.4 meter SM

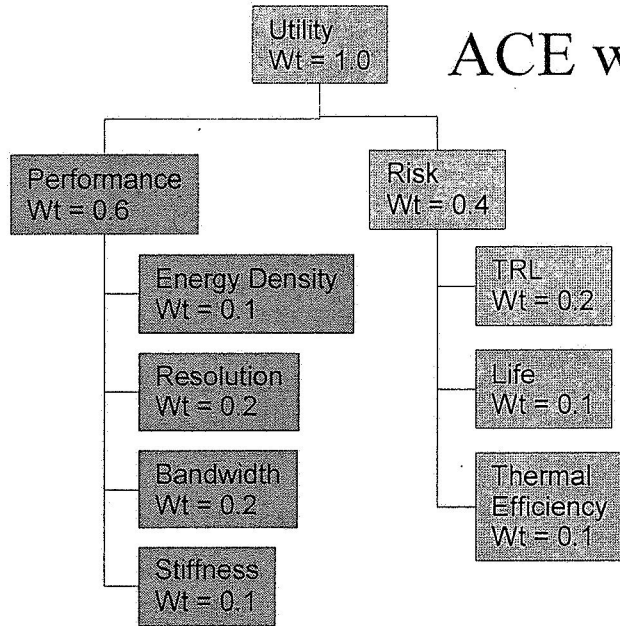
Two-stage design to achieve dynamic range



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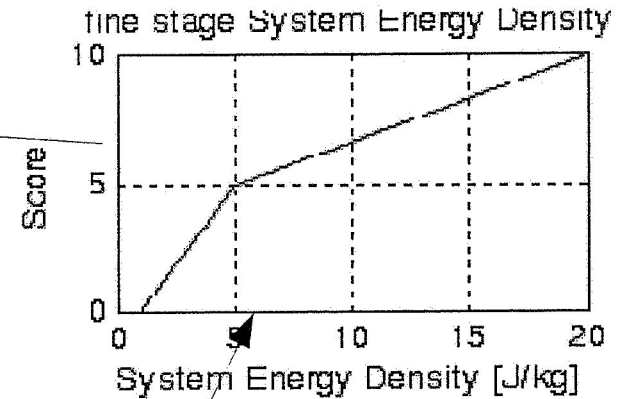
# Material System: ACE

## ACE weighting tree



## Bilinear Utility Curve

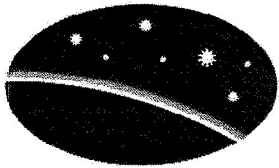
Score  
(0-10)



## Alternative Configuration Evaluator (Bell Helicopter Textron)

- Attributes
- Scores (bilinear utility curve)
- Weights
- Scores
- Sensitivities

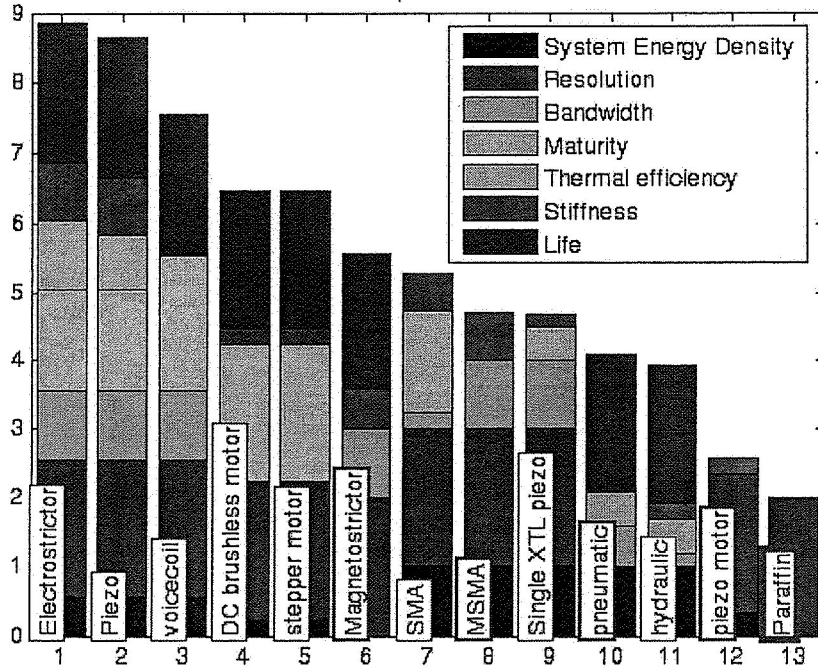
Technology	System energy density J/kg	Resolution	Band-width Hz	Maturity - TRL	Actuator Thermal Efficiency %	Stiffness Gpa	Life Cycles
Piezoceramic	6.3	0.0100%	100000	8	95%	70	1.00E+009
Electrostrictor	0.8	0.0100%	100000	8	99%	70	1.00E+009
Magnetostrictor	0.8	0.0100%	10000	5	50%	30	1.00E+009
Single Crystal Piezo	47.5	0.0100%	100000	4	90%	8	1.00E+006
Shape Memory Alloy	850.0	0.0100%	5	8	10%	30	1.00E+004
Magnetic Shape Mem.	33.6	0.0100%	100	4	50%	50	1.00E+004
Paraffin/phase change	0.5	0.0100%	0.01	6	10%	1	1.00E+007
Voicecoil	6.3	0.0100%	1000	9	10%	1	1.00E+012
Hydraulic	869.6	1.0000%	4	4	90%	10	1.00E+009
Pneumatic	153.8	1.0000%	20	4	90%	1	1.00E+009



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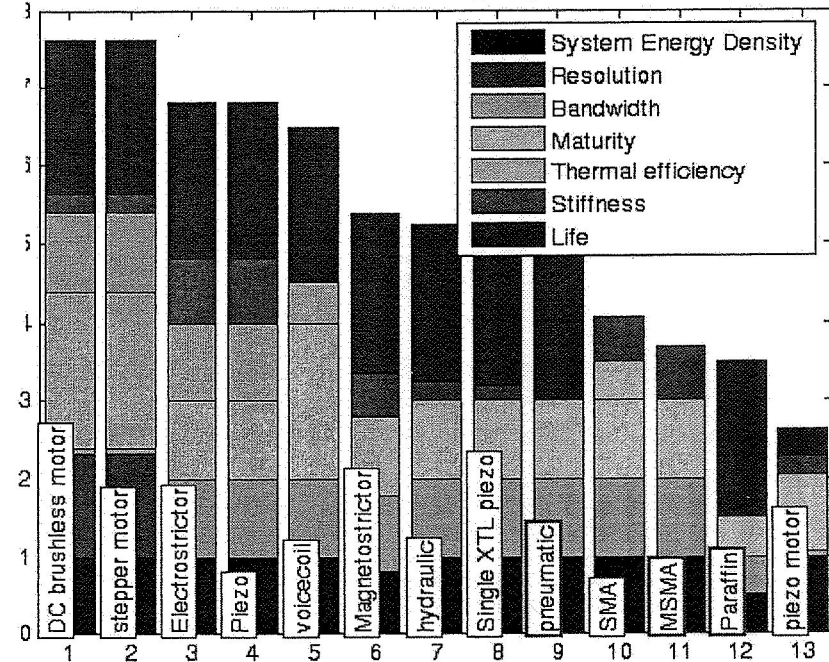
# Material System: ACE Scores

Fine 50/50 performance/risk

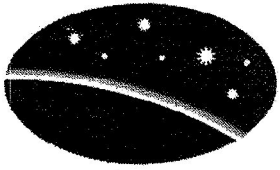


Fine stage: electrostrictor, piezo, or voice coil  
 Coarse stage: geared lead screw, piezo stepper motor

Coarse baseline weighting 50/50



Rankings for performance weighted (60/40) and risk weighted (40/60) gave the same selection



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# Architecture Optimization

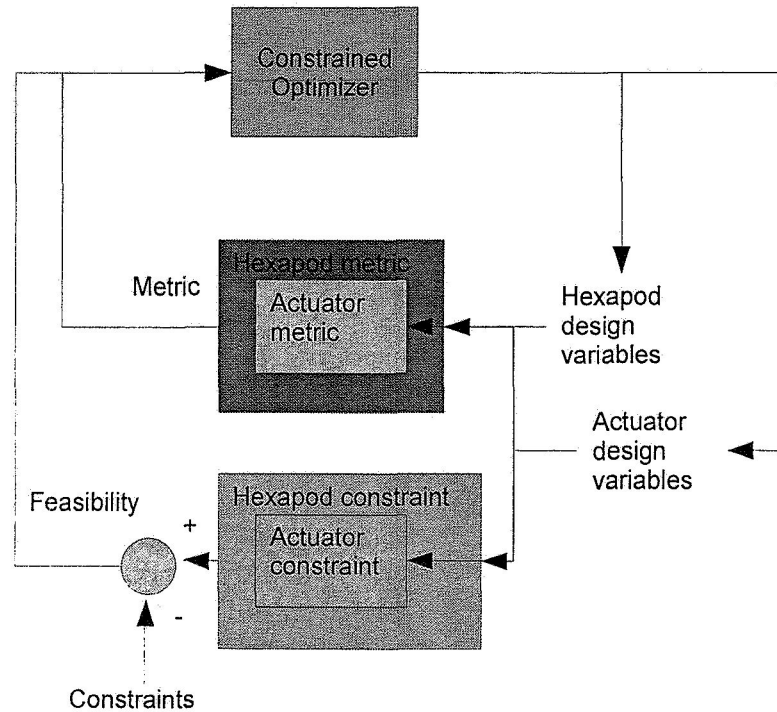
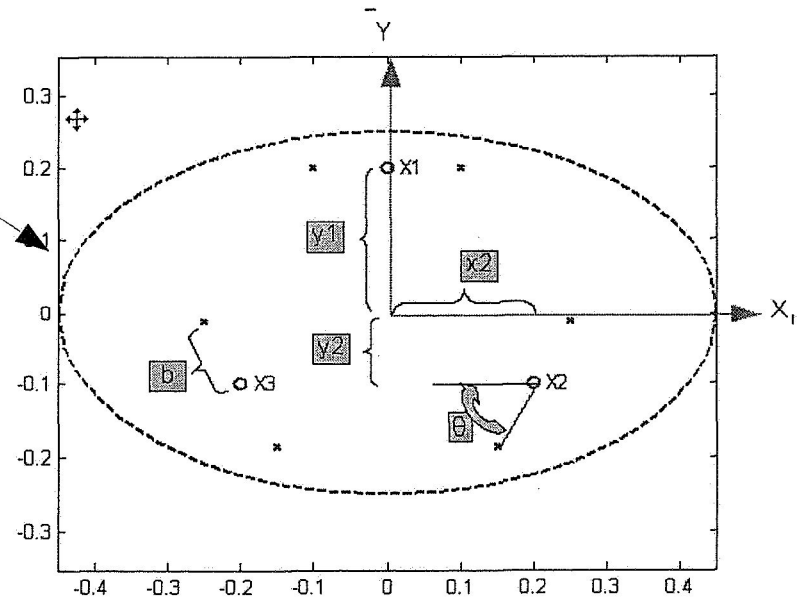
$$\min_x F(x) \text{ subject to } C(x) < 0$$

Objective  $F(x)$ :  
hexapod mass

Parameters  $x$ :

- hexapod geometry
- fine design
- coarse design

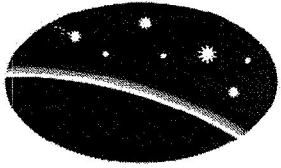
Analyzed series-leg and stacked-hexapod configurations



Constraints  $C(x)$ :

- leg length
- coarse stroke, resolution, velocity
- fine stroke, resolution
- first mode
- envelope

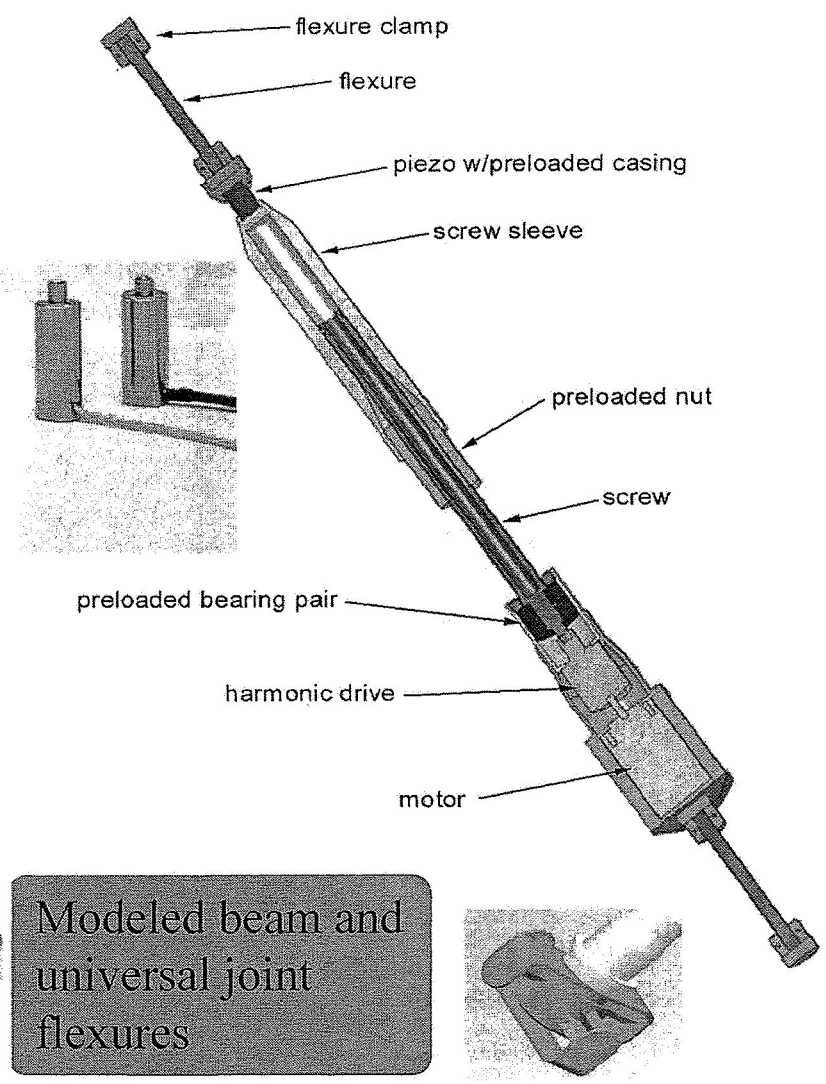
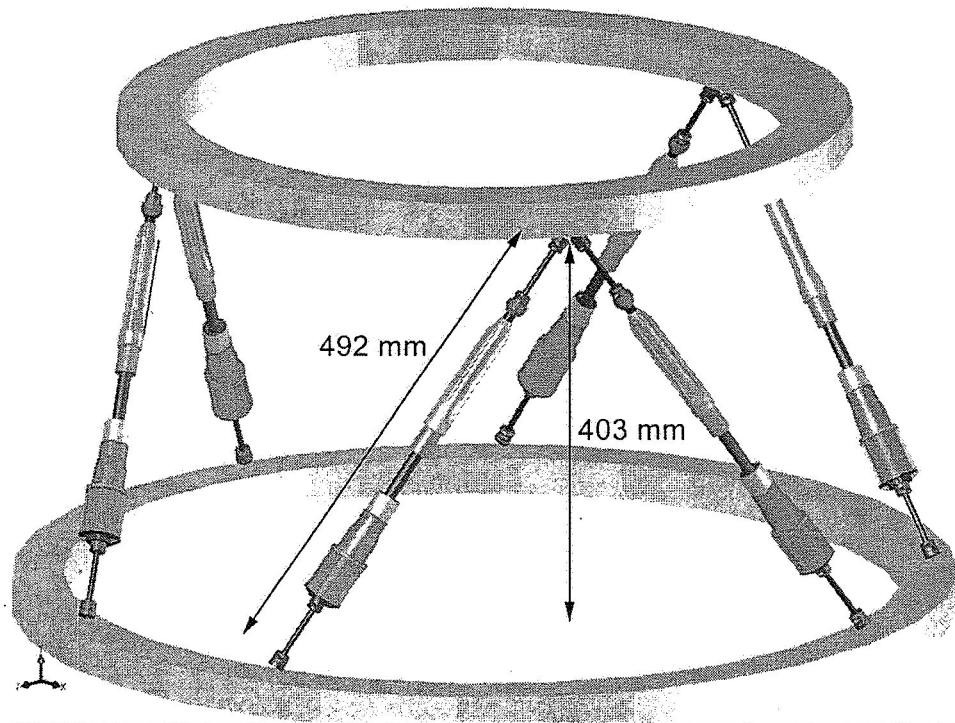




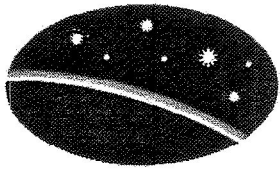
# Detailed design

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**Design Summary**  
EMI VX-U11 stepper motor  
Harmonic Drive, LLC 5-1U 100:1 gearbox  
Rollvis RVR 12x2 screw  
Piezomechanik PST150/5/7 piezo actuator

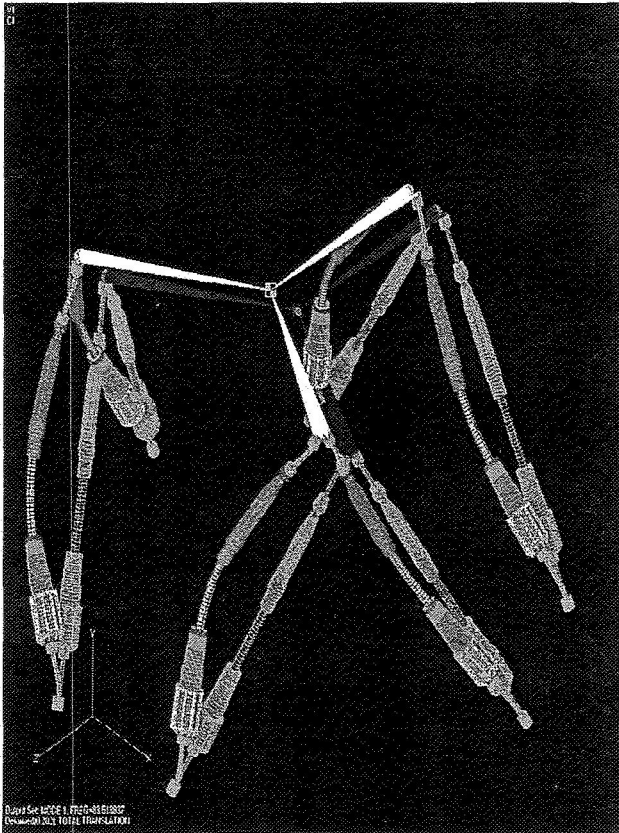


Modeled beam and universal joint flexures

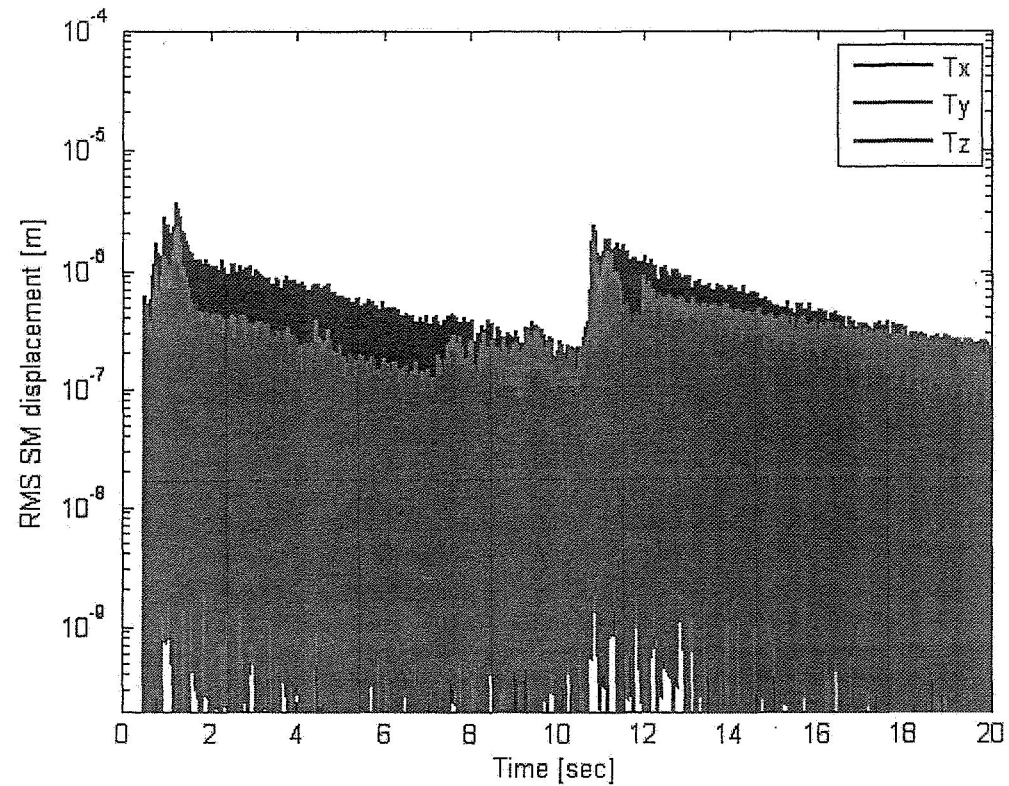


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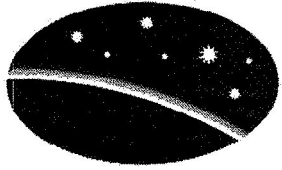
# Detailed Design Performance



Beam flexure design achieves 86 Hz first mode



Jitter during an 11 second, 3.5mm move (1  $\mu$ m settling time 12.7 sec, goal is 12 sec)



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# Conclusions

- ▶ **Developed requirements for SM hexapod actuator to meet TPF-C requirements**
    - 35 mm stroke, 0.2 nm resolution
  - ▶ **Downselected most promising material system candidates using ACE**
  - ▶ **Generated parametrized designs using each of the candidate material systems, and numerically optimized each one for minimum mass, with ACE selection of optimum design**
  - ▶ **Developed a design that meets all requirements except first mode frequency**
  - ▶ **Well-positioned for Phase II experimental demonstration**
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