“The Laser Microengineering Experimental Station” at the Jefferson Laboratory Free Electron Laser Facility

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LPC 2004

Project Goals

- **Establish a working facility that will enable user-friendly application of the unique FEL properties for investigations in laser microengineering science and laser material processing technology development.**
- **Effort delineated into two segments.**
  - Build
    - an engineering model and process development station at The Aerospace Corporation - called Aerospace-Engineering Model (A-EM)
    - a working model at the Jefferson FEL - called JLAB-working Model (JLAB-WM)
  - Operate
    - transition newly developed laser processes and techniques,
    - conducting fundamental investigations in laser material interaction phenomenon,
    - assisting/guiding new users.

Examples of laser microengineering possible

- Multi-color direct-write microfabrication
- Volumetric exposure, multi-photon exposure processing
- Percussion machining, ablative machining
- Polishing
- Chemical vapor deposition (with special cell)
- Crystallization
- Micro-fusing
- Surface texturing
- Investigations: Laser material interaction phenomena
- Mass & optical spectroscopy of desorption and ablation
- Mass removal rate measurement
- Pump-probe physics
- Multiple pulse - rep-pulse physics
- Small Scale Pulsed Laser Deposition (PLD)

System Attributes

- A laser beam delivery system for processing in the UV and IR.
- Automated sequencing of tool changes (e.g. color, objective).
- User selects from three focusing objectives.
- A coordinated three-axis motion system, XY motion range of 100mm.
- An optical table with integrated vibration isolation capability.
- An automated means for laser power and repetition rate control.
- A vision system for process control.
- A means for the User to measure the laser spot size & intensity distribution.
- CAD software for solid modeling of patterns.
- CAM software for generating 3 axes tool-path.
- Software for visual verification of the tool-path geometry.
- Software for converting the tool-path geometry into motion language.
- A generic scheme for mounting user supplied sample holders.
- An enclosure that can be interlocked with JLAB FEL safety systems.
- Additional laser beam delivery lines & stations for other experiments.

Designing for Vibration Control

Motion System is the Primary
"Vibration" Noise Source

Approach

Apply a Multi-tiered Solution to Vibration Control
Apply FEM Methods to Articulate Geometries that Enhance Stiffness

Recommended by Aerotech to use solid granite table and solid granite “bridge/superstructure” for z-drive mounting

- All tapped-hole locations pre-specified

- Very heavy

- Claimed granite was ideal for *stiffness*

- Granite has same specific stiffness as steel

- Geometry has strong affect on stiffness

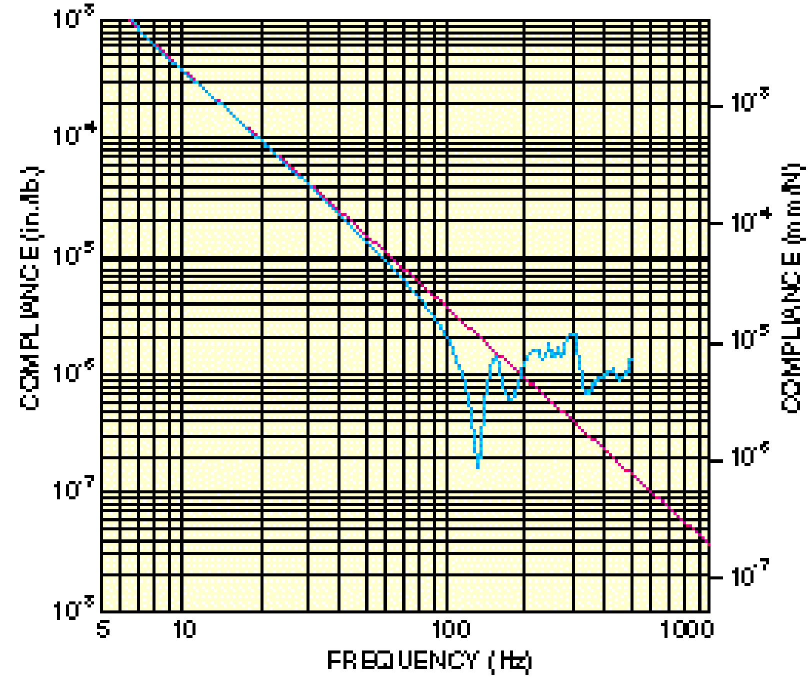
Weight 12,000 lbs

Newport RS 4000 Tables

Maximum Amplification at a Resonance (Q)

Steel Honeycomb Core:
$Q = 1.1\text{x}10^{-5}/3\text{x}10^{-6} \sim 4$

Granite Block:
$Q = 2.3\text{x}10^{-4}/5\text{x}10^{-7} = 460$



Worst Case Relative Motion Value (RM)

$$RM = 2g(1/32\pi^3)^{1/2}\,(Q/f^3)^{1/2}\,(PSD)^{1/2}\,T$$

For Q =1, f=160 Hz, PSD* = 10^{-5} g^2/Hz, T = 0.01

RM = 10nm

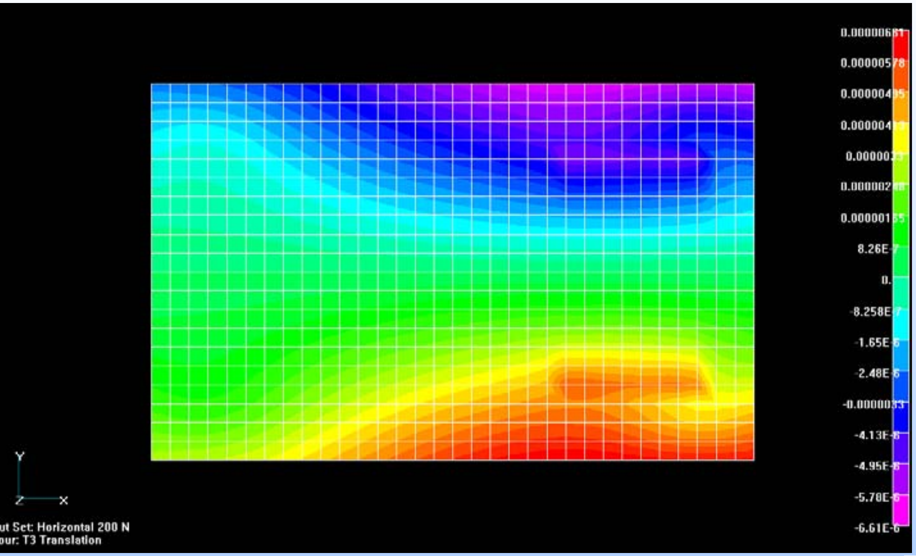
* PSD value is 10^4 times the PSD vibration found in a light manufacturing factory

Static Deflection (SD)

$SD = (PL^3/24EbTH^2) + (PL/4GHb)$

For P = 1000 lbs, L=52”, b=60” and H =12”, T=0.1875”, E =29x10^6 psi, G = 2.25x10^5 psi

SD ~ 3.2x 10^{-4} ” (8 µm)



FEM of table top: Static deflections

Vertical deflection due to horizontal load	
Applied Force	**Deflection**
100 N	0.084 microns
200 N	0.17 microns
1100 N	0.92 microns

Isolation System Design

Multi-tiered Approach

1. Pneumatic isolation (a)
2. + Elastomeric isolation (b)
3. + Magnetic-active isolation (c)

Working isolation system with enhanced rigidity

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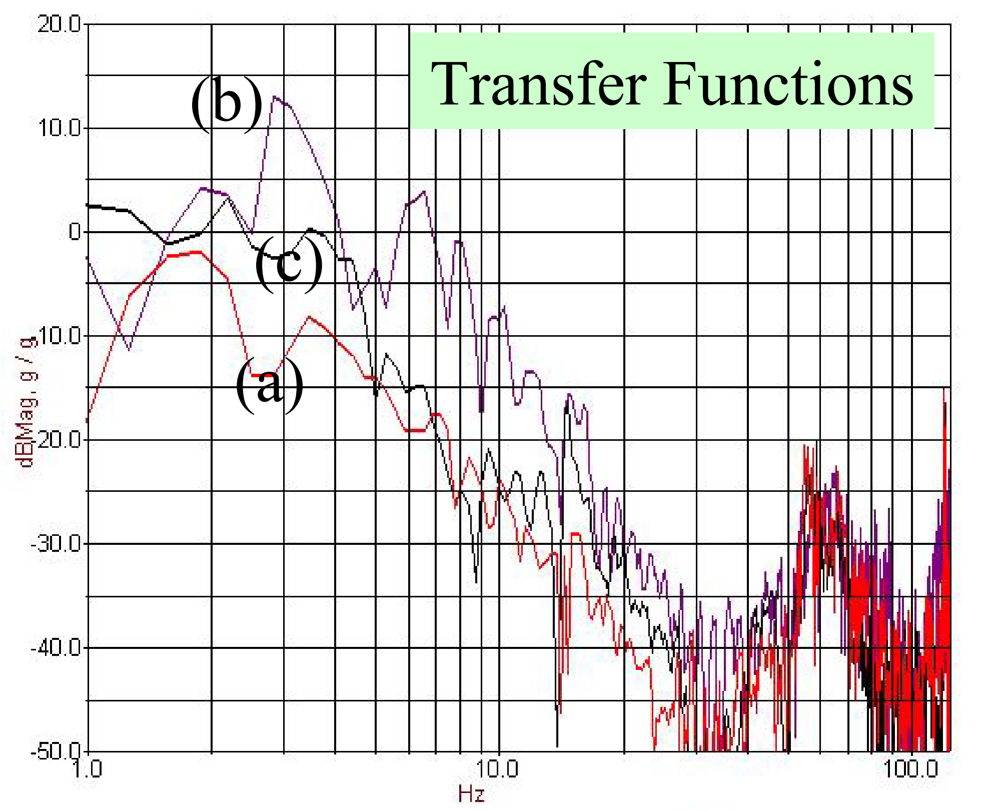
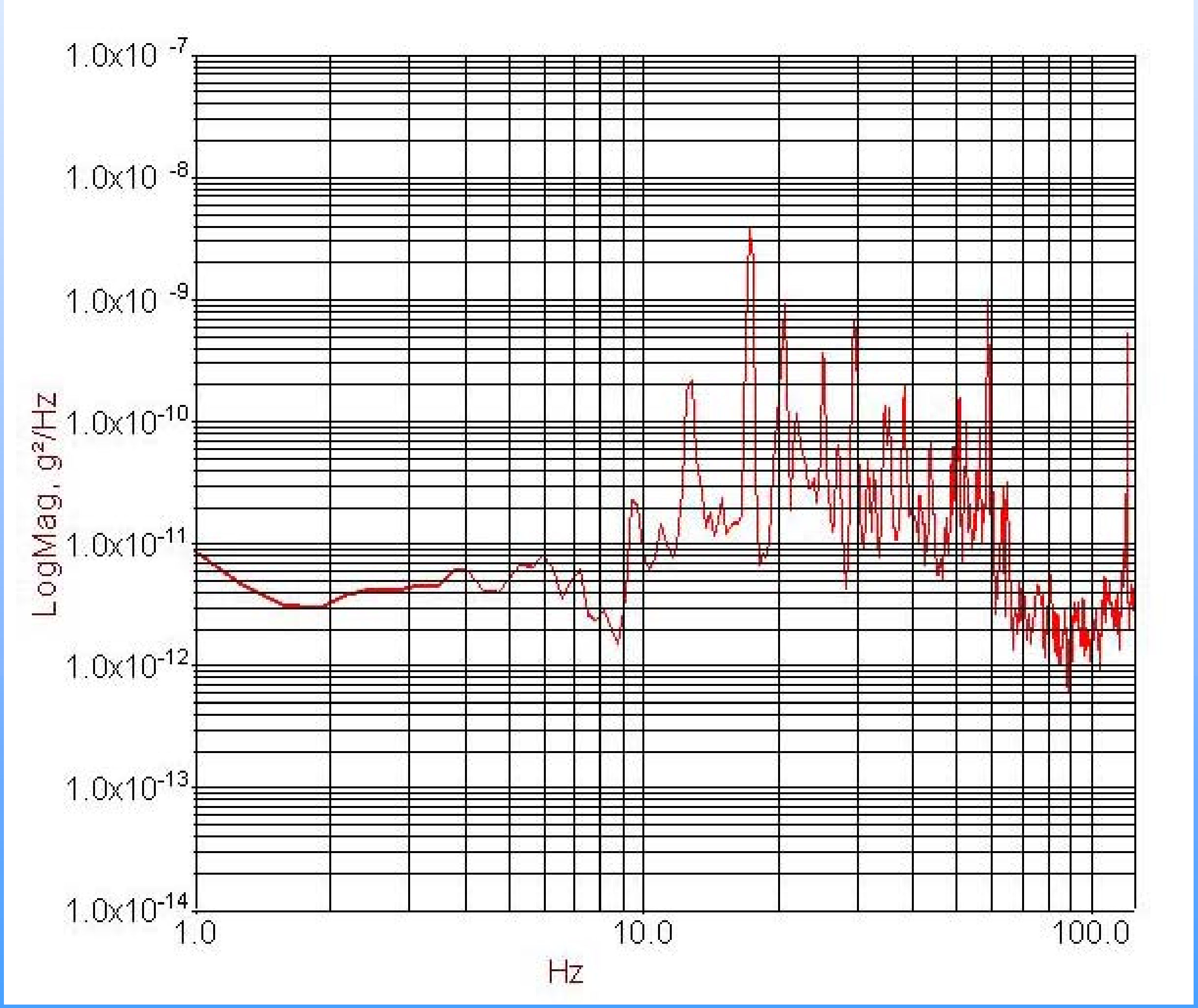


Measure Aerospace Lab Floor Noise for baseline

Power Spectral Density Values

10^{-9} considered a Quite Laboratory

10^{-8} Light Manufacturing



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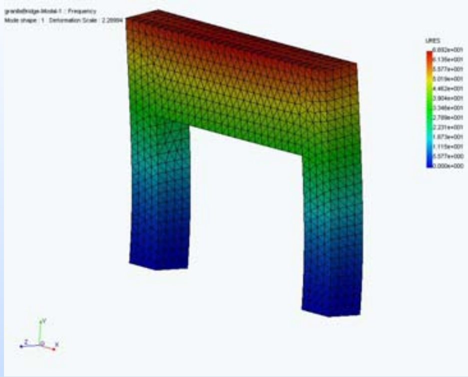
The SuperStructure

Legs 8” square

1209.08 lbm

Modes:	1	49.77 Hz
	2	110.55 Hz
	3	129.42 Hz

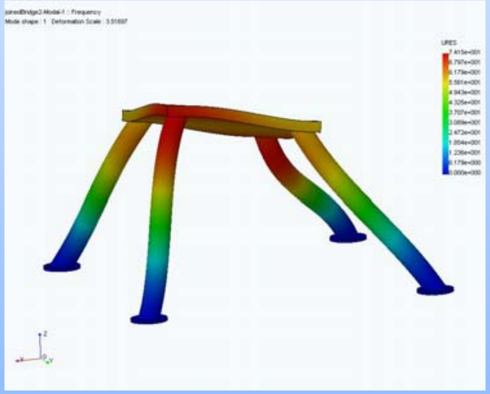


Legs 4” OD, 1/8”wall

324.65 lbm

Modes:	1	64.95 Hz
	2	64.95 Hz
	3	96.65 Hz

- ¼” wall: 645 lb, 73 Hz

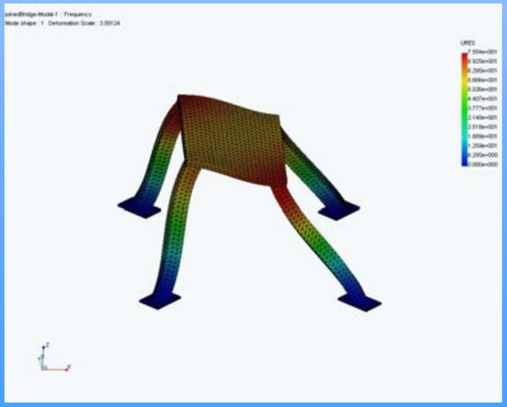


Legs 4” square, 1/8”wall

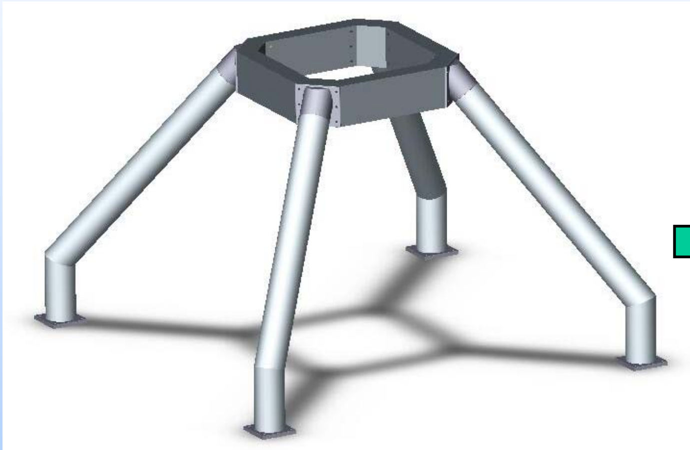
317.42 lbm

Modes:	1	84.03 Hz
	2	84.03 Hz
	3	127.28 Hz

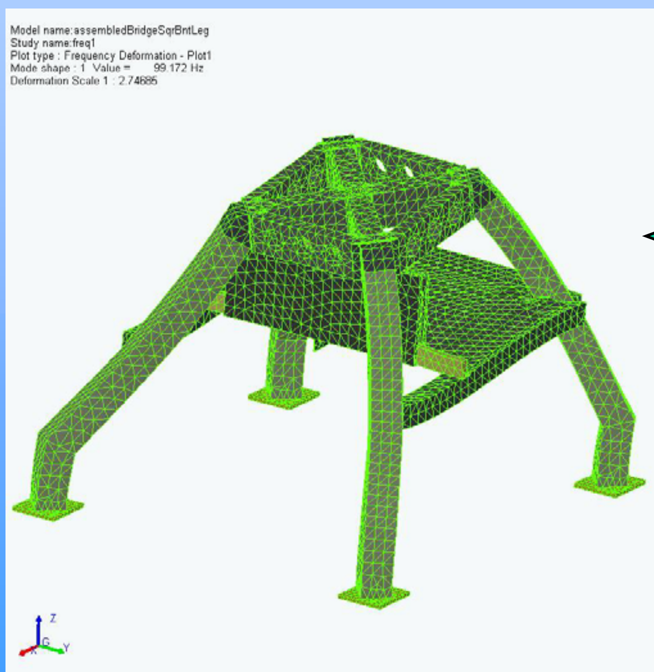
- ¼” wall: 630 lb, 101 Hz



First Design of Support Structure

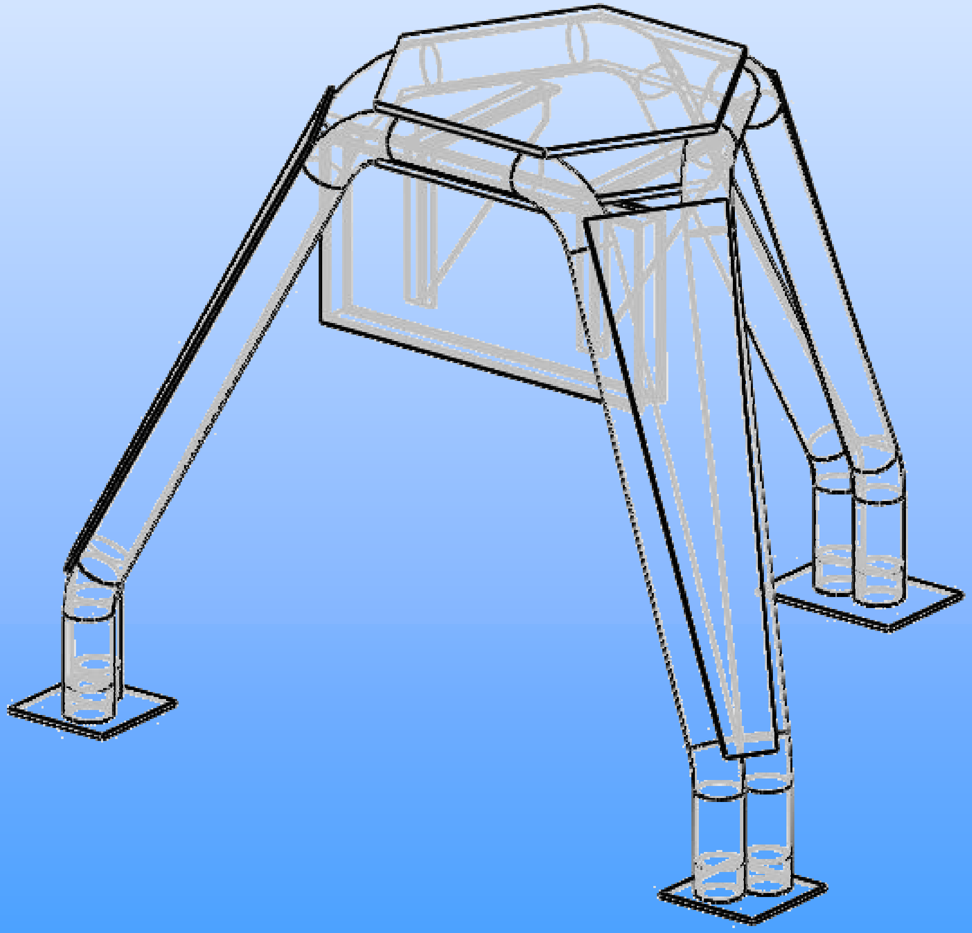


Evolved Design



1107.23* lbm, Alloy Steel
Mode 1: 100.66 Hz
Mode 2: 100.84 Hz
Mode 3: 137.12 Hz
*No Breadboard or vertical-mounted mass

Alternative Design 1 “Tripod”



Tripod Initial Results

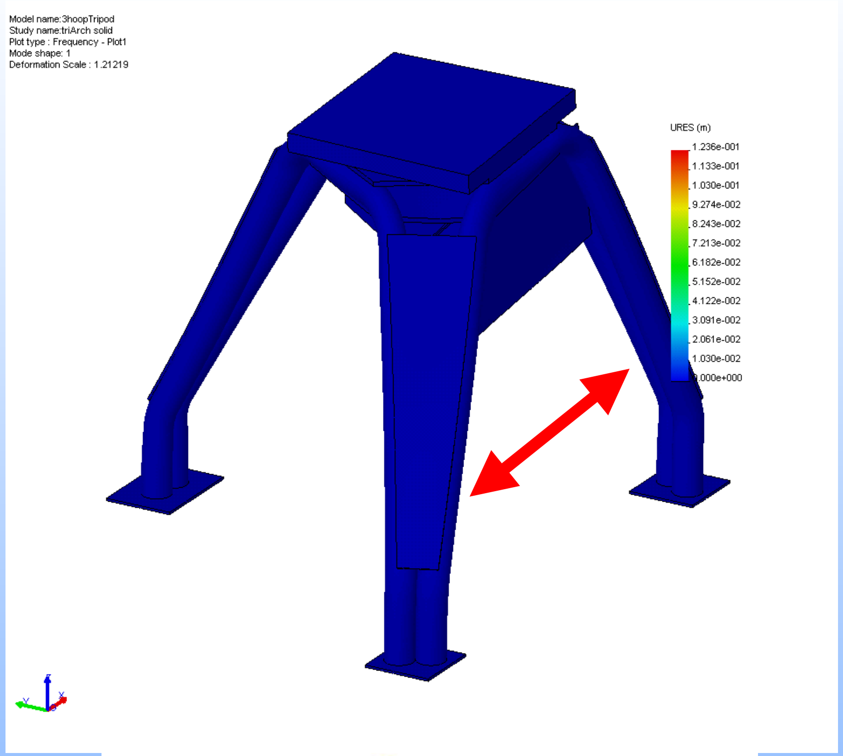
Legs 3” OD, 1/8” thick

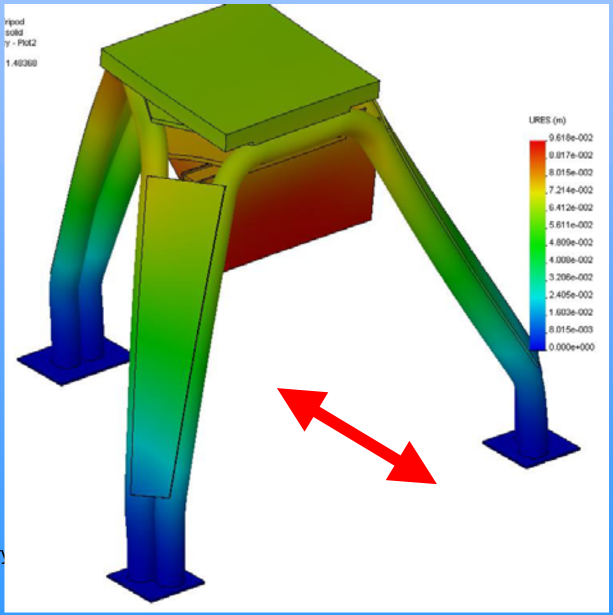
506.32 lbm (includes breadboards)

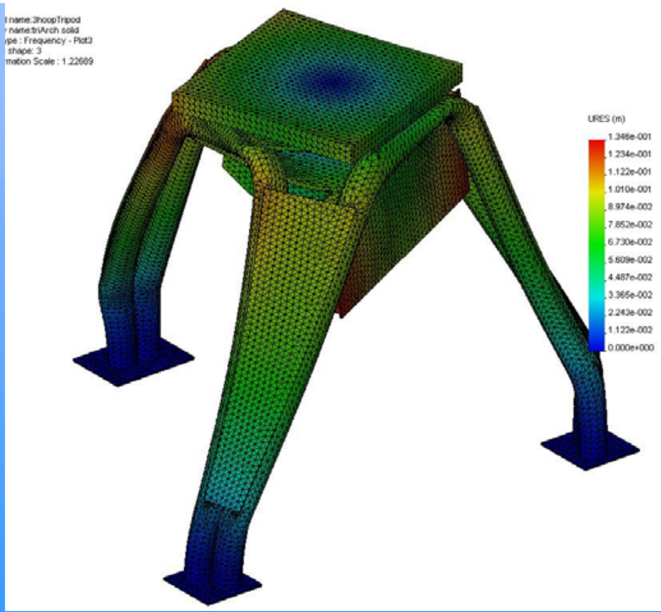
Modes:		
	1	**57.157 Hz**
	2	57.919 Hz
	3	117.13 Hz
	4	180.74 Hz
	5	204.47 Hz

* Solid elements, tetrahedral

107,963 elements, 199,784 nodes







SPACE
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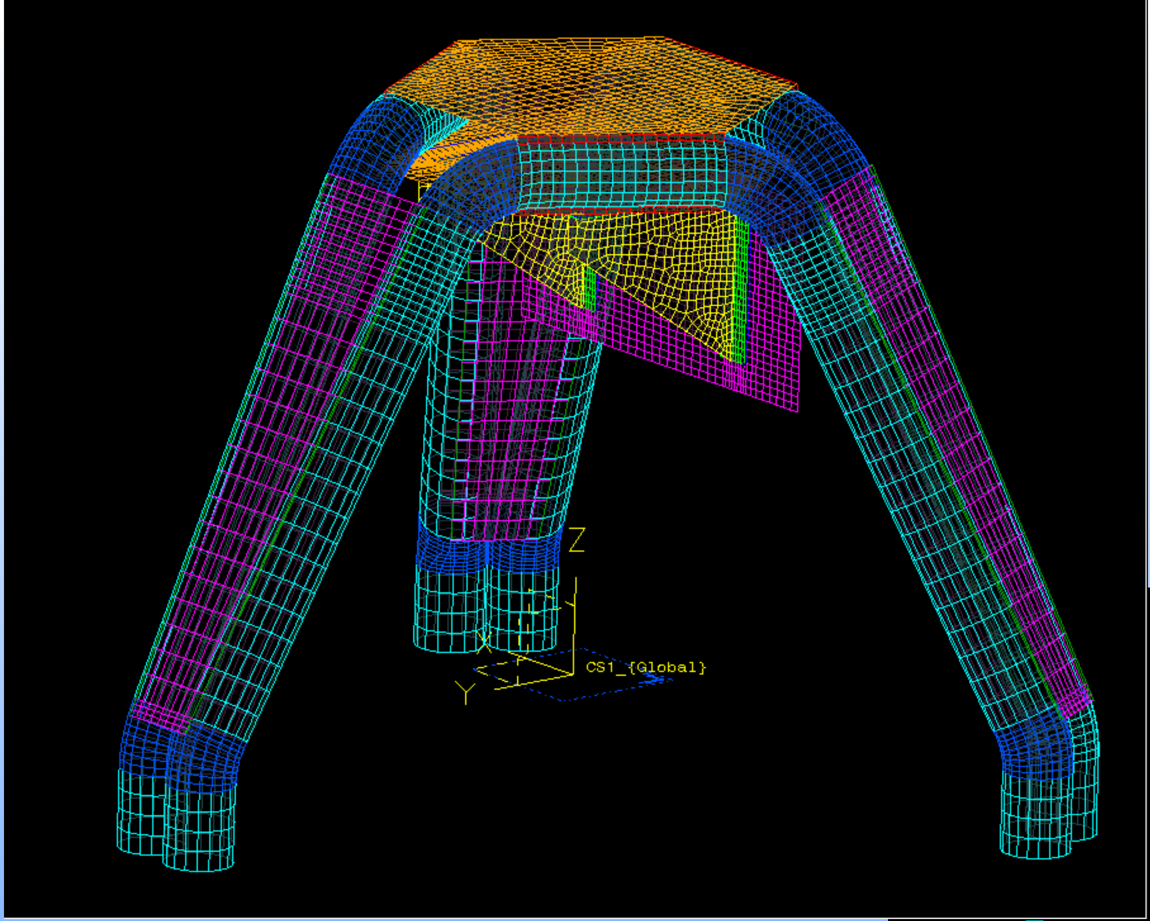
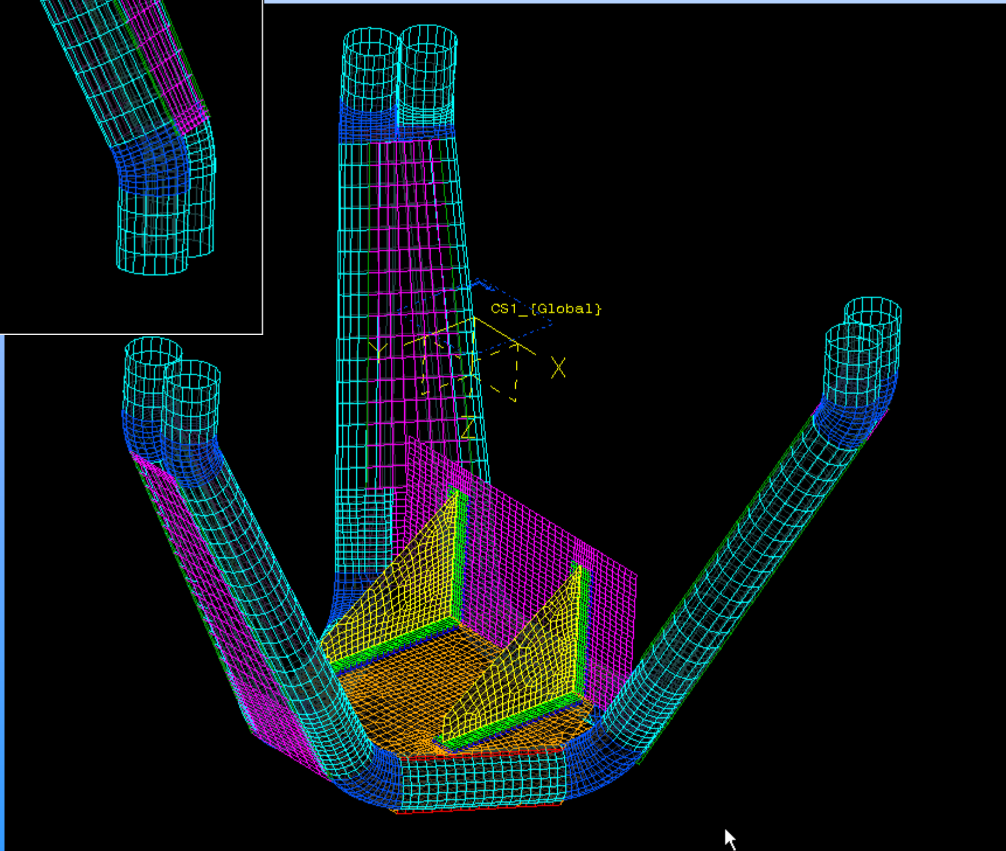


4” OD legs, 1/16” thick

Requires shell elements, switch from CosmosWorks to NASTRAN



Shell mesh quadrilateral elements

Elastic elements for welds

Ideas preprocessor/mesher

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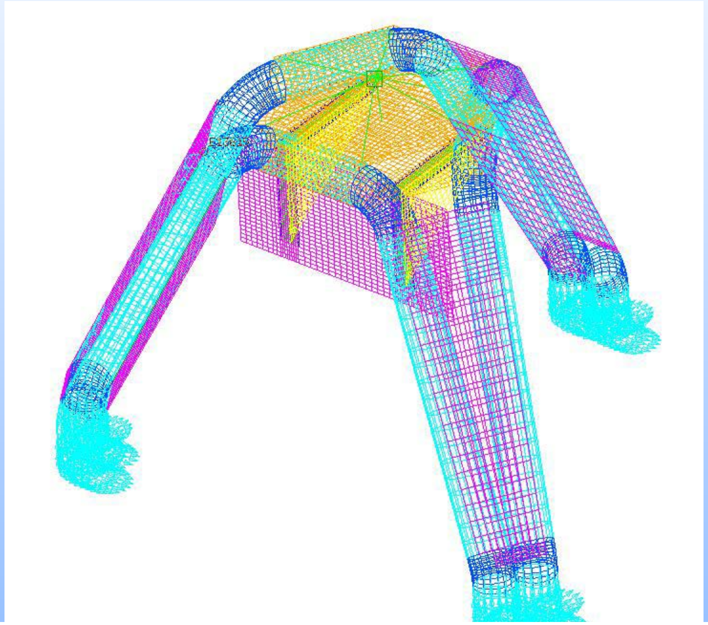
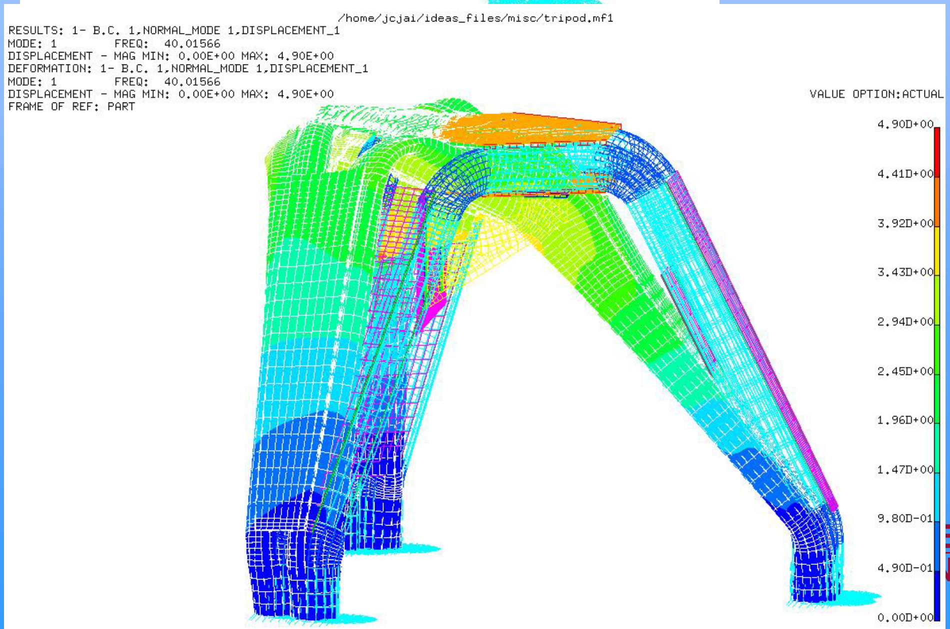
Tripod Analysis and Results

NASTRAN (MSC) solver

Ideas postprocessor/viewer

- 200 lbm point mass at CG of breadboard
- Rigid elements constraints to mounting plate
- 40 lbm breadboard + 15 lbm z-stage added
- Smeared properties for vertical breadboard
- Immovable restraints on bottom of leg, no feet





471.97 lbm (including breadboards & z stage)
First mode at **40 Hz**

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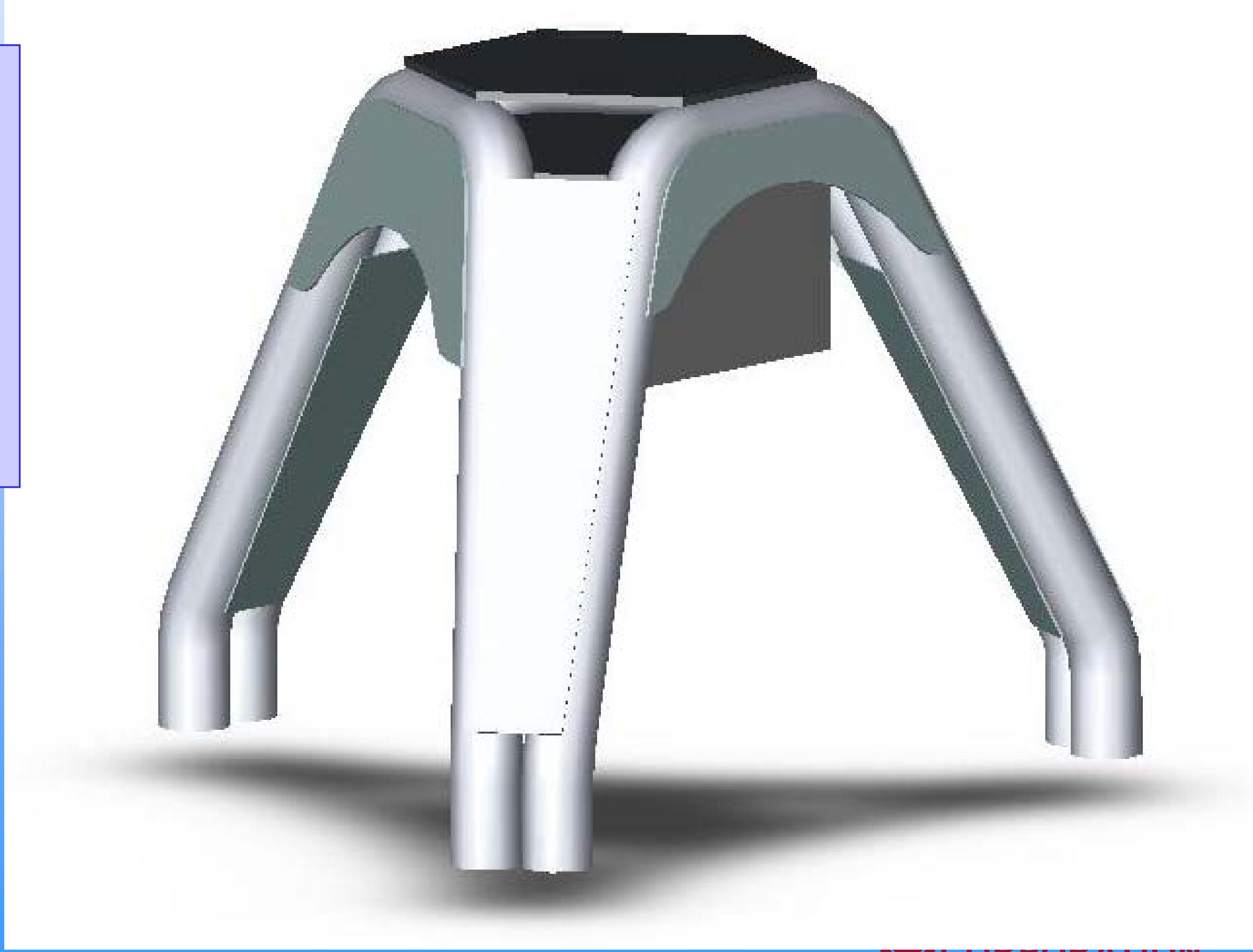
Tripod Design Iteration

Plate gussets were added to stiffen bent joints

Front plate less than 0.5” blocking of breadboard



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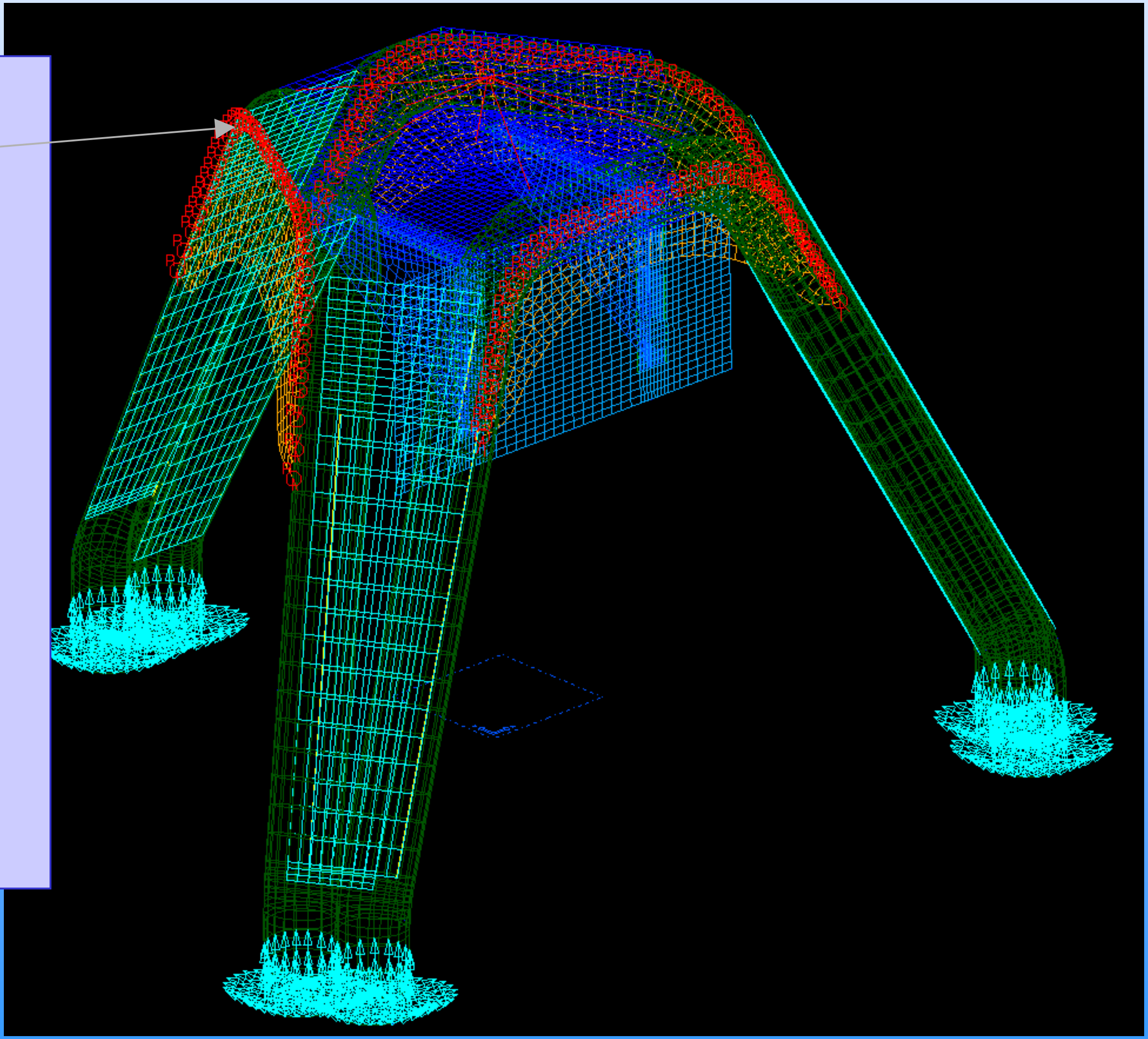
Analysis of New Tripod

Meshed gusset plates separately
Connected by rigid elements

Analysis performed varying
- Leg thickness
- Gusset thickness
- Geometry combinations



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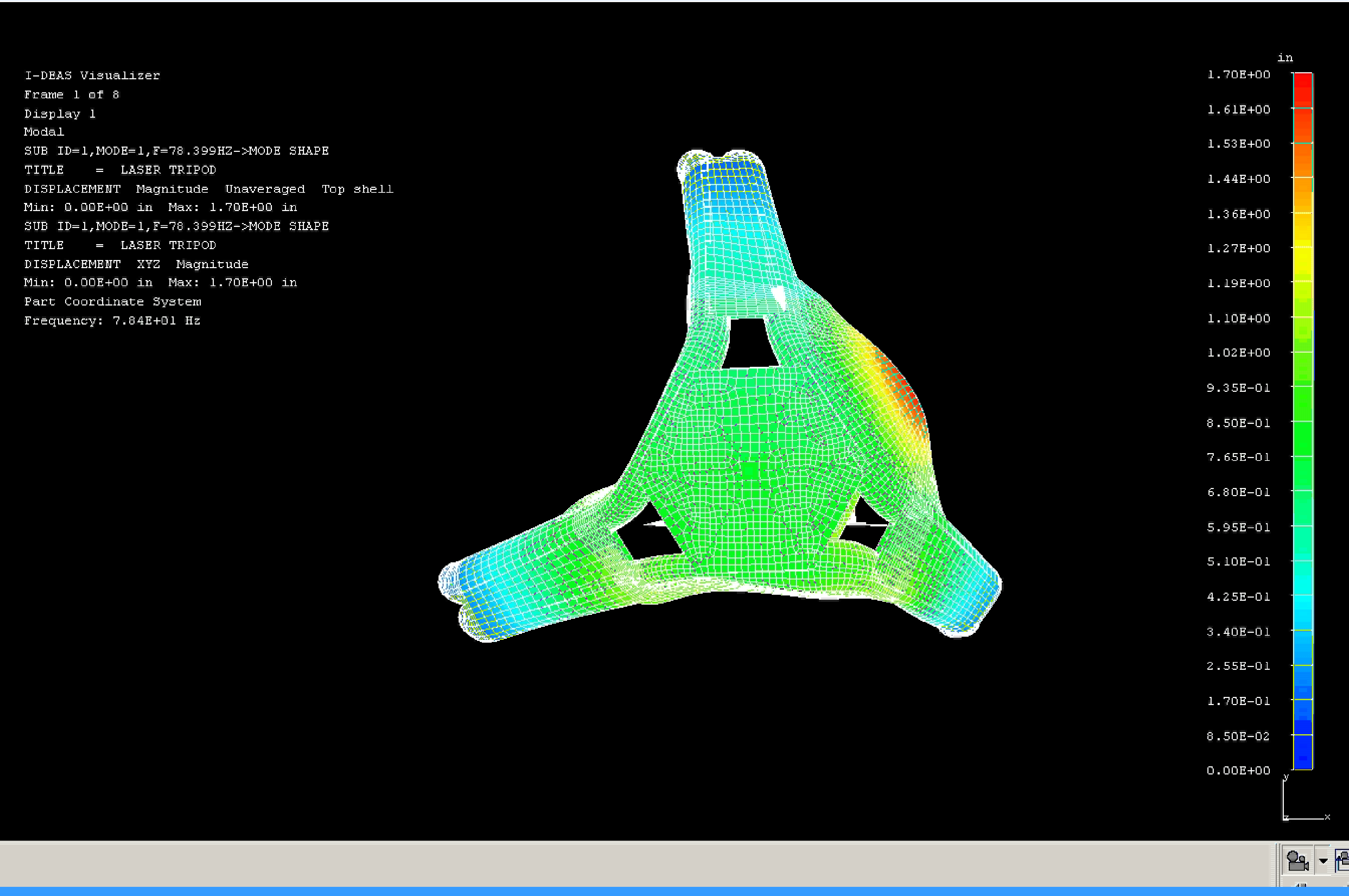
First Mode: Swaying 78 Hz



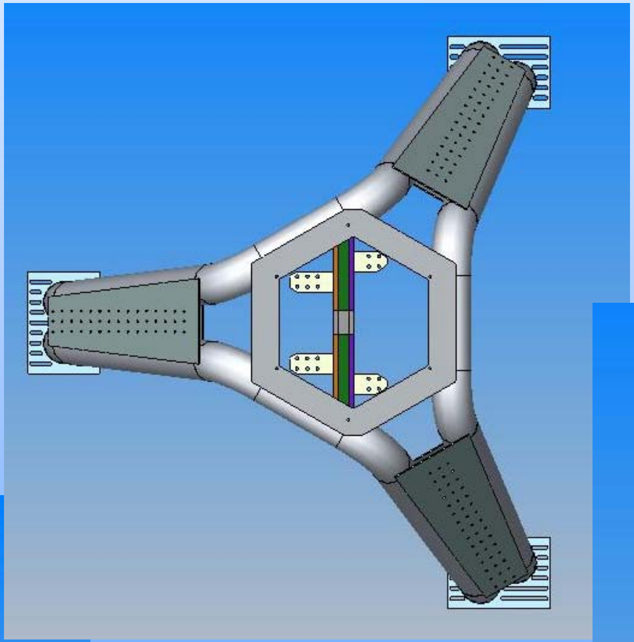
Summary of Analysis Results

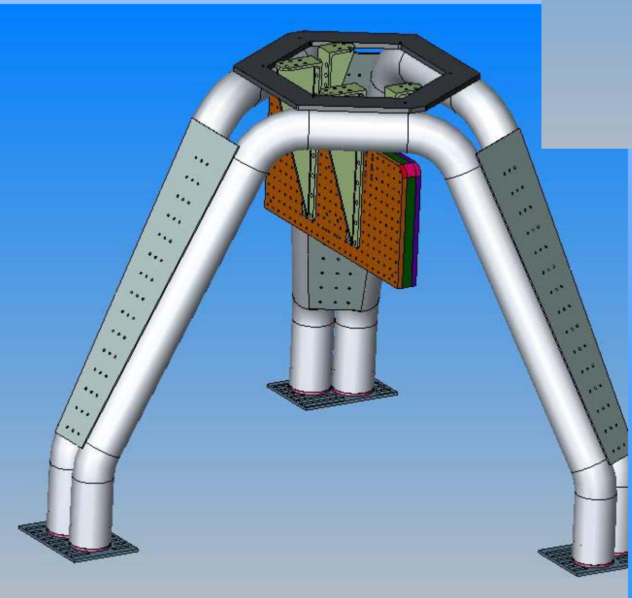
	Baseline (1/16" Legs)	1/8" Legs	1/16" Legs + 3/16" Gusset	1/16" Legs + 1/4" Gusset	1/8" Legs + 3/16" Gusset
Mass (lbm)	471.97	534.43	496.52	504.70	**558.97**
Mode #					
1	39.77	60.39	57.76	58.71	**78.40**
2	41.00	62.31	63.93	64.70	84.98
3	87.81	109.23	92.09	92.66	112.03
4	102.91	143.72	124.49	126.44	156.18
5	121.12	157.75	132.67	139.12	177.69
6	141.76	217.76	137.94	145.99	179.64
7	166.65	246.62	156.83	158.19	200.99
8	228.80	333.08	160.46	160.68	233.63
9	230.26	339.03	184.82	188.93	256.93
10	231.06	340.48	203.29	222.64	265.52

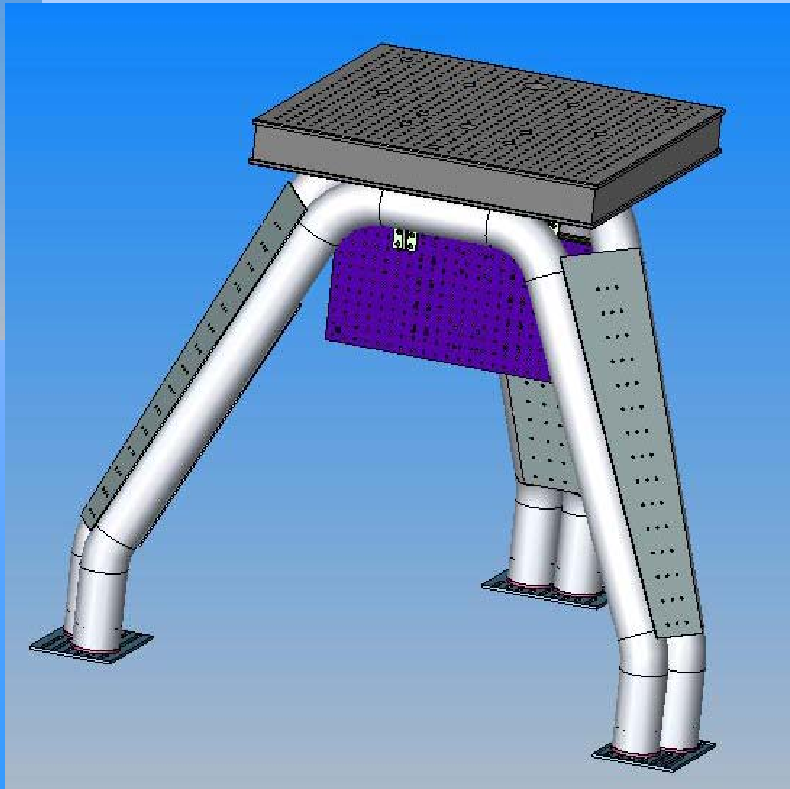
Problem: Too costly to manufacture

"one more try in analysis to refine design"

- Current Design Being Manufactured: 25% Cost Savings
- Material 304SS 4 Inch Diameter Tubing 1/10" Thick
- Weight: 359 lbs (with 100 lbs budget for optical table)
- First resonant mode: 90Hz

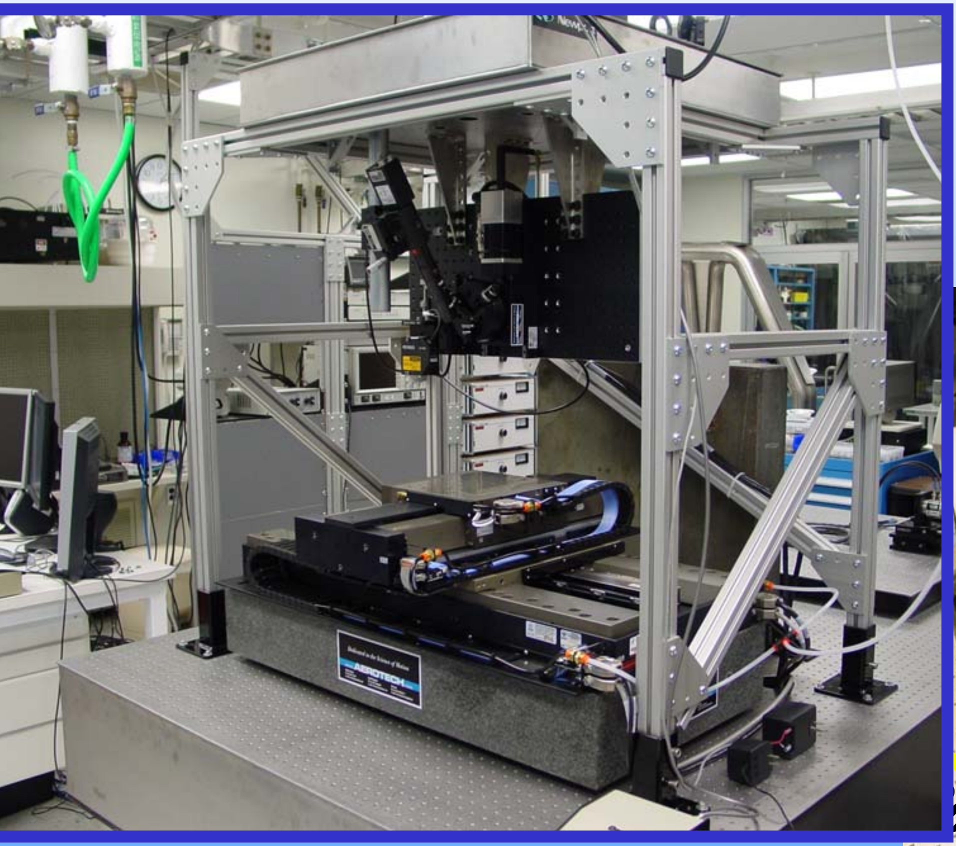


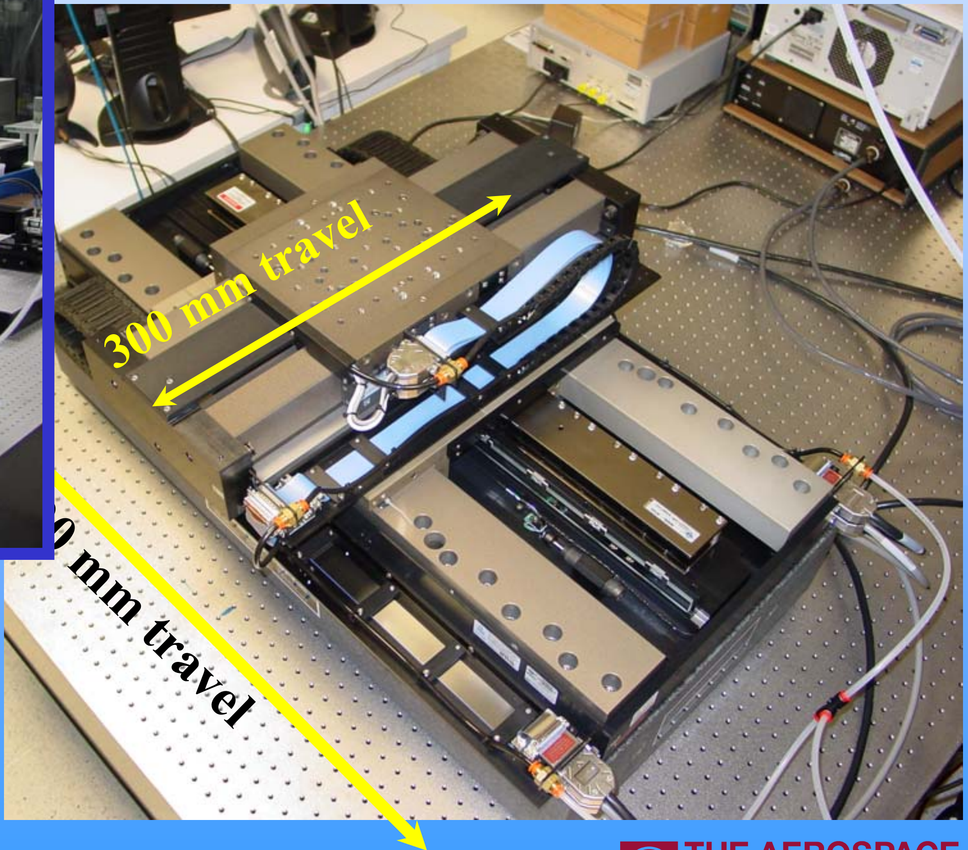




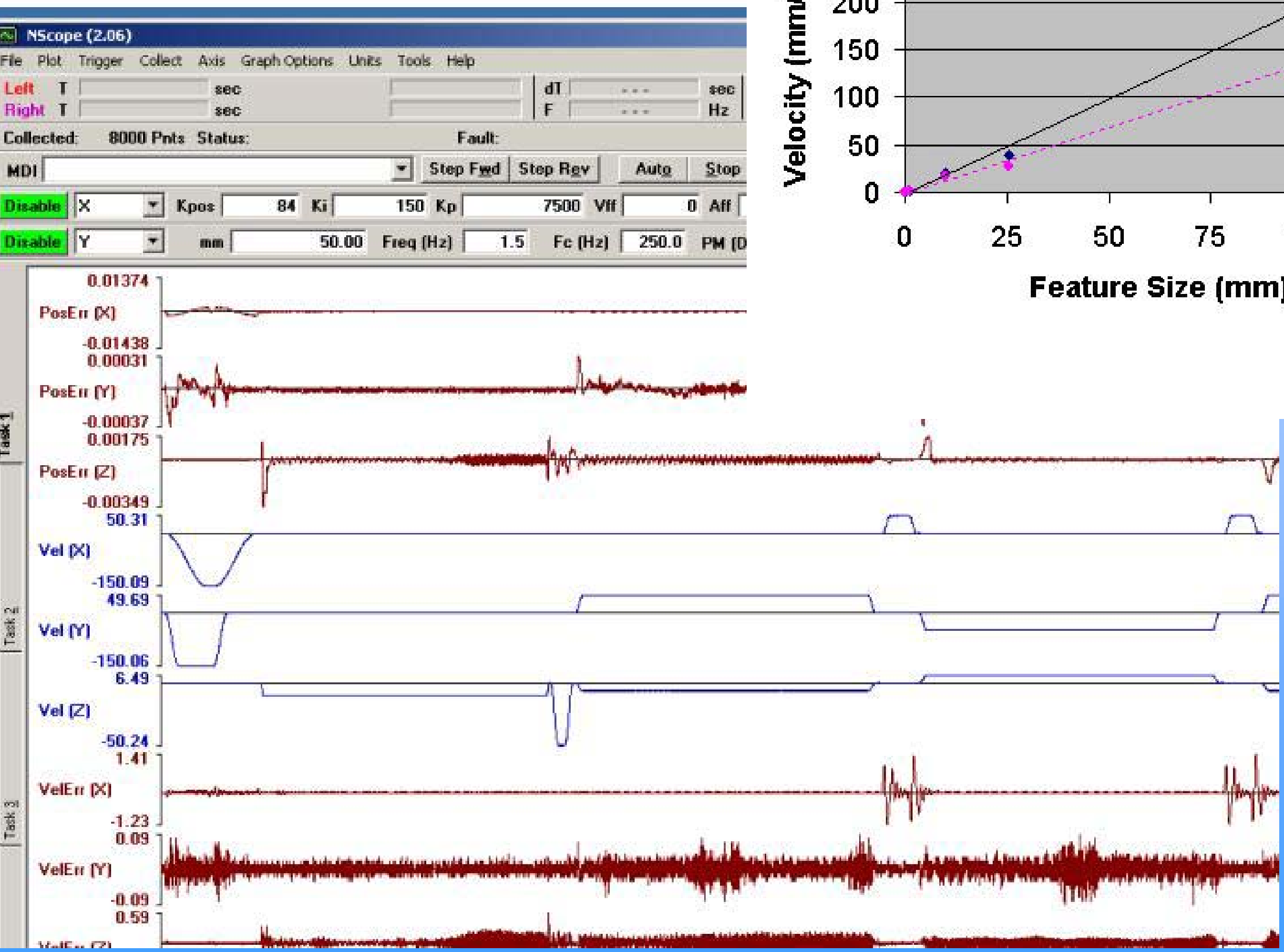
Hardware Delivered Integration Underway

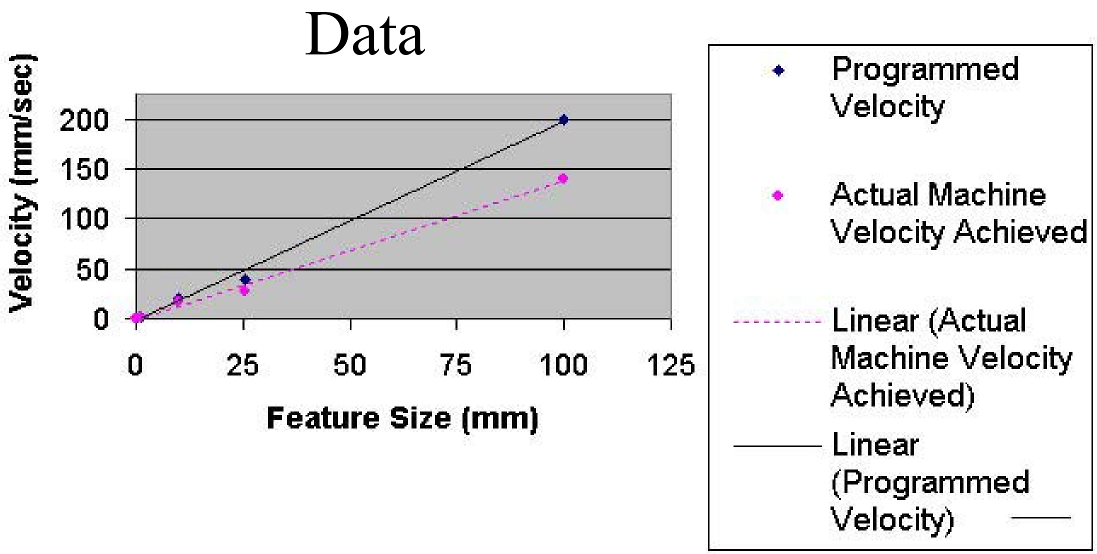
XYZ Motion System





Tradeoff Between Speed and Position-Error

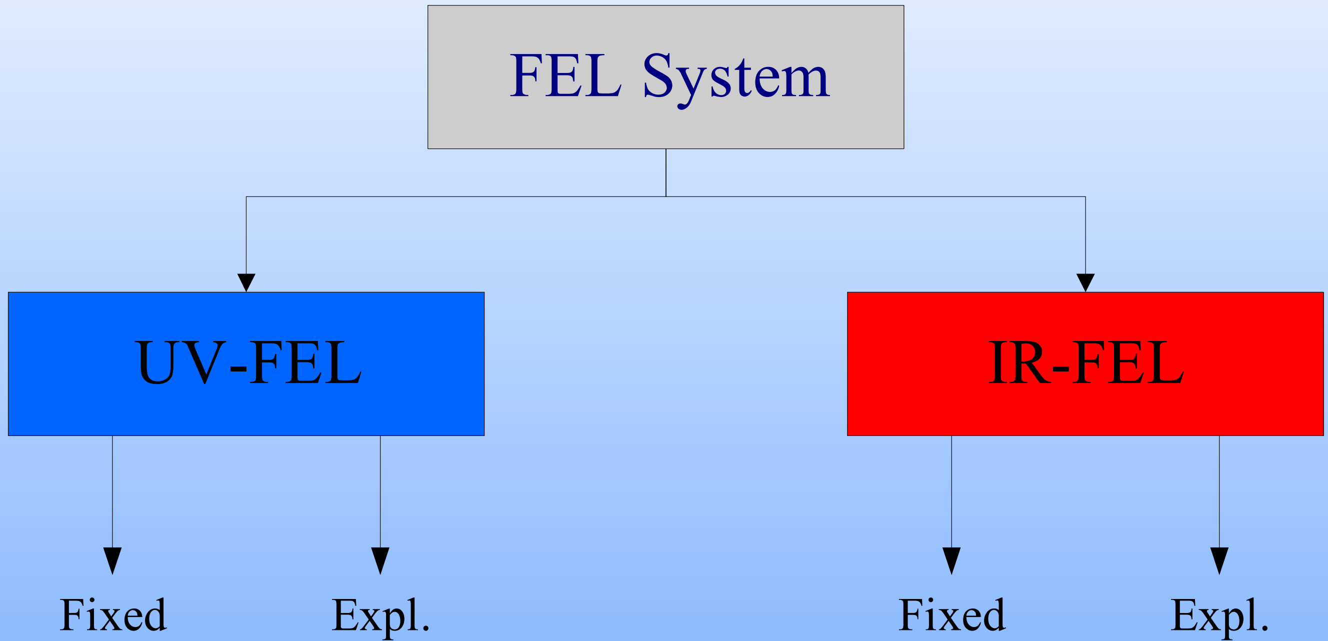




For Measurements Acceptable Upper Limit of Position Error Set to 200 nm

Optical Sub System

Design
Optical Configuration

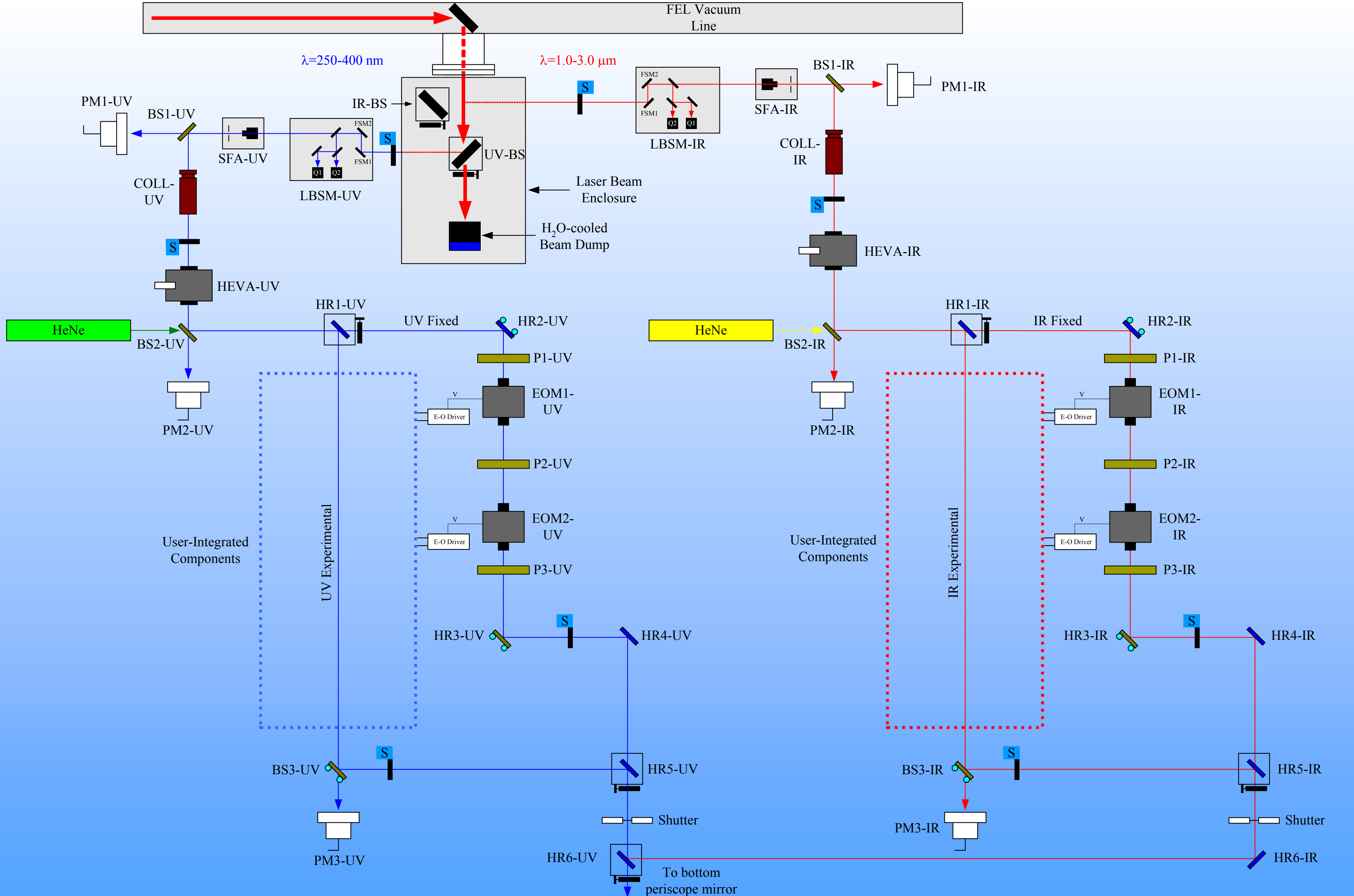


2 - Fixed Optical Lines

2 - Experimental Optical Lines

User-integrated components

- optics
- diagnostics
- instrumentation



FEL-6 ; Optical Design
SRR 8/22/02

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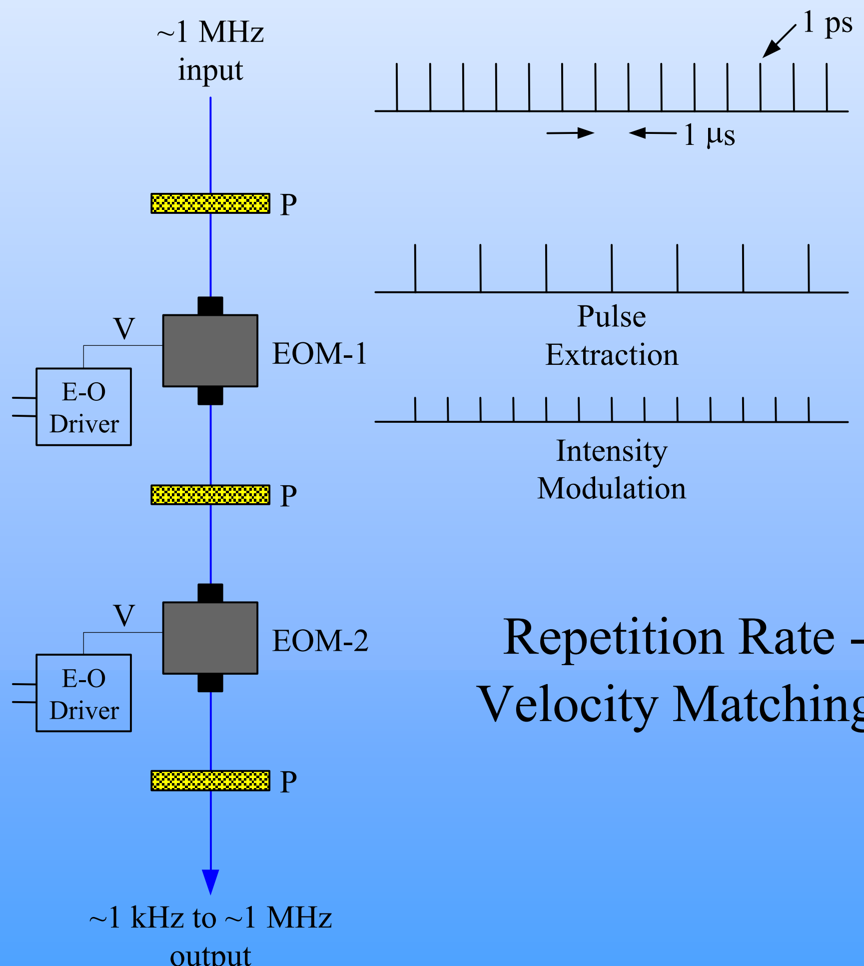
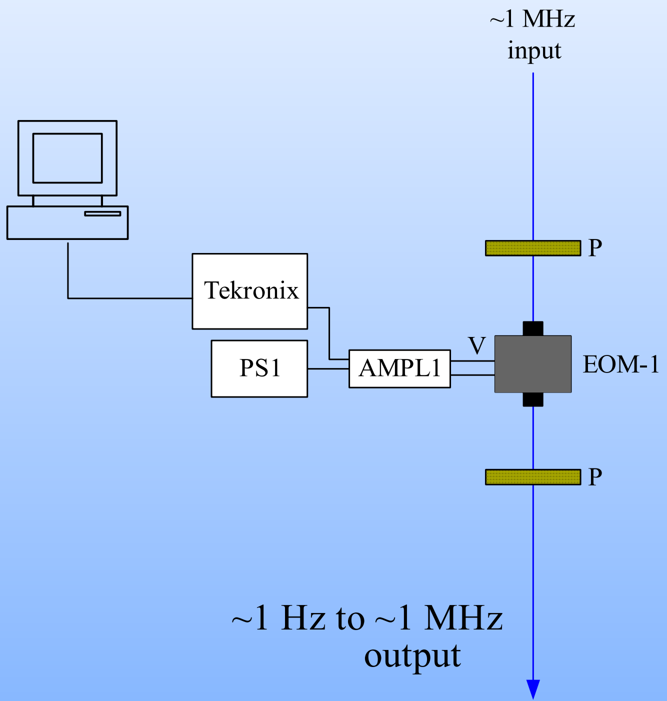
Pulse Picking
Velocity Compensation
Dynamic Control of Laser Power

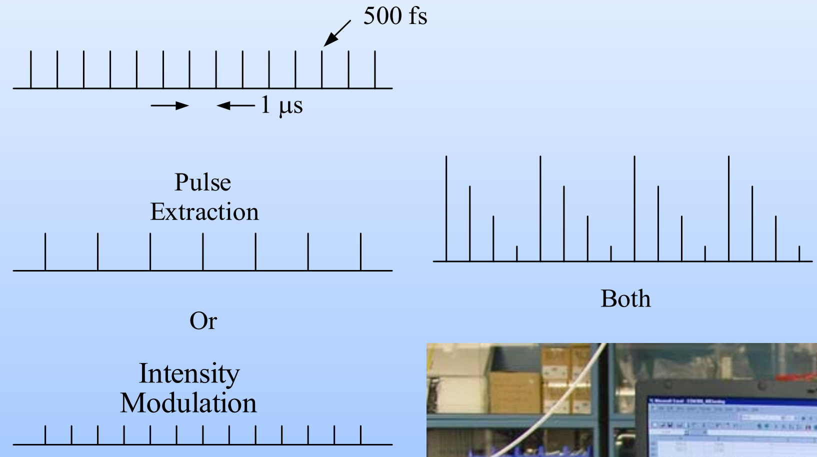
Power Selection and Modulation: EOM Serial Configuration



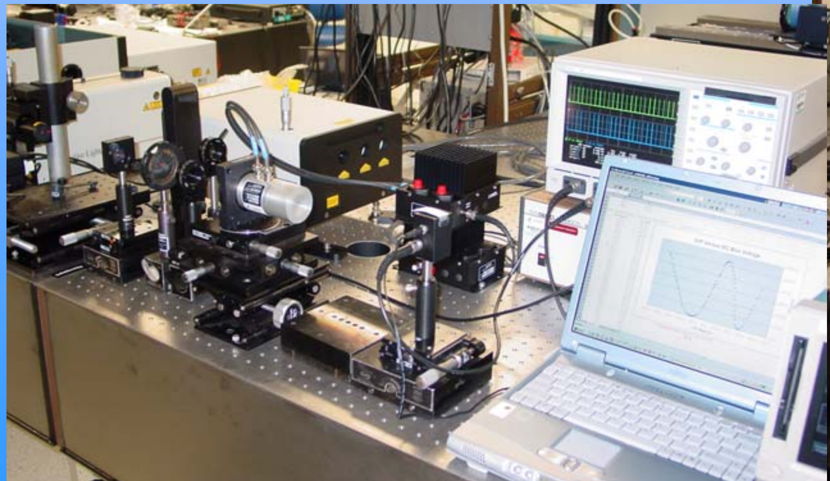
Repetition Rate -
Velocity Matching

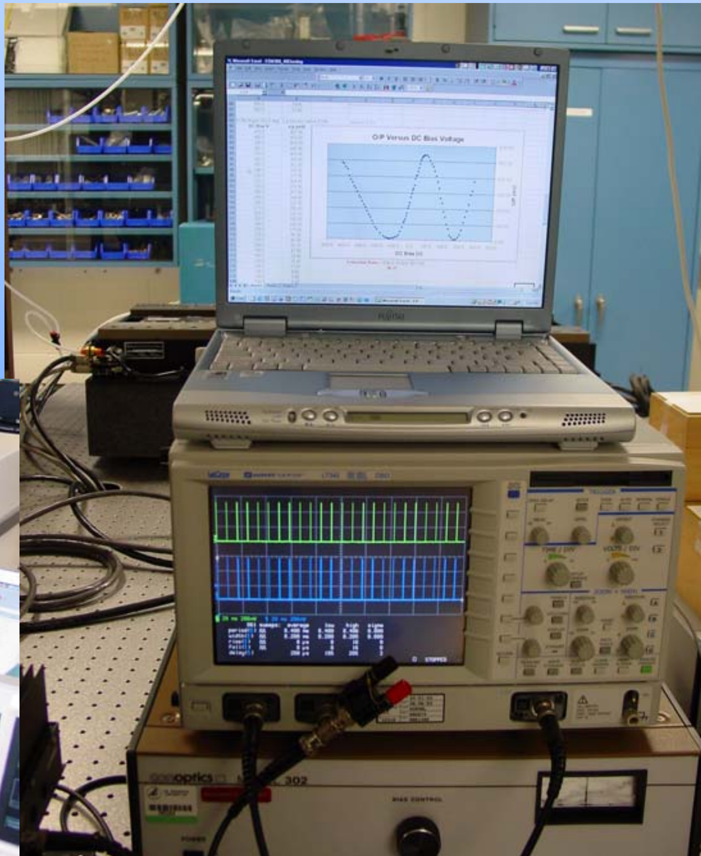
Power Selection and Modulation: EOM Serial Configuration





Pulse Scripting Combined with Repetition Rate-Velocity Matching





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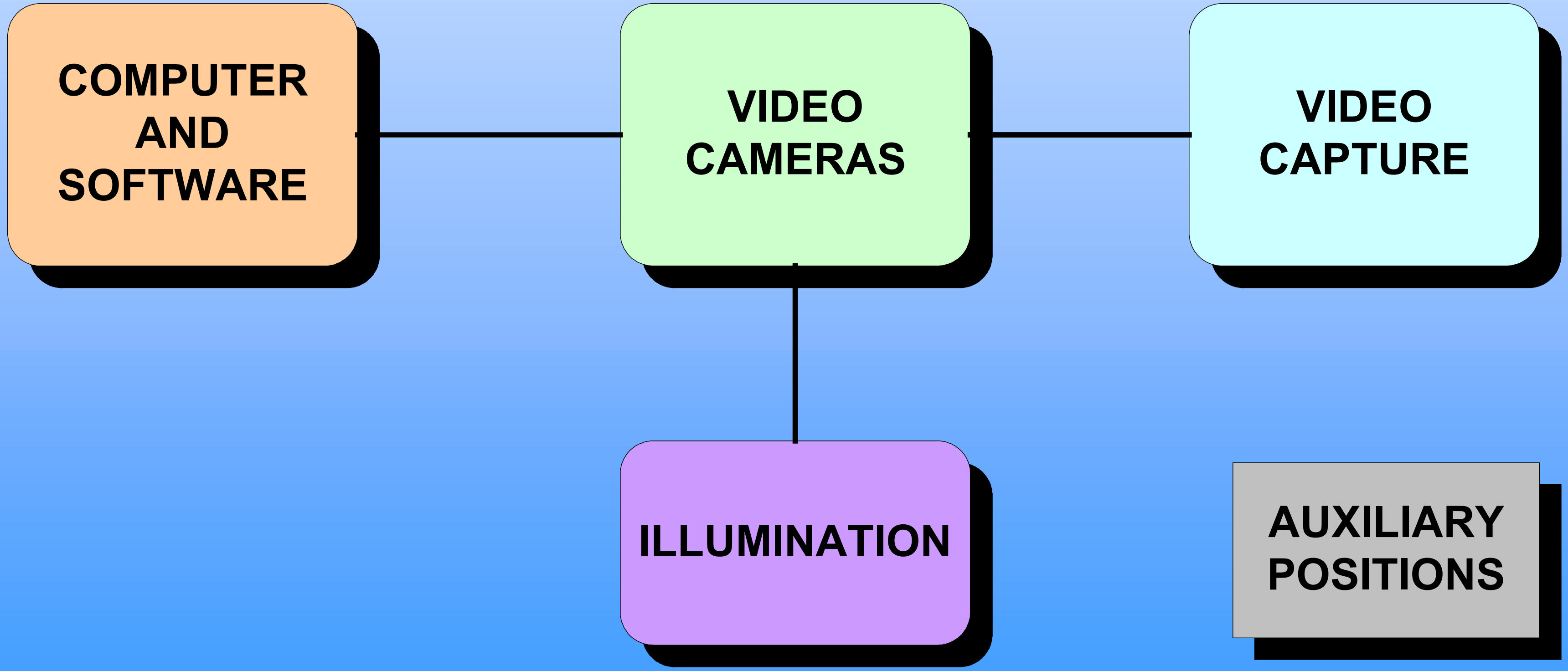
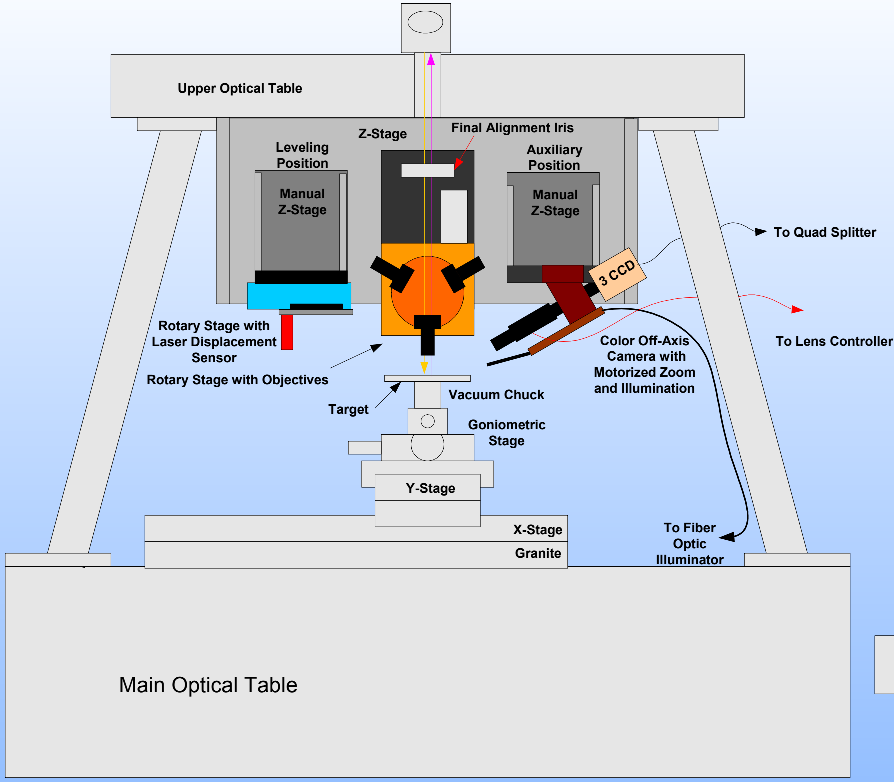
Key Elements of Vision Subsystem



KEY VISION SYSTEM COMPONENTS



FRONT VIEW OF

MICROENGINEERING

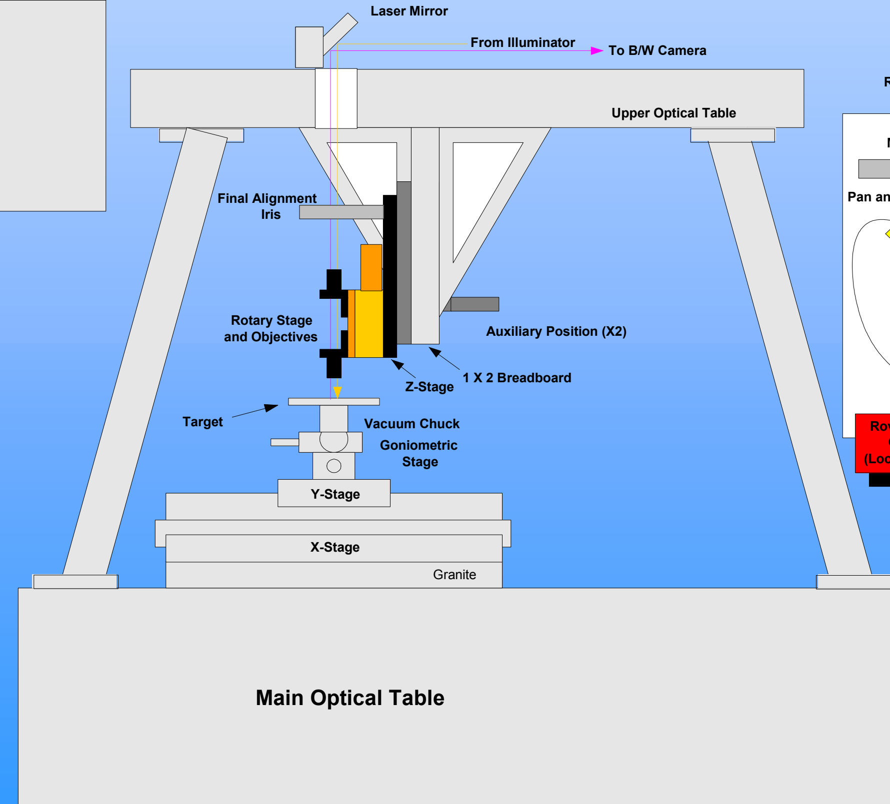
STATION

SIDE VIEW OF

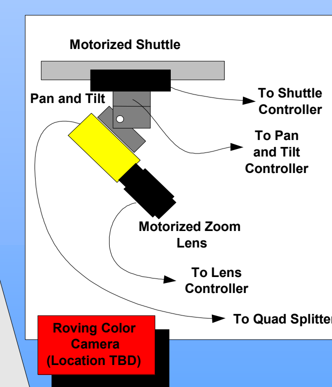
MICROENGINEERING

STATION

KEY VISION COMPONENTS



Revision A - 8-13-02 WWH



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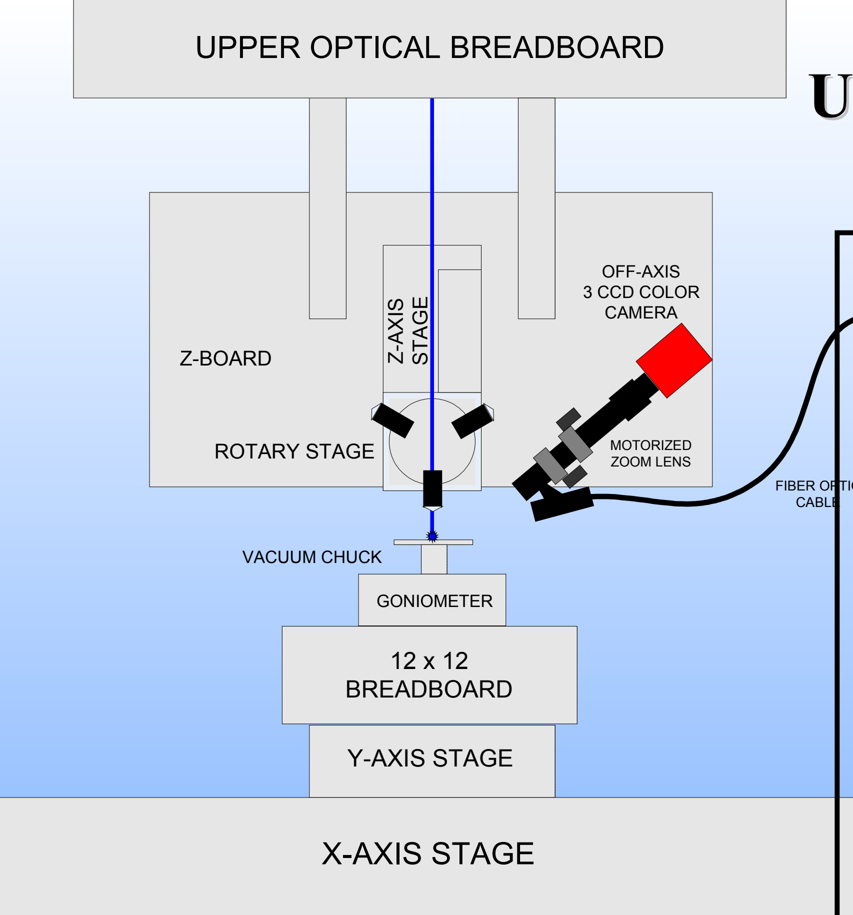
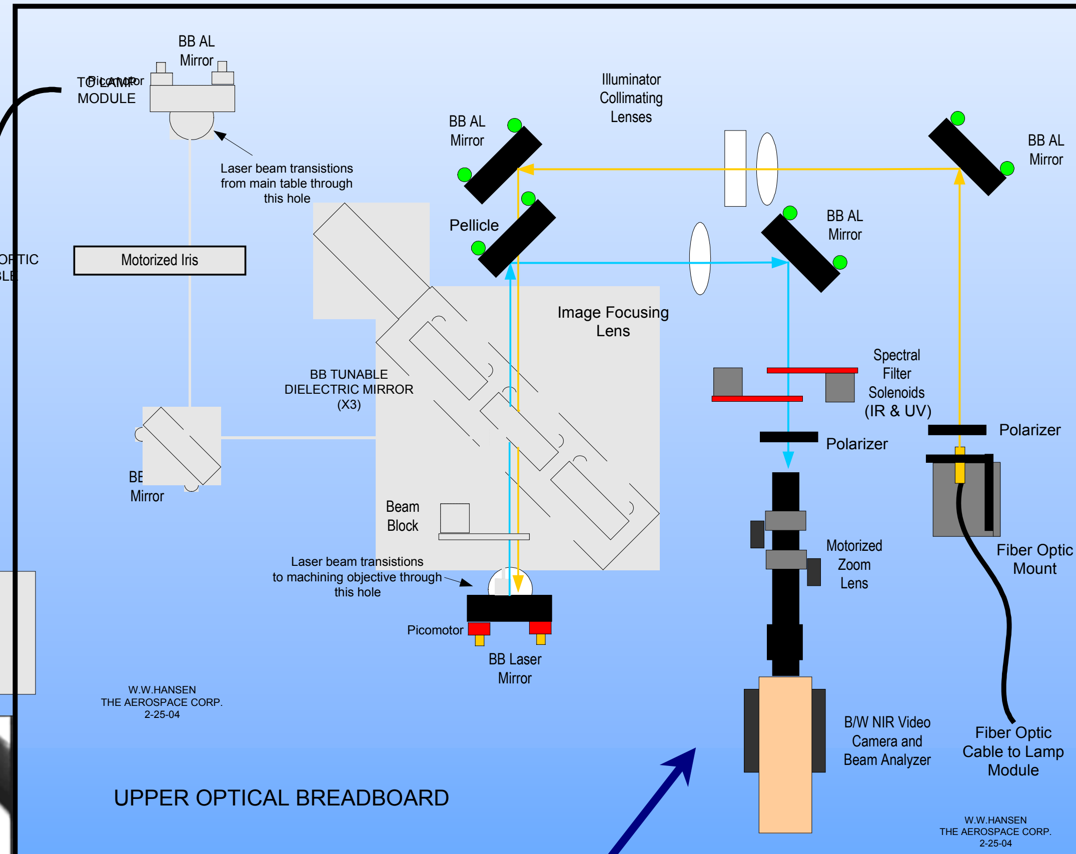
Upper Optical Table & Vision System





FOV 1.3mm

FOV 0.2mm

In situ laser beam analyzer for on target laser spot size and intensity distribution measurements

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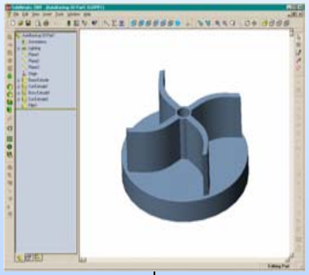
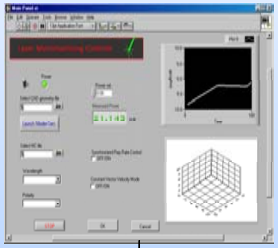
CADCAM

Software Module Sequences





For GPIB/RS232 Instruments

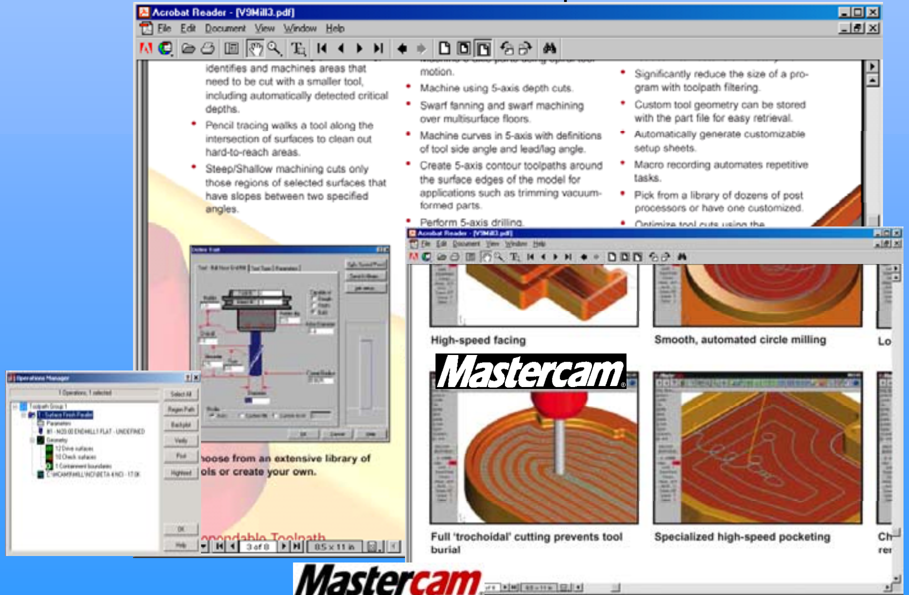
Start

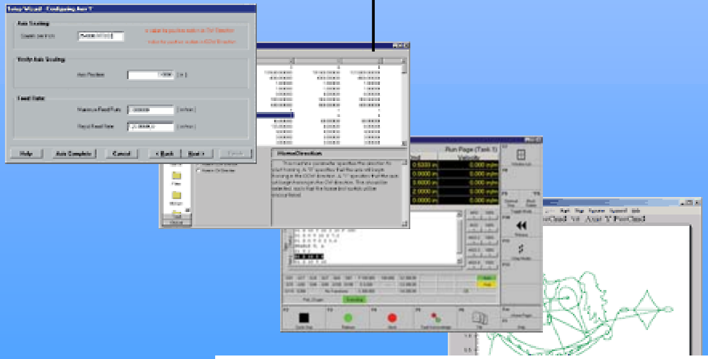
←**Confident of Connectivity**→

End

Synchronous Control Translator/Post Processor

←Initial Tests are Promising→





AUTOMATION 3200 THE INTELLIGENT 32 AXIS MOTION, VISION & I/O SYSTEM

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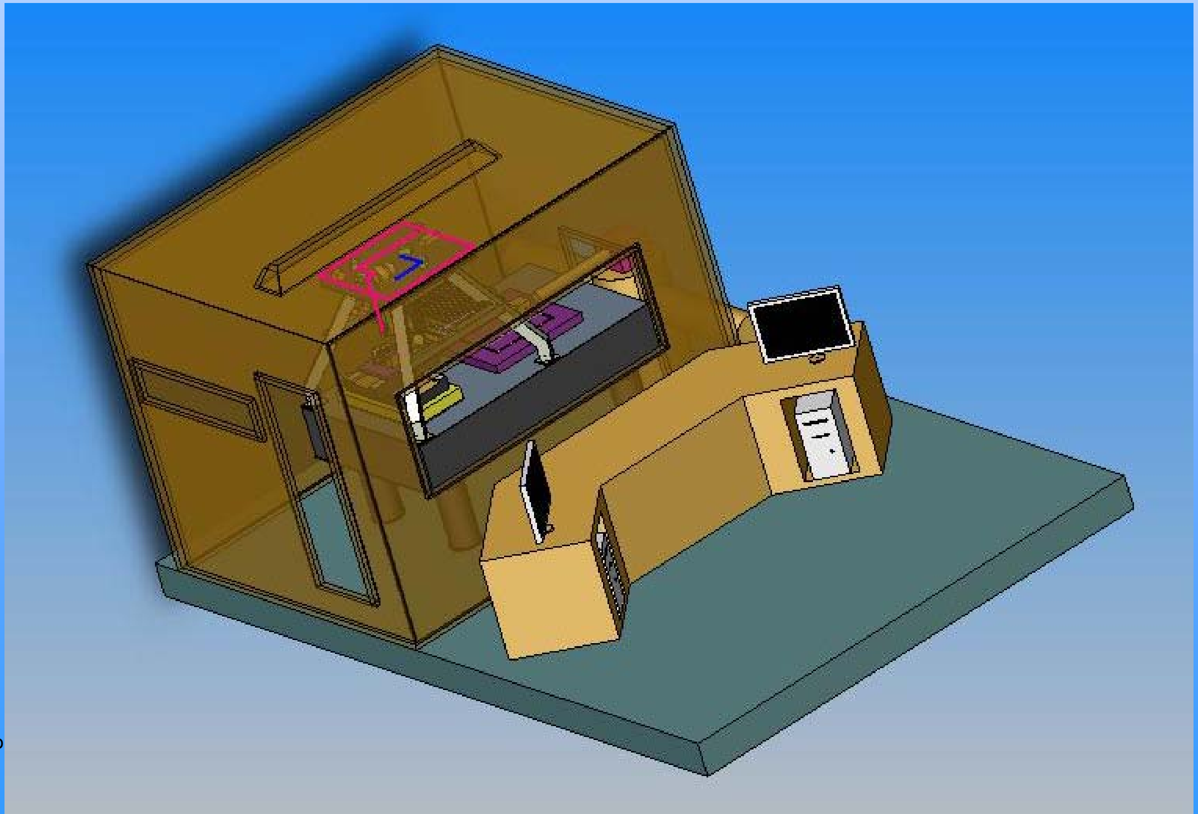
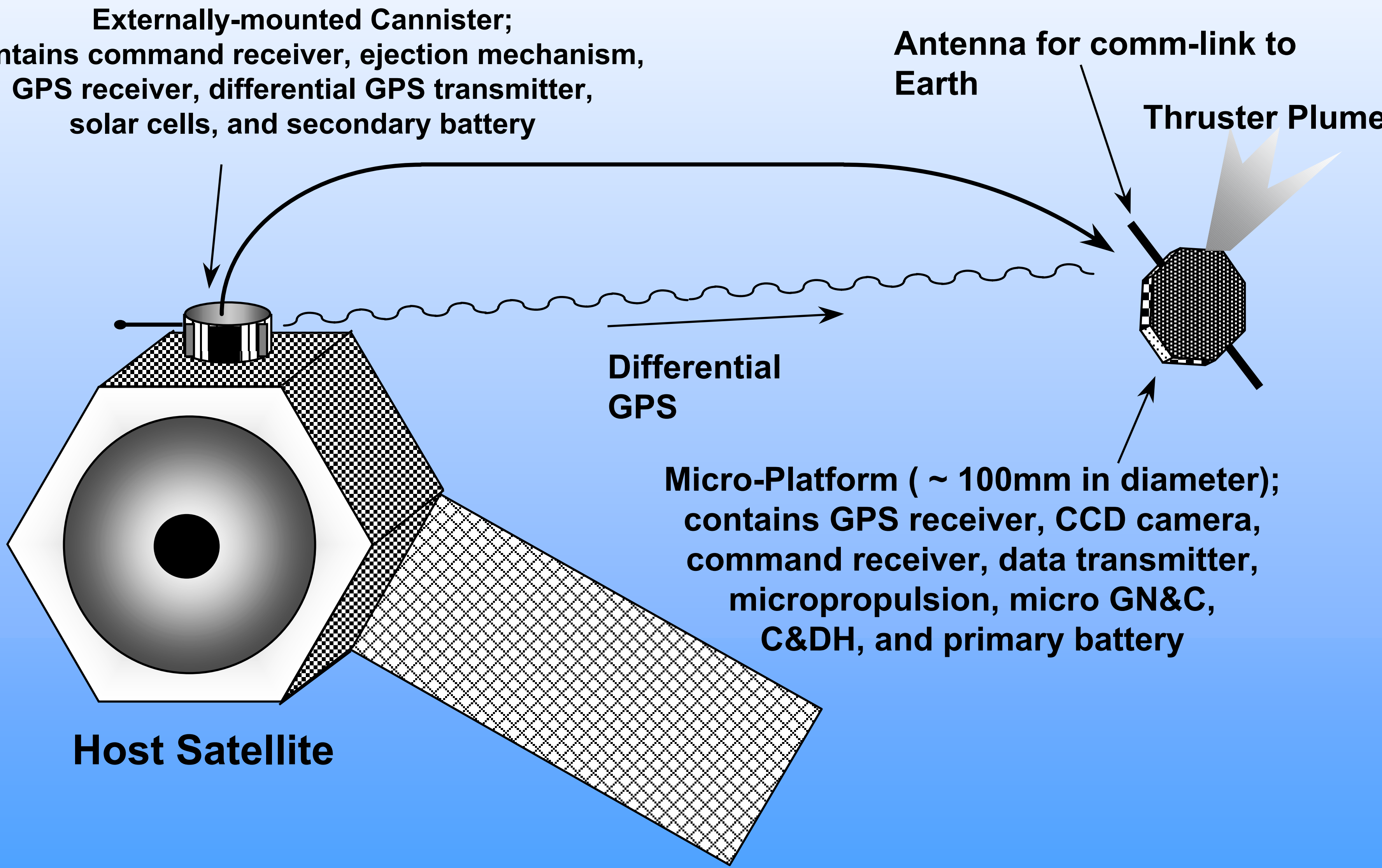
Conclusions

- Have assembled several test ‘stands” and have investigated design properties of critical subsystems,
- Engineering Model testing underway,
- Hope to Deliver JLAB Unit Spring/Summer 2005



The Co-Orbiting Satellite Assistant (COSA)



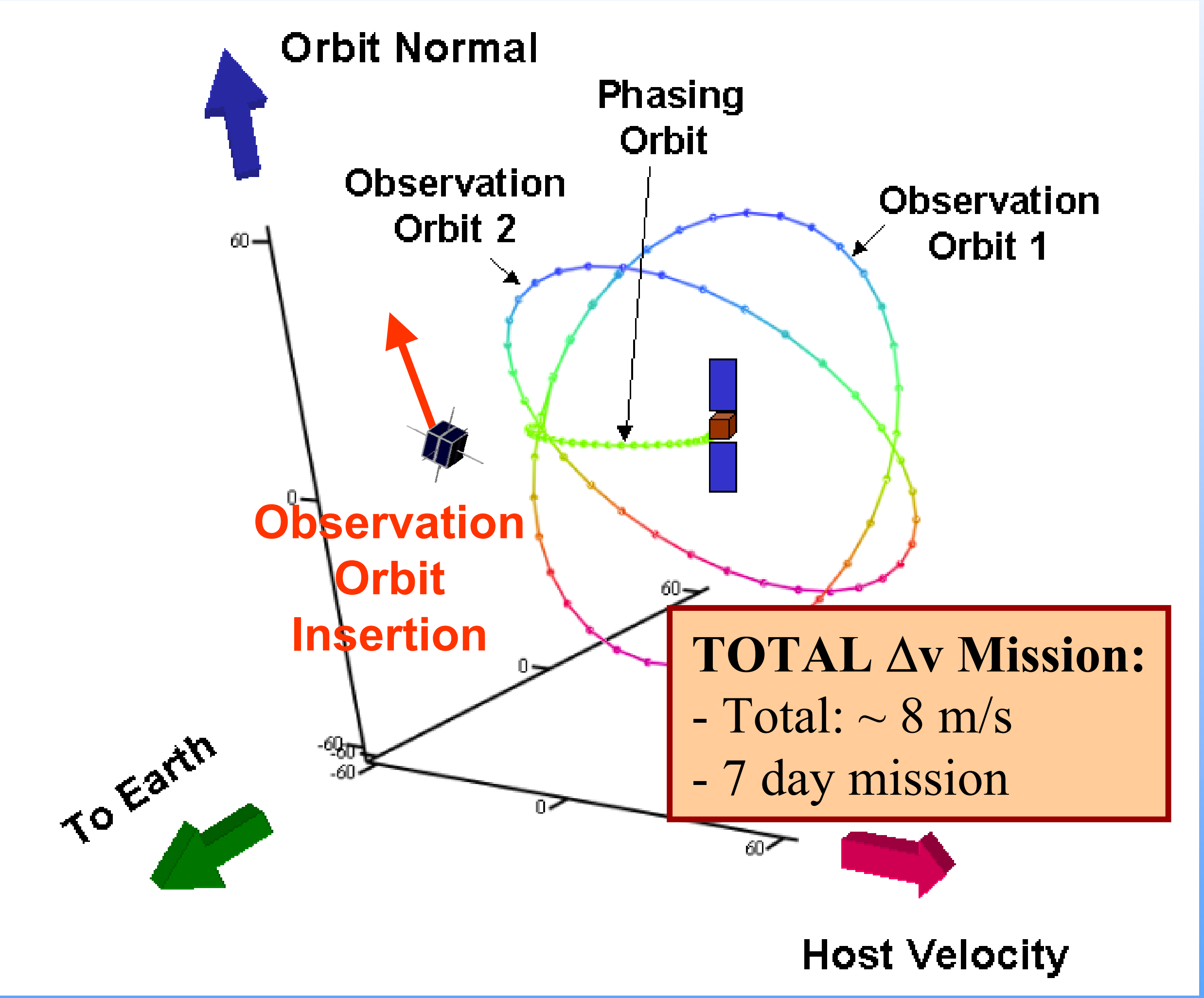
COSA Observation Trajectories

Co-orbital with Inclination:

$F\delta t = m\,\Delta v$

$\Delta v = 1mN(1s)/0.1Kg$

$\Delta v = 0.01m/sec$



TOTAL Δv Mission:
- Total: ~ 8 m/s
- 7 day mission

Phasing orbit (Δv):
- 1st impulse: 0.003m/s
- 2nd impulse: 0.003m/s
- 700 km orbit
- 99 minute/orbit
- mN thrust levels

Observation orbits (Δv):
- Total: ~0.18 m/s

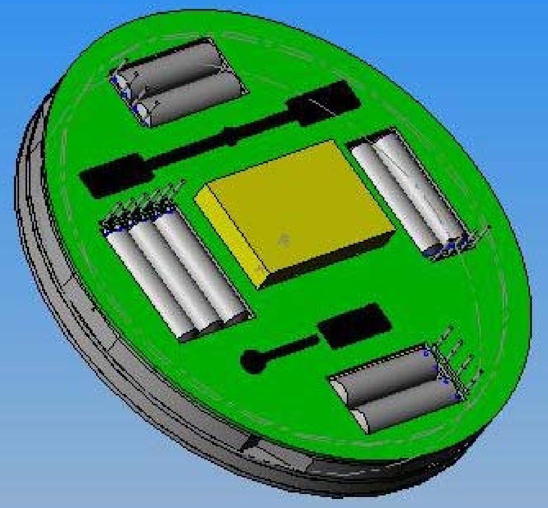
Atmospheric Drag(Δv):
- Total: ~7 m/s

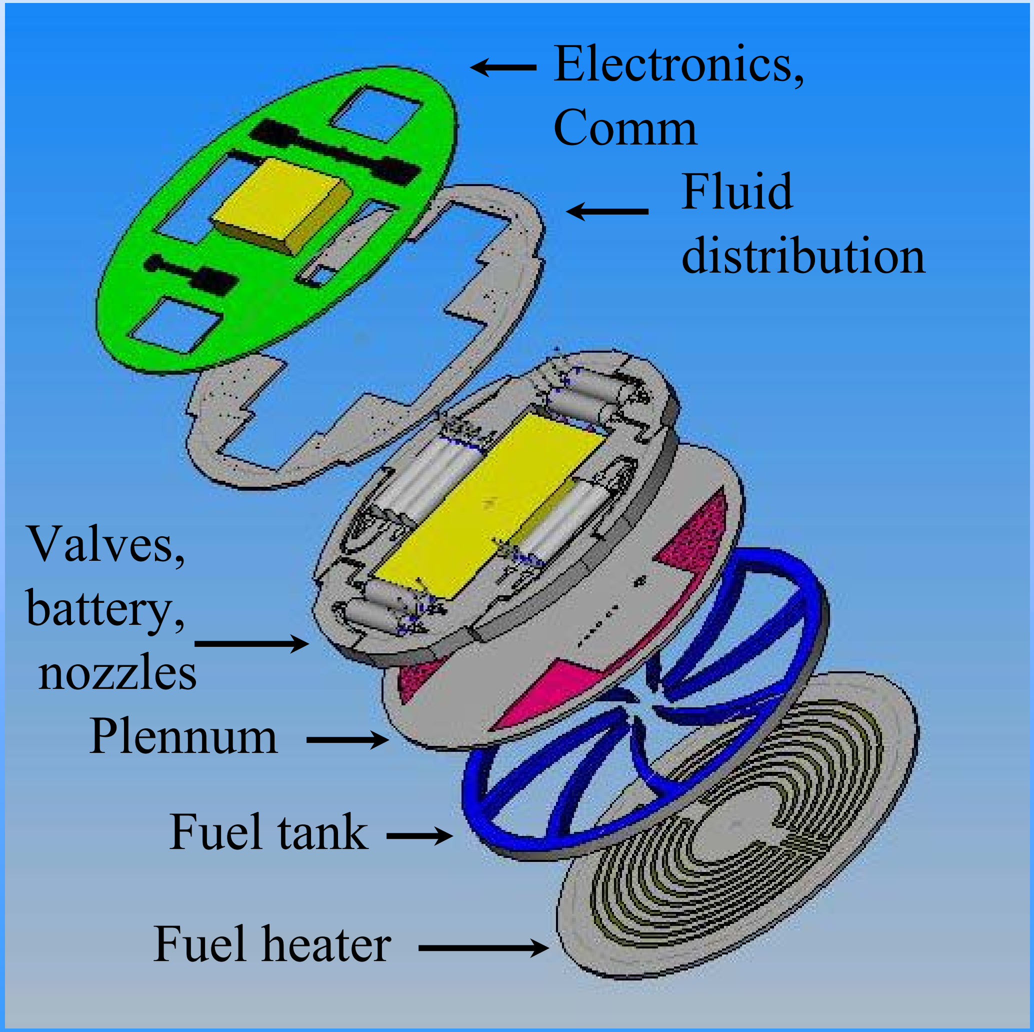
De-orbit (Δv):
- Total: ~0.17 m/s

CO-Orbiting Satellite Assistant (COSA)

- Status
  - –Vehicle design is complete
    - 9cm dia x 1cm thick
    - Total weight 160 gm
    - Mission 1 week
    - Disposable satellite
  - –Fabrication to begin in April.

8 thrust vector nozzles





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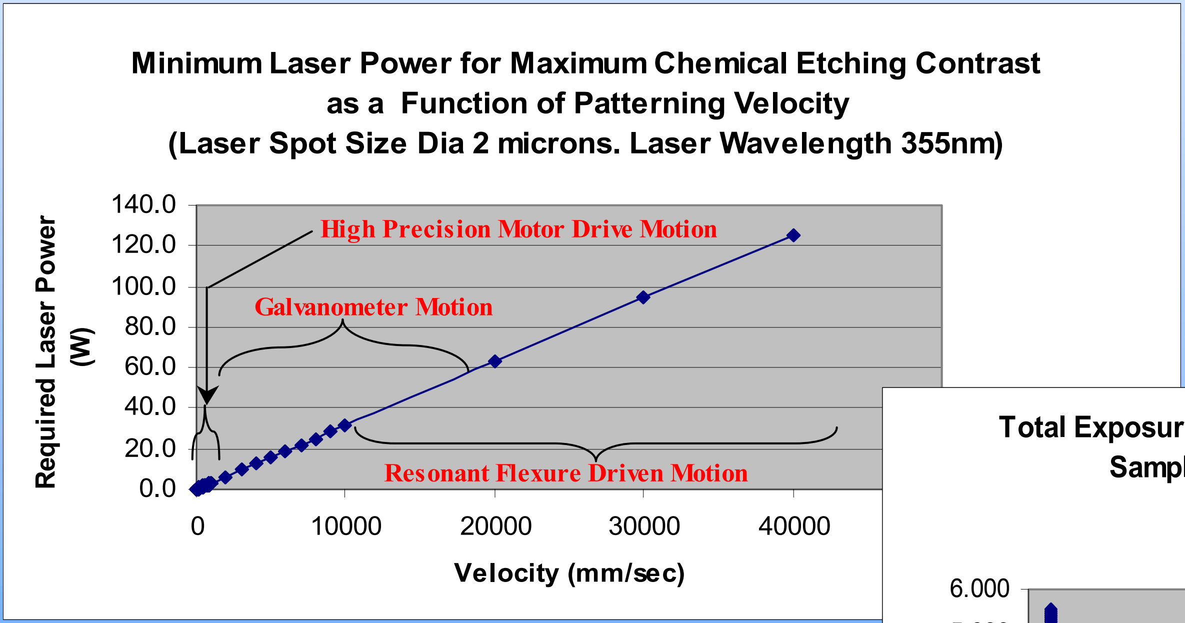
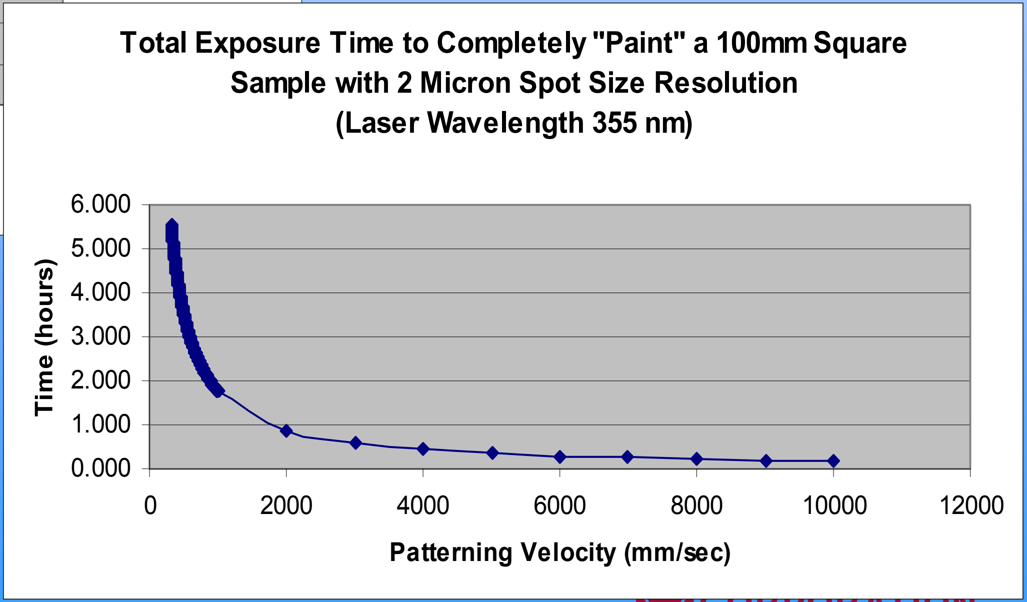
Exposure Time & Required Power: An Illustrative Case Study

For laser wavelength of 355nm, a spot size of 2μm and patterning speed of 1mm/sec, A minimum laser irradiance (I) of 1mw/μm^2 is needed to obtain the maximum etch rate (@ 266nm, I ~ 0.2 mw/μm^2)



For 266nm Laser Wavelength the Required Laser Power is a factor of 5 less, but the penetration depth is ~350 μm



Processing Examples Based on Data from Existing PSGC Material

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Manufacturing Type Scenarios
Using Digital Scripted Processing of PSGC Materials
Using a Direct-Write Scheme

- Small Intranet Linked Workstations
  - Integration of a bench top microscope, with a nominal XYZ motion system coupled with a miniature femtosecond laser for small-scale 3D exposure patterning.
- High Throughput and Very Large Area Manufacturing Facility.
  - Up to KW of UV pulsed laser light,
  - With 250W incident UV laser light,
  - A processing speed of 10 meters/sec,
  - 11 μm diameter spot size,
  - A 100 mm square surface is <u>completely</u> patterned or "painted" in <u>under</u> 2 minutes.

microscope

+

Fs fiber laser

DOE – Jefferson Laboratory Free Electron Laser Processing Facility


Adam Huang
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Bill Hansen
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Thank You
Lee Steffeney
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