LLE Laser Stability Monitoring

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Problem Statement

The Laboratory for Laser Energetics (LLE) is developing nuclear fusion technology and exploring the fundamental science of fusion with the use of the **Omega-60 Laser System**, that focuses up to 40,000 J of energy onto a sample in about one nanosecond using 60 lasers. The laser system control requires high-precision optical measurements and stability monitoring as it needs to hit a target smaller than 1mm in diameter.

According to the ultraviolet targeting stability test report from LLE, the lasers in the Omega-60 are experiencing micro-scale drift, which seems to be the effect of the surrounding conditions in the target bay. The sources of these drifting behaviors must be identified to find a method to minimize the drift.

Requirements and Specifications

Requirements	1	Improve LLE's understanding of drift sources			
	2	Model thermal effects on transport mirrors			
	3	Test hypothesis of stray heat sources in the chamber affecting the transport mirrors			
Specifications		Value	Unit	Description	Method of evaluation
	1	1	µm	The magnitude of drift caused by a thermal source	Simulations and Experiments
	2	0.1	° C	Maximum increase in ambient temperature due to measurement apparatus	Thermal camera

Concept Description

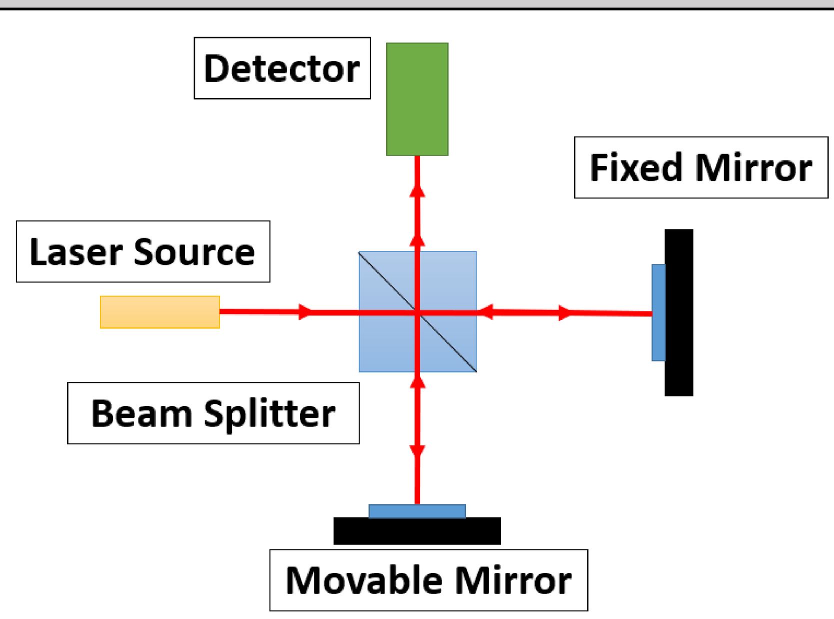

Figure 1: Michelson Interferometer

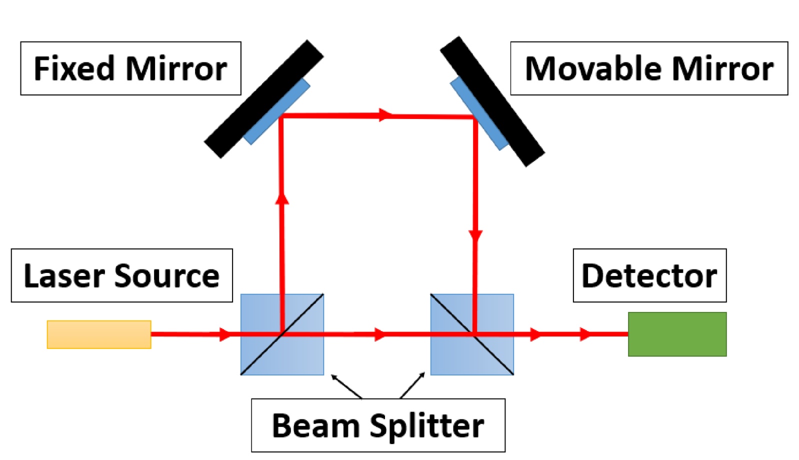

Figure 2: Mach–Zehnder interferometer

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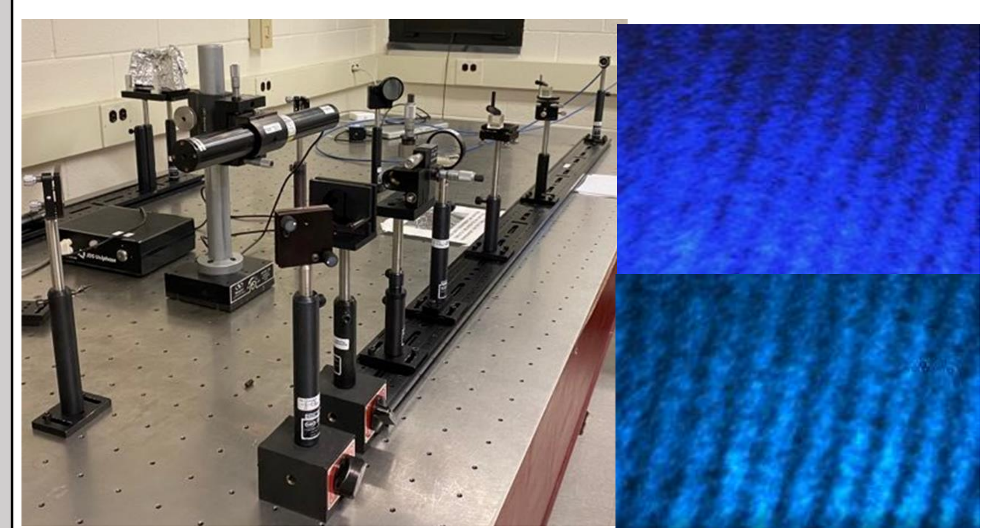
Testing

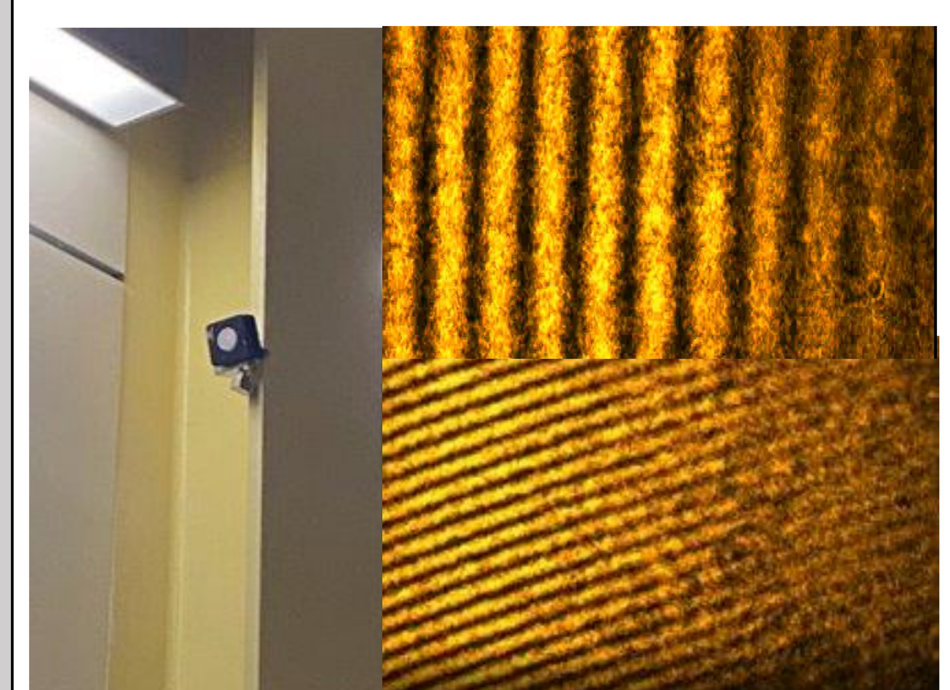
Optical Bench Setup



Optical setup is vibration-isolated with better temperature control, allowing for more accurate model of the thermal effects.

For the purposes of this experiment, the movable mirror mount was positioned on top of a steel plate kinematically supported by 3 aluminum L-blocks. One of the L-blocks was heated using a Kapton heater and then cooled by free convection. As the block was being heated, it was expanding, making the steel plate tilt, translating to the tilt of the mirror.

Rettner Setup

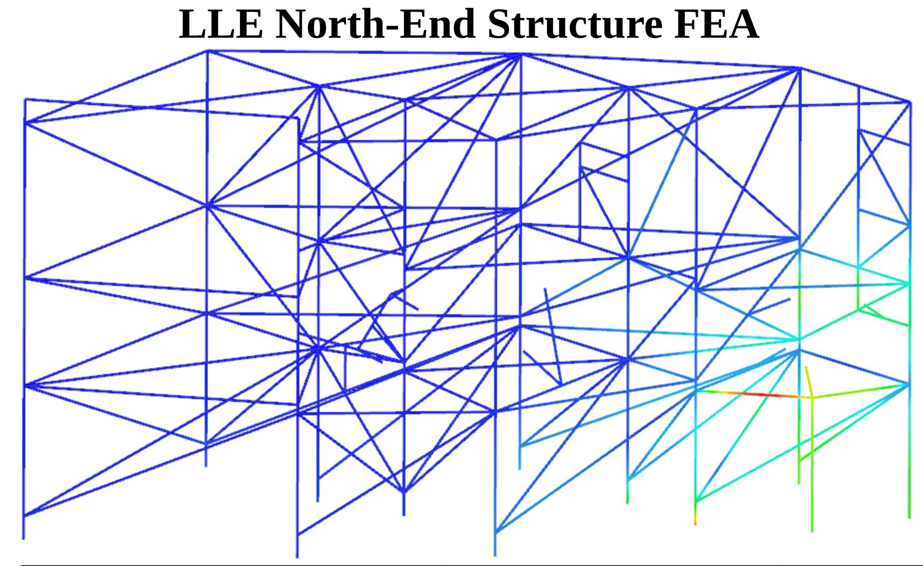


Rettner hall has a large open atrium with long distances and steel structure, which resembles and will better model the LLE transport mirror structures .

To attach the movable mirror on an I-beam , a kinematic magnetic adapter was designed and manufactured. The movable mirror was moved near the middle of the beam and was angled down. The interferometer was tilted upwards using a bolt and moved 12m away from the mirror. Kapton heaters were attached to the bottom of the beam, heating it.

Analysis

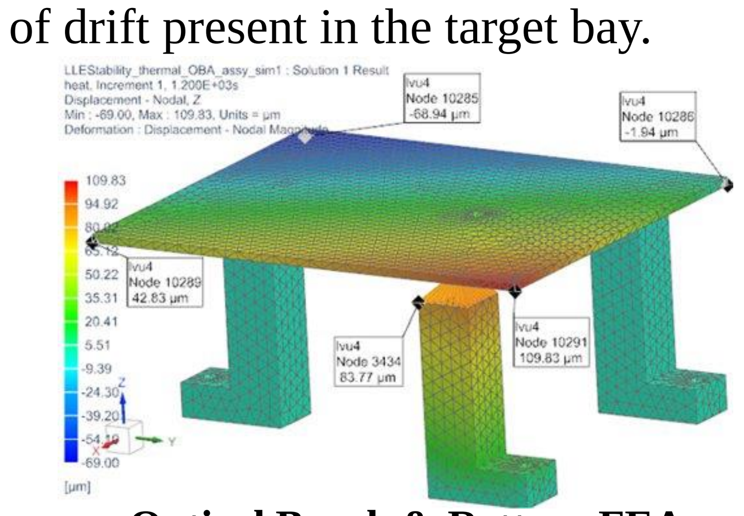
LLE North-End Structure FEA



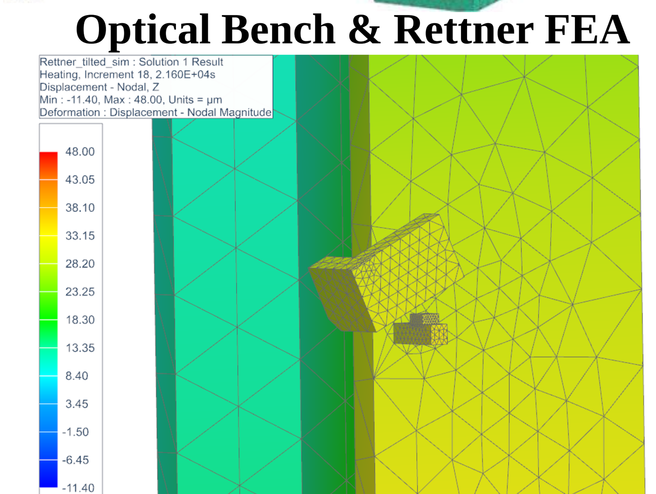
The target bay is kept at 20°C and the peak temperature of transport mirror structure after heating simulation was 20.15°C. The drift values computed from the rotation values from the thermal FEA suggest that a tiny change in the thermal profile in the structure can lead to drift in the laser.

The largest drift magnitude was at transport mirror 30, which was **16.917µm** with **0.98% error** compared to the drift value of mirror 30, **17.092µm**, from LLE's stability data. However, the drift values of all the other mirrors had over 33% error compared to the LLE's stability data. This indicates that there are more sources of drift present in the target bay.

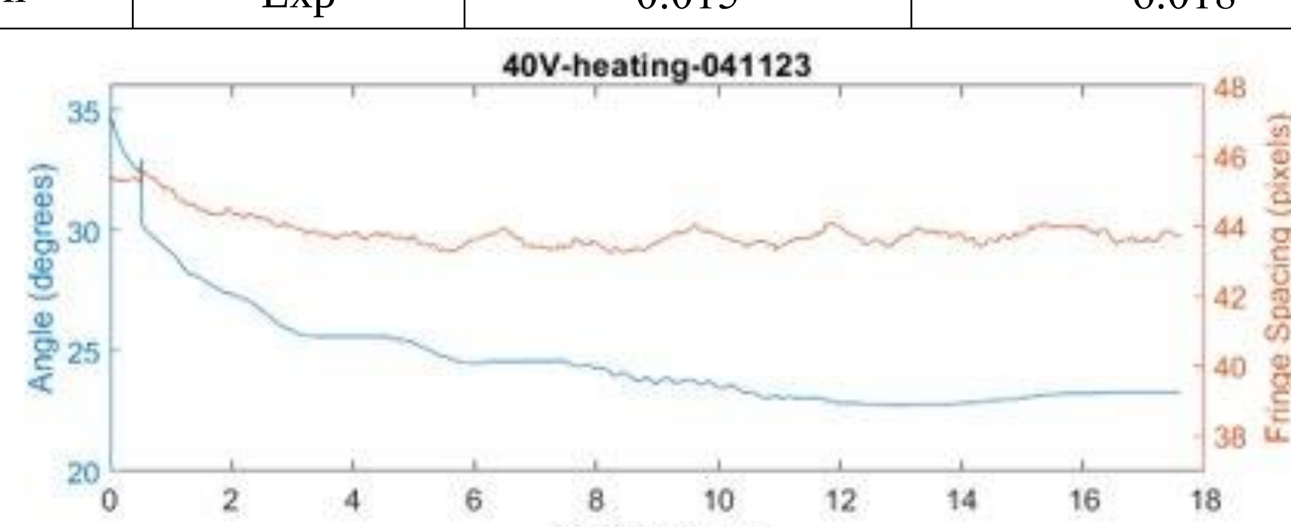
Heating experiment		Tilt angle [deg]	Total drift [mm]
Optical Bench 16.08W – 20min	FEA	0.056	0.750
	Exp	0.036	0.475
Rettner 33.6W - 6h	FEA	0.00485	2.002
	Exp	0.015	6.018



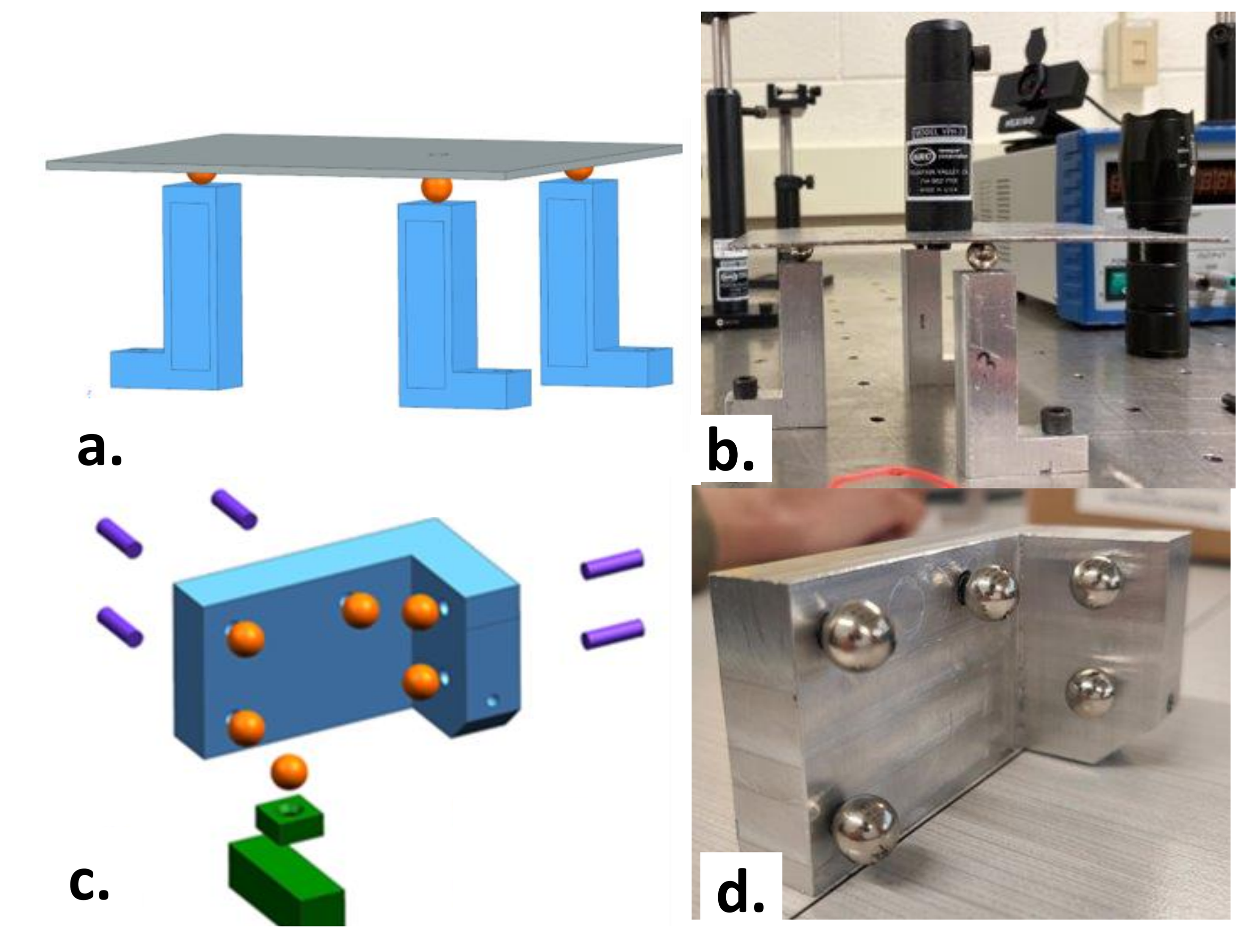
Optical Bench & Rettner FEA



Optical Bench Experiment



Manufacturing



a. CAD model of the Optical Bench Kinematic 3-stage Mount
b. Actual Optical Bench Kinematic 3-stage Mount
c. Exploded view of the Rettner Kinematic Mount
d. Actual Rettner Kinematic Mount

Future Work

- A more accurate model can be simulated by having heat sources radiate or conduct heat to the structure and with thermal images of all the transport mirrors.
- From the thermal images, it was found that the highest temperature profile was observed on the motors on the mirror mount, which are used to hold the mirror at specific orientations. A thermal analysis of the mirror mount on the LLE transport mirror structure can be performed to see if the motors affect the tilt of the mirror.
- A sample transport mirror mount from the LLE can be connected to a control system to actuate the motors to observe their change temperature profile changes.
- Downward-facing mirrors may be associated with increased actuator temperatures and higher drift. This can be verified using the mirror mount sitting at a varying angle. If this is found to be true self-locking power screws may present an alternative to actuators that is more resistant to orientation.
- A quad cell setup is recommended instead of the interferometer because calculations are complex and fringe data is difficult to analyze accurately. In theory, quad cells are much easier use. However, the disadvantage will be the resolution of the data and budget.

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