



Simultaneous Convective and Radiative Heating of Materials with the 200 kW Laser Enhanced Arc Jet Facility (LEAF)

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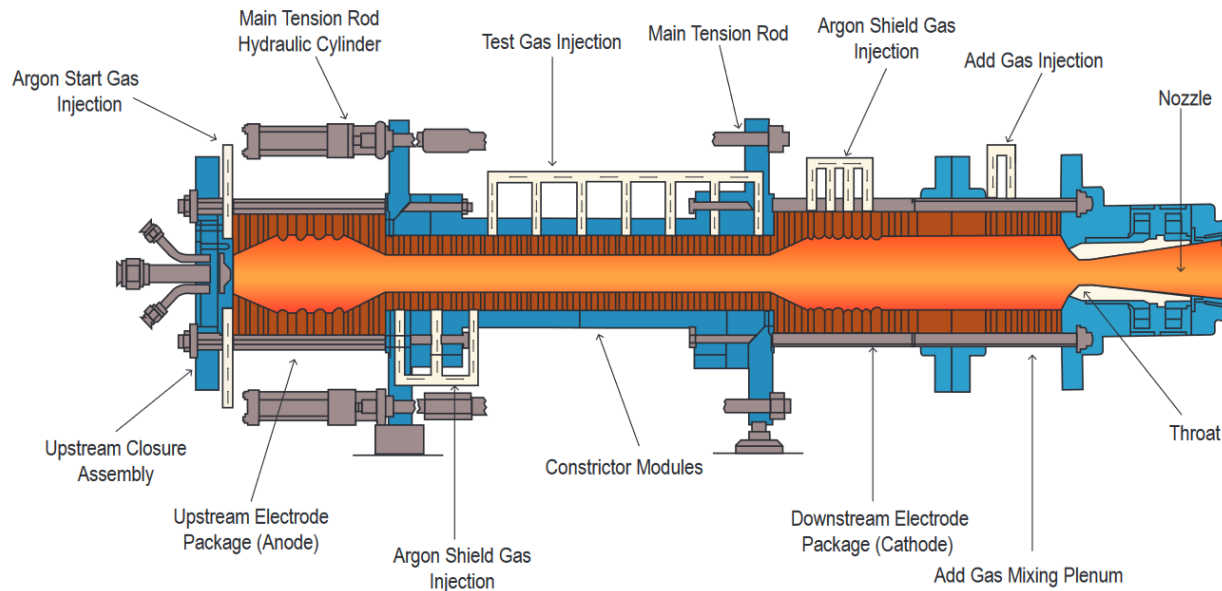
NASA Arc Jet Complex



- 60 MW Interaction Heating Facility (IHF)
- 20 MW Aerodynamic Heating Facility (AHF)
- 10 MW TP3
- 20 MW Panel Test Facility (PTF)
- 20 MW 2x9 Turbulent Flow Duct (TFD)
- Gases
 - Air
 - Nitrogen
 - Oxygen
 - Carbon Dioxide



- The Interaction Heating Facility (IHF) has a 60 MW constricted arc-heater which operates at pressures from 0.1 to 1 MPa and enthalpy levels from 5 to 28 MJ/kg (2000 to 12,000 Btu/lbm).
- With the 7.6 cm (3 in) nozzle, IHF can deliver heat fluxes as high as 4.5 kW/cm² to 5 cm (2 in) diameter iso-q stagnation models
- Can operate in stagnation, free jet wedge, or flat panel test configurations in simulated hypersonic boundary layer flow environments





Laser Enhanced Arc jet Facility (LEAF)



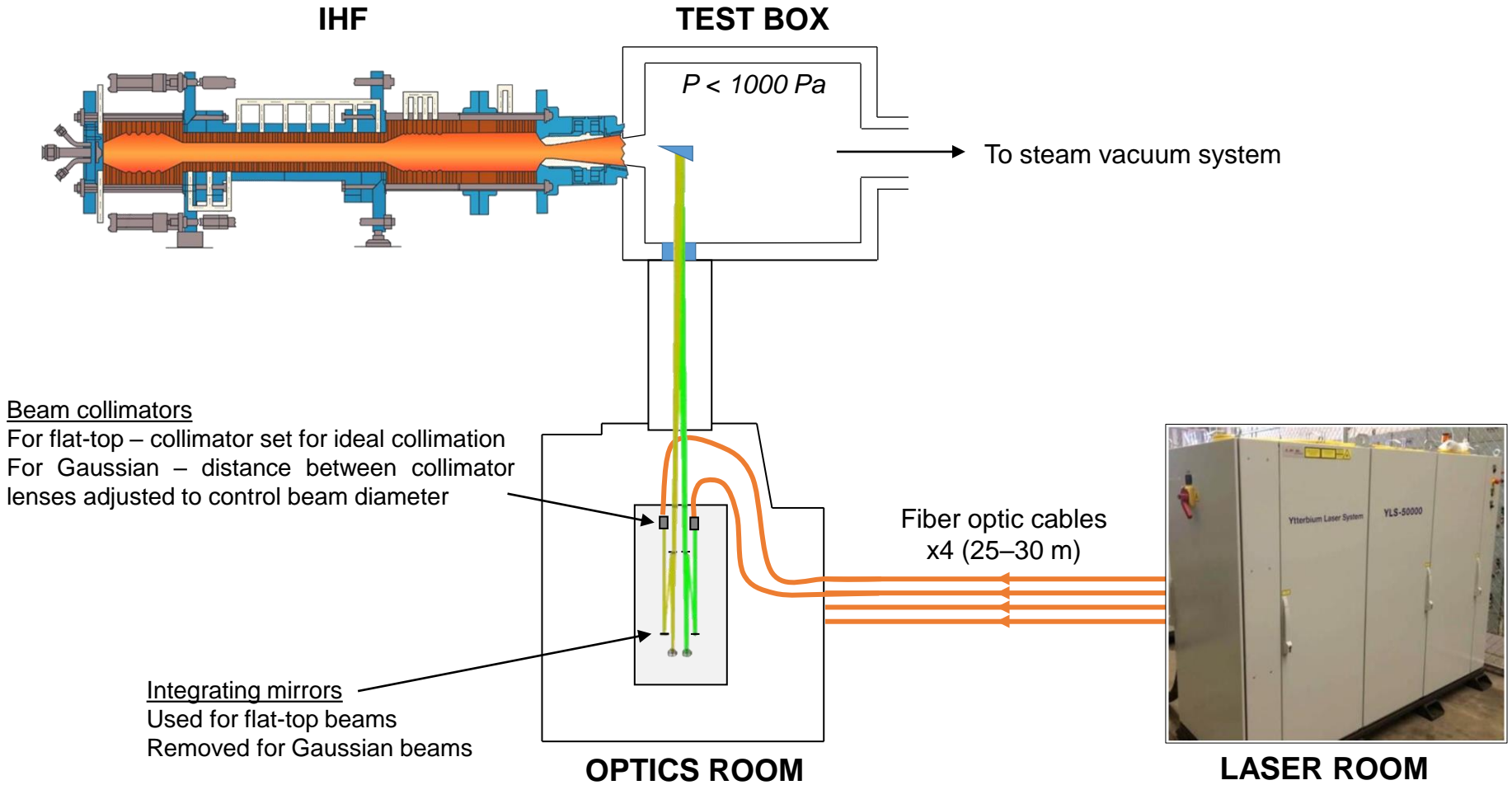
- Orion (capsule for Artemis missions) returns to Earth at 11 km/s. The bow shock produced upon re-entry generates significant radiative heating. The Orion program supported the addition of the LEAF radiant heating capability to IHF.
- In LEAF configuration, IHF can deliver **convective** heat fluxes up to...
 - **160 W/cm²** (141 Btu/ft² s): 22.9 cm nozzle on 20° 15.2 cm square wedge
 - **70 W/cm²** (62 Btu/ft² s): truncated semi-elliptic nozzle on 43.2 cm square panel
- Four 50 kW lasers can be combined to deliver up to 200 kW to a model
- Output wavelength of 1070 nm
- Constrained by existing IHF infrastructure, radiant heating is applied 90° from the arc jet axis, so combined heating for wedge and panel testing only
 - Wedges up to 15.2 cm (6 in) square with angles from 20° to 45°
 - Panels up to 43.2 cm (17 in) square at angles from -5 to 9°

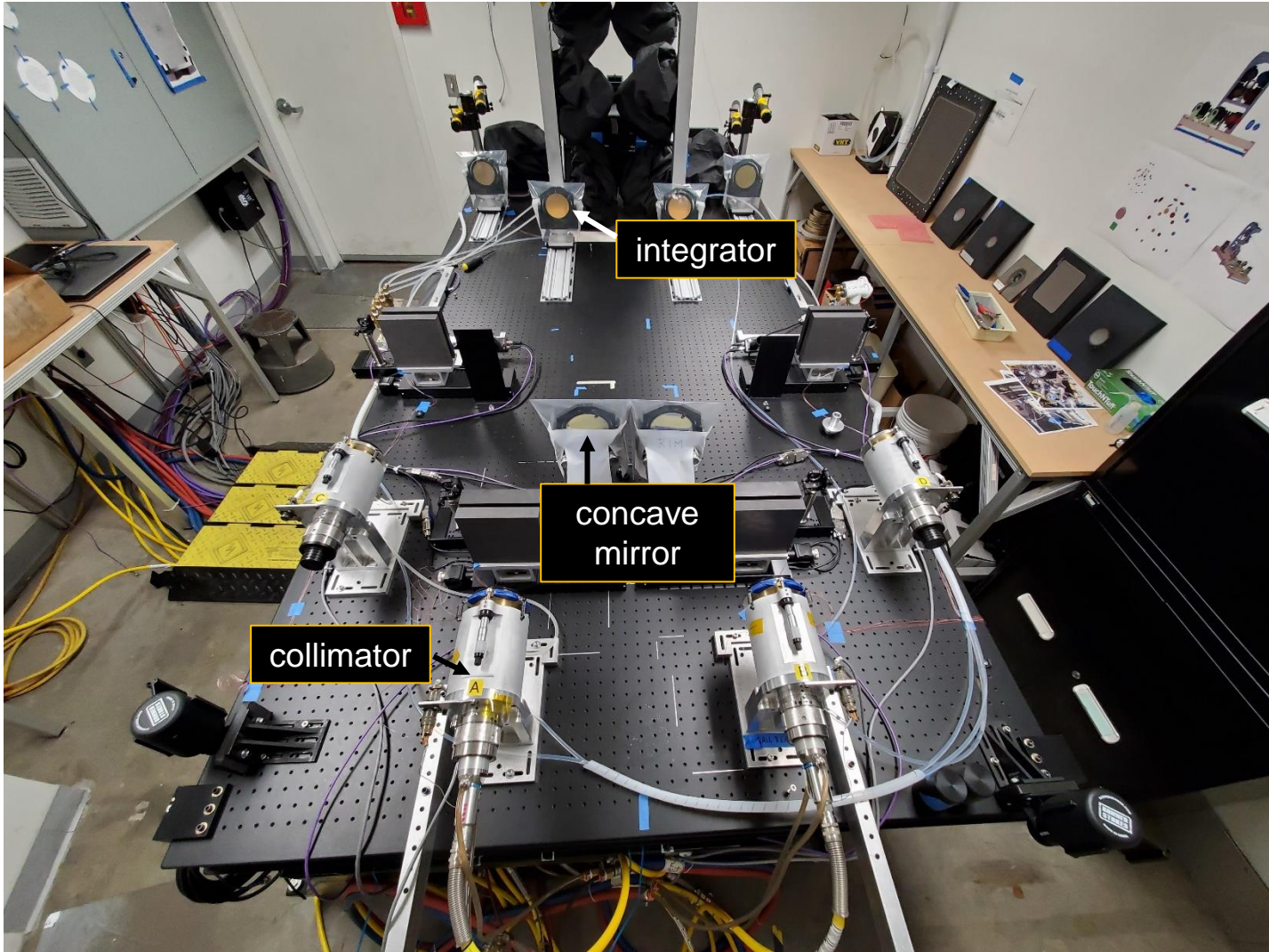


LEAF Addition to IHF



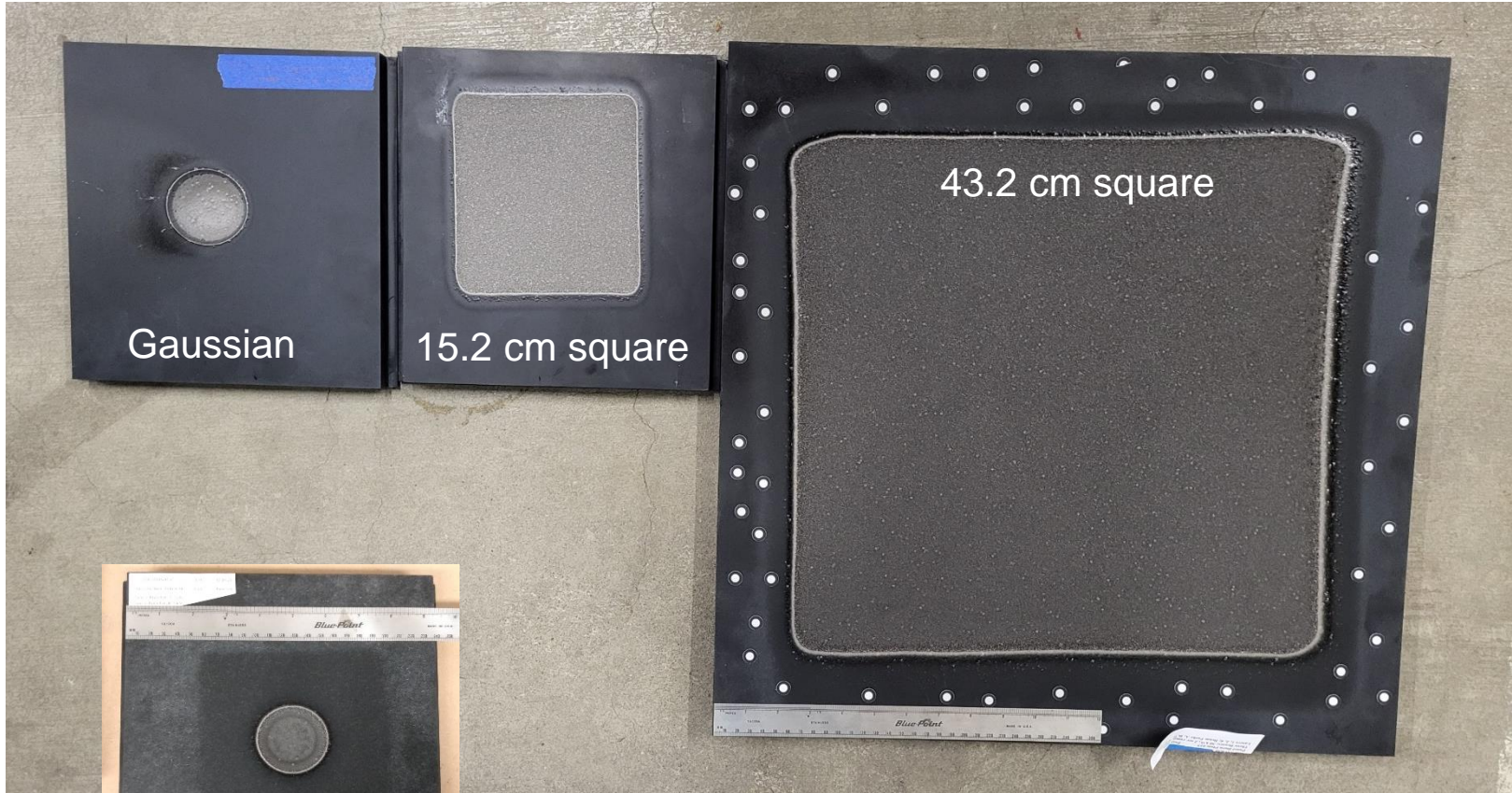
Overhead view (not to scale)





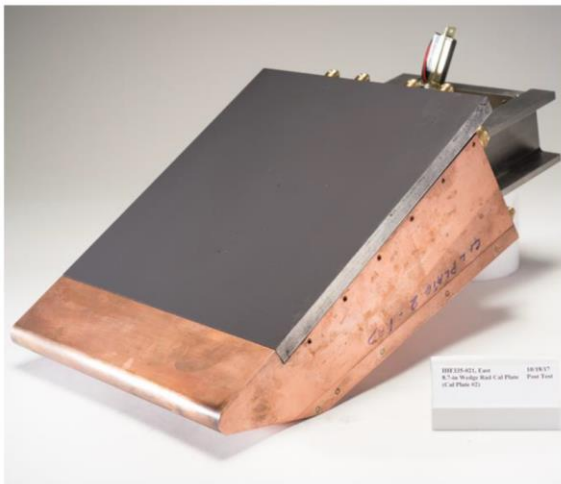
Test location is behind viewer

LEAF Configurations

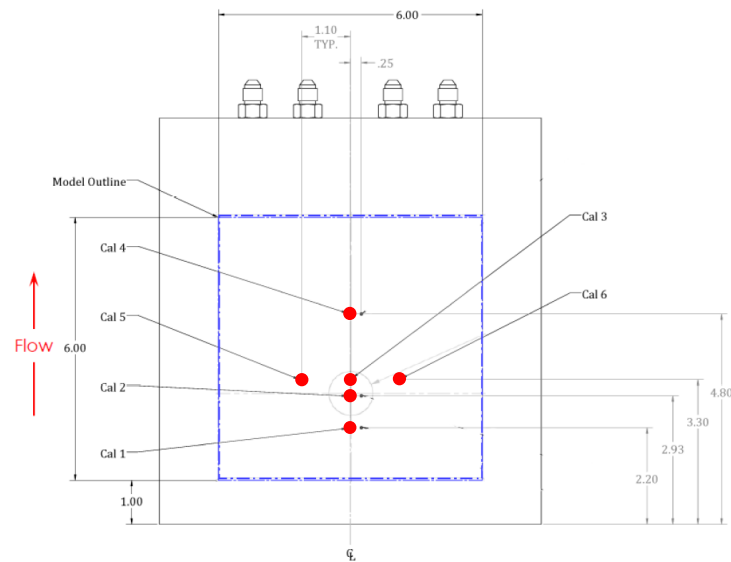


15.2 cm square + Gaussian

- For flat-top square beams, the irradiance is within the working range of radiant calibration plates
 - Water-cooled Gardon gauges
 - Coated with black VHT SP102 paint
 - Plates are placed exactly where the model surface will be
 - Must carry out a separate run specifically to measure the irradiance that will be delivered to the model



AIAA 2018-3273





Square Beam Irradiance



15.2 cm x 15.2 cm Wedge Test

	Set Point Power [kW]	Average Cal Plate Reading [W/cm ²]
Run 1	10	33
Run 2	20	83
Run 3	40	168
Run 4	80	340
Run 5	100	392

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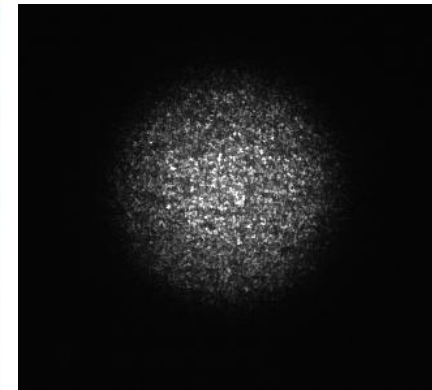
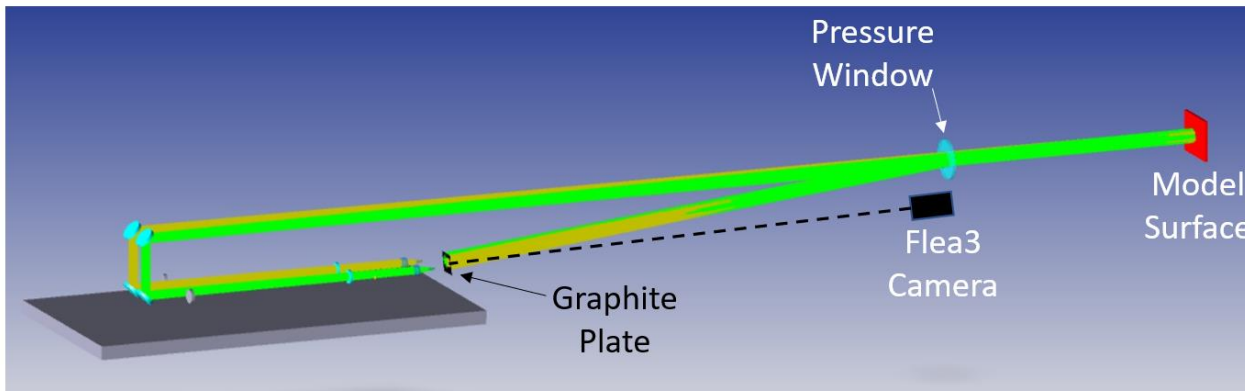
Note: Smaller square only required two lasers to reach Orion requirements

43.2 cm x 43.2 cm Panel Test

	Set Point Power [kW]	Average Cal Plate Reading [W/cm ²]*
Run 6	50	23
Run 7	120	59
Run 8	200	91

*Average towards the center, retesting in 2023

- Gaussian beams produce irradiance levels above the working range of the calibration plate gauges, need another method
- Optical method
 - Beam profile from near-infrared camera (FLIR Flea3)



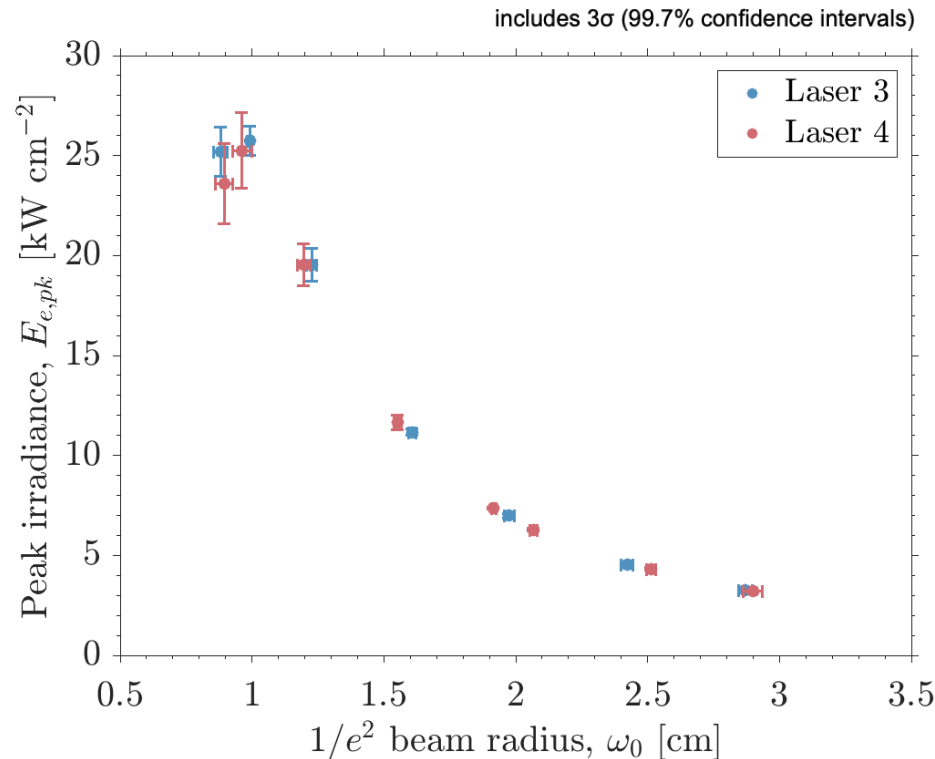
- Laser power from power meter (Ophir)
 - These two measurements together give a 3D irradiance profile
- This measurement can happen during customer testing, no need for a separate run to obtain irradiance
- Current effort - attempting to implement this optical irradiance measurement method for the 15.2 cm flat-top square beam



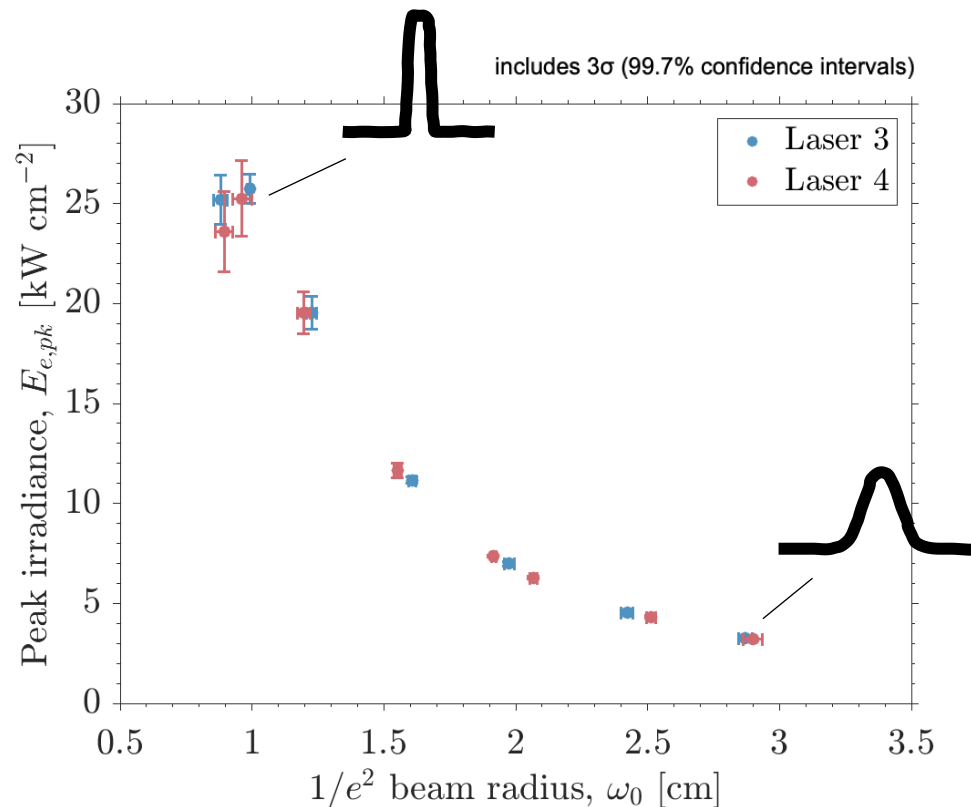
Super-Gaussian Peak Irradiance



- Characterization of beam shape – laser runs at 7 different collimator settings
- All runs at 50 kW
- Peak irradiance levels up to **25.7 kW/cm² per laser** at 1/e² radius of 1 cm



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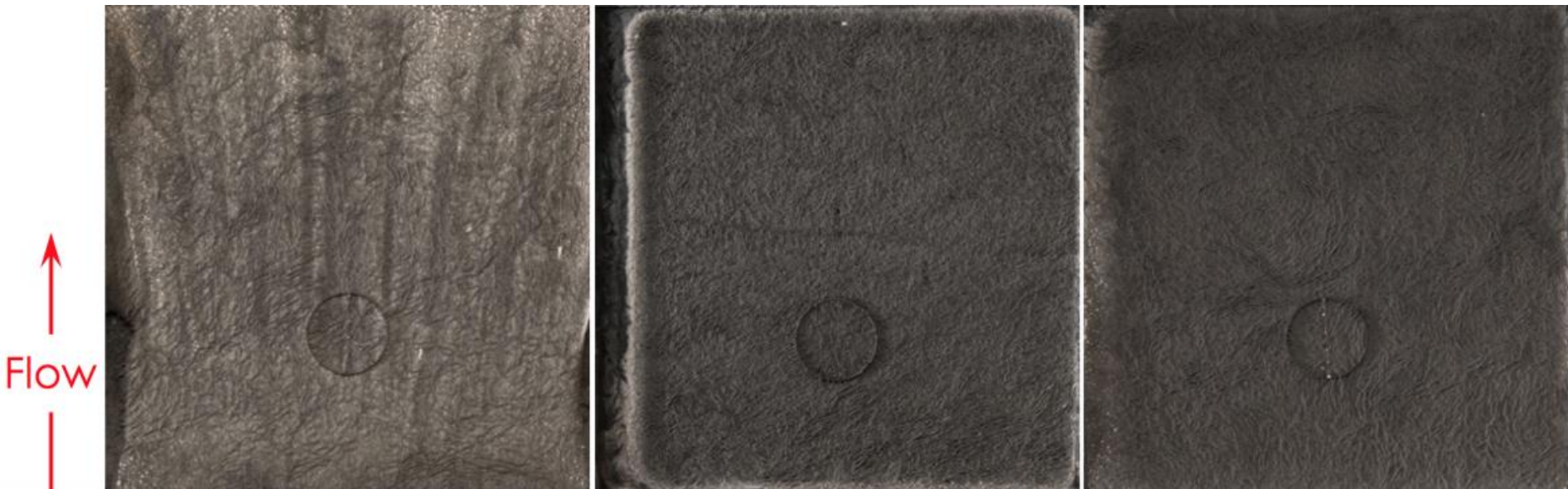


- Orion testing has indicated that material response does depend on the heat transfer mechanism

Convective 160 W/cm²

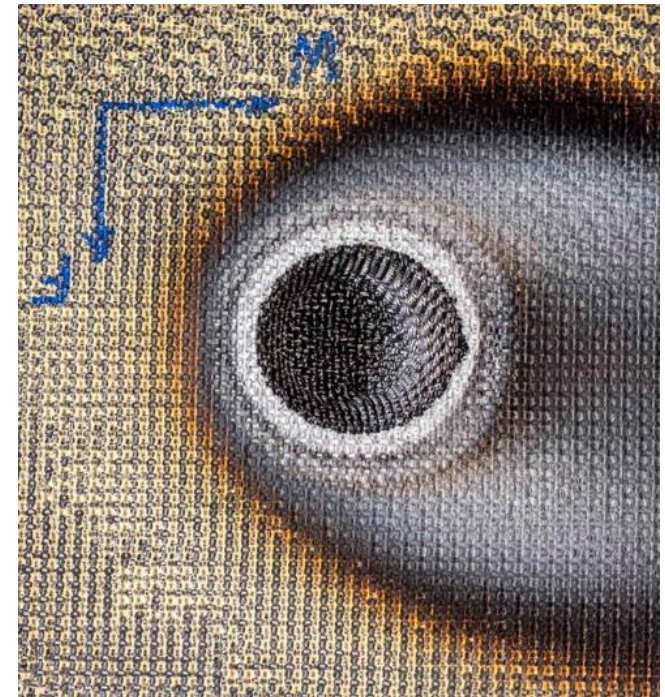
Radiative 168 W/cm²

Combined 88 C + 83 R W/cm²



Venkatapathy et al. NSMMS 2018
NASA NTRS Doc ID 20180006634

- Recent radiant-only super-Gaussian testing for our Thermal Protection Materials Branch
- Insight into 3D woven material performance at 11.6 kW/cm² peak irradiance



- Have also done convective + radiant testing with the super-Gaussian beam



Summary (SI units)



To our knowledge, IHF+LEAF is the only US facility that can simultaneously provide MW-scale convective heating and kW-scale radiative heating of material samples:

- 15.2 cm square configuration
 - 160 W/cm² convective + 392 W/cm² radiative = **552 W/cm² combined**
- 43.2 cm square configuration
 - 70 W/cm² convective + 91 W/cm² radiative = **161 W/cm² combined**
- A range of super-Gaussian profiles:
 - Max 160 W/cm² convective, plus...
 - Max peak irradiance of **25.7 kW/cm²** at **1.0 cm** beam radius (1/e²)
 - Max beam radius (1/e²) of **2.9 cm** gives **3.2 kW/cm²** irradiance



Summary (Imperial units)

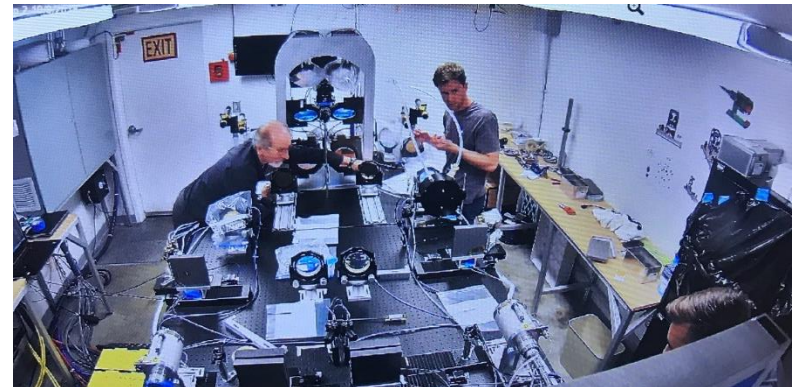


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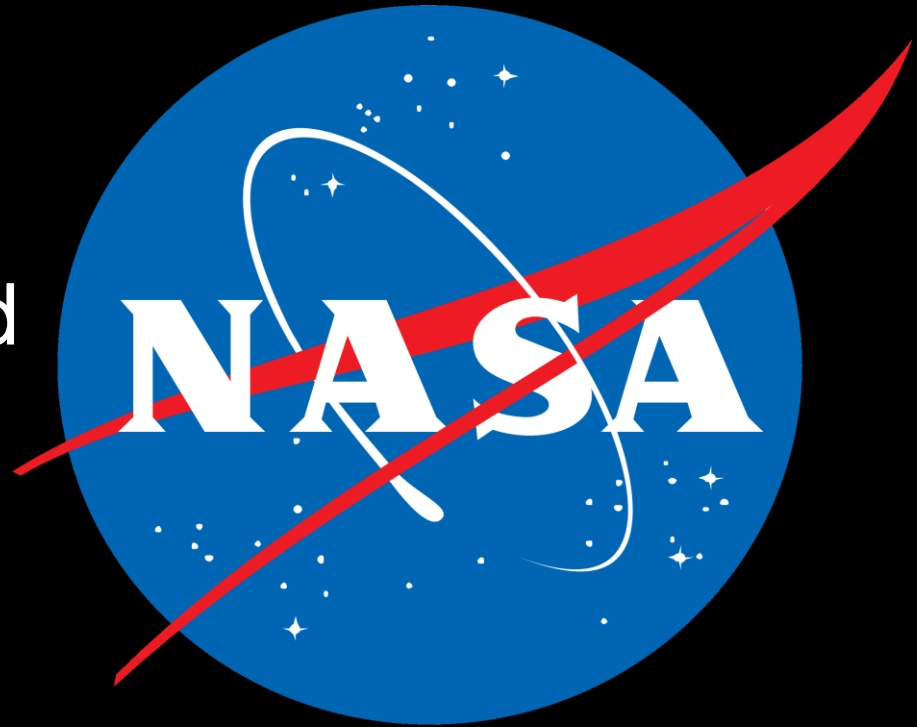
- 6 in square configuration
 - 141 Btu/ft² s convective + 345 Btu/ft² s radiative = **487 Btu/ft² s combined**
- 17 in square configuration
 - 62 Btu/ft² s convective + 80 Btu/ft² s radiative = **142 Btu/ft² s combined**
- A range of super-Gaussian profiles:
 - Max 141 Btu/ft² s convective, plus...
 - Max peak irradiance of **2.3 x 10⁴ Btu/ft² s** at **0.39 in** beam radius (1/e²)
 - Max beam radius (1/e²) of **1.14 in** gives **2.8 x 10³ Btu/ft² s** irradiance

- NASA Orion Program Office
- NASA Thermal Protection Materials Branch
- FCT Portugal (SFRH/B1/154132/2019) for J. Rodrigues
- NASA contract 80ARC022DA011 for J. Hartman
- Craig Walters for his support throughout the LEAF project, especially with beam profiling

Send questions to...
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Entry Systems and Technology Division