

**RMD**

A Dynasil Company (1)

Validation Test Flight of a Holographic Cloud Particle Imager (HCPI) for Unmanned Aircraft Systems (UASs)

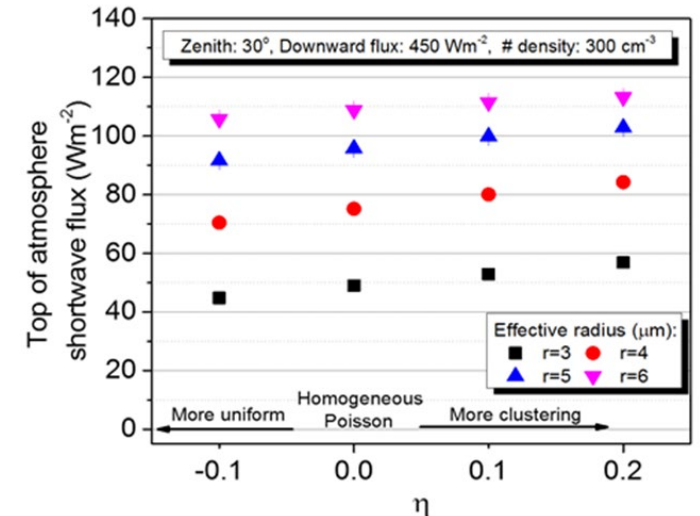
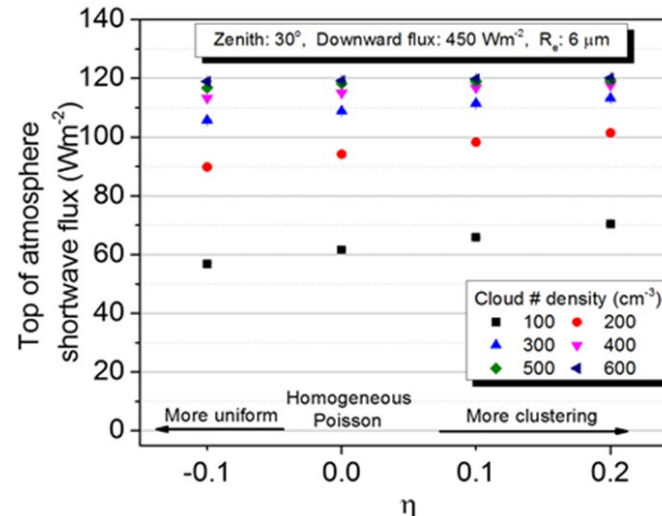
ARM/ASR Joint User Facility and PI Meeting 2021

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Major uncertainty in current climate models pertains to clouds.

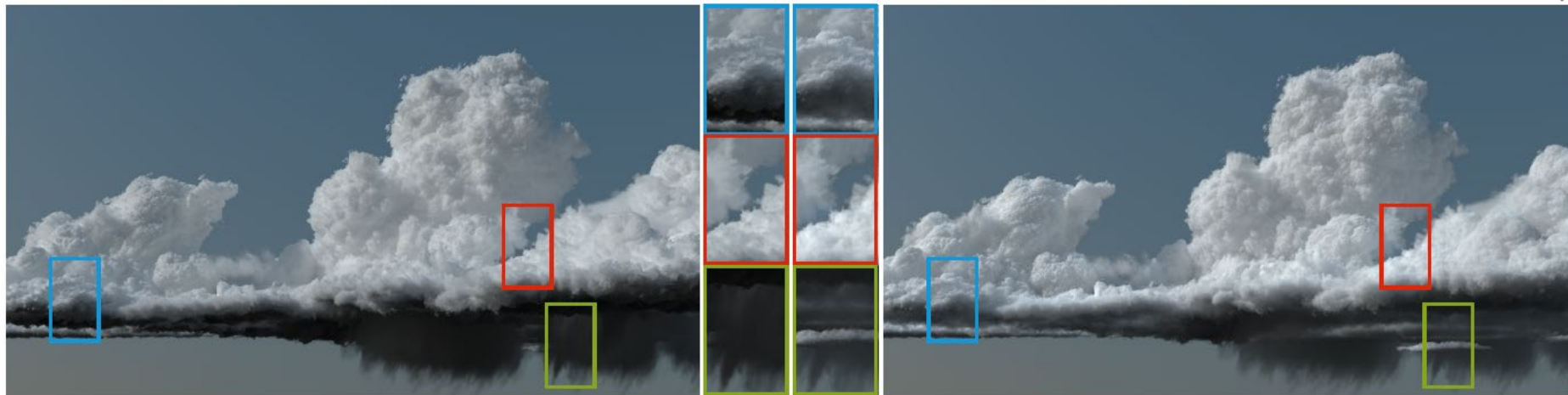
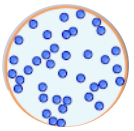
The pair correlation function, $\eta(r)$, quantifies the “patchiness” of a particle distribution.

Monte Carlo models

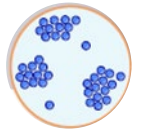


Two renderings of clouds using different distributions

$$\eta = 0$$



$$\eta > 0$$



Benedikt Bitterli, Srinath Ravichandran, Thomas Müller, Magnus Wrenninge, Jan Novák, Steve Marschner, and Wojciech Jarosz. 2017. A radiative transfer framework for non-exponential media. *ACM Trans. Graph.* 9, 4, Article 39 (March 2017).

Jarabo, A., Aliaga, C. and Gutierrez, D., 2018. A radiative transfer framework for spatially-correlated materials. *ACM Transactions on Graphics (TOG)*, 37(4), pp.1-13.

Other Potential Science Goals

- Investigating turbulence and mixing
 - Stochastic condensation → broad size distributions in clouds
 - Correlations in droplet number concentration and droplet mean diameter
 - Droplet growth from $20\text{ }\mu\text{m}$ to $40\text{ }\mu\text{m}$
 - Finding evidence of ice multiplication
-
- We measure the instantaneous distribution of cloud particles with in-line holography.



Rime-splintering



Collision fragmentation



Droplet shattering

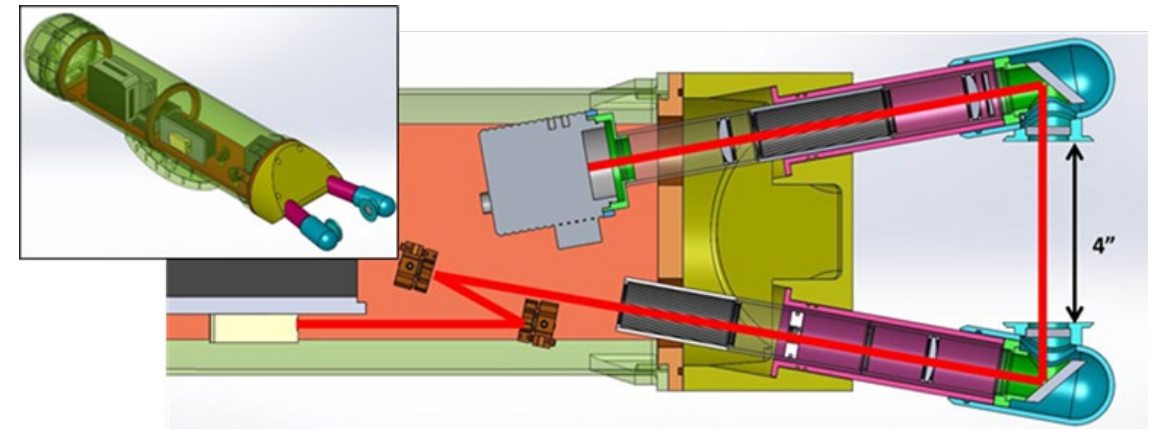
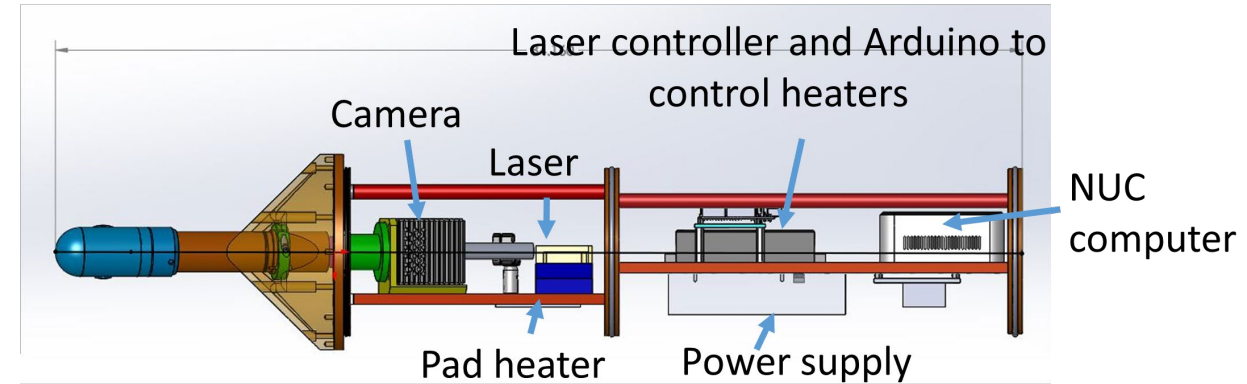


Sublimation fragmentation

From "Field, Paul R., et al. "Secondary ice production: Current state of the science and recommendations for the future." *Meteorological Monographs* 58 (2017): 7-1.

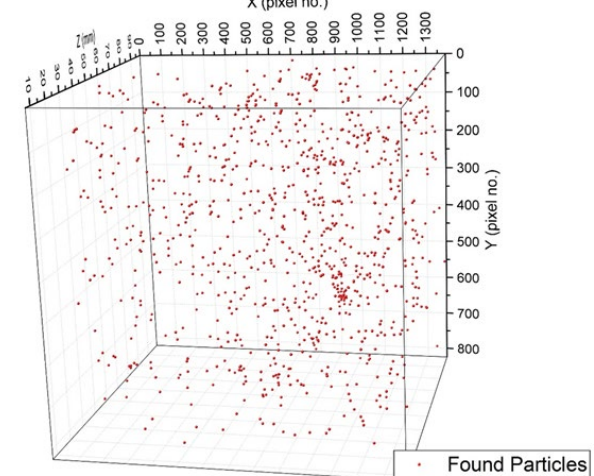
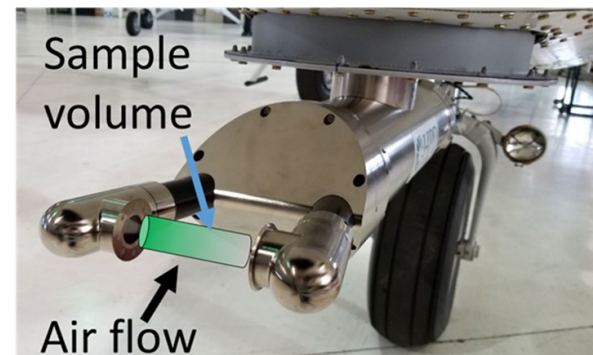
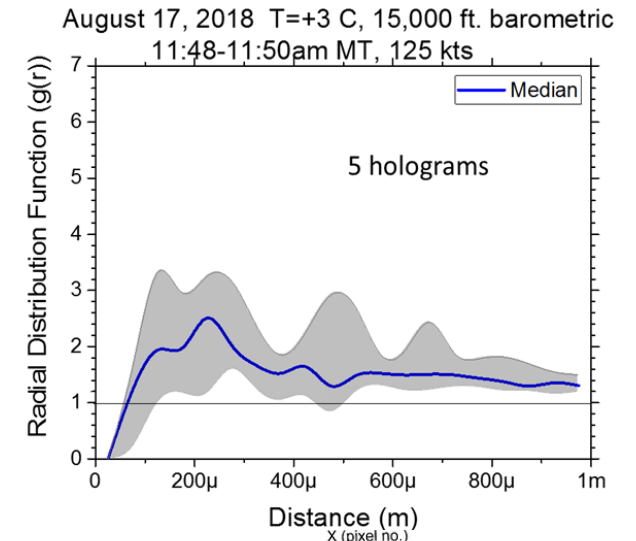
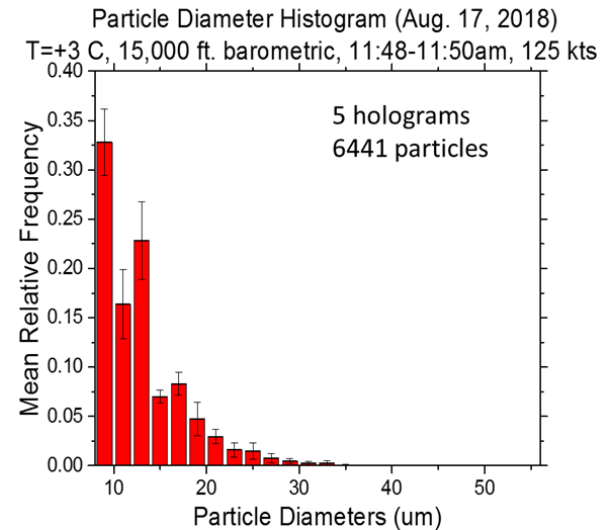
Instrument Overview

- Manned aircraft prototype has components mounted on breadboards within the PMS canister
- In-line holography
- Power: 3.25 A @ 110 VAC
- Weight: 18 kg
- Resolution: $19.68\ \mu\text{m}$ characterized by 1951 USAF resolution target
- $\sim 16\ \text{cm}^3$ sample volume
- Live viewing and control through ethernet



Data products

- Raw holograms (~10 MB each)
- Processed holograms (background subtracted, etc.)
- 3D volume with particles displayed (ASCII file with particle location) (<100 kB each)
- Droplet size distributions (ASCII file, <1kB each)
- Pair correlation functions (radial distribution functions) (ASCII file, <10 kB each)



Validation Test Flights on Univ. of Wyoming King Air

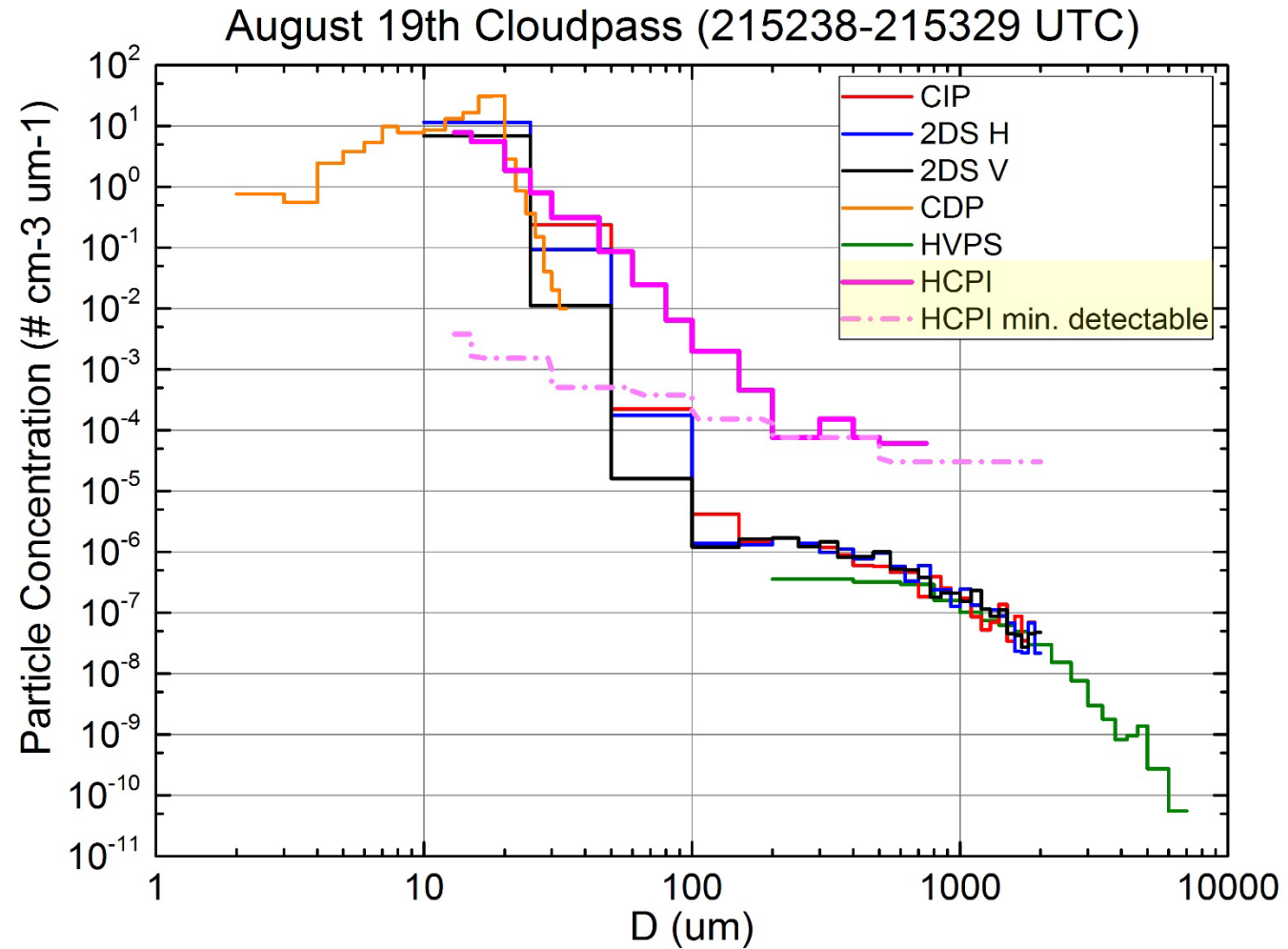
- To confirm the accuracy of holographic data analysis in real atmospheric conditions, HCPI was mounted on same aircraft as several common atmospheric science instruments.
- Other standard measurements including temperature, wind speed, dew point, liquid water content (LWC), etc.

Instrument	Particle size range (μm)	Resolution (μm)
SPEC Inc. 2D-S	20 – 1300	10
SPEC Inc. High Volume Precipitation Spectrometer (HVPS)	300 – 1000's	150
DMT Cloud Droplet Probe (CDP)	2-50	1-2
DMT Cloud Imaging Probe (CIP)	50-1600	25



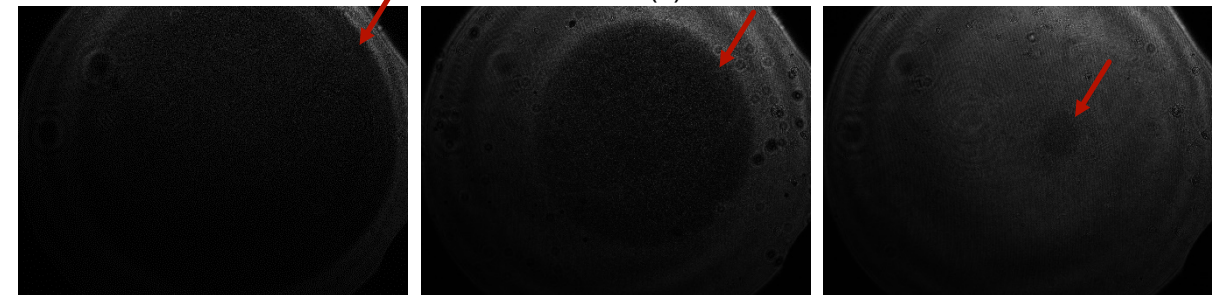
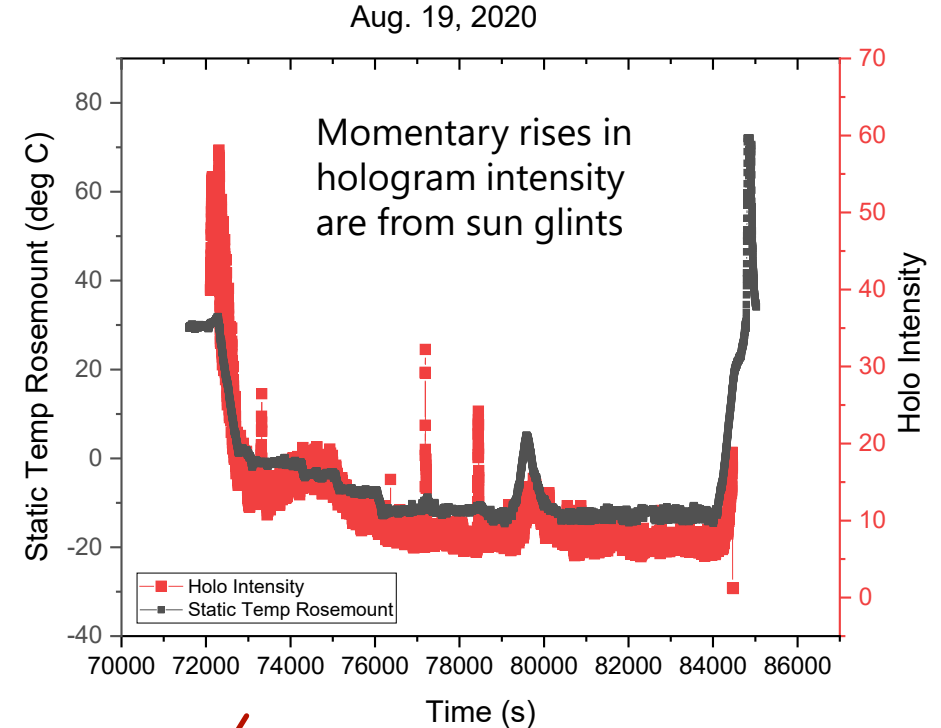
Droplet Size Distributions

- Bins under $60\text{ }\mu\text{m}$ have over 100 particles
- Overlap of HCPI size distribution with the CDP and 2D-S around $20\text{ }\mu\text{m}$ diameter
 - Fairly good
 - Shattering could be causing some particles in this size range to shrink below detection range
- Overlap of HCPI with CIP and 2D-S from $50\text{-}100\text{ }\mu\text{m}$
 - Large overestimation in concentration by HCPI
 - Overlapping particles
 - Astigmatism
 - Small sample size
 - Needs further processing



Hologram Dimming

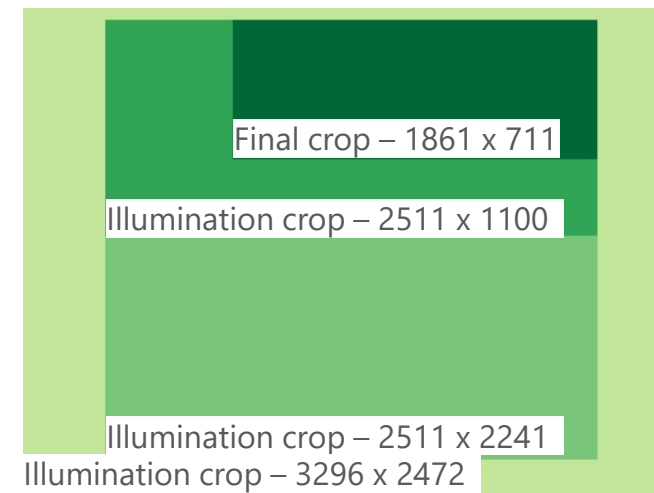
- The hologram brightness tracks the outside air temperature very closely.
- A layer of fog and/or frost developing over the windows may be leading to decreased brightness and contrast in the holograms.
- Solutions:
 - 1) heat the windows more,
 - 2) apply anti-fog/anti-frost coating to windows,
 - 3) purge interior of instrument with nitrogen before flight.



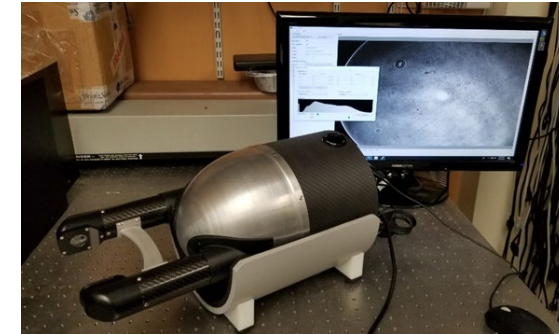
Warming left to right

Future Work

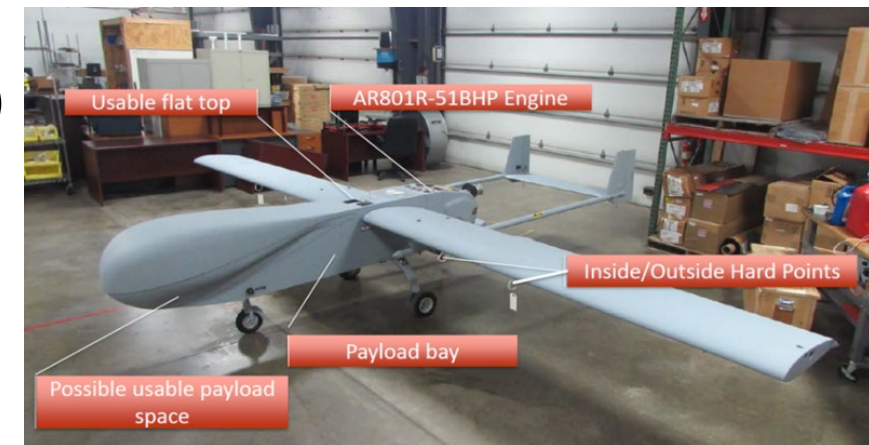
- In the second year of the Phase IIB we will:
 - resolve hologram dimming problem (to increase usable hologram volume) and fly once more,
 - resolve droplet size distribution discrepancy,
 - continue analyzing holograms from validation test flights to answer science questions,
 - continue to accelerate the holographic analysis software in conjunction with EM Photonics, and
 - create a design package (hardware and software) that we could provide to a major vendor like Droplet Measurement Technologies (DMT).
- Longer term:
 - Miniaturize for UAS



Sample area



6.5 kg



DOE ArcticShark
Carrol, Peter.
ArcticShark UAS Overview,
Nov. 7, 2016