Acquisition of Ice Thickness and Ice Surface Characteristics in the Seasonal Ice Zone by CULPIS-X during the US Coast Guard's Arctic Domain Awareness Program

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LONG-TERM GOALS

- Teaming with the SIZRS effort (J. Morrison, Univ. Washington; PI) to:
    - Investigate new technologies, e.g., sensors, platforms and communications, for sustained operation and observation in the challenging Arctic environment
    - Improve understanding of the physical environment and processes in the Arctic Ocean

OBJECTIVES

- *What is the volume of sea ice in the Beaufort Sea SIZ and how does this evolve during summer as the ice edge retreats*? Recent observations suggest that the remaining ice in the Beaufort Sea is younger and thinner in recent years in part because even the oldest ice advected into the region does not survive the summer.
- *How does ice thickness relate to ice surface conditions, such as reflectance and ice surface temperature?* During summer, melting ice is covered extensively by melt ponds, which exhibit a reflectance considerably lower than the surrounding ice. Recent analyses have indicated that ponds on thinner ice are often darker, accelerating the ice-albedo feedback over thin ice in summer. During winter, leads and very thin ice are centers for ocean-atmosphere heat flux, so their fractional coverage and contribution to the surface-to-atmosphere heat flux need to be quantified.

APPROACH

We plan to utilize the US Coast Guard's (USCG) Arctic Domain Awareness (ADA) Program to fly our CULPIS-X (CU Laser Profiler Instrument – extended) and CULPIS-X2 packages over the Beaufort, Chukchi and Bering Seas. ADA utilizes the C-130 Hercules to fly once every two weeks from late March to late November each year. The ADA C-130 flights originate in Kodiak, Alaska and overfly, among other areas, the Chukchi and Beaufort Seas, providing a unique opportunity to provide extensive, repeated observations of sea ice and the ocean in the SIZ.

The first model of this package, CULPIS-X, is jointly supported by NASA and ONR (this grant) and previously by NSF. The package design is ready for flight approval evaluation via a US Coast Guard (USCG) subcontractor, the US Navy's Naval Air System Command (NAVAIR).

CULPIS-X has been designed by a University of Colorado-Boulder student team, led by PI M. Tschudi, to fit into a USCG C-130 flare tube and operate in a near-autonomous mode. The package contains a laser altimeter/profiler, skin-temperature pyrometer, nadir-viewing spectrometer, snapshot and video cameras, pressure and temperature sensors, aircraft inertial measurement unit, a differential-capable GPS receiver, and payload computer. The CULPIS lidar and a few other components were previously deployed in the Arctic as a package called CULPIS [*Crocker et al.,* 2012]. The CULPIS-X instruments are designed to measure:

- distance to surface measured at 400 observations per second (CULPIS lidar)
- surface reflectance (hyperspectral radiometer)
- surface temperature (Everest infrared thermometer)
- digital snapshots and continuous video
- aircraft pitch, roll, yaw and rates of motion
- GPS position (basic position fix and carrier phase data)
- barometric pressure

After some iteration with the USCG, the method to assess our CULPIS-X package has now been finalized and encompasses the the following steps:

1. CULPIS-X design will be provided to the evaluation vendor, the US Navy's Naval Air Systems Command (NAVAIR).
2. NAVAIR will use our CAD design model to integrate with a C-130 model and perform Computational Fluid Dynamics (CFD) simulations to evaluate the affect of air flow around CULPIS-X V2 at nominal C-130 flight speeds. This evaluation has been estimated to be completed within 3 months from its start date.
3. The output of the CFD simulations will be input into a Finite Element Design (FED) model, which has been developed here at CU-Boulder.
4. The results from the FED analysis will be forwarded to CG ALC, where they will be analyzed and a final recommendation to fly CULPIS-X on the C-130 will be made.

A second instrument package, CULPIS-X2, is solely supported by this ONR grant and will be designed similar to CULPIS-X to fit inside of a second USCG C-130 flare tube. CULPIS-X2 would be flown concurrently with CULPIS-X and would contain the Ball Experimental SST Radiometer (BESST, Figure 1). The BESST microbolometer radiometer measures SST with a precision of 0.1 K and absolute accuracy of 0.2 K. The BESST has 200 pixels cross track for the 18 deg FOV, yielding a single pixel FOV of 0.09 degrees and has real-time calibration using two on-board blackbodies. Co-Investigator W. Emery leads the effort to work with Ball Aerospace on the BESST integration effort into CULPIS-X2.

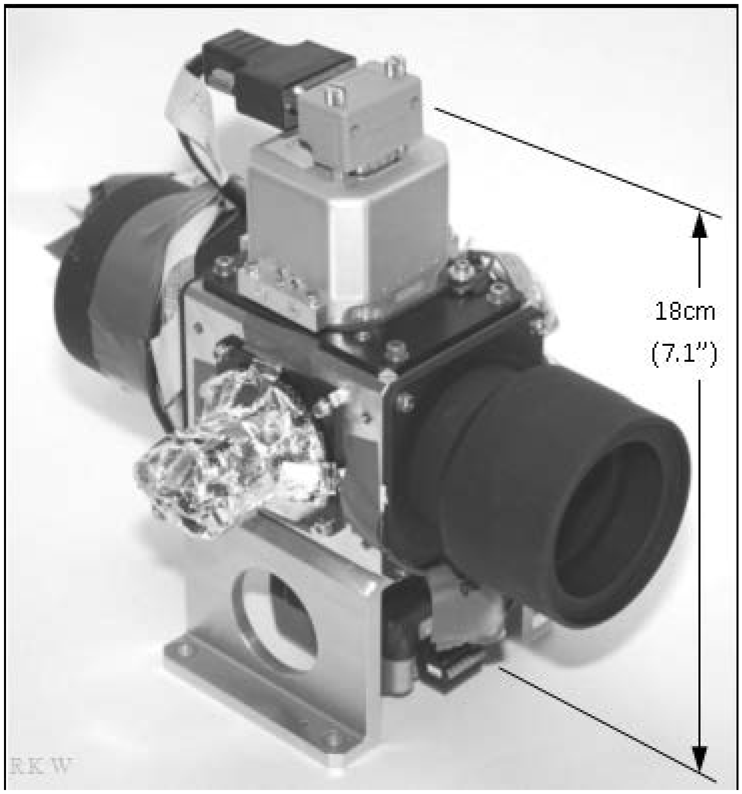

Figure1: BESST thermal radiometer. From Good et al. [2011].

In addition to the BESST, the latest generation of un-cooled imagers (microbolometers) has been identified for inclusion into the CULPIS-X2 package. This IR imager, supported by SIZRS co-funded investigators R. Lindsay and C. Chickadel (Univ. Washington), is a 640x480 pixel focal plane array microbolometer manufactured by DRS (model UC640), sensitive to wavelength of 8-14 microns. The imager fov is 40°, and its thermal sensitivity, quantified by Noise Equivalent Temperature Difference (NETD), is approximately 0.05 °K , which is sufficient resolution to detect typical surface temperature fields that vary by 0.1 °K or more. Camera dimensions are 2.5"x3.3"x2.1" and draws less than 2.5W. 14bit data is transmitted via standard Cameralink format. The camera housing is environmentally sealed and ruggedized, operational down to -40°C and thus suitable for CULPIS-X2 deployment during the ADA flights.

Figure 2: DRS (model UC640) IR imager.

WORK COMPLETED

Due to the lengthy nature of the safety review process, it was decided to proceed with the build of CULPIS-X while the review proceeds. The CULPIS-X instrument package is nearing structural completion by the build team, two upper-level undergraduate students at CU-Boulder. CULPIS-X is lightweight (11.7 kg) with an aerodynamic structure built with materials (mostly carbon fiber) that are resistant to icing (Figure 3 – note that the Everest IR pyrometer is not visible in Figure 3b).

Once NAVAIR completes CFD analysis of the CULPIS-X autoCAD design integrated with the C-130 model, the output will be used as input to a Finite Element Design (FED) model to determine the stress that CULPIS-X will exert on the flare tube and, in turn, the skin of the C-130 in proximity to the flare tube. The FED model was originally intended to be designed by the CG ALC group. However, it was determined by ALC that their workload did not allow time for this task. This effort was instead undertaken at CU, with approval from the USCG ALC. M. Tschudi received assistance from Dr. K. Maute (CU Dept. of Mechanical Engineering), who agreed to have a graduate student (P. Coffin) develop an FED model for CULPIS-X stress analysis, using output from NAVAIR's CFD simulations. P. Coffin built a CAD mockup of CULPIS-X and performed a preliminary analysis of the structural impact on the C-130 flare tube.

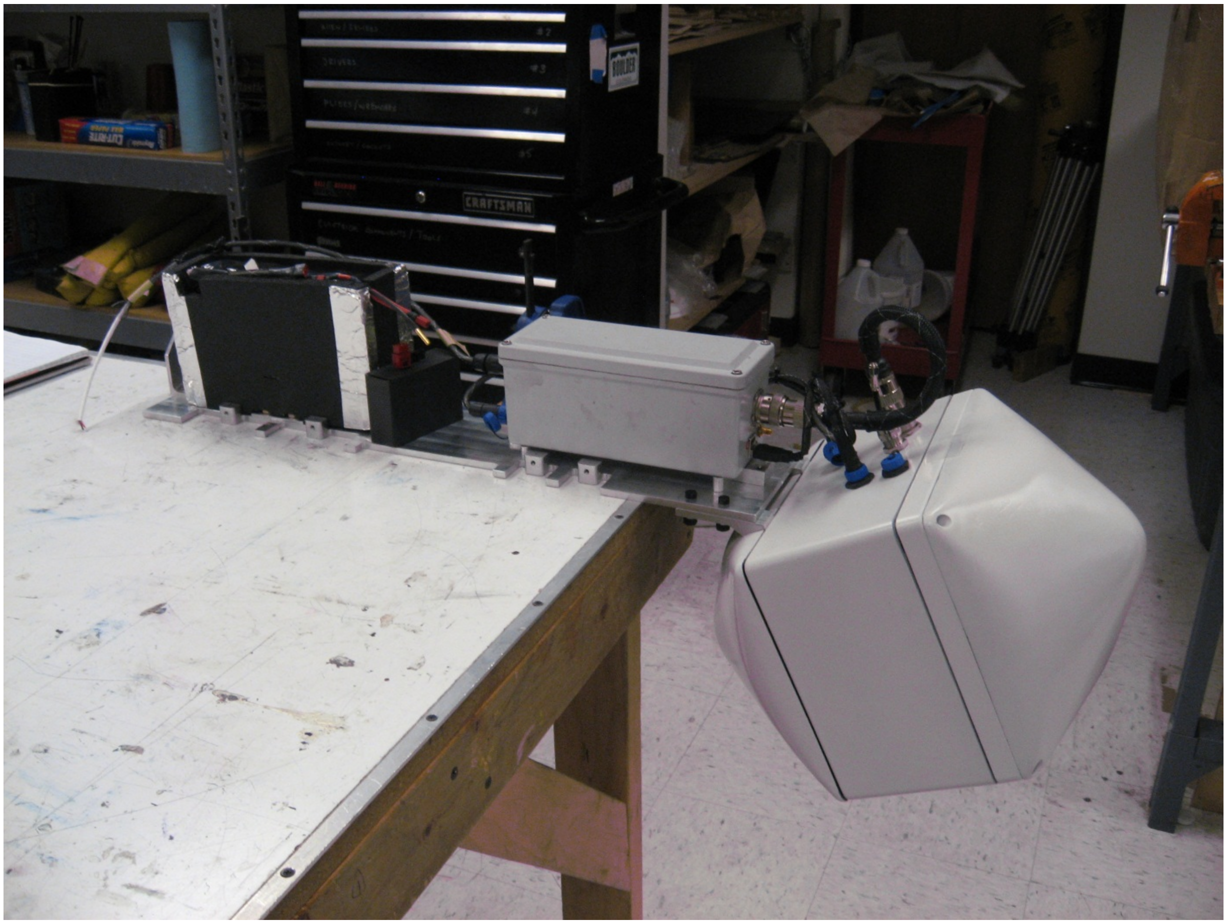

Figure 3a: CULPIS-X in CU-Boulder Lab. Sensor package on right, data acquisition box in middle, battery on left

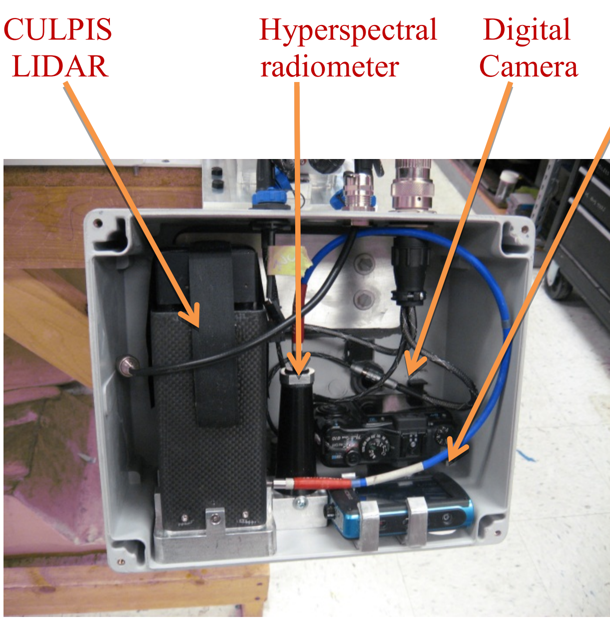

Figure 3b: CULPIS-X V2 sensor package

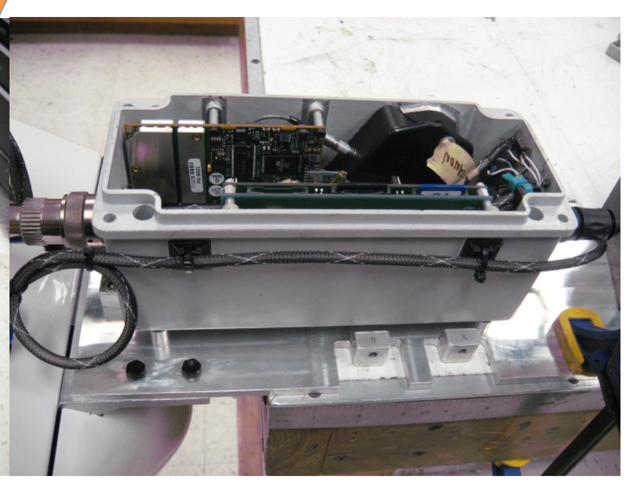

Figure 3c: CULPIS-X V2 data acquisition box

PI Tschudi met with R. Lindsay and C. Chickadel, who are separately funded under the umbrella SIZRS project, to develop integration plans for the DRS infrared imager into CULPIS-X2. Power requirements and data storage methods for this instrument were discussed. These requirements are feasible for the CULPIS-X2 design.

The BESST radiometer, also to be deployed in CULPIS-X2, has already been built by Ball Aerospace – this build was a separate task and not funded in this effort. The availability of BESST has allowed us to plan for its power, weight, size and storage requirements for CULPIS-X2.

Both the CULPIS-X and CULPIS-X2 are designed to each fit into one of the ten C-130 flare tubes and would fly concurrently, providing airborne measurements along designed flight segments during the ADA flights over the Beaufort and Chukchi Seas.

RESULTS

The FED analysis for CULPIS-X, performed by P. Coffin at CU-Boulder, found that stresses were well within reasonable limits for loadings up to 4g's. The largest values of stress on the assembly were 18.1% of the yield stress for the material. Principle stresses were also of similar magnitude. This first analysis was run without input from the CFD analysis to be performed by NAVAIR, but is encouraging.

Evaluation of the power, size and weight requirements for the UW infrared instrument and Ball Aerospace's BESST thermal imager have given the CU design team confidence that CULPIS-X2 can be built and, if approved by the USCG ALC, deployed in the C-130 flare tube and operated in an autonomous manner. An aerodynamic design for CULPIS-X2 will parallel CULPIS-X.

We have received initial positive feedback on the CULPIS-X design from the USCG's Aviation Logistics Center (ALC), but the most important results will occur when the ALC has completed a final evaluation of CULPIS-X, based on the combined runs of the CFD by NAVAIR and the FED model by CU-Boulder . The USCG ALC is responsible for the final decision on C-130 airworthiness of CULPIS-X and CULPIS-X2.

IMPACT/APPLICATIONS

The initial FED analysis is encouraging towards providing a safe stress level on the C-130 flare tube and the aircraft skin in the vicinity of the flare tube attachment. However, input to the FED model from the CFD analysis (to be performed by NAVAIR) of the C-130 with CULPIS-X attached to the tube will produce the final modeling results with which USCG ALC can base their recommendation for deployment on a USCG C-130.

RELATED PROJECTS

None

REFERENCES

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Good, W., R. Warden, P. Kaptchen, T. Finch, and W. Emery, 2011: Absolute thermal radiometry from a UAS, presented at the AIAA *Infotech@Aerospace Conference*, St. Louis, MO.