USAF Cryogenic Technology and Future Direction

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Abstract—The Air Force Research Laboratory (AFRL) Space Vehicles Directorate pursues cryogenic refrigeration system and system integration technology research and development in support of the needs of the Air Force (USAF), Missile Defense Agency (MDA), and Department of Defense (DoD). State-of-the-art of U.S. space cryocooler systems and system integration, the research performed to improve efficiency (particle image velocimetry, computational fluid dynamics), and research that is pushing the technology envelope for future cryocooler systems is the focus. Specific strengths and weaknesses of the current state of technology are compared, as well as the quantum leaps necessary in technology to meet future requirements.

I. INTRODUCTION

Manufacturing techniques of space based cryocoolers involve an interactive process, which is not only time consuming, but costly. Validated prediction models would greatly reduce the time it takes to manufacture a cryocooler and, reduce its cost, as well as find the mechanisms in the pulse tube which create inefficiencies in its function. At the Air Force Research Labs, a Particle Image Velocimetry (PIV) experiment has been developed to accurately measure the fluid flow inside the pulse tube of a cryocooler.

Particle Image Velocimetry (PIV) is a quantitative velocity measurement technique, utilizing fluid flow measurements and high speed photography. Fluid interactions have long been predicted through computational fluid dynamics for pulse tubes, inerter tubes, regenerators, etc in cryocoolers. However, an experiment to validate these models & simulations for the space based cryocooler has been slow to develop.

II. TEST SET UP AND TESTS

A. Test Set Up

A 1Watt, 532nm double pulsed Nd:YAG laser is the illumination source. It is lined up with a vacuum chamber window, into the pulse tube. A window perpendicular to the laser beam allows a high speed camera to take snapshots. The snapshots can be taken with a time delta ranging from microseconds to milliseconds in accordance with the fluid velocity in order to accurately measure velocity vectors. LaVision software, camera, computer interface and timing equipment are used with a New Wave laser.

Running gas through a quartz tube in a vacuum chamber poses a number of problems: vacuum leaks, quartz tube refractions, alignment issues, etc. The camera and laser are aligned with synchronized triggering with computer control for this experiment.

B. Tests

Initially, the test was run with an empty tube under vacuum. The tube was 3 mm thick. Both an alcohol mist and titanium dioxide were used as a seeding material. A thinner tube of 1 mm was also used. A significant amount of the laser light was refracted in the tube due to the imperfections in the quartz. The titanium dioxide also clings to the sides of the pulse tube due to static electric charge assumed to be created by a triboelectric effect due to the dissimilarity of the TiO2 and quartz.

Therefore, after attempting the experiment with the pulse tube, it was decided to remove the pulse tube from the vacuum chamber, and an alcohol spray was blown into the chamber via a mister in order to coordinate the software and photos. Compressed nitrogen was used as the examined fluid when TiO2 was used as seeding material which was provided via a fluidized bed seeding device.

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III. RESULTS

A. Alcohol Mist
The alcohol mist clearly provided moving particles in the pulse tube, however the density of particles was too little to be of value, Figure 1.

![Figure 1. Fluid flow captured on camera with alcohol mist.](image1)

**B. Titanium Dioxide**

The pulse tube was removed for the titanium dioxide to work because the LaVision software program interprets the refraction noise as particles, and assigns it false vectors, figure 2.

![Figure 2. Titanium Dioxide in Pulse Tube](image2)

Without the pulse tube, two forces were interacting on the TiO2 mist, pressure from the N2 and the vacuum inside the chamber. However, usable fog data with velocity vectors was achieved, Figure 3.

![Figure 3. Adequate first fluid data with TiO2](image3)

There is still a low photon count by the high speed camera, and the contrast when optimized by the software does not yield a visible picture. This creates a complication in that noise, in the form of photon counts, both in the area surrounding and within the flow is hard to distinguish from the actual fluid flow.

There are a number of items for future work, including a new seeding material, new seeding device and on-site help from LaVision. PIV will validate the numerous computational fluid dynamics modeling & simulations for the pulse tube of a cryocooler, and allow the Air Force Research Lab to generate design equations for cryocoolers. There is still significant work to be done in order to better understand the fluid flow mechanisms in the pulse tube, as well as expanding the scope to include the inertance tube.

**IV. CONCLUSIONS**

PIV will greatly improve the efficiency of cryocoolers, as well as provide validation to the CFD modeling performed by AFRL. This in turn will allow AFRL to create design equations, reducing the manufacturing time and increasing the efficiency of the cryocooler.

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REFERENCES


