Performance Measurements on a Thermoacoustic Refrigerator at High Amplitudes

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Abstract: Combination of the resonator, stack and heat exchanger from the Space ThermoAcoustic Refrigerator (STAR) with the high-power driver used by the Shipboard Electronic ThermoAcoustic Cooler (SETAC) allowed measurement of STAR performance at acoustic power densities four times greater than previously reported. Measurements with high accuracy (±65 mW) and high data density show small but systematic deviation from the linear predictions of the DETA model at peak-to-mean pressure ratios between 4% and 6%, the largest amplitude measurements made in an electrically-driven thermoacoustic refrigerator to date.

INTRODUCTION

Using the simplest, non-trivial linear approximations and assuming ideal gas behavior, the second order thermoacoustically induced heat flux, $Q_2/A$, can be expressed in terms of the mean gas pressure, $p_m$, the sound speed, $a$, and the peak-to-mean pressure ratio ($P_A/p_m$) as shown below (1):

$$\frac{Q_2}{A} \sim p_m a \left(\frac{P_A}{p_m}\right)^2$$

(1)

This relation tempts designers of thermoacoustic refrigeration systems to increase the pressure ratios of their engines to obtain ever higher cooling power densities. However, the assumptions on which this relationship are based neglect the effects of turbulence and other nonlinear effects which are difficult to characterize theoretically. For this reason, we have attempted to measure the performance of a thermoacoustic refrigerator at high amplitudes which, due to the shape of the resonator (horn and bulb), would be expected to be highly susceptible to nonlinear performance degradation.

APPARATUS AND INSTRUMENTATION

The thermoacoustic refrigerator shown in Fig. 1 is known as "Frankenfridge" because "it is made from parts of others (2)." The resonator, stack and heat exchangers are taken from STAR which flew on the Space Shuttle Discovery (STS-42) in 1992. Data obtained with STAR at pressure ratios below 3% have been reported earlier (3). To obtain higher amplitudes, one of the four drivers developed for SETAC (4) is attached to the STAR resonator. A new water-cooled copper exhaust heat sink flange is placed between the STAR hot-side exchanger flange and the SETAC driver to measure the exhaust enthalpy (heat plus work). The water flow rate is measured with a calibrated Pelton wheel flow meter. A thermopile (ten T-type junction pairs) is attached across the copper tubing inlet and outlet to allow accurate measurement (±65 mW) of the heat.
removed by the hot-side heat exchanger in the STAR resonator. The flange is insulated from the driver with 3 mm thick Delrin™ washer.

The entire system is filled with an 85.5% helium, 14.5% argon mixture to a pressure of 1.07 MPa (155 psia) in order to make the resonator and the driver co-resonant at the free-cone resonance of the SETAC driver (320 Hz). The STAR resonator is insulated from the room with ordinary construction grade fiberglass insulation enclosed in a 10 inch diameter PVC pipe section.

MEASUREMENTS AND ANALYSIS

The measurements reported here were obtained by maintaining the temperature of the cold end of the refrigerator just below room temperature (17 °C) while varying both the electrical heat load applied to the cold end by a Kapton tape strip heater and controlling the acoustic pressure amplitude. The sum of the electrical heat load and the acoustic power delivered by the driver were equal to the measured exhaust heat to within 2% at exhaust powers in excess of 25 W, confirming First Law energy balance. A heat exchanger model, based on standard conduction analysis, accounts for the temperature difference between the heat exchanger fins and the exterior of the resonator (where temperatures are measured).

The driver acoustic power shown at the left in Fig. 2 is higher than the DeltaE model (5). The discrepancy is not apparently a strong function of acoustic amplitude. The comparison of the DeltaE model and measurements of cooling power seem to be in very good agreement for $P_A/P_m \leq 4\%$ and the deviation above that amplitude is small. This leads us to suspect that operation of thermoacoustic refrigerators at pressure ratios of 6% will be desirable.

![Comparison of Measured Results and DeltaE Model](image)

**FIGURE 2.** Measured and modeled acoustic and cooling power as a function of pressure ratio.

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REFERENCES