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A STUDY OF ELEMENT INTERACTION IN THERMOACOUSTIC ENGINES

ANNUAL REPORT

Submitted by:

Richard Raspet and Henry E. Bass
Physical Acoustics Research Group
Department of Physics and Astronomy
The University of Mississippi
University, Mississippi 38677

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Richard Raspet and Henry E. Bass

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The University of Mississippi
University, MS 38677

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13. ABSTRACT *(Maximum 200 words)*

The physical understanding of thermoacoustic engines has progressed rapidly in the past five yeras. The general performance of prime movers and refrigerators is now reasonably well understood and documented. There are, however, notable discrepancies between theory and experiment, especially at large acoustic amplitudes. The disrepancies are typically attributed to non-linear terms not included in the theory. Acoustic streaming is often mentioned as the culprit and this may well be the case. There is evidence, however, that interactions between elements in the engine are at least partially responsible for the differences. This is illustrated, for example, by Swift's observation that the heat exchanger appears to be effective over larger acoustic displacements than simple geometric arguments predict. Additional element interactions will arise when a thermoacoustic prime mover and a refrigerator are placed in the same acoustic cavity. This three year project centers on studies of different thermoacoustic element geometries.

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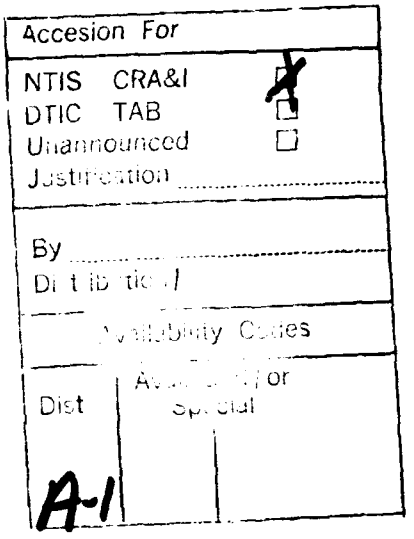

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Brief Description of Project

The physical understanding of thermoacoustic engines has progressed rapidly in the past five years. The general performance of prime movers and refrigerators is now reasonably well understood and documented. There are, however, notable discrepancies between theory and experiment, especially at large acoustic amplitudes. The discrepancies are typically attributed to non–linear terms not included in the theory. Acoustic streaming is often mentioned as the culprit and this may well be the case. There is evidence, however, that interactions between elements in the engine are at least partially responsible for the differences. This is illustrated, for example, by Swift's observation that the heat exchanger appears to be effective over larger acoustic displacements than simple geometric arguments predict. Additional element interactions will arise when a thermoacoustic prime mover and a refrigerator are placed in the same acoustic cavity. This three year project centers on studies of different thermoacoustic element geometries.

Brief Description of Approach Taken

The project concentrates on the analysis and measurement of individual elements in a thermoacoustically driven refrigerator and studies the interaction of the elements. The modular design of the UM helium-filled driver allows the addition of thermoacoustic elements to the basic thermoacoustic prime mover to build up to a thermoacoustic refrigerator driven by the prime mover. The impedance analysis and measurement techniques developed previously are applied to the investigation of an efficient thermoacoustic refrigerator.

Specifically, these techniques are used to design a system which will optimize the efficiency in the presence of non-linear interaction. At high ΔT, the prime mover will

generate sound of sufficient amplitude to generate harmonics. The refrigerator stack, however, will act as a frequency dependent absorber suppressing higher harmonics. A good refrigerator stack design and temperature gradient will minimize second harmonic generation. It should be more efficient to operate the refrigerator in this region than to apply devices in the resonator to suppress harmonics. This effort represents the main thrust of the proposed research.

The following goals were established for the three year duration of the project.

Year 1. Use the acoustics based theory to design refrigerator and muffler elements for use with the thermoacoustic prime mover. These elements will be constructed and then their impedance under load measured and compared to theory.

Year 2. The complete refrigerator system will be assembled and tested. The impedance technique will be used to measure the work and heat flow in the refrigerator. These values will then be compared to theory. Interactions between particular elements will be isolated using the modular design of the experiment.

Year 3. Streaming and turbulence effects will be measured and theory developed to describe the performance degradation at high operating amplitudes.

Brief Description of Accomplishments

The acoustic impedance approach to the analysis of thermoacoustic prime movers developed in previous years has been tested experimentally and the results published in a letter, "Specific acoustic impedance measurements of an air-filled thermoacoustic prime mover."[1]

A single stack longitudinal mode thermoacoustic engine has been constructed and used to investigate the onset of acoustic oscillations. This work has been reported in the article, "Stability Analysis of a Helium Filled Thermoacoustic Engine."[2] The physics of the optimum location of the stack and the minimum temperature for onset are analyzed using an extended short stack approximation.

The system has been extended by the addition of a second stack to investigate element interactions in a thermally driven refrigerator. Figure 1 illustrates this system. The onset-temperature differences of the prime mover stack versus the temperature differences in the refrigerator stack are plotted in Fig. 2. If the two-stack system was linear, this plot would be linear. The system is being modified to achieve higher temperature differences. Jim Belcher will investigate this system in detail for his Ph.D. research.

A separate line of inquiry applicable to low standing wave ratio devices has involved the contribution of traveling waves to the thermoacoustic effect. A theoretical paper has demonstrated that gains displayed by Ceperley's traveling wave engine are thermoacoustic and not due to a Stirling cycle.[3] Cooperative experimental work with Anthony Atchley of the Naval Postgraduate School built and tested a thermoacoustic muffler based on the theoretical work. This work has been presented to the Acoustical Society of America[4] and is being written up for publication by John Kordomenos, a Ph.D. student. John's Ph.D. work will involve non-linear effects in thermoacoustics.

References

1. W. Pat Arnott, Henry E. Bass and Richard Raspet, "Specific acoustic impedance measurements of an air-filled thermoacoustic prime mover," J. Acoust. Soc. Am. **92** (6), 3432-3434 (1992).

2. W. Patrick Arnott, James R. Belcher, Richard Raspet and Henry E. Bass, "Stability analysis of a helium filled thermoacoustic engine," submitted to J. Acoust. Soc. Am., Aug. 1993.

3. Richard Raspet, Henry E. Bass and John Kordomenos, "Thermoacoustics of traveling waves: Theoretical analysis for an inviscid ideal gas," J. Acoust. Soc. Am. **94** (4), 2232-2239 (1993).

4. John N. Kordomenos, Anthony A. Atchley, Richard Raspet and Henry E. Bass, "Thermoacoustic termination for a traveling wave tube," J. Acoust. Soc. Am. **94** (3), 1773 (1993).

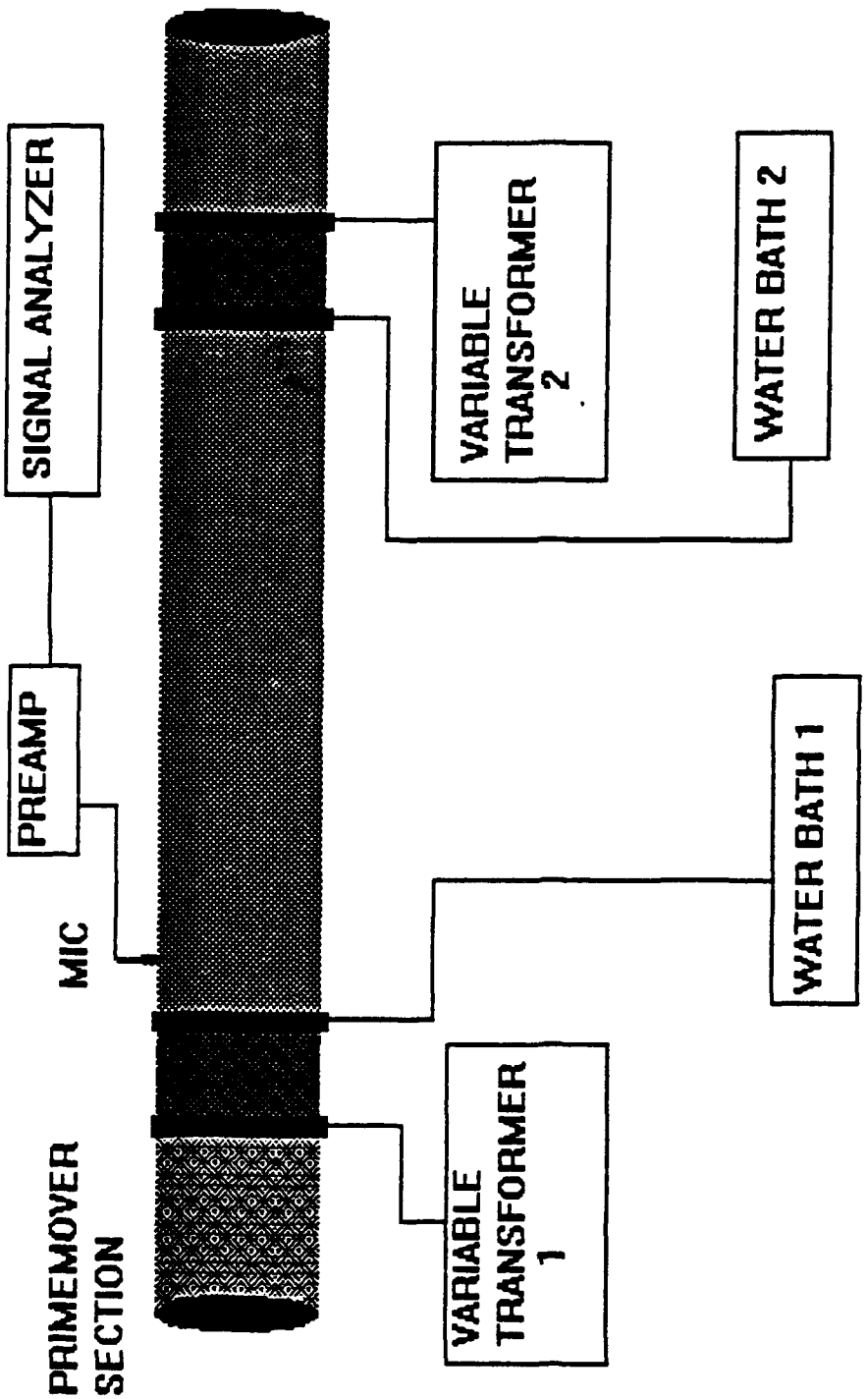
SIGNAL ANALYZER
PREAMP
MIC
PRIMEMOVER SECTION
VARIABLE TRANSFORMER 1
VARIABLE TRANSFORMER 2
WATER BATH 1
WATER BATH 2

Figure 1

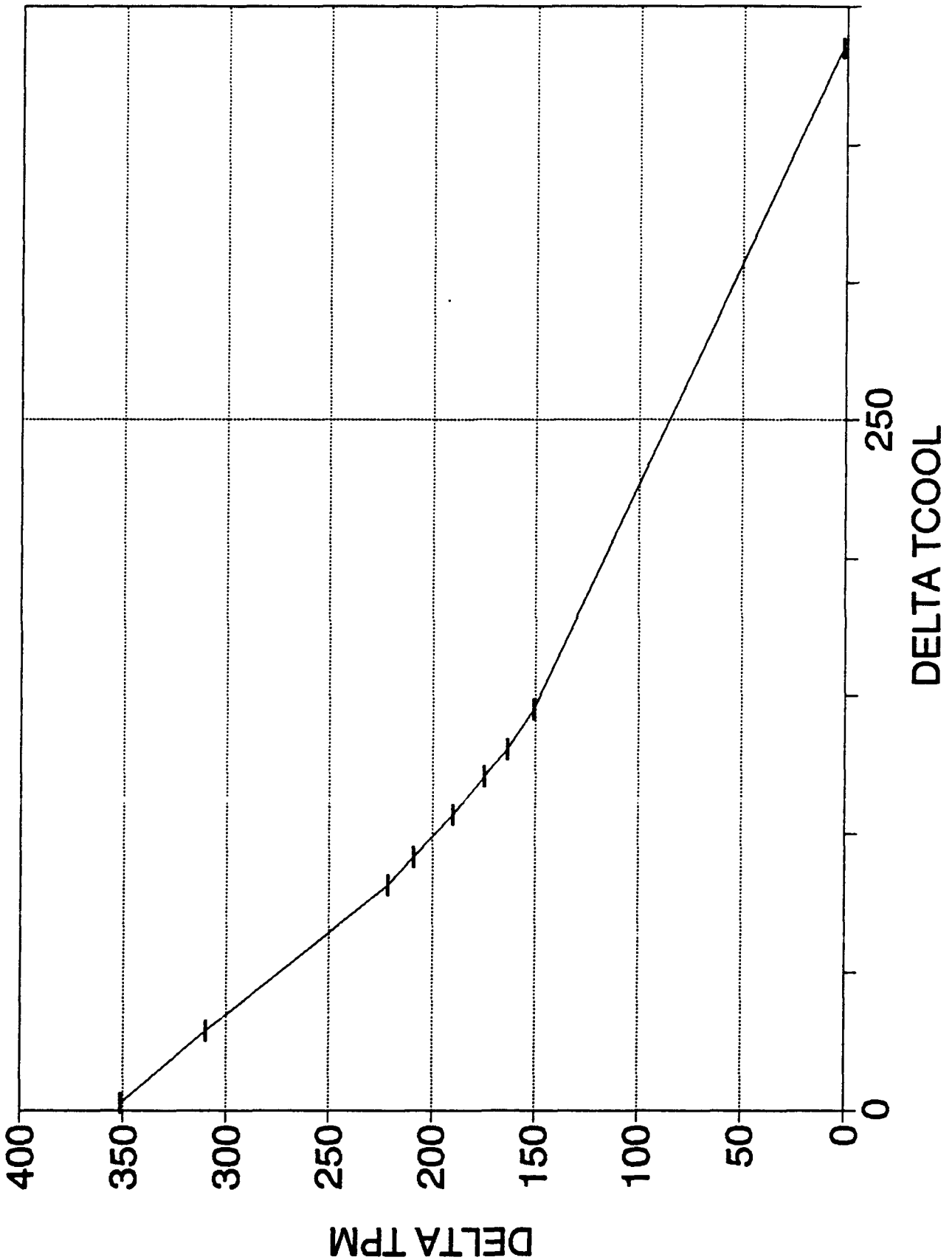

Figure 2

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Mailing Address: Dept. of Physics and Astronomy
The University of Mississippi
University, MS 38677

Phone Number (with Area Code): 601-232-5905

E-Mail Address: pabass@sparc.ncpa.olemiss.edu

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k. Total number of Graduate Students and Post-Docs Supported at least 25%, this year on this contract,grant:
Grad Students 3 and Post Docs 1

How many of each are females or minorities? (These 6 numbers are for ONR's EEO/Minority Reports; minorities Include Blacks, Aleuts Amindians, etc and those of Hispanic or Asian extraction/nationality. This Asians are singled out to facilitate meeting the varying report semantics re "under-represented")

- Grad Student Female 0
- Grad Student Minority 0
- Grad Student Asian e/n 0
- Post-Doc Female 0
- Post-Doc Minority 0
- Post-Doc Asian e/n 0

P³H REPORT CONTINUED

Papers Published in Refereed Journals

1. W. Pat Arnott, Henry E. Bass and Richard Raspet, "Specific acoustic impedance measurements of an air-filled thermoacoustic prime mover," J. Acoust. Soc. Am. **92** (6), 3432-3434 (1992).

3. Richard Raspet, Henry E. Bass and John Kordomenos, "Thermoacoustics of traveling waves: Theoretical analysis for an inviscid ideal gas," J. Acoust. Soc. Am. **94** (4), 2232-2239 (1993).