REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
15 June 1997

3. REPORT TYPE AND DATES COVERED
Summary 1 June 96-31 May 97

4. TITLE AND SUBTITLE
Thermo-fluid Mechanic Study of
Thermoacoustic Devices

5. FUNDING NUMBERS
PE 611-53N
G N0001494J0063

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
ONR 331
800 North Quincy Street
Arlington VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The work is articulated in three separate projects: (*a*) development and study of a simplified model of thermoacoustic devices; (*b*) visualization of oscillating temperature and flow fields; (*c*) numerical modeling. During the past year, in area (*a*), work has focused on an approximate time-domain formulation of the thermoacoustic instability and on the heat and momentum exchange modeling; in area (*b*), heat transfer data have been obtained by holographic interferometry and a new thermoacoustic refrigerator suitable for further experimentation has been designed; in area (*c*) thermal stratification effects have been fully incorporated in a new algorithm with results that are significantly different from the linear theory and compare very well with data.

14. SUBJECT TERMS
Thermoacoustics, Refrigeration, Flow visualization
Vortex methods

15. NUMBER OF PAGES
17

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

The work carried out under this grant is articulated in three separate projects as follows:

1. Simplified model of thermoacoustic devices (A. Prosperetti)
2. Experimental effort: Visualization of oscillating temperature and flow fields (C. Herman)
3. Numerical modeling effort (O. Knio)

Brief description of projects

Project 1. The only theory presently available for the analysis of thermoacoustic devices is formulated in the frequency domain and is only applicable in the linear regime. Its extension to the nonlinear case appears to be formidable and it is likely that nothing short of fully numerical simulations will be available for a quantitatively accurate application to large-amplitude pressure oscillations. For this reason, an approximate, but much more manageable model, might be useful both as an exploratory tool and as a design guide. The project consists in the development of such a model.

A small amount of effort has also been spent on the investigation of a new mechanism for the explanation of sonoluminescence.

Project 2. In order to predict heat transfer rates in the heat exchangers of thermoacoustic devices, a better understanding of the mechanisms underlying heat transfer in oscillatory flows is essential. We investigate such physical situations using holographic interferometry (HI) combined with high speed cinematography. In order to apply HI to acoustically driven flow it was necessary to develop a new evaluation procedure that accounts for the acoustic pressure fluctuations. This evaluation procedure was successfully applied to measure temperature fields as well as heat fluxes in a thermoacoustic refrigerator model. Current efforts are aiming towards the application of HI to an actual thermoacoustic refrigerator that has been designed applying our previously developed optimization algorithm based on the short stack boundary layer approximation.

Project 3. Analysis and prediction of the behavior of thermoacoustic devices have so far relied primarily on a linearized theory based on simplified quasi-one-dimensional flow models. In order to overcome these restrictions, this effort aims at (1) the development of a computational methodology for the simulation of the non-linear multi-dimensional flow within thermoacoustic stacks and heat exchangers, and (2) the implementation of the resulting numerical schemes to analyze the fundamental response of the flow within critical components and to quantify the performance of the device. The computational model development complements parallel efforts aiming at gaining detailed fundamental understanding of thermoacoustic devices through improved analytical models and laboratory experiments.

ACCOMPLISHMENTS – PROJECT 1

Time-domain thermoacoustic instability

In typical thermoacoustic prime movers, the time scale for the development of the instability is long compared with the period of oscillation. The resulting evolution of the system acquires the character of modulated oscillations for which the asymptotic method of multiple time scales is eminently suitable.

In a paper recently submitted to JASA we have studied this problem carrying the expansion to second order. The multiple-scales results can be further simplified by using the standard so-called short-stack approximation. We have found that, when the multiple-scales result works well, so does the short-stack approximation. The final expressions have therefore a closed analytical form that enables them to be very readily evaluated.

An interesting by-product of the analysis has been the (approximate) extension of the concept of critical temperature gradient to the viscous case. The result is

$$\left.\frac{dT_w}{dx}\right|_{crit} = \left(1+\sqrt{\sigma}\right)\left[\frac{\omega^2}{c_p}\frac{P_S}{dP_S/dx} + \sqrt{\sigma}\,\overline{T}_w\frac{dP_S/dx}{P_S}\right] \tag{1}$$

Here σ is the Prandtl number, ω the frequency, c_p the specific heat at constant pressure, $\overline{T}_w$ the mean temperature in the stack, and $P = P(x)$ the pressure eigenfunction of the mode of interest; the subscript S indicates evaluation at the stack position. The minimum value of this critical gradient occurs for

$$\frac{dP_S/dx}{P_S} = \frac{1}{\omega}\left[\sqrt{\sigma}\,c_p\overline{T}_w\right]^{1/2} \tag{2}$$

and is

$$\left.\frac{dT_w}{dx}\right|_{crit,min} = 2\left(1+\sqrt{\sigma}\right)\omega\left(\frac{\sqrt{\sigma}\overline{T}_w}{c_p}\right)^{1/2} \tag{3}$$

In the paper we have treated not only the case of a tube rigidly terminated at both ends, but we have considered all combinations of closed/open ends and all modes in addition to the fundamental one.

Time-domain approximation of the exchange terms

It will be recalled from our previous reports that the model developed in the course of this work has been obtained by integrating the conservation equations for mass, momentum, and energy over the cross section of the thermoacoustic device and is, accordingly, quasi-one dimensional.

In last year's report we pointed out that the necessity to use approximate expressions for the terms describing the exchange of momentum and energy between the stack and the gas worked well for the linear theory, but gave rise to some problems in the nonlinear case. In our first nonlinear study (submitted to JASA) we have circumvented the problem by introducing *ad hoc* dissipation terms in the equations. One of the tasks undertaken since then has been to render the approach more systematic.

The exact linear relation between the wall shear stress τ_w and the mean velocity u is:

$$\frac{\mathcal{P}}{S}\tau_w = -i\omega\rho\frac{f_V}{1-f_V}u \tag{4}$$

where $\mathcal{P}$ is the "wetted" perimeter, S the cross-sectional area, ρ the density, and

$$f_V = \frac{\tanh{(1+i)\ell/2\delta_V}}{(1+i)\ell/2\delta_V} \tag{5}$$

with ℓ the plate spacing and

$$\delta_V = \sqrt{\frac{2\nu}{\omega}} \tag{6}$$

the viscous penetration thickness expressed in terms of the kinematic viscosity ν. The relation between the wall heat flux and the mean temperature has a similar structure.

Our nonlinear model requires a time-domain form for the frequency-domain expression (4). In principle, such a form can be derived by standard Fourier transform theory, but takes on the form of a convolution integral that is very undesirable for numerical purposes. To tackle the problem we have tried to approximate (4) by a form of the type

$$(1+ia\omega)\tau_w = \rho\left(b + ic\omega - d\omega^2\right)u \tag{7}$$

with a, b, c, d suitably chosen real constants. In the time domain, this expression would correspond to

$$\left(1 + a\frac{\partial}{\partial t}\right)\tau_w = \rho\left(b + ic\frac{\partial}{\partial t} + d\frac{\partial^2}{\partial t^2}\right)u \tag{8}$$

If one assumes that, in a low-order sense, u satisfies the wave equation with some effective wave speed c_e, an alternative form of (7) would be

$$(1+ia\omega)\tau_w = \rho\left(b + ic\omega - \frac{d}{c_e^2}\frac{\partial^2}{\partial x^2}\right)u \tag{9}$$

We wish to determine the constants of the previous expressions not by a numerical fit, but by a systematic procedure. We have tried several approaches, and in the end we have concluded that the form (9), with the coefficients determined from a Taylor series expansion of (4) in ω around the frequency of the fundamental mode gives the best result. We are in the process of incorporating this new approach into our nonlinear code and applying it to the thermoacoustic refrigerator case.

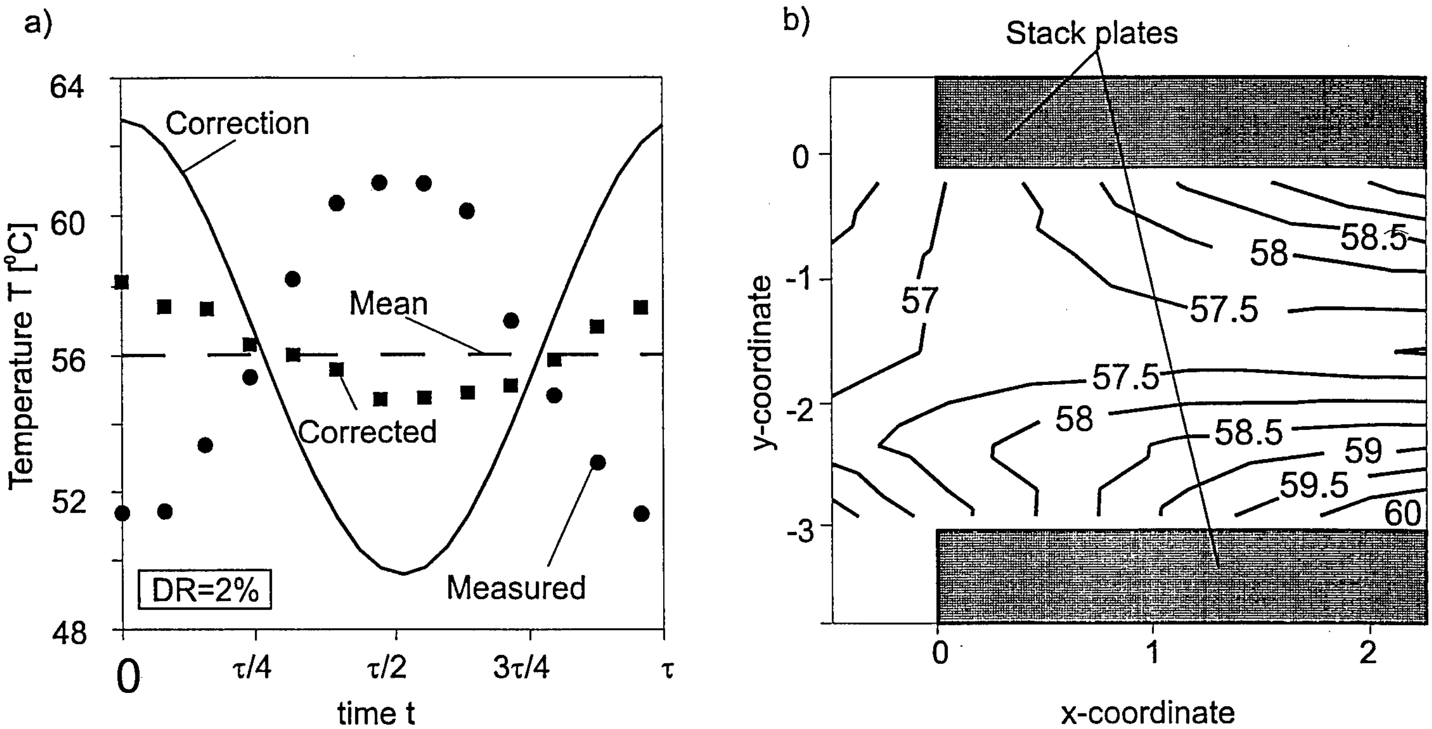

Figure 1: (a) Time dependent temperature measurements with the conventional approach and the required corrections; (b) Contour plot of the time-averaged temperature distribution at the edge of the thermoacoustic refrigerator model's stack plates.

ACCOMPLISHMENTS – PROJECT 2

Temperature and heat transfer measurements with holographic interferometry in the thermoacoustic refrigerator model.

In conventional applications of holographic interfereometry (HI) in heat transfer measurements, the pressures of the reference state and of the measurement state are maintained constant. In an acoustically driven flow, it is naturally not possible to maintain the measurement state's pressure constant. In order to resolve this problem we used additional information available from the acoustic field and developed a new evaluation procedure that allows temperature measurements with HI in the presence of pressure variations. However, we have found that the conventional approach to temperature measurements can still be applied when the experimenter is interested in the time averaged temperature distribution (over one period od oscillation). A detailed discussion of the limitations of conventional temperature measurements with HI in the presence of pressure variations can be found in the recently submitted paper by Wetzel and Herman (1997b).

Figure 1a shows the time dependent temperature measurements at a fixed point within the working fluid and summarizes some of the important aspects of HI applied to an acoustically driven flow. The solid circles in Figure 1a indicate measurement data obtained by the conventional approach. The solid line indicates a correction to these measurements that can be calculated from the error function derived in the paper by Wetzel and herman (1997b). Comparing the corrected time-dependent temperatures with the measured data, indicated as solid squares and solid circles in Figure 1a, respectively, one can see that these two sets of data are 180 degrees out of phase. In addition to the phase difference we can also see that the amplitude of the small temperature fluctuation decreases from about 4K to 2K after applying the described correction. When neglecting temperature gradients within the working fluid, the amplitude of the small temperature fluctuations, induced by the acoustic oscillations, can be roughly estimated by a simple adiabatic model as

$$T_A = \frac{\gamma - 1}{\gamma} \frac{P_A}{p_m} T_m . \tag{10}$$

In this equation, T_A denotes the amplitude of the temperature fluctuations, γ the ratio between isobaric and isochoric specific heats, P_A the peak pressure amplitude, p_m the mean pressure within the resonance tube and T_m the mean temperature. Substituting the relevant values for our experimental conditions, $T_m = 329$ K, $P_a/p_m = 0.02$, and $\gamma = 1.4$ into Eq. (10), we obtain an amplitude of the small temperature fluctuations of 1.88 K. This value agrees well with the 2K of the corrected temperature distribution shown in Fig. 1a. We should also note that both the measured and the corrected temperature distributions have the same value for the mean temperature, as indicated by the dashed line in Fig. 1a. From this discussion, we can conclude that the conventional approach to measure temperatures with HI is feasible for evaluation of time-averaged temperature distributions. If the experimenter is interested in the time resolved temperature distributions, however, it is necessary to add a correction as described by Wetzel and Herman (1997b).

Figure 1b shows a contour plot of the time-averaged temperature distribution at the edge of the thermoacoustic refrigerator model's two stack plates for a drive ratio of 2refrigerator model is also described in the paper by Wetzel and Herman (1997b). The most interesting feature of this mean temperature distribution is the shape of the two isotherms that enter the lower stack plates between 0 mm $< x <$ 1 mm and are marked with the temperatures 57.50 °C and 58 °C. This shape indicates that the mean temperature of the working fluid immediately above the stack plates is higher than the temperature of the stack plate. Therefore heat is transferred from the working fluid to the stack plate. This behavior is different when compared to a steady state flow, where high heat transfer rates from a heated surface to the working fluid are achieved at the entrance of a parallel plate channel because of the development of the thermal boundary layer. A thorough analysis of these phenomena is one of the current research issues and results will be published in the near future.

Design of a thermoacoustic refrigerator suitable for temperature measurements with HI

Since at this stage of our research the problems involved in the application of HI to an acoustically driven flow have been solved, we are currently working on measurements of the temperature field in a thermoacoustic refrigerator. The design of this thermoacoustic

	Thermoacoustic refrigerator model	Thermoacoustic refrigerator	ThermoAcoustic Life Sciences Refrigerator TALSR (Garrett 1991)
normalized stack length $\xi \equiv 2\pi\Delta x/\lambda$	0.46	0.14	0.1188
normalized stack position $\xi_c \equiv 2\pi x_c/\lambda$	0.78	adjustable	0.2
normalized plate spacing $\delta_{\kappa h} \equiv \delta_\kappa/h$	0.035	0.15	0.46
blockage ratio $BR = h/(h+t)$	0.72	0.83	0.8

Table 1: Comparison of geometry specific design parameters between the thermoacoustic refrigerator model (Wetzel and Herman, 1997b), the thermoacoustic refrigerator (Brouillat, 1996), and TALSR Garrett (1991).

refrigerator is based on the optimization algorithm developed by Wetzel and Herman (1997a). One advantage of this algorithm is that all design parameters are presented in normalized form. Therefore, it allows an easy comparison between different devices.

Table 1 shows a comparison of the geometry specific design parameters between the thermoacoustic refrigerator model (Wetzel and Herman, 1997b), the new thermoacoustic refrigerator (Brouillat, 1996) and the ThermoAcoustic Life Sciences Refrigerator (TALSR) designed by Garrett (1991). The most significant improvement when comparing the thermoacoustic refrigerator model (previously used in our experiments) with the new thermoacoustic refrigerator is reflected in the selection of the plate spacing. In the current experimental setup the plate spacing is decreased to about four to six times the thermal penetration depth, which results in a normalized plate spacing of 0.15. Another new feature of the thermoacoustic refrigerator is its modular structure that allows easy exchange of the three main modules, (i) stack, (ii) resonance tube, and (iii) loudspeaker. This structure also allows an adjustable stack center position. When comparing the geometry specific design parameters of the thermoacoustic refrigerator, shown in Table 1, with the values used in the design of TALSR, one can notice the good agreement between the two designs. A detailed description of the new thermoacoustic refrigerator's design can be found in the thesis by Brouillat (1996).

Figure 2 presents a snapshot of the temperature field in the thermoacoustic refrigerator. This interferometric image was recorded with the high speed camera at a framing rate of 3000 frames per second. The black rectangle with the three slots, in the middle of Figure 2, corresponds to the stack, and the dark and bright fringes correspond to "quasi"- isotherms, as discussed by Wetzel and Herman (1997b). For the interferometric image, shown in Fig. 2, one can estimate the temperature difference from a dark to the next dark fringe to be of

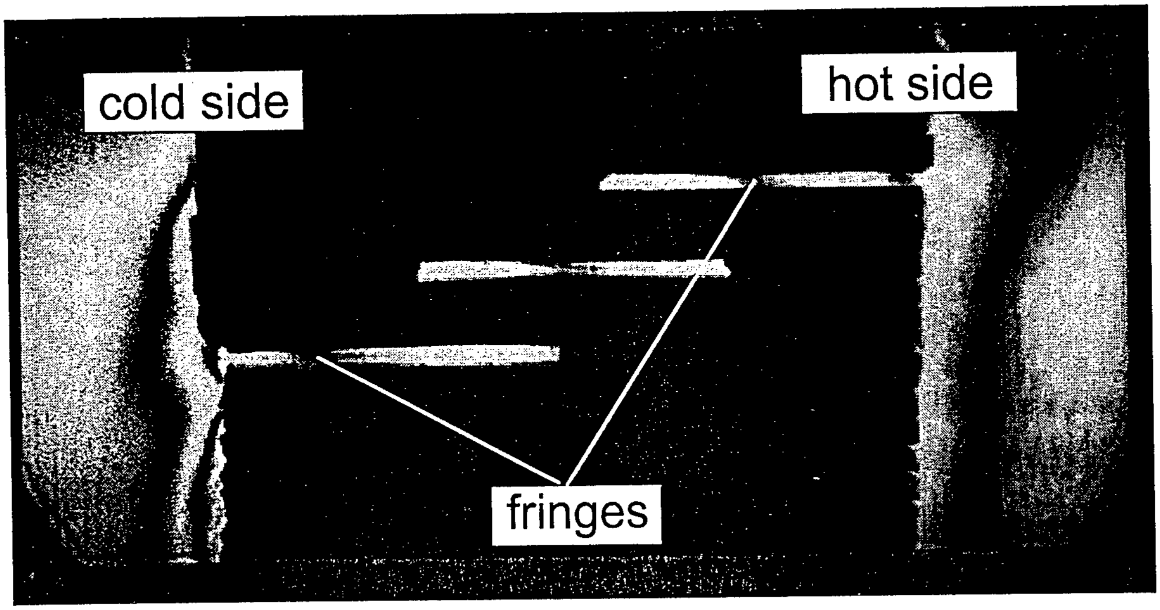

Figure 2: Snapshot of the temperature field in a thermoacoustic refrigerator.

the order of 2K. When now counting the dark fringes from the cold side to the hot side, we can detect 5 dark fringes indicating a temperature difference of about 10K.

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[1] Brouillat, M. (1996) "Design of a thermoacoustic refrigerator model", thesis to complete the DEA (comparable to a Master's degree) at the Ecole Centrale de Lyon

[2] Garrett, S.L. (1991) "ThermoAcoustic Life Sciences Refrigerator", NASA Tech. Report No. LS-10114, Johnson Space Center, Space and Life Sciences Directorate, Houston, TX, 1991.

[3] Wetzel, M., Herman, C. (1997a) "Design optimization of thermoacoustic refrigerators", *Int. J. Refrig.* Vol. 20, No. 1, pp. 3-21

[4] Wetzel, M., Herman, C. (1997b) "Limitations of temperature measurements with holographic interferometry in the presence of pressure variations" to be submitted to *Experimental Thermal and Fluid Science*

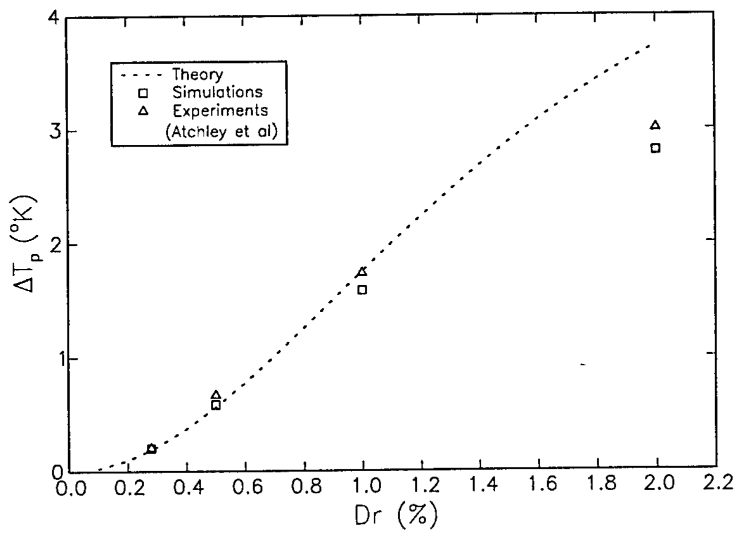

Figure 3: Computed values of the temperature difference across a thermoacoustic stack plotted against experimental measurements and predictions of the linear theory (adapted from [8]).

ACCOMPLISHMENTS – PROJECT 3

Thermoacoustic devices are typically characterized by a multitude of disparate length-scales, which renders analysis or simulation of the non-linear equations of motion extremely difficult. In order to overcome these scale-related difficulties, we have been involved in the development of an efficient, multi-dimensional flow solver that is suitable for the study of thermo-fluid phenomena in the neighborhood of thermoacoustic stacks. The early version of this model is described in a paper recently published in the *Journal of Computational Physics* [1].

In the past, we have focused our attention on stacks operating at low drive ratios, and thus implemented a simplified version of the model which ignores thermal stratification effects. The simplified model has enabled us to analyze the essential features of the unsteady flow, and to perform a detailed analysis of the behavior of hydrodynamic (mechanical energy) losses within the stack [2].

In the past year, we have generalized the original model in order to account for thermal stratification effects, and thus extended the simulations to moderate/high drive ratios. The extension required careful design and analysis of a new fast solver, and its optimization in order to maintain the efficiency of the computations. A paper describing the extended model has been recently submitted for publication [3].

In addition to this model development effort, we have performed extensive tests aiming, in particular, at validation of the extended computations [4, 5]. To this end, the model was used to compute the temperature differences across a thermoacoustic stack at no load conditions, and the results were compared to experimental observations of Atchley et al. [6]. A sample of the computations is given in figure 3, which compares the computed predictions of the temperature drop across the stack to the experimental observations [6] and the predictions of the linear theory [7].

With the extension of the computations to stratified flow, and their validation against experimental data, we have reached an important milestone in the development of the multi-dimensional flow code. Briefly, we are now at stage where the performance of simplified stacks or simplified stacks/heat exchanger configurations (figure 4 [8]) can be predicted and analyzed based on first principles, with minimal or no need for ad-hoc modeling assumptions.

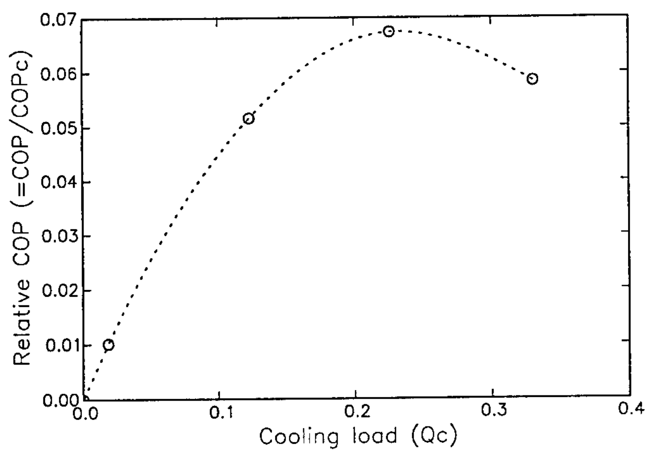

Figure 4: Variation of relative COP with the cooling load. The markers represent the results of multi-dimensional computations (adapted from [8]).

In the coming year, we plan to further extend the current stack model into a model for the entire thermoacoustic refrigerator. To this end, we plan to couple the current low-Mach-number solver with a quasi-1D solver for weakly-nonlinear resonance tube acoustics. We plan to adapt some of our asymptotics-based schemes [9, 10] for this purpose.

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[1] A.S. Worlikar & O.M. Knio (1996) "Numerical Simulation of a Thermoacoustic Refrigerator. Part I: Unsteady Adiabatic Flow Around the Stack," *J. Comput. Phys.* **127**, 424–451.

[2] A.S. Worlikar, O.M. Knio & R. Klein (1997) "Numerical Study of the Effective Impedance of an Idealized Thermoacoustic Stack," submitted to *Phys. Fluids.*

[3] A.S. Worlikar, O.M. Knio & R. Klein (1997), "Numerical Simulation of a Thermoacoustic Refrigerator. II Stratified Flow around the Stack," submitted to *J. Comput. Phys.*

[4] A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical study of unsteady, thermally stratified flow in an idealized thermoacoustic stack," presented at the Third joint meeting of the American and Japanese Acoustical Societies, Honolulu, Dec. 2–6. *J. Acoust. Soc. Am.* **100**, 2815.

[5] A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical Simulation of Acoustically-Generated Temperature Gradients in Short Thermoacoustics Stacks: A Validation Study," accepted for presentation and to appear in the Proceeding of 32nd National Heat Transfer Conference, Baltimore, MD, August 1997.

[6] A.A. Atchley, T.J. Hofler, M.L. Muzzerall, M.D. Kite, and C. Ao, *J. Acoust. Soc. Am.* **88**, 251 (1990).

[7] G.W. Swift, *J. Acoust. Soc. Am.* **84**, 1145 (1988).

[8] A.S. Worlikar, O.M. Knio & R. Klein (1997) "Numerical study of the performance of an idealized thermoacoustic stack", *J. Acoust. Soc. Am.* **101**, 3022. Paper to be presented at the 133rd Meeting of the Acoustical Society of America, State College, PA, June 15–20.

[9] A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical Simulation of an Idealized Thermoacoustic Engine," presented at the DFD96 Meeting of the American Physical Society.

[10] A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical Modeling of a Thermoacoustic Refrigerator," *Vortex Flows and Related Numerical Methods II*, Y. Gagnon, G.-H. Cottet, A.F. Ghoniem, D.G. Dritschel and E. Meiburg, Eds., *ESAIM Proceedings* **1**, 363–375.

PUBLICATIONS AND PRESENTATIONS

Project 1.

The following papers have been published:

1. A. Prosperetti "A new mechanism for sonoluminescence", *J. Acoust. Soc. Am.* **101**, 2003-227, 1997
2. H. Yuan and A. Prosperetti "Gas-liquid heat transfer in a bubble collapsing near a wall", *Phys. Fluids* **9**, 127-142, 1997.

The following papers have been submitted to the *Journal of the Acoustical Society of America*:

1. M. Watanabe, A. Prosperetti, and H. Yuan "A simplified model for linear and nonlinear processes in thermoacoustic prime movers. Part I. Model and linear theory".
2. H. Yuan and A. Prosperetti "A simplified model for linear and nonlinear processes in thermoacoustic prime movers. Part II. Numerical method and comparison with experiment"
3. S. Karpov and A. Prosperetti "Linear thermoacoustic instability in the time domain", submitted on April 25, 1997

The following presentations were made:

1. A. Prosperetti "A new hypothesis on single-bubble sonoluminescence", Acoustical Society of America, Hawaii meeting, *J. Acoust. Soc. Am.* **100** 2677, 1996 (invited paper)
2. A. Prosperetti "A new hypothesis on the mechanism of sonoluminescence", American Physical Society Fluid Dynamics Division Syracuse meeting, 24-26 November, 1996, *Bull. Am. Phys. Soc.* **41** 1693, 1996
3. A. Prosperetti "A new hypothesis on single-bubble sonoluminescence", presented at the symposium *In Fascination of Fluid Mechanics*, Lattrop, The Netherlands, 20-22 March 1997 (invited)
4. A. Prosperetti "Single- and multiple-bubble sonoluminescence", seminar presented at the Institut Meurice, Bruxelles, March 19, 1997

5. A. Prosperetti "Sonoluminescence", seminar presented at the Johns Hopkins University, April 3, 1997

The following abstract has been accepted:

1. S. Karpov and A. Prosperetti (1997) "A time-domain description of the thermoacoustic instability", *J. Acoust. Soc. Am.* **101**, 3022. Paper to be presented at the 133rd Meeting of the Acoustical Society of America, State College, PA, June 15–20.

The following Ph.D. dissertation was accepted in October 1996:

He Yuan, *Some Problems in the Mechanics of Gas Bubbles in Liquids*, Department of Mechanical Engineering, The Johns Hopkins University

Project 2.

The following papers have been published:

1. Wetzel, M., Herman, C. "Design optimization of thermoacoustic refrigerators", Int. J. Refrig. Vol. 20, No. 1, pp. 3-21, 1997a
2. Wetzel, M. Herman, C. "Design issues of thermoacoustic refrigerator and its heat exchangers", HTD-Vol. 331, National Heat Transfer Conference, Vol. 9, ASME, pp.137-144, 1996a
3. Wetzel, M., Herman, C. "Parameter spaces and design optimization of thermoacoustic refrigerators", AES 1071-6947, Symposium on Thermodynamics and the Design, Analysis and Improvement of Energy Systems, Vol. 36, ASME, pp. 355-364, 1996b

The following paper has been accepted for publication:

Herman, C., Kang, E., Wetzel, M. "Expanding the application of holographic interferometry to the quantitative visualization of oscillatory thermofluid processes using temperature as tracer", accepted for publication in Experiments in Fluids, 1997

The following paper has been submitted for publication:

Wetzel, M., Herman, C. "Limitations of temperature measurements with holographic interferometry in the presence of pressure variations" to be submitted to Experimental Thermal and Fluid Science, 1997b

The following presentations were made:

1. The paper "Design issues of a thermoacoustic refrigerator and its heat exchangers" was a selected student paper presented at the National Heat Transfer Conference 1996 in Houston, TX

2. The paper "Parameter spaces and design optimization of thermoacoustic refrigerators" was presented at the 1996 International Mechanical Engineering Congress and Exposition in Atlanta, GA

3. Wetzel, M., Herman, C. "Measurements of oscillating temperature fields in the stack region of a thermoacoustic refrigerator model", presented at the third joint meeting of the Acoustical Society of America and the Acoustical Society of Japan in Hawaii 1996, J. Acoust. Soc. Am. 100, pp. 2846, 1996

The following students completed the requirements for a Master's degree:

1. Magali Brouillat "Design of a thermoacoustic refrigerator model", thesis to complete the DEA (comparable to a Master's degree) at the Ecole Centrale de Lyon

2. Markus Mohne "Entwurf einer thermoakustischen K=E4ltemaschine" diploma thesis (comparable to a Master thesis) to complete the degree at the Technical University in Munich

3. Martin Wetzel finished the degree Master of Science in Engineering (MSE) at the Johns Hopkins University in February 1997.

Project 3.

The following papers have been published:

1. A.S. Worlikar & O.M. Knio (1996) "Numerical Simulation of a Thermoacoustic Refrigerator. Part I: Unsteady Adiabatic Flow Around the Stack," *J. Comput. Phys.* **127**, 424 –451.

2. O.M. Knio, A.S. Worlikar & H.N. Najm (1996) "Mixing and Chemical Reaction in an Idealized Swirl Chamber," *Twenty-Sixth Symposium (International) on Combustion*, 203–209.

3. A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical Modeling of a Thermoacoustic Refrigerator," *Vortex Flows and Related Numerical Methods II*, Y. Gagnon, G.-H. Cottet, A.F. Ghoniem, D.G. Dritschel and E. Meiburg, Eds., *ESAIM Proceedings* **1**, 363–375.

The following papers have been submitted:

1. A.S. Worlikar, O.M. Knio & R. Klein (1997), "Numerical Simulation of a Thermoacoustic Refrigerator. II Stratified Flow around the Stack," submitted to *J. Comput. Phys.*

2. A.S. Worlikar, O.M. Knio & R. Klein (1997) "Numerical Study of the Effective Impedance of an Idealized Thermoacoustic Stack," submitted to *Phys. Fluids.*

3. A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical Simulation of Acoustically-Generated Temperature Gradients in Short Thermoacoustics Stacks: A Validation Study," accepted for presentation and to appear in the Proceeding of 32nd National Heat Transfer Conference, Baltimore, MD, August 1997.

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2. A.S. Worlikar, O.M. Knio & R. Klein (1996) "Numerical Simulation of an Idealized Thermoacoustic Engine," presented at the DFD96 Meeting of the American Physical Society.

The following abstract has been accepted:

1. A.S. Worlikar, O.M. Knio & R. Klein (1997) "Numerical study of the performance of an idealized thermoacoustic stack", *J. Acoust. Soc. Am.* **101**, 3022. Paper to be presented at the 133rd Meeting of the Acoustical Society of America, State College, PA, June 15–20.

HONORS

1. A. Prosperetti: Elected Fellow of ASME
2. A. Prosperetti: Appointed to the U.S. National Committee on Theoretical and Applied Mechanics
3. A. Prosperetti: Appointed Vice-Chair of the Multiphase Flow Technical Committee, ASME
4. A. Prosperetti: Appointed Associate Editor for the *International Journal of Multiphase Flow*
5. C. Herman: Distinguished Faculty Award for Commitment to Undergraduate Research. Awarded by the Student Council of the Johns Hopkins University
6. C. Heramn: CAREER (Faculty Early Career Development Program) Award from the National Science Foundation
7. C. Herman: Nominated By NASA for the Presidential Early Career Award for Scientists and Engineers (PECASE)
8. O. Knio: Associated Western Universities Faculty Fellowship Award, June 1996.
9. O. Knio: Program Subcommittee Member, 26th International Symposium on Combustion.
10. O. Knio: Program Subcommittee Memeber, 27th International Symposium on Combustion.
11. O. Knio: Co-Organizer, Session on Emerging Refrigeration Technologies, 32nd National Heat Transfer Conference.
12. O. Knio: Co-Organizer, Session on Transport Phenomena in Oscillatory Flows, 32nd National Heat Transfer Conference.

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
for
01 June 95 through 31 May 96

Contract/Grant Number: N0001494J0063

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a. Number of papers submitted to refereed journals but not yet published:	8
b. Number of papers published in refereed journals (ATTACH LIST):	6
c. Number of books or chapters submitted but not yet published:	0
d. Number of books or chapters published (ATTACH LIST):	0
e. Number of printed technical reports & non-refereed papers (ATTACH LIST):	0
f. Number of patents filed:	0
g. Number of patents granted (ATTACH LIST):	0
h. Number of invited presentations at workshops or professional society meetings:	2
i. Number of contributed presentations at workshops or professional society meetings:	8
j. Honors/awards/prizes for contract/grant employees, such as scientific society and faculty awards/offices (ATTACH LIST):	12
k. Number of graduate students supported at least 25% this year this contract/grant:	4
l. Number of post docs supported at least 25% this year this contract/grant:	0

How many of each are females or minorities? These six numbers are for ONR's EEO/Minority Reports. Minorities include Blacks, Aleuts, Amindians, etc., and those of Hispanic or Asian extraction/nationality. The Asians are singled out to facilitate meeting reporting semantics re "underrepresented".

Graduate student FEMALE:	0	Post doc FEMALE:	0
Graduate student MINORITY:	0	Post doc MINORITY:	0
Graduate student ASIAN E/N:	2	Post doc ASIAN E/N:	0