DOE/ER/14179-1

DOE/ER/ 14179--1

DE92 007034

Stability and heat transfer in time–modulated flows
Technical Progress Report: DOE/ER/14179–1

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The report outlines research activities currently underway in the Laboratory for Advanced Computation at the University of Massachusetts–Lowell under DOE grant DE–FG02–91ER14179. A summary of results for the period May to October 1991 conducted under the program is given.

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1.0 Introduction

In May 1991, DOE awarded grant DE–FG02–91ER14179 for the investigation of stability and heat transfer in time–modulated flows. The general objectives of the research being: 1) to demonstrate and quantify theoretically and experimentally the physics of modulational instability; 2) to exhibit experimentally and describe theoretically the sensitivity of modulational instability to harmonic content of the basic state; 3) to model the influence of mean–flow on modulational instability; 4) to examine practical design implications of the results with particular attention given to heat transfer.

During the last six months, the emphasis of the research has been placed on objective 1 as it relates to the fundamental physical mechanisms, experiment design, and techniques required for the demonstration and description of the modulational instability.

2.0 Noteworthy accomplishments

2.1 Model of the transition process

During the last six months, preliminary findings on the description of transition to chaos in time–modulated flows has been presented in the literature[1]. It has been observed by Merkli et al. [2] that time–modulated flows can exhibit viscous streaming, instability, and turbulence. The transition between these states has been shown to be a function of the modulation amplitude. The extraction of energy from the oscillatory basic–flow is found to be dependent on the value of the stability parameter T equal to $U_o H_o^{1/2}/((\omega\nu)^{3/4} L_o)$ where U_o is the velocity amplitude of the modulation, ω is the frequency of oscillation, ν is the kinematic viscosity of the fluid and H_o and L_o are geometric length scales. Above the critical value of T equal to 4.11 (T_c), three–dimensional disturbances were found to be linearly unstable. It was found that the critical spanwise wavenumber κ_c, corresponding to the least stable disturbance was equal to .35 times that of the oscillatory boundary layer. In the current study only two spanwise wavenumbers were considered, namely the zeroth and first least stable wavenumbers according to linear theory. When the unsteady amplitude of the outer flow was increased the three–dimensional vortical disturbances exhibited a sub–critical behavior[3]. Upon further increasing the modulation amplitude, the disturbance proceeded to chaotic motion through a cascade of period–doubling bifurcations.

2.2 Enhanced Heat transfer model

For advective transport of heat from an isothermal boundary it was shown that the heat transfer rate is influenced by the magnitude of the Strouhal and Prandtl numbers as well as the amplitude of the unsteady modulation. Such oscillations can produce pronounced physical effects at a phase interface. Typical among these effects is an increase in the rate of heat transfer from a solid object [4]. In this analysis the most unstable vortical disturbance was considered. This disturbance has a spanwise wave number κ equal to 0.35. The boundary curvature was taken to be negative. In all calculations, the velocities were integrated in time till a steady state was reached. At such time, the boundary condition for the temperature was imposed. The instantaneous temperature gradient θ_y at the boundary corresponding to the zeroth spanwise harmonic was evaluated. The heat flux is proportional the negative of the temperature gradient.

The temporal evolution of the temperature gradient corresponding to a value of the stability parameter T equal to $\sqrt{50.0}$ was examined. This value of the stability parameter corresponds to the first period doubling bifurcation in the velocity field. The oscillation frequency in the heat flux is equal to that in the vertical velocity. A decrease in the magnitude of the Prandtl and Strouhal numbers reduced the heat flux, driving the value of θ_y closer to zero. This behavior due to decreasing the Prandtl number is attributed to the large boundary layer thickness of the vertical component of the velocity which is approximately 5δ. As the Prandtl number is increased, the thermal boundary layer becomes thinner. However, the velocity field causes the curvature in temperature profile to be larger locally. This, in turn results in a higher heat flux at the boundary.

For T^2 above 81.5 ,corresponding to the chaotic regime, it was found that for *Pr* equal to 0.7, the heat flux increases almost linearly with increasing Strouhal number and shows little dependence on the chaotic oscillation in the fluid. In fact, for a fixed value of the Strouhal number, the heat flux decreases slightly with increasing T^2. For *Pr* equals 7.0, the temperature gradient is five times greater than in the previous case. However, the heat flux shows greater dependence on Strouhal number and T^2.

3.0 Facilities Enhancements

In January of 1987, the Department of Electrical Engineering, the College of Engineering and the Analog Devices Career Development Professorship provided funds for the creation of the Laboratory for Advanced Computation at the University of Massachusetts–Lowell. The objective of this new laboratory is to undertake projects and develop techniques which are to be used in compute–intensive modeling.

The Laboratory for Advanced Computation occupies 1660 square feet and is equipped with facilities to carry out studies in computation and modeling. Major activities include biomedical imaging, modeling semiconductor processing, pattern recognition, and wave propagation. Students and faculty affiliated with the Laboratory have access to the most advanced computational capabilities available at the University of Massachusetts–Lowell. The Laboratory currently has two Alliant FX/80 mini–supercomputers, ten Apollo DN–3500 graphic workstations, a DN–3500 file server, and a Masscomp 5550 data–acquisition computer. These computers are connected into an integrated network using Ethernet TCP/IP protocols. Network Compute System (NCS) is used for distributed computing across the network.

DOE funds have been used to increase the computational capabilities of the Laboratory for Advanced Computation at the University of Massachusetts–Lowell. To this end an additional Alliant FX/80 mini–supercomputer was purchased and is dedicated to numerical experiments for the DOE tasks. This acquisition allows intermediate scale calculations at a speed of 200 MFLOPS to be performed.

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