FINAL TECHNICAL REPORT

ON

ONR GRANT NO. N00014-87-J-1130

DESTABILIZATION OF SUPERSONIC FREE SHEAR LAYERS BY PARAMETRIC EXCITATION USING MACH WAVES GENERATED BY A WAVY WALL

PERIOD COVERED BY THIS REPORT

MARCH 1, 1989 TO FEBRUARY 28, 1990

PRINCIPAL INVESTIGATOR

Dr. Christopher Tam
Department of Mathematics
Florida State University
Tallahassee, FL 32306-3027

ONR SCIENTIFIC OFFICER

Dr. S. G. Lekoudis
Code 1132F
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

The original objectives of this research project are:

1. To study and classify all the instability wave and acoustic modes of ducted supersonic free shear layers.
2. To investigate the possibility of mixing enhancement by means of a periodic Mach wave system generated by wavy walls of the channel enclosure.

We would like to report that both objectives have been achieved. The technical results have been reported in journal publications or are in the process of submission for publication.

Some highlights of our findings are:

(A) Instability and acoustic wave modes of ducted supersonic shear layers.

1. At supersonic convective Mach numbers two families of instability waves designated as Class A and B waves were discovered. At these operating conditions the usual Kelvin-Helmholtz instability waves no longer exist. The supersonic instability waves A and B are formed by acoustic reflections from the top and bottom channel walls.

2. There are two families of acoustic waves designated as class C and D waves. All the waves propagate downstream. Class C and D waves are formed by reflections from the top and bottom (and side) walls of the channel.

3. At supersonic convective Mach numbers the growth rates of the supersonic instability waves are quite small. This implies that the natural mixing rate of the shear layer is also very small.

4. A grid-search technique for spatial instability waves was developed in the course of this work. Also a phenomenon involving pole merging but without pinching the fourier inversion contour was observed for the first time in our computational

study. This phenomenon must be taken into account in classifying the wave modes.

(B) Mixing enhancement by parametric excitation using periodic Mach waves.

1. We are able to show that by choosing the wave length of the periodic Mach waves appropriately it is possible to induce resonant instability involving two acoustic wave modes of the ducted shear layer flow. The growth rate of the resonant instability is quite large. An amplification of e^9 over a distance of six channel height with a wavy wall amplitude to wave length ratio of less than 3% is possible over a range of frequencies.

2. The presence of periodic Mach waves also can lead to Floquet type secondary instability. A computation study carried out in this investigation clearly indicates the existence of new instability wave modes. Numerical results show that the growth rates of the new instability waves vary linearly with the amplitude of the Mach waves.

The following is a list of publications supported by this ONR grant.

1. <u>Instabilities of High Speed Jets</u> (C. K. W. Tam & F. Q. Hu) Bulletin American Physical Society <u>32</u>, 2051, 1987.

2. <u>Instabilities of Supersonic Mixing Layers Inside a Rectangular Channel</u> (C. K. W. Tam & F. Q. Hu) Proceedings First National Fluid Dynamics Conference, Part 2, 1073-1086, 1988.

3. <u>Enhancement of 3-D Instabilities and Mixing in Supersonic Shear Layers by the Use of a Periodic Mach Wave System</u> (C. K. W. Tam & F. Q. Hu) Bulletin American Physical Society <u>33</u>, 2236, 1988.

4. <u>On the Three Families of Instability Waves of High Speed Jets</u> (C. K. W. Tam & F. Q. Hu) Journal of Fluid Mechanics <u>201</u>, 447-483, 1989.

5. <u>The Instability and Acoustic Wave Modes of Supersonic Mixing Layers Inside a Rectangular Channel</u> (C. K. W. Tam & F. Q. Hu) Journal of Fluid Mechanics <u>203</u>, 51-76, 1989.

6. Resonant Instability of Ducted Free Supersonic Mixing Layers Induced by Periodic Mach Waves (C. K. W. Tam & F. Q. Hu) submitted for publication in the Journal of Fluid Mechanics.

7. Confined Supersonic Mixing Layers: Computational Investigation of Instability and Mixing Enhancement F. Q. Hu, Ph.D. Thesis, Florida State University, 1990.

In addition to the above, two other investigations initiated by this grant will be continued under the support of the Florida State University. These studies are:

1. Secondary instabilities of supersonic mixing layers induced by periodic Mach waves.

2. A wave interpretation of observed large structures of supersonic mixing layers.

The results of these investigations would provide critical understanding of the role played by instability waves in representing large structures and their relationship to observations.