# ANNUAL PROGRESS REPORT

## ONR Grant No. N00014-90-J-1305 and modification P00003

## "Experimental Simulation and Diagnostics of High-Enthalpy Real-Gas Flows"

A) Description of scientific research goals.

The very high flow speeds (up to 8 km/s) of transport to and from space through the earth's atmosphere are necessarily associated with very high temperatures (up to 10,000 K) in ground testing and research facilities. Such facilities therefore have to operate only for very short test times. Various techniques have been devised for generating a test flow of sufficient speed and density to simulate the thermal and kinetic processes of high-temperature gasdynamics correctly. Of these, the shock tunnel and the expansion tube principle are the most successful, and in both cases the high enthalpy regime requires the driver gas to be heated transiently to high temperatures (up to 4,000 K). This can most conveniently be achieved by a piston compression.

A number of piston-driven shock tunnels exist, and a new one, T5, has been completed at GALCIT in December 1990. Funding for the construction of T5 was provided by the National Aerospace Plane (NASP) program through Rocketdyne Division of Rockwell International Corporation (approx. $1.5M) and Caltech (approx. $2.2M). It is the first such facility in the USA, and unique in its performance.

Many new and only partially understood effects occur in the flows associated with the NASP. Dissociative non-equilibrium effects in the external flow, mixing and combustion processes in supersonic combustion ramjet engines and boundary layers in real-gas flows pose new problems that can presently not be solved by computational fluid dynamics (CFD) techniques. Key experimental data are needed to test and supply parameters for CFD methods.

The aim of the research funded by the Grant is to initiate research in this field with the longer-term view of building up the capability and know-how needed for competence in the field. The specific efforts concentrate on

1. Mixing and combustion processes
2. Real-gas boundary layers.



B) Significant results in the last year.

After the severe difficulties of the middle phase of the construction of T5 during 1990, the facility was completed and brought into operation in December 1990. However, as the operating pressure was increased, it soon became apparent that a design error had been made in that the secondary air reservoir, holding the compressed air for accelerating the piston, had been rigidly attached to the building instead of being free to recoil. This caused a very significant force to be exerted on the building, and a modification had to be made. After the design company refused to take responsibility for this error, we designed and effected the modification in house in order to save money. It was completed in April 1991 and the facility was brought up to maximum-pressure operation (130 MPa) in August.

The performance of T5 showed, that the insight gained from the theoretical study of the previous year (see task 3 and reference 3 in last year's report) was very valuable. Operating the facility along the lines suggested by that study gives longer temporally uniform test conditions than had previously been achieved in similar facilities. At the same time, this good performance leads to problems at the high pressure end of the performance envelope. In particular, the nozzle throat, transducer holders and piston get heated so much that local melting degrades them seriously. By making changes, using inserts of different materials, these problems have been partially solved.

The 55 runs of T5 up to the time of writing have allowed us to build a body of know-how in a competent team of faculty, staff and graduate students with a well-equipped unique facility. The machine is now almost ready to begin an extensive test of a combustor model of Rocketdyne's NASP engine. This is expected to be completed in December, and the research program of our graduate students in mixing and combustion, and real-gas boundary layers will begin in the facility. The progress on the five tasks involved in this program, as outlined in last year's report is listed here:

**Task 1 Optical System** The optical system was completed, built and tested. It has not been operated together with T5, but is now ready.

**Task 2 Data Acquisition and Control System** The components were bought, assembled and tested. Extensive software was generated, debugged, and used in the testing of T5 so far. This system is a very powerful but also a essential component of the facility.

**Task 3 Numerical T5-performance Study** As mentioned above, completion of this study enabled the facility performance to be optimized.

**Task 4 Hydrogen Injection System** The small hydrogen injection shock tunnel was designed, built, tested, debugged and installed on T5. After minor modifications next week, it will be ready to be used.

**Task 5 I-R Heat Flux Gauge** This feasibility study showed the technique to be successful, and a modified version of the gauge is being built.

In summary: the Grant has been the key to enabling us to do the preparatory work, in parallel with the construction of T5, that is so necessary to make a facility of this complexity effective as early as possible. The goals of the effort have therefore been achieved.

C) Publications.

During the period, the following publications were produced:

[1] Belanger, Jacques 1990 Description and use of a computer program for unsteady one-dimensional calculations of shock tunnel processes. GALCIT Report FM90-3. (Attached.)

[2] Rein, Martin 1991 Partial chemical equilibrium: Theory and implementation in the program SURF. GALCIT Report FM91-1. (Attached.)

[3] Hornung, H. et al. 1991 Performance data of the new free-piston shock tunnel T5 at GALCIT. Presented at the 18th International Symposium on Shock Waves, Sendai, Japan, July 21-26, 1991, to be published in the Proceedings Volume. (preprint attached).

D) Plans for next year's research.

The Grant terminates in October 1991 (a no cost extention has been requested through June 1992), and has served to enable us to complete the original goals of initiating research in the field and to build competence in it. This implies a beginning to something larger, of course, and the program for 1992 is being funded by NASA and probably by AFOSR. In addition the facility will be used for industrial research by NASP contractors.

The research program by GALCIT faculty and graduate students will use the equipment and techniques developed for the following investigations:

*Detailed study of turbulent structure of supersonic mixing and combustion of hydrogen at high enthalpy*

*Detailed study of the structure of transition and turbulence in a high enthalpy boundary layer on a cone*

*Application of a new IR heat flux gauge to high-enthalpy blunt body flows*

*Investigation of real-gas effects in shock-on-shock interaction*

Virtually all the hardware and techniques are in place for making significant progress in each of these tasks during 1992.

## THE MODIFICATION

In August 1990 we made a proposal to ONR for research into the basic features of the asymmetry of the vortex separation on a cone at high angle of attack. Since this was to be a relatively small program, Dr. Lekoudis suggested that we should treat this as a modification of the existing Grant. Because it is quite a different field, we treat it as a separate item in this report.

a) Description of scientific research goals.

The phenomenon that the vortex pair on the lee side of an axisymmetric pointed body at large angle of attack becomes asymmetric is of considerable importance in the control of the motion of such bodies through water or air. Some of the features of this asymmetry and its causes are well documented. In order to learn better how to deliberately control the asymmetry for the purpose of using it as a flight-mechanical control device it is necessary to study the flow near the nose in detail.

The goals of this project were therefore to rebuild an existing set-up for a similar experiment (including water channel, incidence mechanism and motorised model) that was being dismantled at JPL, and to use this set-up with sufficiently large spherical and elliptical nose tips to see the topological structure of the flow separation in some detail, and to investigate how this responds to deliberate slight asymmetries in the nose geometry, by using flow visualization techniques.

b) Significant results in the past year.

The water channel was rebuilt in a different configuration that required installation of a new motor and pump. Several different nose shapes were designed and made on a numerically controlled milling machine. The water channel was calibrated in the new configuration. The flow visualization system using an existing Argon ion laser for fluorescent dye illumination was completed. Several sets of data have been gathered with spherical nose tips, but the experiments have only just been able to be started.

c) Plans for next year's research.

Now that the water channel and visualization technique are in place, the set-up will be used to gather data virtually all the time, because the equipment is dedicated to this experiment. No major further costs will be incurred, other than the support of David Bridges (former ONR-fellow) who is doing the research. As the Grant is terminating in October, a no cost extension through June 1992 has been requested which would allow Mr. Bridges to complete the project.