Japanese Aerospace Literature This month: *Supersonic Flow*

A90-42583 Analytical study on the influence of non-equilibrium ionization for current flow pattern and flow field of MPD arcjets. ITSURO KIMURA, and TSUNETAKE SHOJI, 21st AIAA, DGLR, and JSASS, International Electric Propulsion Conference, Orlando, FL, July 18–20, 1990. 10 pp. 8 Refs. (AIAA Paper 90–2609).

The effect of non-equilibrium ionization on a one-dimensional supersonic self-field MPD flow, which starts from the point of Mach number 1, is analyzed taking ionization and recombination rate-equations and electron energy equation into consideration. It was observed generally that for given inlet boundary conditions and a total discharge current, the solution exists in a limited region of propellant flow rate and the required electrode becomes longer for lower propellant flow rate, as in the cases of frozen or thermal-equilibrium flow. Based on the calculated results with argon or hydrogen propellant, it was shown that a remarkable deviation from ionization equilibrium appears in the course of plasma acceleration, when the propellant flow rate is near the lower limit, and that for molecular species hydrogen, current concentration on the inlet part, observed in the case of argon, is removed by the influence of dissociation process.

A90-37127 Three-dimensional structures of interacting free jets. TETSUO FUJIMOTO and TOMOHIDE NI-IMI, *16th Rarefied gas dynamics: Space-related studies; International Symposium,* Pasadena, CA, July 10–16, 1988, Technical Papers (A90-37101 16–34). Washington, DC, American Institute of Aeronautics and Astronautics, Inc., 1989, pp. 391–406. 8 Refs.

Three-dimensional structures of two-interacting identical supersonic free jets of Ar are studied by flow visualization using laser-induced fluorescence of I2 molecules seeded in Ar. The flowfield of interacting free jets shows various patterns depending on the angle theta between the jet axes and on the pressure ratio Ps/Pb. For theta up to 90 deg, the flowfield is symmetrical with respect to the interacting plane that bisects the jet axes. For theta over 90 deg, many types of flowfields appear as Ps/Pb varies, suggesting the complexity of flow stability.

A90-36471 Measurements of small signal gain coefficients of a supersonic flow CO chemical laser. WATARU MASUDA, MASATO IKARASHI, and KAZUHIKO SHIRAISHI, *JSME International Journal, Series II* (ISSN 0914–8817), Vol. 33, May 1990, pp. 272–275. 8 Refs.

Small signal gain coefficients of a supersonic flow CO chemical laser are measured using a shock tunnel facility. A high temperature mixture of CS2, CS, S2, S, and Ar is produced in a shock tube, where the thermal dissociation of CS2, diluted in Ar is accomplished by a reflected shock wave. The shock-heated mixture is exhausted through two-dimensional supersonic nozzles mounted at the end of the tube and mixed with the supersonic streams of O2. Then, vibrationally excited CO molecules are produced in the mixed streams. In the present paper, the dependence of the small signal gain coefficients on the downstream distance from the nozzle, the plenum conditions, and the transition branch is studied. The data obtained in the present experiments are available to examine the propriety of the theoretical model which was developed previously.

A90-36465 Oscillation of circular shock wave. MYEONG KWAN PARK, SHUZO OSHIMA, and RYUICHIRO YAMANE, *JSME International Journal Series II* (ISSN 0914–8817), Vol. 33, May 1990, pp. 208–215. 10 Refs.

Oscillation modes of a circular shock wave in a supersonic radial flow were studied both experimentally and theoretically. The pressure fluctuation was measured in concentric positions to investigate the modes of the circular shock wave in the case of mean radii of 70 and 77 mm, and the AD converted signals were statistically correlated. A simple model of an oscillating shock wave was proposed. The frequency of the oscillation increased from low to high values with increasing radius. The oscillation mainly consisted of mode 0 superposed by modes of 1, 2 and 4. The mode 1 is considered to be weak. The experimental frequency of each mode agreed well with the theoretical results.

A90-25782 Numerical study on mixing and ignition of injecting jet into a supersonic flow. MASAHIRO TAKAHASHI and A. KOICHI HAYASHI, *3rd ISCFD Nagoya 1989—International Symposium on Computational Fluid Dynamics,* Nagoya, Japan, Aug. 28–31, 1989, Technical Papers (A90-25720 10–34). Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, pp. 465–470.7 Refs.

A supersonic air flow with the transverse helium injection is simulated numerically by solving the two-dimensional Reynolds averaged full Navier-Stokes equations with an algebraic eddy viscosity model developed by Baldwin and Lomax. The numerical results are compared with the experimental results to study a validity of the turbulence model and this code. The results are also compared with the solution of a laminar flow case to show the effects of using the turbulence model for the calculations of the high Reynolds number flow field. The use of the turbulence model improves the interpretation of the experimental data, but shows the insufficient effects of turbulence at the separation regions and near the injector because of a complex flow field. A modification to the algebraic model or an adoption of higher class models such as a 2-equations model are necessary to improve the simulation.

A90-34835 Kelvin-Helmholtz instability for supersonic shear flow at the magnetospheric boundary. AKIRA MIURA, *Geophysical Research Letters* (ISSN 0094–8276), Vol. 17, May 1990, pp. 749–752. Research supported by the Yamada Science Foundation. 28 Refs.

It is demonstrated by means of an MHD simulation that a finite thick velocity shear layer with super-Alfvenic velocity jump is unstable to the Kelvin-Helmholtz (KH) instability no matter how large the sonic Mach number, a result suggesting that the tail flank boundary is unstable to the KH instability. For supersonic shear flow the unstable mode becomes damped-oscillatory in the magnetosheath. For both subsonic and supersonic shear flows, the energy flux density into the magnetosphere by the KH instability is large enough to replenish the plasma in the low latitude boundary layer with the tailward flow kinetic energy of observed intensity. A significant fraction of the energy flux density can reach deeper into the magnetosphere and its intensity is comparable to an energy flux density required for excitation of a ULF wave in the magnetosphere.

A90-25874 Three-dimensional structure of a supersonic free jet issuing from a rectangular orifice. KOJI TESHIMA, *3rd ISCFD Nagoya 1989—International Symposium on Computational Fluid Dynamics,* Nagoya, Japan, Aug. 28–31, 1989, Technical Papers (A90-25720 10–34). Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, pp. 1144–1149.

The three-dimensional characteristics of a supersonic jet issuing from a relatively small aspect ratio orifice are simulated by solving the Euler equations using the finite difference method, and a numerical prediction method for a supersonic jet issuing from an orifice of arbitrary shape is established. The jet has a core region surrounded by lateral shock corresponding to the barrel shock for an axisymmetric jet and a normal shock. The cross section of the core region has a diamond shape the length of whose longer diagonal is in accordance with the orifice width. Secondary jets caused by interaction of lateral shock on the symmetric plane expand in the directions orthogonal to the sides of the orifice. The distance of the normal shock on the jet center is proportional to the square root of the pressure ratio and increases with almost the square root of the aspect ratio.

A90-25806 Numerical computations of supersonic chemically reacting flows using hydrogen-air combustion models. TOMIKO ISHIGURO, SATORU OGAWA, YASUHIRO WADA, and GORO MUSUYA, *3rd ISCFD Nagoya 1989—International Symposium on Computational Fluid Dynamics,* Nagoya, Japan, Aug. 28–31, 1989, Technical Papers (A90-25720 10–34). Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, pp. 611–616.10 Refs.

The numerical procedures utilized to develop a computer code based on complete Navier-Stokes equations and the chemical species equations are described. The computer code is evaluated by applying it to the analysis of simulated shock-induced chemically reacting flows and flow fields of transverse sonic injection of H2 fuel into a supersonic airstream in a scram jet combustor. The data reveal the method is useful.

A90-16104 Studies on supersonic radial flow behavior in disk channel. DEWASISH BISWAS, HIROYUKI YAMASAKI, TAKAO MATSUI, YOSHINORI SAITO, and SUSUMU SHIODA, *JSME International Journal Series II* (ISSN 0914–8817), Vol. 32, Nov. 1989, pp. 574–582. 14 Refs.

A supersonic radial flow in a disk channel is studied. Under the high stagnation pressure condition, effects of both the stagnation pressure and the channel height on the radial static pressure distribution are investigated. The pressure recovery through the pseudoshock, its length, the velocity profile and the thickness of the boundary layer were also measured. The results have shown that the supersonic region extends downstream with the increase of the stagnation pressure. However, the transition from the supersonic flow to subsonic flow occurs at the region further upstream than that predicted by the normal shock relation. The pressure recovery through the pseudoshock is found to be lower compared to that of a normal shock, particularly at a high, free-stream Mach number. In addition, the axially asymmetric form of the pseudoshock was observed. Furthermore, the measured static pressure, velocity distribution and the boundary layer thickness at the supersonic region agree well with the results of the two-dimensional calculation.

A90-12238 Numerical calculation of unsteady aerodynamic forces for two-dimensional supersonic oscillating cascades by finite element method. KUOCHENG YANG and MASANOBU NAMBA, *Kyushu University, Technology Reports* (ISSN 0023–2718), Vol. 62, June 1989, pp. 239–246. 7 Refs.

Calculation by a finite element method has been conducted to study unsteady aerodynamic forces for two-dimensional oscillating cascades in supersonic flows. In the case of lightly loaded cascades, unsteady aerodynamic forces are dominated by the effect of displacement of an oblique shock reflection point, destablizing a translational blade motion at some interblade phase angles. In the case of moderately or highly loaded cascades with a normal shock in the blade passage also the unsteady pressure is locally high near the shock position, but the translational blade motion is generally stablized.

A90-11342 Characteristics of supersonic mixing CO2 laser combined with N2 axial glow discharge. K. MAENO, A. SAKASHITA, Y. HANAOKA, and K. SHIMIZU, *Proceedings of the 7th International Symposium on Gas Flow and Chemical Lasers,*]Vienna, Austria, Aug. 22–26, 1988, (A90-11326 01–36). Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1989, pp. 235–242. 12 Refs.

This paper deals with experimental and analytical investigation on supersonic CO2 mixing laser with N2 axial glow discharge. Measurements of small signal gain coefficient and laser power are conducted by the setup of cluster of glass channels for supersonic N2 glow discharge and CO2 conical screen nozzles. The discharge characteristics are also monitored. Supersonic flow of population inversion is maintained for about 10 seconds in the experiments. To estimate the characteristics of the present CO2 mixing laser, vibrationally non-equilibrium analysis for steady and quasi-one-dimensional supersonic flow is performed, including N2 molecular activation effects by electron impact in glow discharge. As for the results, steady glow discharge in supersonic N2 flow is obtained, and measured small signal gain and power dependencies on flow parameters, and on discharge parameters are discussed in comparison with the results of numerical estimation.

A89-49827 An experimental study of supersonic mixing process by using shock tunnel using quick-action valves and quick-mass-sampling probe technique. MASAHIRO HATAKEYAMA, KATSUSHI FUNABIKI, and TAKASHI ABE, *Japan Society for Aeronautical and Space Sciences Journal* (ISSN 0021–4663), Vol. 37, No. 425, 1989, pp. 278–284. 5 Refs.

In order to examine the supersonic mixing process in a high enthalpy supersonic flow, a shock tunnel using quick-action valves has been developed and operated. The present shock tunnel generates a high enthalpy flow without contamination. The nozzle is designed to make parallel supersonic flows which are comprised of a high-enthalpy air stream and a helium stream. Mach numbers of the air and helium flows are 3.4 and 4.2, respectively. The structure of mixing region of parallel supersonic flows thus obtained was examined by means of a mass-sampling probe which enables direct examination of the concentration ratio of the mixture gases. The measurement shows that the mixing region almost agrees with the region observed by Schlieren photography.

A89-49759 Investigations of advanced CO2 supersonic mixing laser and propulsion by laser absorption. KAZUO MAENO, YUTAKA HANAOKA, HIROSHI AOYAMA, and AKIHIRO SAKASHITA, *Utilization of laser technology in space* (A89-49757 22–36). Tokyo, Institute of Space and Astronautical Science, 1988, pp. 19–40. 12 Refs.

Experimental and analytical results on a supersonic CO2 mixing laser with axial glow discharge in a supersonic N2 channel are reported. The small signal gain coefficient is measured and the discharge characteristics are monitored; the results confirm steady glow discharge in the supersonic nitrogen flow. A numerical estimate of the vibrationally non-equilibrium flow with electric excitation effect indicates a high gain distribution under the experimental conditions. Optimum operating conditions can be obtained at higher CO2 molar fraction than with conventional gasdynamic CO2 laser. Gasdynamic parameters in supersonic mixing CO2 electric discharge lasers are numerically studied. Experimental results on advanced propulsion by laser beam absorption using a 1 kW-class CW CO2 laser. The effect of SF6 on laser beam absorption in a plenum chamber is found to be remarkable.

A89-49756 Flow visualization of sonic jets exhausting counter to a supersonic free stream using laser induced fluorescence method. SHIGEKI TANAKA, KOJI TESHIMA, KAZUYUKI UENO, and MICHIO NISHIDA, *Aerodynamics in relation to an aeroassisted orbit transfer vehicle* (A89-49751 22–02). Tokyo, Institute of Space and Astronautical Science, 1988, pp. 73–82. 24 Refs.

The flow field resulting from a sonic nose jet exhausting counter to a supersonic free stream of a Mach number of three was visualized by means of a laser induced fluorescence method. The experiments were conducted for various values of the ratio of counter jet total pressure to free-stream total pressure. The ratio of body diameter to jet exit diameter was taken to be 0.2 or 0.4. The results show that the structure of the opposing jets are significantly affected not only by the ratio of jet total pressure to free stream total pressure but also by the ratio of body diameter to jet exit diameter. It was also observed that at the low pressure ratios, there exists unstable flow regime. Simple analysis is applied to the prediction of the position of the free stream shock and Mach disk, and compared with the experimental result. The comparison shows a good agreement. (Numerical simulation was also tried to compare with the experiments.

A91-15034 Accurate computations of compressible Navier-Stokes equations by the spectral collocation method. JIAN-PING WANG, YOSHIAKI NAKAMURA, and MICHIRU YASUHARA, *Japan Society for Aeronautical and Space Sciences Journal* (ISSN 0021–4663), Vol. 38, No. 436, 1990, pp. 232–240. 14 Refs.

The numerical code to solve axisymmetric compressible Navier-Stokes equations by the spectral collocation method was developed and applied to a supersonic flow about a sphere. A Residual-Dependent filter was developed, so that the accuracy could be considerably improved. The influence of filter, time step size, and grid number on accuracy is discussed. The results are compared with experiments, and excellent agreement is shown.

A89-49101 Navier-Stokes computations of the supersonic flows about a Space-Plane. KISA MATSUSHIMA, SUSUMU TAKANASHI, and KOZO FUJII, *AIAA Atmospheric Flight Mechanics Conference,* Boston, MA, Aug. 14–16, 1989, Technical Papers (A89-49051 21–01). Washington, DC, American Institute of Aeronautics and Astronautics, 1989, pp. 475–483. 14 Refs. (AIAA Paper 89–3402).

Three-dimensional flow fields about a Space-plane flying at a supersonic speed are simulated using the Reynolds-averaged Navier-Stokes equations. To realize better performance not only in cruising but also in flying at critical conditions, interest is concentrated on the nonlinear aerodynamic phenomena, including flow separations and vortices due to high angles of attack. Since the Space-Plane is geometrically complicated, the flow field also becomes complicated, and the computational approach with the aid of flow visualization helps understand flow physics as well as provides the aerodynamic coefficients to decide vehicle performance.

A89-41802 Use of high-resolution upwind scheme for vortical flow simulations. KOZO FUJII and SHIGERU OBAYASHI, *9th AIAA Computational Fluid Dynamics Conference,* Buffalo, NY, June 13–15, 1989, Technical Papers (A89-41776 18–02). Washington, DC, American Institute of Aeronautics and Astronautics, 1989, pp. 270–279. 16 Refs. (AIAA Paper 89–1955).

For vortical flow simulations at high Reynolds number, it is important to keep the artificial dissipation as small as possible since it induces unphysical decay of the vortex strength. One way to accomplish this is to decrease the grid spacing. Another way is to use computational schemes having little dissipation. In the present paper, one of the high-resolution upwind schemes called 'MUSCL with Roe's average' is applied to vortical flow simulations. Two examples are considered. One is the leading-edge separation-vortex flow over a strake-delta wing. The other is a high-angle of attack supersonic flow over a space-plane-like configuration. The comparison with the central difference solutions indicates that the present upwind scheme is less dissipative and thus has better resolution for the vortical flows.

A89-12890 Multiple shock wave and turbulent boundary layer interaction in a rectangular duct. H. SUGIYAMA, J. ZHANG, F. ABE, and H. TAKEDA, *Proceedings of the Sixteenth International Symposium, Shock tubes and waves,* Aachen, Federal Republic of Germany, July 26–31, 1987 (A89-12876 03–34). Weinheim, Federal Republic of Germany, VCH Verlagsgesellschaft mbH, 1988, pp. 185–191. 11 Refs.

The effects of the locations of pseudoshock waves in straight square ducts in which the flows are choked at the duct exits on the structure and oscillation phenomena of pseudoshock waves were investigated. The experiments were conducted at the duct-entrance Mach-infinity numbers between 1.72 and 1.88, and the duct length to width ratios (L/D) between 20.6 and 23.6. It was found that the location of a pseudoshock wave moves in a downstream direction with decreasing L/D ratios and increasing Mach-infinity values. As the location of pseudoshock waves moves, the shape of the pseudoshock waves changed from the lambda-type pseudoshock wave, which oscillates with an amplitude of about 0.2 D and low frequencies below 40 Hz, to the X-type wave, which oscillates more regularly with an amplitude of 0.3 D, low frequencies less than 70 Hz, and high frequencies of about 150 to 250 Hz.

A88-40375 Heat flux on the surface of a wedge in Mach reflection and regular reflection of shock waves. MASANORI HAYASHI, SHIGERU ASO, YOSHIHARU TANAHASHI, and AKIRA YAMASHITA, *Kyushu University, Technology Reports* (ISSN 0023–2718), Vol. 61, Jan. 1988, pp. 59–65. 5 Refs.

Measurements of transient temperature and pressure rise on a surface of wedge in a shock tube have been carried out for the case where the incident oblique shock waves on the surface reflect under the conditions of shock Mach numbers 1.34–2.75, with wedge angles of 35.0–48.0 degrees. The heat flux on the surface has been calculated by using the temperature rise. It is known that there are four patterns for the shock reflections. In this paper, these shock reflection patterns have been visualized by the Schlieren method. Finally, it is shown that each flow pattern exhibits characteristic changes of the surface temperature, heat flux and pressure rise with time, and these variations are influenced by the slip stream.

A88-26185 Supersonic expansion of a dusty gas around a sharp corner. H. MIURA, I. I. GLASS, *Proceedings of the Royal Society, (London), Series A—Mathematical and Physical Sciences* (ISSN 0080–4630), Vol. 415, No. 1848, Jan. 8, 1988, pp. 91–105. 12 Refs.

Steady supersonic flows around a corner are studied theoretically for a dusty gas in which the gas and the particles make a significant exchange of momentum and heat. Perfect-gas theory for the dusty gas in an equilibrium limit is used to examine the nature of the flow far from the corner. The maximum flow-deflection angle is found to be increased by the presence of the particles. The equations of motion are solved numerically to study the transition of the flow from a frozen state at the corner to a near-equilibrium state at infinity. The differences in non-equilibrium properties of the flow between the cases of large and small deflection angles of the corner are discussed. Numerical results for large deflection angles show that the gas expands excessively after it enters a pure gas region which forms along the wall surface. In every case, diffusive flow patterns arise around the effective wavehead and wavetail in the far field. It is shown analytically that the length of the diffusive flow domain increases in proportion to the square root of the distance from the wall.