A88-28356 Thermodynamic nonequilibrium of a far hypersonic wake (O termodinamicheskoi neravnovesnosti dal'nego giperzvukovogo sleda). IU. P. SAVEL'EV and M. M. STEPANOV, *Zhurnal Tekhnicheskoi Fiziki* (ISSN 0044-4642), Vol. 57, Nov. 1987, pp. 2178-2183. 8 Refs.

The flow of a low-temperature plasma of a far hypersonic wake is studied theoretically with allowance for nonequilibrium chemical reactions as well as the possible absence of thermodynamic equilibrium. The investigation is based on a numerical analysis of simplified parabolic Navier-Stokes equations for a multicomponent mixture of reacting gases. Numerical results indicate the range of the greatest effect of thermodynamic nonequilibrium on the far-wake parameters.

A88-24622 Hypersonic three-dimensional viscous shock layer in an inhomogeneous gas flow near a critical point (Giperzvukovoi prostranstvennyi viazkii udarnui sloi v neravnomernom potoke gaza v okrestnosti kriticheskoi tochki). S. V. PEIGIN and S. V. TIMCHENKO, *Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza* (ISSN 0568-5281), Nov.-Dec. 1987, pp. 136-145. 11 Refs.

The paper is concerned with three-dimensional hypersonic flow of a viscous gas past smooth blunt bodies in the presence of injection and suction. By using flow from a supersonic spherical source and flow of the far wake type as examples, an analysis is made of the effect of the inhomogeneity of the incoming flow on shock wave detachment, wave structure, and friction and heat transfer coefficients. It is shown that this effect depends to a large degree on the Reynolds number, characteristics of the inhomogeneity, and body shape.

A88-23950 Stability of a supersonic boundary layer during the turning of a flow (Ustoichivost' sverkhzvukovogo pogranichnogo sloia pri povorote techeniia). S. A. GAPONOV and G. V. PETROV, *Akademiia Nauk SSSR, Sibirskoe Otdelenie, Izvestiia, Seriia Tekhnicheskie Nauki* (ISSN 0002-3434), Oct. 1987, pp. 25-29. 8 Refs.

The development of perturbations in the region where supersonic flow turns around a convex surface is investigated by numerically integrating the boundary layer and stability equations and by using estimates based on the gradient Reynolds number. It is shown that flow acceleration in the region of the turn leads to intense flow stabilization. As the turn is completed and the flow reaches a flat plate, complete absorption of acoustic waves by the boundary layer is observed for certain frequencies. Solutions are also obtained which practically become acoustic waves in the external region.

A88-17737 A numerical study of the structure of nonequilibrium three-dimensional hypersonic flow past blunt bodies (Chislennoe issledovanie struktury neravnovesnogo techeniia okolo zatuplennykh tel pri giperzvukovom prostranstvennom obtekanii). V. G. SHCHERBAK, *Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza* (ISSN 0568-5281), Sept.-Oct. 1987, pp. 143-150. 16 Refs.

Three-dimensional flow of a dissociating air around blunt bodies is investigated using parabolized Navier-Stokes equations. The analysis allows for multicomponent diffusion and homogeneous chemical reactions, including dissociation-recombination and exchange reactions. The boundary conditions are specified in the unperturbed flow and on the body surface, with allowance made for heterogeneous catalytic reactions and slip effects. The results obtained are compared with calculations based on a model of a thin viscous shock layer.

A88-21846 Hypersonic flow past axisymmetric rotating bodies in the presence of strong injection (Giperzvukovoe obtekanie osesimmetrichnykh vrashchaiushchikhsia tel pri nalichii sil'nogo vduva). V. A. LEVIN and N. A. KRASILOV, *Moskovskii Universitet, Vestnik, Seriia 1 - Matematika, Mekhanika* (ISSN 0579-9368), Sept.-Oct. 1987, pp. 51-54. 6 Refs.

A solution is presented for the problem of hypersonic flow past an axisymmetric rotating body under conditions of high Reynolds numbers and strong injection. It is shown that, in the case of a rotating body, the separation of the contact discontinuity surface and shock wave from the body is smaller than in the case of a nonrotating body and that the longitudinal component of the velocity vector has a local minimum within the injected gas layer for a rotation parameter of the order of 1.

A88-17730 Effect of angle of attack on supersonic flow past axisymmetric blunt bodies in the presence of injection from the surface (Vliianie ugla ataki na sverkhzvukovoe obtekanie osesimmetrichnykh zatuplennykh tel pri nalichii vduva s poverkhnosti). V. A. ANTONOV, A. M. GRISHIN, and F. M. PAKHOMOV, *Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza* (ISSN 0568-5281), Sept.-Oct. 1987, pp. 95-101. 9 Refs.

The effect of the angle of attack in the range 0-40 degrees on the flow pattern and aerodynamic characteristics of a power-law body under conditions of supersonic flow is investigated numerically for the case of strong localized subsonic injection from the surface and in the absence of injection. The problem is solved using Godunov's finite difference scheme. It is found that strong gas injection significantly reduces the aerodynamic drag of the body without any deterioration of its static stability.

A88-13759 An experimental study of the stability of a supersonic boundary layer on a cone (Eksperimental'noe issledovanie ustoichivosti sverkhzvukovogo pogranichnogo sloia na konuse). A. D. KOSINOV, A. A. MASLOV, and S. G. SHEVEL'KOV, *Akademiia Nauk SSSR, Sibirskoe Otdelenie, Izvestiia, Seriia Tekhnicheskie Nauki* (ISSN 0002-3434), Aug. 1987, pp. 64-69. 15 Refs.

An experimental study is made of the stability of a supersonic boundary layer on a cone against both natural and artificial perturbations. The spatial characteristics of the wave perturbation field of a supersonic boundary layer on a cone are determined, and it is shown that the evolution of perturbations on a cone is similar to the development of perturbations in a boundary layer on a flat plate. It is suggested that the difference in the Reynolds number of the transitions on a cone and on a plate may be due to both the lesser degree of the spatial amplification of perturbations on a cone and the difference in the nature of perturbation generation.

A87-35823 Drag of a slender cone in supersonic flow of a rarefied gas (Soprotivlenie ostrogo konusa v sverkhzvukovom potoke razrezhennogo gaza). F. S. VORONIN and L. N. ZHDANOVA, *Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza* (ISSN 0568-5281), Jan.-Feb. 1987, pp. 187-189. 14 Refs.

The paper reports the results of an experimental study of the drag of a slender cone for flow conditions approaching those of free molecular flow. The experiments were carried out in a wind tunnel at free-stream Mach 11.2 using cones with a half-angle of taper of 5, 10, and 15 deg and a base diameter of 5 and 10 mm. The experimentally determined drag coefficients are found to be close to the values calculated for free molecular flow.

Japanese Aerospace Literature This month: *Supersonics/Hypersonics*

A89-20637 A note on the optimal hypersonic flight path. YOSHINORI WARIISHI and KANICHIRO KATO, *Japan Society for Aeronautical and Space Sciences Journal* (ISSN 0021-4663), Vol. 36, no. 416, 1988, pp. 427-432.

Flight paths of a hypersonic plane are formulated as optimal control problems. Minimum-time, minimum-fuel and maximum-range solutions are shown with varying fuel-to-weight and thrust-to-weight ratios. One of the findings is that an initial path with a slight upward angle is usually advantageous because of the smaller drag (in higher altitude) when in high speed.

A88-19244 Stability of normal shock waves in diffusers. KAZUYASU MATSUO, HIROAKI MOCHIZUKI, and MINORU YAGA, *AIAA Journal* (ISSN 0001-1452), Vol. 25, Nov. 1987, pp. 1515-1517. 5 Refs.

The present analysis of the behavior of a shock wave in a diffuser in response to small-amplitude pressure disturbances indicates that shock wave stability depends not only on the Mach number immediately upstream of the shock, but also on diffuser efficiency for subsonic flow downstream of the shock wave. The neutral stability curve relating the diffuser efficiency to the Mach number is obtained. The maximum diffuser efficiency causing instability decreases as the Mach number increases from 1.0 to 1.48.

A88-13095 The scramjet - Toward Mach 4-25 flight. NOBUO CHINZEI and GORO MASUYA, *Japan Society for Aeronautical and Space Sciences Journal* (ISSN 0021-4663), Vol. 35, no. 400, 1987, pp. 241-252. 51 Refs.

Technological problems in the development of the scramjet are characterized, and scramjet R&D in the United States and Japan is reviewed. Work from 1960 to 1975 is summarized, including the free-jet engine, the variable geometry engine, the component integration model, and the thermal compression engine. Also considered is work after 1975, including the airframe integrated engine and the dual combustor engine.

A89-15680 Numerical simulations of flow field around three-dimensional complex configurations. SATORU OGAWA, TOMIKO ISHIGURO, and YOKO TAKAKURA, *IN: 7th GAMM-Conference on Numerical Methods in Fluid Mechanics*, Louvain-la-Neuve, Belgium, Sept. 9-11, 1987, Proceedings (A89-15651 04-34). Brunswick, Federal Republic of Germany, Friedr. Vieweg und Sohn, 1988, pp. 256-267. 18 Refs.

Numerical simulations of flow around three-dimensional complex configurations are performed by solving both the Euler equations and the Navier-Stokes equations. Recent TVD schemes are used for two problems: (1) transonic and supersonic flow around Shuttle Orbiter, and (2) hypersonic flow in scramjet inlet.

A89-20132 A study on hypersonic shock tunnel. MASANORI HAYASHI, SHIGERU ASO, MASASHI MATSUMOTO, and AKIO ONO, *Kyushu University, Technology Reports* (ISSN 0023-2718), Vol. 61, Aug. 1988, pp. 473-477. 10 Refs.

A hypersonic shock tunnel is designed and constructed. In the design of nozzle contour the effect of boundary layer along the nozzle wall on Mach number profile in the test section is investigated. Two contour nozzles of Mach 8, with and without boundary layer correction, are prepared for the experiments. Cresci's method is used for the design of nozzle contour and Tucker's method for boundary layer correction. The results show that the development of boundary layer along the nozzle wall is remarkable and the correction of boundary layer along the nozzle wall is necessary. Also, the boundary layer along the nozzle wall is overestimated by Tucker's method. The results show that a more precise boundary layer correction method should be developed.

A89-12890 Multiple shock wave and turbulent boundary layer interaction in a rectangular duct. H. SUGIYAMA, J. ZHANG, F. ABE, and H. TAKEDA, *IN: Shock tubes and waves; Proceedings of the Sixteenth International Symposium,* 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.

A88-49844 Thermogasdynamics of hypervelocity vehicle. I—Two-dimensional hypersonic flows including chemical reaction. TOSHI FUJIWARA, KAZUHIRO HORIE, and KAZUMI MASUDA, *Nagoya University, Faculty of Engineering, Memoirs* (ISSN 0027-7657), Vol. 39, no. 2, 1987, pp. 263-305. 17 Refs.

The Euler equations are used to solve two-dimensional hypersonic flows of the order of Mach number 25 for a blunt-body configuration. The study used the beam-warming finite difference technique. The analysis started from a simple set of chemical reactions involved in the dissociation and ionization of oxygen and nitrogen molecules and proceeded to a complicated reaction system including a total of 17 reactions and 11 chemical species. The results show that the beam-warming technique gives convergence to extremely fast hypersonic steady flow problems, even if there are complicated chemical reactions which might cause serious stiffness difficulties. Even less stiff flow fields suffered consistent oscillations in the process of convergence to steady solutions. These difficulties were controlled by adjusting the second-order and fourth-order artificial viscosities and the local time step. The obtained shapes of a bow shock wave and a sonic line agree with other experimental and theoretical results.

A88-22324 Ignition mechanism of scram jet fuel using silane. A. KOICHI HAYASHI, TOSHI FUJIWARA, and KENJI SUGIMOTO, *AIAA, 26th Aerospace Sciences Meeting,* Reno, NV, Jan. 11-14, 1988. 8 pp. 15 Refs. (AIAA Paper 88-0437).

Silane is added to oxyhydrogen combustion to understand its additivity effect in an application of scramjet combustion. A shock tube is used to measure the ignition delay time of the stoichiometric oxyhydrogen mixture with and without 25 percent silane to the hydrogen concentration in the temperature range of 880-1600 K and the pressure range of 1.7-5.1 atm. The results show that the effect of silane addition is strong at the low to medium temperature (880-1300 K) and weak at the high temperature where oxyhydrogen ignition dominates. The slope of ignition delay time versus temperature is different at the medium to high temperature (1000-1600 K) than it is at the low temperature (800-1000 K). A preliminary mechanism of the silane-oxyhydrogen system is developed and numerical simulation of experimental results is performed using the developed mechanism.

A88-22070 A two-dimensional detonation supported by a blunt body or a wedge. T. FUJIWARA, A. MATSUO, and H. NOMOTO, *AIAA, 26th Aerospace Sciences Meeting,* Reno, NV, Jan. 11-14, 1988. 12 pp. 6 Refs. (AIAA Paper 88-0098).

A numerical analysis is performed on the possibility of generating a standing oblique detonation wave around a two-dimensional blunted wedge. The incoming hypersonic flow Mach numbers of premixed stoichiometric oxyhydrogen diluted with 70 percent Ar/He are 6, 8, and 10 where the Chapman-Jouguet Mach number is 4.8. In the present geometry of detonation holder, the complete coupling between a bow shock wave and subsequent exothermic chemical reaction is observed only for freestream Mach number 10, while in the other low-Mach-number cases the reaction front becomes more detached from the shock wave except for the strong shock region near the stagnation point. Regarding the steadiness of the solution, the density residue decreased to 10 to the -7th, indicating convergence to steady flows.

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 slipstream.

A88-39370 Exhaust of NO(x) from high-temperature wind tunnels. RI'ICHI MATSUZAKI, *Japanese Journal of Applied Physics, Part 1* (ISSN 0021-4922), Vol. 26, Nov. 1987, pp. 1844-1849.

Theoretical calculations were performed in order to estimate the concentrations of three main constituents of NO(x) (NO, NO2 and N2O) in the exhaust gas produced by two kinds of hypersonic wind tunnels. One of them had an arc-heater, and the other a pebble-heater. Estimations were performed for the equilibrium air in the plenum chamber, for the equilibrium and nonequilibrium nozzle flows, and for the final exhaust gas. Measurements in the exhaust gas of the arc-heated wind tunnel show that the total concentration of NO(x) (NO and NO2) was of the order of 10,000 ppm, depending on the conditions of operation. Two simple models are proposed to explain the origin of such a high level of NO(x) in the exhaust. It is shown that a model taking account of the isothermal compression of the exhaust gas in rotary pumps of the vacuum system can predict the formation of high concentations of NO(x).

A88-26185 Supersonic expansion of a dusty gas around a sharp corner. H. MIURA and I. I. GLASS, *Royal Society (London), Proceedings, 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 nonequilibrium 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.

A87-39627 Multi-channel two-dimensional MPD arcjet. K. TOKI, K. KURIKI, and M. SUMIDA, *AIAA, DGLR, and JSASS 19th International Electric Propulsion Conference,* Colorado Springs, CO, May 11-13, 1987. 7 pp. 7 Refs. (AIAA Paper 87-1000).

A multichanneled MPD arcjet, which approximated an ideal two-dimensional discharge, was successfully operated in a quasi-steady mode. This device allows easy access to the discharge region by means of optical techniques for obtaining particle species, temperature distribution, and current patterns. Such data are analyzed in order to clarify the correlation between the thrust performance and plasma condition. It was found that the onset phenomenon should be more clearly defined by Isp, which strongly depends on the electrodes design, than the parameter J-squared/m, very low electron temperature of 0.3 eV was found to prevail in H2 propellant, which explained the current concentration on the cathode tip due to dissociative energy absorption of molecular propellant.

A88-48949 A diagonalizing formulation of general real gas-dynamic matrices with a new class of TVD schemes. Y. WADA, S. OGAWA, T. ISHIGURO, and H. KUBOTA, *IN: AIAA, ASME, SIAM, and APS 1st National Fluid Dynamics Congress,* Cincinnati, OH, July 25-28, 1988, Technical Papers. Part 3 (A88-48776 20-34). Washington, DC, American Institute of Aeronautics and Astronautics, 1988, pp. 1455-1462. 21 Refs. (AIAA Paper 88-3596).

The eigenvalues and eigenvectors are analytically derived for general real gas dynamic equations in generalized curvilinear coordinates. In the diagonalizing formulation, the total mass conservation equation is taken into account, and arbitrary nonequilibrium effects, such as chemical reactions or vibrational nonequilibrium, can be treated in the same fashion. This diagonalizing formulation opens the way for chemically reacting flows to the construction of finite difference schemes based on characteristic relations, or the simplification of the inversion work of block-tridiagonal systems that arise in implicit time-split algorithm. Furthermore, a new class of TVD schemes in space discretization is proposed, which has a possibility to retain the second-order accuracy even near shock waves. For sample calculations, it has been chosen two kinds of reacting flows. The one is shock-induced ignition and the other is re-entry flow. Both results show the efficiency and high resolution of the scheme.