NASA SP-7037 (298)
December 1993

AERONAUTICAL ENGINEERING

A CONTINUING BIBLIOGRAPHY WITH INDEXES

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AERONAUTICAL ENGINEERING

A CONTINUING BIBLIOGRAPHY WITH INDEXES

National Aeronautics and Space Administration
Scientific and Technical Information Program
Washington, DC 1993

This publication was prepared by the NASA Center for AeroSpace Information,
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INTRODUCTION

This issue of *Aeronautical Engineering — A Continuing Bibliography with Indexes* (NASA SP-7037) lists 328 reports, journal articles, and other documents recently announced in the NASA STI Database.

Accession numbers cited in this issue include:

Scientific and Technical Aerospace Reports (STAR) (N-10000 Series)	None for this issue
International Aerospace Abstracts (IAA) (A-10000 Series)	A93-52651 — A93-54347

The coverage includes documents on the engineering and theoretical aspects of design, construction, evaluation, testing, operation, and performance of aircraft (including aircraft engines) and associated components, equipment, and systems. It also includes research and development in aerodynamics, aeronautics, and ground support equipment for aeronautical vehicles.

Each entry in the publication consists of a standard bibliographic citation accompanied in most cases by an abstract. The listing of the entries is arranged by the first nine *STAR* specific categories and the remaining *STAR* major categories. This arrangement offers the user the most advantageous breakdown for individual objectives. The citations include the original accession numbers from the respective announcement journals.

Seven indexes—subject, personal author, corporate source, foreign technology, contract number, report number, and accession number—are included.

A cumulative index for 1993 will be published in early 1994.

Information on availability of documents listed, addresses of organizations, and CASI price schedules are located at the back of this issue.

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TYPICAL REPORT CITATION AND ABSTRACT

NASA SPONSORED
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ACCESSION NUMBER → **N93-10098*#** Old Dominion Univ., Norfolk, VA. Dept. of Mechanical Engineering and Mechanics. ← CORPORATE SOURCE

TITLE → **NAVIER-STOKES DYNAMICS AND AEROELASTIC COMPUTATIONS FOR VORTICAL FLOWS, BUFFET AND AEROELASTIC APPLICATIONS Progress Report, 1 Oct. 1991 - 30 Sept. 1992**

AUTHOR → OSAMA A. KANDIL Sep. 1992 38 p ← PUBLICATION DATE

CONTRACT NUMBER → (Contract NAG1-648)

REPORT NUMBER → (NASA-CR-190692; NAS 1.26:190692) Avail: CASI HC A03/MF A01 ← AVAILABILITY AND PRICE CODE

The accomplishments achieved during the period include conference and proceedings publications, journal papers, and abstracts which are either published, accepted for publication or under review. Conference presentations and NASA highlight publications are also included. Two of the conference proceedings publications are attached along with a Ph.D. dissertation abstract and table of contents. In the first publication, computational simulation of three-dimensional flows around a delta wing undergoing rock and roll-divergence motions is presented. In the second publication, the unsteady Euler equations and the Euler equations of rigid body motion, both written in the moving frame of reference, are sequetially solved to simulate the limit-cycle rock motion of slender delta wings. In the dissertation abstract, unsteady flows around rigid or flexible delta wings with and without oscillating leading-edge flaps are considered. L.R.R.

TYPICAL JOURNAL ARTICLE CITATION AND ABSTRACT

NASA SPONSORED

ACCESSION NUMBER → **A93-12007*** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA. ← CORPORATE SOURCE

TITLE → **NUMERICAL SIMULATIONS OF HIGH-SPEED FLOWS ABOUT WAVERIDERS WITH SHARP LEADING EDGES**

AUTHORS → KEVIN D. JONES and F. C. DOUGHERTY (Colorado Univ., Boulder) ← AUTHORS' AFFILIATION

JOURNAL TITLE → Journal of Spacecraft and Rockets (ISSN 0022-4650) vol.

PUBLICATION DATE → 29, no. 5 Sept.-Oct. 1992 p. 661-667. Research supported by Univ. of Colorado and DLR refs

CONTRACT NUMBER → (Contract NAG1-880)

Copyright

A procedure is developed for the numerical simulation of stagnation-free inviscid supersonic and hypersonic flows about waveriders with sharp leading edges. The numerical approach involves the development of a specialized grid generator (named HYGRID), an algebraic solution-adaptive grid scheme, and a modified flow solving method. A comparison of the results obtained for several waverider geometries with exact solutions, other numerical solutions, and experimental results demonstrated the ability of the new procedure to produce stagnation-free Euler solutions about sharp-edged configurations and to describe the physics of the flow in these regions. I.S.

AERONAUTICAL ENGINEERING

A Continuing Bibliography (Suppl. 298)

December 1993

01

AERONAUTICS (GENERAL)

A93-52690#
USAF IN-FLIGHT SIMULATION - A COST-EFFECTIVE OPERATING APPROACH
STEVEN R. MARKMAN (USAF, Wright Lab., Wright-Patterson AFB, OH) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 316-319.
(AIAA PAPER 93-3604)

A major factor in the success of the U.S. Air Force's in-flight simulation program has been keeping operating costs low while retaining needed skills, capabilities, and operational flexibility. A suitable management approach and operating concept are critical to the success of this program. The Air Force has developed, owned, and used in-flight simulators since the early 1950s. The current aircraft, the NT-33A and the NC-131H, are operated as national resources and are available for use throughout the U.S. Government, U.S. industry, and foreign allied governments. The nature of the program often requires quick response and the ability to adapt to the needs of the user. The current operating concept is Air Force management and ownership of the aircraft, contractor operation by a highly specialized contractor, and a tasking type contract on which to employ the contractor. This operating approach has proven to satisfy all of these requirements. This approach has evolved over the history of the program to make the aircraft available to users and to insure valuable and cost effective results.

A93-54104
VARIOUS APPLICATIONS OF ROBOTS IN AIRCRAFT ENGINE OVERHAUL
O. SASAHARA (Japan Airlines Co. Ltd., Engine Maintenance Center, Tokyo) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1323-1326.
(ISABE 93-7129) Copyright

Japan Airlines (JAL) is developing various automated, computer-linked maintenance systems for aircraft engine overhaul. The automation results in (1) Better Quality - Standardizing processes and eliminating defects. (2) Labor Savings - Eliminating monotonous processes. It is also neutralizing Japan's high labor cost. (3) Better Working Environment - Eliminating the hazardous environment caused by chemicals, debris and noise. This paper reports the status of robot applications in JAL engine maintenance.

A93-54287
HELICOPTER OPERATIONS IN SEVERE ENVIRONMENTS; PROCEEDINGS OF THE CONFERENCE, LONDON, UNITED KINGDOM, JUNE 4, 1992
London Royal Aeronautical Society 1992 51 p. For individual items see A93-54288 to A93-54295
(ISBN 1-85768-045-6) Copyright

Consideration is given to helicopter operations in cold climates, operating helicopters in a demanding environment (mountain flying and high evaluations), Royal Navy helicopter operations in the maritime environment, environmental effects on helicopter operations during desert shield and desert storm, and the T-700 helicopter engine. Also discussed are night operations of Royal Air Force support helicopters, avionic systems in support of covert helicopter operations, and the LONGBOW force multiplier for continuous operations. AIAA

A93-54295
LONGBOW - FORCE MULTIPLIER FOR CONTINUOUS OPERATIONS
DAVID L. LUNDQUIST (Martin Marietta Electronic Systems, Orlando, FL) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 8.1-8.5.
Copyright

LONGBOW provides enhanced warfighting capability for Apache enabling it to conduct combat operations under conditions including adverse weather and limited visibility. LONGBOW integrates a Fire Control Radar and RF fire-and-forget HELLFIRE missile onto the Apache attack helicopter. The system operates in terrain profile, ground targeting and air targeting modes. LONGBOW delivers a ten-fold increase in combat effectiveness compared to AH64-A Apache in clear weather and an even greater improvement in adverse environments. As an improvement to a fielded, combat-proven weapon system, LONGBOW is an efficient means to provide a force multiplier in an era of diminishing resources.

02

AERODYNAMICS

Includes aerodynamics of bodies, combinations, wings, rotors, and control surfaces; and internal flow in ducts and turbomachinery.

A93-52770* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
UPWIND-BIASED, POINT-IMPLICIT RELAXATION STRATEGIES FOR HYPERSONIC FLOWFIELD SIMULATIONS ON SUPERCOMPUTERS
PETER A. GNOFFO (NASA, Langley Research Center, Hampton, VA) Apr. 1989 10 p. International Conference on Supercomputing, 4th and World Supercomputer Exhibition, 3rd, Santa Clara, CA, Apr. 30-May 5, 1989, Paper refs
Copyright

An upwind-biased, point-implicit relaxation algorithm for obtaining the numerical solution to the governing equations for three-dimensional, viscous, hypersonic flows in chemical and thermal nonequilibrium is described. The algorithm is derived using a finite-volume formulation in which the inviscid components of flux across cell walls are described with Roe's averaging and Harten's entropy fix with second-order corrections based on Yee's

Symmetric Total Variation Diminishing scheme. The relaxation strategy is well suited for computers employing either vector or parallel architectures, and the relation between computer architecture and algorithm is emphasized. It is also well suited to the numerical solution of the governing equations on unstructured grids. Because of the point-implicit relaxation strategy, the algorithm remains stable at large Courant numbers without the necessity of solving large. block tri-diagonal systems. A single relaxation step depends only on information from nearest neighbors. Predictions for pressure distributions, surface heating, and aerodynamic coefficients compare well with experimental data for Mach 10 flow over a blunt body. Predictions for the hypersonic flow of air in chemical and thermal nonequilibrium (velocity = 8917 m/s, altitude = 78 km.) over the Aeroassist Flight Experiment (AFE) configuration obtained on a multi-domain grid are discussed.

A93-52946
NON-SELF-SIMILARITY OF A BOUNDARY LAYER FLOW OF A HIGH-TEMPERATURE GAS IN A LAVAL NOZZLE [NEAVTOMODEL'NOST' TECHENIYA V POGRANICHNOM SLOE VYSOKOTEMPERATURNOGO GAZA V SOPLE LAVALYA]
A. V. DMITRENKO Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 38-42. In RUSSIAN refs
Copyright

Results of calculations of boundary layer flows of a high-temperature gas in a Laval nozzle are reported. It is shown, in particular, that non-self-similarity in the boundary layer of the nozzle is determined mainly by the combined effect of the Mach number and the temperature factor. The calculated velocity and temperature profiles and turbulent characteristics are in satisfactory agreement with the classical experimental data over a wide range of Mach numbers and temperature factors. AIAA

A93-52958
CALCULATION OF THE POSITION OF THE FLOW SEPARATION LINE IN AN ANALOG MODEL OF FLOW PAST A BODY [RASCHET POLOZHENIYA LINII OTRYVA POTOKA V ANALOGOVOJ MODELI OBTEKANIYA TELA]
A. S. BUT, L. N. MAKAROV, and I. N. RODIONOV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 87-89. In RUSSIAN refs
Copyright

A method for determining the position of the flow separation line on the fuselage of a helicopter is proposed which does not require the full calculation of the boundary layer. In accordance with the method proposed here, the position of the separation line is determined from the separation points, which are determined by using Stratford's formula. The further modeling of flow past the fuselage is carried out using the method of Makarov et al. (1990). AIAA

A93-52959
EFFECT OF BOUNDARY LAYER SUCTION ON THE THRUST AND AERODYNAMIC EFFICIENCY OF A HYPERSONIC FLIGHT VEHICLE [VLIYANIE SLIVA POGRANICHNOGO SLOYA NA TYAGOVO-AEHRODINAMICHESKUYU EHFFEKTIVNOST' GIPERZVUKOVOGO LETATEL'NOGO APPARATA]
YU. P. GUN'KO, I. I. MAZHUL', and D. V. SHCHERBIK Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 89-92. In RUSSIAN refs
Copyright

The effect of boundary layer suction ahead of the air intake on the thrust and aerodynamic characteristics of a hypersonic flight vehicle with a ramjet engine is estimated analytically. In particular, attention is given to suction by means of a suction wedge. Data are presented for various configurations of an air intake with a suction wedge in a flight vehicle. AIAA

A93-53192
NUMERICAL ANALYSIS OF FLOW WITHIN CASCADE WITH TIP CLEARANCE
HOSHIO TSUJITA and SHIMPEI MIZUKI Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 559 March 1993 p. 782-789. In JAPANESE refs
Copyright

Three-dimensional incompressible turbulent flow within a linear turbine cascade with tip clearance is analyzed numerically. The governing equations involving the standard k-epsilon model are solved in the physical component tensor form with a boundary fitted coordinate system using coarse grids. In the analysis, the blade tip geometry is treated accurately in order to predict the detailed flow phenomena through the tip clearance in the case of a blade with large thickness. The results are also compared with the experimental data. Although the number of grids employed in the present study is rather coarse, the computed results show good agreement with the measured ones. Moreover, the results exhibit the locus of minimum pressure at the rear part of the pressure side at the blade tip. Author (revised)

A93-53193
PRESSURE DISTRIBUTION MEASUREMENT AROUND HYPERSONIC DELTA WINGED SEMICONE - MEASUREMENT BY MEANS OF MAGNET TAPE
MASATOMI NISHIO and MUTSUO KOTAKE Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 559 March 1993 p. 790-794. In JAPANESE refs
Copyright

This paper describes measurements of pressure distribution around a semicone body with a wing traveling at the hypersonic speed of Mach number 10. The semiapex angles of the delta wing and semicone are 30 and 15 deg, respectively. The measurements are carried out under the condition that the angles of attack are 0, 10, and 20 deg. In this study, the pressure distribution measuring method using magnetic tape has been improved to be suitable for measuring pressure distribution around hypersonic vehicles. The pressure distributions are measured by utilizing the improved method. Author (revised)

A93-53200* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
NUMERICAL STUDY OF A DELTA PLANFORM WITH MULTIPLE JETS IN GROUND EFFECT
K. CHAWLA, W. R. VAN DALSEM, and K. V. RAO (NASA, Ames Research Center, Moffett Field, CA) Sep. 1989 15 p. SAE, Aerospace Technology Conference and Exposition, Anaheim, CA, Sept. 25-28, 1989 refs
(SAE PAPER 892283) Copyright

The flow past a 60-deg delta wing equipped with two thrust-reverser jets near the inboard trailing edge has been analyzed by numerical solution of the 3D thin-layer Navier-Stokes equations. An implicit, partially flux-split, approximately-factored Navier-Stokes solver coupled with a multiple grid embedding scheme has been adapted to this problem. Studies of the impact of numerical parameters (e.g., grid refinement and dissipation levels), and flow-field parameters such as the height of the delta wing above the ground plane and the jet size on the solution, were performed. Results of these numerical studies indicate some challenges in the accurate resolution of complex 3D free shear layers and jets. Nevertheless, flow features such as jet deformation and ground vortex formation observed in experimental flow visualizations are captured. Further, comparisons with experimental data confirm the ability to simulate the loss of wing-borne lift, commonly referred to 'suckdown, as the delta planform flies at slow speeds in close proximity to the ground. Detailed analysis of the numerical results has also given additional insight into the structure of the ground vortex and the mechanisms of lift loss. Author (revised)

A93-53202* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
LOW ASPECT RATIO WING CODE VALIDATION EXPERIMENT
MICHAEL E. OLSEN and H. L. SEEGMILLER (NASA, Ames Research Center, Moffett Field, CA) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1744-1752. AIAA, Aerospace Sciences Meeting and Exhibit, 30th, Reno, NV, Jan.

6-9, 1992, AIAA Paper 92-0402. Previously cited in issue 09, p. 1352, Accession no. A92-26255 refs
Copyright

A93-53204* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
EFFECTIVE TREATMENT OF THE SINGULAR LINE BOUNDARY PROBLEM FOR THREE-DIMENSIONAL GRIDS
GRANT PALMER (NASA, Ames Research Center, Moffett Field, CA) and ETHIRAJ VENKATAPATHY (Eloret Inst., Mountain View, CA) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1757, 1758. AIAA, Aerospace Sciences Meeting and Exhibit, 30th, Reno, NV, Jan. 6-9, 1992, AIAA Paper 92-0545. Previously cited in issue 10, p. 1555, Accession no. A92-28202 refs
Copyright

A93-53205
ZONAL-LOCAL SOLUTION METHOD FOR THE TURBULENT NAVIER-STOKES EQUATIONS
D. DRIKAKIS and S. TSANGARIS (Athens, National Technical Univ., Greece) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1759, 1760. Abridged. refs
Copyright

A zonal-local solution method is developed for the solution of the compressible Navier-Stokes equations. The main feature of the method is coupling of the Navier-Stokes equations with the Euler equations and the local mesh solution procedure. Mesh sequencing (multilevel) technique is also used for the improvement of the efficiency of the algorithm. The methodology is applied to turbulent flowfields past an airfoil. A flux vector splitting method with an upwind scheme up to fourth-order accuracy is used for the discretization of the inviscid fluxes. The system of the equations is solved by an unfactored implicit method using Gauss-Seidel relaxation.

A93-53207
BOUNDARY LAYER AND PRESSURE MEASUREMENTS ON A CYLINDER WITH UNSTEADY CIRCULATION CONTROL
ALI ZANDIEH and J. G. LEISHMAN (Maryland Univ., College Park) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1769-1776. Research supported by Minta-Martin Fund for Aeronautical Research refs
Copyright

Unsteady boundary-layer and surface pressure measurements were made on a circular cylinder with time-varying blowing applied from a narrow spanwise slot. The effects of mean blowing level, blowing frequency, and boundary-layer trip location were examined at a Reynolds number of 2.2 x 10 exp 5 based on cylinder diameter. Time-resolved pressures were recorded using pressure sensors located on the Coanda surface and around the circumference of the cylinder. Flush-mounted hot film probes were positioned both upstream and downstream of the slot to provide a qualitative measurement of the boundary-layer characteristics. The results have shown that the shear stress just downstream of the slot was always in-phase with the plenum pressure. However, increasing reduced frequency generally resulted in increasingly larger phase lags between the application of blowing and the development of the flow over the remainder of the Coanda surface. For both steady and unsteady blowing, the jet entrained the outer flow at the slot and remained attached to the Coanda surface, provided a fully attached laminar or turbulent boundary layer was obtained just prior to reaching the slot. Author (revised)

A93-53208* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
LOW-REYNOLDS-NUMBER K-EPSILON MODEL FOR UNSTEADY TURBULENT BOUNDARY-LAYER FLOWS
SIXIN FAN, BUDUGUR LAKSHMINARAYANA (Pennsylvania State Univ., University Park), and MARK BARNETT (United Technologies Research Center, East Hartford, CT) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1777-1784. refs
(Contract NAG3-1168)
Copyright

An assessment of the near-wall and low-Reynolds-number functions used in low-Reynolds-number k-epsilon models suggests that they are not suitable for the near-wall region of unsteady turbulent boundary layers, where the flow is characterized by rapid changes in phase. An improved low-Reynolds-number k-epsilon model is developed in this paper. The near-wall and low-Reynolds-number functions in this model are formulated as functions of the local turbulent Reynolds numbers instead of the inner variable y(+). The present model also has the correct asymptotic behavior in the near-wall region. The turbulence model has been incorporated in an unsteady boundary-layer code and validated for unsteady turbulent boundary layers with and without adverse pressure gradients. The predictions agree well with the experimental data and the theoretical analysis. For the cases tested, the present model correctly predicts the unsteady near-wall flow and the unsteady shin friction at various frequencies.
Author (revised)

A93-53209
MULTIGRID NAVIER-STOKES CALCULATIONS FOR THREE-DIMENSIONAL CASCADES
FENG LIU (California Univ., Irvine) and ANTONY JAMESON (Princeton Univ., NJ) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1785-1791. AIAA, Aerospace Sciences Meeting and Exhibit, 30th, Reno, NV, Jan. 6-9, 1992, AIAA Paper 92-0190. Previously cited in issue 08, p. 1169, Accession no. A92-23799 Research supported by DARPA and IBM Corp. refs
(Contract N00014-89-J-1366; N00014-86-K-0759)
Copyright

A93-53212* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
SPACE MARCHING CALCULATIONS ABOUT HYPERSONIC CONFIGURATIONS USING A SOLUTION-ADAPTIVE MESH ALGORITHM
ALBERT D. HARVEY, SUMANTA ACHARYA (Louisiana State Univ., Baton Rouge), and SCOTT L. LAWRENCE (NASA, Ames Research Center, Moffett Field, CA) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1809-1818. refs
(Contract NCA2-326; NCA2-522)
Copyright

A solution-adaptive marching algorithm is developed and applied to a three-dimensional parabolized Navier-Stokes equation solver. The resulting algorithm obtains accurate solutions by using a spatial-marching/adaptive grid procedure. The adaptation step redistributes grid points line by line in both crossflow directions, with grid point motion controlled by forces analogous to tensional and torsional spring forces with the tensional force proportional to the error measure or weighting functions. The solution-adaptive marching procedure is applied to the hypersonic flow about two generic aircraft configurations. The first of these is an all-body-type geometry with elliptical cross sections and is studied at angles of attack of 0.5, and 15 deg. The second geometry is a generic blended-wing-body design. Results are presented that demonstrate the improvements in flowfield resolution obtainable with the solution-adaptive marching procedure over conventional fixed grid techniques. Computed pitot pressure profiles obtained using the solution-adaptive algorithm show improved agreement with experimental data compared to predictions obtained using a fixed grid.

A93-53214* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
OBSERVATIONS OF LIQUID JETS INJECTED INTO A HIGHLY ACCELERATED SUPERSONIC BOUNDARY LAYER
ARTHUR W. JOHNSON and K. R. SREENIVASAN (Yale Univ., New Haven, CT) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1827-1834. Research supported by NASA refs
Copyright

Experiments were conducted to observe the cross-sectional structure and streamwise growth of round transverse liquid jets injected into a highly accelerated boundary layer in supersonic flow. The accompanying shock structure was also visualized. In one case, a round jet of acetone was injected into a fully turbulent Mach 2.5 boundary layer that was subsequently accelerated and partially laminarized through a sharp Prandtl-Meyer expansion corner. In the second case, a jet was injected into the laminarized Mach 3.2 boundary layer downstream of the expansion corner at the same jet-to-freestream momentum ratio. The jet and shock structure in both cases were visualized using schlieren optics. Wall-flow patterns were visualized using paints. It was found that the lateral spreading of jets injected downstream of the expansion fan was augmented close to the wall and had a cross-sectional structure significantly different from that of the jet injected upstream: the upstream jet spreads rapidly at the expansion corner in both the lateral and vertical directions.

A93-53216
SKIN-FRICTION TOPOLOGY OVER A SURFACE MOUNTED SEMI-ELLIPSOIDAL WING AT INCIDENCE
TIMOTHY A. JOHNSON and VIRENDRA C. PATEL (Iowa Univ., Iowa City) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1842-1849. Research supported by DARPA refs
(Contract N00014-88-K-0001; N00014-91-J-1204; N00014-89-J-1342)
Copyright

Flow visualization methods have been used to study the skin-friction topology of a 12:6:1 semi-ellipsoid wing at incidence intersecting a plane wall. Results were obtained for incidences from 0 to 25 deg in 5 deg increments. Major changes in the topology demarcate divisions between general ranges designated as follows: symmetry, low, intermediate, and high incidences. As a function of incidence, the topological evolution is influenced by both three-dimensional pressure gradients and transition to turbulence. A slight twist in the experimental model suggests that the topology and associated separation modes (singular vs nonsingular) are highly sensitive to slight geometric asymmetries.

A93-53217
PRISMATIC GRID GENERATION FOR THREE-DIMENSIONAL COMPLEX GEOMETRIES
Y. KALLINDERIS and S. WARD (Texas Univ., Austin) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1850-1856. refs
(Contract AF-AFOSR-91-0022)
Copyright

The paper describes generation of semiunstructured prismatic grids for three-dimensional complex geometries. A new method of generation is presented, which couples both algebraic and elliptic steps. This combination yields low computation cost, as well as smoothness of the grid. Main advantages of the developed grid generator are its direct control of grid orthogonality and spacing, as well as its generality for treatment of three-dimensional geometries. The method marches a surface consisting of triangular faces away from the body surface. Employment of prismatic elements is a relatively new approach toward three-dimensional, complex geometry numerical simulations of viscous flows. A body surface is covered with triangles, which gives the geometric flexibility, whereas the structure of the mesh in the direction normal to the surface provides better resolution of the viscous regions. An F-16A aircraft geometry was included in the applications to investigate efficiency and to demonstrate robustness of the method in handling relatively complex topologies. Grid generation time for the entire aircraft domain was of the order of minutes on a workstation.

A93-53218
THREE-DIMENSIONAL NAVIER-STOKES/FULL-POTENTIAL COUPLED ANALYSIS FOR VISCOUS TRANSONIC FLOW
LAKSHMI N. SANKAR (Georgia Inst. of Technology, Atlanta), BALA K. BHARADVAJ (Douglas Aircraft Co., Long Beach, CA), and FU-LIN TSUNG (Georgia Inst. of Technology, Atlanta) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1857-1862. AIAA Computational Fluid Dynamics Conference, 10th, Honolulu, HI, June 24-27, 1991, Technical Papers, p. 780-787. Previously cited in issue 17, p. 2850, Accession no. A91-40769 Research supported by U.S. Army refs
Copyright

A93-53219
THRUST IMPARTED TO AN AIRFOIL BY PASSAGE THROUGH A SINUSOIDAL UPWASH FIELD
HERBERT S. RIBNER (Toronto Univ., Downsview, Canada) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1863-1868. Research supported by NSERC refs
Copyright

The passage of an airfoil through a sinusoidal upwash field (Sears, 1941) is analyzed further to yield the wavelength-dependent thrust: the 'Katzmayr effect'. The shed vorticity is shown to induce an opposed flow that reduces the kinetic energy: the decrement is found to match exactly the work done by the thrust. The 'Sears function for thrust' is then applied to passage through turbulence described by a one-dimensional power spectrum. Finally, some acoustical implications of relaxing the postulated incompressibility are briefly discussed. It is argued that the radiated dipole noise, like the thrust, draws its energy from the flowfield.

A93-53231* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
TRANSITION CORRELATION IN SUBSONIC FLOW OVER A FLAT PLATE
J. A. MASAD and M. R. MALIK (High Technology Corp., Hampton, VA) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1953-1955. refs
(Contract NAS1-19299)
Copyright

A 2D subsonic flow over a flat plate with a freestream Mach number M(infinity) up to 0.8 is considered. The flow can experience continuous uniform suction through the wall and the wall can be heated or cooled continuously with a fixed wall temperature. For a specific combination of M(infinity), suction velocity, and level of heat transfer, the mean flow problem is solved and linear stability calculations are performed to compute the location on the flat plate where the factor representing the integration of growth rates reaches nine. These calculations are repeated for several combinations of flow parameters and the theoretically predicted transition location is presented in the form of a correlation that can account for the effect of wall suction, heat transfer, and Mach number. AIAA

A93-53233
FAST THREE-DIMENSIONAL VORTEX METHOD FOR UNSTEADY WAKE CALCULATIONS
KIAT CHUA and TODD R. QUACKENBUSH (Continuum Dynamics, Inc., Princeton, NJ) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1957, 1958. Abridged. AIAA Applied Aerodynamics Conference, 10th, Palo Alto, CA, June 22-24, 1992, Technical Papers. Pt. 1, p. 230-238. Previously cited in issue 19, p. 3246, Accession no. A92-45496 refs
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A93-53314
APPLICATION OF THE SMALL PARAMETER METHOD TO THE PROBLEM OF THREE-DIMENSIONAL FLOW OF A VISCOUS GAS PAST BODIES [PRIMENENIE METODA MALOGO PARAMETRA K ZADACHE PROSTRANSTVENNOGO OBTEKANIYA TEL POTOKOM VYAZKOGO GAZA]
G. A. TIRSKIJ, S. V. UTYUZHNIKOV, and N. K. YAMALEEV Prikladnaya Matematika i Mekhanika (ISSN 0032-8235) vol. 56, no. 6 Nov.-Dec. 1992 p. 1023-1032. In RUSSIAN refs
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The problem of three-dimensional hypersonic flow of a viscous gas past blunt spherical bodies is analyzed using a system of

equations of the full viscous shock layer. It is shown that the use of the small parameter method in conjunction with the method of global iterations makes it possible to reduce the computer time by approximately a factor of 100 in comparison with finite difference computations using a strictly three-dimensional formulation. The validity of the small parameter method is supported by experimental results. The examples considered include flow past blunt cones and bicones of large length at small angles of attack and flow past a nearly axisymmetrical body at zero angle of attack. AIAA

A93-53315
COMPARISON OF GASDYNAMIC MODELS IN HYPERSONIC FLOW [SRAVNENIE GAZODINAMICHESKIKH MODELEJ PRI GIPERZVUKOVOM OBTEKANII TEL]
S. V. ZHLUKTOV, S. V. UTYUZHNIKOV, V. S. SHCHELIN, and V. G. SHCHERBAK Prikladnaya Matematika i Mekhanika (ISSN 0032-8235) vol. 56, no. 6 Nov.-Dec. 1992 p. 1033-1038. In RUSSIAN refs
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Various gasdynamic models describing chemically nonequilibrium flows are compared with particular reference to stationary flow past the nose section of the Buran and Space Shuttle vehicles during their descent from the orbit. The models considered include a locally self-similar approximation of the Navier-Stokes equations, a model of a chemically equilibrium and nonequilibrium full viscous shock layer, and a model of a thin viscous shock layer. In all the models, the physicochemical processes are considered by using the same constants of gas-phase chemical reactions. Good agreement is obtained between the results of calculations of the heat flow at the critical point. AIAA

A93-53333
CONSTRUCTION OF WAKES IN THE DISCRETE VORTEX METHOD [O POSTROENII SLEDOV V METODE DISKRETNYKH VIKHREJ]
I. K. LIFANOV (Voenno-Vozdushnaya Inzhenernaya Akademiya, Moscow, Russia) Rossijskaya Akademiya Nauk, Doklady (ISSN 0869-5652) vol. 330, no. 5 June 1993 p. 574-578. In RUSSIAN refs
Copyright

The use of the discrete vortex method for solving problems of flow of an ideal (nonviscous) fluid past a body is discussed. In particular, attention is given to the calculation of wakes and jets behind bodies of various configurations. Some characteristic phenomena associated with wake and jet flows are briefly examined. AIAA

A93-53364
RECENT ADVANCES IN COMPUTATIONAL ANALYSIS OF HYPERSONIC VEHICLES
R. F. WALTER (W.J. Schafer Associates, Inc., Albuquerque, NM) Fizika Goreniya i Vzryva (ISSN 0430-6228) vol. 29, no. 3 May-June 1993 p. 66-71. refs
Copyright

The nonequilibrium gasdynamics processes of importance to hypersonic aerobraking vehicles are reviewed. Recent improvements in understanding these phenomena and in the detailed numerical modeling of these processes will be discussed. The paper concludes by describing the extent to which these models have been incorporated into multidimensional computational fluid dynamics (CFD) computer codes.

A93-53365
DETERMINATION OF HEAT TRANSFER TO FLOW IN A DUCT WITH A PSEUDODISCONTINUITY [OPREDELENIE TEPLOPODVODA K POTOKU V KANALE S PSEVDOSKACHKOM]
P. K. TRET'YAKOV Fizika Goreniya i Vzryva (ISSN 0430-6228) vol. 29, no. 3 May-June 1993 p. 71-77. In RUSSIAN refs
Copyright

Heat transfer due to propellant combustion in a duct with supersonic flow leads to flow deceleration. The resulting gasdynamic structure is characteristic of a pseudodiscontinuity and is essentially inhomogeneous over the duct cross section. In this case, the extent of combustion or the amount of heat transferred to the flow are determined by measuring static pressure on the duct wall. The use of a one-dimensional method may lead to an erroneous result. The method proposed here is based on the characteristics of the change of the inhomogeneity coefficient, which is derived from a one-dimensional representation of the conservation equations. The method uses the pressure differential of isothermal flow with heat transfer; friction and heat transfer to the wall are taken into account. As an example, the method is applied to the combustion of hydrogen and kerosene. AIAA

A93-53551
CALCULATION OF A COMPRESSIBLE THREE-DIMENSIONAL BOUNDARY LAYER ON A SWEPT WING [RASCHET SZHIMAEMOGO TREKHMERNOGO POGRANICHNOGO SLOYA NA STRELOVIDNOM KRYLE]
V. E. KOVALEV TsAGI, Trudy no. 2465 1990 p. 3-31. In RUSSIAN refs
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A modified version of Keller's block method is proposed for calculating a compressible three-dimensional boundary layer on a wing of finite span. A hybrid difference scheme is developed in which the Keller-Cebeci templates and a zigzag are used with weight coefficients that are dependent on the velocity vector direction relative to the finite difference cell. A comparison of the results of calculations with exact solutions for a laminar boundary layer and experimental data for a turbulent boundary layer demonstrates the sufficient accuracy of the proposed algorithm for solving boundary layer equations. AIAA

A93-53552
CALCULATION OF FLOW FIELDS NEAR A LIFTING WING [RASCHET POLEJ TECHENIYA OKOLO NESUSHCHEGO KRYLA]
S. G. IGNAT'EV, O. V. KARAS', and A. V. SMIRNOV TsAGI, Trudy no. 2465 1990 p. 32-46. In RUSSIAN refs
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Calculations are made of transonic flow fields near a thick swept wing of finite span. The load increment is estimated for the isolated blade of a hypothetical propeller located in the field of flow from an aircraft wing. The possibility of reducing the load increment by changing the propeller orientation is demonstrated. The calculation results are compared with the available experimental and analytical data. AIAA

A93-53555
THE FLOW LAG ANGLE IN THE ROTOR OF A CENTRIFUGAL COMPRESSOR WITH ALLOWANCE FOR VISCOSITY EFFECTS [RASCHET UGLA OTSTAVANIYA POTOKA V RABOCHEM KOLESE TSENTROBEZHNOGO KOMPRESSORA S UCHETOM VYAZKOSTNYKH EHFFEKTOV]
V. G. SHVAROV TsIAM, Trudy no. 1233 1989 p. 12-18. In RUSSIAN refs
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An approximate method is proposed for calculating the flow lag angle and the power loss coefficient of the rotors of the centrifugal stage of a compressor with allowance for total pressure losses in the rotor and rotor friction against the casing of the stage. A comparison is made between theory and results of test calculations for a compressor stage. The accuracy of the method is evaluated. AIAA

A93-53573
MOVING WALL EFFECTS IN TRANSVERSE SUBSONIC FLOW PAST A ROTATING CYLINDER [EHFFEKTY DVIZHUSHCHEJSYA STENKI, VOZNIKAYUSHCHIE PRI POPERECHNOM OBTEKANII VRASHCHAYUSHCHEGOSYA TSILINDRA DOZVUKOVYM POTOKOM]
V. P. KOZLOV Moskovskij Universitet, Vestnik, Seriya 1 - Matematika, Mekhanika (ISSN 0579-9368) no. 1 Jan.-Feb.

1993 p. 79-84. In RUSSIAN refs
Copyright

Pressure distributions on the surface of a rotating cylinder in transverse subsonic flow is investigated experimentally for critical Reynolds numbers. It is found that the presence of a moving wall nearly always leads to a strong asymmetry in pressure distribution. The asymmetry is caused not only by the boundary layer transition but also by other hydrodynamic effects associated with the restructuring of the separated flow in the wall region. AIAA

A93-53574
AERODYNAMIC CHARACTERISTICS OF CONICAL TRIANGULAR-PLANFORM WINGS OF LOW ASPECT RATIO IN SUBSONIC STALLED FLOW [AEHRODINAMICHESKIE KHARAKTERISTIKI KONICHESKIKH KRYL'EV TREUGOL'NOJ FORMY V PLANE MALOGO UDLINENIYA PRI DOZVUKOVOM SRYVNOM OBTEKANII]
V. I. VORONIN, G. S. UL'YANOV, and A. I. SHVETS Moskovskij Universitet, Vestnik, Seriya 1 - Matematika, Mekhanika (ISSN 0579-9368) no. 1 Jan.-Feb. 1993 p. 101-104. In RUSSIAN refs
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Results of theoretical and experimental aerodynamic studies are presented for conical wings of triangular planform at subsonic velocities with leading-edge stall. The wings considered represent conical surfaces with aspect ratios of 1.07-1.86. The aerodynamic characteristics of the wings are presented as a function of the relative deflection and the sweep angle. It is found that, as the Mach number increases from 0.4 to 0.8, the lifting force and drag coefficients increase by 5-7 percent, while the lift-drag ratio remains practically constant. AIAA

A93-53575
UNSTEADY AERODYNAMIC CHARACTERISTICS OF THREE RECTANGULAR WINGS OF DIFFERENT ASPECT RATIOS [NESTATSIONARNYE AEHRODINAMICHESKIE KHARAKTERISTIKI TREKH PRYAMOUGOL'NYKH KRYL'EV RAZLICHNOGO UDLINENIYA]
EH. P. GREBESHOV and E. P. SHAKARVENE TsAGI, Trudy no. 2485 1990 p. 1-31. In RUSSIAN refs
Copyright

Experimental data are presented for three rectangular wings with aspect ratios of 1, 2, and 4, respectively. The results are presented in the form of steady and unsteady coefficients of the lifting force, drag, and longitudinal moment and derivatives of these coefficients. The unsteady characteristics are obtained over a wide range of Strouhal numbers (0.4-4) and angles of attack (0-26 deg). An approximate analytical expression is proposed which relates the drag coefficient, obtained under nonstationary flow conditions, to the kinematic motion parameters (angle of attack, angular velocity, and their first time derivatives). AIAA

A93-53591*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
LASER VELOCIMETER MEASUREMENTS OF THE FLOW FIELD GENERATED BY A FORWARD-SWEPT PROPFAN DURING FLUTTER
GARY G. PODBOY and MARTIN J. KRUPAR (NASA, Lewis Research Center, Cleveland, OH) Jul. 1993 50 p. AIAA, Fluid Dynamics Conference, 24th, Orlando, FL, July 6-9, 1993 refs
(AIAA PAPER 93-2919) Copyright

Results are presented from an investigation to measure the flow field generated by a forward-swept propfan operating in flutter at a low forward velocity. For comparison to the flutter condition, flow field data are also presented for a slightly reduced rotational speed just below flutter. The forward-swept propfan was tested as the front rotor of a counterrotating pusher propeller. A laser Doppler velocimeter (LDV) was used to measure the velocity field in planes normal to the model centerline downstream of the rotor and in planes of constant radius within the blade passages at each operating condition. The mean time-averaged flow about the blades did not change drastically as the propfan rotational speed was increased from the stable operating point to the flutter condition. No regions of flow separation could be identified in the data plots of the mean intrablade flow field. The relative flow about the blades remained subsonic during flutter operation. The blades were found to have a higher than expected tip loading at both operating conditions. This is thought to have been caused by the outer blade sections twisting under load to higher than expected effective blade angles. This high tip loading resulted in strong vortices and a very nonuniform flow downstream of the tips of the forward-swept blades. This high tip loading may also have caused the blade flutter. Author (revised)

A93-53592*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
STREAMWISE VORTICITY GENERATION AND MIXING ENHANCEMENT IN FREE JETS BY 'DELTA-TABS'
K. B. M. Q. ZAMAN (NASA, Lewis Research Center, Cleveland, OH) Jul. 1993 14 p. AIAA, Shear Flow Conference, Orlando, FL, July 6-9, 1993 Previously announced in STAR as N93-31648 refs
(AIAA PAPER 93-3253) Copyright

The effect of triangular tabs, placed at the nozzle exit, on the evolution of free jets is investigated. The effect, a large distortion of the jet cross section and a resultant increase in mixing downstream, has been inferred before to be due to a pair of streamwise vortices originating from each tab. In this paper, the generation mechanism of the streamwise vorticity (omega sub x) is considered first. Two sources are postulated. One is the upstream 'pressure hill', produced by the tab, which appears to be the dominant source. Another is due to vortex filaments shed from the sides of the tab and reoriented downstream by the mean shear of the mixing layer. In the case of a 'delta-tab', a triangular tab with its apex leaning downstream, vorticity from the two sources explain the stronger effect in that configuration. Data on the vorticity evolution for the effect of two delta-tabs are presented, up to twelve jet diameters from the exit, which show that the streamwise vortices persist even at the farthest measurement station. The magnitude of omega sub x-maximum decays continually with distance from the nozzle, its ratio to azimuthal vorticity maximum is found to be about 1/5 everywhere. The relative effect of a delta-tab on jets from an axisymmetric nozzle and a 8:1 rectangular nozzle is also studied. The mixing layer distortion is found to be less pronounced in the rectangular case. The jet mixing, as manifested by the mass flux measured at a downstream station, is increased in the axisymmetric jet but it is decreased in the rectangular jet under consideration by the delta-tab.

A93-53618
3D LAMINAR AND 2D TURBULENT COMPUTATIONS WITH THE NAVIER-STOKES SOLVER FLU3M
C. JOUET and P. D'ESPINEY (ONERA, Chatillon, France) ONERA, TP no. 1993-105 1993 12 p. International Conference on Numerical Methods in Laminar and Turbulent Flow, 8th, Univ. of Swansea, United Kingdom, July 18-23, 1993 Research supported by DRET refs
(ONERA, TP NO. 1993-105)

In the present work, an upwind numerical approach for the solution of the compressible Reynolds averaged Navier-Stokes equations is presented; this work has been done using the 3D multidomain code FLU3M. Turbulence closure is obtained using the Jones-Launder k-epsilon model. A Roe type Riemann solver for the fully coupled hyperbolic system is briefly described; a Beam and Warming type implicit linearization is used in order to accelerate the convergence. First, two laminar 3D-results on a lenticular section missile are compared with available experimental data for flow at supersonic Mach numbers for a validation purpose. Then, two 2D turbulent computations are shown. For the first one, the characteristic features of a single turbulent boundary layer are discussed. For the second one, a shock wave-boundary layer interaction flow is considered and results are compared with experimental data. Author (revised)

A93-53736* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
AERODYNAMIC CHARACTERISTICS OF THE HL-20
GEORGE M. WARE and CHRISTOPHER I. CRUZ (NASA, Langley Research Center, Hampton, VA) Journal of Spacecraft and Rockets (ISSN 0022-4650) vol. 30, no. 5 Sept.-Oct. 1993 p. 529-536. AIAA, Applied Aerodynamics Conference, 9th, Baltimore, MD, Sept. 23-25, 1991, AIAA Paper 91-3215. Previously cited in issue 23, p. 4008, Accession no. A91-53865 refs

A93-53739* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
AERODYNAMIC HEATING ENVIRONMENT DEFINITION/THERMAL PROTECTION SYSTEM SELECTION FOR THE HL-20
K. E. WURSTER and H. W. STONE (NASA, Langley Research Center, Hampton, VA) Journal of Spacecraft and Rockets (ISSN 0022-4650) vol. 30, no. 5 Sept.-Oct. 1993 p. 549-557. refs
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Definition of the aerothermal environment is critical to any vehicle such as the HL-20 Personnel Launch System that operates within the hypersonic flight regime. Selection of an appropriate thermal protection system design is highly dependent on the accuracy of the heating-environment prediction. It is demonstrated that the entry environment determines the thermal protection system design for this vehicle. The methods used to predict the thermal environment for the HL-20 Personnel Launch System vehicle are described. Comparisons of the engineering solutions with computational fluid dynamic predictions, as well as wind-tunnel test results, show good agreement. The aeroheating predictions over several critical regions of the vehicle, including the stagnation areas of the nose and leading edges, windward centerline and wing surfaces, and leeward surfaces, are discussed. Results of predictions based on the engineering methods found within the MINIVER aerodynamic heating code are used in conjunction with the results of the extensive wind-tunnel tests on this configuration to define a flight thermal environment. Finally, the selection of the thermal protection system based on these predictions and current technology is described.

A93-53740* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
HL-20 COMPUTATIONAL FLUID DYNAMICS ANALYSIS
K. J. WEILMUENSTER and FRANCIS A. GREENE (NASA, Langley Research Center, Hampton, VA) Journal of Spacecraft and Rockets (ISSN 0022-4650) vol. 30, no. 5 Sept.-Oct. 1993 p. 558-566. refs
Copyright

The essential elements of a computational fluid dynamics analysis of the HL-20/personnel launch system aerothermal environment at hypersonic speeds including surface definition, grid generation, solution techniques, and visual representation of results are presented. Examples of solution technique validation through comparison with data from ground-based facilities are presented, along with results from computations at flight conditions. Computations at flight points indicate that real-gas effects have little or no effect on vehicle aerodynamics and, at these conditions, results from approximate techniques for determining surface heating are comparable with those obtained from Navier-Stokes solutions.

A93-53798
NUMERICAL ANALYSIS OF A FLAT PLATE IN A PITCHING MOTION. II - EFFECT ON THE FLOW OF THE POSITION OF THE PIVOT, ETC
HIDEYUKI OHBA and SHIGEAKI KURODA Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 560 April 1993 p. 1121-1126. In JAPANESE refs
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Flows around a flat plate exhibiting a pitching motion in a uniform crossflow are studied numerically. Two cases of pitching motion, sinusoidal oscillation, and oscillation with constant velocity are analyzed, and the effects on the flow of the position of the pivot, Reynolds number, angular velocity and maximum angle of attack are researched. Body-fitted grid generation with moving boundaries is used to obtain the numerical solution of the incompressible Navier-Stokes equations. The time-dependent curvilinear coordinate system which coincides with a contour of a moving boundary is transformed into a fixed rectangular coordinate system in the calculation plane. The changes in CD and CL during the pitching motion are obtained. Author (revised)

A93-53799
STUDY ON SURGE AND ROTATING STALL IN AXIAL COMPRESSORS. III - NUMERICAL MODEL FOR MULTIBLADE-ROW COMPRESSORS
HIROSHI ISHII and YASUSHIGE KASHIWABARA Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 560 April 1993 p. 1127-1133. In JAPANESE refs
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This paper proposes a new numerical model expanding on the previous fundamental model, which aims at a more accurate representation of both surge and rotating stall for practical applications. The model deals with the full set of fluid equations for two-dimensional unsteady compressible flow in the axial and circumferential directions throughout the compressor. The blade rows are replaced by semiactuator disks, where the blade row characteristics are expressed by the total pressure loss versus the incidence angle. The basic function and validity of the proposed model are examined through numerical simulation of both surge and rotating stall in multiblade-row compressors.

A93-53837
THREE-DIMENSIONAL VISCOUS FLOW ANALYSIS OF COMPRESSOR CASCADE CHANNELS
HIDENORI YOSHIDA, TAKASHI KAWASHIMA, and KEIJI SAKAGAWA Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 561 May 1993 p. 1524-1531. In JAPANESE refs
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A three-dimensional Navier-Stokes (NS) numerical analysis grid is developed for turbomachinery based on the outer flow grid for aircrafts, in which the Reynolds averaged NS equations are solved using an implicit finite-volume TVD scheme with a two-equation turbulence model. The new grid was validated in two-dimensional compressor cascade tests with solid side walls, measuring the three-dimensional flow pattern, and comparing the test data with the results of the three-dimensional viscous flow analysis. It was found that the computed results agree well with the experimental data, such as the static pressure distribution on the blade surface, the total pressure loss distribution at the outlet of the cascade, and the pitchwide-averaged flow angle distribution. AIAA

A93-53840
SHOCK SHAPES AROUND SLENDER DIAMOND CONES TRAVELING AT HYPERSONIC SPEED
MASATOMI NISHIO and MUTSUO KOTAKE Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 561 May 1993 p. 1566-1572. In JAPANESE refs
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The shock shapes around slender diamond cones were obtained using the law of conservation of mass and the equivalence principle for hypersonic flows passing slender bodies. Theoretical shock shape obtained by this method agreed well with the experimental result obtained by the first electric discharge method. It was confirmed that this method is effective in calculating the shock shape around an arbitrary slender body traveling at hypersonic speed.

A93-53841
ANALYSIS OF UNSTARTED SUPERSONIC FLUTTER IN CASCADE BY SEMIACTUATOR DISK THEORY
HIROFUMI DOI and SHOJIRO KAJI Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 561 May 1993 p. 1573-1579. In JAPANESE refs
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Unstarted supersonic flutter in a cascade is characterized by the existence of a detached bow shock wave ahead of each airfoil. To study the influence of the bow shock wave on this flutter, analysis is performed on the corresponding flowfield with use of the semiactuator disk theory. We investigate oscillation in the bending mode with the interblade phase angle, considering the effect of reflection of the pressure wave and the production of a vorticity wave and an entropy wave by the bow shock wave. The results show that the existence of detached bow shock waves greatly destabilizes bending oscillation, and the flutter boundary drastically extends to a high-frequency region. Author (revised)

A93-53842
VELOCITY FLUCTUATION BASED ON THE DIFFERENCE IN THE FLOW PATTERN IN THE CHANNELS OF A CENTRIFUGAL IMPELLER

HIROMU TSURUSAKI, TOMOHIRO TATEISHI, and YOSHINOBU TSUJIMOTO Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 561 May 1993 p. 1626-1631. In JAPANESE refs

When an open-type impeller was operated near the flow rate for shockless entry, a large component in the velocity fluctuation spectrum was observed outside the impeller. The frequency of this component was equal to that of the impeller rotation. The origin of this component was studied experimentally. The flow conditions near the flow rate where the large component was observed were determined for an open impeller and for a closed impeller. From the experiment, it became clear that the flow pattern including a backflow region in the open impeller was changed near the above mentioned flow rate, and, at that particular flow rate, two types of velocity distributions existed in the impeller channels. Thus, the large component of the velocity fluctuation was observed outside the impeller. The flow pattern which caused the velocity fluctuation is discussed. Author (revised)

A93-53843
NUMERICAL ANALYSIS OF THE FLOW THROUGH A CENTRIFUGAL IMPELLER BY VORTEX DISTRIBUTION MODEL OF A BOUNDARY LAYER. I - THEORETICAL ANALYSIS

HONG GAO and KYOJI KAMEMOTO Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 561 May 1993 p. 1632-1639. In JAPANESE refs

This paper presents a numerical analysis method for a separated unsteady flow in a centrifugal impeller. Considering the influence of the boundary layer, the flow, which is assumed to be two-dimensional, inviscid, and incompressible, is analyzed using both the boundary element method and the discrete vortex method. Based on Karman's momentum and Poisson's equation, the changes in the displacement thickness are solved and the separation point on the boundary layer is determined automatically by the shape factor H of the turbulent flow. The velocity field and the pressure distributions are solved for the discharge coefficient c(e) = Q/Qn (in this paper, c(e) = 0.6). Author (revised)

A93-53852
AN IMPLICIT DIFFERENCE SCHEME OF EULER EQUATION FOR UNSTEADY TRANSONIC FLOW

ZHENG-HONG GAO (Northwestern Polytechnical Univ., Xian, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A7-A13. In CHINESE refs

A continuous flux splitting method for unsteady Euler equations based on time-dependent body fitted coordinates is described, and the method is used to derive an implicit difference equation for solving the unsteady transonic flow with Euler equations. In order to reduce the computer time for solving the block-matrix equations, a characteristic matrix transformation is used. This transformation does not change the discrete order of the equations, but the CPU for solving the matrix equations can be reduced greatly. The numerical computation is made in the moving coordinates, so that not only the boundary conditions are kept on the real body surface, but the time-dependent body-fitted coordinates are built in a very simple way as well. The NACA64A-10 airfoil which oscillates in pitching about its 1/4 chord point is computed, and the computed results are in good agreement with experimental data. Calculated results for the airfoil oscillating in heaving and both in heaving and pitching are also presented. Author (revised)

A93-53853
NUMERICAL STUDY OF SUPERSONIC FLOW OVER A BACKWARD STEP WITH TRANSVERSE INJECTION

WEI-JIANG ZHOU, HAN-DONG MA (Beijing Inst. of Aerodynamics, China), and YAN-WEN MA (Chinese Academy of Sciences, Inst. of Mechanics, Beijing, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A14-A19. In CHINESE refs

The interaction between a supersonic flow around a backward step and transverse injectors (Ma(j) = 1.05) located on the downstream of the step is simulated with finite difference method, by solving the N-S equations numerically. First, the supersonic flows over a backward step without an injector are computed, and the results are compared with the experiment and other calculations. Then, the injector is added, with the pressure ratio p(j)/p(infinity) varying from 3.033 to 7.033 and the injector width, w, equal to 0.1 h or 0.2 h (h = step height). The reasonable structures of vortex and waves are presented, and the effects of p(j)/p(infinity) and w on flow properties are investigated. Within the present parameter region, the calculations show that the pressure at the step bottom is almost linearly related to the factor Q (Q = wp(j)/hp(infinity)). Author (revised)

A93-53858
NUMERICAL SOLUTION OF N-S EQUATIONS FOR HYPERSONIC FLOW OVER CAPSULE-TYPE VEHICLES

WEI-JIANG ZHOU (Beijing Inst. of Aerodynamics, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A68-A71. In CHINESE refs

The laminar N-S equations for hypersonic flow over capsule-type reentry vehicles are solved using the second-order windward TVD scheme. The detailed flowfield structures and pressure distribution along the body surface are given, and its good agreement with experiment and reference is shown. The calculations also show that the variation of radius R2 does not cause much flowfield change in the afterbody, but it has a great effect on the heating rate near the shoulder. In the case of R2 = 0.2, the heating rate peak on the shoulder is slightly less than the stagnation values; however, when R2 is equal to 0.05, this peak is much higher and exceeds the stagnation value by 30 percent. Author (revised)

A93-53859
A PRELIMINARY INVESTIGATION OF THE CONTROL OF SEPARATED FLOW BY MEANS OF EXCITATION

CHENG XU (East China Inst. of Technology, Nanjing, China), SHI-YING ZHANG, and MING-DE ZHOU (Nanjing Aeronautical Inst., China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A72-A75. In CHINESE refs

Force measurements combined with flow visualization are used to investigate the control of two-dimensional leading-edge separation by means of flap oscillation. It is found that the results of control are related to the modeled natural flow patterns. When the natural flow pattern is a closed separation bubble, the excitation causes a lift loss. A reduction of the reattachment length and the drag of the model can be achieved by proper frequency excitation. The most effective Strouhal number range based on the reattachment length and the main stream velocity for drag reduction is 3-5. When the natural flow pattern is full separation, proper frequency excitation changes the flowfield into a closed separation bubble, and a lift increment is achieved. The most effective Strouhal number range based on the chord of the model and the main stream velocity for lift increment is 0.70-2.5. Author (revised)

A93-53860
ANALYTICAL EXPRESSION OF DISSIPATION INTEGRAL FOR KINETIC ENERGY INTEGRAL EQUATION
LONG-DE HE (Chinese Academy of Sciences, Inst. of Mechanics, Beijing, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A76-A79. In CHINESE refs

A dissipation integral method is developed for calculating compressible turbulent boundary layers on planar bodies. An analytical expression of dissipation integral for kinetic energy integral equation is derived by two-layer eddy viscosity turbulence model and the power law of the velocity profile. The analytical expression depends on the local values of skin friction, shape factor, Mach number, and Reynolds number based on momentum thickness. The method is easy to use, and thus the calculation of the turbulent boundary layers is significantly simplified. The analytical expression is in better agreement with experimental data than other theoretical results. Author (revised)

A93-53868
TRANSONIC AREA RULE ABOUT LIFTING CONFIGURATIONS
QING-WEI ZHAO and BING-XUAN ZHANG (Beijing Univ. of Aeronautics and Astronautics, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 2 Feb. 1993 p. B1-B6. In CHINESE refs

This paper develops the nonlinear area ruling method applied to lifting configurations by using the matched asymptotic expansion and gives the conservational condition under which the integral strength of the equivalent sources depending on the lift distribution is equal to zero. This conservational condition can be used to determine the corrective quantities of the above mentioned equivalent sources in the region of the trailing edge of the wing. The computed results show that the method is capable of accurately predicting the transonic wave drag for general airplanes or their components which have zero lift or lift and providing optimal option for the low-cost wave drag configurations, and the method has enough accuracy when applied up to free-stream Mach = 1.5 and alpha = 10 deg. Author (revised)

A93-53982
A 2-D COMPRESSIBLE N-S SIMULATION OF STARTING- AND STALLING-FLOWS IN A COMPRESSOR CASCADES SYSTEM
EISUKE OUTA, DAI KATO (Waseda Univ., Tokyo, Japan), and KAORU CHIBA (Ishikawajima-Harima Heavy Industries Co., Ltd., Research and Development Dept., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 53-62. Research supported by Waseda Univ refs
(ISABE 93-7006) Copyright

A numerical simulation of unsteady flow in linear cascades of a compressor is conducted by applying a TVD finite difference scheme. Two-dimensional compressible Navier-Stokes equations are solved iteratively in a rotor-fixed moving frame and in a stator-fixed frame. Instead of applying a turbulence model, a very fine grid system is used. The flow induced by rotor blade motion are analyzed as an initial value problem without specifying an incidence flow angle. To alter a load on the compressor, a throttle resistance is provided at the outflow boundary. Two combinations of the number of rotor and stator blades are concerned; a one-rotor/one-stator and a three-rotor/five-stator combinations. The Reynolds number and the Mach number in the latter case are 300,000 and 0.3. The stage characteristics such as pressure rise, incidence angle, and wake profiles show very similar features with compressor test data. Configurations of blade vortices, formation and convection of wakes, and propagation of stalled cells are satisfactorily demonstrated. The speeds of the stall propagation at early stages of the development are computed to be 84 percent of the blade speed in the rotor and roughly 15 percent in the stator. The number of stall cells is not found definitely, since the number of blades is very low. Author (revised)

A93-53983
NUMERICAL STUDY ON INCEPTION OF STALL CELLS IN ROTATING STALL
TOSHIO NISHIZAWA (National Aerospace Lab., Chofu, Japan) and HIROYUKI TAKATA (Tokai Univ., Hiratsuka, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 63-72. refs
(ISABE 93-7007) Copyright

This paper discusses numerically the inception of stall cells in rotating stall, especially putting importance on the number of stall cells. Examinations are made for both of the isolated cascade and the rotor with guide vanes upstream. In the isolated cascade operating around the stall inception point, a plural number of stall cells may be propagated only when the flow fluctuation is small. But only one cell propagates for the fully developed rotating stall. With the inlet guide vanes, greater numbers of the stall cells can grow up to steadily propagating ones. The number of stall cells depends on both the axial spacing between the two cascades and the relative exit flow angle of guide vanes. The results are confirmed by comparison with both experiment and analysis. Author (revised)

A93-53984
SOME MEASUREMENTS OF STALL IN AN AXIAL IMPELLER
P. A. RAJAN and S. SOUNDRANAYAGAM (Indian Inst. of Science, Bangalore, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 73-84. refs
(ISABE 93-7008) Copyright

Measurements have been made in a single stage axial impeller, including the stalled flow regime, using conventional combination, yaw-pitch probes as well as a single rotated inclined hot wire. An unexpected finding was that, contrary to the accepted belief that a stall cell is a region of reduced flow, a high velocity jetlike flow existed within the cell at the root, the fluid in the high velocity jet being conjectured to have migrated radially inwards from the tip region. Correlations developed from tests on high hub to tip diameter ratio machines do not conform to the present results though the value of psi-(T-s) at Stall is in broad agreement. The stall cell has a spiral configuration which is oriented parallel to the main flow streamlines in a frame of reference moving with the cell, implying no motion of the external flow through the cell. The flow within the cell is not radically different from the external flow. The stall cell reaches its final velocity after inception in about eight revolutions of the rotor though it takes about 25 revolutions to attain a final size. Author (revised)

A93-53985
THE LEADING EDGE VORTEX OF A ROTATING STALL CELL
F. A. E. BREUGELMANS, E. FABRY, and J. MIJS (von Karman Inst. for Fluid Dynamics, Rhode-Saint-Genese, Belgium) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 85-90. refs
(ISABE 93-7009) Copyright

A single cell rotating stall pattern has been investigated in the leading edge region of the cell. The experimental and data treatment procedures are developed to this purpose. The existence of a vortex is shown and its extent in the axial and tangential direction demonstrated.

A93-53986
THE ENERGY DISSIPATION IN A ROTATING STALL CELL
O. EERTINK and F. A. E. BREUGELMANS (von Karman Inst. for Fluid Dynamics, Rhode-Saint-Genese, Belgium) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p.

91-96. refs
(ISABE 93-7010) Copyright
The stall cell is investigated for the energy dissipation capabilities. The kinetic energy contained in rotating stall cells in an axial flow compressor is determined from measurements with a crossed hot wire in the upstream space between inlet guide vanes and rotor. The closing and opening sequence of the throttling is performed and the transition between the different patterns demonstrated.

A93-53987
REVIEW OF STALL, SURGE AND ACTIVE CONTROL IN AXIAL COMPRESSORS
I. J. DAY (Cambridge Univ., United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 97-105. Research supported by Rolls-Royce, PLC and SERC refs
(ISABE 93-7011) Copyright
This paper reviews the work done on stall, surge and active control over the past ten years. A great deal of theoretical and experimental activity has taken place making this period of research one of the most fruitful since work on compressor instabilities began. The review covers the part played by two-dimensional, long lengthscale disturbances in the theoretical treatment of stall inception, and focuses on the way this work leads to the original proposal that active control might be applied to compressor instabilities. The experimental demonstration of the existence of long lengthscale disturbances is discussed, followed by the successful attempts to control these disturbances. The existence of three-dimensional, short lengthscale disturbances was discovered during this period and it is shown how these disturbances can also be controlled using active techniques. Detailed studies of surge in axial compressors are reported showing clearly that rotating stall is responsible for the onset of surge. The successful attempts to control surge in axial machines follow naturally from this observation. Finally, the review covers the current studies of stall inception in aero-engine compressors.

A93-53988
AN INVESTIGATION OF POST STALL TRANSIENTS AND RECOVERABILITY OF AXIAL COMPRESSION SYSTEMS
J. HU, G. C. TANG, and H. M. ZHANG (Nanjing Aeronautical Inst., China) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 106-116. refs
(ISABE 93-7012) Copyright
A simplified approximate method is proposed to predict the poststall behaviors and recoverability from stalled flow both with uniform and with circumferential nonuniform inlet flow in multistage axial compression systems. The method leads to a set of three simultaneous nonlinear first-order partial differential equations, and the numerical simulations show that the investigation of poststall transient behaviors, recoverability from rotating stall or surge, and the effects of compression system parameters and inlet flow nonuniformity can be carried out through this method. It can be used to deal with rotating distortion too. It has been found that both the inlet distortion amplitude and propagation speed have strong effect on the stability and poststall transient behaviors. The study of the effect of system parameters on recoverability shows that the B, lc, and m all have little effect on the recoverability of the compression system, but alpha and compressor axisymmetrical characteristics have a strong effect on it. Some quantitative comparisons with available experimental results and some qualitative comparisons with test data are made. It shows that the proposed model is very simple, accurate, and dependable. Author (revised)

A93-54005
INVESTIGATION OF THE FLOW FIELD THROUGH A VARIABLE PITCH FAN ROTOR WITH AN INLET TOTAL PRESSURE DISTORTION
T. KAYA, A. CARRERE, and R. BARENES (Ecole Nationale Superieure de l'Aeronautique et de l'Espace, Toulouse, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 332-339. refs
(ISABE 93-7029) Copyright
An experimental and numerical investigation of the flow field through a variable pitch fan rotor has been conducted. First, the steady state measurements have been compared with the results of a quasi-three-dimensional numerical calculation when the inlet flow is homogeneous. Then, the inlet flow has been distorted by a screen placed 1.4 fan diameters upstream of the fan. The periodic and random fluctuations have been separately measured, as a function of the fan-blade incidence. Finally, a linearized method has been used to analyze the attenuation capacity of the fan when the fan-blade incidence is changed.

A93-54006
NAVIER-STOKES COMPUTATION OF THE THREE DIMENSIONAL FLOW FIELDS THROUGH A TRANSONIC FAN BLADE
O. NOZAKI, K. YAMAMOTO, K. KIKUCHI, Y. SAITO, N. SUGAHARA, and A. TAMURA (National Aerospace Lab., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 340-346. refs
(ISABE 93-7030) Copyright
The three dimensional transonic flow fields of a fan stage have been analyzed by a computational solution of Navier-Stokes equations employing an implicit finite difference method with high accuracy upwind scheme. Experimental data were also introduced for verifying the computation. The fan stage model under consideration consists of rotor blades and outlet guide vanes. In order to deal with the flow through multiple rows a zonal approach was utilized, where computational domains are arranged for each row and boundary conditions are replaced repeatedly at each time step. This approach has been applied to a fan model for a wide range of mass flow to evaluate the over-all characteristics. In the paper the numerical approach is illustrated and significant results for actual fan designs are discussed in comparison with experimental data.

A93-54007
THE STREAMLINE THROUGHFLOW METHOD OF AXIAL TURBOMACHINERY FLOW ANALYSIS
T. W. VON BACKSTROM and T. H. ROOS (Stellenbosch Univ., South Africa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 347-354. refs
(ISABE 93-7031) Copyright
The turbomachinery inviscid throughflow equation is fundamentally a statement of the conservation of tangential vorticity under the influence of various source terms. This equation is transformed from an equation for the stream function value in an axial-radial coordinate system to an equation for streamline radial position in an axial-position-streamfunction coordinate system. The transformed equation is shown to satisfy the compatibility equations for incompressible flow across actuator disks and is solved by Gauss-Seidel iteration. The streamline throughflow method is shown to predict streamline radial position well for incompressible flow through an annulus, over a fan nose bullet and through a single and a pair of twin actuator disks in an annulus. The method can be extended to compressible flows and flow within blade rows.

A93-54009
THE EFFECTS OF END-BEND REGULATIONS OF COMPRESSOR BLADE ON THE OUTLET FLOW FIELD
GUOCHUAN WU and JILING XIN (Nanjing Univ. of Aeronautics and Astronautics, China) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 366-370. refs
(ISABE 93-7033) Copyright

The effects of different end-bend regulations of compressor blades on the outlet flow field of a compressor plane cascade are experimentally studied. A method of designing the end-bend compressor blade is theoretically developed. The experimental results show that increasing the end-bend angle and end-bend height restricts the high-loss region in the cascade corner. A new secondary flow model is deduced, leading to a proposal to design end-bend compressor blades in terms of secondary vorticity theory. Reliable and optimal data for application of end-bend blades to engineering practice are also provided. AIAA

A93-54023
THE UNSTEADY FLOW PAST A SUPERSONIC SPLITTER PLATE
N. PEAKE and D. G. CRIGHTON (Cambridge Univ., United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 511-513. refs
(ISABE 93-7047) Copyright

A theoretical analysis of unsteady vortex shedding by supersonic jet nozzles is presented which is relevant to the operation of powerplants for future generations of supersonic passenger aircraft. The model problem of a 2D rigid splitter plate with supersonic mean flow on one side and still air on the other and with a plane acoustic wave incident on the splitter plate from infinity in the moving stream is considered. Emphasis is given to the precise form of the unsteady behavior of the vortex sheet as it leaves the trailing edge of the plate. AIAA

A93-54029
TRANSONIC DISCHARGE FLOWS AROUND DIFFUSER VANES FROM A CENTRIFUGAL IMPELLER
T. YAMANE (National Aerospace Lab., Tokyo, Japan), H. FUJITA, and T. NAGASHIMA (Tokyo Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 563-571. refs
(ISABE 93-7053) Copyright

Complex flow structure within the interaction region of a centrifugal impeller and diffuser vanes due to discharged wake has been analyzed by fully unsteady 3D viscous calculation based upon a TVD code. Computational results revealed that the impeller discharge wake, inside of which speed is transonic, flows into diffuser vanes like traveling waves, but is immediately dissipated before it reaches the vane throat. Time averaged results of fully unsteady calculation have been compared with the results of steady stage calculation that uses pitchwise averaging at the rotor/stator intersection. Some experimental work has been also made and compared with computational results. Author (revised)

A93-54030
CORRELATIONS FOR FLOW PROPERTY VARIATION AT OUTLET OF A CENTRIFUGAL IMPELLER
S. RAMAMURTHY and K. MURUGESAN (National Aeronautical Lab., Bangalore, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 572-579. refs
(ISABE 93-7054) Copyright

Detailed measurements using hot-wire anemometery and high frequency Kulite transducer at centrifugal impeller outlet reveal a complex nature of flow behavior across blade to blade pitch. The impeller outlet flow has two distinct regions called jet and wake. These regions are identified by measuring the variations of flow velocity, angle and pressure. The impeller outlet flow is characterized by defining certain non-dimensional parameters and correlating them with flow coefficient which are useful in the design of centrifugal impellers.

A93-54031
PERFORMANCE IMPROVEMENT BY FORWARD-SKEWED BLADING OF AXIAL FAN MOVING BLADES
NOBUYUKI YAMAGUCHI, TETSUO TOMINAGA, JYO MASUTANI (Mitsubishi Heavy Industries, Ltd., Takasago, Japan), and MITSUSHIGE GOTO (Mitsubishi Heavy Industries, Ltd., Nagasaki, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 580-589. refs
(ISABE 93-7055) Copyright

Forward-skewing, a new concept for reducing secondary losses in axial compressors, was experimentally applied to the moving blades of a low-speed axial fan. An optimized forward-skewed blading confirmed an improvement of peak efficiency by nearly 1 percent and an enlarged iso-efficiency contour area for variable-pitch moving-blade operation. Some experimental and numerical investigations were conducted with respect to the effect of the skewing on the internal flow behavior. They suggested that the forward skewing controlled the microstructure of the tip region flow, which might have reduced the secondary loss around the tip.

A93-54033
TIP CLEARANCE EFFECTS ON THE FLOW FIELD OF AN AXIAL TURBINE ROTOR BLADE CASCADE
M. GOVARDHAN, N. VENKTRAYULU, and V. S. VISHNUBHOTLA (Indian Inst. of Technology, Madras, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 598-608. refs
(ISABE 93-7057) Copyright

The flow through a blade passage and downstream of a blade trailing edge was experimentally studied. Results are presented for four cases of tip clearance, including zero clearance, in the form of contours of local loss coefficient along with secondary velocity vectors, spanwise variation of pitchwise average total pressure loss coefficient, surface static pressure distribution, and the overall loss distribution along the axis of the cascade. The effect of clearance fluid on the passage flow and the growth of the clearance vortex are reported. AIAA

A93-54034
EFFECTS OF WAKE INTERACTION OF TWO TURBINE CASCADES ON SECONDARY/TIP-LEAKAGE FLOWS AND LOSSES
A. YAMAMOTO (National Aerospace Lab., Chofu, Japan), R. MURAO, Y. SUZUKI, and Y. AOI (Aoyama Gakuin Univ., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 609-619. refs
(ISABE 93-7058) Copyright

In order to study the interaction of turbine stator and rotor blade rows, two different linear cascades were installed in series, and the downstream cascade flows were measured in detail where the location of the upstream cascade was changed several times relative to the downstream cascade. The results show that the net total pressure loss generated in the downstream cascade becomes maximum when the wakes of the upstream cascade pass over the blade suction surfaces of the downstream cascade, and that tip leakage loss generated in the downstream cascade does not depend on the relative location of both cascades. Wake interaction with the endwall flow and secondary flows of the downstream cascade are also shown.

A93-54044
RESEARCH AND DEVELOPMENT OF HIGH PRESSURE COMPRESSOR FOR SST AND HST ENGINE
K. CHIBA and K. KOBAYASHI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 711-716. Research supported by Agency of Industrial Science and Technology of Japan refs
(ISABE 93-7068) Copyright

The aerodynamic design of a high pressure compressor for a SST/HST engine requires highly advanced technology in order to achieve the target of high performance. The objective of the present research work is to obtain aerodynamic design technology for achieving higher efficiency in the transonic compressor having five stages, a pressure ratio of 4.85 and a tip speed of 330 m/s. The design of rotors and stators has been carried out by use of a quasi-3D code and a 3D code to reduce losses. The blade element performance has been evaluated by the compressor rig test, while the overall performance of the compressor has been obtained. This paper presents a discussion of the aerodynamic design and the test results. Author (revised)

A93-54051* National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, AL.
NAVIER-STOKES ANALYSIS OF TURBINE FLOWFIELD AND EXTERNAL HEAT TRANSFER
J. LUO and B. LAKSHMINARAYANA (Pennsylvania State Univ., University Park) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 766-780. refs
(Contract NAS8-38867)
(ISABE 93-7075) Copyright

An explicit 2D Navier-Stokes code has been modified and used to analyze the aerodynamics and heat transfer of a transonic turbine cascade. This code is based on a four-stage Runge-Kutta scheme. An algebraic Reynolds stress model (ARSM) and two versions of low Reynolds number (LRN) two-equation turbulence models, Chien's (1982) LRN k-epsilon model and Coakley's (1983) LRN q-omega model, have been employed in the computations. The surface pressure distributions and wake profiles are predicted well by all the models. The k-epsilon model and the k-epsilon/ARSM model yield better predictions of heat transfer than the q-omega model. The k-epsilon/ARSM solutions show some significant, though not dramatic, differences in the predicted skin friction coefficients, heat transfer rates, and performance parameters, as compared to the k-epsilon model. The predicted semiwake width is consistent with the measurement and correlation. Author (revised)

A93-54062* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
AERODYNAMIC INVERSE DESIGN AND ANALYSIS FOR A FULL ENGINE
JOSE M. SANZ (NASA, Lewis Research Center, Cleveland, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 895-902.
(ISABE 93-7086) Copyright

A numerical design methodology for multistage turbomachinery is being developed that minimizes the use of experimental data required in the design process. This approach is resulting in an efficient method of enlarging the design database for turbomachinery blading. This capability has been demonstrated for blade sections, and the goal is to extend it to fully three dimensional, multistage configurations.

A93-54068
EXPERIMENTAL ANALYSIS OF TURBINE ROTOR FLOW AT DESIGN AND OFF-DESIGN CONDITIONS
H. USUI and A. YAMAMOTO (National Aerospace Lab., Chofu, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 949-954. refs
(ISABE 93-7092) Copyright

The paper describes effects of the inlet flow angle on the flows before, within and after a turbine rotor. An annular cascade and a fiber-type L2FV(Laser-2-Focus Velocimeter) were used as the test turbine and the velocimeter. Flows were measured at a total of eight measuring planes for three rotational speeds including a speed corresponding to the design incidence. The test results were shown using velocity vectors and velocity contours to clarify the effects of the inlet flow angle on the rotor internal flow fields.

A93-54069
3D AND 2.5D VISCOUS FLOW COMPUTATIONS FOR AXIAL FLOW TURBINE BLADES
ANTOINE FOURMAUX, GILLES BILLONNET (ONERA, Chatillon, France), and BERTRAND PETOT (SNECMA, Moissy-Cramayel, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 955-964. Research supported by DRET and Service Technique des Programmes Aeronautiques refs
(ISABE 93-7093) Copyright

The application of two methods for the computation of flows in turbine channels is presented. They solve the unsteady sets of quasi-3D and 3D full mass averaged Navier-Stokes equations in a relative frame of reference. The equations are solved by a classical finite volume technique including an implicit stage. A mixing length turbulence model that is adapted to 3D and complex geometries is used. The calculations of several turbine rotor geometries including tip clearance are presented. The first geometry is a stationary low-pressure airfoil cascade and the second one is an actual high-pressure turbine rotating row of airfoils. The influence of the leakage flow on the main flow is analyzed. The application of the quasi-3D code to the calculation of high pressure inlet guide vane including heat transfer with trailing edge cooling is presented. The validation of the heat transfer calculation results vs experimental ones is presented. Two types of the trailing edge geometries are studied and compared in terms of cooling efficiency and global losses. Author (revised)

A93-54070
RECENT DEVELOPMENTS PERFORMED AT ONERA FOR THE SIMULATION OF 3D INVISCID AND VISCOUS FLOWS IN TURBOMACHINERY BY THE SOLUTION OF EULER AND NAVIER-STOKES EQUATIONS
V. COUAILLIER (ONERA, Chatillon, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 965-973. Research supported by DRET and SNECMA refs
(ISABE 93-7094) Copyright

This paper presents a synthesis of the numerical developments performed in the Euler and Navier-Stokes solvers SESAME and CANARI during the last five years. The different physical models used are recalled, and the numerical schemes developed in a cell vertex approach or in a cell centered approach are detailed. Some typical applications obtained with the different methods implemented in the solvers are presented to illustrate the capabilities of these solvers to simulate flows in turbomachinery.

A93-54071* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
THREE-DIMENSIONAL FLOW ANALYSIS INSIDE TURBOMACHINERY STAGES WITH STEADY AND UNSTEADY NAVIER-STOKES METHOD
W. W. COPENHAVER, S. L. PUTERBAUCH (USAF, Aeropropulsion Lab., Wright-Patterson AFB, OH), and C. HAH (NASA, Lewis Research Center, Cleveland, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept.

20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 974-983. refs
(ISABE 93-7095) Copyright

This study presents a numerical method for solving the three-dimensional, Navier-Stokes equations for unsteady, viscous flow through multiple turbomachinery blade rows. The method solves the fully three-dimensional Navier-Stokes equations with an implicit scheme which is based on a control volume approach. A two-equation turbulence model with a low Reynolds number modification is employed in the present study. A third-order accurate upwinding scheme is used to approximate convection terms while a second order accurate central difference scheme is used for the discretization of viscous terms. A second-order accurate scheme is employed for the temporal discretization. The numerical method is applied to study the unsteady flow field of a subsonic turbine stage and the unsteady flow field inside a transonic, high-through-flow, axial compressor stage. The stage calculation is performed by coupling the stator and the rotor flow fields at each time step through an over-laid grid.

A93-54074
OPTIMIZATION OF AFTERBODIES AND ENGINE NOZZLE BY USING CFD METHODS
G. ROLLIN, T. MAUFFRET, M. AH-FA, and E. MAINGRE (SNECMA, Moissy-Cramayel, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1003-1012. Research supported by Direction des Programmes de l'Aviation Civile refs
(ISABE 93-7098) Copyright

In the present and future aircrafts, the demands of efficiency are such that it is and it will be impossible to reach the aircraft aerodynamic optimum just with experimental studies. In this context during the past decade many efforts have been expended to develop numerical methods able to reproduce the phenomena occurring in the engine flow field. This paper presents a review of the afterbody and engine nozzle methods used to optimize these components. In this area, two paths are considered. Firstly the overall geometry must be designed. The aim of this first step is to make sure that the general characteristics of the nozzle and afterbody are correct. A large number of geometries has to be calculated in order to reach the objective. So there is a need for a code able to calculate at low cost the entire flow field around 2D or axisymmetric geometries. Therefore we have developed a method of computation based on an automatic mesh generator connected with CATIA CAO system and a CFD method solving turbulent Navier-Stokes 2D equations. This method permits us to get a first estimation of mass flow coefficient and thrust coefficient of nozzle and afterbody drag. Thus, this methodology was applied to optimize supersonic engine nozzle design with axisymmetric geometry to engine a future supersonic aircraft. These examples show the benefit of using intensively computational method for nozzle and afterbody design. Author (revised)

A93-54075
ADVANCED AERODYNAMIC AIRFRAME/NOZZLE INTEGRATION
DOUGLAS L. BOWERS (USAF, Wright Lab., Wright-Patterson AFB, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1013-1022. refs
(ISABE 93-7099)

A development status evaluation is presented for the computational and analytical methods that are to be used to define complex, next-generation fuselage aft-section/engine nozzle integrations for high performance aircraft. For nonviscous-dominated nozzle flows, the Euler flows with 2D and 3D adaptive unstructured grids are used as design tools. For viscous flows, the Navier-Stokes codes are noted to still suffer from longstanding problems. Special experimental test cases must also be obtained as needed, in order to validate CFD methods. Turbulence models adequate for the nozzle afterbody must still be developed. AIAA

A93-54076
ON THE NUMERICAL SIMULATION OF THE TWO-DIMENSIONAL FLOW FIELD AROUND A HYPERSONIC AIR-INTAKE-COMPRESSIBILITY EFFECTS
G. FRESKOS, D. VANDROMME, and H. H. MINH (Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique, Toulouse, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1023-1032. Research supported by SNECMA and EEC refs
(ISABE 93-7100) Copyright

The flow field around a hypersonic air-intake is computed. The Reynolds-averaged Navier Stokes equations are solved. A two-equation turbulence model simulates the turbulent character of the flow field. The numerical results are compared with available experimental data. Modifications to account for the compressibility effects on the turbulent field are presented. Relative results and expectations are also discussed.

A93-54078
DESIGN OF AIR INTAKES AND NOZZLES FOR TRANSONIC ROTATIONAL FLOWS
FRANCESCO LAROCCA and LUCA ZANNETTI (Torino, Politecnico, Turin, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1042-1048. refs
(ISABE 93-7102) Copyright

In this paper a numerical method for solving inverse problem is presented. It refers to a compressible, two-dimensional, inviscid rotational flow governed by the Euler equations. The pressure distribution is prescribed along the wall as design data and we inquire for the geometry that it assumes by considering the wall itself as impermeable and movable. The shape of the wall is obtained at the end of the transient generated by an initial guessed configuration and described in time by the unsteady Euler equations. The numerical procedure for solving Euler equations is based on a time-dependent technique and uses an upwind finite volume approximation. Some numerical examples, which refer to transonic flow in 2-D nozzles and diffusers, are presented.

A93-54079
A STUDY OF THE STABILITY OF VORTICAL STRUCTURES IN SUPERSONIC INLETS
R. MARSILIO (Torino, Politecnico, Turin, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1051-1061. refs
(ISABE 93-7103) Copyright

The stability of the vortical solutions of the inviscid, supersonic conical corner flows, is investigated. Such flow configurations are typical of supersonic inlet flows. Complex shock interactions appear, with the formation of vorticity field in the corner region and the vorticity itself converging into spiral singularity. Symmetric or asymmetric flow configurations are generated within symmetric corners. The investigation is carried out by a numerical technique based upon a space-marching procedure with a finite volume approximation. A high order accuracy scheme is introduced founded on ENO scheme criteria. Numerical results are presented and discussed.

A93-54080
BOUNDARY CONDITIONS FOR UNSTEADY SUPERSONIC INLET ANALYSES
DAVID W. MAYER and GERALD C. PAYNTER (Boeing Commercial Airplane Group, Seattle, WA) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993,

Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1062-1070. refs
(ISABE 93-7104) Copyright

New bleed and compressor face boundary conditions have been developed to improve the accuracy of unsteady supersonic inlet calculations. The new bleed boundary condition represents changes in the bleed hole discharge coefficient with local flow conditions; the local bleed flow rate can more than double as a shock moves forward over a bleed band. This locally rapid increase in bleed flow affects the motion of the normal shock and thus the stability margin of the inlet. The new compressor face boundary condition accounts for changes in the unsteady flow conditions at the compressor face by specifying the compressor face corrected mass flow or Mach number either as a constant or as a linear function of the stagnation conditions. This boundary condition represents the flow at the compressor face more realistically than traditional fixed static pressure or mass flow conditions. Results are reported for an Euler analysis of the dynamic response of an inlet normal shock to changes in the compressor face corrected mass flow. The dynamic response with both 20- and 90-deg throat bleed hole angles are reported. These results indicate that an extra margin of stability for the inlet is obtained with 90-deg bleed holes because the increase in bleed flow rate as the shock moves forward over a bleed band is much larger for 90-deg holes than for 20-deg holes. Author (revised)

A93-54082
A STUDY ON MACH 3 TWO-DIMENSIONAL MIXED COMPRESSION AIR-INTAKES
KIMIO SAKATA, RYOJI YANAGI, SHIGEMI SHINDO, AKIRA MURAKAMI (National Aerospace Lab., Tokyo, Japan), SHINJI HONAMI (Tokyo Science Univ., Japan), ATSUSHIGE TANAKA, and KAZUO SHIRAISHI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1081-1089. Research supported by Science and Technology Agency, Agency of Industrial Science and Technology, and New Energy and Technology Development Organization refs
(ISABE 93-7106) Copyright

The supersonic air-intakes for the propulsion system of a vehicle flyable at supersonic speed are being studied. Considering the requirement for high Mach number capability, a configuration of two-dimensional type with rectangular cross section and mixed compression system was selected. Several wind tunnel models were developed and tested in a 1m x 1m Mach 4 wind tunnel at National Aerospace Laboratory as the main part of the study. This paper presents the results of the wind tunnel tests on these models designed for Mach 3. The test results with the simplified small scale models are also presented as the supplementary data. The test results and the model modification for the performance improvement show the importance of establishing the shock systems, the optimized bleed to eliminate shock induced boundary layer separation and the improved passage of the subsonic diffuser for higher pressure recovery and stability. The side wall shape effects the pressure recovery and the mass flow characteristics.

A93-54083
NUMERICAL SIMULATION OF A TWO-DIMENSIONAL SUPERSONIC MIXED-COMPRESSION INLET
V. HANNEMANN, M. GIRKE, K. HANNEMANN, and TH. SONAR (DLR, Inst. fuer Stroemungsmechanik, Goettingen, Germany) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1090-1100. refs
(ISABE 93-7107) Copyright

The intention of the paper is to show the potentiality of using highly adapted grids for hypersonic flow simulations. For this purpose a generic 2D supersonic mixed compression inlet was investigated. Here only the results of the different adaption strategies are discussed. The inlet has been designed as part of a propulsion system using subsonic combustion. The supersonic part of the inlet was simulated for inviscid, laminar viscous, and turbulent viscous flow using an implicit upwind TVD finite difference method. The structured grids were adapted to the flow to obtain a good spatial resolution of the flow phenomena such as shocks and shock boundary layer interactions. The results of the Euler simulations compare well with results obtained with a method of characteristics. The results of the turbulent Navier-Stokes simulations show that no separation occurs in the supersonic part. The wall pressure agrees well with experimental results. Additional to these results, first results obtained by using an explicit finite volume method based on unstructured grids are presented. It is shown that the unsteady, local adaption used here is well suited for the simulation of complex, hypersonic flow fields. The second part of the numerical investigation is focused on the simulation of the complete inlet, i.e., supersonic plus subsonic part. The time-accurate development of a steady flow field as well as the development of unstart for an inviscid flow is discussed.
Author (revised)

A93-54087
INFLUENCE OF CHEMICAL KINETICS EFFECTS IN NOZZLES SHAPE DESIGN
M. ONOFRI, B. FAVINI, and R. PACIORRI (Roma I, Univ., Rome, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1143-1152. Research supported by Fiat Aviazione and ASI refs
(ISABE 93-7112) Copyright

Theoretical and experimental studies on axisymmetric nozzles have shown that two dimensional flow effects have an important role on the nozzle performances. These effects are enhanced when nozzles operate in the typical conditions of aerospace applications, since chemical reactions of dissociation and atomic recombination occur, which may be significantly influenced by the radial gasdynamic phenomena. In this paper the influence of the flowfield behavior on the finite rate chemical kinetics is analyzed for Single Expansion Ramp Nozzles (SERN), which display strong unsymmetric flowfields. The analysis is focused on the throat region, where these effects are stronger, in order to indicate the causes of the flow behavior and provide qualitative evaluations of its interaction with chemical kinetics, and consequently of their influence on the nozzle performances.

A93-54093
NUMERICAL AND EXPERIMENTAL STUDY ON TWO- AND THREE-DIMENSIONAL SUPERSONIC FLOW FIELD WITH HYDROGEN INJECTION
KAZUHIKO YOKOTA and SHOJIRO KAJI (Tokyo Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1202-1213. refs
(ISABE 93-7118) Copyright

Nonreacting supersonic flow fields with sonic injection are investigated. As regards 2D investigations, three injection methods are examined by numerical analysis. The highest mixing efficiency is obtained by means of parallel injection. But the results show that sufficient mixing efficiencies cannot be obtained by means of any injection method in a 2D flow. As regards 3D investigations, a perpendicular air injection from a finite length slit is examined by experimental measurement and numerical analysis. Two slit angle cases of 90 deg and 45 deg are treated. Flow visualization by Schlieren pictures and 3D measurement of pitot pressure are performed. In addition, a numerical analysis simulating the experimental condition is performed. In the numerical analysis, the main flow air and the injected air are treated as different species. The numerical results fairly agree with the experimental data both qualitatively and quantitatively. All the results show that the 3D flow effect appears when the injection slit is finite, especially near the slit ends. It is concluded that the three-dimensionality of the flow enhances mixing. Author (revised)

A93-54099
CHARACTERISATION OF CONVENTIONAL AND CONTROLLED DIFFUSION STATOR BLADES IN A TRANSONIC COMPRESSOR STAGE
Q. H. NAGPURWALA, B. R. PAI, and S. A. GURUPRASAD (National Aerospace Lab., Bangalore, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1263-1271. refs
(ISABE 93-7124) Copyright

This paper describes the design and performance evaluation of a controlled diffusion aerofoil (CDA) stator in a transonic axial compressor stage. The overall and blade element performance, determined experimentally, as well as the results of computational flow analysis are compared with those obtained with a NACA double circular arc (DCA) stator tested with the same transonic rotor. The design of the CDA stator, having a low loading level similar to the conventional DCA stator, was based upon a geometric procedure, initially developed by Lubenstein, et al. (1984) but built into a suitable FORTRAN program during the present investigations. The surface Mach number profiles on CDA stator clearly indicated forward loading and were typical of this class of aerofoils confirming the applicability of this geometric procedure for the design of CDA blading. Author (revised)

A93-54105
AERODYNAMICS OF TURBINE BLADES WITH TRAILING-EDGE DAMAGE - MEASUREMENTS AND COMPUTATIONS
S. A. SJOLANDER, D. ISAACS, and W. A. KLEIN (Carleton Univ., Ottawa, Canada) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1327-1334. Research supported by GasTOPS, Ltd. and Univ. Research Incentives Fund of Ontario refs
(ISABE 93-7130) Copyright

The effect of trailing-edge damage on the aerodynamics of turbine blades is examined experimentally and computationally. The work is related to engine health monitoring. Measurements have been made in a low-speed large-scale cascade which includes one blade with a semi-circular cutout to simulate trailing-edge damage. The blade losses and trailing-edge deviation were measured for cutouts of 15 and 25 percent of the blade chord and the incidence was varied through a range of +/- 10 degrees around the design value. The flow-turning ability of the blade was found to be affected more than its total pressure losses. The same flow was also modelled using the three-dimensional Navier-Stokes code of Dawes, with encouraging results.

A93-54266
SEPARATION PHENOMENON IN A HYPERSONIC FLOW WITH STRONG WALL COOLING - SUBCRITICAL REGIME
C. N. ZHIKHAREV (TsAGI, Zhukovski, Russia) Theoretical and Computational Fluid Dynamics (ISSN 0935-4964) vol. 4, no. 5 1993 p. 209-226. refs
Copyright

This paper is concerned with a hypersonic flow past a cooled curved wall. The separation phenomenon at high Reynolds numbers is described using an interactive boundary-layer approach. For a problem of this type, a distinction must be made between two regimes subject to whether the global interaction between the boundary layer and the external flow is strong or weak. This depends on a hypersonic interaction parameter chi is approximately equal to MeRe exp -1/2: if chi is small, the interaction is weak; if it is large, the interaction is strong. The present study is applied to a flow with a weak global interaction regime when chi goes to 0. There are three principal motivations for the study. First, the problem of hypersonic boundary-layer separation is obviously of great practical interest. Second, the desire to demonstrate that marginal separation theory may be successfully applied to the description of a hypersonic flow separation. Third, there is interest in verifying the theoretical prediction by Smith (1988) of a local breakdown or stall occurring in any interactive boundary-layer solution at a finite value of the controlling parameter. Author (revised)

A93-54314
STUDY ON FLOW FIELD AROUND SLENDER DIAMOND CONE TRAVELING AT HYPERSONIC SPEED
MASATOMI NISHIO and MUTSUO KOTAKE Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 562 June 1993 p. 1925-1931. In JAPANESE refs
Copyright

This paper proposes a method to analyze the flow field around a slender diamond cone traveling at hypersonic speed. We used the equivalence principle to analyze the problem. In order to apply the equivalence principle, we assumed that the flow field around a slender diamond cone traveling at hypersonic speed coincides with the two-dimensional unsteady flow field around a diamond shape body expanding at a constant rate. Using conformal mapping, we solved the flowfield to satisfy the boundary condition around the expanding body. Using this analysis, the velocity distribution and the streamline around the body became clear. Consequently, we obtained the flow field around a slender diamond cone traveling at hypersonic speed. Author (revised)

A93-54324* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
MIXING OF MULTIPLE JETS WITH A CONFINED SUBSONIC CROSSFLOW
JAMES D. HOLDEMAN (NASA, Lewis Research Center, Cleveland, OH) Progress in Energy and Combustion Science (ISSN 0360-1285) vol. 19, no. 1 Feb. 1993 p. 31-70. refs
Copyright

An account is given of experimental and computational results on the mixing of single, double, and opposed rows of jets characterized by an either isothermal or variable temperature mainstream in a confined subsonic crossflow; these flow configurations are typical of gas turbine combustor dilution chambers. It is established that the momentum-flux ratio is the most significant flow variable. Combinations of flow and geometry yielding optimum mixing were identified from experimental and computational results. The orifice spacing and momentum-flux relationships affected jet structure, which was significantly different between jets injected from the inner wall of a turn and those injected from the outer wall. AIAA

A93-54347
THE FLUID PHYSICS OF PARACHUTE INFLATION
CARL W. PETERSON (Sandia National Labs., Albuquerque, NM) Physics Today (ISSN 0031-9228) vol. 46, no. 8, pt. 1 Aug. 1993 p. 32-39. Research supported by DOE refs
Copyright

The physics of the motion of the parachute and the surrounding air as the parachute emerges from the payload, inflates and decelerates the payload is described. An attempt is made to model the important event numerically to enable parachute designers to use computers instead of trial-and-error flight tests. It is noted that the complexity of the parachute inflation problem suggests that the development of parachute inflation technology will not be completed soon. AIAA

03

AIR TRANSPORTATION AND SAFETY

Includes passenger and cargo air transport operations; and aircraft accidents.

A93-54288
ARCTIC ENVIRONMENT - HELICOPTER OPERATIONS IN COLD CLIMATES

TORE SKAAR (Royal Norwegian Air Force, Bardufoss Air Station, Norway) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 1.1-1.11.
Copyright

Difficulties associated with helicopter operations in the Arctic environment are described using the Norwegian experience from missions to the Arctic Islands of Svalbard. Different phases of a flight in severe climate conditions including preflight, start-up and take off, en route, and approach and landing are considered.
AIAA

A93-54289
OPERATING HELICOPTERS IN A DEMANDING ENVIRONMENT - MOUNTAIN FLYING/HIGH EVALUATIONS
TONY LOETSCHER (Swissair, Zurich, Switzerland) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 2.1-2.5.
Copyright

Dangers associated with mountain flying are discussed focusing on helicopter performance at increased altitude, the mountain winds effect, optical illusions, avalanches, rock falls, glaciers, power cable and lift lines. It is concluded that the state-of-the-art helicopters equipped with a hoist winch are capable to hover at high altitudes and to conduct air rescues at any slope in the Alps. AIAA

A93-54290
ROYAL NAVY HELICOPTER OPERATIONS IN THE MARITIME ENVIRONMENT
PAUL G. MILLER (Ministry of Defence, Directorate of Naval Warfare, London, United Kingdom) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 3.0-3.7. refs
Copyright

The current status of Royal Navy helicopters and particular areas of operational concern and technical challenge are considered. Particular attention is given to environmental conditions for launch and recovery, landing and recovery aids, helicopter reliability, and future trends in the development of the Merlin helicopter. AIAA

A93-54291
ENVIRONMENTAL EFFECTS OF OPERATIONS DURING DESERT SHIELD/DESERT STORM
JAMES A. RAY (U.S. Army, Aviation Systems Command, Saint Louis, MO) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 4.1-4.8.
Copyright

The environmental problems, the initiatives taken during the Operation Desert Shield/Desert Storm, and the overall results of these efforts are discussed. The Operation Desert Shield/Desert Storm employs about 9000 aircraft with about a fourth of these aircraft involved in southwest Asia operations. This vast deployment and sustainment mission within the severe desert environment represented both a significant challenge to the technology as well as to the support systems. The operational readiness rates were much higher during this operation than in peacetime. AIAA

A93-54293
ROYAL AIR FORCE SUPPORT HELICOPTERS - NIGHT OPERATIONS
R. A. FORSYTHE (RAF Odiham, Basingstoke, United Kingdom) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 6.1-6.6.
Copyright

The night capabilities of the Royal Air Force battlefield helicopter are reviewed. The use of night vision goggles complements the conventional skills of an aircrew and makes it possible to significantly increase the night capabilities. It is concluded that though modern technology has made considerable progress with the introduction of image intensifiers and thermal images, the main problems remain to be associated with human factors and realistic training. AIAA

04

AIRCRAFT COMMUNICATIONS AND NAVIGATION

Includes digital and voice communication with aircraft; air navigation systems (satellite and ground based); and air traffic control.

A93-52881 National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
PASSIVE RANGE ESTIMATION FOR ROTORCRAFT LOW-ALTITUDE FLIGHT
B. SRIDHAR, R. SUORSA, and B. HUSSIEN (NASA, Ames Research Center, Moffett Field, CA) Machine Vision and Applications (ISSN 0932-8092) vol. 6 1993 p. 10-24. Previously announced in STAR as N92-10003 refs
(Contract RTOP 505-66-11)
Copyright

The automation of rotorcraft low-altitude flight presents challenging problems in control, computer vision and image understanding. A critical element in this problem is the ability to detect and locate obstacles, using on-board sensors, and modify the nominal trajectory. This requirement is also necessary for the safe landing of an autonomous lander on Mars. This paper examines some of the issues in the location of objects using a sequence of images from a passive sensor, and describes a Kalman filter approach to estimate the range to obstacles. The Kalman filter is also used to track features in the images leading to a significant reduction of search effort in the feature extraction step of the algorithm. The method can compute range for both straight line and curvilinear motion of the sensor. A laboratory experiment was designed to acquire a sequence of images along with sensor motion parameters under conditions similar to helicopter flight. Range estimation results using this imagery are presented.

A93-53172
A VISION-BASED METHOD FOR AUTONOMOUS LANDING
HUSEYIN H. YAKALI and DANIEL RAVIV (Florida Atlantic Univ., Boca Raton) *In* Mobile robots VI; Proceedings of the Meeting, Boston, MA, Nov. 14, 15, 1991 Bellingham, WA Society of Photo-Optical Instrumentation Engineers 1992 p. 205-216. refs
Copyright

This paper presents eight visual cues to be used as part of a control loop for autonomous landing. The idea is based on fixating the camera at the vanishing point of the projection of the runway in the image. 2-D geometrical cues are used to derive the visual cues. The visual cues that are extracted are the relative location of the camera to the runway in terms of the runway width, orientation of the camera, and relevant angles such as glide slope angle.

A93-53603
A REACTIVE APPROACH FOR DISTRIBUTED AIR TRAFFIC CONTROL
KARIM ZEGHAL (ONERA, Chatillon; Paris VI, Univ., France) and JACQUES FERBER (Paris VI, Univ., France) ONERA, TP no. 1993-83 1993 11 p. International Conference on Artificial Intelligence, Expert Systems, and Natural Language, 13th, Avignon, France, May 24-28, 1993 refs
(ONERA, TP NO. 1993-83)

In this paper, we explore a fully decentralized approach for air traffic, which allows to define the principle of a ground-based air traffic control system as well as the logic of an airborne collision avoidance system. The distributed conflict resolution mechanism we present is based on symmetrical force fields method, which

allows an efficient coordination of avoiding actions. Experimental results highlight the reliability of the conflict resolution method. As opposed to prior approaches used in Robotics or in distributed AI to solve the coordination problem, this mechanism requires no communication or negotiation between agents. In the view of a ground-based system, we also propose the principle of a distributed implementation of the resolution mechanism, which made the system highly tolerant to processors losses.

A93-53604
CRAASH - A COORDINATED COLLISION AVOIDANCE SYSTEM
KARIM ZEGHAL (ONERA, Chatillon; Paris VI, Univ., France) and JACQUES FERBER (Paris VI, Univ., France) ONERA, TP no. 1993-84 1993 6 p. ESM'93, Lyon, France, June 7-9, 1993 refs
(ONERA, TP NO. 1993-84)

This paper defines the logic of an airborne collision avoidance system based on symmetrical force field methods. The mechanism ensures the avoidance of any forms of intruders and particularly, it coordinates the avoidance actions between aircraft equipped with this collision avoidance system. As opposed to prior approaches used in robotics or in distributed AI, this coordination model requires no communication or negotiation between aircraft. Experimentation has highlighted the coordination mechanism resilience or reliability in high intruder density and high dynamics conditions. This approach also depicts the principle of a distributed air traffic control system.

A93-53866
FAULT TOLERANT NAVIGATION FOR AIRCRAFT LANDING
HAN-GUO ZHANG and HONG-YUE ZHANG (Beijing Univ. of Aeronautics and Astronautics, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A104-A108. In CHINESE refs

This paper studies a sensor fault-tolerant system for an aircraft in a microwave landing system environment. The objective of the fault tolerant system is to detect failures in navigation aid instruments and on-board sensors and to provide reliable estimates for the aircraft states in the possible presence of these sensor malfunctions. A failure detection and isolation algorithm is used to detect and isolate the navigation aid instrument failures. The nonlinear filtering technique using separated-bias estimation is used to generate the state estimation of the aircraft. State estimates are used by an automatic guidance and control system to land the aircraft along a prescribed path. Author (revised)

05

AIRCRAFT DESIGN, TESTING AND PERFORMANCE

Includes aircraft simulation technology.

A93-52691#
A RAPID PROTOTYPING SYSTEM FOR INFLIGHT SIMULATION USING THE CALSPAN LEARJET 25
S. A. BUETHE and P. R. DEPPE (Calspan Corp., Buffalo, NY) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 320-323.
(AIAA PAPER 93-3606) Copyright

Inflight simulations of new aircraft and/or flight control systems often require considerable preparation time and expense. Our objective was to develop a new inflight simulator with a 'quick response' capability. The Calspan Learjet 25 inflight simulator has been upgraded to meet this objective through implementation of a graphical block diagram programming system with automatic code generation. The simulation code is targeted to a set of floating point digital signal processors (DSP) which operate in parallel. The system is designed to be capable of full flight-envelope partial model-following and employs new features to reduce checkout and calibration time. These include computer-flown test input sequences and on-line parameter identification. This paper describes the aircraft, its software development system, real-time computer hardware, user interface, and advanced inflight simulation and calibration methods. A 'quick response' inflight simulation capability is now available to the aerospace industry which may be used as a tool in the development of new aircraft and flight control systems.

A93-52937
NONLINEAR DEFORMATION MECHANICS OF MULTILAYER TRANSPARENCY ELEMENTS - SOME CALCULATION RESULTS [NELINEJNAYA MEKHANIKA DEFORMIROVANIYA MNOGOSLOJNYKH EHLEMENTOV OSTEKLENIJ - NEKOTORYE REZUL'TATY RASCHETOV]
A. I. KALASHNIKOV, V. I. PAJMUSHIN, and V. A. FIRSOV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 3-5. In RUSSIAN
Copyright

Solutions are presented for a series of problems concerned with the stress-strain state of multilayer aircraft transparencies. The effect of the geometrical and physical nonlinearity of the problems on the solution results is estimated. Attention is also given to the effect of the deformability of the fastening elements on the stress-strain state of a multilayer porthole. AIAA

A93-52954
ESTIMATION OF THE EFFECT OF THE LONGITUDINAL MOMENT DUE TO THE ENGINE THRUST ON THE MASS OF A SUBSONIC PASSENGER AIRCRAFT [OTSENKA VLIYANIYA PRODOL'NOGO MOMENTA OT TYAGI DVIGATELEJ NA MASSU DOZVUKOVOGO PASSAZHIRSKOGO SAMOLETA]
V. P. GOGOLIN Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 72-74. In RUSSIAN refs
Copyright

An analysis is presented which demonstrates the importance of considering changes in the longitudinal moment due to the engine thrust when changing the location of engines on an aircraft. Thus, changes in the longitudinal moment should be considered in addition to changes in the mass of the wing, mass of the fuselage, drag coefficient, and lifting force when relocating the engines from the fuselage to the wing. A hypothetical passenger aircraft with characteristics similar to those of the Tu-154 aircraft is examined as an example. AIAA

A93-53405
INNOVATIVE BAGGING TECHNIQUES ON A COMPOSITE P-51 MUSTANG REPLICA
MURDO CAMERON (Flight Training Devices, Gardena, CA), RAY CULL (Dow Corning Corp., Midland, MI), and BRUCE MENK (KR Anderson, Santa Ana, CA) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T366-T374.
Copyright

An account is given of the innovative mold-bagging techniques that are being used to fabricate the two fuselage halves of a composite fighter-replica aircraft. The bag was formed by means of a new castable, a high-tear strength translucent silicone elastomer that is applied directly to the mold tool; reinforcing fabric is employed to improve the durability of the bag, which is 10 m in length and 3 m in width; its structure forms not only the fuselage shell, but its longerons and engine mounts, as well. The bag's castable silicone elastomers cure at room temperature. AIAA

A93-53721
ANALYSIS OF SPATIAL MOTION DYNAMICS OF A HELICOPTER FOR VARIOUS MODELS OF THE INDUCED VELOCITY FIELD
Z. DZYGADLO and G. KOWALECZKO (Military Univ. of

Technology, Warsaw, Poland) Journal of Technical Physics (ISSN 0324-8313) vol. 34, no. 2 1993 p. 119-143. refs
Copyright

Problems of dynamics of spatial motion of a helicopter are considered making use of the three models of induced velocity field over the region of the main rotor, which are known from the literature. They are: the uniform velocity distribution and the Glauert and Mangier-Squire models, in which the velocity depends on the azimuth and the radius. The natural motions of the helicopter have been studied for the three models of induced velocity mentioned above, the couplings between the longitudinal and lateral motions being and being not taken into consideration.

A93-53769* National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Facility, Edwards, CA.
FLIGHT RESEARCH SIMULATION TAKES OFF
LAWRENCE J. SCHILLING and DALE A. MACKALL (NASA, Flight Research Center, Edwards, CA) Aerospace America (ISSN 0740-722X) vol. 31, no. 8 Aug. 1993 p. 18-21.
Copyright

The simulation configurations used in research flight test, including nonreal-time, real-time all-software, hardware-in-the-loop, iron bird, and aircraft-in-the-loop, are reviewed. It is concluded that progress in simulation technology will demonstrate new concepts, evaluate designs, enhance the quality of flight test, and minimize flight risks. AIAA

A93-53771
ENGINEERING SIMULATORS ENHANCE 777 DEVELOPMENT
DON BROOKS (Boeing Co., Seattle, WA) Aerospace America (ISSN 0740-722X) vol. 31, no. 8 Aug. 1993 p. 30-32, 41.
Copyright

A new approach to the use of engineering simulators in the new airplane's flight deck design and in its crew interface validation is described. The approach is based on two simulators: the first is dedicated to flight deck development and design, and the second is an integration device with the flexibility to support development. An engineering simulator that is placed in service 50 months ahead of certification and in-context evaluations and exhaustive airline reviews enable the 777 flight deck engineering team to get the design correct the first time. AIAA

A93-53772
REMOVING THE RISK FROM ROTORCRAFT TESTING
MICHAEL FERRANTI (Sikorsky Aircraft, Stratford, CT) Aerospace America (ISSN 0740-722X) vol. 31, no. 8 Aug. 1993 p. 34-37.
Copyright

Full mission simulations aimed at testing high-risk rotorcraft designs in low-risk environments are discussed which are based on engineering development simulation (EDS) as a support tool. The networked simulations complement operational test and evaluation by testing contract exit criteria, evaluating proposed flight test profiles prior to actual flight test, and enabling crews to design the proper tactics, techniques, and procedures for new weapons systems before the aircraft is built. AIAA

A93-53874
INTERCONVERSION OF TWO KINDS OF METHODS FOR CABIN LEAKAGE TEST
QIN-FANG YU (Nanjing Aeronautical Inst., China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 2 Feb. 1993 p. B47-B51. In CHINESE refs

There are two kinds of methods for the cabin leakage test: the flow-rate method and the pressure-drop method. The pressure drop method is simple, but leakage rates cannot be directly read out. If leakage rates should be determined, an interconversion relationship would be used. In this paper, the interconversion of the two kinds of methods for the cabin leakage test is established. Leakage rates can be calculated from the method of the pressure drop test, and the time of pressure drop can be calculated from the method of the leakage rate test. The application to the cabin leakage test is discussed. Charts are established for practical use.

A93-54077
WIND TUNNEL TESTS OF THE MODEL OF INTAKE-AIRFRAME INTEGRATION
TAKESHI ITO, AKIRA MURAKAMI, SHIGEMI SHINDO, KIMIO SAKATA, JUNNICHI NODA (National Aerospace Lab., Tokyo, Japan), ATSUSHIGE TANAKA, and KAZUO SHIRAISHI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1033-1041. refs
(ISABE 93-7101) Copyright

A series of Mach 3 tests of the model for the intake-airframe integration problem was performed in NAL's M4 supersonic wind tunnel, and the data were analyzed aerodynamically. The model of the air-intake with diverter was installed on the bottom surface of the airframe which was designed for Mach 3 flight. Schlieren method and oil-flow technique were applied for considering the flow structure around and on the model. Some qualitative and quantitative considerations on the effects of the existence of the air-intake to the airframe aerodynamic coefficients were made clear, and influence of the forebody boundary layer to the air-intake was also analyzed. Some recommendations for future study were made. Author (revised)

06

AIRCRAFT INSTRUMENTATION

Includes cockpit and cabin display devices; and flight instruments.

A93-52994
SENSORS WITH CENTROID BASED COMMON SENSING SCHEME AND THEIR MULTIPLEXING
E. BERKCAN, J. TEIMANN, and G. BROOKSBY (GE Corporate Research and Development Center, Schenectady, NY) *In* Fiber optic and laser sensors X; Proceedings of the Meeting, Boston, MA, Sept. 8-11, 1992 Bellingham, WA Society of Photo-Optical Instrumentation Engineers 1993 p. 362-370. refs
Copyright

The ability to multiplex sensors with different measurands but with a common sensing scheme is of importance in aircraft and aircraft engine applications; this unification of the sensors into a common interface has major implications for weight, cost, and reliability. A new class of sensors based on a common sensing scheme and their E/O Interface has been developed. The approach detects the location of the centroid of a beam of light; the set of fiber optic sensors with this sensing scheme include linear and rotary position, temperature, pressure, as well as duct Mach number. The sensing scheme provides immunity to intensity variations of the source or due to environmental effects on the fiber. A detector spatially multiplexed common electro-optic interface for these sensors has been demonstrated with a position and a temperature sensors.

A93-53876
INTEGRATED FIRE CONTROL SIMULATION SYSTEMS
JIAN-HUA ZHANG, YONG WU, PEI-SHEN ZHU, and GUAN-ZHONG DAI (Northwestern Polytechnical Univ., Xian, China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 2 Feb. 1993 p. B59-B65. In CHINESE refs

Integrated Fire Control Systems (IFCS) is a program to explore and exploit digital concepts in the integration of avionic systems. Because of such considerations as cost equipment etc., the signal emulation and structure of IFCS are emphasized. The main work is summarized as follows: mimic ADC, INS, RAD, and BU can be

established by a method called static true value plus sensor noise. In order to simulate attacker flight dynamics in the air combat without a pilot, a fuzzy controller is employed to form a pilot-aircraft-fire control system loop, which simplifies the scheme and lowers the cost. An introduction to attack modes in MC is presented. A scheme is put forward for designing a symbol generator of HUD. The implementation development of MIL-STD-1553B data is also considered. Author (revised)

A93-54294
AVIONIC SYSTEMS IN SUPPORT OF COVERT HELICOPTER OPERATIONS
JERRY F. FISHER (GEC Avionics, Ltd., Airport Works, Rochester, United Kingdom) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 7.1-7.3.
Copyright

Covert avionics mission systems for battlefield helicopters capable of operating day and night in poor weather conditions without being detected or jammed are described. A covert mission system integrates a range of capabilities including a night vision system, day/night targeting, autonomous navigation, defensive ESM and ECM, air-to-ground weapon delivery, and air-to-air weapon delivery. The integration of these systems, both electronically and in the cockpit, is the factor which will determine the success of the system. AIAA

07

AIRCRAFT PROPULSION AND POWER

Includes prime propulsion systems and systems components, e.g., gas turbine engines and compressors; and on-board auxiliary power plants for aircraft.

A93-52949
ESTIMATION OF THE CHANGE OF AXIAL-FLOW COMPRESSOR CHARACTERISTICS DURING LONG-TERM SERVICE [OTSENKA DEFORMATSII KHARAKTERISTIK OSEVOGO KOMPRESSORA V USLOVIYAKH DLITEL'NOJ EHKSPLUATATSII]
D. V. BELYAEV, EH. R. PIKULA, and V. S. TALYZINA Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 50-54. In RUSSIAN refs
Copyright

Results of experimental studies of changes in the parameters of plane compressor cascades due to erosion wear are reported. To predict changes in the characteristics of multistage axial-flow compressors due to the erosion wear of the blades, a correction is introduced into a two-dimensional axisymmetric mathematical model for calculating flow in the blade passage. As an example, calculations are presented for an axial-flow compressor in which the blade geometry has been modified and the radial clearance increased to simulate the erosion wear. AIAA

A93-52963
THE COMBINED EFFECT OF CLEARANCES AND PERIPHERAL OVERLAPS ON THE EFFICIENCY OF MICROTURBINES WITH SHROUDLESS ROTORS [SOVMESTNOE VLIYANIE ZAZOROV I PERIFERIJNOJ PEREKRYSHI NA EHFFEKTIVNOST' MIKROTURBIN S RABOCHIMI KOLESAMI BEZ BANDAZHA]
B. A. KRYLOV and S. A. GUSAROV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 103-107. In RUSSIAN refs
Copyright

Experimental data are presented on the combined effect of the upper overlap and of the axial and radial clearances on the efficiency of axial-flow microturbines with shroudless rotors. It is found that the effect of the upper overlap on the efficiency of microturbines with shroudless rotors is substantial and varies depending on the relative area of the radial clearance. Expressions are obtained for calculating the optimal upper overlap with allowance for the clearances. AIAA

A93-52965
ESTIMATION OF THE PARAMETERS OF THE ELECTRODYNAMIC SYSTEM ENGINE-EXHAUST JET [OTSENKA PARAMETROV EHLEKTRODINAMICHESKOJ SISTEMY DVIGATEL'-VYKHLOPNAYA STRUYA]
G. P. POTAPOV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 109-112. In RUSSIAN refs
Copyright

Some analytical expressions are derived which relate the parameters of the electrodynamic system nozzle-exhaust to the thermogasdynamic parameters of the working medium of an engine. These relations can be used for developing new passive diagnostics systems and for refining the existing methods of diagnostics using the electrophysical properties of the working medium. AIAA

A93-53554
SELECTION OF A METHOD FOR PROTECTING AIRCRAFT GAS TURBINE ENGINES AGAINST DAMAGE BY FOREIGN OBJECTS (MATHEMATICAL MODELS) [VYBOR METODA ZASHCHITY AVIATSIONNYKH GTD OT POVREZHDENIJ POSTORONNIMI PREDMETAMI /MATEMATICHESKIE MODELI/]
N. V. VASHCHENKO TsIAM, Trudy no. 1233 1989 p. 6-11. In RUSSIAN refs
Copyright

A classification of methods for protecting aircraft gas turbine engines against damage by foreign objects is presented. The problem of selecting a particular engine protection method is formulated, and mathematical models for solving the problem are developed in terms of stochastic and linear programming. A stochastic model for the selection of a protection method is developed both for the initial selection and for selection at the stage of modernization. AIAA

A93-53589*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
INITIAL RESULTS FROM THE NASA LEWIS WAVE ROTOR EXPERIMENT
JACK WILSON (Sverdrup Technology, Inc., Lewis Research Center Group, Brook Park, OH) and DENNIS FRONEK (NASA, Lewis Research Center, Cleveland, OH) Jun. 1993 10 p. AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference and Exhibit, 29th, Monterey, CA, June 28-30, 1993 Previously announced in STAR as N93-32368 refs
(AIAA PAPER 93-2521) Copyright

Wave rotors may play a role as topping cycles for jet engines, since by their use, the combustion temperature can be raised without increasing the turbine inlet temperature. In order to design a wave rotor for this, or any other application, knowledge of the loss mechanisms is required, and also how the design parameters affect those losses. At NASA LeRC, a 3-port wave rotor experiment operating on the flow-divider cycle, has been started with the objective of determining the losses. The experimental scheme is a three factor Box-Behnken design, with passage opening time, friction factor, and leakage gap as the factors. Variation of these factors is provided by using two rotors, of different length, two different passage widths for each rotor, and adjustable leakage gap. In the experiment, pressure transducers are mounted on the rotor, and give pressure traces as a function of rotational angle at the entrance and exit of a rotor passage. In addition, pitot rakes monitor the stagnation pressures for each port, and orifice meters measure the mass flows. The results show that leakage losses are very significant in the present experiment, but can be reduced considerably by decreasing the rotor to wall clearance spacing.

A93-53702
LOW-FREQUENCY COMBUSTION OSCILLATIONS IN A MODEL AFTERBURNER

M. A. MACQUISTEN and A. P. DOWLING (Cambridge Univ., United Kingdom) Combustion and Flame (ISSN 0010-2180) vol. 94, no. 3 Aug. 1993 p. 253-264. Research supported by Rolls-Royce, PLC and Ministry of Defence Procurement Executive of United Kingdom refs
Copyright

Low-frequency combustion oscillations, involving the interaction between longitudinal acoustic waves and unsteady combustion, are investigated for a model afterburner. An experimental rig, in which a confined flame is stabilized in the wake of a conical gutter, is run with inlet conditions representative of an engine afterburner. Results are presented for inlet Mach numbers in the range of 0.15-0.27, with inlet temperatures up to 630 K. Comparison is made between theory and experiment. Although the theory was developed from low Mach number data, it is found to apply equally well at these faster flow rates. The theory is able to predict the frequency of the instability and the mode shape, accurately reproducing the changes due to variations in the inlet Mach number and temperature. The effect of altering the downstream boundary condition by replacing the open end by a choked nozzle is also investigated. Such a change is found to be highly destabilizing, both experimentally and theoretically. Again, predictions from the theory are in good agreement with the observations.
Author (revised)

A93-53862
A STUDY OF SURGE CONTROL BY USING PULSE CUT-OFF FOR DUAL SPOOL TURBO-JET ENGINE
JIAN-GUO SUN, SI-MING HU (Nanjing Aeronautical Inst., China), CAI-HONG JIANG, and WAN-FENG SUN (Shenyang Aeroengine Research Inst., China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 1 Jan. 1993 p. A85-A89. In CHINESE refs

A dynamic model of dual-spool turbojet engine with post-stall capability is used. By utilizing this model, the surge is successfully induced by opening nozzle, main combustor fuel-step, and throttling nozzle. The simulation results are coincident with test results obtained from the literature. The above dynamic model is adopted to simulate surge operation induced by opening nozzle, and the mechanism of surge control of fuel pulse cut-off (FPCO) for dual-spool turbojet engine is investigated by computer simulations. The effect of parameters of FPCO on surge control is analyzed. Some guidelines of the surge-control design for dual-spool turbojet engines are brought forward. Author (revised)

A93-53976
ISABE - INTERNATIONAL SYMPOSIUM ON AIR BREATHING ENGINES, 11TH, TOKYO, JAPAN, SEPT. 20-24, 1993, PROCEEDINGS. VOLS. 1 & 2
FREDERICK S. BILLIG, ED. (Johns Hopkins Univ., Laurel, MD) Washington American Institute of Aeronautics and Astronautics 1993 p. Vol. 1, 737 p.; vol. 2, 677 p. For individual items see A93-53977 to A93-54109
(ISBN 1-56347-071-3) Copyright

Various papers on air-breathing engines are presented. The general topics addressed include: stall and surge, hypersonic propulsion systems, combustion, turbomachinery flows, fluid mechanics problems, supersonic combustion, structure problems, supersonic transport, mixing, heat transfer problems, engine simulation and control, axial turbines, integration, inlets, nozzles, and engine condition monitoring. AIAA

A93-53978
THE CHALLENGE OF IHPTET
RICHARD J. HILL (USAF, Wright Lab., Wright-Patterson AFB, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 12-18.
(ISABE 93-7001) Copyright

The goals, status, challenges, and future of the IHPTET (Integrated High Performance Turbine Engine Technology) initiative are discussed. The time phases of the IHPTET goals are shown. The ways in which IHPTET can meet new DOD science and technology policy goals are addressed, and steps that need to be taken to assure rapid acceptance of IHPTET are considered. Attention is given to the development and application of advanced aerodynamic and thermodynamic models and theories, the creation of innovative structural designs, and the development and application of advanced high-strength low-density materials.
AIAA

A93-53979
DESIGN AND TECHNOLOGY FOR ENGINE MANUFACTURE
T. BROUGHTON (Rolls-Royce, PLC, Derby, United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 19-25.
(ISABE 93-7002) Copyright

The use of simultaneous engineering to optimize the use of innovative technology in the manufacture of aerogas turbines is demonstrated. It is shown that all the elements of the engineering process can be developed to achieve fast and economic engine design and development through simultaneous engineering aided by computer integration. Examples of successful implementation are given. AIAA

A93-53980 National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
PROPULSION TECHNOLOGY CHALLENGES FOR TURN-OF-THE-CENTURY COMMERCIAL AIRCRAFT
JOSEPH A. ZIEMIANSKI and CALVIN L. BALL (NASA, Lewis Research Center, Cleveland, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 26-37. Previously announced in STAR as N93-32351 refs
(Contract RTOP 505-62-10)
(ISABE 93-7003) Copyright

This paper highlights the efforts being performed or sponsored by NASA, in cooperation with the U.S. civil aviation industry, to address the propulsion system technological challenges that must be met in order to ensure a viable future for the industry. Both the subsonic and supersonic aeropropulsion programs are considered. Subsonic transport propulsion program elements, including ultra-high-bypass-ratio turbofans with attendant noise reduction efforts, high-efficiency cores, and combustor emissions reductions are discussed in terms of goals, technical issues, and problem solutions. Similarly, the high-speed research propulsion efforts addressing a high-speed commercial transport are reviewed in terms of environmental barrier issues, such as oxides of nitrogen and noise reduction, and the related economic issues.

A93-53981
JAPAN'S RESEARCH AND DEVELOPMENT PROGRAM FOR AIRBREATHING ENGINE TECHNOLOGIES
HIROYUKI NOUSE (National Aerospace Lab., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 41-49. refs
(ISABE 93-7005) Copyright

The current status and future directions of some Japanese research and development programs related to air-breathing engine technologies are briefly discussed. The technologies considered include an ultrahigh bypass ratio engine, an air turbo ramjet engine, a super/hypersonic transport propulsion system, and a subscale scramjet engine and test facility. AIAA

A93-53991
MACH 5 TURBORAMJET REQUIREMENTS AND DESIGN APPROACH
WILLIAM L. WEBB and JAMES D. HILL (Pratt & Whitney Group, West Palm Beach, FL) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993,

Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 149-158. refs
(ISABE 93-7015) Copyright

The unique mission requirements of Mach 5 hypersonic aircraft propulsion systems are summarized and related to engine configuration. The appropriate materials for meeting the requirements are considered along with the requirements regarding inlet cooling, accelerator cooling, ram combuster cooling, nozzle cooling, the liner system, and NO(x) requirements. The ram combustor configurations are discussed. AIAA

A93-53992
DEVELOPMENT STUDY ON AIR TURBO RAMJET ENGINE FOR A FUTURE SPACE PLANE

NOBUHIRO TANATSUGU, YOSHIHIRO NARUO, TETSUYA SATO (Inst. of Space and Astronautical Science, Sagamihara, Japan); ITARU ROKUTANDA (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), and MASAHIRO UCHIDA (Kawasaki Heavy Industries, Ltd., Kobe, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 159-172. refs
(ISABE 93-7016) Copyright

An analytical and experimental study of the Air Turbo Ramjet (ATR) propulsion system for the two-stage-to-orbit launch system is discussed. The ATR engine cycles using liquid hydrogen as fuel are analyzed, including design criteria and engine performance characteristics. Test results of the 1/4-scale ATR engine with fan inlet diameter of 300 mm and overall length of 2200 mm are reported, including sea level static tests and test results on the tip turbine, combustor, heat exchanger, and engine operation. Wind tunnel results on the air intake with precooler are also reported. AIAA

A93-53994
CONCEPTUAL DESIGN STUDY ON COMBINED-CYCLE ENGINE FOR HYPERSONIC TRANSPORT

Y. WATANABE, H. MIYAGI, T. SEKIDO, H. MIYAGAWA (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), F. TANAKA (Kawasaki Heavy Industries Co., Ltd., Kobe, Japan), T. AOKI (Mitsubishi Heavy Industries Co., Ltd., Tokyo, Japan), M. MORITA, and R. YANAGI (National Aerospace Lab., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 188-197. Research supported by Agency of Industrial Science and Technology of Japan refs
(ISABE 93-7018) Copyright

The engine of the Hypersonic Transport Propulsion System Research Project, which is a combined-cycle engine composed of a turboaccelerator for the lower speed range and a ramjet engine for the high speed range, is discussed. The cycle definition of the target engine is described and the method and results of a configuration test are described. The status of the design of the demonstrator engine is addressed. AIAA

A93-53995
ENERGY MANAGEMENT

J. VANDENKERCKHOVE (*VDK System, S.A., Brussels, Belgium*) and M. BARRERE (ONERA, Chatenay-Malabry, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 198-212.
(ISABE 93-7019) Copyright

The benefits derived from active management of all energetic resources which can be harnessed along the whole vehicle trajectory, beyond the chemical energy of the propellant stored onboard, are assessed. This harnessing is achieved by heating the hydrogen fuel using exchanges located either internally or externally. The issue of active versus passive cooling is examined along with the practical implications of energy transfer mechanisms and inlet geometry. AIAA

A93-53996
AN ULTRA LOW NO(X) PILOT COMBUSTOR FOR STAGED LOW NO(X) COMBUSTION

M. N. KIM, H. S. ALKABIE, and G. E. ANDREWS (Leeds Univ., United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 215-225. Research supported by Department of Cultural Affairs of Iraq, British Council, and Korean Gas Corp refs
(ISABE 93-7020) Copyright

The pilot zone of a multistage stage lean/lean combustor design was investigated with low NO(x) characteristics using radial swirlers with vane passage fuel injection. The pilot was designed to be connected in series to the next stage through the center of a larger radial swirler with a downstream larger combustor can. Comparison was made with central radial outward fuel injection in the pilot and it was shown that vane passage fuel injection had substantially lower NO(x) emissions, comparable with those of the low NO(x) main stages where the fuel injection was around the main swirler exit periphery. The overall stability of a multistage design is controlled by the proportion of air entering the pilot and this was varied by varying the pilot blockage at a constant pressure loss. Very low pilot NO(x) could be achieved at all pilot flow proportions and at maximum power inlet temperatures of up to 900 K. This pilot design could therefore be used with a low NO(x) main combustor with no adverse influence on the combined NO(x), which is a crucial requirement of ultra low NO(x) multistage combustor designs.

A93-53997
LOW NO(X) COMBUSTOR DEVELOPMENT USING AERODYNAMIC STAGING

ASHWANI K. GUPTA (Maryland Univ., College Park) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 226-233. refs
(ISABE 93-7021) Copyright

The results are presented here from a Variable Geometry swirl Combustor (VGC) that is in the form of multiconcentric telescopic arrangement. Parametric studies have shown the important effect of burner geometry and input operational parameters, including coswirl and counterswirl, on NO(x) emission and combustion characteristics. The results show the potential advantages of CFLG (center fuel lean geometry), CFRG (center fuel rich geometry), and PMG geometries for low NO(x) emission. The effect of coswirl or counterswirl on combustion and emission is also found to be significant. Residence time, turbulent mixing, and temperature have a strong effect on NO(x). The amount of NO2 in NO(x) depends upon the availability of O atom concentration and is effected by the turbulence levels and temperature. Author (revised)

A93-53998
THE PREDICTION OF THERMAL NO(X) IN GAS TURBINE EXHAUSTS

G. F. PEARCE (Defence Science and Technology Organisation, Aeronautical Research Lab., Melbourne, Australia), D. KRETSCHMER, J. ODGERS (*Univ. Laval, Quebec, Canada*), and G. WANG (Royal Military College, Kingston, Canada) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 234-243. Research supported by Canadian Panel on Energy Research and Development, Department of Defence of Australia, DND, and NSERC refs
(ISABE 93-7022) Copyright

Using 2,200 data points from 14 different experimental series, an attempt was made to develop an equation suitable for the prediction of the NO(x) found in gas turbine exhausts. Nine different combustors were investigated of a very wide size range. Inlet temperatures and pressures ranged from 290 to 851 K and from 0.1 to 1.4 MPa respectively. Based upon the data pertinent to

typical gas turbine conditions, it is estimated that the repeatability/reproducibility is of the order of +/- 1 EI unit at the low range (at 1 EI unit, 50 percent) and +/- 2 EI units (at 12 EI units, 17 percent) and +/- 3 EI units (at about 30 EI units, 10 percent). The new equation was developed from a previous one which had been found to correlate data satisfactorily, but which could not be used for prediction purposes without the need of some experimental data. Author (revised)

A93-53999* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
EMISSION CHARACTERISTICS OF A MODEL GAS TURBINE COMBUSTOR AT PRACTICAL CONDITIONS
S. A. DRENNAN, W. A. SOWA, and G. S. SAMUELSEN (California Univ., Irvine) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 244-253. Research supported by Northrop Corp. refs
(Contract F08635-90-C-0100; NAG3-1124)
(ISABE 93-7023)

This paper reports on in situ and exit plane emissions measurements from a model gas turbine combustor at practical air preheat temperatures and pressures for a range of operating conditions. The model combustor chosen for the study features two rows of jets (primary and dilution) with four jets per row, and utilizes effusive air cooling holes on the liner wall. The combustor dome is equipped with a flat-vaned swirler with a vane angle of 60 deg. Data are obtained at combustor pressures ranging from 2 to 10 atmospheres, air preheat temperatures from 204 C to 427 C, and combustor reference velocities from 10.0 to 20.0 m/s. An overall equivalence ratio of 0.3 was constant for all conditions. Exit plane and in situ measurements are presented for HC, O2, CO2, CO, and NO(x). The results from exit plane NO(x) measurements illustrate that the model combustor is representative of current gas turbine combustors. The in situ data reveal effects of fuel/air and wall jet mixing on emission performance. Author (revised)

A93-54000
DESIGN AND TESTING METHODS OF HIGH PERFORMANCE COMBUSTORS FOR AIRBREATHING ENGINES
Y. M. TIMNAT (Technion - Israel Inst. of Technology, Haifa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 254-275. refs
(ISABE 93-7024) Copyright

The aim of this paper is to discuss design and testing methods for high performance combustors used in different types of jet engines. The paper starts with a description of research we performed on the subject, treating the following topics: conventional airbreathing combustors, solid fuel ramjet combustion chambers, including the influence of metal additives, slurry fuels for ramjets, and the development of thermal barrier coatings for blades of coal-fired turbines. A number of diagnostic techniques are treated in detail: millisecond response thermo-couples, and a modified line-reversal method for temperature measurements, particle size, and velocity determination by means of LDA and PDA, including a critical comparison of these techniques. We discuss regression rate measurements by photography, ultrasonics, and MWs. The transition from subsonic to supersonic flow in a ramjet combustor, which takes place for a flight Mach number between 5 and 7, is treated. After reviewing the work performed in the U.S., France and Russia, it is shown that further studies are warranted and we propose to build a facility, in which particular attention is paid to the measurement of the regression rate of energetic solid fuels, preferably in collaboration with investigators of other countries. Author (revised)

A93-54003* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
FORCING FUNCTION MODELING FOR FLOW INDUCED VIBRATION
SANFORD FLEETER (Purdue Univ., West Lafayette, IN) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 305-318. Research sponsored by NASA refs
(ISABE 93-7027) Copyright

The fundamental forcing function unsteady aerodynamics for application to turbomachine blade row forced response are considered, accomplished through a series of experiments performed in a rotating annular cascade and a research axial flow turbine. In particular, the unsteady periodic flowfields downstream of rotating rows of perforated plates, airfoils and turbine blade rows are measured with a cross hot-wire and an unsteady total pressure probe. The unsteady velocity and static pressure fields were then analyzed harmonically and split into vortical and potential gusts, accomplished by developing a gust splitting analysis which includes both gust unsteady static pressure and velocity data. The perforated plate gusts closely were found to be linear theory vortical gusts, satisfying the vortical gust constraints. The airfoil and turbine blade row generated velocity perturbations did not satisfy the vortical gust constraints. However, the decomposition of the unsteady flow field separated the data into a propagating vortical component which satisfied these vortical gust constraints and a decaying potential component.

A93-54004
EFFECTS OF BLADE GEOMETRY AND MODE SHAPE ON FAN FLUTTER
A. PETTERSSON (Chalmers Univ. of Technology, Goteborg, Sweden), L. D. G. SIDEN (Volvo Flygmotor AB, Trollhattan, Sweden), and U. HALL (Chalmers Univ. of Technology, Goteborg, Sweden) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 319-331. Research supported by Volvo Flymotor AB refs
(ISABE 93-7028) Copyright

In this paper the VOLFAP flow code is used to predict the flutter behavior of a fan rotor. The sensitivity to changes in mode shape and blade geometry is studied. The effect or blade leading edge cut-back, increased rotor tip stagger and modified part span shroud angle are simulated and compared with results from engine tests. The first two modifications do not show the improved aeroelastic stability that has been experienced in tests. Simulations using an increased part span shroud angle, however, indicate a drastically increased stability as do also engine test results. This can be explained by a changed modal shape.

A93-54008
DESIGN OF HIGH-LOAD AVIATION TURBOMACHINES USING MODERN 3D COMPUTATIONAL METHODS
M. J. IVANOV, V. K. KOSTEGE, V. G. KRUPA, and R. Z. NIGMATULLIN (Central Inst. of Aviation Motors, Moscow, Russia) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 355-365. refs
(ISABE 93-7032) Copyright

This paper presents a modern mathematical simulation of aerodynamic and thermal problems for gas turbine engine components design. Based on the reached level, the nearest phase of numerical simulation includes the development and application of the complex 3D models of multistage turbomachines, and whole flow passage of core and bypass engines. The following important direction of numerical simulation will be the solution of conjugate multidisciplinary problems for the individual components of air breathing engines. The typical example of this problem is the thermal-stressed state of the high-load cooling turbine. The paper presents results of numerical simulation for multicomponent and

multidisciplinary problems. Developing computational codes are based on the high accuracy finite difference and finite element methods and realized on middle-class computers.

Author (revised)

A93-54010
COMPLEMENTARY ROLE OF GROUND TESTING, FLIGHT TESTING, AND COMPUTATIONS IN AEROSPACE PLANE PROPULSION DEVELOPMENT

V. K. III SMITH (Sverdrup Technology, Inc., Arnold AFB, TN) and A. H. BOUDREAU (USAF, Arnold Engineering Development Center, Arnold AFB, TN) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 373-391. refs
(ISABE 93-7034)

The propulsion systems of conceptualized aerospace planes impose test and evaluation requirements which require large technology steps, not merely an evolution of current technology. The deficiencies in hypersonic propulsion test and evaluation methodology, encompassing ground testing, computation/simulation, and flight testing, are addressed, and specific enabling technologies and approaches have been identified. The need for enhancing the traditional approach through the use of an integrated triad of test and evaluation methodology is illustrated with specific propulsion examples. Opportunities for international collaboration to meet the shortfalls are also cited.

A93-54011
CFD FOR RAMJET AND SCRAMJET POWERED VEHICLES

P. GARNERO and C. STYLEMANS (Aerospatiale, Verrieres-le-Buisson, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 392-402. refs
(ISABE 93-7035) Copyright

Aerospatiale has been using ramjets on its missiles for more than thirty years and began high speed air-breathing studies for missiles, combined cycle engines powered aircraft and single or two stages-to-orbit launchers. The design of such vehicles involves ramjet and scramjet engines. To be able to work more rapidly and with higher accuracy, we adapted our work methodology in using Computational Fluid Dynamics tools from the vehicles design phase. These tools, composed of analytical, Euler, boundary layer and Navier-Stokes codes, are a complementary approach to wind tunnel and propulsion bench tests. This new methodology will allow us to analyze and optimize more rapidly and at lower cost new configurations of air-breathing vehicles.

A93-54012
EFFECT OF FILM COOLING/REGENERATIVE COOLING ON SCRAMJET ENGINE PERFORMANCES

TAKESHI KANDA, GORO MASUYA, FUMIEI ONO, AKIO MORO, and YOSHIO WAKAMATSU (National Aerospace Lab., Kakuda, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 403-412. refs
(ISABE 93-7036) Copyright

Film cooling was modeled for performance prediction of a scramjet engine. The model was based on experimental results of compressible mixing layers for vicinity of the injection slot, and on analytical results of turbulent boundary layer for the far region from the slot. After confirming consistency with the experimental results, the film cooling-model was integrated to a quasi-1D scramjet performance prediction model. Engine performances were compared among three scramjets, which have different cooling systems from each other. In the engine with both film cooling and regenerative cooling, coolant flow rate of the engine slightly exceeded stoichiometric flow rate even in high flight Mach numbers, and it showed the best performances on specific impulse and system pressure. The advantages were achieved with increment of volume flow rate and decrement of velocity difference between main flow and coolant due to increment of the film coolant temperature. The effective cooling system with a combination of regenerative cooling and film cooling also contributed to the advantages due to avoidance of excess cooling of engine wall.

Author (revised)

A93-54013
HYPERSONIC SHOCK-INDUCED COMBUSTION RAMJET PERFORMANCE ANALYSIS

JEAN P. SISLIAN and RUDOLPH DUDEBOUT (Toronto Univ., Downsview, Canada) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 413-420. refs
(ISABE 93-7037) Copyright

Hypersonic propulsion has enjoyed a renewed interest and one possible mode of propulsion, which has yet to be systematically investigated, is that of a shock-induced combustion ramjet. In order to assess the performance of a ramjet utilizing this mode of heat addition, a computational scheme based on Godunov's (1976) method was developed to determine the inviscid hypersonic flow field produced by planar and axisymmetric bodies. The shock-induced finite-rate hydrogen-air combustion process was modeled by 33 reactions between 13 species (H2, O2, H, O, OH, H2O, HO2, H2O2, N, NO, HNO, N2, and NO2). The shock (discontinuity) tracking capability of the computational scheme was used to accurately determine shock or detonation wave and wall intersection points and construct a series of wall contours resulting in a body geometry for given free-stream conditions. Pressures acting on these planar and axisymmetric bodies were calculated and used to determine various aerodynamic and propulsive characteristics of external compressions ramjets over the range of flight Mach numbers 11-20. Author (revised)

A93-54014
STUDY OF A PULSE RAMJET BASED ON TWIN VALVELESS COMBUSTORS COUPLED TO OPERATE IN ANTIPHASE

N. LIBIS and Y. GOLDMAN (Technion - Israel Inst. of Technology, Haifa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 421-435. refs
(ISABE 93-7038) Copyright

An explanation of processes in a new type of pulse ramjet of unusual configuration, the experimental results of its operation and the analytical approach guiding its development are presented. The concept is based on coupling two valveless pulse engines at their common inlet by a symmetric pulse ejector. The tests confirm the expected antiphase mode of the two combustion chambers' operation. A single chamber combustor with a transparent side was used for fast photography, temperature field, gas pressure and composition monitoring to explain the oscillatory burning processes. An optimization process was exploited in order to find the best tailpipe geometry giving the highest achievable performance. For the selected tailpipe, the peak-to-peak phase difference between the pressure in the combustion zone and the stagnation pressure at the exit plane tends to a minimum value of 60 deg. A characteristic method is applied for analysis of the nonsteady flow in the inlet and exhaust pipes. Boundary conditions at the duct ends including the changes in the combustion chamber pressure and temperature are defined. A simple heat release scheme is used to simulate the combustion process.

Author (revised)

A93-54015
A STUDY ON 3-D VELOCITY DISTRIBUTION OF ISOTHERMAL FLOWS BEHIND AN AFTERBURNER FLAME STABILIZER

M. RAVICHANDRAN and V. GANESAN (Indian Inst. of Technology, Madras, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 439-448. refs
(ISABE 93-7039) Copyright

An experimental and numerical investigation of the 3D flow fields behind a typical turbofan afterburner flame stabilizer is presented. Five-hole pitot probe measurements downstream of the flame stabilizer allow the determination of three mean velocity components. The numerical calculations are performed using a SIMPLE based algorithm with staggered grid arrangement. The standard k - epsilon model is used for physical modeling. The numerical results agree satisfactorily well with the time-mean velocity measurements. The predicted turbulence kinetic energy contours have been presented. The flow field predictions have also been extended to a practical turbojet afterburner system.

Author (revised)

A93-54016

ISOTHERMAL FLOW CHARACTERISTICS BEHIND V-SHAPE GUTTER WITH AND WITHOUT INJECTION

YUJI IKEDA, SHIGEO HOSOKAWA, MASASHI MINATO, and TSUYOSHI NAKAJIMA (Kobe Univ., Nada, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 449-456. refs

(ISABE 93-7040) Copyright

Three-dimensional flow characteristics behind the V-gutter with and without jet injection were investigated by LDV measurements. The difference of reverse flows with and without injection was measured in order to specify the flow characteristics for flame holding. The injected jet spread as an elliptical shape. The reverse flow region at low equivalence ratio was a continuous circular-ring shape, while the combination of these reverse flow regions was yielded with increase of equivalence ratio. The reverse flow ratio was almost proportional to the jet flow rate, that is, equivalence ratio. Three typical flow characteristic parameters were proposed in order to specify the flame holding and mixing characteristics at different equivalence ratio.

A93-54017

THE DESIGN AND DEVELOPMENT OF AN AFTERBURNER

H. V. HATTINGH, J. E. VAN NIEKERK, I. P. PENNINGTON, and S. J. VENTER *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 457-469. refs

(ISABE 93-7041) Copyright

The design of an afterburner for a straight jet engine (no by-pass airflow) was executed by using the appropriate theoretical and empirical tools. A non-flying afterburner was built to this design and tested in a laboratory with simulated gas flow into the afterburner. Physical quantities were measured, outlet temperatures with a non-intrusive CARS system, from which thrust levels and combustion efficiencies may be calculated.

A93-54018

LARGE EDDY SIMULATION OF TURBULENT COMBUSTION BEHIND FLAME HOLDERS

R. RYDEN, L.-E. ERIKSSON, and S. OLOVSSON (Volvo Flygmotor AB, Trollhattan, Sweden) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 470-478. Research supported by STU and Defence Materiel Department of Sweden refs

(ISABE 93-7042) Copyright

Flow calculations for a turbulent premixed propane-air flame behind a bluff body flame holder with triangular cross section have been performed using a large eddy simulation (LES) technique together with Magnussens eddy dissipation concept (EDC) combustion model. Computational results for a single-step reaction mechanism are compared to LDA and to temperature profiles obtained by gas analysis. Grid density effects on mean and rms quantities are also presented in order to give some indication of the accuracy of the turbulence modelling. A short discussion on the modelling of NOx formation in an LES context for premixed flames is also given, based on one-dimensional flame calculations with various reaction mechanisms.

A93-54019

PERIODIC CHEMICAL ENERGY RELEASE FOR ACTIVE COMBUSTION CONTROL

K. C. SCHADOW, K. J. WILSON, E. GUTMARK, K. YU, and R. A. SMITH (U.S. Navy, Naval Air Warfare Center, China Lake, CA) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 479-485. refs

(ISABE 93-7043)

An actuator was developed to control combustion in a dump combustor and premixed combustor with flameholder. To suppress pressure oscillations, the actuator generated periodic energy by spark-ignition of a stoichiometric mixture of fuel and air. Tests were performed at near ambient and 180 kPa chamber pressure with the actuator located in the air inlet duct of the dump combustor and integrated into the flameholder for the premixed combustor. Suppression of pressure oscillations was achieved with open and closed-loop control. The effects of the pulse actuator on the shear-flow dynamics in the flameholding regime and therefore on the heat release characteristics were visualized using Mie scattering flow visualization.

A93-54020

NOZZLE EFFECTS ON LINEAR STABILITY BEHAVIOUR OF COMBUSTORS

GIUSEPPE BUSSI, GUIDO COLASURDO, and DARIO PASTRONE (Torino, Politecnico, Turin, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 486-492. Research supported by MURST refs

(ISABE 93-7044) Copyright

The influence of nozzle acoustic admittance on linear stability behavior of liquid propellant combustors is analyzed. Firstly, a means for evaluating the acoustic admittance exhibited by a supercritical convergent nozzle with a given geometry, approached by a 3D oscillatory flow, is presented. The correct conditions which must be assumed at the throat, where the equations are singular, are pointed out. Neutral stability curves are then calculated for different oscillation types and combustors lengths, to show the effect that the proper nozzle admittance assumption has on the stability range. Conspicuous differences from previous published results, which were obtained by assuming the so-called 'short nozzle' admittance, are observed.

A93-54022

NOISE REDUCTION OF SUPERSONIC HEATED JET WITH JET MIXING ENHANCEMENT BY TABS

H. KOBAYASHI, H. OINUMA, M. MINODA (National Aerospace Lab., Chofu, Japan), and E. OUTA (Waseda Univ., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 501-510. Research supported by MITI refs

(ISABE 93-7046) Copyright

Effects of jet gas temperatures on underexpanded supersonic jet noise reduction by small size tabs has been experimentally investigated, using a supersonic jet noise test facility operated in an anechoic room. The small size tab in comparison with ones used previously by other investigators was selected, based on test results of underexpanded supersonic cold jet noise reduction, for acquiring tabs with a large noise reduction level per percent jet thrust loss. The far-field jet noise spectra and directivity were measured from the conical covergent nozzles operated with the two tabs and without tabs, in super-critical jet operating conditions of the maximum jet Mach number 1.684 and in jet gas temperature conditions varied from 303 k to 773 k for each jet operating condition. In the cases of high jet gas temperature, the tabs

efficiently eliminate the screech tone noise as well as reduce broadband shock associated noise, by the maximum 7 dB in overall sound pressure level. Author (revised)

A93-54024
THE DEVELOPMENT OF A NEW AIR FILTRATION SYSTEM FOR THE ALOUETTE III HELICOPTER
L. J. H. DU PLESSIS, C. A. VAN DER MERWE, and I. J. RADEMEYER (Council for Scientific and Industrial Research, Pretoria, South Africa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 514-521. refs
(ISABE 93-7048) Copyright

This paper describes the development and evaluation of a vortex tube filtration system for the SA 316B Alouette helicopter. The AS18 vortex tube which is used in the system demonstrates the exceptionally high filtration efficiency of 96.6 percent with an associated pressure drop of 860 Pa. The tube also passes only 0.86 percent of dust of particle size 10 microns and up. This is between three and ten times better than any other such tube. This results in very good engine erosion protection in South African conditions where the silica content of dust is up to 100 percent at places. The advantages of the new vortex tube filtration system are illustrated. The helicopter performance and handling qualities is unaffected by the installation and it is therefore still able to fulfill all its mission requirements. This filtration system means a significant reduction in direct operating cost of the helicopter due to its excellent erosion protection balanced with good aerodynamic performance and simplicity of installation and operation.
Author (revised)

A93-54026
IGNITION AND COMBUSTION PERFORMANCE OF A SCRAMJET COMBUSTOR WITH A FUEL INJECTION STRUT
GORO MASUYA, TOMOYUKI KOMURO, ATSUO MURAKAMI (National Aerospace Lab., Kakuda, Japan), NOBORU SHINOZAKI, AKIHIRO NAKAMURA (Nissan Motor Co., Ltd., Kawagoe, Japan), MOTOHIDE MURAYAMA, and KATSURA OHWAKI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 533-542. refs
(ISABE 93-7050) Copyright

Ignition and combustion performance of a scramjet combustor with a fuel injection strut was experimentally investigated. A vitiation air heater supplied Mach 2.5 airstream to the combustor at stagnation conditions of 800-2200 K and 1.0 MPa. In order to select strut configuration which does not produce major disturbance in the flowfield, five strut models with different leading edge geometry were tested without fuel injection. The nonreacting flowfields were also investigated by computation with a 2D Navier-Stokes code. Using a less flow-disturbing strut, combustion and ignition tests were conducted. Pitot pressure and gas composition survey was carried out to deduce mixing and combustion efficiencies. It was found that mixing and combustion with a less flow-disturbing strut was considerably worse than those previously studied with a more flow-disturbing strut. Autoignition and forced ignition with plasma torches were tested for hydrogen fuel at the room temperature. Ignition characteristics of fuel injected parallel and perpendicular to the airstream were quite different. The plasma igniters could successfully ignite both parallel and perpendicular fuel jets without noticeable time delay between both sides of the strut. Author (revised)

A93-54028
STUDY ON UNSTART AND ITS PROPAGATION ALONG MODULES DUE TO COMPOUND CHOKING AND/OR FLUCTUATIONS IN COMBUSTOR OF SCRAMJET ENGINES
TETSUYA SATO (Inst. of Space and Astronautical Science, Sagamihara, Japan), TAKUO ONODERA, and SHOJIRO KAJI (Tokyo Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 550-560. refs
(ISABE 93-7052) Copyright

Dynamic characteristics as total systems of scramjet engines were investigated. We focused on unsteady unstart phenomena due to compound choking and unsteady interaction between engine modules. We did quasi-3D compressible inviscid calculations and experiments for analyzing unstart phenomena, and 2D compressible inviscid calculations for interaction between engine modules. It is shown that the boundary layer flow spreads and pushes out the main flow in engine inlets, and that engines designed assuming a uniform inlet flow can be made unstart easily because of the existence of a low flow speed region like a boundary layer. When side walls of engines swept backward, the transition from start to unstart is rather continuous and the inlet performance at unstart conditions is not so badly deteriorated as the performance of inlets without being swept backward. The results of the experiments show that the processes of transition from start to unstart depend remarkably on width and shear strength of the boundary layer. It is shown that a shock wave generated in front of one module extends and that it blocks the flow coming into the adjacent modules quickly, which makes the modules unstarted.
Author (revised)

A93-54037
AXIAL FLOW COMPRESSORS - MECHANICAL DESIGN TRENDS
H. A. GEIDEL, G. ZAEHRING, P. LOTTES, and H. J. SCHMUHL (MTU Motoren- und Turbinen-Union Muenchen GmbH, Munich, Germany) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 644-652. refs
(ISABE 93-7061) Copyright

Design objectives for axial aerocompressors are presented. The main mechanical design challenges which must be met to achieve the objectives are described. Component optimization is emphasized. AIAA

A93-54038
THERMAL FATIGUE LIFE ASSESSMENT OF A CONVECTION-COOLED GAS TURBINE BLADE
TREVOR J. KIRSTEN, DAVID GREENBLATT, and MANFRED O. DEDEKING (Council for Scientific and Industrial Research, Pretoria, South Africa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 653-661. refs
(ISABE 93-7062) Copyright

This paper demonstrates a method for predicting the life of cooled gas turbine hot section components which are subjected to large thermo-mechanical loads during engine operating cycles. The technique made use of an aerothermodynamic component incorporating measured engine data, a mean-line performance code, computational fluid dynamics and empirical correlations, and a structural finite element component. Results of the fluid flow computations were used as boundary conditions for the structural blade life analysis which considered the combined effect of thermo-mechanical fatigue and creep damage. The FEM implementation was designed to be practical and streamlined, as the damage models used require a minimum of materials testing. This system provides the designer with an expeditious prediction of the highly damaged regions and the expected mode of failure. Comparisons are presented between the predicted and actual modes of failure and the critical regions of the component. The prediction compare well with those found to exist in actual engine operation. This fluid-structure configuration can therefore be used with confidence for detecting failure modes during component upgrades, cooling modifications and other aerodynamic or structural modifications.

A93-54039
APPLICATION OF FUNCTIONALLY GRADIENT MATERIALS TO SCRAMJET ENGINES
TOSHIHITO SAITO, SYUICHI UEDA, NOBORU SAKURANAKA, YOSHIO WAKAMATSU, MASAYUKI NIINO (National Aerospace Lab., Kakuda, Japan), TOSHIO NOMURA (Sumitomo Electric Industries, Ltd., Itami, Japan), IKUO YAMAOKA (Nissan Motor Co., Ltd., Kawagoe, Japan), TORU SAITO (Nippon Steel Corp., Chiba, Japan), and SHIN-ICHIRO KIYOTO (Mitsubishi Heavy Industries, Ltd., Nagoya, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 662-669. Research supported by Science and Technology Agency of Japan refs
(ISABE 93-7063)

Thermal-stress relaxation-type functionally gradient materials (FGMs) show promise as high temperature materials, and are presently under development for application to scramjet engines. We applied FGMs to a model of the cooling structure of the scramjet. Two kinds of FGM samples were fabricated and experimentally evaluated with vitiation-type hot air flow. One sample consisted of a CFRC (SiC/TiC) panel coated with an FGM oxidation-resistant layer and the cooling structure made of copper. The other sample had cooling structure which was made of stainless steel and coated with NiCrAlY and partially stabilized zirconia, PSZ (ZrO2). FGM part of these samples showed fair heat resistant characteristics under the high heat flux condition in these tests. However, the results suggested that there was room for improvement of production technology of large FGM panels from the standpoint of application to the scramjet. It seemed that the method of directly building up an FGM layer on the cooling structure surface might be better than a method joining the FGM panel to the cooling structure. Author (revised)

A93-54040 National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
ENGINE TECHNOLOGY CHALLENGES FOR A 21ST CENTURY HIGH-SPEED CIVIL TRANSPORT
ROBERT J. SHAW (NASA, Lewis Research Center, Cleveland, OH), SAMUEL GILKEY (GE Aircraft Engines, Evendale, OH), and RICHARD HINES (Pratt & Whitney Group, Hartford, CT) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 673-683. Previously announced in STAR as N93-31671 refs
(Contract RTOP 537-02-00)
(ISABE 93-7064)

Ongoing NASA-funded studies by Boeing, McDonnell-Douglas, General Electric, and Pratt & Whitney indicate that an opportunity exists for a 21st Century High-Speed Civil Transport (HSCT) to become a major part of the international air transportation system. However, before industry will consider an HSCT product launch and an investment estimated to be over $15 billion for design and certification, major technology advances must be made. An overview of the propulsion-specific technology advances that must be in hand before an HSCT product launch could be considered is presented.

A93-54041
VARIABLE CYCLE ENGINE CONCEPT
MICHAEL E. BRAZIER and RANDY E. PAULSON (GE Aircraft Engines, Cincinnati, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 684-693. refs
(ISABE 93-7065)

GE powered the first United States jet in 1942. Since that time, demands placed on aircraft systems have increased dramatically. Complexities in airframe requirements and mission profiles have spawned the need for more sophisticated and versatile propulsion systems. A system combining the performance of a turbojet in supersonic flight with a turbofan at subsonic flight has many benefits. GE Aircraft Engines (GEAE) has identified a promising system, the double-bypass variable cycle engine concept. This relatively simple concept optimizes engine performance over wide ranges of operation. It is employed in the F120 engine, GEAE's offering to power the United States Air Force's Advanced Tactical Fighter (ATF) aircraft. The F120 is capable of operating in two distinct modes, a single- and a double-bypass mode. The single-bypass (turbojet) mode maximizes thrust in high power operation. The double-bypass (turbofan) mode minimizes fuel consumption during low power operation. Author (revised)

A93-54042
RESEARCH AND DEVELOPMENT OF A TURBO-ACCELERATOR FOR SUPER/HYPERSONIC TRANSPORT
H. ITAHARA, S. KOHARA (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), F. TANAKA (Kawasaki Heavy Industries Co., Ltd., Kobe, Japan), M. SUZUKI (Mitsubishi Heavy Industries Co., Ltd., Komaki, Japan), J. L. CABE (GE Aircraft Engines, Cincinnati, OH), R. YANAGI, and M. MORITA (National Aerospace Lab., Chofu, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 694-700. Research supported by Agency of Industrial Science and Technology of Japan refs
(ISABE 93-7066)

Research and development of a combined cycle engine for future Mach 5 super/hypersonic transport, which could be environmentally acceptable and economically viable, have been carried out since 1989 in Japanese Hypersonic Transport Propulsion System Research Project sponsored by the Japanese Ministry of International Trade and Industry. The combined cycle engine consists of a turbo-accelerator for low-speed range and a ramjet for high-speed range. The turbo-accelerator is required to operate up to Mach 3, to be fuel efficient, to restrain the noxious emissions and to meet ICAO noise regulations. A variable cycle engine concept features the engine in order to achieve both the low noise level at take-off and landing and the high specific thrust at altitude high speed. The demonstrator engine of the turbo-accelerator is being designed and manufactured in the collaboration. The high temperature core engine of the turbo-accelerator is also being designed and manufactured to establish the high temperature technology aimed at the turbine inlet temperature of 1973 K. Author (revised)

A93-54043* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
MATERIAL REQUIREMENTS FOR THE HIGH SPEED CIVIL TRANSPORT
JOSEPH R. STEPHENS (NASA, Lewis Research Center, Cleveland, OH), RALPH J. HECHT (Pratt & Whitney Group, West Palm Beach, FL), and ANDREW M. JOHNSON (GE Aircraft Engines, Cincinnati, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 701-710. refs
(ISABE 93-7067)

Under NASA-sponsored High Speed Research (HSR) programs, the materials and processing requirements have been identified for overcoming the environmental and economic barriers of the next generation High Speed Civil Transport (HSCT) propulsion system. The long (2 to 5 hours) supersonic cruise portion of the HSCT cycle will place additional durability requirements on all hot section engine components. Low emissions combustor designs will require high temperature ceramic matrix composite liners to meet an emission goal of less than 5g NO(x) per Kg fuel burned. Large axisymmetric and two-dimensional exhaust nozzle designs are now under development to meet or exceed FAR 36 Stage III noise requirements, and will require lightweight, high temperature metallic, intermetallic, and ceramic matrix composites to reduce nozzle weight and meet structural and acoustic component performance goals. This paper describes and discusses the turbomachinery, combustor, and exhaust nozzle requirements of the High Speed Civil Transport propulsion system.

A93-54045
TANDEM TRANSVERSE HYDROGEN GAS INJECTION INTO A SUPERSONIC AIRFLOW
S. NOGUCHI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), H. ITOH, Y. KOTANI, and T. NAGASHIMA (Tokyo Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 719-727. refs
(ISABE 93-7069) Copyright

Hydrogen gas has been injected transversely into Mach 1.8 airflow from two circular sonic injectors which are mounted flush and placed in tandem along the center line of the bottom wall plate of a test section. Both cold and hot (i.e., atmospheric and heated to max 1460 K stagnation temperature) air flow conditions were tested. In the cold flow experiments, detailed measurements were successful, and the tandem injection results showed a marked difference from the single injection results in the pattern of shock waves and the distribution of pressure and hydrogen concentration near the injector region. Upon changing the injection pressure ratio between the two injectors, it has been revealed that a prior injection upstream of the main injection would be beneficial in terms of the total pressure loss in the air flow and the hydrogen concentration near the injector region while maintaining the mixing performance. The flow features showed in general little difference as the air flow temperature was raised until the hydrogen burning was observed; then the results became inevitably more qualitative than quantitative. Contrary to expectations from the cold flow tests, a prior injection of cold hydrogen has resulted in quenching the main injector flame. Author (revised)

A93-54048
DIRECT SIMULATION OF REACTING FUEL GAS FLOWS IN A SUPERSONIC MIXING LAYER
S. OBATA and T. NAGASHIMA (Tokyo Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 739-745. refs
(ISABE 93-7072) Copyright

Direct simulation Monte Carlo method based on the Boltzmann equation has been employed to analyze fuel gas mixing and reaction in 2D supersonic shear flow which is formed due to the meeting at a thin plate (lip) edge of two parallel flows, a supersonic air stream and a sonic hydrogen gas flow. The influence of hydrogen gas temperature upon the mixing within the shear layer has been clarified, and by applying 16 reaction system the relationship between the mixing and the endo/exothermic reaction region has been analyzed to reveal the details of the ignition process. Author (revised)

A93-54049
A NEW COOLING SYSTEM FOR ULTRA HIGH TEMPERATURE TURBINES
T. YOSHIDA, M. TAKI, F. MIMURA, T. KUMAGAI (National Aerospace Lab., Chofu, Japan), T. MAYA, and S. YAMAWAKI (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 749-756. refs
(ISABE 93-7073) Copyright

The authors have proposed a new concept of a combined cooling system for ultrahigh temperature gas turbines in which turbine inlet temperature is elevated at around 1700 C or higher. The present paper deals with the introduction of the combined cooling system consisting of ultrahigh temperature turbine elements, heat pipes, and heat exchangers, a description of the successful manufacture of two kinds of turbine elements and a high temperature heat pipe both for heat transfer experiments, and some reports of experimental studies of the heat pipe. Author (revised)

A93-54055
THE COMBUSTION PERFORMANCE OF METHANE-FUELED RAM COMBUSTOR
K. SUZUKI and K. SHIMODAIRA (National Aerospace Lab., Chofu, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 811-821. refs
(ISABE 93-7079) Copyright

The flameholder of a methane-fueled ram combustor is studied experimentally by 2D models. Here we have laid stress on the stability of the flame and combustion efficiency in the high-velocity flow of 100 m/s at 600 K. We have chosen the V-gutter as the basic structure of the flameholder. But the simple gutter cannot have enough ability to stabilize the flame in such a flow. Therefore, we have equipped the gutter with some short cylinders to induce some pairs of small jets impinging oppositely. These pairs of jets play a very important part in stabilizing the primary flame and in increasing the combustion efficiency. In order to increase the combustion efficiency, two ways of injecting the fuel gas are tested and evaluated. The first case is that the fuel is injected far upstream of the flameholder and premixed with the air completely. The other case is that the fuel is injected inside the flameholder and makes the diffusion flame. The higher combustion efficiency is observed in the latter case. A combustion efficiency of more than 95 percent is obtained. There are several rows of flameholders in the actual ram combustor. In this case the combustion performance is influenced by the other flameholder located nearby. The interaction effect has been investigated experimentally using the 2-row flameholder model. Author (revised)

A93-54056
STUDIES ON METHANE-FUEL RAM COMBUSTOR FOR HST COMBINED CYCLE ENGINE
Y. KINOSHITA, J. KITAJIMA, Y. SEKI (Akashi Technical Inst., Japan), and A. TATARA (Kawasaki Heavy Industries, Ltd., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 822-830. Research supported by New Energy and Industrial Technology Development Organization refs
(ISABE 93-7080) Copyright

This paper describes experimental studies on a methane-fuel ram combustor for the super/hypersonic transport propulsion system. A laboratory scale combustor was fabricated and combustion tests were carried out at the conditions of flight Mach 3 and Mach 5. Vitiation technique was used to simulate the air temperature of Mach 5 conditions. Ignition and flame stability characteristics were obtained at the temperature condition of Mach 3. Combustion characteristics, such as combustion efficiency, NO(x) emissions and pressure loss were measured at Mach 3 and Mach 5 conditions. Autoignition was observed clearly at high inlet air temperature conditions. The results indicate that the combustion efficiency at Mach 3 and the NO(x) emissions and autoignition at Mach 5 are critical problems for the ram combustor.

A93-54058
TEST RESULTS OF THE HYDROGEN FUELED MODEL COMBUSTOR FOR THE AIR TURBO RAMJET ENGINE
TAKESHI KASHIWAGI, MASAKAZU OBATA, YOUJI OHKITA (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), NOBUHIRO TANATSUGU, and YOSHIHIRO NARUO (Inst. of Space and Astronautical Science, Sagamihara, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 838-845. refs
(ISABE 93-7082) Copyright

The mixer type flameholder, combining in a single unit the mixer and flameholder to equip air turbo ramjet engine combustors, with a view to more compact combustor design, has been improved to enhance the mixing of hydrogen fuel with air, with a mixer configuration that increases the momentum imparted to the fuel

and air. Comparative tests performed on a land-based stationary bench covering both gutter and mixer types of flameholder have shown the improved mixer type flameholder to provide performance at least equal to the gutter type in terms of: the absence of flame detachment, flame temperature distribution in the combustion chamber, allowable range of fuel equivalence ratio for stable flameholding, and absence of flame instability. The improved mixer type flameholder, while raising the flameholder temperature to the extent of calling for protective measures, and while remaining to be further tested for actual combustion performance, promises successful practical application to ATR engine combustors, bringing with it the possibility of realizing a more compact combustor design. Author (revised)

A93-54059
NUMERICAL SIMULATION OF RAMJET AND SCRAMJET COMBUSTION USING TWO-DIMENSIONAL EULER EQUATIONS WITH FINITE RATE CHEMISTRY

I. S. AKMANDOR (Middle East Technical Univ., Ankara, Turkey) and UGUR ARKUN (Roketsan Missiles Industries, Inc., Ankara, Turkey) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 846-855. refs
(ISABE 93-7083) Copyright

Two dimensional/axisymmetric ramjet and scramjet combustion has been modeled with an implicit flux vector splitting scheme which has been used for the solution of the conservative form of the Euler equations. A weakly coupled chemistry model has been used to simulate the finite rate combustion of Hydrogen-Air and Kerosene-Air mixtures. The scheme is first order upwind. A realistic multicomponent two step chemistry model has been used for H2-Air combustion. Kerosene-Air combustion has been modeled with a single step, irreversible global reaction mechanism. Numerical results are compared with reacting ramp channel and non-reacting duct flow test cases. Flame holding capability of oblique shock wave has been illustrated. Related specific impulse have also been reported.

A93-54060
FINITE-RATE H2/AIR COMBUSTION EFFECTS IN CRJ FOR HYPERSONIC LAUNCHERS

M. CASSETTI (Rome I, Univ., Italy), F. BIAGIOLI (Centre for Advanced Studies, Research and Development in Sardinia, Cagliari, Italy), and C. BRUNO (Rome I, Univ., Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 856-865. refs
(ISABE 93-7084) Copyright

Comparisons of numerical results with available experimental data from an atmospheric H2/CO/N2/air flame are here used to evaluate the accuracy of physical models used to numerically simulate the flowfield in a turbulent combustor with nonpremixed injection of hydrogen and air, as would be involved in such future airbreathing hypersonic propulsion systems as that of Saenger. Attention is given to test results for a novel kinetics model based on the two independent scalars of mixture fraction and a kinetic progress variable. Large emissions of unconsumed H2 are predicted, as confirmed by tests. AIAA

A93-54061
NEW DEVELOPMENTS WITH THE V2500 ENGINE

G. J. SEVICH (Pratt and Whitney Group, East Hartford, CT), T. ALLAN (Rolls-Royce, PLC, London, United Kingdom), K. ISHIZAWA (Japanese Aero Engines Corp., Japan), L. SCHWEIKL (MTU Motoren- und Turbinen-Union Muenchen GmbH, Munich, Germany), and G. BENSI (Fiat Aviazione S.p.A., Turin, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 869-894.
(ISABE 93-7085) Copyright

The International Aero Engines V2500 aircraft engine family has been expanded to cover the range from 25,000 to 30,000 pounds of thrust, with models designed for aircraft fuselage side mounting as well as conventional, under-the-wing mounting. These new models are designated the V2500-A5 for Airbus aircraft installations, and the V2500-D5 for Douglas aircraft installations. The engines incorporate numerous design features, representing the latest aircraft engine technology, for increased thrust, improved fuel efficiency, lower gaseous emissions, and lower noise than the earlier -A1 model and other engines in its class. An extensive test and development program led to simultaneous certification of the -A5 and -D5 models by the FAA in November of 1992. Since then, the engines have been undergoing concurrent flight testing powering the Airbus A320 and A321, and the McDonnell Douglas MD-90 aircraft. V2500 engine development is continuing to further improve fuel efficiency, and to introduce a new combustor technology for a further reduction in emissions. Author (revised)

A93-54063
PERFORMANCE AND CONFIGURATION ANALYSIS OF JET-ENGINE OFF-DESIGN BEHAVIOR

U. GHEZZI, S. PASINI, L. FERRI DEGLI ANTONI, R. ANDRIANI (Milano, Politecnico, Milan, Italy), and F. GAMMA (Roma I, Univ., Rome, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 903-908. refs
(ISABE 93-7087) Copyright

An analysis is conducted of the global off-design behavior of an aircraft gas turbine engine. Attention is given to the ways in which the choice of a suitable working line facilitates the optimization of performance characteristics with respect to such factors as thrust and/or specific fuel consumption. It is emphasized that variable-geometry turbine components are able to yield the degree of operational flexibility associated with many stages on the basis of fewer stages. AIAA

A93-54064
DEVELOPMENTS TOWARDS VERSATILITY IN DIGITAL ENGINE CONTROL UNITS

G. WALLE (BGT - Bodenseewerk Geraetetechnik GmbH, Ueberlingen, Germany) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 909-918. Research supported by BGT - Bodenseewerk Geraetetechnik GmbH refs
(ISABE 93-7088) Copyright

The main features of modern digital engine control units are described on the basis of realized FADEC units for small aeroengines. They show that FADEC units have become very powerful, reliable, and indispensable accessories in modern engines. Control of future engine generations is, in principle, possible with present FADEC units as demonstrated by the results of experiments on a digitally controlled APU-demonstrator with H2-combustion. Nevertheless the versatility of today's units for their use in different applications is still unsatisfactory. By analogy with the engine manufacturer's philosophy of a core that is reusable in a product family by modifying the fan, a core digital engine control unit which easily and rapidly evolves into a customer dedicated specific unit is defined. A dual processor architecture with a microcontroller for input/output and a microprocessor for main processing, a software structure with strong segregation of hardware near-, executive- and application software, large spare capacities in hardware and software, and flexibility to single or dual lane architectures are the main elements of a versatile engine control concept, which is detailed in the paper. Author (revised)

A93-54065
THERMODYNAMIC AND NEUTRAL NETWORK COMPUTER MODELLING OF IMPLANTED COMPONENT FAULTS IN A GAS TURBINE ENGINE

J. D. MCLEOD (National Research Council of Canada, Ottawa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2

Washington American Institute of Aeronautics and Astronautics 1993 p. 919-928. refs
(ISABE 93-7089) Copyright

A gas turbine fault analysis methodology study has developed both thermodynamic and neural-network (AI-oriented) computer-simulation engine models, whose results are presented and compared with experimental data. It is found that the effects of 6-percent turbine nozzle erosion are both measurable and accurately simulated by both computer models. The parameters most affected were compressor pressure ratio, fuel flow, and specific fuel consumption. The effects of turbine blade untwist are also important for engine performance. AIAA

A93-54066
DESIGN OF LIMIT-TRACKING SYSTEMS INCORPORATING A TURBOFAN ENGINE WITH CONSTANT DISTURBANCES
HIDEAKI YAMANE (Japan Defense Agency, Technical Research and Development Inst., Tachikawa, Japan) and BRIAN PORTER (Salford Univ., United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 929-936. refs
(ISABE 93-7090) Copyright

A methodology is proposed for the design of limit-tracking systems incorporating multivariable plants with more outputs than inputs. The plants are subjected to unknown constant disturbances. The synthesis problem of limit-tracking systems and the design of separate digital set-point tracking controllers are discussed. An implementation procedure is formulated in order to integrate separate controllers into a self-selecting controller with lowest-wins strategies. The effectiveness of such controllers is illustrated by designing limit-tracking systems incorporating a linear turbofan engine model with disturbances.

A93-54067
NEURAL NETWORK FAULT DIAGNOSIS OF A TURBOFAN ENGINE
RICHARD EUSTACE (Defence Science and Technology Organisation, Aeronautical Research Lab., Melbourne, Australia) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 937-946. refs
(ISABE 93-7091) Copyright

In this paper neural networks are applied to the problem of fault detection and diagnosis in a turbofan engine. Steady state data are obtained from six different implanted faults involving compressor variable geometry and exhaust nozzle area adjustment. Two different network architectures are applied to the problem and a comparison is made. The first method uses a standard back-propagation network, whilst the second method uses a Learning Vector Quantization (LVQ) network. Results show both networks achieve very high accuracy. The LVQ network has the advantage of being quick to train, while the back-propagation network gives an indication of the confidence of its diagnosis. The question of robustness is also discussed. Neural networks are shown to be a useful diagnostic tool provided sufficient training data are available.

A93-54072
EFFECT OF NOZZLE DESIGN ON THE PERFORMANCE OF A HIGHLY LOADED TURBINE STAGE
S. GIRGIS, S. H. MOUSTAPHA (Pratt & Whitney Canada, Inc., Montreal), and U. W. SCHAUB (National Research Council of Canada, Ottawa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 984-990. refs
(ISABE 93-7096) Copyright

As part of a research program on the performance of a highly loaded turbine stage, two different nozzle designs were tested. A baseline design and a new design which features leading edge ramps, tangential lean, and negative curvature on the suction surface. Both nozzles have an aspect ratio of 0.6, a turning angle of 76 degrees, a mean exit Mach number of 1.2, and the same conical outer wall contour. The experiments were conducted in a large scale, single stage test facility with representative Mach and Reynold's numbers. Measurements in the form of nozzle and rotor exit surveys showed that the new nozzle has 8 percent lower losses as compared to the baseline and that the stage efficiency improved by 0.9 points. Comparison of the experimental results with those obtained from a 3D Euler flow solver is presented.

A93-54073
A COMPARATIVE ASSESSMENT OF TWO PRESENT GENERATION TURBINE ANALYSIS CODES
KEVIN G. KILLEY (Council for Scientific and Industrial Research, Aerotek, Pretoria, South Africa) and GRAHAM SMITH (Natal Univ., Durban, South Africa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 991-999. refs
(ISABE 93-7097) Copyright

Two current analysis codes, LOSS3D and BTOB3D, are independently verified against certain experimental data in an attempt to establish an analysis confidence level. The experimental results are presented on the basis of a series of tests performed on the VKI turbine blade, in the AEROTEK plane cascade wind tunnel. Once these experimental results were validated against the European Cascade Results, they formed the direct inputs into the two analysis codes. Typically, the accuracy of the codes in predicting loss coefficients, exit flow angles, and blade surface pressure distributions were evaluated. A version of LOSS3D (Euler Code) that included a blockage model, and the standard 3D BTOB3D Navier-Stokes code, were used in the computation of total pressure loss. Predicted and measured loss coefficient and flow angles were compared with standard design loss correlations. Author (revised)

A93-54081
STARTING CHARACTERISTICS OF SCRAMJET INLETS
KOUICHIRO TANI, TAKESHI KANDA (National Aerospace Lab., Kakuda, Japan), and TATSURU TOKUNAGA (Mitsubishi Heavy Industries Co., Ltd., Komaki, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1071-1080. refs
(ISABE 93-7105) Copyright

A series of scramjet inlet models were experimentally investigated in a Mach 4 wind tunnel. The effects of sweep angle and contraction ratio to the starting characteristics and aerodynamic performances were examined, as well as the effect of the inflow boundary layer. Top wall pressures along the center line of the inlets were measured, and mass capture ratio and total pressure efficiency were evaluated for each model. The internal flow of the inlets was visualized by the Schlieren method and the oil flow technique. All these data indicated that there existed a gradual transition from start to unstart condition. With a thin boundary layer, aerodynamic performances were good and showed more sensitivity to the change of the contraction ratio. When the model had a large rearward sweep angle, e.g., 60 deg, in this testing, its aerodynamic performances were not good, but it easily started. The total pressure efficiency depended on the throat to freestream Mach number ratio, not on the particular configurations. The separation area was large in the forward sweep models, and the models showed poor starting characteristics. Author (revised)

A93-54084
OFF-DESIGN PERFORMANCE OF SCRAMJET NOZZLES
TETSUO HIRAIWA, SHUUICHI UEDA, SHIGERU SATO, TOHRU MITANI (National Aerospace Lab., Kakuda, Japan), MASAHIKO YAMAMOTO (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan), and MASASHI MATSUMOTO (Ishikawajima-Harima Heavy Industries Co., Ltd., Yokohama, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington

American Institute of Aeronautics and Astronautics 1993 p. 1103-1114. refs
(ISABE 93-7108) Copyright

An experimental study of NASP-like nozzles is presented. This study was conducted to investigate the nozzle flow affected by the ambient pressure. In order to elucidate the aerodynamic properties of the nozzle flow, detailed measurements of thrust, wall pressure and heat flux were carried out using cold nitrogen. The nozzle flow was also visualized using a shear sensitive liquid crystal. Under the over-expanded condition, the interaction between the internal flow and the external flow complicates the characteristics of nozzle performance. Wall pressure distributions and shear stress visualization showed that the flow field in over-expanded nozzles can be approximated as a supersonic inlet flow compressed by sidewalls. The high pressure region generated by shock waves and the boundary layer on the nozzle ramp yields a higher performance in scramjet nozzles than that estimated for a two-dimensional separation from the ramp.

A93-54085
EVALUATION OF TURBORAMJET EXHAUST SYSTEMS FROM SCALE MODEL TEST DATA
D. J. DUSA (GE Aircraft Engines, Cincinnati, OH) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1115-1127. refs
(ISABE 93-7109) Copyright

Advances in aircraft propulsion system technology over the past decade (in materials, structures, and analytical design methods), along with those anticipated for the next decade, have renewed interest in the Mach 4.0 to 6.0 operating regime for both commercial transports and military weapon systems. One of the propulsion systems being considered for these applications is the dual mode turboramjet engine which utilizes a common inlet and exhaust nozzle for both modes of operation. With respect to the propulsion system, there are a number of component technologies that will have to be developed before these Mach 4.0 to 6.0 applications become a reality. Author (revised)

A93-54086
OBSERVATION OF FLUCTUATION OF 2D-NOZZLE FLOWS
TOMOYUKI NAKAMURA and YOKICHI SUGIYAMA (Japan Defense Agency, Technical Research and Development Inst., Tachikawa) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1128-1133.
(ISABE 93-7110) Copyright

In order to determine the fluctuation of 2D nozzle flows, instantaneous flow visualization was carried out using flashing sheet beam for three types of scale models, a boat-tail model, an internal-aerodynamic model, and a transparent model. Both the boat-tail and internal-aerodynamic models made of stainless steel with adjustable nozzle-flaps were tested for exhaust-jet-flow visualization at jet velocities as high as Mach 1.4, and the transparent model was tested for internal-flow visualization at jet velocity of approximately 10 m/s. Results show that entrainment of ambient air takes place in an unsteady 3D manner, a smaller aspect ratio enhances the entrainment, and inlet whirl spreads the jets at high speed but it just rotates middle portion of the jets at low speed, resulting in an S-like section flow-pattern in downstream. Author (revised)

A93-54088
MEASUREMENT AND PREDICTION OF FLOW IN A GAS TURBINE ENGINE EXHAUST PLUME
J. MILBANK, S. M. HENBEST, and J. G. BAIN (Defence Science and Technology Organisation, Aeronautical Research Lab., Fishermens Bend, Australia) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1153-1163. refs
(ISABE 93-7113) Copyright

Measurements have been carried out in the exhaust plume of a small turbojet engine. The measurements were taken in a horizontal plane containing the central axis of the plume and they extended to 20 nozzle exit diameters downstream of the nozzle exit. The measured flow quantities included total temperature, total and static pressure, and CO2 volume fraction. Cross-stream profiles, centerline profiles and contour maps in the plane are presented for measured and calculated flow quantities. Computational fluid dynamic predictions have been made and are compared with the experimental data.

A93-54100
NUMERICAL STUDY OF NITRIC OXIDE FORMATION IN A HYPERSONIC RAMJET ENGINE
P. MUEHLEK and H. SCHUETZ (DLR, Inst. fuer Antriebstechnik, Cologne, Germany) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1275-1283. refs
(ISABE 93-7125) Copyright

The 3D flowfield in a hypersonic ramjet engine is analyzed using a turbulent Navier-Stokes code incorporating finite rate chemistry. The numerical procedure (ALE method) is based on a finite volume discretization of the Lagrangian form of the unsteady compressible balance equations. The ramjet configuration investigated in this study consist of a cylindrical combustion chamber with axial injection of hydrogen through a star-shaped injection device and a subsequent rectangular thrust nozzle. The injection of hydrogen, the combustion process and the expansion of the gas mixture to supersonic flow speeds is treated within one computational domain. The combustion processes of the hydrogen as well as the formation of nitric oxide and the chemical nonequilibrium effects in the nozzle are described by a complex kinetic reaction mechanism. As a consequence of the axial fuel injection only poor mixing is achieved and stratified reaction zones are established. The formation of nitric oxide is controlled by the local stoichiometry, i.e., temperature level, and the concentration of oxygen atoms.

A93-54102
A FINITE ELEMENT CODE FOR GAS TURBINE COMBUSTOR FLOW WITH STRETCHED LAMINAR FLAMELET MODELLING
P. IONTA, D. LENTINI, and F. RISPOLI (Roma I, Univ., Rome, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1293-1304. Research supported by MURST refs
(ISABE 93-7127) Copyright

The computational code XENIOS for gas turbine combustor flow is presented. It introduces powerful solutions for body-fitted grid management and numerical diffusion control, and for finite-rate chemistry, which is the focus of the paper. The physical bases of the Stretched Laminar Flamelet model are discussed, then its application to the prediction of the mean temperature field and of CO and CO2 concentrations is reported. Results indicate the important role of finite-rate chemistry. An extension to the prediction of NO emissions is also discussed.

A93-54103
NUMERICAL SIMULATION OF GAS TURBINE COMBUSTORS WITH COMPLEX GEOMETRIES
P. DI MARTINO and G. CINQUE (Alfa Romeo Avio S.A.p.A., Pomigliano d'Arco, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1305-1320. refs
(ISABE 93-7128) Copyright

A method is presented for calculating steady three-dimensional two-phase turbulent reactive flows with curved irregular boundaries. The gas phase equations are solved in an Eulerian frame of

reference by a numerical technique based on the finite volume approach, while the equations describing droplet motion, evaporation and burning are treated in a Lagrangian frame of reference. Turbulent transport is described by the standard k-epsilon model. The combustion model utilizes a conserved scalar formulation and an assumed shape probability density function to account for chemistry-turbulence interaction. The numerical scheme employs structured non-orthogonal grids, node-centered variable arrangement and Cartesian velocity components. A special interpolation procedure is used to avoid checkerboard oscillations due to pressure-velocity coupling and a low diffusive and bounded scheme is introduced to approximate the convective terms in the transport equations. The capabilities of the numerical procedure are demonstrated by simulating an annular combustion chamber for which experimental results were available. The agreement between calculation and experiments ranges from fair to good.

A93-54106
STRUCTURAL INTEGRITY VALIDATION OF LIMITED-LIFE ENGINES
S. NARAYANA SWAMY, V. UNNIKRISHNAN, and R. V. NARAYANA MURTHY (Ministry of Defence, Directorate of Aeronautics, Bangalore, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1335-1345. refs
(ISABE 93-7131) Copyright

The structural design criteria and validation methodology evolved concurrently with the development of a limited life low-cost turbojet engine incorporating the expendable design concept are described. Relevant hardware distresses revealed during the engine testing are analyzed to identify the primary causes. The approach adopted initially is reviewed in the light of the hardware experience gained during development. Validation requirements including a package of tests to assure structural integrity for this class of low-cost, expendable engine, are suggested. Author (revised)

A93-54107
DEVELOPMENT OF A REAL TIME DYNAMIC ENGINE SIMULATION MODEL OF A TURBO FAN ENGINE
G. BHARGAVA REDDY, SANJAY PALSANE, B. K. LAKSHMANAN, and V. SUNDARARAJAN (Gas Turbine Research Establishment, Bangalore, India) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1349-1352. refs
(ISABE 93-7132) Copyright

Recent developments in fighter aircraft engines have precipitated the requirements of more reliable, dynamic and accurate control systems for the stringent aircraft missions. In order to develop these control systems and to verify their functioning, real-time engine simulation models are inescapable. Large scale non-linear thermodynamic simulation models are not capable of running in real-time even on large computers. Implementation of simplified model offers an attractive and cheaper solution. This paper describes the modeling of components in a simplified way and an iteration and integration logic for the state variables in terms of the partial derivatives. Model is validated for steady state and transients for different fuel inputs against large scale turbofan engine simulation model and are in fair agreement. The time response of engine state variables are also described.

A93-54244
THE LOW FREQUENCY AEROACOUSTICS OF BURIED NOZZLE SYSTEMS
M. V. TAYLOR (International Computers, Ltd., Bracknell, United Kingdom), D. G. CRIGHTON (Cambridge Univ., United Kingdom), and A. M. CARGILL (Rolls-Royce, PLC, Derby, United Kingdom) Journal of Sound and Vibration (ISSN 0022-460X) vol. 163, no. 3 May 22, 1993 p. 493-526. Research supported by SERC and Rolls-Royce, PLC refs
Copyright

Results are presented of an investigation of the LF acoustic and instability properties of a 'buried nozzle' system, a configuration which can be found in some turbofan engines, when the outer cowling of the fan extends beyond the inner nozzle which emits the engine's exhaust gases. In this model, the primary flow issues into a coannular flow within a mixing chamber, and then the coannular flow issues into the ambient medium from a secondary nozzle. Within the mixing chamber only fine-scale mixing takes place, and shear layers within the mixing chamber and downstream of the secondary nozzle are assumed to sustain large-scale instability waves. The response of this system, in the acoustic far field and in the mixing chamber, is obtained analytically from the asymptotic solution, at LF, of model subproblems whose solutions determine the wave reflection and transmission processes at the primary and secondary nozzles. Analytical descriptions are given of the various wave modes, the acoustic field strength and directivity, and the conditions under which near-resonant response may occur, with large amplitudes of the perturbations in the mixing chamber and in the acoustic field. AIAA

A93-54292
THE T700 ... FROM SALT SPRAY TO SAND BLAST
ANNA M. LISZEWSKI and GREGORY D. TALLEY (GE Aircraft Engines, Lynn, MA) *In* Helicopter operations in severe environments; Proceedings of the Conference, London, United Kingdom, June 4, 1992 London Royal Aeronautical Society 1992 p. 5.1-5.6. refs
Copyright

The T700 family of turboshaft and turboprop engines produced by GE Aircraft Engines that has amassed millions of flight hours operating in a range of abusive environments across five continents is described. The T700 is a front-drive turboshaft engine of modular construction based on an inlet particle separator, axi-centrifugal compressor, through-flow annular combustor, air-cooled gas generator turbine, uncooled power turbine, and self-contained lube system. A sound design approach, extensive and comprehensive testing, and demonstration of superior mission capability make it possible to successfully meet helicopter engine mission requirements. AIAA

08

AIRCRAFT STABILITY AND CONTROL

Includes aircraft handling qualities; piloting; flight controls; and autopilots.

A93-52941
STABILIZATION OF THE DYNAMIC CHARACTERISTICS OF THE TWO-CHANNEL AUTOMATIC CONTROL SYSTEM OF AIRCRAFT [STABILIZATSIYA DINAMICHESKIKH KHRAKTERISTIK DVUKHKANAL'NOJ SISTEMY AVTOMATICHESKOGO UPRAVLENIYA SAMOLETA]
A. I. BOGOMOLOV and P. K. SEMENOV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 17-22. In RUSSIAN refs
Copyright

A method is proposed for ensuring the stability of the transient process characteristics in the automatic pilot-aircraft system with considerable crosstalk coupling between the control channels. The approach proposed here is an extension of the method proposed in an earlier study (Bogomolov and Semenov, 1992) for single-channel systems. The efficiency of the method is illustrated by an example. AIAA

A93-52942
A METHOD FOR THE SPECTRAL-TIME IDENTIFICATION OF THE LONGITUDINAL AND LATERAL MOTIONS OF AN AIRCRAFT [METOD SPEKTRAL'NO-VREMENNOJ IDENTIFIKATSII PRODOL'NOGO I BOKOVOGO DVIZHENIYA SAMOLETA]
B. O. KACHANOV and K. B. KHROLOVICH Aviatsionnaya

Tekhnika (ISSN 0579-2975) no. 1 1993 p. 22-26. In RUSSIAN refs
Copyright

A method for the identification of models of the longitudinal and lateral motions of an aircraft is proposed which combines the spectral and time approaches. The spectral approach makes it possible to reduce the identification procedure to a linear problem, while the time approach significantly improves the solution stability with respect to different kinds of measurement noise. Details of the identification procedure are discussed. AIAA

A93-52943
IDENTIFICATION OF THE PHASE CHARACTERISTICS AND WIND-INDUCED PERTURBATIONS OF AN AIRCRAFT FROM FLIGHT TEST RESULTS [IDENTIFIKATSIYA FAZOVYKH KHARAKTERISTIK I VETROVYKH VOZMUSHCHENIJ SAMOLETA PO REZUL'TATAM LETNYKH ISPYTANIJ]
YU. V. KOZHEVNIKOV and A. YU. SIGAEV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 27-29. In RUSSIAN refs
Copyright

A method for the identification of the phase characteristics of aircraft and wind effects due to atmospheric turbulence is proposed which is based on the decomposition of the identification problem. In the approach proposed here, integral quadratic functionals are used as the criteria of identification quality. The method is applicable to any kind of aircraft and flight regimes. AIAA

A93-52944
SOLUTION OF THE BOUNDARY VALUE PROBLEM IN FLIGHT DYNAMICS BY THE OPPOSITE MOTION METHOD [RESHENIE KRAEVOJ ZADACHI DINAMIKI POLETA METODOM VSTRECHNYKH DVIZHENIJ]
E. A. KRAMARENKO and O. G. KOVRIZHKIN Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 30-34. In RUSSIAN refs
Copyright

A nonoptimization approach is proposed for solving the boundary value problem of guiding a flight vehicle to a specified terminal state on the basis of six phase coordinates. Control synthesis is carried out in steps using piecewise constant functions. The method is recommended for the generation of automatic control signals in guiding a flight vehicle to a specified point on the basis of six phase coordinates in relatively simple maneuvers. AIAA

A93-53621
NON-LINEAR FLIGHT DYNAMICS
PH. GUICHETEAU (ONERA, Chatillon, France) ONERA, TP no. 1993-109 1993 14 p. NATO, AGARD, Lecture Series on Non Linear Dynamics and Chaos, 191st, Stanford Univ., CA, June 9-11, 1993 and Valbonne, France, June 16-18, 1993 Research supported by Services Techniques des Programmes Aeronautiques refs
(ONERA, TP NO. 1993-109)

Techniques are presented for more accurately characterizing aircraft behavior in flight regimes for which classical linearized analyses of nonlinear differential equations are either insufficient or invalid. Bifurcation theory is shown to be applicable to such simple nonlinear phenomena as the Dutch roll instability. Attention is given to the results yielded by an application of bifurcation theory to the actual dynamical behavior of the Alpha-Jet military trainer, with a view to oscillatory motions and the results of a sensitivity analysis of departures and spin predictions for a given set of parameters. AIAA

A93-53869
A STUDY OF AIRCRAFT GLOBAL DYNAMIC STABILITY IN RAPID ROLLING MANEUVER
CHANG LIU, JI-PING DING, and MING JIANG (Nanjing Aeronautical Inst., China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 2 Feb. 1993 p. B7-B12. In CHINESE refs

Based on the bifurcation analysis and catastrophe theory methodology (BACTM), the aircraft global dynamic stability in a rapid rolling maneuver is studied in this paper. Based on the study of the bifurcation and catastrophe behavior of an aircraft in a rapid rolling maneuver entering from the vertical symmetry flight plane, the status of a rapid rolling maneuver entering from the horizontal turn is discussed further. A general analytical formula for determining the critical rolling rate is derived in the state-control space. It indicates that the Phillips critical rolling rate criterion is only a special case of the general analytical formula developed in this paper. Author (revised)

A93-53877
HARMONIC OSCILLATION IN FBW SYSTEM
RONG S. SHAO (Shenyang Aircraft Research Inst., China) Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 2 Feb. 1993 p. B66-B71. In CHINESE refs

Taking the research of nonlinear characteristics of the actuator loop as the point of departure, through the spectrum analysis and the experimental verification, the physical essence of control surface buffet excited by the high-frequency odd harmonic of the triangular wave in a high-gain fly-by-wire system has been discovered. The necessary condition of harmonic oscillation, as well as the frequency characteristics and the overcoming measures of the buffet in FBW system are also presented. These are important references for the design of modern flight control systems. Author (revised)

A93-54268 National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
A PARAMETER OPTIMIZATION APPROACH TO CONTROLLER PARTITIONING FOR INTEGRATED FLIGHT/PROPULSION CONTROL APPLICATION
PHILLIP H. SCHMIDT (Akron Univ., OH), SANJAY GARG (NASA, Lewis Research Center, Cleveland, OH), and BRIAN R. HOLOWECKY (Akron Univ., OH) IEEE Transactions on Control Systems Technology (ISSN 1063-6536) vol. 1, no. 1 March 1993 p. 21-36. refs
(Contract NAG3-1146; RTOP 505-62-50)
Copyright

A parameter optimization framework is presented to solve the problem of partitioning a centralized controller into a decentralized hierarchical structure suitable for integrated flight/propulsion control implementation. The controller partitioning problem is briefly discussed and a cost function to be minimized is formulated, such that the resulting 'optimal' partitioned subsystem controllers will closely match the performance (including robustness) properties of the closed-loop system with the centralized controller while maintaining the desired controller partitioning structure. The cost function is written in terms of parameters in a state-space representation of the partitioned sub-controllers. Analytical expressions are obtained for the gradient of this cost function with respect to parameters, and an optimization algorithm is developed using modern computer-aided control design and analysis software. The capabilities of the algorithm are demonstrated by application to partitioned integrated flight/propulsion control design for a modern fighter aircraft in the short approach to landing task. The partitioning optimization is shown to lead to reduced-order subcontrollers that match the closed-loop command tracking and decoupling performance achieved by a high-order centralized controller.

A93-54277
LONGITUDINAL CLOSED-LOOP PILOT/VEHICLE ANALYSIS OF DFBW AIRCRAFT DURING APPROACH AND LANDING
YACHANG FENG, WANG Z. LIN, W. YONG, and CHEN GANG (Beijing Univ. of Aeronautics and Astronautics, China) Zeitschrift fuer Flugwissenschaften und Weltraumforschung (ISSN 0342-068X) vol. 16, no. 6 Dec. 1992 p. 357-362. refs
Copyright

According to flight test data and pilot flying experience, a frequency domain pilot model is developed with its parameters varying through the approach and landing task. The DFBW aircraft

closed-loop pilot/vehicle model is formulated in this paper. The nonlinear time domain computer numerical simulation gives a quantitative analysis of aircraft longitudinal landing dynamic characteristics. The simulation result agrees well with the flight test of MCS aircraft. Thus the accuracy of both mathematical models and simulation computer programs is validated. Many beneficial results are obtained which show that the landing dynamics of some types of DFBW aircraft are acceptable.

A93-54278
AN AERODYNAMIC MODEL FOR THE LONGITUDINAL MOTION OF FLIGHT TRAINING DEVICES [EIN AERODYNAMISCHES MODELL FUER DIE LAENGSBEWEGUNG VON FLUGUEBUNGSGERAETEN]
R. BRAUNSTINGL (Graz, Technische Univ., Austria) Zeitschrift fuer Flugwissenschaften und Weltraumforschung (ISSN 0342-068X) vol. 16, no. 6 Dec. 1992 p. 363-369. In GERMAN refs
Copyright

The paper at hand presents a simulation model for the longitudinal motion of fixed-wing aircraft. This model provides for a more realistic, type-specific flight simulation than has been standard in general aviation until now. The model is meant to be applied to flight training devices used in pilots' training and has already been put to the test there. It describes aerodynamic forces in the longitudinal plane of the aircraft and the pitching moment with the states of flight normally encountered in training courses. Choosing appropriate values for the model parameters makes it possible to adapt the same model for different types of aircraft. The exactness with which the model renders the flight performance data is demonstrated with an example. The measured flight performance data of a PIPER PA28RT-201T, TURBO ARROW IV are compared with the model's simulation results.
Author (revised)

09

RESEARCH AND SUPPORT FACILITIES (AIR)

Includes airports, hangars and runways; aircraft repair and overhaul facilities; wind tunnels; shock tube facilities; and engine test blocks.

A93-52651
AIAA FLIGHT SIMULATION TECHNOLOGIES CONFERENCE, MONTEREY, CA, AUG. 9-11, 1993, TECHNICAL PAPERS
Washington American Institute of Aeronautics and Astronautics 1993 378 p. For individual items see A93-52652 to A93-52695
Copyright

Papers presented in this volume are grouped under the topics of flight simulation history, simulation modeling, simulation facilities, human factors and pilot cueing, modeling the simulation environment, simulation applications, motion systems, simulation networking, software engineering, simulation validation and verification, pilot training, and in-flight simulation. Particular consideration is given to the aircraft threat modeling from performance data, a high-fidelity video delivery system for real-time flight simulation research, a multistage integration model for human egomotion perception, terrain modeling for real-time phototexture-based visual simulation, and use of a simulator in aircraft accident investigation. Attention is also given to simulating motion effects on single-axis compensatory tracking, representation of vehicle location in networked simulations, a reusable code for helicopter simulation, a flexible graphical simulation monitoring system, the future of flying work modeling for pilot educational tasks, and a rapid prototyping system for in-flight simulation using the Calspan Learjet 25. AIAA

A93-52652#
EVOLUTION OF FLIGHT SIMULATION
L. D. ALLEN (CAE Electronics, Montreal, Canada) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 1-11. refs
(AIAA PAPER 93-3545) Copyright

The paper describes the progress made in flight simulation technology, starting with the first flight simulator, introduced in 1910 (the Sanders Teacher). Consideration is given to the early pilot-training devices (such as the Sanders Teacher, the Walters machine, and the Antoinette 'apprenticeship barrel' trainer); the Link Trainer, introduced in 1929; and the Celestial Navigation Trainer, designed in 1939; these were ground-based aircraft or aircraft simulating structures subjected to outside disturbances. The development and evolution of the analog simulators, the electronic simulator, and the modern simulator are then discussed, together with the digital computer techniques for flight simulation, the evolution of motion systems, and various visual systems for producing 'out-the-window' visual scenes, with particualr attention given to the Dome Display and the Helmet Mounted Display. Also discussed are data problems, the programming language, regulation of simulators, international standards, and the Advance Qualification Program regulations being presently developed by simulator manufacturers and airlines. AIAA

A93-52655#
METHODOLOGY FOR INTEGRATION OF DIGITAL CONTROL LOADERS IN AIRCRAFT SIMULATORS
AMNON KATZ and MARC F. SCHAMLE (Alabama Univ., Tuscaloosa) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 36-43. Research supported by FAA and Univ. of Alabama refs
(AIAA PAPER 93-3551) Copyright

A procedure is defined and demonstrated for programming a digital control loader in a flight simulator. The loader makes up for the difference in control force between simulator and aircraft. Aerodynamic forces, inertial effects and artificial feel systems in the aircraft are all included. Inertial effects and artificial feel systems in the simulator, if any, are accounted for.

A93-52665#
VISUAL WEATHER SIMULATION USING METEOROLOGICAL DATABASES
BRUCE MONTAG (Southwest Research Inst., San Antonio, TX) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 114-122. refs
(AIAA PAPER 93-3566) Copyright

This paper presents the results of an internal research program at Southwest Research Institute for the development of a visual weather simulation and modeling system for flight training applications. This weather simulation system concept, first presented at the 1990 AIAA Flight Simulation Technology Conference, provides the means to correlate and synchronize all weather-related cues presented to the aircrew. The approach provides for direct correlation between out-the-window visual weather scenes, weather-processing sensor avionics displays, and aircraft handling qualities through the use of a unified meteorological database. By ensuring dynamic weather cue correlation across all simulator subsystems, this technique enables simulator instruction in weather-related flying to be highly transferable to in-flight, mission-oriented situations. This research effort produced a unique method for generating real-time fly-through weather conditions on a polygon-based visual system. The model architecture also supports sensor simulation for driving forward-look wind profiling models and cockpit displays. Since the weather model is driven by gridded-field, digital meteorological data, aircrews can learn and practice line-oriented weather avoidance skills in a realistic simulated weather environment. Author (revised)

A93-52668#
A PRIMARY FLIGHT DISPLAY FOR FOUR-DIMENSIONAL GUIDANCE AND NAVIGATION INFLUENCE OF TUNNEL SIZE AND LEVEL OF ADDITIONAL INFORMATION ON PILOT PERFORMANCE AND CONTROL BEHAVIOUR
E. THEUNISSEN (Delft Univ. of Technology, Netherlands) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 140-146. refs
(AIAA PAPER 93-3570) Copyright

A perspective display has been developed which integrates primary flight symbology with guidance and short-term navigation information. This serves to keep the pilot in the loop in a four-dimensional ATC environment, and makes use of his ability to oversee complex problems at a glance. The display can be used for both manual and for supervisory control, and has been implemented in the moving-base flight simulator of the Delft University of Technology. Several parameters in a perspective display can be used to influence pilot performance and control behavior. To gain more insight in the underlying relations, an experiment has been conducted to determine the influence of tunnel size, flightpath vector and flightpath predictor configurations on pilot performance and control behavior. It was found that a smaller tunnel yields better performance, while control behavior can be kept at a constant level by introduction of a flightpath predictor.

A93-52670#
THE DEVELOPMENT OF SIMONA - A SIMULATOR FACILITY FOR ADVANCED RESEARCH INTO SIMULATION TECHNIQUES, MOTION SYSTEM CONTROL AND NAVIGATION SYSTEMS TECHNOLOGIES
S. K. ADVANI (Delft Univ. of Technology, Netherlands) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 156-166. Research supported by NWO refs
(AIAA PAPER 93-3574) Copyright

The design and development of a new-technology six-degrees-of-freedom research simulator at the Delft University of Technology is described. This simulator will incorporate an advanced hydraulic motion system and a light-weight moving platform for outstanding dynamic performance. The simulator will become the core of the new International Centre for Research in Simulation, Motion and Navigation Technologies, or 'SIMONA'. Fundamental research in the SIMONA facility will be aimed towards the development of simulation modeling techniques, for the refinement of motion system control, and for investigations into pilot interactions in realistic navigation environments. This simulator, now under construction, can be configured to represent a wide variety of vehicles including fixed and rotary-wing aircraft as well as surface vehicles for land and sea operations. This results in a variety of multidisciplinary research roles for the simulator.
Author (revised)

A93-52671*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
DEVELOPMENT AND OPERATION OF A REAL-TIME SIMULATION AT THE NASA AMES VERTICAL MOTION SIMULATOR
CHRISTOPHER SWEENEY, SHIRIN SHEPPARD, and MONIQUE CHETELAT (SYRE; NASA, Ames Research Center, Moffett Field, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 167-173. refs
(AIAA PAPER 93-3575) Copyright

The Vertical Motion Simulator (VMS) facility at the NASA Ames Research Center combines the largest vertical motion capability in the world with a flexible real-time operating system allowing research to be conducted quickly and effectively. Due to the diverse nature of the aircraft simulated and the large number of simulations conducted annually, the challenge for the simulation engineer is to develop an accurate real-time simulation in a timely, efficient manner. The SimLab facility and the software tools necessary for an operating simulation will be discussed. Subsequent sections will describe the development process through operation of the simulation; this includes acceptance of the model, validation, integration and production phases.

A93-52673#
SEMI-FULL-SCALE DYNAMIC SIMULATION COMPLEX ON THE BASIS OF CENTRIFUGE
V. M. VASILETS (Inst. of Aviation and Space Medicine, Moscow, Russia) and O. A. YAKIMENKO (Military Air Force Engineering Academy, Moscow, Russia) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 187-192.
(AIAA PAPER 93-3577) Copyright

The paper considers a structure and fundamental characteristics of semifull-scale imitative dynamic simulation complex (IDSC) on the basis of centrifuge. Capacities of the complex are illustrated graphically with some results made of different experimental works on investigation, optimization, and ergonomic justification of performances of the closed loop 'pilot-control system-aircraft-environment' with different composition of antistress facilities, different configuration of controls, and action of different flight factors. It must be emphasized that the represented results have a rather particular character, because they pursue an aim only to show IDSC capacities for imitative modeling of the investigation, design, and test of the flying-machine's specific tasks.
Author (revised)

A93-52675*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
SIMULATION MOTION EFFECT ON SINGLE AXIS COMPENSATORY TRACKING
JEFFERY A. SCHROEDER (NASA, Ames Research Center, Moffett Field, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 202-213. refs
(AIAA PAPER 93-3579) Copyright

An experiment that examined how changes in a motion platform drive filter affect pilot-vehicle performance and opinion was conducted on the NASA Ames Vertical Motion Simulator. Pilots controlled a simplified helicopter model in the vertical or the directional axis and tracked a randomly moving target aircraft in the presence of a random disturbance. With both tasks, variations from full motion to fixed-base conditions were made in the high-pass drive filter gain and natural frequency. The results indicate that vertical motion did not affect the open-loop pilot-vehicle target-tracking crossover frequency, but target-tracking phase margins improved with increased filter gain or decreased natural frequency. Vertical disturbance-rejection crossover frequency increased with decreasing filter natural frequency, while disturbance rejection phase margins improved with increasing filter gain. Vertical tracking errors increased significantly when all vertical motion was removed. No significant differences were measured among the directional configurations, which indicates that pure yaw motion cues may not be as important as previously thought in flight simulation.

A93-52676#
PILOT EVALUATIONS OF AUGMENTED FLIGHT SIMULATOR MOTION
STUART T. GARROOD and LLOYD D. REID (Toronto Univ., Downsview, Canada) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 214-221. Research supported by NSERC refs
(AIAA PAPER 93-3580) Copyright

In an earlier paper it was proposed that the turbulence induced motion of a flight simulator could be augmented without affecting the visual and instrument displays. This may be necessary if the

simulator's washout filters severely restrict its motion response to atmospheric turbulence. The present study has implemented the proposed technique on the University of Toronto Institute for Aerospace Studies Flight Research Simulator and carried out pilot evaluations for both high altitude and low altitude operations in the presence of atmospheric turbulence. The results indicate that the technique can successfully increase the simulator's motion response to turbulence in a manner that is acceptable to pilots. It was found that a simple second-order transfer function representation of the aircraft is sufficient within the motion augmentation channel. The resulting motions were judged to add to the realism of the simulation and to compare favorably with other training simulators.

A93-52679*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
PSEUDO AIRCRAFT SYSTEMS - A MULTI-AIRCRAFT SIMULATION SYSTEM FOR AIR TRAFFIC CONTROL RESEARCH
REID A. WESKE and GEORGE L. DANEK (SYRE; NASA, Ames Research Center, Moffett Field, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 234-242. refs
(AIAA PAPER 93-3585)

Pseudo Aircraft Systems (PAS) is a computerized flight dynamics and piloting system designed to provide a high fidelity multi-aircraft real-time simulation environment to support Air Traffic Control research. PAS is composed of three major software components that run on a network of computer workstations. Functionality is distributed among these components to allow the system to execute fast enough to support real-time operation. PAS workstations are linked by an Ethernet Local Area Network, and standard UNIX socket protocol is used for data transfer. Each component of PAS is controlled and operated using a custom designed Graphical User Interface. Each of these is composed of multiple windows, and many of the windows and sub-windows are used in several of the components. Aircraft models and piloting logic are sophisticated and realistic and provide complex maneuvering and navigational capabilities. PAS will continually be enhanced with new features and improved capabilities to support ongoing and future Air Traffic Control system development.

A93-52688#
HOW TO CONSIDER SIMULATION FIDELITY AND VALIDITY FOR AN ENGINEERING SIMULATOR
BODING ZHANG (China Flight Test Establishment, Xian) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 298-305. refs
(AIAA PAPER 93-3598) Copyright

Simulation fidelity and validity for an engineering simulator have always had a strong appeal to the simulation specialists and customers. Along with enhancing the engineering simulator's standing in analysis and test task, simulation test and simulator design are emphasizing the importance of simulation fidelity and validity. Based on some methods in the process of integration, testing, and acceptance for the SB-100 Flight Simulator, and a comparison between simulation testing results and the results from flight, the ways of how to consider simulation fidelity and validity for an engineering simulator are discussed. Author (revised)

A93-52754* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
INSTRUMENTATION AND TELEMETRY SYSTEMS FOR FREE-FLIGHT DROP MODEL TESTING
CHARLES R. HYDE and JEFFREY J. MASSIE (NASA, Langley Research Center, Hampton, VA) Oct. 1993 9 p. International Foundation for Telemetering, Annual International Telemetering Conference, 29th, Las Vegas, NV, Oct. 25-28, 1993, Paper refs

This paper presents instrumentation and telemetry system techniques used in free-flight research drop model testing at the NASA Langley Research Center. The free-flight drop model test technique is used to conduct flight dynamics research of high performance aircraft using dynamically scaled models. The free-flight drop model flight testing supplements research using computer analysis and wind tunnel testing. The drop models are scaled to approximately 20 percent of the size of the actual aircraft. This paper presents an introduction to the Free-Flight Drop Model Program which is followed by a description of the current instrumentation and telemetry systems used at the NASA Langley Research Center, Plum Tree Test Site. The paper describes three telemetry downlinks used to acquire the data, video, and radar tracking information from the model. Also described are two telemetry uplinks, one used to fly the model employing a ground-based flight control computer and a second to activate commands for visual tracking and parachute recovery of the model. The paper concludes with a discussion of free-flight drop model instrumentation and telemetry system development currently in progress for future drop model projects at the NASA Langley Research Center. Author (revised)

A93-52976
A PROCEDURE FOR THE THERMAL AND STRENGTH TESTING OF RADIOTRANSPARENT SHELLS [METODIKA TEPLOPROCHNOSTNYKH ISPYTANIJ RADIOPROZRACHNYKH OBOLOCHEK]
L. G. BELOZEROV, V. A. KIREEV, V. G. KREJNIN, and V. V. PIVOVAROV TsAGI, Trudy no. 11 1989 p. 81-91. In RUSSIAN refs
Copyright

The general design characteristics of radiotransparent shells and their typical operating environment are briefly examined. A procedure is then described for the thermal and mechanical testing of radiotransparent shells under conditions that closely approximate the actual operating conditions. The discussion covers the test program, loading and heating methods, methods of measurement during testing, and evaluation of the quality of radiotransparent shell testing. AIAA

A93-53625
WIND OF CHANGE
SIMON ELLIOTT Flight International (ISSN 0015-3710) vol. 144, no. 4377 July 13, 1993 p. 32, 33.
Copyright

The European Transonic Windtunnel, inaugurated on June 8, 1993, is briefly discussed. The closed-circuit tunnel design is described and a typical daily tunnel schedule is examined. AIAA

A93-53768
FLIGHT SIMULATION - AN OVERVIEW
CARL LAPISKA (CAE-Link Corp., Binghamton, NY), LARRY ROSS (McDonnell Douglas Aerospace, Huntington Beach, CA), and DON SMART (Lockheed Corp., Fort Worth, TX) Aerospace America (ISSN 0740-722X) vol. 31, no. 8 Aug. 1993 p. 14-17, 33.
Copyright

The evolution of simulation technology over the past 60 years is reviewed. Simulation based on a combination of real airframe parts and the duplication of the airframe itself in the computer matches the real aircraft well enough to replace it for training purposes. Two major technology developments of the 70s include the digital computers and the cathode ray tube (CRT) used in multifunction cockpit displays which changed the approach to simulation. By 1980 simulation was capable of providing highly credible evaluations of complete system scenarios. Recent advances in simulation encompass reconfigurable simulator technology based on deployable trainers that can be placed on ships and deployed with troops in the field, networking and new data transfer methods which make virtual battlefield possible and permit large exercises including simulated and live vehicles, and visual systems. AIAA

A93-53774
RED-HOT SIMULATION
RICHARD DEMEIS Aerospace America (ISSN 0740-722X) vol.

31, no. 8 Aug. 1993 p. 42, 43.
Copyright

A unique, large-scale, computer-controlled aircraft fire training simulator, which is currently being installed at Dallas-Ft. Worth airport, is described. Simulators offer realistic training in dealing with fires, with a safety margin never before available. Training scenarios in controlled situations consistently reproduce real-world conditions using a Specialized Aircraft Fire Trainer. AIAA

A93-54275
EUROPE'S NEW WINDTUNNEL
Aerospace (UK) (ISSN 0305-0831) vol. 20, no. 7 July 1993 p. 16-19.
Copyright

The design and behavior of the new European Transonic Windtunnel (ETW) are examined. The way that the tunnel design ensures minimal thermal distortions is shown. Test preparation at the ETW is addressed. The shorter runs that the ETW design allows are discussed, emphasizing the cost savings. AIAA

10

ASTRONAUTICS

Includes astronautics (general); astrodynamics; ground support systems and facilities (space); launch vehicles and space vehicles; space transportation; spacecraft communications, command and tracking; spacecraft design, testing and performance; spacecraft instrumentation; and spacecraft propulsion and power.

A93-52885* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
ANALYSIS OF A TURNING POINT PROBLEM IN FLIGHT TRAJECTORY OPTIMIZATION
C. GRACEY (NASA, Langley Research Center, Hampton, VA) Aug. 1989 20 p. IFAC, Workshop on Singular Perturbations and Asymptotic Methods in Systems and Control, Boston, MA, Aug. 17, 18, 1989, Paper refs

The optimal control policy for the aeroglide portion of the minimum fuel, orbital plane change problem for maneuvering entry vehicles is reduced to the solution of a turning point problem for the bank angle control. For this problem a turning point occurs at the minimum altitude of the flight, when the flight path angle equals zero. The turning point separates the bank angle control into two outer solutions that are valid away from the turning point. In a neighborhood of the turning point, where the bank angle changes rapidly, an inner solution is developed and matched with the two outer solutions. An asymptotic analysis of the turning point problem is given, and an analytic example is provided to illustrate the construction of the bank angle control.

A93-53737* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
SIX-DEGREE-OF-FREEDOM GUIDANCE AND CONTROL-ENTRY ANALYSIS OF THE HL-20
RICHARD W. POWELL (NASA, Langley Research Center, Hampton, VA) Journal of Spacecraft and Rockets (ISSN 0022-4650) vol. 30, no. 5 Sept.-Oct. 1993 p. 537-542. refs
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The ability of the HL-20 lifting body to fly has been evaluated for an automated entry from atmospheric interface to landing. This evaluation was required to demonstrate that not only successful touchdown conditions would be possible for this low lift-to-drag-ratio vehicle, but also the vehicle would not exceed its design dynamic pressure limit of 400 psf during entry. This dynamic pressure constraint limit, coupled with limited available pitch-control authority at low supersonic speeds, restricts the available maneuvering capability for the HL-20 to acquire the runway. One result of this analysis was that this restrictive maneuvering capability does not allow the use of a model-following atmospheric entry-guidance algorithm, such as that used by the Space Shuttle, but instead requires a more adaptable guidance algorithm. Therefore, for this analysis, a predictor-corrector guidance algorithm was developed that would provide successful touchdown conditions while not violating the dynamic pressure constraint. A flight-control system was designed and incorporated, along with the predictor-corrector guidance algorithm, into a six-DOF simulation. which showed that the HL-20 remained controllable and could reach the landing site and execute a successful landing under all off-nominal conditions simulated. Author (revised)

A93-53738* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
EFFECT OF LIFT-TO-DRAG RATIO IN PILOT RATING OF THE HL-20 LANDING TASK
E. B. JACKSON, ROBERT A. RIVERS (NASA, Langley Research Center, Hampton, VA), and MELVIN L. BAILEY (Lockheed Engineering and Sciences Co., Hampton, VA) Journal of Spacecraft and Rockets (ISSN 0022-4650) vol. 30, no. 5 Sept.-Oct. 1993 p. 543-548. refs
Copyright

A man-in-the-loop simulation study of the handling qualities of the HL-20 lifting-body vehicle was made in a fixed-base simulation cockpit at NASA Langley Research Center. The purpose of the study was to identify and substantiate opportunities for improving the original design of the vehicle from a handling qualities and landing performance perspective. Using preliminary wind-tunnel data, a subsonic aerodynamic model of the HL-20 was developed. This model was adequate to simulate the last 75-90 s of the approach and landing. A simple flight-control system was designed and implemented. Using this aerodynamic model as a baseline, visual approaches and landings were made at several vehicle lift-to-drag ratios. Pilots rated the handling characteristics of each configuration using a conventional numerical pilot-rating scale. Results from the study showed a high degree of correlation between the lift-to-drag ratio and pilot rating. Level 1 pilot ratings were obtained when the L/D ratio was approximately 3.8 or higher.

A93-53745* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
HL-20 OPERATIONS AND SUPPORT REQUIREMENTS FOR THE PERSONNEL LAUNCH SYSTEM MISSION
W. D. MORRIS, NANCY H. WHITE (NASA, Langley Research Center, Hampton, VA), and RONALD G. CALDWELL (Rockwell International Corp., Space Systems Div., Downey, CA) Journal of Spacecraft and Rockets (ISSN 0022-4650) vol. 30, no. 5 Sept.-Oct. 1993 p. 597-605. refs
Copyright

The processing, mission planning, and support requirements were defined for the HL-20 lifting-body configuration that can serve as a Personnel Launch System. These requirements were based on the assumption of an operating environment that incorporates aircraft and airline support methods and techniques that are applicable to operations. The study covered the complete turnaround process for the HL-20, including landing through launch, and mission operations, but did not address the support requirements of the launch vehicle except for the integrated activities. Support is defined in terms of manpower, staffing levels, facilities, ground support equipment, maintenance/sparing requirements, and turnaround processing time. Support results were drawn from two contracted studies, plus an in-house analysis used to define the maintenance manpower. The results of the contracted studies were used as the basis for a stochastic simulation of the support environment to determine the sufficiency of support and the effect of variance on vehicle processing. Results indicate the levels of support defined for the HL-20 through this process to be sufficient to achieve the desired flight rate of eight flights per year.

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CHEMISTRY AND MATERIALS

Includes chemistry and materials (general); composite materials; inorganic and physical chemistry; metallic materials; nonmetallic materials; and propellants and fuels.

A93-52870* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
STRESS RELAXATION OF LOW PRESSURE PLASMA-SPRAYED NICRALY ALLOYS
W. J. BRINDLEY and J. D. WHITTENBERGER (NASA, Lewis Research Center, Cleveland, OH) Materials Science and Engineering, Part A - Structural Materials: Properties, Microstructures and Processing (ISSN 0921-5093) vol. A163 1993 p. 33-41. refs
Copyright

The stress relaxation behavior of three NiCrAlY alloys that are commonly used as bond coats for thermal barrier coatings (TBCs) has been directly measured. The relaxation study was conducted at temperatures of 800-1000 C and over a wide range of stresses. It was established that all three bond coat alloys relaxed quite rapidly at temperatures of 900 C and above. Since the upper use temperatures for bond coats in gas turbine engines are between 900 and 1000 C, bond coat relaxation is expected to occur in service. Therefore, relaxation of the bond coat has the potential to affect TBC life. Furthermore, the relaxation differences observed between the three alloys offers a possible explanation for the differences in TBC life observed for these bond coats. While bond coat relaxation is expected to occur for a TBC in service, the mechanism for a relaxation effect on TBC life, if it exists, is yet to be determined. Author (revised)

A93-52961
VISCOSITY OF AVIATION FUEL COMPONENTS - AROMATIC HYDROCARBONS (ALKYL BENZENES) [VYAZKOST' KOMPONENTOV AVIATSIONNYKH TOPLIV - AROMATICHESKIE UGLEVODORODY /ALKILBENZOLY/]
V. I. SKOMOROKHOV and A. F. DREGALIN Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 96-98. In RUSSIAN refs
Copyright

The objective of the study is to present accurate reliable expressions for calculating the viscosity of aromatic hydrocarbons (alkyl benzenes), which are a major component of aviation fuels. A formula is proposed for calculating the viscosity of aromatic hydrocarbons in the region close to the solidification line. In the region close to the saturation line, the use of the Frenkel formula is recommended. AIAA

A93-53419
'NO VOC' WATER-BORNE CORROSION RESISTANT PRIMERS FOR AEROSPACE BONDING APPLICATIONS
MICHAEL J. BARKER and THOMAS MOBLEY (BFGoodrich Co., Adhesive Systems Div., Brecksville, OH) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T551-T562.
Copyright

A comparative investigation has been conducted for the 'No VOC' waterborne primer, which is to be used for protecting secondary-bonding operations-involving aerospace structure surfaces, relative to the current, solvent-based industry standard primer. Lap-shear strength and T-peel strength vs temperature were evaluated for Al substrates, and No VOC was found to have low primer thickness sensitivity and high strength; durability tests results are discussed in the framework of meeting and exceeding prospective corrosion resistance standards. AIAA

A93-53420
EVALUATION OF WATER-BORNE ADHESIVE BONDING PRIMERS FOR USE ON THE ADVANCED AIRCRAFT MATERIAL ALUMINUM-LITHIUM
KAREN L. MEYLER and JOSEPH A. BRESCIA (U.S. Army, Armament Research, Development, and Engineering Center, Picatinny Arsenal, NJ) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T563-T576. refs
Copyright

A comparative study is conducted for three compositions of waterborne structural adhesive primers for Al-Li alloy surfaces. Two of these contained chromates, and one did not; the results obtained for them were compared with those of a widely employed solvent-borne primer. Attention is given to the shear strength of each primer/adhesive system, in view of wedge-crack extension tests conducted on samples in condensing humidity conditions and 60 C temperature during two weeks. Only one of the waterborne primers performed as well as the solvent-borne primer. AIAA

A93-53434
THE CHARACTERIZATION AND DEVELOPMENT OF MATERIALS FOR ADVANCED TEXTILE COMPOSITES
J. T. HARTNESS, TIMOTHY L. GREENE, and LEO E. TASKE (BASF Structural Materials, Inc., Charlotte, NC) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T776-T790.
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Work ongoing under a NASA Langley - Advanced Composite Technology (ACT) program is discussed. The primary emphasis of the work centers around the development and characterization of graphite fiber that has been impregnated with an epoxy powder. Four epoxies have been characterized in towpreg form as to their weaveability and braidability. Initial mechanical properties have been generated on each resin system. These include unidirectional as well as 8-harness satin cloth. Initial 2D and 3D weaving and braiding trials will be reported on as well as initial efforts to develop towpreg suitable for advanced tow placement.

A93-53445
PREPARATION AND CHARACTERIZATION OF CONTINUOUS FIBER REINFORCED ZIRCONIUM DIBORIDE MATRIX COMPOSITES FOR A LEADING EDGE MATERIAL
KEVIN STUFFLE, WAYNE LOUGHER (Advanced Ceramics Research, Inc., Tucson, AZ), and STEPHANIE CHANAT (Buehler Southwest Research Center, Tucson, AZ) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T935-T949. refs
(Contract N60921-90-C-0033)
Copyright

Zirconium diboride with addition of silicon carbide has been demonstrated in earlier studies to be a material with superior properties for leading edges for hypersonic atmospheric flight and reentry vehicles. However, this material is brittle and flaw sensitive, making it unreliable in such applications. Continuous fiber reinforced composites have been prepared with zirconium diboride-silicon carbide matrices, in studies concerned with improved reliability. Composites were characterized for mechanical properties, and for oxidation and ablation response in representative reentry conditions. Room temperature and elevated temperature flexure strengths, recession rate for oxidation at 1200 C, and arc-jet ablation response are reported. Author (revised)

A93-53448
THE PROPERTIES OF NEWLY DEVELOPED HIGHLY DAMAGE TOLERANT AND EASY HANDLEABLE CARBON FIBER/MODIFIED BISMALEIMIDE PREPREG SYSTEM
S. HAYASHI, M. FUKUMOTO, M. SUGIMORI (Mitsubishi Rayon Co., Ltd., Product Development Lab., Nagoya, Japan), F. SAWADA (Mitsubishi Rayon Co., Ltd., Toyama Development Lab., Japan), and H. TADA (Mitsubishi Rayon Co., Ltd., Central Research Lab., Ohtake, Japan) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T972-T982. refs
Copyright

A carbon fiber-reinforced bismaleimide-matrix composite thermosetting prepreg system has been developed with a view to prospective SST structural applications. While materials of this type generally possess good hot/wet processing properties, the matrices thus formed are inherently brittle and exhibit poor damage tolerance. A novel technique is here presented for improving damage tolerance using tough, 'fibriform' thermoplastic resins as coatings on thermoset prepreg surfaces. AIAA

A93-53451
WET LAYUP MATERIALS FOR REPAIR OF BISMALEIMIDE COMPOSITES
PAUL MEHRKAM and ROLAND COCHRAN (U.S. Navy, Naval Air Warfare Center, Warminster, PA) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T1006-T1016. refs

The U.S. Naval Air Warfare Center has conducted an evaluation of a range of candidate materials for elevated-temperature, wet layup patch composite structure repairs on high service temperature aircraft composite structures. The repair-patch materials in question would be used in field and depot-level repair at about 204 C, as in the case of bismaleimide and dicyanate ester. The evaluations gave attention to both vacuum bag processibility and resulting mechanical properties. AIAA

A93-53453* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
OVERVIEW OF NASA'S ADVANCED HIGH TEMPERATURE ENGINE MATERIALS TECHNOLOGY PROGRAM
CAROL A. GINTY and HUGH R. GRAY (NASA, Lewis Research Center, Cleveland, OH) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T1029-T1043. refs

NASA's 'HITEMP' program has been charged with development of propulsion systems technologies for next-generation civil and military aircraft, stressing high-temperature/low-density composites. These encompass polymer-matrix composites for fans, ducts, and compressor cases, and intermetallic and metallic alloy matrix composites for applications in turbine disks, blades, and vanes, and ceramic matrix composites for combustors and turbines. An overview is presented of program concerns and achievements to date. AIAA

A93-53459* National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
EVALUATION OF 2D CERAMIC MATRIX COMPOSITES IN AEROCONVECTIVE ENVIRONMENTS
SALVATORE R. RICCITIELLO, WENDELL L. LOVE (NASA, Ames Research Center, Moffett Field, CA), and ALIZA BALTER-PETERSON (Eloret Inst., Sunnivale, CA) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T1107-T1122. refs
(Contract NAS2-12996)
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An evaluation is conducted of a novel ceramic-matrix composite (CMC) material system for use in the aeroconvective-heating environments encountered by the nose caps and wing leading edges of such aerospace vehicles as the Space Shuttle, during orbit-insertion and reentry from LEO. These CMCs are composed of an SiC matrix that is reinforced with Nicalon, Nextel, or carbon refractory fibers in a 2D architecture. The test program conducted for the 2D CMCs gave attention to their subsurface oxidation. AIAA

A93-53506
ONGOING CHALLENGES FOR TITANIUM ALLOY CLEANLINESS IMPROVEMENT IN AIRCRAFT ENGINE DISK MATERIALS
CLIFFORD E. SHAMBLEN (GE Aircraft Engines, Cincinnati, OH) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M539-M545. refs
Copyright

A review is given of the need and the progress made toward obtaining improved cleanliness in titanium alloy disk materials for aircraft engine applications. Since early fatigue crack initiation from melt related inclusions can be a cause for premature component failure, these anomalies must be considered in component design and life predictions. The need to eliminate or, at least, significantly reduce the size and number of these melt related inclusions in titanium alloy disk materials is required to allow maximum utilization of alloy capabilities. An overview is given of the progress made in identifying hearth melt processes which can achieve significantly improved cleanliness levels compared to current production melt processes. The hearth melt implementation status is also described. That overview is expanded to consider the remaining challenges for both the improved cleanliness melt processes and NDE (non-destructive evaluation) required to verify the reduced inclusion content for design consideration.

A93-53598
ORIGIN OF THE CARBON RICH SLIDING INTERFACE IN ALKALI CONTAINING MATRIX-SIC NICALON FIBRE COMPOSITES
E. MOUCHON (ONERA, Chatillon, France) and PH. COLOMBAN (ONERA, Chatillon; CNRS, Thiais, France) ONERA, TP no. 1993-77 1993 6 p. EUROMAT 93 - European Conference on Advanced Materials and Processes, 3rd, Paris, France, June 8-10, 1993 refs
(ONERA, TP NO. 1993-77)

EDX, SEM, microindentation and flexural strength investigations are here conducted for the effects of the interfacial reaction zone between Nicalon SiC fibers and an alkali-containing Nasicon matrix material. A characterization is made of the reaction mechanisms/mechanical properties relationships. Attention is given to the origin of the carbon sliding interphase that is associated with this type of interface, which arises from the chemical attack of the Nicalon oxycarbide second phase by Na and P. AIAA

A93-53599
CARS TEMPERATURE MEASUREMENTS IN COMBUSTION [THERMOMETRIE DRASC APPLIQUEE AUX MILIEUX EN COMBUSTION]
P. BOUCHARDY, G. COLLIN, P. MAGRE, and M. PEALAT (ONERA, Chatillon, France) ONERA, TP no. 1993-78 1993 15 p. In FRENCH Revue de l'Institut Francais du Petrole, vol. 48, no. 3, May-June 1993, p. 247-259 refs
(ONERA, TP NO. 1993-78) Copyright

Coherent anti-Stokes Raman diffusion (CARS) has now become an operational thermometric technique. After reviewing the principle of the measurement, this article describes a CARS set-up. The

different constraints that an experimenter must cope with are described. The advantages and disadvantages of CARS spectroscopy by scanning and multiplexing are compared. The results of two experiments, one in a high-enthalpy flow and the other in a turbojet engine simulation combustion chamber, illustrate the performances obtained as well as the difficulties most often encountered. Author (revised)

A93-53602
CORROSION OF CERAMIC MATRIX COMPOSITES
T. SCANU (ONERA, Chatillon, France) and PH. COLOMBAN (ONERA, Chatillon; CNRS, Thiais, France) ONERA, TP no. 1993-82 1993 5 p. EUROMAT 93 - European Conference on Advanced Materials and Processes, 3rd, Paris, France, June 8-10, 1993 refs
(ONERA, TP NO. 1993-82)

Air stable ceramic matrix composites are promising for thermostructural applications such as aircraft engine parts. Turbine parts are subject to both sulphuric acid and sodium molten salts corrosion due to sulphate traces in engine fuel and to the NaCl air content. This paper reports a study of acidic and sodium corrosion of various aluminosilicate matrices: LAS matrices in the amorphous, beta eucryptite and beta spodumene forms; BAS matrix in the form of monoclinic and hexagonal celsian, NASICON matrix, and mullite matrix. Microstructure damages and ion exchange were analyzed by XRD, IR absorption, SEM, and Raman microprobe. Drastic corrosion is observed for beta spodumene-containing composites, with the formation or strong hydrogen bond or with the cell expansion due to Li/Na exchange. Medium acidic attack occurs for glassy LAS, beta eucryptite, BAS, and NASICON matrix composites. On the other hand, beta eucryptite, NASICON, and monoclinic celsian resist to alkaline melts. Mullite matrix composites are never corroded. Author (revised)

A93-54001
TWO AND THREE-DIMENSIONAL PREDIFFUSER COMBUSTOR STUDIES WITH AIR-WATER MIXTURE
S. N. B. MURTHY and P. LAING (Purdue Univ., West Lafayette, IN) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 276-291. refs
(Contract DTFA-92-G-002)
(ISABE 93-7025) Copyright

Water ingestion into an aircraft gas turbine engine, arising during flight under conditions of rainfall, is known to have an adverse affect on the operation and handling of the engine due to modifications in the performance of the individual components, and of the engine system. In a continuing effort on establishing performance modifications and design improvements, an experimental investigation has been performed with model two- and three-dimensional gas turbine prediffuser-combustor sectors utilizing a number of mixture and flow conditions in a tunnel operating with a two-phase, air-liquid film-droplet mixture. For given entry conditions into the prediffuser (which can be related to the exit conditions of the core compressor in a bypass engine, and, therefore, also to ingestion conditions at the engine face) the two main issues are (i) the amount of water entering the primary zone of the combustor, and (ii) the local reduction in temperature, flame-water interactions, and the vitiation caused by the vaporizing of water. Flow visualization, and estimates of water flow and droplet size in the primary zone have been undertaken under cold flow conditions. Combustion tests have been carried out to establish the effects on performance, recoverability of performance, and flameout under various flow conditions.

A93-54002
BLOWOUT OF TURBULENT DISC/PILOT STABILIZED JET DIFFUSION FLAMES
Y. H. EL-BANHAWY, A. A. EL-EHWANY (Ain Shams Univ., Cairo, Egypt), S. E. KHALIL, and A. S. ZAKHARY (Petroleum Research Inst., Cairo, Egypt) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 292-301. refs
(ISABE 93-7026) Copyright

The influences of flame operating conditions on the blowout characteristics of turbulent disc/pilot stabilized jet diffusion flames have been experimentally considered. Results of blowout velocity are obtained at different jet and stabilizer disc diameters, combustion air velocities and fuel mixture dilution with nitrogen. The use of pilot flames together with the stabilizer disc to promote flame stabilization is also considered. It is shown that the fuel jet blowout velocity increases with the increase in jet diameter, combustion air velocity, disc diameter and with employing small pilot flames. The blowout velocity is reduced with the addition of nitrogen to the fuel. The results reveal that higher percentages of nitrogen addition to the fuel are only possible for flames operating with large jet and stabilizer disc diameters and for flames operating with pilot flames.

A93-54025
A STUDY OF SELF-IGNITION OF METHANE-HYDROGEN MIXTURE FUEL INJECTED INTO HIGH ENTHALPY SUPERSONIC AIRSTREAMS
H. TAGUCHI, S. TOMIOKA, H. NAGATA, M. KONO (Tokyo Univ., Japan), and Y. UJIIE (Nihon Univ., Narashino, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 525-532. refs
(ISABE 93-7049) Copyright

In order to attain combustion of methane fuel in supersonic airstreams of relatively low temperature, hydrogen fuel was added to the fuel as a ignition promoter. In experiments, rectangular combustor with backward step was adopted, and the methane-hydrogen mixture fuel was injected into supersonic airstreams. The region where the self-ignition occurs was confirmed by high speed direct photographs, and self-ignition characteristics were investigated with parameters of equivalence ratio and fraction of hydrogen in the fuel. The injection form was refined with use of the obtained results to attain self-ignition with low fraction of hydrogen. The combustion of methane-hydrogen mixture fuel was compared with that of hydrogen fuel by using wall static pressure distributions and OH/CH emission images of the flame. It is confirmed that the combustion of methane fuel in the airstreams is obtained by addition of hydrogen fuel, and it is argued that the self-ignition in refined injection form is obtained under same conditions as that of hydrogen fuel, independently of the fraction of hydrogen in total injected fuels. The static pressure distribution and the flame shape in methane-hydrogen mixture fuel case were similar to those in hydrogen fuel case. Author (revised)

A93-54057
HIGH DENSITY STRAINED HYDROCARBON FUELS FOR AIR BREATHING PROPULSION
GABRIEL D. ROY (U.S. Navy, Office of Naval Research, Arlington, VA) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 831-837. refs
(ISABE 93-7081) Copyright

A new class of high density hydrocarbon fuels with strained molecules are being considered for utilization in the propulsion systems for ramjets and cruise missiles. These fuels have the potential of increasing substantially their range. However, there are several scientific issues to be resolved before these fuels can be utilized. Such issues are addressed in a recently initiated research program by the Office of Naval Research. Synthesis routes of these fuels have been established, and preliminary property characterization, and droplet combustion studies have been done. Fundamental studies are undertaken to understand the strain energy release mechanisms, and soot generation and transport in premixed and diffusion flames, and its control. Author (revised)

A93-54241
REINFORCEMENT OF THE F-111 WING PIVOT FITTING WITH A BORON/EPOXY DOUBLER SYSTEM - MATERIALS ENGINEERING ASPECTS
A. A. BAKER, R. J. CHESTER, M. J. DAVIS, J. D. ROBERTS, and J. A. RETCHFORD (Defence Science and Technology Organisation, Aeronautical Research Lab., Fishermens Bend, Australia) Composites (ISSN 0010-4361) vol. 24, no. 6 Sept. 1993 p. 511-521. refs
Copyright

Local regions in the D6ac steel F-111 wing pivot fitting suffer plastic deformation during the cold proof test employed to screen out flaws in the steel components of the airframe. This deformation produces residual stresses which can lead to a fatigue cracking problem in service. This paper describes materials engineering aspects of a program undertaken at the DSTO Aeronautical Research Laboratory to develop an advanced fiber composite doubler system aimed at reducing the strain in these regions during the cold proof test, and also to reduce cyclic strain during subsequent operation of the aircraft. The doubler system chosen is boron/epoxy (over 120 plies thick) bonded with a structural film adhesive. Aspects described include selection and characterization of composite and adhesive bonding system, doubler fabrication and application technology, and evaluation of a representative doubler specimen. Use of the doubler system was demonstrated to reduce the strain in the critical regions by over 30 percent, confirming design predictions. Author (revised)

A93-54250
DEVELOPMENT OF MIL-H-53119, -54 C TO 175 C HIGH-TEMPERATURE NONFLAMMABLE HYDRAULIC FLUID FOR AIR FORCE SYSTEMS
LOIS GSCHWENDER, CARL E. SNYDER, JR., and SHASHI K. SHARMA (USAF, Wright Lab., Wright-Patterson AFB, OH) Lubrication Engineering (ISSN 0024-7154) vol. 49, no. 8 Aug. 1993 p. 621-630. STLE, Annual Meeting, 46th, Montreal, Canada, Apr. 29-May 2, 1991 refs
Copyright

A nonflammable hydraulic fluid for -54 to 135 C operation has been previously developed based on a chlorotrifluoroethylene oligomer (CTFE) base fluid formulated with performance improving additives, a proprietary antiwear additive, now herein described, and a rust inhibitor, a specially prepared barium dinonylnaphthalene sulfonate (BSN). New requirements for advanced high performance aircraft led to a new fluid capable of operating from -54 to 175 C. The earlier nonflammable hydraulic fluid was limited in thermal stability to 135 C by the rust inhibitor. This paper describes research and development leading to a successful formulation consisting of the same CTFE base fluid, the same antiwear additive, and a new zinc-based sulfonate antirust additive. Validation using an actual state-of-the-art hydraulic pump was successfully accomplished at 135 C, and the data are presented.
Author (revised)

12

ENGINEERING

Includes engineering (general); communications; electronics and electrical engineering; fluid mechanics and heat transfer; instrumentation and photography; lasers and masers; mechanical engineering; quality assurance and reliability; and structural mechanics.

A93-52659*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
A HIGH FIDELITY VIDEO DELIVERY SYSTEM FOR REAL-TIME FLIGHT SIMULATION RESEARCH
DANIEL A. WILKINS and CARL C. ROACH (SYRE; NASA, Ames Research Center, Moffett Field, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 68-73.
(AIAA PAPER 93-3558) Copyright

The Flight Systems and Simulation Research Laboratory (Simlab) at the NASA Ames Research Center, utilizes an extensive network of video image generation, delivery, processing, and display systems coupled with a large amplitude Vertical Motion Simulator (VMS) to provide a high fidelity visual environment for flight simulation research. This paper will explore the capabilities of the current Simlab video distribution system architecture with a view toward technical solutions implemented to resolve a variety of video interface, switching, and distribution issues common to many simulation facilities. Technical discussions include a modular approach to a video switching and distribution system capable of supporting both coax and fiber optic video signal transmission, video scan conversion and processing techniques for lab observation and recording, adaptation of image generation and display system video interfaces to industry standards, an all raster solution for 'glass cockpit' configurations encompassing Head up, Head-down, and Out-the-Window display systems.

A93-52667#
TERRAIN MODELING FOR REAL-TIME PHOTO-TEXTURE BASED VISUAL SIMULATION
VENKAT DEVARAJAN and DONALD E. MCARTHUR (Texas Univ., Arlington) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 133-139. refs
(AIAA PAPER 93-3607) Copyright

This paper describes a method for terrain modeling for a real-time phototexture-based visual simulation, in which the terrain is modeled with a set of polygons and organized as a graph with each node corresponding to a polygon. The methods, algorithms, and data structures required to represent terrain elevation for the image generating system are discussed. Particular attention is given to the problem of selection of the required subset of the polygon data base. AIAA

A93-52677#
REPRESENTATION OF VEHICLE LOCATION IN NETWORKED SIMULATIONS
KUO-CHI LIN, BRIAN GOLDIEZ, and HUAT NG (Central Florida Univ., Orlando, FL) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 222-226. refs
(AIAA PAPER 93-3582) Copyright

In a networked simulation environment, it is vital to assure that all vehicles maintain a consistent representation of the geometry between themselves and between vehicles and the terrain over which they operate. Hence, all vehicles should be able to convert their position and orientation to common coordinates. Three coordinate systems, geocentric, geodetic, and topocentric, and the transformation from one system to another are analyzed.

A93-52695#
TEXTURE AS A VISUAL CUEING ELEMENT IN COMPUTER IMAGE GENERATION. I - REPRESENTATION OF THE SEA SURFACE
GREG BOOKOUT (Digital Visions, Mt. Shasta, CA) and JOHN SINACORI (Montallegro Applied Sciences, Inc., Pebble Beach, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 341-347. refs
(AIAA PAPER 93-3560) Copyright

The objective of this paper is to advance hypotheses about texture as a visual cueing medium in simulation and to provide guidelines for data base modelers in the use of computer image generator resources to provide effective visual cues for simulation

purposes. The emphasis is on a texture decoration of the earth's surface data base in order to support low-level flight, i.e., flight at elevations above the surface of 500 feet or less. The appearance of the surface of the sea is the focus of this paper. The physics of the sea's appearance are discussed and guidelines are given for its representation for sea states from 0 (calm) to 5 (fresh breeze of 17-21 knots and sixfoot waves, peak-to-trough). The viewpoints considered vary from 500 feet above the mean sea surface to an altitude just above the wave crests.

A93-52751* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
PROGRESS TOWARDS UNDERSTANDING AND PREDICTING HEAT TRANSFER IN THE TURBINE GAS PATH
ROBERT J. SIMONEAU and FREDERICK F. SIMON (NASA, Lewis Research Center, Cleveland, OH) International Journal of Heat and Fluid Flow (ISSN 0142-727X) vol. 14, no. 2 June 1993 p. 106-128. refs
Copyright

A new era is dawning in the ability to predict convection heat transfer in the turbine gas path. We feel that the technical community now has the capability to mount a major assault on this problem, which has eluded significant progress for a long time. In this paper we hope to make a case for this bold statement by reviewing the state of the art in three major and related areas, which we believe are indispensable to the understanding and accurate prediction of turbine gas path heat transfer: configuration-specific experiments, fundamental physics and model development, and code development. We begin our review with the configuration-specific experiments, whose data have provided the big picture and guided both the fundamental modeling research and the code development. Following that, we examine key modeling efforts and comment on what will be needed to incorporate them into the codes. In this region we concentrate on bypass transition, 3D endwalls, and film cooling. We then review progress and directions in the development of computer codes to predict turbine gas path heat transfer. Finally, we cite examples and make observations on the more recent efforts to do all this work in a simultaneous, interactive, and more synergistic manner. We conclude with an assessment of progress, suggestions for how to use the current state of the art, and recommendations for the future. Author (revised)

A93-52939
A NONLINEAR FINITE ELEMENT OF AN ARBITRARY BEAM [NELINEJNYJ KONECHNYJ EHLEMENT PROIZVOL'NOGO BRUSA]
YU. V. SKOVRTSOV and KH. S. KHAZANOV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 9-12. In RUSSIAN refs
Copyright

A finite element of a curvilinear beam is proposed which can be used for the modeling of aircraft frames, spars, and stringers. The element is developed by using the hypothesis of thin sections. The finite element model is based on an isoparametric formulation. Geometrical nonlinearity is considered in the context of the mean deflection theory. AIAA

A93-52950
EFFECT OF ROTATION ON HEAT TRANSFER AND HYDRAULIC RESISTANCE IN THE RADIAL COOLING CHANNELS OF TURBINE ROTOR BLADES [VLIYANIE VRASHCHENIYA NA TEPLOOBMEN I GIDRAVLICHESKOE SOPROTIVLENIE V RADIAL'NYKH OKHLAZHDAYUSHCHIKH KANALAKH RABOCHIKH LOPATOK TURBIN]
K. M. ISKAKOV, O. V. TRUSHIN, M. I. TSAPLIN, and YU. S. SHATALOV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 55-58. In RUSSIAN refs
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Results of a modeling study indicate that rotation significantly (up to 60 percent) changes local heat transfer and increases, by a factor of 5-6, hydraulic resistance in the smooth radial channels of turbine rotor blades with a low-pressure cooling system. The results of the study have been used in the design of a turbine cooling system for a turbofan engine. AIAA

A93-52968
CALCULATION OF SANDWICH PLATES WITH POLYMER COMPOSITE SKINS UNDER CONDITIONS OF HIGH HUMIDITY [RASCHET TREKHSLOJNYKH PLASTIN S OBSHIVKAMI IZ POLIMERNYKH KOMPOZITSIONNYKH MATERIALOV, NAKHODYASHCHIKHSYA V USLOVIYAKH POVYSHENNOJ VLAZHNOSTI]
I. B. MISHULIN TsAGI, Trudy no. 11 1989 p. 18-28. In RUSSIAN refs
Copyright

An engineering method is presented for estimating the temperature gradients, moisture concentration gradients, and changes in stresses and deflections induced by these gradients in sandwich plates with heat-insulation coatings under conditions of high ambient temperatures and humidity. In particular, attention is given to ambient conditions that vary slowly in time, simulating typical airport storage conditions. Results of calculations are presented for sandwich panels with load-bearing layers of a carbon composite and an organic fiber composite. AIAA

A93-52973
DESIGN AND FABRICATION OF PANELS WITH CUTOUTS [OSOBENNOSTI PROEKTIROVANIYA I IZGOTOVLENIYA PANELEJ S VYREZAMI]
V. F. KUT'INOV, A. A. DUDCHENKO, V. A. KOZLOV, and V. I. REZNICHENKO TsAGI, Trudy no. 11 1989 p. 58-62. In RUSSIAN refs
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A method is presented for determining the shape of a cutout and the surface of a cutout reinforcement element that would guarantee the retention of the undisturbed state of the panel and compatibility of displacements in the panels and those of the reinforcement element. The method makes it possible to reduce the reinforcement mass and to optimize the shape of the cutout and that of the reinforcement element. The validity of the approach is supported by tensile test results for metal/composite sandwich panels with a reinforced round hole. AIAA

A93-52975
AN EXPERIMENTAL STUDY OF REINFORCED PANELS OF COMPOSITE MATERIALS [EHKSPERIMENTAL'NOE ISSLEDOVANIE PODKREPLENNYKH PANELEJ IZ KOMPOZITSIONNYKH MATERIALOV]
V. M. ANDRIENKO, A. A. IONOV, and L. V. KOPYLOVA TsAGI, Trudy no. 11 1989 p. 73-80. In RUSSIAN refs
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The strength and stability characteristics of reinforced panels of composite materials are examined with particular reference to the structural applications of high-strength and high-modulus composites in flight vehicles. Experimental and analytical data are presented on the stability and strength of carbon composite panels of different types. The panels considered include panels reinforced by closed-profile elements, panels with open-type reinforcement elements, and sandwich panels with a corrugated core. The weight efficiency of composite panels is estimated. AIAA

A93-52979
A FINITE ELEMENT FOR MODELING SKINS OF COMPOSITE MATERIALS [KONECHNYJ EHLEMENT DLYA MODELIROVANIYA OBSHIVOK IZ KOMPOZITSIONNYKH MATERIALOV]
I. V. KAZIMIROV TsAGI, Trudy no. 11 1989 p. 114-120. In RUSSIAN refs
Copyright

A finite element is proposed for implementing a model of a reinforced orthotropic shell under plane stress loading. The element is obtained using a linear formulation, with bilinear approximation of the unknown displacements within the element. The element has the shape of an arbitrary convex rectangle and consists of

three layers: a skin and two stringer layers. The application of the finite element is illustrated by examples which demonstrate the sufficient accuracy of the element for practical purposes. AIAA

A93-53224
FLUTTER ANALYSIS OF STIFFENED LAMINATED COMPOSITE PLATES AND SHELLS IN SUPERSONIC FLOW
CHUNG-LI LIAO and YEE-WIN SUN (National Taiwan Inst. of Technology, Taipei) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1897-1905. refs
Copyright

This paper investigates the flutter instability of stiffened and nonstiffened laminated composite plates and shells subjected to aerodynamic forces in the supersonic flow. The equation of motion of the present problem is formulated using Hamilton's principle. Then, using the finite element method along with three-dimensional degenerated shell elements and three-dimensional degenerated curved beam elements, the equation of motion is discretized. The characteristic equation to study the flutter instability of the present problem is obtained from the previous finite element equation of motion. Finally, natural frequency, critical dynamic pressure, and corresponding flutter mode shape are found by solving the characteristic equation. The effects of various parameters, such as skew angle, lamination scheme, subtended angle, and stiffening scheme on the flutter instability of stiffened and nonstiffened plates and shells in the supersonic flow are demonstrated through the numerical examples.

A93-53329
MATHEMATICAL MODELING OF THE THREE-DIMENSIONAL TEMPERATURE FIELDS OF TURBINE BLADES [MATEMATICHESKOE MODELIROVANIE TREKHMERNYKH TEMPERATURNYKH POLEJ TURBINNYKH LOPATOK]
V. M. EPIFANOV and I. V. STANKEVICH (Moskovskij Gosudarstvennyj Tekhnicheskij Univ., Moscow, Russia) Rossijskaya Akademiya Nauk, Doklady (ISSN 0869-5652) vol. 330, no. 3 May 1993 p. 318-320. In RUSSIAN refs
Copyright

A method for the numerical modeling of three-dimensional nonlinear unsteady heat conduction problems is described which is based on the finite element method. The method and the algorithms proposed here have been implemented in a set of application software, GERMES-02-T. The software has been used in a numerical investigation of the thermal state of a cooled turbine blade made of ZhS26VSNK alloy and a noncooled carbon/ceramic composite blade. AIAA

A93-53395* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
DESIGN FOR CYCLIC LOADING ENDURANCE OF COMPOSITES
MICHAEL C. SHIAO (Sverdrup Technology, Inc., Brook Park, OH) and PAPPU L. N. MURTHY (NASA, Lewis Research Center, Cleveland, OH) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T241-T255. refs
Copyright

The present paper describes the application of the computer code IPACS (Integrated Probabilistic Assessment of Composite Structures) to air craft wing type structures. The code performs a complete probabilistic structural analysis for composites taking into account the uncertainties in geometry, boundary conditions, material properties, laminate lay-ups and loads. Results of the analysis are presented in terms of cumulative distribution functions (CDF) and probability density function (PDF) of life of a wing type composite structure under different hygrothermal environments subjected to random pressure. The sensitivity of fatigue life to a number of critical structural/material variables is also computed from the analysis.

A93-53429
STRUCTURAL APPLICATIONS OF AVIMID K3B LDF THERMOPLASTIC COMPOSITES
ANDREW P. PERRELLA (Du Pont Composites, Wilmington, DE) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T711-T723. refs
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Composite applications on advanced aircraft require lightweight, high performance, tough material systems which are capable of operating at high service temperatures. These composite systems must also be producible and cost effective. Avimid K3B composite materials and related process and part manufacturing technologies offers a unique solutions to these requirements. The objective of this paper is to describe selected Avimid K3B processing approaches such as Long Discontinuous Fiber thermoforming and fusion bonding. A review of the Avimid K3B F-16 Strake Door Joint Development Program is presented. This program successfully developed, built and structurally validated a flight demonstration component using these materials and manufacturing methods. Author (revised)

A93-53452
REPAIR MATERIALS AND PROCESSES FOR THE MD-11 COMPOSITE TAILCONE
TETSUYA YAMAMOTO (Mitsubishi Heavy Industries, Ltd., Nagoya, Japan) and GERARD R. BONNAR (McDonnell Douglas Corp., Long Beach, CA) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T1017-T1028.
Copyright

This paper describes field and depot level repair methods for the MD-11 Composite Tailcone. The repair materials, processing methods, and mechanical properties of the test specimens and subcomponents are discussed. According to recent tests, the dry carbon cloth and the liquid resin matrix that can be cured under 93 C have better processing and mechanical properties than the 121 C curing prepregs and film adhesives. The moisture in the parent CFRP is the main cause of creating voids in the adhesive layer during the 121 C/vacuum pressure cure cycle. The lower processing temperature (wet layup) showed better results than higher processing temperature (prepreg/adhesive layup) for composite repair. Author (revised)

A93-53468* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
THE CHEMISTRY OF SAUDI ARABIAN SAND - A DEPOSITION PROBLEM ON HELICOPTER TURBINE AIRFOILS
JAMES L. SMIALEK, FRANCES A. ARCHER, and RALPH G. GARLICK (NASA, Lewis Research Center, Cleveland, OH) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M63-M77. refs
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Operations in the Persian Gulf have exposed military helicopter turbines to excessive amounts of ingested sand. Fine particles, less than 10 microns, are able to bypass the particle separators and enter the cooling and combustion systems. The initial sand chemistry varies by location, but is made up of a calcium aluminum silicate glass, SiO_2 low quartz, $(Ca,Mg)CO_3$ dolomite, $CaCO_3$ calcite, and occasionally NaCl rocksalt. The sand reacts in the hot combustion gases and deposits onto the turbine vanes as $CaSO_4$, glass, and various crystalline silicates. Deposits up to 5 mm thick have been collected. Although cooling hole plugging is a considerable problem, excessive corrosion is not commonly observed due to the high melting point of $CaSO_4$.

A93-53493
TOTAL QUALITY MANAGEMENT OF FORGED PRODUCTS THROUGH FINITE ELEMENT SIMULATION
U. CHANDRA, S. RACHAKONDA, and S. CHANDRASEKHARAN (Concurrent Technologies Corp., Johnstown, PA) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M379-M393. Research supported by U.S. Navy refs
Copyright

The paper reviews the entire thermo-mechanical history experienced by a complex shaped, high strength forged part during all stages of its manufacturing process, i.e. forging, heat treatment, and machining. It examines the current practice of selecting the process parameters using finite element simulation of forging and quenching operations on an individual basis. Some recent work related to the simulation of aging and machining operations is summarized. The capabilities of several well-known finite element codes for these individual simulations are compared. Then, an integrated simulation approach is presented which will permit the optimization of process parameters for all operations, as opposed to a single operation. This approach will ensure a total quality management of forged products by avoiding costly problems which, under the current practice, are detected only at the end of the manufacturing cycle, i.e. after final machining.

A93-53498
CASE STUDIES - APPLICATIONS OF LASER SYSTEMS FOR CUTTING AND WELDING AEROSPACE PARTS
TERRY L. VANDERWERT (Lumonics Corp., Laserdyne Div., Eden Prairie, MN) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M439-M449.
Copyright

This paper presents three case studies of current industrial applications of laser systems, showing that multiaxis laser machining systems are satisfying demands for reduced part-production costs, higher quality, greater flexibility, and faster turnaround on prototype and production aerospace parts. For example, laser cutting has replaced milling for trimming a deep-drawn gas turbine part and increased throughput from 18 pieces per day to 18 pieces in 30 minutes. The case studies described include that of a job shop supplying aircraft engine parts, and those of two aircraft manufacturers. AIAA

A93-53499
FRICTION SURFACING AND LINEAR FRICTION WELDING
E. D. NICHOLAS (TWI, Forge and Resistance Processes Dept., Cambridge, United Kingdom) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M450-M463. refs
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The paper describes the development of the friction-surfacing and linear-friction welding technologies, with particular attention given to the equipment evolution and the application of the processes and advanced materials (such as intermetallics, metal-matrix composites (MMCs), ODS alloys, and powder metallurgy alloys) for the aerospace industry. The use of friction surfacing to modify the surface material with MMCs, to repair defects by plugging, and manufacture/reprocess materials is described. AIAA

A93-53503
CLEAN MELTING AND THE REMOVAL OF DEFECTS FROM AERO-ENGINE MATERIALS
A. MITCHELL (British Columbia Univ., Vancouver, Canada) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M504-M516. Research supported by Nickel Development Inst. and NSERC refs
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The paper discusses the metallurgical reasons for introducing the electron-beam-melting technique to achieve clean melting and to remove defects from superalloys and titanium alloys used in spacecraft engine components. Attention is given to the types of defects encountered in superalloy structures, the types of inclusions and their origin and treatment, the solidification defects, and the particular techniques used to avoid defects. It is concluded that the electron-beam technology is at a stage where the method is viable, from both an economical and technical viewpoints. In spite of the fact that the electron-beam melting brings its own problems in regard to reliable operation, it holds the promise of producing alloys with a level of property reliability far beyond that available at present. AIAA

A93-53514
THE APPLICATION OF DIFFUSION BONDING IN THE MANUFACTURE OF AEROENGINE COMPONENTS
J. A. FITZPATRICK (Rolls-Royce, PLC, Aerospace Group, Barnoldswick, United Kingdom) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M622-M628. refs
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Rolls-Royce has developed and optimized diffusion bonding processes for the manufacture of advanced titanium alloy aeroengine structures and components. Both categories of the joining technique - 'liquid-phase' and 'solid-state' - are being applied in the production of both static fabrications and complex rotating parts. In order to utilize diffusion bonding processes in a production environment, the process parameters which contribute to consistent formation of joints of the required strength have been critically examined. Process variables include temperature, pressure, time, surface roughness and, in the case of liquid-phase diffusion bonding, interlayer composition, density and thickness. Mechanical testing (tensile, impact and fatigue) complemented by metallography has predominantly been used to identify the permitted variations in the processes for the realistic and economical production manufacture of high quality lightweight aeroengine fabrications. The development of a high integrity bond via optimized diffusion bonding processes has been fundamental to the development of Rolls-Royce's unique wide chord fan design concept.

A93-53515
DURABILITY PROPERTIES FOR ADHESIVELY BONDED STRUCTURAL AEROSPACE APPLICATIONS
D. K. SHAFFER, GUY D. DAVIS, DAVID K. MCNAMARA, TUSHAR K. SHAH, and ATUL DESAI (Martin Marietta Labs., Baltimore, MD) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 3 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. M629-M644. refs
Copyright

Causes of bond failures in adhesively joined aerospace components are investigated using the results of stepwise multidisciplinary failure analysis of a wide range of conventional (metal/adhesive) and unconventional (nonmetal/adhesive) interfacial disbonds that are encountered in real-world production and quality assurance environments. It is shown that the primary causes of adhesive bond degradation include poor surface preparation, contamination of adherend surfaces, moisture or aggressive ion ingress into the bonded joint, and improper curing or composition of the adhesive formulation. AIAA

A93-53585*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
MEASUREMENTS AND COMPUTATIONAL ANALYSIS OF HEAT TRANSFER AND FLOW IN A SIMULATED TURBINE BLADE INTERNAL COOLING PASSAGE
LOUIS M. RUSSELL (NASA, Lewis Research Center, Cleveland, OH), DOUGLAS R. THURMAN (U.S. Army, Vehicle Propulsion Directorate; NASA, Lewis Research Center, Cleveland, OH), PATRICIA S. SIMONYI (Sverdrup Technology, Inc., Lewis Research Center Group, Brook Park, OH), STEVEN A. HIPPENSTEELE, and PHILIP E. POINSATTE (NASA, Lewis Research Center, Cleveland, OH) Jun. 1993 28 p. AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference and Exhibit, 29th, Monterey, CA, June 28-30, 1993 Previously announced in STAR as N93-31647 refs
(AIAA PAPER 93-1797) Copyright

Visual and quantitative information was obtained on heat transfer and flow in a branched-duct test section that had several significant features of an internal cooling passage of a turbine blade. The objective of this study was to generate a set of experimental data that could be used to validate computer codes for internal cooling systems. Surface heat transfer coefficients and entrance flow conditions were measured at entrance Reynolds numbers of 45,000, 335,000, and 726,000. The heat transfer data were obtained using an Inconel heater sheet attached to the surface and coated with liquid crystals. Visual and quantitative flow field results using particle image velocimetry were also obtained for a plane at mid channel height for a Reynolds number of 45,000. The flow was seeded with polystyrene particles and illuminated by a laser light sheet. Computational results were determined for the same configurations and at matching Reynolds numbers; these surface heat transfer coefficients and flow velocities were computed with a commercially available code. The experimental and computational results were compared. Although some general trends did agree, there were inconsistencies in the temperature patterns as well as in the numerical results. These inconsistencies strongly suggest the need for further computational studies on complicated geometries such as the one studied.

A93-53596
HIGH TEMPERATURE HEAT EXCHANGERS FOR GAS TURBINES AND FUTURE HYPERSONIC AIR BREATHING PROPULSION
PATRICK AVRAN and PIERRE BERNARD (ONERA, Chatillon, France) ONERA, TP no. 1993-75 1993 18 p. International Conference on Aerospace Heat Exchanger Technology, 1st, Palo Alto, CA, Feb. 15-17, 1993 refs
(ONERA, TP NO. 1993-75)

After surveying the results of ONERA's investigations to date of metallic and ceramic heat exchangers applicable to automotive and aircraft powerplants, which are primarily of finned-tube counterflow configuration, attention is given to the influence of heat-exchanger effectiveness on fuel consumption and exchanger dimensions and weight. Emphasis is placed on the results of studies of cryogenic heat exchangers used by airbreathing hypersonic propulsion systems. The numerical codes developed by ONERA for the modeling of heat exchanger thermodynamics are evaluated. AIAA

A93-53776
FINITE ELEMENT ANALYSIS OF NATURAL VIBRATIONS OF AN AEROPLANE WITH ASYMMETRIC VARIABLE WING GEOMETRY
J. BLASZCZYK (Military Technical Academy, Warsaw, Poland) Journal of Technical Physics (ISSN 0324-8313) vol. 34, no. 1 1993 p. 79-100. refs
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The paper considers a dynamic model of an airplane with an airfoil which can rotate in its plane about a cylindrical joint located on the fuselage. In the general case, the airplane under consideration is an asymmetric structure, which means the existence of a coupling between longitudinal and lateral motions. Equations of dynamic equilibrium of deformable assemblies are established by means of the Zienkiewicz (1971) finite element technique and the multistage synthesis technique of Dzygadlo and Blaszczyk (1981). The vibration spectrum of an airplane of such configuration is calculated assuming uniform distribution of the mass and the elastic parameters of assemblies, if the rotation angle of the wing varies between 0 and 70 deg. Author (revised)

A93-53810
THE REDUCTION OF SKIN FRICTION BY RIBLETS UNDER THE INFLUENCE OF AN ADVERSE PRESSURE GRADIENT
F. T. M. NIEUWSTADT, W. WOLTHERS, H. LEIJDENS (Delft Technical Univ., Netherlands), K. KRISHNA PRASAD, and A. SCHWARZ-VAN MANEN (Eindhoven Technical Univ., Netherlands) Experiments in Fluids (ISSN 0723-4864) vol. 15, no. 1 1993 p. 17-26. refs
Copyright

We address the effectiveness of riblets on skin friction reduction under the influence of an adverse pressure gradient. The measurements were taken in a wind tunnel. Skin friction was observed with a drag balance which has a reproducibility of better than 1 percent. The accuracy of the balance is estimated to be less than 1 percent for the case of a zero-pressure gradient and at most 3 percent for a pressure gradient. The data on skin friction reduction at a zero pressure gradient were consistent with previous results and amount to 5 percent at a dimensionless riblet width of $s(+) = 13$. We find that at all adverse pressure gradients the skin friction reduction by riblets persists. At moderate pressure gradients the reduction increases somewhat to 7 percent. The velocity profile which is also measured exhibits the characteristic shape for a boundary layer with an adverse pressure gradient and agrees well with theory. From the velocity profiles measured at two stations we estimated with the help of a momentum balance the skin friction and skin friction reduction. The results differ from the drag-balance data. Due to the poor accuracy of the momentum balance method which we estimate in our case, we conclude that the results obtained with this method are less reliable than those obtained with the drag balance. This throws some doubt on previous results on drag reduction under the influence of a pressure gradient which were based on the momentum balance method.
Author (revised)

A93-53812
PRODUCTION OF OSCILLATORY FLOW IN WIND TUNNELS
K. AL-ASMI and I. P. CASTRO (Surrey Univ., Guildford, United Kingdom) Experiments in Fluids (ISSN 0723-4864) vol. 15, no. 1 1993 p. 33-41. refs
Copyright

A method for producing oscillatory flow in open-circuit wind tunnels driven by centrifugal fans is described. Performance characteristics of a new device installed on two such tunnels of greatly differing size are presented. It is shown that sinusoidal variations of the working section flow, having peak-to-peak amplitudes up to at least 30 percent of the mean flow speed and frequencies up to, typically, that corresponding to the acoustic quarter-wave-length frequency determined by the tunnel size, can be obtained with negligible harmonic distortion or acoustic noise difficulties. A brief review of the various methods that have been used previously is included, and the advantages and disadvantages of these different techniques are highlighted. The present technique seems to represent a significant improvement over many of them.
Author (revised)

A93-53815
REYNOLDS NUMBER DEPENDENCE OF THE DRAG COEFFICIENT FOR LAMINAR FLOW THROUGH FINE-SCALE PHOTOETCHED SCREENS
T. J. O'HERN and J. R. TORCZYNSKI (Sandia National Labs., Albuquerque, NM) Experiments in Fluids (ISSN 0723-4864) vol. 15, no. 1 1993 p. 75-81. refs
(Contract DE-AC04-76DP-00789)
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The laminar steady flow downstream of fine-mesh screens is studied. Instead of woven-wire screens, high-uniformity screens are fabricated by photoetching holes into 50.8-micron-thick Inconel

sheets. The resulting screens have minimum wire widths of 50.8 microns and inter-wire separations of 254 and 318 microns for the two screens examined. A flow facility has been constructed for experiments with these screens. Air is passed through the screens at upstream velocities yielding wire width Reynolds numbers from 2 to 35. To determine the drag coefficient, pressure drops across the screens are measured using pressure transducers and manometers. Three-dimensional flow simulations are also performed. The computational drag coefficients consistently overpredict the experimental values. However, the computational results exhibit sensitivity to the assumed wire cross section, indicating that detailed knowledge of the wire cross section is essential for unambiguous interpretation of experiments using photoetched screens. Standard semiempirical drag correlations for woven-wire screens do not predict the present experimental results with consistent accuracy. Author (revised)

A93-53819
ON HOVERCRAFT OVERWATER HEAVE STABILITY

M. J. HINCHEY (Newfoundland Memorial Univ., St. John's, Canada) and P. A. SULLIVAN (Toronto Univ., Downsview, Canada) Journal of Sound and Vibration (ISSN 0022-460X) vol. 163, no. 2 May 15, 1993 p. 261-273. Research supported by NSERC and Canadian Transportation Development Centre refs

The dynamic heave stability of an air cushion vehicle or hovercraft hovering over deep water without forward motion is investigated analytically. The principal feature of the analysis is the modeling of the motion of the water surface beneath the cushion caused by fluctuations in the pressure of the cushion or cavity air. This surface motion interacts with the vehicle dynamics by modulating both the volume and exit flow area of the cushion. For analytical simplicity, the geometry chosen for study is a 2D section of a rigid wall plenum chamber; this enables exploitation of classical linear wave formulas developed by Lamb for the surface motion generated by a spatially uniform surface pressure oscillating sinusoidally in time. To assess stability characteristics, the Nyquist criterion is applied to the linearized equations. Results are presented for two cases: one is representative of a small test vehicle, and the other of a large ice-breaking platform. They show that the water surface motion significantly affects stability through both of the proposed mechanisms, with cushion exit flow area modulation usually being more important. A feature of the results is that as the weight of a vehicle decreases many stability transitions occur. This suggests that simple guidelines for avoiding instability may not exist, so that stability augmentation devices may be required for vehicles designed to hover for extended periods over water. Author (revised)

A93-53820
KELVIN-HELMHOLTZ WAVE GENERATION BENEATH HOVERCRAFT SKIRTS

P. A. SULLIVAN, C. WALSH (Toronto Univ., Downsview, Canada), and M. J. HINCHEY (Newfoundland Memorial Univ., St. John's, Canada) Journal of Sound and Vibration (ISSN 0022-460X) vol. 163, no. 2 May 15, 1993 p. 275-282. refs

When a hovercraft is hovering over water, the air flow beneath its skirts can interact with the water surface and generate waves. These, in turn, can cause the hovercraft to undergo violent self-excited heave motions. This note shows that the wave generation is due to the classical Kelvin-Helmholtz mechanism where, beyond a certain air flow rate, small waves at the air water interface extract energy from the air stream and grow.

A93-53847
THE CONSTRUCTION OF NEARLY ORTHOGONAL MULTIBLOCK GRIDS FOR COMPRESSIBLE FLOW SIMULATION

M. J. MARCHANT and N. P. WEATHERILL (Swansea Univ. College, United Kingdom) Communications in Numerical Methods in Engineering (ISSN 0748-8025) vol. 9, no. 7 July 1993 p. 567-578. Research supported by CEC refs

A method is described whereby structured multiblock meshes can be constructed from the solution of elliptic partial differential equations and which possess the property of orthogonality close to boundaries and near orthogonality within the domain. To construct grids for viscous flow simulations which have appropriate point distributions close to solid boundaries these grids are used with point redistribution formulations. The result is high-quality grids for use with both inviscid and viscous flow simulation algorithms. Examples using the approach are given, and these include grids for single and multicomponent aerofoils and bluff bodies.

A93-53881
A STUDY OF DAMAGE TOLERANCE OF THE LANDING GEAR STRUCTURE

FU-QI AN Acta Aeronautica et Astronautica Sinica (ISSN 1000-6893) vol. 14, no. 2 Feb. 1993 p. B106-B108. In CHINESE refs

A brief introduction to the study of the damage tolerance behavior of a main landing gear structure is given in this paper. The study is performed with a landing gear which involves a complete procedure from fatigue crack initiation to crack growth, residual strength and structural overall failure. First, real fatigue cracks are obtained by fatigue testing, then damage tolerance behavior is estimated. It is shown that cracks in the principal critical area are characterized by slow growth, and the crack-tolerant structure satisfies the requirement of residual strength. Improved performance in terms of safety and reliability can be obtained by using the damage tolerance method to design the landing gear structure. Author (revised)

A93-54021
ACTIVE CONTROL OF VORTEX BREAKDOWN BY A SPINNING WAVE GENERATOR

M. KIKUCHI, K. HIRANO, T. YUGE (Miyazaki Univ., Japan), and M. KUROSAKA (Washington Univ., Seattle) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 495-500. refs
(ISABE 93-7045)

The results of an experimental study on an active control of the vortex breakdown are presented. Four different modes of spinning disturbances are imposed on the vortex breakdown by a spinning wave generator, which is a device to produce, at a specified frequency, a sinusoidal wave disturbance spinning in the circumferential direction. It is shown that the $m = 0$ mode disturbances change the spiral type breakdown to the bubble type one and the $m = +1$ mode disturbances change the bubble type breakdown to the spiral one.

A93-54035
NEW APPROXIMATE METHOD OF STRESS ANALYSIS FOR BLADED ROTATING DISCS

H. KIKUCHI (Japan Defense Agency, Third Research Center, Tokyo) and ROY A. COOKSON (Cranfield Inst. of Technology, United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 623-636. refs
(ISABE 93-7059)

A new stress analysis method was presented for determining the stress distribution in a rotating bladed disk by a 2D FEM, including the effects of asymmetry of the disk cross-section, blade loading and stiffening for radial-flow imellerand axial-flow type rotors. In the present analysis the effect of blades was considered as a property of the material, i.e., equivalent density and Poisson's ratio or Young's modulus, in order to use the axisymmetric 2D finite element stress analysis software. A comparison of the stress calculated by the present method with the exact stresses of the bladed rotating disk model and those measured in photoelastic model tests was present with good agreement. Author (revised)

A93-54036
THERMAL DESIGN AND ANALYSIS OF AN EXHAUST DIFFUSER UNIT IN A CERAMIC COMPOSITE
J. D. MCCAFFERTY and J. W. HANCOCK (Glasgow Univ., United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 637-643. Research supported by Rolls-Royce, PLC and SERC refs
(ISABE 93-7060) Copyright

The exhaust diffuser unit of a modern air breathing engine has been chosen for a design study using ceramic composites. This is part of a wider research program to introduce new materials into aero-engines. Although the unit is relatively lightly stressed, it is subject to a severe thermal environment, and poses a significant test of the behavior of new materials. Material selection has been based on deformation maps, using merit parameters for strength and toughness under thermal shock. Heat transfer analysis of the conceptual design has established the thermal transients, and allowed the estimation of thermally induced stresses. The stress levels are sufficient to induce micro-cracking in ceramic composites, and has required the development of appropriate damage mechanics models.

A93-54050
STUDIES ON COOLANT PROBLEMS IN AERONAUTICAL TURBINE CASCADES
F. MARTELLI and V. MICHELASSI (Florence Univ., Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 757-765. *Research supported by CEC* refs
(ISABE 93-7074) Copyright

The investigation of the aerodynamic and heat transfer effects of cooling jets requires both experimental and numerical investigations. A project along this guideline is currently carried out in a BRITE-Euram Program. This paper intends to present some numerical results obtained with three different solvers, explicit single and multistep with and without multigridding, and various mesh arrangements, H, HOH and CH grid types. A simple procedure to treat the cooling jet at the trailing edge of a turbine blade is presented which does not require excessive grid refinement. The features of the different approaches are discussed mainly in terms of the isentropic Mach number distribution of the blade, and some conclusions are drawn on the capability of the methods developed.

A93-54052
HEAT TRANSFER AND MATERIAL TEMPERATURE CONDITIONS IN THE LEADING EDGE AREA OF IMPINGEMENT-COOLED TURBINE VANES
H. P. BERG (BMW Rolls-Royce GmbH, Oberursel, Germany), K. PFAFF (MTU Motoren- und Turbinen-Union Muenchen GmbH, Munich, Germany), and D. K. HENNECKE (Darmstadt Technical Univ., Germany) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 781-791. Research supported by MTU Motoren- und Turbinen-Union Muenchen GmbH refs
(ISABE 93-7076) Copyright

The resultant effects on the cooling effectiveness at the leading edge area of an impingement-cooled turbine vane by varying certain geometrical parameters is described with reference to local internal heat transfer coefficients determined from experiment and temperature calculations. The local heat transfer on the cooling-air side is determined experimentally with the aid of the analogy between heat- and mass transfer. The impingement cooling is provided from an inserted sheet-metal containing a single row of holes. The Reynolds Number and several of the cooling geometry parameters were varied. The results demonstrate the high local resolution of the method of measurement, which allows improved analytical treatment of the leading-edge cooling configuration. These experiments also point to the necessity of not always performing model tests under idealized conditions. This becomes very clear in the case of the tests performed on an application-oriented impingement-cooling configuration like that often encountered in engine manufacture. In conclusion, as an example, temperature calculations are employed to demonstrate the effect on the cooling effectiveness of varying the distances between insert and inner surface of the leading edge. It shows how the effectiveness of the leading edge cooling can be increased by simple geometrical measures, which results in a considerable improvement in service life. Author (revised)

A93-54053* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.
FLUID DYNAMICS AND CONVECTIVE HEAT TRANSFER IN IMPINGING JETS THROUGH IMPLEMENTATION OF A HIGH RESOLUTION LIQUID CRYSTAL TECHNIQUE
K. KIM, B. WIEDNER, and C. CAMCI (Pennsylvania State Univ., University Park) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 792-803. refs
(Contract NAG3-989; NSF CTS-89-06452)
(ISABE 93-7077) Copyright

A combined convective heat transfer and fluid dynamics investigation in a turbulent round jet impinging on a flat surface is presented. The experimental study uses a high resolution liquid crystal technique for the determination of the convective heat transfer coefficients on the impingement plate. The heat transfer experiments are performed using a transient heat transfer method. The mean flow and the character of turbulent flow in the free jet is presented through five hole probe and hot wire measurements, respectively. The flow field character of the region near the impingement plate plays an important role in the amount of convective heat transfer. Detailed surveys obtained from five hole probe and hot wire measurements are provided. An extensive validation of the liquid crystal based heat transfer method against a conventional technique is also presented. After a complete documentation of the mean and turbulent flow field, the convective heat transfer coefficient distributions on the impingement plate are presented. The near wall of the impingement plate and the free jet region is treated separately. The current heat transfer distributions are compared to other studies available from the literature. The present paper contains complete sets of information on the three dimensional mean flow, turbulent velocity fluctuations, and convective heat transfer to the plate. The experiments also prove that the present nonintrusive heat transfer method is highly effective in obtaining high resolution heat transfer maps with a heat transfer coefficient uncertainty of 5.7 percent.
Author (revised)

A93-54054
IMPINGEMENT COOLING WITH FILM COOLANT EXTRACTION IN THE AIRFOIL LEADING EDGE REGIONS
LIGUO LI and ZHAOHUI LI (Nanjing Aeronautical Inst., China) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 804-808. refs
(ISABE 93-7078) Copyright

An extensive experimental study is conducted to determine the heat transfer characteristics of arrays of air jets impinging on perforated target surfaces in turbine blade leading edge regions by six large-scale models. The relations of pressure loss and Nusselt number to jet Reynolds number are obtained in a wide range of parameter combinations of interest in cooled airfoil practice for various models, respectively. These parameter combinations are covered in a test matrix, including combinations of variations in jet Reynolds number, airfoil leading edge curvature radius-to-diameter ratio, jet pitch-to-diameter ratio, and jet impingement gap-to-diameter ratio. Author (revised)

A93-54089
LIF VISUALIZATION OF 3-DIMENSIONAL HYPERSONIC MIXING
TAKEO TOMITA, NAOKI HOMMA, TOSHI FUJIWARA, and AKIRA SAITO (Nagoya Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1167-1173. refs
(ISABE 93-7114) Copyright

Engines for hypersonic transport have problems on fuel-air mixing. To study the flows in such engines, the LIF technique is used, where PLIF (planar laser-induced fluorescence) is convenient because it gives information without any interaction with the flow. To provide a long-time-scale steady-state flow, an arcjet-type electric thruster is used, simulating the main air stream, where a side jet simulating hydrogen fuel is visualized by the iodine-LIF technique. The interaction between these two jets is shown.
Author (revised)

A93-54090
ENHANCED FUEL-AIR MIXING IN HYPERSONIC ENGINES
H. E. GILREATH, G. A. SULLINS, and R. RAUL (Johns Hopkins Univ., Laurel, MD) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1174-1181. refs
(ISABE 93-7115) Copyright

Experiments have been conducted to determine whether or not the impingement of a periodic pattern of waves on a confined supersonic shear layer enhances mixing. The shear layer studied is representative of the fuel-air mixing zone in a hypersonic engine's combustor. Wavy walls, installed on the ceiling and/or floor of a special windtunnel facility, were used to generate various impingement patterns, and the flow development was recorded using spark schlieren photography. In the absence of wave impingement, prominent quasi-coherent structures were observed in the shear layer. These structures became less distinct in the presence of the wave system while smaller scale disturbances became more pronounced.

A93-54092
TWO-DIMENSIONAL AND THREE-DIMENSIONAL MIXING FLOW STRUCTURES WITH INJECTED THROUGH SLOTTED NOZZLE AND CIRCULAR NOZZLE INTO SUPERSONIC FLOWS
SHIGERU ASO, SATOSHI OKUYAMA, SHOZO MAEKAWA, MICHIAKI TANNOU (Kyushu Univ., Fukuoka, Japan), YASUNORI ANDO, YOSHIYUKI YAMANE (Ishikawajima-Harima Heavy Industries Co., Ltd., Yokohama, Japan), and MASAHIRO FUKUDA (National Aerospace Lab., Tokyo, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1192-1201. refs
(ISABE 93-7117) Copyright

Shock wave/turbulent boundary layer interaction regions induced by gaseous secondary flows injected into supersonic flows through slot and circular nozzles have been experimentally and computationally investigated. In the experiments the flow fields are visualized by the Schlieren method and oil flow technique; surface pressure and spatial total pressure distributions are measured in the whole interaction region. The total pressure ratio, P(c)/P(0) (P(c): total pressure of injected secondary flow, P(0): total pressure of freestream) is varied, and the change of the flow field is investigated for slotted injection and circular injection. The detailed flow structures in 2D and 3D mixing flow structures have been revealed. Especially for circular injection the surface oil patterns show quite complicated flow in the interacting region with primary and secondary separations. Also quite interesting pitot pressure fields are revealed. The same flow fields have also been simulated by solving Navier-Stokes equations with turbulent modeling. Surface pressure and spatial pitot pressure distributions show quite good agreement with experiments. The results suggest that the numerical code is quite useful for supersonic mixing flows.
Author (revised)

A93-54094
CHARACTERISTICS OF HEAT EXCHANGER IN SUPERSONIC/SUBSONIC FLOWS
HIDETO MINEKAWA and TOSHI FUJIWARA (Nagoya Univ., Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1217-1221.
(ISABE 93-7119) Copyright

There are a lot of problems to overcome in developing air-breathing engines for a supersonic transporter. One of them is the high temperature of the flow entering the fan section which becomes higher as the fly Mach number increases. One effective method to overcome this is a heat exchanger placed in the air intake (which is called precooler). In this paper, the possibility and problems of the precooler are studied by resorting to the CFD method. This study pointed out that a simply shaped precooler like a flat plate can cool air only in the boundary layer; therefore, the greater part of breathed air remains high-temperature air. When the precooler is located in the supersonic flow, owing to the expansion wave from the corner of the precooler, the flow temperature near the precooler falls so that the effect of precooler drops.
Author (revised)

A93-54095
COMPACT HEAT EXCHANGER FITTED TO ENGINES OF THE INVERTED TYPE
YVES RIBAUD (ONERA, Palaiseau, France) and ISABELLE LURAULT (Ecole Politechnique Feminine, Sceaux, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1222-1231. Research supported by DRET refs
(ISABE 93-7120; ONERA, TP NO. 1993-132) Copyright

An account is given of current practice in the design of cryogenic heat exchangers applicable to hypersonic airbreathing vehicle propulsion using LH2 fuel. Attention is given to the optimization of the geometry, the prediction of heat-transfer coefficients, and the control of inlet air frosting characteristics for the 'PRIAM' counterflow heat-exchanger concept, in both steady and unsteady operational regimes. The present results underscore the critical nature of the heat exchanger in an airbreathing, H2-fueled powerplant.
AIAA

A93-54096
A EULERIAN/LAGRANGIAN MODELLING TO CALCULATE THE EVOLUTION OF A WATER DROPLETS SPRAY
PAUL CREISMEAS (DGA, Orsay, France) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1232-1240. refs
(ISABE 93-7121) Copyright

We introduce a Eulerian/Lagrangian model to compute the evolution of a water spray inside a complex geometry. The air flow is obtained by resolving time dependent incompressible Navier Stokes equation. A finite difference method and a projection method are used. The turbulence is simulated by the Smagorinsky model. The evolution of the water spray is calculated considering no turbulence effect on the droplet trajectories. The turbulence is taken into account through correlations related to the Sherwood number and to the Nusselt number. The numerical results are compared to those from Beard and Pruppacher (1971) and to experimental data. We detect differences in the former case, and we have a very good agreement in the latter one. We present a study of the evolution of the MVD of a water spray in a realistic geometry: we simulate an icing test in a test cell concerning a helicopter air intake screen. We pay attention to determine the evolution of the water spray MVD parameter. It can be seen that in spite of weak inertia, droplets of low diameter are able to bump the nosepiece of the test article. We can conduct the MVD near the air intake, and we notice that the proportion of droplets of large diameter breathed by the engine is negligible.

A93-54098
EXPERIMENTAL INVESTIGATION OF BOUNDARY LAYER TRANSITION ON A FLAT PLATE WITH C4 LEADING EDGE
A. I. KALFAS and R. L. ELDER (Cranfield Inst. of Technology, United Kingdom) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1253-1262. Research supported by CEC refs
(ISABE 93-7123) Copyright

This paper considers the effects of freestream turbulence intensity on the boundary layer transition over a range of Reynolds numbers. Bypass mode of transition has been considered using a flat plate with a C4 leading edge, designed to avoid laminar separation. This configuration provides the opportunity to study the effect of a realistic turbomachinery leading edge shape on transition. Hot wire investigations of the boundary layer have been undertaken in order to acquire detailed information about the effect of the freestream conditions on the structure of the boundary layer. This paper concludes with some global observations and comparisons with theoretical predictions and with experimental observations on a more conventional flat plate with a sharp leading edge.

A93-54276
HEAT LOADS AS KEY PROBLEM OF HYPERSONIC FLIGHT
E. H. HIRSCHEL (Deutsche Aerospace AG, Munich, Germany) Zeitschrift fuer Flugwissenschaften und Weltraumforschung (ISSN 0342-068X) vol. 16, no. 6 Dec. 1992 p. 349-356. refs
Copyright

The problem of heat loads in hypersonic flight is addressed. Technical solutions to the problem as it affects airframes are sketched. The special problems of surface materials and aerothermodynamics are addressed. Related problems encountered involving simulation and prediction in the design of hypersonic vehicles are discussed. AIAA

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GEOSCIENCES

Includes geosciences (general); earth resources; energy production and conversion; environment pollution; geophysics; meteorology and climatology; and oceanography.

A93-52898* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
CASE STUDY OF A LOW-REFLECTIVITY PULSATING MICROBURST - NUMERICAL SIMULATION OF THE DENVER, 8 JULY 1989, STORM
FRED H. PROCTOR (NASA, Langley Research Center, Hampton, VA) Oct. 1993 5 p. AMS, Conference on Severe Local Storms, 17th, Saint Louis, MO, Oct. 4-8, 1993, Paper refs

An intense, low-reflectivity, and pulsating microburst event, detected on July 8, 1989 by the Low-Level Windshear Alert System north of Denver Stapleton Airport is described using a Terminal Area Simulation System (TASS) model (Proctor, 1987). This 3d nonhydrostatic cloud model includes parametrizations for both liquid- and ice-phase microphysics. Simulation results show that the dissipating cloud induces a type-1 pulsating microburst event, with at least three distinct microburst pulses over a period of 20 min. Virga from the dissipating cloud continued to maintain hazardous windshear for a period much longer than the typical lifetime of a single microburst. AIAA

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MATHEMATICAL AND COMPUTER SCIENCES

Includes mathematical and computer sciences (general); computer operations and hardware; computer programming and software; computer systems; cybernetics; numerical analysis; statistics and probability; systems analysis; and theoretical mathematics.

A93-52654#
AN ADVANCED ROTORCRAFT FLIGHT SIMULATION MODEL - PARALLEL IMPLEMENTATION AND PERFORMANCE ANALYSIS
S. SARATHY (Georgia Inst. of Technology, Atlanta) and V. R. MURTHY (Syracuse Univ., NY) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, *Technical Papers Washington American Institute of Aeronautics* and Astronautics 1993 p. 29-35. refs
(AIAA PAPER 93-3550) Copyright

Parallel processing techniques provide a powerful set of tools, which can permit the use of computationally complex models for real-time flight simulation. Elastic blade element models provide adequate fidelity and accuracy needed to simulate advanced rotorcraft configurations. Parallel implementations of blade element code will be needed to model such rotorcraft for real-time simulation applications. Techniques to develop flight simulation models for parallel (MIMD) architectures are presented in this paper. An advanced rotorcraft flight simulation model, using the blade element approach, has been developed for an MIMD parallel computer, based on a portable set of parallel primitives. Issues pertaining to this parallel development and implementation are also discussed. Parallel speedup results for this model are provided based on execution times on an Encore Multimax 14-processor machine.

A93-52656#
DYNAMIC SIMULATION FIDELITY IMPROVEMENT USING TRANSFER FUNCTION STATE EXTRAPOLATION
WILLIAM J. BEZDEK and LARRY A. MOODY (McDonnell Douglas Aerospace, Saint Louis, MO) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 44-52. refs
(AIAA PAPER 93-3552) Copyright

To achieve maximum dynamic fidelity in a real time manned flight simulator, it is imperative that any hardware or computational delays be reduced as much as possible. Unfortunately, some visual systems continue to have a significant processing time delay. To compensate for these delays, general form extrapolation schemes have been employed by the simulation industry. This paper presents a transfer function extrapolation method which takes advantage of the second order nature of most aircraft models to extrapolate aircraft state with greater accuracy and at higher input signal frequencies. To be of practical benefit to the simulation community, issues of commonality and implementation have also been addressed. To allow this approach to be independent of aircraft type, a method to calculate the transfer function damping and natural frequency from the past values of the original aircraft model is presented.

A93-52660#
HYBRID COMPLEX OF THE AIRCRAFT INTELLECTUALIZED CONTROL SYSTEMS SIMULATION AT THE STAGE OF THEIR RESEARCH PROJECTING
A. I. YAKOVLEV and V. M. VASILETS (International Academy of Engineering, Moscow, Russia) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 74-80. refs
(AIAA PAPER 93-3559) Copyright

The paper examines the problem of simulating aircraft intelligent control systems at the initial development state, with emphasis on

the flight factors affecting pilots and operators. Consideration is given to the primary elements of an intelligent control system of flight vehicles, the set of indices for the man-machine system analyses, and the selection tasks for the 'best' man-machine system. The tasks optimization scheme of the 'best' selection system is formulated taking into account the features of human participation. A simulation example of spacecraft intelligent control system is described, and block diagrams of the control system and its elements are presented. AIAA

A93-52663#
TRANSPORT DELAY COMPENSATION - AN INEXPENSIVE ALTERNATIVE TO INCREASING IMAGE GENERATOR UPDATE RATE
FRANK M. CARDULLO and GARY GEORGE (New York State Univ., Binghamton) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 95-102. refs
(AIAA PAPER 93-3563) Copyright

Several delay compensation methods are investigated which illustrate that the phase lag due to system delays can be compensated in many cases. The paper compares the behavior of three methods; a lead/lag formulation by Ricard and Harris (1980), a predictor algorithm devised by McFarland (1988) and a state predictor algorithm developed by Sobiski and Cardullo (1987). The performance of these three algorithms is illustrated in response to system dynamics incorporating simulated aircraft dynamics, a pilot model, and various visual or other subsystem delays. The results indicate the two predictor schemes are both considerably superior to the lead/lag. The differences between the two predictor algorithms are not quite as significant. The McFarland approach has substantial phase lag and gain distortion slightly above the design bandpass. However, the McFarland compensator is considerably simpler to implement. Author (revised)

A93-52678#
IMPLEMENTATION OF EXPERT SYSTEMS WITHIN AN INTERACTIVE TACTICAL ENVIRONMENT
D. N. SIKSIK and R. D. ROURKE (CAE Electronics, Ltd., St.-Laurent, Canada) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 227-233. refs
(AIAA PAPER 93-3583) Copyright

The requirement for an interactive and realistic environment is present in simulation for both training and research. A necessary factor in achieving this environment is the ability to model the intelligence of the entities within it, thus providing a capability for realistic behavior and interaction. CAE's Interactive Tactical Environment Management System (ITEMS) provides simulations with an environment in which entities are closely modelled with respect to both systems and intelligence, allowing them to interact with each other and with their environment in a realistic manner. ITEMS approaches the problem of simulating entity intelligence through the implementation of expert systems. The further improvement of networking geographically remote simulations together and to ITEMS provides several enhancements including the capability for more cost-effective and realistic training.

A93-52680*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
A RADAR ALTITUDE AND LINE OF SIGHT ATTACHMENT
RUSSELL SANSOM and DAVID DARLING (SYRE; NASA, Ames Research Center, Moffett Field, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 243-250. refs
(AIAA PAPER 93-3587) Copyright

This paper describes a method of overcoming much of the computational expense of finding radar altitude and determining lines of sight in flight simulations over databases built from polygons. Methods are described for quantizing polygonal databases and for searching through them quickly. Various tuning parameters are explained and run-time performance figures are offered.

A93-52681#
THE NUMERICAL ERRORS IN INVERSE SIMULATION
K. C. LIN (Central Florida Univ., Orlando, FL), P. LU (Iowa State Univ. of Science and Technology, Ames), and M. SMITH (Central Florida Univ., Orlando, FL) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 251-256. refs
(AIAA PAPER 93-3588) Copyright

This paper analyzes the numerical errors of two categories of inverse simulation algorithms: differentiation inverse method and integration inverse method. A first-order differential equation is used to demonstrate the concept. The results of the inverse simulation are used as step-function inputs to the differential equation for a forward simulation. The result is then compared with the original trajectory for the error measure. A second-order differential equation is used to demonstrate the problem which the integration inverse method may encounter when there are unspecified state variables in the problem. A point-mass aircraft model is used as a numerical example for the comparison of these two methods.

A93-52682#
A DUAL-EULER METHOD FOR SOLVING ALL-ATTITUDE ANGLES OF THE AIRCRAFT
XUEQIAO HUANG (China Flight Test Establishment, Xian) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 257-262. refs
(AIAA PAPER 93-3589) Copyright

This paper presents a new method, called dual-Euler method, for solving exactly all-attitude angles of the aircraft. This method is based on the inverse relationship of both the essence and the singular point-areas between the ordinary and the reversed Euler equations; it separates the area and alternatively calculates their essence areas. That is, it still retains the advantage of straightforwardness and high accuracy of calculation in the essence areas of the ordinary Euler equations, and can utilize the essence areas of the reversed Euler equations instead of the singular areas of the ordinary Euler equations. In this dual-Euler angle coordinate system, the essence area is expanded to the whole area and the singular area can be eliminated. Without principle defects and method errors, the dual-Euler method can overcome the singularity and get the most exact all-attitude angles of the aircraft. The testing results show that the transit of the attitude angle in the whole area with the dual-Euler method is smooth and bona fide, thereby it is an ideal all-attitude equation. Author (revised)

A93-52683#
INITIAL DEVELOPMENT OF A RESEARCH FLIGHT SIMULATOR SOFTWARE
T. CALEFFI and E. M. BELO (Sao Paulo Univ., Sao Carlos, Brazil) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 263-266. refs
(AIAA PAPER 93-3590) Copyright

In this work, steps that were taken to design part of a flight simulator software are described. It comprises the integration, look-up and set of flight differential equation routines, and the aircraft data. The software was made in a modular form, to allow future implementations. The method chosen to make the equations integration was the fourth-order Runge-Kutta. The data were disposed in a bidimensional matrix, called data pool, and the language used was the C language, due to its portability and data structures. Author (revised)

A93-52684*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.
ENHANCING REAL-TIME FLIGHT SIMULATION EXECUTION BY INTERCEPTING RUN-TIME LIBRARY CALLS
NAMEJS REINBACHS (SYRE; NASA, Ames Research Center, Moffett Field, CA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 267-274. refs
(AIAA PAPER 93-3591) Copyright

Standard operating system input-output (I/O) procedures impose a large time penalty on real-time program execution. These procedures are generally invoked by way of Run-Time Library (RTL) calls. To reduce the time penalty, as well as add flexibility, a technique has been developed to dynamically intercept these calls. The design and implementation of this technique, as applied to FORTRAN WRITE statements, are described. Measured performance gains using this RTL intercept technique are on the order of 1000 percent.

A93-52685*# National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
AN EVALUATION OF SOFTWARE TOOLS FOR THE DESIGN AND DEVELOPMENT OF COCKPIT DISPLAYS
THOMAS D. ELLIS, JR. (Unisys Corp.; NASA, Langley Research Center, Hampton, VA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 275-280. refs
(AIAA PAPER 93-3593) Copyright

The use of all-glass cockpits at the NASA Langley Research Center (LaRC) simulation facility has changed the means of design, development, and maintenance of instrument displays. The human-machine interface has evolved from a physical hardware device to a software-generated electronic display system. This has subsequently caused an increased workload at the facility. As computer processing power increases and the glass cockpit becomes predominant in facilities, software tools used in the design and development of cockpit displays are becoming both feasible and necessary for a more productive simulation environment. This paper defines LaRC requirements of a display software development tool and compares two available applications against these requirements. As a part of the software engineering process, these tools reduce development time, provide a common platform for display development, and produce exceptional real-time results. Author (revised)

A93-52686#
REUSABLE CODE FOR HELICOPTER SIMULATION
JO A. PICKERINE (Loral Defense Systems, Akron, OH), KUO-CHI LIN, CURTIS LISLE, and G. GURUPRASAD (Inst. for Simulation and Training, Orlando, FL) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 281-288. refs
(AIAA PAPER 93-3594) Copyright

The paper describes a method for developing reusable software (i.e., reusable without change) for helicopter simulation. The reusability of software is achieved by following five steps: (1) the simulated system is object-oriented, with the object packaged separately from the simulation of the object; (2) for each object, a package of single-function routines must be developed, which simulate that object's behavior; (3) each routine is given an interface module, to ensure unchanging argument lists; (4) each object simulation must be given a generic package which lists the modules used in the simulation of the object and associated generic names; and (5) the routines and modules must be unit-independent, and the routines must be data structure independent. AIAA

A93-52687#
FLIGHT UPDATE OF AERODYNAMIC MATH MODEL
KENDALL W. NEVILLE and A. T. STEPHENS (Boeing Commercial Airplane Group, Renton, WA) *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 289-297. refs
(AIAA PAPER 93-3596) Copyright

Increasingly stringent standards for simulator fidelity have led to a need for continually improving the aerodynamic mathematical models for flight simulations produced by Boeing Commercial Airplane Group (BCAG). An overview of the process used at BCAG for producing and validating the flight updated aerodynamic model is presented. Topics include flight-test planning, instrumentation requirements, aerodynamic coefficient extraction, and simulator-to-flight validation. Particular emphasis is given to the extraction method which is used to identify aerodynamic coefficient information for the entire model in both linear and nonlinear regions, including the effects of flow separation and aerodynamic hysteresis. An actual example is provided showing the flight updated basic lift coefficient compared to predicted data, and the resulting improvement of the simulator-to-flight comparison of a deceleration to full stall and the subsequent recovery.

A93-52732
IDENTIFICATION OF NONLINEAR MECHANICAL SYSTEMS USING COMBINED STATE AND PARAMETER EVALUATION [IDENTIFIKATION NICHTLINEARER MECHANISCHER SYSTEME DURCH KOMBINIERTE ZUSTANDS- UND PARAMETERSCHAETZUNG]
CLAUS-PETER FRITZEN and S. SEIBOLD (Kaiserslautern Univ., Germany) Zeitschrift fuer Angewandte Mathematik und Mechanik (ISSN 0044-2267) vol. 73, no. 7-8 1993 p. T 752-T 755. In GERMAN Gesellschaft fuer Angewandte Mathematik und Mechanik, Wissenschaftliche Jahrestagung, Univ. Leipzig, Germany, Mar. 24-28, 1992, Vortraege. A93-52726 23-31 refs
Copyright

System identification methods permit faulty computational models to be corrected using measured values and also allow model-supported monitoring of rotors. The use of the extended Kalman filter as an evaluator of states and of parameters, and of the method of instrumental variables, is examined. AIAA

A93-52762* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
CHARACTERIZATION OF THE FAULTED BEHAVIOR OF DIGITAL COMPUTERS AND FAULT TOLERANT SYSTEMS
SALVATORE J. BAVUSO (NASA, Langley Research Center, Hampton, VA) and PAUL S. MINER (Planning Research Corp., Aerospace Technologies Div., Hampton, VA) Jan. 1989 8 p. Hawaii International Conference on Systems Sciences, 22nd, Honolulu, HI, Jan. 3-6, 1989, Paper refs

A development status evaluation is presented for efforts conducted at NASA-Langley since 1977, toward the characterization of the latent fault in digital fault-tolerant systems. Attention is given to the practical, high speed, generalized gate-level logic system simulator developed, as well as to the validation methodology used for the simulator, on the basis of faultable software and hardware simulations employing a prototype MIL-STD-1750A processor. After validation, latency tests will be performed. AIAA

A93-52763* National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.
LINEAR QUADRATIC TRACKING PROBLEMS IN HILBERT SPACE - APPLICATION TO OPTIMAL ACTIVE NOISE SUPPRESSION
H. T. BANKS (Brown Univ., Providence, RI), R. J. SILCOX, S. L. KEELING (NASA, Langley Research Center, Hampton, VA), and C. WANG (Brown Univ., Providence, RI) Jun. 1989 7 p. IFAC, Symposium on Control of Distributed Parameter Systems, Perpignan, France, June 26-29, 1989, Paper refs
(Contract NSF MCS-85-04316; F49620-86-C-0111; NAS1-18107)

A unified treatment of the linear quadratic tracking (LQT) problem, in which a control system's dynamics are modeled by a linear evolution equation with a nonhomogeneous component that is linearly dependent on the control function u, is presented; the

treatment proceeds from the theoretical formulation to a numerical approximation framework. Attention is given to two categories of LQT problems in an infinite time interval: the finite energy and the finite average energy. The behavior of the optimal solution for finite time-interval problems as the length of the interval tends to infinity is discussed. Also presented are the formulations and properties of LQT problems in a finite time interval. AIAA

A93-53620
STABILITY ANALYSIS THROUGH BIFURCATION THEORY. I, II
PH. GUICHETEAU (ONERA, Chatillon, France) ONERA, TP no. 1993-108 1993 22 p. NATO, AGARD, Lecture Series on Non Linear Dynamics and Chaos, 191st, Stanford Univ., CA, June 9-11, 1993 and Valbonne, France, June 16-18, 1993 refs
(ONERA, TP NO. 1993-108)

A brief presentation is made of bifurcation theory regarding nonlinear phenomena representative of high performance aircraft dynamical behavior, and a methodology for the analysis of such systems is proposed. In the second part of this work, attention is given to problems associated with the introduction of control laws for the stabilization of unstable dynamic systems. The state-of-the-art in treatments aimed at determining the attracting region of a stable equilibrium point is described. AIAA

A93-53642
ON DEFINITION AND USE OF SYSTEMS ENGINEERING PROCESSES, METHODS AND TOOLS
ARTHUR STONE, CHARLES SCOTT, and SHAWN RAHMANI (Rockwell International Corp., Collins Air Transport Div., Downey, CA) *In* 1993 IEEE Aerospace Applications Conference, 14th, Steamboat Springs, CO, Jan. 31-Feb. 5, 1993, Digest New York Institute of Electrical and Electronics Engineers, Inc. 1993 p. 197-205. refs
Copyright

A case study on the development and deployment of a systems engineering process for use on commercial avionics systems is discussed. The systems engineering process is presented in the context of the overall product development process, called the common process (CP), which identifies goals, objectives, major milestones and top level activities for the systems engineering, hardware engineering, software engineering, project management and authorization/budgeting processes. The systems engineering development plan is described. The scope of the systems engineering process and its major activities are described. Emphasis is on using techniques that reduce cultural and organizational impact and improve the likelihood that the changes are accepted.

A93-53770
NETWORKS EXTEND SIMULATION'S REACH
BRIAN F. GOLDIEZ (Central Florida Univ., Orlando, FL) Aerospace America (ISSN 0740-722X) vol. 31, no. 8 Aug. 1993 p. 22-25.
Copyright

Simulator networking called distributed interactive simulation (DIS) is discussed. DIS standards are capable of supporting concurrent engineering by providing a convenient way to create a rapid prototyping environment. DIS makes it possible to combine diverse simulation models to produce an integrated concurrent engineering environment. AIAA

A93-54108
EXPERT SYSTEMS FOR THE SIMULATION OF TURBOFAN ENGINES
GIOVANNI TORELLA (Italian Air Force Academy, Pozzuoli, Italy) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 2 Washington American Institute of Aeronautics and Astronautics 1993 p. 1353-1366. refs
(ISABE 93-7133) Copyright

The main steps of a work carried out for developing Expert Systems for turbofan simulation are shown. The first part of paper deals with the selection of computer language. Successively the massive use of numerical simulation has allowed to obtain several results about the behavior and performance of engines. The use of numerical data for developing sets of logical rules for high flexibility Knowledge Bases is shown. Finally examples of Expert Systems for different aspects of turbofan simulation are presented and discussed.

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PHYSICS

Includes physics (general); acoustics; atomic and molecular physics; nuclear and high-energy physics; optics; plasma physics; solid-state physics; and thermodynamics and statistical physics.

A93-52945
A STUDY OF OPTICAL DISTORTIONS ARISING IN RADIATION TRANSMISSION THROUGH CAVITIES WITH GAS FLOW AROUND THEM [ISSLEDOVANIE OPTICHESKIKH ISKAZHENIJ, VOZNIKAYUSHCHIKH PRI PROKHOZHDENII IZLUCHENIYA CHEREZ POLOSTI, OBTEKAEMYE GAZOVYM POTOKOM]
A. A. GILERSON and A. R. ALEKSEEV Aviatsionnaya Tekhnika (ISSN 0579-2975) no. 1 1993 p. 34-38. In RUSSIAN refs
Copyright

Methods of pulsed laser interferometry are used to obtain data on the extent of optical distortions associated with air flow past open and closed cavities at Mach 0.59-1.8. It is found that the extent of the distortions depends to a large degree on the flow regime. For radiation wavelengths of 0.55 micron, the distortions may reach 2-5 wavelengths. AIAA

A93-53194
EXPERIMENTAL INVESTIGATION INTO THE MECHANISM OF DISCRETE FREQUENCY NOISE (DFN) GENERATION FROM A NACA 0012 BLADE
HIDECHITO HAYASHI, TOHRU FUKANO, and YOSHIO KODAMA Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016) vol. 59, no. 559 March 1993 p. 802-806. In JAPANESE refs
Copyright

An experimental investigation was made into the mechanism of discrete frequency noise (DFN) generation from a NACA 0012 blade placed in a uniform oncoming flow. It was clarified that DFN was generated when the boundary layer on the blade surface was laminar and separated at the location upstream of the trailing edge. A dead air region was formed just after the trailing edge of the blade. Therefore a Karman vortex street occurred. Meanwhile we could not observe a close relationship between the existence of a separation bubble and the generation of DFN. That is, DFN was generated even when the attack angle of the flow was nearly zero and no separation bubble was observed. When a separation bubble existed, the boundary layer became turbulent and the flow did not separate up to the trailing edge, so a dead air region was not formed behind the blade, which resulted in the disappearance of DFN. The prediction of the sound pressure level of DFN generated from this streamlined blade by Fukano's theory for a flat plate model agreed well with the measured value.
Author (revised)

A93-53206
ACTIVE AERODYNAMIC CONTROL OF WAKE-AIRFOIL INTERACTION NOISE - EXPERIMENT
J. SIMONICH, P. LAVRICH (United Technologies Research Center, East Hartford, CT), T. SOFRIN, and D. TOPOL (Pratt & Whitney Group, East Hartford, CT) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1761-1768. DGLR/AIAA Aeroacoustics Conference, 14th, Aachen, Germany, May 11-14, 1992, Proceedings. Vol. 1, p. 229-237. Previously cited in issue 05, p.

823, Accession no. A93-19153 refs
Copyright

A93-53222
SOME ACOUSTIC FEATURES OF PERFORATED TEST SECTION WALLS WITH SPLITTER PLATES
BORIS L. MEDVED (National Research Council of Canada, Inst. for Aeronautical Research, Ottawa) AIAA Journal (ISSN 0001-1452) vol. 31, no. 10 Oct. 1993 p. 1885-1890. AIAA, Aerodynamic Ground Testing Conference, 16th, Seattle, WA, June 18-20, 1990, AIAA Paper 90-1418. Previously cited in issue 16, p. 2615, Accession no. A90-37955 refs
Copyright

A93-53615
THE ACOUSTICS OF AXIAL COMPRESSORS [ACOUSTIQUE DES COMPRESSEURS AXIAUX]
SERGE LEWY ONERA, TP no. 1993-102 1993 22 p. In FRENCH EUR'Acoustique 93, Ecully, France, June 7-9, 1993 refs
(ONERA, TP NO. 1993-102)
Line noise is examined for axial compressors, with emphasis on subsonic machines. The basic acoustic theory of axial compressors is presented, and the internal measurements that are necessary to gain knowledge of the physical phenomena involved are indicated. Ways to reduce the noise produced by axial compressors are also examined. AIAA

A93-53616
ACOUSTIC-WAVE PROPAGATION IN DUCTS AND FREE-FIELD RADIATION [PROPAGATION DES ONDES ACOUSTIQUES DANS LES CONDUITS ET RAYONNEMENT EN CHAMP LIBRE]
SERGE LEWY ONERA, TP no. 1993-103 1993 27 p. In FRENCH EUR'Acoustique 93, Ecully, France, June 7-9, 1993 refs
(ONERA, TP NO. 1993-103)
The fundamental concepts of guided acoustic-wave propagation are introduced, including plane waves at low frequency and the existence of oblique waves above the cutoff frequency. Analytical calculations have made it possible to determine the complete characteristics of the sound field, decomposed into the natural modes of ducts of rectangular or circular cross section. These are essentially derived from the dispersion relation and the boundary conditions on the walls. The far-field radiation is also investigated. AIAA

A93-53817
A DYNAMIC STIFFNESS/BOUNDARY ELEMENT METHOD FOR THE PREDICTION OF INTERIOR NOISE LEVELS
R. S. LANGLEY (Southampton Univ., United Kingdom) Journal of Sound and Vibration (ISSN 0022-460X) vol. 163, no. 2 May 15, 1993 p. 207-230. refs
Copyright
A method is presented for the prediction of the noise transmission into structures which have a constant cross-sectional geometry. The structural vibrations are analyzed by using the dynamic stiffness method, while the boundary element method (BEM) is used to calculate the interior noise levels. The analysis procedure is a direct one, which means that there is no need to calculate the modes of vibration of either the structure or the interior airspace. Furthermore, a method is presented for the suppression of numerical damping in the BEM analysis, which allows the use of much fewer boundary elements than would otherwise be needed. Particular attention is paid to the case of airborne noise transmission into an aircraft fuselage structure, and comparisons are made with previous experimental and theoretical results for a circular cylindrical test article.

17

SOCIAL SCIENCES

Includes social sciences (general); administration and management; documentation and information science; economics and cost analysis; law and political science; and urban technology and transportation.

A93-52653#
INTERNALLY COHERENT SYSTEM OF INNOVATION - THE CASE OF FLIGHT SIMULATION
ROGER MILLER and F. X. OLLEROS *In* AIAA Flight Simulation Technologies Conference, Monterey, CA, Aug. 9-11, 1993, Technical Papers Washington American Institute of Aeronautics and Astronautics 1993 p. 12-28. refs
(AIAA PAPER 93-3548) Copyright
This paper reports on the finding of a study of the flight simulation industry, from a perspective of industrial economics. Our analysis corroborates two basic insights from the recent literature on industrial dynamics: first, that cooperation and competition are complementary, rather than contrary, aspects of industrial evolution; second, that both cooperation and competition are necessary for the emergence and effective functioning of complex industries. Our main original contribution consists in suggesting that, under conditions of increasing returns to market share, tight oligopolies are ideally suited to deliver an optimal combination of inter-firm cooperation and competition and, hence, a consistently high level performance.

A93-52930
AIR CARRIERS' LIABILITY FOR PASSENGER INJURY OR DEATH - THE JAPANESE INITIATIVE AND RESPONSE TO THE RECENT EC CONSULTATION PAPER
BIN CHENG (London Univ., United Kingdom) Air & Space Law (ISSN 0927-3379) vol. 18, no. 3 June 1993 p. 109-122. refs
Copyright
The response of the Japanese Ministry of Transport to the recent Consultation Paper which criticized the lack of worldwide understanding on the objectives of the Warsaw Convention is discussed. The Japanese Initiative and Response attempts to correct the overemphasis of the Warsaw System on limiting the air carrier's liability for passenger injury and death. To save the Warsaw System, it is recommended that the objective should be absolute, unlimited, and secured liability of air carriers for passenger injury and death. AIAA

A93-52931
AIR TRANSPORT AND THE ENVIRONMENT - REGULATING AIRCRAFT NOISE
PETER DAVIES and JEFFREY GOH (Liverpool Univ., United Kingdom) Air & Space Law (ISSN 0927-3379) vol. 18, no. 3 June 1993 p. 123-135. refs
Copyright
The history and present status of the law regarding regulation of aircraft noise are reviewed. Emphasis is given to European directives implementing ICAO standards and compliance by individual European states. Private actions as a control mechanism are considered, including a human rights perspective. AIAA

A93-53423
3-D BRAIDED PREFORMS; COST TO MANUFACTURE: MAGNAWEAVE. I - IDENTIFYING COST FACTORS
ROBERT A. FLORENTINE (MAGNAWEAVE, Inc., Norristown, PA) *In* International SAMPE Technical Conference, 24th and International SAMPE Metals and Metals Processing Conference, 3rd, Toronto, Canada, Oct. 20-22, 1992, Proceedings. Vol. 24 Covina, CA Society for the Advancement of Material and Process Engineering 1992 p. T621-T629. refs
Copyright
A model is presented for 3D braided preforms'

cost-to-manufacture (CTM) predictions that can establish the commercial viability of the process contemplated. Market selection is conducted as an iterative process in which the more reliable the input, the more tolerable the output is of lower probable return. The way in which the model is used therefore depends on the verifiability of inputs. AIAA

A93-53726
FLIGHT SAFETY IN EUROPE [FLUGSICHERUNG IN EUROPA]
WALTER SCHWENK and RUEDIGER SCHWENK Zeitschrift fuer Luft- und Weltraumrecht (ISSN 0340-8329) vol. 42, no. 2 June 1993 p. 121-143. In GERMAN refs
Copyright
The legal regime of European flight safety is discussed. The Eurocontrol Agreement and its implementation are examined, emphasizing the European integration steps required for the implementation of the agreement. The main problems remaining in developing European flight safety in the framework of Eurocontrol are addressed. AIAA

A93-53727
STUMBLING BLOCKS FOR AIRPORT CONSTRUCTION IN THE NEW GERMAN FEDERAL STATES [STOLPERSTEINE BEIM FLUGPLATZAUSBAU IN DEN NEUEN BUNDESLAENDERN]
STEFAN A. KAISER Zeitschrift fuer Luft- und Weltraumrecht (ISSN 0340-8329) vol. 42, no. 2 June 1993 p. 151-161. In GERMAN refs
Copyright
Ways to shorten the time in which airports of all kinds in Germany are constructed are considered. Emphasis is given to the role of a new traffic planning acceleration law in the German federal states. AIAA

A93-53826* National Aeronautics and Space Administration, Washington, DC.
INTERNATIONAL AEROSPACE STI
LAURIE HARRISON and THOMAS LAHR (NASA, Washington) Sci-Tech News (ISSN 0036-8059) vol. 47, no. 3 Aug. 1993 p. 57, 58. refs
Copyright
A brief discussion is presented of the use being made by the American R&D community of international aerospace scientific and technical information (STI). The incorporation of international STI into the NASA Aerospace Database is addressed. AIAA

19

GENERAL

A93-53977
RESEARCH AND DEVELOPMENT OF AIRCRAFT ENGINE IN JAPAN - HISTORICAL REVIEW
MASAKATSU MATSUKI (Nippon Inst. of Technology, Saitama, Japan) *In* ISABE - International Symposium on Air Breathing Engines, 11th, Tokyo, Japan, Sept. 20-24, 1993, Proceedings. Vol. 1 Washington American Institute of Aeronautics and Astronautics 1993 p. 7-11.
(ISABE 93-7000) Copyright
The history of Japanese aircraft engine production is briefly reviewed. The design targets achieved in engines over this period are identified. The tests performed on the engines are summarized. AIAA

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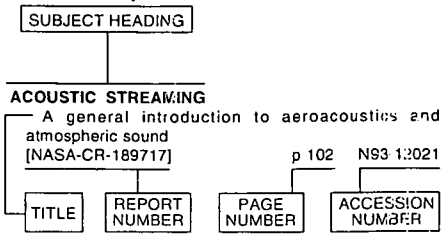

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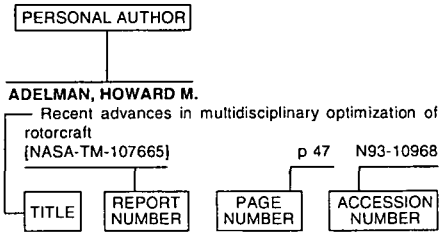

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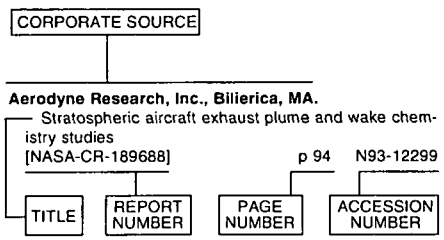

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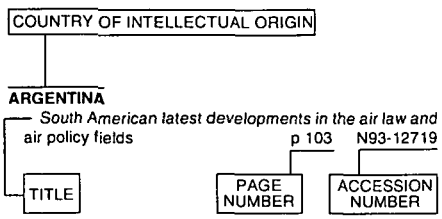

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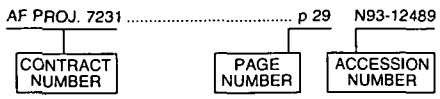

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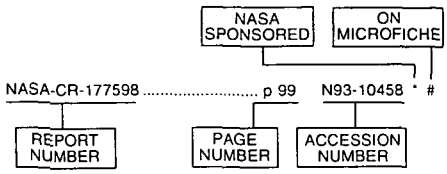

Listings in this index are arranged alphanumerically by report number. The page number indicates the page on which the citation is located. The accession number denotes the number by which the citation is identified. An asterisk (*) indicates that the item is a NASA report. A pound sign (#) indicates that the item is available on microfiche.

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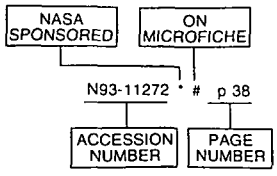

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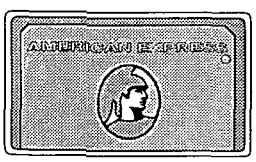

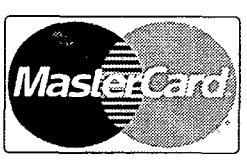

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