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FIFTH INTERNATIONAL SYMPOSIUM ON AIR BREATHING ENGINES
J.R. PATTON, JR.*
29 MAY 1981

\* Office of Naval Research, Arlington, VA

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Fifth International Symposium on Air Breathing Engines was held in Bangalore, India, in February 1981. The program was primarily directed to the discussion of aircraft turbine engines. This report contains comments on various papers that were of special interest to the author. It also contains the names of all the persons who spoke at the symposium and lists the topics they discussed.		

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FIFTH INTERNATIONAL SYMPOSIUM ON AIR BREATHING ENGINESIntroduction

The Fifth International Symposium on Air Breathing Engines (ISABE) was held in Bangalore, India, on 16-22 February 1981 with over 215 representatives of 21 countries in attendance. This series of symposia was first instituted in June 1972, to provide an international forum for discussion of scientific and technical problems pertaining to air breathing flight propulsion systems. The first ISABE was held at the Fluid Mechanics Institute in Marseilles, France, and succeeding symposia were held at Sheffield University, UK, in 1974; in Munich, Germany in 1976; and at Buena Vista, Florida, in 1979. Primary attendance and participation at the symposia has included leading managers, engineers, and scientists from the participating countries throughout the world. Organization of the symposia has been handled through an International Air Breathing Propulsion Committee with the cooperation of established national and international organizations with an interest in propulsion. Recent ISABE symposia have been held under the auspices of the International Council of the Aeronautical Sciences (ICAS) and the American Institute of Aeronautics and Astronautics (AIAA). The Fifth ISABE was co-sponsored by the United Nations Educational Scientific and Cultural Organization (UNESCO) as a part of that agency's support for the Turbomachinery and Combustion Laboratory of the National Aeronautical Laboratory (NAL) in Bangalore. Other cosponsor hosts in India were the Ministry of Defense Aeronautics Research and Development Board, the National Aeronautical Laboratory (NAL), Bharat Heavy Electricals Ltd., Hindustan Aeronautic Ltd., Air-India, and the Indian Airlines. Dr. Paramod A. Paranjpe, project director at NAL represents India on the International Committee, and he was the principal arranger and host for the National Organizing Committee of India for the Fifth Symposium.

Of the 215 delegates attending the Symposium, 95 were from India. Thirty-two delegates attended from the United States and of these, 14 were sponsored by travel grants from the National Science Foundation. A contingent of 6 delegates from the People's Republic of China attended and presented 9 papers. Although the USSR had been represented in previous symposia, they did not send a delegation this year.

Organization of the Symposium

Dr. Frederick S. Billeg of the Johns Hopkins University Applied Physics Laboratory served as chairman of the US National Committee and was responsible for the selection of papers from the United States. Abstracts of proposed papers were solicited in mid-1980 through the AIAA Journal. Of 78 papers from 19 countries selected for presentation at the Symposium, 22 (28%) were from US authors.

The program was organized into 12 sessions with the papers categorized under the headings shown in Table 1. In general, the papers and program covered areas similar to those covered 2 years earlier at the 4th ISABE meeting at Buena Vista, Florida. The program has continued to be primarily aircraft turbine engine oriented, with one session devoted to ramjet missile propulsion. This emphasis has remained fairly constant in all the ISABE Symposia held since 1972, probably because of the classified nature of some of the work on ramjets as well as some lack of mission requirements in countries emphasizing that type of missile propulsion. Generally, over the past 12 years, the US has conducted extensive R&D efforts in ramjet propulsion and the work in other countries has usually been in the form of theoretical and analytic contributions complementary to US efforts. A new session on instrumentation was included this year to reflect an increased awareness of the benefits resulting when nonintrusive optical techniques are applied to specific flow phenomena and component modeling.

In organizing the symposium, the International Committee gave particular attention to a varied selection of chairmen and co-chairmen from participating countries for each of the sessions. Although 28% of the papers were from the US, only two US chairmen and one US co-chairman were selected for the eleven technical sessions. (See Table 2.)

The Indian National Organizing Committee did a fine job in selecting a site (Hotel Ashok in Bangalore), planning the technical program, arranging social functions, and managing all aspects of the meeting. For the Inaugural Session Dr. S.R. Valluri, director of the National Aeronautical Laboratory at Bangalore, presided. His Excellency Sri Govind Narain, Governor of Karnataka, delivered an inaugural address and Smt Chandra Govind Narain inaugurated the Symposium.

#### Technical Highlights

At the Inaugural Session, the keynote address by Dr. Warner Stewart, director of Aeronautics at the NASA Lewis Research Center, Cleveland, Ohio, on "The Future of Aeronautical Propulsion," set the stage and provided an interesting introduction to the symposium. Although many of the US delegates had the opportunity for prior exposure to this subject in the US, the talk served a very useful purpose in bringing the international group into a common focus for the papers and informal discussions that followed. Briefly, Stewart's approach was to summarize some of the challenges and opportunities confronting aeronautics and propulsion from the standpoint of both civil and military aviation, as well as to describe emerging technologies and the possibilities for significant advancement. He emphasized advanced materials and processes, covering such areas as powder metallurgy, single-crystal and directionally solidified turbine blades and ceramics with potential lower costs. Possible new approaches utilizing advanced computers and electronics together with optical diagnostics were outlined for new engine controls and performance monitoring. Emphasis was given, in general, to technology useful in

reducing fuel consumption and noise. Also covered were such subjects as alternative fuels, reduced clearances in rotating parts, and reduced cooling requirements.

Though most of the sessions and papers were interesting and some even stimulating, reference is made here to only a few papers. The numbers attached to the papers cited refer to their listing in the appendix.

The session on "Operation" was in general a balanced coverage of the subject and was presented in such a manner as to be favorably received by specialists in that area while also having some morsels of interest to the research community. US papers covered the status of power plant controls, turbine-diagnostics effectiveness, life-cycle cost considerations, and a review and status of environmental effects of aircraft emissions. Papers from Italy, Egypt, India, and Australia contained essentially operational type information relative to performance monitoring, engine maintenance, transmission fatigue, and vibration problems. ALITALIA, for example, reported on a promising engine monitoring system capable of predicting and detecting early performance degradation.

In the area of "Integration," US coverage was indicative of the considerable efforts undertaken in our country in recent years on inlets, flow separation studies, and ejectors. Significant advances and improvements in performance of the AV-8B aircraft by integration of the resulting new technologies were outlined in a paper by McDonnell Douglas (12). Complementary applied research efforts were described in three additional papers covering computational tools for analysis of designs of complex 3-D inlets and exhaust nozzles (14), flow-separation in inlets at incidence angles (16), and thrust increases in turbojet engines through hyper-mixing ejector shrouds (17). There were two contributions from Germany and one each from China, the Netherlands, Libya, and England. The German papers, from Messerschmitt-Bolkow-Blohm GmbH, discussed engine-airframe integration for high-performance military aircraft (11) and hot gas reingestion and debris ingestion during thrust reversal (13). The remaining papers in this session dealt with four different subjects, but all related to integration phenomena: from China, development of a simplified performance calculation procedure for flow fields of supersonic ejector nozzles (15); from the Netherlands, the outlook for further jet noise suppression without loss of thrust (18); from Libya, the prediction of surge characteristics (19); and from Great Britain, the application of digital controls to helicopter engines.

The session on "Advanced and Hybrid Systems" contained ten contributions on various aspects of ramjet missile propulsion, three of which were from the US. The US coverage included reports of ramjet air induction and gas concentration fields of dump combustors (22), and another new analysis of base flow with and without combustion (27). Two Chinese papers represented recent research in areas reminiscent of US work in the 1960s, i.e., ramjet trajectory simulation tests (23) and experimental studies of a solid rocket ramjet (25). An Indian paper covered theoretical analysis of a fuel-rich

rocket ramjet engine utilizing metallized propellants and this represented current technology (24). The two Australian papers represented competent investigations, complementary to earlier work, on solid-rocket thrust enhancement by ejector augmentation (26), and the factors affecting afterbody drag, i.e., boundary-layer drag (28). In the Swiss paper (29), Prof. Berchtold reintroduced the idea of a wave pressure exchanger (Comprex), with conventional turbo machines, as a possibility for a light aircraft application. The paper from Israel (29A) covered a theoretical and experimental investigation for computing internal reacting flows and use of LDV for sudden expansion flow verification experiments.

Of seven papers in the session on "Turbines and Cooling," only one was from the US and it presented a good summary of transpiration cooling concepts for turbine blades (32). This covered new insights on heat transfer effectiveness and erosion, corrosion, deposition resistance characteristics pertaining to possible future-generation aircraft and industrial turbine engines using coal or coal-derived fuels. Other contributions from China, the UK, Egypt, and India were generally analytic investigations of turbine stator cascades (30), optimum design considerations (31), and film cooling effectiveness (33, 34, 35). Another contribution from Belgium (36) summarized turbine blade cooling research at the Von Karman Institute.

In the session on "Instrumentation," the four papers presented covered work in the area of machinery wear (37), compressor-duct system response to unsteady flows (39), determination of rotor-tip clearances (40), and a review of combustion diagnostics utilizing the CARS technique (41). The Australian paper on wear described a procedure for measurement of optical density values of wear particle depositions by use of a Ferrograph manufactured by Foxboro, Inc., of the US. (It is interesting to note that Dr Peacock of Cranfield Institute of Technology, UK, co-author of the report on a digital technique for the analysis of the response of compressor/duct systems in unsteady flow (39), is presently on sabbatical leave and stationed at the Navy Postgraduate School in Monterey, California where he is involved with similar US Navy programs sponsored by ONR.) The third paper from West Germany (40) covered another crucial area—namely rotor tip clearances—and it was devoted to two measuring techniques developed by MTU - Munich, Germany: (1) an electromechanical gauge (EMAG) useful for stationary and slow transient-operating conditions and (2) a temperature-compensated capacity technique (coulomb system) useful for tip clearances during fast transient conditions. The review paper on the CARS technique (41) covered ONR-supported effort, and it is interesting to note that summaries of this work have been presented in a number of international meetings in the past year. This one in Banglaore, however, was noteworthy, inasmuch as it was in India that the Raman effect was first discovered in 1928 by Chandrasekhara Venkata Raman.

Of ten papers covering "Combustion and Design Problems," only one, on the fundamental aspects of flame stabilization (48), was from the US. Here, models that were previously developed to predict extinction limits in turbulent

combustible mixtures have been applied to available experimental data, and the factors affecting blowout velocities and limits were outlined. Other presentations covered the basic areas of combustor flow characterization and modeling, including swirling flows (43, 44, 49, and 50), mixture entrainment (47), spray characterization (52), and altitude relighting performance (53). An interesting review was given of the factors limiting Turbine Inlet Temperatures (TIT) relative to combustor types, pollutant considerations, pattern factors, etc., and predictions made for TIT limitations in future engine development.

In the session on "Materials," there were two contributions from India and one each from Sweden and China. One Indian paper (55) discussed a photoelastic investigation of stress distribution and concentration factors in gas turbine components. The second paper (56) related to control of amplitude and shaft vibration by influence of O rings to control damping coefficients in a squeeze film-mounted ballbearing. A related paper from China (57) described squeeze-film bearing applications to turbo-fan engines, and covered both rig and engine tests. The Swedish paper (54) discussed the potential for high-temperature metal-matrix composites, (particularly tungsten-wire-reinforced iron and nickel alloy), in meeting advanced turbine engine requirements.

There were four papers presented in the session on "Vibration and Flutter" and they were closely related to important areas of concern as outlined in an ONR/AF/NASA colloquium held in January of 1981. A paper on the effects of mistuning on blade torsional flutter (59) gave new insights on both aerodynamic and mechanical coupling among all the blades of a fan where individual blade inertias, frequencies, or damping could be considered. A paper on the influence of gyroscopic forces on the dynamic behavior of rotating blades (62) concluded that, in principle, an oscillatory instability may develop by cantilever blades attached to a spinning and precessing rotor.

In Session 11 on "Cascade Flow," no US papers were presented, although one, covering the influence of turbulence on laminar separation on an airfoil, was submitted. The general theme in 7 of the 8 papers presented was theoretical and correlation studies emphasizing numerical methods and solutions for 2-D cascade flows and 3-D methods for blade row flows. One report covered an experimental investigation of cascade flow fields by blade surface measurements, schlieren photos and LDV.

Somewhat more advanced and practical investigations were covered in the session on "Compressors," at least in the three US papers (72, 75, and 78). One paper reported on a theoretical and experimental study, performed for NASA and ONR, on solid particle trajectories and locations of collisions between the solid particle and the blade surfaces. The presence of solid particles in the working media often leads to performance deterioration, both structurally and aerodynamically. Blade erosion estimates were reported, based on blade pressure distribution and total pressure loss coefficient parameters. Another area of investigation with practical and operational

overtones covered a study of the effects of water ingestion into jet engine compressors. In this effort, predictive tools and models were developed for studying performance deterioration with water ingestion; these involved such considerations as blade-droplet interactions, entrainment processes, and casing and hub boundary region flows.

#### Impact of US Papers

American participation and leadership has been evident in all aspects of the ISABE Symposium series of meetings since their inception in 1972. The fifth ISABE was no exception, when one considers that 15 percent of the delegates in attendance and 28 percent of the papers selected for presentation were from the US. Since the series started in 1972 the quality from all the contributors has steadily improved and today the various programs in air breathing propulsion are complementary. There is a very active following of US R&D efforts on the part of all participating countries. They keep informed of problem areas we encounter and have displayed keen interest in directing their theoretical and analytical abilities to help understand and solve the problems. As a result, there is very good integration of programs in all the participating countries.

#### Basic Research Highlights

The program contained reports of both fundamental and applied research efforts although very little of the work would be classified basic research as such. Participant delegates from abroad generally gave emphasis to theoretical studies and checking results against known applied or experimental data, usually generated in the United States.

#### Opportunities for Collaboration

During the Fifth ISABE Symposium Meeting, one afternoon was reserved for the delegates to visit the Turbomachinery and Combustion Laboratory of the NAL. The NAL dates back to the early 1960s and is one of a group of laboratories established by the Council of Scientific and Industrial Research to pursue aerospace and engineering research. It has about 1,400 employees in 5 scientific divisions. The Turbomachinery and Combustion Laboratory, set up in 1975, is a part of the Propulsion Division, which has a staff of about 100. This laboratory contains various facilities (Combustion and Dynamics Lab, Subsonic and Transonic Tunnels, Compressor and Turbine Research Rigs) and associated test diagnostic equipment for investigations of all aspects of Turbomachinery. All facilities in the laboratory were designed around a centralized compressed-air source constituting the wind-tunnel center of NAL. The laboratory is very well equipped and appears to have a competent and versatile staff to pursue its objectives of experimental research to generate design data with scale models, development of computer-based design aids and development of novel techniques for component improvement and diagnostics. NAL is partially supported by UNESCO. In the area of aeroelasticity and

blade flutter, it appears that cooperative programs with US counterparts, i.e., Stevens Institute of Technology, (Hoboken, NJ), could prove of value.

Representation from the People's Republic of China has continued to flourish; the following delegates attended this latest symposium:

Prof. Z.K. Huang	Chinese Academy of Sciences P.O. Box 2706, Beijing
Prof. Hui Li Shen	Northwestern Polytechnical University, Xian
Prof. Zhong-Chi Wang	Marbin Institute of Technology, Marbin
Prof. Dr. Ching-Hau Wu	Institute of Engg. Thermophysics Chinese Academy of Sciences, P.O. Box 2706, Beijing
Prof. Shi Ying Zhang	Nanjing Aero Inst., Nanjing
Shang-Zhi Chen	Shenyang Aeroengine Research Institute, Shenyang

As a result of such good representation from the People's Republic of China for the third, fourth, and fifth symposia, a closer relationship is developing between interested groups in both countries. These contacts can only have a profound influence, especially on the Chinese programs, in advancing the quality and relevance of their efforts. There have already been several exchange visits of specialist groups from the US and China as a result of the contacts developed at these symposia.

#### Accomplishments and Conclusions

This was the first time this symposium was held on the Asian continent and it was evident that the representation of the participating countries did not suffer. This was due in large measure to the efforts of the Indian National Organizing Committee as well as the international sponsors. The symposium was well organized and the technical content generally covered important problem areas.

The US continues to play a prominent role in the international air-breathing engine community. This role would be strengthened, however, if US representation were more formally organized before further steps are taken to formally organize the international groups. This would permit a more balanced input from both the government and industry.

In a business meeting of the delegates, it was decided to accept an invitation from France to hold the sixth ISABE in Paris. The seventh ISABE symposium will probably be held in the People's Republic of China. Although the Chinese presently do not support extensive programs in air breathing propulsion and are generally not as advanced in their work as the other participating countries, they do have the potential for conducting theoretical studies. The ISABE series of symposia has played an important role in China's progress; its representatives attended the last three symposia and are becoming familiar with US programs. In addition, they have invited several groups from the US to visit their facilities in China.

5th ISABE - Papers and Sessions - Organization

TABLE I

Sym. Sessions	U.S.	China	Germany	India	U.K.	Australia	Egypt	Italy	France	Japan	Belgium	Canada	Sweden	Switzer-land	Netherlands	Israel	Libya	Africa	Czechoslovakia	
Inaugural Session	1																			
Operation	4			1		2	1	2												
Integration	4	1	2		1										1					
Advanced and Hybrid Systems	3	2		1		2								1		1				
Turbines and Cooling	1	2		1	1		1													
Instrumentation	1		2		1	1														
Combustion and Design Probs. I																1				
Combustion and Design Probs II	1	1			2			1												
Materials		1			2								1							
Vibration and Flutter	3			1																
Cascade Flow	1	1	3				1			1										1
Compressors	3	1					1		2											
No. of Papers	22	9	7	7	6	5	5	3	2	2	2	1	1	1	1	1	1	1	1	1

## Session Chairman - 5th ISABE

Table II

<u>Session</u>	<u>Chairman</u>	<u>Co-Chairman</u>
2. Operation	M. Berchtold, Switzerland	Prof. U. Ghezzi, Italy
3. Integration	V. R. Sinha, India	K. Richey WPAFB, USA
4. Advanced and Hybrid Systems	M. Pianko ONERA, France	T. V. Vareed, India
5. Turbines and Cooling	A. Gopalakrishnan, India	Y. Kakehi, Japan
6. Instrumentation	J. R. Patton, ONR, USA	G. K. Walker, Australia
7. Combustion Design Prob. I	G. Kappler, W. Germany	Gad El Mawla, Egypt
8. Combustion Design Probs. II	J. Swithenbank, U.K.	J. Odgers, Canada
9. Materials	Air Vice-Marshal S.N.R. Choudhary, India	B.E.L. Decker, Canada
10. Vibration and Flutter	F.A.E. Breugelmans, Belgium	S. Soundranayagam, India
11. Cascade Flow	C. H. Wu, China	E. Nilsson, Sweden
12. Compressors	R. O'Brien, USA	K. Celikovsky Czechoslovakia

APPENDIX

SESSION 1: INAUGURAL SESSION

*Keynote address:*

"The Future of Aeronautical Propulsion  
by Dr. Warner Stewart  
Director of Aeronautics  
NASA - Lewis Research Center, USA

SESSION 2: OPERATION

*Chairman*

Prof. M. Berchtold  
ETH, Zurich, Switzerland

*Co-Chairman*

Prof. U. Ghezzi  
Italy

- 01 Powerplant control - "Its a new ball game"  
Robert J. Smuland, General Electric Company, USA
- 02 Effectiveness of Turbine Diagnostics System  
L.T. Barnes, ARO Inc., Arnold AFS, USA
- 03 Engine Performance Monitoring System Expansion  
on Alitalia Aircraft  
B. Signori and F. Traversa, Alitalia, Italy
- 04 Diagnostic and Monitoring of Turboprop Engines  
Ingg. O. Natale and V.P. Riviello, Alfa Romeo, Italy
- 05 The Engineering Basis for the Application of Life Cycle  
Cost or Supportability Criteria to Gas Turbine Engines  
Roger L. Spencer, Wright Patterson AFB, OH, USA
- 06 Contribution to the Improvement of the Classical Method  
of Maintenance of Aircraft  
A.H. Badr and M.T. El Mayah, Military Technical College,  
Cairo, Egypt
- 07 Environmental Aspects of Aircraft Emissions  
R.C. Oliver, Institute for Defence Analysis, USA
- 08 Analysis of Vibration Related Failures in Aero-Turbo-Shaft  
Engines  
K. Srinivasa and M.L. Sidana, CRE (Engines), Bangalore-560017,  
India

- 09 Helicopter Transmission Fatigue Life  
K.F. Fraser and C.N. King, University of Tasmania,  
Australia
- 10 Investigation into the Vibration of the Starter Gearbox of  
an Aircraft Turbine Engine  
P.D. McFadden, Royal Melbourne Inst. of Technology,  
Australia

SESSION 3: INTEGRATION

*Chairman*

Vivek R. Sinha  
Aeronautics Research and Development Board, India

*Co-Chairman*

Dr. K. Richey  
Wright Patterson Airforce Base, USA

- 11 A look at Comprehensive Engine/Airframe Integration for High  
Performance (Modern Military Aircraft  
W. Schreiber and E. Heinz, Messerschmitt-Bolkow-Blohm GmbH,  
West Germany
- 12 Technology Pays off on the AV-8  
Charles C. Cassmeyer, McDonnell Aircraft Company, USA
- 13 Comparisons of Model and Flight Testing with Respect to Hot Gas  
Reingestion and Debris Ingestion during Thrust Reversal  
W. Kurz, Messerschmitt-Bolkow-Blohm GmbH, West Germany
- 14 Development and Validation of Computational Tools for Analysis based  
Designs of Complex 3-D Inlets and Exhaust Nozzles  
E. Tjonneland and S.F. Birch, Propulsion Technology, Boeing  
Military Airplane Company, USA
- 15 The Sweep Finite Element Method for Calculating the Flow Field  
and Performance of Supersonic Ejector Nozzles  
Hui-li Shen, Chuding Tong, Tuenpiao Shyur and Ningkong Kee,  
Northwestern Polytechnical University, Xian, People's Republic  
of China
- 16 Flow Separation in Inlets at Incidence Angles  
A.K. Jakubowski, Virginia Polytechnic Institute and State  
University, USA and R.W. Luidens, NASA - Lewis Research Center, USA

- 17 Noise Attenuation and Associated Thrust Increase of Turbojet Engines through Hyper-Mixing Ejector Shrouds  
B.H. Goethert, Dean Emeritus, UTSI, TN 37388, USA
- 18 Jet Noise Suppression for Low-Bypass Engines - Have we reached the Dead-End?  
S.L. Sarin, Fokker B.V. The Netherlands and W.B. de Wolf, National Aerospace Laboratory, The Netherlands
- 19 Prediction of the Surge Characteristics of Turbojet Engines  
S.M. Ramachandra, Alfateh University, Libya
- 20 The Digital Control Systems as part of an Integrated Accessory Fit for Future Engines  
M.P. Perks and T.G. Morton, Rolls-Royce Ltd., England

SESSION 4: ADVANCED AND HYBRID SYSTEMS

*Chairman*

M. Pianko  
ONERA, France

*Co-Chairman*

T.V. Vareed  
Hindustan Aeronautics Ltd., India

- 21 Ramjet Air Induction System Design for Tactical Missile Applications  
Joseph G. Bendot and E. Heinz Jr., The Marquardt Co., USA
- 22 Flowfield Studies of Dump Combustors  
Raghunath S. Boray, Wright Patterson AFB, USA and Cherrng Chang, Brehm Laboratory, USA
- 23 A Ramjet Trajectory, Ground Simulating Test  
Chiang Shih-Si, China Precision Machinery Co., Beijing, People's Republic of China
- 24 Performance Analysis of Primary and Secondary Systems of a Rocket-Ramjet Engine burning fuel-rich Metallized Propellants  
S. Krishnan, V. Ramanujachari, K.S. Padiyar, and R. Natarajan, Indian Inst. of Technology, Madras-600 036, India
- 25 Experimental Study of Combustion in Solid Rocket-Ramjet Engine  
Chen-Da-Ming, Tu Ye-Ing, Li Uyi-Ing and Sin Zin-Zyn, China Precision Machinery Co., Beijing, People's Republic of China

- 26 Air Augmentation of Rockets for Low Speed Application  
S.A. Fisher, Aeronautical Research Laboratory, Australia and  
R.D. Irvine, Defence Research Centre, Australia
- 27 A Simplified Technique for the Analysis of Base Flow with and  
without Combustion  
Frederick S. Billig, and J.A. Shetz, Johns Hopkins University, USA
- 28 Factors Affecting Afterbody Drag  
W.H. Schofield, Aeronautical Research Laboratories, Australia-3001
- 29 A New Breed of an Air Breathing Engine  
Max Berchtold, Eidg Technische Hochschule, Switzerland
- 29a Sudden Expansion Injection for Ram-Rockets  
J.B. Greenberg and Y.M. Timnat, Technion, Haifa, Israel

SESSION 5: TURBINES AND COOLING

*Chairman*

Dr. A. Gopalakrishnan  
Bharat Heavy Electricals Ltd., India

*Co-Chairman*

Dr. Y. Kakehi  
Japan Defence Agency, Japan

- 30 Calculation of the Effects of Combined Blade Twist and Lean on the  
Performance of Turbine Stator Cascade with Long Blades  
Wang, Zhong-Chi Harbin Inst. of Technology, People's Republic of  
China
- 31 The Optimum Design and Performance Estimation of Transonic Axial-Flow  
Turbine  
Man-Chu Ge, Academia Sinica, Beijing, People's Republic of China
- 32 Transpiration Cooled Blade-A Technology of the Future Generation  
Aircraft and Industrial Gas Turbine Engines using Coal or Coal-  
derived Fuels  
R. Raj, The City College of New York, USA and S. Moskowitz,  
Curtiss-Wright Corporation, USA
- 33 Discrete Hole Film Cooling of Turbine Blades  
Nessim Hay, University of Nottingham, Nottingham, UK
- 34 Film Cooling Performance by Injection through Discrete Holes  
Adel A.M. El Ehwany, and M. Abou El Nasre, Ains Shams University  
Cairo, Egypt

35 Film Cooling Performance of Liner Cooling Devices  
B.R. Pai and R. Lakshminarayana, National Aeronautical Laboratory  
Bangalore-560 017, India

36 Turbine Blade Cooling Research at the Von Karman Institute for  
Fluid Dynamics  
Phillip M. Ligrani, Asst. Professor, VKIFD, Belgium

SESSION 6: INSTRUMENTATION

*Chairman*

James Patton  
Office of Naval Research, USA

*Co-Chairman*

Prof. G.J. Walker  
University of Tasmania, Australia

37 The Analytical Ferrograph-Some Factors affecting Deposit Formation  
G. McVea and M.L. Atkin, Aeronautical Research Laboratory, Australia

38 A System to Measure and Analyse the Pressure and Swirl Distribution  
in Intake Flows  
H. Habig and H R. Leistner, Messerschmitt-Bolkow-Blohm GmbH  
West Germany

39 A Digital Technique for the Analysis of the Response of Compressor/  
Duct Systems in Unsteady Flow  
D.K. Das, Cranfield Inst. of Technology, UK, and R.E. Peacock  
The Naval Post-Graduate School, USA and Cranfield Inst. of Technology

40 Two Advanced Measuring Techniques for the Determination of Rotor Tip  
Clearance during Transient operations  
H. Knoll, K. Schedl and G. Kappler, MTU-Munchen GmbH, West Germany

41 Investigation of Coherent Anti-stokes Raman Spectroscopy (CARS) for  
Practical Combustion Diagnostics  
Alan C. Eckbreth, Robert J. Hall, and John A. Shirely, United  
Technologies Research Center, USA

SESSION 7: COMBUSTOR DESIGN PROBLEMS I

*Chairman*

Dr. G. Kappler  
MTU, West Germany

*Co-Chairman*

Prof. Gad El Mawia  
Ainshams University, Egypt

- 42 Withdrawn
- 43 The Analysis of a Reverse Flow, Annular Combustion Chamber  
F.M. Joubert and H.V. Hattingh, University Stellenbosch,  
South Africa
- 44 Application of Modulatable Cyclone Combustors to form a basis for  
low pollutant emission Gas Turbine Combustors  
N. Syred and A.C. Styles, University College, Cardiff, UK
- 45 The effect of Slot Geometry on the Performance of Supply Air  
Grills and Combustor Holes  
A.A. Rizk, Ain Shams University, Cairo, Egypt, K.Sh. Koddah, Uni  
University of Technology, Baghdad, Irac, and Eng. G.W. Younan,  
Ain Shams University, Cairo, Egypt
- 46 Factors Limiting Turbine Inlet Temperatures  
B.G.A. Sjoblom, Volvo Flygmotor AB, Sweden and J.Odgers  
Laval University, Canada
- 47 Fresh Mixture Entrainment in a Jet Curtain Flame-holder  
K. Sridhara and M.S. Chidananda, National Aeronautical Laboratory  
Bangalore, India
- SESSION 8: COMBUSTOR DESIGN PROBLEMS II
- Chairman*
- Prof. J. Swithenbank  
University of Sheffield, UK
- Co-Chairman*
- Prof. J. Odgers  
Laval University, Canada
- 48 Some Fundamental Aspects of Flame Stabilization  
D.R. Ballal, General Motor Research Laboratory, USA and  
A.H. Lefebvre, Purdue University, USA
- 49 A Comparison of Two Droplet Models for Gas Turbine Combustion  
Chamber Flows  
W.P. Jones, and J. McGuirk, Imperial College, London, UK
- 50 The Combustion Modelling of Swirling Flows for Gas Turbine Combustors  
T.C. Claypole and N. Syred, University College, Cardiff, UK
- 51 Withdrawn

- 52 L.D.A Techniques in Spray Characterization  
U. Ghezzi, A. Coghb, C. Brioschi and F. Gamma  
C.N.P.M. Institute Di Machine, Italy
- 53 The Effect of Oxygen Concentration Distribution on Altitude  
Relighting Performance of a Turbo-Jet Engine Combustor  
Y.F. Wu, Z.X. Huang, S.M. Wang, and Y.Z. Wang,  
Academica Sinica, Beijing, People's Republic of China

SESSION 9: MATERIALS

*Chairman*

Air Vice-Marshal S.N. Roy Choudhary  
Gas Turbine Research Establishment Bangalore, India

*Co-Chairman*

Prof. B.E.L. Decker  
University of Saskatchewan, Canada

- 54 High Temperature Metal Matrix Composites for Gas Turbines  
Leif O.K. Larsson, Volvo Flygmotor AB, Sweden
- 55 Photoelastic Investigation of Stress Distribution around Inclined  
cut-outs in Gas-Turbine Components subjected to Inplane Bending Loads  
R. Padmanabhan, K. Ramachandra, V. Maruthi and B.J. Raghunath,  
Gas Turbine Research Establishment, Bangalore, India
- 56 Influence of O-Rings on the Behaviour of Damping Coefficient in a  
Squeeze Film Mounted Ball Bearing  
V. Arun Kumar, National Aeronautical Laboratory, Bangalore, India
- 57 Investigation of the Squeeze Film Bearing on a Two-spool Turbo-Fan  
Engine  
Wen-Ming Li, Chen Shan-Zhi, Sun-Yen-biao, and Wu-Zhen-qi, Shenyang  
Aeroengine Research Inst., People's Republic of China

SESSION 10: VIBRATION AND FLUTTER

*Chairman*

Prof. F.A.E. Breugelmans  
Von Karman Institute of Fluid Dynamics, Belgium

*Co-Chairman*

Prof. S. Soundranayagam  
Indian Institute of Science, India

- 58 Cascade Modelling of Supersonic Flutter  
Sanford Fleeter, School of Mechanical Engineering, Purdue Univ., USA
- 59 Effects of Mistuning on Blade Torsional Flutter  
A.V. Srinivasan, United Technologies Research Center, USA and  
A. Kurkov, NASA Lewis Research Center, USA
- 60 Self Excited Vibration of Turbomachine Blades  
S. Surya Prakasa Rao, Air India, Bombay, India,  
V. Pukhopadhyaya, Indian Inst. of Technology, Kharagpur, India, and  
J.S. Rao, Indian Institute of Technology, Delhi, India
- 61 Reduction of Strut Induced Rotor Blade Vibration with the modified  
Stator Setting Angles  
S. Yokai, S. Nagano, Ishikawajima-Harima, Heavy Industries Co. Ltd.,  
and Yoh Kakehi, Japan Defence Agency, Japan
- 62 The Influence of Gyroscopic Forces on Dynamic Behavior of Rotating Blades  
F. Sisto and A.T. Chang, Stevens Inst. of Technology, USA

SESSION 11: CASCADE FLOW

*Chairman*

Prof. C.H. Wu  
Academia Sinica, People's Republic of China

*Co-Chairman*

Prof. E. Nilsson  
Chalmer's University of Technology, Sweden

- 63 Flow in Annular Diffusers with Two Vortex Distributions at Entry  
B.E.L. Deckker, University of Saskatchewan, Canada and J. Iwamoto,  
Tokyo Denki University, Japan
- 64 On the Solution of Navier Stokes Equations of the Flow in Turbomachines  
A.M. Elzahaby, Military Technical College, Cairo, Egypt
- 65 Numerical Computations of Compressible Steady Cascade Flows  
H.H. Fruhauf, Inst. fur Raumfahrtantriebe, Stuttgart, West Germany
- 66 The Axial Velocity Density Ratio and the Axial Velocity Density  
Distribution in Axial Flow Compressors and Cascades  
J. Starke, Bayer A.G. West Germany
- 67 Evaluation of Blade Element Performance of Compressor Rotor Blade  
Cascades in the Transonic and Low Supersonic Flow Range  
Heinz-Adolf Schreiber and Hans Starke, DFVLR, KOELN, West Germany

- 68 Investigation of Flow through Supersonic Axial Compressor Cascades  
Karel Celikovsky, Aeronautical Research and Test Inst., Czechoslovakia
- 69 Turbulence Influence on Laminar Separation on an Airfoil  
Willy Z. Sadeh and Peter R. Sullivan, Colorado State Univ., USA
- 70 Finite Difference Solution of Full-potential Equation for Cascade  
Flow along Arbitrary Stream Filament of revolution in Turbomachinery,  
using Non-orthogonal Curvilinear co-ordinates and non-orthogonal Velocity  
Components  
Wang Qing-huan, and Nai-Xing Chen, Inst. of Engineering, Thermophysics,  
Academia Sinica, Beijing, People's Republic of China

SESSION 12: COMPRESSORS

*Chairman*

Robert O'Brien  
United Technologies Research Center, USA

*Co-Chairman*

Dr. K. Celikovsky  
Aeronautical Research and Test Institute, Czechoslovakia

- 71 The Accuracy of Mean Stream Line Method in Sub-sonic and Transonic  
Regions  
Rui-Xian Cai, Academia Sinica, Beijing, People's Republic of China
- 72 Analysis of Boundary Layer and Wakes for a Compressor Rotor blade  
B. Lakshminarayana and T.R. Govindan, The Pennsylvania State University, USA
- 73 Problems encountered in Measurement and Interpretation of Experiments  
with Advanced Axial Compressors  
J. Paulon, O.N.E.R.A., France, and Dominique Dehondt, Societe  
Turbomeca, France
- 74 Blade Row Variable Distance Effects on Compressor Unsteady Phenomena  
Jean Colpin, M. Malina, P. Van Wambeke and D. Van Ham, Centre de  
Technologie Nouvelle Division, Engine, Belgium
- 75 Effects of Solid Particles suspended in Fluid Flow through an  
Axial Flow Compressor Stage  
W. Tabakoff and C. Balan, University of Cincinnati, USA
- 76 Particulate Flow in Centrifugal Compressors used in Helicopters  
A.F. Abdel Azim, Egypt Air Company, Egypt and M.I.I. Rashed  
Cairo University, Cairo, Egypt

- 77 Effects of Corioli's Forces on the Turbulent Field inside  
Centrifugal Impellers  
J.P. Bertoglio, J. Mathieu, and G. Charnay  
L'Ecole Centrale de Lyon, France
- 78 Model for Axial Compressors Operating with Water Ingestion  
T. Tsuchiya and S.N.B. Murthy, Purdue University, USA