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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Technical Evaluation Report on the Propulsion and Energetics Panel 53rd Symposium on Solid Rocket Motor Technology

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TECHNICAL EVALUATION REPORT

on the

PROPULSION AND ENERGETICS PANEL 53rd SYMPOSIUM

on

SOLID ROCKET MOTOR TECHNOLOGY

by

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PREFACE

The 53rd PEP Symposium on Solid Rocket Motor Technology gave a reasonably accurate picture of the present state of the art, both from the research and technology points of view, in NATO countries. A rather wide and qualified spectrum of speakers, participation from industry, a massive (perhaps for the first time) presence of US experts, and the large variety of topics dealt with in the seven technical sessions were positive aspects of the meeting. Some deficiences (mentioned in this report) should be carefully considered for the future. In particular, it is appropriate that a restricted session be added to the open works in order to stimulate the presentation of more advanced results in the field. However, my feeling is that the meeting was globally very successful.

The warm hospitality of the Norwegian coordinator, Mr G.Kristoforsen, the efforts of Mr J.H.Krengel (Executive of PEP), and the cooperation of the members of PEP (Messrs. Barrère, Bayley, Crispin, Culick, Hirsch) are gratefully acknowledged.

Prof. Ing C.Casci

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TECHNICAL EVALUATION REPORT

1. INTRODUCTION

The 53rd meeting of the Propulsion and Energetics Panel on Solid Rocket Motor Technology was held at the Old War School, Oslo, Norway, from 2–5 April 1979. The meeting was organized to give a survey of the state of the art in this field both in research and development.

Most papers reported research and development work in the field of internal ballistics including ignition, extinction, combustion of metal and combustion instability. Additional papers dealt with burn rate modelling, new propellants as well as heat transfer and materials, testing and instrumentation.

The meeting consisted of seven sessions with a total of 36 papers. Conclusions and discussions revealed a high standard of solid propellant rocket technology in the NATO community, but also a lot of deficiencies in the knowledge of what is really happening in a solid rocket. Thus modelling and predicting of the performance of solid rocket components – key for more economic research and development work – are still subject to uncertainties and even mistakes.

2. DISCUSSION

Session I, Survey Papers

These papers give a first impression on the problems and directions of solid rocket motor technology. Most of the topics mentioned are discussed in more detail in the following sessions.

M.Barrère (Paper No.1) presented a concise survey of the research problems in the field of solid rocket technology and the various investigations made at ONERA. Another aspect of solid rocketry at least as important as research is development and industrial realization. Paper No.2 by W.G.Haymes surveys in an impressive manner the current work in the United States on solid rocket motor design automation. This procedure implies a pay-off in terms of reliable and fast optimization, development cost and schedule. This improves the capabilities and competitive position of the users. Mr Haymes' paper certainly was one of the most illuminating contributions to the Symposium.

Session II, Ignition, Extinction and Internal Ballistics

Paper No.3 by G.Lengellé et al. describes the systematic research work done at ONERA in the field of ignition and extinction of doublebase and composite propellants and the test facilities used. It has been shown by experiments that the ignition characteristics are only determined by the propellant components but not by the method of heat transfer from the ignition device. L. de Luca (Paper No.4) has treated this problem analytically for composite propellants assuming heterogenous combustion and a quasi-steady gas phase. The discussion showed that the theoretical results will depend largely on the flame model used and whether the heat transfer into the propellant is assumed to be a steady (de Luca) or an unsteady phenomenon. Results will certainly depend on whether solutions are sought by linearized or non-linearized approaches.

Paper No.5, presented by E.Stampfl, describes the SPP-program (solid propellant rocket motor prediction program) limited to composite propellants. Comparison with experimental data shows, that specific impulses are overpredicted. Two phase losses in aluminized propellants prevail over other losses, but computation is rather uncertain. Therefore, accurate computation of the other losses (such as divergence and combustion efficiency) needs computer time without influence on the overall accuracy of the prediction. Furthermore, correlation of statistical data has proved to be as accurate as expensive theoretical analyses.

H.F.R.Schöyer (Paper No.6) presents a set of equations to estimate the influence of small variations in the throat area of solid rockets. The equations are set up by linearization of the one-dimensional isentropic equations. The method may give fast information during the early phases of a development program.

In paper No.7 by W.H.Diesinger definition and margins of standard solid rocket environment are given. Solid rockets as either very short burning thrusters or applied to shells usually do not encounter a standard environment and need an appropriate grain and igniter design or a special layout to overcome problems arising with axial acceleration and spin, respectively.

H.Florin, Paper No.8, points out that until now propellant igniter design is an art rather than a science. Therefore empirical know-how and high standard laboratory test equipment is needed especially in the development of igniters for small rockets because of environmental compatibility requirements. Paper No.9 by A.R.Hall confirms that igniter design usually is a more or less empirical matter. For some applications this situation can be remedied by pyrogen igniters. The author advocates the view that such minirockets should be preferred because of their predictable and reproducible performance and their smokelessness if doublebase pyrogens are used.

Prediction of erosive burning as a phenomenon and its effects on solid rocket performance is difficult, since it is not yet fully understood what is really happening. Existing theories have deficiencies. R.C.Parkinson (Paper No.10) shows that erosive burning as an interaction of the boundary layer with the combustion zone can be correlated by a boundary layer blow-off criterion. Erosive burning is attributed to the re-attachment of the boundary layer to the burning surface. The theory is not yet fully developed. The effects of erosive and transient burning on performance prediction accuracy have been investigated by H.P.Sauerwein et al. (Paper No.12, Session III). Test results with small solid propellant rocket motors of calibers .11 m and .175 m using a 18 – 19% Al-loaded HTPB composite propellant revealed excellent agreement with theoretical predictions using the approaches of Lenoird & Robillard, and King. During the discussion it has been pointed out, that the agreement is better than one could expect and that additional tests should be made.

Session III, Burn Rate Modelling and Combustion of Metal

Besides combustion instability which is to be discussed later, burn rate modelling and two phase phenomena associated with combustion of metal are very important for rocket motor design technology. Reliable low cost procedures to handle these topics would make modern high performance solid rocket motor design more economic.

N.S.Cohen (Paper No.11) gives a review of the status of steady-state combustion modelling of composite propellants. Active binder propellants commonly known as composite doublebase propellants are included. Research work in this field has now reached a standard enabling a good feedback to propellant combustion and tailoring. Additional theoretical and practical research is needed to eliminate disagreements and other deficiencies, and especially to reduce the great number of parameters. Deficiencies are mainly due to an apparent lack of information concerning the phenomena of metal burning and two phase flow. Therefore tests with high speed color movies (2000 to 5000 fr/s) of propellants burning as strands or in a window motor were of basic interest. They are reported by L.H.Caveny (Paper No.13). Generalization is not yet possible since the investigation has been restricted to phenomenology so far. The following items should be noted: Agglomeration size, combustion efficiency and slag formation are influenced by propellant formulation, particle size, rocket motor internal geometry and chamber pressure. The acceleration field causes break up of the agglomerates in the nozzle region, provided that the Weber number is sufficiently high. The agglomerates decrease in size with burning rate and pressure.

The presentation of E.W.Price (Paper No.14) was very instructive. His color slides showing the microstructure of aluminum burning give a very good view of accumulation of Al to the burning surface, agglomerated Al leaving the burning surface, inflammation and burning of Al droplets in a propellant gas environment. AP hydrocrabon binder Al propellants were used.

It is well known that the Al/Al_2O_3 particles may damp acoustic oscillations caused by combustion instability. Paper No.15 by K.J.Kraeutle describes results of theoretical investigations assuming spherical aluminum oxide particles of flat normal size distribution. Only a small size range (about 1 – 50 μm) is suitable for effective damping of the common oscillation frequencies. The investigations are still under way. Since particle size is one of the important parameters of propellant behavior suitable tailoring of the content and the size distribution of the aluminium oxide could help to prevent costly and time consuming modifications which might be necessary during the later stations of a design process.

Session IV, New Propellants

Grains for recoilless guns are characterized by large burning surfaces and small web thicknesses. Standard techniques using aluminum foils or steel meshes as a support for the propellant are expensive and create problems especially in bonding the propellant to the support. Paper No.16 of A.T.Camp, presented by N.Seiden, describes a new fabrication process. The doublebase propellant is applied to a corrugated plastic screen structure as a lacquer in several dip coats with partial drying after each dip. The lacquer web thickness ranges from about .12 to .60 mm. The grains have not been fired until now. The predicted burning times range from 3 to 15 ms.

Paper No.17 by R.Strecker et al. presents a new type of gas generator propellants. These propellants must meet special specifications particularly a large temperature range (from 219 to 345 K), low gas temperature ($T_c < 1500$ K), small burning rate ($r = .7 - 3$ mm/s) and compatibility of the gases with the structure. Conventional propellants do not fit these specifications. The new gas generator propellant NB 410206 is a HTPB NiO-stabilized AN (ammonium nitrate) composite. The AN oxidizer is polymorphic with unacceptable variations of the specific volume in the temperature range of 248 K to 398 K. Incorporation of 3% NiO by weight into the crystal lattice shifts these phase changes to higher temperatures. Another progress in propellant development is reported by C.Gotzmer et al. (Paper No.18). The development began in 1972 with utilizing epoxide crosslinked agents for a MTBN binder (mercaptan terminated butadien-acrylonitrile) initiating the development of a new binder system. It consists of a low acrylonitrile type carboxy-terminated-polybutadiene-acrylnitrile liquid copolymer (CTBN) which is crosslinked with di- and tri-epoxides. Castable and extrudable composite propellant formulations with very high solids loading (up to 90% of combined AP and Al) appear feasible with tolerable mechanical properties when using this new CTBN binder.

The mechanical properties of propellants change with storage time. This aging process may have undesirable technical and economical consequences. In Paper No.19 by D.Schmitt the aspects of short time accelerated aging at elevated temperatures as a tool to make long time predictions feasible are discussed. In doublebase propellants chemical aging is predominant whereas composites are rather insenitive. They are primarily subject to mechanical aging leading to elevated strength and attenuated crash deformation. The amount of mechanical aging decreases from the propellant surface to the inside.

Smokeless doublebase propellants needed for some military applications have disadvantages such as vitrious behavior at high ambient temperatures which forbids case bonding and small values of mass density and theoretical specific impulse. A.Davenas (Paper No.20) reported on research work at SNPE to create a smokeless propellant, which is castable and has better energetic and mechanical properties than standard doublebase propellants. The preliminary result is a first generation of smokeless composite and doublebase composite propellants using hexogen with energetic crosslinked binders (example: a doublebase composite propellant with 35% hexagen, mass density $\rho_p = 1.65 \cdot 10^3$ kg/m^3, burning or regression rates $r = 7 - 15$ mm/s at pressures $50 - 120$ bar, theoretical specific impulse $I_{s,th} \approx 2400$ N·s/kg).

Session V, Combustion Instability

A better understanding of combustion instability is needed for reliable prediction in the motor design phase. This is true especially for large solid motors since testing is very expensive in terms of time and money. Therefore achieving a wider theoretical background in this field is as important as for burn rate modelling or combustion of metal loaded propellants.

F.E.C.Culick (Paper No.21) discusses an approach to non linear waves in solid rockets. The unsteady flow field is expanded in normal modes of the chamber. Subsequently a method of averaging is used. This approximation is sufficiently accurate under most realistic conditions. Deficiencies of the method can only be remedied by a third order theory. The presentation of P.Kuentzmann (Paper No.22) confirms the problems in handling combustion instability and gives a concise review of the theoretical and experimental investigations at ONERA in this field. Future work will be directed to a better description of the instability phenomena, numerical solution of non linear instability problems to predict instability levels, reduction of computer time and additional experimental investigations. In Paper No.23 by R.L.Derr et al. a straight forward method for practical application is described and a general review of the problems is given. Managing combustion instability means maximizing acoustic energy losses (particle damping) and minimizing acoustic energy gains. There are deficiencies mainly in the linear model, the laboratory techniques and propellant tailoring. It is questionable whether quantitative predictions will be feasible in the near future from the practical and cost point of view.

In Paper No.24 by L. de Luca results of basic theoretical study are presented assuming heterogenous combustion and quasi-steady gas phase for composite propellants. The non linear analysis using an integral method shows that three stable states exist which are stationary combustion, self sustained oscillation and extinguishment. The results are largely dependent on the flame model and other assumptions and could not yet be checked by test results.

For basic work on low frequency oscillatory combustion the L*-burner is the best device because of simplicity. Paper No.25 by H.F.R.Schöyer reports on experiments with this equipment. Two types of doublebase propellants and a polyurethane AP composite propellant were used. To get reliable test results a smooth and reproducible ignition transient is important. An ignitition lacquer initiated by an inbedded electric wire has proved to meet this requirement best. Frequently L*-instability of doublebase propellants led to chuffing whereas the composite propellant tended to dp/dt-extinguishment. The experiments were performed under pressures and with characteristic lengths which are smaller than usual for operational rockets.

P.M.Hughes (Paper No.26) describes basic research work on non linear longitudinal combustion instability in solid rockets of caliber 7 cm. Three different composite propellant case bonded grains (tube, star, slotted tube) and three non-aluminized HTPB/AP propellants were used, varying only in burning rate catalyst and AP size distribution. The motors operated stably in absence of initiating disturbances. These were generated by two black powder charges located in pulse tubes at the head end of each motor. The tests demonstrated the feasibility of the method and revealed increased sensitivity to disturbances with decreased burning rate and increased free volume of the chamber.

G.I.Evans (Paper No.27) describes an approach to the problem of combustion instability damping of smokeless CDB propellants by using refractory particles which are unreactive during combustion and attenuate the visibility of the exhaust gases in comparison to aluminum oxide particles. The method is not restricted to CDB propellants, of course. The investigations are of basic interest for military rockets. Experiments have shown that tailoring the size of the particles is less important than the mass fraction of the refractory powder. At present most information is available for silicon carbide as refractory material. Work is going on with higher density powders such as tungsten and tantalium carbide.

Session VI. Heat Transfer and Materials

Progress in solid rocket motor technology is largely influenced by the characteristics of lightweight structures and refractory materials. The prediction of materials behavior needs accurate and straight forward methods of heat transfer calculations. Therefore, the presentation of only three papers in this session is not adequate to the importance of the subject.

Paper No.28, presented by D.Kampa, discusses the advantages and drawbacks of current TVC systems for highly manoeuverable tactical solid propellant rockets. It is concluded that jet vanes are the best solution because of large deflection angles (up to 30°) and low actuation torques. Additional advantages are the possibility to generate roll moments with a single nozzle arrangement and to jettison the system after the launch phase when aerodynamic control is feasible. The jet vanes must withstand thermal shock and high stagnation temperature. Several jet vane materials were investigated in static tests with a 110 mm and a 240 mm diameter rocket motor using HTPB composite propellants with 16 – 18% and 1% aluminum, respectively and burning times from 2.4 – 3.7 s. For the highly aluminized propellants pure tungsten vanes protected by a low thermal conductivity layer were found to be the best material composition. For the 1% Al propellant molybdenum was sufficient.

A research review on composites in future motor hardware is given by N.J.Parrat (Paper No.29) with special emphasis to tactical solid rockets. Research work is aimed to the best use of composites to reduce weight and cost. Reduction of the inert weight up to 40% compared to conventional structures seems to be feasible in the future. An additional improvement can be expected by combining the material functions of structure, insulation and erosion resistence. Composites are suitable as multifunction materials if properly designed. It cannot be expected that multifunction materials will be as good as each single function material but weight and cost savings are the most compelling arguments.

C.Bonnet reports in his Paper No.30 that refractory metals and graphite successively have been replaced by ablative composites as nozzle materials in long burning solid rockets. The prediction of the behavior of these composites has been uncertain or even impossible for a long period since fabrication processes were not reproducible. Moreover, the performance of analytical methods was poor and the mechanical characteristics of the composite materials in the relevant temperature range were not known. The paper discusses the milestones and the present state of the art at SEP to reliable prediction of composite material behavior, especially of cast and wound graphite-phenolics and carbon-phenolics. Reliable prediction is guaranteed by reproducible measurements and appropriate computer programs using finite element methods.

Session VII. Testing and Instrumentation

It is evident that testing and instrumentation is essential for research and development. Elaboration and standardization of new methods is of vital interest because of cost and competition aspects.

Paper No.31 by A.Goghe et al., presented by L. de Luca, reports on velocity measurements of particle loaded gas flows using LDV techniques (Laser-Doppler-Velocimetry). At present, the investigations are in an early stage. It is notable that the particle rate must be sufficiently high for a continuous velocity output and that agglomeration of the particles should be prevented for accurate measurements since, obviously, only small particles have the same velocity as the gas. A new research program recently started will check whether the LDV method is suitable for measurements of particle size and distribution and velocities in unsteady flows.

R.S.Brown reports in his Paper No.32 on investigations at UTC of low frequency pressure and velocity oscillations occurring in large solid rockets. T-burners results applied to large rockets are unreliable because of thermal losses. Therefore, the rotating valve method has been evaluated. Test results show good agreement with T-burner results as did investigations reported by M.Barrère (Paper No.1). Current work is aimed to a better understanding of the combustion reponse and to mature the RV method as a standard tool to combustion instability investigations.

D.S.Dean, Paper No.33, discusses non-destructive testing of solid propellant charges. Many faults cannot be detected radiographically or only with high inspection cost. Ultrasonic inspection is a potentially better technique since this method is sensitive to interfaces (cracks, delaminations, bonding faults) rather than to missings. Unfortunately ultrasound damping in a propellant increases rapidly with frequency limiting the shortest usable wavelength to 1 – 10 mm. Thus ultrasonic imaging gives low resolution and little margin for additional noise in the data processing system. Since focused images by ultrasonic lenses are not feasible imaging by holographic encoding with optical reconstruction and phase array focusing with presentation on a display unit have been investigated. The impressive amelioration of the resolution by holographic encoding is demonstrated by pictures in the paper. Example: In a .5 m diameter solid rocket motor defects of about 1 cm diameter can be detected when using a .5 MHz ultrasound.

Testing for verification and reliability has a statistical aspect, too. Therefore, overtesting i.e. subjecting full scale units to aggravated load conditions, implies a pay-off in terms of development cost and schedule. Paper No.34, presented by E.Stampfl, shows with application to IUS (Inertial Upper Stage) that this approcah is valuable to solid motor components and complete motors. It is estimated, that three 20% motor overtests are equivalent to ten motor tests at operational conditions. Use of standardized test motors and laboratory tools is an additional method to make development efforts more efficient. R.R.Weiss, Paper No.35, reviews the pertinent efforts of the US Air Force Rocket

Propulsion Laboratory. The most important advantages which are cost saving and comparative evaluation balance by far the disadvantages which are limitation to early development stages and uncertainties in scaling the test results to the full-scale motor. The development program of standard test motors has been initiated in 1960. At present, three families are available, the BATES (ballistic test and evaluation system), Super-BATES and Super-HIPPO standard test motors. The maximum grain weights are 75 lbm, 800 lbm per segment and 90 000 lbm, respectively. Finally a review on standardized laboratory tools used in the United States is given.

D.S.Dean, Paper No.36, discusses the possibilities of thrust transient measurements in rocket motors. Since any force measuring device can be represented by a system of masses and springs with damping the natural frequency of the system must be sufficiently above the frequencies of the thrust fluctuations. Sometimes this does not apply, especially if thrust transients must be measured. The following pertinent methods were successfully tested: Measurement of all terms of the oscillating system (displacement, damping, acceleration) and application of the describing differential equation, use of a ballistic pendulum system or low friction horizontal sliding rods. In the latter systems both the influences of the displacement and the damping are very small and usually can be neglected.

3. SUMMARY AND CONCLUSIONS

As indicated by Professor C.Casci at the end of the Round Table Session, the contributions presented during the Symposium drew a realistic picture of the present situation in the field of solid propellant rocketry. The presentations can be grouped into three main areas of interest:

- propellant steady state burning
- propellant unsteady burning
- rocket motor technology

Those concerned with propellant steady state burning included advances in propellant chemistry and combustion modelling. Particularly noteworthy are the contributions by Caveny[13], Price[14] and Kraeutle et al.[15] on the behavior of aluminum in the combustion process by which the physical understanding was greatly enhanced.

Regarding unsteady burning several contributions of both theoretical and experimental nature revealed that a certain progress has been achieved, still much remains to be done. While considerable emphasis was placed on acoustic instability less interest was observed in two-phase flow with combustion. Nevertheless, a very interesting and apparently effective method to suppress combustion instability in rockets using homogeneous propellants was presented by Evans and Smith[27] who introduced refractory particles for this purpose. It is evident that theoretical, non-linearized approaches to fluid dynamics and combustion need to be pursued.

In the field of rocket motor design and development it became quite clear that the United States have achieved a high standard. As highlighted by Haymes[2], Stampfl[34] and Weiss[35] extensive use of computers and standardized testing procedures and test equipment ensure design and development of rocket motors in a less expensive and less time consuming way in the US than in other countries.

Interesting forecasts were given by Parrat[29], and Dean and Green[33] showing substantial reductions of structural weight and of failure rates.

The authors of this TER agree on the general conclusion that the overall knowledge of solid propellant rocketry is obviously sufficient to develop and produce high performance propellant rockets. Due to the lack of complete understanding of a number of phenomena there are many problems solved empirically today. In consequence, prediction of solid rocket performance is not ensured to the extent really desirable and is not achieved as economically as possible. The meeting has met its aim as set in the meeting theme but fell a bit short in offering the time necessary to discuss all aspects in more detail.

4. RECOMMENDATIONS

Following the review of the present status in solid propellant rocketry a number of specific task fields are recommended for future medium and long term applied research efforts:

(1) design of igniters for small military rockets and development of standardized design methods;
(2) metal combustion and two-phase flow;
(3) systematic data compilation and reduction on specific impulse losses;
(4) thrust modulation;
(5) lightweight structures and multifunction materials;
(6) non-destructive material control methods preferably to be used during production to ensure high quality and reliability.

For immediate action, the following proposals are forwarded to AGARD and the Propulsion and Energetics Panel:

(1) Apparently there is a trend leading to further diverging views on smoke and on visibility. It is understood that an exact definition of "the smokeless propellant" could remedy this situation, and the authors of this report consider this highly desirable. A small Working Group or Subcommittee sponsored and organized by the Propulsion and Energetics Panel would certainly offer the appropriate means.

(2) Equally, a Working Group is recommended to investigate the standardization of prediction methods, especially for specific impulse losses in metal loaded propellants.

5. REFERENCES

Session I – Survey Papers

1 *Les Recherches dans le Domaine des Moteurs Fusèes a Propergols Solides (Vue d'Ensemble)*
par M.Barrère

2 *Solid Rocket Motor Design Automation Technology*
by W.G.Haymes, J.E.Williamson, S.E.McClendon and W.T.Brooks

Session II – Ignition, Extinction and Internal Ballistics

3 *Allumage et Extinction des Propergols Solides*
par G.Lengellé, P.Mentré, J.Guernigou, A.Bizot et Y.Maisonneuve

4 *Ignition and Extinction of Solid Rocket Propellants*
by L. De Luca, L.Galfetti and C.Zanotti

5 *Solid Propellant Specific Impulse Prediction*
by E.M.Landsbaum and M.P.Salinas

6 *A Simple Method to Estimate the Influence of Small Variation in the Throat Area on the Performance of Solid Rockets*
by H.F.R.Schöyer

7 *Internal Ballistic Problems of Highly Accelerated Solid Propellant Rockets*
by W.H.Diesinger

8 *Propellant Igniter Development Problems*
by H.Florin

9 *Some Measurements of Ignition Delay and Heat Transfer with Pyrogen Igniters*
by A.R.Hall, G.R.Southern and D.Sutton

10 *Boundary Layer Models of Erosive Burning*
by R.C.Parkinson and P.D.Penny

Session III – Burn Rate Modelling and Combustion of Metal

11 *Composite Propellant Burn Rate Modeling*
by N.S.Cohen

12 *Erosive and Transient Burning Effects on Performance Prediction Accuracy of Tactical Rockets*
by H.P.Sauerwein, A.Lampert and R.Schmucker

13 *Aluminium Combustion under Rocket Motor Conditions*
by L.H.Caveny and A.Gany

14 *Combustion of Aluminium in Solid Propellant Flames*
by E.W.Price

15 *The Role of Particulate Damping in the Control of Combustion Instability by Aluminium Combustion*
by K.J.Kraeutle, H.B.Mathes and R.L.Derr

Session IV – New Propellants

16 *Plastic Screen Structured Smokeless Propellants for Recoilless Guns and Very Short Burning Rockets*
by A.T.Camp

17 *Gas Generator Propellants for Air-to-Air Missiles*
by R.A.H.Strecker and D.Linde

18 *New Binder System for Composite Solid Propellants*
by C.Gotzmer and N.Seiden

19 *The Ageing Behaviour of Solid Rocket Propellants Regarding their Mechanical Properties*
by D.Schmitt

20 *Amélioration des Proprietes Balistiques et des Proprietes Mécaniques tous Temps des Propergols sans Fumée*
par A.Davenas

Session V – Combustion Instability

21 *Some Problems of Non Linear Waves in Solid Propellant Rocket Motors*
by F.E.C.Culick

22 *Etudes Recentes a l'ONERA sur les Instabilites de Combustion dans les Moteurs Fusées a Propergol Solide*
par P.Kuentzmann

23 *Application of Combustion Instability Research to Solid Propellant Rocket Motor Problems*
by R.L.Derr, H.B.Mathes and J.E.Crump

24 *Self-Sustained Oscillatory Combustion of Solid Rocket Propellants*
by L. De Luca

25 *Low Frequency Oscillatory Combustion: Experiments and Results*
by H.F.R.Schöyer

26 *Non Linear Combustion Instability in Solid Propellant Rocket Motors – Influence of Geometry and Propellant Formulation*
by P.M.Hughes and D.L.Smith

27 *The Suppression of Combustion Instability by Particulate Damping in Smokeless Solid Propellant Motors*
by G.I.Evans and P.K.Smith

Session VI – Heat Transfer and Materials

28 *Material Problems in Jet Vane Thrust Vector Control Systems*
by D.Kampa, A.Weiss and R.Schmucker

29 *Composites in Future Motor Hardware – A Research View*
by N.J.Parrat

30 *Prediction du Comportement des Materiaux Phénoliques Ablatifs – Progrès Recents*
par C.Bonnet

Session VII – Testing and Instrumentation

31 *Gas Phase Velocity Measurements in Solid Rocket Propellants by Laser Doppler Anemometry*
by A.Coghe, L. De Luca, G.L.Sensalari and A.Volpi

32 *Pressure and Velocity Response Function Measurements by the Rotating Valve Method*
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The Propulsion and Energetics Panel 53rd Symposium on 'Solid Rocket Motor Technology' was held in Oslo, Norway in April 1979. A considerable number of experts of nine NATO nations, both from the research and the development side convened and discussed the present status of solid propellant rocketry. With the Technical Evaluation Report, presented as an AGARD Advisory Report, a team of three authors assessed the various contributions and underlined the highlights of the Symposium. The authors offer their conclusions about the meeting and their recommendations for short and long term activities in the field.

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