HIGH ENERGY PROPELLANTS

A CONTINUING BIBLIOGRAPHY WITH INDEXES

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HIGH ENERGY PROPELLANTS

A CONTINUING BIBLIOGRAPHY

WITH INDEXES

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Each entry in the bibliography consists of a citation and an abstract. The listing of entries is arranged in two major groups: all report literature references are contained in the first group and are subdivided according to their date of announcement in STAR; the second group includes all published literature references subdivided according to their date of announcement in IAA, or in Aerospace Medicine and Biology. All reports and articles cited were introduced into the NASA Information System during the period January through December, 1965.

A subject index and a personal author index are included.
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For further details please consult the Introductions to STAR and IAA, respectively.
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STAR ENTRIES

INVESTIGATIONS OF THE MECHANISM OF DECOMPOSITION, COMBUSTION, AND DETONATION OF SOLIDS
Nineteenth Quarterly Technical Operating Report, 1 Jul.-30 Sep. 1964
L. J. Rosen Oct. 1964 16 p refs (Contract AF49(638)-851: ARPA Order 24-60)
(Rept.-0372-01-19Q: AD-450504)

Apparent flame strength measurements have been made on the ammonia-nitric oxide and ammonia-nitrous oxide flame reactions in the opposed-jet reactor, at pressures ranging from 100 to 746 torr. The pressure dependencies of the apparent flame strengths of these systems gave overall reaction orders of 1.56 and 2.0 for NH₃-NO and NH₃-N₂O counterflow diffusion flames, respectively. The overall stoichiometry of the NH₃-NO flame near extinguishment can be represented by the following equation:

\[1.5\text{NH}_3 + \text{NO} \rightarrow 1.25\text{N}_2 + 1.25\text{H}_2 + \text{H}_2\text{O}.\]

The volumetric reaction rate for this flame reaction was computed by using Spalding’s analysis of the opposed-jet flame. At 1 atm, an apparent flame strength of 0.65 gm/cm²-sec corresponded to volumetric reaction rate of 2.93 gm/cm³-sec release rate of 7.22 × 10³ cal/cm³-sec.

Author

N65-10797#  Boeing Co., Seattle, Wash.
THEORETICAL PERFORMANCE OF LIQUID HYDROGEN WITH LIQUID OXYGEN AND NITROGEN OVER A WIDE RANGE OF MIXTURE RATIOS
Glen N. Peterson (1963) 177 p refs (D2-20940: AD-444515)

Propellant performance calculations are presented for the equilibrium composition during expansion of several propellant combinations of liquid hydrogen and liquid oxygen–nitrogen mixtures at a chamber pressure of 500 psia, several area ratios, and various oxidizer–fuel ratios. The different performance parameters were calculated and tabulated. The optimum and vacuum specific impulses are presented graphically as functions of the propellant composition.

G.G.

N65-10804#  National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio
EXPERIMENTAL INVESTIGATION OF SLOSH-SUPPRESSION EFFECTIVENESS OF ANNULAR-RING BAFFLES IN SPHERICAL TANKS
Irving E. Sumner Washington, NASA, Nov. 1964 22 p refs (NASA-TN-D-2519) OTS Prices: HC $0.75/MF $0.50

An experimental investigation was conducted to determine the slosh-suppression effectiveness of rigid and flexible flat-plate annular-ring baffles in suppressing the fundamental anti-symmetric mode of liquid oscillations in rigid spherical tanks having diameters of 3.20 and 9.5 inches. The baffles caused a variation in the fundamental frequency of liquid oscillations by effectively changing the tank geometry. The baffles were most effective in reducing the slosh forces and increasing the damping when the quiescent liquid surface was slightly above the baffle so that it remained submerged during the liquid oscillatory cycle. The optimum baffle width to tank radius ratio of those values investigated was 0.125. The experimental data are presented in terms of dimensionless parameters that generalized the results for a variation in tank diameter for specific values of baffle-width ratio, liquid-depth ratio, and excitation amplitude parameter.

Author

N65-11178#  Utah U., Salt Lake City
IGNITION AND COMBUSTION OF SOLID PROPELLANTS
Rex C. Mitchell, John A. Keller, Alva D. Baer, and Norman W. Ryan (1963) 70 p refs (Grant AF-AFOSR 40-63)
(AD-605729) OTS $3 00

The spreading rate of the flame zone on the surface of a solid propellant was studied by use of a rarefaction tube. Cold gas flow past the burning zone and across the unburned surface produced high flame spread velocities. The experimental data were interpreted and correlated in terms of two theoretically predicted but experimentally determined parameters. One parameter, which is related to the maximum heat flux produced near the flame front, was found to be independent of gas velocity. The second parameter, which determines the rate of decay of heat flux ahead of the flame front, was found to be independent of pressure.

Author

THE ROLE OF ALUMINUM AND ITS OXIDES AS SOURCES OR MODERATORS OF ELECTRONS IN ALUMINIZED SOLID PROPELLANT ROCKET EXHAUSTS, PART 2 Final Report
G. Neil Spokes Aug. 1964 25 p refs (Contract AF 04(694)-128)
(S50-TDR-63-326, Pt. II: AD-447283)

A brief summary of previously reported work is given. Further calculations of electron distributions about a thermionically emitting particle are appended.

Author

N65-11595#  Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div.
ABOUT TAE MECHANISM OF COMBUSTION OF POWDERS
of subscale testing of longitudinal-mode stability limit can be applied to the prediction of the stability of all modes in a full-scale thruster chamber. However, no combustion instability was encountered in the test program. Therefore, a positive evaluation of the technique could not be achieved. Author


THE EXPERIMENTAL DETERMINATION OF UNSTEADY HYDRODYNAMIC FORCES CAUSED BY WAVES OF PROPULSION LIQUIDS [LA DETERMINATION EXPERIMENTALE DES FORCES HYDRODYNAMIQUES INSTATIONNAIRES DUES AU CLAPOTIS DES LIQUIDES DE PROPULSION]

C. Beatrix Paris, NATO, 1964 28 p refs in FRENCH ENG

Author


SOLID PROPELLANT STRUCTURAL INTEGRITY INVESTIGATIONS: DYNAMIC RESPONSE AND FAILURE MECHANISMS, VOLUME I

Quarterly Progress Report No. 1, 15 Jun.–15 Sep. 1964


The results are reported of an investigation of viscoelastic and failure properties of highly filled PBAA and PBAN propellants as a function of solids loading. The temperature rise in shear specimens under constant large-amplitude dynamic strains was investigated and compared with analytical predictions. The theory of thermomechanical effects is extended to include inertia-loading and stationary random-loading conditions. Initial results obtained from piezoelectrical test devices for measuring dynamic bulk and shear properties of propellants are reported. Propellant cross-link density and gel fraction measurements were made. Physicochemical aspects of nitroplastisol propellants are discussed. The effects of solid-particle-size distribution on flow properties in the uncured state and on the physical properties of the cured propellant are described.

Author

N65-13306# National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio.

PHOTOGRAPHIC STUDY OF PROPELLANT OUTFLOW FROM A CYLINDRICAL TANK DURING WEIGHTLESSNESS


The problems associated with the behavior of rocket engine propellants stored in space vehicle tanks while exposed to weightlessness are being studied. As part of this overall study, a photographic investigation was conducted to examine the behavior of the liquid-vapor interface during pumping or outflow from a cylindrical tank in a zero-gravity environment. The results indicate that significant distortion of the interface occurs as the outflow velocity is increased. The effects of diffusing the incoming pressurizing gas and baffling the tank outlet were to minimize the interface distortion and to delay vapor blowthrough.

Author
An investigation of the effect of ionizing radiation on the burning rates and tensile strengths of various composite ammonium perchlorate propellants is reported. The tabulated results show that, in many cases, drastic changes in burning and tensile strengths of various composite ammonium perchlorate propellants over the dose range of 0 to 200 megarads and analysis for possible decomposition products, and the design of ballistic experiments with irradiated propellant systems. Analytical reactions and experimental procedures are treated at length.

D.E.W.
30. FAILURE CRITERIA FOR CAST-DOUBLE-BASE PROPELLANTS H. Leeming and A. Parker (Imperial Metal Ind., Ltd., Kidderminster, Gt. Brit.) p 469-500 refs (See N65-13604 04-27)

31. FAILURE THEORY FOR POLYMERIC MATERIALS UNDER GENERAL MULTIAXIAL LOADING CONDITIONS A. R. Zak (Calif. Inst. of Tech.) p 501-527 refs (See N65-13605 04-27)

MISCELLANEOUS

32. A "MULTI-DATA" METHOD FOR APPROXIMATE LAPLACE TRANSFORM INVERSION T. L. Cost and E. B. Becker (Rohm and Haas Co.) p 529-543 refs (See N65-13606 04-32)

33. MORE METHOD FOR THE MEASUREMENT OF STRAINS IN SOLID PROPELLANTS W. D. Hart (Lockheed Propulsion Co.) p 545-560 refs (See N65-13607 04-27)

34. A BIAXIAL TESTER A. San Miguel (JPL) p 561-572 refs (See N65-13608 04-11)

35. STRESS DISTRIBUTION IN A POKER CHIP SPECIMEN SUBJECT TO COMBINED LOADS G. H. Lindsey (Calif. Inst. of Tech.) p 573-582 refs (See N65-13609 04-32)

36. MODULUS DETERMINATION OF POLYMERS AT LOW TEMPERATURES W. G. Knauss (Calif. Inst. of Tech.) p 583-590 refs (See N65-13610 04-18)

37. THE STRESS DISTRIBUTION IN AN INFINITE ELASTIC SOLID PERFECTLY BONDED TO TWO UNEQUAL RIGID SPHERICAL INCLUSIONS J. L. Hill (Ala. U.) p 591-606 refs (See N65-13611 04-32)

38. RADIAL STRESS MEASUREMENTS IN PROPELLANT GRAINS A. San Miguel and R. H. Silver (JPL) p 607-623 refs (See N65-13612 04-14)


TWO-DIMENSIONAL STRESS ANALYSIS OF SOLID PROPELLANT ROCKET GRAINS


A numerical procedure for the two-dimensional stress analysis of solid-propellant grains subjected to internal and external pressures is presented. The procedure, which is based on the finite element method, has been programmed for the digital computer. An automatic mesh generator allows the program to be used as a rapid design tool, since only the boundary geometry must be supplied as input. The method is illustrated by the analysis of two star grains. Results show excellent agreement with photoelastic analyses.

Author

N65-13582 Rocketdyne Canoga Park, Calif.

FIBER MECHANICS OF REINFORCED STRUCTURES


(Contract Non-3858(0))

A new method has been developed for studying stress transfer in reinforced solid propellants. Specially prepared photoelastic models are used to observe and study the origin and transfer of stresses in a complex reinforced structure. The utility of reinforced photoelastic models has been shown by actual use to be a powerful tool for measuring so-called "internal strain" in anisotropic, nonhomogeneous structures. Initial experiments revealed unexpected phenomena which appear to be of fundamental significance in understanding the mechanics of fiber-reinforced materials. A mathematical model to explain the origin of internal strain forces in reinforced composites is in good agreement with the experimental photoelastic models. The importance of this research effort is that failure mechanisms and criteria may be investigated by quantitative measurement with simulated failure models.

Author

N65-13583 Aerojet-General Corp., Sacramento, Calif.

STRESSES IN PROPELLANT GRAIN BOND SYSTEMS


Case-bonded solid-propellant grains are subjected to discontinuous stresses at the propellant-to-case bond interface. Bond failures frequently occur at the ends of these bonds, and mathematical difficulties have prevented a practical solution based on theoretical considerations. Two methods of resolving this difficulty are suggested in this paper, which also presents an example application of each technique. The first method involves comparisons of stress patterns obtained from numerical solutions which provide a relative measure of the effectiveness of various design details. The second procedure replaces the corner with an appropriate fillet. Numerical solutions are presented for a variety of fillet configurations, which are compared with the stress patterns obtained in sharp corner solutions.

Author

N65-13584 Aerojet-General Corp., Sacramento, Calif.

STRUCTURAL ASPECTS OF MODULUS VARIATIONS WITHIN A SOLID PROPELLANT GRAIN


The modulus of elasticity of solid propellants can frequently be varied over a range of several hundred percent within a single grain, but the structural significance of such variations is not clearly defined. This paper describes a method of analyzing such systems and presents results of an exploratory study of some simple variable-modulus propellant grains. Problems were chosen to illustrate how control of this parameter can be exploited to improve the structural capability of these systems. The solutions indicate that significant strain reductions can be achieved in this manner and that inadequate control of this parameter could result in maximum strain variations as great as ±30% in some geometries.

Author


APPLICATION OF FINITE ELASTIC THEORY TO PROPELLANT BEHAVIOR


(Contract AF 04(611)-9559)

The equations derived by P. J. Blatz for compressible rubbery materials were applied to uniaxial extension data for carboxy-terminated polybutadiene and polyeurethane propellants. Propellant response was adequately described by the analytical expressions at large strains; where extensive dewetting had taken place, reasonable values of Poisson's ratio and shear modulus were obtained. The supremum failure criterion derived by Blatz was examined in connection with polyeurethane-propellant test results. In an effort to extend the applicability of finite elastic theory to propellant data at lower strains, equations similar to those of Blatz were derived using Rivlin's strain invariants I 1, I 2, and I 3.

Author

N65-13590 Rocketdyne, McGregor, Tex.

VISCOELASTIC VIBRATIONS


(Contract N0w-63-0591-d)
Fatigue testing of solid propellants has been conducted since it was discovered that prolonged, large amplitude, relatively high-frequency vibration of solid propellants caused structural failure of the viscoelastic material. Small models have been used for this testing to minimize the expense and complexity of the study program. One model used is a longitudinally-vibrating weighted column. Expressions developed from basic equations of motion were solved to give the response of the column. The solutions, while complex, consider body forces and describe the motion of a plane within the model as a function of time. Uniaxial tensile test data in the form of relaxation modulus curves have been transformed to determine parameters for a mathematical model used to describe the propellant properties in vibration. The relations were then evaluated to predict the model response. It is shown that predicted and experimental response are in good agreement.

Author

N65-13594 Aerojet-General Corp., Sacramento, Calif.

STRAIN DILATION IN SOLID PROPELLANTS

A stochastic model was developed that accurately describes both the stress-strain and dilatation-strain relationships of solid propellants in terms of their frequency of dewetting. This model enables us to calculate the frequency of dewetting vs strain from the dilatation–strain relationship. Comparison of the stress–strain and dilatation–strain relationships of various propellant systems shows that the model is consistent with the data presented.

Author


DIELECTRIC AND ELECTRICAL CONDUCTIVITY PROPERTIES OF CERTAIN SOLID PROPELLANTS

(Contract AF 04(611)-8539)

Dielectric spectroscopy was investigated as an analytical tool to assist in the elucidation of chemophysical effects in solid propellant systems. Complex dielectric properties were measured over a wide temperature range and at frequencies from 50 to 10^6 cps for polybutadiene acrylic acid (PBAAs), carboxy-terminated polybutadiene (CTPB), and nitrocellulose-base propellants and ingredients. The measurement range was extended to low frequencies by measurement of dielectric absorption response to step function d.c potentials over time ranges from 10 to 10^6 seconds. Spectral response of the complex dielectric constant storage and loss components is interpreted in terms of classical electrical polarization mechanisms.

Author

N65-13597 Aerojet-General Corp., Sacramento, Calif.

NONDESTRUCTIVE WAVE-PROPAGATION METHOD FOR MEASURING CURE AND MECHANICAL PROPERTIES OF SOLID PROPELLANTS

A low-frequency sonic wave-propagation method is being developed for the in situ monitoring of cure and mechanical properties in large solid-propellant motors. Standard ultrasonic methods are not applicable to solid propellants because these materials are highly attenuative at high frequencies. A simplified theory of wave propagation is presented with a discussion of its application to propellant. One of the sonic and low-frequency ultrasonic methods that has been developed utilizes a continuous series of 66 to 350 kc sinusoidal bursts from a pulse generator. An oscilloscope is used for signal display. Tests of several batches of polybutadiene propellants with different cross link ratios showed a relationship between the signal transmitted through the propellant and the Instron tensile properties such as modulus, elongation at maximum stress, and elongation at break. A relationship was also found between the output signal and propellant cure, as indicated by Shore hardness.

Author


TRIAXIAL TENSILE FAILURE OF SOLID PROPELLANTS

This paper reports progress in measuring propellant failure criteria in a triaxial tensile stress field by the "poker chip" method. In this test, a thin disk of propellant, bonded between two parallel flat rigid circular plates, is pulled apart in a direction perpendicular to the surface of the plate. Successful application of this method to determine propellant failure criteria depends on: a) maintenance of uniform deflection across the specimen and b) identification of the stress and strain and geometric point at which failure initiates. Axial displacement is measured at three equally spaced points around the specimen by a technique described in the paper; the test record then indicates whether or not uniform deflection has been achieved. Radial displacement is also measured, from which volume change can be calculated. Additionally, an attempt was made to obtain a sonic indication of the failure initiation event by application of a ceramic audio pickup mounted on the specimen. The point of failure initiation was inferred by analysis of the stress-strain curve, the volume change-strain curve, and inspection of the sample after the test.

Author

N65-13600 Aerojet-General Corp., Sacramento, Calif.

A UNIFIED APPROACH TO FAILURE AND ITS APPLICATION TO SOLID PROPELLANT MATERIALS

Two interrelated general approaches to the study of structural failure of solid propellants are described. These consist of the macroscopic (thermodynamics and continuum mechanics) and microscopic (molecular model) methods of analysis in conjunction with solid propellant experimental data. The thermodynamic investigation indicates that propellant material under loading goes through stages of stable and unstable behavior that depend upon the rate at which work is absorbed and dissipated by the material. The instability point seems to correlate with results from subscale motors. The thermodynamic investigation is then extended by a functional analysis of failure treated from a viewpoint of continuum mechanics. Since fracture, per se, is a physical observable, it is represented by a state vector in n-dimensional space. The number of dimensions of this space depends upon the basic variables involved in fracture. Since the correct failure criteria must be tensorially consistent with the tensor rank of fracture, distinct sets of functions can be applied to experimental data. The data are compared to the classical scalar functions of failure.

Author
THE EFFECTS OF FATIGUE LOADING UPON SOLID PROPELLANT


Experimental data were gathered on a typical composite solid propellant under dynamic tension-tension constant amplitude loading. The effects of temperature upon the fatigue properties of propellant are pronounced. These effects are large because of the net energy that is absorbed during cyclic loading in materials that have internal damping. The effects of strain amplitude, temperature, and dynamic frequency from zero to 50 cps were investigated. The failure modes were determined and related to the results of other test methods. These failure modes were shown to be normal fatigue crack propagation with no evidence of slumping or loss of structural integrity due to temperature effects.

FAILURE CRITERIA FOR CAST-DOUBLE-BASE PROPELLANTS


Simple failure theories are considered for cast-double-base propellants based on a maximum stress criterion of failure at low temperatures and high strain rates and a maximum strain criterion of failure at high temperatures and low strain rates. The form of the reduced failing stress-time locus is deduced from a knowledge of the reduced relaxation modulus curve, together with a simple empirical equation for nonlinearity. For complex tensile tests in which several strain rates are used, these simple failure theories do not suffice, and a cumulative damage theory based on energy considerations is necessary to obtain agreement with experimental data. A reduced failing energy-strain rate locus is obtained in a similar manner to the reduced modulus or compliance curves. The predictions of these various failure theories are compared with experimental data from simple tension, biaxial tension, and small-scale rocket motor tests.

MOIRE METHOD FOR THE MEASUREMENT OF STRAINS IN SOLID PROPELLANTS


Procedures are described which demonstrate the use of Moiré fringes for assessment of various experimental methods of propellant physical testing to obtain parameters for the structural analysis of solid grains. A description of experimental work using the Moiré method for the measurement of local strains around circular holes in propellant slabs in biaxial stress fields is given. The experimental data show the excellent resolution which may be obtained in local areas of strain concentration in propellant materials. Work is described which demonstrates the application of the Moiré method to measure strains on curved surfaces. This technique entails the use of "paste-on" Moiré gages which can be prepared in the laboratory and subsequently applied to a curved or planar propellant surface.

A BIAXIAL TESTER


The construction of a versatile biaxial sheet tester is described that is capable of changing or maintaining a relatively uniform rectangular boundary geometry upon a sheet of solid propellant as a function of time. This instrument is analogous to two perpendicularly mounted uniaxial tension machines. Two load cells monitor the instantaneous loading conditions, transmitted to the sheet specimen by means of two independently controlled loading mechanisms. The instrument is designed to induce strains of up to 50% on a propellant sheet specimen 6 in. and 1/10 in. thick. A whiffletree arrangement transmits the load from the specimen to the load cell. The whiffletree is provided with a cross-stretch-compensating mechanism to insure that the loading attachments ride freely when subjected to various biaxial loading schemes. A method is suggested to approximate the magnitudes of the biaxial strains at the center of the propellant sheet. A biaxial relaxation test was performed on a solid propellant to illustrate the potential of the instrument.

VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS

Nicholas W. Tschegg, James R. Smith, and Thor L. Smith 15 Oct. 1964 55 p refs (Contract NOW-64-00730d, ARPA Order 22) (Rept. 4, AD-452309)

Solid propellant investigations concerning dynamic shear properties, bulk compressibility, and tensile properties at constant strain rates are discussed. Important aspects of studies of dynamic shear properties include development of a differential Lissajous method for the precise determination of phase angle, and an evaluation of the dependence of the complex shear modulus of an SBR vulcanize and a polyurethane propellant on specimen thickness and laterally applied pressure. Methods for correcting data are presented along with some data obtained at various strain amplitudes on SBR specimens. A qualitative discussion is given of the dependence of specific volume on pressure, temperature, and time, and also of data obtained previously on two propellants. Static and dynamic compressibility apparatus are described. Tensile data obtained at various strain rates and temperatures on end-bonded specimens of a PBAN propellant are analyzed by methods applied previously to a polyurethane propellant. Included is an evaluation of the effective gage length of the end-bonded specimens. The gage length was found to vary randomly with test conditions, and thus is not a constant as commonly assumed.

SOLID ROCKET PROPELLANTS

Dorde Jaukovic 12 Oct. 1964 21 p Transl. into ENGLISH from Vojnothnički Glasnik (Yugoslavia), no. 8, 1963 p 581-590 (FTD-TT-64-744/1+2; AD-450972)

Discussed are (1) the advantages of solid fuel propellants in rockets for military purposes; (2) an evaluation of effectiveness of rocket engines; (3) the composition and manufacture of solid propellants; (4) physical and mechanical characteristics of solid propellants; and (5) the rate and mechanics of combustion.

This research, relating mechanical behavior and failure mechanisms to processes of propellant microstructure, consisted primarily of determining lateral dimensions by measuring volume changes while carrying out tests under varying conditions of load, temperature, time, and humidity. One approach used to analyze the test data was to define the physical state of the deformed propellant by means of path-independent dilatational state equations which interrelate volume ratio, strain energy, and time. The equations of finite elastic theory were also applied to propellant behavior. Results suggested that a criterion for uniaxial failure in a propellant of high solids content is a minimum lateral area governed by maximum packing density.

R.L.K.

LIQUID ROCKET PROPELLANTS IN ZERO GRAVITY Selected Bibliography, Jan. 1962–Sep. 1964


HYPERGOLIC IGNITION AT REDUCED PRESSURES Five-Month Progress Report, 1 May–30 Sep. 1964


Unconfined impingement tests are being conducted in a large vacuum chamber to define an ignition model for hypergolic propellants and to investigate concepts for reducing ignition delay and resultant pressure spikes. The test setup, experimental program schedule, and concepts for reducing ignition delay are discussed. Results are reported on ignition delay as a function of injection parameters, environmental conditions, and concepts such as injector modifications and propellant additives for reducing delay for tests performed with N₂O₄ and IRFNA as oxidizers and hydrazine-type fuels. Author

STUDIES OF INTERFACIAL SURFACE ENERGIES Summary Report

George A. Lyerly and Henry Peper 2 Dec. 1964 30 p refs (NASA-CR-54175) OTS: HC $2.00/MF $0.50

The contact angles of liquid propellants on prepared surfaces of tank materials were experimentally determined. The surface tensions and densities of the liquid propellants were determined to complement the contact angle measurements. Initial low contact angles in the range of 2° to 0° accompanied by spontaneous spreading were observed for drops of each liquid on each solid substrate. Aging experiments showed that
most of the liquid–solid systems observed remained wet. The exceptions were the liquid–solid pairs of conductivity water on polished aluminum and stainless steel surfaces and of 90% hydrogen peroxide on polished aluminum surfaces. The Marangoni or “wineglass” effect was observed to occur in the spreading of uns-dimethylhydrazine (UDMH), Arizine-50, and dinitrogen tetroxide on each solid surface. This effect was observed also for 90% hydrogen peroxide on satinized stainless steel. Over the time period that the Marangoni effect was observed, the liquids wet the solid surfaces with a true zero contact angle.  

Author

N65-17530# Catholic Univ. of America, Washington, D. C.

FINITE SLUMP STRAINS IN VERTICAL, INFINITELY LONG, HOLLOW, ELASTIC CYLINDER EXTERNALLY CASE-BONDED TO AN ELASTIC TANK Technical Report No. 7 Ramesh N. Vaishnav Dec. 1964 50 p refs

The problem of finite slump strains in a vertical, infinite, hollow, elastic cylinder, case-bonded to an elastic case, is solved assuming the material of the cylinder to be incompressible, and further to possess a strain energy density function of the Mooney type. The problem reduces to that of solution of a transcendental equation in a geometrical parameter. Numerical results for a set of realistic data are obtained, and the effect of change in bore radius, case stiffness, the specific weight of the material, and the departure of the results from those of the linear theory are discussed in detail.  

Author


SOLID PROPELLANT STRUCTURAL INTEGRITY INVESTIGATIONS: DYNAMIC RESPONSE AND FAILURE MECHANISMS Quarterly Progress Report No. 2, 16 Sep.–15 Dec. 1964

D. E. Cantey 15 Jan. 1965 80 p refs

Contract AF 04(611)-9953)

(LPC-667-Q-2: AFRPL-TR-65-20; AD-610615)

The results of an investigation of viscoelastic and failure properties of highly filled PBAA and PBAN propellants as a function of solids loading are reported. Failure surface study results are reported, and the results of a limited study of the relationship between crack propagation velocity and propellant physical characteristics are discussed. Propellant dynamic shear and bulk properties were investigated with small deformation piezoelectric devices. An experimental investigation of propellant thermomechanical response to sustained cyclic inertial loading was completed, and the results, in agreement with theory, are presented. Also discussed are experimental investigations of transient thermoviscoelastic responses of propellants under constant cyclic strain amplitude and inertial loading.  

Author


GENERAL RESEARCH: THERMODYNAMIC PROPERTIES OF HYDRAZINE, UNSYMMETRICAL DIMETHYLHYDRAZINE, AND THEIR MIXTURES

E. T. Chang and N. A. Gokcen 8 Jan. 1964 31 p refs

(ATN-64(9228): 2; AD-458288)

The vapor pressure of N₂H₄ from 2.9°C to 51°C, UDMH from −25°C to 35°C, and their mixtures at 0°C, 9.9°C, and 20°C have been measured. The vapor–liquid equilibrium compositions of the mixtures have been determined at 0°C, 9.9°C, and 20°C. Equations have been derived for the equilibrium vapor pressures of N₂H₄ and UDMH as functions of temperature. For the vaporization process, ΔF° and ΔH° have been expressed as functions of temperature, and ΔF°, ΔH°, and ΔS° at 298.15°C have been presented. The results are compared in detail with other investigations. Preliminary results on the vapor–liquid equilibrium relationships and the activity coefficients of mixtures of N₂H₄ and UDMH are presented in the form of pressure versus composition phase diagram with temperature as the parameter.  

Author

N65-19055# Rocket Propulsion Establishment, Westcott (England)

CORRECTIONS INVOLVED IN ASSESSING THE PERFORMANCE OF LIQUID OR GASEOUS PROPELLANT ROCKET ENGINE THRUST CHAMBERS C. Ramshaw Aug. 1964 20 p refs

(RPE-TM-326; AD-454601)

This memorandum outlines some of the more important corrections which should be applied when the performance of a liquid propellant rocket engine thrust chamber is studied. To determine truly significant performance efficiencies it is necessary to amend the theoretical performance data of a rocket engine to take account of the deviations from ideality of the engine. It is suggested that this be effected by evaluating a thermal advantage for the particular engine, as compared with the corresponding ideal engine and determining the appropriate correction factor, and by taking account of the coefficient of discharge, which if less than unity reduces the effective value of the characteristic velocity. Fundamental combustion loss has little effect on the vacuum exhaust velocity at high pressure ratios, and none if the nozzle terminates at the throat, and the flow remains choked.  

Author


Robert L. Potter 1 Feb. 1965 167 p refs

(Contract NOrd-18728; ARPA Order 22)

(AD-458524)

The multicomponent chemical equilibrium problem is discussed generally and a formulation suitable for use with digital computers is given. Some degree of detail is included in order to indicate various pitfalls that may occur and how they may be overcome. A geometric picture is supplied for a few simple cases, in order to aid in visualizing the iteration processes. The goal of this formulation is to provide a systematic method of solving the multicomponent chemical equilibrium problem with the least amount of knowledge concerning the chemistry of the system that is possible. It is stated that it appears that the objective of requiring estimates of no variables except perhaps the temperature was fairly met.  

D.W.
Initiation of axial combustion instability in an experimental combustor, 40 inches long by 50 inches i.d., containing a radial burning grain, was studied utilizing a wide variety of composite propellants. Where instability occurred, a correlation was found between the threshold pressure at which instability was first observed and propellant ballistic parameters, notably the linear burning rate. Fast-burning propellants, containing either a catalyst or potassium perchlorate, did not sustain axial mode combustion instability. Transverse instability was observed for most nonaluminized propellants in pressure regimes where they were stable to axial combustion instability. An explanation of combustion stability criteria has been sought in terms of either mixing processes within a granular diffusion flame or a thermal explosion process. The granular diffusion flame concept appears thus far to be the more promising explanation; it predicts the stability trends observed in large solid-propellant rocket motors.

Author: W. W. Brandon, Jr. 2 Nov. 1964 61 p refs

HIGH ENERGY PROPELLANTS—A CONTINUING BIBLIOGRAPHY
Mar. 1965 104 p
(NASA-SP-7002(01)) CSFTI: HC $1.75/MF $0.75

A selection of annotated references to unclassified reports and journal articles is presented. Prime emphasis is given to references on solid, liquid, and hybrid propellants and oxidizers. Also, extensive coverage of related topics, such as propellant handling and storage, combustion characteristics, toxicity, hazards, and safety measures, is provided.

Author: R. W. H. N65-19707#

APPLICATIONS OF MICROWAVES IN THE NONDESTRUCTIVE TESTING OF SOLID PROPELLANTS
W. W. Brandon, Jr. 2 Nov. 1964 61 p refs
(Contract DA-01-021-ORD-12341(2))
(S-53; AD-609982)

The feasibility of using microwaves to test various properties of solid propellants was examined experimentally. Power employed was less than 0.1 W at frequencies between 8 and 24 Gc. Results with dummy propellant formulations were evaluated in terms of signal attenuation. Attenuation in a polymer-filled waveguide decreased during polymerization by a factor of from 2 to 10 depending upon the material tested. Changes as small as 0.1 decibel per centimeter of test sample thickness were detectable. Propellant–propellant interfaces between slabs were found to produce detectable attenuation by reflection only at high angles of incidence with the electric field of the test signal perpendicular to the plane of incidence. Gross defects were clearly evident in a small dummy propellant charge having low specific attenuation and contained in a nonmetallic case.

Author: W. W. Brandon, Jr. 2 Nov. 1964 61 p refs

EXPERIMENTALLY DETERMINED PENDULUM ANALOGY OF LIQUID SLOSHING IN SPHERICAL AND OBLATE-SPHEROIDAL TANKS
Irving E. Sumner Washington, NASA. Apr. 1965 26 p refs
(NASA-TN-D-2737) CSFTI: HC $1.00/MF $0.50

An experimental investigation was conducted to determine the general liquid-sloshing characteristics (fundamental frequencies, horizontal or side slosh forces, and damping ratios) as well as quantities for a pendulum analogy that would effectively represent the fundamental mode of liquid sloshing in un baffled oblate-spherical and spherical tanks over a range of liquid depths. Tanks having a diameter of 32.0 inches were used. Vertical and horizontal slosh forces were measured to determine several of the pendulum–analogy parameters. These parameters included the pendulum mass, the length of the pendulum arm, the hinge-point location of the pendulum arm, the maximum angles through which the pendulum can oscillate, and the fixed mass. The experimental results are presented in terms of dimensionless parameters that are independent of tank size, imposed longitudinal acceleration, and density and viscosity of the contained liquid.

Author: John F. Kennedy Space Center N65-20355 Purdue Univ., Lafayette, Ind. Jet Propulsion Center

STUDY OF COMBUSTION PRESSURE OSCILLATIONS IN BIPHASE PROPELLANT SYSTEMS
D. W. Netzer In its 1964 Rev. of Res. [1964] p 63–69 (See N65-20351 10-33)
(Grant AF-AFOSR-753-65)

Studies to determine rocket motor operating conditions which, when exceeded, result in the initiation of combustion pressure oscillations are reported. The problem was reduced to varying the injector pattern in an essentially fixed combustion chamber geometry, using a liquid fuel (gasoline)–gaseous oxidizer (air) system. The location of the combustion zone was found to move closer to the injector face with increasing chamber pressure, decreasing air injection velocity, or mixture ratios closest to the stoichiometric mixture ratio. A method...
for measuring combustion temperature profiles using a water-cooled temperature probe was developed as a result of these investigations. In this method, the gas temperature is calculated from the change in temperature of the cooling water circulated through the probe. Preparations for experiments employing contraction ratios and injector patterns similar to those now used in industry are also described.

N65-20359 Purdue Univ., Lafayette, Ind. Jet Propulsion Center
HYBRID COMBUSTION
B. A. Reese In its 1964 Rev. of Res. [1964] p 121–139 refs (See N65-20351 10-33)
(Contracts N123(60530)29155A; N123(60530)34745A)
The effects of combustion products on the burning rate of solid fuels were investigated, using Plexiglas and hydrazine gel as the fuels and oxygen diluted with carbon dioxide, nitrogen, or helium as a premixed oxidizer in both impinging jet and parallel flow combustion systems. The experimental results were compared to those predicted by a model for the combustion of hybrid fuels adapted from theoretical studies of ablation with combustion. A satisfactory correlation was found only when absorption of heat by the diluent gas was considered in the heat required for vaporization of the fuel. Experimental results for laminar flow show that the burning rate of the solid fuel is reduced as the amount of diluent in the oxidizer is increased and as the specific heat of the diluent is increased. In turbulent flow or in chemically controlled reactions, the burning rate is also reduced with addition of diluent, but the effect of the specific heat of the diluent is not a linear function. The effect of adding a diluent is nearly independent of type of flow and of the fuel. Burning rate data are influenced considerably by the type of experimental system used to obtain the data.

N65-20360 Purdue Univ., Lafayette, Ind. Jet Propulsion Center
CONTINUOUS MEASUREMENT OF SOLID PROPELLANT BURNING RATES UNDER SIMULATED MOTOR CONDITIONS
R. J. Burick In its 1964 Rev. of Res. [1964] p 141–153 refs (See N65-20351 10-33)
(Grant AF-AFOSR-207-64)
An experimental system for the direct and continuous measurement of solid propellant burning rates is described. The system involves a servomechanism for accurately positioning the burning surface of a propellant sample which is located within a test rocket motor. Since the burning surface is maintained at a fixed position with respect to the test rocket motor, the direct measurement of the velocity of the propellant feed mechanism yields the burning rate of the propellant. At present, the fabrication of the servomechanism has been completed, burning rate data for nongaseous conditions have been obtained, and the erosive burning rate apparatus is being designed.

N65-20361 Purdue Univ., Lafayette, Ind. Jet Propulsion Center
FEASIBILITY STUDY OF A MICROWAVE METHOD AND AN ULTRASONIC METHOD FOR CONTINUOUS MEASUREMENT OF THE BURNING RATE OF SOLID ROCKET PROPELLANTS
P. Y. Ho In its 1964 Rev. of Res. [1964] p 155–161 (See N65-20351 10-33)
(Grant AF-AFOSR-207-64)
Two methods of obtaining continuous measurement of solid propellant burning rates are under consideration. The operating principle of the microwave record is to pass a beam of microwaves (30,000 to 300,000 Mc/sec) through a dielectric material window in the motor and to measure the change of effective intensity of the received beam as a function of the position of the movable propellant sample within the test rocket motor. As the burning propellant surface recedes, the intensity of the received beam increases, providing a feedback signal to a servomechanism. The operating principle of the ultrasonic pulse-echo technique involves display by an oscilloscope of the input pulse, the echo pulse, and the time lapse between the two pulses. The thickness of the propellant is then calculated from the propagation velocity of the ultrasonic wave. The technique also provides feedback for a positioning servomechanism. Advantages and disadvantages of each method are listed, and a comparison of the two methods shows the ultrasonic pulse-echo method to be superior to the microwave method.

N65-20364 Purdue Univ., Lafayette, Ind. Jet Propulsion Center
A DETERMINATION OF THE EFFECTS OF ROTATION ON SPIN STABILIZED ROCKETS
B. W. Farquhar In its 1964 Rev. of Res. [1964] p 201–211 refs (See N65-20351 10-33)
(Contract DA-01-021-AMC-428(2))
A spin test rig has been designed to study the effect of high angular velocities on the combustion process of solid propellants, the change in shape of the burning surface of solid propellant rockets because of large radial accelerations, and the influence of rotation of the rocket motor on the internal flow of gases. The rig design chosen allows the rocket motor to be mounted horizontally between bearings. The rocket casing will be mounted on bearings at the nozzle and at a shaft extending from the rear of the casing. The cold flow rocket motor will be 24 in. long with a 6 in inner diameter which, at 30,000 rpm, will yield an acceleration of 70,000 g's at the interior wall. An air feed assembly will complete the rotating assembly. Inserts to simulate various grain configurations will be fabricated so that the "burning surface" location may be varied within the cylinder, and nozzle diameters of 1.2, 2.0, and 2.4 in. will be used in cold flow studies of vortex formations and back flow occurrence. Associated instrumentation is also described.

N65-20669# Dynamic Science Corp., South Pasadena, Calif.
STUDY OF FORCES ON PROPELLANTS DUE TO HEAT TRANSFER INFLUENCING PROPELLANT TEMPERATURE IN A RECOVERY TYPE VEHICLE Final Report
The heat-transfer problem in a partially filled propellant tank system of an Agena space vehicle was formulated in a lumped capacity form which can be solved in principle by using an analog computer. The heat-transfer mechanisms considered contain internal radiation, phase change due to evaporation and condensation, conduction, free convection and convection in liquid layers due to differential surface tension. Transport properties for gaseous UDMH, IRFNA and mixtures of helium with each gas were obtained by computation and experiment. Mass diffusivities for two and three component mixtures were computed by the methods of Bird, Stewart and Lightfoot. Viscosities and heat capacities for gaseous UDMH and nitric
Acid were rigorously computed; thermal conductivities of single gases were then calculated from the Eucken equation. Thermal conductivities of gas mixtures were calculated from the Mason-Saxena equations.

A SUMMARY OF LINEAR VISCOELASTIC STRESS ANALYSIS
Harry H. Hilton Mar. 1965 56 p refs
(AAC-65-2)
Present developments in linear viscoelastic stress analysis with emphasis on solid propellant grain analysis are summarized. Papers, books, and articles pertaining to the stress-strain relations and stress and strain analysis in linear viscoelastic bodies are reviewed. The use of perturbation techniques reduces the solution of actual nonlinear viscoelastic problems to a series of linear viscoelastic formulations with equivalent known body forces. The different linear viscoelastic properties depending on actual stress and strain levels in the various regions of the grain can be used to approximate the actual behavior of solid propellants. The linear viscoelastic analysis proved inadequate to predict finite critical times in problems involving instability. A number of fundamental problem areas of linear quasi-static and dynamic thermoviscoelasticity with time and space dependent material properties remain unsolved.

G.G.

N65-20993# National Aeronautics and Space Administration.
Lewis Research Center, Cleveland, Ohio.
EFFECT OF OXIDIZER PARTICLE SIZE ON SOLID-PROPELLANT COMBUSTION STABILITY
Gerald Morrell and Murray L. Pinns Washington, NASA, Apr. 1965 15 p refs
(NASA-TN-D-2736) CFSTI: HC $1.00/ MF $0.50
Amplitudes of the longitudinal-mode of oscillation were measured in side-vented cylindrical combustors loaded with a composite solid propellant. The binder consisted of a butadiene-carboxylic acid copolymer cross-linked with an epoxy resin, and the oxidizer was ammonium perchlorate. Mean oxidizer particle size was varied by changing the proportions of unground and ground perchlorate while keeping the total oxidizer particle size varied by changing the proportions of unground and ground perchlorate while keeping the total oxidizer particle size to the cross-sectional area. Within some geometry. Some information was obtained on the heat buildup in propellant specimens during oscillatory testing. A qualitative discussion is given of work done to calibrate the dynamic and static bulk compressibility apparatus.

Author

THE EFFECT OF SOUND ON COMBUSTION PROCESSES
The effects of acoustics on combustion processes are discussed, and the acoustic torch nozzle (ATN) which produces sound energy by utilizing the cyclone principle is described. Experiments conducted showed that when the ATN was used, the acoustic energy increased the heat output so much that a smelting temperature was reached in 40 or 50 minutes instead of 1 hour. In addition, fuel consumption was 10% less. Further, metallurgists found that castings obtained by this method had an appreciably better structure and were more suitable for heat treatment. These results probably are derived from the following:
(1) The degree of atomization was increased by the influence of the acoustic energy.
(2) Stability of the combustion front increased the completeness of combustion.
(3) Since the energy was introduced in the flame itself favorable chemo-acoustic phenomena developed.
(4) The probability between fuel droplets and oxidizing molecules is increased.
(5) A more uniform diffusion coefficient results from more uniform temperature distribution.

Author

N65-21274# Bureau of Mines, Pittsburgh, Pa. Explosives Research Center
(BuWeps Order 19-65-8023-Weps) (GR-1; AD-459475)
Techniques for the quantitative study of reaction pressures and rates of propagation were applied to neat and desensitized explosive systems, to determine the effect of scale charge size on the thresholds between high-velocity detonation (HVD), low-velocity detonations (LVD) and noninitiations (NI). A factorial experiment to determine the combined effect of oxygen balance, viscosity, and temperature on the sensitivity of a liquid explosive was made. To substantiate a proposed mechanism for propagation of LVD’s, wall wave positions were localized with respect to the chemical reaction zone. A normalized Hugoniot relationship for several liquids was calculated and an approximate Hugoniot for nitroglycerin-ethylene glycol dinitrate (NG-EGDn) was determined based on an experimentally determined sonic velocity and density.

L.S.

VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 1, Sep. 16-Dec. 15, 1964
(Contract NoW-65-0061-d: ARPA Order 22) (Rept.-13: AD-461073)
Studies of the dynamic shear modulus and bulk compressibility are discussed. The storage shear modulus for a polyurethane propellant was found to increase linearly with lateral compression up to a compressive strain of 10% to 15%. In contrast, the storage modulus of an unfilled styrene-butadiene rubber decreased linearly with the lateral compression. The modulus also depended on specimen geometry, increasing linearly with the shape factor, i.e., the ratio of the (uncompressed) specimen thickness to the cross-sectional area. Within experimental error, the loss modulus did not depend on specimen geometry. Some information was obtained on the heat buildup in propellant specimens during oscillatory testing. A qualitative discussion is given of work done to calibrate the dynamic and static bulk compressibility apparatus.

Author

N65-22360# General Dynamics/Astronautics, San Diego, Calif.
LIQUID PROPELLANT SLOSHING IN MOBILE TANKS OF ARBITRARY SHAPE
D. O. Lomen Washington, NASA, Apr. 1965 70 p refs
(Contract NAS8-11193) (NASA-CR-222) CFSTI: HC $3.00/ MF $0.75

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The irrotational motion of an incompressible, inviscid liquid contained in mobile tanks of arbitrary shape is considered. Hydrodynamic equations are derived for six degrees of freedom. All quantities are written in terms of a coordinate system which moves with the tank. The pressure, forces, moments, and surface wave height are all obtained in terms of nondimensional parameters. For tanks with an axis of symmetry and three degrees of freedom, these equations are matched with corresponding equations of motion of two mechanical systems: spring-mass and pendulum.

N65-22639# IIT Research Inst., Chicago, Ill.

(Contract AF04(611)-9566)
(IITRI-CB024-20. AD-461285)

Explosive sensitivity testing of N-F compounds is continuing. Compound R samples of less than 0.1 g were condensed as gaseous agglomerates on the metal sample cavity, which is held at -180° C. As the incident nitrogen shock wave increases from Mach 2.4 to 3.0, the time delay to ignition from the moment of shock reflection decreases from about 800 to 20 μsec. This measurement is very sensitive at the weaker shocks. Thin films or condensed gaseous agglomerates are one requisite for reproducible results, suggesting that a critical surface-to-volume sample geometry is involved in the ignition by this technique.

Author

N65-22828# Auburn Univ., Ala. Dept of Mechanical Engineering

THERMAL DIFFUSIVITY OF SOLID PROPELLANTS—DEVELOPMENT OF APPARATUS AND INITIAL TEST RESULTS Progress Report, Nov. 1963-Feb. 1964
G. E. Tanger and G. H. Nix. MAR. 1964 40 p. refs
(Contract DA-01-009-ORD-1023)
(PR-8. AD-457934)

Results of recent tests on the thermal conductivity of Pershing propellant are included. A transient heat-transfer system was constructed and tested in an attempt to determine the thermal diffusivity of solid propellant. Details on the construction and calibration of the apparatus are given. Also, thermal conductivity was determined for an inert propellant sample by the line-source and steady-state methods used previously. The density of the specimen was measured and the specific heat was calculated to provide a complete thermal analysis. Derivation of a series solution for the problem of transient heat flow in a semi-infinite solid is given in the appendix. The equations are programmed so as to obtain a trial-and-error solution for the thermal diffusivity.

Author

N65-23667# National Aeronautics and Space Administration.

Marshall Space Flight Center, Huntsville, Ala.

PRELIMINARY INVESTIGATION OF BLAST HAZARDS OF RP-1/LOX AND LH₂/LOX PROPELLANT COMBINATIONS
(NASA-TM-X-53240) CFSTI: HC $2.00/MF $0.50

This report discusses the current status of information regarding the blast hazards of liquid propellants, and presents results obtained from one part of a comprehensive analytical and experimental investigation of this problem. The data generally were consistent with siting criteria now used for RP-1/LOX. However, explosive yields determined for LH₂/LOX were markedly lower, and this suggests that current siting criteria for this propellant combination may be overly conservative.

Author

N65-23790* National Aeronautics and Space Administration.

Marshall Space Flight Center, Huntsville, Ala.

A PROPELLANT SLOSH MEASURING SYSTEM FOR SPACE VEHICLES
B. G. Bynum and John F. Hamlet. In its Astronics Res. and Develop. 1 Mar. 1965 p. 72-77 (See N65-23781 13-34) CFSTI: HC $4.00/MF $0.75

The theory and configuration of a capacitance system are described that may be used to measure the first mode of propellant slosh. Two pairs of parallel flat-plate capacitance probes extending the length of the propellant tank are connected into two bridge circuits. Difference in liquid height on diametrically opposed probes causes a difference in capacitance between the two probes. This difference unbalances the bridge circuit and causes a voltage output from the electronics package proportional to the height of slosh. The electronic theory of the system is presented with an explanation of the circuit design and operation. The design of the probes is described, and supporting theory is presented. Circuit diagrams and illustrations of the electronics network, probe construction, and vehicle installation are included. Tests proved that the system measured slosh accurately within 1.5 cm.

Author

N65-23815* General Dynamics/Astronautics, San Diego, Calif.

DIGITAL ANALYSIS OF LIQUID PROPELLANT SLOSHING IN MOBILE TANKS WITH ROTATIONAL SYMMETRY
(Contract NAS8-11193)
(NASA-CR-230) CFSTI: HC $2.00/MF $0.50

The hydrodynamic forces and moments derived for tanks possessing a longitudinal axis of symmetry are given in terms of coefficients which depend only on the tank geometry. This report explains the steps used to obtain these coefficients, given the tank geometry, and the procedures used in the program checkout. A description of the routines used in the program is included, as well as instructions for use of the program. The output of the digital program gives the spring-mass parameters associated with the system.

Author


15 Jan. 1964 43 p. refs
(Contract NOw-61-1054-c; ARPA Order 22-61)
(AD-458444)

The objective was to define the dynamic shear properties of selected propellants between 25 and 2000 cps at −50° to 75° C and to 1000 psig. Measurements are conducted with an apparatus which applies a sinusoidal shear stress and strain to a propellant sample. Continuous smooth curves depicting compliance of propellants having a hydrocarbon binder and polyurethane binder as a function of frequency and temperature were constructed. Cure time of the hydrocarbon-type propellant was found to influence compliance measurements. Propellant cured under representative conditions of actual grains continued to change with time, particularly as the temperature was raised through a sequence of measurements, but propellant cured for longer lengths of time was stabilized. Small
changes in moisture content were shown to effect compliance. Increasing static compressive strain normal to the shear plane appeared to decrease compliance markedly. Attempts to apply the method of reduced variables to these data was unsuccessful.


Design criteria for a flowmeter calibration system capable of using thixotropic and liquid propellants are reviewed in light of their chemical and physical properties. System design is described in terms of operation, accuracy, and safety precautions. Error analysis for the detector and shear-stress characteristics of various types of liquids are presented. 

Author


Propulsion is discussed as the crucial problem of space exploration. Velocity requirements for lunar, planetary, and interplanetary missions and the associated weight considerations are presented, and rocket principles are reviewed. Chemical propulsion systems, including liquid and solid propellants and methods proposed for improving their performance, are discussed. Nuclear and other advanced propulsion systems are considered, and comparisons are made of performance of the various propulsion systems for different missions. A brief discussion of auxiliary power systems is included. M. P. G.


The combustion of ammonium perchlorate spheres in flowing gaseous fuel is studied in conditions similar to those found in burning solid propellant in rocket motors. The theoretical aspect of the study is based on the following model: a decomposition flame near the surface and a diffusion flame surrounding the decomposition flame are admitted. Results show that the diffusion flame alone controls the sphere combustion rate. An experimental study is made of the combustion rate of compressed ammonium perchlorate spheres. The studied parameters are the gas nature, the velocity of the gaseous fuel, and pressure. It is found that the rates are determined by the equation: $d^2 = d^2 - K t$ for propane and ammonia, and by $d^3 = d^3 - K t$ for hydrogen, either pure or diluted into nitrogen.

Author

N65-25439# Radiation Applications, Inc., Long Island City, N. Y. RADIATION-INDUCED SOLID PROPELLANT DECOMPOSITION 28 May 1964 7 p (Contract AF 49(638)-1125) (AD-461462)

Radiation effects were studied on the deflagration rates of propellant binder and oxidizer apart from each other and independent of additives or other substances, and the chemical products of ammonium perchlorate radioysis. Irradiated ammonium perchlorate was analyzed for its chloride, chlorine dioxide, chlorite, hypochlorite, chlorine, chloride, and total nitrite and nitrate content. The radiolytic yields are tabulated. The products of metal and ammonium perchlorate radioysis were compared. Chlorate is a major product for both but am-

Continued research in radiation induced solid propellant decomposition, which focuses on solid ammonium perchlorate radioysis and the ballistics properties of operational propellants, is reported. Discussed is the use of a laboratory burner that permits studies of both and solid oxidizer component burning with a carefully controlled gaseous fuel environment and the solid fuel component burning with a carefully controlled gaseous oxidizer environment. Preliminary results of deflagration studies of ammonium perchlorate, polystyrene, and poly-methyl methacrylate are reported. Also cited are continued studies on the role of impurities on the apparent sensitivity of irradiation-induced acceleration of the ammonium perchlorate deflagration rate on the source of supply; the possibility of duration between fabrication and radiation exposure of the burners and their ultimate deflagration as a modifier of the irradiation-induced acceleration of the deflagration rate; and the effects of irradiation-induced deflagration rate modification in all solids systems, as opposed to the solid gas system of the burners.

S.C.W.
monium chloride also has major yields of chloride and chlorine. Using a porous-plug burner technique, irradiated and non-irradiated solid ammonium perchlorate oxidizer and solid polystyrene fuel specimens were burnt in unirradiated gaseous methane fuel and gaseous oxygen oxidizer environments and their burning rates measured as a function of dose level. Irradiation resulted in an acceleration of the ammonium perchlorate burning rate and was greater at higher methane flow rates. Radiation decreased the burning rate of polystyrene with the effect greater at the lower oxygen flow rate. Irradiation increased the burning rate of solid mixtures of polystyrene and ammonium perchlorate but to a lesser degree than with ammonium perchlorate alone. R.N.A.
**3. SPECIAL TEST PROCEDURES COMMITTEE** S. C. Britton p 21-26

**4. STRUCTURAL INTEGRITY COMMITTEE** J. E. Fitzgerald p 27-29

**5. AD HOC COMMITTEE ON SURVEILLANCE** Norman Fishman p 31-34

**6. AD HOC COMMITTEE ON DESIGN AUTOMATION** IN STRUCTURAL INTEGRITY Charles H. Parr p 35-38

**7. DYNAMICS PROBLEMS IN SOLID PROPPELLANT GRAIN DESIGN AND ANALYSIS** J. H. Baltrukonis p 39-41

**8. ENVIRONMENTAL EFFECTS** Norman Fishman and Don Saylak p 43-44

**9. MULTI-AXIAL RESPONSE OF SOLID PROPELLANTS** Joseph Marin p 45

**10. INTRODUCTORY COMMENTS ON MULTI-AXIAL RESPONSE OF SOLID PROPELLANTS** Joseph Marin p 47-49

**11. VISCOELASTIC BEHAVIOR INCLUDING NONLINEAR EFFECTS** E. H. Lee p 51-55 refs (See N65-26790 16-26)

**12. A CUMULATIVE DAMAGE CONCEPT FOR PROPELLANT LINER BONDS AND ITS APPLICATION TO FULL-SCALE MOTORS** K. W. Bills, Jr., B. B. White, and R. W. Planck p 57-64 refs (See N65-26791 16-27)


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**N65-26790** Office of Naval Research, Washington, D. C. PROGRESS IN THE NAVY RESEARCH PROGRAM ON THE MECHANICAL BEHAVIOR OF SOLID PROPPELLANT GRAINS. PART I: THE ONR CONTRACT PROGRAM. PART II: THE NAVY "IN-HOUSE" PROGRAM


Current work in numerous contracts in this study of solid propellant grains are summarized. Reports concern rheological evaluation of elastomers, mechanical properties of viscoelastic materials cast in various forms, properties of wire-reinforced propellants, and design criteria for solid propellant rocket motor grain configurations.

J. M. D.

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**N65-26799** Applied Physics Lab., Johns Hopkins Univ., Silver Spring, Md. VISCOELASTIC BEHAVIOR INCLUDING NONLINEAR EFFECTS


A brief review of the theory of nonlinear viscoelasticity is presented, and approaches to simplification of complex mathematical formulas are discussed. Several studies are recommended for application of nonlinear viscoelastic theory to problems of solid propellant grain design.

J. M. D.

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**N65-26791** Aerojet-General Corp., Sacramento, Calif. A CUMULATIVE DAMAGE CONCEPT FOR PROPELLANT LINER BONDS AND ITS APPLICATION TO FULL-SCALE MOTORS


An experimental and analytical study has been performed to apply a cumulative-damage concept to the prediction of the useful life of the propellant-liner bond in certain stored solid propellant motors. Laboratory measurements gave the linear relationship between log constant tensile stress and log time to failure for thin (0.25 in.) propellant-liner test specimens. A structural analysis provided the maximum tensile and shear stresses that were generated by cooling the motor from the cure temperature to 60°F and by gravitational forces. From the maximum principal stresses in the motor and the time-to-failure data on the test specimens, damage ratios were computed and accumulated using Miner's relation. From the damage ratios, predictions were made of the storage life of these motors before bond failures would lead to motor rejections. After a minor revision of stress levels, excellent agreement was found between predicted failures and failures observed in periodic graphical examination of many stored motors of this type.

Author

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**N65-26792** Aerojet-General Corp., Sacramento, Calif. CHEMORHEOLOGICAL STUDIES OF CARBOXY-TERMINATED POLYBUTADIENE TYPE BINDER


The cleavage and crosslinking reactions occurring within propellant binders prepared from carboxy-terminated polybutadiene were studied by means of high temperature stress relaxation. The site of cleavage for a series of binders prepared using various crosslinkers was determined. The effect of different antioxidants, antioxidant concentrations, combinations of antioxidants and various additives was studied. Measurements were also performed under high vacuum and steam pressures in order to isolate oxidative, thermal and hydrolytic reactions.

Author

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**N65-26793** Aerojet-General Corp., Sacramento, Calif. AN OPTICAL SCANNING SYSTEM FOR MULTIAXIAL STRAIN MEASUREMENTS


An electro-optic device for making multiaxial strain measurements is presented. The basic design of the instrument is described, and optical scanner data are reported and compared with data from various other strain measuring techniques. The device requires only visual access to a test surface in order to make the strain measurement; no mechanical contact with the specimen is necessary. Test data are given which demonstrate the case with which the optical scanner can measure multiaxial strains. This prototype instrument appears to be applicable for a variety of strain and deformation measurements of propellant specimens and grain structures.

J. M. D.

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**MATERIALS PERFORMANCE FOR DEFENSE AND SPACE PROGRAMS**

19 Nov. 1964 250 p. Rept. of tech. meeting held at Wright-Patterson AFB, Ohio. 23-24 Sep. 1964 (AD-461995)

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1. MATERIALS REQUIREMENTS AND APPLICATIONS IN THE ARMY P. R. Kosting (Army Mater. Command) 2 p (See N65-27001 16-17)
2. INTRODUCTORY REMARKS FOR THE NAVY PRESENTATION N. E. Promisel (Bur. of Naval Weapons) 2 p

3. DEEP SUBMERGENCE MATERIALS FOR THE NAVY P. A. Gisvold (Bur. of Shps) 16 p (See N65-27002 16-34)

4. REMARKS—AOA MATERIALS DIVISION LUNCH- EON Robert V. Hemm 2 p

5. CURRENT PROBLEMS IN FERROUS METALLURGY G. W. Roust and H. W. Zoeller (AFSC) 23 p (See N65-27003 16-17)

6. LIGHT METALS C. B. Ward (AFSC) 6 p (See N65-27004 16-17)

7. A REVIEW OF HIGH TEMPERATURE NONFERROUS METALS TECHNOLOGY D. R. James (AFSC) 15 p (See N65-27005 16-17)

8. AIR FORCE INTERESTS IN CERAMICS J. D. Latva (AFSC) 20 p refs (See N65-27006 16-17)

9. AIR FORCE REQUIREMENTS AND PROGRAMS PLASTICS R. C. Tomashot (AFSC) 8 p (See N65-27007 16-18)

10. POWDER METALLURGY G. W. Trickett (AFSC) 6 p (See N65-27008 16-17)

11. AIR FORCE REQUIREMENTS FOR PROPELLANTS D. A. Hart (AFSC) 4 p (See N65-27009 16-27)

12. MATERIALS FOR THE MACH 3 SUPERSONIC TRANSPORT G. C. Deutsch (NASA, Washington) 9 p (See N65-27010 16-02)

13. MATERIALS—MEN, MONEY, AND MISSIONS Earl T. Hayes (Defense Dept.) 4 p

14. STATE OF THE ART ON NONFERROUS METALS W. A. Dean (Aluminum Co. of Am.) 32 p (See N65-27011 16-17)

15. STATE OF THE ART IN PLASTICS E. O. Hausmann (Budd Co.) 6 p (See N65-27012 16-18)

N65-27009 Air Force Systems Command, Edwards AFB, Calif. Air Force Rocket Propulsion Lab. AIR FORCE REQUIREMENTS FOR PROPELLANTS Don A. Hart In Am. Ordnance Assoc. Mater. Performance for Defense and Space Programs 19 Nov 1964 4 p (See N65-27000 16-34). Some of the past deficiencies of solid and liquid propellants that represent present requirements as a result of the need for correcting or eliminating these deficiencies are discussed. Outstanding among the requirements listed for both liquid and solid propellants was that of propellant usability. The influence of future mission on both solid and liquid propellant requirements is examined.


Studies were continued on the development of techniques for predicting the flow phenomena and heat transfer of solid rocket igniters. The flow visualization tests and the setup and preliminary firing of the copper tube apparatus were completed. An analysis of wall heat transfer due to a cloud of radiating particles contained in a finite cylindrical duct was initiated.

N65-27210# Auburn Univ., Ala. A STUDY OF THE DECOMPOSITION MECHANISMS OF AMMONIUM PERCHLORATE Quarterly Progress Report, 22 Feb. 1–1 Jul. 1964 James E. Land 1 Jul. 1964 16 p refs (Contract DA-01-009-ORD-1023) (AD-457938) A survey of background information on the decomposition of ammonium perchlorate (AP), and on the decomposition of alkali metal chlorates, perchlorates, nitrates, nitrites, and chromates is presented. The differential thermal analysis technique and pertinent equations, decomposition mechanisms, crystal transformation, thermal explosion of AP, and catalyst influence on AP decomposition are discussed. The review is preliminary to studying the kinetics of the decomposition of AP. By studying the reaction order and the activation energies, a better understanding of the rate controlling step should lead to better selection of catalysts needed to achieve maximum realization of the oxidizing potential of the decomposition reaction.

L. S.


During the course of the Atlas-Centaur separation tests in the Lewis Space Power Chamber recurrent failures were experienced in the firings of the Atlas retarding rockets. In an effort to evaluate the suitability of these rockets for flight use, an investigation into the primary cause for the misfires was instituted and an evaluation of the performance of the rockets was made. The primary cause of the failures of the rocket to ignite was inconsistent igniter functioning and a too short igniter burning period.

Author

The basic operating principles of an experimental system for the direct and continuous measurement of solid propellant burning rates are presented. Several components of the measurement system have been modified in order to increase the precision of the burning rate measurements. A continuous burning rate measurement technique, termed the Servo-mechanism Technique, will be employed for obtaining erosive burning rate data for types BDI and BUU double-base propellants. Burning rate measurements will be made with different gas flow velocities parallel to the burning propellant surface. A feasibility study was conducted for determining the adaptability of microwave techniques to the measurement of the burning rate of a solid propellant. Because of the dependence of the microwave attenuation upon the combustion conditions present in a research rocket motor, microwave techniques are not readily adaptable to burning rate measurements. A feasibility study indicates that a technique employing ultrasonic pulses can be developed for obtaining direct measurements of the burning rate of a solid propellant.

Author
LIQUID PROPELLANTS SAFETY HANDBOOK

George T. Carter 1 Apr. 1965 106 p refs

Presented is a safety handbook which was designed for personnel involved in handling liquid propellants. Included are data on the description and properties of liquid propellants, storage facilities, firefighting facilities, storage and transfer of liquid propellants, spills, leaks and decontamination, and disposal of liquid propellants. Among the liquid propellant fuels and oxidizers considered are: ethyl- and fururyl-alcohol, anhydrous ammonia, nitrous oxide, liquid fluorsine, hydrazine, hydrocarbons, liquid hydrogen, hydrogen peroxide, nitric acids, nitrogen tetroxide, liquid oxygen, unsymmetrical dimethylhydrazine (UDMH), UDMH, and UDMH/hydrazine mixture. Data on the physiological effects of these propellants are also included.

N. Engler and W. Nachbar Jul 1963 103 p refs

An end-burning, side-vented, solid-propellant motor designed to produce essentially one-dimensional acoustic oscillations has been under development and test for the past three years. The immediate purpose of these investigations was to study the growth and decay of self-excited, combustion-driven, acoustic oscillations in chamber pressure and to measure the effects of operating parameters upon the growth rates, amplitudes, and frequencies of the oscillations. An ultimate purpose is to use this information as a guide to the further development of a theory of solid-propellant acoustic combustion instability. The report presents certain results from current experiments in which an essential innovation was the use of a transparent quartz tube containing the propellant sample and serving as part of the combustion chamber during burning.

M. Arshadi et al [1965] 23 p refs

An investigation was conducted in an altitude test chamber to determine the performance of a typical composite solid propellant at high nozzle pressure ratios and for a range of chamber pressure. Specific-impulse measurements were made over a range of pressure ratio from 115 to 1200 for fully expanded flow. The characteristic exhaust velocity and specific impulse were determined for a range of chamber pressure from 180 to 920 pounds per square inch absolute. Experimental measurements of propellant specific impulse and characteristic exhaust velocity were compared with theoretically calculated values for both frozen and equilibrium expansions.

M. A. Greenbaum. (QR-15; AD-465142)

An intensive study of the surface effects on the equilibrium:

BeO(c) + H2O(g) = Be(OH)2(g)

has been made at four temperatures in the range 1567 to 1808° K. The equilibrium is extremely sensitive to the surface area of the crystalline beryllium oxide. The data have been interpreted and extrapolated to yield a free energy of formation at 298° K of -158.4 ± 0.7 kcal/mole for gaseous Be(OH)2.

R. R. Parmerter and M. E. Fournery 1 May 1965 38 p refs

A series of photoelastic tests were conducted to establish the effect of slot width on a family of solid propellant rocket grains. The geometry of a typical cross section for the series is shown and is defined by the four parameters: the number of star points: the port fraction; the slot width factor; and the fillet radius factor. Limit points were determined by a parametric series of tests. The method of analysis is outlined, and the results are presented graphically.

M. A. Greenbaum. (QR-15; AD-465142)

The effect of adding fluorsine to the Vanguard first-stage oxidant was analyzed. An increase in specific impulse of 57.4 percent may be obtained with 30 percent fluorsine. This increase, coupled with increased mass ratio due to greater oxidant density, gave up to 24.6-percent increase in first-stage burnout energy with 30 percent fluorsine added. However, a change in tank configuration is required to accommodate the higher oxidant-fuel ratio necessary for peak specific impulse with fluorsine addition. Increased performance of this order can be obtained without tank-configuration change by addition of unsymmetrical dimethylhydrazine (UDMH) to the fuel coincident with fluorsine addition to the oxidant. With 30 percent fluorsine and approximately 51 percent UDMH, the burnout energy can be increased 23.5 percent. Fluorsine addition will increase the engine heat-rejection rate about 1 percent for each 1 percent fluorsine added up to 30 percent.


EXPERIMENTS WITH A SOLID-PROPPELLANT ACOUSTIC OSCILLATOR: MATERIALS AND CHEMISTRY

J. F. Engler and W. Nachbar Jul 1963 103 p refs

The characteristic exhaust velocity and specific impulse were determined for a range of chamber pressure from 180 to 920 pounds per square inch absolute. Experimental measurements of propellant specific impulse and characteristic exhaust velocity were compared with theoretically calculated values for both frozen and equilibrium expansions.
present research has been designed to study the nature of the processes involved in propellant gasification in the absence of the complicating effects of the gas phase flame. The experimental method being employed in this study permits the measurement of propellant regression rates in the absence of the gas phase flame. An intense radiant flux from an arc-image furnace is substituted for the conductive heat flux generally associated with the flame. The flame itself is eliminated by working at a vacuum below the propellant combustion limit. Preliminary tests on PBAA propellants subject to a radiant flux associated with the flame. The flame itself is eliminated by work.

**N65-29300**


**PROCEEDINGS OF THE FIRST ICRPG COMBUSTION INSTABILITY CONFERENCE, VOLUME 1**

Jan 1965 498 p refs Conf. held at Orlando AFB, Fla., 16-20 Nov 1964 (CP1-68 AD-458060)

Studies on liquid, solid, and composite propellants are presented, concerning combustion mechanisms and instability. For individual titles see N65-29301-N65-29341.

**N65-29302**

**Aerogen-General Corp. Sacramento, Calif. Combustion Dynamics Dept.**

**COMBUSTION STABILITY RESEARCH AT AEROJET-GENERAL**


The combustion dynamics of the liquid oxygen-liquid hydrogen propellant combination at elevated chamber pressures was explored. The experimental hardware consisted of an 8-inch-diameter combustion chamber terminating in a short convergent exhaust nozzle. The chamber length was varied between 6 and 26 inches. The investigation was conducted at three chamber pressure levels of 1000, 1500, and 2500 psia. Nominal mixture ratio was 5 and the nominal thrust of the unit was 25,000 lb. High-frequency combustion instability was induced by tangentially directed pulse generators located near the injector. The injector was used for three experiments: (1) a conventional monofracture type rated at 125-lb thrust per injection element; (2) a coaxial type delivering 1100 lb per element; and (3) a four-element pentad injector rated at 5000 lb per element. The sensitive time lag theory was used to correlate the experimental test results. Other experimentation is discussed to include the acoustic resonance properties of combustion chambers.

**E.E.B.**

**N65-29303**

**Rocketdyne, Canoga Park, Calif.**

**LIQUID PROPELLANT COMBUSTION INSTABILITY RESEARCH AT ROCKETDYNE**


Highlights of the combustion instability studies conducted in support of the Navaho, Atlas, Thor, Jupiter and H-1 engine development programs are reviewed briefly. The current studies in support of the F-1, J-2, and toroidal engine programs are discussed in detail. An analytical model of hydrogen-oxygen combustion, resonance of elliptical cavities, and extension of LOX-RP-1 steady-state combustion model to time dependent form, and two-dimensional thrust-chamber experiments testing dynamic stability are covered.

**E.E.B.**

**N65-29307**

**National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.**

**20K H-O SCREECH WORK AT LEWIS**


High frequency combustion instability in liquid propellant rocket engines is discussed. The investigation was made to determine similarity parameters for liquid propellant rocket engine design; to provide answers to present rocket engine development combustion problems, and to confirm instability theories. Most of the work was done on a scale of 20,000 lb thrust level at a combustion chamber pressure of 300 psia with thrust variations to 5000 and 80,000 lbs and chamber pressure variations to 100 and 1000 psia. Propellant combinations range from conventional rocket fuel and LOX to some of the exotic fuels, with major emphasis on the hydrogen—LOX and NTO-50-50 combinations. Results from initial phases of the program show the effects of propellant injection velocities and acoustic damping devices on temperature. Data from a bench test setup employed to investigate acoustic absorption devices are presented with the results of an analytical study for the design of a lightweight acoustic combustion chamber liner.

**E.E.B.**

**N65-29311**

**Polytechnic Inst. of Brooklyn. Farmingdale, N.Y.**

**HIGH-FREQUENCY COMBUSTION INSTABILITY AND SCALING OF LIQUID PROPELLANT ROCKET MOTORS**


The oscillatory behavior of the 500 lb thrust JP5-LOX rocket engine was investigated and the experimental results are reported. The thrust chamber is comprised of a two-inch internal diameter cylinder of variable length with a contraction ratio of 1.5 such that the nozzle entrance Mach number is about 0.45. The injector is either shower head or doublet. The doublets in the injectors impinge at either one distance from the injector face or at various locations down the chamber. A wave generator is attached to the injector plate. A very small mass of nitrogen gas is contained in the driver section which flows through a variable area channel and generates a continuous wave in the combustion chamber. The experimental results obtained from the determination of kinetic temperature by means of sound velocity measurements, wave analysis, and the effect of chamber length are also discussed.

**E.E.B.**

**N65-29313**

**Bell Aerosystems Co., Buffalo, N.Y.**

**EXPERIMENTAL TECHNIQUES FOR INVESTIGATING INSTABILITY IN LIQUID PROPELLANT ROCKET ENGINES**


The features and theoretical background of two experimental techniques developed to provide realistic information concerning the effect of injector design on the stability of operation of liquid propellant rocket engines and concerning phenomena and processes which are suspected of triggering low or high frequency instability are described. The first technique is the taking of high speed and high resolution spark photographs through windowed combustion chambers firing under actual operating conditions. This method gives single or multiple shadowgraphs of the liquid portions of the gas-liquid mixture in the chamber and provides a realistic insight into the behavior of liquid propellants after injection into a
firing rocket chamber. The second technique is the method of forced oscillations. The method consists in producing controlled pressure oscillations of variable modulating frequency in the fuel or oxidizer manifold which excite forced pressure oscillations in the combustion chamber. Pressure oscillations in the fuel manifold and in the chamber are recorded by means of a cathode ray oscillograph. Such oscillographs are discussed. E.E.B.

LINEAR PYROLYSIS RATE MEASUREMENTS OF PROPELLANT CONSTITUENTS

The design and construction of a porous plate apparatus for the measurement of linear pyrolysis rates of solid propellant constituents and propellant oxidizers are discussed. Ammonium chloride was selected for the calibration of the device because a considerable amount of sublimation rate data are available. The data obtained are given; however, the reducibility of the data was not good. With ammonium perchlorate the data were more reproducible than that obtained with ammonium chloride. Data for AP and GRS rubber are also given and compared with previous measurements. E.E.B.

N65-29319 Stevens Inst. of Tech., Hoboken, N. J.

Contract Nonr-263(48)

Since thermoplastics are generally employed as the binder component of composite solid rocket propellants, a description of the response of the thermoplastic surface to the intense surface heating exposure encountered during combustion appears as a pivotal boundary condition in the formulation of complete theoretical descriptions of solid propellant combustion processes. A testing technique is described which involves porous specimens fabricated by bonding together thermoplastic and passing through them a series of inert and chemically reactive test gases. The experiments were designed to illuminate the nature of the steady state regression process produced by an imposed constant level of surface heating. The measured surface regression rate of polymethacrylate was unaffected; however, that of polystyrene was accelerated by the presence of chlorine and nitrogen dioxide. Neither plastic exhibited an accelerated regression rate when oxygen or perchoryl fluoride were employed. E.E.B.

N65-29320 National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

An experimental approach to the problem of flame structure based on flame radiation measurements is presented. The approach used was to burn propellant strands backlit with a mercury light source and to simultaneously record the spectra of flame gases and mercury light. The cutoff of the mercury light indicates the location of the propellant surface on the recording photographic plate. Comparison of the spectral radiation of the propellant with an adjacent mercury line yields spatial resolution of the species resulting from oxidizer-binder reactions. The CN band head at 3883 Å and an adjacent mercury line were used for comparative analysis. It was concluded that CN emission begins slightly above the burning surface at a distance of 70 microns. Peak CN radiation occurred at less than 165 microns from the propellant surface. The propellants were strands of ammonium perchlorate and polybutadiene acrylic acid. The mean weight diameter of the oxidizer was 11 microns. Spectra obtained at pressure above atmospheric revealed a strong continuum which obscured the CN line to such an extent that meaningful measurements could not be made. E.E.B.

N65-29324 Naval Ordnance Test Station, China Lake, Calif.
PHOTOGRAPHIC SURVEY OF ALUMINUM COMBUSTION IN SOLID PROPELLANTS

Aluminum combustion in solid propellants was studied with high-speed photography. The physical arrangement consisted of a pressure vessel with fused quartz windows and a high-speed motion picture camera. The propellant sample size was varied according to the objective of the particular test; the sample was usually in the form of a slab 1/4-inch square and 1/8-inch thick. The sample was ignited on the top edge by a 10 mil hot wire. It was observed that regardless of the original particle size, the greatest number of aluminum agglomerates had a diameter of about 100 microns. This observation raises the question of what do aluminum particles of different sizes have in common which would explain this behavior? One characteristic the aluminum particles have in common is that the aluminum was contained originally in spaces between the ammonium perchlorate particles. This leads to the speculation that an aluminum agglomerate arises from the aluminum contained in one pocket of binder between ammonium perchlorate particles. If this is correct, the aluminum agglomerates size is determined by the amount of aluminum in the binder pocket. E.E.B.

N65-29325 National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
BEHAVIOR OF LARGE ALUMINUM PARTICLES IN COMPOSITE PROPELLANTS

The factors which influence particle size in the combustion zone of aluminum composite propellants were investigated to determine particle size and if the particles are shed with any periodicity. The importance of both metal particle size and shedding frequency for both acoustic and nonacoustic instability is generally recognized. Also, nozzle design for two-phase flow is strongly dependent on particle size at the nozzle entrance. Three PBAA-AP-A1 propellants in which only the aluminum particle size was varied were used in the experiments. Results with shredded aluminum propellant revealed a mean number diameter of the combustion products of several microns, invariant with pressure. The original size appeared to have no significant influence on the product size. A small number of large particles were observed comparable to the size of the original additive. The size of these larger particles appeared to decrease with increasing pressure. The radiation output revealed frequencies of 30 to 50 cps. At atmospheric pressure 3% of the particles were of size equal to or greater than the original. The number of these particles decreased to less than 1% at 500 psi. E.E.B.
ON SOLID PROPELLANT BURNING RATES

EXPERIMENTAL STUDY OF ACOUSTIC EROSI VITY EFFECTS ON SOLID PROPELLANT BURNING RATES

SOME FURTHER DATA ON NONLINEAR AXIAL-MODE INSTABILITY

SOLID PROPELLANT BURNING RATE UNDER TRANSIENT HEATING AND EXTINGUISHMENT VIA "L* INSTABILITY"

NONACOUSTIC, LOW-FREQUENCY COMBUSTION INSTABILITY OF SOLID PROPELLANTS

SOLID PROPELLANT BURNING RATE UNDER TRANSIENT HEATING AND EXTINGUISHMENT VIA "L* INSTABILITY"

SOME FURTHER DATA ON NONLINEAR AXIAL-MODE INSTABILITY
frequency with mean pressure for several aluminum concentra-
tions, oxidizer particle sizes, and aluminum particles sizes with
two different binders. The investigation of the preferred fre-
quency characteristics of propellant combustion was also in-
vestigated with two additional techniques. The first is the center-
vented end burner which permits study of oscillatory behavior
in the same range as the L" burner but in a pressure-coupled
acoustic wave mode. Also, considerable promise is shown in
results obtained by observing propellant sample burning in a
window bomb equipped with modulated through-flow of inert
gas. The modulated flow produces mild pressure oscillations
which in turn produce combustion oscillations. These oscilla-
tions are monitored with a radiation transducer. The relative
amplitude and the phase of the radiation oscillation is used to
infer the nature of the coupling of the pressure oscillation with
the combustion oscillation.

E. E. B.

N65-29468# National Aeronautics and Space Administration,
Washington, D. C.
SOLID ROCKETS: SEEKING A NEW PLATEAU. PART II:
THE STATE-OF-THE-ART IN SOLID ROCKETS DESIGNED
PRIMARILY FOR SPACE MISSIONS
Irving Silver and William Cohen 30 Jun. 1964 28 p Pre-
sented at the Natl. Meeting of the AIAA
(NASA-TM-X-51749) CFSTI: HC $2.00/MF $0.50 CSCL 21H
Advances in solid motor technology are reviewed, with em-
phasis on the developments which led to the design of motors
with diameters of 120", 156", and 260". Areas of technology,
which are considered as state-of-the-art, include concepts and
developmental work on segmented motors; non-segmented,
monolithic motors; motor cases; weld conditions; selection of
materials and their fabrication; reworking capabilities of
marage steels; nozzle concepts, and the feasibility of wrapped
ablative nozzle designs; thrust vector control systems for solid
rocket motors, such as liquid injection, jet tabs, and movable
nozzles; processing, casting, and curing methodology for large,
heavy motors; slurry insulation; and aft end and hypergolic
ignition. Also discussed are preliminary investigations of fail-
ure warning systems: the re-use of motor cases, insulation
systems, and nozzle components: hazard classifications; and
cost effectiveness in relation to the merits of propulsion sys-
tems for large launch vehicles.

M. G. J.

N65-29668# Aerojet-General Corp., Downey, Calif. Research
Div.
LARGE SOLID-PROPELLANT BOOSTERS, EXPLOSIVE
HAZARDS STUDY PROGRAM (PROJECT SOPHY) Monthly
Progress Report, Mar. 1965
G. L. Roark 12 Apr. 1965 8 p
(Contract AF 04(611)-9945)
(Rept.-0866-01(10)MP)
Progress is reported on a program designed to study ex-
plusive hazard of large solid-propellant booster. This program
consists of two major areas of technical inquiry: critical diam-
eter and critical geometry. Matters concerning the program
are discussed in the following sections: program funds status,
milestone schedule, and problem areas.

N. E. A.

N65-29780# California Univ., Berkeley. Space Sciences Lab.
STUDY OF DETONATION OF MIXTURES OF GASEOUS
1962--Feb. 18, 1965
A. J. Laderman Apr. 1965 267 p refs Its Ser. 6, Issue 11
(Contract NAS8-2634)
(NASA-CR-64032) CFSTI: HC $6.00/MF $1.50 CSCL 07B

Progress is reported on an investigation to determine the
detonability of hydrogen-oxygen mixtures of various com-
positions, in vessels of size comparable to interstage com-
partments, under selected environmental conditions. The
experimental program was comprised of two distinct phases.
The first was devoted primarily to determining steady detonation
parameters, and made use of a high energy ignitor consisting
essentially of a two inch length of 400 grain Primacord, a
commercial detonating fuse. The second phase of the program
was concerned with the use of weak igniters and provided
information on the detonability of hydrogen-oxygen mixtures
in the absence of externally produced shock waves.

N. E. A.

N65-29790# Naval Postgraduate School, Monterey, Calif.
LIQUID HYDROGEN—HIGH ENERGY ROCKET FUEL
Eugene A. Cernan (M. S. Thesis) 1963 92 p refs

Liquid hydrogen has been classed as a high energy fuel
for rocket propulsion. A survey of the latest technical litera-
ture was made and the information compiled in a form which
discusses the value of this fuel in propellant combinations.
Thermodynamic performance, payload comparisons, ad-
vantages, disadvantages, problems, and relative merits of
respective combinations and systems are presented. A dis-
cussion of rocket performance parameters is included as a
basis for a more complete understanding of the information
presented in the above-mentioned areas.

Author

Technology Div.
METHODS FOR STUDYING THE DYNAMICS OF SPACE
VEHICLES
p 14-18 refs (See N65-30207 19-34)

The dynamics of rigid bodies having cavities partially
filled with liquid is studied by theoretical and experimental
methods. Attention is concentrated on calculation of hydrody-
namic coefficients. Numerical results obtained by theoretical
and experimental methods are presented for bodies having
cavities of various forms. A comparative analysis of theoreti-
cal and experimental results is made.

Author

N65-30838# Dynamic Science Corp., Monrovia, Calif.
A BASIC STUDY OF THE NITROGEN TETROXIDE-HYDRA-
ZONE REACTION
Harold G. Weiss Jul. 1965 56 p refs Prepared for JPL
(Contracts NAS7-100; JPL-E-229751)
(NASA-CR-64358; SN-4500) CFSTI: HC $3.00/MF $0.50
CSCL 211

Data from the study of the hydrazine-nitrogen tetroxide
reaction show that hydrazine-nitrogen tetroxide impinging jets
are diverted by interaction between the two propellants. The
principal factors which cause this phenomenon are: (1) im-
miscibility of the two reactants; (2) rapid reaction rate between
N2O4 and N2H4; and (3) the high heat evolution and large gas
volume generated by reaction. These factors are discussed in
detail in addition to the whole experimental program.

N. E. A.

cALCULATION OF EQUILIBRIUM ELECTRON AND ION
CONCENTRATIONS
Eileen A. Cook In APL ICRPG Working Group on the Thermo-
chem., Vol. I Jul. 1965 p 17--20 refs (See N65-31307 20-06)
(Contract AF 04(695)-469)

The thermodynamic data requirements for equilibrium
propellant performance calculations are discussed. The in-
clusion of ionic species to obtain electron densities and ionized
product concentrations for solid propellants and re-entry ablative
materials is considered.

Author
SELECTED METHODS FOR DETERMINING THERMAL CONDUCTIVITY AND DIFFUSIVITY OF SOLID PROPELLANT Final Report
(Contract DA-01-009-ORD-1023)
(Rept.-XII, AD-468279)

A summary of investigations pertaining to determination of thermal conductivity and thermal diffusivity of solid propellant is given. The line-source technique, a transient method, is recommended for routine determination of conductivity. Accuracy is ±5%, and the method compares favorably with steady-state methods currently in use. The method adopted for diffusivity determination is discussed. A finite-difference method of computation yields the closest agreement with experiment and is recommended for future use. Accuracy of results calculated with the finite-difference technique was ±4%. Author

THE INTEGRATED DESIGN COMPUTER PROGRAM AND THE ACP-1103 INTERIOR BALLISTICS COMPUTER PROGRAM
(Contract DA-04-200-ORD-1305(2))
(STM-180: AD-466965)

The Integrated Design and the ACP-1103 Interior Ballistics Digital Computer Programs are described. The Integrated Design Program converts a mission concept (range and payload) into a complete missile design including the number of stages with respect to key parameters and contains a grain design and propellant is given. The line-source technique, a transient method, is recommended for routine determination of conductivity. Accuracy is ±5%, and the method compares favorably with steady-state methods currently in use. The method adopted for diffusivity determination is discussed. A finite-difference method of computation yields the closest agreement with experiment and is recommended for future use. Accuracy of results calculated with the finite-difference technique was ±4%. Author

THE INVENTION OF A NEW TYPE OF FRICTION SENSITIVITY APPARATUS
Carl Armour and Lloyd Smith 11 Jun. 1965 26 p
(RDT-60: AD-617382)

A new type of test apparatus has been invented which obtains an absolute value in foot-pounds for the frictional energy required to ignite explosives, pyrotechnics, propellants and other high energy compositions. The device obtains the frictional energy of ignition by spinning a rod on the sample held in an alundum sample holder. This energy is calculated from the torque load, the deflection, the revolutions per minute and the time to fire. Reproducibility of test results using duplicate samples is within a 1% to 2% range. Author
The 260-SL motor ignition system development program was conducted to demonstrate the capability of an aft-end solid-propellant igniter to ignite the 260-SL motors. A mathematical model was derived to define the gas dynamics of aft-end ignition and to provide the parameters required for aft-end ignition system design. The test program demonstrated the ignition capability of the ignition system and provided sufficient data to verify the mathematical model and the criteria used for the design of the ignition system. The 44-in-dia subscale motor ignition system development program further verified the 260-SL motor ignition system design criteria and provided preliminary data on the igniter ejection sequence. The aft-end ignition performance in three 44-SS motors showed predictable and reproducible performance. All objectives of the development program were achieved and the ignition capability of the 260-SL motor ignition system was fully demonstrated.

Author

R. F. Muraca Oct. 1964 22 p refs
(Contract AT(04-3)-115)
(UCR-L-13136)

Two procedures are described for determining the water content of solid propellants containing nitrate ester oxidants. One procedure has been specifically designed for use by skilled laboratory technicians, it is predicated on the use of an efficient titration system for the Kari Fischer reagent. Water accumulation in the titration vessel from the atmosphere or other sources is minimized by the use of specially-dried helium. As a result, the water content of solid propellants requiring times greater than one hour for dispersion in solvents can be determined accurately. The other procedure embodies the use of a specially-constructed manometric vessel and is based on the measurement of hydrogen pressure resulting from the reaction of calcium hydride with the water content of a solid propellant sample. Both methods are applicable for the determination of water in solid propellants containing from 0.10 to 0.01 per cent water. The role of the solvent in both determinations is discussed.

Author


Progress is reported on the study of the reactions between nitrogen tetroxide and hydrazine; on the firing tests of several ablative thrust chambers; on a method for locating pinholes in metal foils; on high and low temperature tests of a tank and expulsion diaphragm assembly; and of the metallographic examination of an aluminum propellant tank which was subjected to long-term storage test with hydrazine. The data obtained on the study of nitrogen tetroxide and hydrazine are consistent with the fact that nitrogen tetroxide-hydrazine impinging jets are subject to disruption by the rapid reaction occurring at the interface between the two propellants. The principle factors which cause this phenomenon are the rapid reaction rate and the immiscibility of the two reactants. Although these factors are closely related, it appears that immiscibility is a major factor. Photographic studies showing the dropwise addition of N2O4 to N2H4 show that the two materials are completely immiscible. Test results also have shown that tanks of aluminum alloy are essentially unaffected by long-term contact with anhydrous hydrazine from 30° to 100°F.

E. E. B.
As a part of the general study of the behavior of liquid propellants stored in space-vehicle tanks while exposed to weightlessness, an experimental investigation was conducted to determine the motion of the liquid-vapor interface in a cylindrical container in response to a constant translational acceleration. The imposed acceleration was applied parallel to the longitudinal axis of the cylinder and was directed positively from the vapor to the liquid phase separated by an initially highly curved interface. The results indicated that the liquid-vapor interface profile assumes the form predicted by the inviscid potential theory of G. I. Taylor. The rate at which the vapor phase penetrates the liquid phase (the ullage velocity) was empirically correlated as a function of known systems parameters for Bond numbers greater than 1 and fluids possessing low viscosities. The leading edge of the liquid-vapor interface was found to accelerate over distances comparable to fineness ratios of 2: the magnitude of acceleration is a known function of ullage velocity. 

Author

M. Aiao and B. R. Chandler 15 Jul 1965 132 p refs (Contract AF 04(611)-9572) (AD-464736)

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M. G. J.

William J. Masica and Donald A. Petrash Washington, NASA. Sep. 1965 23 p refs (NASA-TN-D-3005) CFSTI: HC $1.00/MF $0.50 CSCL 20D

As a part of the general study of the behavior of liquid propellants stored in space-vehicle tanks while exposed to weightlessness, an experimental investigation was conducted to determine the motion of the liquid-vapor interface in a cylindrical container in response to a constant translational acceleration. The imposed acceleration was applied parallel to the longitudinal axis of the cylinder and was directed positively from the vapor to the liquid phase separated by an initially highly curved interface. The results indicated that the liquid-vapor interface profile assumes the form predicted by the inviscid potential theory of G. I. Taylor. The rate at which the vapor phase penetrates the liquid phase (the ullage velocity) was empirically correlated as a function of known systems parameters for Bond numbers greater than 1 and fluids possessing low viscosities. The leading edge of the liquid-vapor interface was found to accelerate over distances comparable to fineness ratios of 2: the magnitude of acceleration is a known function of ullage velocity.

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M. G. J.
and limitations of the interferometry technique are treated in detail. Preliminary r-P data for a polybutadiene-acrylic acid composite propellant are reported up to 60000 psi. results at higher pressures are indeterminate, owing to leakage and lack of high-pressure dynamic calibration equipment. Author

FAILURE OF AN INERT COMPOSITE PROPELLANT UNDER MULTIAXIAL STRESS FIELDS. Technical Report No. 1
M. G. Sharma and C. K. Lim Mar. 1965 49 p refs Prepared for JPL (Contracts NAS7-100: JPL-950875)
(NASA-CR-67235) CFSTI: HC $2.00/MF $0.50 CSCL 211

The failure criteria of an inert composite solid propellant were evaluated under five biaxial tension stress fields. The effect of rate of loading on failure behavior of the material is considered. A new biaxial testing machine used for failure studies of the inert composite propellant is described. Possibilities of describing failure in terms of octahedral shear stress, octahedral shear strain, and maximum strain energy hypotheses are discussed. Failure curves in the principal stress space indicate that induced anisotropy exists in the material at fracture perhaps due to dewetting occurring in certain biaxial stress states. Maximum strain energy at fracture for various biaxial stress fields evaluated from creep behavior in tensile and volumetric deformation agrees well with experimentally determined energy at fracture for most biaxial stress fields. However, for low biaxial stress ratios, predictions based on the finite deformation theory agree better.  R.W.A.

ON THE CHARACTERIZATION OF MULTIAXIAL DATA IN TERMS OF THE STRAIN ENERGY CONCEPT
Anthony San Miguel 15 Oct. 1965 15 p refs
(Contract NAS7-100)
(NASA-CR-67400; JPL-TR-32-675) CFSTI: HC $1.00/MF $0.50 CSCL 211

An experimental-theoretical approach based on continuous media theory has been suggested as a means of characterizing the multiaxial mechanical behavior of solid propellants (allowing for compressibility). The applicability of this approach to solid propellants has been the subject of one research program. Two multiaxial experiments that have been developed in this program are the inflated cylinder test and the biaxial sheet test. This report deals with characterizing the multiaxial data from these tests in terms of strain energy; only the elastic portion of the viscoelastic response is considered. However, the ultimate aims of the study are to characterize materials with memory. Many of the observations previously reported by the author of compressible propellant were largely repeated upon examination of an unfilled polyurethane binder, which was essentially incompressible. The compressibility theory suggested by the author experimentally converges to the theory as used by Rivlin for an incompressible material.  Author

GENERANT CONTROLLER DEVELOPMENT FOR THE ADVANCED LIQUID PROPULSION SYSTEM (ALPS)
W. F. Mac Glashaw, Jr. 15 Nov. 1965 35 p refs
(Contract NAS7-100)
(NASA-CR-67842; JPL-TR-32-814) CFSTI: HC $2.00/MF $0.50 CSCL 211H

The function of the generant controller is to meter the flow of hydrazine to the gas generator so that constant pressure is maintained in the propellant tank during all firing periods regardless of variations in the rates at which propellants flow out of the tank. The generant controller is essentially a remote-sensing, single-stage, spring-loaded regulator. Four controller versions were built and tested. Controlled 4 incorporates the best features of the preceding three controllers.

Richard B. Cole and Joseph Wenograd 17 Jun. 1965 139 p refs
(Contract Nonr-1858(32); ARPA Order 23)
(Rept.-446-0: AD-467728)

Two composite solid propellant combustion experiments are reported: one deals with burning surface photomicroscopy, and the other with the influence of oxidizer particle size on low pressure combustion. The first investigation involved photography of the surfaces of 1/4 inch square polysulfide-ammonium perchlorate (unmetallized) propellant strands during combustion in a coaxially-flowing nitrogen environment. The experiment and the apparatus used are described in detail. Among the findings were that useful combustion pressures for high resolution surface photography of burning strands is limited to less than about 500 psig. The second investigation deals with the dependence of the subatmospheric pressure burning rates of 1/4 inch square strands of ammonium perchlorate propellants on pressure and oxidizer particle size. An apparatus providing for burning rate determination by sequence photography of the strands burning in an essentially stagnant nitrogen environment is detailed, and burning rate versus pressure results are included.  C.T.C.
Results of water tests that simulate expected operating conditions are recorded. Special features of these controllers, such as the diaphragm backup ring and the Belleville spring package, which were developed as a result of this study, are discussed. The suitability of these special features for scalability and for other components is pointed out. An Appendix is included which describes the function of the generator controller in the ALPS system and in the Mariner '66 system.


N. W. Tschoegl and J. R. Smith [1965], 18 p ref (Contract N0W-65-0061-d: ARPA Order 22) (Rept.-15: AD-470846)

Data were obtained on the dependence of the shear moduli of a polyurethane propellant on shear strain at different frequencies and temperatures, and on the time of storage at low temperatures. The propellant was then tested in the dynamic shear tester over extended ranges of temperature and frequency. The data are presented in graphical form. Investigation of the problem of the variation of output with piston position and diaphragm configuration in the dynamic compressibility apparatus was continued.

N66-11637# United Technology Center, Sunnyvale, Calif. RESEARCH TO RELATE THE EFFECTS OF STRUCTURE AND COMPOSITION OF A PROPELLANT TO THE MECHANICAL PROPERTIES OF A COMPOSITE PROPELLANT First Quarterly Progress Report, 13 May-13 Aug. 1965


Experiments, tests, and evaluation methods to be used in a polymer and propellant preparation program are given. Initial experiments with a carboxy terminated polybutadiene polymer are planned; these include variation of crosslink density with molecular weight, and variation of crosslink density by chain extension. The characteristics of the polymer are tabulated, and incorporate molecular weight, viscosity, specific gravity, carboxy equivalents, and isomer concentration. Tensile, stress relaxation, and failure tests are planned for the evaluations.

C. T. C.


Studies supplementary to the determination of the dynamic shear modulus are reported. The effects of specimen geometry and the magnitude of shear strain on the dynamic modulus of polyurethane propellant AEBA 10 were studied. A method was worked out to correct measurements to the same level of shear strain to allow a direct comparison under all experimental conditions. An evaluation of the differential Lissajous method for determining small phase angles has shown that, at frequencies as low as 0.05 cps, a phase angle of the order of a few thousandths of a radian can be measured with good precision. Factors that influence the reproducibility of data obtained with the dynamic compressibility apparatus were investigated.


The vaporization and diffusion processes for diocyl adipate and ferrocene in a polyurethane propellant were studied in some detail; phenyl-beta-naphthylamine was studied in less detail. Vapor pressures of these three additives were measured. Diffusion studies were carried out on propellant samples containing diocyl adipate and ferrocene. Measurements were made between 30 and 70°C. The diffusion coefficients found for these two materials were nearly the same. The vapor pressures differed by several orders of magnitude. Diffusion appeared to take place predominantly through the polymer phase. There were some indications of structure-dependent diffusion through cracks and boundaries between the binder and the oxidizer. If one assumes a rocket configuration in which the effective throat area is about 3 x 10^-3 times the area of exposed propellant surface, then one concludes that at about 30°C the loss of diocyl adipate will be controlled by the rate of effusion from the nozzle. Over a period of a few years, the loss would be negligible. For ferrocene, with a much higher vapor pressure, the loss is diffusion controlled and in a year would deplete the propellant considerably within a few millimeters of the surface, leaving the bulk of the propellant unaffected.

N66-14010# Naval Radiological Defense Lab., San Francisco, Calif. THE RADIOLYTIC DECOMPOSITION OF 1,1-DIMETHYLYHDRAZINE, DIETHYLENETRIAMINE AND HYDyne ROCKET FUELS

Wesley E. Shelberg 19 Aug. 1965 15 p refs (USNRDL-TR-896: AD-622334) CFSTI: HC $1.00/MF $0.50

One hundred-milliliter samples of the storable liquid rocket fuels, 1,1-dimethylhydrazine, diethylenetriamine, and Hydyme generate respectively 199.0, 101.2 and 164.1 ml of radiolytic off-gas (measured at 25°C and 1 atm) when irradiated to 8,500,000 rads with gamma rays. The result for Hydyme was calculated from those for 1,1-dimethylhydrazine and diethylenetriamine, Hydyme consisting of 60 wt-% of the former and 40 wt-% of the latter. When the samples contain 5 vol-% of the free radical scavenger methacrylate, the off-gas volumes are reduced respectively by 18.2, 11.0 and 16.7 %. Since the free-radical scavenger reduces somewhat the off-gas from the fuels due to laboratory ionizing radiation, it may be expected to improve their storability somewhat with respect to ionizing space and nuclear rocket radiations.

Author (TAB)
range at -11.13.0.0, and 25.0° C. The results show, conclusively, that Henry's law is obeyed for all pressures at each temperature. The standard free energy, enthalpy, and entropy of solution for each gas have been computed.

Author

N66-144560# Battelle Memorial Inst., Columbus, Ohio.
DEVELOPMENT OF LAMINATED SOLID PROPELLANTS
Alfred Rudnick, Robert A. King, James L. Harp, Delbert H. Fisher, Bailey Bennett et al. 30 Nov. 1963 52 p
(Contract Nonr-3506(00)(FBM))
(G-4850-1; AD-622389) CFSTI: HC $3.00/MF $0.75
The concept of reinforcement of a solid-propellant grain through use of combustible metal or plastic laminates is discussed. Procedures used for preparing test samples for mechanical property studies and firing tests are described. Mechanical strength was found to be increased generally in proportion to the amount of reinforcement added. Firing tests demonstrated clearly that the orientation of the reinforcement layers parallel to the combustion surface is not compatible with satisfactory combustion, whereas, when the reinforcement is oriented normal to the combustion surface, burning is either enhanced or unchanged.
Author (TAB)
IAA ENTRIES

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OXIDATION OF GRAPHITE, MOLYBDENUM, AND TUNGSTEN AT 1000° TO 1600°. E. A. Gulbransen, K. F. Andrew, and F. A. Brassart (Westinghouse Electric Corp., Pittsburgh, Pa.), p. 227-250. 9 refs. [See A65-10976 02-06]

COMBUSTION OF PYROLYTIC BORON NITRIDE. M. D. Bower (Martin Marietta Corp., Orlando, Fla.) and G. W.orton (Georgia Institute of Technology, Atlanta, Ga.), p. 251-278. 14 refs. [See A65-10977 02-27]


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RESEARCH IN HYBRID COMBUSTION. T. J. Houser and M. V. Peck (North American Aviation, Inc., Canoga Park, Calif.), p. 559-581. 6 refs. [See A65-10989 02-33]

A POROUS PLUG BURNER TECHNIQUE FOR THE STUDY OF COMPOSITE SOLID PROPPELLANT DEFLATION ON A FUNDAMENTAL LEVEL AND ITS APPLICATION TO HYBRID ROCKET PROPULSION. Robert F. McAlvey, III and Sub Yong Lee (Stevens Institute of Technology, Hoboken, N.J.), p. 581-608. 25 refs. [See A65-10990 02-33]


LAMINAR BOUNDARY-LAYER WEDGE FLOWS WITH EVAPORATION AND COMBUSTION. Tze-ning Chen and Tae-yu Toong (Massachusetts Institute of Technology, Cambridge, Mass.), p. 643-664. 12 refs. [See A65-10992 02-31]

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HOMOGENEOUS NUCLEATION FROM SIMPLE AND COMPLEX SYSTEMS. Welby G. Courtney (Thiokol Chemical Corp., Denville, N.J.), p. 677-699. 27 refs. [See A65-10994 02-33]

CONDENSATION PHENOMENA IN NOZZLES. Peter P. Wexen (Yale University, New Haven, Conn.), p. 701-724. 38 refs. [See A65-10995 02-01]

WATER VAPOR CONDENSATION AS AN EXPLANATION FOR THE GREAT APPARENT RADIANCE OF SUN-LIT HIGH-ALTITUDE ROCKET EXHAUST PLUMES. J. M. Bowyer, Jr. (Kansas State University, Manhattan, Kan.), p. 725-738. 10 refs. [See A65-10996 02-33]

EXPERIMENTAL METHODS FOR THE STUDY OF NUCLEATION AND CONDENSATION. J. S. Dunn (Bristol University, Bristol, England), p. 739-761. 28 refs. [See A65-10997 02-33]

CONTRIBUTORS TO VOLUME 15, p. 763-765.
A65-11055  PROBLEMS INVOLVED IN ASSESSING THE EXPLOSION HAZARDS OF LIQUID BIPROPELLANT SYSTEMS.
A. B. Willoughby, T. C. Goodale, and C. Wilton (URS Corp., Burlingame, Calif.).
Combustion Institute, Western States Section, Fall Meeting, Salt Lake City, Utah, Oct. 26 - 27, 1964, Paper 64-37, 19 p. 6 fig. 5 refs.

Analysis of the explosive properties of propellant combinations such as LO<sub>2</sub>/RP-1, LO<sub>2</sub>/LH<sub>2</sub>, and N<sub>2</sub>O<sub>4</sub>/Aerosene (50% UDMH-50% hydrazine), commonly used in the larger space vehicles. Consideration is given to the blast-wave characteristics. The nuclear motors expressing explosive effects of mixtures in terms of their equivalent TNT yield is found to be useful only for predicting long-distance damage. W. M. R.

A65-11107  RESILIENT SEAL MATERIALS FOR LIQUID ROCKET PROPELLANTS.
Philip A. House (USAF, Systems Command, Research and Technology Div., Materials Laboratory, Wright-Patterson AFB, Ohio).
IN: SOCIETY OF AEROSPACE MATERIAL AND PROCESS ENGINEERS, NATIONAL SYMPOSIUM ON MATERIALS FOR SPACE VEHICLE USE, 6TH, SEATTLE, WASH., NOVEMBER 18-20, 1963. VOLUME 2.

Performance of Teflon, filled Teflon, butyl, Viton, ethylene propylene, polyethylene, silicone, and polybutadiene as fuelfils materials when exposed to N<sub>2</sub>O<sub>4</sub>, CI<sub>2</sub>F<sub>4</sub>, H<sub>2</sub>O, and hydrazine/UDMH. The application of the materials in the form of metal-clad elastomeric O-rings and expansion bladders is described. Expansion bladders are thought to offer promise as a possible solution to the problem of moving liquid propellants from the storage tank to the engine under zero-g conditions. Evaluations of pentabrance and Hybaline are reportedly being made, and the materials that have proven best in previous tests are to be evaluated in the sealability test jigs at 160°F. D. H.

A65-11447  STRESSED AND STRAINS IN A LINEAR VISCOELASTIC SOLID PROPELLANT CHARGE.
Craig-Michael Waryjas (Illinois Institute of Technology, Chicago, Ill.).

Discussion of stresses and strains in an incompressible, linear viscoelastic, tube-shaped fuel element with a solid rocket charge, whose inner surface is continuously destroyed by combustion at a known rate and subjected to a known resultant pressure while its outer surface is restrained by an elastic enclosure. A set of equations is developed, based on an assumed isothermal axisymmetric plane-stressed state, which describe, with a measure of approximation, the strain-stress phenomena occurring in such a propellant charge. V. Z.
of the nucleation rate. P. K.

**A65-14544**

**LINEAR PYROLYSIS RATE MEASUREMENTS OF PROPELLANT CONSTITUENTS.**


Paper 65-55, 8 p. 15 refs.

Members, $0.50; nonmembers, $1.00.

USAF-supported research.

Description of an apparatus for the simultaneous measurement of the surface regression rate and temperature of a material undergoing surface pyrolysis or sublimation. Energy is supplied and the temperature is measured without appreciable obstruction of the flow of the pyrolysis products by the use of a radiantly heated porous plate. Experiments conducted with ammonium chloride and ammonium perchlorate are discussed. Calculated evaporation coefficients are found to be small, of the order of $10^{-3}$ and $10^{-5}$, respectively, for the two materials. Measured pyrolysis rates of pure ammonium perchlorate are found to be much lower for given surface temperatures than corresponding burning rates recently published for ammonium perchlorate-fuel mixtures. This discrepancy suggests that work on the kinetics of the surface gasification reaction of burning solid propellants should be done with propellant mixtures rather than with constituents individually.

P. K.

**A65-14551**

**STUDY OF COMPOSITE SOLID-PROPELLANT FLAME STRUCTURE USING A SPECTRAL RADIATION SHADOWGRAPH TECHNIQUE.**

Louis A. Povinelli (NASA, Lewis Research Center, Cleveland, Ohio).


Paper 65-60, 8 p. 5 refs.

Members, $0.50; nonmembers, $1.00.

Experimental investigation of the fine-scale structure of a composite-propellant flame in the vicinity of the burning surface. The experiment consisted of burning propellant strands backlighted with a mercury light, and simultaneously recording the spectra of flame gases and mercury light. The cutoff of the light by the unburned portion of the strand indicates the location of the propellant surface on a recording photographic plate. A comparison of the position of onset of flame species relative to the onset of mercury emission yields the spatial resolution of the species relative to the propellant surface. It is concluded from microdensitometer scanning that the CN (violet) emission at 3883 Å begins slightly above the burning surface, at about 70 microns, and reaches a peak intensity at a distance less than 235 microns from the surface. P. K.

**A65-14741**

**LABORATORY CHARACTERIZATION OF SOLID PROPELLANT MECHANICAL PROPERTIES.**

R. B. Kruse (Thiokol Chemical Corp., Structural Integrity Section, Huntsville, Ala.).


Paper 65-147, 18 p. 39 refs.

Members, $0.50; nonmembers, $1.00.

Survey of the development of techniques for the laboratory testing of solid propellants, review of the results to date in regard to the degree of understanding they provide about the nature of these materials, with a brief indication of the direction of future work in this area. The characterization of mechanical properties of solid propellants is complicated bywhile the profound effects of temperature and rate upon these properties. Since it is not practical to test a sufficiently wide range of rates in the laboratory, the technique of time-temperature superposition has been generally employed in the solid propellant industry to characterize the stress-strain response of solid propellants from glassy response to equilibrium behavior. In addition, it has been observed that most solid propellants exhibit ultimate properties which may be superposed on a temperature-reduced rate basis. An extension of the empirical superposition of ultimate properties is a curve of ultimate stress vs ultimate strain, which provides a failure boundary for the propellant. The path dependence, or lack thereof, of the failure boundary is presently the subject of considerable experimental investigation, but it is generally agreed that failure boundaries provide the best currently available basis for comparison of various propellants. The general problem of relating uniaxial failure measurements to behavior in combined stress or combined strain states by means of suitable failure criteria has proven extremely difficult of solution. Test techniques have been devised to measure failure of propellant in combined stress states, but one complicating factor appears to be qualitative differences in behavior among different types of propellants. For some propellants, the results can be rationalized with a deviatoric stress failure behavior in compression, and dilatational failure in tension. It is considered that much remains to be done in more realistic analysis of the mechanical response of solid propellants, particularly concerning the nature and extent of their nonlinearity.

(Author) F. R. L.
Members, $0.50; nonmembers, $1.00.

PHOTOGRAPHIC STRAIN-MEASUREMENT TECHNIQUE.

Presentation of a method of experimentally measuring surface strain in solid propellants. A review of other strain-measuring techniques is presented for background information. The basic principle of the photographic strain measurement technique involves photographing the specimen before and after it is strained, and then measuring the projection magnification required to superimpose projections of the two photographs. Detail procedures and lists of equipment are presented so that the photographic method of strain measurement can be easily duplicated. This method is compared with other structural test methods of strain measurement and is shown to be superior when the test specimen is accessible. Close correlation between theory and experimental results is clearly shown for the inner bore strains of several solid propellant rocket motors. (Author) F. R. L.

CHEMICALLY RESISTANT MATERIALS FOR USE IN POSITIVE EXPULSION DEVICES.

Evaluation of flexible polymeric materials, metal foil, and composites for use as multicycle positive-expulsion devices for storable liquid propellants. The materials were investigated for chemical resistance to storable propellants, permeability, and dynamic properties. Formulation development studies led to recommendations of materials for hydrazine-type fuels, Hybaline, nitrogen tetroxide, and fluorne-containing oxidizer applications. Permeability data are given and the applicability of these data to expulsions systems is discussed. The mechanical properties required of materials and the dynamic evaluation of materials currently in use are considered. It is concluded that the ideal material of construction for a universal bladder is a rubber-metal foil laminate. (Author) W. M. R.

EXPERIMENTAL SETUP FOR STUDYING THE EROSION COMBUSTION OF A SOLID ROCKET GRAIN [DISSERTATION D'ETUDE DE LA COMBUSTION EROSIVE D'UN PROPERGOL SOLIDE].

Description of one of the setups used by ONERA for experimental investigations of erosive burning in solid propellants. I onic probes show the development of the flame front in several cross sections of a grain burning in an ordinary propulsor. The combustion velocity is deduced from indications provided by the probes. The definition of the local characteristics of the flow is obtained from pressure measurements performed simultaneously. It is stated that the experimental results achieved by this experimental method which does not disturb the phenomenon justify its use, although the experiment must be carried out with the utmost care. (Author) M. M.

INVESTIGATION OF SILICAGEL-BASED ADSORPTION CHROMATOGRAPHY IN THE GROUP ANALYSIS OF LIQUID FUELS [ISSLEDOVANIE ADSORBTSIONNOI KHROMATOGRAFII NA SILIKAGELE PRI GRUPPOVOM ANALIZE ZHDKOGO TOPLIVA].

Investigation of the efficiency of adsorption chromatography, using ACM and KCM silicagels, in the group analysis of liquid fuels. It is found that untreated silicagel yields a much clearer component separation than silicagel treated with hydrochloric acid and hydrogen peroxide. However, untreated silicagel has the disadvantage of inducing polymerization of olefins. V. P.

LIQUID FILM DRAIN FROM AN ACCELERATING TANK WALL.

Consideration of an analytical and experimental investigation of a draining film from an accelerating cryogenic tank wall. An equation is derived which reveals that the factor of importance in the film profile is the area under the g-x-time curve. It is stated that, according to this analysis, which neglects surface tension and contact angle, the profile is unchanged during periods of zero g. M. M.

PHOTOELASTIC OBSERVATIONS USING TOLYENE DISOCYANATE POLYURETHANE.

FAILURE BEHAVIOR OF COMPOSITE HYDROCARBON FUEL BINDER PROPELLANTS.

Study of the mechanical failure of solid propellants, in order to determine failure prediction criteria. Since, for most propellants the time and temperature dependencies of failure can be combined in a single temperature-reduced time variable, an attempt is made to
construct a failure surface for constant strain rate tests in principal stress space. Experimental data are presented which suggest that such a surface is a triangular prism in the negative principal stress octant, and is a dilatational plane in the positive principal stress octant. Attempts are also made to correlate a portion of the uniaxial failure boundary with various energy criteria. The path dependence of conserved energy is also discussed.

P. K.

**A65-16187**

**NONLINEAR MECHANICAL BEHAVIOR OF SOLID PROPELLANTS.**
R. B. Beyer (United Aircraft Corp., United Technology Center, Propellant Physics Research Group, Sunnyvale, Calif.).
Paper 65-159. 22 p. Ills. ref. Members, $10.50; nonmembers, $1.00.

Analysis of the mechanical response of standard solid propellants, based on data measured under conditions of constant strain rate, constant strain, and dynamic shear strain. Nonlinear viscoelasticity is found to occur when propellant samples are strained beyond a few tenths of one percent by tensile test methods. Studies covered a range of strain rates from 10^-7 to 10^-1 min indicate that nonlinearity can occur by the loss of reinforcement due to dewetting, and by the X''Multima effect'' in a matrix with chemical stress due to bonding between binder and filler. For the first case, dewetting was observed to depend only on the applied stress and the temperature. The linear viscoelastic response obtained from a small constant strain rate and dynamic data differed from the constant strain rate relaxation modulus by as much as an order of magnitude. The time and temperature dependences of both the reinforced and nonreinforced modulus are discussed, and are related to long-term ambient tests and to actual motor behavior.

P. K.

**A65-16274**

**CONTINUOUS PNEUMATIC MIXING.**
A. J. Coli (U.S. Naval Propellant Plant, Research and Development Dept., Indian Head, Md.).
Chemical Engineering Progress, vol. 60, Oct. 1964, p. 81-84.

Description of a method for continuously and rapidly mixing small increments of solid propellant ingredients in a highly pre-dispersed state. The mixer consists basically of a porous tube into which the metered, pneumatically conveyed solids and the liquid are injected. Carrier gas, rapidly flowing through the pores into the tube, moves the solids and droplets in a random manner, mixes them intimately, and prevents the material from adhering to the tube wall. As the solid particles and their associated liquid droplets traverse the tube, uneven radial distributions between the two phases are dissipated. The turbulent motion and continuous acceleration imparted to the material within the mixer tend to attenuate short-term feeding fluctuations. Advantages of the process include the possibility of attaining extremely high solid loading and incipient gaseous dispersion, at a production rate of 5000 lb/hr, less than 1 lb of explosive material is contained in the mixer at any time. Topics discussed are; kinetics of mixing, process description, demonstrative operation, microscopic examination, ballistic parameters, production potential, and correlating properties.

D. H.

**A65-16305**

**FUELS AND PROPULSION [I COMBUSTIBILI E LA PROPULSIONE].**
Corrado Casci (Milano, Politecnico; Consiglio Nazionale delle Ricerche, Centro Nazionale di Ricerca sulla Tecnologia della Propulsione e dei Materiali Relativi, Milan, Italy).

Discussion of problems concerning the use of new and improved fuels. An attempt is made to indicate to technicians a line of research which makes a compromise between technical and economic factors. The field includes the use of heavy oils in marine engines, the improvement of fuels for air and ground transport propulsion, and the production of high-energy propellants of a type to make the boldest space enterprises possible. For supersonic aircraft speeds, improvement of combustion characteristics is necessary, as well as study of the tankage and distribution arrangements on board the aircraft, since these will be affected by the low pressures and temperatures encountered at high altitudes. In the case of high-energy propellants, the density of the propellant plays an important part in the orbiting of various sizes of satellites. The criteria for study of the expansion of gases in rocket nozzles are discussed. It is considered that the use of mixtures rich in combustible material is preferable to the use of lean or stoichiometric mixtures.

F. R. L.
importance, for new solids are often usable in slurries, and new liquids may serve as plasticizers in solid systems. Thermochemical work is said to be especially important and may lead to more effective utilization of propellants already known. F. R. L.

A65-16309
TECHNICAL PROBLEMS IN THE PRODUCTION OF SOLID AND LIQUID PROPELLANTS.

L. A. Dickinson (Stanford Research Institute, Propulsion Sciences Div., Menlo Park, Calif.).


Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.


Investigation of the technical problems in the production of solid and liquid propellants. Conventional chemical energy systems for aerospace vehicles are classified as solid, liquid, and hybrid propellants. In order to simplify the survey of the technical problems related to the various propellant systems, they are reviewed on an individual basis from the standpoint of propellant characteristics derived from end item requirements, and problems in development and utilization of propellants. The industrial production of propellants, as it operates today, and as it is expected to grow in the future to meet the expanding needs of astronautics, is considered. An important problem is finding a compromise between the different mutually influencing factors for a given set of established conditions. These factors include: (1) propellant characteristics sensitivity with respect to the statistical variations of different types of ingredients, (2) consideration of quality control methods, (3) the necessity of duplicating different operations in the case of dangerous processes, and (4) development of continuous production systems. The development of liquid and hybrid propellants is briefly discussed. F. R. L.

A65-16310
LIQUID AND SOLID PROPELLANTS FOR SPACE ROCKETS.


Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.


Discussion of the performance and use characteristics of liquid and solid propellant rocket motors for orbital and interplanetary spaceflight. The NASA program on propellants and their application to space vehicles, or as an attempt to land men on the Moon and return them to Earth is reviewed. The goal is to obtain the maximum useful load for each dollar spent; hence, the equipment is not necessarily the most technically advanced that it is possible to build, but tends to be the most economical equipment that can accomplish the mission. The theoretical background for rocket propulsion is extensively discussed, followed by a detailed presentation of the plan for landing men on the Moon and returning them. The components and propellants selected for the mission are discussed in detail. The emphasis is on liquid propellants, with limited mention of solid propellants. F. R. L.

A65-16612
PROPELLANT FAILURE CRITERIA.


Members, $6.50; nonmembers, $11.00. USAF-supported research.

Analysis of multiaxial fracture data for PBAN propellants at volumetric loadings of 70 to 80%, in order to produce an estimate for the shape of the failure surface in principal stress space. Approximate agreement is found after an empirical tensile criterion of failure in the triaxial tensile stress octant. Data for other regions indicate an internal friction type of criterion. Tensile failure stress measured as superposed on hydrostatic pressure was not altered significantly by pressures up to 1,000 psi. (Author) P. K.

A65-18508
EXPERIMENTAL DETERMINATION OF VELOCITY LAG IN GAS-PARTICLE NOZZLE FLOWS.

Donald J. Carlson (Philco Corp., Aeronutronic Research Laboratories, Fluid Mechanics Dept., Newport Beach, Calif.).


Description of experiments providing a measure of the particle velocity lag in the exhaust flow of solid propellant rockets. In essence, these experiments consist in measuring the transmitted spectral radiant intensity of a tungsten ribbon-filament lamp passed through the exhaust of a solid propellant simulator rocket engine. Such an engine simulates an actual solid propellant exhaust through the addition of solid particles to the combustion chamber gas of a liquid-fueled engine. Since the extinction of the lamp energy depends upon the solid particle concentration, and this concentration is related to particle velocity, measurement of the extinction yields information on the velocity. After brief discussion of theoretical velocity lag, the experimental measurements are presented and compared with lag and equilibrium (no lag) predictions; fairly good correlation with lag predictions is noted. A. B. K.

A65-18807
ZERO-G PROPELLANT GAUGING UTILIZING RADIO FREQUENCY TECHNIQUES IN A SPHERICAL RESONATOR.

Ray Garriott (General Dynamics Corp., General Dynamics/Astronautics, San Diego, Calif.) and G. A. Burns (San Diego State College, San Diego, Calif.).


A65-18870
RESEARCH ON HYBRID PROPELLANTS [RECHERCHES SUR LES PROPELLEURS HYBRIDES].

André Mouet and H. Mouet (ONERA, Châtillon-sous-Bagneux, Seine, France).


Review of the definitions of hybrid rockets and their history, with discussion of certain studies made at ONERA on this new type of propellant. The tests dealt with the perfecting of solid hypergolic combustibles with classic oxidizing agents having mechanical and energy properties which permit the development of various propellants with definite characteristics; the elimination of the instabilities of combustion by the organization of the combustion in the solid/liquid reaction zones, and in gases originating either from solids or oxidizing agents; and research on propellants of high specific thrust. F. R. L.
A65-19123

SOME INVESTIGATIONS AND PRELIMINARY RESULTS OF DEVELOPMENTS IN UPPER STAGE ENGINES FOR ELDO ROCKETS [EINIGE UNTERSUCHUNGEN UND ERGEBNISSE DER VORENTWICKLUNG DER OBERRSTUFENWERKE FUR ELDO-TRAGERRaketEN].


Presentation of the results of an initial program in the development of upper-stage engines for rocket launchers of the European Launcher Development Organization (ELDO). Intermediate energy propellants rather than high energy propellants are chosen for all three launcher stages from the two propellant combinations considered, to step up the program realization. Third-stage engines and control-jet designs are discussed on the basis of results obtained at various testing facilities. The thrust, the optimum operating conditions for the fuel supply system, the pressure required for the combustion chamber, and the mixing ratio are discussed for high thrust upper-stage engines slated for study in the later part of the ELDO program.

V. Z.

A65-20556

EFFECTS OF THERMAL RADIATION ON THE ACOUSTIC RESPONSE OF SOLID PROPELLANTS.

R. H. Cantrell, F. T. McClure, and R. W. Hart (Johns Hopkins University, Applied Physics Laboratory, Research Center, Silver Spring, Md.).


Theoretical calculations for the propellant response function when thermal radiation of the burnt gases is taken into account. Under the assumption that the gas radiates as a gray body, it is found that radiation effects may significantly alter the response function at low frequencies for the low propellant burning rates that are commonly found at low pressures. Thus, this mechanism may offer a partial explanation of the fact that experimental values for the response function at low frequencies and low burning rates tend to be larger than is expected from existing theories. The method of calculation is based on a second-order perturbation scheme where the perturbation parameter is a measure of the ratio of transfer by radiation to convective energy transfer. (Author) M. M.

A65-20571

AN EXPERIMENTAL INVESTIGATION OF THE EROSIUE BURNING CHARACTERISTICS OF A NONHOMOGENEOUS SOLID PROPELLANT.

M. J. Zucrow, J. R. Osborn, and J. M. Murphy (Purdue University Lafayette, Ind.).


A65-13041 06-26

AF 04(061)-7445.

For abstract see Accession no. A65-13041 06-26

A65-20580

HEXANITROETHANE PROPELLANT SLURRIES.

Milton B. Frankel, Leland D. Christensen, and Edgar R. Wilson (Stanford Research Institute, Propulsion Sciences Div., Menlo Park, Calif.).


Performance calculations which show that the high specific impulse (275-278 sec) of the nonmetalized HNE-hydrocarbon propellant system can be retained, whereas the solids loading can be reduced to a practical castable level by the replacement of the hydrocarbon with nitroalkanes or nitramines. It is stated that stability studies have indicated that HNE has the best compatibility with 1,1-dinitroalkanes. Propellant slurries of HNE-nitroalkanes burned smoothly over the pressure range tested, which varied from 200 to 1400 psi. The burning rates are moderate, but the pressure exponents (0.6) are excessive. (Author) M. M.

A65-20588

IGNITABILITY OF NONHYPERGOLIC PROPELLANTS IN PRESENCE OF POTASSIUM PERMANGANATE.

R. P. Rastogi, Kaushal Kishore, and N. L. Munjal (Gorakhpur University, Dept. of Chemistry, Gorakhpur, India).


Results of investigations of the hypergORIZATION of nonhypergolic fuels by the use of stronger oxidizing agents. An increasing amount of potassium permanganate was added to red fuming nitric acid (RFNA) and the ignitability of various alcohols was tested with it. It was found that methyl alcohol, ethyl, propyl, isopropyl, butyl, secondary butyl, and tertiary butyl alcohols all became hypergolic when 20% potassium permanganate was used. The ignition delay was below 0.3 sec in all cases. Studies were undertaken to elucidate the mechanism. The essential steps involved are the following: alcohol + aldehyde or ketone + acid = degradation. It is stated that the intermediates in this reaction could be identified. As a further confirmation of the mechanism, the ignitability of aldehydes and corresponding ketones was investigated. It was found that these ignite with RFNA, which contains 10% potassium permanganate. The role of potassium permanganate was investigated. It is noted that only freshly dissolved potassium permanganate in red fuming acid is effective. This gave a strong suspicion that atomic oxygen is produced which acts as a much stronger oxidizing agent. This conclusion is said to be supported by the fact that benzene also ignites with RFNA containing potassium permanganate. Carbon disulfide also burns with a steel-blue flame. However, the intriguing fact is said to be that no reaction occurs with white fuming nitric acid. The role of NO2 in the ignition reaction is not clear. Further studies are in progress. (Author) M. M.

A65-20987

SOLID PROPELLANT GRAIN STRUCTURAL ANALYSIS USING THE DIRECT STIFFNESS METHOD.


Numerical method for static structural analysis of solid-propellant grains of complex geometry. The method uses infinitesimal-elasticity theory in a finite element formulation. Variations of material properties with position are accommodated by dividing the solid into a network of triangular elements with independent properties. Two IBM 7094 computer programs compute stresses, strains, and deflections resulting from thermal shrinkage or expansion, internal and external pressure and thermal loading, and natural vibrations. The method makes use of anodes and rods assembled to motor case domes can be analyzed. Advantages of the stiffness method, limitations of its present form, and extensions shown to be feasible by results of research described in the paper are discussed. (Author) D. H.

A65-20963

HEAT CONDUCTION IN STAR-PERFORATED SOLID PROPELLANT GRAINS.

Donald A. Willoughby (Rohm and Haas Co., Redstone Arsenal Research Div., Huntsville, Ala.).


Method for the analysis of transient-state heat conduction problems for solid propellant grains having a general star-shaped internal perforation. A conformal transformation is used to map transverse cross sections of star-perforated propellant grains onto an annulus. The two-dimensional heat conduction equation with associated boundary conditions is subjected to the same transformation and is written in explicit finite-difference form for solution
A65-21035
INVESTIGATION OF THE SMOOTHNESS OF THE DETONATION FRONT IN A LIQUID EXPLOSIVE.
Ia. B. Zel'dovich, S. B. Kormer, G. V. Krishkevich, and K. B. Lushko.
Translation.
Direct investigation of the smoothness of a shock front by recording the light reflection from the shock wave front in liquid explosives. The resolving power of the method makes it possible to establish the presence of a nonuniformity with a size of 5 x 10⁻⁴ cm, which is believed to be unattainable by other methods. If individual sections of the surface are deflected from the plane through an angle α, then, by making observations at a distance of L > 1 (where L is the distance from the light source S to the reflecting surface), the image spread amounts to 2 α, which, under actual experimental conditions (0 < 5 mm), enables a value for α > 0.01 radian to be recognized. Wave collision with small angles of inclination cannot cause a significant increase of temperature and pressure and, consequently, is not characteristic for spinning or nonuniform pulsating detonations. It is thus considered that the minimum value of the angle of the detonation front should be an unambiguous criterion of the absence of a spinning or nonuniform pulsating detonation regime.

F.R.K.

A65-21450
NUCLEAR HEATING AND PROPELLANT STRATIFICATION.
Description of a method of analyzing stratification caused by nuclear bottom heating in large tanks and comparison of the results with bulk and inversion-point calculations. The system analyzed is a closed cylindrical-cone-bottomed tank accelerating along its longitudinal axis and filled with liquid to some height, the liquid being subjected to a time- and position-varying group of heat fluxes. An approximate stratification solution is obtained by assuming a temperature profile in the stratified layer, the growth of which is determined by the evaluation of each of the independent heat fluxes.

A.B.K.

A65-21579
REGULATION OF A LIQUID ROCKET MOTOR WITH DEFINITE HIGH-FREQUENCY INSTABILITY CHARACTERISTICS [MISE AU POINT D'UN MOTEUR Fusee A PROPREGOLS LIQUIDES AYANT PRESENTE DES CARACTERES D'INSTABILITE DE HAUTE FREQUENCE].
In French.
A simple experimental technique for regulating liquid fueled rocket motors and a comparison with other established methods. Performance data are given for a Diamant rocket engine. The Diamant, normally fueled with nitric acid and turpentine, uses furfuryl alcohol and nitric acid as a hypergolic mixture to start combustion. It showed high-frequency instability of approximately 800 Hz when a critical pressure was reached in the combustion chamber. The experimental method used to eliminate this condition consisted of controlling pressure increase in the combustion chamber very gradually, until the point of instability was reached, which made it then possible to locate the cause, found to be in the dimensions of the nitric acid injection system. When these dimensions were corrected, the instability disappeared. Two established methods of investigating conditions in the combustion chamber are analyzed. They include (1) introduction, tangentially, of gases from a burning charge of gunpowder into the chamber, so as to induce artificial instability; and (2) introduction of nitrogen under pressure, either in one step or stepwise and repeatedly.

D.P.F.

A65-21580
LIQUID OXYGEN AND HYDROGEN ROCKET MOTORS [LES MOTEURS Fusees A OXYGEN ET HYDROGEN LIQUIDES].
In French.
A survey divided into three parts considering (1) the performance, and chief properties of LO₂/LH₂, (2) specific problems relating to its use in rocket engines, and (3) the general activities in this field of the Société d'Etude de la Propulsion par Réaction. Specific performance data indicate the superiority of LO₂/LH₂ systems over others, and its use is not overly dangerous. Drawbacks are its low specific weight and low temperature, requiring large storage capacities and good insulation. The problems arising from the use of this propellant in rocket engines are discussed, including the selection of adequate low-temperature-resistant materials for seals, combustion chamber design, types of pumping systems, and the requirements for storage facilities. The Société developed the motors for the second and third stages of the satellite launching rocket Diamant, using this propellant. Flight-testing of the third stage is scheduled for early 1966 and of the second stage by the end of 1967.

D.P.F.

A65-21678
ELECTRICAL CONTROL OF SOLID PROPELLANT BURNING.
Analysis of the possibility of using electric fields to control the postignition burning rate of solid propellants. Two methods are studied both theoretically and experimentally. In one, the normal burning rate is varied, and in the other the normal burning surface area is varied. The latter method is shown to be by far the more promising. Ionic winds can be used to increase the rate of flame spread by making the propellant one electrode, or to decrease it by using an electrode contacting the flame in an enclosed system so as to maintain the propellant surface cool by a flow of entrained air. In simple systems at atmospheric pressure, increases of about 200-fold and decreases of about 10-fold with respect to the unperturbed value have been achieved. Theoretical considerations indicate that still larger effects should be possible at the higher pressures associated with combustion in rockets.

(Author) EK.

A65-233036
ON THE METHODS OF EVALUATING THE DECOMPOSITION RATE OF CONCENTRATED HYDROGEN PEROXIDE.
Discussion of methods of estimating the decomposition rate of concentrated hydrogen peroxide passing through the catalyst pack, and deduction of a method from the pressure of decomposition chamber, as suggested by referring to the applications of the method to the tests under various conditions. A simplified method is proposed to make it easy to compare the decomposition abilities of catalyst pack. Some theoretical treatments of decomposition in a packed bed are discussed under simplified assumptions.

(Author) M.M.
obtaining constant burning area are discussed in detail. A method of problems encountered in the design and manufacture of chord grains.

A chord grain is defined as a solid propellant grain in which there is a path, or paths, made of materials other than those of the main propellant. The conditions for obtaining constant burning area are discussed in detail. A method for the calculation of the quantitative evolution of the burning area in chord grains as a function of the web or the burning time is described. The various types of chords, their mode of operation and the technology of their preparation are reviewed. The effects of various parameters on the evolution of the burning area are considered from the cord grain designer point of view.

D. P. F.


A theoretical discussion of the processes which determine the self-ignition of rocket propellant pairs. An automatic device is described which measures the delay in ignition time and can operate selectively on either the two-stream or the drop-test methods. The behavior of liquid-liquid pairs of propellants, using HNO₃, H₂SO₄, H₂O₂ and H₂O as oxidizers and furfury alcohol, unsymmetrical dimethylhydrazine, and aniline as fuels, is discussed in the light of the results obtained from the measurement of ignition delay times. The maximum tolerable delay period for the ignition of hypergolic propellants is given as 30 μs. Nonhypergolic combinations of hydrocarbons may be made hypergolic by the addition of dimethylhydrazine, which is soluble in them. Hypergolic solid-liquid propellant pairs can also be tested with the measuring device, but such tests are necessarily restricted; another type of testing device, similar to that of a rocket ignition chamber, should be used in such cases.

D. P. F.


THEORETICAL PERFORMANCES OF HYPERGOLIC PROPELLANT DIMAZINE-CHLORINE TRIFLUORIDE SYSTEMS. Akira Iwama, Kiroku Yamazaki, and Ken Kikuchi (Tokyo, University, Institute of Space and Aeronautical Science and Dept. of Materials, Propellant Div., Tokyo, Japan). Tokyo, University, Institute of Space and Aeronautical Science, vol. 16, no. 4, Feb. 1965, Report no. 395, p. 101-124. 11 refs. Calculation for various thermodynamic data and the theoretical performance of a dimazine-chlorine trifluoride propellant system and a dimazine : hydrazine-chlorine trifluoride propellant system. The maximum theoretical specific impulse of the dimazine-chlorine trifluoride propellant system is 199.73 sec at a mixture ratio of 5.75, and that of the dimazine : hydrazine-chlorine trifluoride propellant system is 216.32 sec at a mixture ratio of 3.575. The chamber pressure was 20 atm. (Author) B. B.


Study of the chemistry of subliming materials, with a view to determining the parameters governing the selection of subliming solids for microthrust engines. These engines could provide, with low system weight as compared to conventional cold gas systems, the low thrust (0-9 to 10-2 lb) and low total impulse (below 2000 lb-sec) required in such space applications as attitude and station-keeping. Design criteria for these engines are found to involve the stability and corrosiveness of the propellant, the equilibrium vapor pressure, the molecular weight of the gaseous phase, and the mechanism of the vaporization process. Most suitable for low-temperature application are the ammonium salts of carbonic and carbamic acids, while for high temperatures, organic and inorganic salts of stronger acids are better. Vapor pressures and kinetic data on several propellants are given.

P.K.

A65-26835

# APPLICABILITY OF FLOX-LIGHT HYDROCARBON COMBINA-
# TIONS AS LIQUID ROCKET PROPELLANTS.
Arthur I. Masters (United Aircraft Corp., Pratt and Whitney Aircraft Div., West Palm Beach, Fla.).
Members, $0.50; nonmembers, $1.00.
Contract No. NAS 3-4959.

Discussion of the properties of high-energy rocket fuels consisting of fluorine-oxygen (FLOX) mixtures plus such low-molecular-weight paraffinic and olefinic hydrocarbons as methane, ethane, ethylene, and propane. The FLOX-hydrocarbon combinations provide high theoretical Isp and are likely to achieve a higher percentage of theoretical impulse in engine applications than many combinations with equal or higher theoretical performances. These combinations are hypergolic, have compatible liquid ranges, and are readily and economically available. Furthermore, these fuels are capable of adequately cooling rocket engines for long durations. Of the light hydrocarbons, methane is found to provide the highest theoretical performance with FLOX. In addition, it appears to be the most desirable regenerative coolant for cooling with film boiling and cooling at supercritical pressures.

P.K.

A65-26837

# EVALUATION OF THE BRAY SUDDEN-FREEZING CRITERION
# FOR PREDICTING NONEQUILIBRIUM PERFORMANCE IN MULTI-
# REACTION ROCKET NOZZLE EXPANSIONS.
Members, $0.50; nonmembers, $1.00.
Contract No. NASw-166; No. NAS 1-2572.

Evaluation of the Bray sudden-freezing criterion for predicting approximately the nonequilibrium gasdynamic and thermodynamic properties in expanding subsonic and supersonic flows involving several concurrent chemical reactions. Comparisons are made between the approximate results of the sudden-freezing analysis and exact numerical results obtained by solving simultaneously the complete set of gasdynamic and chemical-kinetic equations for several propellant combinations at selected O/F ratios and chamber pressures. These combinations include H2-O2, H2-F2, N2O4 - 50% N2H4/50% UDMH and hydrocarbon-FLOX propellant systems. The results of these analytical studies generally indicate that the sudden-freezing concept can be employed to estimate the specific impulse performance of typical expansion nozzles. However, for some propellant systems, such as H2-F2 and hydrogen-FLOX combinations, a modification of the single-reaction Bray criterion is necessary to account for energy contributions from several concurrent chemical reactions taking place during the nozzle expansion. The limits of applicability of the single-reaction Bray criterion when applied to multireaction recombinations are indicated, and the agreement between the results of exact and approximate analyses when used is made of a modified sudden-freezing criterion in the multireaction schemes is demonstrated.

(Author) A. B. K.

A65-26838

# RADIANT HEAT TRANSFER TO AN ENCLOSURE FROM TWO-
# PHASE FLOWS.
William M. Byrne, Jr. (Beech Aircraft Corp., Wichita, Kan.).
Members, $0.50; nonmembers, $1.00.
Research supported by the Los Alamos Scientific Laboratory of the University of California, and Navy.

Analytical investigation of radiant heat transfer from hot solid combustion products to the walls of a combustion chamber. It was found that, for a typical rocket-engine configuration, the radiation component of heat transfer from burning aluminum in an oxygen-containing atmosphere can be of the same magnitude as the convective component. The analysis was accomplished using illuminating-engineering practices modified to account for absorption and emission of radiation by the particle cloud. Numerical techniques using digital-computer solutions were applied to conduct a parametric investigation of the system. Particle size, particle mass fraction, chamber pressure, location in the chamber, wall temperature, and wall reflectivity were investigated to determine their influence on the radiant-heat flux rate. The assumptions made are given, together with the limitations in the model chosen. The computer results are presented as graphs, with some conclusions concerning the various parameters involved.

(Author) A. B. K.

A65-27160

FLASH-PYROLYSIS OF SOLID-FUEL MATERIALS BY THERMAL RADIATION.
Kenneth A. Lincoln (U.S. Naval Radiological Defense Laboratory, San Francisco, Calif.).
(Combustion Institute, Western States Section, Spring Meeting, Stanford University, Menlo Park, Calif., Apr. 27, 28, 1964, WSS/CI, Paper 64-6.)

Vapor pressures, (Combustion Institute, Western States Section, Spring Meeting, Stanford University, Menlo Park, Calif., Apr. 27, 28, 1964, WSS/CI, Paper 64-6.)

Pressure, vol. 2, Mar. 1965, p. 133-143., 7 refs. (For abstract see Accession no. A64-17823 12-26)

A65-27411

# EXPERIMENTAL PERFORMANCE OF OF2/B2H6 UNDER SEA LEVEL AND SIMULATED SPACE CONDITIONS.
Melvin Sussman, Mario Luperi, and Albert Merrill (Thiokol Chemical Corp., Reaction Motors Div., Denville, N. J.).
Members, $0.50; nonmembers, $1.00.

Experimental evaluation of the space performance potential of OF2/B2H6. Initial sea-level injector tests conducted at the 150-lb thrust level and a chamber pressure of 150 psia indicated the high performance potential of OF2/B2H6. Extension of this work to a 2000-lb (space) thrust level demonstrated the scalability potential of OF2/B2H6. Sea-level injector evaluations conducted at the 2000-lb (space) thrust level demonstrated that OF2/B2H6 delivers a specific impulse (99% of predicted sea-level shifting performance) over a wide mixture-ratio range. Altitude performance tests were conducted with the 2000-lb-thrust, sea-level injector/thrust-chamber hardware in conjunction with a 40-to-1 area-ratio nozzle extension at a simulated altitude of 125,000 ft. Experimental sea-level and altitude performance data are compared with theoretical kinetic performance predictions. The results demonstrate the high performance of OF2/B2H6 at both sea-level and altitude conditions. (Author) M. M.

A65-27425

THE DETERMINATION OF WATER IN STORABLE ROCKET PROPELLANTS - A COMPARISON OF SEVERAL ANALYTICAL TECHNIQUES.
William L. Clark, Anthony Nudo, and Peter Yin (Bell Aerospace Corp., Bell Aerosystems Co., Buffalo, N. Y.).

A65-28039

Determination of water content of storable liquid propellants for rockets by several methods. Due to a need for a field test method for the determination of water in nitrogen tetroxide and a hydrazine fuel blend, the applicability of optical absorption, gas chromatography, electrical conductivity, and the pressure increase due to the reaction of water with CaH₂ and CaC₂ have been studied. Comparable results have been obtained by gas chromatography, optical absorption, and electrical conductivity methods for the fuel and by optical absorption and electrical conductivity methods for the oxidizer (N₂O₄). Electrical conductivity methods have been recommended for this application, but it is the job that processes colorimetric or chromatographic instrumentation in permanent installations would also be feasible.

B. B.

A65-28039

DISCUSSION OF A LARGE SCALE SLUSH HYDROGEN FACILITY. Charles W. Eilo (USAF, Systems Command, Research and Technology Div., Aeropulsion Laboratory, Wright-Patterson AFB, Ohio).

IN: SOCIETY OF AUTOMOTIVE ENGINEERS, AEROSPACE FLUID POWER SYSTEMS AND EQUIPMENT CONFERENCE, LOS ANGELES, CALIF., MAY 19-20, 1965, PROCEEDINGS. [A65-28019 17-01]


Description of a large-scale slush-hydrogen facility at Wright-Patterson Air Force Base. The largest facility of its kind in the country, it is used to simulate operational scale equipment while maintaining the flexibility of small scale research apparatus. Although this is impossible to do ideally, various compromises in design have allowed for a generous portion of both to be achieved. The discussion describes the equipment in the Air Force facility, the use of the equipment, and some equipment design considerations based on small scale observations. The design of a joint Air Force-NASA project is to obtain as much information as possible on the handling characteristics of slush hydrogen. The information will then be integrated into functional and future design considerations for hydrogen-using vehicles.

(Author) D. P. F.

A65-28052


IN: SOCIETY OF AUTOMOTIVE ENGINEERS, AEROSPACE FLUID POWER SYSTEMS AND EQUIPMENT CONFERENCE, LOS ANGELES, CALIF., MAY 19-20, 1965, PROCEEDINGS. [A65-28019 17-03]


Contract No. AF-04-695-AMC-279R.

Description of a new concept for a solid-propellant-powered, hot-gas, high-performance servocommand system for aerospace applications, including a discussion of the program presently being drawn up to develop and demonstrate this system. The system discussed is designed to provide operational flight controls for a two-stage, air-launched missile with goals of improved reliability, weight reduction, and increased range as a result of weight reduction. Two separate systems are discussed with the first stage system providing control of aerodynamic surfaces and the second stage gimbalning the propulsion nozzle and also including reaction nozzle roll control. Both systems are supplied from solid propellant gas generators providing a supply gas at 1930°F. This program has led to the conclusion that high-temperature pneumatic controls will satisfactorily provide the necessary power and response to fly a missile requiring high accuracy and to accomplish this in a severe environment with a reduction in system weight and complexity. The results of performance testing and environmental testing of the system and components are presented to demonstrate the suitability of the system for aerospace applications.

(Author) D. P. F.

A65-28210


Contract No. DA-04-695-AMC-279R.

[For abstract see Accession no. A65-19444 05-27]

A65-28631

AN EXPERIMENTAL INVESTIGATION OF THE DYNAMIC BEHAVIOR OF THE LIQUID-VAPOR INTERFACE UNDER ADVERSE LOW-GRAVITATIONAL CONDITIONS. William J. Martin and Jack A. Salzman (NASA, Lewis Research Center, Cleveland, Ohio).


Experimental investigation of the dynamic behavior of the liquid-vapor interface in response to an adverse constant translational acceleration, positively directed from the vapor to liquid phase. The results of the investigation are divided into three phases: (1) the stability characteristics of the interface, (2) the quantitative description of the motion of the interface, and (3) the mechanism of reorientation or collection of liquids. The discussion of the stability characteristics of the interface is limited to a brief summary of the methods used to acquire the data and the results indicating the validity of the Bond number criterion for the scaling parameter in the discussion of the stability characteristics of the interface. The motion of the liquid-vapor interface in cylindrical containers is correlated with the applied acceleration and certain system parameters. The profile of the interface following its disruption by an adverse axial acceleration larger than critical has been noted to assume the form predicted by the inviscid potential theory of Taylor. The rate at which the vapor phase penetrates the liquid phase can be obtained from a derived empirical relation. The leading edge of the interface was found to accelerate over distances comparable to fineness ratios of two. The mechanism of the reorientation or collection mode in Centaur-Saturn geometrical models has been investigated in low-acceleration environments. The worst condition of propellant location is assumed in the experiments—i.e., the liquid located at the vent portion of the tank model. Following a period of weightlessness to allow the interface to approach its zero-gravity configuration, an acceleration is imposed on the system to relocate the liquid at the desired pump inlet portion of the models. While information on the mode of collection has been largely qualitative, significant results have been obtained. Despite the existence of a prominent "geyser" when the leading edge impinges on the bottom of the tank, records have been taken of the liquid being collected. Methods for alleviating the recirculation problem in collection have been investigated and the results are presented.

(Author) F. R. L.

A65-28757

EARTH-STORABLE PROPELLANTS FOR SPACECRAFT. Diane F. Dipprey (California Institute of Technology, Jet Propulsion Laboratory, Liquid Propulsion Section, Pasadena, Calif.).


NASA-supported research.

Discussion of earth-storable propellants, by which is meant rocket propellants that exist in liquid phase in the 70 ± 10°F range at vapor pressures below 100 psi and that are hypergolic. Propulsion systems based on such propellants achieve reliability through simplicity, predictability, and large number of system components. Control of injector hydraulics is discussed, and satisfactory stability is reportedly attained by using injection elements with large length-to-diameter ratios. Mission requirements are described in terms of the anticipated goals of Earth-storable propellants. Liquid fuel has lower flame temperatures than competing cryogenic combinations, which is an advantage in that this makes possible
Ist, Washington, D. C., June 29-July 2.
A. M. Messner and D. R. Schllessmann (Aerojet-General Corp., Solid Rocket Structures Div., Sacramento, Calif.).

**GRAINS.**
George C. Goldbaum and John B. Douglass (Douglas Aircraft Co., Missiles and Space Systems Div., Santa Monica, Calif.).

**NEED**
DESIGN OF A VERSATILE LIQUID-FLUORINE/LIQUID-HYDROGEN SYSTEM.
Gerald Golub (Martin Marietta Corp., Martin Propulsion Laboratory, Edwards AFB, Calif.).

**UPPER STAGE.**
Ablative or refractory nonregeneratively cooled thrust chambers. The latter are much simpler than regenerative types. Propulsion-system survival is also discussed.
D. P. F.

**A65-28850**
TRANSIENT THERMAL STRESSES IN SOLID-PROPELLANT GRAINS.
A. M. Messner and D. R. Schllessmann (Aerojet-General Corp., Solid Rocket Structures Div., Sacramento, Calif.).

**A65-28851**
DESIGN OF A VERSATILE LIQUID-FLUORINE/LIQUID-HYDROGEN UPPER STAGE.
George C. Goldbaum and John B. Douglass (Douglas Aircraft Co., Missiles and Space Systems Div., Santa Monica, Calif.).

Research sponsored by the Douglas Aircraft Co.
For abstract see Accession no. A64-20477 16-27

**A65-28855**
NEED FOR A VARIABLE BURNING-RATE SOLID PROPELLANT.
Gerald Golub (Martin Marietta Corp., Martin Propulsion Section, Orlando, Fla.).

**A65-29371**
SPACE STORABILITY OF LIQUID PROPELLANTS.
Arnold D. Cohen (General Electric Co., Missile and Space Div., Spacecraft Dept., Valley Forge, Pa.) and Edward E. Stein (USAF, Systems Command, Research and Technology Div., Rocket Propulsion Laboratory, Edwards AFB, Calif.).

**A65-29380**
HIGH ENERGY UPPER STAGES - POTENTIAL APPLICATIONS AND SELECTION CRITERIA.
William H. Wetmore (Aero-space Corp., Los Angeles, Calif.).

**A65-31782**
The Influence of Radiant-Energy Transfer on Propellant Burning Rates and Ablation Rates Controlled by an Intense Radiation Field.


Consideration of the effect of a black radiation field on (1) solid propellant burning rates and (2) ablation tests. In the propellant-burning rate problem, partially transparent propellant is assumed to be gray. The propellant temperature rise is assumed to be small enough to allow the neglect of radiant-energy emission from the propellant grain in comparison with the radiant-energy input from the external radiation field; thus the system is far from a radiative steady state. This analysis is related to wartime studies on the effect of radiation on burning rates, although the methodology and results are somewhat different. The influence of radiant-energy transport on ablation rates is examined for the special case in which the rate of removal of mass from the surface is determined by a rate law, and the temperature rise is calculated for the heat absorption characteristic of the radiative steady state. In the absence of better information, two different functional relations have been assumed for the dependence of ablation rate on temperature. Theoretical results are presented in dimensionless form for ready application.

(Author) D. P. F.

**A65-31954**
LIQUID SLOSHING DUE TO A TIME-DEPENDENT DISCONTINUOUS BOUNDARY.
P. G. Bhuta and G. C. K. Yeh (Space Technology Laboratories, Inc., Redondo Beach, Calif.).


Detailed study of the problem of the sloshing of a liquid due to a time-dependent discontinuous boundary, for the case of axisymmetric motion. The solution of the transient problem for small motions is given when the velocity at the boundary fluctuates according to a known arbitrary function of time. The complete solution for the initial-value problem is obtained for a sinusoidal time variation of the velocity. Numerical examples are worked out to evaluate the velocity and pressure distributions on the bottom of the tank and the free-surface wave heights.

(Author) M. F.

**A65-32540**
**THEORETICALLY INSTABLE IN SOLID-PROPPELLANT ROCKET COMBUSTION.**
R. W. Hart and F. T. McClure (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).


Contract No. NOw-62-0604-c.

Review of the problem of unstable combustion in solid-propellant rockets, with emphasis on the status of the theory and, where possible, a comparison between theory and experiment. The manifestation of the problem in terms of the appearance of periodic pressure waves, and the consequences which ensue when these waves reach sufficient amplitude are outlined. A rocket motor is then viewed as an acoustic cavity. The possible sources and sinks of acoustic energy are enumerated, and the gain-loss balance is discussed with respect to self-excited oscillation, also with respect to influences of outside perturbations on a stable cavity. The quantitative approach to the representation of the various gain-loss mechanisms in the domain of linear stability theory is reviewed. Particular emphasis is placed on the modifications to ordinary acoustic stability theory which are required because of the existence of a mean flow field. The contributions to linear instability of the
response of the burning propellant, both to the pressure and velocity components of the acoustic field, are discussed. Attention is then turned to the fundamental theory of the interaction of the burning surface with a pressure oscillation. The linear (small perturbation) theory of the acoustic response of this region is reviewed in terms of the analytic models and postulates that have been made, and of their theoretical results. A qualitative comparison with experiment is made. Nonlinear effects are considered. The theory of nonlinear instability in such systems is first reviewed to the extent that it exists. Then, the consequences of oscillation of finite amplitude arising from nonlinear effects are discussed. Amplitude limitation in unstable cavities, wave distortion, and changes in the mean properties of the system are considered. Changes in the mean burning rate due to nonlinear pressure response theory of the acoustic response of this region surface with a pressure oscillation. Amplitude limitation in unstable cavities, wave distortion, and finite amplitude arising from nonlinear effects are discussed. Of nonlinear instability in such systems producing increased erosion, decreased nozzle flow, and angular streaming, as described by Swithenbank and Botter and by Flandro, is experimentally made. Nonlinear effects are considered. The theory and their theoretical results.

A65-32541
EXPERIMENTAL SOLID ROCKET COMBUSTION INSTABILITY.
E. W. Price (U.S. Naval Ordnance Test Station, China Lake, Calif.).
IN: SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH,
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.

Pittsburgh, Pa., Combustion Institute, 1965, p. 1067-1080; Comments, N. W. Ruan (University, Salt Lake City, Utah) and L. A. Dickinson (Standford Research Institute, Menlo Park, Calif.), p. 1081-1092. 76 refs.

Observations of high-, intermediate-, and low-frequency instability in the oscillatory combustion of solid rocket propellants. In the frequency range 1000 cps and up, instability (i) is usually encountered in transverse modes of the rocket motor, (2) results from interaction between acoustic pressure and the combustion process, and (3) is suppressed by metal fuel ingredients in the propellant (particularly aluminum), at least in part through acoustic damping by the metal oxide droplets in the gas. In the frequency range 100 to 1000 cps, instability (i) is usually encountered in axial modes of the rocket motor. (2) is often initiated by large disturbances under linearly stable conditions. (3) results from interaction between both acoustic pressure and acoustic pressure in the combustion process, and (4) is not suppressed by metal fuel ingredients, but instead may be aggravated by the metal combustion. In the frequency range 1 to 100 cps, instability may occur in either acoustic or non-acoustic modes. Some qualitative comparison of only to cases of interaction of acoustic pressure with combustion, but velocity-coupled contributions seem likely in rockets with dimensions large enough for axial acoustic modes in this frequency range. Low-frequency instability is more prevalent at low pressures and is often confined to a narrow frequency range. (Author) M. M.

A65-32542
EXPERIMENTAL STATUS OF HIGH FREQUENCY LIQUID ROCKET COMBUSTION INSTABILITY.
R. S. Levine (North American Aviation, Inc., Rocketdyne Div., Canoga Park, Calif.).
IN: SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH,
UNIVERSITY OF CAMBRIDGE, CAMBRIDGE, ENGLAND, AUGUST 17-21, 1964. [A65-32457 21-33]
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.

Pittsburgh, Pa., Combustion Institute, 1965, p. 1083-1097; Comments, p. 1097-1099. 7 refs.

Discussion of data describing the nature of destructive combustion instability in liquid rocket-thrust chambers, and of methods of controlling that instability. High-speed movies and pressure-time traces are presented, showing in a two-dimensional combustion apparatus processes similar to those occurring in full-size chambers. The processes observed in the movies are briefly discussed relative to the various sustaining processes that have been advanced for this kind of instability. Methods of control of high-frequency instability for practical engines include: (1) the use of baffles that interfere with the unwanted gas motion, (2) premix schemes that rapidly disintegrate the unmixed and poorly atomized portion of the spray, and (3) other designs that may combine these processes with effective damping of the wave motion. The application of the baffle principle to the H-3 (Satur) engine injector is discussed. M. M.

A65-32543
THEORETICAL STUDIES ON LIQUID-PROPELLANT ROCKET INSTABILITY.
IN: SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH,
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.


Review of recent achievements of theoretical research on combustion instability in liquid-propellant rocket motors. The emphasis is on theoretical developments: experimental results are only briefly mentioned, as required. It is pointed out that theoretical research in the field of high-frequency instability, although the object of many developments, is still in need of clarification and of a firm conclusion as to the mechanisms of its appearance. Here research on the steady-state and oscillatory combustion of droplets in laminar or turbulent flow, under the action of pressure waves and/or gaseous composition oscillations, could be helpful. It is also noted that more theoretical research on nonlinear mechanisms and behavior is needed, together with analytical studies on the interaction effects due to the feeding system. M. M.

A65-32547
SUPERSONIC COMBUSTION OF STORABLE LIQUID FUELS IN MACH 3.0 TO 5.0 AIR STREAMS.
Frederick S. Billig (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).
IN: SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH,
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.


Experimental demonstration of supersonic combustion of reactive aluminum alkyl fuels in two-dimensional ducted combustors and adjacent to a flat plate. Fuel was injected from the combustor walls through multiple orifices and ignited spontaneously. Stable supersonic heat release was maintained as evidenced by schlieren and direct motion pictures of the flow field and deduced from static and pitot pressure measurements in the combustion zone. The results from the ducted combustor tests were correlated with simple theoretical models, thus permitting a reasonable determination of combustion efficiency. A theoretical model of constant-pressure heat release on a flat plate in supersonic flow is postulated. Normal force coefficients and specific impulse values are tabulated for a variety of flight Mach numbers and altitudes. Additional refinements in this theoretical model were required to adequately describe the experimental results. In a test simulating Mach-5 flight at 66,000 ft altitude, a side force specific impulse of 1350 sec was measured at the equivalence ratio of 1. Combustion was only partially completed 12 in. downstream of fuel injection. Based on the theoretical model, an additional 12 in. of combustor length and 36 in. of
expansion length would be required to obtain the estimated theoretical impulse of 5760 sec. The interaction of a vaporizing liquid droplet with a supersonic stream is considered. Additional refinements were made in the existing theories on droplet trajectory to include the influences of a separated zone and the normal component of velocity of the external stream. Calculations of the trajectory and evaporation of the estimated mean droplet size based on the modified technique were in general agreement with the observed flame zone and with the deduced combustion efficiency. (Author) M.M.

A65-32457
SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH, UNIVERSITY OF CAMBRIDGE, CAMBRIDGE, ENGLAND, AUGUST 17-21, 1964.
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.
Members, $22.; nonmembers, $35.

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PLENARY LECTURE.

FLAME CHEMISTRY. I.

CHEMILUMINESCENCE OF OH RADICALS AND K ATOMS BY RADICAL RECOMBINATION IN FLAMES. P. J. T. Zeegers and C. T. J. Alkemade (Utrecht, State University, Utrecht, Netherlands), p. 33-40. 22 refs. [See A65-32460 21-27]


STRUCTURAL INERTICITY, AND MECHANISM OF A METHANE-OXYGEN FLAME INHIBITED WITH METHYL BROMIDE. W. E. Wilson, Jr. (Johns Hopkins University, Silver Spring, Md.), p. 47-59. 22 refs. [See A65-32462 21-32]


OBSERVATIONS ON THE KINETICS OF HYDROGEN-CHLORINE FLAMES. R. Corbeels and K. Scheller (USAF, Wright-Patterson AFB, Ohio), p. 65-75. 23 refs. [See A65-32464 21-33]

FLAME COMPOSITION. II.


REGRESSION RATES AND THE KINETICS OF POLYMER DEGRADA-
ATION. Bernard Rabinovitch (United Aircraft Corp., United Technology Center, Sunnyvale, Calif.).
IN: SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH, UNIVERSITY OF CAMBRIDGE, CAMBRIDGE, ENGLAND, AUGUST 17-21, 1964. [A65-32457 21-33]
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.

A65-32563
EMITTANCE OF CONDENSED OXIDES IN SOLID PROPELLANT COMBUSTION PRODUCTS. Donald J. Carlson (Philco Corp., Philco Research Laboratories, Newport Beach, Calif.).
IN: SYMPOSIUM (INTERNATIONAL) ON COMBUSTION, 10TH, UNIVERSITY OF CAMBRIDGE, CAMBRIDGE, ENGLAND, AUGUST 17-21, 1964. [A65-32457 21-33]
Symposium supported by the British Section of the Combustion Institute; National Academy of Sciences-National Research Council; National Science Foundation, Grant No. GN-260; National Aeronautics and Space Administration, Grant No. NsG-506; U.S. Army, Contract No. DA-31-124-ARO-D-197.

Recording of the spectral radiance of hydrogen-oxygen-water-alumina and RP-1 oxygen-magnesia rocket flames and the measurement of the magnitude of continuum emission. This measurement, with knowledge of the flame geometry and the oxide particle-size distribution, mass fraction, and concentration, was converted into a quantity of radiation from each particle, and a spectral hemispherical emittance was calculated. The near-infrared emittance
A65-33388

of liquid alumina particles 1 to 10 μ in diameter varied from about 10^-2 to 10^4 as the temperature increased from the melting point to 2900°K. The emittance of solid magnesia particles of a similar size range at 0.59 μ wavelength was found to average 0.4 over a range of temperatures. Mie theory calculations were made for both the magnesia and the alumina. Using best available low-temperature optical properties of magnesia, the emissivity was calculated and found to be about 3 orders of magnitude below the experimental measurements. Calculations were also made for solid-phase alumina particles based upon available temperature-dependent optical properties valid up to the melting point of alumina. These calculations showed that solid alumina particles of the same size as the experimental particles had an average near-infrared spectral emittance varying from about 10^-3 to 10^-4 as the alumina temperature changed from 1800°K to the melting point, 2320°K. The experiments indicate that a discontinuous jump in emittance of alumina occurs as the phase changes from solid to liquid. Some possible physical effects associated with radiant emission from condensed-phase particles are discussed. (Author) M.M.

A65-33389

THE COMING KICK STAGE.

Bernard Kovi, Jr.


Evaluation of the capabilities of a new final or kick stage to meet the high 2V required for advanced space missions. Such a vehicle would be optimized for its job of applying the necessary kick after the regular boosters have completed their task. The most important tradeoff parameters the designer must consider are the specific impulse (Ip), structure ratio (ratio of jettison weight less payload to the original weight less payload), and to a lesser extent the thrust-to-weight ratio. Of available high-energy propellants, the liquid cryogens such as fluorine/hydrogen, oxygen/hydrogen, and lithium/fluorine/hydrogen offer high Ip. In order to operate at an advanced stage, a kick stage would provide an initial rise from low earth orbit, would then coast, and would then restart to establish its final trajectory. Thus, requirements exist for a small, efficient, restart capability, and the capability of throttling to reduce 2V errors; the chief tankage constraints would be insulation and propellant venting under zero-g conditions. Structural and thermodynamic problems are discussed, and throttling and zero-stop-start capability are treated in some detail. Some advanced kick stage concepts are briefly considered.

F.R.L.

A65-33406

A MINIMUM-COST SATELLITE LAUNCHER. 1. Felix Godwof.


Description of the design of a small and cheap four-stage, solid propellant rocket able to launch a 30-lb satellite into an orbit with average height of about 1000 miles. The ways in which the design attempted to fulfill the requirements are summarized and pertinent data are tabulated on the following: (1) vehicle ballistics, (2) stage performance, (3) event table for a characteristic launch, (4) structural weights, (5) propellant characteristics, and (6) guidance and control system parameters. It is noted that the design is such as to lend itself to revision in larger sizes, for which performance and cost are improved. Although standard propellants are assumed, it is noted that the ratio of rocket weight to satellite weight already compares well with figures for rockets ten times the size of this small launcher. This is largely because it is not based on missile components designed for highest performance in a somewhat different mission.

M.M.

A65-33544

CHEMICAL PRESSURIZATION OF HYPERGOLIC LIQUID PROPELLANTS. Richard J. Kenny and Paul A. Friedman (Martin Marietta Corp., Martin Co., Advanced Technology and Development Section, Denver, Colo.).


Contract No. AF 04(61)-8198.

[For abstract see Accession no. A64-20260 16-26]

A65-33550

BALISTIC-MISSILE RESEARCH WITH ATHENA.

Robert F. Friedman and Jack Reed (Atlantic Research Corp., Duarte, Calif.).


[For abstract see Accession no. A64-2037 16-32]

A65-33551

LIQUID OXYGEN AND LIQUID METHANE MIXTURES AS ROCKET MONOPROPELLANTS.

Richard L. Every and James O. Thierne (Continental Oil Co., Central Research Div., Ponca City, Okla.).


Preliminary evaluation of the specific impulse, characteristic velocity, pumpability, and sensitivity of the liquid oxygen (LOX) and liquid methane (LCH4) system as a monopropellant. It was necessary to develop rather elementary test procedures and to compare these data with identical measurements made with other monopropellants. The methane and oxygen used were of 99.9 mole-% purity, and the mixing of solutions was accomplished by remote control. The results of the experiments indicate that a LOX/LCH4 monopropellant has a very good specific impulse (~ 300 sec) and a characteristic velocity of better than 6000 fps. Although LOX/LCH4 mixtures are potentially hazardous, the tests conducted indicate that they can be pumped and handled with conventional apparatus. Under conditions of adiabatic compression, believed to be the cause of many accidental explosions, LOX/LCH4 is three times as safe as nitromethane and five times as safe as n-propyl nitrate. M.M.

A65-33569

ANALYTICAL MODEL TO DETERMINE AFT-END IGNITER DESIGN PARAMETERS.

Arnold G. Plumley (Aerojet-General Corp., Sacramento, Calif.).


Analytical method that permits the sizing of aft-end igniters to obtain desired motor chamber pressure and igniter-gas penetration prior to propellant ignition. The design criteria are presented as functions of the pertinent motor and igniter parameters, and the equations are presented graphically for an igniter operating at 1000 psia. The analytical model is based on the following two elementary concepts: (1) the incoming igniter gas expands to the static pressure in the motor throat and requires a portion of the throat flow area (the remaining flow area must be sufficient to allow the same flow out of the motor at the same static pressure at sonic velocity); and (2) the incoming flow must be turned around in order to flow out of the motor. Since the free volume of the motor determines the pressure in the forward end of the motor, the overall effect of the aft-end igniter gas can be determined without analyzing the intermediate nonsentropic processes of the actual flow field. The analytical model described is found to be useful for sizing aft-end ignition systems with regard to motor pressurization and igniter-gas penetration. The correlation of the analytical model to the test data is shown. It is probable that the greatest cause of error in the analytical model is the assumption of no mixing. Jet mixing reduces the effective flow area in the motor throat which tends to make the pressures higher, whereas, shedding-off of the incoming jet stream would tend to reduce the incoming momentum and consequently lower the chamber pressure. No attempt was made to apply empirical corrections to the analytical model, since such corrections might not be scalable and might introduce errors greater than the assumptions. The error in the analytical model is less than the variation in chamber pressurization caused by igniter flow rate changes resulting from temperature variations of 60 to 100°F in ordinary solid propellants. M.M.

A65-33975

SOLID ROCKETS - A MATURING TECHNOLOGY.

H. L. Thackwell, Jr.

and many different methods of thrust-vector control have been discussed. Boosters larger than 10-ft in diameter have been fired, of rocket motor exhaust gases with electromagnetic radiation, and to motor and vehicle interface problems, and to the propellant rocket motors. Problems arising from the interactions of ever-increasing importance in the design of solid rocket propel- lant motors. Grain structural integrity is defined to be speed in excess of Mach 5. Three recent developments that significantly increase rocket performance and effectiveness have been made. The first stems from recognition of the fact that metals used in modern propellants to enhance specific impulse can be incorporated in a way that will increase the propellant strength by a factor of 100 to 1000, giving the propellant ability to withstand an appreciable fraction of the internal pressure in the rocket case. The second development is the extension in propellant burning rates that has been achieved by incorporation of metal wires in the propellant mix. Finally, the development of very large solid rockets is requiring extension of propellant and pressure-vessel fabrication. Liquid rocket systems have occupied a preeminent position for applications requiring the maximum possible terminal velocity. Hybrid rockets offer a means of combining the controllability and high performance of storable liquid engines with the high volume impulse of solids. Air augmenta- tion and hypersonic airbreathing propulsion are considered. M. F.
containing composite polyurethane propellant aged between 3.5 and 5.6 yr, the reaction compounds have localized to a series of structures termed phenoblasts. These phenoblasts exhibit a structural genesis in size and complexity accompanied by characteristic color changes. The older phenoblasts are composed of a large central aluminum particle and peripheral ammonium perchlorate chloride crystals, all enclosed in a high modulus binder. The ammonium chloride is shown to form in the solid state from ammonium perchlorate. A concentration gradient of phenoblasts expands with age and is related to grain design. Near the bore surface of the oldest motors, the phenoblast concentration decreases inward in opposition to an increasing binder swelling gradient. Two independent reaction mechanisms are thereby indicated which apparently interacted to yield a subsurface binder degradation zone. Combination of phenoblasts in motors of different ages gives an approximate rate and model of chemical aging for these propellants.

**A66-11669**

**PROJECT TOWARD A HIGH-ENERGY STANDARD ENGINE FOR THE ELDO-B CARRIER ROCKET** [DAS PROJEKT EINER HOCH- EINGEKETTER EINHEITSTRIEBWERKES FUR DIE ELDO-B TRAGERRaketEN].

Otfried Stumpf (Entwicklungsort-Nord, ERNO, Bremen, West Germany).


Discussion of the design and development of a hydrogen-oxygen engine with a thrust of 6000 kgf and a chamber pressure from 36 to 40 kgf/cm². Two independent reaction mechanisms of solid propellants and theoretical work focused principally on heterogeneous propellants.

**A66-11681**

**ANALYTICAL AND EXPERIMENTAL STUDIES OF THE STEADY-STATE COMBUSTION MECHANISM OF SOLID PROPELLANTS.**

N. A. H. Rampling (University of California, Los Angeles, Calif.) and F. A. Williams (California University, La Jolla, Calif.), (AGARD, Réunion du Groupe Combustion et Propulsion sur la Propulsion par Fusées Chimiques, 25th, La Jolla, Calif., Apr. 22-24, 1965, Paper.)

ONERA, TP no. 245, 1965. 130 p. 63 refs.

Grant No. AF AFSOR 927-65.

The project included studies of nitrogen pyrolysis of propellant constituents, chemiluminescence of exothermic oxidizers, combustion of oxidizer spheres in gaseous fuels, porous-bed combustion, reactions between gaseous fuel and gaseous oxidizer components, metal combustion, propellant solidified burning, rocket motor combustion chamber, and cinematographic experimentation. A theoretical analysis of a model of homogeneous propellant combustion is outlined in detail, with special emphasis placed on surface gasification laws and on flammability limits in nonadiabatic systems. Low pressure, high pressure, and uniaxial and biaxial stress tests under hydrostatic pressure in which dilatation is measured are described. The range of calculations was extended to begin at 32°F and continue into the supercritical pressure region, ending at 1.0 times the critical density. Experimental data published in the literature were collected, analyzed for consistency, and compared with the correlating equations suggested by Martin.

A Mollier diagram summarizing the tabulated information is shown.

**A66-11760**

**THERMODYNAMIC PROPERTIES OF HYDRAZINE.**

Jimmy L. Haws and Darrel G. Harden (Oklahoma, University, School of Aerospace and Mechanical Engineering, Norman, Okla.).


Results of the machine computation of the thermodynamic properties of hydrazine, using the general equations and procedures outlined by Martin and a revised version of the computer program used by Van Wie and Ebel. The range of calculations was extended to begin at 32°F and continue into the supercritical pressure region, ending at 1.02 times the critical density. Experimental data published in the literature were collected, analyzed for consistency, and compared with the correlating equations suggested by Martin.

A Mollier diagram summarizing the tabulated information is shown.

**A66-13106**

**A PULSE TECHNIQUE FOR THE EVALUATION OF COMBUSTION INSTABILITY IN SOLID PROPELLANT ROCKET MOTORS.**

E. P. Morris (Canadian Aeronautics and Space Establishment, Valcartier, Quebec, Canada).


In the early stages of the development of ammonium perchlorate polyurethane solid propellants, unstable combustion in the finite-size axial mode was occasionally experienced. Although the evaluation of engine characteristics by firing a statistically satisfactory number of small motors is feasible, stability of the motor when scaled up to a larger size is not ensured. To provide a positive method for testing and evaluating instability by a minimum number of firings, a pulse technique employing small gunpowder charges was developed to initiate unstable combustion when the motor is operating in an incipiently unstable regime. This pulse technique is an essential requirement for definitive testing since an inherently unstable motor will operate stably if no triggering flow disturbance occurs during the firing. The method permits a systematic study of the phenomenon. The pulse technique and the devices and some of the general results obtained from the investigations are presented. The technique has been used successfully for rocket motors, heavy-walled and flight-type, from 2 to 17 in. in diameter.

**A66-13226**

**SOLID PROPELLANT GRAINS WITH ORGANIZED SLITS (BLOCS DE PROPERGOL A FISSURES ORGANISEES).**

Marcel Barrère and Pierre Larue (ONERA, Châtillon-sous-Bagneux, Seine, France).


Method of minimizing various difficulties encountered with solid propellants, such as "tail-off," and the possibility of accidental

(Author)
cracking of the grain during the ignition phase. Very narrow radial slits are molded into the grain. The slits commence at the central perforation, and do not quite reach the perimeter of the grain.

F. R. L.

A66-15139 DROPLET COMBUSTION IN THE HYDRAZINE-NITROGEN TETROXIDE SYSTEM.

B. P. Breen and M. R. Beltran (Dynamic Science Corp., Monrovia, Calif.).


Numerous problems were encountered in evaluating the drop-weight sensitivity of explosive liquids with a widely adopted impact apparatus. It was demonstrated that results, loosely termed partials and originally designated as negatives, should be designated positives. Wear or erosion of the cupped ends and of the type of mount used for the apparatus had important effects on the results. Relative sensitivity as measured by this procedure increases slightly with temperature. The original concept that the test involves only adiabatic compression was found to be an oversimplification; an alternate mechanism for the initiation process is proposed.

(Author)

A66-15145 CHEMICAL FACTORS IN N2O4 - N2H4 LIQUID REACTIONS.

Harold Weiss (Dynamic Science Corp., Monrovia, Calif.).


Research supported by the Jet Propulsion Laboratory.

Description of an attempt to find a chemical inhibitor for the N2O4-N2H4 reaction. Ignition delay times are measured for N2O4-hydrazine, and the temperature is determined and a measurement made of the heat evolved in the first step of the reaction, using a differential thermal analysis technique. It is found that the nitrogen tetroxide-hydradine impinging jets are subject to disruption by the rapid reaction occurring at the interface between the two propellants; this is thought to be caused by (1) the rapid rate of reaction between N2O4 and N2H4, and (2) the immiscibility of the two reactants. Additives do not appear to cause even partial miscibility, according to high-speed photographic studies, and it does not appear possible to prevent adduct formation or decomposition by the use of additives.

M. B.

A66-15146 DROPLET COMBUSTION IN THE HYDRAZINE-NITROGEN TETROXIDE SYSTEM.

B. P. Breen and M. R. Beltran (Dynamic Science Corp., Propulsion Dept., Monrovia, Calif.).


Contract No. AF 04(611)-10542.

Review of experimental and analytical investigation of droplet combustion in the hydrazine-nitrogen tetroxide system. The experiments indicate that a single flame front model is not realistic for such propellant systems as hydrazine, monomethyl hydrazine, unsymmetrical dimethyl hydrazine and 50/50. It is noted that the presence of 2 flame fronts has been observed, and that the nature of these fronts was determined from the kinetics of decomposition of the propellant vapor. A 2-flame model is postulated along with its required assumptions. The method of solution of the 2-flame decomposition-oxidation model is explained. The result of the investigation is a physically realistic steady-state combustion model which can be used to predict combustion in liquid rocket engines.

M. M.

A66-15147 HYPERGOLIC IGNITION OF LIGHT HYDROCARBON FUELS WITH FLUORINE-OXYGEN (FLOX) MIXTURES.

S. A. Mosier, R. E. Dotsen, and O. K. Moehrbach (United Aircraft Corp., Pratt and Whitney Aircraft Div., Florida Research and Development Center, West Palm Beach, Fla.).


Additives do not appear to cause even partial miscibility, according to high-speed photographic studies, and it does not appear possible to prevent adduct formation or decomposition by the use of additives.

Contract No. AF 04(611)-10542.

Hypergolic ignition characteristics of light hydrocarbon fuels with fluorine-oxygen (flox) mixtures were determined experimentally. Methane, ethylene, propane, propylene, 1-butene, and a eutectic blend of 14% pentane and 86% isopentane were ignited with flow over a range of propellant temperatures from 940°K to that corresponding to liquid fuel and oxidizer in impinging and concentric injectors. The propellants were all found to be hypergolic; however, the ignition delay times for the flow-fuel combinations were dependent on propellant temperature and precedence, system initial pressure, flow concentration and injector type. In general, for all tests made over the range of variables considered, it was found that as the propellant equivalence ratio (stoichiometric mixture ratio/actual mixture ratio at ignition) increased, the ignition delay time decreased. In order of their decreasing dependency on the equivalence ratio at ignition, the fuels are butane-1, methane, propylene, 14% pentane-86% isopentane eutectic blend, propylene, and ethylene. In addition, it was found that the ignition delay time was also dependent on the fuel/oxidizer injection momentum ratio. Considering all tests the delay time was lowest in the momentum ratio range of 1.0 to 10 and increased as the momentum ratio increased or decreased outside this range.

L.

A66-15151 THE EFFECT OF SURFACE MODIFICATIONS ON THE BURNING RATE OF A COMPOSITE SOLID PROPELLANT.

B. G. Moser, R. E. Weich, and R. F. Landel (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.).


It has been found, using differential thermal analysis, that the temperature at which either the predecomposition or the major decomposition of ammonium perchlorate occurs can be changed by surface treatment of the perchlorate. These changes are reflected in the burning rate of a propellant containing the modified perchlorate. Common burning rate modifiers used to increase a propellant's burning rate, such as magnesium oxide, shift both the predecomposition and the major decomposition to a lower temperature and promote a faster burning rate. On the other hand, an effective surfactant shifts the predecomposition peak to a higher temperature and increases the degree of dispersion. Both factors result in a lower burning rate. One of the paradoxes of the use of a surfactant is that an effective one can also be used to increase the burning rate by permitting a higher solids loading and attendant higher flame temperature.

(Author)

A66-15781 THEORETICAL DETONATION CHARACTERISTICS OF SOLID COMPOSITE PROPELLANTS.


Navy-supported research.

The detonation characteristics of ammonium perchlorate-polyurethane composite propellants are discussed quantitatively in terms of the processes that establish the energy release rate in the shocked propellant. The detonability of essentially nonporous propellant is controlled by the shock-initiation time of the oxidizer and the diffusion-controlled burning rate of the gasified binder. The detonability of porous propellant is controlled by the concentration of "hot-spot" producing voids in the propellant. It is shown that the critical diameters for detonation are very large for nonporous propellants, but decrease rapidly as the concentration of pores in the propellant is increased.

(Author)

A66-15783 FINITE ACOUSTIC OSCILLATIONS AND EROSIIVE BURNING IN SOLID FUEL ROCKETS.

J. F. Bird, R. W. Hart, and F. T. McClure (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).


The acoustic combustion instability of a solid fuel rocket depends vitally on the response of the burning propellant surface to a sound field. The erosive part of this response can be significantly nonlinear at sound amplitudes too low in typical motors for ordinary second-order acoustic nonlinearities to be important. Then moderate amplitude phenomena can be ascribed to erosive nonlinearities, and these can be isolated for analysis. This is done by examining the growth constants of the acoustic modes. A previous paper has shown that nonlinear erosion can destabilize axial modes which are linearly stable or can limit linearly unstable ones to moderate amplitudes. That discussion is generalized here, and a unified summary of acoustic erosion contributions to stability is given. Other effects of nonlinear erosivity are then analyzed. It is shown that erosive generation of harmonics can produce considerable waveform distortion of moderate amplitude axial modes. Also, it is found that the nonlinear erosion mechanism can lead to severe oscillations, with consequent sharp mean pressure peaks, at rocket geometries where two acoustic modes are degenerate. This theory of nonlinear erosive interactions of a mode with itself, with its harmonics, and with degenerate modes seems to agree qualitatively with various experimental observations. (Author)

A66-15847
SOLID PROPELLANT RAMJETS (STATOREATTORI A PROPELLENTE SOLIDO).
Giacone Partel.
Application and advantages of solid propellant ramjets for target aircraft, missiles, and space vehicle boosters. The advantages presented by solid propellant ramjets as compared to both liquid propellant ramjets and solid propellant rockets are described. It is pointed out that the solid propellant ramjet has fundamentally the simplicity of the solid propellant rocket and affords the savings of the air-breathing engine.

M.M.

A66-16494 #
DESIGN CRITERIA OF ADVANCED HIGH-ENERGY UPPER STAGES.
D. E. Koelle (Bölkow GmbH, Ottobrunn, West Germany).
A discussion of design criteria for high-energy stages for a launch vehicle. Features essential for the achievement of high operational reliability and broad mission range with low development effort are outlined. By the utilization of the specifications of the European Launcher Development Organization (ELDO B) launch vehicle, a design for a launch-vehicle high-energy stage is presented.
P.K.

A66-17098 #
A PHYSICAL MODEL OF COMPOSITE SOLID PROPELLANT COMBUSTION WHICH INCLUDES THE OXIDIZER PARTICLE SIZE AND SURFACE HEAT GENERATION.
C. E. Hermance (Waterloo, University, Waterloo, Ontario, Canada).
Research sponsored by the Aeronautical Research Institute of Sweden and the Swedish Institute for Defense Research.
The surface heterogeneity of a burning composite propellant is incorporated in a model of the propellant combustion process. A simple mathematical treatment of this model indicates quite good agreement with a variety of data concerning composite propellant combustion. The combustion process is pictured as the sum of fuel pyrolysis, oxidizer decomposition, heterogeneous chemical reaction between the fuel and decomposed oxidizer in small regions surrounding individual oxidizer particles, and gas phase combustion of final fuel and oxidizer decomposition products. Expressions for the burning rate and the rates of heat generation at the propellant surface and in the gas phase flame are formulated, explicitly including the oxidizer particle size distribution. Assuming planer heat generation regions allowed derivation of expressions for the mean propellant surface and flame temperatures from one-dimensional energy equations in the gas and solid phases. A set of implicit, algebraic equations are collected and solved numerically for the propellant burning rate, surface- and flame-temperatures for a variety of physical parameters. The results agree quite well with experimental data on the effect of pressure and oxidizer particle size on composite propellant burning rates, surface temperatures, and surface structure. (Author)
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