NASA SP-7002(02)

HIGH ENERGY PROPELLANTS

A CONTINUING BIBLIOGRAPHY

WITH INDEXES

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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HIGH ENERGY PROPELLANTS

A CONTINUING BIBLIOGRAPHY

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A Selection of Annotated References to Unclassified Reports and Journal Articles introduced into the NASA Information System during the period January through December, 1965.

Scientific and Technical Information Division
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. APRIL 1966

INTRODUCTION

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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.

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For further details please consult the *Introductions* to *STAR* and *IAA*, respectively.

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a continuing bibliography with indexes APRIL 1966

STAR ENTRIES

N65-10663# Aerojet-General Corp., Sacramento, Calif. Propellant Research Div.
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 AF 49(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 745 torr. The pressure dependencies of the apparent flame strengths of these systems gave overall reaction orders of 1.56 and 2.0 for NH_3-NO and NH_3-N_2O counterflow diffusion flames, respectively. The overall stoichiometry of the NH_3-NO flame near extinguishment can be represented by the following equation.

$$1.5NH_3 + NO \rightarrow 1.25N_2 + 1.25H_2 + H_2O.$$

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/cm^2-sec corresponded to volumetric reaction rate of 2.93 gm/cm^3-sec release rate of 7.22 × 10^3 cal/cm^3-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 antisymmetric mode of liquid oscillations in rigid spherical tanks having diameters of 32.0 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 Technical Report, 1 Oct. 1962–30 Sep. 1963
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

N65-11271# Stanford Research Inst., Menlo Park, Calif.
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)
(SSD-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

P. F. Pokhil and V. M. Mal'tsev 30 Mar. 1964 12 p refs Transl. into ENGLISH from Inzh.-Fiz. Zh. (USSR), v. 6, no. 6 1963 p 94–99
(FTD-MT-63-242; AD-606751)

Experimental data are listed for the study of the main physical properties of a flame of solid fuel—nitroglycerine powder and explosive hexogene—during combustion in a bomb of constant pressure. Author

N65-11806# Stanford Research Inst., Menlo Park, Calif.
SOLID PROPELLANT MECHANICAL PROPERTIES INVESTIGATIONS Quarterly Progress Report No. 3, Apr. 1–Jul. 1, 1964
Norman Fishman and James A. Rinde 4 Aug. 1964 43 p refs
(Contract AF 04(611)-9559)
(Rept.-9; AD-604109)

Equations of finite elastic theory were developed and used to analyze propellant test results. Findings on the degree of deviation of experimental data from calculated curves are presented. By performing the appropriate operations on test results, a path-independent equation was developed that interrelates volume ratio, strain energy, and time for each propellant composition. Constant volume envelopes plotted as log stress versus log strain were shown to depend on path, since constant load data did not fall on the envelopes defined by constant strain-rate data and constant loading-rate data. D.E.W.

N65-11810# California Inst. of Tech., Pasadena W. M. Keck Lab. of Engineering Materials
A RESEARCH PROGRAM ON SOLID PROPELLANT PHYSICAL BEHAVIOR Quarterly Report No. 3, 1 May–30 Jul. 1964
M. L. Williams et al Aug. 1964 5 p refs
(Contract AF 04(611)-9572)
(MATSCIT-PS-64-7; AD-605202)

The research program in the following areas is discussed: (1) behavior of polymeric and composite systems—experimental and theoretical studies on rubberlike materials; (2) standardized material characterization—determination of mechanical and swelling properties, and mathematical descriptions of material properties; and (3) data information—preparation of abstract publication on the structural integrity of solid propellants. D.S.G.

N65-12014# Aerojet-General Corp., Sacramento, Calif. Liquid Rocket Operations
DEVELOPMENT OF A VARIABLE-LENGTH CHAMBER FOR LIQUID ROCKET COMBUSTION RESEARCH, VOLUME 3 Product Engineering Final Report, 1 Jun. 1963–1 Aug. 1964
Allan J. Smith, Jr. and Frederick H. Reardon Oct. 1964 95 p refs *Its* Rept.-212/SA3-F, Vol. 3
(Contract AF 04(694)-212/SA19)
(BSD-TDR-64-137; AD-450547)

A variable-length combustion chamber has been developed that is capable of continuously changing length while firing. The combustion chamber is 6 in. in diameter; its length is variable between 7 and 24 in. It has been tested with the hypergolic propellant combination of nitrogen tetroxide and Aerozine 50. The tests were conducted with a like-on-like injector pattern that was designed to be similar to one developed early in the second-stage Titan II program. Five tests were conducted. Four tests at 500-psia chamber pressure covered the mixture ratio range of 1.87 to 2.1. The fifth test was conducted at a pressure of 850 psia and a mixture ratio of 1.62. These tests successfully demonstrated the length variability and hot-gas sealing concepts. In addition, excellent static pressure measurements of the energy release distribution were obtained. These measurements showed that a large fraction of the energy release occurred close to the injector face, but that combustion was not completed until 13 in. from the face. The primary objective of the program was to determine whether the results of subscale testing of longitudinal-mode stability limit can be applied to the prediction of the stability of all modes in a full-scale thrust chamber. However, no combustion instability was encountered in the test program. Therefore, a positive evaluation of the technique could not be achieved. Author

N65-12465# France. Office National d'Etudes et de Recherches Aeronautiques, Chatillon-sous-Bagneux. Section de Recherches
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; ENGLISH summary Presented at the Agard Mater. and Struct. Group Meeting, Liege, 27 May–2 Jun. 1964
(Rept.-476)

The generation of unsteady hydrodynamic forces due to the oscillation of the propulsion liquids in containers of missiles may influence their performance in flight. Theory permits only a partial solution to this problem and must be supported by tests. The experimental method devised at the O.N.E.R.A. and the synthesis of the tests carried out for one type of missile are described. Author

N65-12552# Lockheed Propulsion Co., Redlands, Calif.
SOLID PROPELLANT STRUCTURAL INTEGRITY INVESTIGATIONS: DYNAMIC RESPONSE AND FAILURE MECHANISMS, VOLUME I Quarterly Progress Report No. 1, 15 Jun.–15 Sep. 1964
D. E. Cantey 14 Oct. 1964 118 p refs *Its* Rept.-667-Q-1
(Contract AF 04(611)-9953)
(AFRPL-TR-64-148, Vol. I; AD-452689)

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
Ralph C. Nussle, Joseph D. Derdul, and Donald A. Petrash Washington, NASA, Jan. 1965 14 p refs
(NASA-TN-D-2572) OTS Prices: HC $1.00/MF $0.50

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 blow-through. Author

N65-13511# Radiation Applications, Inc., Long Island City, N.Y.
RADIATION-INDUCED SOLID PROPELLANT DECOMPOSITION Technical Report, 1 Dec. 1962–30 Nov. 1963
George Odian, Terese Acker, Thomas Pletzke, Ernest Henley, and R. F. Mc Alevy, III 15 Jan. 1964 31 p refs
(Contract AF 49(638)-1125)
(RAI-331; AFOSR-64-1448; AD-604475) OTS: $2.00

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 rate and tensile strength occurred upon radiolysis. A continuing study to elucidate the mechanism of these effects involves cobalt-60 gamma radiolysis of ammonium perchlorate 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.

N65-13577# Applied Physics Lab., Johns Hopkins U., Silver Spring, Md. Chemical Propulsion Information Agency
BULLETIN OF THE 3RD MEETING, INTERAGENCY CHEMICAL ROCKET PROPULSION GROUP, WORKING GROUP ON MECHANICAL BEHAVIOR, VOLUME I
Oct. 1964 606 p refs Meeting held at Army Missile Command, Redstone Arsenal, Ala., 17–19 Nov. 1964
(Contract NOw-62-0604-c)
(CPIA Publ. 61U; AD-451712)

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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. MOIRE 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)

N65-13578 Aerojet-General Corp., Sacramento, Calif.
TWO-DIMENSIONAL STRESS ANALYSIS OF SOLID PROPELLANT ROCKET GRAINS
Edward L. Wilson *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 9-26 refs (See N65-13577 04-34)

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 programed 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
Robert S. Goldberg and Hugh N. Chu *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 91-102 refs (See N65-13577 04-34)
(Contract Nonr-3858(00))

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
R. N. Shearly and A. M. Messner *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 103-117 refs (See N65-13577 04-34)

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
A. M. Messner *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 119-130 refs (See N65-13577 04-34)

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 $\pm 30\%$ in some geometries. Author

N65-13589 Stanford Research Inst., Menlo Park, Calif. Propulsion Sciences Div.
APPLICATION OF FINITE ELASTIC THEORY TO PROPELLANT BEHAVIOR
James A. Rinde and Norman Fishman *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 177-190 refs (See N65-13577 04-34)
(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 polyurethane 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

$$\bar{\sigma}_{max} \leq \mu,$$

derived by Blatz, was examined in connection with polyurethane-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
J. D. Burton, W. B. Jones, and J. D. Frazee *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct 1964 p 191-201 refs (See N65-13577 04-34)
(Contract NOw-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 that 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
R. J. Farris *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 291-302 refs (See N65-13577 04-34)

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

N65-13596 Lockheed Propulsion Co., Redlands, Calif.
DIELECTRIC AND ELECTRICAL CONDUCTIVITY PROPERTIES OF CERTAIN SOLID PROPELLANTS
D. E. Cantey *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 317-344 refs (See N65-13577 04-34)
(Contract AF 04(611)-8539)

Dielectric spectroscopy was investigated as an analytical tool to assist in the elucidation of chemicophysical effects in solid propellant systems. Complex dielectric properties were measured over a wide temperature range and at frequencies from 50 to 10^5 cps for polybutadiene acrylic acid (PBAA), 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
G. J. Kostyrko and R. E. Lee *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 345-356 refs (See N65-13577 04-34)

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

N65-13598 Rocketdyne, McGregor, Tex. Solid Rocket Div.
TRIAXIAL TENSILE FAILURE OF SOLID PROPELLANTS
B. C. Harbert *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 357-370 refs (See N65-13577 04-34)

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 specimens 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
J. N. Majerus *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 395-420 refs (See N65-13577 04-34)

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 tensorally 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

N65-13601 Thiokol Chemical Corp., Brigham City, Utah. Wasatch Div.

THE EFFECTS OF FATIGUE LOADING UPON SOLID PROPELLANT

Joseph H. Stoker *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 421-436 refs (See N65-13577 04-34)

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. Author

N65-13604 Imperial Metal Industries, Ltd., Kidderminster (Gt. Brit.) Summerfield Research Station

FAILURE CRITERIA FOR CAST-DOUBLE-BASE PROPELLANTS

H. Leeming and A. Parker *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 469-500 refs (See N65-13577 04-34)

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 good 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. Author

N65-13607 Lockheed Propulsion Co., Redlands, Calif.

MOIRE METHOD FOR THE MEASUREMENT OF STRAINS IN SOLID PROPELLANTS

W. D. Hart *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 545-560 refs (See N65-13577 04-34)

(Contract NAS7-241)

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. Author

N65-13608 Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.

A BIAXIAL TESTER

Anthony San Miguel *In* APL Bull. of the 3rd Meeting, Interagency Chem. Rocket Propulsion Group, Working Group on Mech. Behavior, Vol. I Oct. 1964 p 561-572 refs (See N65-13577 04-34)

(ARPA Order 107-62)

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 $in.^2$ 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 stresses at the center of the propellant sheet. A biaxial relaxation test was performed on a solid propellant to illustrate the potential of the instrument. Author

N65-13619# Stanford Research Inst., Menlo Park, Calif.

VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Annual Technical Summary Report, Jul. 16, 1963-Sep. 15, 1964

Nicholas W. Tschoegl, James R. Smith, and Thor L. Smith 15 Oct. 1964 55 p refs

(Contract NOw-64-00730-d; 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 vulcanizate, 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. Author

N65-14027# Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.

SOLID ROCKET PROPELLANTS

Dorde Jaukovic 12 Oct. 1964 21 p Transl. into ENGLISH from Vojnothnicki 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. R.L.K.

N65-14033# Stanford Research Inst., Menlo Park, Calif.
SOLID PROPELLANT MECHANICAL PROPERTIES INVESTIGATIONS Final Report, 1 Oct. 1963–1 Oct. 1964
Norman Fishman and James A. Rinde 2 Dec. 1964 75 p refs
(Contract AF 04(611)-9559)
(Rept.-12; AD-608838)

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.

N65-15463 National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
ASPECTS TO CONTROL LIQUID PROPELLANT SLOSHING BASED UPON EXISTING THEORY
W. R. Eulitz *In* Army Res. Office Proc. of the 9th Conf. on the Design of Expt. in Army Res., Develop. and Testing Dec. 1964 p 256–285 refs (See N65-15451 06-19)

During the last decade, many attempts were made to ascribe the response of a liquid to exciting oscillations. Although principally a nonlinear problem, the theory was confined to the first-order terms only, due to mathematical difficulties. This linearized theory was discerned in satisfactory agreement with many experimental results, at least as far as the first liquid resonance is concerned, which likewise is the most adverse condition for the vehicle controls system. The interpretation of the existing theory leads to dimensionless parameters which, incorporated in a nomograph, provide quick orientation on liquid behavior under varying oscillatory conditions. Such data help to define critical vehicle flight periods and to predetermine proper design parameters. The survey of the parameters of oscillatory liquid motion suggests possible means of suppressing liquid sloshing. The pros and cons of several methods are discussed, and furthermore, the prospects for proper measurement of liquid surface motion are indicated. Author

N65-15838# Hughes Aircraft Co., Culver City, Calif.
LIQUID ROCKET PROPELLANTS IN ZERO GRAVITY Selected Bibliography, Jan. 1962–Sep. 1964
Janice L. Hanks, comp. Oct. 1964 6 p refs
(LS-BIB-64-2)

N65-16058# Thiokol Chemical Corp., Denville, N.J. Reaction Motors Div.
HYPERGOLIC IGNITION AT REDUCED PRESSURES Five-Month Progress Report, 1 May–30 Sep. 1964
A. Corbett, T. Seamans, B. Dawson, and C. Cheetham Edwards AFB, Calif., AF Rocket Propulsion Lab., Dec. 1964 80 p
(Contract AF 04(611)-9946)
(AFRPL-TR-64-175; AD-610144)

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 N_2O_4 and IRFNA as oxidizers and hydrazine-type fuels. Author

N65-16081*# Marquardt Corp., Van Nuys, Calif.
FEASIBILITY STUDY OF OXYGEN/HYDROGEN POWDERED METAL IGNITION First Quarterly Progress Report, 16 Sep.–15 Dec. 1964
J. L. Jones 21 Dec. 1964 30 p refs *Its* Rept.-25151
(Contract NAS8-11250)
(NASA-CR-60478) OTS: HC $2.00/MF $0.50

Analytical studies included a review of the use of metallic catalysts and pyrophoric metals to produce ignition of mixtures of hydrogen and oxygen; experimentally, it was found that the noble metal catalysts, such as platinum, reacted well for hypergolic ignition. Another method of ignition considered was based on catalysis of the ortho–para conversion of hydrogen at low temperature. Zinc oxide was found to provide strong adsorption of the hydrogen and very rapid parahydrogen conversion. In the phase of planning experimental programs, a liquid oxygen–hydrogen propellant system was designed for more quantitative tests. Preliminary H_2–O_2 ignition studies were begun, using a platinum catalyst in three different experimental setups that provided varying degrees of parameter control. There was no noticable qualitative deterioration of characteristics in 6 days of use. Further testing with Raney nickel powders and other pyrophoric metal powders showed them to be very pryophoric at room temperature and much more so in a vacuum pretreatment. Successful results were found by forming colloidal suspensions of the metal in suitable liquid carriers. Evaluations are being made of all experimental data. R.E.S.

N65-16158# IIT Research Inst., Chicago, Ill.
LIQUID PROPELLANT VAPORIZATION AND DISINTEGRATION
Ronald Joseph Steinke (M.S. Thesis) Jun. 1964 37 p refs

The results of the calculations revealed that the temperature change of the liquid jet, determined by the mass and heat transfer equations, is of the same order of magnitude as the temperature variation of the drop. The analysis predicted the experimental drop diameter measurements for the Freon-12 and air system within experimental data scatter. The calculated liquid Freon-12 velocities were approximately 8% higher than the experimental values. This discrepancy can be eliminated by using a smaller coefficient of drag in the analysis. The percentage of total heat transfer due to radiation for the drops was calculated to be less than 1% for an airstream and wall temperature of 544° R. However, this percentage increased to 4.7% for an airstream and wall temperature of 1,200° R. At higher temperatures, this percentage is expected to increase further. Also, the percentage of heat radiation was calculated to be at least five times higher for liquid jets than for drops. Author

N65-17256*# Harris Research Labs., Inc., Washington, D. C.
STUDIES OF INTERFACIAL SURFACE ENERGIES Summary Report
George A. Lyerly and Henry Peper 31 Dec. 1964 30 p refs
(Contract NAS3-5744)
(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
(Grant NsG-125-61)
(NASA-CR-60845) OTS: HC $2.00/MF $0.50

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

N65-17926# Lockheed Propulsion Co., Redlands, Calif. Structural Integrity Dept.
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

N65-18413# Aerospace Corp., El Segundo, Calif. Aerodynamics and Propulsion Research Lab.
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 N_2H_4 from 2.9° to 51° C, UDMH from −25° to 35° C, and their mixtures at 0°, 9.9°, and 20° C have been measured. The vapor–liquid equilibrium compositions of the mixtures have been determined at 0°, 9.9°, and 20° C. Equations have been derived for the equilibrium vapor pressures of N_2H_4 and UDMH as functions of temperature. For the vaporization process, $\Delta F°$ and $\Delta H°$ have been expressed as functions of temperature, and $\Delta F°$, $\Delta H°$ and $\Delta S°$ at 298.15° K 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 N_2H_4 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 propellent 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

N65-19369# American Cyanamid Co., Stamford, Conn. Central Research Div.
SOLID ROCKET PROPELLANT RESEARCH AND DEVELOPMENT. VOLUME 2: COMPUTATION OF THE EQUILIBRIUM COMPOSITION OF MULTICOMPONENT CHEMICAL SYSTEMS Annual Report, 1964
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.E.W.

N65-19576# Stanford Research Inst., Menlo Park, Calif.
RESEARCH ON UNSTABLE COMBUSTION IN SOLID PROPELLANT ROCKETS Annual Report, Jan. 1–Dec. 31, 1964
L. A. Dickinson, E. L. Capener, and R. J. Kier 13 Jan. 1965 67 p refs
(Contract AF 49(638)-1367; ARPA Order 317)
(AD-612178)

Initiation of axial combusion 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

N65-19703*# National Aeronautics and Space Administration, Washington, D. C.

HIGH ENERGY PROPELLANTS—A CONTINUING BIBLIOGRAPHY

Mar. 1965 104 p

(NASA-SP-7002(01)) CFSTI: 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. R.W.H.

N65-19787# Rohm and Haas Co., Huntsville, Ala. Redstone Arsenal Research Div.

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(Z))

(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

N65-19919*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

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) CFSTI: 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 unbaffled oblate-spheroidal 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

N65-20065# Bolt, Beranek, and Newman, Inc., Cambridge, Mass.

THE ACOUSTICS OF SOLID PROPELLANT COMBUSTION INSTABILITY

31 Aug. 1964 7 p refs

(Contract DA-19-020-AMC-5755-R)

(QTPR-7; AD-459425)

A simple technique has been developed for estimating the limiting amplitude of oscillation. This is based on the fact that in the Fourier series representation of a function with a discontinuity, the amplitude of the n^{th} harmonic decreases as 1/n relative to the fundamental. Applying this technique to T-burner experiments in solid propellant combustion requires specifying the real and imaginary parts of the acoustic admittance of the propellant for the first three modes. By making crude guesses about these admittances based on data for the first two modes, values of limiting pressure have been calculated which differ from actual values by factors of from 1 to about 1/30. A crude analysis of possible transition in an acoustic boundary layer is presented, to analyze the possible effect on increased boundary layer and erosion losses in T-burners. E.P.V.

N65-20109*# National Aeronautics and Space Administration, John F. Kennedy Space Center

SOLID PROPELLANTS SAFETY HANDBOOK

1 Feb. 1965 63 p refs

(NASA-TM-X-56192; SP-4-45-S) CSFTI: HC $3.00/MF $0.75

The purposes of the handbook are to familiarize personnel engaged in solid propellant operations with the hazards associated with solid propellant handling, storage, transportation, etc.; to help personnel select the most appropriate action; and to recommend procedures to minimize the hazards of solid propellant operations. The safety organization of the Kennedy Space Center is described. Solid propellants, associated hazards, safety precautions, safety procedures, safety limits, and safety material are discussed. E.E.B.

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. M.P.G.

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. M.P.G.

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 nonerosive conditions have been obtained, and the erosive burning rate apparatus is being designed. M.P.G.

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 (30000 to 300000 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. M.P.G.

N65-20364 Purdue Univ., Lafayette, Ind. Jet Propulsion Center

A DETERMINATION OF THE EFFECTS OF ROTATION ON SPIN STABILIZED ROCKET MOTORS

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(Z))

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 30000 rpm, will yield an acceleration of 70000 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. M.P.G.

N65-20569# 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

15 Jan. 1965 128 p refs Prepared for Lockheed Missiles and Space Co., Sunnyvale, Calif.

(R-6)

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. Author

N65-20716# Illinois Univ., Urbana. Aeronautical and Astronautical Engineering Dept.
A SUMMARY OF LINEAR VISCOELASTIC STRESS ANALYSIS
Harry H. Hilton Mar. 1965 56 p refs
(AAE-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 quantity constant at 81% by weight. The experimental results indicate a sharp rise in oscillation amplitude at a well-defined mean oxidizer particle size: 40% to 25% ground perchlorate in a 12-inch long combustor. A similarity parameter calculated on the basis that burning velocity is determined by the rate of turbulent mixing is shown to be in reasonable agreement with the observed behavior. A few experiments conducted with aluminized propellant indicate that the suppression effect associated with the aluminum addition is probably due to energy absorption at or near the surface. Author

N65-21217 Library of Congress, Washington, D. C. Aerospace Technology Div.
THE EFFECT OF SOUND ON COMBUSTION PROCESSES
P. Greguss *In Its* Combust. Technol. of Vostok-Type Eng., Comprehensive Rept. 10 Mar. 1965 p 132–141 refs Transl. into ENGLISH from Akust. Zh. (USSR), v. 8, no. 4, Oct.–Dec. 1962 p 420–425 (See N65-21213 11-33) CFSTI: HC $4.00/MF $1.00

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 boundary increased the completeness of combustion. (3) Since the energy was introduced in the flame itself favorable chemico-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. E.E.B.

N65-21274# Bureau of Mines, Pittsburgh, Pa. Explosives Research Center
SENSITIVITY OF PROPELLANT SYSTEMS Quarterly Report, Oct. 1–Dec. 31, 1964
F. C. Gibson, R. W. Watson, J. E. Hay, C. R. Summers, J. Ribovich et al 2 Mar. 1965 30 p refs
(BuWeps Order 19-65-8023-Weps)
(QR-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.

N65-21894# Stanford Research Inst., Menlo Park, Calif. Industrial Research Div.
VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 1, Sep. 16–Dec. 15, 1964
Nicholas W. Tschoegl, James R. Smith, and Thor L. Smith [1964] 23 p ref
(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

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. Author

N65-22639# IIT Research Inst., Chicago, Ill.
A STUDY OF THE FUNDAMENTALS OF LIQUID PROPELLANT SENSITIVITY Fifth Technical Progress Report, Dec. 1, 1964–Feb. 28, 1965
Ted Erikson Mar. 1965 21 p
(Contract AF 04(611)-9566)
(IITRI-C6024-20; 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 programed 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 LH_2/LOX PROPELLANT COMBINATIONS
John B. Gayle, Charles H. Blakewood, James W. Bransford, William H. Swindell, and Richard W. High 9 Apr. 1965 35 p refs
(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 LH_2/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* Astrionics 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
D. O. Lomen Washington, NASA, May 1965 38 p refs
(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

N65-24738# Atlantic Research Corp., Alexandria, Va.
DYNAMIC MECHANICAL PROPERTIES OF SOLID PROPELLANTS Final Summary Report, 23 Jun. 1961–31 Jul. 1963
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. Author

N65-24750# Rocketdyne, Canoga Park, Calif. Research Dept.
A STUDY FOR DESIGN OF A FLOWMETER CALIBRATION SYSTEM CAPABLE OF THIXOTROPIC AND NEWTONIAN FLUID USE Final Report
T. B. Thomson, Jr. Edwards AFB, Calif., AF Rocket Propulsion Labs., Jan. 1965 65 p refs
(Contract AF 04(611)-9702)
(R-5938; AFRPL-TR-64-166; AD-461173)

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 sheer-stress characteristics of various types of liquids are presented. Author

N65-24928# Los Alamos Scientific Lab., N. Mex.
ROCKET PROPULSION
Ralph S. Cooper *In* Smithsonian Inst. Ann. Rept. of the Smithsonian Inst., 1962 [1962] p 299–313 (See N65-24925 14-34) GPO: $4.75

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.

N65-25307# France. Office National d'Etudes et de Recherches Aerospatiales, Chatillon-sous-Bagneux.
COMBUSTION OF AMMONIUM PERCHLORATE SPHERES IN A FLOWING GASEOUS FUEL
Marcel Barrère and Lionel Nadaud 1964 50 p refs Presented at the 10th Intern. Symp. on Combust., Cambridge, 17–21 Aug. 1964
(ONERA-TP-113(1964))

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 $d^2 = d_0^2 - Kt$ for propane and ammonia, and by $d^3 = d_0^3 - Kt$ 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)

Continued research in radiation induced solid propellant decomposition, which focuses on solid ammonium perchlorate radiolysis 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 polymethyl 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.

N65-25455# Library of Congress, Washington, D. C. Aerospace Technology Div.
INVESTIGATION OF THE SURFACE STRUCTURE OF BURNING MODEL MIXTURES OF SOLID FUELS . [ISSLEDOVANIYE STRUKTURY POVERKHNOSTI GORENIYA MODEL' NYKH SMESEVYKH TVERDYKH TOPLIV]
P. F. Pokhil and L. D. Romodanova 17 May 1965 10 p refs Transl. into ENGLISH from Zh. Fiz. Khim. (Moscow), v. 39, no. 2, 1965 p 294–299
(ATD-T-65-28; AD-463137) CFSTI: HC $1.00/MF $0.50

To understand the burning mechanism of composite solid propellants, the structure formed during the burning of stoichiometric model mixtures was investigated. The following oxidants were used in the mixtures: ammonium perchlorate, which does not melt, but is self-inflammable at 360° to 380° C; potassium perchlorate, which melts with decomposition at 610° C; and sodium perchlorate, which melts at 482° C and decomposes at 505° C. The following fuels having different physiochemical properties were selected for the investigation: graphite, which does not melt and does not decompose; tungsten, which melts at about 3200° C; naphthalene, which melts and sublimes at 80° C; starch, which melts and decomposes at 260° C; succinic acid, which melts at 185° and decomposes at 235° C; and malonic acid, which melts at 135.6° C. Among the conclusions drawn from this investigation was that in the pressure region of less than 30-atm absolute, oxidant crystals appear on the surface of burning mixtures containing the nonmelting oxidant ammonium perchlorate and of fuels melting or decomposing at temperatures close to the oxidant decomposition temperature. E.E.B.

N65-25747# Radiation Applications, Inc., Long Island City, N. Y.
RADIATION-INDUCED SOLID PROPELLANT DECOMPOSITION Final Technical Report
15 Jan. 1965 28 p refs
(Contract AF 49(638)-1125)
(RAI-347; AFOSR-65-0429; AD-612536)

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 radiolysis. Irradiated ammonium perchlorate was analyzed for its chlorate, chlorine dioxide, chlorite, hypochlorite, chlorine, chloride, and total nitrite and nitrate content. The radiolytic yields are tabulated. The products of metal and ammonium perchlorate radiolysis were compared. Chlorate is a major product for both but am-

monium chlorate 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.

N65-26246# Bureau of Mines, Pittsburgh, Pa. Explosives Research Center

SENSITIVITY OF PROPELLANT SYSTEMS Quarterly Report, Jan. 1–Mar. 31, 1965

F. C. Gibson, R. W. Watson, J. E. Hay, C. R. Summers, J. Ribovich et al 21 May 1965 43 p

(BuWeps Order 19-65-8023-Weps)

(AD-464200)

The effects of scaling on the high-velocity–low-velocity and low-velocity–non-initiation thresholds were completed for nitroglycerin–ethylene glycol dinitrate–triacetin (NG–EGDN–TA) systems. As anticipated, there was a well-defined relationship between scale size and sensitivity. Also, acetone as a desensitizer of NG–EGDN was compared with triacetin and found to be somewhat more effective in suppressing the low-velocity detonation, although the high-velocity detonation threshold characteristics were essentially unchanged. A further examination was made of the role of occluded gas on the development of the cavitated region ahead of the low-velocity detonation reaction zone by comparing the behavior of vacuum degassed NG–EGDN with the material as-received. Although there were observed differences in the cavity sizes and the propagation rates, the response to a given stimulus was essentially the same. E.E.B.

N65-26321# Rocketdyne, Canoga Park, Calif.

BASIC PHYSICAL PROCESSES OF SOLID PROPELLANT COMBUSTION: RESUME OF FIRST YEAR'S ACTIVITIES

L. W. Carlson 19 Mar. 1964 44 p

(Contract AF 49(638)-1208)

(HTUM-64-14; AD-461596)

Basic physical processes of solid propellant combustion were studied in an experimental and analytical program. Emphasis was placed on factors influencing unstable combustion; in particular propellant surface response to non-linear (shock) pressure disturbances, for aluminized and non-aluminized propellants. The past year's effort was limited to studying the effects that transient pressure disturbances have on the phenomena which occur at burning solid propellant surfaces, and developing techniques for making these studies; a model combustion chamber and shock tube assembly was used in the experimental portion of the program. Electronic Data Processing Machine (EDPM) programs were used to analyze the experimental data generated. The four experimental phases were divided into two study categories: in two of the phases grazing incidence waves were studied, two phases examined normal incidence waves. One of the grazing wave studies carried out in the model combustion chamber called the Pancake Motor; the other three were done in a shock tube, which is modified with internal apparatus for each individual experiment. Author

N65-26368# Atlantic Research Corp., Alexandria, Va.

DYNAMIC MECHANICAL PROPERTIES OF SOLID PROPELLANTS Quarterly Technical Summary Report, 1 Jun.–31 Aug. 1964

C. N. Robinson Oct. 1964 33 p refs

(Contract NOw-64-0189-c; ARPA Order 22-61)

(QTSR-3; AD-461609)

The dynamic shear properties of selected solid propellants and the effects of certain variables on these properties are being investigated. Problems in the Fitzgerald apparatus temperature monitoring system were eliminated and earlier data corrected. Dynamic shear modulus measurements were made on a new batch of TPH-1001 polybutadiene acrylonitrile propellant. Comparisons of these data with results from an earlier batch show a significant difference between the mixes. Dynamic shear modulus data were obtained showing accelerated aging effects on the TPH-1001 propellant and moisture effects on the AEBA-10 polyurethane propellant. R.N.A.

N65-26647*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

ARC-JET THRUSTOR FOR SPACE PROPULSION

Lewis E. Wallner and Joseph Czika, Jr. Washington, NASA, Jun. 1965 72 p refs

(NASA-TN-D-2868) CFSTI: HC $3.00/MF $0.75 CSCL 21H

The arc-jet thrustor represents an engine for potential space applications requiring a specific impulse in the range from 1000 to 2000 seconds. As such it was originally thought that missions for the engine would fit somewhere between those suitable for the high thrust chemical and the very low thrust ion propulsion systems. The considerable effort expended to develop the arc thrustor has resulted in operation in the power range from 1 to 200 kilowatts, at specific impulse levels between 1000 and 2000 seconds, and for continuous running as long as 500 hours with overall efficiency up to 55 percent. Progress has been made on many of the early operating problems such as electrode-erosion, nozzle-cooling, and propellant-feed systems. In addition, theories have been advanced to explain, at least partially, the electric-arc operation. In substance then, the thermal arc-jet thrustor is now fairly well developed. Because of several factors unrelated to impulse and efficiency levels, however, the mission application of the arc thrustor is somewhat doubtful at the present time. These factors, for the larger arc-jet thrustor, include biological shielding, hardware availability, excessive electric generator weight, and reliability, for example. Author

N65-26788# Applied Physics Lab., Johns Hopkins Univ., Silver Spring, Md.

BULLETIN OF THE 3RD MEETING OF THE INTERAGENCY CHEMICAL ROCKET PROPULSION GROUP, WORKING GROUP ON MECHANICAL BEHAVIOR, VOLUME III

Apr. 1965 101 p refs Meeting held at Redstone Arsenal, Ala., 17–19 Nov. 1964

(Contract NOw-62-0604-c)

(CPIA Publ.-61-A; AD-463151)

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N65-26789 Office of Naval Research, Washington, D. C.
PROGRESS IN THE NAVY RESEARCH PROGRAM ON THE MECHANICAL BEHAVIOR OF SOLID PROPELLANT GRAINS. PART I: THE ONR CONTRACT PROGRAM. PART II: THE NAVY "IN-HOUSE" PROGRAM
J. M. Crowley and J. G. Tuono (Naval Propellant Plant) *In* APL Bull. of the 3d Meeting Interagency Chem. Rocket Propulsion Group Apr. 1965 p 3–19 refs Prepared jointly with Naval Propellant Plant (See N65-26788 16-27)

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.

N65-26790 Applied Physics Lab., Johns Hopkins Univ., Silver Spring, Md.
VISCOELASTIC BEHAVIOR INCLUDING NON-LINEAR EFFECTS
E. H. Lee *In its* Bull. of the 3d Meeting Interagency Chem. Rocket Propulsion Group Apr. 1965 p 51–55 refs (See N65-26788 16-27)

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.

N65-26791 Aerojet-General Cyrp., Sacramento, Calif.
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 *In* APL Bull. of the 3d Meeting Interagency Chem. Rocket Propulsion Group Apr. 1965 p 57–64 refs (See N65-26788 16-27)

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 gammagraphic examination of many stored motors of this type. Author

N65-26792 Aerojet-General Corp., Sacramento, Calif.
CHEMORHEOLOGICAL STUDIES OF CARBOXY-TERMINATED POLYBUTADIENE TYPE BINDER
P. C. Colodny, L. A. Waddle, and J. S. Wood In APL Bull. of the 3d Meeting Interagency Chem. Rocket Propulsion Group Apr. 1965 p 65–84 refs (See N65-26788 16-27)

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

N65-26793 Aerojet-General Corp., Sacramento, Calif.
AN OPTICAL SCANNING SYSTEM FOR MULTIAXIAL STRAIN MEASUREMENTS
C. C. Surland and G. R. Givan *In* APL Bull. of the 3d Meeting Interagency Chem. Rocket Propulsion Group Apr. 1965 p 85–99 ref (See N65-26788 16-27)

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.

N65-27000# American Ordnance Association, Washington, D. C. Materials Div.
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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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. N.E.A.

N65-27054*# United Technology Center, Sunnyvale, Calif. Engineering Dept.

HEAT TRANSFER STUDIES OF SOLID ROCKET IGNITERS Quarterly Progress Report No. 3

B. G. Mullis 15 Apr. 1965 10 p ref Prepared for JPL
(Contract NAS7-302)
(NASA-CR-63540; UTC-2096-QPR-3) CFSTI: HC $1.00/MF $0.50 CSCL 20M

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. R.N.A.

N65-27210# Auburn Univ., Ala.

A STUDY OF THE DECOMPOSITION MECHANISMS OF AMMONIUM PERCHLORATE Quarterly Progress Report, 22 Feb.–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.

N65-27399*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

INVESTIGATION OF ATLAS SOLID FUEL RETARDING ROCKET DURING ATLAS-CENTAUR SEPARATION TESTS

Richard W. Heath, Henry Synor, Ralph F. Schmiedlin, and John H. Povolny Washington, NASA, Jul. 1955 21 p refs
(NASA-TM-X-1119) CFSTI: HC $1.00/MF $0.50 CSCL 21H

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

N65-27842# Purdue Univ., Lafayette, Ind. Jet Propulsion Center.

CONTINUOUS MEASUREMENT OF SOLID PROPELLANT BURNING RATES Annual Report

J. R. Osborn, R. J. Burick, and P. Y. Ho Feb. 1965 57 p refs
(Grant AF-AFOSR-207-64)
(JPC-405; I-65-2; AD-616098)

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

N65-27959*# National Aeronautics and Space Administration. John F. Kennedy Space Center, Cocoa Beach, Fla.
LIQUID PROPELLANTS SAFETY HANDBOOK
George T. Carter 1 Apr. 1965 106 p refs
(NASA-TM-X-56611; SP-4-44-S) CFSTI: HC $4.00/MF $0.75 CSCL 21I

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 furfuryl-alcohol, anhydrous ammonia, aniline, ethylene oxide, liquid fluorine, hydrazine, hydrocarbons, liquid hydrogen, hydrogen peroxide, nitric acids, nitrogen tetroxide, liquid oxygen, unsymmetrical dimethlhydrazine (UDMH), UDMH, and UDMH/hydrazine mixture. Data on the physiological effects of these propellants are also included. S.C.W.

N65-28328# Lockheed Missiles and Space Co., Sunnyvale, Calif.
EXPERIMENTS WITH A SOLID-PROPELLANT ACOUSTIC OSCILLATOR: MATERIALS AND CHEMISTRY
J. F. Engler and W. Nachbar Jul. 1963 103 p refs
(Rept.-6-90-63-80; AD-615200)

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. Author

N65-28446*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
ANALYSIS OF FLUORINE ADDITION TO THE VANGUARD FIRST STAGE
William A. Tomazic, Harold W. Schmidt, and Adelbert O. Tischler Washington, NACA, 24 Jan. 1957 29 p refs
(NACA-RM-E56K28) CFSTI: HC $2.00/MC $0.50 CSCL 21I (Declassified)

The effect of adding fluorine to the Vanguard first-stage oxidant was analyzed. An increase in specific impulse of 5.74 percent may be obtained with 30 percent fluorine. 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 fluorine added. However, a change in tank configuration is required to accommodate the higher oxidant-fuel ratio necessary for peak specific impulse with fluorine addition. Increased performance of this order can be obtained without tank-configuration change by addition of unsymmetrical dimethyl hydrazine (UDMH) to the fuel coincident with fluorine addition to the oxidant. With 30 percent fluorine and approximately 51 percent UDMH, the burnout energy can be increased 23.5 percent. Fluorine addition will increase the engine heat-rejection rate about 1 percent for each 1 percent fluorine added up to 30 percent. Author

N65-28457*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
PERFORMANCE OF A COMPOSITE SOLID PROPELLANT AT SIMULATED HIGH ALTITUDES
Carl C. Ciepluch Washington, NASA, Dec. 1959 15 p refs (Declassified)
(NASA-TM-X-95) CFSTI: HC $1.00/MF $0.50 CSCL 21I

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. Author

N65-28598# Mathematical Sciences Corp., Seattle, Wash.
PARAMETRIC STUDY OF ROCKET GRAIN CONFIGURATIONS BY PHOTOELASTIC ANALYSIS Quarterly Progress Report No. 1, 4 Jan.–30 Apr. 1965
R. R. Parmerter and M. E. Fourney 1 May 1965 38 p refs
(Contract AF 04(611)-10529)
(MSC-65-29-3; AD-464943)

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.R.W.

N65-28606# Rocket Power, Inc., Pasadena, Calif. Research Labs.
STUDY OF ROCKET ENGINE EXHAUST PRODUCTS Quarterly Report, 1 Feb.–30 Apr. 1965
M. A. Greenbaum, R. E. Yates, J. A. Blauer, M. A. Frisch, M. Arshadi et al [1965] 23 p refs
(Contract AF 04(611)-7414)
(QR-15; AD-465142)

An intensive study of the surface effects on the equilibrium:

$$BeO(c) + H_2O(g) = Be(OH)_2(g)$$

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 $Be(OH)_2$. Author

N65-29103# Princeton Univ., N. J. Guggenheim Labs. for the Aerospace Propulsion Sciences.
SOLID PROPELLANT COMBUSTION MECHANISM STUDIES Nineteenth Progress Report, 1 Jan.–31 Mar. 1965
Thomas J. Ohlemiller, Joseph Wenograd, and Martin Summerfield Jun. 1965 30 p refs
(Contract Nonr-1858(32); ARPA Order 23)
(Rept.-446-r; AD-466278)

In the combustion of composite solid rocket propellants based on ammonium perchlorate, the important rate determining processes have generally been presumed to occur within the gas phase flame. Recent results obtained in this laboratory suggest that condensed phase processes could also be important, particularly in low pressure combustion. The

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 of 10 cal/cm^{2}sec have given burning rates of the order of 1/2 mm/sec with no evidence of a gas phase flame being present.
Author

N65-29300# Applied Physics Lab., Johns Hopkins Univ., Silver Spring, Md. Chemical Propulsion Information Agency.
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
(CPIA-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 Aerojet-General Corp., Sacramento, Calif. Combustion Dynamics Dept.
COMBUSTION STABILITY RESEARCH AT AEROJET-GENERAL
Frederick H. Reardon *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 25–37 (See N65-29300 18-33)

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 25000 lb. High-frequency combustion instability was induced by tangentially directed pulse generators located near the injector. Three injectors were used: (1) a conventional multiorifice 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
R. B. Lawhead *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 39–45 (See N65-29300 18-33)

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
Harry E. Bloomer *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 99–110 (See N65-29300 18-33)

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 20000 lb thrust level at a combustion chamber pressure of 300 psia with thrust variations to 5000 and 80000 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 flightweight 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
Vito D. Agosta, Sanford S. Hammer, and William T. Peschke *In* APPL Proc. of the 1st ICRPG Combust. Instability Conf. Vol. 1 Jan. 1965 p 153–164 (See N65-29300 18-33)
(Contract AF 49(638)-1263)

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
T. G. Rossmann *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 251–274 (See N65-29300 N65-29300 18-33)

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.

N65-29318 Lockheed Propulsion Co., Redlands, Calif.
LINEAR PYROLYSIS RATE MEASUREMENTS OF PROPELLANT CONSTITUENTS
R. L. Coates *In* APL Proc of the 1st ICRPG Combust. Instability Conf., Vol. I Jan. 1965 p 313–318 refs (See N65-29300 18-33)

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 sublimination 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.
THERMOPLASTIC SURFACE DEGRADATION-VAPORIZATION: A PIVOTAL BOUNDARY CONDITION FOR THEORIES OF SOLID PROPELLANT COMBUSTION PHENOMENA
Robert F. Mc Alevy, III *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 319–327 refs (See N65-29308 18-33)
(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 pivotally important 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 beads of the 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 perchloryl fluoride were employed. E.E.B.

N65-29320 National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
SPECTROGRAPHIC MEASUREMENTS OF COMPOSITE PROPELLANT FLAME ZONE STRUCTURE
Louis A. Povinelli *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. I Jan. 1965 p 331–333 (See N65-29300 18-33)

An experimental approach to the problem of flame structure based on flame radiation measurements is presented. The approach used was to burn propellant strands backlighted 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 adjancent 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
J. E. Crump *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. I Jan. 1965 p 367–370 (See N65-29300 18-33)

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
Louis A. Povinelli *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. I Jan. 1965 p 373–376 (See N65-29300 18-33)

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.

N65-29326 Princeton Univ., N. J.
ENTROPY WAVE OBSERVATIONS IN OSCILLATORY COMBUSTION OF SOLID PROPELLANTS
R. H. Woodward Waesche, Joseph Wenograd, and Martin Summerfield *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. I Jun. 1965 p 377-380 refs sponsored by AFOSR and ARPA (See N65-29300 18-33)

A search was made for entropy waves using photographic and radiometric techniques with a T-burner as the source of oscillating pressure. These experiments ranged from 75 to 1000 cps at pressures from 200 to 1000 psi. The propellant compositions included perchlorate composites and plastisol nitrocellulose types. The predicted entropy waves were not observed. The absence of these predicted waves implies that the simple flame zone models which were deduced from steady-state experiments to predict such waves may not be correct. Calculated flame temperature variations due to thermal lags in the solid phase were often quite large, although these variations could account for the absence of entropy waves only at the higher test frequencies. Since the experimental results do not confirm the theoretical predictions, further knowledge of steady-state combustion mechanisms is required before the dynamic coupling involved in combustion instability can be explained. E.E.B.

N65-29331 Aberdeen Proving Ground, Md. Ballistic Research Labs.
EXPERIMENTAL STUDY OF ACOUSTIC EROSIVITY EFFECTS ON SOLID PROPELLANT BURNING RATES
Leland A. Watermeier, William P. Aungst, and Richard C. Strittmater *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 413-423 refs (See N65-29300 18-33)

The burning rate variations were studied as functions of amplitude and frequency of gas oscillations parallel to the propellant burning surface. A standard, double-end burning T-motor was used as the basic apparatus with propellant test samples located at the velocity antinode of the self-excited oscillating system. Results indicate the following: (1) The burning rate of the test sample is increased when it is located at the velocity antinode of the chamber. (2) The increase in the test sample burning rate is dependent upon the amplitude of the particle or velocity displacement parallel to the burning surface up to a certain value. (3) The burning rate tends to drop or decrease as the amplitude exceeds a certain value. (4) The wall temperature at the end of the chamber and at the longitudinal center of the chamber may be as much as 50° to 100° K apart. These conclusions are preliminary and may be altered as more data become available. E.E.B.

N65-29335 Canadian Armament Research and Development Establishment, Valcartier (Quebec).
SOME FURTHER DATA ON NONLINEAR AXIAL-MODE INSTABILITY
A. K. Roberts and W. G. Brownlee *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 459-470 refs (See N65-29300 18-33)

Experiments were made to confirm and extend earlier data on axial combustion instability. The critical pressure is a function of propellant composition. Over the broad range of burning rates, higher critical pressures are associated with the faster propellants. This gross trend cannot be applied within a narrow burning rate range. For a given propellant, any single change in formulation which accelerates the burning rate tends to increase the critical pressure. At a given binder level the highest critical pressure is obtained when the aluminum level is such that the stable burning rate is a maximum. For a propellant with 10% aluminum, a reduction in the binder level from 25% to 20% by weight led to an increase in the critical pressure from 770 to 1575 psia. For a propellant with 27% binder and 17% aluminum, an increase in the critical pressure from 750 to about 1300 psia was obtained when 1% of copper chromate was added. Ferric oxide was not nearly as effective as copper chromite in promoting stability. A propellant containing 27% binder, 17% aluminum, and 1% copper chromite gave a critical pressure of about 1300 psia in an 8-inch diameter motor and 800 psia in the 17-inch diameter motor. E.E.B.

N65-29337 Utah Univ., Salt Lake City.
NONACOUSTIC, LOW-FREQUENCY COMBUSTION INSTABILITY OF SOLID PROPELLANTS
Norman W. Ryan *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. I Jan. 1965 p 477-480 (See N65-29300 18-33)

Preliminary results are presented for nonacoustic, low-frequency combustion instability studies for solid propellants. Data for TF propellant under conditions at which F propellant burns stably show that chuffing occurred throughout the test at a frequency of 25 cps. Oscillations are evident on the crests of later chuffs. A similar test of TF propellant extending to larger values of combustor volume to vent area ratio concluded with burning at a steady mean pressure with low-frequency oscillations that finally died away. The terminal rapid-fire chuffing in all runs was due to uneven burn-out. The structure of a single chuff on an expanded time scale is shown. The growth of nonacoustic oscillations to the degree that burning was quenched is clearly illustrated. It is not possible to draw any general conclusions from this work. Possibly, eventual conclusions will pertain quantitatively only to the burner used in the tests. Comparison of propellants with respect to the tendency toward nonacoustic instability should be possible. E.E.B.

N65-29339 Aerojet-General Corp., Sacramento, Calif.
SOLID PROPELLANT BURNING RATE UNDER TRANSIENT HEATING AND EXTINGUISHMENT VIA "L* INSTABILITY"
B. E. Paul, N. S. Cohen, and L. Y. Fong *In* APL Proc. of the 1st ICRPG Combust. Instability Conf. Jan. 1965 p 491-506 refs (See N65-29300 18-33)

An expression has been derived describing the burning rate as a function of dp/dt as well as of p. This expression, earlier applied to transient ballistics problems such as the ignition interval, has recently been employed to analyze the initiation of solid propellant extinguishment. Permanence of extinguishment by L* instability is shown to be governed by ignition theory; it is hypothesized that the instability may really be successive instances of extinguishment followed by reignition It is suggested that this basic approach now be applied to oscillatory transients, such as acoustic instability, for purposes of computing the response function. The analysis should consider transient heating in general, i.e. due to velocity as well as pressure fluctuations, to note pressure and velocity coupling. Qualitative prediction of some experimental trends are encouraging. Author

N65-29340 Naval Ordnance Test Station, China Lake, Calif.
L* COMBUSTION INSTABILITY
E. W. Price *In* APL Proc. of the 1st ICRPG Combust. Instability Conf., Vol. 1 Jan. 1965 p 507-512 refs (See N65-29300 18-33)

The low-frequency oscillatory behavior of solid propellant combustion was studied in a low L* (combustor volume to vent area ratio) burner which exhibits low frequency oscillations, chuffing, and quenching with most propellants. Typical results are illustrated which show the variation of oscillation

frequency with mean pressure for several aluminum concentrations, oxidizer particle sizes, and aluminum particles sizes with two different binders. The investigation of the preferred frequency characteristics of propellant combustion was also investigated 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 oscillations 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 Presented 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 emphasis 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 failure 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 systems 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 explosive hazard of large solid-propellant booster. This program consists of two major areas of technical inquiry: critical diameter 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 HYDROGEN AND GASEOUS OXYGEN Final Report, Jun. 1, 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 compositions, in vessels of size comparable to interstage compartments, 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 ignitors and provided information on the detonability of hydrogen–oxygen mixtures in the absence of externally produced shock waves. N.E.A.

N65-29970# 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 literature was made and the information compiled in a form which discusses the value of this fuel in propellant combinations. Thermodynamic performance, payload comparisons, advantages, disadvantages, problems, and relative merits of respective combinations and systems are presented. A discussion of rocket performance parameters is included as a basis for a more complete understanding of the information presented in the above-mentioned areas. Author

N65-30211 Library of Congress, Washington, D. C. Aerospace Technology Div.
METHODS FOR STUDYING THE DYNAMICS OF SPACE VEHICLES
L. Kacinskas *In its* Foreign Sci. Bull., Vol. 1, No. 7 Jul. 1965 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 hydrodynamic coefficients. Numerical results obtained by theoretical and experimental methods are presented for bodies having cavities of various forms. A comparative analysis of theoretical and experimental results is made. Author

N65-30838*# Dynamic Science Corp., Monrovia, Calif.
A BASIC STUDY OF THE NITROGEN TETROXIDE–HYDRAZINE REACTION
Harold G. Weiss Jul. 1965 56 p refs Prepared for JPL
(Contracts NAS7-100; JPL-BE4-229751)
(NASA-CR-64338; SN-4500) CFSTI: HC $3.00/MF $0.50 CSCL 21I

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) immiscibility of the two reactants; (2) rapid reaction rate between N_2O_4 and N_2H_4; 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.

N65-31309 Aerospace Corp., El Segundo, Calif. Labs. Div.
CALCULATION OF EQUILIBRIUM ELECTRON AND ION CONCENTRATIONS
Eileen A. Cook *In* APL ICRPG Working Group on the Thermochem., 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 inclusion of ionic species to obtain electron densities and ionized product concentrations for solid propellants and re-entry ablative materials is considered. Author

N65-31601# Auburn Univ., Ala. Dept. of Mechanical Engineering.

SELECTED METHODS FOR DETERMINING THERMAL CONDUCTIVITY AND DIFFUSIVITY OF SOLID PROPELLANT Final Report

G. E. Tanger, S. C. Cheng, H. C. Kim, and G. H. Nix May 1965 44 p refs

(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 difusivity 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

N65-31611# Aerojet-General Corp., Sacramento, Calif. Grain Design Section.

THE INTEGRATED DESIGN COMPUTER PROGRAM AND THE ACP-1103 INTERIOR BALLISTICS COMPUTER PROGRAM

T. R. Threewit, R. A. Rossini, and R. L. Vecker 1 Dec. 1964 379 p

(Contract DA-04-200-ORD-1305(Z))

(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, diameters, lengths, and weights. The final design is optimized with respect to key parameters, and contains a grain design and a real propellant. The Integrated Program is a continuing effort to automate procedures for designing solid rocket systems, and its computer program reproduces human functions involved in conducting preliminary missile and propulsion design. The ACP-1103 Computer Program provides an incremental solution to the problem of one-dimensional gas flow with mass addition in a propellant bore. To achieve this solution, the designer must know the ballistic properties of the propellant, must have a description of all ballistically significant parameters (throat area, firing temperature, and atmospheric pressure), and has to input an axially incremented description of burning-surface area and area of gas flow for each time point in the burning traverse of the grain. For grain designs of a more common type, the program automatically calculates these surface areas and areas of flow down the grain bore. R.R.D.

N65-31615# Purdue Univ., Lafayette, Ind. Jet Propulsion Center.

CONTINUOUS MEASUREMENT OF SOLID PROPELLANT BURNING RATES Final Report

J. R. Osborn, R. J. Burick, and R. F. Panella Jul. 1964 34 p refs

(Grant AF-AFOSR-207-63)

(JPC-386; F-64-3)

An experimental apparatus has been developed for the direct and continuous measurement of the burning rates of solid rocket propellants under conditions closely approximating those occurring in a solid rocket motor. The apparatus utilizes a positioning type servomechanism as a feed system which moves a sample of solid propellant within a two-dimensional rocket motor so that the receding burning surface of the sample is maintained at a fixed position with respect to the motor walls. Because the burning surface is maintained at a fixed position; the measurement of the velocity of the propellant feed system is identical with the burning rate. The servomechanism incorporates a 50 millicurie cesium-137 source of gamma rays coupled with a scintillation probe for detecting the position of the burning propellant surface. A ratemeter is employed for converting the output of the probe into a voltage which is then amplified and compared to a standard voltage that is proportional to a desired position for the propellant surface. The resulting difference in voltage is amplified and drives a 0.6 hp servomotor which positions the burning surface of the propellant sample; the dimensions of the latter were approximately 1 inch square by 4 inches long. Author

N65-31686# Stanford Research Inst., Menlo Park, Calif.

VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 2, 16 Dec. 1964–15 Mar. 1965

Nicholas W. Tschoegl, James R. Smith, and Thor L. Smith [1965] 29 p

(Contract NOw-65-0061-d; ARPA Order 22)

(Rept.-14; AD-465908)

The effect of specimen geometry and the magnitude of shear strain on the dynamic modulus of polyurethane propellant AEBA-10 was 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. An evaluation was made of the static compressibility apparatus by determining the compressibility of dioctylsebacate at 25 and 50 C and at pressures up to 2000 psi. Author

N65-31691# Aerojet-General Corp., Sacramento, Calif.

SOLID PROPELLANT-LINER BONDING INVESTIGATIONS Quarterly Report, 1 Mar.–31 May 1965

C. Gustavson Jun. 1965 56 p refs

(Contract AF 04(611)-9959)

(Rept.-0907-81Q-3; AD-465547)

Variables governing the apparent bond strength of polybutadiene propellant systems, imine-cured carboxy-terminated polybutadiene (CTPB) and epoxy-cured polybutadiene-acrylic acid-acrylonitrile terpolymer (PBAN) were investigated. The effects of solvent-extractable mobile ingredients, and the effect of the substrate polymer type were studied. Variations of the propellant formulation were investigated. The influence of the oxidizer on the characteristics of the propellant binder adjacent to the substrate surface, and the effect of CTPB prepolymer fractions on bonding were also studied. Although propellants are usually not formulated to enhance bonding, understanding of the ingredient-bonding relationship is useful in aiding the selection of substrate chemical composition. L.S.

N65-31960# Naval Ammunition Depot, Crane, Ind.

THE INVENTION OF A NEW TYPE OF FRICTION SENSITIVITY APPARATUS

Carl Armour and Lloyd Smith 11 Jun. 1965 26 p

RDTR-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

N65-32258*# Aerojet-General Corp., Sacramento, Calif.
260-IN.-DIA MOTOR FEASIBILITY DEMONSTRATION PROGRAM. VOLUME I: 260-SL MOTOR AFT-END IGNITION SYSTEM DEVELOPMENT Final Phase Report
20 Aug. 1962 275 p refs
(NASA-CR-54454; FPR-1) CFSTI: HC $6.00/MF $1.50 CSCL 21H

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 250-SL motor ignition system was fully demonstrated. Author

N65-32340# Stanford Research Inst., Menlo Park, Calif.
THE DETERMINATION OF WATER IN SOLID PROPELLANTS Final Technical Report, Jun.–Oct. 1964
R. F. Muraca Oct. 1964 22 p refs
(Contract AT(04-3)-115)
(UCRL-13136)

Two procedures are described for determining the water content of solid propellants containing nitrato 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 Karl 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

N65-32442* Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
ADVANCED LIQUID PROPULSION SYSTEMS
R. N. Porter, D. D. Evans, W. H. Tyler, W. F. Mac Glashan, and O. F. Keller *In its* Space Programs Sum. No. 37-33, Vol. IV 30 Jun. 1965 p162–171 refs (See N65-32410 21-11) CFSTI: HC $7.00/MF $1.75

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 miscibility is a major factor. Photographic studies showing the dropwise addition of N_2O_4 to N_2H_4 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.

N65-32723*# Pratt and Whitney Aircraft, West Palm Beach, Fla. Florida Research and Development Center.
INVESTIGATION OF COMBUSTION INSTABILITY WITH LIQUID OXYGEN AND LIQUID OR COLD GASEOUS HYDROGEN PROPELLANTS, PHASE II Quarterly Progress Report No. 3
W. J. Mc Anally 30 Mar. 1965 59 p refs
(Contract NAS8-11024)
(NASA-CR-64602; PWA-FR-1308) CFSTI: HC $3.00/MF $0.50 CSCL 21B

Twenty-five tests with the 1 × 5-inch two-dimensional slab motors were conducted during the third quarter. Initial analysis of test results confirms the previously observed stabilizing trends of increased hydrogen temperature, increased injection momentum ratio, and increased chamber contraction ratio. Detailed analysis will be presented in the final report. Author

N65-32949# United Research Services, Burlingame, Calif.
STUDY OF LIQUID PROPELLANT BLAST HAZARDS Quarterly Technical Documentary Report No. 6, 19 Dec. 1964–19 Mar. 1965
A. B. Willoughby, C. Wilton, and J. Mansfield Edwards AFB, Calif., AF Rocket Propulsion Lab., 8 Apr. 1965 91 p refs
(Contracts AF 04(611)-9558; AF 04(611)-10739)
(URS-652-1; AD-464970)

Progress is reported on a program to develop a philosophy for predicting credible damage potential which may be expected from the accidental explosion of liquid propellants during launch or test operations of missiles or space vehicles. During this report period emphasis was placed on a preliminary analysis of results from initial 200 lb cryogenic tests, the design of the experimental arrangement and test tankage for the second high velocity impact test series, the design of a method for implementing the selected S-IV failure mode, and consideration of the design of a small scale charge geometry study. R.N.A.

N65-33139*# Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
AN EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF COMBUSTION ON THE MIXING OF HIGHLY REACTIVE LIQUID PROPELLANTS
Bruce H. Johnson 15 Jul. 1965 25 p refs
(Contract NAS7-100)
(NASA-CR-64616; JPL-TR-32-689) CFSTI: HC $1.00/MF $0.50 CSCL 21I

The effects of combustion on the liquid-phase mixing of several storable liquid bipropellants were investigated. It was found that combustion effects were severe when nitrogen tetroxide was used as the oxidizer with various storable fuels, including hydrazine, unsymmetrical dimethylhydrazine, and monomethylhydrazine. Other combinations tested were found to be less affected by the combustion process. Several attempts were made to induce propellant mixing by mechanical means, and the effects of chemical inhibitors on the mixing process were investigated. None of the mechanical and chemical techniques studied influenced the prereaction mixing of the propellants to an appreciable extent. Author

N65-33353*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
MOTION OF LIQUID-VAPOR INTERFACE IN RESPONSE TO IMPOSED ACCELERATION
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. Author

N65-33884*# Marquardt Corp., Van Nuys, Calif.
DESIGN STUDY AND EVALUATION OF A MULTIFUEL ENGINE FOR A SPACE POWER SYSTEM Final Report, 19 Apr.–4 Jun. 1965
M. Arao and B. R. Chandler 15 Jul. 1965 132 p refs *Its* Rept.-6095
(Contract NAS9-857)
(NASA-CR-64897) CFSTI: HC $4.00/MF $1.00 CSCL 21H

The feasibility, performance, and endurance of a modified hypergolic ignition engine operating on gaseous hydrogen and oxygen was studied. Slight changes in the injector system, and the addition of a starting ignition glow plug were used to modify the original hypergolic engine. The wide range of engine power delivery including overspeed and overload, was demonstrated without damage with propellants at stoichiometric O/F ratios up to 8:1 and high volumetric expansion ratios of from 23:1 to 38:1. A detailed analysis of the propellant flow measurements and flow characteristics, combustion efficiency, indicator and heat rejection, performance improvement tests, and vacuum operation is given. An appendix contains performance comparisons of candidate H_2–O_2 power systems for extended missions in space. G.G.

N65-34151# California Inst. of Tech., Pasadena. W. M. Keck Lab. of Engineering Materials.
A RESEARCH PROGRAM ON SOLID PROPELLANT PHYSICAL BEHAVIOR Quarterly Reports Nos. 5 and 6, 1 Feb.–31 Jul. 1965
Aug. 1965 16 p refs
(Contract AF 04(611)-9572)
(MATSCIT-PS-65-4; AD-619699)

Microscopic theory of gum rubber failure and factorization of nonlinear viscoelasticity to constant load creep data are applied to the mechanical behavior of gum rubber vulcanizates. To test the failure theory, average stretch ratio is calculated and used in data reduction. For a viscoelastic body the time dependence of the shear modulus is factored from the time dependence of the stretch ratio, and creep data is plotted for enough different load levels to cover the range of break times up to 2000 min. At each instant the material behavior is shown to be essentially Mooney–Rivlinear; there is a marked deviation from linearity for strain less than 20% and the start of the usual upswing for stretches in excess of five. Standardized material characterizations studies deal with a Solithane system, an experimental resin, and Telagen CT. Computer programs are being developed in the area of material properties interconversions. M.W.R.

N65-34839# California Inst. of Tech., Pasadena. Firestone Flight Sciences Lab.
SOLID ROCKET STRUCTURAL INTEGRITY ABSTRACTS, VOLUME 2, NO. 2
R. A. Westmann, ed. Apr. 1965 127 p refs
(Contract AF 04(611)-9572)
(AD-464736)

CONTENTS:

ABSTRACTS

N65-34840 Illinois Univ., Urbana
A SUMMARY OF LINEAR VISCOELASTIC STRESS ANALYSIS
Harry H. Hilton *In* Calif. Inst. of Tech. Solid Rocket Structural Integrity Abstr. Apr. 1965 p 1–56 refs (See N65-34839 23-28)

Developments in linear viscoelastic stress analysis as they affect solid propellant grain analysis are summarized. In discussing stress–strain relationships, various experimental approaches resulting in analytical and/or graphical representations were reviewed. Such approaches to viscoelastic stress analysis as direct solutions, exact analogies, approximate analogies, and approximate solutions are briefly described. References are cited, and a bibliography is included to provide background material for a detailed study of the linear viscoelasticity field. M.G.J.

N65-34852# Rohm and Haas Co., Huntsville, Ala. Redstone Arsenal Research Div.
HIGH PRESSURE SOLID PROPELLANT COMBUSTION STUDIES USING A CLOSED BOMB
Richard B. Cole [1965] 63 p refs
(Contracts DA-01-021-ORD-11909(Z); DA-01-021-AMC-11536(Z))
(S-68; AD-471575)

A self-pressurizing closed-bomb system is described for observing deflagration characteristics of solid propellants at pressures as high as 200 000 psi. Regression rates are obtained by microwave interferometry, a newly-adapted method which eliminates the need for introducing foreign bodies in the forms of wires, probes, etc., into the system. Pressure measurements are made with strain gauges mounted on the exterior of the bomb body, obviating many sealing problems associated with conventional transducers. The relative merits of the available instrumentation are discussed; the principles

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

N65-35109*# Pennsylvania State Univ., University Park. Dept. of Engineering Mechanics.
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 21I

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 field 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.N.A.

N65-36443*# Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
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 21I

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

N66-10213# Princeton Univ., N. J. Dept. of Aerospace and Mechanical Sciences.
SOLID PROPELLANT COMBUSTION MECHANISM STUDIES Fifteenth and Sixteenth Progress Report, 1 Oct. 1963–31 Mar. 1964
Richard B. Cole and Joseph Wenograd 17 Jun. 1965 139 p refs
(Contract Nonr-1858(32); ARPA Order 23)
(Rept.-446-o; AD-467728)

Two composite solid propellant combustion experiments are reported; one deals with burning surface photomacroscopy, 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.

N66-10614*# Pennsylvania State Univ., University Park. Dept. of Engineering Mechanics.
STRESS-STRAIN BEHAVIOR OF AN INERT COMPOSITE PROPELLANT FOR MULTIAXIAL LOADING CONDITIONS Technical Report No. 2
M. G. Sharma and Y. S. Les Aug. 1965 42 p refs Prepared for JPL
(Contracts NAS7-100; JPL-950875)
(NASA-CR-67809) CFSTI: HC $2.00/MF $0.50 CSCL 21I

Research was conducted to determine the mechanical characterization of an inert composite propellant for biaxial loading conditions from its observed behavior under uniaxial tension loading. The effect of rate of loading on stress-strain behavior is considered. Experimental data are included on the behavior of the material under several biaxial stress fields for two rates of loading. The experimental data were compared with predicted values based on linear viscoelastic theory and finite viscoelastic theory. Results show that the effect of biaxial stress fields reduces the extension ratios in either tangential or axial directions. Mechanical behavior is a border line case where both linear and finite viscoelastic theories may apply and is somewhat substantiated by predictions based on linear viscoelastic theory. For a stress ratio of 1.681, predicted and experimentally determined axial stress-strain curves compare well. Deviations are great between experimental and theoretical values for unaxial tension for a stress ratio of 0, but are reasonably good for stress ratios of 0.824 and 1.288. R.N.A.

N66-10650*# Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
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 21H

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.

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 generant controller in the ALPS system and in the Mariner '66 system. Author

N66-10893# Stanford Research Inst., Menlo Park, Calif.
VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 15 (Report No. 3 for Contract Period), 16 Mar.–15 Jun. 1965
N. W. Tschoegl and J. R. Smith [1965] 18 p ref
(Contract NOw-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. Author (TAB)

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
R. B. Beyer, L. S. Bain, and R. O. Mac Laren 13 Sep. 1965 12 p
(Contract NOw-65-0463-c)
(UTC-2147-QPR-I; AD-470132)

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.

N66-11639# Stanford Research Inst., Menlo Park, Calif.
VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 14 (Report No. 2 for Contract Period), 16 Dec. 1964–15 Mar. 1965
Nicholas W. Tschoegl, James R. Smith, and Thor L. Smith [1965] 30 p
(Contract NOw-65-0061-d; ARPA Order 22)
(Rept.-14; AD-468430)

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. Author (TAB)

N66-12871*# Battelle Memorial Inst., Columbus, Ohio.
A STUDY OF SOLID-PROPELLANT VAPORIZATION AND DIFFUSION PROCESSES Final Technical Report
J. W. Droege, R. W. King, J. S. Mc Nulty, and A. Levy 31 Aug. 1965 32 p refs
(Contracts NAS7-100; JPL-950813)
(NASA-CR-68228) CFSTI: HC $2.00/MF $0.50 CSCL 21I

The vaporization and diffusion processes for dioctyl 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 dioctyl 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 3×10^{-3} times the area of exposed propellant surface, then one concludes that at about 30° C the loss of dioctyl adipate will be controlled by its 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. Author

N66-14010# Naval Radiological Defense Lab., San Francisco, Calif.
THE RADIOLYTIC DECOMPOSITION OF 1,1-DIMETHYLHYDRAZINE, 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 Hydyne generate respectively 199.0, 101.2 and 164.1 ml of radiolytic off-gas (measured at 25C and 1 atm) when irradiated to 8,500,000 rads with gamma rays. The result for Hydyne was calculated from those for 1,1-dimethylhydrazine and diethylenetriamine, Hydyne consisting of 60 wt-% of the former and 40 wt-% of the latter. When the samples contain 5 vol-% of the free radical scavenger methyl 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)

N66-14076 # Aerospace Corp., El Segundo, Calif. Aerodynamics and Propulsion Research Lab.
GENERAL RESEARCH. SOLUBILITIES OF N_2, He, AND Ar IN LIQUID N_2O_4
E. T. Chang and N. A. Gokcen 20 Oct. 1964 22 p refs
(ATN-64-(9228)-4)

The solubility of nitrogen, helium, and argon in liquid dinitrogen tetroxide has been measured over a wide pressure

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

N66-14228# Southwest Research Inst., San Antonio, Tex.
LUBRICATION RESEARCH AND TEST METHOD DEVELOPMENT FOR AEROSPACE PROPULSION SYSTEMS Technical Report, 15 Feb. 1964–15 Apr. 1965
B. B. Baber, W. R. Blackstone, and P. M. Ku Wright-Patterson AFB, Ohio, AF Aero Propulsion Lab., Aug. 1965 68 p refs (Contract AF 33(657)-11088)
(AFAPL-TR-65-70; AD-621072) CFSTI: HC $3.00/MF $0.75

This program was concerned with the further development of the ABMA impace tester and the investigation of different test methods used to determine the impact sensitivity of materials in contact with rocket propellants. It was found that the specimen cup material and design had a significant effect on plummet rebound height. The use of a modified anvil region assembly, including a steel specimen cup, significantly increased the reactivity of materials subjected to impace in the presence of LOX in addition to improving plummet rebound height repeatability. The 'up-and-down' test procedure, from which a statistical estimate of the drop height producing a 50-percent probability of reaction may be obtained was investigated. The results of 10 separate up-and-down tests on one grease material showed repeatability to be excellent. Results were also obtained for additional greases and these results showed that some greases rated as satisfactory had about the same 50-percent points as other greases considered unsatisfactory with the only apparent difference being the intensity of the reactions. Author (TAB)

N66-14560# Battelle Memorial Inst., Columbus, Ohio.
DEVELOPMENT OF LAMINATED SOLID PROPELLANTS Final Technical Report 15 Apr. 1961–30 Nov. 1963
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-4890-1; AD-622399) 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, buring is either enhanced or unchanged. Author (TAB)

IAA ENTRIES

A64-28533
PROPELLANT HEATING STUDIES WITH WALL AND NUCLEAR HEATING.
B. H. Anderson, S. C. Huntley, and D. J. Connolley (NASA, Lewis Research Center, Cleveland, Ohio).
American Society of Mechanical Engineers, Winter Annual Meeting, New York, N. Y., Nov. 29-Dec. 4, 1964, Paper. 30 p. 7 refs.

Description of an approximate method of obtaining the temperature history of a fluid contained in a tank which is subjected to nuclear and wall heating. Under conditions of relatively low wall heat flux, with and without nuclear heating, the temperature profiles obtained from the analysis are considered to agree well with experimental data. However, the temperature gradients in the fluid are said to differ slightly. With higher amounts of wall heating, this difference is more pronounced. This was caused primarily by the use of a simplified expression for the exponent used in describing the temperature profile. The approximate technique of assuming a plausible temperature profile that is made to satisfy the conservation of energy gives results considered sufficiently accurate to warrant further exploration. Eleven illustrations are presented, including a schematic diagram of the test apparatus, Schlieren photographs showing flow patterns resulting from nonuniform source and wall heating, and a temperature history of the liquid-hydrogen wall-heating experiment. D. H.

A65-10457
KINEMATICS OF THE BURNING SURFACE OF A PROPELLANT GRAIN.
O. P. Chugh (Defence Research and Development Organization, Scientific Evaluation Group, Delhi, India).
Indian Journal of Pure and Applied Physics, vol. 2, Aug. 1964, p. 254-259. 9 refs.

Application of the general law of burning to the study of the kinematics of the burning surface of a propellant grain. The procedure for finding the subsequent area of cross section, perimeter, and the rate of change of the perimeter of a directrix is explained in detail by two different methods - geometrical and analytical - and applied to a few typical cases. The procedure suggested is said to be simple and to give a better insight as to how the burning surfaces move. Also, the need to depend on any chart as in conventional practice is obviated. An approach for analyzing the behavior of the burning surface of a grain of any shape is indicated. For comparison, a few common designs of propellant grain are also presented diagrammatically, indicating how the burning surfaces move, and showing the formation of slivers, if any.
(Author) M. M.

A65-10468
EVALUATION OF THEORETICAL PROPELLANT PERFORMANCE. II - THEORETICAL METHOD OF DETERMINATION OF CHARACTERISTIC PARAMETERS OF LIQUID AND SOLID PROPELLANTS [EVALUATION DES PERFORMANCES THEORIQUES DES PROPERGOLS. II - METHODE THEORIQUE DE DETERMINATION DES PARAMETRES CARACTERISTIQUES DES PROPERGOLS LIQUIDES ET SOLIDES].
J. Boisson.
Doc-Air-Espace, Sept. 1964, p. 23-28. 5 refs. In French.

Theoretical method for determining the characteristic parameters of liquid and solid propellants. The subjects considered are: (1) basic thermodynamic data, (2) thermodynamic functions of gaseous combustion products and of condensed combustion products, (3) heat of formation, (4) calculation of the performance of chemical propellants, (5) calculation of the composition of a mixture in equilibrium at a given pressure and temperature, (6) calculation by equilibrium constants, and (7) calculation by the search for a mixture of minimum free energy. Other subjects include: (1) calculation of the combustion temperature, composition, and thermodynamic properties of the combustion mixture; (2) determination of the local flow characteristics during isentropic expansion; (3) calculation of theoretical performances; and (4) influence of the conditions of emplóyment on these performances. The relative results of various systems of chemical propellants are presented. M. M.

A65-10482
HYBRID PROPULSION TECHNOLOGY.
D. D. Ordahl and W. A. Rains (United Aircraft Corp., United Technology Center, Sunnyvale, Calif.).
Spaceflight, vol. 6, Nov. 1964, p. 182-186.

Comparison of hybrid propulsion systems with the liquid bipropellant and solid-propellant systems from which they are derived. Hybrid systems are described which use N_2O_4 for an oxidizer and a rubber-based solid fuel (which may or may not contain powdered metals). Such systems are said to have numerous advantages, including: ease and safety of processing because the grains will generally not sustain combustion; simplification of pressurization, valving, and injection problems (compared to bipropellant systems); and greater start/stop and throttling capabilities than solid-propellant systems. Potential applications of hybrid propulsion systems are said to cover the entire range from attitude control and orbital rendezvous of satellites to lunar-landing systems and launch vehicles having 24 million lb of thrust. M. M.

A65-10646
SOME BASIC STUDIES OF LIQUID PROPELLANT INJECTION PROCESSES.
J. D. Lewis (Ministry of Aviation, Rocket Propulsion Establishment, Westcott, Bucks., England).
(Royal Aeronautical Society, College of Aeronautics, and British Interplanetary Society, Rocket Propulsion Symposium, 2nd, Cranfield, England, Apr. 26, 27, 1962, Paper.)
Royal Aeronautical Society, Journal, vol. 68, Nov. 1964, p. 743-750; Discussion, p. 756-758. 12 refs.

Discussion of recent analytical studies of rocket-engine combustion based on propellant vaporization as the rate-controlling parameter. The studies by Spalding, and Priem and Heidmann, in particular, are thought to have contributed greatly to the understanding of the mechanism of stable combustion. Critical combustion experiments on a small-scale engine reportedly have shown fair agreement with vaporization predictions but have also revealed the need to understand and improve the mixing process. In parallel with performance measurements in a combustion system, detailed measurements of the atomization process including the break-up mechanism and drop-size distribution have been made. It is indicated that gaps exist in the present understanding of the subject and that further work remains to be done. It is thought that the high-speed photographic and gas-sampling techniques developed for these investigations provide useful research tools for more detailed studies of the problems. (Author) D. H.

A65-10967
HETEROGENEOUS COMBUSTION (PROGRESS IN ASTRONAUTICS AND AERONAUTICS. VOLUME 15).
Edited by Hans G. Wolfhard (Institute for Defense Analyses, Research and Engineering Support Div., Washington, D. C.), Irvin Glassman (Princeton University, Dept. of Aerospace and Mechanical Sciences, Guggenheim Laboratories for Aerospace Propulsion Sciences, Princeton, N. J.), and Leon Green, Jr. (USAF, Systems Command, Research and Technology Div., Washington, D. C.).
New York, Academic Press, Inc., 1964. 765 p.
Members, $8.25; nonmembers, $11.00.

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PREFACE. Irvin Glassman (Princeton University, Princeton, N. J.), Leon Green, Jr. (USAF, Washington, D. C.), and Hans G. Wolfhard (Institute for Defense Analyses, Washington, D. C.), p. ix-xi.

A65-11013 #

ON THE SPONTANEOUS IGNITION OF HYPERGOLIC PROPELLANT SYSTEMS AT LOW PRESSURES AND TEMPERATURES.

Paul C. Wilber, Michael A. Merrigan (Celestial Research Corp., South Pasadena, Calif.), P. Roy Choudhury (Southern California, University, Los Angeles, Calif.), Stephen P. Vango (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.), and William Lee (USAF, Systems Command, Flight Test Center, Rocket Propulsion Laboratory, Edwards AFB, Calif.).

Combustion Institute, Western States Section, Fall Meeting, Salt Lake City, Utah, Oct. 26, 27, 1964, Paper 64-29. 24 p.
Contract No. AF 04(611)-9890.

Preliminary results of an experimental program to determine the reaction characteristics of a typical hypergolic propellant pair in a low-pressure, low-temperature environment. The intent of the program is to uncover possible hazards to structure and personnel, occasioned by propellant leakage and condensation on cold surfaces in the chamber. Three reaction systems of different size (for scaling purposes) and two basically similar propellant pairs were used. Homogeneous and heterogeneous gas-gas, gas-condensed phase, and condensed phase-condensed phase reactions were studied. In most of the tests, the propellant pair consisted of a 50-50 blend of hydrazine and UDMH as a fuel and nitrogen tetroxide as the oxidizer. Hydrazine and nitrogen tetroxide served as the propellant pair in the

tests conducted in the smallest reactor. Energy sources of accidental ignition to be considered in the continuing research include: visual and UV radiation such as might be expected from a solar simulation system; hot gas and particle impact such as might result from the firing of vehicle attitude-control rockets; simulated and actual active elements of pressure instrumentation, including hot filaments, low-pressure electrical discharges, and radioactive sources; and mechanical impacts. W.M.R.

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. 5 refs.

Analysis of the explosive properties of propellant combinations such as LO_2/RP-1, LO_2/LH_2, and N_2O_4/Aerozene (50% UDMH-50% hydrazine), commonly used in the larger space vehicles. Consideration is limited to the blast-wave characteristics. The practice of expressing explosive effects of mixtures in terms of their equivaler TNT yield is found to be useful only for predicting long-distance damage. W.M.R.

A65-11167
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.
Seattle, Society of Aerospace Material and Process Engineers, 1963. 12 p.

Performance of Teflon, filled Teflon, butyl, Viton, ethylene propylene, polyethylene, silicone, and polybutadiene as resilient seal materials when exposed to N_2O_4, ClF_3, H_2O_2, and hydrazine/UDMH. The application of the materials in the form of metal-clad elastomeric O-rings and expulsion bladders is described. Expulsion 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 pentaborane 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.

A65-11496 #
SOLIDS - A NEW CHALLENGE.
I. Silver (U.S. Navy, Bureau of Naval Weapons, Washington, D.C.)
Astronautics and Aeronautics, vol. 2, Dec. 1964, p. 60-65.

Discussion of typical solid-propellant rocket performance since the Korean conflict, including extrapolations of future requirements in regard to design and performance. It is concluded: (1) that the potential for improved ballistic performance for solid-rocket motors remains high, but limiting factors such as storability, sensitivity, processability, and cost determine military applicability; (2) polybutadiene propellants continue to rate high for a wide variety of military rocket motors, particularly when there are extreme operational temperatures and high grain stresses; (3) problems such as radar attenuation, combustion instability, grain-acceptance criteria, and grain structural integrity require further investigation to improve the performance, safety, and reliability of solid-rocket motors; and (4) requirements for thrust controls limit the use of solid motors and this factor, coupled with the safety, reliability, and processing problems of high-performance solid motors, make liquid-rocket engines highly competitive for many advanced applications. D.H.

A65-11592 #
FLOW OF COMBUSTION GASES THROUGH A PERFORATION IN A SOLID PROPELLANT GRAIN.
John E. Bush (United Aircraft Corp., United Technology Center, Engineering Sciences Branch, Sunnyvale, Calif.).
AIAA Journal, vol. 2, Nov. 1964, p. 2022, 2023. 5 refs.

Analysis of the steady one-dimensional equilibrium flow of a perfect gas and condensed phase mixture in a duct whose cross-sectional area varies with length and whose mass-flow rate increases with length. An approximate solution that lends itself to hand calculations is presented, and eddy mixing effects due to abrupt expansions or contractions are also considered. F.R.L.

A65-13381
THE HYBRID ROCKET ENGINE.
Björn Ankarswärd (Svenska Flygmotor AB, Trollhättan, Sweden).
Interavia, vol. 19, Dec. 1964, p. 1838-1840.

Discussion of hybrid rocket engine research conducted at Svenska Flygmotor AB, including a brief description of work done at General Electric, United Aircraft's United Technology Center, and Aerojet General. At Svenska Flygmotor AB, white fuming nitric acid is used in combination with different solid fuels with hypergolic ignition characteristics developed by the company's chemical division. The combustion chamber has been designed for static tests for evaluating the internal ballistics of a hybrid engine, and the system employs an impinging-jet type of nitric acid injector. The most promising method of monitoring burning rate is said to be a continuous registering of grain thickness by means of ultrasonics, but this method is not yet fully approved. As a result of the experiments, a thrust program has been developed which involves a boost phase and a sustain phase with a thrust ratio of 5 to 1. In photographs of typical firings, shock diamonds are clearly visible in the case of high-pressure combustion but are much less distinct in the more divergent exhaust of the low-pressure combustion case. The hybrid engine is said to have only potential advantages at present, and these advantages have still to be proved by engines in production. D.H.

A65-14447 #
STRESSES AND STRAINS IN A LINEAR VISCOELASTIC SOLID PROPELLANT CHARGE.
Craig-Michael Waryjas (Illinois Institute of Technology, Chicago, Ill.).
AIAA Student Journal, vol. 2, Dec. 1964, p. 14-18. 5 refs.

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 encasement. 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.

A65-14537 #
A THEORETICAL MODEL FOR PREDICTING ALUMINUM OXIDE PARTICLE SIZE DISTRIBUTIONS IN ROCKET EXHAUSTS.
Harvey L. Fein (Atlantic Research Corp., Alexandria, Va.).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, Paper 65-10. 14 p.
Members, $0.50; nonmembers, $1.00.
Contract No. NOw 61-0687-c ; Jet Propulsion Laboratory Contract No. 950227.

Derivation of a model for the oxide-particle distribution obtained from the internal burning of cylindrically-perforated aluminized solid-propellant grains. Particle growth is assumed to occur by the diffusion of gaseous aluminum and aluminum oxides to the

particle surface, followed by a heterogeneous reaction to form condensed oxide, the overall rate being proportional to a concentration driving force and the particle area. The particle nucleation is assumed to be constant. Excellent agreement is obtained between experimental particle-size distributions and the distributions predicted by the model. This agreement implies that the distribution is independent of chamber length and possibly chamber diameter, and depends only on one arbitrary parameter which is characteristic of the nucleation rate. P.K.

A65-14544 #
LINEAR PYROLYSIS RATE MEASUREMENTS OF PROPELLANT CONSTITUENTS.
R. L. Coates (Lockheed Aircraft Corp., Lockheed Propulsion Co., Engineering Research Dept., Redlands, Calif.).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, 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^{-2}, 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).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, 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 scannings 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.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1-3, 1965, Paper 65-147. 16 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 by 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 viscoelastic 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 in defining the nature and extent of their nonlinearity. (Author) F.R.L.

A65-14743 #
THE MECHANICAL BEHAVIOUR OF CAST-DOUBLE-BASE PROPELLANTS IN ROCKET MOTORS.
H. M. Darwell, A. Parker, and H. Leeming (Imperial Metal Industries (Kynoch), Ltd., Summerfield Research Station, Propellant Dept., Kidderminster, Worcs., England).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1-3, 1965, Paper 65-161. 24 p. 9 refs.
Members, $0.50; nonmembers, $1.00.

Description of theoretical and experimental work aimed at the prediction of the mechanical behavior of solid propellant charges in rocket motors. Two extreme cases are considered, the quasi-steady thermal problem encountered when case-bonded motors are cooled at slow rates, and the problem of pressurization effects during ignition. Using suitable assumptions, analytical expressions are derived for the stress-strain-time fields. These are evaluated, using experimental data for cast-double-base propellants, and comparisons are made with values from motor tests. For the thermal problem, strains can be predicted up to failure, except for motors with high loading densities, where case distortion becomes important. Observed bond failures can only be accounted for by local imperfections. For rapid pressurization, results are given illustrating the effects of case stiffness, charge geometry and temperature, and ignition time. Methods of determining propellant mechanical properties are reviewed, and data from relaxation and constant strain-rate tests are presented for double-base formulations. These propellants are essentially nonlinear. Uniaxial failure results can be misleading, and comparisons are made with biaxial data. Theories of failure are examined, and predictions based on cumulative damage compared with experimental figures. Future work on combining the approaches is outlined. (Author) F.R.L.

A65-14801 #
REGRESSION RATE MECHANISMS OF NONMETALIZED HYBRID FUEL SYSTEMS.
L. D. Smoot and C. F. Price (Lockheed Aircraft Corp., Lockheed Propulsion Co., Engineering Research Dept., Redlands, Calif.).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, Paper 65-56. 28 p. 15 refs.
Members, $0.50; nonmembers, $1.00.
ARPA Contract No. DA 04-495-AMC 218(Z).

Investigation of the regression rate of rubber/fluorine/oxygen systems, using a laboratory-scale slab burner. Two different binder compounds are studied by varying the oxidizer from 100%

fluorine to 100% oxygen. The oxidizer flow rate and pressure are varied from 0.014 to 0.17 lb/in^2 -sec and 20 to 160 psia, respectively. It is found that,in the regions of low flow rate, the regression rate is independent of pressure, and increases as the 0.8 power of the specific total flow rate for each of the propellant formulations studied. At the higher flow rates, the regression rate is nearly independent of flow but increases markedly with pressure. Increasing the percent oxygen results in a reduction in the regression rate. The classical hybrid regression rate law was extended to include the effects of condensed-phase surface products and nonunity Prandtl number. Agreement between experimental and predicted regression rates is shown to be good in the low flow-rate regions where regression rates are independent of pressure. However, the classical turbulent "heat transfer" model does not account for the observed pressure dependence of regression rate in the high flow-rate regions Gas-phase reactions are postulated as the most likely cause of the observed pressure dependence. (Author) J.R.

A65-14833 #

PHOTOGRAPHIC STRAIN-MEASUREMENT TECHNIQUE.

John R. Ulrich (Aerojet-General Corp., Sacramento, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1-3, 1965, Paper 65-170. 16 p.
Members, $0.50; nonmembers, $1.00.

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 soft or inaccessible. 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.

A65-15614

CHEMICALLY RESISTANT MATERIALS FOR USE IN POSITIVE EXPULSION DEVICES.

Joseph Green, N. B. Levine, and R. C. Keller (Thiokol Chemical Corp., Reaction Motors Div., Denville, N.J.).

IN: CHEMICAL ENGINEERING TECHNIQUES IN AEROSPACE.
Edited by D. J. Simkin.
Chemical Engineering Progress, vol. 60, Symposium Series, no. 52. [A65-15607 06-28]
New York, American Institute of Chemical Engineers, 1964, p. 45-53. 10 refs.
Contracts No. AF 33(616)-7227; No. AF 33(657)-11093.

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 fluorine-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.

A65-15646

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

Pierre Larue and Maurice Guinet.

La Recherche Aérospatiale, Nov.-Dec. 1964, p. 11-18. 6 refs.
In French.

Description of one of the setups used by ONERA for experimental investigations of erosive burning in solid rocket propellants. Ionic 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.

A65-15841 #

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

O. Eizen, S. Rang, and L. Kudriavtseva (Akademiia Nauk Estonskoi SSR, Institut Khimii, Tallinn, Estonian SSR).

Eesti NSV Teaduste Akadeemia, Toimetised, Füüsika-Matemaatika- ja Tehnikateaduste Seeria, no. 4, 1964, p. 285-289. 9 refs. In Russian.

Investigation of the efficiency of adsorbtion chromotography, 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.

A65-16099 #

LIQUID FILM DRAIN FROM AN ACCELERATING TANK WALL.

John R. O'Loughlin (Boeing Co., Launch Systems Branch; Tulane University, New Orleans, La.).

AIAA Journal, vol. 3, Jan. 1965, p. 158.

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-vs-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.

A65-16138

PHOTOELASTIC OBSERVATIONS USING TOLYLENE DI-ISOCYANATE POLYURETHANE.

D. J. Bynum, L. U. Rastrelli, and R. C. DeHart (Southwest Research Institute, Dept. of Structural Research, San Antonio, Tex.).

(Experimental Mechanics, vol. 4, July 1964, p. 191-199.)
IN: SOCIETY FOR EXPERIMENTAL STRESS ANALYSIS, PROCEEDINGS. VOLUME 21, NUMBER 2.
Edited by B. E. Rossi.
Westport, Conn., Society for Experimental Stress Analysis, 1964, p. 191-199. 19 refs.
[For abstract see Accession no. A64-20827 17-26]

A65-16176 #

FAILURE BEHAVIOR OF COMPOSITE HYDROCARBON FUEL BINDER PROPELLANTS.

T. M. Jones and R. B. Kruse (Thiokol Chemical Corp., Huntsville, Ala.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1-3, 1965, Paper 65-156. 8 p. 6 refs.
Members, $0.50; nonmembers, $1.00.

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 inscribes 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.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D. C., Feb. 1-3, 1965, Paper 65-159. 22 p. 11 refs.

Members, $0.50; 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 conducted over 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 "Mullins effect" in a matrix with chemical adhesive 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 stress-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. Colli (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 predispersed 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 increased safety since, 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).

IN: FUELS AND NEW PROPELLANTS; FEDERAZIONE ASSOCIAZIONI SCIENTIFICHE E TECNICHE, CONFERENCE, MILAN, ITALY, JUNE 10-14, 1963, PROCEEDINGS. (INTERNATIONAL SERIES OF MONOGRAPHS IN AERONAUTICS AND ASTRONAUTICS. DIVISION IX - SYMPOSIA. VOLUME 17). [A65-16304 07-27] Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.

Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1964, p. 1-62. 59 refs. In Italian.

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.

A65-16306

FUELS FOR TURBOJETS AND RAMJETS.

Robert R. Hibbard and Walter T. Olson (NASA, Lewis Research Center, Cleveland, Ohio).

IN: FUELS AND NEW PROPELLANTS; FEDERAZIONE ASSOCIAZIONI SCIENTIFICHE E TECNICHE, CONFERENCE, MILAN, ITALY, JUNE 10-14, 1963, PROCEEDINGS. (INTERNATIONAL SERIES OF MONOGRAPHS IN AERONAUTICS AND ASTRONAUTICS. DIVISION IX - SYMPOSIA. VOLUME 17). [A65-16304 07-27] Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.

Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1964, p. 217-236. 20 refs.

Examination of the chemical possibilities for so-called high-energy fuels, with a review of findings pertinent to their application to flight propulsion. The heat developed per unit of fuel weight and volume, and per unit weight of combustion air, is considered. These characteristics are studied and compared for diboranes, pentaboranes, aluminum, and magnesium. Also, a comparison is made of the characteristics of conventional fuels in aircraft engine service. Problems of corrosion are considered, as well as the physical properties of the fuels as they affect the distribution system. Combustion chamber requirements at high temperatures, and deposit formation are discussed. The qualities of fuels with reference to their use in heat exchangers are examined; at very high speeds the problem of thermal stability arises, and economic factors are important. Experiments are being carried out by NASA on fuel tanks to reproduce all flight conditions. It is hoped to determine the necessary qualities of fuels for supersonic aircraft, cooling being the most important problem. Economic factors which affect the use of certain types of fuels are analyzed, and possible future research is briefly discussed. F. R. L.

A65-16308

RECENT ADVANCES IN THE CHEMISTRY OF LIQUID AND SOLID PROPELLANTS.

Walter H. Jones (Institute for Defense Analyses, Washington, D.C.).

IN: FUELS AND NEW PROPELLANTS; FEDERAZIONE ASSOCIAZIONI SCIENTIFICHE E TECNICHE, CONFERENCE, MILAN, ITALY, JUNE 10-14, 1963, PROCEEDINGS. (INTERNATIONAL SERIES OF MONOGRAPHS IN AERONAUTICS AND ASTRONAUTICS. DIVISION IX - SYMPOSIA. VOLUME 17). [A65-16304 07-27] Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.

Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1964, p. 249-259; Discussion, Masaniello Riccardo Corelli (Roma, Università, Scuola di Ingegneria Aerospaziale, Rome, Italy) and Aurelio C. Robotti (Torino, Politecnico, Scuola di Ingegneria Aerospaziale, Turin, Italy), p. 260-264. 16 refs. In English and Italian.

Review of research in propellant chemistry, with special reference to the search for higher specific impulse. This involves both flame temperature elevation and molecular weight reduction. Higher flame temperatures are being achieved through preparation of new oxidizers and by discovery of new combustion products. Molecular weight reduction is being attained by preparation of new fuels and by discovery of novel formulations of known materials. In the course of this research, the distinction between solid and liquid propellant chemistry is becoming of progressively lesser

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.).
IN: FUELS AND NEW PROPELLANTS; FEDERAZIONE ASSOCIAZIONI SCIENTIFICHE E TECNICHE, CONFERENCE, MILAN, ITALY, JUNE 10-14, 1963, PROCEEDINGS. (INTERNATIONAL SERIES OF MONOGRAPHS IN AERONAUTICS AND ASTRONAUTICS. DIVISION IX - SYMPOSIA. VOLUME 17). [A65-16304 07-27]
Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1964, p. 265-278; Discussion, Massimo Pallotta (Bombrini Parodi-Delfino S.p.A., Rome, Italy), p. 279. In English and Italian.

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.
Adelbert O. Tischler (NASA, Office of Manned Space Flight, Washington, D.C.).
IN: FUELS AND NEW PROPELLANTS; FEDERAZIONE ASSOCIAZIONI SCIENTIFICHE E TECNICHE, CONFERENCE, MILAN, ITALY, JUNE 10-14, 1963, PROCEEDINGS. (INTERNATIONAL SERIES OF MONOGRAPHS IN AERONAUTICS AND ASTRONAUTICS. DIVISION IX - SYMPOSIA. VOLUME 17). [A65-16304 07-27]
Conference sponsored by the Consiglio Nazionale delle Ricerche. Edited by Corrado Casci.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1964, p. 281-343; Discussion, Giancarlo Ghidoli (Consiglio Nazionale delle Ricerche, Centro Nazionale di Ricerche sulla Tecnologia della Propulsione e dei Materiali Relativi, Milan, Italy), p. 344-352. In English and Italian.

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 for 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 at length. The emphasis is on liquid propellants, with limited mention of solid propellants. F.R.L.

A65-16612 #
PROPELLANT FAILURE CRITERIA.
J. W. Jones (Lockheed Aircraft Corp., Lockheed Propulsion Co., Redlands, Calif.) and W. G. Knauss (California Institute of Technology, Pasadena, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1-3, 1965, Paper 65-157. 5 p. 12 refs.
Members, $0.50; nonmembers, $1.00.
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 with a maximum tensile stress 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.).
AIAA Journal, vol. 3, Feb. 1965, p. 354-357. 9 refs.
Contract No. NOw 61-0905-c.

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 depend 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.).
(WESTERN ELECTRONIC SHOW AND CONVENTION, LOS ANGELES, CALIF., AUGUST 25-28, 1964, TECHNICAL PAPERS. VOLUME 8. PART VI - INSTRUMENTATION, p. 14.2-1 to 14.2-7.)
IEEE Transactions on Aerospace, vol. AS-3, Feb. 1965, p. 22-29.
[For abstract see Accession no. A64-28285 24-15]

A65-18870 =
RESEARCH ON HYBRID PROPELLANTS [RECHERCHES SUR LES PROPULSEURS HYBRIDES].
André Moutet and H. Moutet (ONERA, Châtillon-sous-Bagneux, Seine, France).
(Centre National d'Etudes Spatiales, Journées d'Etude sur la Propulsion Chimique, Paris, France, May 4-6, 1964, Paper.)
ONERA, TP no. 140, 1964. 41 p. 23 refs. In French.

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.

A65-19132
SOME INVESTIGATIONS AND PRELIMINARY RESULTS OF DEVELOPMENTS IN UPPER STAGE ENGINES FOR ELDO ROCKETS [EINIGE UNTERSUCHUNGEN UND ERGEBNISSE DER VORENTWICKLUNG DER OBERSTUFENTRIEBWERKE FÜR ELDO-TRÄGERRAKETEN].
Otfried Stumpf (Entwicklungsring Nord, Bremen, West Germany).
Luftfahrttechnik Raumfahrttechnik, vol. 11, Feb. 1965, p. 47-54. 7 refs. In German.

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.).
AIAA Journal, vol. 3, Mar. 1965, p. 418-426. 5 refs.
Contract No. NOw 62-0604-c.

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 EROSIVE BURNING CHARACTERISTICS OF A NONHOMOGENEOUS SOLID PROPELLANT.
M. J. Zucrow, J. R. Osborn, and J. M. Murphy (Purdue University Lafayette, Ind.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-107.)
AIAA Journal, vol. 3, Mar. 1965, p. 523-525. 5 refs.
Contract No. AF 04(611)-7445.
[For abstract see Accession no. A64-13041 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.).
AIAA Journal, vol. 3, Mar. 1965, p. 540-542.
Research supported by the Lockheed Missiles and Space Co.

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 (0.8) are excessive. 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).
AIAA Journal, vol. 3, Mar. 1965, p. 554.
Research supported by the Aeronautical Research Committee of the Council of Scientific and Industrial Research.

Results of investigations of the hypergolization 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 NO_2 in the ignition reaction is not clear. Further studies are in progress. M. M.

A65-20887 #
SOLID PROPELLANT GRAIN STRUCTURAL ANALYSIS USING THE DIRECT STIFFNESS METHOD.
B. L. Black, J. M. Daly, and L. D. Webb (North American Aviation, Inc., Rocketdyne Div., Solid Rocket Div., McGregor, Tex.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, 6th, Washington, D.C., Feb. 1-3, 1965, Paper 65-176. 32 p. 11 refs.
Members, $0.50; nonmembers, $1.00.

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 pressurization, and acceleration forces acting on grains contained in cylindrical and tapered elastic cases. One program is for systems with irregular cross sections assumed to be in plane strain; the second is for axisymmetric systems with irregular longitudinal profiles. Grain end release from the outer case, arbitrarily distributed pressure and thermal loading, orthotropic properties, and grains bonded 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.).
Journal of Spacecraft and Rockets, vol. 2, Mar.-Apr. 1965, p. 239-243. 5 refs.
Contract No. DA-01-021-AMC-10037(Z).

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

on a digital computer. The solution of the transformed problem in the annulus and the correspondence of points between the two geometries provide a solution for the star geometry. Results of computations for the exothermic cure of a star-perforated grain with a capacitive inner boundary condition and a convective outer boundary condition are compared with a similar problem having convection on both boundaries. The cool-down history of a fully cured grain having convection on both boundaries is illustrated.
(Author) M.M.

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. Iushko.
(Akademiia Nauk SSSR, Doklady, vol. 158, Oct. 1964, p. 1051-1053.)
Soviet Physics - Doklady, vol. 9, Apr. 1965, p. 851-853. 10 refs. 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 5×10^{-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 $L \gg l$ (where l is the distance from the light source S to the reflecting surface), the image spread amounts to $2\alpha l$, which, under actual experimental conditions ($l \sim 50$ mm), enables a value for $\alpha \gg 0.01$ 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 mirror nature of the light reflection from the detonation front should be an unambiguous criterion of the absence of a spinning or nonuniform pulsating detonation regime. F.R.L.

A65-21450 =
NUCLEAR HEATING AND PROPELLANT STRATIFICATION.
Edward E. Duke (Aerojet-General Corp., Sacramento, Calif.).
AIAA Journal, vol. 3, Apr. 1965, p. 760-762. 7 refs.

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 PROPERGOLS LIQUIDES AYANT PRESENTE DES CARACTERES NETS D'INSTABILITE DE HAUTE FREQUENCE].
Fouesnant (Ministère des Armées, Laboratoire de Recherches Balistiques et Aérodynamiques, Vernon, Eure, France).
Centre National d'Etudes Spatiales, Semaine d'Etudes sur la Propulsion Chimique, Paris, France, May 4-6, 1964, Paper. 10 p. 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 chambe 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 gas 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 OXYGENE ET HYDROGENE LIQUIDES].
J. Dardare (Société d'Etude de la Propulsion par Réaction, Argenteuil, Seine-et-Oise, France).
Centre National d'Etudes Spatiales, Semaine d'Etudes sur la Propulsion Chimique, Paris, France, May 4-6, 1964, Paper. 16 p. In French.

A survey divided into three parts considering (1) the performance and chief properties of LO_2/LH_2, (2) specific problems relating to its use in rocket engines, and (3) the general activities in this field of the Societe d'Etude de la Propulsion par Reaction. Specific performance data indicate the superiority of LO_2/LH_2 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.
P. J. Mayo, L. A. Watermeier, and F. J. Weinberg (London, University, Imperial College of Science and Technology, Dept. of Chemical Engineering and Chemical Technology, London, England).
Royal Society (London), Proceedings, Series A, vol. 284, Mar. 23, 1965, p. 488-498. 11 refs.

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) P.K.

A65-23036 #
ON THE METHODS OF EVALUATING THE DECOMPOSITION RATE OF CONCENTRATED HYDROGEN PEROXIDE.
Kyosuke Yamada and Kiyosi Nisioka (Defense Academy, Dept. of Aeronautical Engineering, Yokosuka, Japan).
Japan, Defense Academy, Memoirs, vol. 4, Jan. 1965, p. 285-303.

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 pack are discussed under simplified assumptions. (Author) M.M.

A65-23062 #
PROPULSION WITH CHORD GRAINS.
D. Helman and E. Spiegler (Ministry of Defence, Scientific Dept., Tel Aviv, Israel).
(Israel Journal of Technology, vol. 3, Feb. 1965, p. 38-49.)
IN: ISRAEL ANNUAL CONFERENCE ON AVIATION AND ASTRONAUTICS, 7TH, TEL AVIV AND HAIFA, ISRAEL, FEBRUARY 23, 24, 1965, PROCEEDINGS. [A65-23055 13-01]
Conference sponsored by the Israel Ministry of Transport; Israel Ministry of Defence; National Council for Civil Aviation; Technion - Israel Institute of Technology; Paz Oil Co., Ltd., Paz Aviation Service; El-Al, Israel Airlines, Ltd.
Jerusalem, Weizmann Science Press of Israel; Jerusalem Academic Press, Ltd., 1965, p. 38-49.

An investigation of the ballistic behavior and the technological 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 thrust-time program of an engine with a chord grain is defined by the engine dimensions and by the ballistic properties of the chord and 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.

A65-24295
IGNITION DELAY FOR HYPERGOLIC ROCKET PROPELLANTS [ÜBER DEN ZÜNDVERZUG HYPERGOLER RAKETENTREIBSTOFFE].
G. Spengler and J. Bauer (München, Technische Hochschule, Munich, West Germany).
Brennstoff-Chemie, vol. 46, Apr. 1965, p. 117-124. 14 refs. In German.

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 HNO_3, N_2O_4, H_2SO_4, and H_2O_2 as oxidizers and furfuryl 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 μ. 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.

A65-24430 #
COMBUSTION TERMINATION OF SOLID ROCKET MOTORS.
H. J. Taback, E. E. Day, and T. P. Browne (Aerojet-General Corp., Solid Rocket Operations, Space Booster Div., Advanced Development Dept., Sacramento, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-229.)
Journal of Spacecraft and Rockets, vol. 2, May-June 1965, p. 332-337. 20 refs.

A65-24434 #
BALLISTIC BEHAVIOR OF SOLID PROPELLANT GRAINS UNDER HIGH ACCELERATION.
Z. H. Landau and J. M. Cegielski (Douglas Aircraft Co., Inc., Missile and Space Systems Div., Santa Monica, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-228.)
Journal of Spacecraft and Rockets, vol. 2, May-June 1965, p. 358-362.

A65-24440 #
COLLECTION OF LIQUID PROPELLANTS IN ZERO GRAVITY WITH ELECTRIC FIELDS.
J. B. Blackmon (Douglas Aircraft Co., Inc., Missile and Space Systems Div., Advance Propulsion and Power Dept., Santa Monica, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-265.)
Journal of Spacecraft and Rockets, vol. 2, May-June 1965, p. 391-398. 26 refs.

A65-24446 #
A PRELIMINARY APPRAISAL OF THE CORNUCOPIA CONCEPT.
C. J. Swet (Johns Hopkins University, Applied Physics Laboratory, Space Development Div., Silver Spring, Md.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-213.)
Journal of Spacecraft and Rockets, vol. 2, May-June 1965, p. 431-436. 9 refs.

A65-24452 #
SOME ASPECTS OF THE APPLICATIONS OF HYBRID PROPULSION SYSTEMS.
A. L. Wahlquist and G. C. Panelli (Lockheed Aircraft Corp., Lockheed Propulsion Co., Redlands, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-225.)
Journal of Spacecraft and Rockets, vol. 2, May-June 1965, p. 452, 453.

A65-24744 #
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. 30, no. 4, Feb. 1965, Report no. 395, p. 101-114. 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 216.33 sec at a mixture ratio of 3.575. The chamber pressure was 20 atm. (Author) B. B.

A65-26114 #
ACCELERATION OF BURNING RATE OF COMPOSITE PROPELLANTS BY SOUND WAVES.
Isidor Elias (Acoustica Associates, Inc., Los Angeles, Calif.), Henry Cheung, and Norman S. Cohen (Aerojet-General Corp., Solid Rocket Plant, Propellant Ballistics Laboratory, Los Angeles, Calif.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-108.)
AIAA Journal, vol. 3, June 1965, p. 1167, 1168.
Contracts No. NASw-64; No. NAS 7-69.

A65-26433 #
THE CHEMISTRY OF SUBLIMING SOLIDS FOR MICRO THRUST ENGINES.
Alexander P. Hardt, W. M. Foley, and R. L. Brandon (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Palo Alto, Calif.).
American Institute of Aeronautics and Astronautics, Propulsion Joint Specialist Conference, Colorado Springs, Colo., June 14-18, 1965, Paper 65-595. 12 p. 18 refs.
Members, $0.50; nonmembers, $1.00.
Research sponsored by the Lockheed Independent Research Program.

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 (10^{-6} 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 COMBINATIONS AS LIQUID ROCKET PROPELLANTS.

Arthur I. Masters (United Aircraft Corp., Pratt and Whitney Aircraft Div., West Palm Beach, Fla.).

American Institute of Aeronautics and Astronautics, Propulsion Joint Specialist Conference, Colorado Springs, Colo., June 14-18, 1965, Paper 65-581. 16 p.
Members, $0.50; nonmembers, $1.00.
Contract No. NAS 3-4195.

Discussion of the properties of high-energy rocket fuels consisting of fluorine-oxygen (FLOX) mixtures plus such low-molecular-weight parafinic and olefinic hydrocarbons as methane, ethane, ethylene, and propane. The FLOX-hydrocarbon combinations provide high theoretical I_{sp} 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 MULTIREACTION ROCKET NOZZLE EXPANSIONS.

V. J. Sarli, W. G. Burwell, R. Hofland, Jr. (United Aircraft Corp., Research Laboratories, East Hartford, Conn.), and T. F. Zupnik (United Aircraft Corp., Pratt and Whitney Aircraft Div., East Hartford, Conn.).

American Institute of Aeronautics and Astronautics, Propulsion Joint Specialist Conference, Colorado Springs, Colo., June 14-18, 1965, Paper 65-554. 20 p. 18 refs.
Members, $0.50; nonmembers, $1.00.
Contracts No. NASw-366; No. NAS 3-2572.

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 H_2-O_2, H_2-F_2, N_2O_4 - 50% N_2H_4/50% 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 H_2-F_2 and hydrocarbon-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 recombination mechanisms are indicated, and the agreement possible between the results of exact and approximate analyses when use 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.).

American Institute of Aeronautics and Astronautics, Propulsion Joint Specialist Conference, Colorado Springs, Colo., June 14-18, 1965, Paper 65-559. 16 p. 17 refs.
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.)
Pyrodynamics, vol. 2, Mar. 1965, p. 133-143. 7 refs.
[For abstract see Accession no. A64-17823 12-26]

A65-27411 #

EXPERIMENTAL PERFORMANCE OF OF_2/B_2H_6 UNDER SEA LEVEL AND SIMULATED SPACE CONDITIONS.

Melvin Sussman, Mario Luperi, and Albert Merrill (Thiokol Chemical Corp., Reaction Motors Div., Denville, N. J.).

American Institute of Aeronautics and Astronautics, Propulsion Joint Specialist Conference, Colorado Springs, Colo., June 14-18, 1965, Paper 65-621. 25 p. 13 refs.
Members, $0.50; nonmembers, $1.00.

Experimental evaluation of the space performance potential of OF_2/B_2H_6. 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 OF_2/B_2H_6. Extension of this work to a 2000-lb (space) thrust level demonstrated the scalability potential of OF_2/B_2H_6. Sea-level injector evaluations conducted at the 2000-lb (space) thrust level demonstrated that OF_2/B_2H_6 delivers a high 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 OF_2/B_2H_6 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.).

(International Symposium in Humidity and Moisture, 1st, Washington, D. C., May 20-23, 1963.)
IN: HUMIDITY AND MOISTURE - MEASUREMENT AND CONTROL IN SCIENCE AND INDUSTRY. VOLUME 4 - PRINCIPLES AND METHODS OF MEASURING MOISTURE IN LIQUIDS AND SOLIDS. [A65-27424 16-14]
Edited by P. N. Winn.
New York, Reinhold Publishing Corp., 1965, p. 55-61. 9 refs.
Contract No. AF 04(694)-72.

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 CaH_2 and CaC_2 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 (N_2O_4). Electrical conductivity methods have been recommended for this application, but it is suggested that process 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. Elrod (USAF, Systems Command, Research and Technology Div., Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio).

IN: SOCIETY OF AUTOMOTIVE ENGINEERS, AEROSPACE FLUID POWER SYSTEMS AND EQUIPMENT CONFERENCE, LOS ANGELES, CALIF., MAY 18-20, 1965, PROCEEDINGS. [A65-28019 17-03]
Conference sponsored by the Society of Automotive Engineers. New York, Society of Automotive Engineers, 1965, p. 192-197.

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 purpose of this 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

A HOT GAS SERVOCONTROL SYSTEM FOR AEROSPACE APPLICATIONS.

J. G. Rivard (Bendix Corp., Research Laboratories Div., Southfield, Mich.), P. L. Ochs (Bendix Corp., Eclipse-Pioneer Div., Teterboro, N. J.), and D. J. Wallick (Bendix Corp., Vehicle Power Div., Wright-Patterson AFB, Ohio).

IN: SOCIETY OF AUTOMOTIVE ENGINEERS, AEROSPACE FLUID POWER SYSTEMS AND EQUIPMENT CONFERENCE, LOS ANGELES, CALIF., MAY 18-20, 1965, PROCEEDINGS. [A65-28019 17-03]
Conference sponsored by the Society of Automotive Engineers. New York, Society of Automotive Engineers, 1965, p. 319-334. 5 refs.
Contract No. AF 33(657)-8455.

Description of a new concept for a solid-propellant-powered, hot-gas, high-performance servocontrol 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 gimbaling the propulsion nozzle and also including reaction nozzle roll control. Both systems are supplied from solid propellant gas generators providing a supply gas at 1950°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 #

LINEAR PYROLYSIS RATE MEASUREMENTS OF PROPELLANT CONSTITUENTS.

R. L. Coates (Lockheed Aircraft Corp., Lockheed Propulsion Co., Engineering Research Dept., Redlands Calif.).

(American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, Paper 65-55.)
AIAA Journal, vol. 3, July 1965, p. 1257-1261. 15 refs.
Contract No. DA-04-495-AMC-239(R).
[For abstract see Accession no. A65-14544 05-27]

A65-28631 #

AN EXPERIMENTAL INVESTIGATION OF THE DYNAMIC BEHAVIOR OF THE LIQUID-VAPOR INTERFACE UNDER ADVERSE LOW-GRAVITATIONAL CONDITIONS.

William J. Masica and Jack A. Salzman (NASA, Lewis Research Center, Cleveland, Ohio).

USAF, Office of Scientific Research, and Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Symposium on Fluid Mechanics and Heat Transfer Under Low Gravitational Conditions, Palo Alto, Calif., June 24, 25, 1965, Paper. 17 p. 7 refs.

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 as the scaling parameter in an induced low gravity environment. In particular the critical Bond number delineating the stable and unstable regions of the interface has been verified to be 0.84 for solid-liquid-vapor systems possessing zero-degree contact angles, and is independent of the applied acceleration field. 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 to date 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 tankage, it has been noted that a large portion of the liquid is 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.

Duane F. Dipprey (California Institute of Technology, Jet Propulsion Laboratory, Liquid Propulsion Section, Pasadena, Calif.).

Astronautics and Aeronautics, vol. 3, June 1965, p. 64-67. 6 refs.
NASA-supported research.

Discussion of earth-storable propellants, by which is meant rocket propellants that exist in liquid phase in the 70 ± 30°F range at vapor pressures below 100 psia and that are hypergolic. Propulsion systems based on such propellants achieve reliability through simplicity, predictability, and minimizing the number of systems 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 specific missions. Earth-storable propellants have lower flame temperatures than competing cryogenic combinations, which is an advantage in that this makes possible

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. Schliessmann (Aerojet-General Corp., Solid Rocket Structures Div., Sacramento, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-233.)
Journal of Spacecraft and Rockets, vol. 2, July-Aug. 1965, p. 565-570. 7 refs.
[For abstract see Accession no. A64-18904 14-26]

A65-28851 #
DESIGN OF A VERSATILE LIQUID-FLUORINE/LIQUID-HYDROGEN UPPER STAGE.
George C. Goldbaum and John B. Douglass (Douglas Aircraft Co., Inc., Missiles and Space Systems Div., Santa Monica, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-277.)
Journal of Spacecraft and Rockets, vol. 2, July-Aug. 1965, p. 570-576. 11 refs.
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 Co., Propulsion Section, Orlando, Fla.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-372.)
Journal of Spacecraft and Rockets, vol. 2, July-Aug. 1965, p. 593, 594.
[For abstract see Accession no. A64-20520 16-26]

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.).
American Institute of Aeronautics and Astronautics, Annual Meeting, 2nd, San Francisco, Calif., July 26-29, 1965, Paper 65-534. 16 p. Members, $0.50; nonmembers, $1.00.

Demonstration, through a series of tests, that the so-called earth-storable propellants can be considered space-storable as well. The average temperature of the exposed external surfaces of the storage tanks can be closely controlled by application of suitable coatings. The results of tests with liquid nitrogen have been used to predict the performance of cryogenic rocket propellants. A summary of the findings for a simulated orbit is tabulated; here it is seen that the loss rates of propellants other than hydrogen are acceptable for the given tank sizes. Analysis and component tests show that heat leaks to the cryogenic tanks are caused primarily by the heat flow through the insulation penetrations. B.B.

A65-29380 #
HIGH ENERGY UPPER STAGES - POTENTIAL APPLICATIONS AND SELECTION CRITERIA.
William H. Wetmore (Aerospace Corp., Los Angeles, Calif.).
American Institute of Aeronautics and Astronautics, Annual Meeting, 2nd, San Francisco, Calif., July 26-29, 1965, Paper 65-345. 19 p. Members, $0.50; nonmembers, $1.00.

Discussion of propulsion technology with specific examination of high-energy chemical propulsion systems for upper-stage application. A number of propellant candidates are assessed against specific operational criteria to determine which candidates offer maximum flexibility and capability for the future. It is considered that F_2/H_2 and O_2/H_2 continue to be the first choices. There do not appear to be any combinations in the liquid bipropellant family which will make them obsolete; hence these two propellant combinations continue to be the choice for present and future developments. F.R.L.

A65-31782
THE INFLUENCE OF RADIANT-ENERGY TRANSFER ON PROPELLANT BURNING RATES AND ABLATION RATES CONTROLLED BY AN INTENSE RADIATION FIELD.
S. S. Penner and D. B. Olfe (Institute for Defense Analyses, Washington, D.C.).
Astronautica Acta, vol. 11, Jan.-Feb. 1965, p. 65-78. 9 refs.

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, the 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.).
International Journal of Mechanical Sciences, vol. 7, July 1965, p. 475-488. 9 refs.

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
THEORY OF ACOUSTIC INSTABILITY IN SOLID-PROPELLANT ROCKET COMBUSTION.
R. W. Hart and F. T. McClure (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).
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. 1047-1064; Comments L. A. Dickinson (Stanford Research Institute, Menlo Park, Calif.) and G. von Elbe (Atlantic Research Corp., Alexandria, Va.), p. 1064, 1065. 42 refs.
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 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. Some 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 and due to the erosion associated with the velocity component of the acoustic field are noted. The induction of vortex flow by acoustic streaming, as described by Swithenbank and Sotter and by Flandro, is discussed with particular reference to its consequences in producing increased erosion, decreased nozzle flow, and angular torques. Brief mention is made of the effects of amplitude oscillation on combustion efficiency and on the composition of the product gases. (Author) M.M.

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, 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. 1067-1080; Comments, N. W. Ryan (Utah, University, Salt Lake City, Utah) and L. A. Dickinson (Stanford Research Institute, Menlo Park, Calif.), p. 1081, 1082. 70 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 (1) 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 (1) 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 velocity and acoustic pressure with 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. Experience to date, at low frequency, pertains 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-1 (Saturn) engine injector is discussed. M.M.

A65-32543
THEORETICAL STUDIES ON LIQUID-PROPELLANT ROCKET INSTABILITY.
Luigi Crocco (Princeton University, Princeton, N.J.).
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. 1101-1128. 26 refs.

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 appearence; 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, 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. 1167-1178; Comments, E. E. Zukoski (California Institute of Technology, Pasadena, Calif.), p. 1178. 11 refs.
Contract No. NOw-62-0604-c.

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.
Pittsburgh, Pa., Combustion Institute, 1965. 1488 p.
Members, $22.; nonmembers, $35.

CONTENTS:

A65-32561

REGRESSION RATES AND THE KINETICS OF POLYMER DEGRADATION.

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.
Pittsburgh, Pa., Combustion Institute, 1965, p. 1395-1404. 26 refs.

Method of calculating regression rates ṙ of simple polymer fuels and its application to poly(methyl methacrylate), polystyrene, and polyethylene. The method depends upon (1) invoking the concept of a critical fragment size (CFS), and (2) the use of a first-order rate equation $-dn/dt = kn$, for describing the scission of backbone bonds in the polymer. The CFS is the chain length of the volatile product of chain degradation, above which size it is energetically more economical to continue breaking backbone C-C bonds than to remove the fragment from its environment. From random scission of these bonds, a rate of loss-in-weight law was derived - $m_l/m_0 = 1 - \exp(-ikt)[i + 1 - \exp(-kt)]$, in which i is the maximum chain length of the CFS. For other mechanisms of chain degradation, the average chain length of the CFS was used, and a rate of loss-in-weight law $m_l/m_0 = 1 - \exp(-kt)$ was involved. The first-order rate equation, above, was shown to be consistent with these laws. Agreement with measured r values is very good, being off by not more than a factor of 2, but depends upon the application of the appropriate surface temperature T_s. Extension of this method to composite fuels did not give results in agreement with experiment, even when limiting values of T_s were used, and $KClO_4$ or NH_4ClO_4 was the oxidizing filler. The conclusion is drawn that the two-temperature model of a burning composite fuel is more likely to succeed. It is shown that an NH_4ClO_4 crystallite surface temperature of 1010°K can be calculated without invoking a solid-phase reaction.
(Author) M.M.

A65-32562

CHEMICAL KINETICS OF THE CORDITE EXPLOSION ZONE.

J. George Sotter (Sheffield University, Dept. of Fuel Technology and Chemical Engineering, Sheffield, England).

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. 1405-1411; Comments, K. N. Bascombe and G. K. Adams (Ministry of Aviation, Explosives Research and Development Establishment, Waltham Abbey, Essex, England), p. 1411. 21 refs.
Research supported by Imperial Metal Industries, Ltd., and the Ministry of Aviation.

Theoretical analysis of the chemical behavior of the gas-phase induction zone and explosion zone of a solid double-base rocket propellant through consideration of sixteen reversible chemical reactions involving the twelve species N, N_2, NO, N_2O, H, H_2, CO, CO_2, O, O_2, OH, and H_2O, and four irreversible reactions implicitly including the formation of HNO. The most important processes were found to be the reactions $H_2O + H \rightarrow H_2 + OH$, $CO + OH \rightarrow CO_2 + H$, $2\,NO + H_2 \rightarrow 2\,HNO$ ($+\,H_2 \rightarrow 2\,H_2O + N_2$). The results are found to be in qualitative agreement with published experimental work. (Author) M.M.

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.
Pittsburgh, Pa., Combustion Institute, 1965, p. 1413-1424. 18 refs.
Contracts No. Nonr-3907(00); No. NOw-61-0905-c.

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

of liquid alumina particles 1 to 10 μ in diameter varied from about 10^{-2} to 10^{-1} 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^{-5} 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.

A65-33388
THE COMING KICK STAGE.
Bernard Kovit.
Space/Aeronautics, vol. 44, Aug. 1965, p. 55-61.

Evaluation of the capabilities of a new final or kick stage to meet the high ΔV 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 (I_{sp}), 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 cryogenics such as fluorine/hydrogen, oxygen/hydrogen, and lithium/fluorine/hydrogen offer high I_{sp}. In order to operate to best advantage, a kick stage would expend a large first pulse from low earth orbit, would then coast, and would then restart to establish its final trajectory. Thus, requirements exist for fuel storability in space, an engine-restart capability, and a capability of throttling to reduce ΔV errors; the chief tankage constraints would be insulation and propellant venting under zero-g conditions. Structural and thermodynamic problems are discussed, and throttleability and 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. I.
Felix Godwin.
Spaceflight, vol. 7, Sept. 1965, p. 146-154.

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.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-367.)
Journal of Spacecraft and Rockets, vol. 2, Sept.-Oct. 1965, p. 746-753.
Contract No. AF 04(611)-8198.
[For abstract see Accession no. A64-20260 16-26]

A65-33550 #
BALLISTIC-MISSILE RESEARCH WITH ATHENA.
Robert F. Friedman and Jack Reed (Atlantic Research Corp., Duarte, Calif.).
(American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-275.)
Journal of Spacecraft and Rockets, vol. 2, Sept.-Oct. 1965, p. 781-786. 8 refs.
[For abstract see Accession no. A64-20137 16-32]

A65-33551 #
LIQUID OXYGEN AND LIQUID METHANE MIXTURES AS ROCKET MONOPROPELLANTS.
Richard L. Every and James O. Thieme (Continental Oil Co., Central Research Div., Ponca City, Okla.).
Journal of Spacecraft and Rockets, vol. 2, Sept.-Oct. 1965, p. 787-789. 5 refs.

Preliminary evaluation of the specific impulse, characteristic velocity, pumpability, and sensitivity of the liquid oxygen (LOX) and liquid methane (LCH_4) 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/LCH_4 monopropellant has a very good specific impulse (~ 300 sec) and a characteristic velocity of better than 6000 fps. Although LOX/LCH_4 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/LCH_4 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.).
Journal of Spacecraft and Rockets, vol. 2, Sept.-Oct. 1965, p. 824-826.

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 nonisentropic 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, shredding-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.
Astronautics and Aeronautics, vol. 3, Sept. 1965, p. 74-77.

General review of the technology of solid propellants, with reference to stress analysis and failure criteria of propellant grains, to the effects of the rocket jet on systems performance and launch environment, to motor and vehicle interface problems, and to the status of large booster development. Grain structural integrity analysis is of ever-increasing importance in the design of solid propellant rocket motors. Problems arising from the interactions of rocket motor exhaust gases with electromagnetic radiation, and problems arising during launch due to radiation heating, starting pressure pulses, and toxic exhaust products are outlined. Problems which occur in the process of mating major vehicle components are discussed. Boosters larger than 10-ft in diameter have been fired, and many different methods of thrust-vector control have been successfully demonstrated. Brief comment is made on certain special problems. F.R.L.

A65-34137
VISCOELASTIC STRESSES DUE TO INTERNAL PRESSURIZATION OF A SOLID PROPELLANT ROCKET GRAIN.
T. M. Jones (Thiokol Chemical Corp., Bristol, Pa.).
IN: DEVELOPMENTS IN THEORETICAL AND APPLIED MECHANICS PROCEEDINGS OF THE SECOND SOUTHEASTERN CONFERENCE, ATLANTA, GA., MARCH 5, 6, 1964. VOLUME 2. [A65-34121 22-32]
Conference sponsored by the Georgia Institute of Technology.
Edited by W. A. Shaw.
Oxford, Pergamon Press, Ltd., 1965, p. 247-260. 12 refs.

Determination of the state of stress and strain in a solid-propellant rocket grain due to internal pressurization, by obtaining a plane strain solution for a linear viscoelastic thick-wall cylinder. The cylinder is enclosed in a thin elastic case and is subjected to pressurization on a moving inner boundary. Since the Laplace transform technique is not applicable to problems with moving boundaries, the field equations are reduced to two integral equations of the Volterra type. These equations are solved on a high-speed computer in a finite difference form utilized by Hopkins and Hamming and by Lee and Rogers. The solution is found to satisfy the boundary conditions reasonably well. (Author) F.R.L.

A65-36156
STATUS AND FUTURE TRENDS IN HIGH SPEED CHEMICAL PROPULSION.
W. H. Avery (Johns Hopkins University, Applied Physics Laboratory, Aerospace Div., Silver Spring, Md.).
APL Technical Digest, vol. 4, July-Aug. 1965, p. 2-9.

Examination of the status of five areas of chemical propulsion now receiving active research support for their potential use for high-speed propulsion during the decade of the 1970's. Interest is focused on the whole range of high-speed chemical propulsion possibilities, bringing out the potentialities as well as some of the major problems in a context that embraces all of the principal types adapted to high-speed flight. "High speed" is arbitrarily defined to be speed in excess of Mach 5. Solid, liquid, and hybrid rockets are considered. 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 manufacturing technology, particularly in those aspects involved in 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 augmentation and hypersonic airbreathing propulsion are considered. M.F.

A65-36407 #
REGRESSION RATES OF NONMETALIZED HYBRID FUEL SYSTEMS.
L. D. Smoot and C. F. Price (Lockheed Aircraft Corp., Lockheed Propulsion Co., Engineering Research Dept., Redlands, Calif.).
(American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, Paper 65-56.)
AIAA Journal, vol. 3, Aug. 1965, p. 1408-1413. 11 refs.
Contract No. DA-04-495-AMC-218(Z).
[For abstract see Accession no. A65-14801 05-27]

A65-36461 #
A STUDY OF COMPOSITE SOLID-PROPELLANT FLAME STRUCTURE USING A SPECTRAL RADIATION SHADOWGRAPH TECHNIQUE.
Louis A. Povinelli (NASA, Lewis Research Center, Cleveland, Ohio).
(American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 2nd, New York, N.Y., Jan. 25-27, 1965, Paper 65-60.)
AIAA Journal, vol. 3, Sept. 1965, p. 1593-1598. 10 refs.
[For abstract see Accession no. A65-14551 05-27]

A65-80506
VIABILITY OF BACILLUS SUBTILIS SPORES IN ROCKET PROPELLANTS.
Rogene M. Godding and Victoria H. Lynch (Lockheed Missiles and Space Co., Res. Labs., Palo Alto, Calif.)
Applied Microbiology, vol. 13, Jan. 1965, p. 10-14. 7 refs.

The sporicidal activity of components used in liquid and solid rocket propellants was tested by use of spores of Bacillus subtilis dried on powdered glass. Liquid propellant ingredients tested were N_2O_4, monomethylhydrazine, and 1,1-dimethylhydrazine. N_2O_4 was immediately sporicidal; the hydrazines were effective within several days. Solid propellants consisted of ammonium perchlorate in combination with epoxy resin (EPON 828), tris-1-(2-methyl) aziridinyl phosphine oxide, bis-1-(2-methyl) aziridinyl phenylphosphine oxide, and 3 modified polybutadiene polymers. There was no indication of appreciable sporicidal activity of these components.

A66-10174
VISCOELASTIC PRESSURE DEPENDENCE.
Darryl Kent Backman (Utah, University, Salt Lake City, Utah).
American Institute of Aeronautics and Astronautics, Western Regional Student Conference, Los Angeles, Calif., May 6, 7, 1965, Paper. 43 p. 10 refs.

Description of a method for approximating the mechanical response or viscoelastic properties of a material at a given hydrostatic pressure. A piston-type pressure vessel and hydraulic press were used to obtain the pressure required to conduct the experiments by ramming the piston into the vessel. The pressure vessel used was of the composite-cylinder type, and the extension measurements were made with a differential transformer. The samples used were polyethylene which is viscoelastic. Plots are shown which indicate that pressure has a very marked effect on the viscoelastic properties of polyethylene. The instantaneous modulus is increased almost twice by a pressure change from atmospheric to 755.3 atm. The long-time modulus is changed in about the same proportion. Another effect is the change of shape of the modulus curve. The time required to reach the long-time modulus is greatly increased. It is also noted that at very high pressure (3433.0 atm or 50,465 psi), the long-time and short-time moduli become about 40 times greater than at atmospheric pressure. It is apparent that, for viscoelastic polyethylene, and perhaps for most other viscoelastic materials that are used in conditions of pressure, the pressure effects of its mechanical properties must be considered. M.M.

A66-11540 #
MICROSCOPIC DETERMINATION OF NEAR SOLID STATE CHANGES IN AGED PROPELLANTS.
J. L. McGurk (Aerojet-General Corp., Sacramento, Calif.).
AIAA Journal, vol. 3, Oct. 1965, p. 1890-1895. 11 refs.

Study of solid-propellant thin sections by petrographic microscopy has led to a thorough optical characterization of the phase composition. In aged propellants, phases with different optical properties demonstrate the presence of reaction compounds with lower energy and altered mechanical properties. In six motors

containing composite polyurethane propellant aged between 3.5 and 5.6 yr, the reaction compounds have localized into 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 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. Comparison of phenoblasts in motors of different ages gives an approximate rate and model of chemical aging for these propellants. (Author)

A66-11669 #

PROJECT TOWARD A HIGH-ENERCY STANDARD ENGINE FOR THE ELDO-B CARRIER ROCKET [DAS PROJEKT EINES HOCH-ENERGETISCHEN EINHEITSTRIEBWERKES FÜR DIE ELDO-B TRÄGERRAKETEN].

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

European Space Flight Symposium, 5th, Munich, West Germany, July 19-22, 1965, Paper. 13 p. In German.

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/cm^2. The engine is designed to power the third stage of the ELDO rocket as a single unit, and the second stage as a cluster of four units. The engine will use a nozzle with regenerative cooling. V.P.

A66-11681 #

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

M. Barrère (ONERA, Paris, France) 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. 240, 1965. 130 p. 63 refs.

Grant No. AF AFOSR 927-65.

Our present state of understanding of the steady-state combustion mechanisms of solid propellants is reviewed. Attention is focused principally on heterogeneous propellants. Both experimental and theoretical work is discussed. The recent advances considered include studies of linear pyrolysis of propellant constituents, deflagration of exothermic oxidizers, combustion of oxidizer spheres in gaseous fuels, porous-bed combustion, reactions between gaseous fuel and gaseous oxidizer components, metal combustion, propellant strand burning, rocket motor combustion, and microcinematographic 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, moderate pressure, plateau and high pressure domains of combustion are identified for ammonium perchlorate composite propellants. It is concluded that a better foundation for investigating composite propellant combustion properties is available for ammonium perchlorate than for any other oxidizer. Avenues for potentially fruitful future research are recommended. (Author)

A66-12734 #

BEHAVIOR AND VARIABILITY OF SOLID PROPELLANTS AND CRITERIA FOR FAILURE AND FOR REJECTION.

John N. Majerus (Aerojet-General Corp., Methods Development Dept., Sacramento, Calif.), Herman P. Briar (Aerojet-General Corp., Solid Propellant Research and Development Div., Mechanical Properties Laboratory, Sacramento, Calif.), and James H. Wiegand (Aerojet-General Corp., Solid Propellant and Development Div., Mechanical Properties Laboratory and Ballistic Research Laboratory, Sacramento, Calif.).

Journal of Spacecraft and Rockets, vol. 2, Nov.-Dec. 1965, p. 833-845. 62 refs.

Consideration of the general effects of parameter variability for solid propellants and examination of ballistic variability. The effect of solid propellant modulus variability on structural analysis and the effect of nonlinear behavior are also considered, with an examination of failure variability from single loadings as well as from multiple loadings, which lead to cumulative damage effects. The practical and interim solution of the problem through the statistical treatment of empirical correlating parameters is illustrated in terms of full motor prediction. It is concluded that the ballistic and mechanical properties of solid propellants must be treated as statistically distributed parameters. Estimation of these parameters is essential to design and failure analysis with the failure properties of the propellant being reflected in a range of failure behavior of motors on cycling, storage and firing. To reduce the uncertainties of a grain analysis, the observed nonlinear mechanical behavior must be characterized. Present nonlinear theories involve a number of unknown time-dependent functionals, and only for incompressible materials can the unknown material parameters be readily characterized; even so, a large number of relaxation and creep tests are necessary to evaluate the unknowns. A more generalized, but approximate, nonlinear theory can be generated by characterizing the relaxation response of a statistically significant number of uniaxial and biaxial stress tests under hydrostatic pressure in which dilatation is measured. It appears that a nonlinear theory is necessary for complete calculation of the effects of pressurization on firing, but it may not be necessary for the cases of thermal cycling or slump. M. M.

A66-12760 #

THERMODYNAMIC PROPERTIES OF HYDRAZINE.

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

Journal of Spacecraft and Rockets, vol. 2, Nov.-Dec. 1965, p. 972-974. 6 refs.

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. M. M.

A66-13106 #

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

E. P. Morris (Canadian Armament Research and Development Establishment, Valcartier, Quebec, Canada).

(Interagency Chemical Rocket Propulsion Group, Meeting on Static Testing, Arnold Air Force Station, Tenn., Oct. 17, 18, 1963, Paper.) Canadian Aeronautics and Space Journal, vol. 11, Nov. 1965, p. 329-333.

In the early stages of the development of ammonium perchlorate polyurethane solid propellants, unstable combustion in the finite-wave 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 are described 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. (Author)

A66-13226

SOLID PROPELLANT GRAINS WITH ORGANIZED SLITS [BLOCS DE PROPERGOL A FISSURES ORGANISEES].

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

La Recherche Aérospatiale, Sept.-Oct. 1965, p. 53-56. In French.

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

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 #
DROP-WEIGHT TESTING OF EXPLOSIVE LIQUIDS.
Charles M. Mason, Robert W. Van Dolah, and Milton L. Weiss (U.S. Bureau of Mines, Explosives Research Center, Pittsburgh, Pa.).
Combustion Institute, Western States Section, Fall Meeting, Santa Barbara, Calif., Oct. 25, 26, 1965, Paper WSCI 65-28. 21 p. 17 refs.

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 sample cups 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 N_2O_4 - N_2H_4 LIQUID REACTIONS.
Harold Weiss (Dynamic Science Corp., Monrovia, Calif.).
Combustion Institute, Western States Section, Fall Meeting, Santa Barbara, Calif., Oct. 25, 26, 1965, Paper WSCI 65-20. 16 p.
Research supported by the Jet Propulsion Laboratory.

Description of an attempt to find a chemical inhibitor for the N_2O_4-N_2H_4 reaction. Ignition delay times are measured for N_2O_4-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-hydrazine 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 N_2O_4 and N_2H_4, 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.
B. 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.).
Combustion Institute, Western States Section, Fall Meeting, Santa Barbara, Calif., Oct. 25, 26, 1965, Paper WSCI 65-21. 17 p. 9 refs.
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. Dotson, and O. K. Moehrbach (United Aircraft Corp., Pratt and Whitney Aircraft Div., Florida Research and Development Center, West Palm Beach, Fla.).
Combustion Institute, Western States Section, Fall Meeting, Santa Barbara, Calif., Oct. 25, 26, 1965, Paper WSCI 65-23. 32 p. 5 refs.

The 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 flox over a range of propellant temperatures from 540°R 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 flox-fuel combinations were dependent on propellant temperature and precedence, system initial pressure, flox 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 butene-1, methane, propane, the 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.
(Author)

A66-15151 #
THE EFFECT OF SURFACE MODIFICATIONS ON THE BURNING RATE OF A COMPOSITE SOLID PROPELLANT.
B. G. Moser, R. E. Wiech, and R. F. Landel (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.).
Combustion Institute, Western States Section, Fall Meeting, Santa Barbara, Calif., Oct. 25, 26, 1965, Paper WSCI 65-36. 21 p. 7 refs.

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.
P. K. Salzman, O. R. Irwin, and W. H. Andersen (Aerojet-General Corp., Research Div., Downey, Calif.).
AIAA Journal, vol. 3, Dec. 1965, p. 2230-2238. 35 refs.
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 EROSIVE BURNING IN SOLID FUEL ROCKETS.
J. F. Bird, R. W. Hart, and F. T. McClure (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).
AIAA Journal, vol. 3, Dec. 1965, p. 2248-2256. 18 refs.
Contract No. NOw-62-0604-c.

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].
Glauco Partel.
Rivista Aeronautica, vol. 41, Nov. 1965, p. 1587-1608. 7 refs. In Italian.

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).
European Space Flight Symposium, 5th, Munich, West Germany, July 19-22, 1965, Paper. 14 p.

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).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 3rd, New York, N.Y., Jan. 24-26, 1966, Paper 66-112. 20 p. 15 refs.
Members, $0.50; nonmembers, $1.00.
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 planar 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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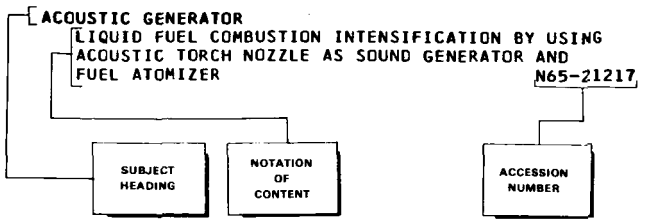

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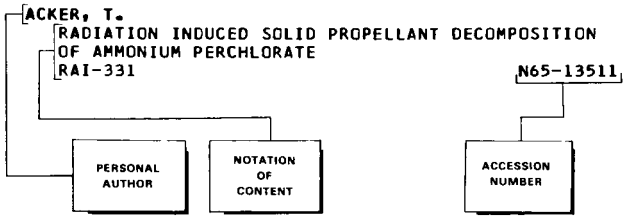

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