NASA SP-7002(01)

HIGH ENERGY PROPELLANTS

A CONTINUING BIBLIOGRAPHY

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HIGH ENERGY PROPELLANTS

A CONTINUING BIBLIOGRAPHY

A Selection of Annotated References to Unclassified Reports and Journal Articles introduced into the NASA Information System during the period April, 1964–December, 1964.

Scientific and Technical Information Division
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WASHINGTON, D.C. MARCH 1965

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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 April, 1964–December, 1964.

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High Energy Propellants

A CONTINUING BIBLIOGRAPHY MARCH 1965

STAR ENTRIES

N64-13403* Little (Arthur D.) Inc., Cambridge, Mass.
DESIGN OF THERMAL PROTECTION SYSTEMS FOR LIQUID HYDROGEN TANKS
Apr. 1963 79 p refs
(NASA Contracts NAS5-664 and NASw-615)
(NASA CR-55252; C-65008-3-01) OTS: $7.60 ph, $2.57 mf

An account is given of the progress achieved in the design, experimental measurement, and analysis of thermal protection systems for liquid hydrogen tanks in the following areas: (1) environments affecting thermal protection systems; (2) selection of materials for thermal protection systems; (3) thermal conductivity measurements; (4) experimental results—temperature, density, mechanical load, contact resistance, emissivity, and gas pressure; (5) requirements for application of multilayer insulation to liquid hydrogen tanks and (6) spherical, cylindrical, and flat plate thermal conductivity apparatus.
R.T.K.

N64-13490 Atlantic Research Corp., Alexandria, Va.
SOLID-PROPELLANT FLAME MECHANISMS
R. Friedman, A. Macek, and J. M. Semple *In* Va. U. Project Squid 1 Oct. 1963 p 63-65 refs (See N64-13476 05-01)

The objective of this program is to gain basic information pertinent to solid-propellant combustion mechanisms by studying combustion of single metal particles (aluminum or beryllium) injected into flame gases of known temperature and composition.
Author

N64-13933 Army Missile Command, Huntsville, Ala.
THE CHARACTERIZATION OF SOLID ROCKET PROPELLANTS BY DIFFERENTIAL THERMAL ANALYSIS
J. D. Burnett and A. F. Findeis 17 Sept. 1963 31 p refs
(RK-TR-63-21; AD-423152)

Differential thermal analysis (DTA) is described for the characterization of solid rocket propellants. Variables, such as sample size and heating rates, are discussed. A DTA apparatus is tested and recommended for routine characterizations of a wide variety of propellant materials.
Author

N64-14024 Stanford Research Inst., Menlo Park, Calif.
SOLID PROPELLANT MECHANICAL PROPERTIES INVESTIGATIONS *Final Report, 1 Jun. 1962-31 May 1963 [and] Quarterly Progress Report No. 4, 1 Mar.-31 May, 1963*
Norman Fishman and James A. Rinde 6 Nov. 1963 57 p refs
(Contract AF 04(611)-8388)
(SRI-12; AD-426094)

Dilatometric studies were undertaken to evaluate the mechanical response of a polyurethane and a carboxy-terminated polybutadiene composition by extension at constant strain rates and constant loads. The effects of strain rate, load, temperature, and humidity were investigated. Mechanisms of propellant dilatation were postulated on the basis of three regions of behavior. The first region was exemplified by the linear viscoelasticity of filled rubber; the second region was considered to consist of dewetting, with binder-particle bond rupture and retardation due to frictional forces at the binder-particle interface having the greatest influence on response; the final region was thought to behave primarily in the manner of a filled, dewetted foam. Some observations of propellant mechanical behavior were made on the basis of postulated mechanisms and interactions.
Author

N64-14441 Aerojet-General Corp., Sacramento, Calif. Solid Rocket Plant
ANALYSIS OF PROPELLANT IGNITION, AND ITS APPLICATION TO MOTOR INITIATION
R. L. Lovine, L. Y. Fong, and B. E. Paul 4 Nov. 1963 40 p refs
(Tech. Memo. 235 SRP)

In order to relate igniter energy output to motor ignition, a model of solid-propellant ignition is given. Difficulties inherent in the nonlinear partial differential equations of heat and mass diffusion describing the ignition system prevent the model from being completely analytical. However, certain results are derived from the equations, and when combined with arc-image furnace ignitibility data, a reasonably coherent view of the process is obtained. Numerous examples of ignitibility data are given. Analysis of heat and mass transfer from igniter to motor grain is given for the case of propellant-type igniter. This analysis, along with the pertinent ignitibility data, is applied to ignition of the second stage Minuteman motor.
Author

N64-14547 Princeton U., N.J. Guggenheim Labs. for the Aerospace Propulsion Sciences
THE MEASUREMENT OF TEMPERATURE PROFILES THROUGH SOLID PROPELLANT FLAMES USING FINE THERMOCOUPLES

A. J. Sabadell, J. Wenograd, and M. Summerfield N.Y., Am. Inst. of Aeron. and Astronautics [1964] 9 p refs Presented at the AIAA Solid Propellant Rocket Conf., Palo Alto, Calif., 29–31 Jan. 1964
(Contract Nonr-1858(32); Partially supported by NASA)
(AIAA Paper 64-106) AIAA: $0.50 members, $1.00 nonmembers

Temperature profiles in the solid preheat zone and gaseous combustion zone of burning solid propellants have been obtained by recording voltage from fine thermocouples embedded in burning solid-propellant strands. These temperature records were used to estimate the surface temperature of the burning solid. Techniques have been developed for routine fabrication and handling of fine (0.0003 in.) noble metal thermocouples. Surface temperatures were estimated by noting departure from pure conductive heat flow in a solid continuum. Variations of pressure and particle size and introduction of catalysts failed to give observable changes in surface temperature. The shapes of these temperature profiles can be used to deduce the site of energetic chemical reactions in the combustion zone. These observations demonstrate important differences in combustion mechanism between composite and double-base propellants. Author

N64-14548 Princeton U., N. J. Guggenheim Labs. for the Aerospace Propulsion Sciences
IGNITION OF AN EVAPORATING FUEL IN A HOT, STAGNANT GAS CONTAINING AN OXIDIZER
C. E. Hermance, R. Shinnar, and M. Summerfield N.Y., Am. Inst. of Aeron. and Astronautics [1964] 14 p refs Presented at the AIAA Solid Propellant Rocket Conf., Palo Alto, Calif. 29–31 Jan. 1964
(Supported by NASA and AFOSR)
(AIAA Paper 64-118) AIAA: $0.50 members, $1.00 nonmembers

The theoretical characteristics of ignition in heterogeneous systems have not been established heretofore. In this paper, these characteristics were found first by similarity theory and then by numerical analysis of the systems' mathematical models. It was found that certain common simplifying assumptions and ignition criteria, valid for homogeneous systems, are invalid in heterogeneous systems. In heterogeneous systems with igniter gas temperatures near E/R, the particular choice of ignition criterion affects the formula connecting the ignition delay and the chemical or physical parameters of the gas phase. Furthermore, a log–log plot of ignition delay versus concentration of gaseous oxidizer exhibits a variable slope having any negative value, and is not a simple multiple of the controlling reaction order. These theoretical results require verification by critically designed experiments. Author

N64-14627 Rocket Power, Inc., Pasadena, Calif.
STUDY OF ROCKET ENGINE EXHAUST PRODUCTS Ninth Quarterly Report, 1 Jun. 1963-31 Aug. 1963
M. A. Greenbaum, R. E. Yates, J. A. Blauer, M. Arshadi, and H. C. Ko et al [1963] 15 p refs
(Contract AF 04(611)-7414)
(QR-7414-9; AD-426166)

The heat and entropy of sublimation of MgF_2 have been determined over the temperature range 1,273° to 1,513° K from a study of the vapor pressure of MgF_2(s). Based on the experimental data combined with available thermal functions, the second-law value for ΔH^{298}_{sub} was found to be 83.21 ± 1.03 kcal/mole. The corresponding third-law value obtained was 83.95 ± 0.65 kcal/mole. The experimental ΔS^{298}_{sub} was found to be 41.78 ±0.75 cal/deg/mole. Preliminary information on the nature of the BeO(s)–H_2O(g) reaction in the temperature range 1,538° to 1,738° K and at 10^{-4} atm pressure has been obtained. Author

N64-14687 Martin Co., Denver, Colo.
DEVELOPMENT AND DEMONSTRATION OF MAIN TANK INJECTION (MTI) PRESSURIZATION SYSTEM Final Report, 1 Jun. 1962-[Sep. 1963]
R. J. Kenny, P. Freedman, A. P. Lane, and P. Bingham Edwards AFB, Calif., AF Flight Test Center, Dec. 1963 580 p refs
(Contract AF 04(611)-8198)
(FTC-CR-63-23; RTD-TDR-63-1123; AD-426714)

The overall program was conducted in four phases: (1) preliminary investigations including the basic research and development of a small-scale system; (2) design and fabrication of a flight-type test article; (3) full-scale system development and demonstration test; and (4) system analysis resulting in the formulation of a design handbook and study of specific vehicle applications. Considerable experimental data were accumulated during the course of the program and were analyzed to identify pertinent effects resulting from the chemical pressurization process. Composition and properties of the pressurizing gas and rate of ullage saturation with propellant vapors are reported based on extensive mass spectrometer gas analysis. An investigation of propellant degradation due to the reaction process and dilution by condensate is also included. Author

N64-14794 Aerojet-General Corp., Azusa, Calif.
INVESTIGATION OF THE MECHANISMS OF DECOMPOSITION, COMBUSTION, AND DETONATION OF SOLIDS Fifteenth Technical Operating Report, 1 Jul.-30 Sep. 1963
J. P. Kispersky Nov. 1963 16 p refs
(Contract AF 49(638)-851; ARPA Order 24-60)
(Rept. 0372-01-15; AD-428627)

Reanalysis of the apparent flame strength data for the ammonia–oxygen system indicates that the overall order of the NH_3-O_2 reaction is 1.7, rather than 2.0 as was reported previously. Opposed-jet measurements at 300 torr show that the apparent flame strength of the ammonia–oxygen–chlorine system varies inversely with the mass fraction of chlorine in the initial mixture. This result agrees with the results of previous measurements at 745 torr. The apparent flame strength of the ammonia–nitrogen dioxide system has been determined as a function of reactor pressure between 400 and 745 torr. At 1 atm, the measured apparent flame strength of 1.13 g/cm^2-sec corresponds to a volumetric rate of fuel consumption of 2.15 g/cm^3-sec. The apparent flame strength versus pressure data indicates that the overall reaction order is 2.45. Author

N64-14820 Lockheed Propulsion Co., Redlands, Calif.
SOLID PROPELLANT STRUCTURAL INTEGRITY INVESTIGATIONS. DYNAMIC RESPONSE AND FAILURE MECHANISMS Research Contract Status Report No. 11, 21 Nov.-20 Dec. 1963
J. E. Fitzgerald 8 Jan. 1964 9 p
(Contract AF 04(611)-8539)
(LPC-618-P-11; AD-429088) OTS: $1.10

Progress is reported in the investigation of dynamic response behavior of composite propellants, and in the study of the mechanism of propellant rupture. Also reported is progress in the general areas of finite deformation study, vibration mode analysis for case-bonded viscoelastic grains under isothermal and nonisothermal steady state thermal field conditions, and dynamic heat generation in viscoelastic materials. Author

N64-14853* Acoustica Associates, Inc., Los Angeles
ACCELERATION OF BURNING RATE OF COMPOSITE PROPELLANTS BY SOUND WAVES

Isidor Elias, Henry Cheung, and Norman Cohen (Aerojet-Gen. Corp.) N.Y., Am. Inst. of Aeron. and Astron. [1964] 11 p refs Presented at the AIAA Solid Propellant Rocket Conf., Palo Alto, Calif. 29-31 Jan. 1964
(NASA Contract NASw-64; NASA Contract NAS7-69)
(AIAA Paper 64-108) AIAA: $0.50 members, $1.00 nonmembers

The effect of a controlled sound field, produced by a helium-excited whistle, on the burning of an ammonium perchlorate-polyurethane-type composite solid propellant in rocket motors was investigated. Results indicate that: (1) The burning rate of the propellant can be increased by irradiation of the burning surface by a traveling wave sound field. (2) The burning rate increase does not appear to be a strong function of the mass flow of helium; therefore, practical use of a helium-excited whistle would not have serious logistic disadvantages. (3) The effect of sound decreases with increasing pressure. (4) Stop-fire tests have established that the grain burns normally in parallel layers at an accelerated rate when irradiated by the sound field. (5) The sound field produced by the whistle operating in a rocket motor has amplitudes higher than those predicted from a cold flow whistle calibration. I.v.L.

N64-14854* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
ALUMINA SIZE DISTRIBUTIONS FROM HIGH-PRESSURE COMPOSITE SOLID-PROPELLANT COMBUSTION
Louis A. Povinelli and Robert A. Rosenstein N.Y., Am. Inst. of Aeron. and Astron. [1964] 10 p refs Presented at the AIAA Solid Propellant Rocket Conf., Palo Alto, Calif., 29-31 Jan. 1964
(AIAA Paper 64-115) AIAA: $0.50 members, $1.00 nonmembers

Alumina size distributions were obtained for both a coarse and a fine oxidizer composite propellant burning in a nitrogen atmosphere over the pressure range from atmospheric to 500 psi. The amount of additive agglomeration was found to be significantly higher for the coarse oxidizer propellant and decreased with increasing pressure to the 0.3 power over the range from atmospheric pressure to 250 psi. High-speed photographs of the burning propellant surface revealed that the additives moved on the surface with the average particle velocity decreasing with pressure to approximately the 0.3 power over the pressure range from atmospheric to 50 psi. The volume mean diameter of the alumina was found to decrease with increasing pressure. Author

N64-14856* Princeton U., N.J. Guggenheim Labs. for the Aerospace Propulsion Sciences
A STUDY OF THE IGNITION OF SOLID PROPELLANTS IN A SMALL ROCKET MOTOR
E. H. Grant, Jr., R. W. Lancaster, J. Wenograd, and M. Summerfield N.Y., Am. Inst. of Aeron. and Astron. [1964] 11 p refs Presented at the AIAA Solid Propellant Rocket Conf., Palo Alto, Calif., 29-31 Jan. 1964
(Sponsored by NASA and AF)
(AIAA Paper 64-153) AIAA: $0.50 members, $1.00 nonmembers

A small rocket motor that permitted systematic variation of heat transfer rate, chemical reactivity of the igniting gas, flame temperature, mass flow, and chamber pressure was developed for investigating the essential nature of practical ignition processes. In this motor, hot gaseous products from a controllable gas-fed torch were used to apply heat to the internal surface of a cylindrical grain. To simplify interpretation, heat-transfer rate was held constant by maintaining constant mass flow and flame temperature while pressure and oxygen concentration of the test gas were varied. Oxygen concentration (0% to 75% by weight) and pressure (35 to 80 psia) influenced the ignition delay time significantly. Ignition delays for one composite propellant varied from 3 to 37 msec. These results demonstrate the strong influence of gas phase properties on solid-propellant ignition delay and substantiate theoretical models of ignition that include such effects. Author

N64-14941* National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
FLUID OSCILLATIONS IN THE CONTAINERS OF A SPACE VEHICLE AND THEIR INFLUENCE UPON STABILITY
Helmut F. Bauer Washington, NASA, Feb. 1964 149 p refs
(NASA TR R-187) OTS: $3.00

To obtain the eigenfrequencies and mode shapes of a liquid, forced oscillations of a frictionless fluid in a cylindrical container of circular ring-sector cross section are treated. The assumption of frictionless liquid is justified, since only very small damping is provided by the friction at the tank walls. In a cylindrical container, the lower part of the liquid performs the forced oscillation like a rigid body, and only the liquid in the immediate vicinity of the free surface moves independently. The oscillating propellant can be represented as a spring-mass-system, in which location and magnitude of the model values, are determined to give the same forces and moments as the liquid. After the introduction of the mechanical model for the propellants, the derivation of the equations of motion presents no problem. The influence of propellant sloshing is then determined by stability boundaries. This paper gives the results of theoretical studies for the response of the liquid in an arbitrary cylindrical ring-sector container, derives the model for the most frequently used tank forms, and presents stability boundaries for various control systems. Author

N64-14986* National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio
EFFECT OF INTERCHANGING PROPELLANTS ON ROCKET COMBUSTOR PERFORMANCE WITH COAXIAL INJECTION
Martin Hersch Washington, NASA, Feb. 1964 23 p refs
(NASA TN D-2169) OTS: $0.75

The effect of reversing propellants in coaxial injection on combustor performance was determined with a nominal 200-pound-thrust rocket combustor burning gaseous hydrogen with liquid oxygen. Reversing propellants refers to the change from oxidant in the tube to fuel in the tube. The effect of this change was determined by measuring characteristicvelocity efficiency for a combustor having two interchangeable injectors. The injectors were designed so that the propellants could be reversed without changing their respective injection flow areas. The performance was evaluated for three chamber lengths over a range of oxidant-fuel weight ratios from about 1.5 to 10 and for various total propellant flow rates. Higher performance was obtained when the liquid oxygen was injected from the annulus. It was also observed that the combustion noise level was lower with annularly injected liquid oxygen. Also, with annular oxygen injection, the injector face was less subject to high heat-transfer rates. Author

N64-15357 Princeton U., N.J.
SOLID PROPELLANT IGNITION STUDIES: IGNITION OF THE REACTION FIELD ADJACENT TO THE SURFACE OF A SOLID PROPELLANT Final Technical Report, 1 Oct. 1962-30 Sep. 1963
Clarke E. Hermance (Ph.D. Thesis), Reuel Shinnar, and Joseph Wenograd 1 Dec. 1963 248 p refs
(AF Grant AF-AFOSR-92-63)
(Aeron. Eng. Rept.-674; AD-428602)

Discussions are presented concerning the ignition of solid propellants. Reviews of previous ignition studies are given, which include early thermal ignition theory and past experiments on the ignition of combustible mixtures. The thermal

theory of ignition for homogeneous and heterogeneous systems is discussed as is a simplified model for the thermal ignition of a diffusion flame near a cool surface. Reviews are given of recent research on the mechanism of solid-propellant ignition and of experiments on the ignition of composite solid propellants convectively heated in a shock tunnel. C.L.W.

N64-15691 Lockheed Propulsion Co., Redlands, Calif.
SOLID PROPELLANT STRUCTURAL INTEGRITY INVESTIGATIONS, DYNAMIC RESPONSE AND FAILURE MECHANISMS Research Status Report No. 10, 21 Oct.-20 Nov. 1963
J. E. Fitzgerald [12 Dec. 1963] 9 p
(Contract AF 04(611)-8539)
(LPC-618-P-10)

Measurement of sinusoidal viscoelastic moduli has been completed for Polycarbutene-R propellant at temperatures from −46° F to +138° F. Good agreement has been obtained between dynamic moduli calculated from shear stress relaxation and directly measured shear dynamic moduli for the same sample. Stress relaxation characterization has been completed for the Polycarbutene-R cross-link density and recast oxidizer particle size formulation variations. Significant variations in relaxation response are observed for the cross-link density variations. A critical defect radius of approximately 0.02 in. was found to be the most acute fracture concentration that could be induced in PBAA propellant artificially or by tearing. Author

N64-15880* National Bureau of Standards, Boulder, Colo. Cryogenic Engineering Lab.
A PRELIMINARY STUDY OF THE ORIFICE FLOW CHARACTERISTICS OF LN^2 AND LH^2 DISCHARGING INTO A VACUUM
James A. Brennan [1963] 29 p refs Prepared for the Cryog. Eng. Conf., Boulder, Colo., Aug. 19–21, 1963
(NASA Order R-45)
(NASA CR-55329; NBS-R-291; Paper No. E-6) OTS: $2.60 ph, $1.07 mf

Flow characteristics of the propellants through holes made in the tank walls by meteoroid puncture were studied. Overall discharge coefficients for small-diameter, thick-plate orifices were determined as a function of discharge pressure using liquid nitrogen and liquid hydrogen. Discharge pressures from 3 mm Hg to slightly above the triple point were investigated. Flow characteristics appear to be sensitive to discharge pressure and the condition of the liquid upstream of the orifice. A marked difference in flow pattern was observed that depended on whether the liquid was nearly saturated or there was two-phase flow. If the liquid was nearly saturated and no gas phase passed through the orifice, the flow could be very nearly predicted by the adiabatic, incompressible flow equations. When gas phase was present upstream of the orifice, it appeared that solid formation could take place in the orifice itself and thereby retard the flow. In addition to the orifice discharge coefficients, a general discussion of observed flow patterns is presented. Author

N64-15904* Guggenheim Labs., Princeton, N.J.
A THEORETICAL STUDY OF UNSTEADY DROPLET BURNING: TRANSIENTS AND PERIODIC SOLUTIONS
Warren C. Strahle [1963] 258 p refs
(NASA Grant NsG-99-60)
(NASA CR-55516; Aeron. Eng. Rept. 671) OTS: $16.50 ph, $7.94 mf

Through unsteady analysis, conditions are established whereby it is possible to consider that droplets vaporize and burn in a nearly steady state during most of their lifetime. Periodic solutions are then obtained when the droplet is burning in an unsteady acoustic field of the ambient gas. It is shown from the periodic solutions that extremely strong response of the vaporization rate and burning rate can occur throughout the frequency spectrum. Application to the problem of combustion instability is indicated. Author

N64-16080 Hercules Powder Co., Kenvil, N.J.
DEVELOPMENT OF HIGH TEMPERATURE-RESISTANT PROPELLANTS [Final Report]
R. L. Simmons Wright-Patterson AFB, Ohio, AF Flight Dyn. Lab., Jan. 1964 36 p ref
(Contract DA-36-038-507-ORD-3572M; Contract AF 33(657)-2-R&D-111)
(RTD-TDR-63-4209; FA-R-1703; AD-430591)

Trimene Base was found to be a more effective curing agent for potassium perchlorate/Hycar 4021 propellants than DMP-30 and sulfur. Propellant HES-6573 utilizing this approach performed satisfactorily in M73 PAD cartridges in firings from −65° to 400° F. Hycar 1051 was successfully cross-linked with triallyl cyanurate, but the resulting propellant binders did not provide increased heat resistance over the straight Hycar 4021/Trimene Base system. Propellants with silicone and fluorocarbon binders possessed superior heat resistance to the Hycars, but lacked energy. Cyclotetramethylene tetranitramine (HMX) was found to have promise as an organic heat-resistant oxidizer in a Hycar binder where it gave greater impetus than potassium perchlorate; however, burning rate was considerably slower. Limited studies were made for processing the extrudable Hycar propellants in grains up to 1-in. diam. and in fine granulations as small as 0.04-in. diam. for fast-burning applications. Author

N64-16559 Sheffield U. (Gt. Brit.)
COMBUSTION INSTABILITY RESEARCH ON SOLID AND LIQUID PROPELLANT ROCKET MOTORS AT SHEFFIELD UNIVERSITY
J. Swithenbank Jun. 1963 25 p refs

The high-frequency tangential mode of oscillation in a premixed gaseous-fueled rocket motor of 14-in. ID was investigated. In particular, the first tangential traveling mode was studied. Theoretical and practical studies indicated that a net velocity of the gas (in the form of a vortex) is associated with this mode. The following conclusions were drawn as a result of these studies: (1) There is a difference in wave shape between traveling and standing tangential modes. (2) High-amplitude traveling modes will produce vorticity. (3) The stability will decrease if the vorticity is artificially or self-increased. (4) The vorticity will exert a torque on the motor. (5) Swirl in the nozzle will reduce the effective throat area. (6) The vorticity will reduce the frequency of oscillation. Also, research has been extended to cast double-base propellants, and experiments are being conducted to obtain a deeper understanding of the theoretical work being carried out by McClure et al at A.P.L. I.v.L.

N64-16616 Vitro Labs., Silver Spring, Md.
RESEARCH AND DEVELOPMENT OF MATERIEL ENGINEERING DESIGN HANDBOOK – BALLISTIC MISSILE SERIES, PROPULSION AND PROPELLANTS
M. J. Zucrow (Purdue U.) Washington, Army Mater. Command, Aug. 1963 102 p refs Prepared under contract for Duke U.
(AMCP-706-282)

Information is presented on the fundamental operating principles of propulsion systems as found in ballistic missiles. The following topics are discussed: (1) essential features of

rocket engines; (2) criteria of rocket-engine performance; (3) thermodynamic relationships for rocket engines; (4) properties and characteristics of liquid propellants; and (5) properties and characteristics of solid propellants. R.T.K.

N64-16658 IIT Research Inst., Chicago, Ill.
A STUDY OF THE FUNDAMENTALS OF LIQUID PROPELLANT SENSITIVITY
Ted Erickson Edwards AFB, Calif., AF Flight Test Center, 10 Jan. 1964 26 p refs
(Contract AF 04(611)-9566)
(IITRI-C6024-4; AD-428841)

A cryogenic adaptation of the IITRI shock tube has been designed, and it is expected that it can be used for the testing of materials at temperatures down to −150° C. The final assembly of this modification has been started. A chromatographic column and the associated equipment are being provided for purification of the test materials before sensitivity testing. Author

N64-16688* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
CALCULATED TEMPERATURE HISTORIES OF VAPORIZING DROPLETS TO THE CRITICAL POINT
Paul R. Wieber Repr. from AIAA Journal, v. 1, no. 12, Dec. 1963 p 2764–2770 refs
(NASA RP-138)

Digital computations of droplet steady-state temperatures and droplet mass and temperature histories were made to determine if droplet temperatures could approach the critical point. Pressures to 2000 psia were investigated. At sufficiently high pressure, the calculations showed both heptane and oxygen droplets heating to their respective critical temperatures. With increasing total pressure, a reduction occurred in both the downstream distance after injection and the mass evaporated before the droplet reached the critical point. This implied that a vaporization model may be inadequate in describing overall combustion rates at high total pressures. Rapid droplet heating rates indicated that droplets could approach the critical point during combustion instability at high pressures. This phenomenon could thus be involved in a mechanism for high-pressure combustion instability. Author

N64-16870 Monsanto Research Corp., Dayton, Ohio
EVALUATION OF ELASTOMERS AS O-RING SEALS FOR LIQUID ROCKET FUEL AND OXIDIZER SYSTEMS Technical Documentary Report, Sep. 1961-Mar. 1963
Carmen L. Bellanca, Ival O. Salyer, and Jay C. Harris Wright-Patterson AFB, Ohio, AF Materials Lab., Sep. 1963 78 p refs
(Contract AF 33(616)-8483)
(ASD-TDR-63-496; AD-422466)

Elastomeric and plastic O-ring seals were exposed to liquid and vapor phases of nitrogen tetroxide, chlorine trifluoride, a 1:1 mixture of hydrazine-unsymmetrical dimethylhydrazine, and 90% hydrogen peroxide under in-use conditions. Materials included polyethylene, Teflon, butyl, ethylene/propylene, Vitons A and B, silicone, and others. To simulate service conditions, O-rings were tested under compression, in closed static systems, in direct contact with test fluid. The rate of fluid loss through the seal was determined directly. Test method and results are described. Polyethylene encapsulated O-rings and metal-clad elastomeric O-rings as seals for nitrogen tetroxide systems are also discussed. Author

N64-16971 General Electric Co., Philadelphia, Pa.
PROPELLANT STORABILITY IN SPACE Second Quarterly Report, 1 Oct. 1963-31 Jan. 1964
W. Benton et al Edwards AFB, Calif., Rocket Propulsion Lab., Feb. 1964 83 p
(Contract AF 04(611)-9078)
(RPL-TDR-64-22; AD-431823)

Presented are the details of the preparation for the first series of tests in the Space Environmental Simulator. Results of the first test are given, and an analysis of these results are presented. The first test has indicated that earth storable propellant-tank temperatures may be suitably controlled by means of selected coatings. In addition, any short-term heat fluxes will be damped out in the propellant tank. Tests with cryogenic propellants were conducted and indicate the need for a longer data taking period in the second test. Author

N64-17116 Automation Industries, Inc., Danbury, Conn. Sperry Products Div.
FEASIBILITY STUDY TO DETERMINE WHETHER ULTRASONIC TECHNIQUES CAN BE USED TO MEASURE MECHANICAL PROPERTIES OF CAST POLYURETHANES INTENDED FOR APPLICATION AS SOLID PROPELLANT BINDERS [Final Report] 15 Mar. 1960-15 Apr. 1962
A. M. Murdoch and H. E. Van Valkenburg Wright-Patterson AFB, Ohio, Aeron. Systems Div., Jul. 1963 38 p refs
(Contract AF 33(616)-7069)
(ASD-TDR-62-886; AD-415828)

Several series of specimens simulating both binder and propellant materials in various conditions of aging were studied. Ultrasonic examination of these specimen materials was performed, with the objective of finding ultrasonic properties that would indicate their physical condition. Results of tests indicate a significant dependence of both shear wave attenuation and relative acoustic impedance of certain specimen materials on their condition of aging. Author

N64-17152* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
AN EXPERIMENTAL INVESTIGATION OF CHEMICAL REACTION BETWEEN PROPELLANT TANK MATERIAL AND ROCKET FUELS OR OXIDIZERS WHEN IMPACTED BY SMALL HIGH-VELOCITY PROJECTILES
Robert P. Dengler Washington, NASA, Aug. 1963 39 p refs
(NASA TN D-1882) OTS: $1.00

High-velocity projectile penetrations of simulated propellant tanks were made to determine the impact sensitivity of tank materials in contact with liquid and solid rocket propellants. Tank materials investigated were aluminum, stainless steel, two titanium alloys, and three reinforced plastics. The propellants included the liquids oxygen, hydrazine, unsymmetrical dimethylhydrazine, and nitrogen tetroxide, and the solids Arcite 373 and Hercules CLW. Projectile penetration of titanium specimens acting as a wall of a tank containing liquid oxygen caused a chemical reaction between the tank wall and the contained propellant regardless of the material used for the impacting projectile. Violent reactions were initiated by penetrations having kinetic energies as low as 10.4 foot-pounds. Once a reaction was initiated, it propagated vigorously until one of the reactants was consumed. A complete penetration of the titanium tank wall was necessary for a reaction to occur. All other penetrations of tank materials in contact with the various propellants resulted in no reaction of the tank wall and the contained propellant. Author

N64-17156* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
SPONTANEOUS REIGNITION OF PREVIOUSLY EXTINGUISHED SOLID PROPELLANTS
Carl C. Ciepluch Washington, NASA, Mar. 1964 16 p refs
(NASA TN D-2167) OTS: $0.50

The spontaneous reignition phenomenon associated with the extinction of solid propellants by sudden depressurization was investigated experimentally. The results indicated that many solid-propellant compositions may be susceptible to the reignition phenomenon; however, the occurrence is a function of the operating conditions. All propellant compositions exhibited a minimum ambient pressure limit below which reignition was not obtained. Decreasing the characteristic time for the expansion, defined as the time required for the pressure to reach 50 percent of its initial value, suppressed the tendency for reignition to occur. Author

N64-17333 Hercules Powder Co., Cumberland, Md. Allegany Ballistics Lab.
MEASUREMENT OF HEAT FLUX IN SOLID PROPELLANT ROCKETRY
Charles E. Brookley Nov. 1963 55 p refs Presented at the 18th Ann. Conf. of Instr. Soc. of Am., Chicago, 9 Sep. 1963
(Contract NOrd-16640)
(ABL/Z-60; AD-432472) OTS: $5.60

A radiometer and slug-type calorimeters were designed, calibrated, and mounted flush with the inner surface of the internal chamber insulation of a solid-propellant rocket motor. During repeated static firing of this motor, the magnitude of the heat flux was measured and divided into radiant and convective components. Measurements were taken in the unit when using both aluminized and nonaluminized propellants. Author

N64-17375 Naval Ordnance Lab., White Oak, Md.
CALIBRATION FOR THE GAP TEST WITH A PENTOLITE DONOR
I. Jaffe, G. Roberson, and J. Toscano 29 Jan. 1963 21 p refs
(NOLTR-63-19; supersedes NOLTR-62-78; AD-401686)

A second calibration of the gap test was made with a pentolite donor replacing the tetryl donor of the standardized test. The calibration consisted of measuring the attenuation of the shock velocity in a Plexiglas rod, and calculating the corresponding shock pressure as a function of gap distance. Author

N64-17534* United Technology Corp., Sunnyvale, Calif.
THEORY OF IGNITION AND IGNITION PROPAGATION OF SOLID PROPELLANTS IN A FLOW ENVIRONMENT
R. S. Brown, T. K. Wirrick, and R. Anderson N.Y., Am. Inst. of Aeron. and Astronautics [1964] 12 p refs Presented at the AIAA Solid Propellant Rocket Conf., Palo Alto, Calif., 29-31 Jan. 1964
(NASA Contract NAS7-156)
(AIAA Paper-64-157) AIAA: $0.50 members, $1.00 nonmembers

Ignition and subsequent ignition propagation on the surface of a solid propellant in a flow environment have been subjected to a detailed theoretical analysis that has as its basis the recently developed heterogeneous ignition theory. The general theoretical model of ignition and ignition propagation is described by the two-dimensional unsteady-state heat-conduction equation with a variable rate of external heat transfer to the exposed surface of the propellant. Heat transfer by convection, radiation, hypergolic heating, and conduction of heat along the longitudinal axis of the propellant surface parallel to the gas flow is considered. The solution of the resulting equations describes the temperature history of the propellant surface and flowing gases as a function of longitudinal position. Verification of the theoretical model is demonstrated by comparison with experimental data. Author

N64-17751* National Aeronautics and Space Administration, Washington, D.C.
FORMATION OF DETONATION WAVES IN HYDROGEN-OXYGEN MIXTURES FROM 0.2 TO 2 ATMOSPHERES INITIAL PRESSURE IN A 54-METER LONG TUBE
Loren E. Bollinger (Ohio State U.) Apr. 1964 41 p refs
(NASA Grant NsG-44-60)
(NASA TN D-2256) OTS: $1.00

Experimentally it was found that the flame propagation rate of mixtures containing different fuel concentrations was retarded near the end of the closed detonation tube, but remained essentially constant when the end was open to the atmosphere. A tentative explanation is that the shock wave, separated by an appreciable distance from the combustion wave of the detonation wave, reflects from the closed end of the tube and retards the oncoming combustion wave. Author

N64-17820* Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena
AN EXPERIMENTAL INVESTIGATION OF UNCOOLED THRUST CHAMBER MATERIALS FOR USE IN STORABLE LIQUID PROPELLANT ROCKET ENGINES
R. W. Rowley 15 Feb. 1964 30 p refs
(NASA Contract NAS7-100)
(NASA CR-53367; JPL-TR-32-561) OTS: $2.60 ph, $1.10 mf

An experimental investigation of the comparative merits of various uncooled thrust chamber materials was conducted by performing engine tests in which N_2O_4/N_2H_4 propellants were used at a nominal mixture ratio of 1.0. The chamber pressure was 150 psia and the nominal sea-level thrust was 85 lb. Erosion of graphites, ablative plastics, and refractory metals was found to be a function of the local thermal and chemical environments existing at the thrust chamber wall. The role of a particular impinging-stream injector influencing local conditions at the wall was determined by (1) evaluating the properties of the spray produced by nonreacting liquids and (2) measuring local heat-transfer rates to the chamber wall in the operating rocket engine by means of embedded thermocouples and a transient conduction analysis. Author

N64-18013 Rocketdyne, Canoga Park, Calif.
DEVELOPMENT OF HIGH-ENERGY SOLID PROPELLANT FORMULATIONS VOLUME 2: BERYLLIUM PROPELLANT HANDLING MANUAL Final Summary Report
K. R. Regier, R. B. Gordon, D. R. V. Golding, J. R. Glantz, H. Weiss et al Jan. 1964 64 p refs
(Contract AF 04(611)-8179)
(RPL-TDR-64-10, Vol 2, AD-433006)

This report outlines the purpose, objectives, and results of the industrial hygiene program. A detailed description of the facilities and methods utilized for the control of beryllium during the production and static test firing of beryllium-containing propellants is presented. Environmental sampling data, as well as the data collected from a downwind sampling network, are included. The data demonstrate the feasibility of producing and static test firing beryllium-containing propellants Author

N64-18470 Lockheed Missiles and Space Co., Sunnyvale, Calif.
RIFT RADIATION EFFECTS PROGRAM, IRRADIATION NO. 9: MONOMETHYL HYDRAZINE
A. J. Steele 15 Feb 1964 37 p refs
(NSP-64-10)

A radiation test was conducted on monomethyl hydrazine to evaluate the effects of reactor radiation on (1) the hypergolicity of this material with nitrogen tetroxide as the oxidizer, and (2) the production of off-gas In addition, the effects of

radiation on viscosity, density, melting point, and the monomethyl hydrazine assay were also measured. Samples of monomethyl hydrazine were exposed to an integrated flux of approximately 5×10^{15}nvt (E > 0.5 Mev) and 1×10^{8}r. Based on measurements of ignition time delay, this exposure produced no significant effect on the hypergolicity of monomethyl hydrazine when oxidized with nitrogen tetroxide. After exposure to 1×10^{8}r, the off-gas volume (at 1 atmosphere pressure and 77 F) was 21 ml per ml of liquid. The chromatographic analysis of the off-gas showed it to be a mixture of approximately 28-mole-percent hydrogen, 41-mole-percent nitrogen, and 31-mole-percent methane with minor amounts of oxygen, ammonia, and monomethyl hydrazine vapor. The irradiated liquid material exhibited a 4.5-percent decrease in monomethyl hydrazine assay, a 5.5-percent increase in viscosity, and a 0.9-percent increase in density. The melting point was unaffected by radiation. Author

N64-18495 Bureau of Mines, Pittsburgh, Pa. Explosives Research Center
INITIATION OF DETONATION BY LOW AMPLITUDE SHOCKS Semi-Annual Report, 1 Aug. 1963-31 Jan. 1964
F. C. Gibson, R. W. Watson, J. E. Hay, C. R. Summers, and F. H. Scott. 10 Apr. 1964. 39 p. refs
(ARPA Order 44-63, Amend. 6)
(Rept. 3916)

Mechanisms leading to the initiation of detonation in explosives and propellants are discussed. Emphasis was placed on reactions that occur in liquid explosives and sensitive liquid systems as a result of relatively mild shock stimuli. Ensuing reactions take the form of low-velocity detonations wherein the velocity of the reaction is only slightly higher than the sonic velocity in the liquid and less than the sonic velocity in the wall of the liquid's container. If both the liquid and the container are subjected to the same stimulus, e.g., an attenuated shock wave from a solid explosive donor that is less than that required to instantaneously initiate the material to a high-velocity detonation, then the waves in the container wall as well as the waves in the liquid have adequate time to disrupt the homogeneity of the system. As a result of the liquid breakup and subsequent decomposition, a reaction wave is generated that is unstable when the container has a sonic velocity less than that of the liquid but is steady when the cavitational process is continuously induced by the wall waves. I.v.L.

N64-18570 National Engineering Science Co., Pasadena, Calif.
NEW CHEMICAL EXTINGUISHING AGENTS FOR ROCKET PROPELLANT AND METALLIC FIRES Technical Documentary Report [Feb. 1962-Oct. 1963]
Herbert Landesman and Eugene B. Klusmann. Wright-Patterson AFB, Ohio, Res. and Tech. Div., Dec. 1963. 72 p. refs
(Contract AF 33(657)-8015)
(RTD-TDR-63-4208; AD-427683)

Fluoroalkyl esters of boric, phosphoric, silicic, and sulfurous acids, boroxines, and alkoxydifluoroborane trimers have been prepared as possible extinguishants for metallic and/or exotic propellant fires. Their mode of action is to form an inorganic oxide coating on metals. For propellants, they dissolve the fuel and produce nonflammable dilute solutions. The fluoroalkyl groups utilized have been $H(CF_2CF_2)_xCH_2$, where x = 1, 2, 3 and, in the borate case, 4. Attempts to prepare fluoroalkyl esters of aluminic acid gave products that could not be purified. Fluoroalkoxydifluoroborane trimers and fluoroalkyl sulfate esters could not be prepared. Physical properties, stabilities, and compatibilities with materials of construction and with metals and propellants are reported for all materials synthesized. It was found that nonflammable solutions containing esters with pentaborane and with hydrazines could be prepared. Author

N64-18618 Stanford Research Inst., Menlo Park, Calif.
VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS
Nicholas W. Tschoegl, James R. Smith, and Thor L. Smith. 15 Feb. 1964. 45 p. refs
(Contract NOw-64-0073-d; ARPA Order 22, Amend. 60)
(AD-434853)

Improvements have been made in the design and operation of the low-frequency dynamic shear tester. Special techniques have been evaluated for determining precisely the phase angle between the applied displacement and the resultant force. In addition, theoretical work was directed toward determining the manner in which the specimen shape-factor depends on the laterally applied compressive force. A complete description is given of a dynamic bulk compressibility apparatus and of the calibration and evaluative work done to date. Also described is a new apparatus for determining the static (isothermal) bulk compliance over an extended temperature range at pressures up to about 3,000 psi. Factors that influence the effective gage length of both end-bonded and JANAF tensile specimens of the PBAN propellant TP-H-1001 were evaluated. It appears that reliable strain data can be obtained only by determining directly the strain produced in the gage section during tests at various temperatures and crosshead speeds. Author

N64-18709 Douglas Aircraft Co., Inc., Santa Monica, Calif. Missile and Space Systems Div.
CRYOGENIC PROPERTIES OF SEVEN EXPERIMENTAL TITANIUM ALLOYS
S. M. Weiman. 17 Mar. 1964. 29 p.
(SM-44674)

This report provides room temperature, −196° C(−320° F), and −253° C(−423° F) smooth- and edge-notch tensile data for sheet specimens of seven experimental titanium alloys. Also provided are a few partial crack toughness data points for Ti-4Al alloy. The most promising alloys were Ti-5Al-2.5Sn with low iron content and Ti-4Al. Author

N64-18742 Aeronutronic, Newport Beach, Calif. Research Lab.
AN EXPERIMENTAL PROGRAM FOR OBTAINING THE THERMODYNAMIC PROPERTIES OF PROPELLANT COMBUSTION PRODUCTS Final Technical Report
D. L. Hildenbrand, L. P. Theard, W. F. Hall, F. S. La Viola, F. Ju et al. 15 Dec. 1963. 22 p. refs
(Contract NOw-61-0905-c)
(U-2403; AD-427831)

Some preliminary studies of the free evaporation of crystalline boron have been made by the torsion–Langmuir method in the range 1,950° to 2,130° K. The results indicate a vaporization coefficient close to unity and a boron heat of sublimation of 136 ±1 kcal/mole at 298° K. The latter is in good agreement with a value obtained earlier from B_4C decomposition pressure studies. The entropies of a number of Group II gaseous metal dihalides have been reviewed, and it is concluded that the available molecular constant–spectroscopic data for the Be, Mg, and Zn dihalides yield entropies that are too low by 5 ±1 e.u. There is indirect evidence that this discrepancy may be due to the use of bending frequencies that are too high. The thermodynamic data obtained from the program to date have been summarized, and the status of the data for each species is briefly reviewed. Author

N64-18743 Martin Co., Denver, Colo.
CRYOGENIC MATERIALS DATA HANDBOOK Yearly Summary Report [Jun. 1962-Jun. 1963]

F. R. Schwartzberg, S. H. Osgood, and R. D. Keys Wright-Patterson AFB, Ohio, AF Mater. Lab., Sep. 1963 11 p
(Contract AF 33(657)-9161)
(AD-420406)

The background, organization, and maintenance of the *Cryogenic Materials Data Handbook* are discussed. An experimental program and its accomplishments in the past year are described. Handbook insert reports 12 and 13 were distributed in the past year. A new format for data presentation was introduced. Author

N64-18801 Applied Physics Lab., Johns Hopkins U., Silver Spring, Md. Chemical Propulsion Information Agency
PROCEEDINGS OF THE FIRST MEETING OF THE INTER-AGENCY CHEMICAL ROCKET PROPULSION GROUP, WORKING GROUP ON THERMOCHEMISTRY, NEW YORK, NOVEMBER 5-7, 1963, VOLUME 1
Feb. 1964 252 p refs
(Contract NOw-62-0604-c)
(CPIA-44, Vol. 1; AD-435000)

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17. EXPERIMENTAL EVALUATION OF THE HEATS OF FORMATION OF BORON-CONTAINING COMPOUNDS J. D. Rockenfeller (United Aircraft) p 149-159 refs (See N64-18818 11-13)

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20. A SURVEY OF CERTAIN THERMODYNAMIC DATA ON SOME LIGHT-ELEMENT MIXED-METAL AND MIXED-NONMETAL COMPOUNDS T. B. Douglas (NBS) p 173-182 refs (See N64-18821 11-13)

21. THE THERMODYNAMIC PROPERTIES OF SOME OXYHALIDES OF THE LIGHT ELEMENTS M. A. Greenbaum, M. Farber et al (Rocket Power, Inc.) p 183-185 (See N64-18822 11-13)

22. A REVIEW OF DATA ON HEAVY METAL REFRACTORY COMPOUNDS H. L. Schick (Avco Corp.) p 187-212 refs (See N64-18823 11-19)

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N64-18811 Aeronutronic, Newport Beach, Calif.
SURVEY OF THERMODYNAMIC DATA FOR BERYLLIUM SPECIES
D. L. Hildenbrand *In* JPL Proc. of the 1st Meeting of the ICRPG Working Group on Thermochem., New York, 5-7 Nov. 1963, Vol. 1 Feb. 1964 p 81-86 refs (See N64-18801 11-13)
(Supported by ARPA)

The available thermodynamic data for beryllium species (Be-O, Be-O-H, Be-F, and Be-Cl species) that are of interest in advanced propellant applications are summarized. In particular, the following data are presented in tabular form: (1) heats of formation and bond energies of Be-O and Be-O-H vapor species; (2) entropy data for gaseous dihalides; and (3) heats of formation and bond energies of beryllium halides. P.V.E.

N64-18818 United Aircraft Corp., East Hartford, Conn.
EXPERIMENTAL EVALUATION OF THE HEATS OF FORMATION OF BORON-CONTAINING COMPOUNDS
J. D. Rockenfeller *In* JPL Proc. of the 1st Meeting of the ICRPG Working Group on Thermochem., New York, 5-7 Nov. 1963, Vol. 1 Feb. 1964 p 149-159 refs (See N64-18801 11-13)

A description is presented of experimental apparatus in which heats of formation measurements are made. Experimental techniques for determining reliable values of heats of formation of B-H-C-N compounds are discussed, and a preliminary value for the heat of formation of hydrazine monoborane (HMB) is presented ($\Delta H = -8 \pm 2$ kcal/mole). P.V.E.

N64-18864 Atlantic Research Corp., Alexandria, Va.
SOLID-PROPELLANT FLAME MECHANISMS
R. Friedman, A. Maček, and J. M. Semple *In* Va. U. Project Squid 1 Apr. 1964 p 63-65 refs (See N64-18851 11-24)

The mechanisms of solid-propellant combustion were investigated by studying the combustion of single metal particles (aluminum or beryllium) injected into flame gases of known temperature. Systematic observations of burning aluminum particles, made by a technique using magnifying photography, revealed fine details of two rather different modes of combustion of aluminum, vapor combustion, and a peculiar quasi-surface combustion. Combustion of beryllium powder in a closed bomb, which has given somewhat rough but quantitatively reproducible data on the ignition of particles over a wide range of temperatures and pressures, has been completed. The study of the combustion of beryllium particles under more closely controlled ambient conditions at atmospheric pressure has begun. Preliminary results have been obtained with nonspherical beryllium particles, averaging about 40μ in diameter. The particles, injected into product gases of propane–oxygen–nitrogen flames, show a dull red glow at all ambient temperatures above about 2,200° K, indicating some self-heating. However, bright burning was observed only with relatively small particles at the highest temperatures of about 2,700° K, and after a maximum residence time at those temperatures (10 to 12 sec), attainable with the propane flames on the burner employed. Larger particles do not have sufficient time to heat to the ignition temperature. I.v.L.

N64-18887 Army Missile Command, Huntsville, Ala. Propulsion Lab.
EFFECT OF FILLER CONCENTRATION ON THE VISCOELASTIC RESPONSE OF A COMPOSITE SOLID PROPELLANT
Donald L. Martin, Jr. 2 Mar. 1964 39 p refs
(RK-TR-64-2; AD-433612)

An investigation was conducted to determine the effect of volume fraction of filler on the viscoelastic response of the PBAA propellant system. Formulations containing up to 84% filler fraction were investigated in uniaxial tension with strain rates varying from 0.05 to 5.0 inches per inch per minute and temperatures of 180° to −90° F. A modification of the Williams, Landel, Ferry relationship, relating time to changes in temperature, was satisfactorily applied to the reduction of the test data. Close agreement between calculated and experimental values of log a_T was obtained for all formulations. Mechanical response spectra are presented for maximum stress, modulus, strain, strain-energy-density at failure, and for the stress–strain relationship, indicating the dependence of these parameters on strain rate, temperature, and filler fraction. Author

N64-18890 Air Force Systems Command, Wright-Patterson AFB, Ohio. Foreign Technology Div.
VIBRATIONAL COMBUSTION
B. V. Raushenbakh 16 Apr. 1963 525 p refs Transl. into ENGLISH of "Vibratsionnoye Goreniye", Moscow, Gosizdat. Fiz.-Mat. Lit., 1961 p 1–500
(FTD-TT-62-942/1+2; AD-402909)

This book is devoted to the problem of combustion-process instability encountered in the design of liquid-fuel rocket engines, air-breathing jet engines, highly forced fireboxes in chemical electric-powerplants, and in conducting various types of physical tests and experiments in combustion theory. It gives a systematic exposition of contemporary theory of the excitation of longitudinal acoustic vibrations by application of heat. The qualitative laws inherent in this type of vibration are given detailed consideration, with information from hydromechanics, acoustics, and combustion, with information from hydromechanics, acoustics, and combustion theory drawn upon extensively for their analysis, and with application of the mathematical apparatus of control and vibration theories. Author

N64-18905 Rohm and Haas Co., Huntsville, Ala. Redstone Arsenal Research Div.
Quarterly Progress Report on Engineering Research, 15 September–15 December 1963 [A METHOD FOR DETERMINING THE THERMAL DIFFUSIVITY OF SOLID PROPELLANTS]
Donald E. Mastin 6 Mar. 1964 20 p refs
(Contract DA-01-021-ORD-11878(Z))
(P-63-27; AD-433635)

A method for the determination of the thermal diffusivity of solid propellants was developed based on the transient temperature response of a propellant specimen. The method is simple, accurate, and well suited to materials of low diffusivity. Author

N64-19142 Stanford Research Inst., Menlo Park, Calif.
VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 1, 15 Jul.–15 Oct. 1963
Thor L. Smith and James R. Smith 1963 5 p
(Contract NOw-64-0073-d; ARPA Order 22; Amend. 60)
(AD-436695; Rept. 9)

Information on work completed and on studies in progress in the following areas related to solid propellants and propellant binder development is presented: (1) dynamic shear properties; (2) dependence of specific volume on pressure, temperature, and time; and (3) large deformation tensile properties at constant strain rates. R.T.K.

N64-19414 Aeronutronic, Newport Beach, Calif. Research Labs.
PROPELLANT OPTIMIZATION PROGRAM FOR COMPUTERS, MATHEMATICAL PROCEDURES, AND PROGRAMMING [Final Report]
E. R. Buley, D. G. Piper, B. Kubert, and L. Sashkin 14 Feb. 1964 40 p refs
(Contract AF 04(611)-8546)
(U-2502, RPL-TDR-64-35, AD-433734)

Modifications to an existing computer program are described. The resulting program can determine the composition yielding maximum impulse for multicomponent propellant mixtures subject to both equality and inequality constraints on the components. The program is coded for the IBM-7090 and 7094 computers and has been demonstrated for systems containing up to 8 components. The actual capability extends to 10 components. Also described are the mathematical formulation of the problem and procedures used for the optimization process with modifications. Instructions for using the program and program flow charts are included. Author

N64-19651 Lockheed Propulsion Co., Redlands, Calif.
SOLID PROPELLANT STRUCTURAL INTEGRITY INVESTIGATIONS. DYNAMIC RESPONSE AND FAILURE MECHANISMS Final Report
Dalton Cantey 17 Apr. 1964 169 p refs
(Contract AF 04(611)-8539)
(LPC-618-F; RPL-TDR-64-32, Vol. 1; AD-437140)

Discussed is the correlation of mechanical response and failure in solid propellants with basic material structural characteristics. Propellant dynamic physical properties and structural failure phenomena were studied in detail. Major emphasis was directed at the problems of propellant viscoelastic properties and failure mechanisms together with examination of the effects of propellant binder and filler physical characteristics on its behavior. Measurements of viscoelastic properties of propellants using transient techniques are demonstrated, and results are presented. Investigation of propellant viscoelastic properties in dynamic shear is also discussed. Failure criteria studies are presented in

which propellants were tested. Conclusions are given on the isolation of a maximum tensile stress failure criterion, and on methods of engineering evaluation of propellants. Subcontract research, directed at problems in photoviscoelasticity, finite viscoelasticity, dynamic problems in finite viscoelasticity, and heat generation due to forced vibrations, is documented. Classified material (formulation data) for propellants studied in the program are presented. Author

N64-19669 General Electric Co., Philadelphia, Pa.
PROPELLANT STORABILITY IN SPACE Third Quarterly Report, 1 Feb.-31 Mar. 1964
R. Carr, A. Cohen, C. Lankton, and B. Zeldin Edwards AFB, Calif., Rocket Propulsion Lab., Apr. 1964 28 p refs
(Contract AF 04(611)-9078)
(RPL-TDR-64-56; AD-437581)

Presented are the details of preparation for the second series of tests in the solar environmental simulator. Results of this test are given and compared with those obtained in the first test. In terms of steady-state data, the second test yielded excellent results. The numerical information indicates that insulated tankage systems do not perform as well as predicted, but give adequate protection for long term storage. It is also evident that the performance of large tanks is superior to that of smaller units. Author

N64-19723* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
HYDROSTATIC STABILITY OF THE LIQUID-VAPOR INTERFACE IN A GRAVITATIONAL FIELD
William J. Masica, Donald A. Petrash, and Edward W. Otto Washington, NASA, May 1964 19 p refs
(NASA TN D-2267) OTS: $0.50

A study was conducted in a l-g acceleration field to determine the hydrostatic stability of the liquid-vapor interface in a cylinder. The result was a verification of the contention that the Bond number criterion is valid for predicting the regions of hydrostatic stability of the liquid-vapor interface. Factors affecting the stability of the interface are the specific surface tension of the liquid and the orientation of the interface with respect to the acceleration. Author

N64-19728 Rohm and Haas Co., Huntsville, Ala. Redstone Arsenal Research Div.
AN ANALYSIS OF SOME ASPECTS OF THE WENOGRAD THERMAL STABILITY EXPERIMENT
Joseph D. Clem, Jr. and W. H. Growtzinger, III 3 Mar. 1964 32 p refs
(Contract DA-01-021-ORD-11878(Z))
(S-44; AD-432598)

An analysis was made of some aspects of the Wenograd experimental technique for investigating the thermal stability of explosives at high temperatures. A mathematical model of the experiment was formulated; the equations were solved numerically and investigated parametrically. Results indicated that first estimates of the activation energy and preexponential factor of the explosives may be obtained from analysis of the experimental data. Author

N64-19890* National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala.
PROPULSION IMPROVEMENTS ACHIEVED DURING FLIGHT TESTING OF SATURN VEHICLES
B. K. Heusinger N.Y., AIAA [1964] 11 p Presented at the AIAA Aerospace Propulsion Meeting, Cleveland, 4-6 May 1964
(AIAA Paper 64-537) AIAA: $0.50 members, $1.00 nonmembers

A description is given of the improvements on a one-million pound Saturn vehicle propulsion system for earth orbit and deep-space probes. A correlation was made between the propellants and the payloads for each of the different Saturn vehicle stages. Improvement measurements were determined by installing a flowmeter in each propellant suction line to establish individual engine and total vehicle flow rates. A.L.B.

N64-20307 Rohm and Haas Co., Huntsville, Ala. Redstone Arsenal Research Div.
ENGINEERING RESEARCH Quarterly Progress Report, Dec. 10, 1963-Mar. 10, 1964
B. Becker, J. J. Brisbane, T. L. Cost, C. Parr, H. B. Wilson et al 23 Apr. 1964 27 p refs
(Contracts DA-01-021-ORD-11878(Z), DA-01-021-ORD-11909(Z))
(P-64-6; AD-437772)

Progress is summarized for the following projects: Thermal Properties of Propellants, Determination of Curing Kinetics, Analysis of Diffusion Processes Coupled to Chemical Reactions in Solid-Propellant Grains, Analysis of Flow Reactors, Analysis of the DTA Test, Dynamic and Thermal Nonequilibrium in Two-Phase Flow in Rocket Nozzles, Conformal Mapping and Determination of Stresses in Star-Perforated Grains, Development of Approximate Methods of Viscoelastic Stress Analysis, Thermal Stresses in Viscoelastic Materials, Mechanics of Curing Propellants, Mathematics of Composite Materials, Stress Analysis of Infinite Cones Under Axial Acceleration, Analysis of Stress Singularities, Analysis of the Biaxial Strip Test, and Development of Stress Analysis Programs Based on the Finite-Element Method. Author

N64-20710* National Aeronautics and Space Administration, Marshall Space Flight Center, Huntsville, Ala.
INTERACTION OF STRUCTURAL VIBRATIONS, PROPELLANT SLOSHING AND CONTROL FOR LARGE SPACE VEHICLES
Helmut F. Bauer Stuttgart-Flughafen, Arbeits- und Forschungsgemeinschaft Graf Zeppelin [1961] 88 p refs Presented at the 51st Aeronautics Conf., Stuttgart-Flughafen, 8 Sep. 1961 In GERMAN

The control problem of large space vehicles is discussed from two aspects: (1) structural vibrations and propellant sloshing, and (2) vehicle stability. A mechanical model of propellant sloshing is presented. Simple criteria as to the effect of various control elements, as well as stability limits, for the case of flying bodies with sloshing propellants, are discussed. Also, a control-feedback stability analysis, which includes the effects of bending vibrations, propellant sloshing, and control systems, is given. I.v.L.

N64-20721* Southwest Research Inst., San Antonio, Tex.
LIQUID SURFACE OSCILLATIONS IN LONGITUDINALLY EXCITED RIGID CYLINDRICAL CONTAINERS Technical Report No. 2
Franklin T. Dodge, Daniel D. Kana, and H. Norman Abramson 30 Apr. 1964 89 p refs
(NASA Contract NAS8-11045; SRI Proj. 13-02-1391)
(NASA CR-56135) OTS: $8.10 ph

Results of a theoretical and experimental study of low frequency liquid motions in a longitudinally vibrated tank are presented and discussed in some detail. Large amplitude free surface motions occur when the liquid responds as a one-half subharmonic of the excitation. This form of response exhibits the "jump" phenomena common to nonlinear systems. Harmonic and superharmonic liquid surface motions are also observed, although their amplitudes are considerably smaller than those corresponding to the one-half subharmonic

response. Comparisons between theoretical and experimental results are given, in most instances the correlation being rather close. Author

N64-20816* Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena
SPACE PROGRAMS SUMMARY NO. 37-26, VOLUME IV FOR THE PERIOD FEBRUARY 1, 1964 TO MARCH 31, 1964. SUPPORTING RESEARCH AND ADVANCED DEVELOPMENT
R. Broucke et al 30 Apr. 1964 280 p refs
(Contract NAS7-100)
(NASA CR-56175; JPL-SPS-37-26, Vol. 4) OTS: $12.50

Areas discussed are: (1) systems analysis (trajectory and launch probability studies, etc.); (2) spacecraft electrical power; (3) guidance and control analysis and integration; (4) guidance and control research; (5) materials research; (6) electrochemical engineering support; (7) aerodynamic facilities; (8) solid-propellant engineering; (9) polymer research; (10) propulsion research; (11) advanced propulsion engineering; (12) space-instruments systems; (13) applied science (electron-excited X-ray fluorescence for lunar-surface analysis and the Rutherford experiment); (14) chemistry; (15) fluid physics; (16) physics; (17) communications-elements research; and (18) communications-systems research. I.v.L.

N64-20846 Naval Ordnance Lab., White Oak, Md. Chemistry Research Dept.
ANALYSIS OF THE OPTICAL DETERMINATION OF DETONATION VELOCITY IN SHORT CHARGES
A. Robert Clairmont, Jr. and Irving Jaffe May 1964 31 p refs
(NOLTR-64-23; AD-600059)

A transformation equation was derived whereby the data from smear camera records of the peripheral detonation of a short (L/D of 2.5) tetryl charge can be interpreted to obtain a detonation velocity measurement. The results are in excellent agreement with the values measured along the axis as well as with those published in the literature. Author

N64-20853 Stanford Research Inst., Menlo Park, Calif.
***SOLID PROPELLANT MECHANICAL PROPERTIES INVESTIGATIONS* Second Quarterly Progress Report, Jan. 1-Apr. 1, 1964**
Norman Fishman and James A. Rinde 20 Apr. 1964 49 p refs
(Contract AF 04(611)-9559)
(Rept. 6; AD-439403)

Continued progress was made toward developing a method for defining the path-independent physical state of a propellant in terms of stress–strain–time history. The general form of the dilatational state equation, developed by least squares curve fitting of all constant strain rate test data, is as follows:

$$\log V/V_0 = A[\log W + B(\log t/b_T) + C(\log t/b_T)^2]^n.$$

Analysis of test data by application of the modified finite elastic theory continued. Considerable development of this method of data analysis remains to be done, but significant progress toward effective material characterization was made. Results of all tests to date are presented in either tabular or graphical form. Preliminary results of tests of two model systems based on the polybutadiene binder (one with glass beads, the other with aluminum powder) and results of studies of the effects of moisture on dilatation are also discussed. Author

N64-21061 Rocketdyne, Canoga Park, Calif. Research Dept.
RESEARCH IN THE CHEMICAL, PHYSICAL, AND METALLURGICAL SCIENCES Final Report, 25 Jun. 1962-10 Dec. 1963
B. L. Tuffly et al Edwards AFB, Calif., AF Flight Test Center, Feb. 1964 160 p refs
(Contract AF 04(611)-8502)
(R-5462; RTD-TDR-64-21; AD-432599)

The current program was directed toward advancing the state-of-the-art of analytical chemistry as applied to rocket propellants. Specific efforts discussed include: (1) development of a fast-responding, highly sensitive detector for electroactive materials in gases and liquids; (2) development of techniques for chemical analysis of cryogenic materials; and (3) establishment of the chemical structure of pentaboranehydrazine firing residues. Author

N64-21466 Catholic U. of America, Washington, D.C. Stress Analysis Lab.
DEVELOPMENT OF EXPERIMENTAL STRESS ANALYSIS METHODS TO DETERMINE STRESSES AND STRAINS IN SOLID PROPELLANT GRAINS. EXPERIMENTAL SOLUTION OF SOME MIXED BOUNDARY VALUE PROBLEMS
A. J. Durelli and V. J. Parks Apr. 1964 88 p refs Presented at an Eng. Colloq., Brown U.
(Contract Nonr-2249(06))
(IR-4; AD-600546)

This paper deals with means of applying known displacements and known stresses to the boundaries of models used in experimental stress analysis. Reviewed is the solution of several problems in which these means are used. The evaluation of the stresses, strains, and displacements in the field is conducted using several experimental stress analysis methods. Particular emphasis is placed on the methods used to study several kinds of shrinkage problems with two- and three-dimensional photoelasticity. The application of these methods is illustrated with examples, several of which are in the field of stress analysis of solid-propellant grains. Author

N64-21586 Hercules Powder Co., Cumberland, Md. Allegany Ballistics Lab.
MECHANICAL PROPERTIES OF SOLID PROPELLANTS FOR COMBINED STATES OF STRESS AT VARIOUS TEMPERATURES
M. G. Sharma and C. K. Lim Sep. 1963 155 p refs Prepared from work performed at Pa. State U.
(Contract NOrd-16640)
(ABL/X-114; AD-439959)

Three separate methods were developed for characterizing inert solid fuel propellants under combined states of stress at room temperature conditions as follows: (1) The material is characterized in terms of a stored energy function and a dissipated energy function. These functions are determined from hysteresis tests under combined loading. (2) The energy functions are determined experimentally by using a finite viscoelastic theory that is an extension of the finite elastic theory. By this method, the energy functions are determined from one single combined stress test. (3) The combined stress test behavior is predicted from uniaxial-tension stress–strain law. None of the classical failure criteria apply to this material. Failure envelopes corresponding to the various criteria of failure considered are drawn for various rates of extension ratios. A new criterion of failure for the material is developed. D.S.G.

N64-21673 Martin Co., Denver, Colo.
TOXICANT ENTRAINMENT TEST —CLOTHING OUTFIT, ROCKET FUEL HANDLERS A/P 22P-1
R. G. Hanson Jan. 1964 12 p
(Contract AF 04(647)-576)
(AD-431540)

The objective of this test was to determine the danger to personnel wearing torn protective clothing while subjected to vaporous propellants. Only $NO_2-N_2O_4$ vapors were used in the test that was conducted in a test chamber 8 × 8 × 8 ft. The reading of the two ASI sensors was taken at time 0. Under normal operation the suit is pressurized to 0.5 in. of water pressure from the (environmental control units) airflow in conjunction with the suit pressure relief valves. When the suit is torn, it deflates and the airflow escapes through the hole. The test shows that NO_2-N_2O_4 will enter the suit at such a high rate that the wearer must remove it immediately. The closer a tear occurs to the recirculation inlet of the ECU, the faster the concentration builds up in the helmet. A.W.

N64-21687 Space Technology Labs., Inc., Redondo Beach, Calif. Aerosciences Lab.
THERMAL RADIATION FROM THE EXHAUST PLUME OF AN ALUMINIZED COMPOSITE PROPELLANT ROCKET
Technical Report No. 6121-7904-RU-000
S. J. Morizumi and H. J. Carpenter Jan. 1964 37 p refs
(Contract AF 04(694)-1)
(BSD-TDR-64-16; AD-431500)

A technique is developed for calculating rocket base heating and spacecraft heating environments due to particle radiation from a single nozzle rocket exhaust plume. The analysis treats radiation from a cloud of particles as that from an equivalent radiating surface. Thus, the problem is reduced to the determination of the proper values of the apparent surface emissivity and the effective temperature. The particle flow field information (particle concentrations, temperatures, and trajectories) necessary to determine these two quantities is provided by a two-phase flow field computer program. Author

N64-21749 Picatinny Arsenal, Dover, N.J.
NITROCELLULOSE PAPER COMBUSTIBLE MANDRELS
Edward Daniels and David Eliezer Feb. 1964 18 p
(TM-1324; AD-431528)

Satisfactory combustible mandrels were fabricated by convolutely wrapping nitrocellulose paper on a cylindrical form using a lacquer to bond the layer of paper. A modified M8 JATO propellant grain was successfully cast around one of these mandrels and statically fired with satisfactory results. Author

N64-21794 Army Missile Command, Huntsville, Ala. Propulsion Lab.
CURE STUDY OF "FLUID BALL" POWDER
Everette M. Pierce 3 Jan. 1964 15 p refs
(RK-TR-64-1; AD-431674)

A cure study of Fluid Ball powder and triethylene glycoldinitrate was conducted to determine the cure mechanism. The objective was to determine if all the ball powder was completely dissolved during the curing process or if most of the cure was by gelation. Experimental results showed that ball powder spheres were discrete after normal cure time and temperature. Author

N64-21901 Rocketdyne, Canoga Park, Calif.
HYDROGEN OXYGEN CATALYTIC IGNITION
Charles Bendersky Jan. 1963 95 p refs
(RR-63-9)

The results of an experimental program for evaluating the feasibility of catalytic techniques for igniting hydrogen–oxygen propellant combinations are reported. Ignition capability at preignition environmental temperatures as low as −250° F was demonstrated at a mixture ratio of 1.0, and a mass velocity of ~4 lb/ft^2-sec. Reignition capability was demonstrated in a series of 15 reignitions conducted nominally at −260° F inlet propellant temperature, ambient (~70° F) hardware, 1.0 mixture ratio, and mass velocity of ~3 lb/ft^2-sec. The program was conducted in 1-in.-diam hardware capable of about 10-lb thrust. Author

N64-21939 Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div.
PRINCIPLES OF PROPELLANT APPLICATION IN LIQUID-PROPELLANT ROCKETS
N. N. Bobrov and P. I. Voropay 26 Mar. 1964 40 p Transl. into ENGLISH of Chapter 5 of a Book "Primeneniye Topliva i Smazochnykh Materialov" Moscow, Gostop, 1962 p 172–199
(FTD-TT-63-1063/1+2+4; AD-600523)

The discussion of the principles of propellant application in liquid-propellant rocket engines is divided into brief discussions of the following: (1) arrangement and operation of liquid rockets—thrust, specific thrust, specific propellant consumption, engine specific weight, actual-liquid rocket work cycle, relative efficiency, and internal efficiency; (2) cooling—external-flow cooling, internal cooling, and capacitive cooling; (3) methods of feeding propellants to the combustion chamber—pressure-tank feeding system and pump feeding system; (4) formation of propellant mixture and propellant combustion; (5) heat of combustion and gasification of liquid propellants; (6) liquid propellants—propellant requirements, monopropellants, bipropellants, oxidants, nitric acid, hydrogen peroxide, fuels, hydrocarbon fuels, amines, hydrazine and organic hydrazines, and metals and metal compounds; (7) effects of fuel and oxidant properties on propellant quality; and (8) promising energy sources for rocket engines. P.V.E.

N64-22009 Aerojet-General Corp., Sacramento, Calif.
VaPAK, A SIMPLE SELF-PRESSURIZATION SYSTEM
5 Jun. 1964 72 p refs
(Rept.-8290-5S)

VāPak is a lightweight vapor pressurization system that offers a potential improvement in flexibility over any of the liquid propulsion systems. In principle, it is similar to that of a self-discharging insecticide or paint can. The propellant is expelled by its own vapor without a significant change in discharge pressure. No high-pressure gas bottles, regulators, or pressurization cartridges are required; in fact, no components or devices whatsoever must function, once liquid flow from the VāPak tanks is initiated. In appropriate applications, this vapor pressurization concept results in a liquid rocket with system simplicity exceeding that of a solid rocket, but retaining the performance and controllability obtained with liquid propellants. The feasibility of expelling various earth storable and cryogenic propellants by VāPak have been successfully demonstrated. Long duration storage and rocket engine tests verified the instant readiness and combustion characteristics of saturated propellants. Throttling tests indicated a wide thrust range capability with a fixed-area injector. I.v.L.

N64-22240 Atlantic Research Corp., Alexandria, Va.
THE EVALUATION AND CONTROL OF TOXICITY HAZARDS IN SOLID PROPELLANT OPERATIONS
Kenneth D. Johnson Jan. 1963 27 p Presented at the Solid Propellant Rocket Conf., ARS, Philadelphia, 20 Jan.—1 Feb. 1963
(ARS Paper-2766-63)

The risks of injury by toxic releases to the atmosphere from propellant operations depend upon physiological, physicochemical, and meteorological factors, as well as the composition of the propellant. The estimation of these statistical risks from an evaluation of these factors is discussed. Minimization of the risks through containment of toxic exhaust products, scheduling of operations during periods of meteorology favorable for rapid

atmospheric dilution of toxic emissions, and by operation at highly isolated sites is discussed in principle and illustrated by example. Author

N64-22270 Aerojet-General Corp., Sacramento, Calif.
AGING CHARACTERISTICS OF MINUTEMAN POLYURETHANE BINDERS
V. D. Celentano May 1964 195 p refs
(Contract AF 33(600)-36610)
(AFBSD-TDR-64-52; AD-600881)

Results of aging and research investigations on polyurethane binders are reported. Emphasis was placed on the chemical reactions that occur in the binder structure during storage at elevated temperatures. Among the findings reported are: (1) The degradation of Minuteman Wing I and II ANP-2862 polyurethane binder aged at 180° F in air proceeds by oxidative attack on the polyether chains, followed by chain scission and chemical transformation of polyether chains to polyester–polyether chains. (2) The acid number, when correlated with mechanical property data, may prove a valid aging index of polyurethane-based propellants. (3) The selective extraction of sol fraction components was accomplished, and the solubility parameter concept proved useful in separating linear polyurethane components from unaged ANP-2862 binders. M.P.G.

N64-22274 Hercules Powder Co., Kenvil, N.J.
FEASIBILITY INVESTIGATION OF A HYBRID ROCKET FOR CREW ESCAPE CAPSULE APPLICATIONS Summary Report No. 1, Sep. 1961–Jun. 1962
A. J. Kavall Wright-Patterson AFB, Ohio, AF Flight Dyn. Lab., Mar. 1964 58 p
(Contracts DA-36-034-ORD-3538-RD; AF 33(657)-2-R&D-111)
(FA-R-1715; FDL-TDR-64-31; AD-600691)

Thermodynamic calculations of various fuel-oxidizer combinations were performed on a computer so that optimum propellant systems could be formulated and investigated. Theoretical performance curves were plotted from the computer values. The fuels contained aluminum and magnesium powders in combination with four binder materials. The oxidizers considered were nitrogen tetroxide and red fuming nitric acid. Fuel formulations were selected and processed into sample mixes for laboratory scale testing and evaluation. Tests were conducted to ascertain the reactive properties of the fuel samples when sprayed with the candidate oxidizers. High-temperature storage testing was conducted on several sample fuels. A test motor was designed and fabricated to permit testing of full-sized fuel grains. Grain formulations containing 40% aluminum or magnesium with a Hycar binder system were fired in a "work horse" motor, and the results of these tests are included. R.T.K.

N64-22380 Picatinny Arsenal, Dover, N.J. Ammunition Engineering Directorate
EXPERIMENTAL STUDY OF LIQUID ROCKET SIMULATION OF SOLID PROPELLANT ROCKET EXHAUST CHARACTERISTICS
L. Jablansky and L. Stibrany Apr. 1964 45 p refs
(PA-TR-3165; AD-600938)

A substantial cost saving can be realized if a small liquid propellant rocket engine, using cheap propellants, can be used to screen nozzle materials for eventual use with large solid rocket motors using costly propellants. Work was completed in which the nozzle erosion experienced in a solid rocket motor using AHH propellant was simulated by a liquid propellant engine using white fuming nitric acid and benzene. The work was conducted at a one-to-one scale ratio, and the approach taken was to simulate erosion by simulating nozzle environment. Approximate simulation of nozzle erosion was achieved. Author

N64-22554 General Dynamics/Astronautics, San Diego, Calif.
THERMOPHYSICAL PROPERTIES OF PLASTIC MATERIALS AND COMPOSITES TO LIQUID HYDROGEN TEMPERATURE (−423° F) Technical Documentary Report, Jul. 1962–Feb. 1964
James F. Haskins, Malcolm D. Campbell, Julius Hertz, and Joseph L. Percy Wright-Patterson AFB, Ohio, AF Materials Lab., Jun. 1964 179 p refs
(Contract AF 33(657)-9160)
(ML-TDR-64-33, Pt.I; AD-601337)

Existing room-temperature test methods for the determination of specific heat, thermal conductivity, and thermal expansion were modified so that measurements could be made at temperatures down to −423° F. Seventeen materials were evaluated. Thermal conductivity measurements on laminated materials parallel to a continuous reinforcement were as much as four times as high as measurements made normal to reinforcement. The use of higher conductivity reinforcements resulted in higher conductivity laminates. Thermal expansion measurements on laminated materials showed that, in the direction normal to the reinforcement, the component with the largest coefficient of thermal expansion has the greatest influence on the overall expansion. In directions parallel to the reinforcement, the expansion of the higher modulus component controlled the overall expansion. Difficulties were encountered in determining the specific heat properties of the test materials at low temperatures. Test methods, problem areas, and preliminary data are discussed. Author

N64-22706 Naval Ordnance Lab., White Oak, Md.
A PROCEDURES MANUAL FOR COMPUTING PROPELLANT THERMODYNAMIC PROPERTIES
Bernard A. Burke May 1964 102 p
(NOLTR-63-202; AD-600988)

This manual describes the procedures used to compute propellant thermodynamic properties. A typical specific impulse problem is solved, followed by the procedure used to add thermodynamic data to the calculation system, and a discussion of various difficulties that might be met. An appendix contains the FORTRAN listing of the specific impulse program. The operating system used with the IBM-7090 is described wherever applicable to the work, and each kind of program output sheet is illustrated. Author

N64-23280 Applied Physics Lab., Johns Hopkins U., Silver Spring, Md.
EFFECTS OF THERMAL RADIATION ON THE ACOUSTIC RESPONSE OF SOLID PROPELLANTS
R. H. Cantrell, F. T. Mc Cluren and R. W. Hart Jun. 1964 45 p refs
(Contract NOw-62-0604-c)
(TG-335-18)

Theoretical calculations are given 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 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 energy transfer by radiation to convective energy transfer. Author

N64-23426 Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div.
UNSTABLE PERFORMANCE OF LIQUID FUEL ROCKET ENGINES
R. Staniszewski 27 May 1963 15 p refs Transl. into ENGLISH from Wojskowy Przeglad Lotniczy (Warsaw), no. 8, Aug. 1962 p 48–56
(FTD-TT-63-357/1+2; AD-411495)

The following causes for the unstable operation of rocket engines are discussed: (1) delay in ignition time; (2) external disturbances transmitted to the rocket engine; (3) change in flight altitude; (4) change in flight velocity; (5) chamber and nozzle cooling; and (6) unstable operation of individual elements of the fuel feeding system. I.v.L.

N64-23611* Bell Aerosystems Co., Buffalo, N.Y.
WELDED METAL BELLOWS, A RELIABLE POSITIVE EXPULSION DEVICE FOR LIQUID PROPELLANTS
Leo M. Thompson N.Y., AIAA [1964] 7 p Presented at the 1st AIAA Ann. Meeting, Washington, D.C., 29 Jun.–2 Jul. 1964
(Contract NAS7-149)
(AIAA Paper-64-264) AIAA: $0.50 members, $1.00 nonmembers

The results of this parametric analysis demonstrated the superior potential of the metal bellows, and it was therefore selected for a comprehensive design study. The selection criteria included those conditions imposed during long-term orbital missions and spacecraft applications, including operations through a wide range of temperatures and high radiation levels. Low rates of permeation and diffusion through a gas–liquid barrier were also considered. Compatibility with selected propellants and the reliability associated with manned applications became important criteria for consideration. G.D.B.

N64-24004 France. Office National Detudes et de Recherches Aeronautiques, Chatillon-Sous-Bagneux
THE EXPERIMENTAL DETERMINATION OF MOBILE HYDRODYNAMIC FORCES DUE TO THE WAVE-MOVEMENT OF PROPULSION LIQUIDS [LA DETERMINATION EXPERIMENTALE DES FORCES HYDRODYNAMIQUES INSTATIONNAIRES DUES AU CLAPOTIS DES LIQUIDES DE PROPULSION]
Christian Béatrix [1964] 30 p refs Presented at the Meeting of the Groupe Materiaux et Structures de L'AGARD, Liege, France, 27 May–2 Jun. 1964 In FRENCH
(ONERA-TP-136)

The generation of nonstationary hydrodynamic forces provoked by the sloshing of liquid propellants in the fuel tanks of missiles can influence their behavior in flight. Since theoretical studies are inadequate for resolving part of the problem, experimental methods were developed, and studies were carried out on this type of engine. The conclusions are useful in the selection of proper arrangements for minimizing the effect of sloshing and in the comparison of the effects of liquids having different properties. M.P.G.

N64-24376 Technische Hochschule Munchen (W. Germany)
MEASUREMENTS OF IGNITION DELAYS OF HYPERGOLIC LIQUID ROCKET PROPELLANTS
G. Spengler, A. H. Lepie, and J. Bauer [1964] 23 p refs Presented at the 1964 Spring Meeting of the Western States Section Combustion Inst., Stanford U., Apr. 1964
(WSS/CI Paper-64-12)

After a theoretical discussion of hypergol ignition and a description of instrumentation for measuring ignition delays, some of the results obtained using nitric acid and nitrogen tetroxide and their mixtures as oxidizers are presented. The factors investigated include the influence of the following: (1) the inside diameter of the capillary injection tube; (2) the injection velocity and mixing ratio; (3) the gas pressure in the combustion chamber; (4) the temperature of fuel and oxidizer; and (5) the water contents in fuel and oxidizer. In order to investigate the possibility of the hypergolization of fuels that are not self-igniting with nitric acid, the ignition delay of numerous two-component fuel systems was measured as a function of their mixture ratios. Some of the mixtures investigated include furfurylalcohol and primary amines, UDMH and phenylacetylene with nitric acid, soluble metal ions dissolved in the oxidizer or the fuel, and combinations of furfurlalcohol, UDMH, nitric acid, and nitrogen tetroxide. M.P.G.

N64-24849 National Cash Register Co., Dayton, Ohio Capsular Research and Product Development Dept.
A STUDY OF THE ENCAPSULATION OF HIGH ENERGY SUBSTANCES Final Report, 1 Apr. 1959–31 Dec. 1963
Constantine C. Petropoulos Apr. 1964 65 p refs
(Contract Nonr-2848(00))
(AD-601772)

Research in the following areas is summarized: (1) film permeability studies; (2) the compatibility of various polymers with hydrazine; (3) the preparation of polyamides and two-stage polymers; and (4) encapsulation studies. Also discussed are polymer studies and further encapsulation studies. Polymer studies include the synthesis of prepolymers based on glycidyl methacrylate, 2-vinyloxyethyl methacrylate, 2-hydroxyethyl methacrylate, and on methallyl methacrylate, and the interfacial polycondensation of bisphenol A with a 1:1 mixture of terephthaloyl chloride and fumaroyl chloride. The encapsulation studies include the use of the cationic polymerization product of glycidyl methacrylate, the use of the vinyl homopolymer of glycidyl methacrylate, and amine encapsulation by interfacial polymerization. I.v.L.

N64-24974 Frankford Arsenal, Philadelphia, Pa.
PROPELLANT ACTUATED DEVICES Progress Report, Sep.–Oct. 1963
[1963] 74 p
(Rept.-90-1; AD-437564)

The current progress relating to propellant actuated devices for escape systems includes the following: (1) High-temperature tests were conducted on three oxidizers — nitrogen tetroxide, red fuming nitric acid, and chlorine trifluoride. (2) A quantity of sample lengths of the new, mild detonating fuse with a high-temperature vinyl outer jacket was assembled with the old FA end booster caps, and a similar quantity was assembled using the newly designed end booster caps. These samples were used in a test program after exposure to high temperature, low temperature, temperature and humidity cycling, and water immersion. (3) Drawings of the final design assembly of the XM47 ignition element were completed. (4) Twelve firing tests were made with complete rocket catapults. (5) Four each of three

time-delay mechanisms (0.1, 1.0, and 15.0 seconds) were completely assembled and tested for proper-function characteristics. (6) Data from the firings conducted with XM90 and XM91 initiators, previously subjected to random vibrations tests, are presented. (7) Design studies were completed on a prototype XM18 gas generator. (8) Firings were conducted with a gas-generator propellant identified as MDB7, lot PA-E 3-39241. (9) The silver-infiltrated tungsten insert, previously fired, was measured, and it appears that this material actually shrinks under firing conditions. (10) *Gas-analysis results were obtained* for the HES 6573 and Standard Oil P-1 propellants fired previously. I.v.L.

N64-25020* Little (Arthur D.) Inc., Cambridge, Mass.
CRYOGENIC PROPELLANT FEED SYSTEMS FOR ELECTROTHERMAL ENGINES
Washington, NASA, May 1964 287 p refs
(Contract NAS8-2575)
(NASA-CR-60) OTS: $4.00

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N64-25021* Little (Arthur D.) Inc., Cambridge, Mass.
HYDROGEN FEED SYSTEM
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 4–73 (See N64-25020 17-26)

The high specific impulse attainable by using hydrogen as a propellant in an electrothermal engine is the reason why a hydrogen feed system is highly desirable. This report discusses such a system in terms of the basis for its design, a description of the overall system, the storage vessel, the expulsion system, the metering and control system, and projected system operation. G.D.B.

N64-25022* Little (Arthur D.) Inc., Cambridge, Mass.
AMMONIA FEED SYSTEM
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 74–108 (See N64-25020 17-26)

A thermal arc-jet system using ammonia as a propellant is considered as a competitive alternate to a hydrogen fuel system. Such a system is described in the following categories: mission parameters, overall system description, storage vessel, expulsion system, and metering and control system. G.D.B.

N64-25023* Little (Arthur D.) Inc., Cambridge, Mass.
SIZING OF THE HYDROGEN STORAGE VESSEL
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 109–127 (See N64-25020 17-26)

Described are some of the functional features of the liquid-hydrogen tank for the arc-jet feed system. The tank size and shape are presented, the operating pressure is determined, and the tank launch weight as a function of liquid reserve is discussed. Two systems are considered, one using an internal tank heater only and the other, the alternate system, using a rotary phase-separating heat exchanger. G.D.B.

N64-25024* Little (Arthur D.) Inc., Cambridge, Mass.
MATERIAL SELECTION FOR THE HYDROGEN STORAGE VESSEL
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 128–157 refs (See N64-25020 17-26)

The inner vessel of the hydrogen propellant tank for the arc-jet vehicle must be constructed of a material that has a high strength per unit weight and suitable toughness and ductility at −423° R. Annealed 5Al–2.5Sn titanium alloy with extra-low interstitial content was selected as the material for the liquid-hydrogen tank. Other materials, such as stainless steel and aluminum, were also investigated. G.D.B.

N64-25025* Little (Arthur D.) Inc., Cambridge, Mass.
SUPPORT SYSTEM FOR THE HYDROGEN STORAGE VESSEL
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 158–174 refs (See N64-25020 17-26)

The mechanical support system for the inner hydrogen tank on the arc-jet feed system must support the tank and isolate it thermally from the rest of the structure on the vehicle. The system described in this report was selected as the lightest weight—one which would sustain all the imposed loads and have a heat leak equal to the target heat leak of 7 w. G.D.B.

N64-25026* Little (Arthur D.) Inc., Cambridge, Mass.
THE METEOROID HAZARD TO THE HYDROGEN STORAGE TANK
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 175–192 refs (See N64-25020 17-26)

To estimate the hazard that meteoroids pose to space vehicles, it is necessary to have a description of the flux of meteoroids in space, their velocity and mass distributions, and their composition. This information was surveyed from the literature as a basis for selecting the appropriate hydrogen storage tank; this report discusses meteoroid hazard and the resulting protective measures taken. G.D.B.

N64-25027* Little (Arthur D.) Inc., Cambridge, Mass.
ESTIMATES OF THE THERMAL RADIATION INCIDENT ON HYDROGEN TANK DURING THE TRANSFER TRAJECTOR
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 193–205 refs (See N64-25020 17-26)

A transfer from an initial orbit near the plane of the ecliptic results in minimum thermal input to the hydrogen vessel. The thermal flux to the hydrogen tank from the SNAP-8 powerplant must be limited. Deployment of the powerplant to a location remote from the hydrogen vessel is an effective means for limiting the gamma heating of the tank's contents. G.D.B.

N64-25028* Little (Arthur D.) Inc., Cambridge, Mass.
THERMAL PROTECTION SYSTEM FOR THE LIQUID HYDROGEN STORAGE VESSEL
In its Cryog. Propellant Feed Systems for Electrothermal Engines May 1964 p 206–226 refs (See N64-25020 17-26)

The liquid-hydrogen storage vessel should be thermally isolated to the degree necessary to preserve the propellant

without loss from the moment of launch until it reaches its final 24-hr synchronous orbit. This protection system is described in terms of requirements for ground handling, during ascent, and for 48-hr orbit and orbit transfer. G.D.B.

N64-25476 Atlantic Research Corp., Alexandria, Va.
DYNAMIC MECHANICAL PROPERTIES OF SOLID PROPELLANTS Quarterly Technical Summary Report, 1 Dec. 1963–28 Feb. 1964
Apr. 1964 23 p refs
(Contract NOw-61-1054-c; ARPA Order 22-61)
(QTSR-1; AD-437276)

This report includes the following: (1) plots of G''_p and G'_p of the TPH-1001 propellant (a polybutadiene acrylic acid copolymer) as a function of frequency and temperature in which G'' and G' are the imaginary and real components of the complex dynamic shear modulus, subscript p indicates that the values have been reduced for temperature by the ratio T_o/T (i.e., $G''_p = G''T_o/T$), T is the absolute temperature of the test, and T_o is an arbitrary reference temperature; (2) the shift factor curve of the TPH-1001 propellant; (3) the master curves of G''_p and G'_p of the TPH-1001 propellant obtained using the empirically determined shift factor; (4) the shift factor curve of the AEBA-10 propellant (a polyurethane); and (5) the master curves for G''_p and G'_p of the AEBA-10 propellant. Also, sample preparation and conditioning, the relocation of the Fitzgerald apparatus, and the calibration check of transducer I are discussed. I.v.L.

N64-25501 IIT Research Inst., Chicago, Ill.
A STUDY OF THE FUNDAMENTALS OF LIQUID PROPELLANT SENSITIVITY
Ted Erikson 10 Mar. 1964 19 p refs
(Contract AF 04(611)-9566)
(IITRI-C6024-8; AD-602504)

Preliminary sensitivity tests of lead azide samples, with initial temperatures to −170° C, have been performed in the cryogenic shock-tube facility. Detonations were generally identified within 200μsec of the time that incident Mach 2.6 nitrogen shocks were reflected from the surface of the sample. Two characteristic induction periods were noted. The first period can be considered typical. The second period exhibited an increasing light output that stabilizes. Subsequent light output jumps instantaneously and work output follows within 10μsec to 30μsec. An appreciable sensitivity increase was identified with traces of air (oxygen) in the driven gas and lowered initial azide sample temperatures of 200° C; at otherwise constant conditions time delays decreased by factors of 10 and 2, respectively. Author

N64-25582 Purdue U., Lafayette, Ind. Jet Propulsion Center
CONTINUOUS MEASUREMENT OF THE BURNING RATES OF SOLID ROCKET PROPELLANTS Interim Report
J. R. Osborn and R. J. Burick Apr. 1964 77 p refs
(Grant AF-AFOSR-207-63)
(JPC-369; I-64-3; AD-601648)

An experimental system for the direct and continuous measurement of solid rocket propellant burning rates has been developed. A sample of solid propellant is bonded to a holder with an attached shaft that moves the propellant sample within a two-dimensional rocket motor. The flat burning surface of the propellant sample recedes normally as a servomechanism moves the propellant in a direction opposite to the receding propellant surface. The servomechanism operates in such a manner that the burning propellant surface is maintained at a fixed position within the rocket motor. Since the burning surface of the propellant remains fixed, the direct measurement of the velocity of the shaft yields the burning rate. The servomechanism incorporates a radioactive isotope feedback transducer system for detecting the position of the burning surface of the propellant sample. The experimentally determined burning rate data for two composite propellant formulations were reproducible and correlated well with published data. Author

N64-25780 Shell Development Co., Emeryville, Calif.
VAPORIZING AND ENDOTHERMIC FUELS FOR ADVANCED ENGINE APPLICATION Quarterly Progress Report No. 3, Dec. 1963–Feb. 1964
A. C. Nixon et al [1964] 55 p refs
(Contract AF 33(657)-11096)
(S-13911)

Studies leading toward the development of specifications for heat sink fuels for hypersonic aircraft are continuing. Consideration of the effect of design parameters on the conditions under which endothermic reactions can be carried out has led to the conclusion that space velocities of 20 or higher would be necessary due to volume limitations in high-speed aircraft. A preliminary study of the dehydrogenation of propane to propene has been completed at temperatures up to 1,300° F, pressures up to 10 atm, and liquid hourly space velocities up to 50, over a chromia on alumina catalyst. The maximum heat sink achieved was 1,600 Btu/lb of fuel at 1,200° F. Author

N64-25889 Aerojet-General Corp., Azusa, Calif.
RESEARCH ON NEW TECHNIQUES FOR ANALYSIS OF CONTAMINANTS IN LIQUID PROPELLANTS
R. M. Roberts and J. R. Finkel Wright-Patterson AFB, Ohio, AF Aero Propulsion Lab., Mar. 1964 87 p refs
(Contract AF 33(657)-7936)
(Rept.-2638; APL-TDR-64-3; AD-437979)

This program was a several-phased effort aimed at improving the state-of-the-art of propellant-contamination surveillance. Detectable contaminants in 12 different storable propellants were characterized, and coherent gaschromatograph methods were developed for their analysis. The end item, an automatic gas chromatograph for launch-site employment, was then designed and fabricated to incorporate this developed methodology. Author

N64-25901* Monsanto Research Corp., Everett, Mass. Boston Lab.
STUDY OF FUEL CELLS USING STORABLE ROCKET PROPELLANTS Final Report, 28 Jun. 1963–27 Jan. 1964
J. O. Smith, R. E. Chute, R. G. Gentile, D. L. Kavanagh, E. A. Mc Elhill et al 11 May 1964 160 p refs
(Contract NAS3-2791)
(NASA-CR-54116, MRB-5002F) OTS $11.50 ph

A feasibility study of hydrazine-type fuels and dinitrogen tetroxide (N_2O_4) or chlorine trifluoride (ClF_3) oxidants for use in fuel cells is discussed. Theoretical studies were made of the thermodynamic properties of the fuel cell systems under study. The potentials and energy density for the most probable reactions were calculated. The heat absorbed or evolved during the reversible operation of a fuel cell was calculated. The data obtained are used as a basis for defining the theoretical performance of the various proposed systems. P.V.E.

N64-25902* Monsanto Research Corp., Everett, Mass. Boston Lab.
STUDY OF FUEL CELLS USING STORABLE ROCKET PROPELLANTS Quarterly Progress Report No. 1, 28 Jan. – 27 Apr. 1964

J. C. Orth, R. E. Chute, S. Matsuda, W. H. Power, J. O. Smith et al 20 May 1964 66 p refs
(Contract NAS3-4175)
(NASA-CR-54117; MRB-5007Q1) OTS: $6.60 ph

This report describes a systematic study of the solid palladium diffusion electrode, including pretreatments (heat treatment and catalyst deposition) that are required for using the palladium foil for transporting and anodically oxidizing hydrogen. The use of hydrazine as a fuel for supplying hydrogen to the palladium foil anode is also described. The use of a porous Teflon diffusion electrode for the anodic oxidation of hydrogen or hydrazine and also for the cathodic reduction of oxygen and hydrogen peroxide is described. Such electrodes are combined for initial construction and demonstration of full-cell systems. Construction details for a full cell with 3- by 3-in. electrodes are described. Polarization data are given for the anodic oxidation of hydrogen and hydrazine at flow-through electrodes and solid palladium foils in the anhydrous hydrogen fluoride system. Author

N64-26009 Battelle Memorial Inst., Columbus, Ohio
EXPERIMENTAL AND THEORETICAL STUDIES OF COMBUSTION OSCILLATIONS
A. A. Putnam *In* AGARD Nonsteady Flame Propagation 1964 p 199-290 refs (See N64-26003 18-26) Pergamon: £5 10 s

This paper gives the results of a number of studies of organ-pipe oscillations and transverse oscillations in combustion systems. The studies are divided according to the basic arrangement of the components of the combustion unit. G.D.B.

N64-26014 American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York, N.Y.
THE ROLE CRYOGENICS IS PLAYING IN EXPANDING MECHANICAL ENGINEERING
V. J. Johnson, ed. [1963] 88 p refs Papers Presented at Am. Soc. of Heating, Refrig. and Air-Conditioning Engr. Cryog. Symp., New York, 11-14 Feb. 1963 NBS, Boulder, Colo. $2.00

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1. A JOULE-THOMSON NEON LIQUEFIER Abraham Lapin (Air Products and Chemicals, Inc.) p 1-12 refs

2. THE QUEST FOR DESIGN DATA R. B. Stewart (NBS) p 13-24 refs (See N64-26015 18-13)

3. MODERN METHODS OF ANALYSIS FOR DESIGN OF CRYOGENIC EQUIPMENT AND PROCESSES T. R. Strobridge and D. B. Mann (NBS) p 25-38 refs (See N64-26016 18-13)

4. LIQUID NITROGEN: AN ALL PURPOSE EXPENDABLE REFRIGERANT F. Notaro (Linde Co.) p 39-52 refs (See N64-26017 18-13)

5. CRYOGENIC EQUIPMENT DEVELOPMENT FOR SPACE A. A. Fowle (Arthur D. Little, Inc.) p 53-66 (See N64-26018 18-13)

6. HEAT-TRANSFER AND FLOW DATA WITH HYDROGEN FOR NUCLEAR ROCKET SYSTEM DESIGN D. M. Straight (NASA) p 67-84 refs (See N64-26019 18-13)

N64-26018 Little (Arthur D.), Inc., Cambridge, Mass. Cryogenics and Fluid Mechanics Group
CRYOGENIC EQUIPMENT DEVELOPMENT FOR SPACE
Arthur A. Fowle *In* Am. Soc. of Heating, Refrig. and Air-Conditioning Engr. The Role Cryog. is Playing in Expanding Mech. Eng. [1963] p 53-66 (See N64-26014 18-13) NBS, Boulder, Colo.: $2.00

The role of low-temperature technology in present and future space programs is reviewed. Some proven or promising applications, as the use of liquefier gases as propellants; the simulation of the low-temperature and high-vacuum characteristics of outer space in environmental test facilities; and the sub-zero refrigeration of electronic components, such as infrared detectors, inertial guidance devices, optical masers, etc., are discussed briefly. The function and nature of the cryogenic systems involved, their current development status, and future development needs are presented. The need for compact, efficient, and reliable low-temperature refrigerators and thermal protection systems is emphasized. Various technical approaches to the solution of problems in these critical areas are outlined, and, finally, some major challenges yet facing the engineer developing the cryogenic equipment needed for space ventures are set forth. Author

N64-26340 Institut Franco-Allemand de Recherches, St. Louis (France)
THERMAL RADIATION OF A FLAME WITH CONDENSED MgO PARTICLES
Fritz Rossler *In* AGARD Supersonic Flow, Chem. Processes and Radiative Transfer 1964 p 433-438 refs (See N64-26326 18-11) Pergamon: 9 £

Solid rocket propellants and explosives often contain metallic additives that are oxidized and radiate as solid particles in a flame. Aluminum and magnesium are the most commonly used metallic additives. Calculations have not yet been carried out because of the strong scattered radiation. However, success was attained in considering two fluxes of radiation in opposite directions. Two simultaneous differential equations allow an explicit solution. The brightness and color temperatures of such flames can be calculated. To demonstrate the method, published data of a stationary MgO frame are interpreted by the resulting equations. Author

N64-26632 Canadian Armament Research and Development Establishment, Valcartier
THE INFLUENCE OF AXIAL COMBUSTION INSTABILITY ON THE DEVELOPMENT OF A 23KS20000 MOTOR
F. Jackson, W. G. Brownlee, and A. K. Roberts Apr. 1964 11 p refs Presented at Fourth Mdeting of the Tech. Panel on Solid Propellant Instability of Combust., Menlo Park, Calif., 1 Feb. 1964
(CARDE-TN-1620/64)

Axial combustion instability was found to be the limiting factor in the development of a 17-in.-diam-180-in.-long 23KS-20000 motor. The ensuing applied research investigations at CARDE led to a clear phenomenological description of finite wave axial combustion instability. This knowledge was used to overcome the adverse design limitations initially imposed on the 23KS20000 motor. Author

N64-26642 Aerojet-General Corp., Sacramento, Calif.
NEW DEVELOPMENTS IN CONTINUOUS PROPELLANT PROCESSING FOR THE POLARIS PROPULSION SYSTEMS
Report Period Ending Nov. 1963
L. G. Schwieger 19 Dec. 1963 41 p
(Contract Nord-18171)
(Rept.-0178-07M-10; AD-437752)

Both the nondispersive X-ray and reflectance refractometer were moved to the pilotplant. The units are undergoing final evaluation tests, and specific results are presented on Brabender produced propellant for the reflectance refractometer. The response equations and the theoretical controller settings on the oxidizer feeder of the oxidizer loop are presented. R.T.K.

N64-26666 Rocketdyne, Canoga Park, Calif.
DENSE PHASE TRANSPORT OF POWERED METALS FOR A TRIPROPELLANT ROCKET SYSTEM
H. L. Burge, R. W. Roberts, and E. V. Zettle 21 Oct. 1963 31 p ref Presented at the AICHE Meeting, Houston, Tex., 1-5 Dec. 1963

The feasibility of adding a light metal to a rocket thrust chamber as a third propellant in a cryogenic engine to increase potential payload is discussed. The combustion process was analyzed in terms of the theoretical requirements for burning light metal and efficiently transferring the generated heat to hydrogen injected into the chamber as a working gas. The theory of fluidized metal transport, which is important to rocket engine application, is discussed, and preliminary experiments are presented. These experiments have conclusively demonstrated the feasibility of transport solid particles with a fluidizing gas (hydrogen) with weight ratios (W_S/W_g) up to 150/1.

Author

N64-26813 Air Force Systems Command, Wright-Patterson AFB, Ohio AF Aero-Propulsion Lab.

FLUID MECHANICS AND TANKAGE DESIGN FOR LOW GRAVITY ENVIRONMENTS Technical Documentary Report, Jun. 1961–Apr. 1963

Robert G. Clodfelter Sep. 1963 59 p refs

(ASD-TDR-63-506; AD-423554)

Electric propulsion systems for space vehicles must be able to restart and operate at zero and low gravity. This operation can be achieved if the tankage delivers only single-phase propellants. The requirements for feed systems of electric engines are described briefly. Also, the 1.85-second drop-test facility is described, and the testing techniques are discussed. The minimum energy principle is presented along with a method for determining the direction of mass transfer in tapered tubes and liquid-vapor interface shapes in an annular space between concentric cylinders. Possible feed systems for electric engines are given, which utilize surface tension for fluid positioning and transfer. Zero-gravity and static-fluid configurations in cylindrical and spherical containers are discussed along with experimental observations. The interface overshoot of the equilibrium zero-gravity configuration is also disucussed.

Author

N64-26865 Frankford Arsenal, Philadelphia, Pa.

FORM FUNCTIONS FOR DUAL COMPOSITION INCREMENTS OF PROPELLANT GRAINS

J. F. Vowalick and M. S. Silverstein Sep. 1963 20 p ref

(R-1692; AD-603520)

It is mathematically demonstrated that any desired form function can be approached by the burning of increments or groups of dual composition propellant grains of neutral geometry (constant surface during burning). This scheduled burning is achieved by varying the thickness of each of the outer layers of propellant, with the outer layers having the lower burning rate. The pertinent parameters are the total burning distance of the propellant system, the burning distances of grains in each increment of propellant, the number of groups or increments, the mass of each group, and the number of groups that are burning simultaneously. The relationship of these parameters to the desired form function is expressed as a series of equations, each of which is an incremental form function. The sum of the series approaches, to any desired degree of accuracy, the specified form function.

Author

N64-27287* Princeton U., N.J. Guggenheim Labs. for the Aerospace Propulsion Sciences

NONLINEAR ASPECTS OF COMBUSTION INSTABILITY IN LIQUID PROPELLANT ROCKET MOTORS Fourth Yearly Progress Report, 1 Jun. 1963–31 May 1964

David T. Harrje and William A. Sirignano 1 Jun. 1964 207 p refs

(Contract NASr-217; Grant NsG-99-60)

(NASA-CR-56946; Rept.-553-d)

Theoretical studies were made of the nonlinear oscillations that commonly occur in rocket combustion chambers and exhaust nozzles. Both the longitudinal and transverse mode of combustion instability were analyzed. The results of experimental studies of nonlinear combustion-instability mechanisms are presented. These include transverse mode, nonlinear, rocket-motor studies; longitudinal, nonlinear rocket studies using the square motor; the vapor-displacement mechanism; and basic experiments in droplet resonant phenomena. The mechanism for combustion instability in droplet and wake burning is discussed; and the original time-lag theory of Crocco and Cheng is extended to include higher order Mach-number effects.

R.T.K.

N64-27409 Douglas Aircraft Co., Inc., Santa Monica, Calif. Missile and Space Systems Div.

STUDY OF TITANIUM ALLOY TANKAGE AT CRYOGENIC TEMPERATURES

W. J. Martin, T. Matsuda, and E. F. Kaluza 5 May 1962 77 p refs

(SM-43116)

A project was initiated to develop titanium pressure vessel fabrication and welding methods. Using Ti-6Al-4V and Ti-5Al-2.5Sn alloys and incorporating three weld designs, a total of eight 16-in.-diam pressure vessels were manufactured and burst tested at temperatures between ambient and −423° F (−253° C). In addition, three 30-in. cylinders of sandwich construction were fabricated and tested under selected thermal gradients. The results showed that resistance of fusion welded Ti-6Al-4V tankage can be manufactured and used at temperatures between ambient temperature and −320° F (−196° C). The compressive strengths of sandwich cylinders varied little within the range of the thermal gradients investigated. Information on the fabrication and testing methods as applied to titanium tankage is presented in this report. The possible causes of premature failure at −423° F (−253° C) and the subject of "texture strengthening" are briefly discussed.

Author

N64-27454 General Electric Co., Philadelphia, Pa. Spacecraft Dept.

PROPELLANT STORABILITY IN SPACE Final Report, 15 May 1963–30 Jun. 1964

W. Benton, R. Carr, A. Cohen, G. Gustafson, C. Lankton, and B. Zeldin Edwards AFB, Calif., Rocket Propulsion Lab., Jun. 1964 207 p refs

(Contract AF 04(611)-9078)

(RPL-TDR-64-75; AD-603215)

Presented here are the results and interpretation of tests performed in the space environmental simulator to investigate storability of propellants in space. The purpose of the work is to demonstrate the long-term storage capability of cyrogenic and earth storable propellants in a simulated orbital environment. Tanks of various sizes and shapes were tested. The test articles included a simulated meteorite shield and employed advanced support techniques suitable for a low g environment. A simulated sun was used as the source of heat input. The sun was cycled to represent the conditions in a high-inclination, low-altitude earth orbit. The test results were analyzed and related to the storage of actual propellants.

Author

N64-27548 Stanford Research Inst., Menlo Park, Calif.

VISCOELASTIC PROPERTIES OF SOLID PROPELLANTS AND PROPELLANT BINDERS Quarterly Technical Summary Report No. 3, Jan. 16–Apr. 15, 1964

Nicholas W. Tschoegl, James R. Smith, and Thor L. Smith 15 May 1964 19 p

(Contract NOw-64-0073-d; ARPA Order 22)

(Rept.-11; AD-443509)

Experiments were carried out with the low-frequency dynamic shear tester on unfilled styrene-butadiene rubber

specimens to determine how the observed complex modulus depends on the laterally applied clamping force, specimen size, and cam displacement. The experiments proved the suitability of the differential Lissajous method for the precise determination of small phase angles. Above about 60 pounds, the results were sensibly independent of clamping force. The dependence of the modulus on specimen size and cam displacement appeared to result from nonlinear viscoelastic effects. The current state of development of the dynamic bulk compressibility apparatus and the static (isothermal) compressibility apparatus is discussed. Author

N64-27735 Stanford Research Inst., Menlo Park, Calif.
SOLID PROPELLANT MECHANICAL PROPERTIES INVESTIGATIONS Quarterly Progress Report No. 1, Oct. 1, 1963–Jan. 1, 1964
Norman Fishman and James A. Rinde 20 Jan. 1964 21 p refs
(Contract AF 04(611)-9559)
(Rept.-3; AD-602531)

Progress has been made toward achieving a major objective of this research, i.e., the development of a method for defining the path-independent physical state of a propellant in terms of stress–strain–time history. The applicability of an "equation of state" to constant strain rate and constant load test results is demonstrated by comparison of calculated and experimental test data at three temperatures. The general form of the equation being evolved is: $\log V/V_o = A[\log W + B (\log t - \log b_T)]^n$ where W is strain energy as expressed by the area under the stress–strain curve, t is the time in minutes, and $\log b_T$ is a temperature shift factor. Preliminary tests under conditions of constant loading rate, constant strain rate cycling, and constant load recovery were undertaken, and results are reported. Author

N64-27743 Canadian Armament Research and Development Establishment, Valcartier
A PULSE TECHNIQUE FOR THE EVALUATION OF COMBUSTION INSTABILITY IN SOLID PROPELLANT ROCKET MOTORS
E. P. Morris Jun. 1964 17 p refs
(CARDE-TR-487/64)

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 assured. 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 in. to 17 in. in diameter. Author

N64-27956 Picatinny Arsenal, Dover, N.J. Feltman Research Labs.
CELLULOSE NITRATE-ACETATE MIXED ESTERS
Yvon P. Carignan and Jack Bobinski Jun. 1964 70 p refs
(PA-TR-3105; AD-602750)

A preliminary investigation of the preparation and properties of cellulose nitrate–acetate mixed esters was conducted. These mixed esters can be prepared in a wide range of substitutions of both acetate and nitrate groups either through acetylation of cellulose nitrate or nitration of cellulose acetate. The degree of polymerization of the products, as estimated from viscosity data, shows the occurrence of chain degradation for both procedures. The hygroscopicity of the cellulose nitrate–acetate esters was found to be a linear function of total substitution. Films prepared from these mixed esters showed tensile strength at least comparable to that of films of cellulose nitrate or cellulose acetate. The impact sensitivity of the mixed esters varied from 6 to 18-in. for a 2-kg weight depending on the substitution of nitrate groups. Author

N64-28064 Imperial Metal Industries, Ltd., Kidderminster (Gt. Brit.) Summerfield Research Station
FAILURE CRITERIA FOR CAST-DOUBLE-BASE PROPELLANTS
H. Leeming and A. Parker Jul. 1964 43 p refs
(TR-64/17)

This paper considers simple failure theories 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. The predictions of these various failure theories are compared with experimental data from simple tension, bi-axial tension, and small-scale rocket motor tests. Author

N64-28096 Tokyo U. (Japan) Aeronautical Research Inst.
STUDIES OF HIGH FREQUENCY COMBUSTION OSCILLATIONS IN A GASEOUS PROPELLANT ROCKET MOTOR
Hiroshi Tsuji and Tadao Takeno Mar. 1964 32 p refs *Its* Rept. 391 (vol. 29, no. 13)

The experimental studies were conducted in a research rocket motor burning premixed gases as propellants for investigating the effects of several variables upon the high-frequency combustion oscillations in a rocket motor in detail and making clear the driving mechanism of these oscillations. The effects of the combustion chamber length, the propellant equivalence ratio, the mean chamber pressure, and the shape of the nozzle upon the longitudinal-mode pressure oscillations were examined. The research rocket motor had a rectangular combustion chamber of 5 cm × 8 cm cross section, and the propellants used were the premixed city gas and air. Three modes of the longitudinal pressure oscillations, namely, the fundamental-, the second harmonic- and the third harmonic-mode oscillations were observed in the combustion chamber, and the measured periods of each mode oscillation satisfied the relation of acoustic-mode oscillations. Therefore the high-frequency combustion pressure oscillations may be treated essentially as the standing waves of the longitudinal mode, though the propagating shock-type pressure waves appeared as the feed energy to the oscillation was increased. Author

N64-28176 Advisory Group for Aeronautical Research and Development, Paris (France)
COMBUSTION AND PROPULSION

R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner, ed. Oxford, N.Y., Pergamon, 1963 686 p refs Papers Presented at the 5th Colloq. of the AGARD Combust. and Propulsion Panel on High-Temp. Phenomena, Braunschweig, 9-13 Apr. 1962 Pergamon: £7

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N64-28194 Rocketdyne, Canoga Park, Calif.
STABLE COMBUSTION PROCESSES IN LIQUID PROPELLANT ROCKET ENGINES
S. Lambiris, L. P. Combs, and R. S. Levine *In* AGARD Combust. and Propulsion 1963 p 569-636 refs (See N64-28176 20-11) Pergamon: £7
(Contracts AF 04(647)-672; AF 49(638)-817)

Information is presented on the combustion processes necessary for successful analytical modeling of liquid-propellant rocket engine combustion during stable operation. The theoretical and experimental results of single-propellant droplet combustion and their application in spray-combustion analyses are reviewed. Propellant-spray formation and droplet-size distributions from particular rocket injector types are considered. Recent experimental data, found sufficient for approximate model verification, are shown to be useful for guiding the development of an analytical bipropellant combustion model without the necessity of making simplifying and restrictive assumptions. A description of a new combustion model is given, which is based on detailed spatial accounting of the combustion field for each particular injector-chamber configuration and propellant combination. Author

N64-28236 Thiokol Chemical Corp., Brigham City, Utah. Wasatch Div.
STUDY OF ARC IGNITION TECHNIQUES FOR SOLID ROCKET PROPELLANTS Technical Documentary Report, 1 Apr.-31 Jul. 1964
V. T. Dinsdale Edwards AFB, Calif., Rocket Propulsion Lab., Aug. 1964 51 p
(Contract AF 04(611)-9706)
(RPL-TDR-64-116; AD-444623)

The feasibility of igniting solid-propellant rocket motors using carbon-to-carbon arc probe, gas generator-arc probe,

and comb-shaped arc igniters was proven in laboratory and subscale motor tests. Ten 5-in. CP motors were ignited using variations of the three igniter types. Stop-start capability was partially demonstrated with the quenching and reignition of two motors using the comb-shaped igniter. Tests conducted to verify information retrieved in a literature survey proved the superiority of carbon electrodes for propellant ignition. Other tests showed that either RTV 732 silicone adhesive or polyvinylchloride shrinkable tubing provides satisfactory insulation for the electrodes. Author

N64-28592 France Office National d'Etudes et de Recherches Aeronautiques, Chatillon-sous-Bagneux
MEASUREMENT OF COMBUSTION DELAY [MESURE DES DELAIS D'ALLUMAGE]
L. Nadaud and M. Dugibet *In* AGARD Exptl. Methods in Combust. Res. 1964 24 p refs In FRENCH (See N64-28584 20-26)

Methods for determining ignition delay and their applications are reviewed. It is indicated that laboratory methods employed for the measurement of initial ignition delay permit a systematic study of the various parameters effecting this delay, as well as the classification and selection of hypergols in such a manner that delay can be ameliorated by the action of additives. Methods of measuring initial ignition delay with the help of a microrocket permit an approximation of the operating conditions of rocket engines and a study of the effect of such parameters as the type of injection and the injection pressure. It is possible that the microrocket could be used to measure initial ignition delay during flight. Another method of delay measurement during flight is proposed. It consists of instrumentation for detecting the first elevation of pressure in the piping of one of the components of the bipropellant, detecting the first elevation of chamber pressure, and of instrumentation for measuring flow time. I.v.L.

N64-28594* Princeton U., N.J.
COMBUSTION INSTABILITY IN LIQUID PROPELLANT ROCKET MOTORS
Luigi Crocco and David T. Harrje *In* AGARD Exptl. Methods in Combust. Res. 1964 23 p refs (See N64-28584 20-26) (Grant NsG-99-60)

Three types of combustion instability are described—LF instability, IF instability, and HF instability. The latter, which is referred to as acoustic instabilty, is by far the most important for the development of large rocket thrust chambers. The instrumentation on which the detecting of HF instability is based depends on the mode or modes to be detected. Pressure transducers represent a very sound means for the quantitative observation of HF instability. However, accelerometers, placed on the walls of rocket chambers, are often used when it is difficult or impossible to install pressure transducers. Optical means of observation also provide a very effective tool in the study of HF instability. Probably the most effective method to study unstable operations is by determining stability limits. Each mode may have its own stability limits. With this in mind, methods for determining the following are discussed: longitudinal spontaneous stability limits, transverse spontaneous stability limits, and transverse pulsed instability limits. I.v.L.

N64-28595 Naval Ordnance Test Station, China Lake, Calif.
EXPERIMENTAL MEASUREMENTS IN SOLID PROPELLANT ROCKET COMBUSTION INSTABILITY
E. W. Price *In* AGARD Exptl. Methods in Combust. Res. 1964 22 p refs (See N64-28584 20-26)

Two systems for studying instability are described--full-scale testing and research combustors. The occurrence of combustion instability is usually detected by the occurrence, at low frequency, of erratic pressure fluctuations, associated with the fluctuations in propellant burning rate during oscillatory combustion. Thus, pressure measurements, made by transducers, are important. Another symptom of combustion instability is the presence of vibrations in the structure of the rocket vehicle. These vibrations are measured by accelerometers. High-frequency response instrumentation is often added only after such difficulties have been encountered in the development program. The high-frequency and wideband requirements for recording HF pressure oscillations concurrently with slow variations in mean pressure can be met by the galvanometer oscillograph, the magnetic tape recorder, the cathode-ray oscillograph, and the oscilloscope with attached camera and triggered sweep. Techniques for analyzing data recorded by these instruments consist of frequency-time-amplitude analyses. I.v.L.

N64-28646 Stanford Research Inst., Menlo Park, Calif.
THE STUDY OF THE ORIGIN AND PROPAGATION OF DISTURBANCES IN THE BURNING OF SOLID PROPELLANTS. PHASE II: A STUDY OF COMBUSTION INSTABILITY AND ITS DEPENDANCE ON PROPELLANT COMBUSTION CHARACTERISTICS Final Report
L. A. Dickinson and E. L. Cadener 14 May 1964 27 p refs (Contract AF 49(638)-565; ARPA Order-317-62, Amend.3) (AD-442392)

A range of propellants including several advanced aerospace propellants were studied to learn how the unstable burning characteristics were affected by the following: (1) burning-rate catalysts; (2) oxidizer type; and (3) particle-size variation in the oxidizers and metallic fuels. The studies were conducted in a 5-in.-diameter by 40-inch-long motor that was pulsed, using a well-proven triggering technique. It was found that as the nominal burning rates of the propellants increased, the burning propellants became less responsive to pulsing. In addition, it was noted that the peak-to-peak pressure amplitude of the oscillation steadily decreased as the burning rate increased. The exact role that the burning-rate catalysts performs in the combustion zone is not clear; copper chromite and iron oxide contain cations that complex with ammonia, and they have been shown to be effective catalysts for the decomposition of pure ammonium perchlorate. The incorporation of a coarse oxidizer and coarse spherical aluminum powder lowered the pressure level at which instability could be triggered. Potassium perchlorate produced a fast-burning propellant that would not respond to axial-flow disturbances. I.v.L.

N64-28831* National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
THEORY OF LIQUID SLOSHING IN COMPARTMENTED CYLINDRICAL TANKS DUE TO BENDING EXCITATION
Helmut F. Bauer 23 Jul. 1962 49 p refs
(NASA-TM-X-51944; MTP-AERO-62-61) OTS: $4.60 ph

Propellant sloshing may be established by the bending of a space vehicle that exhibits low structural frequencies. Forces and moments exerted by the oscillating propellant on the tank are determined due to forced bending excitation for a liquid in a circular cylindrical ring sector tank with a free fluid surface. Special cases such as the tank with sector and circular cross section are obtained by limit consideration. As is expected, force and moment of the liquid increase sharply at the resonant frequency of the propellant. The total force and moment are generally less for a given maximum bending amplitude than for a translational motion of the same magnitude. The maximum dynamic effects occur when the free fluid surface is located around the point of maximum bending displacement. Author

N64-29672 Lockheed-Georgia Co., Marietta
ANALYSIS OF THERMAL STRATIFICATION OF LIQUID HYDROGEN IN ROCKET PROPELLANT TANKS
J. W. Tatom, W. H. Brown, L. H. Knight, and E. F. Coxe [1963] 27 p refs
(ER-6759)

The test program was conducted to provide information on the nature of stratification and to support the analysis. The analytical study, which involved the definition of two empirical constants, was directed toward obtaining a realistic mathematical model of stratification. The results of the study indicate that the developed analytical model can adequately predict stratification effects in liquid hydrogen. Author

N64-29706* Aerojet-General Corp., Sacramento, Calif. Advanced Technology Div.
HIGH CHAMBER PRESSURE OPERATION FOR LAUNCH VEHICLE ENGINES PROGRAM Final Report, 1 Apr. 1963–31 Mar. 1964
R. Beichel 1 Jun. 1964 97 p refs
(Contract NAS8-4008)
(NASA-CR-56672; Rept.-4008-SA4-F) OTS: $8.60 ph

The effects of chamber pressure, injector type and size, and thrust chamber length on combustion stability were experimentally and theoretically studied. A series of 21 valid tests was conducted using LO_2/LH_2 as propellants. The sensitive time lag theory was used for evaluation and correlation of experimental test results. The test program included tests with 6-, 12.5-, and 26-in.-length chambers using pentad (5,000-lb thrust per element), coaxial (1,100-lb thrust per element), and conventional (220-lb thrust per element) types of injectors, in an 8-in.-diam chamber. The conventional injector was observed to be marginally unstable in the first tangential mode over the range of pressures (1,000 to 2,500 psia) and chamber lengths employed. The coaxial injector also showed instability; but it was found to be in the first longitudinal mode, and only with the 26-in.-length chamber at 2,500 psia. The pentad injector was stable over the entire ranges of pressure and length. Author

N64-29841 Purdue U., Lafayette, Ind. Jet Propulsion Center
ANALYSIS OF A SERVO SYSTEM FOR CONTINUOUS MEASUREMENT OF THE BURNING RATE OF A SOLID PROPELLANT Interim Report
J. R. Osborn and R. F. Panella May 1964 69 p refs
(Grant AF-AFOSR-207-63)
(JPC-374; I-64-4; AD-604556)

By controlling the position of the burning surface of the solid propellant within the rocket motor, the burning rate can be measured. The object of this project was to determine the servosystem dynamics. Stability, time response, and optimization of the servosystem were investigated. A theoretical analysis was made to determine component transfer functions. From the component transfer function the overall system transfer function was derived. The Bode diagram was then used to determine system stability. The system transfer function was programed on an analog computer, and the time response of the system was characterized. The servosystem was built, and experimental results were obtained to verify the theoretical system transfer function. The nonlinearity of the servosystem in the amplitude range considered was found to be 11%. The system transfer function was optimized using two different criteria—optimum phase margin and minimum ITAE. Author

N64-29889 General Electric Co., Philadelphia, Pa. Missile and Space Div.
EXTRATERRESTRIAL RESOURCES DEVELOPMENT AND PROPELLANT PRODUCTION
Rodney W. Johnson, Duane L. Barney, and Dandridge M. Cole 13 Nov. 1963 64 p refs

The establishment of semipermanent and permanent bases on the moon will be governed by the degree to which the lunar resources can be exploited and developed. This report pertains to extraterrestrial propellant production. Schemes are described for the extraction of water from lunar rock and for the removal of oxygen from nonwater-containing silicate minerals of the type suspected to be present on the moon. A carbon dioxide thermal-recovery process is described for water extraction; a carbon recycle system is proposed for the reduction of silicate rocks. Results of process analyses are discussed, and simple mission requirements are explored. Economic advantages are examined from the standpoint of the amount of propellant produced per pound of hardware as would be required for propellant production on the moon. I.v.L.

N64-30004 Syracuse U. Research Inst., N.Y. Coll. of Engineering
THE USE OF FOAMED PROPELLANTS FOR COMPACTION AND STABILIZATION OF VARIOUS TYPES OF TERRAIN Final Report
Louis J. Goodman, Cornelius S. Grove, Jr., and Ardeshir Aidun Jul. 1964 63 p refs
(Contract AF 19(628)-492)
(SURI-CE-974-647FI; AFCRL-64-622; AD-604446)

A proposed new method for compacting soil, which is based on the principle of pressure waves as a source of compaction energy, is described. This method has a formulation containing hydrazine, ammonium perchlorate, and a foaming agent—hydrolized protein base foam liquid. The mechanics of this new compaction method are relatively simple, with a blanket of the foamed propellant system placed on the surface of the soil to be compacted, and then detonated. The results of using the foamed propellant system to compact both cohesionless and cohesive soils are presented and discussed. This includes a preliminary investigation of the influence of both surface area and multiple detonation on compaction control parameters. Results show that this compaction method is effective in increasing the density of the soil to depths of as much as 15 inches. Author

N64-30012 Applied Physics Lab., Johns Hopkins U., Silver Spring, Md. Chemical Propulsion Information Agency
PROCEEDINGS OF THE EIGHTH MEETING OF THE ICRPG WORKING GROUP ON DESIGN AUTOMATION
[1964] 30 p Meeting Held at NASA. Marshall Space Flight Center, Huntsville, Ala., 16 Apr. 1964
(Contract NOw-62-0604-c)
(CPIA-48; AD-440309)

Short abstracts are given of the following: (1) The Analysis of Temperature and Stress in Solid Propellant Grains, and (2) Practical Applications of Aerodynamic Theory for Determining Load Distribution on Bodies of Revolution. Brief reports from performance, design, and evaluation subcommittees are included. R.L.K.

N64-30086* Rocketdyne, Canoga Park, Calif.
INVESTIGATION OF CATALYTIC IGNITION OF OXYGEN/HYDROGEN SYSTEMS Final Report, 19 Jun. 1963–19 Apr. 1964
R. W. Roberts Aug. 1964 156 p refs
(Contract NAS3-2565)
(NASA-CR-54086; R-5709) OTS: $11.50 ph

The results of an investigation of catalytic ignition of the oxygen–hydrogen system are presented. Included in this report are the results of preliminary laboratory screening for

catalyst surface characterization and relative activity measurements at various temperatures for several commercially available catalysts. Also included are ignition evaluations of selected catalysts at environmental temperatures of −250° F for both catalyst and propellants, and of evaluations with liquid propellants and catalyst environmental temperatures equivalent to those of liquid hydrogen. Ignition lag measurements are presented for reaction systems with both liquid and gaseous propellants. Author

N64-30089* National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
INVESTIGATION OF S-IV ALL SYSTEMS VEHICLE EXPLOSION
J. B. Gayle Washington, NASA, Sep. 1964 53 p refs
(NASA-TN-D-563) OTS: $1.50

Investigation of the S-IV All Systems Vehicle explosion indicated the following: high explosive equivalent, 1%; fireball diameter, 380 ft; fireball duration, 11 sec; maximum fragment radius, 1,500 ft. The relatively low yield was due to substantially instantaneous ignition of the spilled propellants, which probably resulted from the extreme flammability of hydrogen. Author

N64-30140 Maremont Corp., Pasadena, Calif. Research and Development Labs.
STUDY OF ROCKET ENGINE EXHAUST PRODUCTS Quarterly Report No. 11, 1 Dec. 1963–29 Feb. 1964
M. A. Greenbaum, R. E. Yates, J. A. Blauer, M. Arshadi, H. C. Ko et al [1964] 16 p refs
(Contract AF 04(611)-7414)
(QR-7414-11; AD-600280)

The study of the reaction: $BF_3(g) + 2B(s) = 3BF(g)$ has been completed. The second and third law values for ΔH_{f298} for BF(g), in excellent agreement, are, respectively, -29.0 ± 2.6 and -28.6 ± 0.5 kcal/mole. The entropy, S_{298}^0, obtained from this study is 47.6 ± 1.9 cal/deg/mole, which compares with the theoretical value of 47.9 cal/deg/mole. Studies of the $BeO(s) - H_2O(g)$ reaction and $AlF_3(g) - Al(l)$ reaction are continuing and are near completion. Investigation of the $MgCl_2(g) - Al(l)$ reaction has commenced, and apparatus for the study of the dissociation energy of $F_2(g)$ is under construction. Author

N64-30144 Bureau of Mines, Pittsburgh, Pa. Explosives Research Lab.
INITIATION OF DETONATION BY LOW AMPLITUDE SHOCKS Quarterly Report, Feb. 1–Apr. 30, 1963
F. C. Gibson, R. W. Watson, C. R. Summers, F. H. Scott, and E. J. Hay 28 May 1963 22 p
(ARPA Order-44-63)
(AD-406438)

The initiation and growth of detonation in explosives and propellants were investigated, and particular emphasis was placed on reactions resulting from initiation by low-amplitude shocks. An expendable pressure transducer was used to study the behavior of nitroglycerin ethylene glycol dinitrate (NG-EGDN) during the period between the application of the initial shock and subsequent reactions. The transducer consisted of a resistive element imbedded in a polyethylene rod that was immersed in the liquid to a predetermined level. Framing-camera studies were also performed simultaneously to aid in interpreting the pressure–time traces. D.E.W.

N64-30504* Little (Arthur D.) Inc., Cambridge, Mass.
ON CREDIBLE CATASTROPHIC ENVENTUALITIES IN SELECTED AREAS OF GOVERNMENT-SPONSORED ACTIVITIES
Sep. 1963 127 p refs Prepared for Columbia U.
(Contract NASr-181)
(NASA-CR-58145) OTS: $4.00 fs; $1.00 mf

Using the criterion of $20 million damage as the threshold of catastrophic devastation, eventualities are selected that are credible since they result from a combination of incidents, each of which has occurred in the past on separate occasions. One hazard considered is the transportation of missile propellants and their incompatibility with industrial compounds that are shipped in much larger quantities. Shipping regulations are directed to the properties of the chemicals per se, with reduced attention given to incompatibility with other chemicals. A second credible hazard of lower probability, because of the limited number of firings, is from the failure of a large chemical rocket during launch. Hazards peculiar to military aircraft during an increased alert status, or under automatic direction from the ground, are evaluated. Nuclear-propulsion danger is difficult to specify because designs for candidate motors are still under investigation, but the most serious credible accident does not appear to be in the catastrophic range. The most hazardous of weather-control attempts—hurricane control—might produce calamitous damage during experimental work. R.L.K.

N64-30525* Thiokol Chemical Corp., Denville, N.J. Reaction Motors Div.
INVESTIGATIONS OF SPACE STORABLE PROPELLANTS First Interim Summary Report, Mar. 1963–Jan. 1964
M. Luperi [1964] 123 p
(Contract NAS3-2553)
(NASA-CR-58800; RMD-6028-F) OTS: $4.00 fs; $1.00 mf

Ablative cooling for high-combustion-temperature propellants was investigated experimentally in 150-lb-thrust chambers using OF_2 and B_2H_6 propellants with a variety of state-of-the-art ablative material combinations. Ablative materials were shown to behave in a predictable manner with OF_2/B_2H_6. Sea-level injector evaluations conducted at the 2,000-lb (space thrust) level demonstrated that OF_2/B_2H_6 delivers high specific impulse (99% of predicted sea-level shifting equilibrium) over a wide mixture ratio range. Four types of injectors (mid-diameter vortex, full-diameter vortex, coaxial showerhead, and impinging stream) were tested. High performance was obtained with all injectors except for the impinging stream type. Reliable hypergolic ignition of OF_2/B_2H_6 was demonstrated at sea level and at altitude conditions over extreme ranges of environment, operating conditions, and propellant states. Author

N64-30556 Applied Physics Lab., Johns Hopkins U., Silver Spring, Md. Chemical Propulsion Information Agency
THE HANDLING AND STORAGE OF LIQUID PROPELLANTS
Neil I. Safeer Washington, Office of the Director of Defense Res. and Eng., Jan. 1963 347 p refs
(AD-442849) GPO: $1.75

This manual is intended for use as a basis for the preparation of regulations governing the handling of liquid-propellant fuels and oxidizers. Instructions are given for the following: personnel training and supervision; the construction and installation of electrical and lightning-protection systems; elimination or reduction of static electricity; prevention of fire, explosion, and health hazards; safety measures; storage; transfer procedures; and disposal and decontamination. Regulations are given for the following propellants and oxidizers: the alcohols, alkyl boranes, anhydrous ammonia, aniline, chlorine trifluoride, ethylene oxide, fluorine, hydrazine, hydrocarbon fuels, liquid hydrogen, hydrogen peroxide, monomethylhydrazine, fuming nitric acids, liquid nitrogen, nitrogen tetraoxide, liquid oxygen, pentaborane, perchloryl fluoride, inert pressurizing gases, normal propyl nitrate, and asym-dimethylhydrazine. I.v.L.

N64-30563 Applied Physics Lab., Johns Hopkins U., Silver Spring, Md. Chemical Propulsion Information Agency
PROCEEDINGS OF THE SIXTH MEETING OF THE ICRPG WORKING GROUP ON DESIGN AUTOMATION
Nov. 1963 16 p refs Meeting held at NASA. Langley Res. Center, Hampton, Va., 7 Nov. 1963
(Contract NOw-62-0604-c)
(CPIA-Publ-35; AD-602882)

Abstracts concerning the following are presented: (1) solid rocket-propulsion-system optimization study; (2) generalized three-dimensional grain design program; (3) program integration committee report; (4) performance subcommittee report; (5) design subcommittee report; (6) evaluation subcommittee report; and (7) program inventory committee report. Also presented is a list of publications and schedules. P.V.E.

N64-30605* Monsanto Research Corp., Everett, Mass. Boston Lab.,
STUDY OF FUEL CELLS USING STORABLE ROCKET PROPELLANTS Quarterly Report No. 2, 28 Apr.–27 Jul. 1964
J. C. Orth, R. E. Chute, R. Havlin, K. W. Klunder, S. Matsuda et al 25 Sep. 1964 99 p refs
(Contract NAS3-4175)
(NASA-CR-54170; MRB-5007Q2) OTS: $3.00 fs; $0.50 mf

Developmental work on a fuel cell operating on storable reactants, and design progress on a fuel cell that will operate relatively efficiently on a variety of fuels and oxidants are reported in the following areas: (1) porous teflon vapor-diffusion-electrode development; (2) evaluation of fuel cells with ion-exchange membranes; (3) construction of a monomethylhydrazine reformer; and (4) palladium–hydrogen diffusion-electrode testing. M.P.G.

N64-31048 Naval Ordnance Lab., White Oak, Md. Physical Chemistry Div.
SOLID-PROPELLANT ROCKET IGNITION RESEARCH Final Report
C. F. Sharn et al Sep. 1964 114 p refs
(NOLTR-64-107; AD-448068)

A theoretical and experimental study was made of solid rocket ignition for the purpose of obtaining igniter design criteria. Heat-transfer, ballistic, and ignition data were obtained by firing a rocket-type igniter, venting noncondensable products at an unsteady rate, into a small rocket. Measurements were made of igniter and rocket pressures, grain surface temperatures, and ignition times. In the tests, the heat fluxes ranged from 19 to 48 cal/cm^2-sec, and ignition times from 0.002 to 0.015 sec. It was found that the ignition test data were in fair agreement to those predicted from the von Elbe ignition theory. An igniter design method, developed from the test data and the von Elbe theory, is described. Author

N64-31171 Research Management Associates, Inc., South Pasadena, Calif.
TEST SYSTEM ANALYSIS STUDY FOR PROPULSION RESEARCH ENVIRONMENTAL CHAMBER Technical Documentary Report, 20 May–12 Sep. 1963
M. R. Raleigh and R. Mickola Edwards AFB, Calif., AF Rocket Propulsion Lab., 23 Sep. 1963 331 p refs
(Contract AF 04(611)-9094)
(RTD-TDR-63-1083; RMA-63-123-100; AD-421020)

The feasibility of developing a facility for the testing of rocket propulsion systems employing high-energy, toxic, and hypergolic propellants under simulated space environmental conditions has been established through analytical studies. It is determined that two of the required modes of testing—propellant storage and main propulsion unit firing—can be achieved with a combination of a double-walled vacuum chamber and an exhauster system separated by an impermeable flexible metallic interface that allows full gimbaling of the rocket motor. The simulation of thermal flux to the test item due to solar and planetary radiations can be achieved through an array of incandescent lamps individually controlled by a computer-operated program. The testing of attitude-control rockets in the vacuum chamber (the third mode of testing) must be limited to very short durations to preserve vacuum integrity and assure rapid vacuum recovery, unless a special device, the molecular flow trap, is employed. Author

N64-31675 Naval Ordnance Lab., White Oak, Md.
REVIEW OF NOL SENSITIVITY WORK APPLICABLE TO LARGE SOLID MOTOR EXPLOSION HAZARDS
Donna Price Oct. 1964 17 p refs
(NOLTR-64-148; AD-448349)

The purpose of this report is to summarize sensitivity work that is particularly relevant to the hazards encountered in large propellant motors. Previously unreported data on pressure loading by the detonation products of tetryl and references to reports, now in preparation, for the most recent work are presented. Author

N64-31693 Malaker Labs., Inc., High Bridge, N.J.
KINETIC STUDY OF ROCKET EXHAUST GASES
1 Oct. 1963 4 p
(Contract DA-30-069-ORD-2918)
(PR-6; AD-421967)

Breadboard optical equipment was assembled for spectrographic determination of combustion products and temperature in well-defined solid-propellant combustion zones. The resulting schemes were reconstructed to improve operability and accuracy. Some specific changes are as follows. The moving slit mechanism was replaced by a fixed slit and a motor-driven final mirror. All system controls were assembled into two adjacent control panels. The sequence camera now monitors pressure, gas flow, propellant pusher position, time, and actuation of diagnostic equipment, as well as the burning rate. All position readouts now employ Selsyns. A high-range flowmeter was added. All these changes were tested, but some are not in final form. D.E.W.

N64-31982 Aerospace Corp., El Segundo, Calif. Aerodynamics and Propulsion Research Lab.
REDUCTION OF ALUMINUM OXIDE BY PROPELLANT COMBUSTION GASES AT HIGH-TEMPERATURES
S. G. Gibbins and B. Siegel 1 Sep. 1964 14 p refs
(Contract AF 04(695)-269)
(SSD-TDR-64-160; TDR-269(4210-10)-7; AD-606158)

The effect of hydrogen on crystalline Al_2O_3 was studied at pressures ranging from 2 mm to approximately atmospheric at 1700° to 1800° C. At the higher pressures there was no observable reduction of the alumina in the presence of hydrogen alone. However, when graphite was also present, aluminum carbide was formed at an appreciable rate. The formation of the carbide is explained on the basis of a reaction between graphite and H_2 to form methane, which reduces the alumina. At very low pressures hydrogen alone did reduce alumina appreciably, but the product was not identified. Alumina was also reduced at a small but observable rate by carbon monoxide at 1700° C and a pressure of ~0.5 atm. The implications of these phenomena for propulsion are discussed with reference to their effects on propellant performance and missile detection. Author

N64-32052 Aerojet-General Corp., Azusa, Calif. Chemical Div.
APPLICATIONS OF STORABLE PROPELLANTS TO SPACE FLIGHT

S. B. Kilner and Louis R. Rapp [1961] 37 p refs *Its* Contrib No. 225

The types of space mission to which storable propellants are applicable are discussed, requirements on the propellants are outlined, and some special environmental factors in space are mentioned. Various storable propellants and storable systems are described and compared with other propulsion systems. Author

N64-32125 Aeronutronic, Newport Beach, Calif. Research Lab.

AN EXPERIMENTAL PROGRAM FOR OBTAINING THE THERMODYNAMIC PROPERTIES OF PROPELLANT COMBUSTION PRODUCTS Fifth Quarterly Technical Report

D. L. Hildenbrand, L. P. Theard, W. F. Hall, and N. D. Potter 15 Sep. 1963 38 p refs

(Contract NOw-61-0905-c; ARPA Order-22-62)

(U-2289; AD-421609)

The vapor pressures of LiF, LiCl, MgF_2, and $MgCl_2$ have been measured by the torsion-effusion method. The lithium halide vaporization data have been analyzed to yield heats of sublimation of monomer and dimer species that are consistent with available data on vapor composition, heats of dimerization, and the normal boiling points. Derived heats of sublimation of monomer and dimer at 298° K are 66.5 and 71.6 kcal/mole for LiF, and 51.0 and 52.0 kcal/mole for LiCl, respectively. An analysis of the data obtained here and other vaporization data on the magnesium halides indicates that the available entropy and free-energy functions for $MgF_2(g)$ and $MgCl_2(g)$ may be low by 4 to 5 cal/mole deg. Possible reasons for the discrepancy are discussed. The heats of sublimation of $MgF_2(g)$ and $MgCl_2(g)$ at 298° K are 93 and 59 kcal/mole, respectively. Author

N64-32241 Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div.

COMBUSTION IN LIQUID-PROPELLANT ROCKET MOTORS

Yu. Kh. Shaulov and M. O. Lerner 31 Jul. 1964 240 p refs Transl. into ENGLISH of the book "Goreniye v Zhidkostnykh Raketnykh Dvigatelyakh" Moscow, Gos. Nauch.-Tekhn. Izd. Oborongiz, 1961 p 1–194

(FTD-MT-64-272; AD-605460)

This book contains seven chapters as follows: Chapter I, "Elements of Kinetics of Chemical Reactions"; Chapter II, "Homogeneous and Heterogenous Combustion"; Chapter III, "Kinetics of Chemical Reactions in Flame"; Chapter IV, "Carburetion"; Chapter V, "Steady-State Regime of Burning"; Chapter VI, "Instability of Combustion Process"; Chapter VII, "Simulation of Process of Burning." E.C.

N64-32482 Aerospace Corp., El Segundo, Calif. Aerodynamics and Propulsion Research Lab.

NONEQUILIBRIUM RECOMBINATION IN NOZZLES. FUNDAMENTAL RECOMBINATION PROCESSES IN LOX-HYDROGEN, FLUORINE-HYDROGEN, AND FLOX-HYDROGEN PROPELLANTS

S. W. Mayer, E. A. Cook, and L. Schieler 18 Sep. 1964 33 p refs

(Contract AF 04(695)-269)

(TDR-269(4210-10)-6; SSD-TDR-64-139; AD-606703)

The significant nozzle recombination steps are tabulated for combustion products formed by LOX–hydrogen, fluorine–hydrogen, and FLOX–hydrogen propellants. Kinetic data for each of these 23 nozzle reactions are summarized in terms of the rate constants, $k_i = A_i T^{\eta i} \exp(-E_i/RT)$. A systematic basis is presented for selecting the significant nozzle reactions of atoms, radicals, and molecules for inclusion on the data tapes of computer programs for nonequilibrium calculations of propellant performance. The relative importance of the preexponential factor in high-temperature recombinations is emphasized. A method is given for reducing the number of equations needed in nonequilibrium performance calculations involving termolecular recombinations. A procedure for calculating concentrations of light-emitting excited states in the exhaust is presented. Ionization constants for the formation of cations, anions, and electrons in nozzle gases are computed and discussed briefly. Author

N64-32486* National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.

PROPULSION DEVELOPMENT PROBLEMS ASSOCIATED WITH LARGE LIQUID ROCKETS

A. A. Mc Cool and G. H. Mc Kay, Jr. 12 Aug. 1963 29 p (NASA-TM-X-53075) OTS: $2.00 fs; $0.50 mf

Propulsion development problems of the Saturn I and Saturn V vehicles are reviewed. The problems discussed include the following: (1) cluster tankage problems; (2) propellant feed-system development; (3) propellant-tank location for S-IC stage; (4) propellant conditioning for engine start; and (5) base heating from engine-exhaust gases. D.S.G.

N64-32597 Frankford Arsenal, Philadelphia, Pa.

PROPELLANT ACTUATED DEVICES Progress Report, May–Jun. 1964

[1964] 92 p refs

(PAD-94-1; AD-449223)

This report describes the progress of certain development programs relating to propellant actuated devices (PAD). The work covered includes the design and development of specific devices, such as thrusters, catapults, and initiators; investigations of related subjects, such as propellants and structural materials; and feasibility studies, aimed at improving the performance of propellant actuated devices and extending their application. Author

N64-32632* Stanford Research Inst., Menlo Park, Calif.

INVESTIGATION OF O_3F_2 AND THE HYPERGOLIC BIPROPELLANT LH_2/LO_2:O_3F_2

A. B. Amster, E. L. Capener, L. A. Dickinson, and J. A. Neff 15 Jun. 1964 52 p refs

(Contract NASr-49(00))

(NASA-CR-54072; SRI-PRU-4391) OTS: $3.00 fs; $0.50 mf

The properties of ozone fluoride and its solution in liquid oxygen have been studied. Neat ozone fluoride has been shown to be nondetonable at a diameter of 1 inch. The solubility relationship of ozone fluoride in liquid oxygen versus temperature has been determined. Ignition studies made by using quartz and steel combustion chambers (500-thrust) have shown that hypergolic ignition occurs between hydrogen and liquid oxygen containing 0.095% ozone fluoride. Both a single-element triplet injector and a multielement coaxial stream injector were studied. Author

N64-32647 Little (Arthur D.) Inc., Cambridge, Mass.

COMBUSTION INSTABILITY STUDIES

Aubrey C. Tobey [1964] 48 p refs Presented at the 1964 Spring Meeting, Western States Sect., The Combust. Inst., Stanford U., Apr. 1964

(Contract AF 49(638)-1120)

(AD-449764)

This paper contains analytical and experimental data for the flame-piloting mechanism in rocket combustions and the effect of external disturbances on it, with emphasis on the recirculation zone in a coaxially fed rocket system using inert injection, for improved control methods of high-frequency

combustion oscillation of rocket engines. Variables of local concentration and temperature, as well as rocket-chamber pressure variations with time, have been studied as functions of oxygen to fuel ratio, chamber length, injection configuration, inert-gas injection rate, and position of inert gas injection relative to the injector face. A primary reaction zone bordered on one side by a fuel-rich zone and on the other by an oxygen zone was indicated by data, with an increase of reactant concentration with the distance from the primary reaction zone. The rates of mass transfer to the primary reaction zone are derivable from the classical diffusion theory. G.G.

N64-32882 Lockheed Missiles and Space Co., Palo Alto Aerospace Science Lab.
STRATIFIED LAYER FLOW MODEL: A NUMERICAL APPROACH TO TEMPERATURE STRATIFICATION IN LIQUIDS CONTAINED IN HEATED VESSELS
Gary C. Vliet Nov. 1963 78 p refs

A stratification model "Stratified Layer Flow Model" and its accompanying numerical machine program are presented. The proposed model is based on a turbulent natural convection boundary layer that flows upward along the heated vessel walls to the liquid surface. The boundary layer continuously supplies liquid to the surface and simultaneously exchanges mass and energy with the previously stratified liquid as it passes through it. Mass and energy transfers occur at the surface between the liquid and ullage. Additionally, the liquid may be drained while being subjected to nuclear heating. Negative temperature gradients in the bulk liquid (in the upward direction) caused by nuclear heating result in a statically unstable condition, and by turbulent mixing these gradients tend to be eliminated. Due to the complexity of the above process, the model is treated numerically in discrete time-steps by an IBM 7094 machine program. Author

N64-32958 Rohm and Haas Co., Huntsville, Ala. Redstone Arsenal Research Div.
FURTHER DEVELOPMENT OF CONFORMAL MAPPING TECHNIQUES
Eric B. Becker, Howard B. Wilson, Jr., and Charles H. Parr 31 Jul. 1964 54 p refs
(Contract DA-01-021-ORD-11878(Z))
(S-46; AD-447289)

A significant improvement in the previously reported method of conformally mapping singly connected regions having at least one axis of symmetry was achieved. In addition, the method was extended to include mapping of interior regions. The method was tested by conformally mapping several solid-propellant-grain cross sections, a splined shaft, and notches in and a protrusion on a half plane. Listings of and operating procedures for the pertinent computer programs written in FORTRAN IV are given. Author

N64-33076* Technidyne Inc., West Chester, Pa.
GELLING OF LIQUID HYDROGEN Final Report
Herbert Kartluke, C. Dana Mc Kinney, Richard Pheasant, and William B. Tarpley 31 Jul. 1964 58 p refs Prepared jointly with Marquardt Corp.
(Contract NAS3-2568)
(NASA-CR-54055; RR-64-47) OTS: $3.00 fs; $0.75 mf

The most effective commercially available particulate gellant, pyrogenic silica (in the finest particle size, 7 mμ) formed gels in LH_2 at a loading of 35 to 37 wt.%. A search for high-energy, low-density solid fuels that might be preparable in the ultrafine particle size requisite for gelation revealed, for example, lithium borohydride ($LiBH_4$, 0.66 g/cm^3). Calculations, without optimization, have shown that, even with as much as 20 wt.% of $LiBH_4$ loading, LH_2 performance degradation with lox would amount to only 4.5%, or with LF_2 only 2.5%. Preliminary preparations of fuel-gellants were made for screening purposes, although the particle sizes were larger than optimal. LH_2 gels were made as follows: lithium borohydride 67 wt.%, and lithium aluminum hydride 86 wt.%. Other candidate fuel-gellants that were briefly examined and appear promising include boron, boranes, methane (in situ), hydrazine, and certain light metal hydrides. The ultimate choice depends on such factors as low density, high energy contribution, and ease of preparation of particles in sizes below 50 mμ. Author

N64-33273 Colorado School of Mines, Golden
EXPERIMENTAL DETERMINATION OF MECHANICAL RESPONSE OF SOLID ROCKET PROPELLANT UNDER HIGH STRAIN RATE AND LOW TEMPERATURE Final Report
Richard S. Culver and John S. Rinehart 15 Jul. 1964 44 p
(Grant Nonr-3774(00)(FMB))
(MRL-ONR-3; AD-603871)

Described in this report are the results of an experimental investigation of the mechanical properties of two simulated solid rocket propellants. The "green" propellant is salt-filled polyurethane; the "gray" propellant is Adiprene L-100, filled with aluminum powder, aluminum sulphate, and castor oil. In low temperature tests the expected inverse relation between temperature and U.T.S. was found. In static torsion tests, the gray propellant exhibited a marked notch sensitivity and a tensile fracture mode, while the green had no notch sensitivity and a shear fracture mode. The impulsive fracture strength of the green propellant was found to be about 16 000 psi, in confirmation of tests run by previous investigators, and the shock attenuation at this stress level is about 5000 psi/in. An approximate value of 24 000 psi for the impulsive fracture strength of the gray was obtained by indirect means, along with a shock attenuation of 1500 psi/in. Author

N64-33287* Martin Co., Denver, Colo.
STUDY OF TERMINAL DRAINING FOR LIQUID OXYGEN AND LIQUID HYDROGEN PROPELLANTS Final Summary Report
J. J. Traxler and A. P. Lane Aug. 1964 158 p refs
(Contract NAS8-5417)
(NASA-CR-59255; Martin-CR-64-47) OTS: $5.00 fs; $1.00 mf

A mathematical model is derived for describing vortexing outflow behavior in a central outlet of a cylindrical tank with a convex lower dome. The derivation is based on the constancy of circulation and on the value of the gravitational potential gradient. Two methods of designing propellant tank outlets to minimize propellant residuals are presented. The first, the noncavitating outlet concept, defines an outlet profile that maintains the flowing liquid static pressure constant throughout the outlet. The second concept, the nondropout outlet approach, employs the solution of the two-dimensional Bernoulli equation with the constraint that maintains a flat velocity profile in the outlet, i.e., insures a geometrically flat liquid surface as terminal draining occurs. All mathematical models requiring automatic machine computation have been programed for the IBM 1620 computer, and sample program listings are presented in this report. Author

N64-33324 California Inst. of Tech., Pasadena W. M. Keck Lab. of Engineering Materials
A RESEARCH PROGRAM ON SOLID PROPELLANT PHYSICAL BEHAVIOR Quarterly Report No. 1, 1 Nov. 1963–31 Jan. 1964
M. L. Williams Feb. 1964 8 p refs
(Contract AF 04(611)-9572)
(MATSCIT-PS-64-1; AD-602754)

This integrated program applies to research in the physical behavior of solid propellants for solid rocket motors. The following studies are proposed and outlined: Behavior of Polymeric and Composite Systems; Standardized Material Characterization; Data Information Facility; and Distribution of the Library Additions List. G.G.

N64-33573 IIT Research Inst., Chicago, Ill.
A STUDY OF THE FUNDAMENTALS OF LIQUID PROPELLANT SENSITIVITY Third Technical Progress Report
Ted A. Erikson Edwards AFB, Calif., AF Flight Test Center, 15 Jul. 1964 27 p refs
(Contract AF 04(611)-9566)
(IITRI-C6024-12; AD-445350)

Shock-tube tests with approximately 0.1 g samples of Compound R at initial temperatures near −180° C were performed with measured induction times of 0 to 1 msec; a 400μsec time delay from shock reflection to detonation was measured for six identical tests at an incident nitrogen shock near Mach 2.4 with less than 10μsec deviation. The initial mode of initiation by the shock-tube test is either energy transfer to, or heterogeneous attack at, the surface of the condensed phase. Increased gas temperature will increase the initial energy flux but decrease the rate of heterogeneous attack. The maximum energy accumulation during the conditions for the 40μsec delay time by energy transfer is 8.33 cal/cm^2. Assuming a 10 kcal/mole heat of heterogeneous reaction, the corresponding energy accumulation is 30 cal/cm^2. Author

N64-33896 Sheffield U. (Gt. Brit.)
A STUDY OF THE ACOUSTIC PROPERTIES OF SOLID FUEL ROCKET PROPELLANTS Progress Report No. 1
J. D. Willis [1964] 14 p refs
(Contract MOA-PD/31/014/RI)
(FTCE/41/3/64; HIC-38)

The acoustic properties of solid-propellant rocket fuels are studied in order to determine some way of using the propellant to damp out the acoustic waves that develop in the combustion system. Two methods are proposed, one involving additives that damp sound waves, and the other being the choice of propellant elasticity so as to damp out the unwanted vibrations. Previous work is reviewed, and a pulse technique for measurement of sound velocity in solids is described. D.E.W.

N64-33926 Ethyl Corp., Baton Rouge, La.
RESEARCH ON LIGHT METAL FUELS AND OXIDIZER CHEMISTRY. PART II: OXIDIZER CHEMISTRY Quarterly Progress Report No. 4, May–Jul. 1964
W. E. Becker and D. H. Campbell [1964] 9 p refs
(Contract AF 04(611)-9376; ARPA Order 24)
(EC-670; AD-607168)

The cryoscopic behavior of HNF_2 in concentrated sulfuric acid solutions has been measured. The average of the values for the molecular weight of HNF_2 was 52.7 compared to the calculated formula weight of 53. These data indicate that little or no ionization of HNF_2 occurs in H_2SO_4 at room temperature. A kinetic investigation of the reaction of HNF_2 with deuterium oxide is in progress. The results indicate that HNF_2 ionizes slightly in tetrahydrofuran (THF) solutions. The ionization constant is lower than that of water. A similar investigation of the isotopic exchange of $ClNF_2$ with HCl has been initiated. An investigation of the conductivity of $ClNF_2$ in nitrobenzene solution is in progress. Author

IAA ENTRIES

A64-11120
STUDY OF QUENCHED ALUMINUM PARTICLE COMBUSTION.
Charles M. Drew, Alvin S. Gordon, and R. H. Knipe (U. S. Naval Ordnance Test Station, Chemistry Div., China Lake, Calif.).
AIAA Heterogeneous Combustion Conference, Palm Beach, Fla., Dec. 11-13, 1963, Preprint 63-487. 8 p.
Members, $0.50; nonmembers, $1.00.

Experimental investigation of the morphology of burning aluminum particles under actual burning conditions, by using various techniques to interrupt the burning at different stages of ignition and combustion. The experimental procedure and quenching methods used are described, and the results of the studies are presented and discussed, with particular reference to models of the burning.

A64-11121
COMBUSTION DURING PERPENDICULAR FLOW.
W. G. Courtney, W. R. Kineyko, and B. E. Dawson (Thiokol Chemical Corp., Reaction Motors Div., Denville, N. J.).
AIAA Heterogeneous Combustion Conference, Palm Beach, Fla., Dec. 11-13, 1963, Preprint 63-515. 14 p. 16 refs.
Members, $0.50; nonmembers, $1.00.
ARPA Order 22-62.

Review of an experimental investigation of combustion during the perpendicular flow of two vapor streams, such as occurs in hybrid combustion. Systems examined include vapor-vapor, vapor-solid, vapor-solid propellant grain, and spray-grain systems, e.g., NH_3-O_2, O_2-Plexiglas, N_2-NH_4ClO_4/CH_2, and N_2H_4(l)-NH_4ClO_4/CH_2, respectively. Low velocities of the vapor streams (1-5 ft/sec at 1 atm) gave a steady laminar parabolic diffusion flame which involved a multizone flame front about 1/2 in. thick. Medium velocities of the main stream (10-20 ft/sec) gave essentially a wavy laminar flame with some eddy curling, but some molecular mixing also occurred prior to combustion. Comparison of cold and flame flow indicated that the flame acts as a buffer zone to decrease the turbulent mixing between the two vapor streams, but this buffer action begins to break down at the higher flowrates.

A64-11122
THEORY OF HYPERGOLIC IGNITION OF SOLID PROPELLANTS.
R. Anderson, R. S. Brown, G. T. Thompson, and R. W. Ebeling (United Aircraft Corp., United Technology Center, Sunnyvale, Calif.).
AIAA Heterogeneous Combustion Conference, Palm Beach, Fla., Dec. 11-13, 1963, Preprint 63-514. 10 p. 10 refs.
Members, $0.50; nonmembers, $1.00.

Demonstration that the ignition of solid propellants which results from contact with hypergolic oxidizers proceeds through spontaneous interfacial chemical reactions. These reactions are exothermically energetic and proceed at a high enough rate to raise the solid-propellant or fuel surface temperature to the point where the propellant or fuel undergoes spontaneous combustion. A hypergolic ignition theory is presented which focuses attention on the spontaneous gaseous oxidizer and solid propellant heterogeneous chemical reactions, and predicts quantitatively the effect of oxidizer concentration on ignition delay time. The theory also explains quantitatively the effect of gaseous oxygen and other reactive species (which are not normally considered as hypergolic agents) on the ignition delay time.

A64-11125
COLLISIONAL DEPENDENCE OF GAS-CONDENSATE ENERGY EXCHANGE DURING A CONVERGENT-DIVERGENT EXPANSION.
W. H. McLain (Martin Marietta Corp., Martin Co., Denver, Colo.).
AIAA Heterogeneous Combustion Conference, Palm Beach, Fla., Dec. 11-13, 1963, Preprint 63-513. 7 p.
Members, $0.50; nonmembers, $1.00.

Review of an experiment in which a nonreactive gas (helium) was injected into the chamber of a solid propellant rocket in order to study the aerodynamics of gas-particle interactions in the nozzle. The results are interpreted both in terms of current theories of gas-particle nozzle flow, and in terms of the frequency of gas-particle collisions, and correlations between the interpretations are noted.

A64-11622
THERMODYNAMIC CALCULATION OF PERFORMANCE DATA ON ROCKET PROPELLANTS. III - EXAMPLES OF APPLICATION [THERMODYNAMISCHE BERECHNUNG DER LEISTUNGSDATEN VON RAKETENTREIBSTOFFEN. III - ANWENDUNGSBEISPIELE].
G. Spengler, E. Büchner, A. Lepie, and H. Gemperlein (München, Technische Hochschule, Munich, Germany).
Brennstoff-Chemie, vol. 44, Sept. 1963, p. 268-275. 16 refs.
In German.

Application of a previously developed method to the calculation of performance data of 9 propellant-oxidant systems: UDMH (Dimethylhydrazine) and ($2F_2 + O_2$); UDMH and F_2O; UDMH and O_2; NH_3; and NF_3; UDMH and HNO_3; UDMH and $NOClO_4$; $(CN)_2$ and HNO_3; furfuryl alcohol and HNO_3; and UDMH and NF_3. The combustion equations are used as a basis for discussing the thermochemical and thermodynamic properties, which yield the specific impulse, mass-flow coefficient, and thrust for each propellant system. The results, presented graphically, are discussed and compared.

A64-11773
TEMPERATURE DISTRIBUTION IN A CASE - BONDED CYLINDRICAL ROCKET ASSEMBLY.
Myron Levitsky and Bernard W. Shaffer (New York University, School of Engineering and Science, New York, N.Y.).
AIAA Journal, vol. 1, Dec. 1963, p. 2870-2872.
Contract No. NOrd-16640.

Presentation of a method for simplifying the lengthy equations for the exact temperature distribution in an axially symmetric case-bonded propellant grain when the ambient temperature is suddenly changed from a state of equilibrium. It is found that when the Biot modulus is small, the temperature variation within the propellant in the radial direction is also relatively small. It is then reasonable to assume in an engineering calculation that the temperature of the propellant grain is uniform and varies with the time coordinate only.

A64-11955
PROGRAMMES IN ROCKET PROPULSION AT CARDE.
I. R. Cameron (Canadian Armament Research and Development Establishment, Valcartier, Quebec, Canada).
(NRC Symposium on Experiments at Fort Churchill, Canada, Mar. 28, 29, 1963.)
Canadian Aeronautics and Space Journal, vol. 9, Dec. 1963, p. 307-312. 16 refs

Presentation of new findings on unstable combustion in solid propellant rockets which use a CARDE (Canadian Armament Research and Development Establishment) pulse technique of injecting flow disturbances into the burning rocket motor. The performances and present limitations of the motors in 10 in. and 17 in. diameters are reviewed with some indication of their future limitations. The development trend in the search for a rocket motor for the Black Brant IIB vehicle is indicated.

A64-12466
DETERMINATION OF THE DYNAMIC SHEAR MODULUS OF A COMPOSITE SOLID PROPELLANT.
Lionel H. Layton, G. A. Sheppard, and S. John Bennett (Thiokol Chemical Corp., Wasatch Div., Brigham City, Utah).
Review of Scientific Instruments, vol. 34, Dec. 1963, p. 1333-1340.

Theoretical analysis of the principles of high- and low-frequency measurement of the dynamic behavior of viscoelastic materials, and application of these principles to determine the shear modulus of a composite solid propellant, in the frequency range from 0.10 to 1,000 cps. The test specimen consists of two concentric metal rings carried by a flat plate of propellant. The high frequency data (70-1000 cps) are obtained by applying a known sinusoidal motion to the outer ring and measuring the response at the center. The transducer and center mounting are used as an inertial mass and are included in the analysis of the viscoelastic plate. The low frequency data (0.10-45 cps) are obtained by applying a known sinusoidal motion to the center of the specimen with the outer edge in a clamped position. The applied force and displacement are both measured at the center of the specimem. Typical results for the complex dynamic shear modulus with its real and

imaginary parts, as well as the loss tangent, are given for a composite solid propellant. These data indicate a precision of approximately ±10%.

A64-12720
COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty (Ministry of Aviation, Rocket Propulsion Establishment, Westcott, Bucks., England), A. L. Jaumotte (Bruxelles, Université Libre, Institut de Mécanique Appliquée, Brussels, Belgium), O. Lutz (Deutsche Forschungsanstalt für Luft- und Raumfahrt EV, Institut für Strahlantriebe, Braunschweig, Germany), and S. S. Penner (Institute for Defense Analyses, Washington, D.C.).
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963. 698 p.
$20.

A collection of 20 papers, with discussion, in the fields of air-breathing engines, chemical rockets, and advanced propulsion devices. The papers are divided into six groups: equilibrium properties of high-temperature gases, high-temperature fluids, physical processes in combustion and propulsion, transport properties of ionized gases, high-temperature materials for solid propellant grains and liners, and basic combustion studies of rocket engines using high-energy fuels. Theoretical and applied aspects are treated. The papers are individually abstracted and indexed in this issue.

A64-12726
STUDIES OF ATOMIZATION AND INJECTION PROCESSES IN THE LIQUID PROPELLANT ROCKET ENGINE.
J. D. Lewis (Ministry of Aviation, Rocket Propulsion Establishment, Westcott, Bucks., England).
IN: COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963, p. 141-169; Discussion, p. 169-174. 26 refs.

Investigation of combustion in the liquid propellant rocket engine, liquid atomization from rocket engine injectors, and injector behavior under combustion conditions. The following subjects of future research are indicated: (1) more detailed investigation of the mechanism of liquid atomization; (2) basic studies of the problems of combustion instability in order to determine how these can be influenced by injector characteristics; and (3) an assessment of injector requirements at high combustion pressures.

A64-12736
EXPERIMENTAL STUDIES OF UNSTABLE COMBUSTION IN SOLID PROPELLANT ROCKET ENGINES.
G. F. P. Trubridge and H. Badham (Imperial Chemical Industries, Ltd., Summerfield Research Station, Kidderminster, Worcs., England).
IN: COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963, p. 497-520; Discussion, p. 520-530. 17 refs.

Description of the methods used at the Summerfield Research Station to suppress unstable combustion occurring with cast double-base propellants. The three basic methods tried are the use of resonance rods in the charge conduit, additives in the propellant, and non-combustible inserts in the charge. It is concluded that resonance rods and the use of aluminum in the propellant are the best methods of suppressing the instability. Consideration is also given to the effects of engine and charge characteristics on instability, and the effect of unstable combustion on engine performance.

A64-12737
COMBUSTION IN SOLID PROPELLANT ROCKET ENGINES.
L. A. Dickinson and F. Jackson (Canadian Armament Research and Development Establishment, Valcartier, Quebec, Canada).
IN: COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963, p. 531-544; Discussion, p. 544-550. 18 refs.

Description of the research program on combustion phenomena associated with solid propellants for rocket engines, which is being carried out by the Defence Research Board of Canada. The principal areas being investigated and reported on are: (1) influence of composition on ballistic performance; (2) erosive burning characteristics of propellants; and (3) combustion instability phenomena. A number of new experimental techniques have been developed for studies connected with erosive and unstable burning. One research procedure has recently been successfully applied as a test method to reduce the number of proving rounds needed to clear the ballistic design of a rocket engine.

A64-12738
THE EFFECT OF PARTICLE SIZE AND NON-STOICHIOMETRIC COMPOSITION ON THE BURNING RATES OF COMPOSITE SOLID PROPELLANTS.
W. Nachbar (Stanford University, Dept. of Aeronautics and Astronautics, Stanford, Calif.) and G. B. Cline, Jr. (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Sunnyvale, Calif.).
IN: COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963, p. 551-568.
Contract No. AF49(638)-412.

Generalization of the analysis of the steady burning of a composite solid propellant of sandwich construction, which was proposed previously by the first author as a mathematical model with which to investigate steady burning, to include non-stoichiometric proportions of fuel and oxidizer. The theoretical dependence of burning rate upon "particle size" and upon stoichiometry is obtained and is illustrated by calculations with data for two composite solid propellants. A rough qualitative comparison is made of the theoretical predictions with some published experimental data.

A64-12739
STABLE COMBUSTION PROCESSES IN LIQUID PROPELLANT ROCKET ENGINES.
S. Lambiris, L. P. Combs, and R. S. Levine (North American Aviation, Inc., Rocketdyne Div., Canoga Park, Calif.).
IN: COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963, p. 569-634; Discussion, p. 635, 636.
Contracts No. AF 04(647)-672; No. AF 49(638)-817.

Presentation of information on the combustion processes necessary for successful analytical modeling of liquid-propellant rocket engine combustion during stable operation. The theoretical and experimental results of single-propellant droplet combustion and their application in spray-combustion analyses are reviewed. Propellant-spray formation and droplet-size distributions from particular rocket injector types are considered. Several assumptions concerning the propellant combustion processes, as used by a number of investigators in the development of rocket combustion models, are examined and the experimental evidence necessary for confirming the model predictions is discussed. Recent experimental data, found sufficient for approximate model verification, are shown to be useful for guiding the development of an analytical bipropellant combustion model without the necessity of making simplifying and restrictive assumptions. A description of a combustion model is given, which is based on detailed spatial accounting of the combustion field for each particular injector-chamber configuration and propellant combination. Using machine solutions of such a "comprehensive" model for liquid oxygen-kerosene propellants, the previous simplifying assumptions are incorporated individually and the effects of each on the model prediction are shown graphically by comparison with the experimental data.

A64-12740
COMBUSTION INSTABILITIES IN LIQUID PROPELLANT ROCKETS [LES INSTABILITES DE COMBUSTION DANS LES FUSEES A PROPERGOL LIQUIDE].
Marcel Barrère (ONERA, Châtillon-sous-Bagneux, Seine, France) and Jean Corbeau (Laboratoire de Recherches Balistiques et Aérodynamiques, Vernon, France).
IN: COMBUSTION AND PROPULSION; Fifth AGARD Colloquium on High-Temperature Phenomena, Braunschweig, Germany, Apr. 9-13, 1962.
Edited by R. P. Hagerty, A. L. Jaumotte, O. Lutz, and S. S. Penner.
Oxford, Pergamon Press, Ltd.; New York, Macmillan Co., 1963, p. 637-685, in French; Discussion, p. 685-692. 43 refs.

Presentation of a coordinated view of many conflicting experimental results on the subject of combustion instability. Described are the extensive investigations of high-frequency instability which were carried out, and the results obtained, which aid in understanding the acoustic type of instability. The progress of research on low-frequency instability is surveyed. The importance of the energy rates released by combustion in the interpretation of experimental results is stressed. The methods which permit the setting off of instability phenomena are described.

A64-12754
HEAT-TRANSFER ANALYSIS OF ROCKET NOZZLES USING VERY HIGH TEMPERATURE PROPELLANTS.
John R. Howell, Mary Kern Strite, and Harold Renkel (NASA, Lewis Research Center, Cleveland, Ohio).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, New York, N. Y., Jan. 20-22, 1964, Preprint 64-62. 6 p.
Members, $0.50; nonmembers, $1.00.

Application of the Monte Carlo method as a basis for determining two-dimensional propellant temperature distributions and wall heat-transfer rates as functions of axial position in a nozzle of arbitrary shape. The propellant is considered to be at such elevated temperatures that radiation is the dominant mode of heat transfer, although the effect of convection is also considered. The propellant is assumed to be an absorbing-emitting gas with a constant absorption coefficient, and the effects of flow, variable heat-transfer coefficient, propellant heat capacity, and nozzle wall temperature are included.

A64-12948
CATALYSIS OF NOZZLE FLOWS.
H. Girouard (General Dynamics Corp., General Dynamics/Astronautics, San Diego, Calif.).
American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, New York, N. Y., Jan. 20-22, 1964, Preprint 64-98. 11 p. 32 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. NAS 8-2534.

Description of two methods of attaining high propellant performance: chemical catalysis and optimum nozzle contours. A theory and experimental data on the catalysis of hydrogen atom recombination are presented. The evidence is described to show that small amounts of catalyst can increase the rates of highly exothermic combination reactions by orders of magnitude. The theory is extended to show the nature of catalysis in more complex propellants. The catalysis of hydrogen atom recombination for nuclear rockets is evaluated in connection with an original approach toward obtaining optimized nozzle geometries for chemically reacting propellants. It is noted that the results indicate that the propellant specific impulse could be substantially improved using a chemically reacting propellant concept. One use of the higher propellant performance would be to largely compensate for lower thrust-to-weight ratios in orbital escape maneuvers. This would allow slower reactor start-up and lower heat fluxes to be used which would reduce thermally induced stresses in the reactor fuel elements.

A64-12998
A STUDY OF THE IGNITION OF SOLID PROPELLANTS IN A SMALL ROCKET MOTOR.
E. H. Grant, Jr., R. W. Lancaster, J. Wenograd, and M. Summerfield (Princeton University, Guggenheim Laboratories for the Aerospace Propulsion Sciences, Princeton, N. J.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-153. 11 p. 14 refs.
Members, $0.50; nonmembers, $1.00.
USAF-NASA-sponsored research.

Experimental investigation of the nature of practical ignition processes by means of a small-rocket motor developed for this purpose. The basic structural features and characteristics of the motor are described; they permit systematic variation of the heat transfer rate, the chemical reactivity of the igniting gas, the flame temperature, mass flow, and the chamber pressure. The obtained results demonstrate the significant effect of gas phase properties upon solid-propellant ignition delay. They also substantiate the theoretical models of ignition which take such effects into account.

A64-12999
TRIAXIAL TENSILE STRESS EVALUATION OF PROPELLANT-TO-CASE BOND INTEGRITY.
S. C. Britton, B. M. Corley, R. L. Hall, and L. D. Webb (North American Aviation, Inc., Rocketdyne Div., McGregor, Tex.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-152. 21 p. 19 refs.
Members, $0.50; nonmembers, $1.00.

Determination of failure criteria for the propellant-liner combinations in triaxial tension which represent the stress field developed at the grain-liner-case boundary when a case-bonded solid-propellant grain is cooled. A finite difference method of elastic stress analysis is proposed for two parallel flat rigid circular plates comprising two layers of material of different moduli, simulating a propellant-liner combination. The analysis is used to calculate strain rates in each layer, and the center axial stress in both the bond plane between layers and the plane of maximum stress, as a function of aspect ratio, modulus ratio, Poisson's ratio, and layer thickness ratio. Experiments to determine the influence of test variables on the mode and location of fracture in the plate specimens, the stress at the locus of fracture, and material failure criteria, are described. The results are used to deduce an optimum test approach.

A64-13001
THE T-BURNER METHOD OF DETERMINING THE ACOUSTIC ADMITTANCE OF BURNING PROPELLANTS.
R. L. Coates (Hercules Powder Co., Bacchus, Utah), N. W. Ryan (Utah, University, Salt Lake City, Utah), and M. D. Horton (U.S. Naval Ordnance Test Station, China Lake, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-137. 7 p.
Members, $0.50; nonmembers, $1.00.

Discussion of three methods for operating a T-burner and analyzing the obtained acoustic admittance data for solid propellants. The close correlation of the results obtained by the three methods tends to disprove the criticisms commonly expressed with respect to this type of experiments, namely: questioning of the admittance values on the grounds that adequate corrections cannot be made because the acoustic losses in the apparatus are not sufficiently understood; and that these losses in the T-burner are so large that some operational propellants known to produce oscillations in motors, will burn stably in the burner.

A64-13002
ROLL TORQUE AND NORMAL FORCE GENERATION IN ACOUSTICALLY UNSTABLE ROCKET MOTORS.
G. A. Flandro (Utah, University, Mechanical Engineering Dept., Salt Lake City, Utah).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-145. 14 p. 16 refs.
Members, $0.50; nonmembers, $1.00.
Sperry Utah Co. Contracts No. DA-04-4951-ORD-18; No. DA-30-069-ORD-1783.

Discussion of the relation between the generation of roll torque and normal forces and acoustic combustion instability, observed in firings of internal-burning solid-propellant rocket motors. The analysis indicates that steady secondary flows can be produced at the burning surface of a rocket combustion chamber by nonlinear viscous effects in the presence of certain high-amplitude acoustic modes. Superposition of these modes on the motor through-flow can produce vortex-like flow about the chamber axis. Generation

of these swirling flows gives rise to roll torque in cylindrical grains, and to both longitudinal torque and forces normal to the chamber axis in more complicated grain geometries. These findings correlate with the measured forces and the associated flow patterns at the nozzle. The magnitude of the secondary forces depends on the initial grain temperature. Star grains are capable of producing several discrete levels of roll torque for a given initial temperature. The problem of eliminating the secondary-force effects from a motor of a given design is seen to be of the same order of magnitude as the elimination of the corresponding combustion instability effects. Some recommendations are made for further studies of the phenomena discussed.

A64-13003

CHUFFING AND NONACOUSTIC INSTABILITY PHENOMENA IN SOLID PROPELLANT ROCKETS.

R. A. Yount and T. A. Angelus (Hercules Powder Co., Allegany Ballistic Laboratory, Cumberland, Md.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-148. 10 p. 14 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. NOrd 16640.

Theoretical and experimental investigation of chuffing and low-frequency nonacoustic instability, to determine the interrelationship of these phenomena, as well as their relation to motor parameters and combustion processes. Dependence of frequency and amplitude on pressure indicates that a common mechanism may be ascribed to both phenomena: burning strands of aluminized propellant in a closed bomb exhibit periodic behavior; no effect of motor free volume or grain port velocity upon the frequency of nonacoustic instability is observed. This suggests that low-frequency nonacoustic instability is an intrinsic propellant property, and manifests itself in rockets in indirect dependence on motor parameters. Similar dependence for chuffing is proposed. On the assumption of initiation by thermal explosion and Arrhenius-type surface reactions, a logarithmic relation is derived between induction time and the pressure associated with quasi-steady reaction before a chuff. Motor firing data are shown to obey this relation, since the logarithm of time to ignition of propellant samples in contact with a heated block depends inversely on absolute block temperature.

A64-13004

CORRELATION OF MOTOR AND STRAND BURNING RATE.

L. E. Herrington (Aerojet-General Corp., Propellant Ballistics Dept., Sacramento, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-150. 5 p.
Members, $0.50; nonmembers, $1.00.

Correlation of the burning rate of composite propellants, measured in Crawford-bomb testing of uncured strands, with data taken from small motor test firings, using the concepts of Summerfield's granular diffusion flame theory. Data are presented showing that differences in pressure dependence can be attributed to the diffusion and reaction-time parameters of the model. Using polyurethane and polybutadiene propellants containing aluminum, it is shown that the differences in the two types of burning can result from a lower strand flame temperature. This conclusion is confirmed by plots of the ratio of pressure to burning rate for the motor vs the same value for the strand.

A64-13010

THE IGNITION TRANSIENT IN SOLID PROPELLANT ROCKET MOTORS.

K. H. Parker, J. Wenograd, and M. Summerfield (Princeton University, Guggenheim Laboratories for the Aerospace Propulsion Sciences, Princeton, N. J.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-126. 10 p.
Members, $0.50; nonmembers, $1.00.
USAF-NASA-sponsored research.

Dimensional analysis of the flame-spreading-interval model of the over-all ignition transient, based on successive ignition of adjacent surface elements. The nondimensional groups, which depend on the propellant ballistic properties and the motor design, are derived. Experimentally, in a ten inch long, solid propellant burner, photographic and pressure measuring techniques have been used to study flame spreading. Flame spreading rates in the downstream direction of 100 in/sec and more have been observed. A typical division of a 300 msec over-all ignition transient might be: 50 msec-ignition lag, 100 msec-flame spreading; and 150 msec-chamber filling. These values may be much larger or smaller depending upon geometry and propellant properties. It is noted that the agreement between the theory developed and the experiments is exceptionally good in some aspects, particularly in the chamber filling interval. However, the validity of the central assumption of the theory, the dominance of a "laminar-like" convective heat transfer remains uncertain.

A64-13011

NONLINEAR EFFECTS IN INSTABILITY OF SOLID-PROPELLANT ROCKET MOTORS.

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

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-140. 7 p.
Members, $0.50; nonmembers, $1.00.
Contract No. NOw 62-0604-c.

Discussion of the erosive response of propellants to finite-amplitude disturbances, without taking into account the nonlinear properties of the burnt gas and the pressure response of the propellant. Specifically discussed are the effects which erosion may have on nonlinear stability, on limitation of amplitude, and on wave form, for the case of inside-burning cylindrical charges. The analysis indicates that even for quite small amplitudes, appreciable nonlinear effects may arise from the erosive response of propellants. Under certain conditions, acoustic erosion may contribute to nonlinear instability. It is found that, especially for axial modes, significant waveform distortion may develop at small amplitudes of the pressure oscillation, and that the wave shape tends to be a sensitive function of the time-dependent response of the propellant.

A64-13015

VORTEX GENERATION IN SOLID PROPELLANT ROCKETS.

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

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-144. 11 p. 15 refs.
Members, $0.50; nonmembers, $1.00.

Discussion of vortex generation in solid-propellant rocket motors, with a view toward defining the mechanisms of irregular combustion. The analysis is based on the findings that vortices are formed as a second-order viscous effect of pressure oscillation within the motor, and that they are closely related to the classical phenomenon of acoustic streaming (nonlinear viscous effects). It is found that the viscous effects predominate in the boundary layer and near the axis of the vortex; source-vortex spiral flow effects, superimposed on the acoustic motion, predominate in the remainder of the motor. It is shown that combustion heat-release effects increase the intensity of the vortices, and that the erosive velocity of a vortex can cause significant increase in burning rate. When normal flow through the nozzle is impaired by swirl, pronounced changes in chamber pressure will result.

A64-13016

IGNITION OF SOLID PROPELLANTS.

E. W. Price, H. H. Bradley, Jr., J. D. Hightower (U.S. Naval Ordnance Test Station, China Lake, Calif.), and R. O. Fleming, Jr. (Bermite Powder Co., Saugus, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-120. 39 p. 19 refs.
Members, $0.50; nonmembers, $1.00.
Navy-supported research.

Review of theories on the ignition of heterogeneous materials and one-dimensional models, with emphasis on the case where condensed phase exothermic reaction was the dominant chemical heat source during ignition. The results of experiments made with ammonium perchlorate composite propellants are given. It is noted that these results conformed moderately well at intermediate flux levels to a model in which the propellant heats up by conduction to a temperature at which ammonium perchlorate begins to decompose. In the absence of severe dilutional or cooling effects from the atmospheric gas, the heat release from gas phase or surface reactions then quickly becomes self-sustaining, so that most of the ignition energy goes to heating up the solid. While determinations of the effect of catalysts

were not made in the low-intermediate flux range, at higher flux levels (40 cal/cm^2 sec and above), the ignition energies deviate upwards from the correlating curves for the low flux data, indicating the increasing dependence on the gas phase as a heat source. Carbon and copper chromite caused substantial reductions in ignition energy at the high heat flux level at which additives were tested, but the energies remained high compared to those measured with pressed ammonium perchlorate, and remained above the straight extension of the low flux correlating curve, suggesting that the additives acted primarily in the gas phase without reducing surface temperature. At higher flux (above 40 cal/cm^2), the ignition behavior becomes very complex. Carbon and copper chromite produced major reductions in ignition energy. The effect of pressure and ballistic modifier concentration was very complicated.

A64-13017

A BALLISTIC EXPLANATION OF THE IGNITION PRESSURE PEAK.

B. E. Paul, R. L. Lovine, and L. Y. Fong (Aerojet-General Corp., Propellant Ballistics, Sacramento, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-121. 7 p.

Members, $0.50; nonmembers, $1.00.

Presentation of an analysis which shows that a more generalized consideration of the ballistics, which included a variable gas temperature, as well as pressure, can lead to overpressures exceeding equilibrium during the ignition transient. The magnitude of the overpressure is shown to depend strongly on an initial temperature-pressure relationship. Initial experimental results apparently verify the temperature dependence reasoning. Two additional effects were introduced - the burning rate and nozzle flow dependencies. These are shown to depend on the time derivative of pressure, as well as the instantaneous pressure as conventionally assumed. The consideration of these factors results in overpressures where their existence may already be established. It is noted that the results presented clearly show that the ballistic description of the ignition transient will in fact describe the overpressure phenomenon which has been so long experienced.

A64-13018

FLAME-SPREADING AND IGNITION TRANSIENTS IN SOLID GRAIN PROPELLANTS.

S. deSoto and H. A. Friedman (North American Aviation, Inc., Rocketdyne Div., Research Dept., Mathematics and Statistics Group, Canoga Park, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-122. 14 p. 10 refs.

Members, $0.50; nonmembers, $1.00.

Transient analysis of grain ignition and flame-spreading in solid propellant rocket engines, in order to calculate chamber pressure as a function of time during this phase. Assumed for the analysis were one-dimensional gas flow in the chamber with constant gas temperature, uniform gas pressure, two-dimensional transient heat conduction in the grain, and mass transfer from the grain after ignition. Further assumptions include perfect gas properties, chocking of the nozzle at all times, and generation of gas only by the deflagration of the grain surface. Finally, the analysis allows for the option of having a diaphragm stretched across the throat entrance until the pressure buildup is great enough for it to burst. A procedure, quasi-analytic in each time step, is used to solve for the chamber pressure and is coupled, through changes in the burning wall area, to finite-difference solution of the two-dimensional transient heat conduction problem in the grain. The latter is performed using the alternating direction method of Peaceman and Rachford which is stable for all mesh lengths and time intervals. A computer program was written to perform the calculations, and the results are discussed.

A64-13019

THE CONTROL OF IGNITION TRANSIENTS THROUGH PROPELLANT GRAIN INHIBITING.

Howard Gibby (Thiokol Chemical Corp., Wasatch Div., Rocket Design Div., Motor Performance and Design Dept., Brigham City, Utah).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-124. 11 p. 10 refs.

Members, $0.50; nonmembers, $1.00.

Presentation of a practical method to control ignition transient conditions by the use of an inhibitor. Described is the ability of an inhibitor technique to control the ignition transient of a rocket motor. Data are presented to demonstrate that each phase of the nonequilibrium conditions, prior to full pressurization of the chamber, can be regulated and controlled extensively by varying inhibitor location and thickness, and the percentage of surface area covered by the inhibitor. Twenty-four combinations of these variables were evaluated, and each combination produced separate and distinct results. By varying the inhibiting pattern only, the initial pressure peak was regulated over a 300 psi range in motors otherwise of identical design. The rate of pressure rise was regulated over a 30,000 psi/sec range. It is noted that the approach to transient control by inhibiting involves direct elimination of the cause of undesirable transient characteristics without sacrificing motor performance or necessitating basic motor design changes.

A64-13020

PROPELLANT SURFACE FLAME PROPAGATION IN ROCKET MOTORS.

B. E. Paul, R. L. Lovine, and L. Y. Fong (Aerojet-General Corp., Propellant Ballistics, Sacramento, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-125. 8 p.

Members, $0.50; nonmembers, $1.00.

Presentation of analytical expressions based on a given ignition model, which enable calculation of the flame spread rates along the propellant surface of solid rocket motors during the ignition transient. Flame propagation in both the downstream (towards the nozzle) and upstream (towards the forward end of the motor) directions is considered. In the downstream case, the final results give the total time required to completely ignite the surface downstream from the igniter flow impingement point. For upstream flame propagation, the flame penetration rate is obtained. A reasonable agreement was obtained between the results of the analysis and those of a static firing of a motor having a substantial fraction of its initial surfaces unignited by a direct igniter flow. It is noted that the ignition criterion used in the analysis is raising of the propellant surface temperature to the auto-ignition temperature. The resulting problem then becomes one of the transient heat transfer to the propellant wall.

A64-13021

FLAME SPREAD ON SOLID PROPELLANT.

Rex C. Mitchell and Norman W. Ryan (Utah, University, Dept. of Chemical Engineering, Salt Lake City, Utah).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-128. 7 p.

Members, $0.50; nonmembers, $1.00.

Contract No. AF49(638)-170; Grants No. AF-AFOSR 62-99; No. AF-AFOSR 40-63.

Description of a study of flame spread across the surface of a solid propellant with a gas stream flowing parallel to the surface under controlled conditions of pressure and velocity. An approximate analysis of the process is presented which results in a general flame position versus time curve, expressed in dimensionless form involving two parameters, one empirical and the other containing propellant thermal and ballistic properties. The correlation of experimental data in terms of these parameters indicates that one is a function of pressure but not of velocity, and the other a function of velocity only, thereby conveniently isolating the effects of these important variables for the system employed. It is noted that, although the findings of this study are not directly applicable to engine design, they do provide qualitative guidance and suggest a general approach that might be useful for more complex systems.

A64-13022

USE OF STRESS RELAXATION TESTS TO CHARACTERIZE TIME DEPENDENCIES OF A COMPOSITE SOLID PROPELLANT.

Joseph H. Stoker (Thiokol Chemical Corp., Wasatch Div., Development Laboratory, Brigham City, Utah).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-131. 7 p.

Members, $0.50; nonmembers, $1.00.

Characterization of the time-dependent qualities of a viscoelastic material, such as a composite solid propellant, made to enable a generalized stress-strain law to be formulated. Such a function is described to aid the structural analyst in predicting the reactions of a solid-propellant rocket motor to an applied stress or strain. Within the framework of linear viscoelasticity, the mathematical relationships of the propellant were described and a transformation was made

from the stress relaxation function to the dynamic shear modulus. Laboratory dynamic testing results were used to check the accuracy of these transformations and they showed good correlation with predicted results. The results of the transformation indicated that a good mathematical definition of the propellant reactions has been made through the use of stress relaxation measurements.

A64-13023
USE OF THE T BURNER TO STUDY OSCILLATORY COMBUSTION.
M. D. Horton (U.S. Naval Ordnance Test Station, China Lake, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-136. 11 p. 21 refs.
Members, $0.50; nonmembers, $1.00.

Description of a simple burner used for the study of oscillatory combustion, and of the results obtained. The burner, commonly called the T-burner, consists of a side-vented cylindrical steel chamber, in the ends of which propellant disks are burned. If the propellant combustion spontaneously generates pressure oscillations, use is made of the over-all one-dimensional acoustic behavior in the system to characterize the transient combustion of the propellant. The important variables used in the characterization are the growth rate of the oscillations, and their decay rate following the consumption of the propellant. Described are the several types of investigations in which the T-burner is the primary research tool. These investigations concern the response function of the combustion zone, the effect of normal pressure perturbations upon the average burning rate of the propellant, the participation of the propellant in the acoustic motion of the system, the mechanism by which aluminum suppresses oscillatory combustion, and the influence of propellant composition upon the response function of the combustion zone. The latter two descriptions are made in some detail.

A64-13041
AN EXPERIMENTAL INVESTIGATION OF THE EROSIVE BURNING CHARACTERISTICS OF A NON-HOMOGENEOUS 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. 8 p. 14 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. AF 04(611)-7445.

Description of observed changes in the burning rate of an ammonium perchlorate-polyurethane propellant containing a large percentage of aluminum, caused by a change in velocity of the combustion gases wetting the burning surface of the propellant ("erosive burning"). A recently developed photographic technique was used to determine the burning rate of a given solid propellant under different conditions. This technique permits the instantaneous values of the burning rate (< 0.1 sec) to be determined under realistic conditions. Erosive burning data are presented for combustion pressures between 400 and 600 psi, with the Mach number of the combustion gases flowing parallel to the burning surface of the propellant varied between zero and one. The results indicate that under erosive burning conditions, the solid propellant exhibits a threshold burning velocity which is pressure dependent and which is influenced by the type of binder used in the propellant composition. A decrease in the propellant temperature increases the erosive burning rate.

A64-13042
ACCELERATION OF BURNING RATE OF COMPOSITE PROPELLANTS BY SOUND WAVES.
Isidor Elias (Acoustica Associates, Inc., Los Angeles, Calif.), Henry Cheung, and Norman Cohen (Aerojet-General Corp., Sacramento, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-108. 11 p.
Members, $0.50; nonmembers, $1.00.
Contracts No. NASw-64; No. NAS 7-69.

Experimental investigation of the effect of a controlled sound field on the burning of composite solid propellants in a Crawford Bomb and in rocket motors. The Summerfield granular diffusion flame theory for the combustion of ammonium perchlorate composite solid propellants is reviewed, and the requirements for an acoustic field capable of mixing the gaseous fuel and oxidizer pockets in the manner desired are considered. Two types of experiments are described, one involving the use of the Crawford Bomb in which propellant strands were burned in an acoustic field under controlled temperature and pressure conditions, and the other involving the use of rocket motor firings. The Crawford bomb experiments had negative results, no effect of the sound on the propellant burning rate being noted. The rocket motor firings were made with 5-in.-diam, 20-in.-long chambers containing ~ 15 lb of propellant. The sound field produced by a Levasseur whistle was found to increase the burning rate. Introduction of helium into the chamber was found to further increase this rate.

A64-13043
FLAME SPREADING OVER THE SURFACE OF DOUBLE BASE PROPELLANTS.
Robert F. McAlevy, III, Richard S. Magee, and John A. Wrubel (Stevens Institute of Technology, Hoboken, N. J.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-109. 7 p. 12 refs.
Members, $0.50; nonmembers, $1.00.

Determination of the flame spreading velocity over the surface of igniting nitrate ester propellants, as a function of the pressure level and chemical reactivity of the surrounding quiescent atmosphere. Small propellant test specimens mounted horizontally, freshly cut surface upward, in a relatively large vacuum-tight test chamber were ignited by an electrically heated wire fastened to the top of their shorter edge, and the spreading velocity was determined cinematographically. Spreading velocities were found to vary directly with both the pressure level and oxygen concentration of the surrounding atmosphere, composed of varying mixtures of oxygen and nitrogen. A gas phase theory of flame spreading is presented, based on the assumption that the principal exothermic process of interest occurs in the gas phase. The theory is closely related to the gas phase theory of solid propellant combustion. Flame spreading during the ignition of propellant rocket motors is discussed, and improvements of igniter efficiency are suggested.

A64-13044
PLATEAU BALLISTICS IN NITROCELLULOSE PROPELLANTS.
R. F. Preckel (Hercules Powder Co., Allegany Ballistics Laboratory, Cumberland, Md.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-113. 4 p.
Members, $0.50; nonmembers, $1.00.

Review of experiments indicating that the plateau ballistic phenomenon originally found in propellants containing lead oxides or salts of aliphatic acids also occurs with salts of aromatic acids. The plateaus are relatively flat regions of the curves relating burning rate and pressure. The ballistics presented are strand burning rates in a closed bomb equipment using a 5-in. burning distance. Aromatic lead salt plateaus are found to be obtainable at propellant energies up to at least 11,450 cal/gm, compared with a 900 cal/gm limit for the aliphatics. The principal effect of additions of pigments, such as carbon black, is found to be a significantly increased burning rate, generally accompanied by an increase in plateau pressure range.

A64-13045
ALUMINA SIZE DISTRIBUTIONS FROM HIGH-PRESSURE COMPOSITE SOLID-PROPELLANT COMBUSTION.
Louis Povinelli and Robert A. Rosenstein (NASA, Lewis Research Center, Cleveland, Ohio).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-115. 10 p. 13 refs.
Members, $0.50; nonmembers, $1.00.

Study of the behavior, close to the burning propellant surface, of metal additives. Small strands of polybutadiene acrylic acid-ammonium perchlorate-aluminum propellants were used, having either coarse or fine oxidizers. The alumina was trapped close to the burning surface, and size distributions were obtained over the pressure range from atmospheric to 500 psi. Several tests were performed with an erosive type of flow across the test strand. Additive agglomeration is found to be higher for the coarse-oxidizer propellant. High-speed photographs of the burning propellant structure reveal that the additives move on the surface with an average particle velocity which decreases with pressure to approximately the 0.3 power. The empirical relation between

particle velocity and pressure is used to modify a previously given agglomeration criterion. A theoretical evaluation of the critical aluminum diameter required for agglomeration indicates that both propellant types studied should experience some agglomeration, and that the required aluminum size should increase with increasing pressure. The experimental results are in reasonable agreement with these findings.

A64-13046
ON THE PERFORMANCE OF SOLID PROPELLANTS CONTAINING METAL ADDITIVES.
Henry Cheung and Norman S. Cohen (Aerojet-General Corp., Solid Propellant Research and Development Div., Sacramento, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-116. 14 p. 37 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. AF 33(600)-36610.

Review of test firings of solid propellant research rockets made to study the effects of propellant composition and pressure, and engine size, on the exhaust oxide particle size and on the composition of the solid exhaust products. The experimental results are combined with those of other investigators to provide a description of the aluminum combustion and oxide condensation processes in solid propellant rocket motors. The combustion of aluminum is found to occur in the vapor phase, and was essentially complete, although some combustion took place in the nozzle. The condensation of the oxide is described by first-order chemical kinetics. Further particle growth by agglomeration may exist. For some of the motors tested, the two-phase flow loss is found to be significant. Where this is the case, improved performance can be realized by reducing the aluminum content.

A64-13047
DIFFUSIONAL ANALYSIS OF COMPOSITE PROPELLANT IGNITION, AND ITS APPLICATION TO SOLID ROCKET IGNITION.
R. L. Lovine, L. Y. Fong, and B. E. Paul (Aerojet-General Corp., Propellant Ballistics, Sacramento, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-117. 7 p.
Members, $0.50; nonmembers, $1.00.

Description of a model for the ignition process in a composite solid propellant which takes into account the effects of pressures. The model assumes (1) primary decomposition of the solid propellant into gases, and (2) gas phase reactions of decomposition products which transfer a sufficient amount of energy back to the propellant surface to produce the combustion of the solid propellant. The time required to complete the primary surface decomposition can be calculated with some certainty. While exact solutions of the equations of mass and energy diffusion in a reacting gas are not made, a form of solution is obtained by considering the mass transfer at the propellant surface before the gaseous products of pyrolysis have reacted significantly.

A64-13049
IGNITION OF COMPOSITE PROPELLANTS BY LOW RADIANT FLUXES.
A. D. Baer and N. W. Ryan (Utah, University, Dept. of Chemical Engineering, Salt Lake City, Utah).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-119. 9 p.
Members, $0.50; nonmembers, $1.00.
Contract No. AF 49(638)-170; Grants No. AF 62-99; No. AF 40-63.

Experimental determination of the ignition characteristics of several composite propellants subjected to black body thermal radiation. A simple ignition theory is proposed which postulates that the ignition is controlled by a single surface reaction, the rate of this reaction being exponentially related to the propellant surface temperature. The characteristic constants for this reaction may be determined from the effect of surface heat flux on the experimentally measured ignition times. Once these constants are known, theoretical predictions of the variations in ignition times for changes in initial propellant temperature, pressure, and surface geometry are possible for flux levels in the range investigated. Good agreement between experimental results and theoretical predictions was observed. Ignition tests on propellants formed by pressing ammonium perchlorate with nonvolatile carbon black and graphite showed that the surface ignition temperatures of these materials were the same as for normal propellants. Thus, for ignition times greater than one second, the ignition mechanism appears to be the decomposition of ammonium perchlorate followed by reaction between the decomposition products and the solid fuel.

A64-13050
THE MEASUREMENT OF TEMPERATURE PROFILES THROUGH SOLID PROPELLANT FLAMES USING FINE THERMOCOUPLES.
A. J. Sabadell, J. Wenograd, and M. Summerfield (Princeton, University, Guggenheim Laboratories for the Aerospace Propulsion Sciences, Princeton, N. J.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-106. 9 p. 11 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. Nonr 1858(32); NASA-supported research.

Determination of microscopic temperature profiles through propagating solid propellant flames in composite and double-base propellants, and application of these profiles to study the combustion mechanism and to estimate surface temperatures. The profiles are obtained using fine platinum and platinum-rhodium 10% thermocouples embedded in the propellants. Surface temperatures generally in the range 530°-660°C at pressures between 1 and 15 atm were observed for composite propellants based on polybutadiene acrylic acid fuel and containing fine unimodal ammonium perchlorate. A double base propellant was found to burn with a surface temperature of about 300°C. For the double-base propellants, the temperature profiles are quite smooth. For the composite propellants, sharp upward breaks are noted in the temperature profile curves, generally occurring about 600°C, and preceded by an undulating, but approximately linear, region. Possible mechanisms explaining the observed behavior are considered.

A64-13063
THEORY OF A HOMOGENEOUS MODEL OF ROCKET MOTOR IGNITION TRANSIENTS.
H. H. Bradley, Jr. (U.S. Naval Ordnance Test Station, China Lake, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-127. 7 p.
Members, $0.50; nonmembers, $1.00.

Theoretical analysis, based upon conservation of mass and energy, of pressure transients expected to occur in a rocket motor under adiabatic, homogeneous (space-uniform) conditions. The mechanism of flame spread is not considered, but the effect of various functional relations between spreading velocity and pressure is incorporated into the theory and resulting numerical analysis. For convenience, equal molecular weights are assumed for igniter and propellant combustion products. Parameters whose effects were studied include L (characteristic length) of the motor, ratio of igniter weight to motor free volume, igniter form function, propellant K (burning area) ratio, igniter and propellant flame temperatures, pressure exponents, and densities. By appropriate choice of parameters, the transient due to either the propellant or igniter alone, and the behavior of pyrogen-type igniters may be studied. The principal purpose of the study was to assess the relative effect of parameters on the pressure-time history and to provide a basis for determining the importance of factors not contained in the homogeneous model.

A64-13065
APPROXIMATE LAPLACE TRANSFORM INVERSIONS IN VISCOELASTIC STRESS ANALYSIS.
Thomas L. Cost (Rohm and Haas Co., Redstone Arsenal Research Div., Huntsville, Ala.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-132. 16 p. 24 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. DA-01-021-ORD-11878.

Investigation of approximate methods for inverting Laplace transforms which occur in viscoelastic stress analysis when use is made of the elastic-viscoelastic analogy. Viscoelastic solutions to two problems involving deformations and stresses in solid propellant rocket motors under axial and transverse acceleration loads were obtained by means of several of the methods discussed. It is concluded that Schapery's direct method and ter Haar's method generally give good results when applicable. Widder's general inversion formula, which includes Alfrey's method as a special

case, is not usable for the type of problems considered. The orthogonal polynomial methods possess characteristics which make them especially suited to the problem of inverting functions known only numerically for discrete values of the transform parameter, although their use appears limited by severe computational difficulties. Schapery's least squares method gives good results to most problems of interest and is easy to apply.

A64-13069

ACOUSTIC INSTABILITY: INFLUENCE OF AND ON THE SOLID PLANT.

Norman W. Ryan (Utah, University, Dept. of Chemical Engineering, Salt Lake City, Utah) and Ralph L. Coates (Lockheed Aircraft Corp., Lockheed Propulsion Co., Redlands, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-139. 8 p.

Members, $0.50; nonmembers, $1.00.

Contract No. AF 49(638)-1074; Grant No. AFOSR 62-451.

One-dimensional, linearized analysis of acoustic instability in T-burners. The values of the ad hoc viscoelastic parameters defined, which are computed from experimental data, show that acoustic instability can change viscoelastic properties during a firing. The change tends to reduce the elasticity and viscosity of the solid propellant. It is also shown that relevant viscoelastic properties, inferred from burning data, can be used to calculate the solid phase contribution to the acoustic admittance. In the tests made, the change was brought about by normal stress amplitudes, rarely, if ever, as great as 50 psi. Presumably shear stresses were no greater. As the acoustic energy pumped into the system was not sufficient to raise the temperature significantly, the inference is made that mechanical working of the solid produced the changes. It is noted that, if acoustic instability at innocent levels of severity can soften at least some propellants, then either susceptible propellants, marginal in their viscoelastic properties, should not be used, or acoustic instability must be avoided. It is speculated that propellant softening is the key first step in the mechanism whereby acoustic instability sometimes provokes more serious combustion irregularities.

A64-13070

ADMITTANCE MEASUREMENTS OF SOLID PROPELLANTS BY AN ACOUSTIC OSCILLATOR TECHNIQUE.

S. N. Foner, R. L. Hudson, and B. H. Nall (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-138. 10 p.

Members, $0.50; nonmembers, $1.00.

Contract No. NOw 62-0604-c.

Description of a dynamic acoustic oscillator technique for measuring the response of a burning solid-propellant surface. The arrangement consists essentially of a centrally vented cavity, with propellant at one end and a phase-locked mechanical driver at the other end. The mechanical driver excites the cavity in a resonance mode. The bandwidth of the resonance is determined by phase modulation of the mechanical driver and by measurement of the resultant sideband amplitudes. An independent method for measuring the decay constant of the cavity, incorporated into the system, involves momentarily shorting out the drive system and observing the free-decay or growth of the oscillations. Designed primarily for investigating stable or marginally stable propellants, the system can be used with unstable propellants by introducing a 180° phase shift in the drive circuit, whenever the amplitude exceeds a predetermined value. Experiments in which lock-on to resonance was achieved and maintained for runs of several seconds duration, show that the oscillation amplitude and bandwidth change appreciably and irregularly during a run, indicating substantial damping variations in the cavity.

A64-13071

THE EFFECT OF ACOUSTIC ENVIRONMENT ON THE BURNING RATE OF SOLID PROPELLANTS.

J. E. Crump and E. W. Price (U.S. Naval Ordnance Test Station, Aerothermochemistry Group, China Lake, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-141. 8 p. 12 refs.

Members, $0.50; nonmembers, $1.00.

Determination of the change in burning rate (surface regression rate) of solid propellants in the presence of acoustic environments of rocket motors. It is shown how, by using specially designed burners, a relatively simple and sustained oscillatory behavior can be achieved. By interrupting burning, the resulting effect on the propellant burning rate can be determined. The standing-wave nature of the oscillatory behavior makes it possible to correlate the change in burning rate at any point of the propellant surface with the nature of the acoustic environment. It is found that the burning rate is decreased by acoustic pressure, and is increased by acoustic velocity; the two effects are of comparable magnitude. The fluctuations in equilibrium pressure during unstable firings are explained in terms of the burning rate effects obtained in the interrupted burning tests.

A64-13072

ACOUSTIC EROSIVITY EFFECTS ON SOLID PROPELLANT BURNING RATES.

Richard C. Strittmater, Leland A. Watermeier, and William P. Aungst (U.S. Army, Ballistic Research Laboratories, Aberdeen Proving Ground, Md.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-142. 5 p.

Members, $0.50; nonmembers, $1.00.

Army-supported research.

Application of a resonant-tube technique, developed for acoustic-admittance studies, to the measurement of acoustic erosivity as a function of frequency and amplitude of the acoustic environment. Results obtained for a double-base propellant (ARP), burning in a T-burner in the presence of acoustic velocities in the order of 600 ft/sec are presented and discussed. Preliminary tests showed only slight acoustic erosivity effects for ARP.

A64-13073

NON-ACOUSTIC COMBUSTION PULSATIONS OF AMMONIUM PERCHLORATE CONTAINING ALUMINUM.

Y. H. Inami and H. Shanfield (Philco Corp., Aeronutronic Div., Newport Beach, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-147. 7 p.

Members, $0.50; nonmembers, $1.00.

Experimental investigation of the low-frequency combustion pulsation behavior of nonacoustic nature, that was observed with aluminum-containing solid propellants. The pulsating behavior of ammonium-perchlorate strands containing aluminum powder is investigated qualitatively by direct contact with a glass-blowing hand torch at atmospheric pressure. The combustion pulsations are studied by observing the radiation from the flashes which occur in the strands under the test conditions. It is found that the frequency of the flashes increases with increasing aluminum content. The strand surface recedes in a normal linear manner. The flash is due to a pulse of burning aluminum, and an aggregate network of aluminum is observable on the surface with a microscope when heating is stopped just prior to a flash. To illustrate the characteristics of a metal having a low ignition temperature, the experiments are extended to molybdenum-ammonium perchlorate. The observed effects are presented in the form of diagrams.

A64-13074

PREFERRED FREQUENCY OSCILLATORY COMBUSTION OF SOLID PROPELLANTS.

J. L. Eisel, M. D. Horton, E. W. Price, and D. W. Rice (U.S. Naval Ordnance Test Station, Aerothermochemistry Group, China Lake, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-149. 9 p. 16 refs.

Members, $0.50; nonmembers, $1.00.

Experimental investigation of low-frequency oscillatory combustion for several solid propellants, using two different combustion systems. The first system is a small end-vented burner which employs end-burning grains to produce nonacoustic pressure oscillations. The second system is a side-vented double-end burner producing acoustic pressure oscillations of a frequency of 5 to 120 cps. Oscillations are observed under somewhat restricted conditions, equal in each type of burner for one specific propellant, but differing for each propellant employed to provide for the occurrence of oscillations. The results indicate that for most of the propellants tested at relatively low test pressures, the response function-frequency curve of propellant combustion exhibits a marked peak at low frequencies.

A64-13075
EROSIVE BURNING: NEW EXPERIMENTAL TECHNIQUES AND METHODS OF ANALYSIS.
J. W. Kreidler (Hercules Powder Co., Allegany Ballistic Laboratory, Cumberland, Md.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-155. 8 p. 13 refs.
Members, $0.50; nonmembers, $1.00.
Contract No. Nord 16640.

Investigation of the erosive burning of a high-energy composite-modified double-base propellant, with the objective of studying combustion processes and obtaining rocket-motor design criteria. A special propellant-grain design incorporating linear increase of port area and neutral surface during burning is employed in test firings of a small rocket motor. Data from a series of firings are used to derive grain-dimension versus burning-time relations. After appropriate conversion to desired variables, the derivatives of these relations yield the instantaneous burning and flow rates. Propellant grain surfaces are defined by means of cineradiography. The obtained results show that the erosive burning rate ratio can be expressed as a simple function of the local mass velocity and pressure in the grain port, when the flow is above a threshold mass velocity. This observed threshold velocity for the onset of erosion varies directly with pressure. Erosion is more pronounced under lower pressure conditions for a given mass velocity. Burning rate depression occurs when flow at a given pressure is below the threshold mass velocity.

A64-13147
DETERMINATION OF PROPELLANT PROPERTIES BY THE ARC IMAGE FURNACE TECHNIQUE.
R. O. Fleming, Jr. and R. W. Fleming (Bermite Powder Co., Research and Development Div., Research Group, Saugus, Calif.).
AIAA Journal, vol. 2, Jan. 1964, p. 117, 118.
Contract No. NOw 62-0236-c.

Brief description of a method for the determination of threshold ignition energies of propellants and igniter materials by the arc-image furnace technique. Approximate relationships of threshold ignition energy to flux at three environmental pressure levels for a metal-oxidant mix are given in graphical form.

A64-13184
HETEROGENEOUS REACTIONS IN IGNITION AND COMBUSTION OF SOLID PROPELLANTS.
Ralph Anderson, Robert S. Brown, and Larry J. Shannon (United Aircraft Corp., United Technology Center, Research and Advanced Technology Dept., Sunnyvale, Calif.).
AIAA Journal, vol. 2, Jan. 1964, p. 179, 180. 12 refs.

Brief discussion of the role of heterogeneous reactions in solid propellant ignition and combustion in order to produce a unified theory that permits the quantitative prediction of the effects of the independent variables on ignition and burning-rate characteristics of solid propellant. It is indicated that heterogeneous reactions between the oxidizing gases from solid oxidizer decomposition and the binder fuel constitute the rate-controlling mechanism in ignition response of the propellant regardless of the mode of external heat flux. This same mechanism is also shown to play a dominant role in the deflagration characteristics of the propellant.

A64-13249
HEAT-EXCHANGE IN MICROTHERMOCOUPLES FOR COMBUSTION OF CONDENSED SUBSTANCES [O TEPLOOBMENE MIKROTERMOPAR V USLOVIIAKH GORENIIA KONDENSIROVANNYKH VESHCHESTV].
A. A. Zenin.
Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Sept.-Oct. 1963, p. 125-131. In Russian.

Discussion of the requirements which should be satisfied by thermocouple parameters (shape, thickness) to provide minimum distortion of a temperature profile obtained for the combustion of solid propellants and similar substances. For this purpose, the heat exchange of a fine thermocouple in the condensed phase and gas phase regions is investigated in conditions approximating the temperature changes in a combustion wave. The errors in thermocouple measurements are assessed. It is shown that ∩-shaped thermocouples should be preferred to L-shaped ones.

A64-13309
SONIC COMBUSTION CONTROL.
Isidor Elias (Acoustica Associates, Inc., Los Angeles, Calif.).
Sound, vol. 2, Nov.-Dec. 1963, p. 8-12. 22 refs.

Discussion of work associated with the application of acoustic-combustion interactions to control the combustion of a solid propellant. This involves the introduction of a sonic field consisting of plane traveling waves into a solid-propellant rocket motor, and affecting the processes connected with the combustion event in order to vary the motor's burning rate. The basic aspects of double-base and composite solid-propellant combustion are reviewed. The control of the rate of propellant consumption by introducing an acoustic field into the reaction zone to mix the granules is discussed, and the required frequency and intensity of the sound field are examined. The selection of a suitable sound source is considered, and experiments using a Levasseur whistle excited by helium are briefly described.

A64-13348
ENTROPY WAVE OBSERVATIONS IN OSCILLATORY COMBUSTION OF SOLID PROPELLANTS: A PROGRESS REPORT.
R. H. W. Waesche, J. Wenograd, and M. Summerfield (Princeton University, Guggenheim Laboratories for the Aerospace Propulsion Sciences, Princeton, N.J.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-154. 9 p. 14 refs.
Members, $0.50; nonmembers, $1.00.
USAF-ARPA-NASA-sponsored research.

Experimental assessment of an explanation for combustion instability, proposed by McClure, according to which the driving disturbance originates with a pressure interaction between the surface flame and the oscillating gas field. The nature of the acoustic interaction is investigated by measuring the entropy variation in the gas emerging from the thin flame, using a 2-in. I.D. T-tube rocket combustor and high-speed cinematography and spectral-radiometry techniques. A comparison of the results obtained with AP composite propellants at frequencies of about 200 cps with Wood's results obtained with AP-nitrocellulose composite propellants at the same frequencies but somewhat higher pressures (900 psi), shows, as the most prominent feature, the absence of thermal waves as prominent as those reported by Wood. An unexpected result is the zero-amplitude of entropy observed in one of the test runs.

A64-13349
AXIAL MODE, INTERMEDIATE FREQUENCY COMBUSTION INSTABILITY IN SOLID PROPELLANT ROCKET MOTORS.
E. W. Price (U.S. Naval Ordnance Test Station, Aerothermochemistry Group, China Lake, Calif.).
American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-146. 53 p. 43 refs.
Members, $0.50; nonmembers, $1.00.
Navy-ARPA-sponsored research.

Discussion of the low-frequency acoustic instability in the axial mode of solid propellant rocket motors, on the basis of available laboratory and motor-firing data. An analysis of an unstable combustion system is presented, in which the rocket motor is treated as an acoustic oscillator, propellant combustion as an energy source or amplifier, and the coupling between the incident acoustic disturbance and the combustion, and between the resulting combustion disturbance and the gas flow, as elements of the feedback loop. Each of these elements of the self-excited oscillator is examined, with particular emphasis on the feedback loop. The results obtained for an end-vented and a center-vented motor are presented and discussed.

A64-13416
STUDY OF ELECTRON GENERATION BY SOLID PROPELLANT TECHNIQUE.
R. Friedman, L. W. Fagg, T. K. Millar, W. D. Charles, and M. C. Hughes (Atlantic Research Corp., Alexandria, Va.).
(American Rocket Society, Ions in Flames and Rocket Exhausts Conference, Palm Springs, Calif., Oct. 10-12, 1962.)
IN: IONIZATION IN HIGH-TEMPERATURE GASES (PROGRESS IN ASTRONAUTICS AND AERONAUTICS, VOL. 12).
Edited by Kurt E. Shuler and John B. Fenn.
New York, Academic Press, 1963, p. 379-393. 10 refs.
Contracts No. AF 49(638)-651; No. AF 19(628)-295.

Description of the development and test-firing (in an altitude chamber) of electron generators functioning by the combustion of cesium nitrate-aluminum pressed charge. A thermodynamic analysis of the combustion and nozzle-expansion process indicates that the cesium nitrate-aluminum electron generator should deliver a plasma to the upper atmosphere containing at least 0.86×10^{20}

electrons per gram of charge. Experimental studies of the generator yield results which agree well with this prediction. Details of the generator operation are given and alternate chemical systems for electron generation are briefly discussed.

A64-13641
APPARATUS FOR DETERMINING COMBUSTION RATE OF SOLID PROPELLANTS.
J. P. Picard (Picatinny Arsenal, Dover, N. J.), C. J. Anderson, R. Del Grosso, and E. Bryant (Malaker Laboratories, High Bridge, N. J.).
I & EC - Industrial and Engineering Chemistry, vol. 56, Jan. 1964, p. 49-52.

Description of a system used for over one year for the determination of propellant combustion rates. Most of the propellants were of a nitroglycerin base with various metal additives such as magnesium and aluminum. The burning rates of these propellants ranged from 0.1 to 1 in./sec. The type of flame varied from a well defined shape to a flare sparkler. The apparatus is capable of controlling all the propellants that were tried. In most instances, the position of the burning surface varied less than ±0.005. The basic components of the system are shown in a figure. The apparatus is useful to laboratories and companies interested in materials that can be formed into strands and burned. It is particularly applicable to research combustion studies and quality control testing of solid propellants, pyrotechnic materials, and solid fuels. It is noted that the main advantages of the apparatus are the longer observation times and the constant position of the burning surface. Spectrograms and pictures were obtained at various pressures during one burning because the pressure could be increased during the burning period.

A64-13854
SOLID PROPELLANTS: THE COMBUSTION OF PARTICLES OF METAL INGREDIENTS.
A. Davis (Explosives Research and Development Establishment, Waltham Abbey, Essex, England).
(Rocket Propulsion Symposium, 2nd, Cranfield, England, Apr. 1962.)
Combustion and Flame, vol. 7, Dec. 1963, p. 359-367.

Experimental investigation of the combustion of metal particles at atmospheric pressure, by the introduction of the particles into a premixed flame. For observations at higher pressures, propellants of known compositions and containing only a small concentration of metal powder were used. The combustion of a particle occurs in two stages - an ignition delay and then burning. The effects of particle composition, temperature, pressure, and gas composition on these two stages indicate that different mechanisms are involved. The ignition delay is determined essentially by the external rate of heating of the particles, while the burning time depends more on the concentration of oxidant in the atmosphere. The burning mechanism of an aluminum particle at 1000 lb/in^2 and above appears to be similar to that operating in hydrocarbon droplet combustion which seems to indicate that, at least at high pressures, the presence of a condensed product, namely alumina, does not drastically alter the diffusion mechanism in the gas phase.

A64-13910
SURFACE TEMPERATURE MEASUREMENTS ON BURNING SOLIDS.
A. Greenville Whittaker and David C. Barham (Sandia Corp., Albuquerque, N. M.).
Journal of Physical Chemistry, vol. 68, Jan. 1964, p. 196-199.
AEC-Aerospace Corp.-supported research.

Experimental investigation of the possibility of measuring the surface temperature of pure solids that melt at the burning surface to produce a liquid layer that would be thick enough to act as a burning liquid. The temperature profiles obtained showed a plateau when the thermocouple was dwelling in the burning surface. In fact, most of the profiles also showed a distinguishable change in slope at the melting point of the material studied. It is noted that the striking feature about the surface temperature shown in tables is that, in all cases, the surface temperature is constant over a rather wide range of burning rates. This is essentially the same result that was obtained for burning liquids, and may be related to the fact that each of these systems forms a liquid layer at the burning surface. The second outstanding feature of the results is that the surface temperatures for ammonium nitrate and the ammonium nitrate-hydrazine nitrate eutectic were the same, whereas the surface temperature for hydrazine nitrate was considerably lower than the other two.

A64-13952
NONLINEAR AXIAL COMBUSTION INSTABILITY IN SOLID PROPELLANT MOTORS.
W. G. Brownlee (Canadian Armament Research and Development Establishment, Valcartier, Quebec, Canada).
(American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, Calif., June 17-20, 1963, Paper 63-228.)
AIAA Journal, vol. 2, Feb. 1964, p. 275-284. 10 refs.
[For abstract see Accession no. A63-19323 17-27]

A64-13993
HYBRID PROPULSION.
D. D. Ordahl and W. A. Rains (United Aircraft Corp., United Technology Center, Sunnyvale, Calif.).
Flight International, vol. 85, Jan. 16, 1964, p. 107-109.

Introduction of the basic technological concepts of liquid and solid propulsion. Hybrid propulsion is suggested as a combination of both. Discussed are the combustion processes, and the impossibility of inadvertent ignition or detonation is pointed out. The possibility of a combination of many advanced components which up to now could not be used because of chemical incompatibility is discussed. Suggested are the safety features of storage assembly, and transportation. The need for new thermal and oxidizer-resistant materials is pointed out.

A64-14023
ACOUSTIC ABSORPTION COEFFICIENTS OF COMBUSTION GASES.
D. W. Blair (Brooklyn, Polytechnic Institute, Dept. of Mechanical Engineering, Brooklyn, N.Y.), E. Eriksen, and G. K. Berge (Norwegian Defence Research Establishment, Div. of Explosives, Kjeller, Norway).
AIAA Journal, vol. 2, Feb. 1964, p. 392, 393.

Presentation of some initial results from an experimental investigation of the acoustic damping constant of solid propellant combustion gases. The data apply to combustion gases that have been cooled to room temperature. The experiments were carried out in an acoustic resonance tube patterned after the one used by Parker. A Goodman VR-11 electromagnetic shaker driver was used to drive a rigid flat-topped piston that closed one end of a 50 mm diam. steel tube. The other end of the tube was closed by a rigid brass plate which carried a flush-mounted condenser microphone at its center. The tube length between the closures was 683 mm.

A64-14123
COMMENTS ON "GAS-FILM EFFECTS IN THE LINEAR PYROLYSIS OF SOLIDS."
W. H. Andersen (Aerojet-General Corp., Ordnance Research Div., Downey, Calif.).
AIAA Journal, vol. 2, Feb. 1964, p. 404-406; Author's Reply, R. H. Cantrell (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.), p. 406, 407. 23 refs.

Observations on Cantrell's paper regarding the measurement of the surface temperature in studying the thermal decomposition of solids by the linear pyrolysis (LP) technique. It is noted that this paper, if taken too literally, can tend to discredit certain generally accepted hypotheses regarding propellant combustion and solid decomposition which have been developed from the experimental data and concept of LP kinetics. The comments emphasize that many of these hypotheses are relatively insensitive to the absolute values of the experimental rate data, so that their validity is essentially unaffected by treatments such as that of Cantrell. Also appraised in some detail is the general validity of the published LP data. It is stated that much of the original experimental data requires refinement using the published theoretical treatments to help correct for gas-film effects. For substances such as ammonium perchlorate which react chemically while undergoing pyrolysis, it is possible that further corrections are necessary.

A64-14333
ANALYSIS OF STORED GAS PRESSURIZATION SYSTEMS FOR PROPELLANT TRANSFER.
Frank Bizjak, Chres Oki, William J. Hines, and Donald J. Simkin (North American Aviation, Inc., Space and Information Systems Div., Propulsion Dept., Propellant Systems Analysis, Downey, Calif.).

Journal of Spacecraft and Rockets, vol. 1, Jan.-Feb. 1964, p. 103-107. 5 refs.

Performance analysis of a pressure-fed propellant system employing a low molecular weight, inert gas. The subsystems considered are: (1) pressure storage bottle, (2) heat exchanger, and (3) propellant tank ullage. Ideal gas parameters are assumed in (2) and (3). The experimental compressibility factor is included in the equation of state for the gas contained in the pressure storage bottle, to correct for nonideality. Equations for the subsystems are derived from fundamental thermodynamics and heat-transfer. Using these equations and the equations-of-state of the compounds in the system, the overall analysis of the pressurization system is achieved by a numerical methods treatment on a digital computer. With appropriate corrections, the derived equations may be applied to systems of different pressurant/propellants combinations and comparable gas pressurization.

A64-14773

IGNITION THEORY OF SOLID PROPELLANTS.

R. Anderson, R. S. Brown, and L. J. Shannon (United Aircraft Corp., United Technology Center, Sunnyvale, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-156. 14 p. 11 refs.

Members, $0.50; nonmembers, $1.00.

Development of the heterogeneous ignition theory for describing the rate-controlling mechanism leading to ignition of composite solid propellants. Ignition of solid propellants through contact with chemically reactive oxidizers is shown to proceed through the development of rapid heterogeneous chemical reactions at the interface between the reactive oxidizer and the solid propellant. If the rate of heat generated by these heterogeneous reactions at the surface is greater than the heat losses to the external oxidizer phase and to the solid-propellant phase, the surface temperature of the propellant rises rapidly to the level where the propellant can undergo stable combustion. A mathematical model based on the heterogeneous reaction concept is shown to predict quantitatively the experimentally observed effects of environmental oxidizer concentration, pressure, temperature, and heat flux on the ignition delay of solid propellants in both static and highly turbulent flow environments.

A64-14799

THEORY OF IGNITION AND IGNITION PROPAGATION OF SOLID PROPELLANTS IN A FLOW ENVIRONMENT.

R. S. Brown, T. K. Wirrick, and R. Anderson (United Aircraft Corp., United Technology Center, Sunnyvale, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-157. 12 p. 8 refs.

Members, $0.50; nonmembers, $1.00.

Contract No. NAS 7-156.

Analysis of ignition and subsequent ignition propagation on the surface of a solid propellant in a flow environment based on the heterogeneous ignition theory. The model is described by the two-dimensional unsteady-state heat conduction equation with a variable rate of external heat transfer to the exposed surface of the propellant Convection, radiation, hypergolic heating, and conduction of heat along the longitudinal axis of the propellant surface parallel to the gas flow are included in the heat transfer equations. The solution of these equations describes the temperature history of the propellant surface and flowing gases as a function of longitudinal position. The propagation of the ignition front is the result of a variation in the heating rate with position on the propellant surface. The effects of gas mass flow rate, temperature, pressure, and gas composition on the ignition and subsequent ignition propagation process are determined. The theoretical model is verified by comparison with experimental data.

A64-14928

TWO-PHASE TURBULENT FREE JET EXPANSIONS WITH LARGE PRESSURE AND TEMPERATURE GRADIENTS.

Norman S. Cohen (Aerojet-General Corp., Solid Propellant Research and Development, Sacramento, Calif.).

American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-123. 11 p. 14 refs.

Members, $0.50; nonmembers, $1.00.

Contract No. NOw 63-0050, LMSC P.O. 18-10277.

Presentation of an uncoupled solution for the flow properties of free jet expansions produced by the operation of solid propellant igniters. The problem is reduced to integrating the one-dimensional momentum equation by assuming an a priori radial decay function for the gas velocity, and by assuming that the state parameters decay in the same manner as does the velocity. These assumed functions have experimental basis. With the flow field of the gas phase defined, the interphase equations yield particle trajectories and temperature history. Additional considerations suggest experimental work to supplement the analysis, for application to solid propellant ignition studies.

A64-14973

CONTROLLING THE LIQUID-VAPOR INTERFACE UNDER WEIGHTLESSNESS.

D. A. Petrash and E. W. Otto (NASA, Spacecraft Technology Div., Lewis Research Center, Cleveland, Ohio).

Astronautics and Aeronautics, vol. 2, Mar. 1964, p. 56-59, 61.

Study of the problem of storing liquid propellants in tanks under zero gravity conditions. It is suggested that proper employment of the surface tension properties of the liquid concerned will aid in problems of tank venting, pump inlet design, orientation control, and long-term propellant storage. Results of studies at the Lewis Research Center indicate that the interface configuration depends on minimizing the system's free surface energies and preserving the liquid-to-solid contact angle. Other factors are the geometry of the system and the amount of fuel in it. Liquid properties and system geometry are examined and it is found that, whatever the contact angle of the liquid to the tank wall, there is, at zero gravity, a constant surface curvature. The minimum energy principle was verified experimentally, and capillary tube design and the effects of pumping and acceleration disturbances were studied. In the design of tank and baffle systems, use of the principles established can be of value in the development of geometries which will position the interface in a predictable configuration.

A64-15011

STUDIES OF THE STABLE BURNING OF COMPOSITE PROPELLANTS AT LOW PRESSURE.

I. Yoshiyama, M. Tanno (Tokyo, University, Institute of Industrial Science, Tokyo, Japan), and T. Fukuda (Nippon Oils and Fats Co., Ltd., Taketoyo-machi, Aichi-ken, Japan).

IN: INTERNATIONAL SYMPOSIUM ON SPACE TECHNOLOGY AND SCIENCE, TOKYO, JAPAN, AUGUST 27-31, 1962, 4th, PROCEEDINGS.

Edited by Tamiya Nomura.

Tokyo, Japan and Rutland, Vt., Japan Publications Trading Co., 1963, p. 333-344.

Investigation of the development of rocket engines with low chamber pressure and high mass ratio. The following information on the phenomenon of the chuffing which occurs below the lower combustion pressure limit is presented: the experiment revealed that explosion occurred below the limit in firings of the propellant grains containing the ammonium perchlorate exposed to X-rays for 2 hours, although all the propellant grains burned out very stably above the limit. The explanation of the mechanism of chuffing given by Avery and others is nearly the same as this. As the pressure in the chamber is lowered, the thickness of the gas phase reaction zone increases. With further decreases in pressure, the thickness of the layer in which reaction is taking place may eventually become so large that the final stages of the reaction do not occur before the gas is discharged from the chamber. The theoretical final temperature of the gas is therefore not fully attained, the heat conducted to the surface is decreased, and, as a result, the burning rate decreases. This leads to a still lower temperature and a lower burning rate and so on, until burning ceases or equilibrium is re-established at the pressure appropriate to the flame temperature of the incomplete reaction. The assumption is made that it seems to be reasonable that amines, heavy metal oxides, or light metal and heavy metal oxide mixtures decrease the lower combustion pressure limit.

A64-15012

MECHANICAL PROPERTIES OF COMPOSITE PROPELLANTS.

T. Yokoyama, T. Harada, and K. Ichiyanagi (Asahi Chemical Industry Co., Ltd., Technical Research Laboratory, Tokyo, Japan).

IN: INTERNATIONAL SYMPOSIUM ON SPACE TECHNOLOGY AND SCIENCE, TOKYO, JAPAN, AUGUST 27-31, 1962, 4th, PROCEEDINGS.

Edited by Tamiya Nomura.

Tokyo, Japan and Rutland, Vt., Japan Publications Trading Co., 1963, p. 345-349.

Study of the mechanical properties of systems filled with spherical glass beads. It is noted that this system is very useful to study the effects of fillers on the mechanical properties and to deduce the mechanical properties of composite propellants from these results. However, in the most composite propellants, the solid oxidizers are not spherical, and there are interactions between the oxidizers and the binders. The mechanical properties of such a system largely depend on the composition, the size and the shape of the filler, the viscoelastic properties of the binder, the action of the binder to the filler, and the temperature. Therefore, the mechanical properties of the system filled with spherical glass beads, and those of the system filled with composite propellant oxidizers, are not identical, the spherical oxidizer having some effects on the binder. There are some correlations between the mechanical properties and the motor performance or combustion instability of a solid propellant; however, it is stated that relatively little work has been reported on the mechanical properties of solid propellants.

A64-15014

CALCULATION OF BURNING RATE SOLELY BY MEANS OF BOTH DIAGRAMS OF THRUST - TIME AND PRESSURE - TIME.

Chai Chin Suh (Seoul National University, College of Engineering, Dept. of Mechanical Engineering, Seoul, Korea).

IN: INTERNATIONAL SYMPOSIUM ON SPACE TECHNOLOGY AND SCIENCE, TOKYO, JAPAN, AUGUST 27-31, 1962, 4th, PROCEEDINGS.
Edited by Tamiya Nomura.
Tokyo, Japan and Rutland, Vt., Japan Publications Trading Co., 1963, p. 359-362.

Presentation of a method for the calculation of the burning rate of pressure-dependence in JPN solid propellant. It is noted that, compared with other methods, the calculation by this method is comparatively easy and accurate, even though the method of calculation of the burning rate is indirect, since the data which are utilized are solely diagrams of both thrust time and pressure time. The correlation obtained in this study is expressed as follows: $B = 0.00276\ P_c^{0.78}$, where B is the burning rate in in./sec, and P_c is the chamber pressure in lb/in.^{2} It is noted that both constant and exponent are in good agreement with the values of existing bibliographies.

A64-15140

COMMENT ON "SOLID PROPELLANT DRIVEN SHOCK TUBE."

W. S. Filler (U.S. Naval Ordnance Laboratory, Explosions Research Dept., Silver Spring, Md.).

AIAA Journal, vol. 2, Mar. 1964, p. 592. 5 refs.

A64-15209

THE SEMITOROIDAL TANK.

J. F. Blumrich (NASA, Propulsion and Vehicle Engineering Laboratory, Structural Engineering Branch, Marshall Space Flight Center, Huntsville, Ala.).

Astronautics and Aeronautics, vol. 2, Feb. 1964, p. 64-68.

Discussion of semitoroidal tanks used for storage of liquid propellants in large boosters. Typical structural areas are investigated and several possible designs are established. Some of the advantages of a semitoroidal system are: (1) length reduction of stages and vehicles, (2) elimination of common bulkheads, and (3) smaller volumes stored within a given diameter rather than conventional tanks.

A64-15358

LIQUID PROPULSION.

Henry Burlage, Jr. (NASA, Liquid Propulsion Systems, Washington, D.C.).

Space/Aeronautics, vol. 41, Feb. 1964, p. 60-67.

Discussion of the problems encountered in the use of liquid propellants. Various factors such as: specific impulse, bulk density, storability, and safety are explained and the problems of optimizing the liquid propulsion system are presented. The advantages and disadvantages of consolidated and separated liquid propellant systems are considered, and comparisons are made with nuclear and solid fuel systems.

A64-15658

VIBRATION OF A PROPELLANT LINE CONTAINING FLOWING FLUID.

Ta Li and O. D. DiMaggio (North American Aviation, Inc., Space and Information Systems Div., Aerospace Sciences Div., Dynamic Sciences Dept., Downey, Calif.).

IN: AIAA ANNUAL STRUCTURES AND MATERIALS CONFERENCE, FIFTH, PALM SPRINGS, CALIF., APRIL 1-3, 1964 (AIAA Publication CP-8).
New York, American Institute of Aeronautics and Astronautics, 1964, p. 194-199. 5 refs.

The transverse vibration of a propellant line with internal flowing fluid has been a problem for the space industry. The coupling term which appears in the mathematical formulation of the problem presents a classic difficulty which is fully resolved in the paper. The frequency equation, a fourth order determinantal equation, is reduced to the third order by a simple transformation and is further simplified to a transcendental equation involving hyperbolic functions. This equation is shown to have a polynomial factor which has only extraneous roots. The remaining factor is transcendental and contains all the eigenvalues. The final equation for the eigenfrequency is a very rapidly converging power series set equal to zero. Numerical results compared with the experimental data of Long show good agreement. Frequencies are plotted against velocity ratio and mass ratio. All quantities are nondimensionalized for ready application. It is also shown that in case of zero flow velocity this method leads to an eigenvalue problem of a beam with exactly the same eigenfrequencies as the classic beam problem, indicating that this approach is more general than the classic treatment.

A64-16121

THE EFFECT OF COMPOSITIONAL VARIABLES UPON OSCILLATORY COMBUSTION OF SOLID ROCKET PROPELLANTS.

M. D. Horton and D. W. Rice (U.S. Naval Ordnance Test Station, China Lake, Calif.).

Combustion and Flame, vol. 8, Mar. 1964, p. 21-28. 9 refs.
Navy-supported research.

Experimental investigation to determine the oscillatory combustion of an ammonium perchlorate propellant system, first as a function of fuel type (binder), and, secondly, as influenced by burning rate modifiers including ammonium perchlorate particle size with copper chromite and lithium fluoride as additives. The propellant burner used was a side-vented cylindrical cavity in the ends of which two disks of propellant were placed and burned. The propellant grains were cemented into the ends of the chamber with epoxy resin, and their inner surfaces were covered with a pyrotechnic igniter paste. Burners of various lengths were used so that the frequencies obtained ranged from 200 cps to 10 kc. The results show that the variation of binders, polysulphide, polyurethane, and polybutyl-acrylic acid, had a comparatively small effect upon the oscillatory combustion of the propellant system. The burning rate modifiers, however, greatly affected the oscillatory combustion of a polybutyl-acrylic acid propellant.

A64-16144

THE EFFECT OF ACOUSTIC PRESSURE ON THE BURNING RATES OF SOLID ROCKET PROPELLANTS.

John L. Eisel (U.S. Naval Ordnance Test Station, Aerothermochemistry Group, China Lake, Calif.).

(Combustion Institute, Western States Section, Fall Meeting, Sacramento, Calif., Nov. 1962, Paper 62-23.)
Pyrodynamics, vol. 1, Jan.-Feb. 1964, p. 61-70.
Navy-sponsored research.

A one-dimensional end burner is used to examine the response of propellant burning rates to acoustic pressure. It is found that for the propellants tested (both double-base and composite) the burning rates are reduced in the presence of acoustic pressure; that the reductions in burning rates are larger for higher frequencies of oscillations; and that the effects of oscillatory pressure on the burning rates of double-base propellants decrease with increasing mean pressure, whereas for composites they increase with increasing mean pressure.

A64-16145

TECHNIQUES FOR STUDYING THE COMBUSTION OF ALUMINUM IN SOLID PROPELLANTS.

K. P. McCarty (Allegany Ballistics Laboratory, Cumberland, Md.).

(Combustion Institute, Western States Section, Fall Meeting, Sacramento, Calif., Nov. 1962, Paper 62-18.)

Pyrodynamics, vol. 1, Jan.-Feb. 1964, p. 71-87.

A combination of photographic and particle collection techniques using laboratory scale experiments to obtain information on the nature of aluminum combustion in solid propellants. The performance of rocket motors can be predicted from this information. The basic

mechanism, a vapor phase reaction of the aluminum, has been demonstrated by observation of the combustion of individual aluminum particles under conditions that approach rocket motor conditions using a long working distance microscope and a large window bomb. A large bomb is necessary for the firing of samples that are large enough to reduce heat loss. The results are consistent with the theory developed by Glassman and Brzustowski at Princeton. Added complications that are of importance in motor performance are delayed particle ignition and agglomeration of the aluminum at the surface of the propellant.

A64-16146

ONE-DIMENSIONAL UNSTEADY AEROTHERMOCHEMICAL ANALYSIS OF COMBUSTION INSTABILITY IN LIQUID ROCKET ENGINES.

T. Paul Torda and Leo A. Schmidt (Illinois Institute of Technology, Chicago, Ill.).

(International Astronautical Congress, 13th, Varna, Bulgaria, Sept. 1962.)

Pyrodynamics, vol. 1, Jan.-Feb. 1964, p. 89-111. 20 refs.

Review of the background of analytical investigations on combustion instability in liquid rocket engines as an introduction to discussion of a particular analysis performed on the longitudinal mode of instability. This latter analysis neglects viscous and heat transfer effects in the gaseous equations of motion, thus greatly simplifying the numerical treatment because the equations are then cast in hyperbolic form. Furthermore, variations in properties across the chamber are neglected. This leads to a mathematical representation susceptible to feasible evaluation by a mesh technique on a high-speed digital computer. Numerical solutions are presented for a variety of examples of oscillatory phenomena that may occur. The results provide a testing ground for future multi-dimensional studies of combustion instability.

A64-16180

THE COMBUSTION DOMAINS OF COMPOSITE POWDERS [LES DOMAINES DE COMBUSTION DES POUDRES COMPOSITES].

Marcel Barrère and Lionel Nadaud.

La Recherche Aérospatiale, Jan.-Feb. 1964, p. 15-29. 10 refs.

In French.

Definition of the various combustion domains of composite solid fuel rocket propellants. The pressure and the mean diameter of the grains of perchlorate are taken as parameters. According to the magnitude of the parameters, five domains can be defined, each one being characterized by particular phenomena. In each case the combustion velocity is determined and compared to the experimental results. The conditions which make the speed of combustion independent of the pressure are determined.

A64-16635

INTEGRATION OF CRYOGENIC DYNAMIC POWER SYSTEM WITH VEHICLE COOLING SYSTEM.

Gerald L. McArthur and James H. Tarter (Bendix Corp., Research Laboratories Div., Energy Conversion and Dynamic Controls Laboratory, Energy Conversion Systems Dept., Southfield, Mich.).

(American Rocket Society, Space Power Systems Conference, Santa Monica, Calif., Sept. 25-28, 1962, Preprint 2517-62.)

Journal of Spacecraft and Rockets, vol. 1, Mar.-Apr. 1964, p. 149-154. 13 refs.

Bendix Corp.-supported research.

[For abstract see Accession no. A63-11770 05-06]

A64-16704

A THEORY OF LOW-FREQUENCY COMBUSTION INSTABILITY IN SOLID ROCKET MOTORS.

Robert Sehgal and Leon Strand (California Institute of Technology, Jet Propulsion Laboratory, Pasadena, Calif.).

AIAA Journal, vol. 2, Apr. 1964, p. 696-702. 6 refs.

Contract No. NAS 7-100.

Theoretical investigation of low-frequency combustion instability where the mechanism of instability is the lag of burning-rate response to pressure disturbances near the propellant surface due to the temperature gradient just below the surface, and its interaction with lag in exhausting the chamber due to nozzle flow. The period of low-frequency chamber fluctuations is considered large compared to any time lags in the gas-phase burning process. The burning-rate perturbations and pressure perturbations are related through a closed-loop feedback system analysis. The burning-rate fluctuations cause pressure fluctuations through the chamber transfer function. These pressure fluctuations are, in turn, fed back to the burning-rate fluctuations through the combustion transfer function. Expressions are derived for the two transfer functions, and an instability criterion is developed by the application of Cauchy's theorem, resulting in the correlation of the critical pressure for a given propellant and chamber characteristic length L^*. The results are compared with experimental data obtained at the Jet Propulsion Laboratory.

A64-16930

LIQUID SLOSHING IN A 45° SECTOR COMPARTMENTED CYLINDRICAL TANK.

Helmut F. Bauer (Georgia Institute of Technology, School of Engineering Mechanics, Atlanta, Ga.).

AIAA Journal, vol. 2, Apr. 1964, p. 768-770.

Study of the use of compartmented propellant containers with longitudinal walls to avoid strong dynamic coupling of the propellant motion and the control system. This results in smaller sloshing masses and higher natural frequencies. The stability of such a system is investigated by studying the response of a liquid with a free fluid surface due to various forced tank excitations that is contained in a 45° sector compartmented cylindrical tank. The liquid is considered to be irrotational, incompressible, and inviscid. Using a procedure developed by the author in a previous paper, an expression for the velocity potential is obtained. A comparison shows that the theoretical natural frequencies are larger than the measured values obtained by Abramson, Chu, and Garza and that these frequencies vary with the excitation amplitude. The theoretical frequencies of a liquid in a compartmented tank are only approached when the excitation is infinitesimal. Although there is a decrease in natural frequencies with increasing amplitudes, the increase of the frequencies because of compartmentation is much more effective.

A64-17192

HYBRID PROPULSION.

D. D. Ordahl (United Aircraft Corp., United Technology Center, Propulsion Research Branch, Sunnyvale, Calif.).

Space/Aeronautics, vol. 41, Apr. 1964, p. 108-113. 6 refs.

Discussion of the current developmental stage of hybrid propulsion. Considered are the separation of fuel and oxidizer, narrow combustion zone, small effect of pressure, throttling problem, pressure-sensitive fuel solution, absence of burning in fuel cracks, wide range of fuels, major problems solved, engine clustering, and engine for large missiles. It is stated that, with the improvements in combustion efficiency and throttling performance that have been made in the past year, engines using solid fuel and liquid oxidizer appear increasingly attractive for missiles, large boosters, and long-duration space missions.

A64-17319

CURRENT TRENDS IN LIQUID ROCKET PROPELLANTS.

E. G. Haberman (USAF, Systems Command, Air Force Rocket Propulsion Laboratory, Edwards AFB, Calif.).

American Institute of Chemical Engineers, Symposium on Aerospace Fuels Technology, National Meeting, 53rd, Pittsburgh, Pa., May 17-20, 1964, Preprint 2c. 12 p.

Members, $0.50.

Discussion of the current trend of using metals and metal compounds in advanced liquid rocket propellants. Also noted is the use of simple liquid compounds (pentaborane), complexes (hybalines), and heterogeneous formulations (gels, slurries) in liquid propellants, as well as extensive synthesis work in the oxidizer area (primarily of fluorinated compounds), aimed at developing a storable highly fluorinated oxidizer. Research on mixtures of oxidizers is carried out in an effort to combine desirable physical properties with high performance. Some fuels and oxidizers recently developed are described, and their performance potential and characteristics are discussed within the limits imposed upon classified information. Some problems arising from the use of these advanced propellants, such as the accumulation of solid particles in the exhaust, and high combustion temperatures are reviewed.

A64-17376

PROPELLANT OSCILLATIONS IN ROCKET FUEL TANKS, AND THEIR INFLUENCE ON THE OVERALL STABILITY. I [TREIBSTOFFSCHWINGUNGEN IN RAKETENBEHÄLTERN UND IHR EINFLUSS AUF DIE GESAMTSTABILITÄT. I].

Helmut F. Bauer.

Zeitschrift für Flugwissenschaften, vol. 12, Mar. 1964, p. 85-101.

In German.

Theoretical analysis of the forces and moments exerted by an oscillating liquid, with a free fluid surface, in a cylindrical container with circular-ring cross sections. The analysis is undertaken to determine values for the forces and moments which are applicable

to practical rocket fuel tank shapes, such as circular cylindrical and sectional tanks. The liquid is assumed to be incompressible, irrotational, and frictionless. Equivalent linear damping is introduced by means of an analytical model describing the fluid motion. This model incorporates the effects, on the oscillations, of the tank geometry, the position of the tank in the vehicle, the modulation factors of the vehicle control system, and the oscillation characteristics of an accelerometer employed as an accessory control element.

A64-17649

THE VAPOR PRESSURE AND HEAT AND ENTROPY OF SUBLIMATION OF SOLID MAGNESIUM FLUORIDE.

Michael A. Greenbaum, Hon Chung Ko, Madeline Wong, and Milton Farber (Rocket Power, Inc., Research Laboratories, Pasadena, Calif.).

Journal of Physical Chemistry, vol. 68, Apr. 1964, p. 965-968. 12 refs.

Experimental determination of the vapor pressure of MgF_2(c) by means of the torsion effusion procedure. The measurement was carried out over the temperature range 1273-1513°K. The MgF_2 employed in the investigation was 99.8 + % pure material. Since MgF_2 is nonhygroscopic, no special handling precautions were taken. The material was placed in graphite effusion cells which were placed in the torsion apparatus. Two different cells with orifice areas differing by a factor of four were used. The furnace temperature was recorded and automatically controlled to ±1°K. The suspension wire used was a 1.5-m length of 2-mil-diam. molybdenum. It is pointed out that no dependence of the vapor pressure on orifice area was observed. This is stated to be consistent with previous experimental observations made in studies of BeF_2[5] and $BeCl_2$[6], where orifice areas of cells were varied by as much as a factor of 16.

A64-17659

ROCKET PROPELLANT AND PRESSURIZATION SYSTEMS (Prentice-Hall Space Technology Series).

Edited by Elliot Ring (Martin Marietta Corp., Martin Co., Denver, Colo.).

Englewood Cliffs, N. J., Prentice-Hall, Inc., 1964. 310 p. $13.00.

A collaborative study of rocket propellant and pressurization systems is presented. Topics covered are: (1) propellant loading tolerances of density variations, manufacturing, vertical alignment, tank stretch and shrinkage, and countdown and engine bleed; (2) propellant inventory; (3) a comparison of volume loading and mass loading; (4) loading measurements and control; (5) outage control; (6) pressure surges and frictional losses in propellant system feed lines; (7) fluid flow problems encountered in propellant tank outlet design; (8) design techniques for the prevention of cavitation in nozzle outlets; (9) prevention of fluid dropout in propellant tank outlets; (10) propellant slosh; (11) temperature and pressure effects of cryogenic propellant loading; (12) the geysering phenomenon and methods of preventing geysering; (13) cryogenic propellant stratification analysis and test data correlation; (14) special zero gravity fluid problems; (15) methods of level sensing, design parameters affecting level sensing, and level sensing devices; (16) types of pressure systems; (17) desirable characteristics of pressurants; (18) methods of tank pressure control; (19) ullage requirements for pressure control systems including volume, composition, and temperature; (20) thermodynamic considerations of pressurizing gas such as heat transfer, mass transfer, and the thermodynamic properties of gases; (21) pressurization hardware requirements; (22) theoretical analysis of propellant performance; and (23) operation, component structure, and basic parameters associated with rocket engines.

A64-17700

TECHNICAL ASPECTS OF ORTHO-PARAHYDROGEN CONVERSION.

G. E. Schmauch and A. H. Singleton (Air Products and Chemicals, Inc., Research and Development Dept., Allentown, Pa.).

I & EC - Industrial and Engineering Chemistry, vol. 56, May 1964, p. 20-31. 61 refs.
USAF-sponsored research.

Presentation of a review of the literature on ortho-parahydrogen conversion and the results of a comparative experimental study of catalysts employed in this process. Based on an analysis of the conversion process, it is felt that heterogeneous conversion is the most promising technique for increasing the rate of conversion. The extraction of additional low-temperature refrigeration from a cold parahydrogen stream through the para-to-ortho conversion process is considered to have aerospace applications. An experimental program resulted in the development of a catalyst (APACHI-1) having the following properties: high physical adsorptive capacity for hydrogen, high concentration of a para-magnetic component on its surface, and a large magnetic moment associated with the paramagnetic component. The conversion activity of APACHI-1 is compared with that of iron gel and chromia on aluminum. The conversion activity of APACHI-1 is found to be ten times that of hydrous ferric oxide gel catalysts on a weight basis.

A64-17778

EFFECT OF CYCLIC LOADING ON THE TEMPERATURE IN VISCOELASTIC MEDIA WITH VARIABLE PROPERTIES.

R. A. Schapery (Purdue University, Dept. of Aeronautical and Engineering Sciences, Lafayette, Ind.).

AIAA Journal, vol. 2, May 1964, p. 827-835. 16 refs.
Contract No. AF 94(611)-8539.

Determination of steady-state and transient temperature distributions resulting from dissipation calculated for a linear viscoelastic slab and hollow cylinder subjected to cyclic shear loading. Temperature dependence of the dissipation function is introduced through the familiar assumption of thermorheologically simple behavior, wherein frequency-dependent mechanical properties measured at different temperatures are superposed by shifting with respect to the logarithmic frequency scale. This assumption leads to a nonlinear heat-conduction equation, and an exact closed-form solution is obtained for just the steady-state temperature distribution. In order to solve the transient problem, two approximate methods of analysis are proposed. Numerical results for a solid propellant are given, and it is found that a large temperature rise will occur as the result of a thermal instability when the shear stress is above a certain critical value that depends on thermal and mechanical properties and geometry. In this paper, inertia is neglected; however, many of the considerations, including the approximate methods, are potentially applicable to dynamic problems as well as to other configurations and loading conditions.

A64-17823

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. 22 p. 5 refs.

Description of techniques for effecting the pyrolysis of solid materials and for determining the composition of the products. Methods and equipment for flash heating by thermal radiation are considered. Radiant pulses can be very intense and very short, thereby producing in an absorbing material short periods of very high temperature. In addition, radiant heating provides a method for producing clean, rapid heat in which only the light-absorbing solid material under study is heated while the container and other equipment remain cool. The pyrolysis products, both volatile and non-volatile, of this process are studied with particular emphasis on the identifying and measuring of the volatiles produced under various rates of heating in a vacuum and in an inert atmosphere. The application of pulsed thermal radiation from carbon arcs and xenon flashtubes to the flash heating of solid materials is discussed. The techniques developed have application to the study of solid propellants.

A64-17830

TEMPERATURE-ENTROPY DIAGRAM OF MONOMETHYLHYDRAZINE.

Frank Bizjak and Donald F. Stai (North American Aviation, Inc., Space and Information Systems Div., Propulsion Dept., Downey, Calif.).

AIAA Journal, vol. 2, May 1964, p. 954-956. 5 refs.

Outline of the methods used for obtaining thermodynamic data of monomethylhydrazine under real gas conditions at 14.7 psia. The saturated vapor entropies from the fusion to the critical temperature were derived from ideal entropies at standard pressure and from vapor-pressure data. Enthalpy data of Lawrence were expanded to obtain enthalpy at pressures above critical in the solid-vapor region and in the superheated vapor region. The data developed are presented as a temperature-entropy diagram. The accuracy of the data is estimated to be within 0.5% of ambient conditions. The accuracy

decreases when temperature and pressure approach and exceed the critical values, with a possible deviation of about 2%.

A64-17844
EFFECT OF RATE AND TEMPERATURE ON THE TENSILE PROPERTIES OF DOUBLE-BASE PROPELLANT.
E. McAbee and M. Chmura (U.S. Army, Munitions Command, Picatinny Arsenal, Dover, N. J.).
IN: HIGH SPEED TESTING. VOLUME 4.
Albert G. H. Dietz and Frederick R. Eirich.
(Annual Symposium on High Speed Testing, 4th, Boston, Mass., May 15, 16, 1963.)
Symposium sponsored by Plas-Tech Equipment Corp.
New York, Interscience Publishers, Division of John Wiley and Sons 1964, p. 3-24.

Study of the tensile properties of two cast and two extruded solid rocket propellants at 25°C and 50% RH over a range of failure times from 0.005 to 2500 sec. The effects of temperature are also investigated at the highest rate of loading and at 0.1 in./in./min over a range of -60° to +80°C. The results indicate that both temperature and rate of loading greatly affect the tensile properties of double-base propellants.

A64-17963
PROPULSION IMPROVEMENTS ACHIEVED DURING FLIGHT TESTING OF SATURN VEHICLES.
B. K. Heusinger (NASA, Propulsion Div., Propulsion and Vehicle Engineering Laboratory, Propulsion Evaluation Branch, Marshall Space Flight Center, Huntsville, Ala.).
American Institute of Aeronautics and Astronautics, Aerospace Propulsion Meeting, Cleveland, Ohio, May 4-6, 1964, Paper 64-537. 11 p.
Members, $0.50; nonmembers, $1.00.

Discussion of some of the performance gains achieved during the flight testing of Saturn research and development vehicles. Both the Saturn vehicles and the performance programs are described. Improvements in the performance of these vehicles are attributed primarily to more accurate engine and vehicle prediction, reduced weight of the fuel pressurization system, increased propellant utilization, lox depletion cutoff, reduced lox tank pressure, reduction of hold-down time, and lox interchange. Data gathered from the flights of these vehicles are used to support redesign efforts to be applied to the Saturn IB program. The weight reductions include thinner container walls and new thrust structure, fins, and spider beams.

A64-17997
INTERACTION BETWEEN SOUND AND FLOW IN ACOUSTIC CAVITIES - MASS, MOMENTUM, AND ENERGY CONSIDERATIONS.
R. H. Cantrell and R. W. Hart (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).
Acoustical Society of America, Journal, vol. 36, Apr. 1964, p. 697-706. 16 refs.
Contract No. NOw 62-0604-c.

Discussion of the conditions for neutral acoustic stability in cavities with a transpiring wall, for the case of a mean flow in the absence of acoustic disturbances. The analysis takes the growth rates of the acoustic fields into account, and employs a calculation method based on the use of time averages of the mass, momentum, and energy-conservation equations expanded to second order in the acoustic-field quantities. It is found that growth rate neutral stability can be expressed in terms of first-order quantities alone. The results are shown to correlate well with calculations based on first-order admittance considerations, but to differ from Dyer's results obtained by a similar method. An explanation for this discrepancy is suggested. It is shown that the effect of mean flow can be substantial, and that the extent to which flow tends to excite or damp the acoustic field depends in a great measure upon mode configuration and flow-field geometry. The application of this effect to the problem of determining the acoustic response of burning rocket propellants is examined.

A64-18012
MEASUREMENTS OF IGNITION DELAYS OF HYPERGOLIC LIQUID ROCKET PROPELLANTS.
G. Spengler, A. H. Lepie, and J. Bauer.
Combustion Institute, Western States Section, Spring Meeting, Stanford University, Menlo Park, Calif., Apr. 27, 28, 1964, WSS/CI Paper 64-12. 23 p. 10 refs.

Experimental study of the effects of variations in chemical, thermodynamic, and flow parameters on the ignition delay times of hypergolic liquid rocket propellants. The parameters investigated are: (1) chemical composition of fuel and oxidizer, (2) reaction enthalpy and reaction velocity, (3) surface tension and intermixture, (4) ratio of reaction components, (5) temperature of reaction components, (6) injection velocity of the components, and (7) type of gas and gas pressure in the chamber. The catalytic effect of metal compounds is also investigated, and the dependence of the ignition delay time on the various parameters is presented graphically.

A64-18125
ELECTRONIC CONTROL SYSTEM FOR CRYOGENIC SPACE POWER SYSTEM.
M. G. Chesnut (Sundstrand Corp., Sundstrand Aviation-Denver Div., Denver, Colo.).
(International Conference and Exhibit on Aerospace Electro-Technology, Phoenix, Ariz., Apr. 20-23, 1964.)
IEEE Transactions on Aerospace, vol. AS-2, Apr. 1964, p. 401-411.

Evaluation of an electronic technique to control mixture ratio in a combustion process using cryogenic propellants. Propellant density variation from liquid to gaseous hydrogen dictated an elaborate pulse-width-amplitude-modulated control system. Requirements of millisecond total flow change, mixture-ratio variation, and summed-rate plus dual temperature sensing caused further sophistication. The resultant system provides positive control (3%) of critical temperature for catalytic H_2-O_2 combustion even during an abrupt, nonpredictable relocation of the reaction flame front within the catalyst bed.

A64-18419
ANOMALOUS BURNING PROPERTIES OF COMPOSITE PROPELLANTS CONTAINING LITHIUM FLUORIDE.
E. L. Capener and L. A. Dickinson (Stanford Research Institute, Menlo Park, Calif.).
Combustion Institute, Western States Section, Spring Meeting, Stanford University, Menlo Park, Calif., Apr. 27, 28, 1964, WSS/CI Paper 64-18. 7 p.

Study of the strand burning characteristics of lithium-fluoride-containing propellants by means of a series of polyurethane propellants. The composition and burning characteristics of the propellants are shown in a table. Also shown are the Crawford strand burning rate data for propellants, Codes 1 through 5. It is pointed out that addition of LiF to the propellant produces a mesa in the strand burning rate curve. It is shown that the extinction pressure correlates well with the LiF content in the propellants. The following conclusions are made: (1) the incorporation of LiF into propellants produces a slower burning propellant by modification of the overall reactions in the gas phase of the normal propellant ingredients, (2) the extinction of combustion observed in small propellant samples does occur in rocket motors, and (3) the use of LiF to aid extinction during burning aggravates the problem of combustion instability.

A64-18421
ADVANCES IN SPACE SCIENCE AND TECHNOLOGY. VOLUME 5.
Edited by Frederick I. Ordway, III (General Astronautics Research Corp., Washington, D.C.; Space Science and Technology Information Center, Huntsville, Ala.).
New York, Academic Press, Inc., 1963. 334 p.
$13.

Collection of papers on space problems covering: astronomical investigations of the Sun; advances in communication relay-satellite techniques; solid-propellant rocket technology; environmental control of manned space vehicles; terrestrial, lunar, and planetary applications of navigation and geodetic satellites; and orbital operations. The advantages, disadvantages, and prospects of large solid-propellant rockets and the role of orbital operations in astronautics are also discussed. Lists of references supplement the articles, which are individually abstracted and indexed in this issue.

A64-18497
THEORETICAL BURN RATE.
W. E. Crane (Martin Marietta Corp., Martin Co., Propulsion and Mechanical Engineering Dept., Denver, Colo.) and George Lehto (Olin Mathieson Chemical Corp., Winchester-Western Div., Advanced Research Section, New Haven, Conn.).
Ordnance, vol. 48, May-June 1964, p. 654, 655.

Presentation of a model for arriving at a linear burn rate expression for spherical propellant grains which does not suffer

from the limitations previously encountered and which can be used with computers. Linear burn rate models for cord and solid propellants are discussed, and equations are obtained which are stated to be expressions for relating propellant burn rate to the ballistic bomb experimental data, and the readily measurable properties of spherical propellants. It is noted that, although the model presented does not take into account the variation in diameter and in chemical composition as occurs in some commercial solid propellants, the equations derived offer the advantage of their convenient use with analog computers by the methods developed by Wallace, which save considerable time and effort in application.

A64-18542
RECENT DEVELOPMENTS IN SOLID PROPELLANTS, EMPHASIZING BINDERS [NEUERE FESTTREIBSTOFFENTWICKLUNGEN UNTER BESONDERER BERÜCKSICHTIGUNG DER BINDER].
U. Deisenroth.
Raumfahrtforschung, vol. 8, Apr.-June 1964, p. 74-77. 8 refs. In German.

Review of recent advances in solid-propellant research, emphasizing developments of polyurethane, polybutadiene, and nitrocellulose binders. The physical and chemical properties of these substances are delineated, and methods for their preparation are outlined. Also considered are inert and explosive softeners, high-energy oxidizing agents, and high-energy additives to solid propellants. In each case, tables are presented showing the composition and properties of the more promising materials.

A64-18543
OZONE AND ITS PROPERTIES WITH RESPECT TO ITS APPLICATION AS A ROCKET-PROPELLANT COMPONENT [OZON UND SEINE EIGENSCHAFTEN IM HINBLICK AUF DIE VERWENDUNG ALS RAKETENTREIBSTOFFKOMPONENTE].
D. Genthe.
(Deutsche Gesellschaft für Raketentechnik und Raumfahrt, Jahrestagung, 15th, and Europäisches Raumfahrt-Kongress, 3rd, Stuttgart, Germany, May 20-24, 1963.)
Raumfahrtforschung, vol. 8, Apr.-June 1964, p. 77-81. 35 refs. In German.

Basic consideration of the physical and chemical properties of ozone which make it attractive as a component in rocket propellants. The general properties which a liquid fuel must possess in order to be considered for use in rockets are discussed. The possible structures of the ozone molecule are delineated in terms of the interatomic distances, its collision cross section, and its dipole moment. Methods of preparing ozone which have been described in the literature are reviewed, as are methods for its handling. Also considered are the preparation and handling of ozone-oxygen mixtures.

A64-18618
STORABILITY DESIGN CRITERIA FOR SPACE PROPULSION.
Philip D. Gray (Aerojet-General Corp., von Kármán Center, Production Projects Div., Space Environment Dept., Azusa, Calif.).
(American Institute of Aeronautics and Astronautics, Summer Meeting, Los Angeles, Calif., June 17-20, 1963, Paper 63-259.)
Journal of Spacecraft and Rockets, vol. 1, May-June 1964, p. 340-342.
Contract No. AF 04(611)-7441.
[For abstract see Accession no. A63-18796 17-26]

A64-18877
A PRELIMINARY APPRAISAL OF THE CORNUCOPIA CONCEPT.
C. J. Swet (Johns Hopkins University, Space Development Div., Applied Physics Laboratory, Silver Spring, Md.).
American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-213. 8 p. 5 refs.
Members, $0.50; nonmembers, $1.00.

Description of a method for extending the utility of storable rocket propellants to include life support and other essential services in the space environment. The method employs the off-stoichiometric combustion of hydrazine with either hydrogen peroxide or nitrogen tetroxide to produce water, a two-gas atmosphere, thermal management, and power. Each aspect of performance has been examined quantitatively, with some discussion of the assumptions and computational methods. Problems of contamination, safety, and reliability were considered, and various applications of the concept were explored. Although this concept has not been validated experimentally, the potential payoff and the likelihood of feasibility are stated to appear high enough to justify such action.

A64-19079
T-BURNER METHOD OF DETERMINING THE ACOUSTIC ADMITTANCE OF BURNING PROPELLANTS.
R. L. Coates (Lockheed Aircraft Corp., Lockheed Propulsion Co., Engineering Research Dept., Redlands, Calif.), M. D. Horton (U.S. Naval Ordnance Testing Station, China Lake, Calif.; Brigham Young University, Chemical Engineering, Provo, Utah), and N. W. Ryan (Utah, University, Chemical Engineering, Salt Lake City, Utah).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Paper 64-137.)
AIAA Journal, vol. 2, June 1964, p. 1119-1122. 7 refs.
[For abstract see Accession no. A64-13001 06-26]

A64-19080
ADMITTANCE MEASUREMENTS OF SOLID PROPELLANTS BY AN ACOUSTIC OSCILLATOR TECHNIQUE.
S. N. Foner, R. L. Hudson, and B. H. Nall (Johns Hopkins University, Applied Physics Laboratory, Research Center, Electronic Physics Group, Silver Spring, Md.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Paper 64-138.)
AIAA Journal, vol. 2, June 1964, p. 1123-1129. 10 refs.
Contract No. NOw 62-0604-c.
[For abstract see Accession no. A64-13070 06-26]

A64-19081
ACOUSTIC INSTABILITY - INFLUENCE OF AND ON THE SOLID PHASE.
Norman W. Ryan and Ralph L. Coates (Utah, University, Salt Lake City, Utah).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Paper 64-139.)
AIAA Journal, vol. 2, June 1964, p. 1130-1134. 7 refs.
Contracts No. AF-OSR 49(638)-1074, No. AF-OSR 62-451.
[For abstract see Accession no. A64-13069 06-26]

A64-19083
USE OF THE ONE-DIMENSIONAL T-BURNER TO STUDY OSCILLATORY COMBUSTION.
M. D. Horton (U.S. Naval Ordnance Test Station, Research Dept., China Lake, Calif.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Paper 64-136.)
AIAA Journal, vol. 2, June 1964, p. 1112-1118. 21 refs.
[For abstract see Accession no. A64-13023 06-26]

A64-19084
LINEAR ACOUSTIC GAINS AND LOSSES IN SOLID PROPELLANT ROCKET MOTORS.
R. H. Cantrell, R. W. Hart, and F. T. McClure (Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Paper 64-134.)
AIAA Journal, vol. 2, June 1964, p. 1100-1105. 19 refs.
Contract No. NOw 62-0604-c.
[For abstract see Accession no. A64-13067 06-27]

A64-19085
MEASUREMENTS OF PARTICULATE ACOUSTIC ATTENUATION.
Richard A. Dobbins and S. Temkin (Brown University, Div. of Engineering, Providence, R.I.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Paper 64-114.)
AIAA Journal, vol. 2, June 1964, p. 1106-1111. 16 refs.
Contract No. NOrd 16640.
[For abstract see Accession no. A64-13008 06-24]

A64-19118
EFFECT OF RADIATION ON AMMONIUM PERCHLORATE PROPELLANTS.
T. Acker, E. Henley, R. F. McAlevy, III, and G. Odian (Radiation Applications, Inc., Long Island City, N.Y.).
AIAA Journal, vol. 2, June 1964, p. 1165.
Contract No. AF 49(638)-1125.

Tabulation of the results of experiments to determine the effects of radiation on propellants, employing a 2-Mev Van de Graaff electron accelerator. The radiation dose, burning rate, and tensile strength are tabulated for the following ammonium perchlorate propellants: polysulfide (Thiokol TP-L-3014 and TP-L-3014a); hydrocarbon (Thiokol TP-H-3062); polyurethane (Thiokol TP-6-3129); polyacrylonitrile (Hercules HES 6648); polyethyl acrylate (Hercules HES 6420); and cellulose acetate (Hercules HES 5808).

A64-19150

THERMAL STABILITY APPARATUS FOR LIQUID PROPELLANTS.

L. Stiefel and E. D. Grossmann (U.S. Army, Pitman-Dunn Institute for Research, Frankford Arsenal, Philadelphia, Pa.).

Review of Scientific Instruments, vol. 35, June 1964, p. 727, 728.

Description of a thermal stability apparatus for liquid propellants which consists of a closed chamber (bomb) that can be maintained at fixed elevated temperatures. The sample can be rapidly pumped directly into the chamber by means of a remotely operated, syringe-type pump. A check valve, incorporated into the pump, seals off the bomb after the liquid is injected. Time from injection to ignition can be recorded. The method is stated to offer the advantage that no container or capsule intervenes between the heating medium and the sample, and there are no temperature lags due to the intermediate wall.

A64-19873

WELDED METAL BELLOWS - A RELIABLE POSITIVE EXPULSION DEVICE FOR LIQUID PROPELLANTS.

Leo M. Thompson (Bell Aerospace Corp., Bell Aerosystems Co., Tank and Positive Expulsion Device Group, Buffalo, N.Y.).

American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-264. 7 p.

Members, $0.50; nonmembers, $1.00.

Report of a program conducted to evaluate metallic positive expulsion devices and to select the device having the greatest potential for manned application. The selection criteria included those conditions imposed during long-term orbital missions and spacecraft applications, such as operation through a wide range of temperatures and at high radiation levels. The parametric advantages which influenced selection of a welded metal bellows, and which were demonstrated with prototype units, included highly reliable cycle life, zero leakage during extended storage life in space environments, high volumetric and expulsion efficiencies, and excellent response characteristics for pulse-mode operation.

A64-20298

ZERO G LIQUID PROPELLANT ORIENTATION BY PASSIVE CONTROL.

Howard L. Paynter, C. Malcolm Mackenzie, Ralph Z. Marsh, and Vernal M. Tyler (Martin Marietta Corp., Aerospace Div., Friendship International Airport, Md.).

Society of Automotive Engineers and American Society of Mechanical Engineers, Air Transport and Space Meeting, New York, N.Y., Apr. 27-30, 1964, Paper 862D. 27 p. 23 refs.

Members, $0.75; nonmembers, $1.00.

Discussion of the use of passive liquid-containment systems that utilize liquid intermolecular forces for propellant orientation in reduced or zero gravity environments. Passive orientation systems employ only the fluid intermolecular forces to control the liquid in a zero-g state. Liquid orientation is required to provide reliable engine restart and tank venting operations of space vehicle propulsion systems. Various liquid containment systems concepts and associated design criteria are presented, and general problem areas of interface stability, liquid slosh, and effects of thermal energy are described. Present and planned test facilities designed to provide reduced gravity environments and extended time durations are also considered.

A64-20305

CAPACITANCE MASS SENSING OF BOILING PROPELLANTS.

Clay K. Perkins and R. D. Wilburn (General Dynamics Corp., General Dynamics/Astronautics, San Diego, Calif.).

Society of Automotive Engineers and American Society of Mechanical Engineers, Air Transport and Space Meeting, New York, N.Y., Apr. 27-30, 1964, Paper 859A. 12 p. 5 refs.

Members, $0.75; nonmembers, $1.00.

Presentation of the results of an experimental analysis of methods for mass sensing of boiling propellants in the Centaur vehicle, with particular emphasis on a capacitance system and a point sensor system. It is shown that a manometer-type capacitance probe can reduce, if not eliminate, the errors caused by density variation. Further, the manometer probe can be used to eliminate undesired slosh effects by hydraulic rather than electrical filtering. Results from medium-scale tests are helpful in evaluating gaging problems in vehicles other than Centaur.

A64-20308

CHEMICAL PHYSICAL PHENOMENA IN GELLED PROPELLANT TECHNOLOGY.

William H. McLain (Martin Marietta Corp., Martin Co., Denver, Colo.).

American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-368. 18 p. 19 refs.

Members, $0.50; nonmembers, $1.00.

Calculation of the performance of several representative gelled-propellant systems. The physical properties of gelled propellants, such as vapor pressure, surface tension, and yield point, are discussed on the basis of a theory due to Flory and Huggins. The flow characteristics and stabilization of gels and slurries are discussed, and a theoretical analysis of non-Newtonian pipe flow with uniform heat input is presented.

A64-20317

THE EFFECTS OF CRYOGENIC FUELS ON CAPACITANCE TYPE MASS AND LEVEL MEASUREMENT.

John M. Henness and Lloyd W. Barnard (Bendix Corp., Pioneer-Central Div., Davenport, Iowa).

Society of Automotive Engineers and American Society of Mechanical Engineers, Air Transport and Space Meeting, New York, N.Y., Apr. 27-30, 1964, Paper 859B. 9 p. 11 refs.

Members, $0.75; nonmembers, $1.00.

Discussion of reasons why improvements in readout accuracy of capacitance measurement systems have not resulted in improvement of propellant gaging accuracy. Such systems are affected by various properties of cryogenic fuels such as ullage gas formation, radial and vertical density gradients, and boiling effects. Ullage gas has a dielectric effect; density gradient affects probe placement; and the boiling effect introduces vapor barrier and bubble discontinuities. Compensation methods and optimum designs for some major cryogenic fluid effects are evaluated. It is concluded that, although present readout systems offer accuracies in the 0.01% area, this accuracy cannot be realized without a complete system design which takes into account the effects of the cryogenic fluid on the system.

A64-20416

MATHEMATICAL DETERMINATION OF STRESSES AND DISPLACEMENTS IN STAR-PERFORATED GRAINS.

Howard B. Wilson, Jr. (Alabama, University, Engineering Mechanics and Applied Mathematics, University, Ala.).

AIAA Journal, vol. 2, July 1964, p. 1247-1253. 12 refs.

Contract No. DA-01-021-ORD-11878.

Presentation of a mathematical method for determining stresses in solid propellant rocket grains due to pressurization, steady thermal gradients, and uniform propellant shrinkage. The type of solid propellant grain considered is a long cylinder containing a longitudinal perforation with an arbitrary number of identical star points of general shape. The external boundary of the propellant grain is bonded to a cylindrical motor case. The propellant has constant mechanical and thermal properties and is in a state of plane strain. Linear elasticity theory and complex-variable methods are used to formulate a general stress problem for a doubly connected region that has a star-shaped internal boundary and a circular external boundary and is subjected to steady thermal gradients and uniform boundary pressures. This problem is solved approximately by considering a related problem for an infinite plane with a star-shaped hole. Effects of bonding the external boundary to an elastic case are deduced approximately by superposition. A general stress program for a digital computer is described, and computations testing the validity of the assumed approximations are made. The method is found to provide a practical means of analyzing stresses in solid propellant grains.

A64-20477
THE APPLICATION OF LIQUID FLUORINE AND LIQUID HYDROGEN TO A "UNIVERSAL" UPPER STAGE DESIGN.
George C. Goldbaum and John B. Douglass (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 64-277. 13 p. 19 refs.
Members, $0.50; nonmembers, $1.00.
Research sponsored by the Douglas Aircraft Co.

Presentation of the design of a fluorine-hydrogen upper stage that can be developed and produced with current technologies and which is universally applicable to boosters ranging in size from small to large. When used in an upper stage, a propellant combination of fluorine and hydrogen gives the highest performance of any state-of-the-art propellant. The presented detailed sizing studies show that an upper stage of 30,000-lb propellant capacity, powered by a 35,000-lb thrust fluorine-hydrogen engine, will provide near-maximum payload capability for boosters from small to large-class vehicles for missions from low orbit to escape. The lightest, strongest, and most easily insulated structural configuration is shown to be a load-bearing outer shell of aluminum honeycomb with spherical fluorine and hydrogen tanks suspended internally.

A64-20754
PROPELLANT GAGING AND UTILIZATION FOR THE APOLLO SPACECRAFT.
Edward Ulicki (Simmons Precision Products, Inc., Tarrytown, N.Y.).
Society of Automotive Engineers and American Society of Mechanical Engineers, Air Transport and Space Meeting, New York, N.Y., Apr. 27-30, 1964, Paper 870D. 9 p.
Members, $0.75; nonmembers, $1.00.

Description of the application of capacitive propellant-gaging techniques to the aerospace environment. The propellant utilization and gaging system developed for Apollo is presented. In addition, some problems peculiar to aerospace and solution of these problems are discussed. The gaging system generates information that the astronaut uses to correct the propellant mixture. The astronaut does this by using the oxidizer valve.

A64-20785
TRANSIENT PERFORMANCE PREDICTION OF A NON-ADIABATIC PROPULSION SYSTEM UTILIZING A REAL GAS PROPELLANT.
I. M. Sommerville (General Electric Co., Missile and Space Div., Advanced Space Projects Dept., Thermodynamics, Philadelphia, Pa.).
American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-373. 7 p.
Members, $0.50; nonmembers, $1.00.

Description of a method for predicting the state of any gas (for which equations of state are available) under transient conditions of loading (compression) or use (expansion) from a storage container. The basic differential equations relating the change in internal energy, enthalpy, and entropy to the independent variables are used, and heat losses and gains are taken into account. The equations are put in finite-difference form, are completely general, and do not require any ideal gas assumptions. The solutions are obtained with a digital computer program which solves the thermodynamic equations incrementally. The method is checked by comparing predicted temperatures and pressures with experimental values obtained during the filling of a tank with "Freon 14," a far from ideal gas. The method is found to be practical and applicable to many transient gas compression and expansion problems, such as are encountered with gas propellants and pressurants.

A64-20834
HYBRID PROPULSION FOR ADVANCED MISSIONS, RECENT DEVELOPMENTS, CURRENT STATUS, AND FUTURE OUTLOOK.
D. D. Ordahl and W. A. Rains (United Technology Center, Research and Advanced Technology Dept., Sunnyvale, Calif.).
American Institute of Aeronautics and Astronautics, Annual Meeting, 1st, Washington, D.C., June 29-July 2, 1964, Paper 64-226. 12 p.
Members, $0.50; nonmembers, $1.00.

Discussion of the development and possible applications of hybrid propulsion, a method which involves the use of combinations of both solid and liquid propellant materials. Many potential capabilities ranging from high impulse to variable thrust have been verified and progress has been made in the understanding and solution of the four principal problems that have blocked the effective exploitation of the hybrid concept. These problems have been: (1) poor fuel utilization, (2) low combustion efficiency, (3) very low burning rates of the fuel, and (4) loss of performance of throttling. The on/off thrust capabilities of a number of propellant systems have been demonstrated with impulse efficiencies of over 93% and nearly total fuel utilization. Advanced fuel formulations for which burning rates approximate those of conventional solid propellants have been developed.

A64-22763
MEASUREMENT OF IGNITION DELAY [MESURE DES DELAIS D'ALLUMAGE].
L. Nadaud and M. Pugibet (ONERA, Châtillon-sous-Bagneux, France).
IN: EXPERIMENTAL METHODS IN COMBUSTION RESEARCH; SECOND SUPPLEMENT TO THE MANUAL.
Published for NATO AGARD.
Oxford, Pergamon Press, 1964. 24 p. 16 refs. In French.

Description of methods for measuring ignition delays for hypergolic fuels. The physical significance of the ignition delay is discussed, and laboratory techniques for studying the effects of such parameters as the mixing ratio of the fuels and the pressure and temperature in the reaction zone are described. Procedures involving the use of microrockets to study the effects on ignition delay of injection pressure, the nature of the injection, and the conditions in the chamber prior to ignition are described. A method for measuring delay in an engine while in flight is discussed.

A64-23044
EXPLODING WIRES.
William G. Chace (USAF, Office of Aerospace Research, Cambridge Research Laboratories, Space Physics Laboratory, Plasma Astrophysics Branch, Hanscom Field, Bedford, Mass.).
Physics Today, vol. 17, Aug. 1964, p. 19-24. 5 refs.

Brief review of the phenomenon of explosion of a fine wire subjected to a large flow of electrical current. Uses of the phenomenon in modern technology are specified. They include high-speed photography, missiles, and space exploration equipment. Replacement of the ordinary bridge wires with exploding bridge wires in rocket ignitors is described. The study of the phenomenon by electrical measurements, high-speed photography, spectroscopy, interferometry, and X-ray pulses of nanosecond duration is discussed. A report on the 1964 Exploding-Wire Conference, held in Boston, is included.

A64-23078
NONSTEADY FLAME PROPAGATION.
Edited by George H. Markstein (Cornell Aeronautical Laboratory, Inc., Buffalo, N.Y.).
AGARDograph 75.
Oxford, England, Pergamon Press, Ltd.; New York, Macmillan Co., 1964. 328 p.
$16.

This monograph covers material on nonsteady flame propagation, which is either unpublished or available only in scattered original publications, for persons concerned with research on combustion processes. The subject is treated from the standpoint of fluid dynamics and stresses the interaction between flames and flow fields. The topics covered include: perturbation analysis of stability and response of plane flame fronts; experimental studies of flame-front instability; flame propagation in tubes and in closed vessels; general considerations of autonomous combustion oscillations; experimental and theoretical studies of combustion oscillations; and practical considerations of combustion oscillations. The monograph is also designed for study courses on combustion, gas dynamics, and jet and rocket propulsion.

A64-25344
VELOCITY EFFECTS IN TRANSVERSE MODE LIQUID PROPELLANT ROCKET COMBUSTION INSTABILITY.
F. H. Reardon, L. Crocco, and D. T. Harrje (Princeton University, Princeton, N.J.).

AIAA Journal, vol. 2, Sept. 1964, p. 1631-1641. 15 refs.
Grant No. NsG 99-60; Contracts No. NOas 60-6078-C; No. NOw 61-0686-d.

Extension of the theory of transverse-mode combustion instability to include linearized velocity effects. Fluctuations of the radial and tangential velocity components are assumed to influence the combustion-process rates in a manner analogous to that previously proposed by Crocco for pressure perturbations. A physical mechanism is suggested in the enhancement of the reactant mixing, which can be affected by the transverse components of the gas velocity. The analysis predicts that the tangential velocity perturbation may have a strong destabilizing effect on spinning tangential modes but will have no effect on standing modes. The radial velocity fluctuation is shown to have a smaller but significant influence. Experimental verification of the predicted effects has been obtained for a fuel-on-oxidizer impinging doublet-injector pattern and for like-on-like injection using close spacing (0.1 in.) of the liquid spray fans.

A64-25444

HIGH-ENERGY ROCKET ENGINES.
The Engineer, vol. 218, Sept. 4, 1964, p. 364-366.

Discussion of some of the practical implications of building a liquid oxygen/liquid hydrogen engine in the light of British experience. The subjects considered are American engines, British developments, performance, liquid fluorine, and turbopump. It is stated that engineers at the Rocket Propulsion Establishment have already designed a small uncooled gas generator to operate at a fuel-rich mixture ratio (about 1:1 by weight) and that this is in the process of manufacture. It is noted that this is indicative that the establishment will go on to design a turbopump, which will be built and run later.

A64-25466

A DRIVING MECHANISM FOR HIGH FREQUENCY COMBUSTION INSTABILITY IN LIQUID FUEL ROCKET ENGINES.
P. D. McCormack (Dublin, University, Trinity College, Engineering School, Dublin, Ireland).
Royal Aeronautical Society, Journal, vol. 68, Sept. 1964, p. 633-637.
USAF-supported research.

Study of a suspected capability of all liquid fuel rocket engines for producing high-frequency chamber pressure variations. It is contended and demonstrated that the onset of this phenomenon can be initiated by massive vibration response to the engine noise field component arriving at the vehicle surface. Application of the theory to a typical engine, subject to a known resonance vibration frequency, is said to predict a large-amplitude pressure variation. The pressure disturbance reportedly will be produced near the injector and must be sustained by some mechanism that adds energy to replace losses. The presence of pressure sensitive available energy, as postulated by Pickford and Peoples, is said to appear promising as a sustaining mechanism. The assumption made by Pickford and Peoples that the perturbation index is independent of the total energy added by the pressure waveform predicted by the author should solve the difficulty and lead to a more realistic index. A more refined and exact analysis of the combustion system in the presence of a modulated fuel flow rate is planned. An estimate of combustion time lag is given in an appendix.

A64-25663

EFFECT OF OXIDIZER CONCENTRATION ON COMBUSTION INSTABILITY OF A SOLID PROPELLANT.
D. W. Rice (U.S. Naval Ordnance Test Station, Aerothermochemistry Group, China Lake, Calif.).
AIAA Journal, vol. 2, Sept. 1964, p. 1654, 1655. 6 refs.

Report of an investigation. The theory of the ability of a propellant to drive oscillations in an end-burning motor is presented. The experiment to evaluate the response function of a composite ammonium perchlorate-PBAA propellant with different oxidizer-fuel ratios is described. The results show that the oxidizer-fuel ratio has only subtle effects on the unstable behavior of a solid composite propellant as compared to the effects of oxidizer particle size and burning-rate modifier.

A64-25673

CORRELATION OF MOTOR AND STRAND COMPOSITE PROPELLANT BURNING RATE.
L. E. Herrington (Aerojet-General Corp., Propellant Ballistics Dept., Sacramento, Calif.).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-150.)
AIAA Journal, vol. 2, Sept. 1964, p. 1671-1673.
[For abstract see Accession no. A64-13004 06-26]

A64-25677

HIGH-ENERGY ROCKET ENGINES. II.
The Engineer, vol. 218, Sept. 11, 1964, p. 415-417.

Description of the liquid hydrogen/liquid oxygen chambers used for development by the Rocket Propulsion Establishment, Westcott, UK, and manufactured by Bristol Aerojet, Ltd., with discussion of manufacturing details. Three chamber configurations have been designed, and outline illustrations are presented. The walls of the chambers are cooled with the propellants. A fundamental policy behind the design of the chambers was that they should be built to flight standard, that conventional building techniques should be used during manufacture, and that the whole engine should be constructed as far as possible from stainless steel to reduce thermal contraction on cooldown, and to unify hydrogen/metal compatibility. Two designs of injectors have been made and are illustrated. They are machined from aluminum bar without resorting to fabrication. A small glow plug protruding into the combustion region provides ignition. The tubular chamber consists of 72 double-taper tubes brazed together to form the combustion chamber and the nozzle. **A table shows the performances theoretically available with several tri-propellant combinations: liquid oxygen, liquid hydrogen, and aluminum, boron, and beryllium slurries.**

A64-26044

SOLID-PROPELLANT TECHNOLOGY - NEW DIMENSIONS.
Chemical and Engineering News, vol. 42, Sept. 28, 1964, p. 50-53.

General discussion of Aerojet-General's part in the DOD program for large solid-fuel rocket motors. The effect of the jump in size to 260-in.-diam. motors has affected all operations up to and including the firings. Different mechanical properties of the propellants are required to prevent slump, and processibility takes on greater importance. Different raw materials and additives are included in the formulation of the propellant. The problem of reproducibility is of prime importance. The new Aerojet test center near Homestead, Fla., is described in some detail.

A64-26177

AN IMPROVED METHOD FOR DETERMINING THE EFFECTS OF SLOSHING ON LIQUID-PROPELLANT-FILLED BOOSTER TRANSFER FUNCTIONS.
Ernest D. Ryan (North American Aviation, Inc., Space and Information Systems Div., Downey, Calif.).
IN: JOINT AUTOMATIC CONTROL CONFERENCE, 5TH, STANFORD UNIVERSITY, STANFORD, CALIF., JUNE 24-26, 1964, PREPRINTS OF CONFERENCE PAPERS.
Sponsored by the American Automatic Control Council (American Institute of Aeronautics and Astronautics, American Institute of Chemical Engineers, American Society of Mechanical Engineers, Institute of Electrical and Electronics Engineers, and the Instrument Society of America).
Stanford, Calif., Stanford University, 1964, p. 551-557.
Contract No. NAS 7-200.

Presentation of a more straightforward approach than the spring-mass system in the determination of sloshing effects on liquid-propellant-filled boosters. Starting with Euler's equation and the condition of continuity, an expression is derived for the fluid pressure on the moving tank wall. The surface integral of the pressure is then taken over the tank wall to obtain forces and moments due to sloshing. The center of pressure is also computed. The force and moment expressions are derived for a booster with cylindrical tanks. Parameters are then calculated for the commonly accepted spring-mass model. A comparison is then made between the model and the actual physical situation.

A64-26270
HIGH-ENERGY PROPELLANT COMBINATIONS FOR SPACE-FLIGHT MISSIONS [HOCHENERGETISCHE TREIBSTOFFKOMBINATIONEN FÜR RAUMFLUGAUFGABEN].
Eckart W. Schmidt (Deutsche Versuchsanstalt für Luft- und Raumfahrt, Institut für Raketentreibstoffe, Stuttgart, West Germany).
Wissenschaftliche Gesellschaft für Luft- und Raumfahrt, and Deutsche Gesellschaft für Raketentechnik und Raumfahrtforschung, Jahrestagung, Berlin, West Germany, Sept. 14-18, 1964, Paper no. 74. 11 p. In German.

Discussion of some of the problems associated with selection criteria for propellant combinations for such space-flight missions in which there are longer unpowered periods between powered phases. A survey is made of the existing high-performance propellants, with particular emphasis on fluor-containing oxidizers.

A64-26541
ALUMINA SIZE DISTRIBUTIONS FROM HIGH-PRESSURE COMPOSITE SOLID-PROPELLANT COMBUSTION.
Louis A. Povinelli and Robert A. Rosenstein (NASA, Lewis Research Center, Cleveland, Ohio).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-115.)
AIAA Journal, vol. 2, Oct. 1964, p. 1754-1760. 14 refs.
[For abstract see Accession no. A64-13045 06-26]

A64-26552
USE OF STRESS RELAXATION TESTS TO CHARACTERIZE TIME DEPENDENCIES OF A COMPOSITE SOLID PROPELLANT.
Joseph H. Stoker (Thiokol Chemical Corp., Wasatch Div., Development Laboratory, Brigham City, Utah).
(American Institute of Aeronautics and Astronautics, Solid Propellant Rocket Conference, Palo Alto, Calif., Jan. 29-31, 1964, Preprint 64-131.)
AIAA Journal, vol. 2, Oct. 1964, p. 1816-1818.
[For abstract see Accession no. A64-13022 06-26]

A64-26574
THERMAL ASPECTS OF LONG-TERM PROPELLANT STORAGE ON THE MOON.
Tibor Buna (Martin Marietta Corp., Martin Co., Baltimore Div., Propulsion and Thermodynamics Dept., Baltimore, Md.).
(American Rocket Society, Annual Meeting, 17th, and Space Flight Exposition, Los Angeles, Calif., Nov. 13-18, 1962, Paper 2690-62.)
Journal of Spacecraft and Rockets, vol. 1, Sept.-Oct. 1964, p. 484-491. 17 refs.
[For abstract see Accession no. A63-12228 06-30]

A64-26822
HIGH ENERGY ROCKET ENGINES - LIQUID FLUORINE.
J. A. Williams.
The Engineer, vol. 218, Sept. 25, 1964, p. 510.

Discussion of some advantages of the LF_2/LH_2 (liquid fluorine/-liquid hydrogen) fuel system. The disadvantages of toxicity and reactivity are considered to be well understood and to be susceptible of adequate control by known procedures. Comment is made that hydrogen and fluorine have a high chemical affinity for one another, which in practice makes the combustion completely self-igniting. Although the exhaust gas is highly toxic, it is considered that its high exit temperature could be used to form relatively inert inorganic fluorides, such as calcium fluoride, followed by cooling and scrubbing of the remaining uncombined gas. It is indicated that the necessary plant would be relatively compact. F. R. L.

A64-26947
ROCKET PROPELLANTS FROM THE MOON.
Dandridge M. Cole and Ronald Segal (General Electric Co., Missile and Space Div., Valley Forge, Pa.).
Astronautics and Aeronautics, vol. 2, Oct. 1964, p. 56-60, 63. 21 refs.

Discussion of the possibility of using made-on-the-Moon propellants to supplement or replace supplies carried from the Earth to improve the cost feasibility of supplying and maintaining a lunar base. A criterion is presented for measuring the effectiveness of the lunar plant as a function of its manufacturing efficiency. "Break-even" points are found which must be exceeded for refueling to be competitive with or superior to direct flight. These points are determined for a typical manned Mars mission using chemical-fuel rockets, nuclear-thermal rockets, and for chemical rockets with refueling vs nuclear rockets on direct flight. An estimate is made of the ability of some commonly proposed lunar propellant-manufacturing systems to meet the criteria established. Consideration is given also to the possibilities for reducing transportation costs for lunar-base logistics, with the measures of effectiveness being applied to various types of missions. A listing is made of some of the implications of propellant production in the lunar environment as regards space exploration. M. M.

A64-27256
INCREASING THE SPECIFIC IMPULSE OF HYBRID ROCKETS BY HYDROGEN ADDITION [AUGMENTATION DE L'IMPULSION SPECIFIQUE DES LITHERGOLS PAR ADDITION D'HYDROGENE].
Hélène Moutet and Maurice Pugibet.
La Recherche Aérospatiale, July-Aug. 1964, p. 21-31. In French.

Description of experiments carried out on solid-fuel chambers and aiming at reducing the mean molar mass of the combustion products. A third propellant of low molar mass is injected into the combustion chamber. Hydrogen, the lightest of all known gases, is used for this purpose. Various types of solid fuels are utilized. The performance increase is important particularly in the case of conventional aminated solid fuels. In some cases better combustion has been observed. F. R. L.

A64-27306
CHEMICAL PROPELLANTS ARE INADEQUATE FOR INTERPLANETARY TRAVEL [LOS PROPERGOLES QUIMICOS SON INSUFICIENTES PARA LOS VIAJES INTERPLANETARIOS].
Demetrio Iglesias Vacas.
Revista de Aeronáutica y Astronáutica, vol. 24, Aug. 1964, p. 645-652. In Spanish.

Discussion of the reasons for replacing chemical propellants with other propulsion systems, in order to make possible manned interplanetary travel. It is demonstrated that chemical propellants cannot achieve an ejection velocity of 15.51 km/sec, necessary to reach an orbiting speed of 11 km/sec. M. M.

A64-28006
INVESTIGATION OF THE HEAT TRANSFER IN THE THROAT OF LIQUID-OXYGEN CONTAINERS [ISSLEDOVANIE PERENOSA TEPLA PO GORLOVINE SOSUDOV DLIA ZHIDKOGO KISLORODA].
M. G. Kaganer and R. S. Semenova (Institut Kislorodnogo Mashinostroeniia, Moscow, USSR).
Inzhenerno-Fizicheskii Zhurnal, vol. 7, Aug. 1964, p. 97-102. 5 refs. In Russian.

Discussion of the experimental results for heat transfer along tubes with inside gas flow, imitating conditions which cause liquid-gas loss due to heat infiltration through insulation into liquid-gas containers during storage and transportation. Copper, brass, German-silver, and stainless-steel tubes of different diameters are used in tests to estimate the heat influx in the throat of containers and the vaporization of liquid oxygen as it leaves the container. A method of calculation of the heat influx is described. V. Z.

A64-28208
LIQUEFACTION, STORAGE, AND TRANSPORT OF HYDROGEN AND FLUOR ON AN INDUSTRIAL SCALE [VERFLÜSSIGUNG, LAGERUNG UND TRANSPORT VON WASSERSTOFF UND FLUOR IN TECHNISCHEM MASSSTAB].
Martin Streich (Adolf Messer GmbH, Frankfurt am Main, West Germany).
Wissenschaftliche Gesellschaft für Luft- und Raumfahrt and Deutsche Gesellschaft für Raketentechnik und Raumfahrtforschung, Jahrestagung, Berlin, West Germany, Sept. 14-18, 1964, Paper. 19 p. 28 refs. In German.

Lecture on liquid gases as rocket propellants. Criteria for evaluating rocket propellants are defined. The principles of liquefaction of H_2 by the classical Linde method, the double-pressure method, the Claude process, and the helium-hydrogen condensation technique are outlined, and the liquefaction energy required in each

case is illustrated as a function of the applied pressure. The enthalpy-temperature diagram of hydrogen and the energy required for irreversible heat transfer are examined. The two-phase and four-phase cooling methods are described, as are some ortho-para conversion methods. Current types of storage tanks, pump systems, and insulation materials are examined, including the storage techniques used for space vehicles and rockets. Finally, safety requirements and measures are treated in some detail. V. P.

A64-28526

ENERGETICS OF PROPELLANT CHEMISTRY.

Bernard Siegel (Aerospace Corp., High Temperature Chemistry Section, Los Angeles, Calif.) and Leroy Schieler (Aerospace Corp., Chemical Propulsion Dept., Los Angeles, Calif.).

New York, John Wiley and Sons, Inc., 1964. 240 p.

$10.00.

An introduction to propellant chemistry for chemists, advanced chemistry students, and propulsion engineers is presented. The basic principles of energetics, which form the foundation upon which the science of propellant chemistry rests, are described. Initially, the energetics of combustion products and propellant reactants are considered separately, thus permitting a development of the subject matter in the detail necessary for a minimum understanding of the subject. This separation is also advantageous because the principles used in evaluating products and reactants are entirely different. The general importance of selecting products with large negative standard heats of formation (highly exothermic products), the factors leading to high exothermicity, reduced dissociation at high temperature, the factors leading to stability at high temperature, and the desirability of having low molecular-weight combustion products are emphasized in the discussion of these products. This is augmented by an extended discussion of combustion products from the viewpoint of working gas properties rather than exothermicity. In the discussion of propellant ingredients, the viewpoint is again that of the relationship between energetics and molecular bonding. Although only simple compounds are treated, the systematic consideration of energetics and physical properties is considered sufficient to demonstrate the principles that govern the selection of desirable ingredients. The principles involved in propellant performance calculations, selection of desirable combustion products, and selection of desirable ingredients are integrated in a final chapter on real propellant systems. Three appendices give the physical and thermodynamic properties of propellant ingredients, the thermodynamic properties of propellant ingredients, and exhaust products as a function of temperature, and performance tables. Author and subject indices are presented. F. R. L.

A64-80230

ATMOSPHERIC MONITORING OF TOXIC LEVELS OF MISSILE PROPELLANTS.

John T. Nakamura (Rocket Res. Lab., Edwards, Calif.) and Kenneth E. Ball (Mine Safety Appliances Co., Pittsburgh, Pa.)

American Industrial Hygiene Association Journal, vol. 25, Jan.–Feb. 1964, p. 77–80.

The Chemical and Materials Section of the Rocket Research Laboratories, Edwards Air Force Base, is responsible for hazard appraisal of various storable liquid propellants. Evaluating the toxic hazards posed by spills or inadvertent releases has been curtailed by a lack of suitable instrumentation and by the shortcomings of applying laboratory wet chemical techniques to field experiments. Under contract to Edwards Air Force Base, the Mine Safety Appliances Company developed an instrument suitable for continuous monitoring for toxic levels of NO_2, dimethylhydrazine, B_5H_9, N_2H_4, F_2, and ClF_3. Based on spill test data, realistic performance specifications are suggested for any continuous toxic-hazard monitoring equipment for missile facilities.

A64-80273

AEROSPACE MEDICAL SURVEILLANCE OF THE TITAN II.

Robert N. Reiner and John J. Mc Cambridge (Headquarters Fifteenth AF, Office of the Surgeon, March AFB, Calif.)

Aerospace Medicine, vol. 35, Mar. 1964, p. 233–238.

Air Force medical service surveillance of the development of an operational capability for the Titan II weapon system is discussed. This system uses storable propellants, aerozine-50, the fuel, a mixture of hydrazine and unsymmetrical dimethylhydrazine (UDMH), and nitrogen tetroxide as the oxidizer. Of these compounds, nitrogen tetroxide is the most serious hazard. The toxic hazard associated with exposure to aerozine-50 is due mainly to the UDMH compound. The maximum allowable concentration for nitrogen tetroxide has been set at 2.5 parts per million; however, higher concentrations of the vapor can normally be tolerated for relatively short periods of time. The threshold limit of UDMH is 0.5 part per million and for hydrazine, 1.0 part per million. Procedures for personnel selection, treatment, and protection are described. Methods by which medical service personnel become familiar with the Titan II weapon system are also described.

A64-80887

MODERN PROBLEMS OF TOXICOLOGY AND PREVENTIVE MEDICINE BROUGHT ABOUT BY THE USE OF MISSILE PROPELLANTS (MODERNI PROBLEMI DI TOSSICOLOGIA E DI MEDICINA PREVENTIVA DERIVANTI DALL'IMPIEGO DI PROPELLENTI PER MISSILI).

Renato Pons (Centro Studi di Med. Navale, La Spezia, Italy).

Annali di Medicina Navale, vol. 68, Sep.–Oct. 1963, p. 773–796. 19 refs. In Italian.

A discussion is presented on toxic missile fuels and propellants including red nitric fuming acid, unimetric dimethyl hydrazine, M-3 propellant, nitrogen peroxide, and ethylene oxide. A summary is given of their chemical and toxic properties, and the clinical aspects, symptomatology, and treatment of toxic states. The following recommendations are made for the prevention of acute and chronic injury to personnel working in the area of missile propellants and fuels: (1) selection and preventive instruction of personnel involved in their production and handling; (2) periodic medical examination of all personnel; (3) frequent periodic inspection of work areas to determine hazardous concentrations and to determine safety tolerance levels; (4) obligation of all personnel to adhere to prescribed safety rules and to wear masks when necessary; and (5) instruction of all personnel in first aid.

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