NASA
SPACE VEHICLE
DESIGN CRITERIA
(CHEMICAL PROPULSION)

NASA SP-8126

GLOSSARY OF TERMS AND TABLE OF CONVERSION FACTORS USED IN DESIGN OF CHEMICAL PROPULSION SYSTEMS

OCTOBER 1979

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This Glossary is an outgrowth of the work done by NASA-Lewis Research Center and its associated contractors in generating a set of 33 Design Criteria monographs on Chemical Propulsion. (A list of the monographs in this series is included in the list of all published NASA Space Vehicle Design Criteria monographs presented on the final pages of this document.) In the course of preparing these monographs, it became apparent that a unified collection of terms and definitions and table of conversion factors for units as they are used in the design and development of chemical propulsion systems for space vehicles would fill an obvious need, serving both as a useful addition to the set of monographs in achieving better communication among design personnel and as an aid in producing greater consistency in design and greater efficiency in the design effort.

The Glossary presented is neither exhaustive nor all-inclusive; it is based entirely on terms used in the monographs on Chemical Propulsion. It does not include general scientific and engineering terms with well-accepted conventional meanings (e.g., airfoil, pressure, force) nor does it include highly specialized design terms unique to a small segment of a chemical propulsion system. No materials are included, but significant terms relating to material properties and to material fabrication are presented. The terms are arranged in alphabetical order, with multiple-word terms appearing in the normal sequence of usage; for example, ablative cooling appears as such, not as cooling, ablative, and lip seal appears as such, not as seal, lip. Conversion Factors for converting U. S. customary units to the International System of Units (SI units) are presented in alphabetical order of the physical quantity (e.g., density, heat flux, specific impulse) involved.

The Glossary was compiled and edited by Russell B. Keller, Jr. of the Lewis Research Center, who also edited the Design Criteria monographs on Chemical Propulsion.

Comments concerning the technical content of this Glossary will be welcomed by the National Aeronautics and Space Administration, Lewis Research Center (Design Criteria Office), Cleveland, Ohio 44135.

October 1979

CONTENTS

GLOSSARY OF TERMS

-A-

ablation. process in which thermal energy is expended by a sacrificial loss of material. In the process, heat is absorbed, blocked, dissipated, and/or generated by mechanisms that include phase transitions (melting, vaporization, and sublimation); mass transfer into the boundary layer; convection in the liquid layer (if one exists); radiant-energy transport; conduction into the solid body; chemical reactions; and erosion.

ablative cooling. reduction of the heat transferred from hot combustion products to a nozzle or chamber wall by ablation of material on the wall

ablative material. material designed or formulated so as to dissipate incident heat by degrading through the process of ablation

accelerometer. an instrument, usually a transducer, that measures change in velocity, or measures the gravitational forces capable of imparting a change in velocity

acceptor charge. charge on the internal side of an igniter that is detonated by the shock wave transmitted through the internal diaphragm in a through-bulkhead initiator

acoustic absorber. an array of acoustic resonators distributed along the wall of a combustion chamber, designed to prevent oscillatory combustion by increasing damping in the engine system

action time. interval from attainment of a specified initial fraction of maximum thrust or pressure level to attainment of a specified final fraction of maximum thrust or pressure level

actuation time. elapsed time from receipt of signal to first motion of the device being actuated

actuator. device that converts hydraulic, pneumatic, electrical, or potential energy into mechanical motion

adhesive. material applied between components to bond the components together structurally

adiabatic. term applied to a thermodynamic process in which heat is neither added to nor removed from the system involved; when the process is reversible, it is called isentropic

adiabatic wall. in a thermodynamic system, a boundary that is a perfect heat insulator (neither emits nor absorbs heat); in boundary-layer theory, the wall condition in which the temperature gradient at the wall is zero

adiabatic wall temperature. steady-state temperature of the wall of a combustion chamber or nozzle when there is no heat transfer between the wall and the exhaust gas; also called recovery temperature

aerodynamic heating. heating of a body by the friction generated by high-velocity air or other gas passing over the body surfaces

aerodynamic performance. portion of the nozzle performance due to nozzle divergence efficiency (the degree of perfection of the nozzle contour)

aerodynamic throat area. effective flow area of the nozzle throat; the effective flow area is less than the geometric flow area because the flow is not uniform

aerospike nozzle. annular nozzle that allows the gas to expand from one surface – a centerbody spike – to ambient pressure

all-fire limit. minimum energy (e.g., voltage) required to consistently fire an electroexplosive device

allowable load (or stress). load that, if exceeded, produces failure of the structural element under consideration. Failure may be defined as buckling, yielding, ultimate, or fatigue failure, whichever condition prevents the component from performing its intended function. Allowable load is sometimes referred to as criterion load or stress; allowable stress is equivalent to material strength

altitude engine. rocket engine that is designed to operate at high-altitude conditions (see sea-level engine)

ambient. term referring to a condition or state (e.g., temperature, pressure) of the environment surrounding a component or system

anisotropy. condition in a material in which properties are not the same in all directions; observed or measured properties change when the axis of observation or test is changed

annular nozzle. nozzle with an annular throat formed by an outer wall and a centerbody wall

anodize. to produce a protective oxide film on a metal (usually Al) by electrochemical means

anti-extrusion ring. ring installed on the low-pressure side of a seal or packing to prevent extrusion of the sealing material; also called a backup ring

anti-rotation device. mechanical device (e.g., a key) used in rotating machinery to prevent rotation of one component relative to an adjacent component

anti-slosh baffle. device provided in a tank to damp liquid motion; can take many forms including flat ring, truncated cone, and vane

anti-vortex baffle. radial vane attached to inner tank wall adjacent to the inlet to engine feedline to inhibit fluid vortexing at the inlet

area ratio. ratio of the geometric flow area of the nozzle exit to the geometric flow area of the nozzle throat; also called expansion area ratio or simply expansion ratio

articulated. segmented or jointed and thereby able to accommodate motion

aspect ratio. 1. ratio of width to height in a rectangular flow passage; 2. ratio of blade height to chord length; 3. ratio of width to depth in a rectangular combustion chamber

asperities. minute irregularities or roughnesses on the surface of a component, usually the result of the surface-finishing process

asymmetric separation. separation of the exhaust jet from the nozzle wall nonuniformly or at localized regions not in the same plane

autoignition. self-ignition or spontaneous combustion of propellant

axial deflection. elongation or compression along the longitudinal axis

-B-

backlash. 1. dead space or unwanted movement that results from fabrication and assembly tolerances in linkages; excessive backlash produces poor positional control of the controlled element or errors in position instrumentation; 2. the clearance between the tooth spacing of a gear and the tooth thickness of a meshing gear

baffle. partitioning device (plate, wall, screen) used to deflect, check, or interrupt fluid motion; used, for example, in a combustion chamber for stabilizing combustion, or in a tank for preventing slosh

balance chamber. pressurized chamber used to counteract the unbalanced pressure forces exerted on a poppet valving element and thereby decrease the force necessary to actuate the element

balance piston. special mechanical device used to balance axial thrust in a turbopump and thereby reduce axial loads imposed on the bearings

balance ratio. ratio of the effective closing area of the seal face to the actual area of the seal face

balance ribs. blades on the back of the pump impeller that reduce the pressure on the impeller back side and help control the axial thrust loads

ball flow tube. tube inserted into a hollow ball to reduce pressure drop through a ball valve

ball valve. rotary-action valve incorporating a ball with a flow passage that rotates to align the flow passage with the mating upstream and downstream lines

bandwidth. limits of variation of a regulated variable (e.g., pressure) above and below its desired value

barrier cooling. use of controlled mixture ratio near the wall of a combustion chamber to provide film of low-temperature gases to reduce the severity of gas-side heating of the chamber

Barske pump. low-specific-speed partial-emission pump having an open-face impeller, often with radial blades

base. 1. configuration of a plug nozzle in the plane of truncation; 2. portion of a blade (or vane) that forms the attachment to the rotor (or vane support)

base cavity. the opening in the base of a plug nozzle

base fixity. index of the relative tightness in the mounting of a blade in the rotor or a vane in the vane support

base pressure. static pressure in the base cavity of a plug nozzle

bearing (rolling-element). mechanical device, usually consisting of two integral concentric channels with rolling elements (e.g., spheres or cylinders) confined between them, used to support and position a rotating shaft with as little friction as possible

bed reactor. term for a gas generator design in which the combustion chamber is nearly filled with a solid material that assists decomposition by either catalytic or thermal action

Belleville spring. truncated conical metal washer that exerts a nonlinear spring rate when compressed axially; some configurations produce a negative rate over a portion of the travel

bell nozzle. nozzle with a circular opening for a throat and an axisymmetric contoured wall downstream of the throat that gives the nozzle a characteristic bell shape

bellows. thin-wall, circumferentially corrugated cylinder that can be elongated or compressed longitudinally and, when integrated into a duct assembly, can accommodate duct movements by deflection of the corrugations (convolutions); also used in tanks to provide positive expulsion of fluid and in fluid systems to isolate a regulator or valve or similar component

bevel gear. one of a pair of toothed wheels whose working surfaces are inclined to nonparallel axes; also, a gear whose teeth are at an angle to the rotating axis

bias spring. spring used to maintain a detail part in a preferred position while the assembly is nonoperating

bifurcation joint. junction of two tubes or flow passages with another tube or passage

bird-cage attachment. method for attaching chamber to injector, in which bolts extend the length of the chamber from the injector to a separate retaining ring at the aft end

bipropellant valve. valve incorporating both fuel and oxidizer valving units driven by a common actuator

blade. 1. one of a set of slat-like objects rigidly fixed to a rotatable shaft, each slat being carefully shaped as an airfoil such that (a) rotation of the shaft in a fluid creates a flow of fluid, or (b) fluid flow impinging on the blades rotates the shaft; 2. a flat plate used to adjust flow in a blade valve

blade valve (rotary). valve that controls flow by means of a flat plate that is rotated transversely in a slotted chamber between upstream and downstream lines

blade valve (slide). valve that controls flow by means of a flat plate that slides transversely in a slotted chamber between upstream and downstream lines

bleed. 1. continuous flow of gas through a pilot valve. 2. to remove or draw off fluid from a system

bleeder cloth. open-weave fabric used to facilitate complete removal of gas in vacuum-bag processing of reinforced-plastic parts

blockage. 1. decrease in pump effective flow area due to the blade thickness and the boundary layer on the blades and end wall; 2. restriction in a cavity or flow passage

blockage factor. the fraction or percentage by which design flow area is increased to account for blockage; conversely, the ratio of flow area corrected for blockage to design flow area

blowdown system. closed propellant/pressurant system that decays in ullage pressure level as propellant is consumed and ullage volume thereby is increased

B-nut. coupling nut used to connect and seal tubing to a threaded connector

boattail. aft (rear) end of a rocket that contains the propulsion system and its interface with vehicle tankage

Boltzmann superposition. overlaying of a series of step functions to find the gross response to a time-varying input

booster. the first or basic separable self-propelled section (stage) in a rocket vehicle having two or more such sections

boss. thickened protuberance in the wall of a duct or tank for the purpose of allowing attachment of components or connection of other lines or instruments

borescope. arrangement of mirrors or fiber optics that makes possible the inspection of otherwise inaccessible locations

boundary layer. in fluid flow, the film of fluid next to a bounding surface such as the combustion chamber wall or nozzle wall; its thickness usually is taken as the radial distance from the surface to the point at which fluid velocity reaches 99 percent of freestream velocity

boundary-layer trip. discontinuity or local turbulence in the boundary layer generated by a protrusion from the surface in contact with the boundary layer; tripping usually increases the severity of the thermal environment

breakaway disconnect. separable connector that is disengaged by the separation force as the vehicle rises from the launch pad or a stage separates from a lower stage; also called a rise-off or staging disconnect.

bridgewire. resistance wire, attached to the leads of an electroexplosive device, whose function is to convert the electrical firing signal into thermal energy adequate to ignite the prime charge of an igniter

Brinell hardness. indentation hardness determined by pressing a hardened-steel sphere into the test material under a specified load for a specified time; the diameter of the impression produced is an index to the hardness

brittle failure. rupture of structural material that is not preceded by appreciable deformation of the material

B-stage. intermediate stage in the polymerization of a thermosetting resin; in this stage the resin is dry and relatively stiff at room temperature but softens when heated

bubble point. gas pressure at which a gas bubble forms at the surface of a filter immersed in a test fluid; used to determine filter rating

builtup shaft. shaft with a multiplicity of components such as collars, sleeves, and couplings

bulkhead. structural membrane perpendicular to the axis of the structure containing it; usually used in a rocket vehicle to physically separate two fluids contained in a single tank

burndown weld. fusion butt weld with no material added; usually applies to thin-gage duct materials with burndown lips bent up on ends to be welded

burn rate. literally, the rate at which a solid propellant burns, i.e., rate of recession of a burning propellant surface, perpendicular to that surface, at a specified pressure and grain temperature; in grain design, the rate at which the web decreases in thickness during motor operation

burning surface. all surface of a solid-propellant grain that is not restricted from burning at any given time during propellant combustion

burn time. for a solid propellant, the interval from attainment of a specified initial fraction of maximum thrust or pressure level to web burnout

burst disk. passive physical barrier in a fluid system that blocks the flow of fluid until ruptured by fluid pressure

burst pressure. fluid pressure at which a pressurized component will rupture

burst test. pressure test of a component to rupture to determine whether the component can withstand the calculated burst pressure

butterfly valve. valve constructed to close off or throttle flow by rotation of a circular disk around a transverse axis within the flow passage

-C-

cage. mechanical contrivance in a bearing that contains the rolling elements and confines them to the bearing raceways

camber. curvature of the mean line of an airfoil; the distance from the point of greatest curvature to the chord

Campbell diagram. plot of rotational speed vs blade frequency with forcing function as a variable, used to identify resonant conditions in a pump or turbine or rotating machinery in general

capacity (pump). volume of liquid pumped per unit time

captive firing. test firing of a propulsion system, in which the engine is operated at full or partial thrust while restrained in a test stand; the system is completely instrumented, and data to verify design and demonstrate performance are obtained

case. 1. the structural envelope for the solid propellant in a solid rocket motor; 2. the outer portion of metallic materials

case bonding. cementing of the solid propellant to the motor case through the insulation by use of a thin layer of adhesive (the liner)

case hardening. infiltration of a metallic surface with carbon so that the outer portion of the material (case) is made harder than the inner portion (core)

casing. the part of the pump housing that surrounds the impeller

casting powder. small (e.g., 0.050-in. (1.27 mm)) grains used in the interstitial casting process

"cat-eyes". long, narrow openings between thrust-chamber coolant tubes provided to discharge turbine exhaust gases

cavitating venturi. convergent-divergent constriction in a line that produces cavitation at its throat; because of the cavitation effects, flow of the liquid in the line is a function only of pressure upstream of the constriction even though the downstream pressure varies

cavitation. formation and instantaneous collapse of vapor bubbles in a flowing liquid whenever the static pressure becomes less than the fluid vapor pressure

chamber. see combustion chamber

chamber filling interval. time period from complete ignition of the solid-propellant grain to achievement of equilibrium burning pressure

chamber pressure. stagnation pressure of the exhaust gases in a combustion chamber

channel construction. use of machined grooves in the wall of the nozzle or chamber to form coolant passages

char. rigid, porous material remaining after severe thermal degradation of an organic material; also refers to any solid residue formed by thermal degradation of a material

characteristic length. ratio of combustion chamber volume to nozzle throat area

characteristic line. mathematical line inclined to the direction of flow, used to compute the flow field

characteristic velocity. ratio of effective exhaust velocity to thrust coefficient; also called characteristic exhaust velocity

characterization. 1. definition of physical or chemical properties of a material in relation to its application or use in a propellant formulation or rocket motor; 2. definition of the total functional capability of a component or system

chatter. uncontrolled rapid seating and unseating of a flow-control device, usually at low-flow conditions

check valve. flow-control device that allows flow in one direction only

chevron seal. term for a set of seals having a V-shaped cross section loaded by mechanical or fluid wedging action

chilldown. cooling of all or part of a cryogenic engine system from ambient temperature to cryogenic temperature by circulating cryogenic fluid through the system prior to engine start

choked flow. flow condition in a flow passage such that flowrate through or upstream of the passage cannot be increased by a reduction of pressure downstream of the passage

chord. straight line connecting the ends of an arc; usually, the line joining the leading and trailing edges of an airfoil

chugging. low-frequency oscillatory combustion; in a fluid system, the oscillations are hydraulically coupled to the propellant feed system

circular lay. circular direction of the predominant pattern of a machined surface; ordinarily determined by the production method used

circumferential seal. seal, composed of a continuous ring or of one or more split or segmented rings, whose sealing surface is parallel to the centerline of the flow passage (also called radial seal)

clean room. a delimited space in which dust, temperature, and humidity are controlled as necessary for the fabrication and/or assembly of critical components

clearance seal. seal that limits the leakage between a rotating or reciprocating shaft and a stationary housing by controlling the annular clearance between the two

closed loop. term applied to an electrical or mechanical system in which the output is compared with the input command signal, and any discrepancy between the two results in corrective action by the system elements

coaxial injector. type of injector in which one propellant surrounds the other at each injection point

cohesive fracture. rupture or cracking of material within the body of the material, not at a bondline at the interface with other material

coil clash. contact of adjacent coils as a helical spring is compressed

coined groove. narrow channel or depression stamped in a burst disk to provide localized thinning of material in a desire pattern

coking. deposition of a solid residue by a material when it is burned or distilled

cold flow. 1. term applied to a test of an engine or all or part of engine system, in which fluid is flowed through the test configuration without the engine being started; term also is applied to tests of model fluid systems; 2. permanent deformation of material caused by a compressive load that is less than the load necessary to yield the material; some time is required to obtain cold flow

combined stresses. stresses resulting from simultaneous action of all loads to which a structure is subject

combustion chamber. portion of a rocket engine in which propellants are burned

combustion stabilization device. contrivance in the combustion chamber that reduces or eliminates oscillatory combustion by reducing the coupling of the oscillations with the driving combustion processes or by increasing the damping inherent in the engine system

compliance (fluid). effective compressibility of a fluid, i.e., the change in fluid volume per unit pressure change

composite propellant. solid propellant system comprising a discrete solid phase dispersed in a continuous solid phase

compressibility factor. ratio of ideal-gas density to real-gas density

compression set. percent of deflection by which an elastomer fails to recover after a fixed time under specified squeeze and temperature

compression system. duct system wherein the fluid-column loads due to internal pressure are reacted by the support structure

connector. mechanical device for joining or fastening together two or more similar parts, e.g., lines or tubes in a fluid system or wires in an electrical system

conocyl. coined word for "cone in cylinder", a specific solid-propellant grain configuration

Conoseal. trademark of Aeroquip Corp., Marman Div. for a leak-proof joint using an all-metal radial seal

contact ratio. average number of teeth in contact in a pair of meshing gears

contaminant tolerance. amount (by weight) of a standard contaminant (added at the inlet of a filter under specified fluid flowrate, temperature, and pressure) that causes the pressure loss in the filter to exceed a maximum allowable value

contamination tolerance level. value of contaminant particle size, or level of contamination, in a fluid system at which the specified performance, reliability, or life expectancy of the components of the system is adversely affected

contraction ratio. ratio of the area of the combustion chamber at its maximum diameter to the area of the throat

controller. device that converts an input signal from the controlled variable (temperature, pressure, level, or flowrate) to a valve actuator input (pneumatic, hydraulic, electrical, or mechanical) to vary the valve position to provide the required correction of the controlled variable

convolution. longitudinal wave (corrugation) plastically formed in a thin-wall (usually metal) tube

coolant tube. relatively small-diameter thin-wall conduit attached to or forming the wall of a regeneratively cooled combustion chamber or nozzle and carrying propellant to cool the wall

Coulomb damping. dry-friction damping; friction force is constant in magnitude but always directed opposite to the velocity

counterpermeation. simultaneous migration of propellant vapor and pressurant (in opposite directions) across a permeable membrane

coupling. mechanical device that fastens together two parts of a turbopump shaft or connects the shaft to other components of the turbopump; also, a separable connector in a fluid system line or duct

coupon. piece of material, representative of the material used in a part, that accompanies the part during processing and subsequently is used as a test specimen to evaluate properties of the part material

cracking. 1. thermal decomposition of heavy (complex) hydrocarbons into lighter and simpler hydrocarbons and other products; 2. opening of a flow-control device to allow flow of fluid

cracking pressure. effective differential pressure above which a flow-control device (e.g., a valve) will open and allow flow of fluid

creep. permanent deformation of material caused by a tensile or compressive load that is less than the load necessary to yield the material; some time is required to obtain creep

creep strength. degree to which a given material resists creep; also, the maximum load at which a given material will not exhibit a significant amount of creep

crevice corrosion. corrosion that occurs in a narrow, relatively deep opening where two similar surfaces meet and trap a reactive fluid that acts as an electrolyte; corrosion occurs because of the concentration gradient of the reactive species established within the trapped fluid

critical crack size. crack or flaw size in a pressure vessel at or above which the crack, at a specified stress level, will grow and become unstable (i.e., will lead to brittle failure)

critical flow capacity. point in the performance of a tank-pressurization heat exchanger at which pressurant volumetric flowrate is at a maximum and an increase in pressurant produces a decrease in volumetric rate

critical ignition pressure. pressure below which propellants cannot be ignited

critical speed. shaft rotational speed at which a natural frequency of a rotor/stator system coincides with a possible forcing frequency

crowned spline. spline modified along the face width or profile to anticipate misalignment

cryogenic. fluids or conditions at low temperatures, usually at or below −150°C (123K)

cryogenic propellant. propellant that is liquid only at temperatures below −150°C (123K)

cryogenic seal. seal that must function effectively at temperatures below −150°C (123K)

cryopump. to reduce pressure in a cavity by condensing confined vapors and gases on extremely cold (cryogenic) surfaces

curvic coupling. trade name of the Gleason Works for a face-gear type of coupling generated in manner similar to that used for bevel gears

cycle life. number of times a unit may be operated (e.g., opened and closed) and still perform within acceptable limits

cyclic vibration. vibration mode, induced by rough combustion in a rocket engine, that periodically produces severe g loads at one predominant frequency

cylindrical grain. solid-propellant grain in which the internal cross section is a circle

cylindrical slide or piston valve. valve with a cylindrical bore with radial holes that are covered or uncovered by sliding of a piston in the bore

-D-

dam. flat plate inserted perpendicularly into a fluid manifold in order to partially or fully separate two streams approaching from opposite directions

datum. reference surface for locating critical points (e.g., bearing locations) on a turbopump shaft; normally the shaft longitudinal axis or the shaft shoulder

debond. localized failure of adhesive at the interface of two components cemented together

debulk. to compact prepreg (q. v.) by the application of pressure prior to initiation of cure

deep-space vacuum. term applied to pressure less than 10^{-11} mm Hg (1.333×10^{-13} N/cm^2)

decontamination. cleaning process to neutralize or remove harmful fluids from a component, system, or assembly

deflagration. burning process in which large quantities of gas and energy are released rapidly. In a deflagration, the reaction front advances at less than sonic velocity and gaseous products move away from unreacted material; a deflagration may, but need not, be an explosion

design allowables. precise accepted values of material mechanical properties for use in design and analysis

design burst pressure. maximum limit pressure multiplied by the ultimate factor of safety

design load (or pressure). product of the limit load (or pressure) and the design safety factor

design margin. term for the difference between the capability of a component to perform and the specified use requirement; e.g., if an expulsion devices's cycle life under full working pressure and dynamic environments exceeds mission requirements by 100,000 cycles, then the device has a design margin of 100,000 cycles

design safety factor. arbitrary multiplier greater than 1 applied in structural design to account for design uncertainties such as slight variations in material properties, fabrication quality, load magnitude, and load distributions within the structure; the safety factor may be based on yield, buckling, or ultimate strength or on fatigue life

design stress. the stress, in any structural element, that results from the application of the design load or combination of design loads, whichever condition results in the highest stress

design ultimate load. limit load multiplied by the ultimate design safety factor

design yield load. limit load multiplied by the yield design safety factor

detonation. explosion characterized by propagation of the reaction front within the reacting medium at supersonic velocity and by motion of reaction products in same direction as reaction-front movement

deviation angle. angle between outlet-fluid direction and the tangent to the blade mean camber line at the trailing edge

dewetting. phenomenon in solid propellants, in which the binder (fuel) breaks free from the embedded oxidizer and metal particles

diffusion factor. index of local diffusion on the blade suction surface in a pump

diaphragm. 1. thin membrane that can be used as a seal to prevent fluid leakage or as an actuator to transform an applied pressure to linear force; 2. positive expulsion device used to expel propellant from a tank in zero-g conditions

diffusion bonding. method of joining two metals, wherein temperature and pressure create intermolecular bonds

digital. proceeding or operating in discrete increments or decrements

dilatation. the action of enlarging or expanding in bulk (volume) or extent

diluent. fluid (often excess fuel) added to the exhaust gas to cool the gas below the temperature resulting from chemically balanced combustion; also, any substance added to a material to attenuate one or more properties of the material

discharge coefficient. ratio of the actual flowrate to the ideal flowrate, calculated on the basis of one-dimensional inviscid flow

disconnect. short term for a quick-disconnect -- a separable connector characterized by two separable halves, an interface seal and, usually, a latch-release locking mechanism; it can be separated without the use of tools in a very short time

displacement thickness. distance by which the outer streamlines in fluid flow are shifted (displaced) as a result of the formation of the boundary layer

dissociation. separation of a compound into chemically simpler components

divergence angle. see half-angle

divergence efficiency. ratio of thrust calculated for the actual nozzle contour (potential flow) to the thrust of an ideal-flow nozzle

DN. index to bearing speed capability: the product of bearing bore in millimeters (D) and shaft speed in revolutions per minute (N)

dome manifold. manifold that spans the back of the injector

donor charge. external charge in a through-bulkhead initiator whose detonation transmits a shock wave through the bulkhead to detonate the charge on the internal side

double-base propellant. propellant with two explosive ingredients, e.g., nitrocellulose and nitroglycerin

double pilot. registry between mating components wherein two surfaces establish relative location or where location is transferred from one surface to another

doublet. injector orifice pattern consisting of one or more pairs of orifices that produce converging streams

downcomer. 1. axial feed passage from the rear of the injector; 2. vertical feedline that conveys fluid from a higher to a lower location on a vehicle; 3. coolant tube in which coolant flows in the same direction as exhaust gas

drag pump. pump whose rotor consists of a disk with many short radial blades. The flow enters radially and is carried within the blade passages around the disk and is discharged radially through a port

dry cycle. operation of a valve or similar component without propellant or test fluid in the flow passages

dry-film lubricant. material that reduces rolling or sliding friction between mating surfaces by coating one or both of the surfaces with a slippery film, often permanently bonded to the surface; also called solid lubricant

dynamic imbalance. distribution of rotor mass such that the principal inertia axis of the rotor is rotationally misaligned with the bearing axis. Moments are generated when the rotor rotates about the bearing axis. Dynamic imbalance, also referred to as moment imbalance, requires measurement and correction in two or more planes perpendicular to the rotor axis

dynamic seal. mechanical device used to minimize leakage of fluid from the flow-stream region of a fluid-system component when there is relative motion of the sealing interfaces

duct. see line

ductile failure. rupture of structural material after plastic deformation; also, unacceptable dimensional change without fracture

dump cooling. method of reducing heat transfer by flowing the nozzle collant turbine exhaust gas down the nozzle coolant passages and discharging the gas at the exit, expansion at the exit being used to increase performance

-E-

E-D nozzle. short term for expansion-deflection nozzle, which has an annular throat that discharges exhaust gas with a radial outward component

effective area. actual area acted on that results in a force in any device; for example, the area of a bellows joint at the main diameter of the convolutions: internal pressure exerted over this area creates axial or end thrust (pressure separating force) tending to elongate the bellows

effective heat of ablation. figure of merit for a given material subjected to steady-state heating conditions and undergoing steady-state ablation; the quantity represents the heat dissipated per unit mass of ablated material under specified conditions

efficiency. ratio of energy output to energy input

elastic limit. maximum stress that can be applied to a body without producing permanent deformation

elastomer. polymeric material that at room temperature can be stretched to approximately twice its original length and on release return quickly to its original length

electrical delay. time period from the initial electrical signal to first motion of the activated part

electroexplosive device (EED). contrivance in which electrically insulated terminals are in contact with, or adjacent to, a composition that reacts chemically when the required electrical energy level is discharged through the terminals

electron-beam welding. process in which a controlled stream of high-velocity electrons produces the heat for fusion by striking the workpiece in a vacuum

electroforming. production of seamless hollow containers by electrodeposition

electroless plating. chemical reduction process for deposition of a metallic coating

end effects. 1. the effects on total burning surfaces of internal-burning grains contributed by burning in the longitudinal direction; 2. three-dimensional strain condition near the ends of a long cylindrical structure under stress

end strength. axial-load-carrying capability of braided wire sheath of a flexible hose section; load is created by the pressure separating force in the hose

endurance limit. maximum stress at which a material presumably can endure and infinite number of stress reversals (cycles)

end wall. surface of the housing and rotor hub between adjacent blades on a pump rotor

"energetic" propellants. 1. liquid bipropellants that contribute energy to the exhaust gas through exothermal decomposition prior to oxidation reactions; 2. solid propellant with added ingredients that raise energy output above the norm for that class of propellant

energy release system. portion of a solid rocket igniter that provides the heat efflux necessary to ignite the propellant and raise it to a self-sustaining combustion level

engine. see rocket engine

entry. region of the thrust chamber where the contour of the chamber converges to the nozzle throat

envelope. external boundary defining the limits on the dimensions of the component, subsystem, or system

Enzian-plate injector. type of injector that produces atomization by impingement of a jet on a solid plate

equal-percentage characteristic. relation between valve flow and the valving element stroke in which a percentage change in opening at any stroke increment will cause an equal percentage change in flow

equilibrium composition. chemical composition that the exhaust gas would attain if given sufficient time for reactants to achieve chemical balance

erosion. wearing away of surface material by the action of moving liquids or gases; may be accelerated by presence of suspended solid particles and in some cases by corrosive action of the fluid

erosive burning. increased burning of solid propellant that results from combustion products moving at high velocity over the burning surface

erosive burning rate. burning rate of solid propellant that includes augmentation induced by high-velocity flow of combustion products over the burning surface

evaporative freezing. freezing that can occur when a liquid leaks into hard vacuum and expands to pressures below the triple point of the liquid

exfoliated laminate. plies of the laminate stripped from the surface

exhaust plume. hot gas ejected from the thrust chamber of a rocket engine; the plume expands as the vehicle ascends, thus exposing the engine and vehicle to greater radiative area

exhaust plume blowback. condition in which ambient pressure drives the nozzle exhaust gases forward, over the motor and its attachments

exit. aft end of the divergent portion of a nozzle, the plane at which the exhaust gases leave the nozzle; also called exit plane

exit pressure. pressure of the exhaust gas at the nozzle exit

expansion geometry. contour of the nozzle from throat to exit plane

expansion ratio. see area ratio

exploding bridge-wire (EBW). initiator consisting of a small wire (1 to 4 mils) running between two terminals and exploded by application of a high voltage

explosion. very rapid chemical reaction or change of state in a material involving production of a large volume of gas and resulting in rupture of the material container (if present) and generation of a shock wave in surrounding medium

explosive valve. valve having a small explosive charge that when detonated provides high-pressure gas to change valve position (also known as a squib valve)

expulsion efficiency. index of the ability of an expulsion device to expel the liquid from a tank: the ratio of expelled volume to loaded volume

external expansion. expansion of the exhaust gases from the nozzle throat directly without a controlled-expansion wall

-F-

fabricability. capability of being fabricated into a desired configuration and size without loss of properties

face seal. seal whose sealing surface is perpendicular to the centerline of the flow passage; generally, a face seal prevents leakage of fluids along rotating shafts by a means of a stationary primary-seal ring that bears against the face of a mating ring mounted on a shaft. Axial pressure maintains the contact between seal ring and mating ring. Also called face-contact seal.

fail safe. term for philosophy in the design of propulsion system hardware that seeks to avoid the compounding of failures; fail-safe design provisions ensure that the component (e.g., a valve element) will move to a predetermined "SAFE" position if electrical, pneumatic, or hydraulic power is lost

fatigue life. number of cycles of stress, under a stated test condition, that can be sustained by a material prior to failure

filler. substance added to another material (usually an elastomer or plastic) to improve material properties, alter one or more specific properties (e.g., change hardness), or extend or dilute the material

fillet. material faired into the angle formed by the junction of two surfaces, primarily to relieve stress concentrations at the junction

fill yarn. yarn running perpendicular to the length of the fabric

film cooling. technique for reducing heat transfer to the gas-side wall of a combustion chamber or nozzle by maintaining a thin layer (film) of cooling fluid over the surface. The film may be self-generated by thermally induced phase change in the surface material, or fluid may be injected through holes or slots in the surface or through a porous surface.

filter. device in a fluid system that limits size and amount of particulate contamination in the system downstream of itself

finite-element method. computer-based technique for structural or hydrodynamic analysis, in which the structure or flow system is divided into many small segments (called elements), for which a matrix of coefficients of algebraic equations is set up and solved for values of the desired parameter (stress, strain, velocity, etc.)

finocyl. coined word for "fin in cylinder", a specific solid-propellant grain configuration

flame spreading interval. time period from first ignition of the solid propellant grain to the ignition of the entire grain surface

flaw. unplanned discontinuity in a structure, particularly a solid propellant grain

flexible hose. pliant conduit consisting of a flexible inner core of convoluted metal or plastic tubing and an outer braided wire sleeve that is attached to fixed ends to prevent buckling and separation when the core is pressurized

flexible joint (flexible section). nonrigid connector such as metal bellows, flexible hose, or ball-joint assembly that joins two duct sections and permits relative motion between the ducts in one or more planes; includes both the flexible member and the restraint linkage

flexure disk. supporting member in a poppet valve that allows poppet axial motion but restrains rotation and prevents misalignment of concentric fits

flexure tube. in a torquemotor-design valve, the interconnecting member between the valving element and a dc torquemotor that transmits motion and seals the flow stream. the tube is rigidly attached to the valve body at one end and acts as a spring

flow angle. direction of gas flow at any point in the nozzle, referred to nozzle axis

flow coefficient. in a pump, ratio of axial absolute fluid velocity to rotor tangential velocity (blade tip speed); in a flow-control device, volumetric flowrate at specified pressure drop across the device

flowfield. aerodynamic and thermodynamic states of the gas flow in the chamber or nozzle

flow limiter. device to control flowrate at or below a specified value over a range of pressures, in particular restricting flow during pressure surges

flow separation (separated flow). detachment of the flow from the wall of the flow passage

flow-to-close valve. valve in which the flow direction and forces acting on the valving element provide a closing force

flow-to-open valve. valve in which the flow direction and forces acting on the valving element provide an opening force

flow tube. tube inserted in hollow ball of a ball valve to smooth the flow and to reduce turbulence and pressure drop

fluid-cooled. term applied to a chamber or nozzle whose walls are cooled by fluid supplied from an external source, as in regenerative cooling, transpiration cooling, or film cooling

fluid-film bearing. type of bearing wherein separation of the bearing and journal depends on the shearing of a lubricating film in the clearance between parts; viscous forces within the fluid support the bearing load

fluid interface. common boundary of two or more surfaces exposed to fluid (e.g., mating flanges of a duct) or the interface between a fluid and containing device (e.g., tube wall)

forced-separation disconnect. separable connector that is disengaged by explosive, hydraulic, or pneumatic pressure

forced-vortex flow. flow in which the fluid tangential velocity is forced to vary in a manner other than inversely with radius of the flow passage

forcing function. vibration or alternating stress that imposes an oscillation on a system

four-way valve. valve having four controlled working passages such that there are two simultaneous flow paths through the valve; commonly used to control double-acting actuators

fractographic analysis. examination of a fractured surface under very high magnification in order to determine the nature of the fracture

fracture mechanics. science dealing with brittle fracture of structural material under load; this discipline emphasizes the importance of minute flaws and cracks in structural materials and provides principles and techniques for analyzing the effects of such discontinuities and nonhomogeneities on material behavior

fracture toughness. capability of a material to resist brittle failure

free-free. term used to designate a complete lack of restraint applied to the first lateral bending mode of shaft resonance

free height. height of a spring in the free (unloaded) condition

free stream. 1. length of the jet from the orifice exit to the point of impingement on another jet or a surface; 2. the central flow region in a flow passage, where flow is unimpeded by any constraints

free-vortex flow. flow in which the fluid axial velocity is constant from hub to tip while the fluid tangential velocity varies inversely with radius of the flow passage

fretting. mechanism of wear that acts on mating metallic surfaces to produce surface damage when one surface repeatedly moves through small-amplitude displacements relative to the other surface

friability. tendency of crystalline structure to crumble

frozen composition. exhaust-gas chemical composition that does not change during expansion in the nozzle

fuel. liquid or solid material used to supply thermal energy by chemical reaction (combustion) with an oxidizer

fuel binder. continuous phase that contributes the principal structural condition to solid propellant but does not contain any oxidizing element, either in solution or chemically bonded

full-complement bearing. needle or roller bearing that does not incorporate an inner race (a rolling-element retainer spacing the elements); the needles or rollers ride directly on the shaft and fill the bearing cavity fully

function time. in an electroexplosive device, the time period between application of initiating energy and some later function such as bridgewire break, ignition of output charge, or start of pressure rise

fuse. igniting device consisting of a detonating or deflagrating train for propagation of ignition energy

FV factor. term in seal design for the product of total contact load per unit circumferential length (F) and rubbing speed (V)

-G-

gain. overall increase in the value of a given parameter that is produced by a pneumatic, hydraulic, or electrical system

galling. progressive surface damage of mating sliding surfaces under high loads, the result being increased friction and possible seizure

galvanic corrosion. surface damage due to generation of an electric current resulting from the exposure of electrically connected dissimilar metals to an electrolyte; the metal that is lower on the EMF scale is rapidly attacked

garter spring. helically coiled wire spring with its ends connected, used in tension for maintaining a radial (sealing) force on an element on a shaft

gas distributor. passive device that determines the flow pattern of the gas entering an ullage space

gas generator. assemblage of parts similar to a small rocket engine, in which propellant is burned to provide hot exhaust gases to (1) drive the turbine in the turbopump assembly of a rocket vehicle, or (2) pressurize liquid propellants, or (3) provide thrust by exhausting through a nozzle

gasket. deformable element used to prevent leakage between two relatively static surfaces in a fluid system

gas-metal-arc (GMA) welding. inert-gas welding process using as a heat source an electric arc between a bare consumable filler wire and the workpiece

gas permeativity. capability of a gas to penetrate or diffuse through another substance

gas solubility. capability of a given gas to dissolve in a given fluid under specified conditions

gas-tungsten-arc (GTA) welding. inert-gas welding process wherein heat is produced by an electric arc between a nonconsumable electrode and the work; a filler metal is optional

gel stage. condition reached during curing of a liquid polymer mix when viscosity tests show an essentially "no flow" condition

gimbal. to incline freely in any direction from a fixed support (i.e., a pivot point)

gimbal ring. circular structural member of a gimballed joint to which the yokes or clevises of the joint are attached, so that the joint can be angled in any direction

Gimbar. coined word for a gimbal ring with crossed bars for structural strength

gland. cavity in which an O-ring is installed; includes the groove and the surface of the mated part that together confine the O-ring

Goodman diagram. plot of mean stress vs alternating stress in a component, used to appraise structural adequacy (fatigue life) of the component

go/no-go. term for a test or inspection process that establishes the acceptability of any component in a set by determining whether a given parameter falls below (or, conversely, stays above) a specific value

grain. integral piece of molded or extruded solid propellant that comprises both fuel and oxidizer in a solid rocket motor and is shaped to produce, when burned, a specified performance-vs-time relation

grain anomaly. nonhomogeneity in cured propellant grain (e.g., a void, or a fuel-rich pocket)

grain conditioned temperature. uniform temperature of the propellant grain just before ignition

guide vane. see vane

gyroscopic moment. moment induced on rotating components by the angular displacement of the rotating axis, as in a gyroscope

-H-

half-angle. angle between the nozzle center line and a line parallel to the inner surface of the nozzle exit cone; also called divergence angle

hard line. line or duct that incorporates no flexible joints but is provided with deflection capability by the use of loops and elbows and low-modulus or thin-wall material

hard poppet. poppet with a hard sealing surface

hard sealing surface. surface fabricated of material (metal, ceramic, or cermet) that does not permanently yield or deform except with wear (flexible metal disks are a special type of hard sealing surface)

hard seat. seat with a hard sealing surface

hard vacuum. term applied to pressure less than 10^{-8} mm Hg (1.333×10^{-10} N/cm^2)

hat. descriptive term for a flanged, square-bottom-"U" cross section

head or headrise. increase in fluid pressure supplied by a pump: the difference between pressure at the pump inlet and pressure at pump discharge, fluid pressure being expressed as equivalent height (in feet) of a fluid column

head coefficient. measure of headrise related to impeller discharge tip speed

heat-affected zone (HAZ). the region of material affected by the heat of welding or brazing

heater blanket. electrical heater in sheet form wrapped around all or a portion of a cryogenic component (e.g., an actuator) to prevent the temperature within the component from falling below a stated operating minimum

heat of ablation. total of the incident heat that an ablative material dissipates per unit mass ablated. See effective heat of ablation

heat-sink chamber. combustion chamber in which the heat capacity of the chamber wall limits wall temperature (effective for short-duration firing)

heat soak. increase in temperature in rocket-engine components after firing has ceased, the result of heat transfer through contiguous parts when no active cooling exists

heat-transfer coefficient. analytically or emprically determined parameter that expresses the rate of heat transfer per unit area per unit temperature difference between two substances

hermetic seal. seal evidencing no detectable leakage or permeation of gas or moisture

Hertz stress. maximum compressive stress due to the pressure between contacting load-carrying elastic bodies, at least one of which is a curved body

heterogeneous decomposition. separation of a substance into simpler components that differ in phase

high-cycle fatigue. life-cycle capability determined by the elastic strain range; generally greater than 10^4 cycles

hi-pot test. dielectric-strength test performed at a high electric potential

hob. tool used for cutting the teeth of worm wheels or gear wheels

homokinetic plane. in universal joints (or gimbal joints), the plane that is normal to the plane containing the shafts and bisecting the angle between them

hot-core injector. injector that produces a central hot-gas combustion region surrounded by a "cold" fuel sheath

hot fire. term applied to a test of an engine system in which the engine is started (ignited) and operated while performance of the system and its components is observed and measured; period of operation need not be full operational duration

hot-gas valve. valve that controls the flow of hot gases, opening at low power levels but restricting the flow at mainstage; it operates at temperatures in excess of 200°F (366K) and as high as 1000°F (811K) or higher

hot-short. term applied to materials having low elongation (brittle) at elevated temperatures

hot streaking. stratification of burning gases in a combustion chamber into longitudinal zones of high-temperature gases that do not break up and mix with cooler gases; term derives from the localized heat marks visible on the chamber wall after firing has ended

housing. physical structure that forms the containing envelope for an assembly

hub/tip ratio. ratio of radius of pump rotor at blade hub to radius of rotor at blade tip

hydraulic. 1. operated, moved, or effected by liquid used to transmit energy; 2. a system or device using a liquid as the operating fluid

hydraulic dashpot. device used to reduce the velocity of the actuator as it approaches a fixed stop, so that impact energy levels are reduced

hydrogen embrittlement. decrease in a metal's tensile strength, notched tensile strength, fatigue strength, resistance to crack growth, and especially ductility as a result of absorption by the metal of newly formed gaseous hydrogen

hydrostatic bearing. fluid-film bearing wherein the pressure required to maintain separation of the surfaces is externally supplied

hydrostatic pressure. fluid pressure due to gravitational force

hydrostatic seal. seal that incorporates features that maintain an interfacial film thickness by means of pressure provided either by an external source or by the pressure differential across the seal

hypergolic ignition. ignition that involves no external energy source, but results entirely from the spontaneous reaction of two materials when they are brought into contact; materials may be two liquids or a liquid impinging on a solid

hypergolic propellants. propellants that ignite spontaneously when mixed with each other

ideal nozzle. nozzle that when analyzed on the basis of one-dimensional point-source flow provides theoretically perfect performance for a given area ratio

ideal velocity. speed that a rocket vehicle could achieve if free of drag and gravity

idiot pin. locating pin that matches two parts in correct orientation so that mating components cannot be mated incorrectly

igniter. device that can, in a controlled and predictable manner, induce self-sustaining combustion of propellants in the combustion chamber of a rocket engine or motor

ignition. attainment of self-sustaining combustion of propellants in a rocket engine or motor

ignition delay. in solid rocket motors, time period from the moment of arrival of the thermal energy from the igniter at the propellant grain surface until an exothermic gas-phase reaction is self-sustaining (i.e., the propellant is burning); in liquid rocket engines, the time from initial contact of fuel and oxidizer until a measurable pressure is generated

ignition lag time. time period from initiation of the igniter until first ignition of solid propellant

ignition temperature. surface temperature of a solid-propellant grain at the moment combustion begins; the temperature depends on the extent of pyrolysis, on heating rate, and on pressure, especially at low pressures and high flux levels

impeller. disk with curving radial ribs (blades) or spiralled screw that rotates within a casing and accelerates fluid in the flow passage outwardly into a collector or into flow passages of a following stage

impulse. product of average thrust and the time during which it acts; mathematically, the integral of the thrust-time function over a definite time interval

impulse stage. stage in a pump or turbine in which there is no change in static pressure across the rotor

incidence angle. angle between inlet-fluid direction and the tangent to the blade mean camber line at the leading edge of the blade

inducer. an auxiliary pump with a spiral impeller, mounted at the inlet of a main pump, whose function is to raise the fluid pressure at the inlet by an amount sufficient to preclude cavitation in the main pump

inertance. impeding effect of fluid inertia on transmission of oscillations in a fluid-filled conduit

inert gas. gas that will not react with other materials

inert weight. weight of all rocket vehicle parts that do not produce thrust

inhibitor. 1. material applied to surface(s) of solid-propellant grains to prevent combustion of the surface; 2. material applied to surfaces to reduce chemical reactivity of the surface, i.e., prevent or reduce corrosion or deterioration of the surface

initiation. process of starting combustion, explosion, or detonation of materials by such means as impact, friction, electrostatic discharge, shock, fragment impact, flame, or heat

initiator or initiation system. part of the solid rocket igniter that converts a mechanical, electrical, or chemical input stimulus to an energy output that ignites the energy release system

injection cooling. method of reducing heat transfer to a body by mass-transfer cooling accomplished by injecting a fluid into the local flow field through openings in the surface of the body

injector. device in a liquid rocket engine that atomizes and mixes fuel and oxidizer to produce efficient and stable combustion

innercore. pressure-carrying tubular flexible member of a flexible hose

insulation (thermal). material applied to a surface to prevent or reduce heat transfer to or from that surface

interegen. coined word meaning internally regenerative; term refers to a combustion chamber design in which heat is conducted away from the throat region and is absorbed by liquid film coolant over the forward part of the chamber

interface. region of mating (common boundary) between interconnected elements

interference diagram. plot of the various vibrational modes of a gear to determine whether any modal-shape standing-wave frequencies coincide with gear meshing frequency

interference fit. retention of a component in a mounting solely by virtue of the friction between the interfaces; the degree of friction (and hence retention force) is governed by the relative dimensions of the mating parts; also called a press fit

interflow. term for simultaneous flow into and out of the control-pressure region in a pilot circuit for a pressure regulator

intergranular corrosion. type of corrosion generally associated with stainless steels, caused by formation of a complex chromium carbide that depletes the chromium content along the grain boundaries

internal ballistics. study of the parameters that govern the relations among temperature, pressure, burning rate, mass discharge rate, etc. in a solid rocket motor during firing

internal-burning grain. grain in which the surface of the perforation is a burning surface

internal expansion. gas expansion within a controlled expansion wall or shroud

interstitial casting. process that introduces a liquid into a bed of solid granular material

inviscid. having zero viscosity

isentropic. a reversible adiabatic process

isotropy. condition in a material in which properties are the same in all directions

isochoric flame temperature. flame temperature at constant volume, i.e., in a closed vessel

iterative. proceeding in a step-by-step repetitive manner

-J-

Joule-Thomson effect. the change in gas temperature with gas pressure as the gas expands through a throttling device

journal bearing. sliding-surface bearing that uses combinations of metals or nonmetals to achieve low friction, compatibility, and wear resistance

-K-

Kiel probe. total-pressure probe consisting of an impact tube surrounded by a smoothly contoured ring that collects and converges the flow stream

kinematics. study of motion exclusive of the influences of mass and force

kinetic performance. that portion of the nozzle performance that depends on the equilibrium state of the chemically reacting system during gas expansion

Knoop hardness. indentation hardness determined by pressing a rhombohedral diamond into a material; similar to the Brinell test

K seal. flexible metal seal with a cross section shaped like a K

-L-

labyrinth seal. clearance-type seal in which the fluid being sealed must traverse a tortuous path in order to escape

Lamé's equation. equation for stresses in thick cylinders

laminar flow. fluid flow in which the motion of the fluid is smooth and regular, and there is no crossflow between adjacent streamlines

laminar-flow bench. controlled-cleanliness bench used for critical assembly operations; the bench is closed at the sides and top and has a rear wall that distributes filtered low-velocity air across the work area to prevent entry of airborne contaminants into the assembly

laminarization. process by which a turbulent boundary layer reverts to laminar-like characteristics as a result of flow acceleration

land. the actual sealing surface of the part that mates with a seal

latch. 1. mechanical or magnetic device that maintains a flow-control component in a desired position without the constant application of power; 2. device that fastens one part to another but is subject to release so the parts can be separated

launch vehicle. the combination of booster, upper stages, and spacecraft (or other payload) adapter making up the total rocket at time of launch; the spacecraft or payload itself is not regarded as part of the launch vehicle

leakage rate. the quantity of fluid escaping past a seal in a given length of time

"leak-before-burst" condition. condition requiring that cracks penetrating a pressure-vessel wall do so without reaching the (critical) size for unstable propagation (i.e., the size that leads to brittle fracture)

lever link. mechanical linkage between the actuator and the valving element of rotary valve that consists of a lever or crank on the rotary member and a link with clevis connections from the lever to the actuator shaft

Lewis number. dimensionless parameter, the ratio of mass diffusivity to thermal diffusivity

liftoff. term designating the instant of vehicle flight at which vehicle contact with all holddown and support devices is terminated; also called "first motion" of the vehicle

limit load (or pressure). maximum expected load (or pressure) on a structure that will occur under the specified conditions of operation, with allowance for statistical variation

limits testing. exposure of a component to the extremes of the operational conditions that are expected to occur in final engine-system and flight testing

line (or duct). enclosed passageway (usually circular in cross section with relatively thin walls) that conveys fluid under pressure

linear characteristic. straight-line relation between valve flow and valving element stroke at a constant value of pressure drop

liner. 1. thin layer of adhesive specifically used to bond solid propellant to the motor case or to the insulation; 2. ablative material used to line the inner wall of the combustion chamber or nozzle to reduce heat transfer to the wall

lip seal. pressure-actuated seal that prevents leakage in dynamic and static applications by employing a scraping or wiping action on the mating surface

liquid length. distance along chamber wall over which film coolant remains in liquid state

live length. overall length of the convolutions in a bellows that are capable of accommodating imposed deflections

load factor. ratio of vehicle thrust to its overall mass

loading efficiency. in a solid rocket motor, the achievement of the required propellant surface area and web thickness within the smallest practicable volume

lockup. the no-flow condition when a pressure regulator is kept closed in response to downstream pressure being at or above the regulator setpoint

lockwire. 1. flexible slender rod or thread of material (usually metal) that is passed thru matching holes in two (rotating) parts so as to fasten them together securely; 2. to fasten securely in place by means of a wire

longitudinal slot. slot inside a propellant grain parallel to the axis of the grain

low-cycle fatigue. life-cycle capability determined by the plastic strain range; generally less than 10^4 cycles

lumped mass. concept in (shaft) dynamic analysis wherein a mass is treated as if it were concentrated at a point

-M-

Mach number. ratio of the velocity of fluid flow to the velocity of sound in the fluid

magnification factor. ratio of the structural deflection produced by an alternating load to the deflection produced by a steady load of the same magnitude

mainstage. attainment of 90 percent or more of the steady-state rated thrust level of a rocket engine

main valve. valve, usually located just upstream of the thrust chamber injector, that controls flow of propellant to injector

mandrel. tool that forms the geometry of the central cavity in the casting of a solid-propellant grain

manifold. fluid-flow enclosure that distributes the flow in a desired manner from an inlet or inlets to an outlet or outlets

manually operated disconnect. separable connector that is engaged or disengaged by manual forces, usually with the aid of a lanyard, cam, or similar device

margin of safety. fraction by which the allowable load or stress exceeds the design load or stress

mass addition. technique of analysis that evaluates the gas dynamics within a rocket motor in terms of addition of small amounts of mass at specific locations

mass flux. mass flowrate through a given area expressed as the ratio of mass flowrate to flow area

mass ratio. 1. ratio of usable-propellant mass to vehicle total launch mass; 2. ratio of vehicle initial mass to vehicle final (burnout) mass

mass-transfer cooling. cooling technique characterized by an energy-consuming expenditure of mass (solid, liquid, or gas)

master lap. lapping of the work piece with a master tool

match lap. lapping together of two mating detail parts so that they are matched to each other in contour

mating ring. ring-like or disk-like part on the shaft or housing that provides the sealing surface for a face seal

metal-to-metal seal. 1. internal seal in a poppet-type valve achieved with hard-on-hard or hard-on-soft metallic seats; 2. static seal wherein two metallic surfaces, usually one hard and one soft, are mechanically joined

method of characteristics. technique for facilitating the solution of a set of partial differential equations by the use of lines or surfaces that are at all points tangent to characteristic directions determined by certain specified linear combinations of the equations; method often is used in nozzle design

mission duty cycle. total propulsion system requirement for a scheduled number of operations over the total elapsed mission time

mixture ratio. mass flowrate of oxidizer divided by mass flowrate of fuel

modality. number of peaks (or modes) in a plot of particle-size distribution

mode. any of the various stationary vibration patterns of which an elastic body is capable

modified linear characteristic. relation between valve flow and valving element stroke that is comprised of a parabolic relation up to approximately 30% of stroke, followed by a linear relation up to 80 or 90% of stroke, with the remainder a square-root relation

modulating. term applied to a control system or device in which the controlled variable is proportional to a sensed parameter and is continuously variable within the regulated range

momentum separation. stratification of flow in a combustion chamber (esp. in a gas generator) as a result of the high relative velocity of the hot core gases

momentum thickness. thickness of the potential flow with a momentum equal to that lost in the boundary layer as a result of wall shear forces

monocoque. term applied to a structure in which the stressed outer skin carries all or a major portion of the torsional and bending stresses

monopropellant. liquid propellant that decomposes exothermally to produce hot gas; e.g., hydrogen peroxide, and hydrazine

-N-

Naflex seal. trade name for a U-shaped flexible metal seal

NASTRAN. acronym for NASA computer program for structural analysis

Natorq seal. trade name for a modified ring seal

needle valve. valve with a long tapered rod (pintle) for gradual opening or closing of the valve throat when translated

negative gain. term for a control circuit in which an increase in regulated pressure causes an amplified decrease in control pressure

negative spring rate. change of mechanical spring force per unit of deflection in a flexure element, with the characteristic that an increase in deflection is accompanied by a decrease in flexure force opposing deflection

net positive suction head (NPSH). the difference, at the pump inlet, between the head due to total fluid pressure and the head due to propellant vapor pressure, expressed in feet of the propellant being pumped; this is the head available to suppress cavitation in the pump

no bleed. term applied to a control circuit in which there is no flow of gas through the pilot valve under steady-state conditions

nodal circle. pattern of vibration nodes that forms a circle

nodal diameter. pattern of vibration nodes that forms a diametral line

no-fire limit. maximum current, power, voltage, or capacitance that can be applied to the firing circuit of an electroexplosive device without firing the device

noncavitating valve. flow-control valve that meters the flow of liquid propellant without cavitation occurring in its operating range

nonequilibrium composition. exhaust gas chemical composition resulting from incomplete chemical reaction of the products of combustion in the exhaust gas

noninterflow. term applied to a control circuit in which simultaneous flow into and out of a control-pressure region is prevented by a pressure-positioned three-way valve

nonmodulating. term for a control system or device in which the controlled variable (flow, pressure, etc.) cycles between limits; sometimes called a "bang-bang" system

nonpositive-displacement pump. pump in which the fluid pressure is raised by alternately adding to and then diffusing the kinetic energy of the fluid; examples of this type of pump are the axial-flow, Barske, centrifugal-flow, drag, Pitot, and Tesla

normally closed valve. powered valve that returns to a closed position on shutoff or on failure of the actuating energy or signal

normally open valve. powered valve that returns to an open position on shutoff or on failure of the actuating energy or signal

normal positions. positions assumed by the elements in a fluid-system component when no operating forces are applied

"normal" propellants. bipropellants that derive thermal energy primarily from oxidizer-fuel reactions; see "energetic" propellants

nozzle. 1. carefully shaped aft portion of the thrust chamber that controls the expansion of the exhaust products so that the thermal energy produced in the combustion chamber is efficiently converted into kinetic energy, thereby imparting thrust to the vehicle; 2. convergent passage in a pump or turbine that directs fluid into or leads it away from the impeller or turbine wheel

nozzle extension. nozzle structure that is added to the main nozzle in order to increase expansion area ratio or provide a change in nozzle construction

nozzle ring. set of channels or passages through which fluid is directed onto the turbine wheel

NPSH. net positive suction head

nucleate boiling. formation and breaking away of bubbles from active bubble sites (nuclei) on a submerged heated surface; the rising bubbles stir the liquid so that heat transfer from the surface to the liquid is much greater than that due to normal convection

Nusselt number. dimensionless parameter expressing the ratio of convective heat transfer to conductive heat transfer

nutation. motion of the axis of a spinning object (e.g., a top or a gyroscope)

-O-

O/F. ratio of mass flowrate of oxidizer to mass flowrate of fuel at the time of combustion

offset or shear deflection. lateral deflection of one end of a flexible joint or duct such that its centerline is parallel to the centerline of the opposite end

oil canning. flexing of unsupported sheet metal

omega joint. expansion joint shaped like the upper-case Greek letter omega; used in the wall of a manifold or duct to relieve stresses due to thermal growth

on-off. term referring to a system or device in which full-stroke actuation or deactuation occurs in response to input signals

open loop. term referring to an electrical or mechanical system in which the response of the output to the input is scheduled or preset; there is no feedback of the output for comparison and corrective adjustment

operating pressure. nominal pressure to which the fluid-system components are subjected under steady-state conditions in service operations

operational deflections. deflections imposed on a structure during engine operation or flight (e.g., by thrust vector gimballing, thermal differential, flight accelerations, and mechanical vibration)

operational pressure transients. rises in operating pressure (due to water hammer, rapid startup, or shutdown) with sufficient duration to be felt as loads on the system or structure

operator. any device that causes an actuator to function

orange peel. surface roughening that occurs when a metal of coarse grain is stressed beyond its elastic limit; the grain pattern formed resembles the outer surface of an orange

"O"-ring. sealing ring with a circular cross section, which may be either hollow or solid; generally made of elastomer or plastic but can be metal

O-ring squeeze. compression of the O-ring cross section between opposite surfaces of a gland

oscillatory combustion. unstable combustion in the rocket engine or motor, characterized by pressure oscillations in either transverse or axial modes

outgassing. release of gas from a material when it is exposed to an ambient pressure lower than the vapor pressure of the gas; generally refers to the gradual release of gas from enclosed surfaces when an enclosure is vacuum pumped

overexpansion. expansion of nozzle exhaust gas to a pressure lower than the ambient pressure

overstroke. displacement of an operating component that exceeds the maximum allowable displacement

overtravel tolerance. feature of rotary valves such as the ball or blade whereby shutoff can be achieved even when the valving element is not rotated to exactly the same closure position each time

oxidizer. material whose main function is to supply oxygen or other oxidizing materials for deflagration of a solid propellant or combustion of a liquid fuel

-P-

pack cementation. method of applying a coating by packing the article to be coated in a powder mixture and heating to reaction temperature

packing fraction. volume fraction of solids when packed to minimum volume

parabolic characteristic. relation between valve flow and valving element stroke in which flow varies with the square of stroke

passivation. formation of a compact and continuous corrosion-resistant film on the surface of metal exposed to air (natural passivation) or to a chemical solution (artificial passivation)

payload penalty. extent to which the weight of a given component in any part of the vehicle decreases the weight allowable for the useful load (usually the spacecraft) that the vehicle carries

percussion primer. mechanical initiator in which the impact of a firing pin against an anvil ignites an impact-sensitive initiating charge

perforation. central cavity of a propellant grain

perimeter. outer boundary of the flow area at a given station in a solid-propellant rocket

permeability. index to the resistance of a given penetrable barrier to passage (permeation) of a given gas

phase. solid, liquid, or gaseous homogeneous form existing as a distinct part of a heterogeneous system

pilot. 1. mechanical element acting on another mechanical element to provide correct alignment or proper relative position; 2. auxiliary unit in a hydraulic or pneumatic circuit (see pilot valve)

pilot circuit. flow-control elements (orifices, diaphragms, springs, etc) that, in combination with a pilot valve, control the operation of a larger valve

pilot operated. term denoting the use of an auxiliary or relay valve that controls the actuation pressure to a large valve so that low-energy circuits can be used for the control of high-energy systems

pilot valve. low-capacity valve that amplifies a low-power control signal to operate a larger valve

pinion. toothed wheel with a small number of teeth designed to mesh with a larger wheel or rack

pintle valve. flow-control device utilizing a translating tapered shaft (pintle) to change flow area through an orifice or flow passage

pitch. 1. angular motion of a vehicle about a lateral axis passing through its midpoint or center of gravity and perpendicular to the longitudinal axis; 2. distance between corresponding points on adjacent teeth of a gear or on adjacent blades on a turbine wheel, as measured along a prescribed arc, the pitchline

Pitot pump. pump in which a rotating liquid ring is created inside a rotating drum; pressurized fluid is scooped from this ring by stationary Pitot heads and ducted to the outside

Pitot tube. tube having a short right-angle bend immersed vertically in a moving fluid with the mouth of the bent part pointed upstream; used to measure fluid velocity

pitting. creation of surface voids by mechanical erosion, chemical corrosion, or cavitation

plain Dutch single weave (PDSW). woven wire cloth in which each shute wire passes successively over one and under one warp wire, each successive shute wire alternating the order; the shut wires are smaller than the warp wires and are closely spaced, the result being a dense weave

planish. to produce a smooth surface finish on a wrought metal, usually by rolling with highly polished rolls

plastic. high-molecular-weight material that while usually firm and hard (although often flexible) in its finished state is at some stage in its manufacture soft enough to be formed into a desired shape by application of heat or pressure or both

plastic deformation. permanent distortion of material under applied stress great enough to strain the material beyond its elastic limit; also called plastic flow, permanent strain, and permanent distortion

plastisol. flowable suspension of a polymer in a plasticizer that the polymer may later imbibe to produce gelation

plug nozzle. annular nozzle that discharges exhaust gas with a radial inward component; a truncated aerospike

pneumatic. operated, moved, or effected by gas used to transmit energy

pogo. term for feed-system-coupled longitudinal oscillations of a rocket vehicle; named after motion of a pogo stick

point-source flow. concept in flowfield analysis in which flow is considered to originate at a point from which it diverges outward uniformly in all directions

poison. any material that interferes with catalytic action

poppet. valving element (ball, cone, or disk) that moves perpendicularly to and from its seat to control flow

poppet valve. valve constructed to control flow by translating a poppet to or from a seat in the valve housing; translation of the poppet away from the seat can result in essentially orifice flow

popping. sudden, short-duration surges of pressure in a combustion chamber

positive-displacement pump. pump in which fluid is forced into a high-pressure region by reducing the volume of a chamber that is momentarily sealed off from a low-pressure region; examples of this type of pump are the piston, Rootes, and vane

positive gain. term for a control circuit in which an increase in regulated pressure causes an amplified increase in control pressure

potential core. length of unmixed flow in a gas generator

potential flow. flow with effects of viscosity not considered

pot life. length of time a polymerizing fluid system can be held or worked before setting up to a gel or solid

Prandtl-Meyer angle. angle through which supersonic flow may turn during expansion in the nozzle

Prandtl number. dimensionless parameter expressing the ratio of momentum diffusivity to thermal diffusivity

preflight. occurring before vehicle liftoff

preload. the mechanical load applied to components in an assembly at the time of assembly to ensure dimensional accuracy and proper operation; bolt or nut torque, and spring force, for example, are means for providing preload

prepreg. reinforcing material impregnated with the full complement of resin when received from supplier

prepressurization. sequence of operations that increases the ullage pressure to the desired level some time before the main sequence of propellant flow and engine firing; in launch vehicles, prepressurization occurs prior to liftoff

pressurant. gas that provides ullage pressure in a propellant tank

pressure-actuated seal. seal designed such that the pressure of the fluid being sealed activates or increases the sealing action

pressure divider. term applied to a pneumatic or hydraulic circuit in which an intermediate pressure between two flow restrictors in series is used as a control signal

pressure fed. term for a propulsion system in which tank ullage pressure expels the propellants from the tanks and into the combustion chamber of the engine; cf. pump fed

pressure-ladder sequence. method to effect fail-safe engine starts by sequencing the operation of rocket engine control valves, the sequencing is achieved by vent mechanisms in the control system or propellant feed system or both that are triggered by pressure changes

pressure overshoot. maximum or relative-maximum point that occurs on the pressure-time curve, as in ullage pressurization or engine ignition

pressure ratio. 1. ratio of combustion chamber pressure to ambient pressure; 2. ratio of turbine inlet pressure to turbine outlet pressure

pressure recovery. conversion of velocity head to pressure head in a fluid system

pressure regulator. pressure control valve that varies the volumetric flowrate through itself in response to a downstream pressure signal so as to maintain the downstream pressure nearly constant

pressure separating force (or load). force (or load) generated by internal pressure tending to separate two parts of a line assembly along the line of the force; for a convoluted section such as a bellows or metal innercore, this force is equal to the product of the internal pressure and the cross-sectional duct area at the mean diameter of the convolutions

pressure surface. concave surface of a pump or turbine blade; along this surface, the fluid pressures are highest

pressure-volume compensator (PVC). flexible duct system that, by means of mechanical linkage to a series of secondary bellows having an effective area equal to that of the primary bellows, creates an opposing force that counteracts the end thrust

pressurization system. the set of fluid-system components that provides and maintains a controlled gas pressure in the ullage space of space vehicle propellant tanks

prevalve. valve in the propulsion system located between the vehicle propellant tankage and the main valves

primary leakage. leakage from the upstream side to the downstream side of a fluid-system component

primary seal. seal intended to limit primary leakage

primary-seal ring. ring-shaped member in a face seal or in a ring seal; the face of the primary-seal ring forms the primary seal with the mating ring

prime charge. in an electroexplosive device, the material in contact with the bridgewire, the electrical heating of which causes the material to deflagrate

primer. material applied to surfaces of solid rocket motor cases, insulation, or liners to enhance bond strengths

processability. measure of relative ease with which a component, assembly, or system can be produced with state-of-the-art techniques

profile loss. pressure loss in a blade or vane row attributable to the airfoil

progressive burning. condition in which thrust, pressure, or burning surface increases with respect to time or to web burned

progressivity ratio. ratio of final to initial burning surface of a solid propellant

proof pressure. pressure that a pressurized component must sustain and still function satisfactorily; proof pressure is the maximum limit pressure multiplied by the proof-test safety factor and is the reference from which the pressure levels for acceptance testing are established

proof test. pressure test to prove the structural integrity of a component or assembly without exceeding allowable stresses or producing any permanent deformation

propellant. material carried in a rocket vehicle that releases energy during combustion and thus provides thrust to the vehicle

propellant stratification. non-isothermal temperature distribution in the propellant

propulsion system. vehicle system that includes the engines, tanks, lines, and all associated equipment necessary to provide the propulsive force as specified for the vehicle

pump. machine for transferring mechanical energy from an external source to the fluid flowing through it, the increased energy being used to lift the fluid or increase the fluid pressure

pump fed. term for a propulsion system that incorporates a pump that delivers propellant to the combustion chamber at a pressure greater than the tank ullage pressure; cf. pressure fed

purge. gas flow used to clear a volume (e.g., a manifold) of propellant or combustion products

PV factor. term in seal design for the product of face pressure (P) and relative sliding velocity (V); the factor provides an index to severity of service and thus relates to a seal's wear life

pyrogen. small rocket motor used to ignite a larger rocket motor

pyrolysis. chemical decomposition of a material by heat

pyrotechnics. igniters (other than pyrogens) in which solid explosives or energetic propellant-like chemical formulations are used as the heat-producing material

-Q-

quality assurance program. planned and systematic pattern of all actions necessary to provide adequate confidence that an end item will perform satisfactorily in actual operation; also called quality control

quantity/distance. term for a system for specifying safe distances for location of buildings for processing or storing propellant or propellant ingredients (liquid or solid)

quick disconnect. see disconnect

quincunx. geometrical pattern in which four items are spaced equally around a central item

-R-

race (or raceway). track or channel in a bearing in which the rolling elements ride

rack and pinion. mechanical linkage for operation of a rotary valve in which the actuator shaft incorporates a straight-sided rack to drive a pinion gear attached to the rotary shaft

radial-burning. term applied to a solid-propellant grain that burns in the radial direction, either outwardly (e.g., an internal-burning grain) or inwardly (e.g., an internal-external burning tube or rod and tube)

radial equilibrium. flow in an annular passage in which there is no radial velocity component; i.e., the fluid pressure forces in the radial direction are in equilibrium with the centrifugal forces

radial lip seal. radial seal that features a flexible sealing member, the lip: usually made of elastomeric material, the lip exerts radial sealing pressure on a mating shaft

radial passage. manifold passage that is normal to the injector flow direction

radial seal. positive-contact seal that exerts radial sealing pressure over an annular shaft area

radiation cooling. cooling of a combustion chamber or nozzle in which heat loss by radiation balances heat gained from the combustion products, and the chamber or nozzle wall thereby operates in thermal equilibrium

radius ratio. ratio of radius of curvature of the wall in the nozzle throat region to the radius of the nozzle throat

ramping. opening or closing of a valve at a controlled rate to achieve a desired flow-vs-time relation

random vibration. vibration characterized by a wide continuous band of multiple frequencies

Rayleigh flow. steady frictionless flow in a constant area duct with heat being added or removed

reaction. 1. term in pump and turbine design for the ratio of static headrise in the rotor to static headrise in the stage; 2. response of a vehicle to the thrust of the vehicle engines; 3. chemical activity between substances (e.g., propellant and contacting surfaces)

recompression. reflection of exhaust gas from ambient jet boundary

recovery moment. bending caused by centrifugal force in a blade that is tilted from a radial line

recovery temperature. see adiabatic wall temperature

redline. 1. term denoting a critical value for a parameter or a condition that, if exceeded, threatens the integrity of a system, performance of a vehicle, or success of a mission; 2. to establish a critical value as described in 1.

redundant. incorporating multiple identical components to achieve increased reliability

redundant design. design in which more than one unit is available for the performance of a given function, so that failure of a unit will not cause failure of the system or abort the mission

reference load. relatively constant force that is used to modulate a valve within a desired value

reference streamline. path of the flow along which the velocity is assumed for transonic flow calculations

regenerative cooling. cooling of the wall of a combustion chamber or nozzle by circulating a propellant, usually fuel, in coolant passages in or wrapped around the outer surface of the wall to be cooled

regression. erosion of the surface of a material

regression analysis. statistical technique based on the method of least squares for establishing a mathematical representation of empirical data

regressive burning. condition in which thrust, pressure, or burning surface decreases with time or with web burned

regulator. flow-control device that adjusts the pressure and controls the flow of fluid to meet the demands of a liquid-propellant rocket system

reliability. the probability that a system, subsystem, or component will perform its required functions under defined conditions at a designated time and for a specified operating period

relief valve. pressure-relieving device that opens automatically when a predetermined pressure is reached

repeatability. capability of a component or assembly to operated in the same way and in the same time each time it is actuated

repressurization. sequence of operations during vehicle flight that utilizes an on-board pressurant supply to restore the ullage pressure to the desired level after a burn period

reseat pressure. pressure at which a flow-control device (e.g., a valve) will close and shut off flow as specified

resilience. the property of a material that enables it to return to its original shape and size after deformation; e.g., it is this property of a sealing material that makes it possible for a seal to maintain sealing pressure despite wear, misalignment, or out-of-round conditions

response. 1. the behavior of material when a stimulus is applied; 2. the reaction of a component to an input stimulus or signal

response time. in a flow-control device, the interval from receipt of signal to completion of the commanded action, a total comprised of electrical delay plus pneumatic or hydraulic control system delay plus travel time for the movable element

restricted surface. surface of a solid propellant grain that is prevented from burning by the use of inhibitors

restriction inlet. flow path of reduced cross section or an orifice through which gas flows into a control-pressure region; gas is discharged through a throttling valve positioned by the pressure sensor

restriction outlet. flow path of reduced cross section or an orifice through which gas is discharged from a control-pressure region; gas flows into the control-pressure region through a throttling valve positioned by the pressure sensor

restrictor. discrete flow resistance in a fluid flow passage; usually an orifice

retort. vessel used in an oven or furnace to enclose the work being heat treated in a controlled atmosphere

retro rocket. small rocket engine used to produce a retarding thrust or force on the vehicle so as to reduce vehicle velocity

reverse-flow design. design of a gas generator that produces turbulent mixing and largely prevents hot streaking by forcing the flow to stagnate and then reverse its direction

reverse transition. change from a turbulent to a laminar boundary layer as a result of flow acceleration (laminarization)

Reynolds number. dimensionless parameter expressing the ratio of the inertial forces to the viscous forces in fluid flow

right characteristic. characteristic line that travels downstream and to the right of the supersonic flow direction

ring seal. piston-ring type of seal that assumes its sealing position under the pressure of the fluid to be sealed

rise off. term denoting that a given event occurs only as a result of vehicle vertical motion from the launch pad

rise time. interval from first continuous chamber pressure increase to attainment of a specified level of thrust or pressure

rocket engine. the portion of the chemical propulsion system in which combustible materials (propellants) are supplied to a chamber and burned under specified conditions and the thermal energy is converted into kinetic energy, or thrust, to propel the vehicle to which the engine is attached. The term "rocket engine" usually is applied to a machine that burns liquid propellants and therefore requires rather complex systems of tanks, ducts, pumps, flow-control devices, etc.; the term "rocket motor" customarily is applied to a machine that burns solid propellants and therefore is relatively simple, requiring basically only the solid propellant grain within a case, an igniter, and a nozzle. In this monograph, the term "rocket engine" is used to refer to chemical-propulsion-system engines as a class.

rocket motor. see rocket engine

Rockwell hardness. indentation hardness (of metals and plastics) determined by measuring surface indentation or penetration by a diamond cone or steel ball under a specified load

rolling-element bearing. see bearing

rolling element. ball, needle, or tapered roller in a rolling-element bearing

rolloff chart. graph paper onto which the involute surface of an actual gear tooth is translated by an inspection machine to a straight line, so that deviations of the tooth surface from a perfect involute are readily observed

root. juncture of blade and rotor hub or of vane and vane support

Rootes pump. rotary pump consisting of two intermeshing cam-like rotors that produce a positive-displacement pumping action

rosette layup. spiral arrangement of plies in which plies are laid up at an angle with the inner surface of the thrust chamber wall in both radial and axial directions

rotary seal. mechanical seal that rotates with the shaft and is used with a stationary mating ring

rotor. turbopump shaft plus all attachments that rotate with it

runaway regulator. regulator that has failed in the fully open position, the result being uncontrolled downstream pressure

run in. period of initial operation during which the wear rate is greatest and the contact surface of mating components is developed

R = -1. expression showing that imposed strain in fatigue testing is equal in both directions from neutral

-S-

safe/arm (S/A) system. mechanism in a solid-propellant igniter that in the SAFE condition physically prevents the initiating charge from propagating to the energy release system; in the ARM condition, the mechanism reliably and reproducibly propagates ignition to the energy release system

safe operating pressure. maximum operating pressure allowable without using shields to protect personnel and associated hardware

safety factor. see design safety factor

Schmidt number. dimensionless parameter expressing the ratio of momentum diffusivity to mass diffusivity

screech. high-frequency oscillatory combustion, characterized by shrill noise emanating from the combustion chamber

scuffing. mild degree of galling that results from the welding of asperities by frictional heat; the welded asperities break, causing surface degradation

seal. device in a fluid system that limits or controls leakage of fluid from one location to another in the system, limits or controls leakage from the system to the exterior, or excludes contaminants from the system

sealant. liquid/solid mixture installed at joints and junctions of components to prevent leakage of fluid (esp. gas) from the joint or junction

seal extrusion. permanent displacement, under the action of fluid pressure, of part of a seal into a gap provided for such displacement

sea-level engine. rocket engine designed to operate at sea level; i.e., the nozzle flows full at sea-level pressure

seal lip. part of a lip seal that comes in contact with the mating surface and that, together with the mating surface, forms the primary seal

seal nose. part of a face seal that contains the sealing surface; also called seal nosepiece

seal rubbing speed. speed at which the rotating mating ring on the shaft rubs against the stationary seal nosepiece

seal weld. weld seam with the primary function of sealing against fluid leakage

seat. surface in valve housing that the valving element contacts to shut off flow and limit primary leakage

secondary leakage. leakage from a fluid-system component to the exterior

secondary seal. seal intended to limit secondary leakage; e.g., a seal on a valve shaft

self-cooled. term applied to a combustion chamber or nozzle in which wall temperature is controlled or limited by methods that do not involve flow within the wall of coolant supplied from an external source

self-pressurization. increase of ullage pressure by vaporization or boiloff of contained fluid without the aid of additional pressurant

sensible atmosphere. that part of an atmosphere that offers significant resistance to a body passing through it

sensitivity. measure of relative susceptibility of a propellant to deflagration or detonation under specified conditions

separated flow. flow detached from the wall of the flow passage

servovalve. modulating operator that amplifies a low-power control signal for variable-displacement, closed-loop control of actuator position

shaft. a bar (almost always cylindrical) used to support rotating pieces or to transmit power or motion by rotation

shaft-riding elements. components such as collars and sleeves that are attached to the surface of the pump shaft and are not an integral part of the shaft

shaft-riding seal. circumferential seal that is keyed to the shaft and whose outer surfaces mate with the shaft housing

shaft runout. twice the distance by which the center of a shaft is displaced from the axis of rotation, i.e., twice the eccentricity

shake table. device for subjecting components or assemblies to vibration in order to reveal vibrational mode patterns; also called simply "shaker"

shelf life. storage time during which an item remains serviceable, i.e., will operate satisfactorily when put in use

shingle layup. geometric arrangement of plies in which the plies overlap each other as in a roof covering

Shore hardness. indentation hardness of plastics or elastomers measured by use of a blunt indenter point under a specified load

shroud. 1. short extension of the outer wall of a plug nozzle downstream of the throat; 2. continuous covering of the outer surfaces of an impeller or other rotative component

shutoff valve. valve that terminates the flow of fluid; usually a two-way valve that is either fully open or fully closed

sigma. term in statistics: the standard deviation from the mean

sleeve valve (linear). valve with a cylindrical sleeve element that reciprocates in the cylinder bore to open or close the flow area by uncovering or covering annular slots in the bore

sleeve valve (rotary). valve with concentrically mated slotted cylinders that open and close the flow area by rotation of one cylinder relative to the other

slinger. washer-like device mounted next to a mating ring and used for imparting radial momentum to a liquid in order to keep the liquid away from the sealing interface

slip coefficient. index to the ability of an impeller with a finite number of blades to impart the same tangential whirl to the fluid as an impeller with an infinite number of blades

slip effects. discontinuities in momentum and temperature in the boundary layer due to rarefaction of the exhaust gas

slip flow. flow in the transition regime of gas dynamics, wherein the mean free path of the gas molecules is of the same order of magnitude as the thickness of the boundary layer. The gas in contact with a body surface immersed in the flow is no longer at rest with respect to the surface

slipstream. flow of fluid around a structure that is moving through the fluid

sliver. portion of solid-propellant grain remaining at time of web burnout

slotted crank. valving-element linkage mechanism in which a slot in the lever of the rotating member holds the pin from the reciprocating actuator shaft so that linear actuator motion is translated to rotary motion without additional linkage to compensate for the change due to rotation

slump. flow or sag of material (e.g., filled elastomer) after it has been applied to a chamber wall or otherwise cast or troweled in place

S-N. stress vs number of cycles to failure; plots of such data are used in fatigue testing

soft poppet. poppet that has a soft sealing surface

soft sealing surface. surface fabricated of material (plastic or elastomer) that can yield or deform to provide the sealing action

soft seat. seat that is fabricated of an elastomer or plastic

solenoid. helically wound coil of insulated wire that when conducting electricity generates a magnetic field that actuates a movable core

solenoid valve. poppet, spool, or piston valve actuated by an integrally mounted solenoid actuator

solid height. height of a coil spring compressed to the point where the coils are in contact and no further compression is possible

solidity (blade). ratio of blade chord length to blade spacing

solid lubricant. see dry film lubricant

solidus temperature. temperature at which melting starts

spacecraft. separable, self-contained, self-propelled vehicle designed to operate in space either in orbit about earth or in travel to and orbit about another heavenly body; generally is the final stage (useful payload) atop a launch vehicle

spalling. flaking off of particles and chunks from the surface of a material as a result of localized stresses

specific diameter. parameter in pump design used to relate pump physical size, head, flowrate, and performance

specific impulse. performance index for rocket propellants, equal to the thrust produced by propellant combustion divided by the mass flowrate

specific speed. parameter in pump design used to relate pump rotational speed, head, flowrate, and performance

spillage. amount of fluid that remains trapped within a double-valve disconnect when the disconnect is partially disengaged and both valves have closed

spiral-wound gasket. static seal formed by winding a metal strip or ribbon and a suitable filler layer into a spiral; it is usually comprised of strips having a "V"-shaped cross section

spool valve. valve utilizing a solid cylindrical valving element (spool) having two or more lands that fit closely within the bore of the housing; the valve opens or closes by translating the spool within the bore

spring rate. the force, independent of initial tension, required to extend the working length of a spring unit distance

square-root characteristic. relation between valve flow and valving-element stroke in which flow varies with the square root of the stroke; this characteristic is also termed quick opening

squeeze-film damping. friction damping produced by pressure and flow forces in a thin film of fluid subjected to high load and shear

squib. term for an electroexplosive device

stabilization device. see combustion stabilization device

stacking. assembling the coolant tubes of a liquid rocket thrust chamber vertically on a mandrel that simulates the chamber/nozzle contour; this procedure facilitates fitting and adjusting the tubes to the required contour prior to brazing

stacking axis (or line). term in pump design for the imaginary line on which the centers of gravity of the profile sections are stacked to form the blade or vane shape from hub to tip

stackoff. eccentricity of the convolutions of a bellows with respect to each other, the eccentricity accumulating in the same direction during fabrication

stage. 1. a separable, self-contained, self-propelled section of a space vehicle; 2. a set of rotor blades and stator vanes in a turbine or an axial-flow pump, or one set of impeller and associated flow passages in a centrifugal-flow pump; 3. the degree of polymerization of a synthetic resin

staged combustion. rocket engine cycle in which propellants are partially burned in a preburner prior to being burned in the combustion chamber

stagger angle. angle between the chord line and a reference direction, which usually is the axis normal to the plane of the blade row

staging. 1. separating a stage or set of stages from a spent stage of a launch vehicle; 2. incorporating two or more stages in a pump or turbine; 3. increasing the molecular weight of a resin without effecting a cure

stagnation. condition in which flowing fluid is brought to rest isentropically

stagnation point. point in a flow field about a body immersed in a flowing fluid at which the fluid particles have zero velocity with respect to the body

stagnation pressure. 1. pressure that a flowing fluid would attain if brought to rest isentropically; 2. pressure of a flowing fluid at a point of zero fluid velocity on a body around which the fluid flows

stagnation region. the region in the vicinity of a stagnation point in a flow field about a body where the fluid velocity relative to the body is negligible

stagnation temperature. temperature that a flowing fluid would attain if the fluid were brought to rest isentropically from a given flow velocity (same as total temperature); for an ideal gas, the process need only be adiabatic

stall. 1. in a valve, condition wherein the actuation force is equal to the dynamic force plus the friction force, the valving element thus being stopped in a partially open position; 2. in a pump, loss of pumping capability when flow separation in the rotor or stator flow passages progresses to the point at which headrise drops abruptly

stall margin. margin between pump operation at the design-point flow coefficient and operation at the flow coefficient at which the pump will stall

Stanton number. dimensionless parameter expressing the ratio of heat transferred to a fluid to heat transported by the fluid

starting torque. turning or twisting force required to initiate rotary motion

static imbalance. distribution of rotor mass such that the rotor center-of-gravity axis is translationally eccentric to the bearing axis. This mass eccentricity generates centrifugal forces that are reacted by the bearings when the rotor rotates about the bearing axis. Static imbalance, also referred to as force imbalance, can be corrected by adding or subtracting mass in a single plane perpendicular to rotor axis

static seal. device used to prevent leakage of fluid through a mechanical joint in which there is no relative motion of the mating surfaces other than that induced by changes in the operating environment

stator. part of a turbopump assembly that remains fixed or stationary relative to a rotating or moving part of the assembly

stay time. average length of time spent within the combustion chamber by each gas molecule or atom involved in the combustion process; also called residence time

steady state. condition of a physical system in which parameters of importance (fluid velocity, temperature, pressure, etc.) do not vary significantly with time; in particular, the condition or state of rocket engine operation in which mass, momentum, volume, and pressure of the combustion products in the thrust chamber do not vary significantly with time

sterilization. process in which a propulsion system package is rendered sterile (free from micro-organisms and bacteria) by the application of heat or by the use of a special sterilization fluid or both

stiffness. resistance to deflection

stoichiometric combustion. the burning of fuel and oxidizer in precisely the right proportions required for complete reaction, with no excess of either reactant

strain gauge. instrument used to measure the strain or distortion in a structural member or test specimen subjected to a load

streamline. line tangent to the velocity vector at each point in a flowfield; in steady flow, a streamline is the pathline of a fluid element

stress concentration. localized increase in the stress in a structural member

stress corrosion. corrosion of a metallic surface enhanced (i.e., increased in rate) by the existence of localized stresses, whether applied or residual

stress-corrosion cracking. delayed fracture of a material as a result of the combined action of static tensile stress and a corrosive (agressive) environment

structural test motor (STM). motor model constructed for the purpose of evaluating the structural integrity of a solid rocket motor design

stubout. tubular nipple protruding from a component to which the connecting line is welded or brazed

stuffing box. cavity in the housing of a pump shaft designed to accept a packing for the purpose of preventing leakage along the shaft

subcritical. coined word denoting (1) operation of rotating machinery below a critical speed or (2) fluid maintained at pressures or temperatures below its corresponding critical point

sublimation. phase change of a substance directly from solid to gas (without apparent liquefaction)

submerged nozzle. nozzle configuration in which the nozzle entry, throat, and part or all of the nozzle exit cone are cantilevered into the combustion chamber

subsynchronous whirl. whirl condition in which shaft whirl velocity is less than shaft rotational speed

subsystem tank. container of pressurized fluid or gas that is mounted internally in a vehicle, is essentially isolated from adverse vehicle loads, and is of monocoque design

suction specific speed. index to pump suction performance relating rotational speed and flowrate to the minimum NPSH at which the pump will deliver specified performance

suction surface. convex surface of a pump or turbine blade; along this surface, the fluid pressures are lowest

supercritical. coined word denoting (1) operation of rotating machinery above a critical speed or (2) fluid maintained at pressures or temperatures above its corresponding critical point

super-insulation. high-efficiency laminated-foil insulator used in low temperature applications; thermal conductivity is 1/10 to 1/150 that of common insulating materials

sustainer engine. auxiliary booster engine in a propulsion system that provides thrust after the main booster engines cease firing

synchronous whirl. whirl condition in which shaft whirl velocity equals shaft rotational speed

swaging. process of tapering or reducing the diameter of a rod or tube by hammering or squeezing

-T-

tailoff. period of decay in rocket motor thrust after the end of effective propellant burning time

tailoring. modification of a basic solid propellant by adjustment of propellant properties to meet requirements of a specific rocket motor

tangled-yarn. term used to describe a nonrepetitive whirl orbit of a pump rotor

tank. pressure vessel containing propellant or pressurant to be used in a rocket vehicle fluid system

tank components. 1. devices for controlling the behavior of propellants (positioning devices, slosh and vortex suppression devices, baffles, standpipes, expulsion devices); 2. tank insulation

tap density. bulk density of granular powder measured after tapping the container several times

taper. 1. gradual reduction in or enlargement of coolant-tube diameter; 2. gradual axial increase in grain perforation area along a section of fixed shape

taper ratio. ratio of maximum coolant-tube diameter to minimum tube diameter; usually kept below 4

temperature jump. difference in temperature between the nozzle wall and the layer of gas molecules next to the wall, a result of rarefaction of the exhaust gas

tension system. duct system wherein the fluid-column or longitudinal forces due to internal pressure are not transmitted to the supporting structure; the fluid-column loads of such a duct system are reacted by axial tension in the duct walls

thermal-compensating orifice. orifice whose flow area adjusts to compensate for temperature changes in the controlled fluid

thermal cycling. exposure of a component to alternating levels of relatively high and low temperatures

thermal induction interval. time period during which the temperature of the solid propellant surface is raised by external heating to the temperature at which chemical reaction rates become significant

thermal reactor. term for a monopropellant gas-generator design in which the combustion chamber does not contain a catalyst bed, and convection processes are depended on to promote the decomposition reactions

thermodynamic suppression head. an effect, due to a decrease in fluid vapor pressure and in fluid density, that acts to decrease the critical NPSH requirement of a turbopump

thermorheological simplicity. term for a concept in material studies denoting that effects of temperature on the relaxation modulus can be accounted for by adjusting the time scale, expanding (for cold) or contracting (for hot)

three-dimensional grain configuration. grain whose burning surface is described by three-dimensional analytical geometry (one that considers end effects)

three-way valve. valve having three controlled ports, usually one inlet and two outlet ports

threshold stress intensity. highest stress intensity for which there is no crack growth in a material in a particular environment during a sufficiently long loading period

throat. portion of a convergent/divergent nozzle at which cross-sectional area is minimal, the region of transition from subsonic to supersonic flow of exhaust gases

throat gap. width of the annular passage at the throat of an annular nozzle or of a variable venturi valve

throttle valve. valve to control flowrate of a fluid by means of a variable-area flow restriction; this kind of valve may have an infinite number of operating positions as contrasted to a shutoff valve, which is either fully open or fully closed

through-bulkhead initiator. contrivance in which a small charge of material is detonated such that the resulting shock wave is transmitted through a solid metal interface; the transmitted shock wave detonates an acceptor charge on the internal side of the interface, which then initiates the deflagration of heat-producing material that ignites the propellant

thrust. propulsive force developed by a rocket engine during firing

thrust-balance system. set or arrangement of devices that provides the (pressure X area) force necessary to balance axial thrust in a turbopump

thrust barrel. structure in the rocket vehicle designed to accept the thrust load from two or more engines; also called thrust structure

thrust chamber. the assembly of injector, combustion chamber, and nozzle

thrust coefficient. ratio of engine thrust to the product of nozzle throat area times nozzle inlet pressure

thrust collector. structure attached to a rocket engine during testing to transmit the engine thrust to thrust-measuring instruments

thrust-time profile. plot of thrust vs time for the firing duration of a rocket engine

thrust-vector control. steering or guidance of vehicle by angular deflection of the rocket engine thrust vector; e.g., by gimballing the engine

time-temperature shift factor. shift in time required to superpose curves of tensile relaxation modulus vs time onto a single curve

timing. operation of a valve in a prescribed manner within a prescribed time

tolerance stackup. additive effect of all the allowable manufacturing tolerances on the final dimensions of the assembly; also called tolerance buildup

torquemotor. electrical motor of small rotary displacement that incorporates a control winding composed of two separate coils and a permanent magnet

torsional deflection. deflection imposed on a flexible joint by applying a torque about its longitudinal axis

total pressure. same as stagnation pressure

total temperature. same as stagnation temperature

transient. condition of a physical system in which parameters of importance (temperature, pressure. fluid velocity, etc.) vary significantly with time; in particular, condition or state of rocket engine operation in which the mass, momentum, volume, and pressure of the combustion products within the thrust chamber vary significantly with time

transient period. interval from start or ignition to the time when steady-state conditions are reached

transpiration cooling. cooling of a porous inner wall of a combustion chamber or nozzle by flow of coolant fluid through the porous material; the fluid may be supplied from an external source or generated within the material (as in ablation)

transverse slot. slot inside a propellant grain, positioned at an angle approximately 90° to axis of the rocket motor

travel time. elapsed time from first motion of the movable element in a flow-control device to full-open or full-closed position

triple point. intersection of the solid/vapor, solid/liquid, and liquid/vapor lines in a phase diagram; at this point, solid, liquid, and vapor phases may coexist is equilibrium

triplet. injector orifice pattern consisting of one or more sets of three orifices that produce streams converging to a point; usually fuel is injected through outer orifices, and oxidizer is injected through the central orifice

tripping. see boundary-layer trip

tube crown. portion of the coolant tube that forms the outer wall of the cooling jacket

tube-wall construction. use of parallel metal tubes that carry coolant to form the combustion chamber or nozzle wall

turbine. machine consisting of one or more bladed disks (rotor or turbine wheel) and one or more sets of fixed vanes (stator) inside a casing, so designed that the wheel is turned by incoming fluid (usually hot gas) striking the blades

turbine velocity ratio. ratio of pitchline velocity to isentropic spouting velocity, an index for classifying turbine type and for estimating performance

turbopump. an assembly consisting of one or more pumps driven by a hot-gas turbine

turbopump system. an assembly of components (e.g., propellant pumps, turbine(s), power source) designed to raise the pressure of the propellants received from the vehicle tanks and deliver them to the main thrust chamber at specified pressures and flowrates

turbulence ring. circumferential protuberance in the gas-side wall of a (gas generator) combustion chamber intended to generate turbulent flow and thereby enhance the mixing of burning gases

turbulent flow. fluid flow in which the velocity at a given point fluctuates randomly and irregularly in both magnitude and direction

turndown ratio. ratio of maximum to minimum controlled flowrates of a throttle valve

turning vane. see vane

twilled double Dutch weave (TDDW). woven wire cloth in which each shute wire passes successively over two and under two warp wires and each warp wire passes successively over two and under two shute wires; the shute wires are smaller than the warp wires and overlap, the result being a dense weave; used for filter elements

two-dimensional grain configuration. solid-propellant grain whose burning surface is described by two-dimensional analytical geometry (cross section is independent of length)

two-phase flow. simultaneous flow of gases and solid particles (e.g., condensed metal oxide), or of liquid and vapor

-U-

ullage. volume by which a container (tank) falls short of being full of liquid, the empty space being filled with gas

ullage pressure. pressure in the ullage space of a container, either supplied or self-generated

ultimate load (or pressure). load (or pressure) at which catastrophic failure (general collapse or rupture) of a structure occurs

ultimate stress. stress at which a material fractures or becomes structurally unstable

umbilical. line or duct connecting the launch vehicle to ground facilities that supply power or fluids

UMR injector. injector that produces a uniform mixture ratio and thus a combustion region with relatively uniform temperature distribution

underexpansion. expansion of the nozzle exhaust gas to a pressure higher than the ambient pressure

untwist forces. forces acting on a twisted blade that produce a torque tending to reduce the blade twist

upcomer. nozzle tube in which coolant flows in a direction opposite to that of the exhaust gas flow

upper stage. the second or later self-propelled separable section in a rocket vehicle having two or more such sections

valve. mechanical device by which the flow of fluid may be started, stopped, or regulated by a movable part that opens, closes, or partially obstructs a passageway or port in a containing structure, the valve housing

valve-type disconnect. quick-disconnect coupling that includes valve elements for sealing purposes at separation

valving element. the movable portion of a valving unit that translates or rotates to vary flow or to shut off the flow of liquid

valving unit. combination of the valving element and the valve seat contained in a suitable housing

valving-unit throat. flow area between the valving element and seat of the valving unit

vane. one of a set of slat-like objects rigidly fixed to a wall or other nonmoving part of a fluid system, each slat being carefully shaped, usually as an airfoil, so as to guide or direct the flow of fluid or create a special kind of flow

vane pump. pump consisting of a rotor with sliding vanes (blades as herein defined) that is mounted in an eccentric housing

vapor honing. method of eroding (or cleaning) a metal surface by blasting a fine erosive material against the surface, a vaporized fluid being used as a carrier for the material

vehicle tank. tank that serves both as primary integral structure of a vehicle and as a container of pressurized propellants

velocity head. pressure (i.e., head) of a fluid due to speed of flow, i.e., the difference between total pressure and static pressure

velocity slip. velocity of the gas molecules next to the nozzle wall, a result of rarefaction of the exhaust gas

vent-and-relief valve. specialized version of a relief valve wherein the assembly acts as an outlet for ullage vapor during filling of a tank and then performs as a relief valve during operation

vent valve. pressure-relieving shutoff valve that is operated on external command, as contrasted to a relief valve, which opens automatically when pressure reaches a given level

vernier engine. small rocket engine attached to a rocket vehicle to provide low thrust levels for precise control of velocity

Vickers hardness. indentation-hardness test in which the indenter is a diamond cone of a specified angle between opposite faces; the load, test duration, and rate of descent of the indenter are specified

virtual mass. mass of fluid near a moving body (e.g., a blade) that moves with the body and thereby increases the effective mass in motion

viscosity. fluid resistance to flow caused by internal molecular attraction

visor valve. ball valve utilizing only a segmented shell of the ball; this design reduces weight

void. air bubble in a cured propellant grain or in rocket motor insulation

volumetric efficiency. measure of the desirability of a given design for an expulsion device: ratio of loaded liquid volume to internal tank volume

volute. spiral-shaped part of a pump casing that collects fluid from the impeller in a single channel of gradually increasing area

-W-

warmant passages. passages provided in cryogenic-valve hydraulic actuators to maintain actuator temperatures above specified operating minimums under extended hold conditions

warp yarn. yarn running parallel to the length of the fabric

water hammer. literally, the sound of concussion in a conduit when a flowing liquid is suddenly stopped; more generally, the pressure surge in the system that results from such stoppage

wave spring. disk/washer element deformed to have a multiple-wave pattern in a plane perpendicular to its axis

wear rate. amount of surface wear in a designated time period

web. minimum thickness of a solid propellant grain from the initial ignition surface to the insulated case wall or to the intersection of another burning surface at the time when the burning surface undergoes a major change; for an end-burning grain, the length of the grain

web fraction. ratio of web to grain outer radius

weld dropthrough. excessive weld-bead projection on the inner walls of a fluid passage

wet cycle. operation of a flow-control device with propellant or test fluid in the flow passage

wettability. ease with which a fluid will flow over and adhere to a surface (e.g., molten solder on a heated metal surface)

whirl. motion of a rotating shaft in a path or orbit about a longitudinal axis different from the axis of rotation; whirl may be forced or self-excited

wind. flow of gas from region of high pressure to region of low pressure as a result of mass and mixture-ratio maldistribution. When the flow is radial to equilibrate pressure across a given axial location, the movement is termed radial wind

windage. circulation or pumping of fluids caused by impeller action of rotating components; a gas contained in a cavity with rotating shafts, gears, or bearings will circulate within the cavity by windage

work hardening. an increase in hardness (stiffness) of a metal brought about by subjecting it, at temperatures below the recrystallization range, to stresses great enough to plastically deform the metal; work hardening may occur during fabrication or during use, but in either event the material loses ductility

worm screw (or ball screw). mechanical device used to convert rotary motion to reciprocating motion for positioning the valving element

wraparound. term for a flexible duct or hose assembly that "wraps around" the thrust-vector-control gimbal of a rocket engine in the plane of the gimbal

-Y-

yaw. angular motion of a vehicle about a vertical axis through its midpoint or center of gravity and perpendicular to the longitudinal axis

yield load. load that must be applied to a structure to cause a permanent deformation of a specified amount

yield stress. stress at which a material exhibits a permanent deformation, usually specified as 0.0020 inch per inch (0.2 percent)

yoke. cross member used in mechanical devices (e.g., valves) to connect two movable elements with a single driver

-Z-

zero-g. term applied to a condition or state in which the force of gravity is absent

TABLE OF CONVERSION FACTORS

(Factors for Converting U.S. Customary Units* to SI Units*)

Physical quantity	U.S. customary unit	SI unit	Conversion factor**
Acceleration	ft/sec^2	m/sec^2	3.048×10^{-1}
Angle	deg	rad	1.745×10^{-2}
Angular velocity	rpm	rad/sec	1.047×10^{-1}
Area	circ. mil	mm^2	5.067×10^{-4}
	ft^2	m^2	9.290×10^{-2}
	$in.^2$	cm^2	6.452
Bending moment	in.-lbf	N-m	1.130×10^{-1}
Burn rate	in./sec	mm/sec	2.54×10^{1}
Chamber pressure times thrust	$lbf^2/in.^2$	N^2/cm^2	3.067
Density	gm/cm^3	kg/m^3	1.00×10^{3}
	lbm/ft^3	kg/m^3	1.602×10^{1}
	$lbm/in.^3$	kg/m^3	2.768×10^{4}
DN	mm-rpm	mm-rad/sec	1.047×10^{-1}
Energy	Btu	J	1.054×10^{3}
	cal	J	4.184
	ft-lbf	J	1.356
Enthalpy	Btu	J	1.054×10^{3}
	cal	J	4.184
Enthalpy (specific)	Btu/lbm	J/kg	2.324×10^{3}
Flowrate	gpm	m^3/min	3.785×10^{-3}
	lbm/sec	kg/sec	4.536×10^{-1}
Force	lbf	N	4.448
	ozf	N	2.780×10^{-1}
Fracture toughness	$ksi\text{-}in.^{1/2}$	$(kN/m^2)\text{-}m^{1/2}$	1.099×10^{3}
FV factor	lbf/in. × ft/sec	N/cm × m/sec	5.338×10^{-1}
g	ft/sec^2	m/sec^2	3.048×10^{-1}

*A definition of all symbols and abbreviations for units appears at the end of the table. The symbol gm is used for gram to distinguish it from the symbol g used for the unit force of gravity.

**Except for temperature conversions, which are to be made as shown, multiply value given in U.S. customary unit by conversion factor to obtain equivalent value in SI unit. For a complete listing of conversion factors for basic physical quantities, see Mechtly, E. A.: The International System of Units. Physical Constants and Conversion Factors. Second Revision, NASA SP-7012, 1973.

Gas constant, specific	(ft-lbf)/(lbm-°R)	J/(kg-K)	5.380
	(in.-lbf)/(lbm-°R)	J/(kg-K)	4.483×10^{-1}
Gas constant, universal	cal/(mol-°K)	J/(kg-mol-K)	4.184×10^{3}
	(ft-lbf)/(lbm-mol-°R)	J/(kg-mol-K)	5.380
	(in.-lbf)/(lbm-mol-°R)	J/(kg-mol-K)	4.483×10^{-1}
Head or headrise	ft	m	3.048×10^{-1}
	(ft-lbf)/lbm	J/kg	2.989
Heat flux	Btu/(ft^2-sec)	W/m^2	1.135×10^{4}
	Btu/(ft^2-hr)	W/m^2	3.152
	Btu/(in.^{2}-sec)	W/cm^2	1.634×10^{2}
	cal/(cm^2-sec)	W/cm^2	4.184
Heat generation rate	Btu/sec	W	1.054×10^{3}
Heat generation rate per unit area	Btu/(sec-in.^{2})	W/cm^2	1.634×10^{2}
Heat of ablation	Btu/lbm	J/kg	2.324×10^{3}
Heat of explosion	cal/gm	J/kg	4.184×10^{3}
Heat-transfer coefficient	Btu/(hr-ft^2-°F)	W/(m^2-K)	5.674
	cal/(sec-cm^2-°C)	W/(cm^2-K)	4.184
Humidity	gr/lbm	kg/kg	1.428×10^{-4}
Impact energy	ft-lbf	J	1.356
Impulse (total)	lbf-sec	N-sec	4.448
Imbalance	in.-ozf	N-m	7.061×10^{-3}
Leakage rate*	scfm	scmm	2.832×10^{-2}
		sccm	2.832×10^{4}
	scim	sccm	1.639×10^{1}
		scch	9.834×10^{2}
Length	Å	cm	1.00×10^{-8}
		μm	1.00×10^{-4}
	ft	m	3.048×10^{-1}
	in.	cm	2.54
	mil	μm	2.54×10^{1}
	μ in.	μm	2.54×10^{-2}
Load	lbf	N	4.448
	psi	N/cm^2	6.895×10^{-1}
Load factor	lbf/lbm	N/kg	9.807
Load/unit length	lbf/in.	N/cm	1.751
Magnetic field strength	gamma	T	1.00×10^{-9}
Mass	gr	kg	6.480×10^{-5}
	lbm	kg	4.536×10^{-1}
	ozm	kg	2.835×10^{-2}

*Conversion to non-SI units scmm, sccm, etc. are provided for completeness.

Mass density	(lbm-sec^2)/in.^{4}	(kg-sec^2)/cm^4	1.090×10^{-2}
Mass diffusivity	ft^2/hr	m^2/hr	9.290×10^{-2}
Mass flux	lbm/(in.^{2}-sec)	kg/(cm^2-sec)	7.030×10^{-2}
	lbm/(in.^{2}-min)	kg/(cm^2-min)	7.030×10^{-2}
	lbm/(ft^2-sec)	kg/(m^2-sec)	4.882
Modulus (compressive; elastic; tensile)	psi	N/cm^2	6.895×10^{-1}
	ksi	N/cm^2	6.895×10^{2}
		N/m^2	6.895×10^{6}
		kN/m^2	6.895×10^{3}
Molecular weight	lbm/(lbm-mol)	kg/(kg-mol)	1.00
Peel strength	lbf/in.	N/cm	1.751
Permeativity	(lbm-mol)/(in.^{2}-hr-psi)	(kg-mol)/(cm^2-hr-N/cm^2)	1.020×10^{-1}
Power	hp	W	7.457×10^{2}
Power flux	W/in.^{2}	W/cm^2	1.560×10^{-1}
Pressure	atm	N/m^2	1.013×10^{5}
		N/cm^2	1.013×10^{1}
	in. Hg (60°F)	kN/m^2	3.386
	ksi	kN/m^2	6.895×10^{3}
	mm Hg (0°C)	N/cm^2	1.333×10^{-2}
	psf	N/m^2	4.788×10^{1}
	psi	kN/m^2	6.895
		N/cm^2	6.895×10^{-1}
	torr (0°C)	N/cm^2	1.333×10^{-2}
PV factor	psi X ft/sec	MN/(m-sec)	2.102×10^{-3}
Resistivity	ohm/cmf	μohm-cm	1.667×10^{-1}
	ohm-in.	ohm-cm	2.54
Roll moment	ft-lbf	N-m	1.356
Rotational speed	rev/sec	rad/sec	6.283
	rpm	rad/sec	1.047×10^{-1}
Section modulus	in.^{3}	cm^3	1.639×10^{1}
Specific heat	Btu/(lbm-°R)	J/(kg-K)	4.184×10^{3}
	cal/(gm-°C)	J/(kg-K)	4.184×10^{3}
Specific impulse	(lbf-sec)/lbm	m/sec	9.807
		(N-sec)/kg	9.807
Spring rate or stiffness	lbf/in.	N/cm	1.751
Stefan-Boltzmann constant	Btu/(hr-ft^2-°R^4)	J/(sec-m^2-K^4)	3.310×10^{1}
Strain	in./in.	cm/cm	1.
Strength (compressive, tensile, shear, yield, etc.)	psi	N/cm^2	6.895×10^{-1}
	ksi	kN/m^2	6.895×10^{3}
Stress (compressive, tensile, etc.)	psi	N/cm^2	6.895×10^{-1}
	ksi	kN/m^2	6.895×10^{3}

Surface finish	μ in.	μm	2.54×10^{-2}
Surface speed (rubbing speed)	ft/sec	m/sec	3.048×10^{-1}
Surface tension	dynes/cm	N/m	1.00×10^{-3}
	lbf/ft	N/m	1.459×10^{1}
Taper	in./in.	cm/cm or mm/mm	1.00
Temperature	°C	K	K = °C + 273.15
	°F	K	K = (5/9) (°F + 459.67)
	°R	K	K = (5/9) (°R)
Temperature difference	°C	K	K = °C
	°F or °R	K	K = (5/9) (°F or °R)
Tensile strength or stress	ksi	kN/m^2	6.895×10^{3}
	psi	N/m^2	6.895×10^{3}
		N/cm^2	6.895×10^{-1}
Thermal conductivity	Btu/(hr-ft-°F)	W/(m-K)	1.730
	Btu/(hr-in.-°F)	W/(m-K)	2.075×10^{1}
	(Btu-in.)/(hr-ft^2-°F)	W/(m-K)	1.441×10^{-1}
	Btu/(sec-ft-°F)	W/(m-K)	6.227×10^{3}
	cal/(cm-sec-°C)	W/(cm-K)	4.184
Thermal diffusivity	ft^2/hr	m^2/hr	9.290×10^{-2}
	$in.^2$/hr	cm^2/hr	6.452
Thermal energy	Btu	J	1.054×10^{3}
Thermal expansion coefficient	in./(in.-°F)	m/(m-K)	1.8
Thermal resistance	(°F-sec)/Btu	K/W	5.269×10^{-4}
Thrust	lbf	N	4.448
Torque	ft-lbf	N-m	1.356
	in.-lbf	N-m	1.130×10^{-1}
	in.-ozf	N-m	7.061×10^{-3}
Velocity	ft/sec	m/sec	3.048×10^{-1}
	in./sec	cm/sec	2.54
Viscosity, absolute	(lbf-sec)/ft^2	(N-sec)/m^2	4.788×10^{1}
	(lbf-sec)/$in.^2$	(N-sec)/cm^2	6.895×10^{-1}
Viscosity, dynamic	lbm/(ft-sec)	(N-sec)/m^2	1.488
	lbm/(in.-sec)	(N-sec)/cm^2	1.786×10^{-3}
	gm/(cm-sec)	(N-sec)/cm^2	1.00×10^{-5}
Viscosity, kinematic	$in.^2$/sec	cm^2/sec	6.452
	centistokes	cm^2/sec	1.00×10^{-2}
Volume	ft^3	m^3	2.832×10^{-2}
	gal	m^3	3.785×10^{-3}
	$in.^3$	cm^3	1.639×10^{1}
Wear rate	in./hr	mm/hr	2.54×10^{1}
Yield strength or stress	psi	N/cm^2	6.895×10^{-1}
	ksi	kN/m^2	6.895×10^{3}
Young's modulus	psi	N/cm^2	6.895×10^{-1}

DEFINITION OF SYMBOLS AND ABBREVIATIONS FOR UNITS

Å	angstrom unit (10^{-10}m)
atm	atmosphere
Btu	British thermal unit
°C	degrees centigrade (Celsius)
cal	calorie (thermochemical)
circ. mil	circular mil (area of a circle 1 mil in diam.)
cm	centimeter (10^{-2}m)
cmf	circular mil foot
deg	degree
°F	degrees Fahrenheit
ft	foot
g	acceleration due to gravity
gal	gallon
gm	gram (10^{-3} kg)
gpm	gallons per minute
gr	grain
hp	horsepower
hr	hour
in.	inch
J	Joule
K	degrees Kelvin
kg	kilogram
kg-mol	kilogram-mole (mass in kilograms numerically equal to molecular weight)
kN	kilonewton (10^3 N)
ksi	10^3 pounds force per square inch
lbf	pound force
lbm	pound mass

m	meter
mil	10^{-3} in.
min	minute
mm	millimeter (10^{-3} m)
MN	meganewton (10^{6} N)
mol	mole (mass in grams or pounds numerically equal to molecular weight)
N	newton
ozf	ounce force
ozm	ounce mass
psf	pounds force per square foot
psi	pounds force per square inch
°R	degrees Rankine
rad	radian
rev	revolution
rpm	revolutions per minute
scch	standard cubic centimeters per hour*
sccm	standard cubic centimeters per minute*
scfm	standard cubic feet per minute*
scim	standard cubic inches per minute*
scmm	standard cubic meters per minute*
sec	second
T	tesla
W	watt
μin.	micro-inch (10^{-6} in.)
μm	micrometer (10^{-6} m)

*Measured at a pressure of 1 atm and temperature of 70°F (standard condition)

NASA SPACE VEHICLE DESIGN CRITERIA MONOGRAPHS ISSUED TO DATE

ENVIRONMENT

SP-8005	Solar Electromagnetic Radiation, Revised May 1971
SP-8010	Models of Mars Atmosphere (1974), Revised December 1974
SP-8011	Models of Venus Atmosphere (1972), Revised September 1972
SP-8013	Meteoroid Environment Model 1969 (Near Earth to Lunar Surface), March 1969
SP-8017	Magnetic Fields Earth and Extraterrestrial, March 1969
SP-8020	Surface Models of Mars (1975), Revised September 1975
SP-8021	Models of Earth's Atmosphere (90 to 2500 km), Revised March 1973
SP-8023	Lunar Surface Models, May 1969
SP-8037	Assessment and Control of Spacecraft Magnetic Fields, September 1970
SP-8038	Meteoroid Environment Model 1970 (Interplanetary and Planetary), October 1970
SP-8049	The Earth's Ionosphere, March 1971
SP-8067	Earth Albedo and Emitted Radiation, July 1971
SP-8069	The Planet Jupiter (1970), December 1971
SP-8084	Surface Atmospheric Extremes (Launch and Transportation Areas), Revised June 1974
SP-8085	The Planet Mercury (1971), March 1972
SP-8091	The Planet Saturn (1970), June 1972
SP-8092	Assessment and Control of Spacecraft Electromagnetic Interference, June 1972

SP-8103	The Planets Uranus, Neptune, and Pluto (1971), November 1972
SP-8105	Spacecraft Thermal Control, May 1973
SP-8111	Assessment and Control of Electrostatic Charges, May 1974
SP-8116	The Earth's Trapped Radiation Belts, March 1975
SP-8117	Gravity Fields of the Solar System, April 1975
SP-8118	Interplanetary Charged Particle Models (1974), March 1975
SP-8122	The Environment of Titan (1975), July 1976

STRUCTURES

SP-8001	Buffeting During Atmospheric Ascent, Revised November 1970
SP-8002	Flight-Loads Measurements During Launch and Exit, December 1964
SP-8003	Flutter, Buzz, and Divergence, July 1964
SP-8004	Panel Flutter, Revised June 1972
SP-8006	Local Steady Aerodynamic Loads During Launch and Exit, May 1965
SP-8007	Buckling of Thin-Walled Circular Cylinders, Revised August 1968
SP-8008	Prelaunch Ground Wind Loads, November 1965
SP-8009	Propellant Slosh Loads, August 1968
SP-8012	Natural Vibration Modal Analysis, September 1968
SP-8014	Entry Thermal Protection, August 1968
SP-8019	Buckling of Thin-Walled Truncated Cones, September 1968
SP-8022	Staging Loads, February 1969
SP-8029	Aerodynamic and Rocket-Exhaust Heating During Launch and Ascent, May 1969
SP-8030	Transient Loads From Thrust Excitation, February 1969
SP-8031	Slosh Suppression, May 1969

SP-8032	Buckling of Thin-Walled Doubly Curved Shells, August 1969
SP-8035	Wind Loads During Ascent, June 1970
SP-8040	Fracture Control of Metallic Pressure Vessels, May 1970
SP-8042	Meteoroid Damage Assessment, May 1970
SP-8043	Design-Development Testing, May 1970
SP-8044	Qualification Testing, May 1970
SP-8045	Acceptance Testing, April 1970
SP-8046	Landing Impact Attenuation for Non-Surface-Planing Landers, April 1970
SP-8050	Structural Vibration Prediction, June 1970
SP-8053	Nuclear and Space Radiation Effects on Materials, June 1970
SP-8054	Space Radiation Protection, June 1970
SP-8055	Prevention of Coupled Structure-Propulsion Instability (Pogo), October 1970
SP-8056	Flight Separation Mechanisms, October 1970
SP-8057	Structural Design Criteria Applicable to a Space Shuttle, Revised March 1972
SP-8060	Compartment Venting, November 1970
SP-8061	Interaction with Umbilicals and Launch Stand, August 1970
SP-8062	Entry Gasdynamic Heating, January 1971
SP-8063	Lubrication, Friction, and Wear, June 1971
SP-8066	Deployable Aerodynamic Deceleration Systems, June 1971
SP-8068	Buckling Strength of Structural Plates, June 1971
SP-8072	Acoustic Loads Generated by the Propulsion System, June 1971
SP-8077	Transportation and Handling Loads, September 1971

SP-8079	Structural Interaction with Control Systems, November 1971
SP-8082	Stress-Corrosion Cracking in Metals, August 1971
SP-8083	Discontinuity Stresses in Metallic Pressure Vessels, November 1971
SP-8095	Preliminary Criteria for the Fracture Control of Space Shuttle Structures, June 1971
SP-8099	Combining Ascent Loads, May 1972
SP-8104	Structural Interaction With Transportation and Handling Systems, January 1973
SP-8108	Advanced Composite Structures, December 1974

GUIDANCE AND CONTROL

SP-8015	Guidance and Navigation for Entry Vehicles, November 1968
SP-8016	Effects of Structural Flexibility on Spacecraft Control Systems, April 1969
SP-8018	Spacecraft Magnetic Torques, March 1969
SP-8024	Spacecraft Gravitational Torques, May 1969
SP-8026	Spacecraft Star Trackers, July 1970
SP-8027	Spacecraft Radiation Torques, October 1969
SP-8028	Entry Vehicle Control, November 1969
SP-8033	Spacecraft Earth Horizon Sensors, December 1969
SP-8034	Spacecraft Mass Expulsion Torques, December 1969
SP-8036	Effects of Structural Flexibility on Launch Vehicle Control Systems, February 1970
SP-8047	Spacecraft Sun Sensors, June 1970
SP-8058	Spacecraft Aerodynamic Torques, January 1971
SP-8059	Spacecraft Attitude Control During Thrusting Maneuvers, February 1971

SP-8065	Tubular Spacecraft Booms (Extendible, Reel Stored), February 1971
SP-8070	Spaceborne Digital Computer Systems, March 1971
SP-8071	Passive Gravity-Gradient Libration Dampers, February 1971
SP-8074	Spacecraft Solar Cell Arrays, May 1971
SP-8078	Spaceborne Electronic Imaging Systems, June 1971
SP-8086	Space Vehicle Displays Design Criteria, March 1972
SP-8096	Space Vehicle Gyroscope Sensor Applications, October 1972
SP-8098	Effects of Structural Flexibility on Entry Vehicle Control Systems, June 1972
SP-8102	Space Vehicle Accelerometer Applications, December 1972

CHEMICAL PROPULSION

SP-8089	Liquid Rocket Engine Injectors, March 1976
SP-8087	Liquid Rocket Engine Fluid-Cooled Combustion Chambers, April 1972
SP-8113	Liquid Rocket Engine Combustion Stabilization Devices, November 1974
SP-8120	Liquid Rocket Engine Nozzles, July 1976
SP-8107	Turbopump Systems for Liquid Rocket Engines, August 1974
SP-8109	Liquid Rocket Engine Centrifugal Flow Turbopumps, December 1973
SP-8125	Liquid Rocket Engine Axial Flow Turbopumps, April 1978
SP-8052	Liquid Rocket Engine Turbopump Inducers, May 1971
SP-8110	Liquid Rocket Engine Turbines, January 1974
SP-8081	Liquid Propellant Gas Generators, March 1972
SP-8048	Liquid Rocket Engine Turbopump Bearings, March 1971
SP-8121	Liquid Rocket Engine Rotating-Shaft Seals, February 1978

SP-8101	Liquid Rocket Engine Turbopump Shafts and Couplings, September 1972
SP-8100	Liquid Rocket Engine Turbopump Gears, March 1974
SP-8088	Liquid Rocket Metal Tanks and Tank Components, May 1974
SP-8094	Liquid Rocket Valve Components, August 1973
SP-8097	Liquid Rocket Valve Assemblies, November 1973
SP-8090	Liquid Rocket Actuators and Operators, May 1973
SP-8119	Liquid Rocket Disconnects Couplings, Fittings, Fixed Joints, and Seals September 1976
SP-8123	Liquid Rocket Lines, Bellows, Flexible Hoses, and Filters, April 1977
SP-8112	Pressurization Systems for Liquid Rockets, October 1975
SP-8080	Liquid Rocket Pressure Regulators, Relief Valves, Check Valves, Burst Disks, and Explosive Valves, March 1973
SP-8064	Solid Propellant Selection and Characterization, June 1971
SP-8075	Solid Propellant Processing Factors in Rocket Motor Design, October 1971
SP-8076	Solid Propellant Grain Design and Internal Ballistics, March 1972
SP-8073	Solid Propellant Grain Structural Integrity Analysis, June 1973
SP-8039	Solid Rocket Motor Performance Analysis and Prediction, May 1971
SP-8051	Solid Rocket Motor Igniters, March 1971
SP-8025	Solid Rocket Motor Metal Cases, April 1970
SP-8093	Solid Rocket Motor Internal Insulation, December 1976
SP-8115	Solid Rocket Motor Nozzles, June 1975
SP-8114	Solid Rocket Thrust Vector Control, December 1974
SP-8041	Captive-Fired Testing of Solid Rocket Motors, March 1971

NASA-Langley, 1980