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AEROSPACE RECOMMENDED PRACTICE

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TERMINOLOGY AND DEFINITIONS FOR AEROSPACE FLUID POWER, ACTUATION, AND CONTROL TECHNOLOGIES

FOREWORD

This SAE Aerospace Recommended Practice (ARP) is intended as a guide toward standard use of the data herein by industry and government agencies engaged in aerospace technical activities within the United States. Further, once a revised and updated version is accepted by domestic users it will be recommended as a basis for an International Standard to the International Organization for Standardization (ISO).

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1. SCOPE:

This document comprises the technical terms and nomenclature together with their definitions and abbreviations used in the field of aerospace fluid power, actuation, and control technologies. The terms listed herein, both general and specific, are believed to be most useful as a reference in the design of future aerospace vehicle fluid power, actuation, and control systems.

1.1 Field of Application:

The data contained herein applies to all types of aerospace vehicles including manned and unmanned aircraft, fixed and rotary winged aircraft, commercial and military aircraft, missiles, and space systems and their related fluid power, actuation, and control systems.

1.2 Purpose:

The purpose of this document is to identify, consolidate, and standardize the terminology and definitions contained in a number of existing SAE documents into one document. A second purpose is to eliminate the use of any definition or definitions that may be confusing, conflicting, or ambiguous.

This ARP supersedes and replaces the following documents:

AIR1799 Missile Flight Control Actuation Terminology
AIR1891 Mechanical Control Actuation Terminology
AIR1916 Aerospace Fluid Power and Control/Actuation System Glossary
ARP243B Nomenclature, Aircraft Hydraulic and Pneumatic Systems
ARP1181 Terminology for Flight Control Systems

An additional purpose in implementing the one document concept is that it permits an easy and ready reference of the basic definition rather than searching through several documents. Also, the duplication of identical and similar word items as required by use of multiple documents is eliminated.

1.3 Document Preparation:

1.3.1 Guidelines and Rules: To meet the intended purposes of 1.2 and SAE standards, certain guidelines and ground rules were established. Essentially these are as follows:

a. Use the outline prepared and approved by SAE A-6 Panel sponsoring this document. Except for minor changes the Table of Contents represents this outline.

b. Use "SAE Format Guidelines for the Electronic Capture of SAE Documents" dated November 21, 1989 and "SAE Guide for Preparation of Aerospace Documents, AS, ARP, AIR, MA, and MAP" dated January, 1987.

1.3.1 (Continued):

c. Consolidate only those terms contained in the five listed documents (1.2).

d. Do not introduce any new terms.

1.4 Definitions:

1.4.1 GROUPS: A number of definitions were listed in two or more of the documents of 2.1.1. However, because of the variance in many cases it became necessary to devise a procedure whereby a selection of the most appropriate could be made. Thus, the initial step was to divide such definitions into groups that were:

a. identical
b. similar
c. near similar
d. dissimilar

1.4.2 SELECTION: The second step was a listing of the same word or word items of the various groups, in order that a side-by-side comparison could be made. The final step was to select the definition that most clearly and concisely expressed the best description in an unambiguous manner.

1.4.3 FUTURE TERMS: This document was prepared, to the extent most practical, so that future terms, word items, or expressions could be added without making extensive modification or revision of any part, or parts, as originally written. Also see Appendix B.

1.4.4 REVISIONS: As revisions are made to this document the following procedure should be used:

a. Review present document for current use of definition, or expression to determine:

(1) If it is up to date.
(2) If it needs modification.

b. Determine new terms that should be added to reflect present technology

c. Review other SAE terminology documents to ascertain what other definitions or terms should also be included in this document.

2. REFERENCES:

2.1 Applicable Documents:

2.1.1 SAE Documents: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

Format Guidelines for the Electronic Capture of SAE Documents, November 21, 1989

2.1.1 (Continued):

SAE Guide for Preparation of Aerospace Documents AS, ARP, AIR, MA, and MAP, January 1, 1987

ARP243B Nomenclature, Aircraft Hydraulic and Pneumatic Systems
ARP1181 Terminology for Flight Control Systems
AIR1799 Missile Flight Control Actuation Terminology
AIR1916 Aerospace Fluid Power and Control/Actuation System Glossary
AIR1891 Mechanical Control Actuation Terminology

2.1.2 Government: Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-721A Definition of Terms for Reliability Engineering

2.1.3 Other Publications:

ISO 6771 Pressure and Temperature Classifications - Fluid Systems and Components - Aerospace

ISO/TC20/SC10B/WG10 Terminology DP 8625 - Aerospace Fluid Power and Control/Actuation System Glossary

2.2 Abbreviations and Acronyms:

2.2.1 Abbreviations:

ACT	Active controls technology
ADIRU	Air data/inertial reference unit
ADM	Air data module
AFCS	Automatic flight control system
AOA	Angle of attack
AOG	Aircraft on ground
a/p	Airplane
ARINC	Aeronautical radio incorporated
ATE	Automatic test equipment
BUFCS	Backup flight control system
CAS	Control augmentation system
CBL	Control-by-light
CBW	Control-by-wire
CM	Conditions monitored (or monitoring)
CTC	Canadian transport commission
dB	Decibel
DFO	Dual fail operative
DOT	Department of Transportation
E/E/ bay	Electronics equipment bay
EED	Electroexplosive device
EHA	Electrohydraulic actuator
EHV	Electrohydraulic servovalve
ERFE	Electromagnetic radio frequency emission
FBL	Fly-by-light
FBW	Fly-by-wire

2.2.1 (Continued):

FCS	Flight control system
FS	Fail safe
HSCT	High speed civil transport
HT	Hard Time
IACS	Integrated avionics computer system
IAP	Integrated actuator package
ISM	Input signal management
LRU	Line replaceable unit
LVDT	Linear variable differential transformer
MEDP	Minimum equipment and dispatch procedures
MEL	Minimum equipment list
MFCS	Manual flight control system
MIS	Item, maintenance significant
MTBF	Mean time between failures
MTBM	Mean time between maintenance action
MTBR	Mean time between removals
MTBJR	Mean time between justified removals
NDI	Inspection, nondestructive
OC	On Condition
PCE	Pilot control electronics
PCU	Pilot control unit
PFC	Primary flight computer
PFCS	Primary flight control system
PM	Permanent magnet
Pst	Static pressure
Pt	Total pressure
PWM	Pulse width modulated
SAARU	Standby attitude and air data reference unit
SAS	Stability augmentation system
SFO	Single fail operative
STCM	Stabilizer trim control module
TBI	Through bulkhead initiator
TBO	Time between overhauls
Vmo	Maximum operating speed
Vd	Dive speed

2.2.2 Acronyms:

ACE	Actuator control electronics
BIT	Built-In test
BUSAS	Backup stability augmentation system
DATAC	Digital autonomous terminal access communication
DEMOD	Demodulator
EMA	Electromechanical actuator
RAT	Ram air turbine
STAB	Stabilizer

3. TERMINOLOGY, DEFINITIONS, AND RELATED DATA:

3.1 Power and Fluid Power Terms:

3.1.1 General: As the constituents of fluid power are pressure and flow, it seems only proper to address these terms up front in this terminology document. Temperature has also been included in this first section as it plays an important part as well.

3.1.1.1 Pressure Terminology:

ABSOLUTE PRESSURE: The pressure value using absolute vacuum as a reference.

AMBIENT PRESSURE: The static pressure surrounding a component.

ATMOSPHERIC PRESSURE: The absolute pressure of the atmosphere at a given location and time.

BACK PRESSURE: The pressure caused by resistance to flow in the return line, or by precharged reservoirs, or both.

BREAKOUT PRESSURE: The pressure required to overcome static friction in a component.

BURST PRESSURE: The test pressure which a component or system must withstand without rupture.

BURST PRESSURE, ACTUAL: The pressure at which a component bursts, exhibits massive leakage due to permanent or nonpermanent structural failure, or due to structural deflection.

BURST PRESSURE, MINIMUM: The pressure during burst pressure testing up to which no externally visible bursting and no significant external leakage occurs. Deformation and permanent set are permitted. Function may be impaired.

CERTIFICATION PRESSURE: The authorized pressure for formal acceptance tests.

CONTROL PRESSURE: The pressure required to control or influence any motion or change in motion.

CRACKING PRESSURE: The pressure at which a valve becomes unseated and begins to pass fluid.

CUTOUT PRESSURE: The pressure at which the sequence of reduced flow of a component or system begins.

DIFFERENTIAL PRESSURE: The difference in value between two functionally related pressures occurring simultaneously at different points, such as at opposite sides of an actuator piston.

DYNAMIC PRESSURE: That portion of the local pressure in a fluid which is recovered when the fluid is brought to rest without loss.

3.1.1.1 (Continued):

FLUSHING PRESSURE: The pressure required to flush a system at defined conditions (for instance, at defined flow).

GAUGE PRESSURE: The absolute pressure minus atmospheric pressure.

IDLING PRESSURE: The pressure required to maintain a system or component at the idling speed, or flow.

INLET PRESSURE: The pressure at the inlet of a component.

INTERNAL PRESSURE: The pressure inside a system or component.

LOAD PRESSURE: The pressure reacting to a static or dynamic load. (Same as Pressure Under Load)

MAXIMUM PERMISSIBLE PRESSURE: The highest pressure that is permitted for safety reasons.

MAXIMUM PRESSURE: The highest transient pressure that can occur temporarily.

MINIMUM OPERATING PRESSURE: The lowest pressure at which a system or component must function; that pressure below which a mechanism may not operate (as in a pilot operated valve, which requires a certain minimum pressure for operation).

MINIMUM PRESSURE: The lowest transient pressure that can occur temporarily.

NO LOAD PRESSURE: Pressure required to maintain a system at a specified speed with no external load.

NOMINAL PRESSURE: The general pressure setting of the system.

OPERATING PRESSURE: The pressure available to a component or system.

OPPOSING LOAD PRESSURE: The pressure acting to oppose operating pressure.

OUTLET PRESSURE: The pressure at the outlet of a component.

OUTPUT PRESSURE: In a pressure control device, such as a pressure reducer or power brake valve, the pressure which will be produced at the outlet port. In a pressure modulating unit, as in a brake valve, the output pressure should be specified as maximum or the range stated.

PEAK PRESSURE: The maximum pressure, usually of short duration.

PILOT PRESSURE: The pressure required to control or influence any motion or change in motion. (Same as Control Pressure)

3.1.1.1 (Continued):

PRESSURE: The pressure is defined as fluid force per unit area. The pressure in a fluid at rest is equal in all directions. In many aerospace applications it is normally used as a modifier to designate a portion of a system or unit which operates at, or is exposed to, the system pressure. Except as specified otherwise, the term pressure is considered to mean gage pressure.

PRESSURE CURVE: The pressure variation, expressed graphically in relation to another variable, for example, time. (See Figure 1.) Note the magnitude of the various pressure terms.

PRESSURE DROOP: The change in pressure from a higher level to a lower level with flow of a pressure compensated pump or regulator.

PRESSURE DROP: The reduction in fluid pressure due to flow. When applied to a fluid control unit, pressure drop is measured between given ports of the unit at a given flow and does not include the loss in fittings which are installed in ports (normally the value applicable to a complete flow pattern at rate flow unless otherwise stated).

PRESSURE FLUCTUATION: The variation of pressure with time, usually occurring randomly.

PRESSURE GRADIENT: The change in pressure value with distance in a steady-state flow.

PRESSURE HEAD: The equivalent height of a column of liquid required to produce a given pressure.

PRESSURE IMPULSE: A rapid rise and fall of pressure, or vice versa, of extremely short duration.

PRESSURE LOSS: The pressure loss is the reduction in pressure caused by resistance to flow or by any extraction of energy that is not converted into useful work.

PRESSURE OPERATED: Operated by application of pressure through a control port or ports such as in a pressure control valve.

PRESSURE PULSATION: Periodical variation of pressure in synchronism with the operating speed of rotating equipment.

PRESSURE RATIO: Numerical ratio of the value of two pressures.

PRESSURE RESEAT: In a valve which closes itself against pressure, as in a check valve or relief valve, that pressure at which the valve will close itself so that flow rate recedes to a certain specified leakage.

PRESSURE RIPPLE: Periodical variation of pressure in synchronism with the operating speed of rotating equipment. (Same as Pressure Pulsation.)

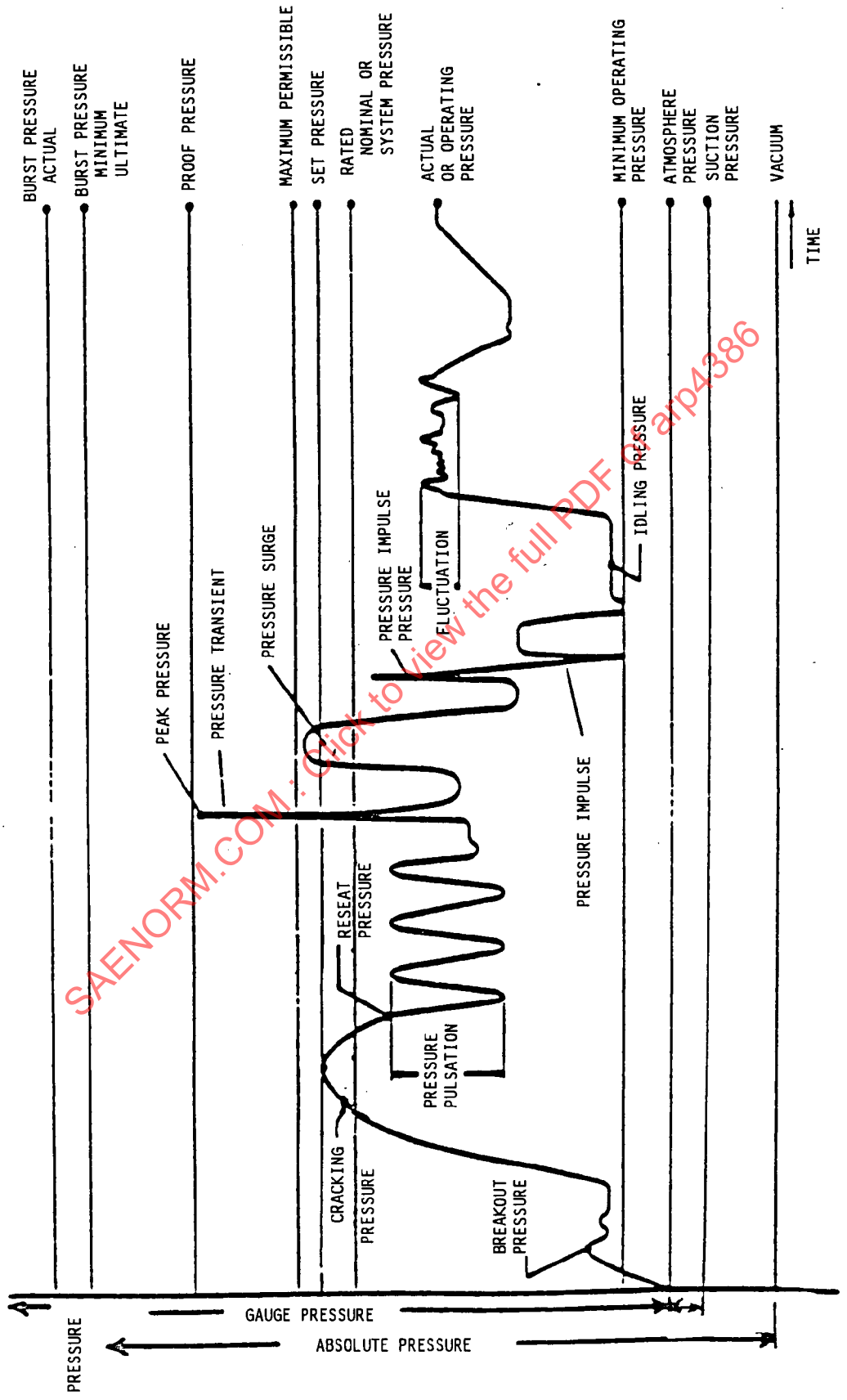


FIGURE 1 - Graphical Presentation of an Arbitrary Pressure Curve

3.1.1.1 (Continued):

PRESSURE RISE: Change in pressure from a lower level to a higher level (due to energy addition or kinetic energy recovery).

PRESSURE SURGE: Pressure rise and fall over a period of time; the maximum magnitude of a transient pressure rise.

PRESSURE TRANSIENT: Pressure rise or drop, or both, of extremely short duration with negligible energy.

PRESSURE UNDER LOAD: The pressure reacting to a static or dynamic load.

PRESSURE WAVE: A cyclic variation of pressure with relative low amplitude and long period.

PROOF PRESSURE: Pressure above nominal system pressure of the component or system when the application at defined test conditions must not lead to external leakage, permanent deformation, or detrimental influence on function; the pressure which a component must withstand as a production inspection test without damage, normally related to rated pressure.

RATED PRESSURE: The nominal maximum input or operating pressure.

REFERENCE PRESSURE: The pressure established as a reference value.

RESEAT PRESSURE: The pressure at which the valve is reseated and flow is interrupted. (Also see Pressure Reseat.)

RESPONSE PRESSURE: The pressure at which a function is initiated.

RETURN PRESSURE: Pressure caused by resistance to flow in the return line or by precharged reservoirs, or both. (Same as Back Pressure.)

SET PRESSURE: The pressure which a component is designed to provide for a defined operation.

STANDARD ATMOSPHERIC PRESSURE: Mean atmospheric pressure related to sea level (corresponding to the definition for the physical atmosphere 1013.25 mbar).

STATIC PRESSURE: The local pressure in a fluid that has no element due to velocity of the fluid.

SUCTION PRESSURE: The atmospheric pressure minus absolute pressure for values below atmospheric pressure.

SWITCHING PRESSURE: The pressure at which a system or component is activated, deactivated, or reversed.

TOTAL PRESSURE: The sum of the static and dynamic pressures at a location.

3.1.1.1 (Continued):

ULTIMATE PRESSURE: Same as Burst Pressure, Minimum.

3.1.1.2 Flow Terminology:

CALIBRATED FLOW: In a unit which controls or limits rate or quantity of flow, that rate or quantity of flow for which the unit is calibrated or adjusted. When calibration is related to specific conditions, the condition of calibration must be stated. Example, a restrictor may be calibrated to pass 1 gpm (4 L/min) at 1500 psi (10 500 kPa) pressure differential.

CASE DRAIN FLOW: Cooling flow and internal leakage of a hydraulic pump or motor to the housing and out of the case drain port, not provided in all models.

CAVITATION: Formation of cavities, either gaseous or vapor, within a liquid stream, which occurs where the pressure is locally reduced to vapor pressure of the liquid. It may include gas coming out of solution in the liquid as pressure is reduced (soft cavitation).

CHOKED FLOW: Flow of a compressible fluid (gas), limited by the speed of sound in the fluid at the throat of a control section.

EXTERNAL LEAKAGE: Leakage from the interior of a device to the exterior, other than out of the fluid ports.

FLOW: Rate of fluid movement, usually expressed in gallons per minute (liter/min); the quantity of a fluid (volume or mass) crossing the transverse plane of a flow path per unit of time. Gas volume flow may be expressed at standard reference condition of sea level atmospheric pressure and ambient temperature.

FLOW DIVIDER: A flow proportioner which operates only with dividing flow.

FLOW EQUALIZER: A flow proportioner in which the portions are equal.

FLOW PROPORTIONER: A device which automatically maintains a relatively constant ratio between the portions of dividing or combining flow passing through it regardless of differences in pressure between the portions. A flow proportioner may operate only with combining flow, dividing flow, or with both.

FLOW SURGE: Temporary rise and fall of flow.

INTERNAL LEAKAGE: Leakage between internal cavities of a device.

LAMINAR FLOW: Flow of a fluid characterized by the gliding of fluid layers (laminae) past one another in orderly fashion.

3.1.1.2 (Continued):

LEAKAGE: Flow through a passage that is in a nominally closed position or at a location which normally should permit no flow.

NULL LEAKAGE: Internal leakage of a valve when output flow is negligible.

QUIESCENT FLOW: Total internal leakage of a complete hydraulic system or a branch of a hydraulic system at rest.

RATED FLOW: Specified flow at steady-state conditions for a component or system; the nominal maximum operating flow, applicable where control of that flow rate is not basic: for example, a one-way restrictor valve with a calibrated flow of 1 gpm (4 L/min) at 1500 psi (10 500 kPa) pressure differential may have a rated flow of 3.5 gpm (14 L/min) in the reverse or free flow direction.

SEEPAGE: Occurrence of extremely slight amount of fluid at the surface of a component or part of a hydraulic system, normally due to "breathing" of seals under cyclic pressure load. No drops are allowed over an extended period of observation.

TURBULENT FLOW: Flow of a fluid characterized by the random motion of fluid particles in directions transverse to the direction of the main flow.

WEEPAGE: Occurrence of slight amount of fluid at the surface of the sliding parts, such as piston rods, pump shafts, and valve spools, due to wiping of fluid from the wetted surface by seals or scrapers. Drops of fluid may be formed after a number of actuation cycles have been defined. If there is no relative motion, such as parting lines, weepage should not occur.

3.1.1.3 Temperature Terminology:

AMBIENT TEMPERATURE: Temperature of the environment in which the apparatus is working.

AUTOIGNITION TEMPERATURE: Temperature at which the fluid flashes into flame without an external ignition source and continues burning. Actual value is to be determined by one of several approved test methods.

CHAMBER TEMPERATURE: The temperature of combustion products in the combustion chamber, generally considered to be the adiabatic isobaric flame temperature.

COLD START TEMPERATURE: The temperature at which the hydraulic system will start to operate, but need not necessarily meet full performance.

EQUIPMENT TEMPERATURE: Temperature of the unit at a specified position and measured at a specified point, normally at the surface.

3.1.1.3 (Continued):

FLASH POINT: Temperature at which a liquid gives off sufficient vapor to cause it to ignite when a small flame is applied, under controlled conditions.

FLUID TEMPERATURE: Temperature of the fluid measured at a specified point in the system.

INLET TEMPERATURE: Fluid temperature at the plane of the inlet port.

MAXIMUM FLUID TEMPERATURE: Highest fluid temperature in the system at which the fluid is intended to be operated.

NORMAL FLUID TEMPERATURE: The stabilized fluid temperature normally reached during continuous operation.

OUTLET TEMPERATURE: Fluid temperature at the plane of the outlet port.

POUR POINT: Lowest temperature at which a liquid will flow under specified conditions.

TEMPERATURE RANGE OF THE FLUID: Specified range of fluid temperature that should not be exceeded for satisfactory operation of a system.

3.1.2 Power Generation and Distribution:

3.1.2.1 General Definitions:

POWER CONVERTER: The component of the power system that transforms energy from the power source into a form compatible with the servoactuator requirements.

POWER MODULATOR: The component of the actuation system that regulates the potential energy of the power source to the actuator as a function of controller output. In a simple hydraulic power boost system, which has no separate controller, the power modulator controls the power to the actuator directly as a function of the command or error signal.

POWER SOURCE: The component of the power system which supplies energy for load actuation. This power, supplied by the vehicle, may be AC or DC electrical power, hydraulic power, or pneumatic power.

POWER SYSTEM: The power system generates, conditions, and distributes power to the power utilization actuator systems. The power system is not a part of the actuation system.

3.1.2.2 Power Sources Terminology and Definitions: The fluid power source, whether on an aircraft or missile is a hydraulic pump. On aircraft the pump in almost all cases is driven by the main engine, whereas on a missile it may be driven by a turbine (gas driven) or an electric motor.

3.1.2.2 (Continued):

a. HYDRAULIC PUMPS:

AXIAL PISTON PUMP: A pump utilizing multiple pistons arranged such that the pistons stroke in sequence as the pump drive shaft rotates. Normally, piston stroke is determined by the angle between a swashplate and the piston housing such that, at a given pump speed and swashplate angle, flow output will be essentially constant for any system pressure.

CENTRIFUGAL PUMP: A pump which creates high fluid velocity through centrifugal action. Fluid momentum is recovered as a pressure head at the pump outlet. A centrifugal pump is not a positive displacement device and output pressure remains essentially constant at constant speed for varying output flows up to pump cavitation.

FIXED DISPLACEMENT PUMP: A pumping unit in which the displaced volume is fixed by design, i.e. its output at a fixed revolutions per minute and output pressure cannot be varied. Pump outlet flow is essentially constant for any given pump speed regardless of system pressure level.

GEAR PUMP: A pump utilizing two or more counter rotating gears to provide a positive volume displacement. Gear pumps are usually fixed displacement; and at a given speed, output flow is essentially constant at any system pressure.

MECHANICAL VOLUME CONTROL PUMP: A variable delivery pump whose output per cycle is controlled by external mechanical means.

PILOT CONTROL PUMP: A variable delivery pump whose output is controlled by the pressure at a control port.

PRESSURE VOLUME CONTROL PUMP: A variable delivery pump whose output is controlled by its discharge pressure.

VANE PUMP: A variable or fixed displacement pump having a number of cavities such that the rotation varies the volume of fluid entrapped between vanes which creates a pumping action through positive volume displacement.

VARIABLE DISPLACEMENT PUMP: A pumping unit in which the displaced volume is varied by a control mechanism. The output can be controlled independently of revolutions per minute by varying the output volume per cycle (one revolution of the pump). This mechanism is typically a pressure sensitive device which reduces pump output flow when a preset pressure level is attained. The pump will deliver only that output flow necessary to meet system flow demands. Other variations include constant torque and flow control hydraulic pumps.

3.1.2.2 (Continued):

b. GAS GENERATOR: A device in which a liquid monopropellant is decomposed (also called a decomposition chamber), or in which liquid bipropellants or solid propellants are burned to produce a sustained flow of gas at a pressure (also called a combustor).

c. TYPES OF GASES:

COLD GAS: Gas at essentially room (ambient) temperature, or at a temperature that is generally available from a pressure source without burning, decomposition, or external heating. Examples are gas drawn from a storage vessel, or that extracted from an operating compressor. Cold gas is used typically for pressurization, inflation or expulsion purposes, or both. However, it is also used as the potential energy source and the fluid medium in some servoactuator control systems.

HOT GAS: Gas at a temperature over 2500 °F (1400 °C) and typical of gases used in rocket motors for propulsion. Because materials that can operate at temperatures above 2500 °F (1400 °C) for sustained periods of time are relatively rare and expensive, hot gas is generally not used as the power source for aircraft actuator control systems.

WARM GAS: Gas at 1000 °F (540 °C) to 2500 °F (1400 °C) and typically available from the decomposition of a liquid monopropellant (for example, ammonium nitrate composite), or from burning liquid propellants at nonstoichiometric conditions (for example, JP-fuel and oxygen). Typical warm gas applications for actuation systems are to drive turbines and displacement motors, to pressurize tanks, and to expel fluids.

d. PHYSICAL ELEMENTS:

BINDER: A composition that holds together a charge of finely divided particles and increases the mechanical strength of the resulting propellant grain when it is consolidated under pressure. Binders are usually resins, plastics, or asphaltics used dry or in solution.

BIPROPELLANT: A propellant consisting of two unmixed or uncombined chemicals (a fuel and an oxidizer) fed to the gas generator (combustion chamber) separately. Bipropellants are usually liquids.

BREECH: A reloadable pressure vessel used to contain a propellant cartridge.

CARTRIDGE: A replaceable unit used in a pressure vessel which is capable of producing pressurized gas when ignited. An example is the solid propellant cartridge used with an aircraft engine starter.

CASE: A pressure vessel designed to contain a propellant charge before and during burning.

3.1.2.2 (Continued):

CATALYST: A substance, which by its mere presence, changes the rate of a reaction (decomposition) and may be recovered unaltered in nature or amount at the end of the reaction.

COMPOSITE SOLID PROPELLANTS: Composite solid propellants are commonly defined as those propellants in which a granular inorganic oxidizer is suspended in an organic fuel binder, neither of which would burn without the presence of the other. Typical oxidizers are ammonium nitrate and ammonium perchlorate; fuel binders are usually either rubber or plastic.

DOUBLE BASE SOLID PROPELLANT: A propellant using two unstable compounds, such as nitrocellullose and nitroglycerin.

FLAME SHIELD: The metal shield adjacent to the case insulation which prevents erosion of the insulation and objectionable insulation pyrolysis products from entering the gas stream.

GRAIN: An elongated molding or extrusion of solid propellant, regardless of size.

INHIBITOR: A material applied to selected areas of a propellant charge to prevent burning in these areas.

INSULATION: A thermal barrier designed to prevent excessive heat transfer from hot combustion products to the case.

LIQUID PROPELLANT: A propellant in liquid form generally consisting of a single liquid (monopropellant) or two liquids (a bipropellant). Examples of liquid propellants include fuels such as alcohol, gasoline, Aerozine 50 and liquid hydrogen, and oxidants such as liquid oxygen, hydrogen percloride, and nitric acid.

MONOPROPELLANT: A liquid propellant consisting of a single homogeneous chemical agent or substance capable of producing a heated gas without the addition of a second substance. Examples are hydrazine, ethylene oxide, hydrogen peroxide, and nitromethane. Monopropellants are stable at ordinary atmospheric conditions, but decompose in the presence of heat or a catalyst, or both, to yield decomposition gases and heat.

PROPELLANT: Any agent used for consumption or combustion in a gas generator and from which the chamber generates its gas, such as a fuel, oxidizer, additive, catalyst, and any compound mixture of these. Specifically, a fuel, oxidant or a combination or mixture of fuel and oxidant used in a gas generator.

SAFETY DIAPHRAGM: A diaphragm, usually metal, that will rupture should excessive pressure develop. Also called a Burst Disc.

3.1.2.2 (Continued):

SOLID PROPELLANT: A propellant in solid form usually containing both the fuel and oxidizer combined or mixed, and formed into a monolithic (not powdered or granulated) grain. Solid propellants may be roughly divided into two principal types: composite propellants, and double base propellants. However, this division is not rigid and examples of propellants exist which actually fit both categories.

WEB: The length of grain measured in a direction of burning. Examples are the axial length of an externally inhibited, cylindrical (cigarette burning) grain. Also, the radial thickness of a grain with an internal cavity (inside burning).

e. COMBUSTION TERMS:

BURNING: Rapid release of energy through chemical reaction between fuel and an oxidizing agent (see Combustion). Burning rate is the propagation rate of a pyrotechnic or propellant mixture. Burning time is the elapsed time between initiation and completion of the reaction of the pyrotechnic or propellant mixture. Burning time depends on many factors such as length of column, degree of consolidation, temperature, pressure, percentage of ingredients and their particle size.

COMBUSTION: A continuous, rapid chemical process accompanied by the evolution of energy which is commonly the union of a fuel and an oxidizing agent.

DECOMPOSITION/DISASSOCIATION: The chemical separation of a substance into two or more substances which may differ from each other and from the original substances. Example: the thermal decomposition of the monopropellant hydrazine (N_2H_4) into ammonia (NH_3), nitrogen (N_2), and hydrogen (H_2) as described by the following:

(1) $3N_2H_4 + 4NH_3 + 44\ 300$ Btu (+103 000 kJ) (Decomposition)

(2) $4NH_3 + 2N_2 + 6H_2 - 79\ 200$ Btu (-184 000 kJ) (Disassociation)

where masses are in lb/mole (kg/mole).

NEUTRAL BURNING: The burning of a propellant grain in which the reacting surface area remains approximately constant during combustion.

PROGRESSIVE BURNING: The burning of a propellant grain in which the reacting surface area or burning rate increases during combustion. The mass flow rate produced increases as the web increases.

REGRESSIVE BURNING: A condition in which the mass flow produced by the propellant grain decreases as the web is consumed due to decreasing area, decreasing burn rate, or both.

3.1.2.2 (Continued):

f. IGNITION DEVICES:

BOOSTER CHARGE: The ignition component, ignited by the primer charge, which either pressurizes the generator to operating pressure or generates a higher energy shock pulse.

CONFINED DETONATOR FUSE: A mild detonating fuse completely contained within a shock absorbing sheath to prevent damage to the surroundings when the fuse is detonated.

DETONATOR: In an ignition train, that component which, when detonated by the primer, in turn detonates a less sensitive but larger explosive (usually the booster); or when containing its own primer, initiates the detonation. A detonator can be activated by either an explosive impulse (primer) or a nonexplosive impulse. When activated by a nonexplosive impulse, the detonator contains its own primer. Detonators generally are classified as percussion, stab, electric, or flash, according to method of initiation. Also called an initiator.

ELECTROEXPLOSIVE DEVICE (EED): Any detonator or initiator initiated by an electric current.

EXPLODING BRIDGEWIRE DETONATOR OR INITIATOR: A detonator or initiator that is initiated by capacitor discharge that explodes (rather than merely heats) the bridgewire. These devices cannot be initiated by any normal shock or electrical energy.

IGNITION TRAIN: The step-by-step arrangement of charges in a pyrotechnic or propellant mixture by which initial fire from a primer is transmitted and intensified until it reaches and sets off the main charge. Also called burning train or explosive train.

INITIATION: The functioning of the first element in the ignition train.

MILD DETONATING FUSE: A flexible tube containing an explosive that is initiated by shock and will propagate a low velocity detonation of low brisance.

PERCUSSION: A method for initiating an explosive device by a sudden sharp blow.

PERCUSSION PRIMER: A percussion actuated explosive device.

PREMATURE IGNITION: A type of malfunctioning in which a combustion device functions before the expected time.

PRIMER CHARGE: A secondary component in an ignition train, which is ignited by an initiator, starts pressurization of a generator, and ignites the ignition booster charge.

3.1.2.2 (Continued):

PYROGEN: A gas generating ignition system consisting of case, initiator grain, and sonic discharge nozzle.

SQUIB: A small explosive device similar to a detonator but loaded with low explosive so its output is primarily heat (flash). Usually a squib is electrically initiated and is used to initiate action of pyrotechnic devices. An electric squib is a tube containing flammable material and a small charge of powder compressed around fine resistance wire which is connected to electrical leads or terminals. Squib is also used as a general term to mean any of various pyrotechnic or explosive devices.

SUSTAINER CHARGE: A component (optional) of an ignition train that maintains the operating pressure until thermal equilibrium is obtained.

THROUGH BULKHEAD INITIATOR (TBI): An initiator which carries an ignition command through the wall of a pressure vessel.

g. GAS GENERATOR PERFORMANCE:

ADIABATIC HEAD: The head of gas available to do work, expressed by Equation 1:

$$H_{ad}{}^{/1/} = \left(\frac{\gamma}{\gamma - 1}\right) \frac{R'}{M} \quad T\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{(\gamma - 1)}{\gamma}}\right] \qquad \text{(Eq.1)}$$

where:

H_{ad} = adiabatic head, ft (m)
γ = gas ratio of specific heats, dimensionless
R' = universal gas constant (1544 ft-lb/mole°R)/1/
M = molecular weight of gas, lb/mole (kg/mole)
T = gas temperature, °R (K)
$\frac{P_2}{P_1}$ = exhaust-to-inlet pressure ratio, dimensionless

/1/ In SI metric units, R' is replaced by (R'/g), where:

R' = 8.31 kJ/mole K
g = 9.81 m/s²

CHAMBER PRESSURE: The pressure within the case during combustion.

EXIT PLANE PRESSURE: The static pressure of the gas stream existing at the nozzle exit plane.

3.1.2.2 (Continued):

GAS POWER: The amount of energy in the gas theoretically available to do work, expressed by Equation 2:

$$GP/1/ = W \frac{H_{ad}}{E} \qquad \text{(Eq.2)}$$

where:

GP = available gas power, hp (kW)
W = gas flow rate lb/s (kg/s)
E = energy equivalent (550 ft-lb/s/hp) (1000 Nm/s/kw)
H_{ad} = adiabatic head, ft (m)

/1/ In SI metric units, W is replaced by (Wg), where g = 9.81 m/s^2

h. PNEUMATIC PRESSURE VESSELS:

CANADIAN TRANSPORT COMMISSION (CTC) REGULATIONS: Regulations of the CTC (previously called the Board of Transport Commissioners or BTC) are contained in the document "Regulations for the Transportation of Dangerous Commodities by Rail".

DEPARTMENT OF TRANSPORTATION (DOT) REGULATIONS: DOT regulations for transportation of explosives and other dangerous articles by land and water in rail freight, express and baggage service, and by motor vehicle (highway) and water, including specifications for shipping containers, are contained in the Code of Federal Regulations, Title 49, Parts 171 to 179.

EXEMPT PERMIT: An exemption from provisions of the DOT Code of Federal Regulations (CFR Title 49, Parts 173.302 and 175.3) based upon safety control measures defined by the gas container manufacturer.

i. GAS CLASSIFICATION:

COMPRESSED GAS IN SOLUTION: A nonliquified gas (such as Acetylene) which is dissolved in a solvent.

FREE AIR OR FREE GAS: Air or gas measured at sea level, Standard Day conditions, that is, pressure of 14.7 lb/in^2 (absolute) (760 mm Hg abs) and a temperature of 59 °F (15 °C).

LIQUIFIED COMPRESSED GAS: A gas which, under the charging pressure, is partially liquid at a temperature of 70 °F (21 °C). A flammable compressed gas which is normally nonliquified at 70 °F (21 °C), but which is partially liquid under the charging pressure and temperature, shall follow the requirements for liquified compressed gases.

3.1.2.2 (Continued):

NONLIQUIFIED COMPRESSED GAS: A gas not in solution which, under the charging pressure, is entirely gaseous at a temperature of 70 °F (21 °C).

PRESSURIZED LIQUID COMPRESSED GAS: A compressed gas not in solution, which cannot be liquified at a temperature of 70 °F (21 °C), and which is maintained in the liquid state at a pressure not less than 40 lb/in² (abs) (2.07 m Hg abs) by maintaining the gas at a temperature less than 70 °F (21 °C).

j. PNEUMATIC PRESSURE VESSEL RATINGS AND DEVICES:

APPROACH CHANNEL: The passage or passages through which gas must flow from the vessel to reach the operating parts of the safety relief device.

BURST PRESSURE: The maximum pressure at which the vessel will not rupture.

DISCHARGE CHANNEL: The passage or passages beyond the operating parts through which gas must flow to reach the atmosphere exclusive of any piping attached to the outlet of the safety relief device.

FILL PRESSURE: The nominal pressure to which the vessel is charged. Sometimes referred to as charge pressure.

GAS RELEASE: The capability of pressurizing a specified downstream volume to a specified pressure level within a defined time.

OPERATING PARTS: The portion of a safety relief device that normally closes the safety discharge channel but can move as a result of heat or pressure, or a combination of the two, to permit the escape of gas from the vessel.

PROOF PRESSURE: The maximum pressure which a component must withstand as a production inspection test without damage.

SAFETY RELIEF DEVICE: A device intended to prevent rupture of a pressure vessel under certain conditions of exposure. This term, as used herein, includes the approach channel, the operating parts, and the discharge channel.

TEST PRESSURE OF A VESSEL: The minimum pressure at which a pneumatic pressure vessel must be tested as prescribed in the specification for compressed gas cylinders by the DOT or CTC.

k. GAS PROCESSES:

ISOBARIC PROCESS: Of equal or constant pressure, with respect to either space or time.

3.1.2.2 (Continued):

ISOCHORIC PROCESS: Of equal or constant volume, usually applied to a thermodynamic process during which the volume of the system remains unchanged.

ISOPYCNIC PROCESS: Of equal or constant density with respect to either space or time; equivalent to isosteric.

ISOSTERIC PROCESS: Of equal or constant specific volume with respect to either space or time; equivalent to isopycnic.

ISOTHERMAL EXPANSION: An expansion process in which the gas temperature remains constant.

POLYTROPIC EXPANSION: An expansion process in which changes of pressure (P) and density (ρ) are related to Equation 3:

$$P\,\rho^{-n} = P_o\,\rho_o^{-n} \qquad \text{(Eq.3)}$$

where:

n is a dimensionless constant and the subscript o denotes initial values of the variables. Therefore, pressure and temperature are similarly related:

$$P/P_o = (T/T_o)^k \qquad \text{(Eq.4)}$$

where:

k is the coefficient of polytrophy ($k = n/(n-1)$)

For isobaric processes, k = 0; for isosteric processes, k = 1; for adiabatic processes, $k = C\rho J/R$ where $C\rho$ is the specific heat at constant pressure, R is the gas constant and J is the mechanical equivalent of heat.

REVERSIBLE ADIABATIC OR ISENTROPIC EXPANSION: An expansion process in which no heat transfer takes place. This is the standard for determining energy extraction from expanded gas and represents the theoretical (100% efficient) reversible process. For air, n = 1.4, k = 3.5, and $P/P_o = (T/T_o)^{3.5}$.

1. BATTERIES AND CELL TYPES:

FAST CHARGE BATTERY: A battery which can be charged at a fast charging rate and which gives a signal that can be used to terminate the fast charge without damage to the battery.

PRIMARY CELL: A cell designed to be used only once, then discarded. It is not capable of being returned to its original charged state by the application of current.

3.1.2.2 (Continued):

QUICK CHARGE BATTERY: A nickel-cadmium battery that can be charged fully in 3 to 5 h by a constant-current charger and is also capable of continuous overcharge at this quick charge rate.

SECONDARY CELL: A cell that is capable of being recharged.

WET CELL: A cell utilizing liquid electrolyte.

m. PHYSICAL ELEMENTS OF A BATTERY:

ANODE: An electrode at which an oxidation reaction (loss of electrons) occurs. In secondary cells either electrode may become the anode depending upon direction of current flow.

CATHODE: An electrode at which a reduction reaction (gain of electrons) occurs. In secondary cells either electrode may become the cathode depending upon direction of current flow.

CELL: An electrochemical device composed of positive and negative plates, a separator, and an electrolyte, which is capable of storing electrical energy. When encased in a container and fitted with terminals, a cell is the basic "building block" of a battery.

ELECTRODES OR PLATES: A conducting body containing active materials by which the electrochemical reaction occurs.

NEGATIVE PLATE: The plate which has an electrical potential below that of the other plate during normal cell operation. With a nickel-cadmium cell, a negative plate is impregnated with cadmium salts that undergo chemical oxidation during discharge.

POSITIVE PLATE: The plate which has an electrical potential higher than that of the other plate during normal cell operation. With a nickel-cadmium cell, the positive plate is impregnated with nickel salts which undergo chemical reduction during discharge.

n. CHARGING AND DISCHARGING:

(1) CHARGING: The process of supplying electrical energy for conversion to stored chemical energy.

CHARGE RETENTION: The tendency of a charged cell to resist self-discharge.

CONDITIONING: A maintenance procedure consisting of deep discharge, short, and constant-current charge used to correct cell imbalance which may have been acquired during battery use.

FAST CHARGING: The rapid return of energy to a battery at the C Rate or greater. See C Rate definition under Battery Performance.

3.1.2.2 (Continued):

FLOATING CHARGE: The use condition of a storage battery wherein charge is maintained by a continuous, long-term constant-potential charge.

OVERCHARGING: A continuing charge after the battery has accepted its maximum amount of charge. In a vented cell, a result of overcharging will be decomposition of water in the electrolyte into hydrogen and oxygen gas. In a sealed cell, a result of overcharging will be increased cell temperature.

QUICK CHARGE: A charging rate that ranges from 0.2 to 0.5 C rate.

SLOW CHARGE: An "overnight" return of energy to a battery at 0.05 to 0.1 C rates.

SPLIT CHARGE RATE: A charging method in which the battery is charged at a high rate and then automatically reduced to a lower charge rate as the battery approaches full charge.

STANDBY CHARGE: A low overcharge current rate, on the order of 0.01 to 0.03 C, applied continuously to a vented-cell battery to maintain its capacity in a ready-to-discharge state. Often called "trickle" charging. Sealed cells used for emergency standby power are usually given a continuous "slow" charge (0.05 to 0.1 C) rather than the lower current "standby" charge.

THERMAL RUNAWAY: A condition whereby a battery on constant-potential charge at elevated temperature will destroy itself through internal heat generation caused by high overcharge currents during constant-potential charging.

TOPPING CHARGE: A reduced rate charge that completes (tops) the charge on a cell and one that can be continued in overcharge without damaging the cell.

VOLTAGE LIMIT: In a charge-controlled battery, the limit of voltage beyond which battery potential is not permitted to rise.

(2) DISCHARGING: The withdrawing of electrical energy from a battery.

DEEP DISCHARGE: The condition where a cell is discharged to 0.5 V or less at low rate.

DEPTH OF DISCHARGE: The capacity removed from a battery during a discharge in relation to the available capacity. Depth of discharge may be expressed as a percent.

3.1.2.2 (Continued):

HIGH-RATE DISCHARGE: The withdrawal of large currents for short intervals of time, usually at a rate that would completely discharge a cell or battery in less than 1 h.

LOW RATE DISCHARGE: The withdrawal of small currents for long periods of time, usually longer than 1 h.

MAXIMUM POWER DISCHARGE CURRENT, IMP: The discharge rate at which the terminal voltage is equal to one half of the fully charged voltage. This will be the current at which maximum power is transferred to the external load.

SELF-DISCHARGE: The spontaneous decomposition of battery materials from the charged to the discharged state.

o. BATTERY PERFORMANCE:

CAPACITY: The product of current multiplied by the time current is flowing. Capacity of a cell or battery is usually expressed in ampere hours.

CELL REVERSAL: The reversal of polarity of the terminals of a cell in a multicell battery due to overdischarge.

C-RATE: The discharge or charge rate in amperes which is numerically equal to the rated capacity of a cell in ampere-hours.

CUTOFF VOLTAGE: The voltage at which a discharge or charge is terminated.

EFFECTIVE INTERNAL RESISTANCE, R_e: The apparent opposition to current within a battery that manifests itself as a drop in battery voltage proportional to the discharge current. Internal resistance is dependent upon battery design, state of charge, temperature, and age.

ENERGY: The output capability of a cell or battery expressed as capacity times voltage, or watt-hours (Wh).

ENERGY DENSITY: A figure of merit for batteries, expressed by the stored energy per unit of battery weight or volume. Energy density is dependent upon the discharge rate.

NOMINAL VOLTAGE: The midpoint voltage observed across a battery during discharge at a selected rate, usually 0.2 or 0.1 C.

3.1.2.3 Power Conversion Terminology and Definitions:

a. GAS TO FLUID CONVERSION: The definitions listed in this section apply primarily to missile applications and although a gas is also a fluid, the term gas to fluid implies a gas source driving a component whose output is pressurized hydraulic fluid.

3.1.2.3 (Continued):

BLOW DOWN ACCUMULATOR: Similar to a direct blow down system except that the stored cold gas is applied to a vessel containing hydraulic fluid with provision for fluid separation. The incompressible fluid then powers the actuation components. This system is primarily used for short duty cycles where the higher stiffness resulting from the use of hydraulic fluid is desired. The hydraulic fluid is usually dumped overboard after providing actuation power.

DIRECT BLOW DOWN SYSTEM: A simple power conversion system wherein stored cold gas is used directly by a pneumatic actuator. The only power system elements are a gas bottle, a squib valve, and a pressure regulator. Direct blow down systems are used primarily for short duty cycle applications.

FREE PISTON PUMP: A reciprocating piston device that converts pneumatic power to hydraulic power. The free piston pump usually acts as an intensifier with the pneumatic pressure increased to a higher hydraulic pressure. This allows the stored cold gas to be bled down to a lower pressure, thus increasing the energy extraction from the pneumatic power source. The term "free piston" implies the absence of a mechanical drive.

b. GAS TO MECHANICAL CONVERSION (TURBINES):

TURBINE: A rotary engine which derives power from gas flow by the action of the gas on a rotor (wheel) mounted on an output shaft. The gas is directed against blades on the periphery of the rotor by an inlet stator, that is, series of nozzles. Turbines generally contain a speed control (governor) which limits speed by throttling the inlet or varying stator angles. Turbines may be powered by solid grain warm gas generators, liquid monopropellant gas generators, or liquid bipropellant gas generators.

c. MECHANICAL TO FLUID CONVERSION (HYDRAULIC PUMPS): In missile control systems the mechanical power is usually provided by a turbine or an electric motor. In aircraft systems, the hydraulic pump is usually driven by the main engine.

PUMP: A device for converting mechanical energy into fluid energy.

d. FLUID TO MECHANICAL CONVERSION:

HYDRAULIC STARTER: A device for converting fluid energy into rotary mechanical energy intended to provide continuous torque for engine starting purposes, and usually incorporating a suitable mechanism to connect the starter to the engine during starting cycles only.

HYDRAULIC STARTER, FIXED DISPLACEMENT: A starter whose displacement remains constant under all operating conditions, and which theoretically requires a constant volume of fluid per revolution.

3.1.2.3 (Continued):

HYDRAULIC STARTER/PUMP: A rotary device capable of converting fluid energy into mechanical energy when operating as a starter, and capable of converting mechanical energy into fluid energy when operating as a pump. A starter/pump is usually equipped with suitable controls to automatically provide a smooth transition from operation as a fixed or variable displacement starter to operation as a pressure compensated pump.

HYDRAULIC STARTER, VARIABLE DISPLACEMENT: A starter whose displacement during the starting cycle is automatically controlled, usually to limit the flow rate to a predetermined maximum.

e. ELECTRICAL TO MECHANICAL CONVERSION:

AIR COOLED MOTOR: A motor incorporating a fan which pulls cooling air axially around the stator (air over) or through internal passages and air gaps in the stator and rotor (air through).

ELECTRIC MOTOR: Electric motors are divided into two categories, direct current (DC) and alternating current (AC). Motors are wound to operate on the specified voltage and frequency of the input current to provide the speed and torque conditions required by the pump. Basic motor design practice applies. Options to be considered include:

a. Continuous or intermittent duty cycle
b. Explosion proofing
c. Interfaces
d. Noise filter requirements
e. Cooling requirements

OIL COOLED MOTOR: A motor utilizing internal fluid flow from the hydraulic pump, or system, for cooling. Fluid passages may be positioned around the stator (oil over), or the flow may be forced through passages and gaps in the stator and rotor (oil through).

3.1.3 Power Modulator Terminology and Definitions:

a. FLUID CONTROL VALVES:

ADJUSTABLE RESTRICTOR VALVE: A restrictor valve having provisions for external adjustment.

AUTOMATIC VALVE: A valve in which operation is controlled entirely by action of fluid which passes through it.

BLOWOFF VALVE: A valve which releases fluid to overboard when its setting is exceeded.

3.1.3 (Continued):

BRAKE VALVE: A valve for control of wheel brake actuating pressure. A brake valve is usually a mechanical or pressure operated variable pressure reducing valve with provision for opening brake pressure outlet port to "Return" when outlet pressure exceeds the pressure setting at the moment.

CHECK VALVE: A valve which allows free flow of fluid in one direction only and prevents flow in the opposite direction.

CONTROL VALVE: A valve in which flow pattern or rate is controlled by external means.

CONTROLLABLE CHECK VALVE: A two position manually operated valve which functions as a conventional valve in one position, but permits free flow in either direction when actuated to the other operating position.

DIRECTIONAL CONTROL VALVE: A selector valve having four working ports: "Pressure", "Return", and two "Cylinder" or "load" ports; and a reversible flow pattern.

DUAL INPUT SERVOVALVE: A servovalve which receives two inputs (e.g., electrical and mechanical or two independent electrical).

DUMP VALVE: A two position control valve having two or more ports with all ports blocked in "Off" position and all ports interconnect in "On" position.

ELECTROHYDRAULIC SERVOVALVE: A servovalve wherein the input is electrical and the output is hydraulic fluid.

ENGINE START VALVE: A valve whose function is to initiate or terminate hydraulic starter operation by opening or closing the fluid inlet line in response to an external signal, and which usually provides automatic shutoff at the end of an engine starting cycle.

FLOW CONTROL SERVOVALVE: A servovalve that modulates output flow with respect to an input.

FLOW REGULATING VALVE: A valve which limits flow in a line to a predetermined value, irrespective of variation in pressure differential caused by back pressure or working against load.

FOUR-WAY VALVE: A multiorifice flow control valve with a supply port, return port, and two control ports arranged so that the valve action in one direction opens the supply port to control port No. 1 and opens control port No. 2 to the return port. Reversed valve action opens the supply port to control port No. 2 and opens control port No. 1 to the return port. The valve also can have positions where supply is blocked and both ports are open to return, or where both control ports are blocked.

3.1.3 (Continued):

HYDRAULIC AMPLIFIER: A fluid valving device which acts as a power amplifier, such as a sliding spool, or a nozzle/flapper, or a jet pipe with receivers.

LATCHING SOLENOID VALVE: An electrically pulsed solenoid valve which remains at its last operating position when electrical power is removed.

LOCK VALVE: A pressure operated controllable check valve, sometimes known as a "Counter Balance Valve" or "Ratchet Valve".

MECHANICAL INPUT SERVOVALVE: A servovalve wherein the input is mechanical and the output is hydraulic fluid.

OUTPUT STAGE: The final stage of hydraulic amplification used in a servovalve.

PNEUMATIC INPUT SERVOVALVE: A servovalve wherein the input is pneumatic.

PRESSURE CONTROL SERVOVALVE: A servovalve that modulates output pressure with respect to an input.

PRESSURE REDUCING VALVE: A valve which reduces any inlet pressure to a predetermined maximum outlet pressure regardless of flow or inlet pressure.

PRESSURE REGULATING VALVE: A valve which directs flow from pump port to system port until pressure at the system port, or a control port, reaches cutout pressure. The valve then opens and diverts flow from pump port to return port until system pressure recedes to cutin pressure.

PRESSURE RELIEF VALVE: A valve which limits maximum pressure in a circuit by releasing excess to return on the basis of differential pressure between pressure and return ports. A pressure relief valve must be able to accommodate full rated flow of the line size for which it is constructed.

PRIORITY VALVE: A valve whose relief pressure is independent of downstream pressure and which opens and permits free flow when both upstream and downstream pressures exceed its setting. A priority valve also permits free reverse flow. Normal use of a priority valve is to provide pressure priority to one subcircuit over another.

RELIEF VALVE: A valve automatically releasing pressure higher than its setting; see Pressure Relief Valve and Thermal Relief Valve.

RESTRICTOR VALVE: A valve whose function is to produce a relatively high pressure drop in a fluid circuit by means of a reduced flow area or orifice.

3.1.3 (Continued):

SELECTOR VALVE: A control valve having more than one flow pattern. A selector valve will have a minimum of three working ports.

SEMIAUTOMATIC VALVE: A valve incorporating automatic operation subject to external control.

SERVOVALVE: A valve that is capable of proportional fluid control in response to an input.

SHUTOFF VALVE: A two port, two position valve which opens or closes a fluid passage. A shutoff valve may be reversible operating equally well with pressure at either port or nonreversible, performing satisfactorily only with pressure entering at one of its ports.

SHUTTLE VALVE: A three-port valve with one outlet and two inlet ports which automatically connect the "Outlet" port to the "Inlet" port having the higher pressure and blocks the "Inlet" port having the lower pressure.

SOLENOID VALVE: An electrically operated valve capable of two or more discrete operating positions, but not capable of proportional fluid control, except through pulse width modulation techniques.

STAGE: A stage of hydraulic amplification used in servovalves. Servovalves may have one, two, or three stages.

SURGE DAMPING VALVE: A valve whose function is to reduce surge pressures during intermittent flow.

THERMAL RELIEF VALVE: A valve designed to bypass only the additional volume caused by thermal expansion of the fluid, i.e., no appreciable flow required.

THREE-WAY VALVE: A multiorifice flow control valve with a supply port, return port, and one control port arranged so that valve action in one direction opens the supply port to the control port and reversed valve action opens the control port to the return port.

TWO-WAY RESTRICTOR VALVE: A restrictor valve which restricts flow in either direction, usually through a fixed orifice.

TWO-WAY VALVE: An orifice flow control valve with a supply port and one control port arranged so that flow is in one direction only: from supply port to control port.

VALVE: A device for directing, regulating or stopping flow, or regulating pressure in a fluid system, usually through the operation of one or more movable members.

3.1.3 (Continued):

b. VALVE DESIGNS AND DESCRIPTIONS:

CLOSED CENTER: No position allows flow from "Pressure" to "Return" port; "Pressure" port blocked in "Off" position.

CLOSED NEUTRAL: In a directional control valve, "Cylinder" or "Load" ports are blocked in "Neutral" or "Off" position.

INTERFLOW: Flow between ports of a valve at intermediate positions (between established positions) which is not in accordance with nominal or intended flow pattern.

NORMALLY CLOSED: In a valve which repositions itself to a given or normal position when external actuation is removed, "Pressure" port is blocked when valve is deactivated or de-energized.

NORMALLY OPEN: In a valve which repositions itself to a given or normal position when external actuation is removed, "Pressure" port is connected to an outlet port when valve is deactivated or de-energized.

NUMBER OF PORTS: The number of working ports will be designated. Additional ports such as control or drain ports should be designated separately.

NUMBER OF POSITIONS: The number of established operating positions, including "Off" position. Not normally applied to servovalves.

OPEN CENTER: A valve designed for use in an open center system. "It will have an "Off" position in which the pressure supply is passed through the valve to "Return" or to other parts of the system.

OPEN NEUTRAL: In a directional control valve, "Cylinder" or "Load" ports are interconnected and open to return in "Neutral" or "Off" position (sometimes termed "Trail" position).

VALVE FLOW GAIN: The increment of valve flow per change in valve input variable at no load across the output.

VALVE PRESSURE GAIN: Ratio of change in controlled pressure to the corresponding change of a controlling variable at no flow.

c. ELECTRIC MOTOR CONTROLLERS:

CURRENT LIMITING CONTROL: A motor control for restricting the maximum motor torque or force by limiting the current supplied to the motor.

VARIABLE FREQUENCY VARIABLE VOLTAGE AC CONTROL: An AC motor controlled by varying the frequency and voltage of the AC power supplied to the motor. The power is regulated to maintain a constant voltage to frequency ratio.

3.1.3 (Continued):

VARIABLE PULSE WIDTH DC CONTROL: A DC motor controlled by modulating DC power into a pulse train and varying the individual pulse widths. The pulse train frequency is usually held constant.

VARIABLE VOLTAGE DC CONTROL: A mechanically commutated DC motor controlled by varying the voltage of the DC power supplied to the motor.

d. MECHANICAL POWER CONDITIONING DEVICES:

BRAKE: A rotary mechanical device that resists motion.

CAPSTAN CLUTCH: A coaxial spring and shaft with a preloaded fit wherein power can be transmitted through the shaft spring interface.

CAPSTAN COIL: The capstan coil operates on the principle that a mechanical coil, under a torque in an unwind direction, radially expands and engages the housing, thus grounding the input torque above a predetermined level. In this case, the load weighing and braking are both accomplished by the capstan coil.

CAPSTAN COIL (WRAP SPRING) NO BACK: A capstan coil is essentially a coil spring placed in a housing with a slight interference fit. Motion in either direction, (to unwind the spring) initiated at the output end, will prevent backdriving motion. Motion in either direction (to wind the spring) initiated at the input end will result in coupling and drive.

CLUTCH: A mechanical device that transfers or interrupts mechanical power from an input shaft to an output shaft. See Figure 2 for various types.

DISCRIMINATOR TYPE (OR SERVO) NO BACK: A device that contains a discriminator and a brake. When the discriminator detects that motion was initiated from the output end of the device, it activates the brake.

DOG CLUTCH: Two interfacing, rotating elements which transmit mechanical power when in contact by means of pins, teeth, dowels, or other load carrying elements.

ENERGY POWER BRAKE: A dynamic brake that brings to a stop a shaft that is in motion.

FACE CLUTCH: Two interfacing, rotating elements which transmit mechanical power when in contact by means of friction surfaces.

IRREVERSIBLE COMPONENT: Any component of the system (such as gearing or screw threads) which has a forward driven mechanical efficiency of less than 50% (under all operating conditions) is an irreversible component, and can fulfill the function of a no back.

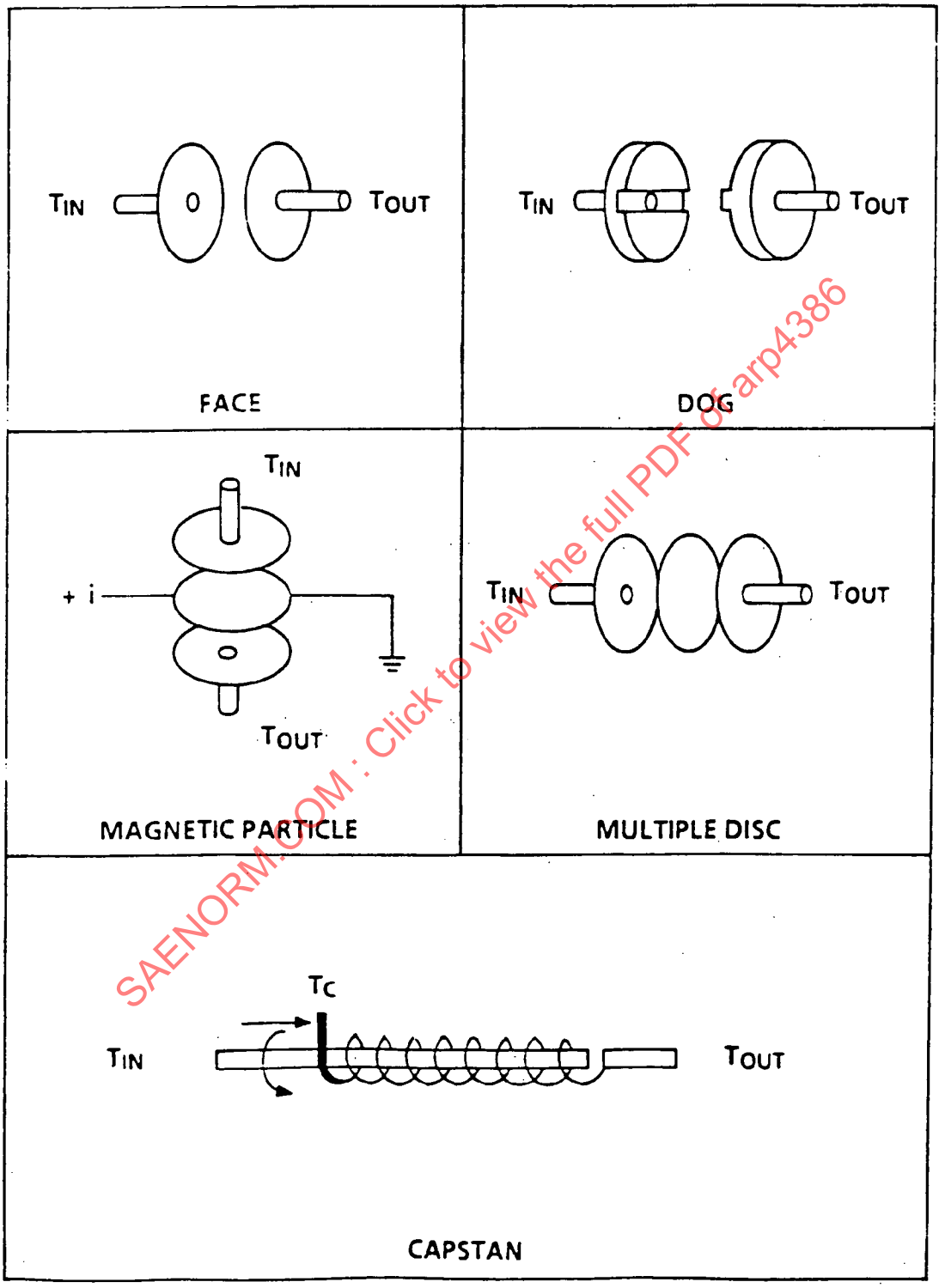


FIGURE 2 - Clutches

3.1.3 (Continued):

LOAD WEIGHING TORQUE LIMITER: The load weighing device torque limiter operates on the principle that the magnitude of the torque is detected by a suitable device, such as a ball ramp, roller ramp, high helix single ball screw thread, or acme thread. When the torque exceeds the predetermined value, the weighing device activates the brake.

MAGNETIC PARTICLE CLUTCH: Two rotating interfaces that are coupled by a magnetically oriented material when current is applied to create a magnetic field. The coupling is both mechanical and viscous in nature.

MULTIPLE DISC CLUTCH: A series of interfacing, rotating discs which transmit mechanical power when in contact by means of a friction facing on their surfaces.

NO BACK DEVICES: No back devices are essentially mechanical one-way mechanisms that permit power to flow in one direction only (from the prime mover toward the load). No power, that is no motion and/or force, originating at the load can flow back toward the power unit. There are two basic types: parking and energy absorbing.

PARKING BRAKE: A static brake that when actuated continuously holds a load or prevents motion.

STOP MODULE: A mechanical device that limits rotational displacement between predetermined values.

THRUST COLLAR: The thrust collar is a device which creates an axial force which is proportional to the load on the output. This axial force produces sufficient friction torque through the thrust collar to prevent backdriving.

TORQUE LIMITING BRAKE: A mechanical device that permits free flow of torque below a predetermined level. Once that level is exceeded, the excess torque is routed to ground through a brake or the torque is disrupted in slippage as in a slip clutch. There are two basic types of torque limiters, load weighing and capstan coil.

3.1.4 Standard Markings:

ARROW: An arrow, used alone, may indicate permissible direction of flow, as in filters and nonreversible shutoff valves; or direction of rotation, as in pumps and motors. The arrow may also be used with appropriate words or notes to indicate directional characteristics, as in restrictors, flow regulators and fuses, or in conjunction with port markings for reversible motors.

3.1.4 (Continued):

ARROW OUTLINE: FREE FLOW - An arrow outline enclosing the words "free flow". Applicable where relatively unobstructed flow in one direction is characteristic, as in check valves and units having check valve attributes. Use of the outline arrow should be restricted to indication of free flow.

a. PORT IDENTIFICATION:

AIR: A port for application of pressurized air. Applicable to hydropneumatic accumulators and air pressurized reservoirs.

BLEED: A port for removal of air, water, etc., in servicing. Applicable where local removal of accumulation is required in servicing, as in brakes, actuators and pneumatic reservoirs.

BRAKE: An outlet port carrying modulated brake actuating pressure. Applicable to brake valves and pressure generating cylinders.

CONTROL (CONT): A port for connection of pilot line for operation or control of the unit. Applicable to remote pressure controlled units, such as valves and pumps.

CYLINDER (CYL): A port selectively carrying operating pressure, to be numbered when more than one. Applicable to selector valves, inlet ports of dump valves, etc.; see also Load.

DRAIN: A port carrying internal leakage flow for independent return to reservoir or for connection of a valved drainage connection.

EXTEND (EXT): Port to which pressure is applied for extension of an actuator such as a cylinder. Applicable only where direction of operation is not obvious, as in swivel end cylinders.

FILL: A port provided for filling purposes in servicing of a unit. Applicable on units containing integral small reservoirs, such as brake pressure generating cylinders and units which may require filling before operation.

FLUID: The fluid pressure port of a hydropneumatic accumulator. (Sometimes termed "Oil Port").

IN: Fluid entrance port, not otherwise designated, where direction of flow is critical. Applicable to filters, flow dividers, motors, nonreversible shutoff valves, pumps, priority valves, shuttle valves, etc.

LOAD: A port which carries output or outlet pressure to actuated load. Applicable to pressure reducers, selector valves, etc.; see also CYLINDER.

OUT: The fluid outlet port of a component, not otherwise designated, in which the direction of flow is critical. Applicable when inlet port is marked "IN".

3.1.4 (Continued):

PRESSURE (PRESS): Inlet port for system pressure supply. Applicable to selector valves, pressure reducers, brake valves, relief valves, etc.

PUMP: Port receiving flow directly from the pump before entering operating portion of the system. Applicable to unloader valves.

RESERVOIR (RES): Outlet port of reservoir pressure regulating unit for connection to reservoir.

RETRACT (RETR): Port to which pressure is applied for retraction of an actuator such as a cylinder. Applicable only where direction of operation is not obvious, as in swivel end cylinders.

RETURN (RET): Outlet port having rated flow capacity for return of working fluid to reservoir. Applicable to brake valves, selector valves, low pressure ports of compensating type accumulators, pressure reducers, relief valves, etc.

VENT: A port provided for breathing or overflow, to be connected to a line which is continuously open to atmosphere, or an opening without provision for attachment of a line.

NOTE: Port markings will usually be used singularly as listed; however, when found desirable they may be combined. For example, in a five ported open center directional control valve utilizing an extra port, which, in the "Off" position, transmits fluid to the downstream system, this port may be designated "PRESS OUT" and the pressure entrance port "PRESS IN".

3.1.5 Data and Definitions Related to Fluid Power: The fluid power distribution system in aircraft is commonly referred to as the hydraulic system which also includes the power source (hydraulic pump). This system is far more complex than the simple system shown in Figure 3 . In addition to supplying hydraulic power to the flight control system, which is usually designed for primary and secondary controls, there are other systems requiring hydraulic power. For example:

a. Landing gear and brakes
b. Drives for gun mounts
c. Drive of engine gimbals for thrust vector control
d. Engine air inlets and exhaust nozzles
e. Other services that require precise positioning

The purpose of this description is to explain the listing of a number of items that are related to 3.1, 3.2, or 3.3, but cannot be classed as directly belonging to one of the previously defined subsections. Further, these items are contained in one or more of the documents of 1.2, and therefore, should be listed in this document.

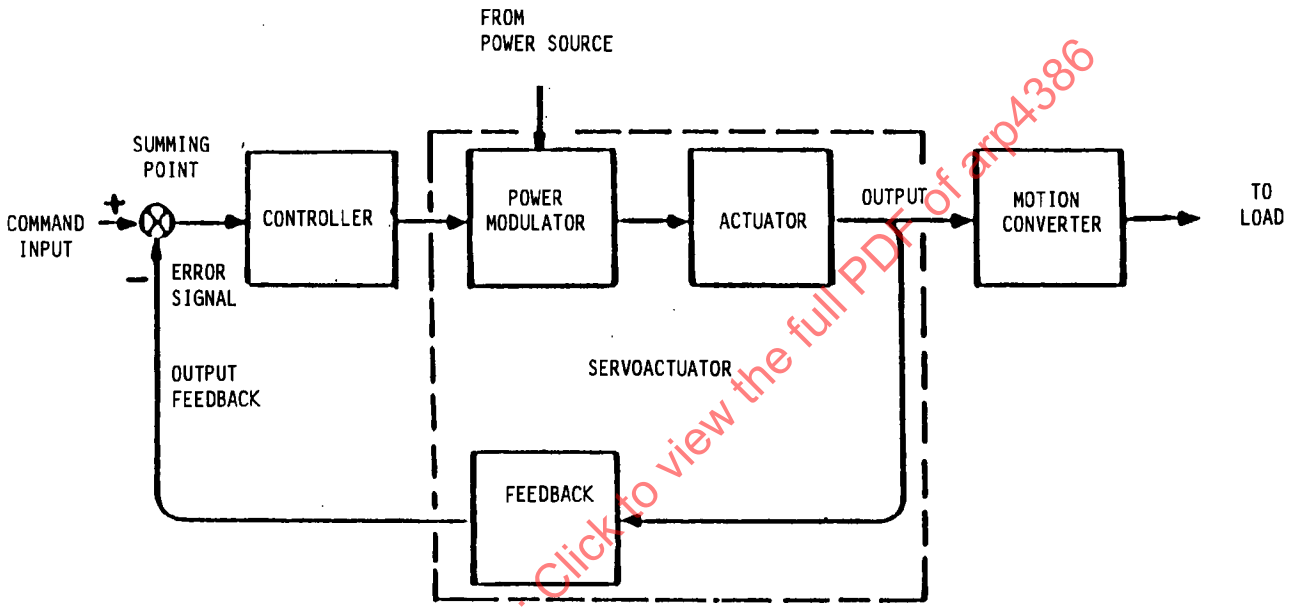


FIGURE 3 - Complete Actuation System

3.1.5 (Continued):

a. HYDRAULIC SYSTEMS:

TYPE OF HYDRAULIC SYSTEM: A classification standard for a military aircraft hydraulic system based on minimum and maximum allowable fluid temperatures is defined as follows:

(1) Type I -54 to +71 °C (-65 to +160 °F)
(2) Type II -54 to +135 °C (-65 to +275 °F)
(3) Type III -54 to +199 °C (-65 to +390 °F)

CLOSED CENTER: In a hydraulic system, when no service is actuated the system is closed to flow, as distinguished from an open center system. A closed center system may utilize a continuous pressure supply, as with a variable displacement pump, or an intermittent pressure supply by means of unloader valve, motor driven pump, or pump bypassing provisions.

OPEN CENTER: In a hydraulic system, when no service is actuated the system is open to flow, completing the circuit through the control units back to reservoir. An open center system will normally employ a fixed displacement pump.

3.2 Actuation Terms:

3.2.1 ACTUATION SYSTEM: An actuation system is comprised of a control system which receives input power from a power generation and distribution system to control an output load. Actuation systems include a controller, power modulator, actuator, and feedback elements (if needed). Figure 3 illustrates a typical actuation system.

3.2.1.1 Actuation System Components:

ACTUATOR: The component of the actuation system that does work or dissipates energy to control a load. Actuator output is achieved by conversion of energy from the power system or load into mechanical work, torque, or force.

CONTROLLER: The component of the actuation system that controls the power modulator as a function of the command or error signal. Many of the electronic controllers have dynamic compensation as well as significant gain, so they must be recognized as separate components in the actuator loop.

FEEDBACK ELEMENT: The component of the actuation system that measures the system output and transforms it into a form compatible with the command signal.

MOTION CONVERTER: The component of the actuation system that converts the motion of the actuator into the motion of the load. For example, a ball screw converts rotary motion into linear and a crank arm converts linear motion into rotary.

3.2.1.1 (Continued):

POWER-BY-WIRE ACTUATION: An integrated servoactuator which incorporates an electric motor to receive power from the aircraft main electric power system in lieu of an actuator connected directly to the aircraft main hydraulic system. Power conversion from electrical to mechanical may include mechanical devices such as ballscrews, gears, chains, cables, etc. or through a motor/pump and hydraulics. See INTEGRATED ACTUATOR PACKAGE.

SERVOACTUATOR: A servoactuator consists of the power modulator, the actuator, and the feedback element, typically packaged together as a single component.

3.2.1.2 Actuation System Operation Terms:

a. DUTY CYCLE: A description of the load position and the load conditions throughout the total mission time with sufficient detail to determine load velocity requirements and dynamic load characteristics. A complete duty cycle description will define the actuation energy required for the total mission.

b. LOAD TERMINOLOGY: Definitions of the actuation system load include both static and dynamic actuation loads, as well as structural loads that may be imposed on the actuator. In general, load definitions refer to loads imposed from outside the actuator. Friction losses within the actuator, including the attach point bearing, are considered to be actuation system inefficiencies.

AIDING OR OPPOSING LOAD: An aiding load is a force or torque on the actuator provided by load restoration or inertia, or both, which acts in the same direction as the desired direction of load motion. A force or torque, which acts in the opposite direction resisting motion, is called an opposing load.

BIAS OR PRELOAD: A steady-state load that is unidirectional and constant over full load travel.

BREAKOUT LOAD: The minimum load under which the system starts moving while the controller is gradually moved towards saturation.

COULOMB FRICTION LOAD: A steady friction load that is present whenever the load is moving or about to move and opposes load motion.

INERTIA LOAD: A load proportional to load acceleration or deceleration. The load is usually opposing for acceleration and aiding during deceleration.

INTERNAL SYSTEM LOAD: A load which is dynamically generated by the system and which may exceed the externally applied loads, e.g., dynamic jam loads.

3.2.1.2 (Continued):

MISALIGNMENT LOAD: A force component perpendicular to the actuator output motion, which is the resultant of a load not in line with the actuation output.

RATED LOAD: A specified steady-state load applied to the actuator for determining rated velocity. Usually, rated load is an opposing load.

SPRING LOAD: A load that varies proportionally with load position. This load may be caused by aerodynamic forces on a movable surface, or by thrust deflection reaction forces on a movable nozzle element. The load can be either opposing or aiding, depending on output position and motion direction.

STALL LOAD: The steady-state force or torque from the actuator at zero velocity, when the controller has a saturated input. It is the load that the servoactuator cannot overpower.

VISCOUS FRICTION LOAD: A load opposing motion and proportional to load velocity.

c. VELOCITY TERMINOLOGY:

NO LOAD VELOCITY: The output velocity of the actuation system measured with no external load. Maximum no load velocity is determined with a saturation input to the power modulator.

RATE LIMIT: The maximum velocity of the control system output. Usually, rate limit is defined under maximum aiding load conditions with saturation signals applied to the servoactuator.

RATED VELOCITY: The required actuation system output velocity when the specified rated load is applied at the actuation motion attach point. Rated velocity can be determined at any load position.

SLEW RATE: The steady-state output velocity of the actuation system in response to a step input command. Slew rate is usually determined by the average velocity between 10 and 90% of load position (so as to avoid actuator acceleration and deceleration effects) when both static and dynamic loads are imposed at the actuation output.

VELOCITY GAIN: The proportional change of actuator velocity with error signal. This parameter is usually specified for no load conditions and is usually measured open loop.

3.2.1.2 (Continued):

d. ACTUATOR POWER TERMINOLOGY:

CONTINUOUS POWER: The maximum power which can be delivered by the actuation system for an indefinite period without sustaining damage or reducing life. With an electric actuator, continuous power is generally much less than rated power due to material limitations, which are time and temperature related.

RATED POWER: The product of rated load and rated velocity, also called the Power Point. This point usually determines the maximum power required from the actuation system.

PEAK POWER: The maximum power that the actuation system is capable of delivering. This may be higher than rated power determined by system actuation requirements.

SPEED VERSUS FORCE OR TORQUE CHARACTERISTIC: The curves of steady-state speed versus steady-state force or torque when the actuator is driven by the power modulator with constant values of signal input.

TORQUE-TO-INERTIA OR FORCE-TO-MASS RATIO: The ratio of actuator stall load to rotary actuator inertia or linear actuator mass. This ratio determines the maximum actuator output acceleration.

VELOCITY VERSUS FORCE OR TORQUE CHARACTERISTIC: Same as Speed versus Force or Torque Characteristic.

e. ACCURACY TERMINOLOGY:

BACKLASH: The uncontrolled load motion due to clearance in actuation elements, including the load attach point, usually expressed in terms of absolute load motion.

HYSTERESIS: The difference in command inputs required to produce the same actuation system output as the output is cycled throughout the full plus or minus range of travel. The cycling rate must be significantly below the control bandpass so that velocity error signals are not included in this parameter.

INPUT/OUTPUT CURVE: The graphical representation of actuation system output versus command input. This is usually a continuous plot throughout a complete cycle between plus or minus rated commands. The cycling must be sufficiently below the control bandpass so that velocity errors are not included in this measurement.

LINEARITY: The degree to which the normal input/output curve conforms to a straight line under specified load conditions, usually expressed as percentage of full output.

NORMAL INPUT/OUTPUT CURVE: The locus of the midpoints of a complete input/ output curve. This locus is the zero hysteresis output curve.

3.2.1.2 (Continued):

NORMAL INPUT/OUTPUT GAIN: The slope of the normal input/output curve in units of output/input.

RESOLUTION: The smallest increment of actuator output produced by a change in command input.

THRESHOLD: The increment of input command required to produce a change in system output expressed as a percent of full output. Threshold is normally specified as the command increment required to reverse the direction of output motion when the input is cycled at a rate sufficiently low to minimize dynamic effects.

f. STIFFNESS TERMINOLOGY: Stiffness terms fall into two general categories:

a. That relating to structural stiffness of the actuator and its attach points

b. That relating to closed loop control displacement reactions to changes in external load (dynamic stiffness)

Structural stiffness definitions are necessary to determine load resonance. Inaccuracies due to external loadings, however, are affected by both types of stiffness. Stiffness terms are expressed as spring rates in units of force or torque per unit displacement and should be specified at a particular load.

ACTUATOR STIFFNESS: Same as Drive Stiffness.

BACKUP STIFFNESS: The mechanical stiffness of the actuator attach point(s) through which load reaction forces are transmitted.

DRIVE STIFFNESS: The stiffness of the actuator between the mounting and output motion attach points. It is the resultant of the mechanical stiffness of the load carrying elements and of the actuation system stiffness.

DYNAMIC STIFFNESS: The stiffness associated with the output deflections of an active actuation system caused by externally applied dynamic forces, usually sinusoidal, over a specified frequency range. Since Dynamic Stiffness is a complex quantity, it is also called Dynamic Impedance.

FLUID BULK MODULUS: The fluid bulk modulus of a trapped fluid volume is:

$$\frac{\text{incremental pressure}}{(\text{incremental volume/total volume})} \qquad \text{(Eq.5)}$$

3.2.1.2 (Continued):

FLUID STIFFNESS: The pressurized fluid chamber on each side of the piston in an actuator contains a trapped volume of fluid when the control valve is at null. The trapped fluid exerts stiffness, opposing change in fluid volume, when an external load is applied to the piston.

INFINITE FREQUENCY STIFFNESS: The stiffness associated with the output deflections of an active actuation system caused by externally applied loads where the frequency of the load disturbance is significantly above the bandpass of the actuation system. Since the system cannot actively react against high frequency load disturbances, this stiffness is identical to stiffness to ground at frequencies well beyond the system bandwidth. See Figure 4.

LOW FREQUENCY STIFFNESS: The stiffness associated with the output deflections of an active actuation system caused by externally applied loads where the frequency of the load disturbance is below the bandwidth of the actuation system. Since the actuation system error signals will cause reaction against these load disturbances, this term is sometimes called closed loop stiffness.

STIFFNESS: Force or torque per unit displacement.

STIFFNESS TO GROUND: The combined stiffness of all spring rates which determine the spatial position of the load mass under a static load. This stiffness, in conjunction with the load inertia, determines the load natural frequency. It is sometimes called static stiffness.

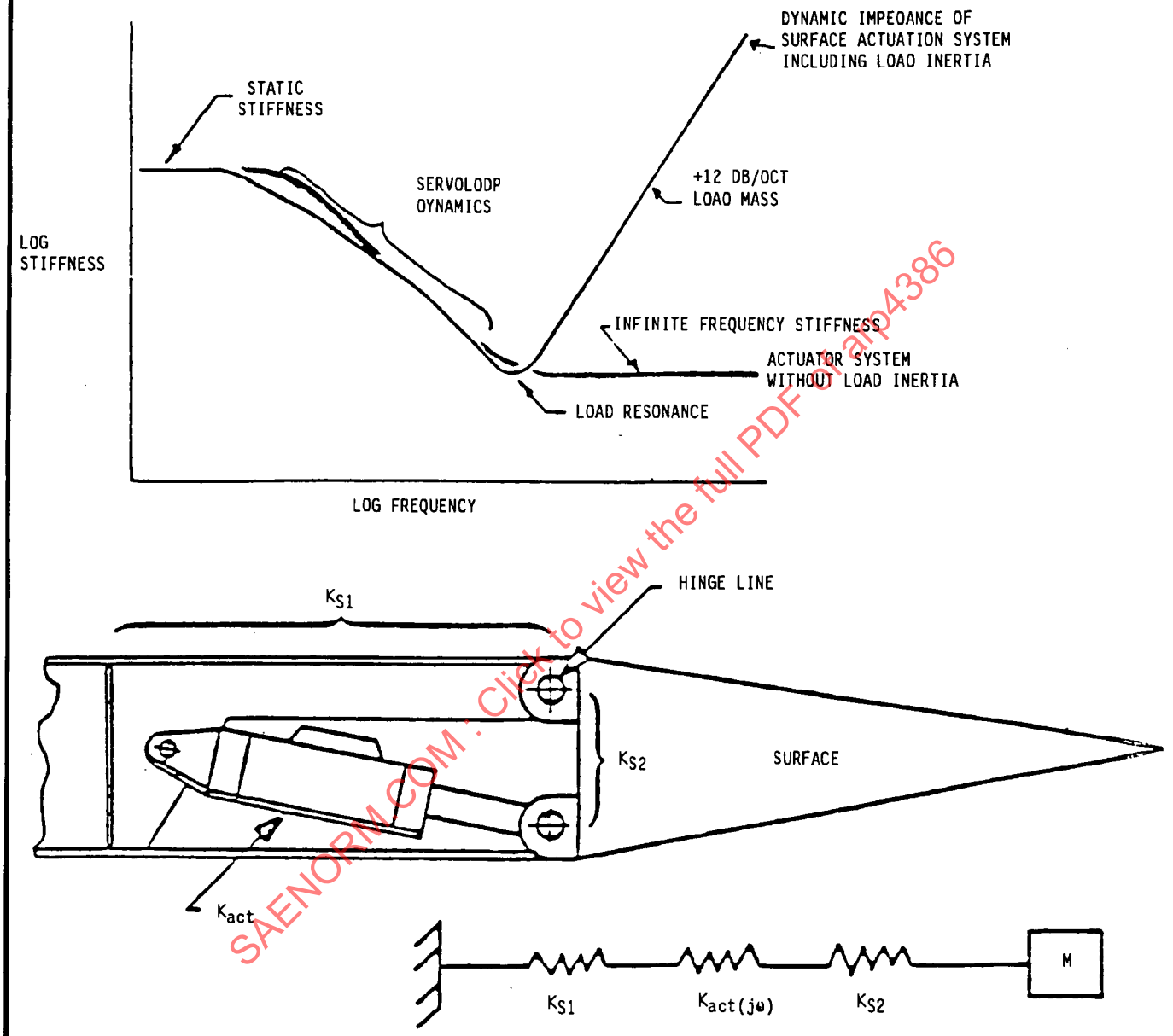
g. DYNAMIC RESPONSE TERMINOLOGY:

BANDWIDTH: The frequency range over which the actuation system has acceptable dynamic response. This spectrum extends from DC up to a specified frequency, which is usually the frequency where the open loop amplitude ratio has unity gain (0 dB). For a first-order system, this is the frequency where the closed loop response is down 3 dB with 45° phase lag.

CLOSED LOOP FREQUENCY RESPONSE: The frequency response between command input and control system output with the feedback signal summed with command. Actuation system response for a closed loop system is usually specified as a closed loop frequency response.

DECIBEL: A unit of measure used to express amplitude ratio of control input and output.

$$\text{Decibels} = 20 \log_{10} (\text{Amplitude Out}/\text{Amplitude In}) \qquad \text{(Eq.6)}$$



ω is the oscillation frequency, in radians per second, and j is the square root of minus one.

FIGURE 4 - Actuator Stiffness Determination

3.2.1.2 (Continued):

FREQUENCY RESPONSE (BODE PLOT): The complex ratio of the actuation system output to the command input, while the input is cycled sinusoidally and the frequency is varied. Frequency response is usually presented as a combined plot of normalized amplitude ratio in dB, and of the input to output phase angle, in degrees, versus the logarithm of frequency (called a Bode Plot).

GAIN CROSSOVER AND PHASE MARGIN FREQUENCY: The point on the Bode Plot of the transfer function at which the magnitude crosses over unity:

$$\text{Log}_m G(j\omega) = 0 \text{ dB} \qquad \text{(Eq.7)}$$

where:

ω is the oscillation frequency, in radians per second, and j is the square root of minus one.

The frequency at gain crossover is called the phase margin frequency.

GAIN MARGIN: A measure of system stability defined as the reciprocal of the magnitude of the open loop gain at 180° of phase lag crossover frequency, usually expressed in decibels.

LOAD NATURAL FREQUENCY: The undamped resonant frequency of the load mass or inertia working against the stiffness to ground.

OPEN LOOP FREQUENCY RESPONSE: For a closed loop control system, the frequency response of the feedback signal to the error signal. Open loop frequency response may be specified with or without a load.

OVERSHOOT: The increment by which the output exceeds the input when responding to a step command, usually expressed as a percentage of the input command.

PHASE CROSSOVER AND GAIN MARGIN FREQUENCY: The point on the Bode plot of the transfer function at which the phase angle is -180°. The frequency at which phase crossover occurs is called the gain margin frequency.

PHASE MARGIN: A measure of system stability defined as the phase lag to be added to achieve 180° of phase lag at the open loop frequency response corresponding to 0 dB amplitude ratio.

STEP RESPONSE: The time response of the actuation system output following a step command input. Step response is usually specified as the time required to reach a particular percentage of the final output, together with limits on the percentage overshoot.

3.2.1.2 (Continued):

SYSTEM RESONANCE: The closed loop resonant frequency observed with complete system operation. The system resonance is usually lower than the load natural frequency due to dynamic effects of system control elements, damping, and backlash.

TRANSIENT RESPONSE: Same as STEP RESPONSE.

3.2.2 Actuator Terminology:

3.2.2.1 General Types: A single or two channel actuator may be designed for a linear or rotary output. See Figure 5. Rotary Drive Classifications are shown in Figure 6.

CLUTCH COUPLING DRIVE: A motion transmission which allows interruption of the load path for control purposes.

DIRECT COUPLING DRIVE: A motion transmission with a continuous load path.

IRREVERSIBLE DRIVE: A drive which cannot, with no input torque (or force), be back-driven from the output by a torque (or force) less than the maximum design load at the output.

LINEAR ACTUATOR: An actuator which develops rectilinear motion and force as outputs.

MULTICHANNEL ACTUATOR: An actuator which contains more than one torque or force generating device.

POSITION SUMMING: A multichannel summing arrangement which sums the position outputs of multiple actuators into a single output.

REVERSIBLE DRIVE: A drive which can, with no input torque (or force), be back-driven from the output by a torque (or force) less than the maximum design load at the output.

ROTARY ACTUATOR: An actuator which develops rotary motion and torque as outputs. The term rotary actuator implies that the actuator is capable of limited output rotation. If the device is capable of continuous rotation, it is referred to as a motor.

SINGLE CHANNEL ACTUATOR: An actuator which contains a single torque or force generating device.

TORQUE/FORCE SUMMING DRIVE: A multichannel summing arrangement which sums the torque or force outputs of multiple actuators wherein individual actuators are constrained to have the same position.

VARIABLE RATIO DRIVE: A motion transmission which has the capability of varying output velocity and torque (or force) with constant velocity and torque (or force) input.

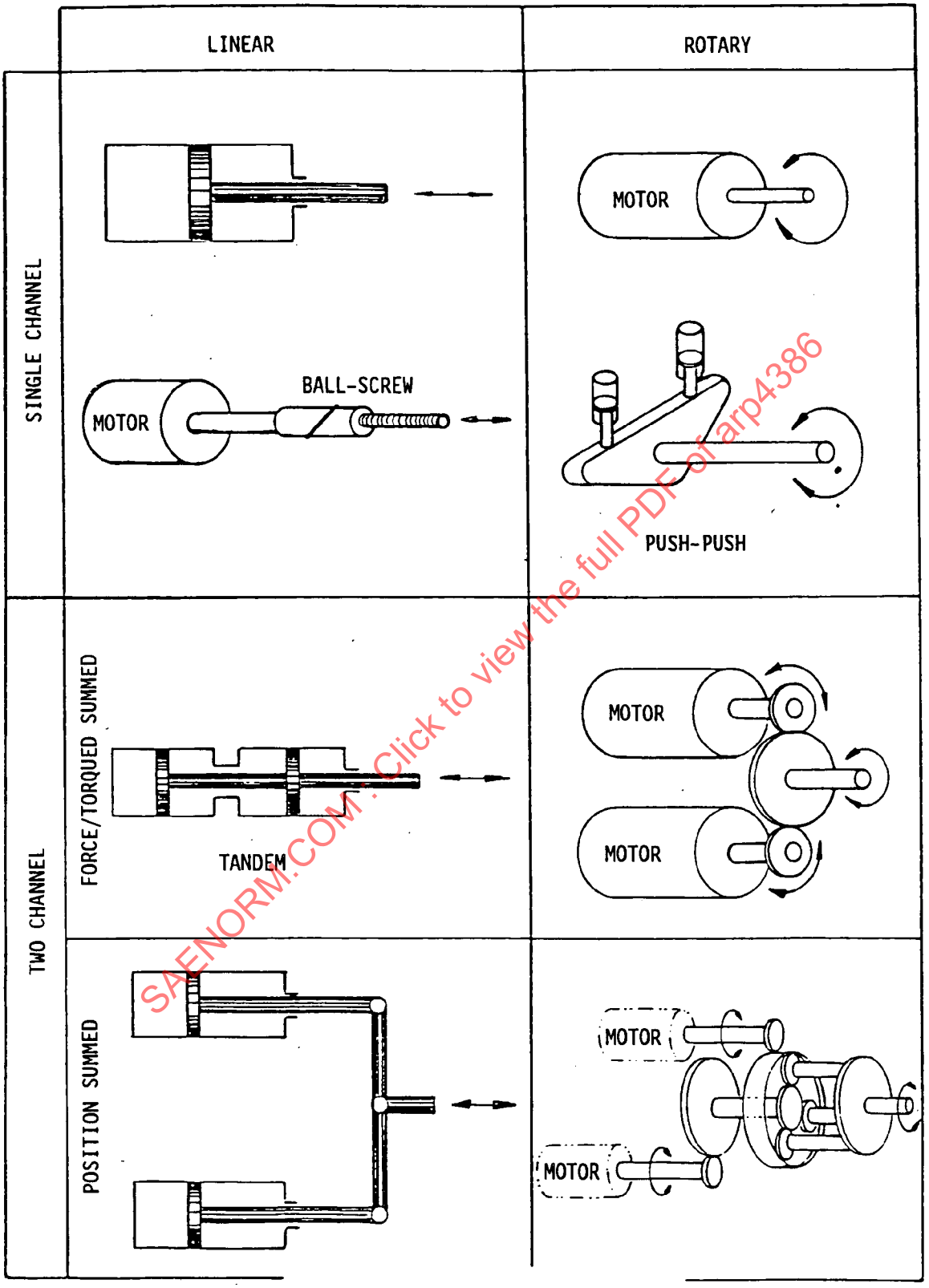


FIGURE 5 - Actuator Types

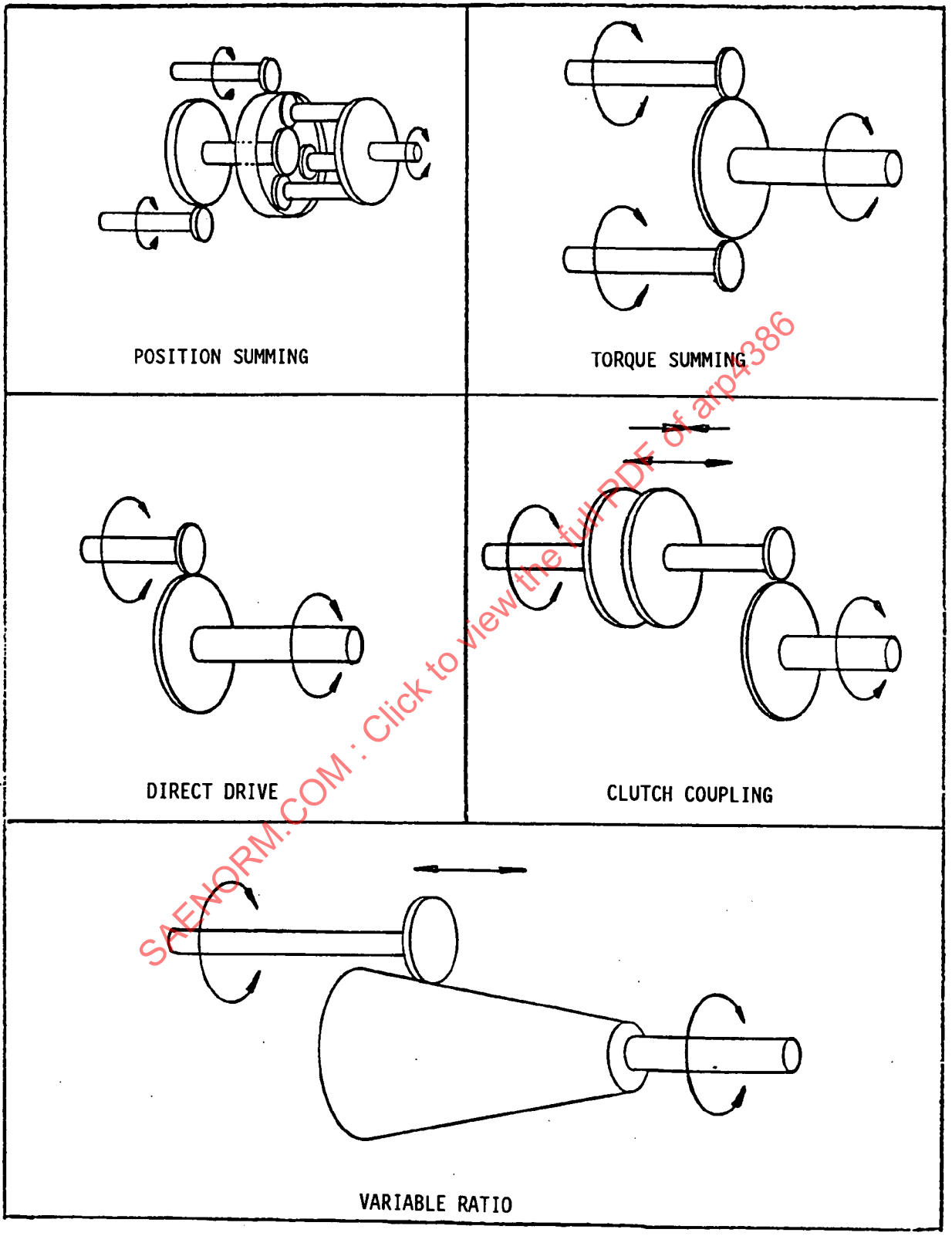


FIGURE 6 - Rotary Drive Classification

3.2.2.2 Fluid Actuators:

a. LINEAR ACTUATORS:

BEARING MOUNTED ACTUATOR: An actuator mounted between the support structure and load with spherical bearings at each end. This type of actuator can articulate in two axes.

DOUBLE ENDED ACTUATOR: An actuator with a single cylinder and a piston which has two rods extending to atmosphere.

EQUAL AREA ACTUATOR: An actuator having equal effective piston areas and equal force output for both directions of motion.

FIXED BODY ACTUATOR: An actuator with mounting provisions wherein the body is rigidly attached to the load bearing support. The output necessarily lies along one axis with no articulation possible.

FOUR-WAY SERVOACTUATOR: A servoactuator having two control ports connecting to a four-way servovalve. A four-way linear servoactuator is usually, but not necessarily, a double ended actuator.

MOVING BODY ACTUATOR: An actuator with the body attached to the moving load and the piston rod attached to the support structure.

PARALLEL ACTUATOR: Two or more actuators arranged in parallel to drive a single output or load. Usually, parallel actuators are physically separated, each with its own output connection, and are tied together by the load in a force or torque-summing fashion. Sometimes, referred to as side-by-side actuators.

RIP STOP: A mechanical design technique for achieving mechanical separation of hydraulic systems where more than one pressure source exists. If material fracture occurs in one portion of a rip stop design, the fracture cannot propagate from one hydraulic system containment to a second hydraulic system containment and cause loss of two hydraulic systems. Thus, if two hydraulic supplies are to be used, they can never enter the same piece of material anywhere in a system designed to provide rip stop.

SIDE-BY-SIDE ACTUATOR: An actuator having two or more separate actuation elements in parallel which provide a single output motion.

SINGLE ENDED ACTUATOR: An actuator with a single cylinder and a piston which has only one rod extending to atmosphere.

TANDEM ACTUATOR: Two or more coaxial actuators that are mechanically constrained to move together. A tandem actuator usually has two pistons on the same rod, carried in a single actuator cylinder housing. Separate cylinders (with a common piston rod) can be used to give partial rip stop protection. Dual tandem actuators are commonly used where two hydraulic sources are utilized.

3.2.2.2 (Continued):

THREE-WAY SERVOACTUATOR: A servoactuator having a single control port connecting to a three-way servovalve. The control port is connected to the large actuator area and system pressure is usually applied to the small area. A three-way linear servoactuator is usually, but not necessarily, a single ended actuator.

TRIPLE TANDEM ACTUATOR: A tandem actuator having three separate actuation sections.

TRUNNION MOUNTED ACTUATOR: An actuator having the body mounted through a trunnion to the actuator support. The output rod can articulate in one axis only.

UNEQUAL AREA ACTUATOR: An actuator having different effective piston area for each direction of motion. An unequal area actuator may be either single ended or double ended. Since an unequal area actuator will have a higher force output in one direction, it is usually used where a significant bias load is anticipated. An actuator having an area ratio of 2:1 used with a three-way control valve is equivalent to an equal area actuator since the force output and actuation power consumption will be equal in both directions. Unequal area actuators are sometimes referred to as unbalanced actuators.

b. ROTARY FLUID ACTUATORS:

(1) LIMITED MOTION TYPES:

PUSH-PUSH ACTUATOR: An actuator wherein two linear pistons act on the opposite ends of a crank arm attached to a rotary output shaft.

RACK-AND-PINION ACTUATOR: An actuator wherein the rotary motion is achieved by piston driven linear racks engaging a rotary output gear.

VANE ACTUATOR: An actuator wherein fluid pressure is applied to either side of a vane or vanes which are integral with or geared to a rotary output shaft. Vane cavities are separated by center dams which limit rotation.

c. CONTINUOUS MOTION TYPES:

AXIAL PISTON MOTOR: A motor utilizing multiple pistons which are pressurized in sequence as the output shaft rotates. Usually one half the pistons are pressurized to provide output torque. The linear motion of the pistons is converted to rotary motion by a swashplate, which is set at an angle with respect to the motor housing. Output speed control can be obtained by either controlling input flow or controlling swashplate angle.

3.2.2.2 (Continued):

GEAR MOTOR: A motor utilizing two or more counter rotating gears which provide a fixed volumetric displacement per revolution of the output shaft. Since the displacement is fixed, output shaft speed can be controlled only by controlling input flow.

RADIAL PISTON MOTOR: A motor utilizing multiple pistons arranged radially around a shaft with an eccentric cam. The pistons are pressurized in sequence and the linear to rotary motion conversion is accomplished by the eccentric cam action. Output speed control can be obtained by either varying input flow or controlling can eccentricity.

VANE MOTOR: A motor having a number of vanes attached to a shaft or an outer housing which are eccentric with respect to each other. The eccentricity provides differential volumes in the vane cavities so that sequential pressurization of the cavities causes output rotation. Output speed control can be obtained by either controlling input flow or shaft eccentricity.

3.2.2.3 Electromechanical Actuators: These definitions apply to electric motors used as torque generators in an electromechanical actuator. See Figure 7. Other electric motor definitions are covered under 3.1.2.3.

a. AC MOTORS: Electric torque generators which are powered by polyphase alternating current. The following types can be considered for electromechanical actuation.

INDUCTION MOTOR: An AC motor in which alternating current supplied to the stator produces a rotating magnetic field. Alternating current is induced in the rotor by transformer action and the interaction between the induced rotor currents and the stator field produces torque.

LINEAR INDUCTION MOTOR: A linear motor in which polyphase alternating current supplied to the primary winding produces a translating magnetic field. Alternating current is induced in the secondary winding by transformer action and the interaction between the induced secondary current and the primary magnetic field produces force.

SQUIRREL CAGE MOTOR: An induction motor in which the rotor consists of inserted or cast, parallel conductors, electrically shorted at each end.

b. DC MOTORS: Electric torque generators which are powered by direct current. The following types can be considered for electromechanical actuation.

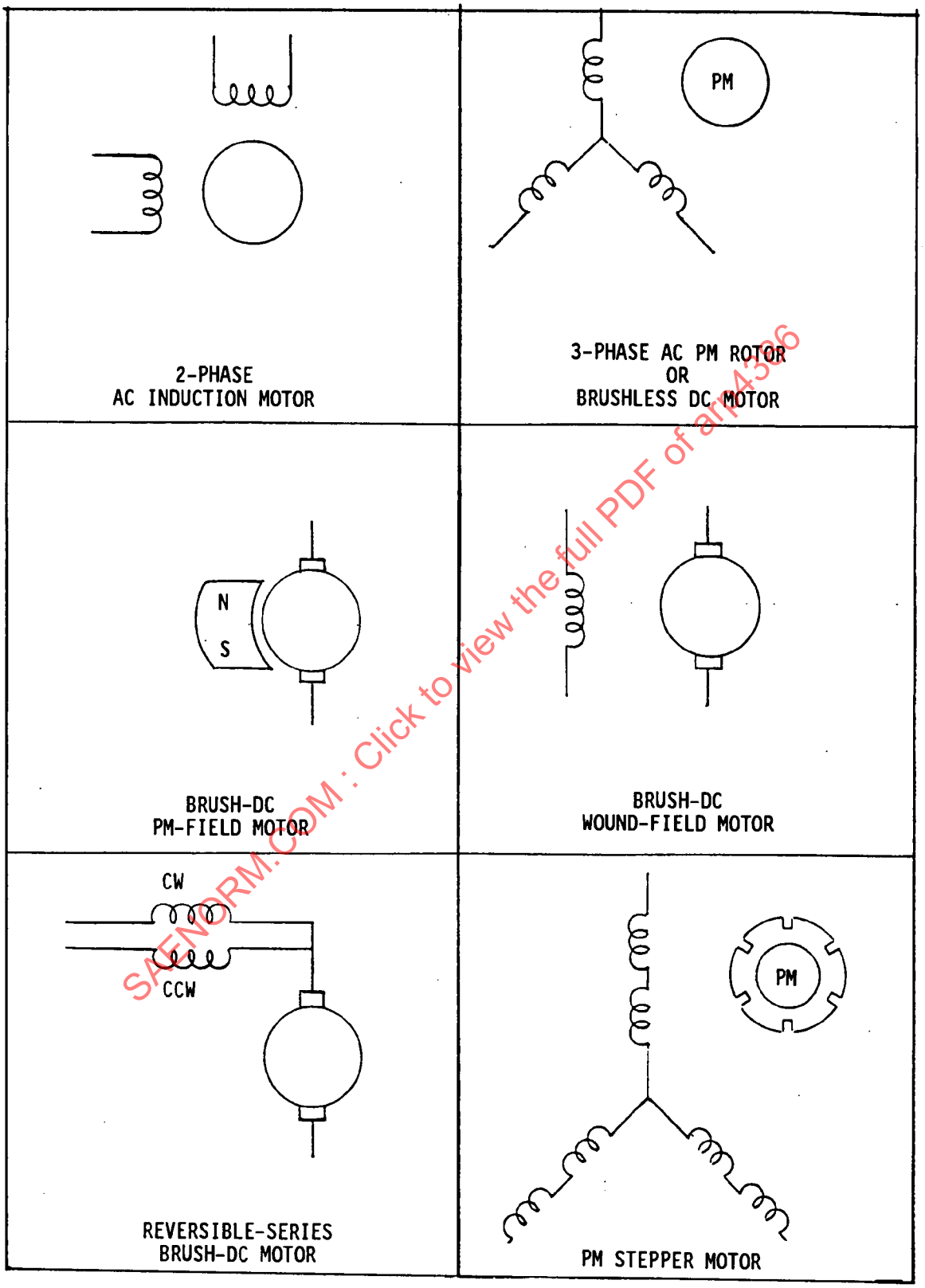


FIGURE 7 - Electromechanical Actuator Motors

3.2.2.3 (Continued):

BRUSHLESS PERMANENT MAGNET MOTOR: A DC motor in which DC current supplied to conductors in the stator reacts with the PM field developed by permanent magnets located in the rotor, resulting in motor torque. Electrically switched direct current is supplied to three or more sets of stator conductors in a sequence such that unidirectional torque can be developed. A rotor position transducer is used to sequence stator currents.

BRUSH PERMANENT MAGNET MOTOR: A DC motor in which direct current supplied to the conductors in the rotor reacts with a magnetic field developed by permanent magnets located in the stator, resulting in motor torque. A commutator and brushes ensure that direct current is supplied to the rotor conductors such that unidirectional torque is produced with one polarity of current.

BRUSH WOUND FIELD MOTOR: A DC motor similar to a brush PM motor, except that a wound coil supplied with continuous and unidirectional direct current is used in place of a PM field in the stator.

COMPOUND WOUND MOTOR: A wound-field DC motor which incorporates both shunt and series windings in the stator.

LINEAR DC MOTOR: A linear DC motor in which direct current supplied to the armature winding reacts with the stator field to produce a rectilinear force. Commutation is not required if the armature is always located within the magnetic field of the stator throughout its design stroke.

SERIES WOUND MOTOR: A wound-field DC motor in which the rotor conductors and stator field coil are connected in series. A reversible series motor has two field coils oppositely connected and energized one at a time. This permits rapid switching of motor direction.

SHUNT WOUND MOTOR: A brush wound-field DC motor in which the rotor conductors and the stator field coil are connected in parallel to the DC power source.

STEPPER MOTOR: A motor whose rotor moves in discrete angular steps determined by the number of poles of stator and rotor located around the circumference of the motor air gap. Sequential pulsing of multiphase windings causes the rotor to move one step for each pulse. Variable reluctance stepper motors require continuous energization to develop torque to hold rotor position. PM stepper motors hold the last energized position. Stepper motors are often used for open loop control.

3.2.2.4 Turbomechanical and Mechanical Actuators:

CLUTCH COUPLE TURBOMECHANICAL ACTUATOR: A turbomechanical actuator wherein a constant speed turbine is coupled to the load through a double acting servocontrolled clutch. The clutch controls both the speed and direction of the load. A large gear reduction between the high speed turbine and the load is included in the actuator.

DOUBLE TURBINE TURBOMECHANICAL ACTUATOR: A turbomechanical actuator utilizing two turbines of opposite directional sense mechanically coupled together. A control valve is used to proportionally control gas flow to either of the two turbines thus providing control of load speed and direction. Speed reduction between the turbine and load is usually included.

MECHANICAL ACTUATOR: A device to move the load through the use of mechanical components such as acme screws, ball screws, or geared devices.

TURBOMECHANICAL ACTUATORS: Typically these types of actuation systems utilize a high speed turbine powered by a warm gas generator. Turbine output is coupled to the load by some type of mechanical motion conversion.

3.2.3 Data and Terms Related to Actuation:

3.2.3.1 HYDRAULIC SYSTEM COMPONENTS: When several types of components exist the name of the component is given followed by the modifier.

ACCUMULATOR: A closed container for pressure storage of fluid energy.

ACCUMULATOR, COMPENSATING: An accumulator which, in addition to its high pressure volume, incorporates low pressure volumetric capacity which will accommodate a like volume of fluid to that discharged from the high pressure chamber. The sum of the volumes of the high and low pressure chambers remains constant.

ACCUMULATOR, CYLINDRICAL: An accumulator in which the fluid is separated from the compressible medium by means of a piston operating in a cylindrical container.

ACCUMULATOR, FLEXIBLE SEPARATOR: An accumulator in which the fluid is separated from the compressible medium by means of a flexible bladder or diaphragm.

ACCUMULATOR, HYDRAULIC: An accumulator in which the stored operating medium is hydraulic fluid.

ACCUMULATOR, HYDROPNEUMATIC: An accumulator in which the stored operating medium is hydraulic fluid, pressurized by means of compressed gas.

3.2.3.1 (Continued):

CYLINDER, ACTUATING (Sometimes called "Jack", "Ram", or "Strut"): A linear motion device in which the thrust or force is proportional to the effective cross-sectional area and the pressure differential.

CYLINDER, FIXED END: A cylinder which is held in a rigid position.

CYLINDER, ROTATING END: A cylinder mounted to permit limited rotary movement about a fixed point.

CYLINDER, SINGLE ACTING: A cylinder in which fluid pressure is introduced in one end so that fluid force is exerted in one direction only. Gravity, spring forces, or other means are used to accomplish the return stroke.

CYLINDER, SWIVEL END: A cylinder with one or both ends provided with a joint which not only allows oscillation of the cylinder but which also incorporates stationary fluid connections.

CYLINDER, TRANSFER: A device for transmitting fluid pressure from one circuit to another without intermixture of fluid between the circuits.

DASHPOT: A snubbing device within a fluid operated unit which operates at the extremity of the stroke by displacing operating fluid through a restricted passage, as sometimes used in an actuating cylinder.

FILTER: A device serving to remove solid particles from a flowing fluid by passing it through a porous element.

FILTER, LINE TYPE: A filter designed for installation in a fluid line and having a case capable of withstanding the operating pressure of the line, usually system pressure.

FILTER, RESERVOIR TYPE: A filter to be housed within the shell of a reservoir for purification of the return flow to the reservoir, usually applied to the filter element alone.

FILTER, VENT TYPE: A filter for installation in an atmospheric vent line.

FLOW PATTERN: The paths of fluid flow connecting various ports in a given valve position.

FUSE: A device which automatically shuts off flow in a line in event of downstream system rupture.

FUSE, QUANTITY MEASURING: A fuse which closes when more than a predetermined quantity of fluid has passed through it.

FUSE, RETURN FLOW: A fuse which closes both pressure and return lines when the ratio between the flows deviates beyond a predetermined value.

3.2.3.1 (Continued):

GASKET: The flexible sealing element in a stationary or static fluid seal.

GLAND: The cavity or space provided for the accommodation and operation of an elastic packing or gasket for sealing of a fluid vessel or compartment.

INTENSIFIER: A device which converts an input pressure to a higher output pressure which is proportional to its input pressure.

LINE: A tube, pipe or hose which acts as a conductor of fluid.

LINE, BLEED: A line, selectively open to overboard, which serves only for removing foreign substances from a system or unit, as for removal of entrapped air from a hydraulic circuit.

LINE, DRAIN: A line returning leakage fluid independently to reservoir or return circuit. Also, a line selectively open to overboard for removing fluid from the system.

LINE, PILOT: A line which acts as a conductor of control actuating fluid.

LINE, PRESSURE: A line which conducts fluid from the pressure source to a control unit or units.

LINE, RETURN: A line which conducts working fluid back to the reservoir.

LINE, SUPPLY: A line which conducts a fluid supply, as from a reservoir to a pump.

LINE, VENT: A line which is continuously open to atmosphere.

ORIFICE: A short fluid passage which produces a substantial reduction in flow by virtue of its cross-sectional area. A true orifice has zero length.

PACKING: The flexible sealing element in a fluid seal which is subject to sliding motion.

PISTON: A cylinder part which slides in a cylinder or barrel and serves to transfer force to or from the enclosed fluid.

PISTON ROD: A coaxial column or rod, attached to or integral with a piston, which serves to transmit force between the piston and another mechanical member.

PORT: An opening at a surface of a component incorporating provisions for attachment of a fluid carrying passage, line, fitting or removable plug.

3.2.3.1 (Continued):

RESERVOIR: A storage container for the operating fluid.

RESERVOIR, PNEUMATIC: A pressure storage chamber in which pneumatic pressure energy may be accumulated and from which it may be withdrawn.

SCHEMATIC: A flow diagram of a fluid unit or system of units including all interconnections.

SEPARATOR: The movable or flexible member in a fluid container, such as an accumulator or reservoir, the function of which is to prevent intermixture of fluids, such as air and hydraulic fluid.

SETTING: In an adjustable or calibrated unit (such as a relief valve pressure switch, or flow control device), operating characteristics which result from an adjustment or setting.

SLAVE OPERATED: Pressure operated, so as to position in a manner equivalent to rigid mechanical interlock, by means of a master or control unit.

SLEEVE: In general, a hollow cylindrical member used to line a housing to impart different metallurgical properties to the rubbing surface than those inherent in the housing. In a slide valve, the hollow cylindrical member which directly affects the flow pattern through its relative position to an internal slide or spool.

SLIDE: In a slide valve, the moving member which directly affects the flow pattern, usually cylindrical and internal to a sleeve. Also see Spool.

SPOOL: The internal member of cylindrical slide valve which directly affects the flow pattern through its relative position to a surrounding sleeve.

SWIVEL: A rotatable fluid connection.

SWIVEL FITTING: A fitting, directionally adjustable without lateral movement, usually retained by a flange, and not free to rotate in service.

SWIVEL JOINT: A fluid connection which is free to rotate in service, usually under pressure.

VALVE POSITION: The position of the valve mechanism which determines the flow pattern.

3.3 Controls Terms:

3.3.1 General:

a. CONTROL SYSTEM CLASSIFICATION:

ADAPTIVE CONTROL: A control system which maintains optimum system performance by automatically changing system parameters.

BISTABLE AND TRISTABLE CONTROL: A control system in which the power to control the load is fully on in either polarity (bistable), or fully on in one polarity, off, or fully on in the other polarity (tristable). These systems are sometimes called on-off systems or bang-bang systems. When the time duration of the application of power is modulated by the input, the system is called pulse width modulated (PWM).

CLOSED LOOP CONTROL SYSTEM: A control system in which the command is compared with a measurement of system output and the resulting error signal is used to drive the load towards the desired output. Figure 8 illustrates a closed loop control system.

CONTROL SYSTEM: A system in which deliberate guidance or manipulation is used to achieve a prescribed value of a variable. A control system has at least one input and one output.

INTEGRAL CONTROL (TYPE 1, 2): A control system which uses integration in the control loop elements to provide an output in response to the error signal. This is referred to as a Type N system where N is the order of the integrator.

OPEN LOOP CONTROL SYSTEM: A control system in which gain and power control elements are used to provide an output in direct response to a command without feedback comparison. Figure 9 illustrates an open loop control system.

PROPORTIONAL CONTROL (TYPE 0): A control system which uses proportional forward and feedback control elements to provide an output in response to the error signal. This is referred to as a Type 0 control system.

b. CONTROL SYSTEM SIGNALS:

COMMAND: An input which represents the desired output of the control system.

ERROR SIGNAL: The output of the summing point which compares an input signal with one or more feedback signals.

INPUT: An independent variable supplied to the control system.

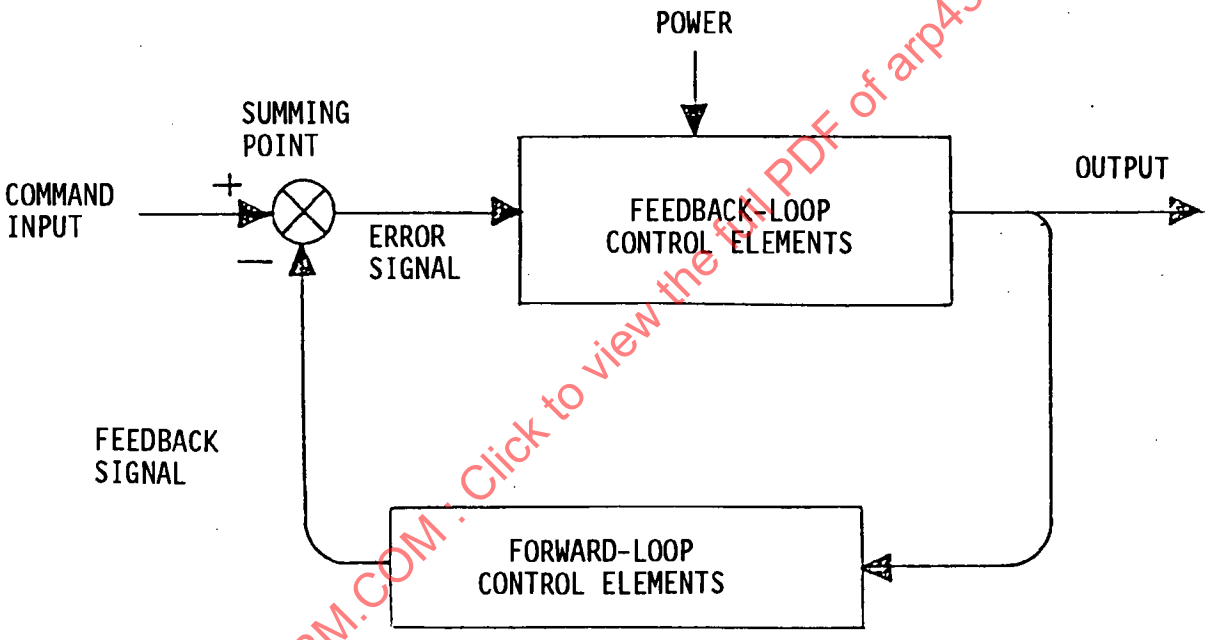


FIGURE 8 - Closed Loop Control System

FIGURE 9 - Open Loop Control System

3.3.1 (Continued):

LOOP: The signal path in a closed loop control system beginning with the error signal and ending with the resultant feedback signal which functionally interconnects the forward loop and feedback loop control elements.

OUTPUT: The controlled variable(s) resulting from activity of the control system. Typically, position or velocity is the controlled output.

SUMMING POINT: Any point in a control system where an algebraic summation of two or more control loop variables is performed.

c. CONTROL SYSTEM ELEMENTS:

FEEDBACK ELEMENTS: Those elements in a closed loop control system which relate the feedback signal to the controlled variable.

FORWARD LOOP CONTROL ELEMENTS: Those elements situated between the error signal and the controlled variable.

3.3.2 Control System Terminology: The definitions and terms set forth in this section deal primarily with flight control systems; consequently, in a number of cases, there may be some that parallel like terms in missile or general use, previously covered in other sections of this document.

3.3.2.1 Flight Control Terms:

ACTIVE: An adjective which describes a system or portion of a system which is in control in contrast to being in standby; also, the operational status of a servocontrol device after a failure if the device is activated or remains in control.

ACTIVE CONTROL TECHNOLOGY: An airplane design concept in which vehicle performance, weight, and economic characteristics are optimized through a reliance on automatic subsystems within the flight control system to augment the airplane's stability, to reduce the design loads through load reduction or redistribution and structural mode damping, and to manage the airplane's configuration for aerodynamic efficiency. Active control functions include:

a. Pitch stability augmentation
b. Lateral and/or directional stability augmentation
c. Angle-of-attack limiting
d. Wing-load alleviation
e. Maneuver-load control
f. Gust-load alleviation
g. Flutter-mode control
h. Ride smoothing

3.3.2.1 (Continued):

ADAPTIVE FLIGHT CONTROL SYSTEM: A flight control system having the capability to vary its performance parameters in flight and thus adapt to the changing flight conditions so that the vehicle's structural integrity and stability limitations are not exceeded during critical phases of flight.

ANALYTICAL REDUNDANCY: A concept wherein an estimate of a physical parameter (e.g., aircraft attitude, acceleration, etc.) is computed by combining and filtering information from other sensed data which have a known physical relationship to the signal of interest. In this way a signal may be synthesized from other sensor signals rather than be obtained from direct measurement. In control systems, the synthesized signal can be used to add a level of redundancy.

ARTIFICIAL INTELLIGENCE: A characteristic of a knowledge-based concept or process that involves decision making and reasoning based on stored knowledge. A system possessing such a characteristic is sometimes referred to as an "expert system", i.e., it uses knowledge and inference procedures to solve problems or diagnose conditions by their symptoms.

AUTOMATIC FLIGHT CONTROL SYSTEM (AFCS): An Automatic Flight Control System consists of electrical, mechanical, and hydraulic components which generate and transmit automatic control commands which provide pilot assistance or relief through automatic or semiautomatic flight path control or which automatically control airframe response to disturbances. This classification includes automatic pilots, stick or wheel steering, autothrottles, structural mode control, and similar control mechanizations.

a. AFCS functions include:

(1) Airspeed hold
(2) All-weather landing
(3) Altitude hold
(4) Altitude select
(5) Attitude hold (pitch and roll)
(6) Automatic carrier landing
(7) Automatic instrument low approach
(8) Automatic navigation
(9) Automatic terrain following
(10) Automatic vectoring/traffic control
(11) Heading hold
(12) Heading select
(13) Mach hold

AFCS PRE-ENGAGE SYNCHRONIZATION: The process of biasing a new input signal to correspond with the AFCS output position prior to switching to the new input signal. The bias is ramped out after switching.

3.3.2.1 (Continued):

AVERAGING SYSTEM: The type of fault-tolerant system using two or more active channels wherein the individual channel outputs are summed to provide an average output. All channels are normally operative so performance degradation may occur after a failure. An example of an averaging system is the use of multiple control surfaces on an airplane, each individually actuated.

BACKUP SYSTEM: A mode of control which is engaged upon failure of the primary operational system. Usually used to refer to a system which is as independent as possible from the primary system. Sometimes used as protection against multiple generic failures.

BUILT-IN-TEST: An operational status checkout or test system which is integrated into a control system or function. Usually used to verify operational status of as many aspects of a control function as possible within the limits of integrated test capability. May be initiated automatically or on command.

CHANNEL: One signal or control path of a redundant set. A channel is an entity within itself and contains elements individual to that channel. A model may be used as a reference channel in a detection-correction system.

CHANNEL BUFFERING: A technique used in fault-tolerant systems that minimizes the possibility of a failure in one channel to induce a failure in another channel.

CHANNEL PRIORITY: The order of authority of the various channels in a redundant system where the channels are not equivalent. Examples of channel prioritizing are:

a. Primary/secondary
b. Active/standby
c. Normal/alternate

CHANNEL SUMMING: The combining of multiple channels to provide a control function. Examples of channel summing techniques are:

a. Flow summing
b. Flux summing
c. Force summing
d. Position summing
e. Torque summing
f. Velocity summing

CONTROL AUGMENTATION SYSTEM: A function of the flight control system, including command shaping, sensors, actuators, etc., that perform in such a manner so as to augment the static and dynamic stability, and maneuver response of the aircraft. When considered as an entity it is essentially a closed loop tracking control system, responding to pilot commands.

3.3.2.1 (Continued):

CONTROL AUTHORITY: The amount of control surface or thrust vector deflection that can be produced by AFCS signals relative to the total available control deflection. This phrase is often preceded by the word electrical, or abbreviations such as CAS or SAS, in order to be more explicit.

CONTROL-BY-LIGHT (FLY-BY-LIGHT) SYSTEM: A flight control system wherein vehicle control information is transmitted by light through a fiber-optic cable.

CONTROL-BY-WIRE (FLY-BY-WIRE) SYSTEM: A flight control system wherein vehicle control information is transmitted completely by electrical means.

CONVERSION: The process of changing from one type of control or operational state to another; e.g., from an active to a standby control or from a primary to a secondary system.

DETECTION-CORRECTION SYSTEM: The type of fault-tolerant system wherein a failure or out-of-operating tolerance condition is detected and corrective action is taken automatically. This may involve switching to a standby system; or, if two or more systems are normally operating, correction may involve switching-out the failed channel. Inherent in this type of system is the existence of a finite time for detection and correction. With detection-correction systems, it is possible to use a model of an active system as a reference in order to extend the failure correction capability of the total system.

DUAL FAIL OPERATIVE: A condition or requirement wherein an active control device or system can sustain any two failures within the system and remain operative. It is implicit with a Dual Fail Operative system that it be able to accept identical but nonsimultaneous failures in two of its channels and continue to operate with no nominal loss of performance. Unless specifically stated, it is understood that no nominal loss of performance occurs after one or two failures.

DUAL LOAD PATH: A type of mechanical paralleling wherein two separate load carrying paths exist from the control system input to the system output. Each load path is capable of carrying sufficient load such that failure of any one member will not jeopardize system performance.

DUAL TANDEM VALVE: A tandem valve having two separate control sections.

DUPLEX: An adjective meaning twofold, as a duplex valve, duplex actuator, etc.

ELECTRICAL LOGIC: Logic for mode switching or failure detection and correction performed with electronic or electrical components.

3.3.2.1 (Continued):

EQUALIZATION (CHANNEL BALANCING): The use of feedback to achieve close coincidence between the outputs of two or more elements or channels in a fault-tolerant control system. Equalization may be necessary to reduce the transient that could occur while shutting off a failed channel, or it may be necessary to minimize the adverse effects of normal tolerances.

EXPERT SYSTEM: Same as ARTIFICIAL INTELLIGENCE.

FAILURE: A noun describing the state of having failed. In dealing with fault-tolerant flight control systems a failure occurs when a device within the system fails to function within prescribed limits without regard to the cause of the failure. Thus a failure may be:

a. Any loss of function of any element within the control system.
b. Loss of supply power to the system.
c. Erroneous hardover conditions or loss of control intelligence at the signal input.
d. Any out-of tolerance condition that exceeds normal operating limits.

FAILURE MODE: A manner in which a device can or did fail. Simple devices may have only one failure mode; whereas, more complex devices can have several failure modes.

FAIL FUNCTIONAL: A more limited case of fail operative wherein performance is degraded following a failure.

FAIL HARDOVER: The type of failure wherein the output of the failed element is at an extreme condition (e.g., position, force, etc.). In cases having a polarity of output, a hardover failure may be of either polarity.

FAIL NEUTRAL: A failure mode where the control device or system fails to a passive null or locked-at-null condition.

FAIL OPEN: The type of failure wherein the failed element disconnects the normal control path within a device. Such a failure either prevents the signal from passing or seriously alters the signal that passes through a system.

FAIL OPERATIVE: A quality wherein a control device or system can continue operation after a failure or failures. A more explicit description is given by Single Fail Operative or Dual Fail Operative. In a true fail operative situation, a failure will cause no nominal loss of performance.

FAIL PASSIVE: A condition or requirement where the failed device or system ceases to create any active output. In the purest sense, a device that fails passively would simply remove its presence from the control system. However, a device is still considered fail passive if it remains in the system but acts only as an additional load.

3.3.2.1 (Continued):

FAIL SAFE: A quality wherein the control device or system ceases to function but the conditions or consequences resulting from the failure are not hazardous and do not preclude continued safe flight. The condition following failure may be completely passive, or it may involve driving to a predetermined nonactive condition.

FLIGHT CONTROL SYSTEM: A system which includes all aircraft subsystems and components used by the pilot or other sources to control one or more of the following: aircraft flight path, attitude, airspeed, aerodynamic configuration, ride, and structural modes.

FLY-BY-LIGHT: Same as Control-By-Light.

FLY-BY-WIRE: Same as Control-By-Wire.

ISOLATION: A technique used in fault tolerant systems that removes the effects of a failure or prevents a failure from propagating or affecting the continued operation of the system.

MAJORITY VOTING SYSTEM: A fault-tolerant system wherein the outputs of three or more signals are summed to provide a single signal representative of the majority of the individual signals, often providing detection logic for identifying a failed channel. Also see Voter.

MANUAL FLIGHT CONTROL SYSTEM: Manual flight control systems consist of electrical, mechanical, and hydraulic components that transmit pilot commands, or generate and convey commands that augment pilot control commands, and thereby accomplish flight control functions. This classification includes the longitudinal, lateral directional, lift, drag, and variable geometry control systems. In addition, their associated augmentation, performance limiting, and control devices are included. A manual flight control system does not include vehicle motion or flight path sensors.

MODEL: A device used in a failure detection-correction system to simulate the performance of a component or a channel used for control. Typical models are electrically implemented.

MONITOR: A device used for sensing the operation of a component or channel such that failures may be detected. In-line and cross-channel are two forms of monitoring. In-line monitoring compares output performance to the command input or a model. Cross-channel monitoring compares equivalent performance features of two or more channels.

NONDETECTABLE FAILURE: A failure that, upon occurrence, is not recognized by the failure detection scheme(s) of a fault tolerant flight control system. Unless stated otherwise, a flight control system must maintain its fail operative status after the occurrence of a nondetectable failure.

3.3.2.1 (Continued):

PARALLEL SERVO: A servo located in a control system so that the servo output drives in parallel with the major input. This arrangement usually is used with actuators which perform an alternate function to that of the pilot. The parallel servo output will drive both the pilot controls and the flight control system.

PASSIVE FAILURE: The type of failure wherein the failed device or system has no effect on the operational performance of a fault-tolerant system even when it is commanded to function. Usually associated with standby or inactive features of a fault-tolerant system.

PASSIVE PARALLELING: The simplest and most common type of redundancy wherein two parallel functional devices are utilized such that if one fails the second is still available. This approach is limited to the more simple elements of the control system which can only fail passively, such as springs and linkages. When failure of one element occurs, there may be a change in performance or capability.

QUADRUPLEX: An adjective meaning fourfold, as used for a four channel system.

QUADRUPLEX SYSTEM: A control system containing four signal paths so as to provide multiple failure capability such as Single Fail Operative/Fail Safe, Dual Fail Operative, or Dual Fail Operative/Fail Safe.

QUAD VOTER: A voter that selects one common output to represent the four input signals or values.

RECONFIGURABLE: That characteristic of a fault-tolerant device or system whereby continued functional operation, subsequent to a failure, is provided by rearranging or recombining the surviving control elements. Sometimes referred to as self-repairing.

REDUNDANCY MANAGEMENT: That portion of the system logic and control (hardware or software) which detects and isolates failures in a fault-tolerant system; and reconfigures the system after the failure is detected and isolated so as to maintain the same or a reduced level of operation.

REDUNDANT: An adjective to denote the use of duplicate or alternate components for the purpose of improving mission safety or reliability.

SELF-REPAIRING: Same as Reconfigurable.

SERIES SERVO: A servo located in a control system so that the servo output adds algebraically to that of a major input. This arrangement is commonly used with Stability Augmentation System actuators to superimpose control on primary commands. The series servo output will not cause motion at the major input.

3.3.2.1 (Continued):

SINGLE FAIL OPERATIVE: A quality wherein a control device or system can sustain any single failure and remain operative. Unless specifically stated, it is understood that no nominal loss of performance occurs after the failure.

STABILITY AUGMENTATION SYSTEM: The portion of a flight control system that improves handling characteristics by modifying the aerodynamic response of the vehicle. The SAS generally has limited authority. To prevent undesirable coupling between the SAS signals and the pilot inputs, the SAS signals are normally introduced in a fashion that does not cause stick motion or forces.

STANDBY: A term used to describe the normal status of a channel in a fault detection-correction fault-tolerant system when that channel may be switched into control in the event of a failure of a normally active operating channel.

TRACKING ACCURACY: The accuracy with which a channel output or combination of channel outputs match one another and/or the commanded output or outputs.

TRIPLEX: An adjective meaning threefold, as a triplex valve, a triplex actuator, etc.

TRIPLEX SYSTEM: A fault-tolerant control system containing three signal paths.

VOTER: A logic element or device that selects one signal to represent the output (of the voter) from three or more signals input to the device.

3.3.3 Data and Terms Related to Control Technology:

HYDROMECHANICAL LOGIC: Logic, as for failure detection or correction, performed with only mechanical elements where the information is in the form of hydraulic pressures or flows.

MANUAL OVERRIDE: The capability of a flight control system to enable the pilot to override the Automatic Flight Control System (AFCS) through a cable and/or linkage system and exert control in excess of the AFCS authority or in opposition to the AFCS command.

MECHANICAL REVERSION: The capability of reverting from fly-by-wire control to a state wherein the pilot's control is mechanically coupled to the actuator control valves.

MID-VALUE LOGIC SYSTEM: A fault-tolerant system having an odd number of active channels (usually three) where the system output is determined by the middle of the (three) input signals.

PSEUDO FLY-BY-WIRE: A fly-by-wire control system having a means to mechanically control or override the servoactuators.

3.3.3 (Continued):

RESET: The process for returning a system to an operational state after a failure has occurred and has been corrected or isolated. Some systems have the capability for providing this function automatically.

REVERSION: The process for changing over control from an active to a standby channel or from a primary to a secondary channel.

3.4 Reliability and Maintainability Definitions:

In this section there are lists where a definition of a word or word items is given followed by a list of the word plus modifier: for example, Reliability; Reliability, Assessed; etc. A number of definitions although not directly falling into the Reliability-Maintainability category but used on aerospace equipment or aerospace activities are also listed in this section.

3.4.1 Reliability and Related Terms:

BURN-IN: The operation of an item under stress to stabilize its characteristics.

CONFIDENCE LEVEL: The probability that a given statement is correct, usually associated with statistical predictions.

CRITICALITY: A relative measure of the consequences of a failure mode.

DEPENDABILITY: A measure of the item operating condition and of the degree to which the item is capable of performing its required function at any (random) time during a specified mission profile, given item availability at the start of the mission.

DERATING: a. Using an item in such a way that applied stresses are below rated values or,
b. The lowering of the rating of an item in one stress field to allow an increase in another stress field.

DISCREPANCY: Any difference or inconsistency between a requirement for a characteristic of a material or an item, as specified in a contract, drawing specification, standard, test procedures, or other document and the actual characteristic of the material or item.

ERROR: A mistake in specification, design, production, maintenance, or operation that causes an undesired performance of a function.

EXPOSURE TIME: The period (in hours or cycles) during which a system, subsystem, unit, or part is exposed to failure, measured from when it was last verified as functioning to when its proper performance is or may be required.

3.4.1 (Continued):

FAILURE: The inability of a system, subsystem, unit, or part to perform within previously specified limits. Note that some failures may have no effect on the capability of the airplane and therefore are not failure conditions.

FAILURE CONDITION: A consequential airplane state that has an impact on the functional capability of the airplane or the ability of the crew to cope with adverse operating conditions, or that would prevent continued safe flight and landing. A failure condition can result from the occurrence of a specific single event or a combination of related faults, failures, errors, operating conditions, or environment. Postulated failure conditions are assessed for their impact on safety and assigned an appropriate probability classification. A defined failure condition provides the criteria for classifying system functions as nonessential, essential, or critical.

FAILURE CONDITION, CATASTROPHIC: Failure conditions that would prevent continued safe flight and landing. A failure condition is considered catastrophic if more than a relatively few occupants incur serious injuries or fatalities.

FAILURE CONDITION, MAJOR: Failure conditions that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions to the extent that there would be, for example:

a. A significant reduction in the safety margin

b. A significant increase in crew workload, or in conditions that impair crew efficiency

c. In more severe cases, adverse effects on occupants

FAILURE CONDITION, MINOR: Failure conditions that would not significantly reduce airplane safety, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example:

a. A slight reduction in safety margins

b. A slight increase in workload, such as routine flight plan changes

c. Some possible discomfort to occupants.

FAILURE, DORMANT (HIDDEN): A defect that is not visible, which cannot be detected and which does not cause failure under normal conditions, but can cause failure within the design envelope. In airline parlance this is usually called "hidden failure".

FAILURE EFFECT: The consequences of item failure on system operation.

3.4.1 (Continued):

FAILURE, EXPECTED: Expected failures are based on failure rates and exposures. The number is obtained by multiplying the official failure rate for each age interval by the exposures in the interval and then adding the results.

FAILURE FREE WARRANTY: A procurement requirement intended to have the manufacturer, or the design control agent, continuously upgrade the field reliability of designated equipment.

FAILURE MISSION: Failure to complete the intended mission as a consequence of equipment failure.

FAILURE MODE AND EFFECTS ANALYSIS: A procedure by which each potential failure mode in a system is analyzed to determine the results, or effects on the system, and to classify each potential failure mode according to its severity.

FAILURE, RANDOM: Failure of an item whose occurrence is only predictable in a probabilistic or statistical sense.

FAILURE RATE, INITIAL: An initial estimate of the expected failure pattern of an item, which may later be adjusted, as actual experience is gained.

FAILURE RATE, SMOOTH: Rates determined when sufficient failures and exposures per age intervals are available; enough to eliminate peaks and valleys from the data.

FAILURE, WEAROUT: Failures that occur as a result of progressive deterioration and with a probability of occurrence that increases with the age of the device.

FAULT: An undesired anomaly in the functional operation of a system, subsystem, unit, or part.

MEAN TIME BETWEEN FAILURES: A basic measure of reliability for repairable items. The main number of life units during which all parts of the item perform within their specified limits during a particular measurement interval under stated conditions.

REDUNDANCY: The existence of more than one independent means of accomplishing a given function.

REDUNDANCY, ACTIVE: That redundancy where all means for accomplishing a given function operate simultaneously and share the output load, rather than being activated when needed.

REDUNDANCY, STANDBY: That redundancy where the alternative means of performing a function is inoperative until needed, and is activated upon failure of the primary means of performing the function.

3.4.1 (Continued):

RELIABILITY: The probability that a system, subsystem, unit, or part will perform its intended function for a specified interval, under stated operational and environmental conditions.

RELIABILITY, ASSESSED: The reliability of an item determined within stated confidence limits, determined by tests or using failure data and compared to nominally identical items.

RELIABILITY, DISPATCH: The probability that a scheduled, or planned flight will depart without incurring a delay (technical) or cancellation (technical).

RELIABILITY, ESTIMATED: A reliability factor that is postulated for a system, subsystem, or equipment under specified conditions of test or use.

RELIABILITY, INHERENT: The reliability potential in a given design configuration when used in accordance with the design specification.

RELIABILITY, MISSION: The probability that a system or an item will give specified performance for the duration of a mission, when used in the manner and for the purpose intended, given that the item is functioning properly at the start of the mission.

SURVIVABILITY: The measure of the degree of capability to which a system will withstand a hostile environment without suffering an abortive impairment of its ability to accomplish its designated function.

USEFUL LIFE: The length of time a population of items is expected to operate with a constant failure rate. This excludes infant mortality and wearout periods.

WEAROUT: The process that results in an increase of the failure rate or probability of failure with an increasing number of life units.

3.4.2 Maintainability and Related Terms:

CHECK, BENCH: A functional check of an item in the shop to determine whether the item may be returned to service, or whether it requires adjustment, repair, overhaul, or replacement.

CHECK, C: A heavy maintenance check; also see Letter Check.

INSPECTION, NONDESTRUCTIVE: A family of methods for investigating the quality, integrity, properties, and dimensions of materials and components, without damaging or impairing their serviceability through the use of dye penetrant, magnetic eddy current, ultrasonic, radiographic, infrared, etc. devices. Nondestructive testing is widely used in aircraft structural inspection.

3.4.2 (Continued):

INSPECTION, PERIODIC: The periodic inspection is a thorough and close check of the overall aircraft. Each periodic inspection comprises all intermediate, preflight, thru-flight and postflight inspections. It is repeated at regular intervals of calendar time or hours of operation.

INSPECTION, SAMPLE: The monitoring or withdrawal, or both, of random selected devices from assembly line or service to permit determination of their condition at predetermined progressive intervals.

LETTER CHECK: In airline industry, the alphabetic designations given to scheduled maintenance packages. A maintenance package is a group of maintenance tasks scheduled for accomplishment at the same time.

MAINTAINABILITY REQUIREMENT: A comprehensive statement of required maintenance characteristics, to be satisfied by the design of an item (for example, Mean Maintenance Man-hours per Flight Hour).

MAINTENANCE: All action necessary to sustain or restore the integrity and performance of an item to a specified condition. It includes inspection, testing, servicing, classification as to serviceability, repair, rebuilding, and reclamation.

MAINTENANCE, CONDITION MONITORING: Same as Condition Monitoring.

MAINTENANCE, DIRECT: A measure of maintainability that is the sum of direct maintenance man-hours divided by the total number of maintenance actions during a stated period of time.

MAINTENANCE DIRECT COSTS: Maintenance labor and material costs directly expended in performing maintenance on an item or aircraft.

MAINTENANCE, HARD TIME: Same as Maintenance, Scheduled.

MAINTENANCE INDIRECT COSTS: Maintenance labor and material costs, not considered to be direct maintenance costs, that contribute to the overall maintenance program costs through overhead operation, administration, record keeping, supervision, tooling, test equipment, facilities, etc.

MAINTENANCE, ON CONDITION: A maintenance process, where a component's suitability for continued service is determined by periodic inspection or test, or both, in situ on the airplane. Such a plan gives full recognition to the fact that failure is random in nature and cannot be completely obviated by a known maintenance scheme.

MAINTENANCE, SCHEDULED: A maintenance process performed at defined intervals to retain an item in a serviceable condition.

MAINTENANCE, UNSCHEDULED: Corrective maintenance performed, as required by item condition.

3.4.2 (Continued):

MAINTENANCE ITEMS AND TIME:

a. ITEM, CRITICAL: An item that:

(1) Has a limitation to warrant controlled surveillance under specified conditions

(2) Is known to require special handling, transportation, storage, or test precautions

(3) Does not have sufficient history of its own, or a similarity to other items that have the demonstrated high reliability to provide confidence in its reliability

b. ITEM, COMPLETED: Items of equipment (including basic or end items, components, assemblies) that have been overhauled, modified, renovated, and completed in accordance with terms of contracts, project orders, or other work directives and authorizations, and are ready for their intended use after receiving final mechanical acceptance inspection.

c. ITEM LEVELS: Item levels from the simplest to the more complex are as follows: Part, Subassembly, Assembly, Unit, Group, Set Subsystem, System.

d. ITEM, LIFE LIMITED: An item that must be removed from service and discarded before a specified time is achieved. It is referred to as an XXX time life part or component.

e. ITEM, MAINTENANCE SIGNIFICANT: Items identified by the manufacturer whose failure:

(1) Could affect safety,
(2) Could be undetectable during operations,
(3) Could have significant operational economic impact
(4) Could have significant nonoperational economic impact.

f. ITEM, SERVICEABLE: An item that can be returned to service with appropriate airworthiness documentation.

g. LINE REPLACEABLE UNIT: A unit that can be readily changed on an aircraft during flight line maintenance operations.

h. MEAN TIME BETWEEN MAINTENANCE: A measure of the reliability taking into account maintenance policy is the total number of life units expended by a given time, divided by the total number of maintenance events (scheduled and unscheduled) due to that item.

i. MEAN TIME BETWEEN REMOVALS: A measure of the system reliability parameter related to demand for logistic support is the total number of system life units, divided by the total number of items removed from that system during a stated period of time.

3.4.2 (Continued):

j. MEAN TIME BETWEEN UNSCHEDULED REMOVALS: A performance figure calculated by dividing the total unit flying hours (airborne) accrued in a period by the number of unscheduled unit removals that occurred during the same period.

k. MEAN TIME TO REPAIR: The statistical mean of the distribution of times-to-repair is the summation of active repair times during a given period of time, divided by the total number of malfunctions repaired during the same interval.

l. TIME: Any appropriate unit of life measurement such as hours, cycles, landings, etc.

m. TIME, AWAITING MAINTENANCE: That time during which a vehicle is not operationally ready because of maintenance and no maintenance work is as yet being performed on either the vehicle or its related equipment.

n. TIME, BLOCK: Block time is the time an aircraft is underway. It covers the time from pulling the chocks at the parked position until parked at the destination. Block time is entered on the aircraft log sheets and is used in computing airline statistical information. It includes taxi time, waiting on taxiways and at the end of runways, takeoff run, flight time, landing roll, and taxi-in. It excludes running of engines or systems, or both, while aircraft are parked or for strictly maintenance check/test purposes.

o. TIME, FAULT CORRECTION: The element of Maintenance Time during which a failure is corrected by:

(1) Repairing in place

(2) Removing, repairing, and replacing

(3) Removing and replacing with a like serviceable item

p. TIME, FAULT LOCATION: The element of active Maintenance Time during which testing and analysis are performed on an item to isolate a malfunction.

q. TIME, FINAL TEST: The element of active repair time required, after completion of maintenance adjustments and calibration to verify by measurement of performance, that the item is in a condition to perform its function satisfactorily.

r. TIME, FLIGHT: The airborne time elapsed from "wheels off" at takeoff to "touchdown" at landing.

s. TIME, LOGISTICS DELAY: The portion of downtime during which repair is delayed solely because of the necessity to wait for a replacement part or other subdivisions of the system.

3.4.2 (Continued):

t. TIME, MISSION: The time period from "pulling the chocks" at the parked departure position to the end of the landing roll, with the aircraft safely on the ground. Taxi-in time is excluded.

u. TIME, OPERATING: The time period during which the equipment is performing its intended function.

v. TIME, TESTING: The time required to determine whether designated characteristics of a system are within specified values.

REMOVAL AND REPAIR:

a. REMOVAL, CONFIRMED: A removal where a failure or defect is found that substantiates the reason for removal.

b. REMOVAL, JUSTIFIED: The total removals of some unit may include items removed for maintenance convenience, as well as those for which no problems are found, and those for which a shop check reveals a defect. The last group is the only one for which removals are justified.

c. REMOVAL, UNCONFIRMED: The removal of an item where no defect or failure is found, which substantiates the reason for removal, even though another defect or failure may be found.

d. REMOVAL, SCHEDULED:

(1) Removal of an item when the hard time limit is reached

(2) Removal of an "On-Condition" item during a scheduled periodic inspection or test

e. REMOVAL, UNSCHEDULED: The removal of an item brought about as a result of a known or suspect malfunction or defect or both at a time other than scheduled maintenance, inspection, or test. It includes:

(1) All conditions monitored items

(2) Only those on-condition items removed prior to their scheduled check

(3) Only those hard-time items removed prior to their schedule.

f. REPAIR: The restoration of an item to a serviceable condition. Repair includes airworthiness documentation.

g. REPAIRABLE ITEM: An item that can be restored to perform all of its required functions by corrective maintenance.

h. REPAIR CYCLE: The period that elapses from the time the item is removed in a repairable condition to the time it is returned to stock in a serviceable condition.