

GAS MOTOR

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Revised

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1. PURPOSE:

- 1.1 General: It is intended that this ARP will set down guidelines for the development and test of gas motors to provide a practical and reliable hot gas rotary actuation mechanism. Specific operational and test requirements shall be specified in a detail specification.
- 1.2 Specific: The areas to be discussed are: Requirements (performance, environment, life, and reliability), design and fabrication, and test considerations.

2. SCOPE:

2.1 Definitions:

- 2.1.1 Gas: Gas for the purpose of this ARP shall be defined as the gaseous product(s) resulting from the decomposition, dissociation, or combustion of liquid or solid mono or bi-propellants. Where other gases such as heated N<sub>2</sub>, H<sub>2</sub>, H<sub>2</sub>O (steam), etc., which may have similar physical and/or chemical properties as the defined "gas", are used to effect testing economies; they may be considered as being included in this ARP.
- 2.1.2 Gas Motor: A gas motor, for the purpose of this ARP, shall be considered to include any gas powered device, which in its energy converting stage changes gas energy to rotating mechanical power.
- 2.1.3 Exclusions: To be considered in the development of the "gas motor" but not a part of this ARP development are such devices as the servo control valve, the speed reducer or output conversion device, the servo loop feedback mechanisms, and dynamic characteristics of the driven load.

2.2 Design Considerations:

- 2.2.1 Life: This ARP will define in a general way the life requirements of "gas motors" for three broad categories of flight vehicles.
- 2.2.1.1 Long Range Air Breathing Vehicles: The motors for vehicles which will have a long operational life in proportion to their ground checkout life.
- 2.2.1.2 Manned Re-Entry Vehicles: The motors for vehicles which will have a moderately long operational life which will be significantly less than their ground checkout life.
- 2.2.1.3 Single Use Vehicles: The motors for vehicles which have a long ground checkout life in proportion to their operational life which may range from seconds to an hour or more.

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2.2.2 Environment and Performance: This ARP will be confined to discussing the environments and gas temperatures most likely to be encountered, listing some of the performance parameters without numerically defining them, and to specifying tests to show compliance with the performance and reliability requirements under the expected environmental conditions. This ARP will not define a specific "gas motor".

### 3. DESIGN AND FABRICATION:

3.1 Materials: All materials must be carefully selected to insure against wide variations of thermal expansion between adjacent members.

3.1.1 All materials under highly stressed conditions must be carefully selected so that stress-creep at temperature is held to a minimum.

3.1.2 Factors to be considered for the selection of materials at the operating temperature for a given time shall include: Thermal coefficient of expansion, stress level at that temperature, creep, corrosion and heat resistance, and erosion.

3.1.3 Protective coatings to guard against oxidation and corrosion of the base metal must be used wherever the base metal may be subjected to levels and durations of temperatures above its upper limit of oxidation resistance.

3.1.4 Solid-phase dry lubricants to reduce friction forces and increase life may be advisable where the temperature range is such that they may be used.

3.1.5 Organic materials for seals, diaphragms, etc., may be used, but are not recommended for long life applications, in critical areas.

3.1.6 The use of material combinations whose chemical reactions to each other are accelerated by high temperature shall be avoided.

3.2 Design and Construction: Design and construction of the motor shall be such that the erosion or build up due to the reaction of the gases and the materials will not result in reduced reliability or abnormal operation at the required temperature for specified time.

3.2.1 Rotating members shall be mounted in bearings of adequate size to carry the maximum loads for the design life of the unit.

3.2.2 Inasmuch as no handbook data exists on bearing operations at highly elevated temperatures, cautious judgment should be exercised at all times, even at the possible expense of added weight, to insure against seizure or galling.

3.2.3 In applications where output shaft seals may be required, low-force, pressure-balanced seals should be employed. If shaft seal leakage is critical, there may be some advantage in dual shaft seals.

3.2.4 All motor clearances should be selected so that a minimum quiescent flow is attained when the unit is motionless under a static load, or unloaded.

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- 3.2.5 All moving members shall be mounted in such a manner that G loadings and shock do not deteriorate performance and life, and so that they do not cause destructive vibrations in themselves or to the rest of the motor and related and/or attached equipment.
- 3.2.6 The moment of inertia of the rotating members of the motor shall be as low as possible consistent with ruggedness, reliability, and good design practice. For any specific motor application the maximum allowable inertia of the rotating members should be specified.
- 3.2.7 Due to the high weight penalty for the hot gas to be used in most cases the motor overall gas consumption shall be as low as possible. However, gas consumption at maximum output horsepower may not, in many cases, be as critical as low gas consumption at either low output torque, low output speed, or even under quiescent conditions. In all probability a large amount of the motor usage will be at less than 10 per cent of peak power, with high system pressure on the motor.
- 3.2.7.1 The choice in selection between positive displacement and non-positive displacement motors is dependent upon a careful review of rated conditions and operational environments.
- 3.2.7.2 Fixed displacement, partial admission motors provide a higher degree of efficiency of gas usage at the expense of greater motor weight for the same power level and perhaps greater complexity to attain reversibility.
- 3.2.7.3 Variable displacement (load sensitive) piston motors provide high efficiency at low output power levels, and may be the most desirable from the standpoint of gas usage for control applications, but at the expense of greater complexity.
- 3.2.7.4 In all cases the volume of the pressurizing gas, not doing useful work, shall be held to a minimum. This means that stroke displacements, clearances, and volumes must be minimized.
- 3.2.7.5 In all types of motors the clearances between the moving members shall be held to the absolute minimum consistent with good design practices and the dead gas volumes shall be as low as possible.
- 3.2.8 In the event that any dynamic spring-mass systems are used in the motor, they shall be sufficiently damped to insure against adverse operation under conditions of anticipated vibration.
- 3.2.9 The design of the motor bearings shall not require the motor to withstand any loads other than the torsional and thrust loads resulting from the motor operation. The motor shall be mounted in such a manner to the speed reducer or other use function that the misalignment load imparted to the motor output shaft is minimized.

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- 3.2.10 In many cases the motor may be designed to operate with a servo valve of specific performance characteristics. In the design of the servo, the entire servo loop must be considered to the extent that the motor dynamics match the dynamics of the valve, speed reduction, driven member, and necessary feedback circuitry.
- 3.2.11 Because of the high reliability requirements, a high degree of workmanship must be exercised in fabricating the motor. In particular, care must be exercised to avoid free particles, hanging burrs, or other contaminants which may dislodge during operation and initiate a malfunction within the motor or within the system in which it will operate. In addition, great care must be taken to insure that the correct surface finishes and clearances are specified and accomplished so that random failures, premature wearout, and/or unnecessary loss of efficiency can be minimized. Quality control inspection of the highest caliber, most rigid integrity, and utmost thoroughness must be exercised on even the most insignificant seeming component of the motor to insure against faulty workmanship.
- 3.3 Static Performance: For positive displacement units the following three tests shall apply:
- 3.3.1 Stall Torque: The maximum allowable stall torque shall be defined in inch pounds. Since the stall torque will have a significant effect on the weight of the unit, it should be optimized based on a trade between servo torque response, rate, and supply pressure.
- 3.3.2 Friction: The maximum allowable breakout friction shall be defined in inch pounds. Since the breakout friction will have a significant effect on servo resolution, it should be minimized as much as is possible within the clearance limits required for low leakage.
- 3.3.3 Quiescent Leakage: The maximum allowable quiescent leakage flow shall be defined in pounds per minute of gas. It will occur in two forms, leakage across the load ports and external leakage to the ambient atmosphere. Here again, a trade study must be made to determine the optimum condition. All leakage is detrimental from a fuel consumption standpoint, but leakage across the load ports adds damping to the servo.
- 3.4 System Dynamics: The motor with its speed reducer, driven function, input servo valve, amplifiers, command input, and feedback network shall comprise the control servo system. In considering the motor dynamics, the entire system must be integrated. The dynamic values should be those for the whole actuation loop.
- 3.4.1 The inertia loads shall be specified in lb. in.-sec.<sup>2</sup>.
- 3.4.2 The maximum load shall be specified in inch-pounds or pounds thrust.
- 3.4.3 The aerodynamic spring rate shall be specified in in.-lbs/radian.
- 3.4.4 The maximum surface deflection shall be specified in + radians.

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- 3.4.5 The output motion shall be specified in radians per second in the case of rotary motion, and inches per second in the case of sliding motion or a combination thereof.
- 3.4.6 The frequency response shall be specified as a db envelope vs. given frequency range with a corresponding phase lag envelope.
- 3.4.7 Assuming a rigid attachment point to structures, the minimum allowable natural frequency shall be specified in radians/sec.
- 3.4.8 The static stiffness, assuming a rigid attachment point, shall be specified in in-lbs/radians.

#### 4. ENVIRONMENTAL CONDITIONS:

- 4.1 Vehicle Environment: The vehicle environment is that environment to which the motor will be subjected due to the requirements of the vehicle mission profile. Such environmental parameters as ambient temperature, atmospheric pressure, vibration, acceleration, shock, etc., fall into this category.
  - 4.1.1 Ambient Temperature: The ambient temperatures shall be based on the anticipated mission profile and shall be defined for each specific application in a detail specification. These may vary in the neighborhood of 500°F to 2000°F.
  - 4.1.2 Vibration: The amplitude, frequency, and G loads of the vibrational spectra to which the motor will be subjected depend on the type of vehicle and the profile of the mission in which it will be used. Some applications may require that a Random Excitation Spectrum be specified as well as a Sinusoidal Envelope.
  - 4.1.3 Shock: The motor shall be capable of withstanding the required impact shocks along any axis without compromising its performance. The specified shock load represents the maximum condition to be expected in the handling and transportation of missiles and/or missile and aircraft components and/or subsystems.
  - 4.1.4 Acceleration: The maximum acceleration along any axis shall be specified for each motor application in a detailed specification.
  - 4.1.5 Atmospheric Pressure: The atmospheric pressure to which the motor will exhaust shall be specified in terms of time vs. altitude. It is of importance, especially for low pressure units, that an atmosphere pressure vs. motor power curve be included so that the motor can be properly sized to suit the power use function requirements at the various operational altitudes. In many cases the maximum power requirements will occur at sea level or slightly above.
- 4.2 Motor Environment: The motor environment is that environment resulting from the use of the gas motor itself. Parameters such as motor gas temperature and pressure are the principle ones to be considered in this case, although motor noise generation and unbalanced vibration are important.

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- 4.2.1 Gas Temperature: The temperature of the pressurizing gas for the motor will be largely dependent on the fuel selected to provide the gas. Other factors such as vehicle ambient temperature can influence the gas temperature in cases where it is much higher or much lower than the gas temperature and the uninsulated tubing runs are quite long. The motor shall be designed so that it will perform satisfactorily from a gas source of the temperature to be encountered in service. Various types of fuels will provide pressurizing gas at different temperatures depending on how they are used.
- 4.2.1.1 A hydrogen-oxygen fuel-oxidizer combination can provide good fuel efficiency at gas temperatures as low as 700°F. Higher SFC's can be obtained by increasing the temperature, but the overall advantages are somewhat dubious in that a greater proportion of oxygen is required. This reduces the amount of hydrogen available for a heat sink, and as the ratio of hydrogen to oxygen decreases to the stoichiometric combustion condition the actual gas temperature rises above 4000°F.
- 4.2.1.2 Liquid monopropellents such as hydrogen peroxide and hydrazine have decomposition temperatures in the 1200°F to 1800°F range. In the case of hydrazine, the lower unit (1200°F) can be approached without a great penalty by causing a relatively high ammonia dissociation to occur in the decomposition chamber.
- 4.2.1.3 Most of the solid propellents, either single base or double base, have combustion temperatures in excess of 2000°F. These temperatures will undoubtedly be tempered somewhat by the time the gas reaches the motor if they travel for any distance through uninsulated tubing in a lower vehicle ambient temperature.
- 4.2.2 Rated Gas Pressure: This document will not specify the rated gas pressure, as this will be entirely dependent on the propellant and system selected. The motor type chosen will in turn depend, to a large extent, on the rated pressure and the work function selected. The rated gas pressure and its upper and lower limits shall be clearly specified in the detail motor specification.
- 4.2.3 Noise Generation: The upper limit of allowable noise generation radiated by the motor to the vehicle shall be specified.
- 4.3 Storage Environments: The complete storage environments shall be reviewed and considered in the motor design.
5. TEST REQUIREMENTS:
- 5.1 Functional Tests: Functional tests may be run on the motor alone without the other portions of the servo loop.