SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP719	REV. B
Issued 1961-12 Revised 1990-11 Reaffirmed 2007-11 Stabilized 2013-06 Superseding ARP719A	

Gas Motor

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

STABILIZED NOTICE

This document has been declared "Stabilized" by the A-6C6 Power Sources Committee, and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1. SCOPE:

1.1 General:

It is intended that this SAE Aerospace Recommended Practice (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.

1.2.1 Life: This ARP will define in a general way the life requirements of "gas motors" for three broad categories of flight vehicles.

1.2.1.1 Long-Range Air Breathing Vehicles: The motors for vehicles, which will have a long operational life in proportion to their ground checkout life.

1.2.1.2 Manned Reentry Vehicles: The motors for vehicles, which will have a moderately long operational life and will be significantly less than their ground checkout life.

1.2.1.3 Single Use Vehicles: The motors for vehicles, which have a long ground checkout life in proportion to their operational life and that range from seconds to an hour or more.

1.2.2 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."

2. REFERENCES:

2.1 Applicable Documents:

The following documents form part of this ARP specified herein. The latest issue of SAE documents shall apply. The applicable issue of other documents shall be as specified in the procurement specification.

2.1.1 U.S. Government Publications:

Military Specifications

MIL-P-8564 Pneumatic System Components, Aeronautical, General Specification

2.2 Definitions:

The following terms used in this document are defined as follows:

2.2.1 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 bipropellants. Where other gases such as heated N_2, H_2, H_20 (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.

2.2.2 Gas Motor: A gas motor, for the purpose of the ARP, shall be considered to include any gas powered device including positive displacement devices, which in its energy converting stage changes gas energy to rotating mechanical power.

2.2.3 Exclusions: To be considered in the development of the "gas motor" but not a part of this ARP, are such devices as the servocontrol valve, the speed reducer or output conversion device, the servoloop feedback mechanisms, and dynamic characteristics of the driven load.

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: (a) thermal coefficient of expansion, (b) stress level at that temperature, (c) creep, (d) corrosion and heat resistance, and (e) 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 buildup, due to the reaction of the gases and the materials will not result in reduced reliability or abnormal operation at the required temperature for a 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 judgement 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. Dual seals may require venting to avoid overpressure. A checkout/inspection method for determining if either seal is faulty should be incorporated, if practical.

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

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 minimum frequency response 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% of peak power, with high system pressure on the motor.

3.2.7.1 The choice of selection between positive displacement and nonpositive 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 and weight.

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.

3.2.10 In many cases the motor may be designed to operate with a servovalve of specific performance characteristic. In the design of the servo, the entire servoloop 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 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 force (newton-meters). Since the breakout friction will have a significant effect on the weight of the unit, it should be optimized based on a trade between servotorque response, rate, and supply pressure.

3.3.2 Friction: The maximum allowable breakout friction shall be defined in inch pounds force (newton-meters). Since the breakout friction will have a significant effect on servoresolution, it should be minimized as much as possible within the clearance limits required for low leakage.

3.3.3 Quiescent Leakage: The maximum allowable quiescent leakage flow shall be defined in pound mass (kilograms) 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 servovalve, amplifiers, command input, and feedback network shall comprise the control servosystem. 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 inch-pound force s^2 (N-m-s^2).

3.4.2 The maximum load shall be specified in inch-pound force (N-m) or pounds (N) thrust.

3.4.3 The aerodynamic spring rate shall be specified in in-lb force/radian (N-m/radian).

3.4.4 The output motion shall be specified in ± radians.

3.4.5 The output motion shall be specified in radians per second in the case of rotary motion, and inches (meters) per second in the case of rectilinear motion.

3.4.6 The frequency response shall be specified as a decibel output/input ratio versus frequency with a corresponding output to input phase lag.

3.4.7 Assuming a rigid attachment point to structures, the minimum allowable natural frequency shall be specified in radians/s.

3.4.8 The static stiffness, assuming a rigid attachment point, shall be specified in in-lb force/radian (N-m/radian).

3.5 Environmental Conditions:

3.5.1 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.

3.5.1.1 Ambient Temperature: The ambient temperature 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 (260°C) to 2000°F (1093°C).

3.5.1.2 Vibration: The amplitude, frequency, and G loads of the vibrational spectra to which the motor will be subjected depending 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.

3.5.1.3 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.

3.5.1.4 Acceleration: The maximum acceleration along any axis shall be specified for each motor application in a detailed specification.

3.5.1.5 Atmospheric Pressure: The atmospheric pressure, to which the motor will exhaust, shall be specified in terms of time versus altitude. It is of importance, especially for low pressure units, that an atmosphere pressure versus 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.

3.5.2 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.

3.5.2.1 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.

3.5.2.1.1 A hydrogen-oxygen, fuel-oxidizer combination can provide good fuel efficiency at gas temperatures as low as 700°F (370°C). Lower SFC's (specific fuel consumption) can be obtained by increasing the temperature. As the ratio of hydrogen to oxygen decreases to the stoichiometric combustion condition, the actual gas temperature rises above 4000°F (2204°C).

3.5.2.1.2 Liquid monopropellants such as hydrogen peroxide and hydrazine have decomposition temperatures in the 1200°F (649°C) to 1800°F (642°C) range. In the case of hydrazine, the lower unit 1200°F (640°C) can be achieved with a blended fuel, but with a decrease in fuel energy content.

3.5.2.1.3 Most of the solid propellants, either single base or double base, have combustion temperatures in excess of 2000°F (1093°C). 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.