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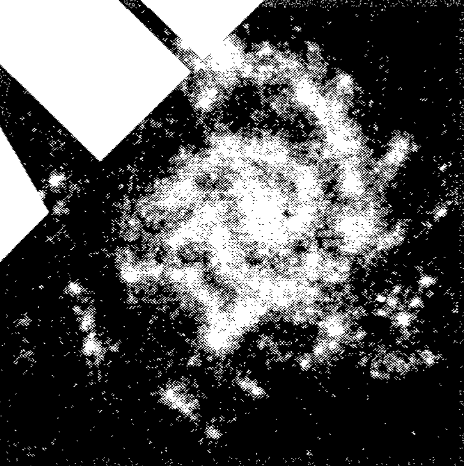

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NASA
SPACE VEHICLE
DESIGN CRITERIA

NASA SP-8006

LOCAL STEADY AERODYNAMIC LOADS DURING LAUNCH AND EXIT

VOLUME III: STRUCTURES
PART B: LOADS AND STRUCTURAL DYNAMICS
CHAPTER 3: LAUNCH AND EXIT
SECTION 2: LOCAL STEADY AERODYNAMIC LOADS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform design criteria for space vehicles. Accordingly, criteria are being developed in five areas of technology, outlined as follows:

Volume I — Environment
Volume II — Material Properties and Processes
Volume III — Structures
Volume IV — Stability, Guidance, and Control
Volume V — Chemical Propulsion

The individual components of this work are regarded as being sufficiently useful to justify publication separately in the form of monographs as completed. This document, Section 2 of Volume III, Part B, Chapter 3, is one such monograph. The planned general outline of Volume III is set forth on page ii.

These monographs are to be regarded as guides to design and not as design requirements, except as may be specified by NASA project managers or engineers in formal project specifications. It is expected, however, that these documents, revised as experience may indicate to be desirable, will eventually become uniform design requirements for NASA space vehicles.

Comments from addressees concerning the technical content of the monographs are solicited. Please address such comments to the National Aeronautics and Space Administration, Office of Advanced Research and Technology (Code RVA), Washington, D. C. 20546.

May 1965

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PLANNED OUTLINE OF
VOLUME III: STRUCTURES

PART A: DESIGN PRINCIPLES

- Chapter 1 - General Criteria
- Chapter 2 - Detail Design Practices

PART B: LOADS AND STRUCTURAL DYNAMICS

- Chapter 1 - General Criteria
- Chapter 2 - Prelaunch
- Chapter 3 - Launch and Exit
- Chapter 4 - Space Flight
- Chapter 5 - Entry and Atmospheric Flight
- Chapter 6 - Landing

PART C: STRUCTURAL ANALYSIS

- Chapter 1 - General Criteria
- Chapter 2 - Structural Components and Systems

PART D: TESTING

- Chapter 1 - Model Tests
- Chapter 2 - Structural Tests (Ground)
- Chapter 3 - Structural Tests (Flight)

Volume III: Structures
Part B: Loads and Structural Dynamics
Chapter 3: Launch and Exit

SECTION 2: LOCAL STEADY AERODYNAMIC LOADS

2.1 INTRODUCTION

Many critical structural loads on space vehicles originate in steady or quasi-steady aerodynamic flow about the vehicle during ascent through the atmosphere. Bending moments, shear forces, and longitudinal loads on the complete vehicle, and pressure-differential loads that tend to burst or collapse shrouds and fairings are examples of steady aerodynamic loads that must be considered in the structural design of space vehicles.

In-flight structural failures have occurred because inadequate consideration was given to local pressures and pressure differential loads in the design of components such as shrouds, fairings, and insulation panels. For this reason the local load considerations relating to external aerodynamic pressures and to pressure differentials as affected by vents and the heating of gases within unvented compartments are covered in this monograph. Overall vehicle forces and moments that arise from either unprogramed or programed inputs such as winds or control motions will be covered in other monographs.

All steady aerodynamic loads are dependent on vehicle shape, angle of attack, dynamic pressure, and Mach number. Pressure-differential loads across enclosure walls are, in addition, dependent on the location of venting orifices and on the discharge capacity of the venting system. Critical loads may occur in any of several regimes of the launch and exit phase of flight; thus, in general, the loads have to be determined throughout the launch and exit trajectory.

While this monograph is concerned only with steady or quasi-steady aerodynamic loads, the launch and exit phase of flight is a time-varying process and requires that the designer consider dynamic influences such as vehicle linear and angular velocities and body flexibility. Also, buffeting and other fluctuating pressure loads may occur in the same location on the vehicle and at the same time as the maximum steady loads. Consideration must, therefore, be given to the possibility that steady and fluctuating loads may occur in combination.

2.2 STATE OF THE ART

Several theoretical and semiempirical methods are available for the determination of steady aerodynamic loads. The accuracy of each of these methods, however, must be individually investigated with the flight regime and vehicle configuration taken into consideration. Based primarily upon potential flow, the theoretical methods do not permit prediction of the existence of regions of separated flow, nor do they generally define loads throughout the Mach number range with sufficient accuracy for final structural design. Consequently, the analytical methods are generally useful in preliminary design and are usually modified in accordance with the best available experimental results for configurations similar to those under consideration.

References 1 to 5 contain methods for the prediction of pressure distributions on bodies at subsonic and transonic speeds. Examples presented in reference 2 for zero angle of attack indicate fair agreement with measured results for some bodies of revolution at Mach numbers less than 0.9. At higher transonic Mach numbers, the agreement is poor. Excellent agreement, however, has been reported in reference 3 for a limited number of body shapes at transonic speeds. A study to determine compatibility of an aircraft as a launcher for missiles (ref. 4) contains much useful information on calculation of body pressure distributions in subsonic and supersonic flow. This work extends reference 5 and presents a method for calculation of body aerodynamic influence coefficients.

For the supersonic speed range, calculation methods and typical comparisons of calculated and experimental results are contained in reference 2 and references 6 to 10. As noted in reference 7, the available analytical methods permit fairly accurate predictions of pressure distributions at an angle of attack of zero, but the fact that they are based primarily on potential flow theory causes discrepancies when angle of attack is increased and flow separation due to viscous effects occurs. Some methods of handling angle of attack by introducing cross flow are described in reference 11.

Protuberances may have a strong influence on local vehicle loadings, as they may involve loadings on the protuberances themselves, induced loads on adjacent regions of the vehicle, or loads downstream of the protuberances associated with wake effects.

While analytical procedures are often employed at all stages in the design process to estimate the load distributions, pressure distributions for checking the final design are generally obtained through the use of scaled model tests and full-scale protuberance tests in wind tunnels. Results of investigations of pressure distributions for a wide range of configurations are presented in references 12 to 21.

The characteristics of air outlets have been studied experimentally and results are reported in references 22 to 25. Effects of outlet geometry and discharge rates on coefficients of discharge are shown. These data are applicable to the determination of the internal pressure of a vented compartment.

2.3 CRITERIA

The surfaces of space vehicles, including shrouds, fairings, and insulation panels, that are exposed to the airstream shall be designed to withstand the maximum external aerodynamic loads and the maximum pressure-differential loads that may occur on them at any time during the launch and exit phase of flight. In determining these loads, consideration should be given, but not limited to, the following:

a. All combinations of dynamic pressure, Mach number, and angle of attack expected to be encountered

b. The influence of abrupt changes in external surface geometry such as flares, corners, and steps on local pressures and on the effectiveness of vents

c. The local pressures on, and influenced by, protuberances

d. The location and effectiveness of vents under all expected flight conditions with particular emphasis on the transonic Mach number region

e. The effects of aerodynamic and other heating on internal pressures

f. The possible occurrence of oscillating pressure loads in combination with the steady loads

2.4 RECOMMENDED PRACTICES

2.4.1 EXTERNAL AERODYNAMIC LOADS

Theoretical load estimates should, when possible, be compared with experimental results on similar configurations and appropriate adjustments should be made to the analytical results where changes are indicated.

References 2 to 5 provide information for analytical determination of pressure distributions in subsonic flow and for some configurations at transonic speeds. Analytical methods applicable to supersonic flow are given in references 6 to 10. The analytical methods, however, apply only to nonseparated flows. For transonic speeds and for configurations involving separated flows at all speeds, model tests are recommended. (See refs. 12, 14, and 16.)

In the use of scaled models in wind tunnels, the effects of Reynolds number on flow separation should be considered. In particular, the size and location of "transition strips" of rough particles should be chosen to insure turbulent flow in the region of corners since pressure peaks are extremely sensitive to the type of flow existing at junctures, steps, and shapes which produce abrupt changes in flow direction. For example, transition strips that are located far forward on a cone-shaped body may not be effective because of the steep favorable pressure gradient between the strip and the area of change in flow direction. No generally applicable method is available for the determination of the location of transition strips in the presence of highly favorable pressure gradients such as frequently occur on space vehicle shapes; however, some useful information is available in reference 26. A simplified method for the determination of the critical height of the rough particles in a zero pressure gradient field is contained in reference 27.

The loading on protuberances may be estimated by considering the protuberance as a low-aspect-ratio wing or body in the presence of a reflection plane. Corrections for boundary-layer effects and crossflow effects due to angle of attack should be made. Wind-tunnel tests are recommended to verify the analytical estimate. In such tests, consideration should be given to the effects of Reynolds number on flow separation and to the simulation of the boundary-layer thickness relative to the protuberance height. Where possible full-size protuberances should be tested.

2.4.2 PRESSURE-DIFFERENTIAL LOADS

The pressure-differential loading at any point is obtained from the external pressure distribution and the internal compartment pressure.

2.4.2.1 Vented Compartments

A time history of internal pressure for vented compartments should be determined over the design launch and exit flight trajectory. If vents are located within the influence of rapidly varying pressure fields (for example, slightly downstream of a flare-cylinder rear juncture), a close examination of the time variation of the local pressure at the vent location is required in the transonic speed range, since large pressure variations may occur almost instantaneously. (See ref. 12.) Significant and abrupt local pressure changes are also associated with rear-facing step bases in the transonic range. Consideration should also be given to the effects of angle of attack on the local surface pressure at the vent location. Such effects can be minimized by distributing the vents around the vehicle.

The discharge rates of vents may be calculated through the use of references 23 to 25, which give experimental discharge coefficients of various air outlets into a stream for Mach numbers from 0.7 to 1.3. If there are significant internal impedances, such as narrow passages or other restrictions to the flow, they should be taken into account either by suitable calculations or by tests on the restricted areas. Methods for measuring and calculating flow rates are given in reference 22. In the case of air, equations for compressible fluid should be used. In flow calculations the differential pressure at the vent location will be the difference between the external static pressure at the vent location and the compartment pressure, both of which are variable with flight time. After the flow rates have been determined the Reynolds number and Mach number of the discharging air should be checked for compatibility with the discharge coefficients. If there are significant changes an iterative procedure may be followed to obtain the final discharge rates.

2.4.2.2 Unvented Compartments

Some space-vehicle components and equipment incorporate compartments that cannot be completely vented to relieve internal pressures that develop during flight. These components and equipment include various types of honeycomb shell structures, electronic chassis, propulsion valves, etc., and the internal pressures developed in them are caused by heating of the initially contained gas, augmented in some cases by generation of other gases through evaporation or decomposition of materials exposed to heat.

Space-vehicle components and equipment subject to such internal pressures should be designed to withstand the pressure-differential loads resulting from these pressures and other simultaneously acting pressures. The effects of heat on the mass of gas generated as well as on the pressure within the compartment should be considered in the design analysis. This analysis should take into consideration the entire sequence of flight events beginning with launch. All heating sources should be considered, including: aerodynamic heating, chemical heating, electrical heating, and solar heating.

Tests of full-size honeycomb panels and shrouds are recommended. In these tests a time history of the noise and vibration, heating, and loading environment expected to be encountered in the launch and exit phase of flight should be simulated.

2.4.3 OTHER CONSIDERATIONS

Although the loads are considered here as steady loads, they are really functions of the time-variable quantities Mach number, dynamic pressure, and angle of attack. In the application of these loads to the design of the structure, consideration must be given to dynamic influences such as normal and angular velocities of the vehicle and body-flexibility effects.

Configurations should be examined for the possible occurrence of oscillating pressures caused by separated-flow phenomena, interaction of shock and boundary layer, unsteady flow produced by protuberances, and other fluctuating loads. These oscillating pressure loads often are maximum at the flight conditions and at the same location on the vehicle as the steady loads.

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