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HREC-6464-1
LMSC-HREC D162796

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SPACE SHUTTLE COMPARTMENT VENTING

FINAL REPORT

March 1971

Contract NAS8-26464

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FOREWORD

This document presents results of work performed by Lockheed's Huntsville Research & Engineering Center for the George C. Marshall Space Flight Center on Contract NAS8-26464, "Inflight Venting of Space Shuttle Vehicles."

The NASA technical monitor for this contract is Mr. D. L. Bacchus of the Aero-Astrodynamics Laboratory.

SUMMARY

A study was conducted to investigate and define the problems associated with the in-flight venting of space shuttle vehicles. The McDonnell Douglas delta wing booster and high crossrange orbiter vehicles were selected as being representative of current space shuttle vehicle configurations. Compartmental-type areas within these vehicle configurations were identified as being likely to require venting. A preliminary venting analysis indicated that the more severe pressure stresses on compartment walls will occur during ascent. Special provisions for venting during descent, therefore, do not appear to be required. Since only a limited amount of in-flow orifice efficiency data were available for this study, experimental measurements were recommended to provide data over a broader range of conditions. Remaining to be answered are the temperature of the air vented into the compartments during descent, and the need for a positive pressure differential to alleviate panel flutter and vibration.

CONTENTS

Section 1
INTRODUCTION

The development of reusable launch and space vehicles (space shuttles) will require technological advancements in a number of areas. Among these is venting of vehicle compartmental areas to relieve stresses on the vehicle skin due to pressure differentials. Space shuttle development introduces new problems of compartment venting not encountered during the Saturn program. In addition to compartment depressurization during ascent, the shuttle will require compartment repressurization as the vehicle descends into the earth's atmosphere during the return trip. Also, the shuttle will contain a number of compartmental-type areas to be vented that were not encountered in previous launch vehicles. These areas include the interior of wings, fins and other protruding portions of the vehicle involved in aerodynamic lift and control.

The repressurization of the compartments during descent may be accomplished either by allowing external air to enter the compartments through vent ports, or by refilling the compartments with stored inert gases. If external air is used, no special provision for repressurization is required, since the air may flow into the compartments through the same vent ports used for depressurization during ascent. The air flowing into the compartments, however, may be at sufficiently elevated temperatures (due to high velocities attained during descent) to weaken structures or to damage components located within the compartment. If stored inert gases are used, the resulting weight penalty must be taken into account in the vehicle design.

A large amount of orifice efficiency data has been generated for flow from a compartment into an external stream. Very little data are available, however, for flow from an external stream into a compartment. If the compartments are to be repressurized by venting external air into the compartments, additional orifice efficiency data for in-flow will be required for accurate predictions of pressure differentials during descent.

The purpose of this study effort was to investigate and define the problems associated with the in-flight venting of reusable Space Shuttle vehicles. This document presents results obtained during the study.

Section 2
DISCUSSION

This preliminary study of space shuttle venting requirements was conducted in the following fashion. First, preliminary design drawings of space shuttle vehicle configurations were obtained, and the compartmental areas which would require venting were identified. Next, an attempt was made to determine the most appropriate means for venting these compartmental areas during both ascent and descent phases of flight. This involved preliminary calculations of anticipated compartment pressure histories. Finally, a determination was made as to the requirements for additional orifice efficiency data for both in-venting and out-venting. These efforts were applied to the McDonnell Douglas (MDAC) delta wing booster (Fig. 1) and the MDAC high crossrange orbiter (Fig. 2) as being representative of proposed space shuttle configurations. The results of this study program are described in the following paragraphs.

2.1 IDENTIFICATION OF COMPARTMENTAL AREAS

Compartmental areas which will require venting were tentatively identified, and their volumes were estimated. These compartmental areas, along with their estimated volumes, are pointed out in Figs. 1 and 2. Compartments that are pressurized will not require venting. This includes the crew cockpit compartment and the connecting tunnel. The payload compartments, however, may require special venting considerations since tentative plans call for both a pressurized and depressurized state during the mission. More extensive identification of compartmental areas which require venting can be made as the vehicle design becomes more nearly finalized.

2.2 VENTING SCHEMES

The selection of a particular venting scheme for use in space shuttle vehicles depends largely on structural design requirements that have not

All compartment volumes typical

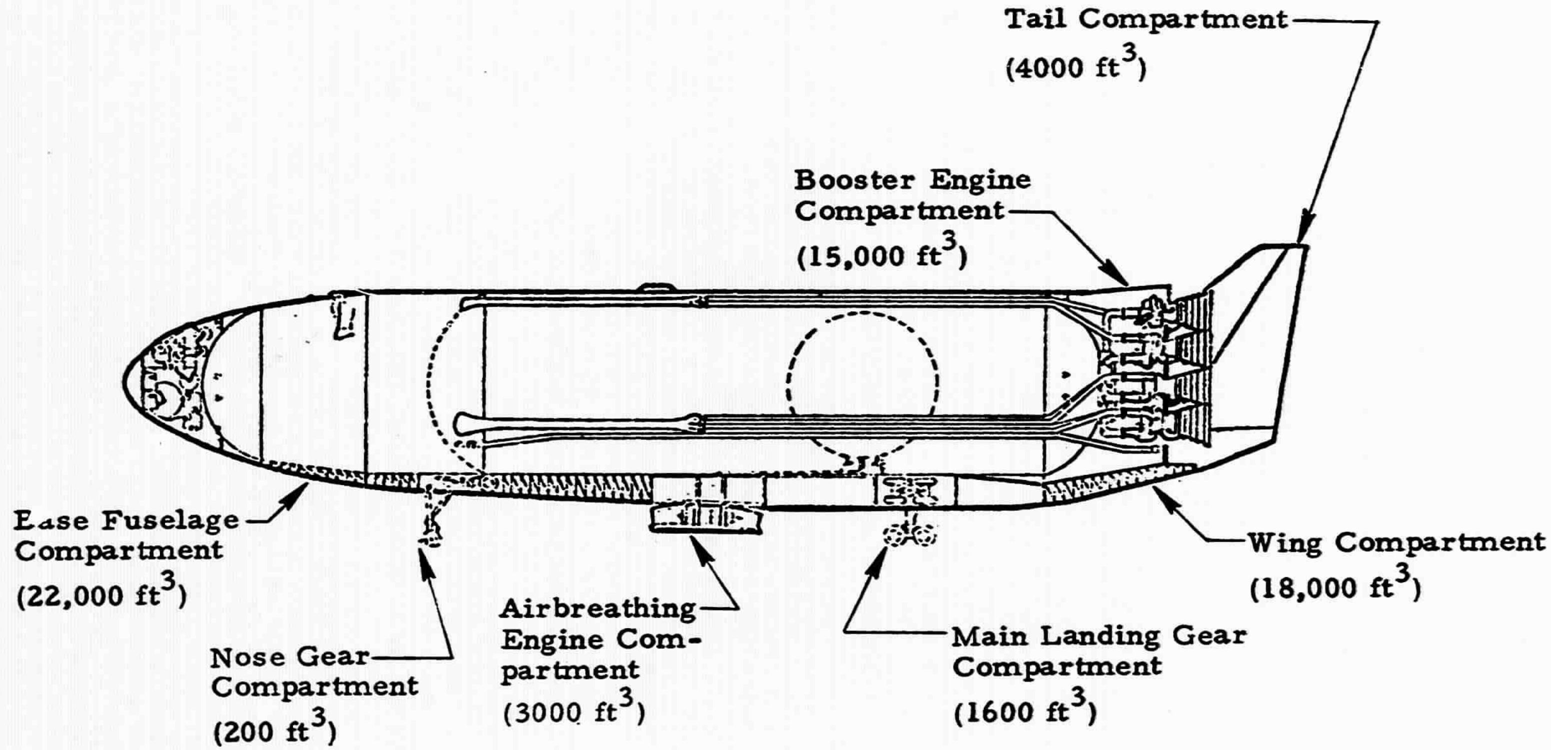

Fig. 1 - McDonnell Douglas Delta Wing Booster Configuration Showing Basic Compartments that Require Venting Analysis

All compartment volumes typical

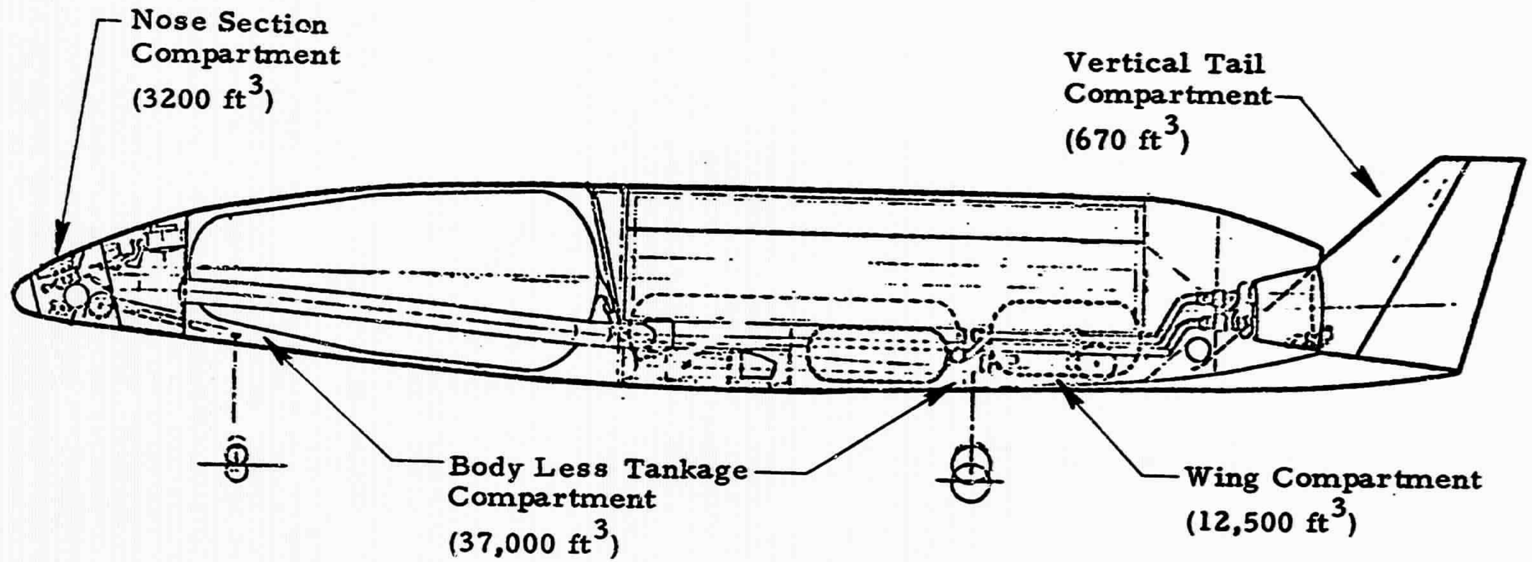

Fig. 2 - McDonnell Douglas High Crossrange Orbiter Configuration Showing Basic Compartments that Require Venting Analysis

been finalized. In the Saturn launch vehicle program, venting considerations were required only for ascent trajectories, with the result that the compartment walls were subjected only to positive pressure differentials, or "bursting" loads. The simplest possible venting scheme, a vent port cut into the compartment wall, was found to be satisfactory. The space shuttle, on the other hand, will require venting considerations for both ascent and descent trajectories. During descent, the compartment walls will be subjected to negative pressure differentials, or "crush" loads, which are inherently more detrimental to vehicle structures than bursting loads.

In Saturn launch vehicles, a small positive pressure differential was considered an asset because it tended to eliminate panel flutter and vibration problems. A positive pressure differential can be maintained in space shuttle vehicles during descent only by internal pressurization with stored gases. The weight penalty associated with internal pressurization must be weighed against the structural requirements with regard to panel flutter and vibration.

During the high aerodynamic heating portion of the descent trajectory, the air vented into the space shuttle compartments may be at sufficiently elevated temperatures to weaken structures or damage components located in the compartments. Through the use of a valving arrangement, it may be possible to delay in-flow into the compartment until after the high aerodynamic heating portion of the descent trajectory. Any valving arrangement, however, would involve a weight penalty. It may be possible to avoid a valving arrangement by locating the vent ports on the backside of the vehicle, as it is oriented during reentry, such that the in-flowing air is at reasonably low temperatures. Additional information concerning the thermal environment during reentry will be required before a determination can be made concerning the need for valving.

Consultations with Phase B contractor personnel revealed that very little detailed consideration had been given to the space shuttle venting requirements, especially as pertaining to descent. In general, these detailed venting considerations were awaiting more up-to-date structural design requirements. Some of the venting considerations discussed in preceding paragraphs, however, had been considered, in a cursory way, by several of the Phase B contractor personnel.

2.3 PRELIMINARY VENTING ANALYSIS

Since the actual venting scheme for space shuttle vehicles cannot be designated at this time, it was decided to proceed with a preliminary venting analysis based on several assumptions. First, it was assumed that the venting scheme, for both ascent and descent, would consist of vent ports cut into the vehicle skin without any valving. Next, it was assumed that the maximum allowable differential pressure across the compartment wall would be of the order of 1 psi, which is typical of that allowed in Saturn vehicle compartments.

The approach taken in this preliminary analysis was to calculate compartment pressure histories for a typical compartment volume, with various vent port areas, for both ascent and descent. A comparison of the calculated differential pressures for ascent and descent would provide an indication of the relative severity of the two phases of flight insofar as the pressure stress on compartment walls is concerned.

The preliminary venting analysis was performed using the computer program described in Ref. 1. This computer program was developed for use in the Saturn program and, therefore, was originally intended for use in out-flow venting studies. Rather extensive modifications were required in the original program in order to include the capability for in-flow calculations.

It was necessary to obtain flow discharge coefficient (orifice efficiency) data for use as inputs to the computer program. The discharge coefficient, a measure of the efficiency of flow through the orifice, accounts for such effects as jet contraction, viscosity, and external flow influences. A large amount of experimental data was obtained and reported in Ref. 2 for a variety of orifice geometries and a wide range of flow conditions for venting into an external stream. These data were used in compartment venting analyses for Saturn vehicles, and the range of data is sufficient for use in the ascent phase of space shuttle flights. Only a limited amount of discharge coefficient data is available, however, for in-flow into a compartment from an external stream. These data, taken from Refs. 3 through 5, are presented in Figs. 3 and 4. The data in Fig. 3 are for circular orifices. The discharge coefficient K, ratioed to the still air discharge coefficient K_o, is given as a function of the ratio of the compartment pressure P_{comp} to the external pressure P_{ext} for various external Mach numbers, M. The solid lines on the figure are extrapolations obtained by cross-plotting the data. The shaded portion of the figure is the anticipated data band for the space shuttle descent trajectory. The data in Fig. 4 are for elongated rectangular orifices of length to width ratio 16, with the length oriented in the direction of flow. The data are shown compared to the extrapolated circular orifice data of Fig. 3. The elongated orifice data indicate discharge coefficients generally higher than those for circular orifices at the same Mach number and pressure ratio. The elongated orifice data, however, are even more limited than the circular orifice data.

For this preliminary analysis, out-flow discharge coefficients were obtained from Ref. 2 for an elliptical shaped orifice of aspect ratio 4, with the long dimension oriented in the direction of flow. These data had been used in previous Saturn venting studies and were already incorporated into the compartment venting computer program (Ref. 1) when the program was made available to the present study. In-flow discharge coefficients were obtained from the extrapolated data for circular orifices in Fig. 3. The circular orifice data were used for descent calculations because discharge

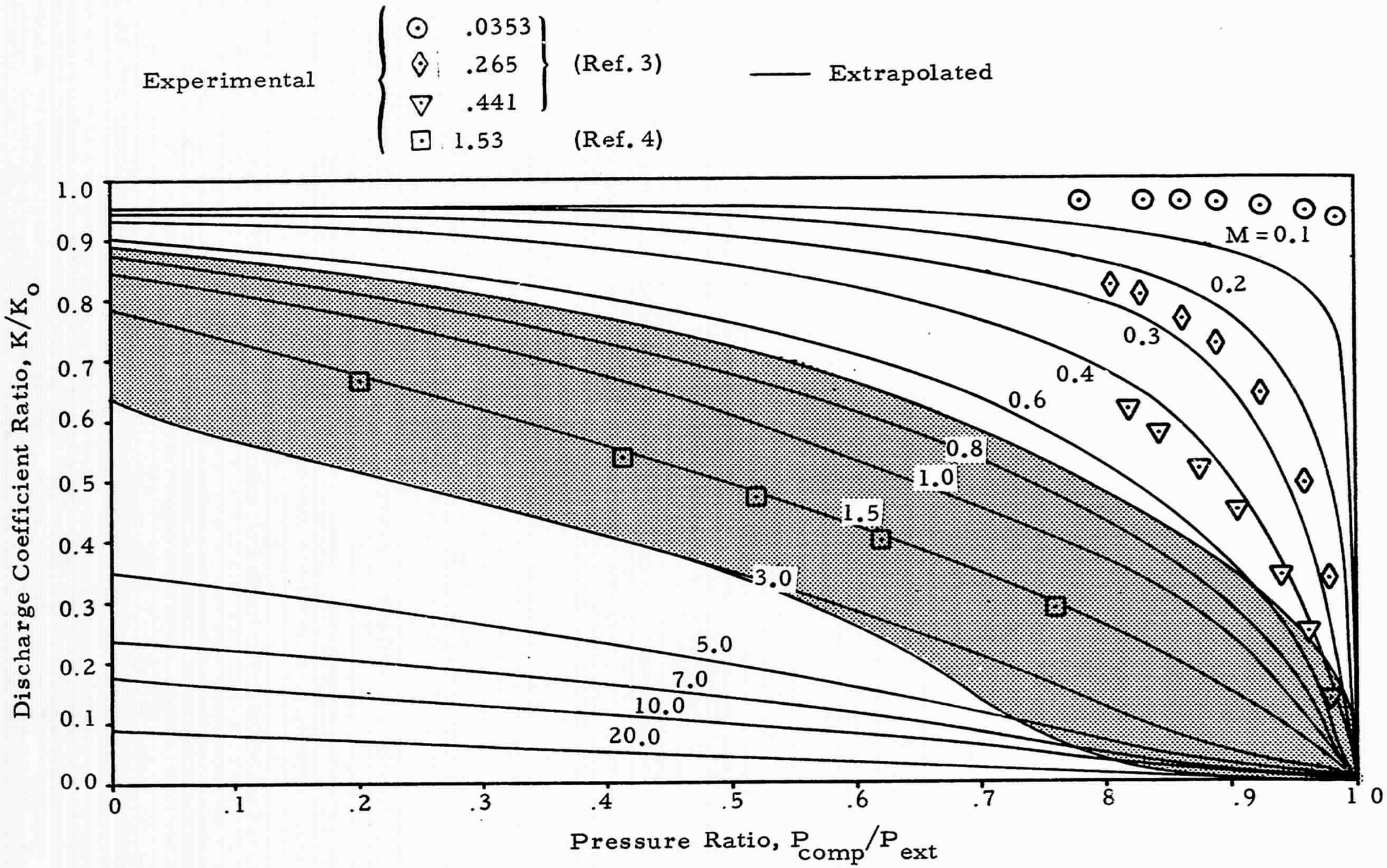

Fig. 3 - In-Flow Discharge Coefficient Ratio vs Pressure Ratio for a Family of Mach Numbers — Experimental and Extrapolated with Anticipated Space Shuttle Data Band (Shaded)

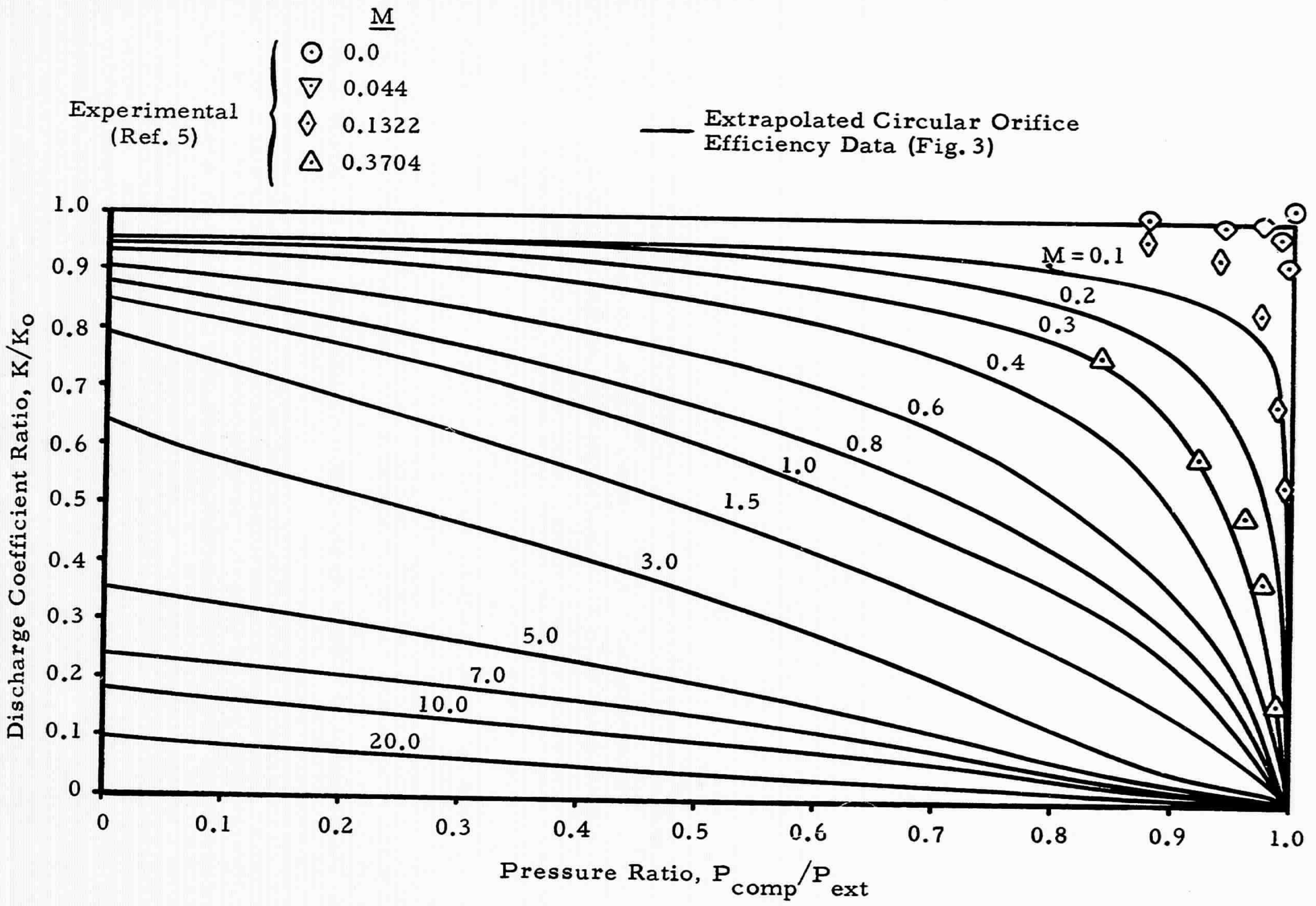

Fig. 4 - Comparison of Rectangular Orifice (Length/Width = 16) Discharge Coefficient Data with Extrapolated Circular Orifice Data

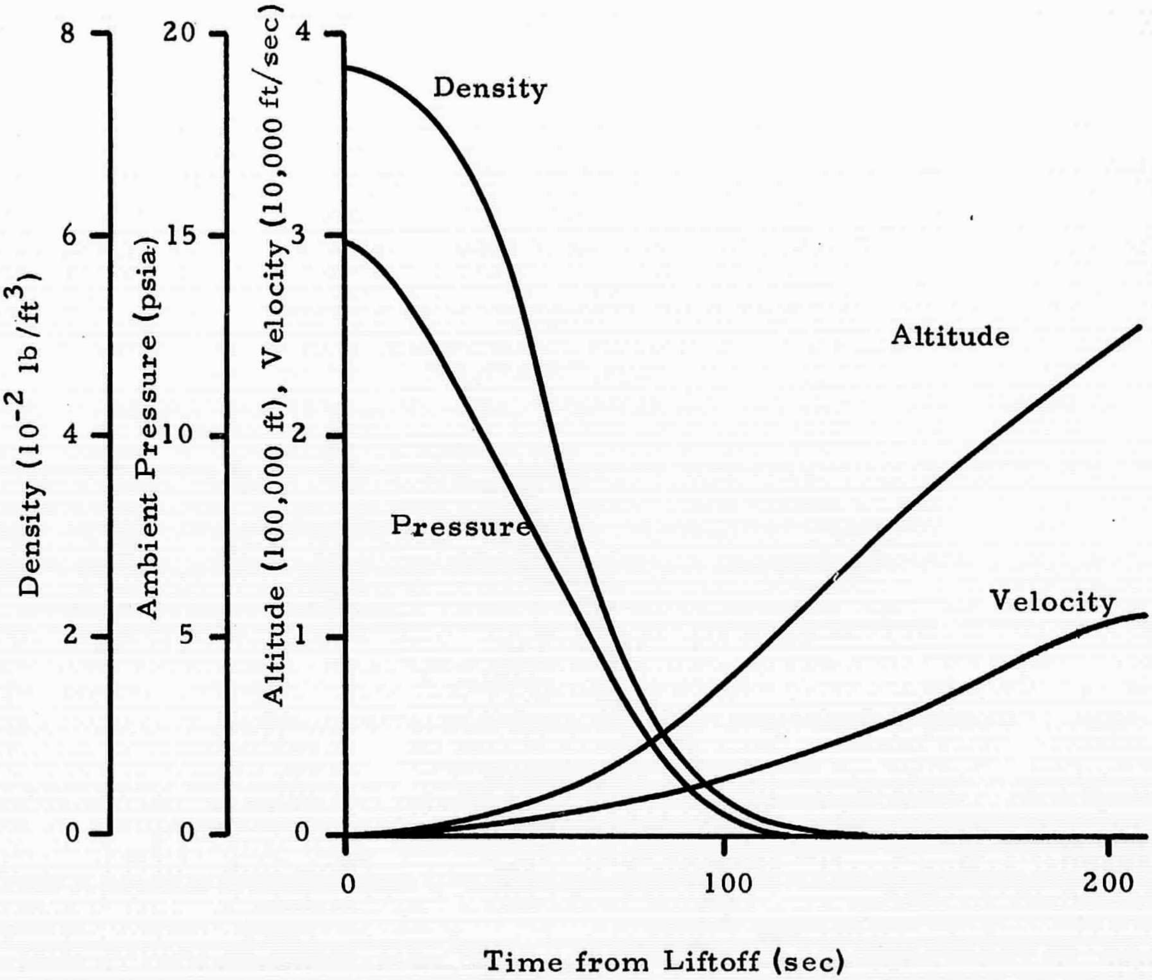

Fig. 5 - Typical Shuttle Ascent Trajectory Parameters

coefficient data for more appropriate geometries were not available, and the data shown in Fig. 4 indicate that the circular orifice data provide a reasonable approximation for elongated orifice data.

External flow conditions (pressure, density, and Mach number) as a function of time, at the orifice location, are required as computer program inputs in addition to the discharge coefficient data. These external flow conditions are usually obtained from vehicle trajectory data in conjunction with a knowledge of the flow field over the vehicle surface.

To date, only preliminary trajectory data have been available for space shuttle vehicles. Typical trajectory data for the ascent phase are presented in Fig. 5. These data apply to both the booster and orbiter vehicles, since they are joined during this phase of flight. Along with the usual vehicle trajectory information (altitude and velocity as a function of time) ambient conditions of pressure and density are shown on the figure. Typical trajectory data are presented in Fig. 6 for the descent flight of the booster vehicle. Shown for comparison is an altitude history from a typical high crossrange orbiter descent. The booster trajectory, for purposes of this preliminary study, is considered to be representative of both the booster and orbiter vehicles. This consideration is justified by a comparison of the altitude histories for both vehicles, which indicates roughly the same rate of descent in the lower regions of the atmosphere.

Since the vent locations on the vehicle have not been specified, and since detailed flowfield information over the vehicle surface has not been obtained, it was assumed that the external flow conditions at the vent were identical to freestream conditions. For a vehicle at low angle of attack, with the vent port located far from any stagnation region, this assumption should provide reasonable approximations. Under conditions other than these, however, the assumption would not yield realistic numbers and the local external pressure can be much greater than ambient pressure.

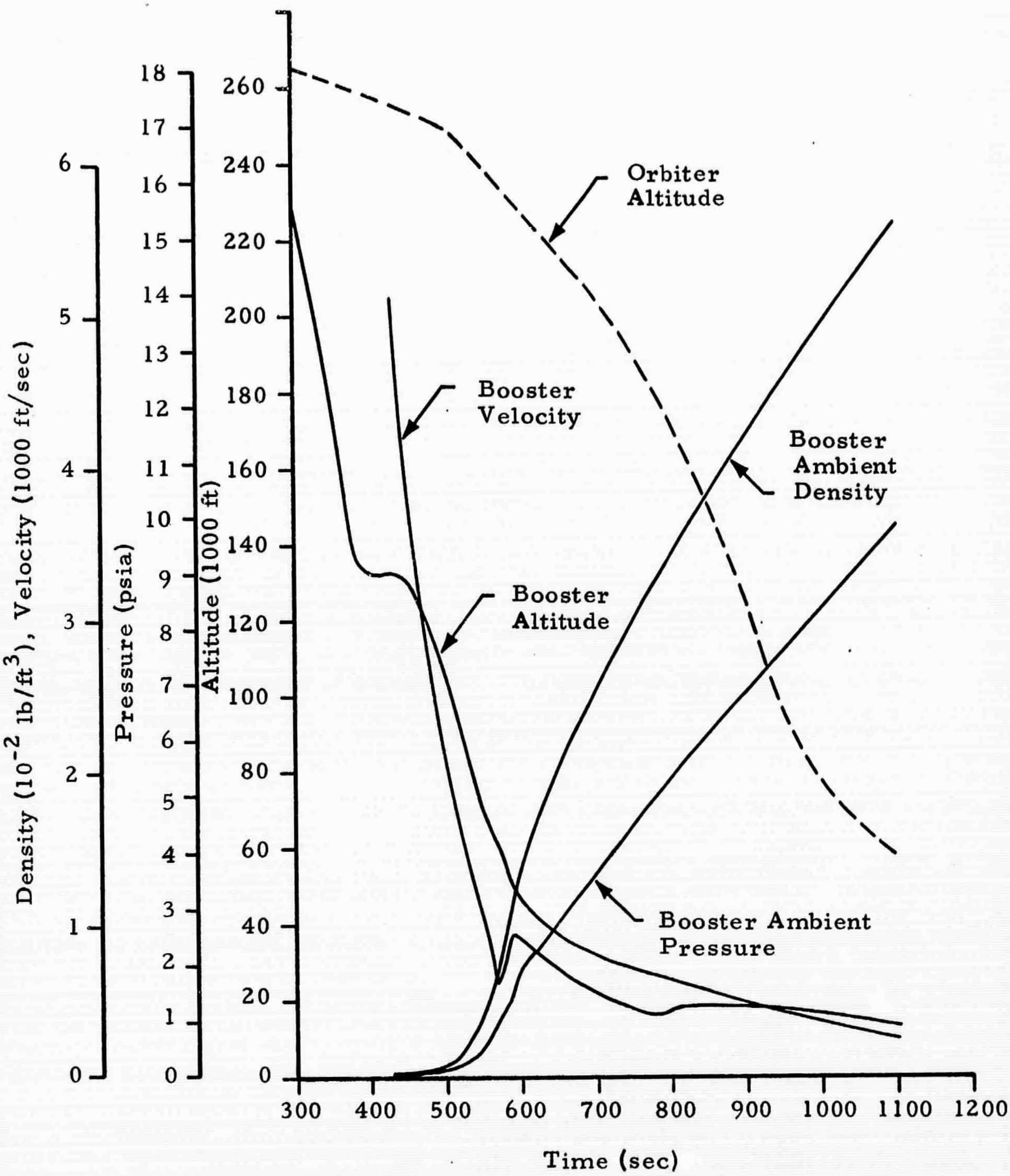

Fig. 6 - Typical Shuttle Vehicle Descent Trajectory Parameters

Utilizing the modified compartment venting computer program along with the previously described discharge coefficient, trajectory and external flow data, compartment pressure histories were calculated for both ascent and descent for a compartment of 3000 ft^3 volume and for vent areas of 10, 50, 75 and 150 in^2. The results are shown in Fig. 7 for ascent and in Fig. 8 for descent. The vents are also described in terms of vent area to compartment volume ratios, since the calculated compartment pressure histories would apply to any compartment with identical vent area to compartment volume ratios. A comparison of the calculated results assuming that the local external pressure is equal to ambient pressure, for ascent and descent clearly indicates that the more severe pressure stresses occur during the ascent phase. This is primarily due to the greater rate of change in altitude during ascent, which results in a greater lag in the compartment pressure.

2.4 ADEQUACY OF ORIFICE EFFICIENCY DATA

The descent compartment pressure history calculations described in Section 2.3 were based on a limited amount of in-flow orifice efficiency data, as shown in Fig. 3. The data available are in the low Mach number range and high pressure ratio range. It was necessary to extrapolate these data over a relatively wide range of Mach numbers and pressure ratios to perform the compartment pressure history calculations. Although these extrapolated data are considered adequate for purposes of this preliminary investigation, later studies involving the final vehicle design should utilize more reliable orifice efficiency and local external pressure data.

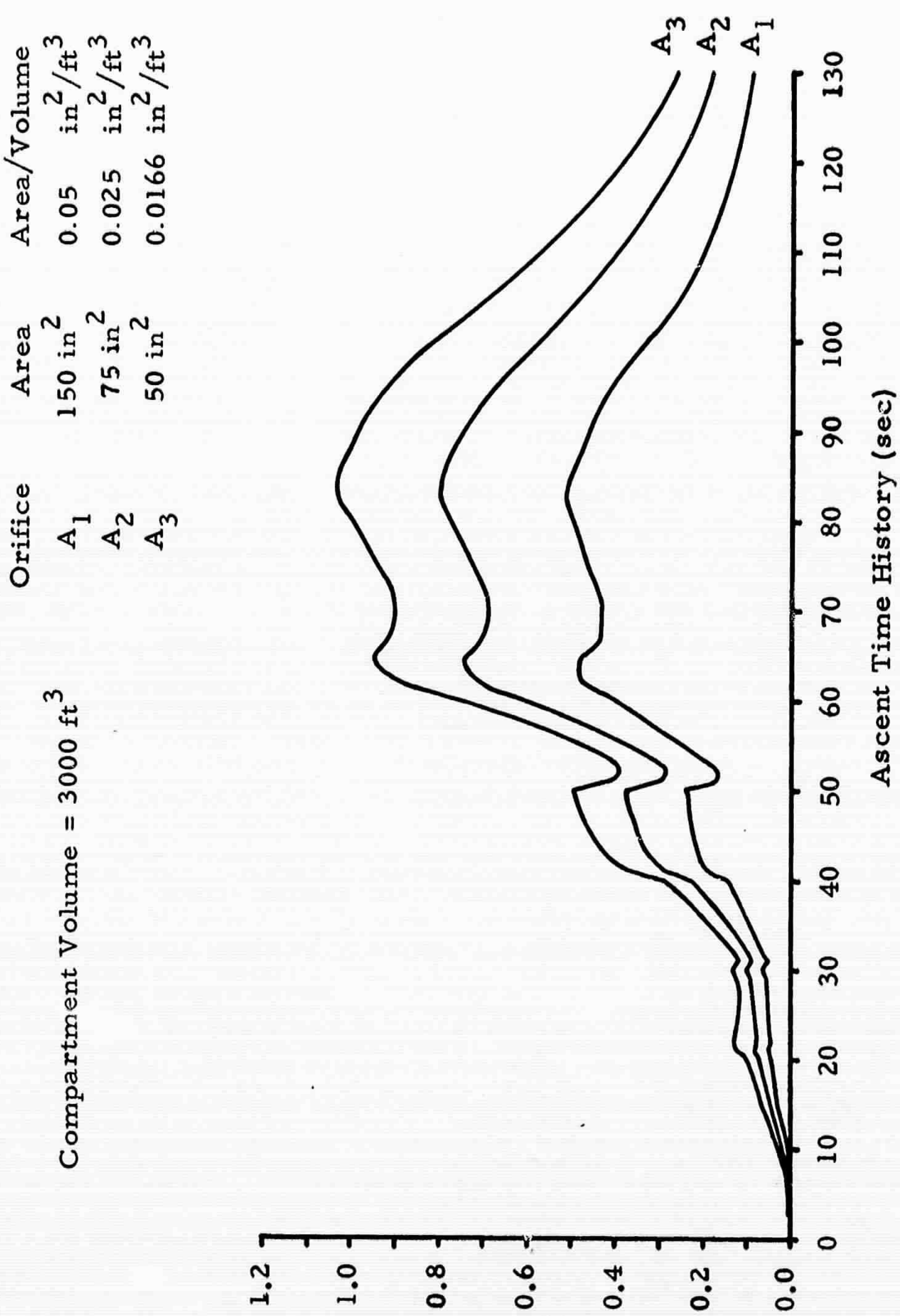

Fig. 7 - Skin Differential Pressure as a Function of Time for a Typical Ascent Trajectory

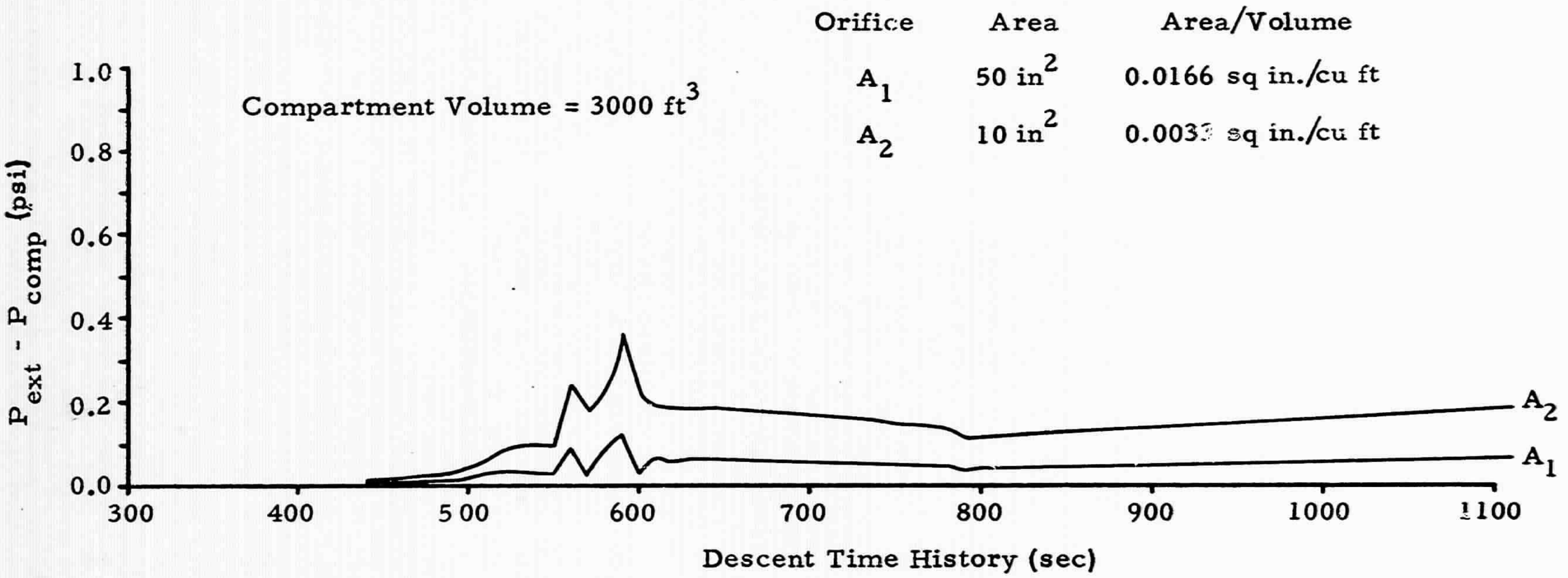

Fig. 8 – Skin Differential Pressure as a Function of Time for a Typical Descent Trajectory

Section 3
CONCLUSIONS AND RECOMMENDATIONS

This preliminary investigation resulted in the identification of compartmental-type areas within the current MDAC version of the space shuttle booster and orbiter vehicles which are likely to require venting. It further revealed, based on existing in-flow orifice efficiency data and assuming venting through simple vent port cut-outs, that the more severe pressure stresses on compartment walls will occur during the ascent trajectory. Special provisions for compartment venting during descent, therefore, do not appear to be required. Finally, the existing in-flow orifice efficiency data, though adequate for this preliminary study, were judged to be inadequate for compartment venting studies involving the final vehicle design. Experimental measurements are therefore recommended to provide in-flow orifice efficiency data over a broader range of conditions.

There are some questions which remain to be answered concerning venting during descent. One question concerns the temperature of the external air which will be vented into the compartments. Presumably, the vent ports would be located on the backside of the vehicle, as it is oriented during descent, where cooler external air temperatures would be expected. A study should be made, however, to establish the severity of this thermal environment. This question is crucial to the venting scheme to be employed, since a valving arrangement may be required to delay venting into the compartments until after the period of high aerodynamic heating.

Another question concerns the possible need for maintaining a positive pressure differential across the compartment walls to alleviate panel flutter and vibration. If structural design considerations impose the requirement of a positive pressure differential, the compartments will have to be internally pressurized with stored gases. Contingent on this possibility, the weight penalty involved with stored gases should be estimated.

Of somewhat less importance is the question concerning the insulation thickness to be required on the vehicle skin. This thickness will have an effect on the discharge coefficient for flow through the vent.

Future venting studies, involving the final vehicle design, should be based on a knowledge of the flow field over the vehicle surface. During ascent, the fact that the two vehicles are joined together may result in high pressure regions due to shock interaction.

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