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FINAL REPORT

LAUNCH VEHICLE FLIGHT DYNAMICS

UNDER

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DELIVERY ORDER NO. 27

SUBMITTED TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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PREFACE

This report summarizes the work done under Delivery Order No. 27 of Contract NAS8-39131 between Marshall Space Flight Center and Auburn University during the period 20 January 1994 through 19 January 1995. The NASA Technical Representative was Ms. Chris Barret. The primary contributors to this effort, besides the Principal Investigator, were Mr. Y-M Cheng and Mr. Scott Bigelow. The work was done in an "advisory mode," with the Principal Investigator, and the other authors to a lesser extent, providing technical expertise to, and addressing questions of, the COTR in the areas covered by the delivery order.

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Principal Investigator

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1. INTRODUCTION

1.1 Background

The development of new launch vehicles will require that designer use innovative approaches to achieve greater performance in terms of payload capability. The objective of the work performed under this delivery order was to provide technical assistance to the COTR in the development of her ideas and concepts for increasing the payload capability of launch vehicles by incorporating aerodynamic controls. The method used was provide advice principally in informal meetings held at Marshall Space Flight Center (MSFC).

Although aerodynamic controls, such as movable fins, are currently used on relatively small missiles, the evolution of large launch vehicles has been in the direction away from aerodynamic control for some time. The COTR reasoned that a closer investigation of the use of aerodynamic controls on large vehicles was warranted by the new technology available in materials, structures, and controls.

1.2 Scope of this Effort.

Technical information regarding fundamental concepts and methods of analysis was generated and presented to the COTR by the Principal Investigator in a consulting mode during five meetings at Marshall Space Flight Center (MSFC) [Dates: 4/19/94, 5/30/94, 7/11/94, 11/15/94, and 1/17/95]. There were three tasks. Task 1 concerned use of the aerodynamic characteristics prediction code MISSILE DATCOM [1] to study the aerodynamic characteristics of certain generic missile configurations and was a follow-on to last year's effort. Task 2 was to provide technical assistance in the area of flight dynamics of launch vehicles modeled as

structurally rigid, variable-mass bodies. The following section of this report describes in more detail the work accomplished on each of these three tasks.

2. DESCRIPTION OF WORK DONE

2.1 Task 1. Aerodynamic Analysis of Launch Vehicles Using MISSILE DATCOM

The work accomplished in the previous effort included the application of the capabilities of the aerodynamic characteristics prediction code MISSILE DATCOM to launch vehicle problem. MISSILE DATCOM is an aerodynamic characteristics prediction code used fairly widely in the air-to-air missile community. It was written for the U. S. Air Force and is in the public domain (distribution unlimited). Aerodynamic coefficients for several launch vehicle configurations were generated to study the effects of adding different types of fins to a basic vehicle. Under the present delivery order two additional aerodynamic characteristics areas were investigated at the direction of the COTR: (1) the effects of the addition of canards and (2) the estimation of hinge moments. Results of these calculations were discussed with the COTR during scheduled meeting at MSFC. The principal result verified by the use of MISSILE DATCOM was that on a vehicle that is statically unstable with respect to perturbations in angle of attack, the addition of canards forward of its center of mass makes it more unstable. However, if the canards are movable, the control moments they are capable of generating may be large enough to provide active control that can counteract perturbations due, for example, to winds. Results were discussed with the COTR.

Hinge moments were estimated for the certain fins in the set considered previously. The

result appear to indicate that with proper choices of hinge location hinge moments on the fins would be reasonable. Results were discussed with the COTR.

2.2 Task 2. Flight Dynamics of Rigid Launch Vehicles.

This task had two parts. The first was to provide general technical assistance to the COTR concerning the analysis of the flight dynamics of launch vehicles modeled as structurally rigid, variable mass bodies. Of particular interest to the COTR were the similarities and differences in the launch vehicle stability and control problem and the conventional aircraft stability and control problem as addressed by Etkin [2]. These topics were discussed at scheduled meetings at MSFC. Principal differences resulting from the fact that the nominal motion of a launch vehicle is transient nature, rather than a uniform steady-state motion of an aircraft, were covered. The rather commonly used "snapshot" stability analysis approach was discussed. In this approach, the stability characteristics of a launch vehicle are calculated for specific flight conditions along the nominal trajectory. Although not rigorous, this approach provides useful design information that may be coupled with simulations to provide more definitive stability information.

The second part of Task 2 was to provide to the COTR a copy of the computer code MISSILE DATCOM and assistance in (1) getting the code operational on a computer, or computers, at MSFC and (2) running the code with typical data. Although some problems were encountered in the process of getting MISSILE DATCOM running at MSFC, partial success was achieved during the November 15, 1994 meeting. At a later meeting January 17, 1995, several runs were made at MSFC.

2.3 Task 3. Analysis of Flexible Launch Vehicles.

The third task required the Principal Investigator to provide technical assistance to the COTR on analyzing the flight dynamics of flexible launch vehicles. In this regard mathematical models were developed and discussed with the COTR. The use of finite elements to model the flexibility of the missile was covered in one scheduled meeting. The use of mode shapes and structural frequencies in a planar motion model of a launch vehicle was discussed at a second meeting.

3. CONCLUSIONS AND RECOMMENDATIONS

The three tasks stated in the scope of work have been completed to the COTR's satisfaction. One result of this project is that the COTR has more expertise in the analysis of the stability and control of launch vehicles that may be rather unconventional. A second result is that MSFC now has an enhanced capability for predicting analyzing the aerodynamics of launch vehicles using MISSILE DATCOM.

It is recommended that work on the use of aerodynamic control surfaces on advanced launch vehicles be continued.

REFERENCES

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2. Etkin, B., Dynamics of Flight - Stability and Control, John Wiley & Sons, Inc., New York, second edition, 1982.