1. Introduction

Transatmospheric vehicles (TAVs), with aerodynamic properties similar to conventional aircraft, have the promise of flying into space and delivering payloads into low earth orbit (LEO). A key distinguishing feature between TAVs and aircraft is propulsion. Jet engines or pure air-breathing propulsion systems cannot provide the thrust levels needed to ascend into space. Traditional rockets overcome this limitation by carrying their own oxidizer. However, traditional rocket boosters are expended after use. TAVs would be Reusable Launch Vehicles (RLVs) capable of returning to earth and flying again after refurbishment and refueling.1 Because of their reusability, TAVs could potentially launch payloads into orbit or into suborbital trajectories at much lower costs than expendable launch vehicles.

Purpose of the Workshop

The Air Force asked RAND to examine the utility, feasibility, and cost of procuring a TAV capable of carrying out military missions. As part of this study, a workshop was held at RAND on April 18 and 19, 1995, to examine TAV technical feasibility and design issues. Experts from the Department of Defense, NASA, and industry participated (a list of workshop participants can be found in Appendix B). A variety of commercial RLV and military TAV design concepts were presented and discussed, including designs submitted for the NASA X-33 and X-34 program competitions. The proceedings of this workshop and certain ancillary analyses are summarized in this report.

Lessons from Recent Programs

In past decades a number of military TAV concepts were proposed, but none resulted in an operational system. The first National Aerospace Plane (NASP) program, which took place from the late 1950s to the early 1960s, demonstrated a number of important technologies, such as real-time air liquefaction, and operations such as hypersonic refueling, which could be important in Two Stage

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1Although some use the terms TAV and RLV interchangeably, we distinguish between the two in this report. We will refer to civil or commercial reusable launch systems as RLVs, and to reusable launch systems that are designed for military-specific missions as TAVs. TAVs have more recently been referred to as military spaceplanes.
To Orbit (TSTO) vehicles. The second NASP program, during the 1980s, was equally ambitious. The 1980s NASP design called for a Single Stage To Orbit (SSTO) fully reusable system based on a combined cycle air-breathing propulsion system concept. Because of the high technological risk of combined cycle propulsion and other aspects of the NASP design, this program never proceeded beyond the technology development phase. The program was canceled after an expenditure of $1.73B when it became clear the cost of an operational prototype would on the order of $10B. In light of the difficulties encountered in the NASP program, caused in part by reliance on risky propulsion technologies, only TAVs based on traditional jet engines or rocket propulsion are considered in this report. Indeed, the focus of the RAND TAV workshop was to explore the technical and cost issues associated with “conventionally” powered TAVs.

Because of the problems encountered in the NASP program, we believe it is also useful to determine whether there are any other technology “show stoppers” that could seriously impede development of a TAV even if existing or near-term conventional rocket propulsion is used and whether an X-vehicle or TAV prototype could be developed with relatively modest funding. At the workshop, several additional technology risk areas were identified. And depending upon the type of TAV design chosen for development, these technology risk areas could be more or less severe barriers to overcome. Achieving operationally useful and economical payload delivery capabilities regardless of the TAV design approach chosen will be challenging, but is certainly possible given the advances made in key technology areas in the past few decades. A necessary step in determining the technical feasibility of one challenging TAV design concept has already been taken by NASA with initiation of the X-33 program. However, it is important to note that there are several other promising TAV design concepts, and some of these may be better suited for military missions and may not have all the technical risks associated with the SSTO X-33 design.

At the RAND TAV workshop, other TAV design concepts, including an air-launched TSTO TAV, were identified that may be better suited for military missions than the TAV designs submitted in the NASA X-33 SSTO competition.

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2The NASP propulsion system was designed to operate like an air-breathing engine at low Mach numbers during the initial ascent phase and in ram and scram jet modes at high Mach numbers during the last phases of the ascent into space. The promise of scram jets is that they may reduce the amount of oxidizer that needs to be carried internally by the vehicle. However, scram jet technology is significantly more complex and much different from traditional rocket and jet engines. Consequently, existing rocket or jet engine designs cannot be extrapolated to the scram jet regime, especially at high Mach numbers.

3The space shuttle, a partially reusable launch vehicle, is based on late 1970s technology.
In addition, RAND has determined by independent cost analysis that it may be possible to develop both an X and Y vehicle prototype for an air-launched military TAV for significantly less than it would be to develop a full scale RLV based on the current X-33 design. This difference in costs is due partly to the smaller size and smaller payload delivery capability of an air-launched military TAV, but also to the fact that the first stage for this type of system would be composed of modified commercial off-the-shelf large transport aircraft, such as a Boeing 747. This cost analysis is reported in a companion RAND report.4 The results of this analysis are summarized in Section 3.

Before any decision is made to develop a military TAV, an examination of potential TAV military missions is needed to assess their operational utility, as is a cost-effectiveness comparison of TAVs relative to other terrestrial, airborne, or space system alternatives that might accomplish the same missions.

Report Outline

Section 2 reviews the launch needs of civil, commercial, and military users and how these needs could potentially be met by new types of RLVs or TAVs. We review the economic motivations of commercial users, the size and weight characteristics of space payloads of the various user communities, potential changes to the types of payloads the DoD may deploy in the coming decades, and new or existing DoD missions that could be carried out by TAVs. We also contrast the cost and performance of a few representative TAV designs. Finally, we review the guidelines of current U.S. National Space Launch policy and suggest ways the policy could be improved while still maintaining effective coordination of NASA and DoD space launch research and development activities.

In Section 3, the TAV design options presented at the RAND TAV workshop are reviewed and issues associated with them are discussed. Technology, development, and operational employment risks (risks associated with particular launch or recovery modes or in flight maneuvers) associated with each design option are assessed based on workshop discussions or on subsequent system performance estimates done at RAND.

Section 4 discusses the technical challenges associated with development of commercial RLVs and military TAVs in general, and those associated with particular design alternatives. We examine the state of the art in key technology

areas, such as thermal protection systems, propulsion, and composite materials, to assess what further advances may be required to develop a commercial RLV or a military TAV.

Caveats

We caution the reader that not all the RLV or TAV concepts discussed in this report have received the same level of analysis, development, or criticism (due or undue, as the case may be). We could have chosen to drop certain TAV concepts presented at the workshop from this report for any of the above reasons. However, we have chosen not to do so, as many “immature” concepts appear quite promising and deserve further investigation. In some cases, however, certain TAV performance claims, such as LEO payload delivery capabilities, were made by the presenters. Discussions at the workshop revealed that some of these claims were considered controversial within the expert community. Rather than publish these claims without comment, we attempted to verify or disprove certain payload delivery claims of some of the less-mature TAV concepts. These analyses unfortunately took time, but have been completed and are included in Section 3. Publication of this report was delayed while the calculations were performed.

Most of the data presented in this report originate from material presented at the workshop. Consequently, the information cutoff date for that material is April 1995. The major exceptions to this cutoff date are the descriptions of the X-33 RLV concepts and their associated subsystems. The X-33 designs of the three competitors were still in flux when the workshop was held, so we updated the descriptions of these system concepts with publicly available or nonproprietary information made available in the months preceding the selection of the X-33 winning bid.

A number of proprietary contractor presentations were given at the workshop. To enable as broad a distribution as possible of this report, we kept the report nonproprietary. Similarly, some presentations were considered to contain sensitive information regarding potential future DoD space missions and means to accomplish them. These presentations or information resulting from them are not included in this report.