LVX – AN INTEGRATED AERODYNAMIC DESIGN AND ANALYSIS METHOD

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Abstract

LVX is an integrated aerodynamic design and analysis procedure for launch vehicles which incorporates prediction methods, historical knowledge, and corporate memory into a knowledge-based system. The objective is an economical means to conduct aerodynamic design and analysis of future launch vehicles to minimize the risk of aerodynamic-induced failures. LVX provides a guide to the aerodynamic-related information needed during the conceptual and preliminary design stages. The user has access to historical information on similar vehicles, the ability to set up geometric characteristics, and a capability to predict preliminary aerodynamic characteristics. LVX includes searchable databases which contain technical references on launch vehicle aerodynamics, engineering experiences and anecdotes on previous launch vehicle programs. It has the capability to store wind tunnel or computational data in databases which can be searched as needed. It has project capability to associate the designs, searches, experimental and computational data, and various notes for later retrieval and editing. The method can be used as a stand-alone tool for traditional design procedures, or it has application as an integral component of a multidisciplinary design method. The projects and databases can be updated with new information as it becomes available.

1 Introduction

A primary mission goal for the aerospace community is to design, develop, and maintain high quality and reliable space launch systems at less cost.[1] This will be achieved only through increased efficiency of the many disciplines required to design a launch vehicle. The objective of this work was to demonstrate an approach to increase the efficiency of a single discipline, aerodynamics. An integrated aerodynamic design and analysis procedure will be used to illustrate a technical approach which can be applied to other disciplines to provide a positive influence on the design process.

The aerodynamics design and analysis system called LVX (Launch Vehicle eXpert) [2] has been developed to assist the launch vehicle designer in the analysis and evaluation of the aerodynamics of new launch vehicles during all phases of the design cycle, but it has primary application during conceptual and preliminary design. The objective is to increase engineering efficiency and reduce development costs through a reduced number of design cycles and more timely interaction with other disciplines needing aerodynamic information. LVX has as a primary goal the reduction of risk in the aerodynamics of new launch vehicles by making past experience accessible for new designs. It incorporates analysis methods, historical design guidelines, corporate memory, and a documents database into a knowledge-based system.

The development of LVX combined expertise in launch vehicle aerodynamics with capabilities in information management to develop a practical tool to increase the efficiency and effectiveness of the aerodynamicist in his interaction with the many disciplines involved in the design. Useful and hard-to-find information was identified and collected in the system to create an online knowledge base of aerodynamics of launch vehicles. Information technologies are used to assist the system user in retrieving applicable knowledge that will help in the design. The method can be used as a stand-alone application for the aerodynamics discipline, to be run off-line to analyze and evaluate a number of potential configurations during conceptual and preliminary design. An overview of LVX is shown in Figure 1.

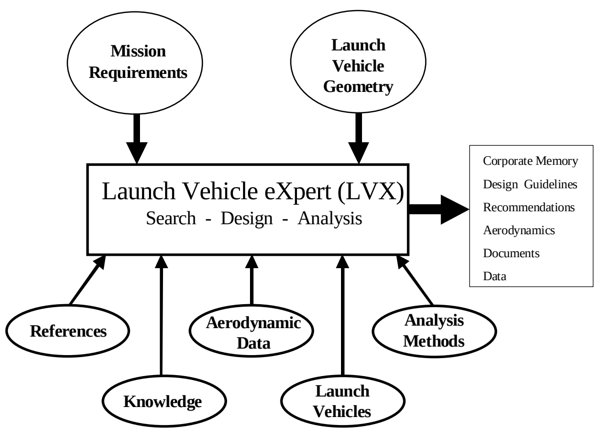

Figure 1.- LVX overview

2 Background

The experienced designers and analysts who learned from the successes and failures of the 1960s and 1970s are leaving the industry as a result of retirement and downsizing; thus much of this corporate memory and experience has the potential to be lost.[3] Because of budget constraints, many young engineers are not receiving the benefits of the training and mentoring process enjoyed by more mature engineers. There are fewer new launch vehicle programs available to give these engineers the experience they need. Without the necessary mix of talent and experience, it will be difficult or impossible to build advanced launch vehicles to perform the required missions. One possible result is new vehicles which simply cannot carry out the launch capabilities promised. An even worse result is a repeat of past failures with the associated increased costs and lost confidence in the new vehicles. This latter result is not only bad for the organization in question, it is bad for the launch industry as a whole.

The development of LVX is based in part on NEAR's experience in the computational and experimental aerodynamic design and analysis of several launch vehicles. This work has been conducted for new companies who have not demonstrated a history of success in this area. For example, NEAR provided the initial aerodynamics for the Orbital Sciences Corporation's Pegasus [4] and Taurus launch vehicles before Orbital had accumulated experience and established a history as a successful launch provider. NEAR also developed the initial aerodynamics for the concept studies for the early X-34 vehicle. In an extensive integrated computational and experimental program, NEAR did the aerodynamic design and analysis for the Kistler Aerospace Corporation's K-1 reusable launch vehicle.[5,6] In a similar combined computational and experimental aerodynamics program, the preliminary aerodynamics database was developed on the Beal Aerospace BA-1 and -2 ELV.[5] An experimental database was developed for the Intrepid family of launch vehicles for Rocket Development Company. NEAR also provided analytical aerodynamic analysis for the conceptual design of the Kelly Space and Technology 2nd Generation Reusable Launch Vehicle.

Concurrently with the above aerodynamics design and analysis tasks, NEAR was working in the information technology and knowledge-based system area to identify efficient ways to develop and search information databases for many different technology areas. For example, NEAR's CFDexchange was developed to capture and store CFD code usage and procedures and match CFD technologies with engineering applications.[7] This involved database design to store problem descriptions, available technology information, and calculation results, and more importantly, it involved the retrieval of information through sophisticated search capabilities. This database stores an archive of the configurations and flow fields solved, the CFD technologies used, the computational and labor resources required, and the results for previous calculations. In additional work, a scheme was devised for inserting new CFD calculations into the database automatically, and for compiling data from related runs which could then be viewed within a multidimensional design space.[8]

LVX demonstrates the merger of aerodynamic design and analysis capability with knowledge-based system methods to produce a tool to assist the aerodynamicist during the development of new launch vehicles. As noted by Hart [9], "Expert systems are tools to help the engineer. The engineer will still make decisions, but the KBS (Knowledge Based System) will provide some justification for the answers…."

3 Technical Description

3.1 LVX Overview

LVX, an integrated aerodynamic design and analysis method, is made up of a collection of searchable databases with information linked together across these databases. As illustrated in Figure 1, mission requirements and launch vehicle geometry can be specified, and the LVX system accesses the various databases to supply the requested aerodynamic information. It provides an economical and practical means to analyze and evaluate the aerodynamics of new launch vehicles during the conceptual and preliminary design phases. The related databases incorporate

- Corporate memory and experience
- Expert knowledge relating to the aerodynamics of launch vehicles
- Historical information
- Pictures and drawings of existing designs
- References to published reports
- Detailed information on analysis options
- Specific code critiques and suggestions for appropriate prediction methods
- Aerodynamic analysis codes for preliminary aerodynamics
- Experimental data

LVX also provides a means to archive aerodynamic design and analysis results during the development of a new launch vehicle. Although developed as a stand-alone tool, LVX can be adapted for use as an integral component of a multidisciplinary design method.

The method can be used at different levels of the design cycle depending on the needs of the user. The user can use the search features to look for information prior to beginning a design or for education and training purposes. It is possible to set up a conceptual design and search for information on previous similar vehicles or potential problem areas to be considered. Aerodynamic analyses can be carried out at different levels for preliminary information on aerodynamic characteristics. Finally, the method can be used in the project mode to archive the historical progress of a particular design study, or it can be used to archive the corporate memory of the user organization for future training and educational purposes. This latter process will make this valuable information available for use in future projects.

3.2 Databases

LVX is built around four principle databases. Each database is dedicated to a specific area and function of the method, and the individual items in each database are identified and connected by keywords. The major databases described below contain keywords, technical information, references, and aerodynamic data.

3.2.1 Keywords

A hierarchical keyword structure was selected as the most efficient and functional to model the knowledge stored in the databases. Each node in the hierarchy is represented by a keyword that describes a topic. This model allows the information stored to be linked in a logical fashion, which assists in both the knowledge acquisition and the knowledge retrieval mechanism. There are more than four hundred keywords in the current LVX hierarchy.

The keywords were chosen from several sources. First, NASA-assigned terms [10] used to document relevant technical reports and papers were selected for the first level of keywords. However, this preliminary list proved to be limiting in that it did not include terms that were in common usage by the engineers involved in launch vehicle aerodynamics.[11,12] Additional terms identified in conversations with aerodynamics experts and those used by the authors in their launch vehicle experience were added to the database.

It is anticipated that important keywords may have been omitted from the original list in LVX. The user is provided a means to add keywords to the list.

3.2.2 Technical Information

LVX is built around an aerodynamic knowledge base which includes design rules and engineering rules-of-thumb for launch vehicles. It includes knowledge gained during the aerodynamic design and analysis experience of the authors on several commercial launch vehicle programs, as well as information from launch vehicle design tutorials and position papers. Valuable information was obtained from a number of historical data reports and key interviews with active and retired launch vehicle design experts from NASA and industry. All of the design rules and comments gleaned from the multitude of sources are included in the database with links to design information associated with specific configurations and to published documents. The following paragraphs document details of the development of the technical information database.

Published guidelines.- Some significant and valuable information was obtained from technical publications; however, limitations were imposed on the information included in the technical information database. This was dictated by the scope and direction of the work. For example, to be included in the database, it was required that the information be essential and not readily available in the current literature. The accumulation of launch vehicle design guidelines based on NASA experience is a good example of such information.[13] Supporting information is referenced by documents in the references database and linked to the design information. It was also a requirement that the information be directly related to the aerodynamics discipline. It was very easy for the information collection to begin to deviate from its focus on aerodynamics and expand into a peripheral discipline; for example, the technical information could be dominated by aeroelasticity or structures or control systems.

Personal interviews.- In keeping with the stated goal of collecting and preserving the corporate memory of the space program in the United States, a significant portion of the technical information database was obtained from personal interviews with active and retired engineers who had experience in launch vehicle aerodynamics.

Before the interviews were accomplished, the author investigated various interviewing techniques and the pitfalls which may occur with them.[9,14] One common problem is that no useful information will be obtained. To keep the interviews focused, a summary of the goals and expectations of the interview were stated to the participants, and in addition, a series of photographs of launch vehicles, existing and future, were used to guide the conversations. In each case, the interviews were as informal as possible, and the interviewees were allowed to discuss any aerodynamic topic of interest as long as it did not wander too far afield. The author would try to guide the conversations in useful directions, and when a particularly interesting point was made, some directed questions were asked to try to draw out more information. A conscious effort was made not to bias the information collected by inadvertently including the knowledge and opinions of the interviewer.

The interview process was conducted at several NASA centers, and it was accomplished with both individual and group interviews. Each knowledge acquisition session was taped and subsequently transcribed. The transcriptions were later edited for accuracy, grammar, and completeness. A knowledge engineer worked from the edited transcripts to sort the individual pieces of information or knowledge data. In the LVX technical information database, no specific piece of information is attributed to any individual based on an agreement in the interview sessions. This was an effort to keep the interviewees open and unselfconscious about the information they were presenting from memory for most cases. However, in an effort to provide the user with some indication of the source of the information, many of the information items show the location and date of the interview.

Unpublished information.- A large quantity of useful information is unpublished; for example, tutorials, white papers, wind tunnel tests, and personal notes. Some of this type of information was identified during the interview process, and it was deemed important that this information, though unsupported by a formal publication process, be included in the database. Some of this information was deemed important enough that a special search procedure was set up within LVX to search for specific information stored in .pdf files.

Authors' experiences.- As noted previously, the authors have had experience with the aerodynamic design and analyses of a number of different launch vehicles. These efforts have used different combinations of experimental and computational methods to produce the aerodynamics required by the many disciplines involved in the design. The computational work, which began in the 1980s, has evolved from limited use of CFD methods (which were still in the research and development stage in this time period) through the current situation of nearly routine use of CFD methods, even during preliminary design. Many of the insights on computational methods are based on this experience. It should be noted here that this information in LVX is also the information which will become dated and subject to change sooner than other more general information.

Dynamic database.- Finally, it is important for the user to understand that much of the information in the technical information database is based on current knowledge, and as the technology advances and the knowledge base is increased, the information must be updated. It is also important that the user be aware that there is much information not included in the database. Some of this can be blamed on oversight by the first author, but other key items of information were omitted because they were proprietary or commercially sensitive data. All classified data were omitted for obvious reasons. Therefore, it should be apparent that the technical information in the database is dynamic and changing. Some of the information in the database will change with the interests of the user and the particular application. For all these reasons, the capability for the user to add information to the database has been included in LVX.

3.2.3 References

The LVX system includes a database of references to published reports. This extensive database contains more than 2,300 citations to technical documents on launch vehicle aerodynamics and data. Keywords are assigned to each document, and these keywords are used in the search and retrieval process. Searches can also be conducted using title words and author names.

The documents were identified through a number of sources, including (1) a list of relevant papers and reports collected by the authors in the course of past work on launch vehicles, (2) citations from survey papers and other work of prominent researchers in the field, (3) a search for applicable reports in the NEAR Technical Library, and (4) a search in the NASA RECONplus database using selected keywords.

In an effort to make this database as useful and relevant as possible, each citation was checked to be sure only appropriate documents were included. It was necessary to limit the citations included to the narrow topic of aerodynamics because of the volume of information available in the open literature. There are a number of citations to documents in related technical disciplines such as aerothermodynamics, controls, and structural analysis, but these areas are not as complete as the aerodynamics discipline. No classified documents are included. There are some foreign publications cited, but in general, only documents published in the United States are shown because of the difficulty obtaining foreign documents.

There is no doubt that some favorite documents have been overlooked. There are also a large number of documents published each year; therefore, the references database must be dynamic to keep up-to-date. The capability for the user to add new references to the database is an important feature in LVX.

3.2.4 Aerodynamics Data

The aerodynamic databases in the system can be modified by the user to include both experimental data and computational analysis results as they become available during the configuration design. When adding aerodynamic information to the system, the user tags the data with the appropriate keywords which describe or identify it; descriptive text can also be included to identify the data. Data files may also be imported into the system, and when the data are in ASCII format, the user may view it in LVX. The data may be exported from LVX to the user's system disk for plotting and other manipulations.

3.2.5 Analysis Methods

The system includes an analysis capability using codes of varying fidelity that the user can call upon to produce preliminary aerodynamic analyses for the design or designs under consideration. Three codes can be run directly from the system, and the results are immediately available for analysis and archive purposes. LVX can create input files for three codes, R1307[15], Missile DATCOM[16,17], and APAS[18,19]. R1307 is a linear aerodynamics, slender-body-theory method used to calculate aerodynamic characteristics of wing-body-tail combinations. Missile DATCOM uses both analytic and empirical methods to calculate aerodynamics of simple configurations. APAS is based on linear potential theory at subsonic and supersonic speeds, and at hypersonic speeds it uses impact solutions. Both R1307 and Missile DATCOM are easy to set up and run, but they are constrained to address conventional geometries, such as geometries with axisymmetric bodies and wings without winglets or camber. APAS can handle arbitrary geometries but requires more detail in the geometry input and added user effort in running the code.

Every possible aerodynamics code cannot be included in the system, but an interface is provided so that the user can run any desired code outside the boundaries of the system, and the results can be imported into LVX for analysis and archive purposes. It is possible to extend LVX to include any desired aerodynamics prediction method.

4 LVX Features

A detailed discussion of the use of the system, its capabilities, and some alternate uses of LVX is presented in this section. At the highest level after starting LVX, the user has four major paths from which to select to begin use of the method. They are shown in Figure 2 as Search, Project, Advanced, and Help. The following sections consider each of these paths individually.

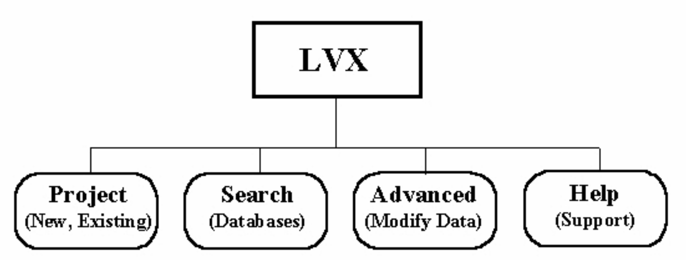

Figure 2.- LVX user options.

4.1 Search

At this first level of use, the user is permitted to browse the databases for information on Vehicles, Tech Info, Data, and References. Using selected keywords, the databases can be searched for the information tagged with these keywords. The references database can also be searched for citations by specifying title information, author name, report number, or the organization which published the document. The search results include links to pertinent related information stored in all the databases.

These searches can be accomplished outside the boundaries of a project as a stand-alone capability, or they can be conducted as part of a project. In either case, the user can edit the contents of the search results and save the final results to a file for later use. In the project area, the results will be saved as part of the project archives.

4.2 Project

In the Project option, the user is allowed to produce and archive a range of information on the aerodynamic design and analysis of a specific launch vehicle or family of launch vehicles. This information can include various configurations, preliminary aerodynamic characteristics of each configuration, and results of the database searches. At the Project level, the user has three options from which to choose any or all: Design, Searches, and Notes as illustrated in Figure 3. Any work accomplished in any of these areas can be attached to a specific project and saved for future use or archive purposes. The capabilities of each area are described below.

4.2.1 Searches

Searches of the databases using user-selected keywords or other information are also possible under the Project application. The search is conducted as described previously; however, when accomplished under the Project area, the results of the search (as edited by the user) can be saved as part of the project for later use or archive purposes.

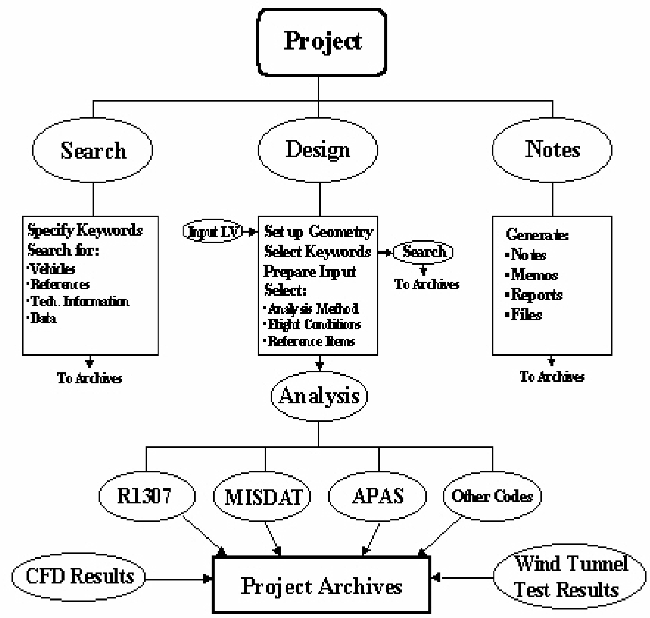

Figure 3.- LVX project options.

The information contained in the results of the search of the Tech Info database will include any evaluations of the configuration and any warnings on potential problems of which the user should be aware. As with all searches, the results will depend on the keyword selection. The user should be sure to select keywords which identify the configuration (as listed in the design window), or which relate to the computational scheme or code being used.

4.3.2 Design

This area executes one of the major capabilities of LVX, the design and analysis of a launch vehicle, and the user has many options and choices in this feature. A general path for this option is shown in Figure 3.

The user has the option of reading in a surface geometry description of the configuration of interest. This is called the "Input" model. At a very early stage of a conceptual design, this information may not be available, but at a later stage during preliminary design, this information may be input to guide the LVX design and analysis effort. The user can choose to set up the geometry model of the configuration with the component buildup approach. This permits the user to tailor the launch vehicle model to a known configuration by matching various components for the nose, body, wing, and tail until a best-fit to the configuration is achieved. If a configuration is not available at this stage, the user can still build up a configuration using the available components.

During the process of building the configuration, the user can see the geometry progress as components are added, and if a configuration has been previously input, the build up configuration is shown in overlay so there is a constant check between the input configuration and the LVX Model. All the while the geometry model is being assembled with the various components, keywords appropriate to the configuration are automatically selected for later use.

When the geometric configuration is complete, the user can define and specify the Reference Conditions (area, length, moment center) and the Flight Conditions (Mach number, angles of attack and sideslip, altitude, etc.). Similarly the user can select Mission Characteristics (RLV, SSTO, Vertical Launch, etc.) appropriate to the configuration. During the selection of the Flight Conditions and Mission Characteristics, LVX is automatically choosing keywords and adding them to the list displayed on the screen.

Given the component buildup model of the configuration of interest, the user can choose to perform an aerodynamic analysis appropriate to the conceptual or preliminary design level. Following the Analysis path shown in Figure 3, the user can select from three different codes: R1307, MISDAT, and APAS. When a code selection is made, the user has the option of setting up a new geometric configuration, or if an input model is available, the user can simply have LVX create the best fit to this model using the components available to that code.

LVX will prepare an input file which can be edited by the user, and if the R1307 or MISDAT codes are selected, the run can be made at the click of the mouse. The aerodynamics output can be viewed on the screen, and the user has the option of saving it as part of the project. Everything that has been done to this point can be saved in the project for later retrieval.

If the APAS code is selected, the user saves the input file, and the analysis program APAS is run external to the LVX system. The computed results are brought back into the LVX system for archiving the results.

A similar procedure can be followed for any code or other prediction method available to the user. An interface between LVX and the code is required. In addition, if CFD or wind tunnel data are available for the configuration of interest, this information can be included in the project archives for future use.

With regard to the keyword list developed during the configuration buildup, it may now be used to search the databases for information related to the configuration, mission, and flight conditions of interest. These results can be edited by the user and saved in the project archives.

4.3.3 Notes

The user may include text files describing the design process, the results, or any other pertinent information in the notes. A note can contain text copied from an outside source; for example, minutes of a review meeting can be saved for record purposes. All the notes generated can be saved with the project for later use or archive purposes.

4.4 Advanced

The Advanced feature of LVX shown in Figure 2 is the database maintenance area. The user is allowed to add or modify all of the databases: Keywords, References, Data, and Technical Information. This feature is included to provide the user the greatest flexibility in the use of LVX for specific tasks. It is here that the user organization can customize LVX to include proprietary information or to create a version of LVX as an archive for a specific project or assignment.

4.5 Help

Help features for the LVX system in Figure 2 are provided for user support. A Glossary containing all the keyword definitions is provided. In an Analysis section, the different levels of aerodynamics prediction methods are described along with pro and con information for their use. General recommendations on the level of technology required are also provided. Example code descriptions provide the user with guidance in selecting a code for analysis purposes. The codes are categorized by their analysis fidelity; for example, engineering, intermediate, and CFD.

5 Lessons Learned

There were a number of lessons learned in each part of LVX development. Some were expected, but a number were unexpected. The latter are of course the most interesting.

Some of the interesting problems which occurred in the knowledge acquisition process involved directing the interviews and keeping the discussions on topic. The interviews were taped and transcribed for use in sorting out the relevant facts. One of the interesting aspects of the interview process was the difficulty in obtaining relevant information from expert interviews. Often the pieces of information were unconnected and incomplete, and some follow-up was necessary to insure the accuracy of the data. It was also necessary to sort out proprietary information from the content of the interviews.

Another problem was creating appropriate links to other information in the database. Technical information and facts are included without attribution; however, this creates a problem evaluating the quality of the information. The user should have some means to assess the accuracy of the data; therefore, some source information may need to be attached to each item in the knowledge database. A compromise reached in the initial release of LVX is to note the location and date of the interview associated with some items to give the user an indication of the source of the knowledge.

The generation of the technical references database, although seemingly straightforward, provided a number of unanticipated problems. One search of the NASA database produced more than 2,600 citations which needed to be examined to eliminate inappropriate documents. It was during this process that one of the major problems was discovered, and that involved incorrect, inconsistent, and missing information in the citations. In addition, it was surprising that the reference lists in a number of published reports were found to have many errors and inaccuracies. In some cases it was not possible to locate cited references from the information provided in the report/paper reference list. Truncated titles, misspelled and missing authors' names, and incorrect dates all contribute to this problem.

For the aerodynamic analysis codes portion of LVX, it was necessary to be aware of proprietary, licensing, and ITAR requirements. This is the reason that more codes are not included and that provision was made to run codes outside of LVX.

6 Conclusions

A knowledge-based system has been developed which provides a tool to assist in the aerodynamic design and analysis of advanced launch vehicles. LVX was designed to help the engineer accomplish the aerodynamic design and analysis more efficiently and more quickly. It is anticipated that the knowledge base included in LVX will assist the engineer in making decisions and provide a solid basis and justification for these decisions.

The technical information database was generated from numerous interviews with active and retired launch vehicle aerodynamicists, and this database can be expanded with current information as it becomes available to the user. Collective knowledge on aerodynamics design increases over time, and much of this knowledge may be proprietary and specific to a design project. The capability for LVX users to add their own knowledge to the databases allows LVX to remain current and relevant.

LVX is just one component of a multidisciplinary design system for advanced launch vehicles. It provides access to historical technical information and current knowledge on the aerodynamic design and analysis process for these vehicles, and it will permit more efficient interaction between aerodynamics and the other major disciplines in the design cycle.

7 Acknowledgements

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