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Conducting the NASP Ground Test Program

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Abstract

The National Aero-Space Plane (NASP) program has recently entered a new phase of the program known as Phase 2D. During this period, five aerospace companies and the Government have formed a National Team. This team has focused on developing a single experimental (X-30) vehicle design and are pursuing a technology validation and demonstration program to prove out the design concepts and design tools. This paper presents an overview of the Phase 2D ground testing being conducted to validate the X-30 design and to demonstrate the critical technologies needed to build and fly a research vehicle during Phase 3 of the program. The Phase 2D exit criteria are discussed to identify how they provide top-level guidance for developing the ground test program. An overview of major test facility modifications being performed in support of the test program is also presented. Emphasis is placed on propulsion and structures testing since these are felt to be the primary areas requiring technologies beyond the current state-of-the-art. Also discussed is the use of uncertainty analysis as a method to account for uncertainties in test data. In addition, this paper addresses the use of these uncertainties to develop qualitative indicators of how well the design and technology developed during Phase 2 have matured.

Introduction

The NASP program is a Presidentially directed research and technology program managed jointly by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD). The program goal is to develop and demonstrate in flight, the enabling technologies needed to build and operate manned hypersonic vehicles, with emphasis on attaining single-stage-to-orbit (SSTO). Concepts for operating such vehicles will also be explored. NASA and the DoD have been conducting research in aeronautical hypersonics since the early 1950's. Current efforts date to 1982 when the Defense Advanced Research Projects Agency (DARPA) initiated a new program focused on supersonic combustion ramjet technology. This program became known as Phase 1 of the NASP program and ended in 1986 when Phase 2 was initiated to accelerate the airframe design and the development of key technologies. If the Phase 2 program shows the technology is feasible and the risk has been sufficiently reduced, NASP will be ready to enter Phase 3 of the program. During this phase, two experimental aircraft (X-30) will be built and flown as research/demonstration vehicles to validate design concepts and design tools. The X-30 will also be used to conduct additional research in flight, and demonstrate the technology required for hypersonic flight and SSTO. In 1990, Phase 2 was restructured to end competition among three airframe and two engine contractors. These five companies have been merged into one contractor team focused on developing a single X-30 design versus six competitive configurations (3 airframes, 2 engines each). This new phase of the program, called Phase 2D, is designed to ensure one vehicle concept is developed in sufficient depth to obtain a positive Phase 3 decision.

Research and development efforts in Phase 2D may be divided into two categories as illustrated in figure 1. X-30 system design encompasses efforts at developing a credible vehicle design and the support systems necessary to conduct the research program during Phase 3. Technology Development / Demonstration involves producing the technologies needed to bring the X-30 system design to life, demonstrating the technologies will work, and acquiring test data to validate design concepts and tools. Funding and schedule constraints limit the amount of technology that can be developed and demonstrated during Phase 2D. In addition, limitations in current hypersonic ground test capabilities means design concepts and tools may not be fully validated during this phase. Technology development and validation efforts will continue in Phase 3 via additional ground tests and during actual manned flights of the X-30 research vehicle. The purpose of the Phase 2D ground test program is to acquire test data and conduct demonstrations needed to show that the X-30 vehicle design and enabling (or critical) technologies are sufficiently developed to support a decision to proceed into Phase 3.

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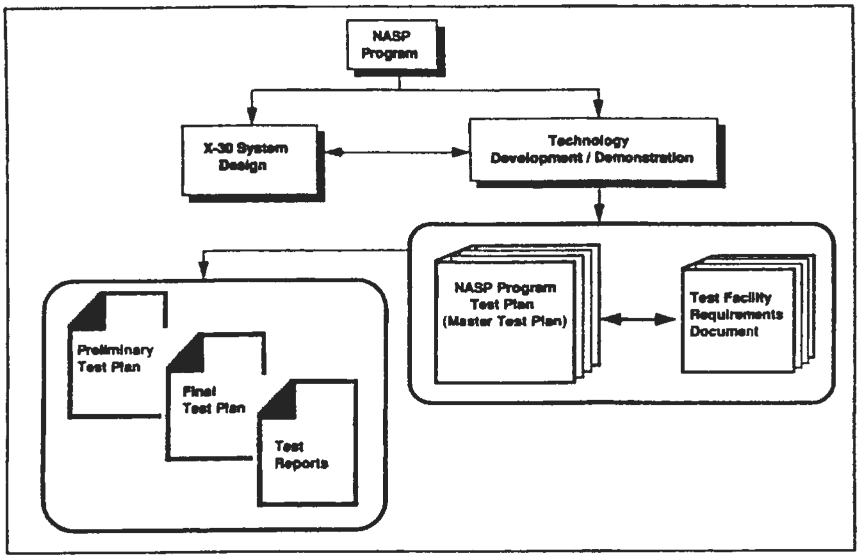

Figure 1. Test Documents - Phase 2D Test Planning

Table 1. Number of Tests in Phase 2D

	Test Facilities Government	Industrial
Propulsion	33	13
Aero/Aerothermal/ Stability & Control (Wind Tunnel Tests)	53	06
Structures (Airframe & Engine)	120	45
Systems	29	36
Total: 335	235	90

Note: Numbers are approximate and subject to change based on facility availability and updates to test program

Table 1. Phase 2D Tests

Test Program

The Phase 2D test program has been structured to address four exit criteria established for NASP. These criteria provide top-level definition of the critical technical demonstrations and accomplishments necessary to exit Phase 2D and begin Phase 3. In general, these criteria address the following:

- Credible vehicle design within a gross take-off weight (GTOW) window
- Demonstrated materials and structures that support the design
- Demonstrated propulsion system
- Slush hydrogen technology development

The exit criteria are further defined by technical objectives that specify technical milestones the program should have reached prior to making the Phase 3 decision. These objectives and milestones serve as a primary source for test requirements that drive the Phase 2D ground test program. A program test plan (see figure 1) has been developed to provide an integrated plan for conducting the tests / demonstrations that need to occur in order to meet the established milestones, technical objectives and ultimately the four exit criteria. The test program documented in this Master Test Plan is used to develop requirements for test facilities. This includes identifying Government and Industry facilities where tests will be done as well as defining facility upgrades that may be needed to execute the test.

Tests conducted during Phase 2D will provide data to support the X-30 vehicle design cycles. Referring to figure 2, there are currently five cycles planned. These include three conceptual design cycles to achieve the final vehicle size, followed by two preliminary cycles to achieve sufficient design detail before entering Phase 3. At present, there are three propulsion system design cycles that support the vehicle design. During these three cycles, the propulsion system will be developed in sufficient detail to produce and test first small-scale, then large-scale hardware. In addition, the program will design flight capable hardware for testing in Phase 3. Over 300 tests are scheduled to be performed at various Government and Industrial test facilities during the 26 months allocated for Phase 2D. These tests may be divided into the technical areas shown in table 1. As indicated, the majority of tests will be conducted at Government (DoD and NASA) facilities.

The NASP program embodies a range of technologies which are beyond the current state-of-the-art. These are primarily in two areas: propulsion and materials/structures. Propulsion tests are planned to support design validation and to address major performance and operability technical objectives. A coordinated series of engine tests will evaluate several classes of test articles. They include subscale engines, multiple flowpath module-to-module interaction (MTMI) rigs and large-scale, integrated flowpath engines. Subscale engine tests will be used to predict X-30 performance levels and operability over the full flight envelope. The MTMI test articles will simulate the internal aerodynamic and module-to-module effects of a scaled engine. MTMI tests will be conducted with engine flowpath, inlet, combustor, and nozzle components that are representative of current design configurations. Engine tests culminate with a Concept Demonstrator Engine (CDE) test which will validate the performance and operability of large-scale, integrated engine

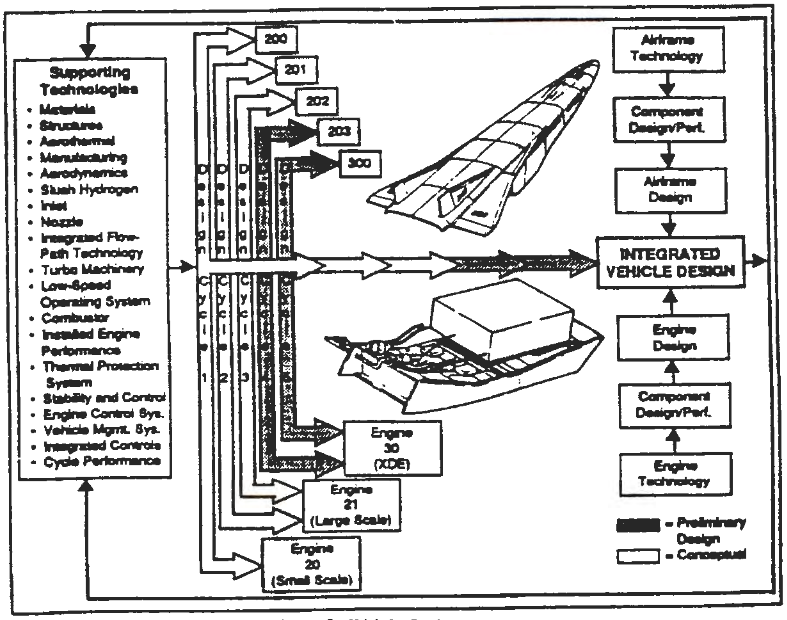

Figure 2. Vehicle Design Process

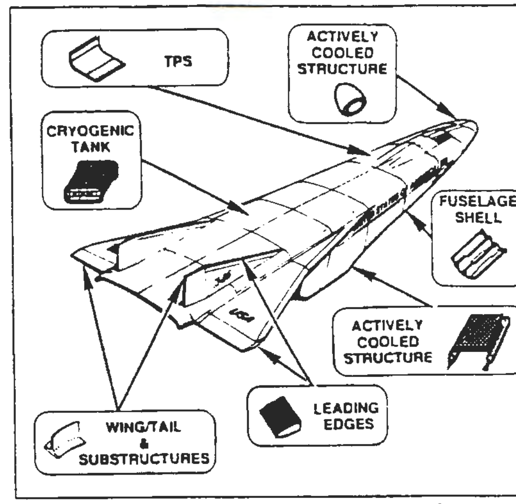

Figure 3. Airframe Structure and Materials Requirements

components at ramjet and scramjet operating conditions. The CDE test will also help verify component performance demonstrated in other subscale and isolated rig tests.

Engine structures and materials technology development activities will address the high-heat flux conditions expected in the engine environment. Testing will be performed to characterize the properties of current and advanced materials planned for primary engine structures, heat exchangers, seals, plumbing, leading edges, and thermal protection systems (TPS). Both subscale and full-scale engine coolant panel test articles will be tested to prove out design concepts. The X-30 must be able to withstand the demanding environment of hypersonic flight. Examples of airframe structures and materials required to make this happen are illustrated in figure 3. Subcomponent test articles are being built and tested to refine the design data base and quantify material

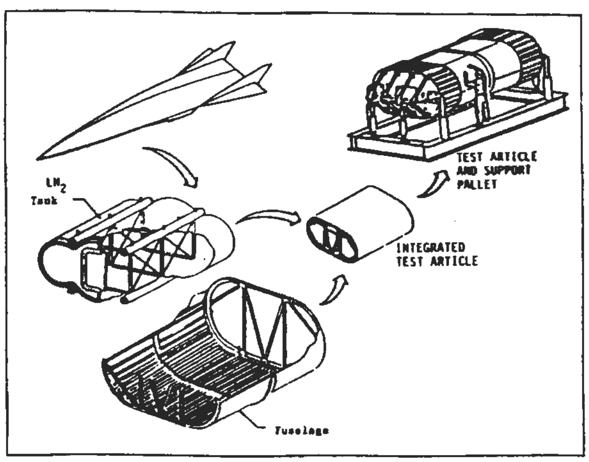

Figure 4. Fuselage/Tank Test Article

properties. Actively cooled structures are being manufactured and tested to demonstrate the technology is sufficiently developed for use in Phase 3. Full-scale sections of the primary airframe structures have been designed, fabricated, and are being tested. These includes testing of a full-scale fuselage section for which experience has already been gained earlier in Phase 2. For example, the fuselage/tank test article shown in figure 4 was developed prior to Phase 2D and is the largest titanium matrix composite (TMC) assembly built to date. The insulated multibubble hydrogen tank is fabricated from graphite epoxy. The test article shown has already completed initial tests that subjected it to mechanical and thermal conditions simulating a realistic flight trajectory. This test article will be used for further tests during Phase 2D.

Test Facilities

One of the many challenges to conducting the Phase 2D ground test program is being able to simulate the flight conditions that the X-30 is expected to encounter. Unfortunately, the United States does not currently possess the hypersonic ground test facilities needed to test proposed X-30 systems over the entire flight corridor. In addition, NASP does not have the funds nor time to fully develop this test capability. These funding and schedule constraints mean the program must minimize the development of new facilities. Existing facilities must be used as much as possible; modifying them only to the extent needed to meet the established exit criteria and technical objectives. Twenty facility upgrades are currently being planned and conducted to support Phase

2D testing. Additional long-lead facility upgrades are being worked for Phase 3 as well. The majority of Phase 2D facility upgrades are in support of structures and propulsion testing with most of the structural related upgrades being done to provide increased structural heating capabilities.

Figure 5 lists the various structures test facilities that have been modified since 1985, when Phase 2D began. The stair-step blocks represent the various sources or methods of generating desired heat flux levels. Going up the stairs, to the right represents an increase in heat flux capability. Those facilities above the stairs have been or are currently being modified in support of Phase 2D structures testing. Most of these upgrades are occurring at the Wright Lab (WL) facilities located at Wright-Patterson Air Force Base, Ohio.

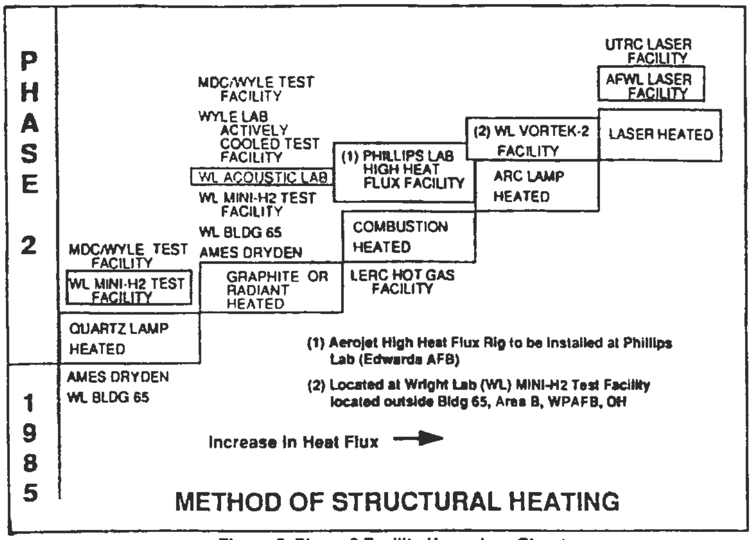

Figure 5. Phase 2 Facility Upgrades - Structures

Figure 6 identifies various aeropropulsion facilities that have been modified since 1985, either in support of NASP or via other initiatives. The facilities below the stair-step blocks of Mach numbers are some of the facilities available to NASP when Phase 2 began. Facilities above the stair-step are facilities that have been upgraded to provide the propulsion test capability applicable to NASP at the Mach numbers indicated. Those facilities that have been or are currently being modified in support of the Phase 2D test program are shown within boxes. Figure 7 illustrates the test facility capability in terms of altitude, free stream Mach number, and test article size that these upgrades are designed to provide within the air-breathing corridor for SSTO ascent trajectories. Examples of key propulsion tests that these modifications support include MTMI testing at the Aerojet Engine Test Facility (ETF) as well as CDE testing at the Marquardt ETF and NASA Langley's 8 Ft High Temperature Tunnel (HTT).

Other facility modifications are also underway or being planned to support systems tests and wind tunnel testing. These upgrades and those for structures and propulsion tests are significant pacing items along the path towards a Phase 3 decision. Several major tests and demonstrations cannot happen until key facility upgrades are completed. Many of these upgrades are being done concurrent with the design of the test article to be tested. This means the actual test conditions the facility can provide may not be adequately known until just prior to, during or, in some cases after the test has been accomplished. For example, modifications at the Aerojet ETF to provide a Mach 5 test capability have just recently been completed. MTMI testing is about to begin, but only a limited number of checkout runs have been conducted to quantify the flow of hot gas the facility produces to simulate the flight conditions of interest. Further surveying of the flow is desirable, but this must be weighed against program schedule and cost constraints. To address this issue, additional instrumentation will be added to the MTMI test article so that during the test, the flow entering the test rig can be sufficiently quantified. This will allow those who analyze the data to determine if test results are attributable to the facility or to the performance of the test article.

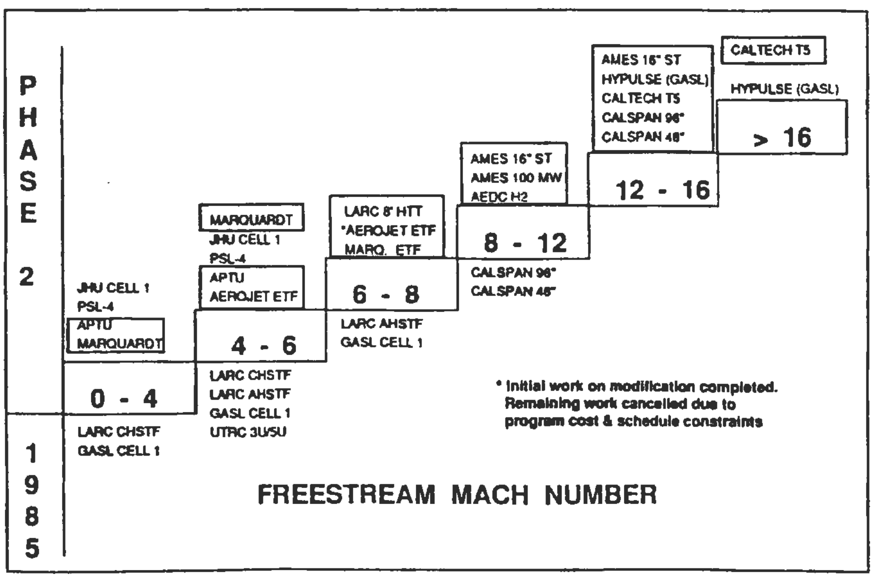

Figure 6. Phase 2 Facility Upgrades - Aeropropulsion

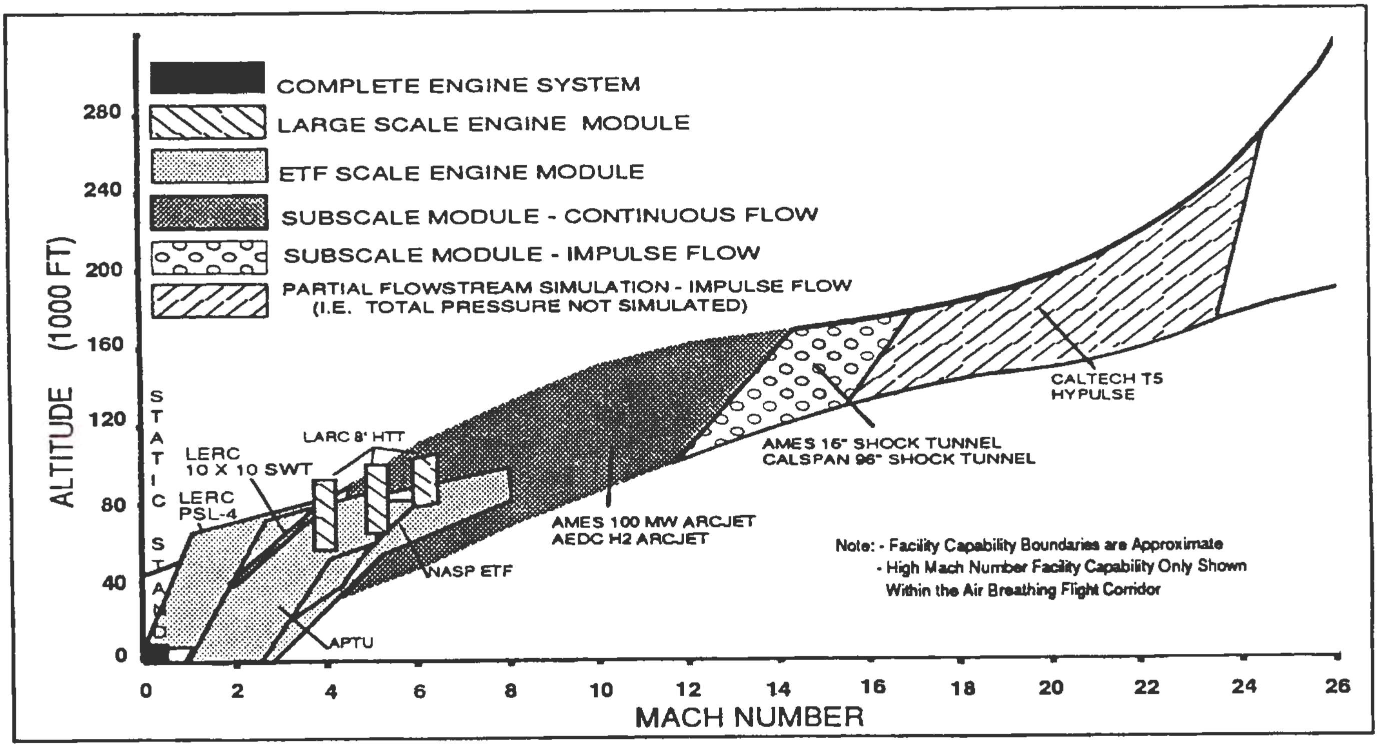

Figure 7. Phase 2 Aeropropulsion Test Facility Capabiity - Altitude vs Mach Number

Adequately quantifying the test conditions a facility provides will not be unique to the Aerojet ETF. NASP engineers will need to account for facility conditions when developing quantifiable measurements of how well the technology and vehicle design has matured. This applies especially to wind tunnel and propulsion test facilities since uncertainty in the data from these tests may have the greatest effect on vehicle performance uncertainty.

In God We Trust ... All Others Bring Data

The exit criteria established for the program provide broad guidance for determining if the technology has been sufficiently developed. The technical objectives and milestones associated with each exit criteria further define this guidance by specifying certain technical accomplishments to be achieved by a given date. Performing required demonstrations and tests will help show the design and technology is mature. However, these accomplishments alone provide only a qualitative indicator of whether or not exit criteria have been met and of how confident we can be that the Phase 3 program will be successful. Quantitative indicators will also be needed to substantiate the story NASP presents to those that will make the Phase 3 decision. Potential indicators may include such parameters as specific impulse, vehicle mass fraction, inlet efficiency, and combustion efficiency of the engine. Other indicators that provide a composite picture of these lower level indicators must also be developed. A key example of a top-level indicator is vehicle performance uncertainty which NASP engineers have been tasked to estimate so that sufficient margin can be designed into the X-30 vehicle to account for off-nominal performance during flight. To accomplish this task, statistical methods such as uncertainty analysis is being proposed to account for design uncertainties and uncertainties in test data. An example of the insight this methodology may yield is shown in figure 8 which illustrates the probability of a given vehicle configuration (baseline) achieving orbital velocity. The curves were generated using Monte Carlo simulation of the uncertainties in various performance parameters such as combustor efficiency and vehicle drag. [1] An increase in TOGW margin means the vehicle may carry additional fuel to get to orbit. The curves show that as this margin increases, the probability of achieving orbit increases. When applied to the vehicle design that will be reviewed at the Phase 3 decision point, this type of graph may be

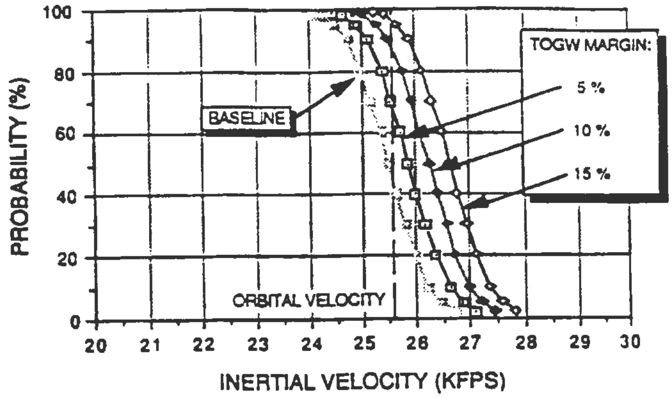

Figure 8. TOGW Margin Increase the Probability of Reaching Orbit

used to indicate the probability of the proposed X-30 design achieving SSTO.

The implications to the Phase 2D test program is that uncertainty analysis must be addressed upfront, when planning tests and selecting the facilities where the tests will be executed. Variances in the parameters that define a facility's test environment must be known since they are an important part of applying uncertainty methodologies to the test data. Efforts NASP has initiated to identify such variances include facility calibration projects at the Von Karman tunnels A, B, and C (Arnold Engineering Development Center, Tennessee) and Tunnel 9 at the Naval Surface Warfare Center, Maryland. These facilities are some of the major high speed wind tunnel test facilities scheduled for use during Phase 2D. A major objective of the calibration projects is to verify the tunnels' freestream conditions and quantify the associated uncertainties. These projects are now underway and will be completed prior to initiating wind tunnel testing in support of the current and future vehicle design cycles. As Phase 2D progresses and the program completes each design cycle illustrated in figure 9, data from the various tests will help reduce the uncertainties in vehicle and engine design parameters to some acceptable level. What will be defined as acceptable is still being worked. However, the test program can still proceed, but a concerted effort must be made to ensure uncertainty analysis is an integral part of the Technology Development / Demonstration effort. As the X-30 design matures and more test data is collected to validate the design, the program must ensure test data are well documented. In addition, any indicators used to assess design maturity must be clearly traceable to the supporting test data and analysis. The decision to enter Phase 3 cannot be made by faith alone... the data must be there to substantiate the story NASP will present at the end of Phase 2D.

Conclusion

Conducting the NASP ground test program presents significant technical and management challenges. Over 300 tests, scheduled at various Government and Industrial facilities, will be executed by five contractors as well as various universities and government research agencies. Obtaining needed test time requires extensive coordination among numerous government agencies as well as among the five contractor team members. Many tests are interrelated and several are linked to on-going

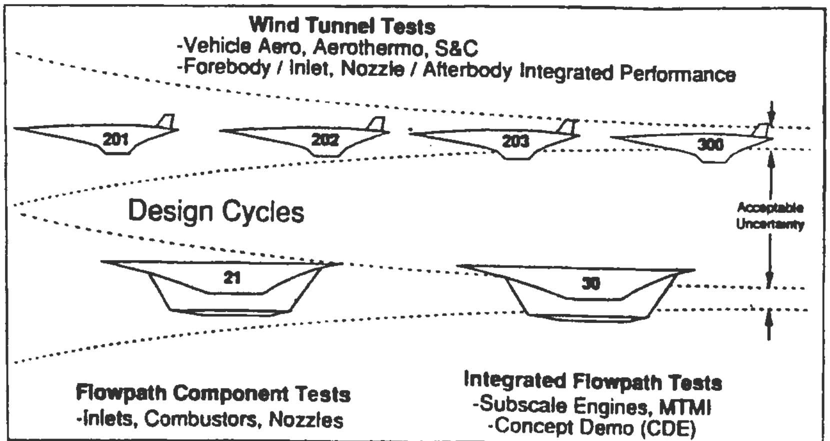

Figure 9. Test and Design Cycle Relationships

modifications to the test facility where the test will be conducted. Ensuring these modifications are completed in time to support testing means test planners must identify detailed facility requirements much earlier than usual. Establishing these requirements early will allow the facility modifications to be initiated with sufficient lead time. Even with these upgrades, acquiring the test data needed to support the X-30 design will still stretch current ground test capabilities both in terms of providing the required test conditions as well as collecting the desired test data. But perhaps the major technical challenge is in analyzing the data to determine what has been learned, and then extrapolating the data / analysis to the full-scale X-30 vehicle design. Successfully executing the NASP ground test program will require good up front planning and ensuring tests are clearly linked to the technology demonstration / development objectives and the Phase 2D exit criteria.

References

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