THE X-30 STRUCTURAL INTEGRITY PROGRAM: THE CHALLENGES AHEAD

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Some major issues are discussed that need to be addressed in the structural integrity program for the X-30 (NASP) vehicle. The primary emphasis in this paper is a method that may prove attractive for qualifying the structure for flight. A probabilistic approach is described that will enable the structural engineer to determine the risk of structural failure from the loading environment imposed on a hypersonic vehicle. The basis for the method is a time domain analysis where the loads from all significant sources are calculated and then a Monte Carlo technique is used to determine their probability distribution function. The probability distribution for strength is then determined based on an examination of the failure modes for each critical location. The combination of these distributions can then be used to determine the probability of failure.

INTRODUCTION

Over the last five years, the Air Force and NASA have conducted a wide range of design studies to identify the best technical course for building the next generation of manned Transatmospheric Vehicles (TAV) and supersonic and hypersonic military and commercial aircraft. Central to these studies was a joint Air Force/NASA technical study to assess the scientific feasibility of building a single-stage-to-orbit aircraft. In the fall of 1985, the Air Force and NASA jointly concluded that it was within the capabilities of this country to develop and demonstrate, through a tightly focused experimental aircraft program, the requisite technologies for a generation of new and highly advanced aircraft.

The National Aero-Space Plane (NASP) program—a joint Air Force, NASA, Navy, Defense Advanced Research Projects Agency (DARPA), and the Strategic Defense Initiative Organization (SDIO) program—was initiated to develop and demonstrate the technologies needed for safe and economical single-stage-to-orbit (SSTO) flight and endoatmospheric hypersonic cruise. To achieve and demonstrate these program goals, the NASP program will design, build, and flight test two experimental aircraft which have been designated the X-30. These two X-30 aircraft will be the first of a new generation of Transatmospheric Vehicles that can efficiently operate in the atmosphere or in space in low Earth orbit.

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While the X-30s will be experimental aircraft, one of the primary goals of the program will be to develop and demonstrate not only the technologies needed to accomplish SSTO flight and sustained hypersonic cruise capabilities, but to also develop and demonstrate those technologies needed to accomplish these flight capabilities in a safe and economical manner. Because of this latter emphasis, the X-30 primary design goals include the following:

- Aircraft-like operations (ground support, maintenance, flight planning, etc.).
- A fully reusable aircraft with no expendable parts other than normal wear and tear (brakes, tires. etc.) and extended time between subsystem replacement or repair.
- Normal aircraft horizontal takeoff and landing.
- Normal aircraft safe flight characteristics (system redundancies, safe abort, safe unpowered flight characteristics, etc.).
- Good overall system reliability, safety, and maintainability.

The achievement of these design goals, while at the same time producing an aircraft capable of SSTO flight, is the major challenge in deciding upon the appropriate structural integrity program for the NASP program.

THE NASP PROGRAM

The NASP Program has been organized into three phases (Figure 1). Phase I focused on the assessment of the feasibility of the concept of a SSTO vehicle and the technologies needed to build such a vehicle. This phase concluded in the fall of 1985 with the aforementioned decision to proceed with the X-30 program.

Phase 2 of the program began in 1986 and will extend until the fall of 1990. In this phase of the program, the propulsion and airframe contractors, working under separate contracts, are defining the propulsion system and airframe concepts. In conjunction with these conceptual design studies, the contractors and the government are conducting highly focused technology maturation programs to ready needed technologies in time for Full Scale Development.

At the end of FY 90, following a formal program technical review and decision to proceed, the program will enter Phase 3 which includes full scale development, production, and the flight test program. As Figure 1 shows. the current program schedule is aiming at a FY 1995 first flight, followed by two years of flight test envelope expansion leading to the first SSTO flight in FY 1996. Phase 2 and Phase 3 will take about ten years. In perspective, this is about the same amount of time as the Mercury, Gemini, and Apollo space programs of the 1960s took to develop the technology needed to land men on the moon.

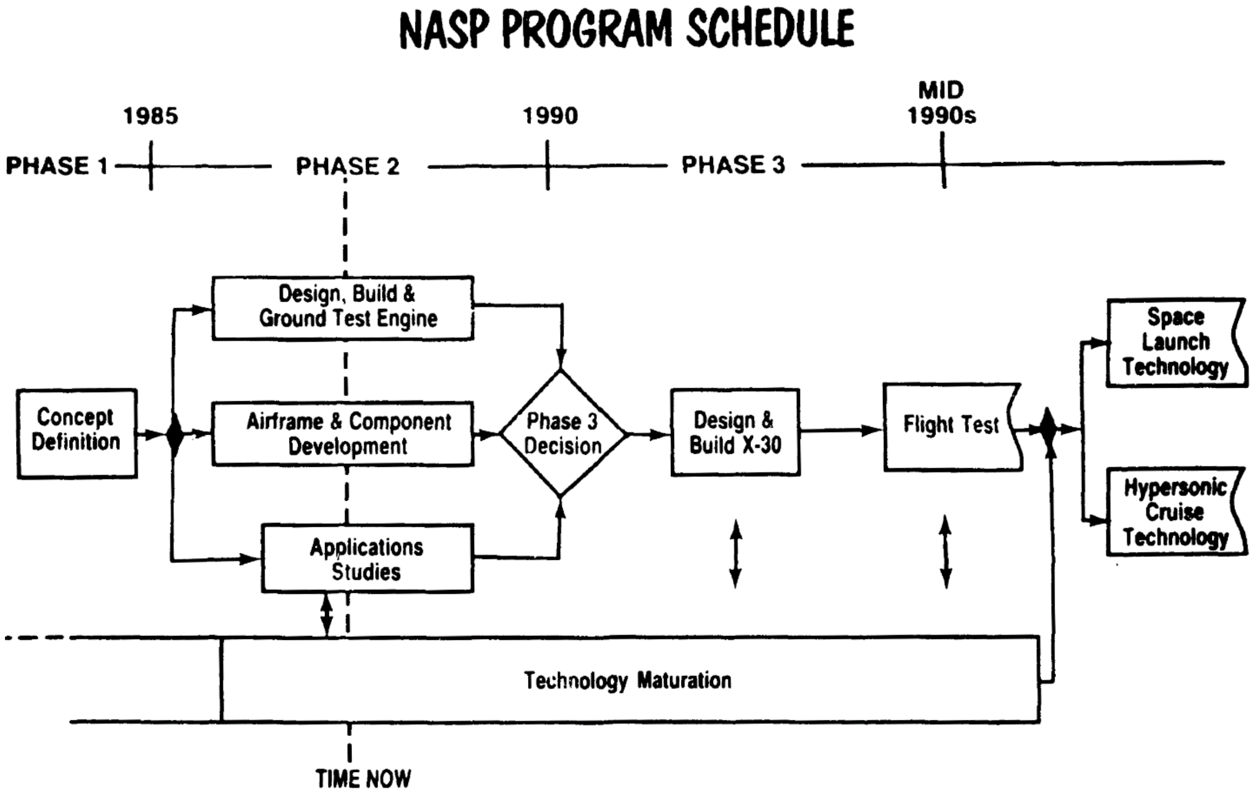

Figure 1: NASP program schedule as defined in 1988.

STRUCTURAL DESIGN DRIVERS

The central issue in designing a SSTO vehicle is the ability to synthesize a vehicle design that can carry sufficient propellant to accelerate the vehicle from the earth into low Earth orbit (LEO). The total change in velocity required is on the order of 24,500 feet per second.

Rockets have had this capability for thirty years. But they achieve orbital velocity through the mechanism of staging where all stages but the last stage, which carries the payload, are discarded as the rocket accelerates to orbital velocity. Staging is necessary to compensate for the low propulsion efficiency of these rockets. The problem with staging in this manner is that these expensive stages are only used once and then discarded. This prevents the rockets from achieving the economics of operation that fully-reusable vehicles, such as aircraft, routinely achieve.

The goal of having routine and economical access to space drives the design of advanced space transportation systems towards fully-reusable systems. The Space Shuttle system was originally intended to be fully reusable but reductions in development funding forced the program into substituting throw-away stages (the external tank) and partially-reusable stages (the solid rocket boosters) for a fully-reusable first stage. The economic impact of these decisions was not fully appreciated when these design changes were made.

The NASP program has selected a true single-stage-to-orbit vehicle over competing designs of quasi-SSTO and two stage systems. [A quasi-SSTO system is one such as the Boeing Reusable Aerospace Vehicle (RASV) which drops the main landing gear during takeoff and lands on a second, much lighter landing gear. This is a version of staging and was needed because the RASV was rocket powered.] The design of a true SSTO vehicle is governed by a single equation:

$$V_{orbit} = -g_0 I_e \ln\left(\frac{W_{orbit}}{W_{takeoff}}\right)$$

where:

V_{orbit} = Orbital velocity (24,500 feet per second)

I_e = Trajectory averaged propulsion efficiency (specific impulse, seconds)

W_{orbit} = Vehicle weight in orbit (empty weight plus payload plus propellant reserves)

$W_{takeoff}$ = Vehicle weight at the mission start

While simple in appearance, this equation, sometimes referred to as the “rocket equation", is deceptive in actual application to a vehicle design. The first item to note is that the required orbital velocity is a constant for a given orbital altitude, orbit inclination, and takeoff latitude. The second item to note is that the ratio of weights is, in the first order, an expression of the structural efficiency of the design. This ratio relates the weight of the structure to the mass (or volume) of the propellant required to be carried. For a typical SSTO vehicle design, this ratio will have values between 0.25 and 0.50. This means that every pound of structure must carry one to three pounds of propellant.

The structural difficulty in designing a SSTO vehicle comes from the demands placed on the structures from the remaining term in this equation. This is the propulsion efficiency or, in rocket terms, the specific impulse. (Aircraft designers are usually used to this being expressed as specific fuel consumption.) Our design studies have shown that in order to incorporate the aforementioned program goals into a vehicle of reasonable size, the trajectory averaged propulsion efficiency must be significantly higher than what can be achieved using only rocket propulsion. These studies have indicated that airbreathing propulsion must be used throughout most of the flight trajectory, perhaps as high as Mach 24, which is essentially orbital speeds, in order to obtain a sufficiently high enough average specific impulse that vehicle design closure can be achieved.

The demands that this very high speed flight within the atmosphere place on the airframe and engine are very severe. External leading edges would see radiation equilibrium temperatures in excess of 4000 °F. The upper fuselage radiation equilibrium temperatures would exceed 1200 °F and the lower, forward fuselage surface, which is the inlet compression surface for the engines, and the lower, aft fuselage surface, which is the engine nozzle expansion surface, would see significantly higher temperatures. These structures are also exposed to high dynamic pressures and high acoustic loads.

In addition, airbreathing propulsion systems above Mach 3 utilize ramjet and scramjet engines. Above approximately Mach 6, hydrogen must be used as the propellant in order to sustain combustion. This places the additional demands on the structure of safely housing a very cold (-427 °F) liquid with a very low density (5 lbm per cubic foot). Typical jet fuels have a density of 50 lbm per cubic foot—about ten times more dense than liquid hydrogen. This low propellant density, combined with the high propellant fractions (the percentage of the takeoff weight which is propellant), means that most of the vehicle houses propellant tanks.

These demands on the structures for the X-30 are very challenging. They must be very light weight in order to achieve the closure weight ratio, but they must be able to withstand a very severe environment of high temperatures, high dynamic pressures, and high acoustic loads dictated by the flight trajectory required to achieve the closure propulsion efficiency.

STRUCTURAL INTEGRITY ISSUES

The current USAF approach to developing structural integrity in military aircraft is embodied in the USAF Aircraft Structural Integrity Program (ASIP), MIL-STD-1530A, and the Engine Structural Integrity Program (ENSIP), MIL-STD-1783. These two programs were developed to apply a systematic technical management technique to new aircraft and engine development programs to ensure that the new products achieved the desired structural utility, safety, and economic cost of ownership. These programs have been successful because they have incorporated the lessons learned from prior development programs; they have been applied to aircraft and engines that are highly similar in design, materials, and use; and, there has been a large body of applicable engineering knowledge and test capabilities to support the many technical decisions made throughout the structural development program.

The instances where the structural integrity program for a new system runs into difficulty is typically with the implementation of new structures and materials technologies. New technology brings new problems and requires new engineering solutions. A well laid out structural integrity program recognizes the possibility of unknown problems and expands such areas as materials and component testing to help identify these new problems early to allow time for effective engineering solutions to be developed.

As described above, the demands placed on the X-30 airframe and propulsion system are substantial. To meet these demands, much of the airframe and propulsion system will be made from advanced materials utilizing advanced fabrication methods. The government and the NASP contractors have recognized the challenge of successfully transitioning these new technologies to the X-30. To aid this transition, the NASP program has instituted a broad series of technology maturation activities to help identify the unknown problems and to develop the needed effective solutions.

Table 1 lists several of the structural integrity issues that are being addressed for the NASP program. The remainder of this paper discusses these issues in more detail.

Table 1

X -30 Structural Integrity Issues

- Instrumentation for hot structures.
- Hot structure material development.
- Hot structure testing with hydrogen.
- Hot structure design criteria.
- Acoustic loading.

INSTRUMENTATION FOR HOT STRUCTURES

One of the main concerns in the development of a vehicle of this type is the lack of mature instrumentation for hot structures testing. This concern includes all of the coupon, component, full scale, and flight testing. As has been the case for previous programs, the structural instrumentation is the element that ties all of this testing together for analysis verification and for identification of failure modes in the development and full-scale testing which leads to first flight release. It is the essential basis for expansion of the flight boundaries after the initial clearance for flight.

The current family of structures test instrumentation has been developed for conventional materials operating in moderate temperature ranges. Because of the large temperature extremes and use of advanced materials, the X-30 poses a number of test instrumentation problems that include:

- Gage survival at elevated temperatures and liquid hydrogen cryogenic temperatures. This is especially a problem for flight test instrumentation where the gage location may be inaccessible after the completion of the vehicle assembly.
- Gage bonding techniques that can withstand the temperature extremes but also the rapid temperature changes that induce localized thermal strains at the attachment. For some materials, such as refractory composites, bonding gages is very difficult because of the large difference in the coefficient of thermal expansion (CTE) between the base material and the gage material. On these materials it is also not possible to weld the gage as has been done on some high temperature metallic structures.

- Shielding the attachment wiring from the thermal environment and routing the wiring in such a way as to prevent it from interfering with the temperature, heat flux, or strains that it is intended to measure. This is a particular problem in designing component tests that are radiation heated to simulate aerodynamic heating. In the extreme case, gage and wiring effects can induce localized thermal strains and cause local structural failures.
- Gage calibration over a very wide temperature range.
- Protecting the instrumentation wiring from damage due to exposure to the severe temperature environment.

Although there are many areas of the X-30 that have structural temperatures that are within the current strain gage capability, there are large areas that are heated to temperatures in excess of 1200 °F. The actively cooled nose cap and leading edges are heated to temperatures in excess of 2000 °F and some shock impingement points, which generate extreme localized heat fluxes and temperatures, could be heated to temperatures in excess of 5000 °F if uncooled.

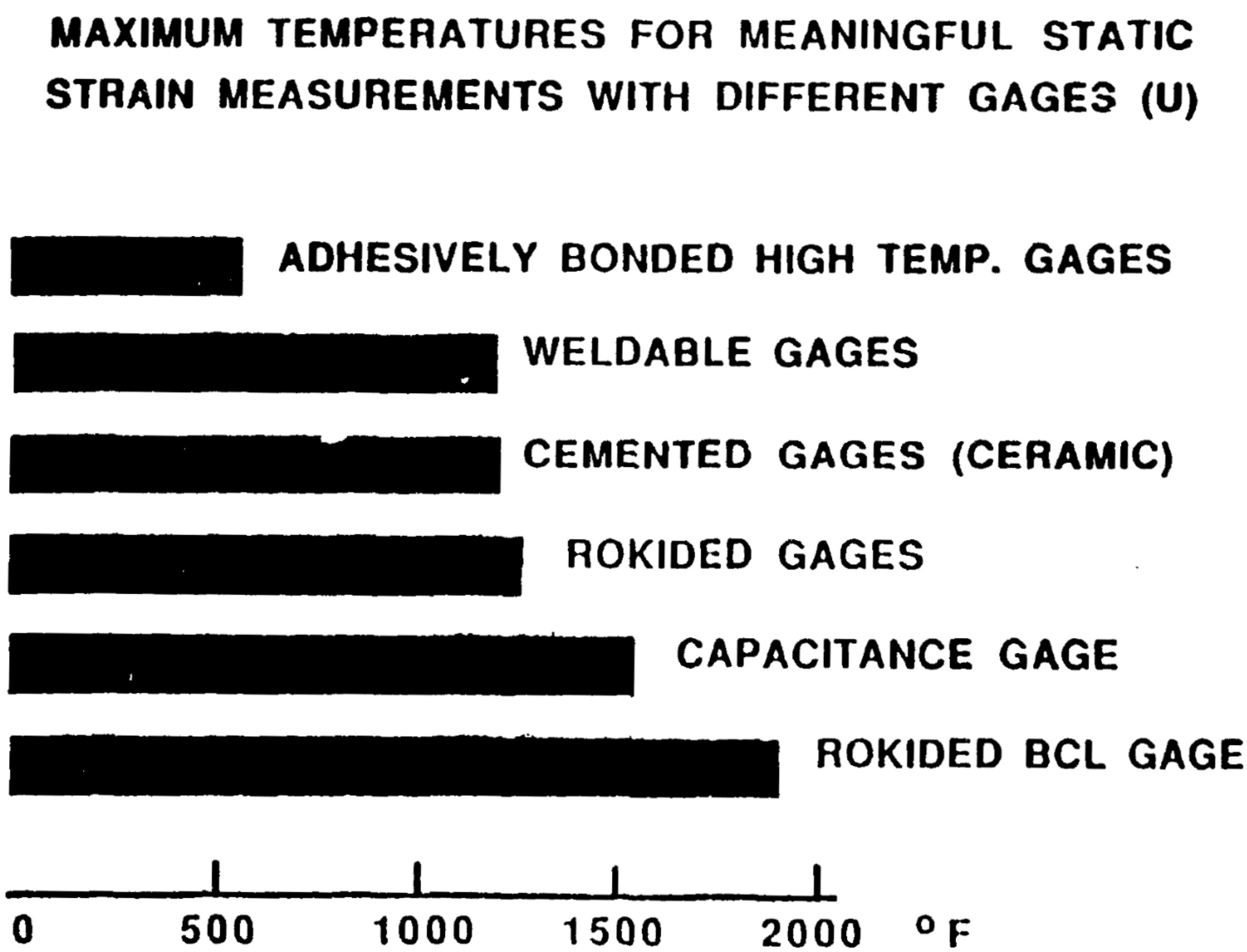

Figure 2: M. Lemcoe 1988 chart on high-temperature strain gages.

The presentation by M. Lemcoe at the Workshop on High Temperature Structures Testing held at NASA Ames-Dryden on 15-17 November 1988 provided an excellent assessment of the state of the art for strain gages. One of his charts is reproduced in Figure 2. It is evident that the capabilities of the gages listed are not adequate for all of the X-30 testing. It is not evident from this figure that the higher temperature gages are still in the experimental stages and that the cost of these gages will be significantly more than the conventional room temperature strain gages. The NASP program is also assessing the use of fiber optic measurement techniques and advanced remote sensing techniques using various laser applications.

HOT STRUCTURE MATERIALS

The stringent structural weight requirements in conjunction with the heating environment for the X-30 require that the use of materials that are not currently state of the art. The X-30 material goals are shown in Figure 3 relative to a conventional titanium alloy and Rene 41. The materials development is being addressed in the NASP Materials and Structures Augmentation Program. This program, which is a consortium of the NASP airframe and propulsion contractors, is focusing on five classes of materials: titanium aluminides, refractory composites, high specific creep strength, high conductivity composites, and titanium aluminide metal matrix composites. This materials effort will require three years to complete at a cost of 140 million dollars. It is the intent of this work to achieve the following goals:

- Develop and characterize new materials.
- Develop material processes.
- Verify the structural applications.
- Demonstrate producibility.

This work is being accomplished by assigning the primary responsibility for each of the material classes to an airframe or engine contractor. The contractors are sharing their results (and, in some cases, sharing researchers and facilities) with one another. This plan is proving to significantly reduce the overall cost of the material development and to compress the schedule.

Most of the selected materials are moving from the coupon stage to the small component stage. The initial environmental testing of representative small components (one and two feet square) will begin in the fall of 1989. By the end of Phase 2, the materials selected for use on the X-30 will be produced in panel sizes representative of those needed for assembly (4 feet x 8 feet) and similarly tested.

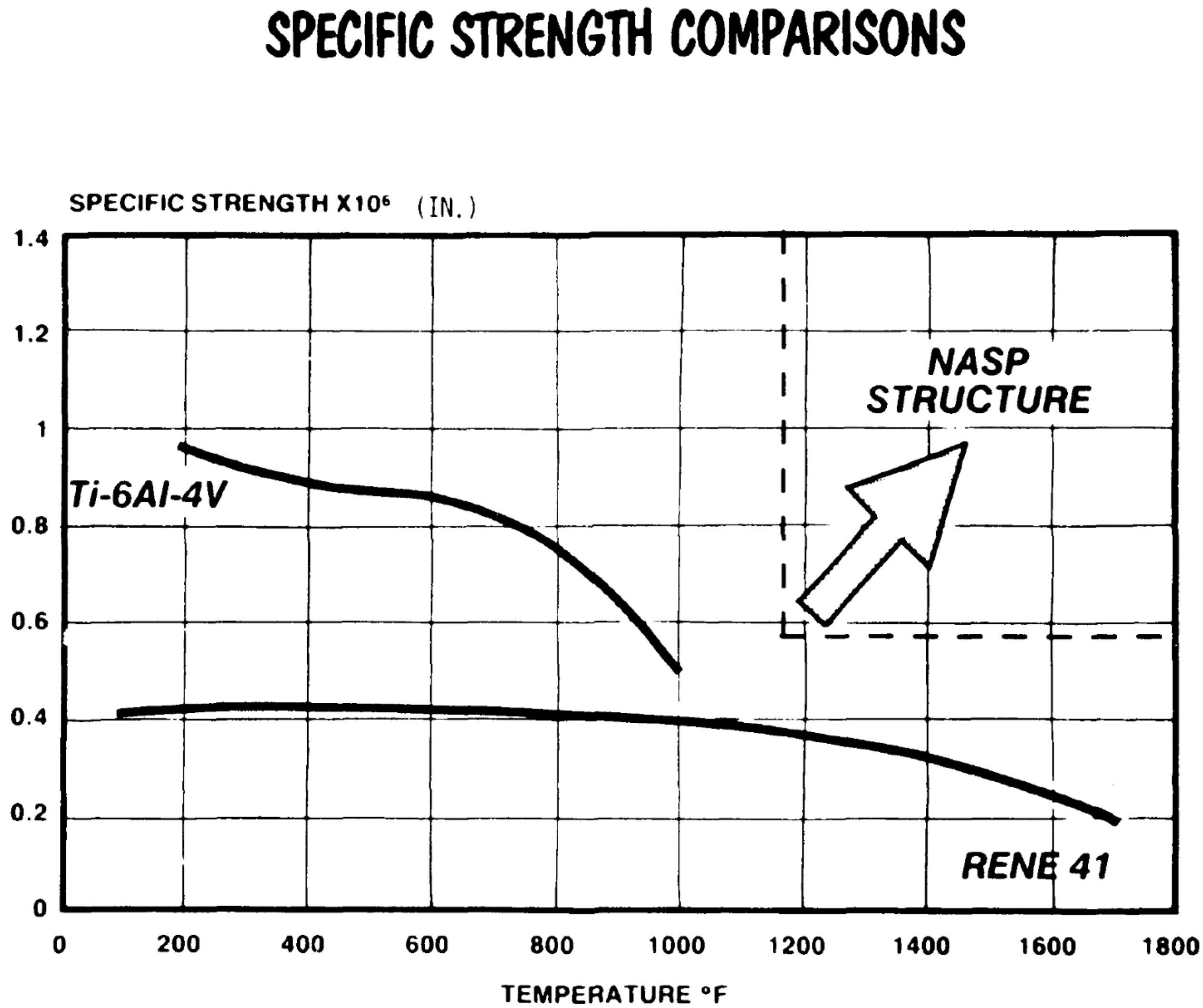

Figure 3: The specific strength of titanium and Rene 41 alloys compared to that needed for the X-30 NASP. Specific strength is the allowable tensile strength divided by the density.

HOT STRUCTURE TESTING WITH HYDROGEN

The X-30 will use hydrogen for its propellant because it is the only effective fuel for high Mach number airbreathing engines. Hydrogen also is an excellent heat transfer agent and can be efficiently used for cooling structural components exposed to high temperatures. Most of the ramjet and scramjet engine flow path structure, the lower fuselage surface inlet compression ramps, the aft lower fuselage nozzle, the engine cowl lip, the wing and control surface leading edges, and the nose cap will be cooled by hydrogen. Besides cooling the structure, this also heats the hydrogen from its normal boiling point temperature of -427 °F to the desired injection temperatures which are in excess of 1000 °F. This is done to maximize the propulsion efficiency.

Unfortunately, we have not yet identified a good simulant for hydrogen for use in structural testing of these actively cooled components. None of the other cryogens are near enough to hydrogen in heat transfer characteristics to provide an adequate simulation. Nitrogen and helium have been used in some design development testing and for analytical code correlation testing, but these cryogens are inadequate for testing the components at the design temperatures and heat fluxes without risking a structural failure. Further, there is a need to properly simulate the panel temperatures, the coolant pressures. and the through-the-wall temperature differentials, which requires the use of hydrogen conditioned to the proper inlet temperatures and pressures. The use of hydrogen, especially at elevated pressures and temperatures, adds significant complexity and cost to running these tests.

In the testing of the hydrogen storage tanks onboard the vehicle, neither nitrogen or helium may be a suitable simulant for liquid hydrogen. Again, the different thermodynamic properties of nitrogen and helium make their use in tank testing difficult. As with component testing, the large scale use of liquid hydrogen will add to test complexity and cost—especially that related to safety.

HOT STRUCTURE DESIGN CRITERIA

The USAF Aircraft Structural Integrity Program (ASIP) has been the basis for verifying that the aircraft structure has adequate strength to provide for a safe and economical operational life. The program to accomplish this is contained in MIL-STD-1530A. The detail requirements and guidance for analyses and ground testing are given in MIL-A-87221. This specification is the result of the evolution in requirements that has taken place over eighty years of powered flight. The detail requirements in this specification are deterministic although the background for the requirements in many cases is probabilistic in nature. For example, the statement that limit loads are the maximum loads which can result from a lifetime of usage of the aircraft is a probabilistic statement since it deals with expectation derived from previous experience with similar aircraft. Also, the A and B basis material allowables, which are statistically derived from test data, are used appropriately to make the likelihood of failure remote. There are other examples to be found in the damage tolerance requirements where their basis is tied to a probabilistic concept. The deterministic methods have gained widespread acceptance because they are easy to use and the precedents which they have established over the years have provided confidence in a new aircraft that is to operate in an environment similar to its predecessors. These precedents are important for release of an aircraft for first flight.

The most significant precedent for the X-30 is the X-15 aircraft. This rocket powered aircraft was designed to be released from a B-52, boosted by the rocket to attain its desired trajectory, and recovered by means of a landing without power. This program was terminated in the late 1960s. It had been flown almost 200 times and it had reached an altitude of 354,000 feet and a Mach number of 6.7. This vehicle was designed for a maximum temperature of approximately 900 °F. The design criteria for the structure is shown in Figure 4. It is seen that there was a different criteria for brittle materials than for ductile materials. It is also seen that, at ultimate, the ductile materials criteria does not include thermal stresses and the brittle material criteria includes only one times the maximum thermal stress. It should be noted that the X-30 materials will not be the same as the X-15 and the X-30 thermal environment will be significantly more severe.

STRUCTURAL DESIGN CRITERIA FOR THE X-15

DUCTILE MATERIALS
- AT LIMIT
  - MAX. MECH STRESS + MAX THERMAL STRESS < MIN YIELD STRESS
- AT ULTIMATE
  - 1.5 MAX MECH STRESS < MIN ULTIMATE STRESS

BRITTLE MATERIALS
- AT LIMIT
  - MAX MECH STRESS + MAX THERMAL STRESS < MIN YIELD STRESS
- AT ULTIMATE
  - 1.5 MAX MECH STRESS + 1.0 MAX THERMAL STRESS < MIN ULTIMATE STRESS

Figure 4: X-15 structural design criteria.

The X-30 aircraft will therefore be exposed to a thermal and mechanical loads environment that is far removed from the experience base from which MIL-A-87221 was derived. Not only are the thermal loads significant in magnitude, but there is an inherent uncertainty in the computational accuracy for the thermal and mechanical loads at high Mach numbers that have not been previously experienced. Also, the X-30 materials, which have been developed to withstand the severe thermal environment, may not lend themselves to the deterministic procedures that have been traditionally used for conventional materials.

These attributes indicate that the use of the current deterministic approach may be unconservative. However, the requirement for a low structural weight fraction for the X-30 indicates that no unnecessary conservatism can be tolerated. Therefore, the question is: "How can the aircraft be designed with no more than adequate strength to perform its mission?" The answer to this question may be derived by the use of a probabilistic approach to design.

The Probabilistic Approach

The primary motivation for the adoption of the probabilistic approach is that the designer can decide a priori the risk of failure he is willing to assume and then design the vehicle with that inherent risk. The risk of failure (probability) that the designer is willing to accept is, in general, dependent on the proposed usage for that aircraft. (Reference 1) For production USAF aircraft there have been two criteria used to determine an acceptable level of risk. The first criterion is that risk of structural failure in a single flight should be no greater than the risk normally accepted in an activity such as driving to work in an automobile. The second criterion is that the risk should be controlled such that the expected number of losses due to structural failure in the lifetime of the fleet should be less than one. The application of these principles indicate that the single flight probability of failure should be 10^{-7} or less. For experimental aircraft, the risk that could be accepted may be somewhat greater. However, it must be kept low enough to not present a significant threat to the goals of the program. It is judged that for an experimental program the probability of failure on any given flight should not exceed 10^{-5}.

Once the acceptable level of risk has been established, the loads calculations and the strength calculations can be made with the goal of deriving the probability distribution function for loads and the probability distribution function for strength. These distribution functions are independent of one another and, consequently, the joint density function for loads and strength can be derived from the product of the respective marginal density functions. This joint density function can be integrated over the region where the load is greater than the strength to determine the probability of failure. If this calculation does not yield the desired result, then the strength probability distribution can be changed by a structural redesign or the operational envelope can be changed to modify the loads probability distribution function such that the desired risk can be achieved. This process is illustrated in Figure 5.

PROBABILISTIC APPROACH

1. ESTABLISH ALLOWABLE FAILURE RATE
2. DETERMINE PROBABILITY DISTRIBUTION FOR LOADS

$$P(X_L < x_L) = F(x_L)$$

3. DETERMINE PROBABILITY DISTRIBUTION FOR STRENGTH

$$P(X_S < x_S) = F(x_S)$$

4. CALCULATE FAILURE PROBABILITY P

$$P_f = \int_{L>S} F_L' F_S' d x_L X_S$$

5. IF P_F IS NOT IN AGREEMENT WITH THE ESTABLISHED FAILURE RATE THEN MODIFY 2 OR 3

Figure 5: Probabilistic approach to be used for non-deterministic structural analysis.

The Loads Probability Distribution Function

It is evident that the loads on a vehicle such as the X-30 are dependent on many random and nonrandom phenomena. The random events include at least the following:

- Runway roughness.
- Atmospheric density, pressure, and temperature.
- Gusts and winds.
- Abort maneuvers.
- Control system errors.
- Initial thermal condition of the vehicle.
- Landing initial conditions.

In addition, there are also some phenomena that must be treated as random because they can be determined only to a limited degree of certainty. The following items are included in this category:

- Heat flux in and out of the vehicle.
- Aerodynamic loads at high Mach numbers.
- Engine thrust perturbations.
- Vehicle flight conditions while under direct pilot control.

There are, of course, the nonrandom loads associated with the planned flight path. A time domain procedure will determine the loads for all of these influences. Therefore, the recommended approach is to solve the equations of motion for the vehicle with sufficient degrees of freedom included to adequately determine the load time histories. It is judged that six degrees of freedom will need to be included to represent all important aspects of the rigid body motion. Additional degrees of freedom will be required to represent the deformation of the structure and its dynamic response to abrupt load changes. This can be accomplished through the use of the orthogonal vibration modes of the structure with a suitable boundary condition such as free–free. The number of these modes should be adequate to determine the response due to gusts and landing, and to determine the loading changes due to aeroelasticity. These modes will be dependent on the mass of the fuel burned by the engines and on the stiffness changes in the structure due to elevated temperatures. When the deformation degrees of freedom are included, it is desirable to use Lagrange's equations to generate the equations of motion.

The rigid body motion is most easily represented by the body axis components of the aircraft velocity and angular velocity vectors. These velocity and angular components cannot, in general, be integrated to orient the body in space and, consequently, are not generalized coordinates as required by the standard form of Lagrange's equations. This problem can be overcome through a modification of Lagrange's equations which was identified by Whittaker. (Reference (2) This modification of Lagrange's equations was used to develop the equations for finding the trajectory of the vehicle.

The abort maneuvers may be the primary source of load on the vehicle. Therefore, is it important that as these maneuvers are developed there is a loads calculation performed with a program such as the one described in this paper. This should help to keep the abort maneuver loads within the loads envelope from loads sources for which there is limited control. Wind and gust loads fall into this category.

The guidance and control equations are also included in the equations of motion. A major challenge is in the determination of the system errors that could influence the applied loads. This must be done on an ad hoc basis since the sensor and gyro technology used has a strong influence on the errors. Another major challenge is to obtain a stabilized version of the guidance and control system. Late changes in the system architecture may have a significant effect on the airframe loads.

The heat flux in and out of the vehicle is a source of concern since the analytical tools for predicting this at high Mach numbers are limited. In addition to this complication, the thermal loads calculations are difficult and time consuming to make. Therefore, these calculations will be made in a computer routine that is separate from the trajectory calculations. These calculations will be made at enough points of the trajectory time history to ensure that the thermal effects are properly reflected in the vehicle stiffness and, subsequently, in the vibration modes.

The engine thrust force determination is complicated by the fact that test facilities are generally inadequate to quantify the thrust for all Mach numbers of interest. Also, the effect of the rigid body and deformed body motion on the thrust may not be well known before the start of flight testing. It is essential that estimates of the expected thrust errors be included in the simulation. Available wind tunnel test results should help in the identification of these thrust perturbations.

Methods of Solution

Since the solutions of the equations of motion required for this problem do not lend themselves to simple probability calculations, the Monte Carlo method is the approach chosen to determine the loads probability distribution function. This may be accomplished in several ways. One approach is to obtain solutions of the equations of motion from repetitive sampling of the boundary conditions of the problem. The critical mechanical loads may then be determined for a number of time segments along the trajectory. These mechanical loads are then combined with the time correlated thermal loads. These loads will then be used to generate an exceedance function for a given time segment in the trajectory. These exceedance functions may then be used as a basis for establishing the probability distribution function. The exceedance functions are modified by dividing each of the ordinates of the exceedance functions by the number of occurrences expected in a single flight. This result is the sample probability of exceeding a given load on a single flight. This sample distribution is approximated by a Weibull, Gumbel, log normal, or other distribution for the purpose of obtaining an analytical representation which may be extended to cover remote loading situations. Another approach for doing this is similar to the first except that loads calculations are made for the purpose of defining a solution surface (normally represented by regression equations) which may then be sampled by the Monte Carlo method.

The strength probability distribution is determined for each critical structural element by assessing the features that influence the failure mode(s) for that element. This process is augmented by testing through the building block process which is a procedure of identifying strength and failure modes through testing of progressively more complex specimens.

Benefits from Use of a Probabilistic Design Criteria

The procedure outlined above is believed to have the following benefits:

- The approach will determine the risk of structural failure based on the knowledge of the random inputs.
- These calculations will show where testing can be utilized cost effectively to reduce the risk of failure.
- The approach will identify the need for envelope expansion flight testing.
- The areas of analysis shortcomings will be identified.
- The scope of the materials characterization effort will be defined.
- The approach will be a significant part of the basis for first flight release.

ACOUSTIC LOADING

The acoustic environment on the X-30 is expected to be very severe. D. Mulville, at the NASA Ames-Dryden Workshop on High Temperature Structures Testing, presented the estimates of the acoustic environment on the X-30 as compared with the AV-8B measured data. This comparison is shown in Figure 6. The validation of this estimated environment will not be easy since a significant portion of it is engine related and that data will not be available in the near term. The complications with this severe environment are compounded by the fact that much of the affected structure also has a severe thermal environment. This will obviously impose a significant challenge for the test verification of these structures.

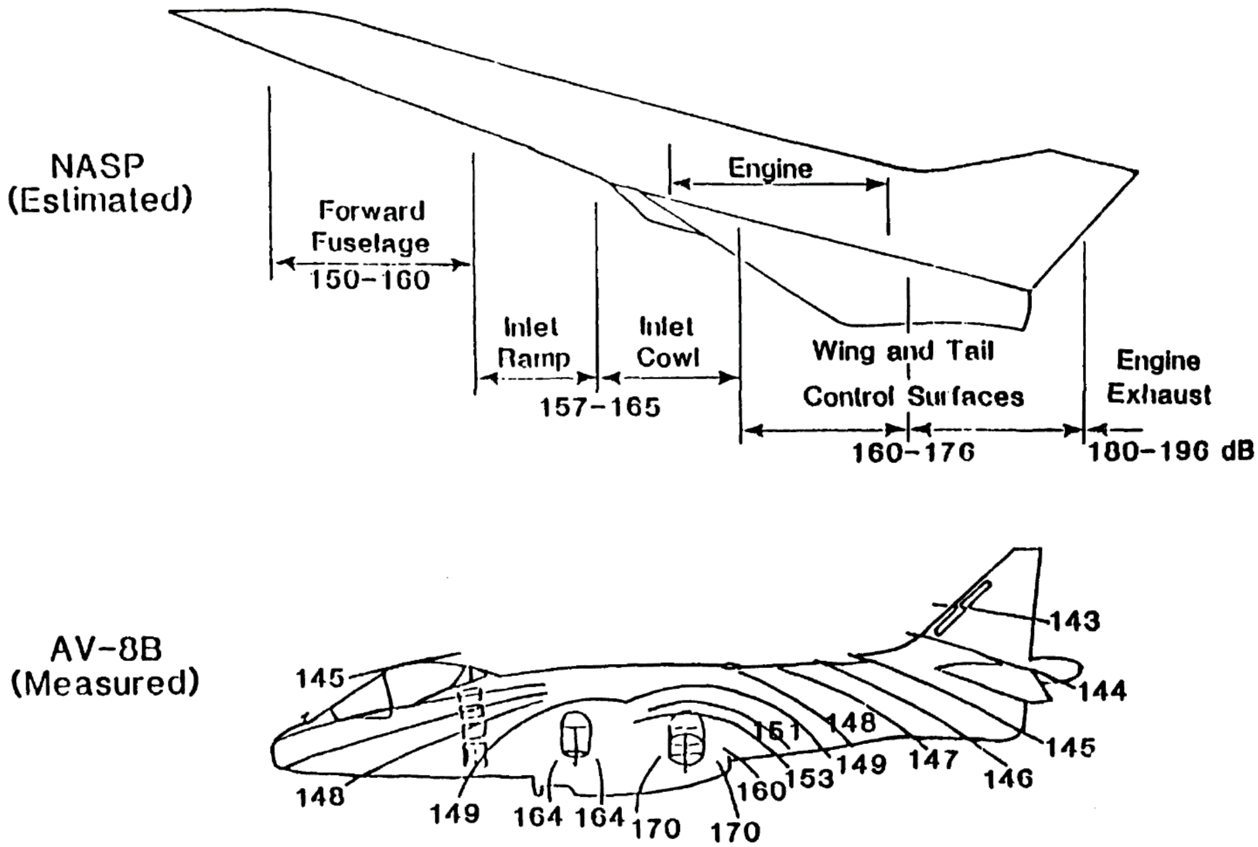

Figure 6: D. Mulville comparison of NASP estimated and AV-8B measured acoustic loads.

CONCLUSIONS

It is evident from the foregoing discussion that the X-30 structural integrity program will provide a significant challenge to the structural engineer. The basic doctrine of the ASIP will need to be used, but as indicated above, the problem will need to be tailored to meet the design goals for this aircraft. The probabilistic approach provides one means for the tailoring to be accomplished in a manner that will provide the best opportunity for the X-30 to meet its design objectives.

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