High Speed Research, Programmatic Focus on Flight for the Next Century

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Case Study

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Approach

This case study was developed in the interest of continuously improving program and project management at NASA. To augment a traditional case method approach, a theoretical framework was adopted from the sociotechnical systems tradition. Research for this case included comprehensive literature review, and detailed interview. To augment this case study, there is an available instructor's guide. In addition, learning modules have been developed based on the sociotechnical systems framework. These exercises prompt participants to understand HSR success from the perspective of the NASA Project Cycle. Project cycle variances and key practices and tools are identified in the context of project management.

It should be noted that the focus of this case study series is in the area of project management. Projects were selected based on the potential of providing lessons learned to current and future program and project managers. An outcome-based assessment of the projects studied may ultimately determine that mission objectives were ultimately not realized, but nevertheless project management lessons can be transferred for the betterment of program and project management at NASA and elsewhere.

High Speed Research: Programmatic Focus on Flight for the Next Century

In 1899, Orville and Wilbur Wright began their adventurous careers in aeronautics with their first publication for the Smithsonian. Within four years on December 17, 1903, human flight as a dream would be replaced with reality. Orville Wright would take his place in history as the first pilot of the first powered heavier-than-air machine to achieve sustained and controlled flight at Kill Devil Hills, North Carolina. In a twenty-seven mile per hour wind, Wilbur Wright with men from the local lifesaving station, would push the 605 lb. flyer along a rail with Orville mounted inside. Twelve seconds and 120 feet later, Orville recalled his historic flight:

> "The course of the flight up and down was exceedingly erratic, partly due to the irregularity of the air, and partly to lack of experience in handling this machine. The control of the front rudder was difficult on account of its being balanced too near the center. This gave it a tendency to turn itself when started; so that it turned too far on one side and then too far on the other. As a result the machine would rise suddenly to about ten feet, and then as suddenly dart for the ground. A sudden dart when a little over a hundred feet from the end of the track, or a little over 120 feet from the point at which it rose into the air, ended the flight. As the velocity of the wind was over 35 feet per second and the speed of the machine over the ground against this wind ten feet per second, the speed of the machine relative to the air was over 45 feet per second, and the length of the flight was equivalent to a flight of 540 feet made in calm air. This flight lasted only 12 seconds, but it was nevertheless the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in full flight, had sailed forward without reduction of speed and had finally landed at a point as high as that from which it started."
>
> (Excerpt from "How We Made the First Flight" by Orville Wright)

As the next millenium approaches, mankind is looking forward to new pioneers of transportation just as the Wright Brothers were in their time. The aeronautics industry has evolved significantly since the Wrights' historic flights. With a growing global economy, the airline transportation industry must be able to meet the future needs of the growing number of travelers. In the past 20 years, the number of travelers has tripled, with future travel expected to reach $2000 billion in revenue-passenger-miles per year by the year 2002, twice the present value. With these growing concerns, NASA along with industry began conducting studies in the mid-eighties to better understand the needs of the future travelers and the technology required to fulfill these needs. Eventually, NASA and industry would jointly undertake the technology development for a new supersonic aircraft under a focused effort, the High-Speed Research (HSR) Program. The HSR Program is a joint effort between NASA and industry that aims to produce the technology base for the development of a supersonic aircraft that is both **economically viable** and **environmentally compatible**, something yet to be achieved by any supersonic aircraft.

This case study was developed in support of the NASA Program and Project Management Initiative. The authors would like to acknowledge those individuals who contributed their recollections and expertise to this case study. Special thanks to the people at NASA Langley, NASA Lewis, General Electric, and Boeing. Also, thanks to the NASA Office of Training and Development and W. Warner Burke Associates, Inc. for their support.

Drivers for the High Speed Research Program

In the sixties, the Soviet Union, the United States, and a British/French consortium all had separate programs developing a supersonic transport (SST). However, only the Soviet Union and the British/French consortium proceeded to develop a supersonic transport. In 1971, the United States elected not to proceed with the transport due to environmental constraints, technology concerns, and economic and market uncertainties. Eventually, the Soviet Union would proceed to develop and produce the short lived TU-144 supersonic transport, while the British/French consortium would develop and produce the Concorde, which remains in service today. The Concorde was recognized with a number of technological achievements and accolades, however using 30-year old technology, the Concorde failed to be either economically productive nor environmentally compatible.

Figure 1: Conceptual Drawing of High Speed Civil Transport (Courtesy of General Electric)

In 1985 and 1986, the White House Office of Science and Technology Policy (OSTP) conducted several studies identifying future national R&D goals, (McDonnell Douglas Aerospace, 1994; NASA Office of Aeronautics, 1996) which would ultimately set the stage for a national strategy for future aeronautic endeavors which were necessary in order to maintain U.S. aeronautical preeminence. One of the major goals set by the OSTP was "... **development of technology for efficient, long-distance supersonic cruise for both future**

military aircraft and transpacific supersonic transports." (NASA Office of Aeronautics, 1996) With this study, a new push for research in SST would begin to take shape. By the late eighties, NASA began to plan what would become the HSR Program. NASA and industry conducted a series of studies to determine the viability of a High Speed Civil Transport (HSCT). From this effort, it was determined that a substantial HSCT market would be present if (NASA Office of Aeronautics, 1996):

1. the projected fleet would have no harmful effects on the atmosphere,
2. acceptable standards on sonic boom levels and airport noise levels could be met, and
3. the fare premium did not exceed about 20 percent of the new-generation long-haul subsonic transport fares.

According to Wally Sawyer, Director of the HSR Project Office:

> "it (the HSR Program) was laid down in two phases, Phase I was to look at the environmental concerns and to see if there were any show stoppers, and by that we really wanted to see if we were going to run into emission problems that we couldn't solve with technology, if there were environmental problems, if there were any noise problems. . . What that (Phase I) told us is that we can be successful, that we think we know ways to make engines quieter, we think we know that we can make an economically viable airplane by not flying supersonically over land. . . Now we are in Phase II, which really has to do with the performance and economic side of developing the airplane."

Program Definition

Phase I of the program, which began in 1990 and ended in 1995, sought to provide evidence that the technologies could be developed for a future environmentally compatible HSCT. This phase focused on identifying HSCT environmental compatibility requirements relating to atmospheric effects, community noise, and sonic boom using the facilities and resources from a variety of NASA centers, and industry partners.

Table 1: High-Speed Civil Transport Comparison (NASA Office of Aeronautics, 1996)

Concorde		**HSCT Goals**
North Atlantic	Market	Atlantic and Pacific
1976	Entry into Service year	2006
2.0	Speed (Mach No.)	2.4
3000	Range (nautical mi.)	5000
100	Payload (passengers)	300
400,000	Takeoff Gross Weight (lbs).	750,000
87	Required Revenue (cents/RPM)	10
Premium	Fare Levels	Standard
Exempt	Community Noise Standard	FAR 36 - Stage 3
20	Emissions Index (gm/Kg fuel)	5
75	Noise footprint (sq. mi.)	5

As a result of the early encouraging findings in Phase I, Phase II was initiated concurrently with Phase I. Phase II aimed "to develop technologies which will ensure the economic viability and environmental compatibility of future HSCT." (NASA Office of Aeronautics, 1996)

The final outputs of Phase II involve full scale demonstrations of major components of the aircraft such as the wing, the fuselage, and various engine components, and full scale validation of the cockpit visualization system. Most of the technology in the HSR Program will be developed to a readiness level 6 as described in Table 2:

Table 2: Technology Readiness Levels used by NASA

Technology Readiness Levels	
9	Actual system "flight proven" on operational flight
8	Actual system completed and 'flight qualified" through test and demonstration
7	System prototype demonstrated in flight
6	System/subsystem model or prototype demonstrated in a relevant environment
5	Component (or breadboard) validation in a relevant environment
4	Component and/or breadboard validation in a laboratory environment
3	Analytical and experimental critical function and/or characteristic proof-of-concept
2	Technology concept and/or application formulated
1	Basic principles observed and reported

The major outputs of the various phases is shown in figure 2:

CY	1993–1996	1997–1999	2000–2002
Major HSR Milestones	Technology Concept	Technology Configuration	Final Technology Configuration
Regulatory/ Environment	•Phase I Assessment of Atmospheric Impact •Preliminary Noise Assessment	•Phase II Assessment of Atmospheric Impact •Refined Environmental Goals and Configuration Assessment	•Final Updated of Environmental Goals •Environmental Impact Assessment of Validated Technologies
Propulsion	•Engine cycle, Inlet and Nozzle Concept Selected •Combustor Rig Verification	•Testbed Nozzle Designed •Testbed Inlet Designed •Combustor Configuration Selected •Tested Engine Combustor Designed •Engine Architecture Established	•Nozzle Acoustics and Performance Validated •Inlet Performance Validated •Core Engine Combustor Emissions w/CMC's demonstrated •T/M Disk and Turbine Airfoil Systems Validated in Engine Tests
Airframe	•Technology Concept Defined •Wing and Fuselage Structural Preliminary Concepts •Candidate Flight Deck Concepts Selected •High-Life Concept Defined •Preliminary Planform Defined	•Wing and Fuselage Subcomponent Tests Completed •Wing and Fuselage Component Designed •Preliminary Flight Deck Configuration Selected •SLFC Tests Complete and Evaluated •Tech. Concept Aero. Verified	•Validated Materials Database •Validated Wing and Fuselage Structures •Firm Flight Deck Configuration Defined (Nose Droop Decision) •Full External Visibility System Capability Validated •Aerodynamic Performance Verified

Figure 2: HSR Program Milestones

Aiming High

With the studies from OSTP, NASA, and industry, it was clear the HSCT could be a viable aircraft if it met certain environmental and economic requirements. However, it was recognized that the requirements, especially the environmental requirements, may not remain the same by the time the aircraft is certified. With this mind, HSR program management set its sight on aggressive goals to recognize that the HSCT already has a competitor, the subsonic plane, which will be able to fly quieter, and be more environmentally friendly than the subsonic planes of today. Thus, the HSCT goals were set with the future in mind, with regulations that are stricter than those regulations existing today, and those that may not even exist today, as Wally Sawyer explained:

> "The vision being there (by 2002) that you lay the technology on the table for industry to make the decision to go forth with the development of an airplane. And that technology is in such shape that they can develop an economically viable, environmentally compatible airplane. That would go 5000+ miles, carry 300 people, and 2.4 times the speed of sound."

Along with the environmental and economic challenges of the airplane, several technological developments needed to be achieved in order for the aircraft to be both environmentally compatible and economically viable. The major program objectives that will determine the success of the airplane include the following (NASA Office of Aeronautics, 1996):

- Enabling Propulsion Materials (EPM)
  Advanced materials for achieving combustor liner with no internal film cooling and 9,000 hot hour life at 3000°F, and 30 percent reduction in nozzle weight and 18,000 hour life at 2400°F.
- Critical Propulsion Components (CPC)

  Advanced components for achieving NO_x Emissions Index of 5 grams per kg fuel burned, Stage III airport noise levels.
- Propulsion Systems Technology Integration

  Demonstration through analytical predictions of 4 percent/10 percent reduction in fuel consumption at supersonic/subsonic cruise operation relative to the Concorde's Olympus engine.
- Aerodynamic Performance and Integration

  Advanced materials and structural concepts for achieving 30-40 percent reduction in weight and 60,000 hour life at 350°F relative to the Concorde.

- Flight Deck Systems
  Advanced cockpit systems and certification guidelines for safe and efficient aircraft operation in international airspace system

A New Way of Doing Business

High-Speed Research Program Partners

INDUSTRY
- Boeing
- GE Aircraft Engines
- McDonnell Douglas
- Pratt & Whitney
- 40+ Major Subcontractors/Suppliers

NASA
- Office of Aeronautics
- Office of Mission to Planet Earth
- Langley Research Center
- Lewis Research Center
- Ames Research Center
- Dryden Research Center
- Jet Propulsion Laboratory

Mode of Operation

In Phase II, HSR management decided upon instituting an equal partnering arrangement between themselves and industry. The impetus behind this arrangement was that industry had already been heavily involved with supersonic research studies with NASA from the eighties, and that ultimately, industry, not NASA, would be the customer of the HSR program deliverables. Partnering with industry was just not enough. NASA centers would also have to partner amongst themselves to avoid duplication of effort and to ensure that work would be sent to the facility that was best suited for the job.

Organizational Design

Early on, Lou Williams, former HSR Program Manager and Rob Anderson, former HSR Program Deputy Manager, decided the HSR organizational structure should be split along two major lines: Airframes, and Propulsion (see figure 3). Even with this structure, HSR program management knew the relationship between these divisions should not be necessarily equal, since it would be the propulsion system that would be ultimately mounted onto the airframe. Thus, through initial planning, the organizational structure would be set up so that the propulsion system design would be rolled up into the airframe system design rather than vice versa. The question for NASA would be: "How did each center fit into this organizational structure?" Ultimately, NASA Headquarters and HSR program management agreed it was in the best interest of the program that NASA Langley Research Center (LaRC) would have the primary responsibility for the Airframe division, while NASA Lewis Research Center (LeRC) would have the responsibility for the Propulsion division. This agreement was based on the prior experience of each of the centers. Within that structure, other NASA centers would have the responsibility of specific tasks within each of those divisions. As Wally Sawyer commented:

> "In fact, what my vision is as program manager in dealing with industry, as we get closer and closer to the end of our program, that the program structure should look more and more like what an airplane development program (looks like) in industry. So as where we started out over here as all research, the NASA way, divisions, how you might set something up. As we are marching through time, we are starting to develop the teamwork, and the teams we have are looking more and more and more like what an industry airframe-propulsion team would look like to build an airplane. Such that when we hand that off, airplane people think of wing, fuselage, propulsion system, systems. The teams and the packaging of the material will go right into that such that we would have a really clean hand off, nice transition, and they can go with it."

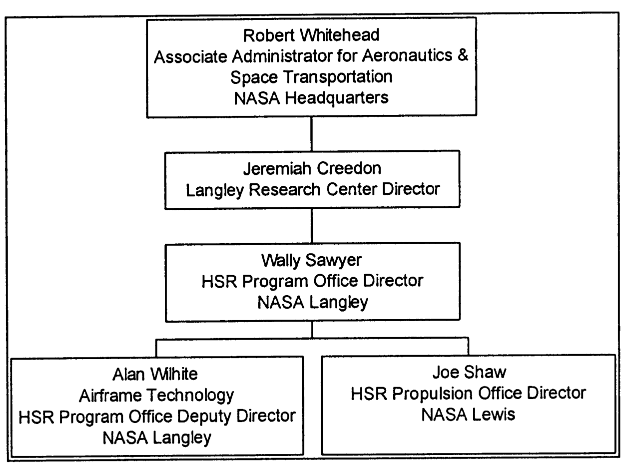

Figure 3: Major Organizational Breakdown of Current HSR Structure

Another area that needed to be dealt with up front would be the role of NASA Headquarters in the program structure. With the downsizing of NASA Headquarters, Administrator Dan Goldin ordered program management to be transferred from headquarters to the centers. Dr. Robert Whitehead, Associate

Administrator for Aeronautics and Space Transportation Technology (ASTT) selected NASA Langley Research Center as the lead center to manage the HSR Program. The Airframe and Systems Integration management was incorporated into the Program Office at NASA LaRC, while the Propulsion management reports to the Program Manager and also the functional manager at NASA Lewis Research Center. This relationship would be formalized in the HSR Program Plan.

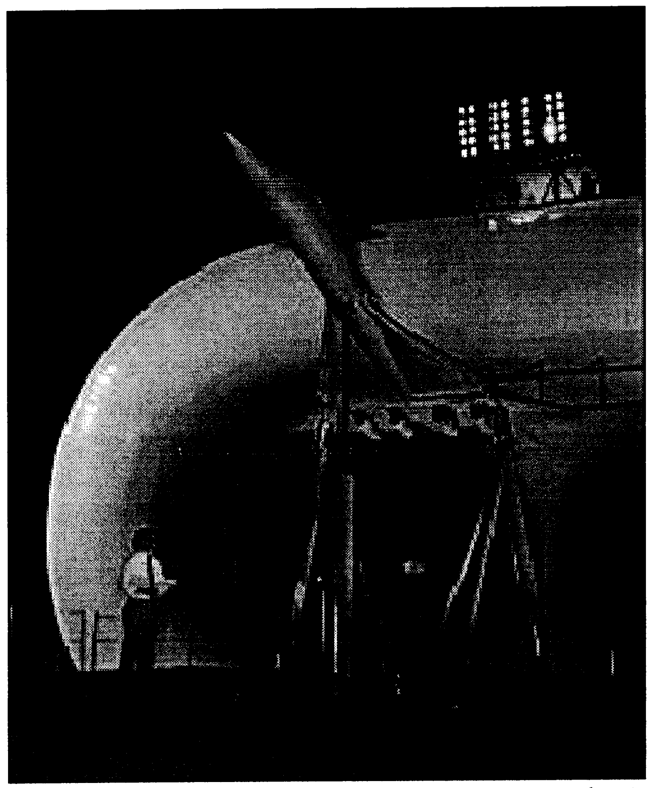

Figure 4: Technician inspects a HSCT model between wind tunnel tests at NASA LaRC (Courtesy of NASA Langley Research Center)

Although there was some resistance by NASA to conduct business in this way, NASA Headquarters and NASA ASTT Centers were able to buy into this new arrangement and effectively communicate this to the NASA program members. As part of this equal partnership between industry and NASA, cost, schedule, scope, and technical objectives would have to be dealt with by all the partners. With this new mode of operation, it became clear that a new mechanism of working these issues would have to be instituted and formalized.

High Stakes

With a projected $600 billion dollars at stake and a potential $409 billion swing in U.S. sales, the aeronautics industry and the United States have a vested interest in the outcome of HSR. For the United States, the HSR program is essential to insure American industry preeminence in the aeronautics market. However, there are other SST efforts being conducted by the Europeans, and the Japanese. It is estimated that nearly 150,000 new jobs may be created from bringing a HSCT online. However both industry and NASA need to be wary. As Wally Sawyer explains, "If we don't provide the right technology and they make the wrong decision based on that and try to launch an airplane program that is unsuccessful that ruins a Boeing, and ruins a McDonnell Douglas and takes them down such that in the future we are totally dependent on the European market, then they can ask for the price they want... There is a tremendous opportunity for us to develop 140-150,000 new jobs, five hundred billion dollars worth of economics but if we are not, and it can't be done I don't want to see our companies be the ones that go under because of it."

Managing for Success

To help with this new management approach, General Electric had proposed utilizing consensus management with HSR based on their experience with other industry programs. Consensus management could help ensure involvement of NASA and industry team members, but team members would need training in consensus management so everybody would have a common set of ideas on this new management approach. General Electric and West Virginia University would set up a consensus management training program in which the propulsion team members participated. Eventually, the Airframe members would undergo a similar program. With this training, HSR members would be better able to operate under this new partnering arrangement.

As part of the partnering arrangement between NASA and industry, contracting issues needed to be dealt with up front in order to avoid future problems. Although different contracting methods were utilized by the Airframe and Propulsion Teams, the basic contract type was still the same: a cost plus no fee contract. Since industry was the ultimate customer of the technology development of HSR, it was only logical that industry should not make money off the contracts issued by NASA, as they would eventually benefit from the technology development from the program in building the HSCT. Furthermore, the technology developed from the program also could be used by industry in other commercial ventures. Thus, NASA awarding a fee to industry really did not make sense. However, NASA LaRC decided to use task-order contracts, while NASA LeRC chose to use mission-oriented contracts. This arrangement allowed each center to work with the contracting arrangements that they were accustomed to and familiar with in the past.

With all industry members having cost plus no fee contracting arrangements, all industry members would be treated the same financially. This would help reinforce the idea that not only were NASA and industry treated equally, but even among industry participants there were no favorites. Using the contracting arrangement, team members were motivated to employ resources where they would benefit the program most. This became especially important as work began in HSR, as resources had to be split up among industry members. As a result, individuals were less likely to compete for work, rather they were more apt to divide work according to who was the best suited for the task. David Utah, EPM's Ceramic Matrix Composite Combustor Team Leader at GE Aircraft Engines explained:

> "well there's two approaches, one is competitive contracts between GE and Pratt and the second is teaming. . . The one big advantage of teaming is that you're sending one message to the suppliers. . . for years GE would go into our suppliers that makes our composites, and we would say we need certain properties. And Pratt & Whitney would come in probably on the very next day and say they need something else. And the supplier is sitting there, who do I listen to? Now, they hear one story from both GE and Pratt. . . so we take one message to the supplier. . . and when we talk, they listen, I think that's an advantage. We've tapped into NASA capabilities, which I think is a definite advantage, having NASA work with us, the scientists from NASA. Helping us identify the problems and the solutions. So I think that's the advantage of working together. And even between the GE and Pratt, probably to less of a degree than between for example, GE and NASA or Pratt and NASA, we help each other. Another advantage of the teaming is that quite honestly, GE doesn't have the manpower to do everything that would be required in both the scale up and the production, or the development.....It spreads the work load. . . "

Keeping the Lines Open

Without a doubt, partnering would not come easy to HSR, since many within NASA and industry were inexperienced with consensus management. As a result, teams would require time to build the trust and relations which are essential components to consensus management. The problem was that team members were usually hundreds or even thousands of miles away. Therefore special arrangements and tools for team building would have to used to deal with this problem. One of the ways to deal with this geographic dispersion was simply to use technology to overcome the distance, however the value of face to face meetings was still crucial for team building and development. For most team members throughout HSR, face to face meetings would be set up in order to build the trust and the camaraderie within each team. The team building was also supplemented by the use of video and audio conferencing technology, although it took more time than it would have if the team members had been collocated from the beginning. Informal and formal meetings using conferencing technology would become the norm for communication, decision making, and reporting.

Once a month, several team members participate in a "Wallycon", a teleconference where Wally Sawyer is briefed about progress from the various teams, and any major issues or concerns. This allows Wally and others in HSR program management to be in touch with the major issues of the program especially those dealing with cost, schedule, scope, and technical objectives. Preparing for the Wallycons initially took a great deal of effort from the teams, however, the Wallycons were necessary for program management to understand and deal with programmatic issues as they come up from month to month. With the extra effort, HSR members realized that these Wallycons could also be used at the Independent Annual Reviews required by NHB 7120.5. Therefore preparing for the Independent Annual Reviews was merely a formality that only required integrating and formatting the Wallycons from the previous year.

"Communication is the most important part of the program," commented Ed Graber, Critical Propulsion Components Manager. To deal with the lack of collocation would require the recognition of HSR team members that people had to keep the communication lines open. Several HSR members estimated that nearly one quarter of the resources spent on HSR is towards communication and coordination with other team members. HSR has developed a comprehensive secure web site to help disseminate some of the information that teams may require at any time and to deal with the lack of geographic dispersion. Using secured internet technology, various teams are able to provide information on Work Plans, and Planning and Control Documents, the minutes of weekly meetings, configuration control, action items, deliverables, etc. and are able to share this information with other teams. The web site also facilitates the exchange of files which are necessary between teams, and which cannot be exchanged using unsecured email. Using the various technologies and making an extra effort towards open communication have helped most HSR team members forget about the distances between them.

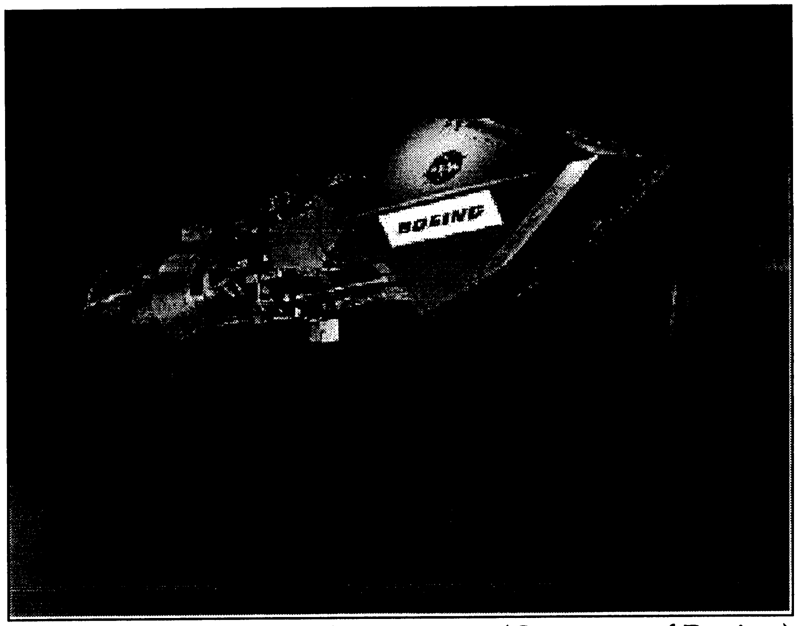

Figure 5: Testing of Inlet Concept (Courtesy of Boeing)

Focusing on the Airplane

With the complexity of the teaming environment, focusing work efforts on technology development of the entire aircraft was a challenge to the HSR members. However a focus on the aircraft as a complete system with many subsystems has helped the program meet this challenge. This has been accomplished through the careful design of HSR's organizational structure. At the lowest levels, known as Integrated Technology Development (ITD) teams, the HSR structure represents a logical breakdown of specific technology areas needed for the technology development to be successful. The ITD teams are the ones who are developing the technology for the HSCT. Above the ITD teams, the Technology Management Teams (TMT) exist to do additional work and to integrate the work from the ITD teams into subsystems and eventually into a complete aircraft. Above the TMT and the ITD teams, the Airframe and Propulsion Teams, Integrated Planning Team, and Leadership Team exist to provide planning, direction and an overall strategy to HSR. Within the HSR Program, there are approximately sixty teams, thirty-three being ITD teams. A small section of the HSR Program structure is shown in figure 6:

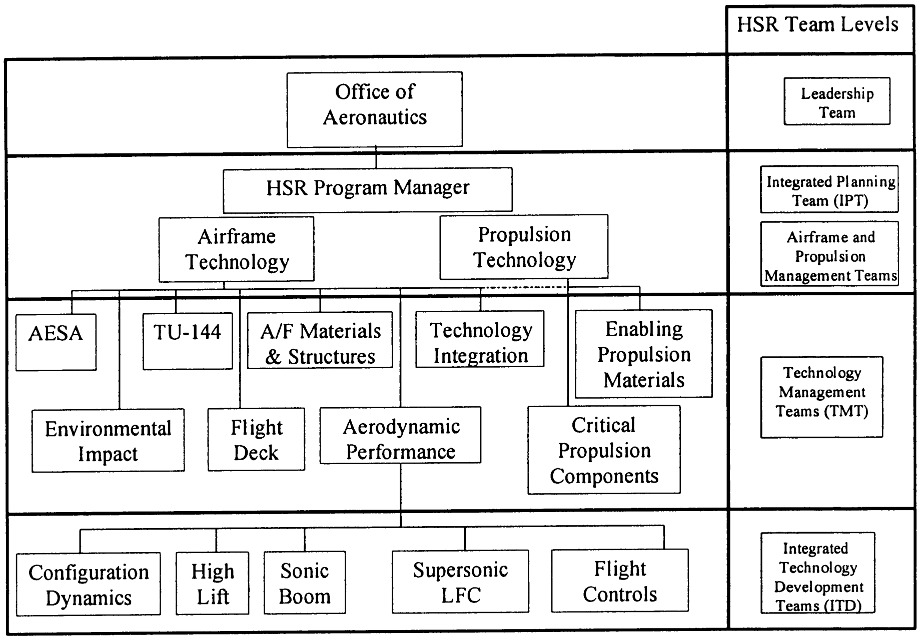

Figure 6: HSR Program Organizational Structure (NASA Office of Aeronautics, 1996)

The roles and responsibilities of each team level were clearly defined from the very beginning of the program (NASA Office of Aeronautics, 1996):

- **Program Leadership Team** (PLT): Provides high level NASA and industry management concurrence, direction and strategy regarding HSCT business potential and performance goals, investment and focus, future needs, and program advocacy. The PLT is made up of the Associate Administrator for Aeronautics, the Vice Presidents of the major industry partners, and the LaRC Deputy Center Director.

- **Integrated Planning Team** (IPT): Provides overall integration and implementation of the program. The IPT consists of the top leadership involved with HSR from the various industry partners and NASA centers.

- **Airframe Management Team** (AMT): Reviews status and provides leadership for Airframe elements. AMT consists of top leadership for the airframe portion of the HSR Program from the various industry partners and NASA centers.

- **Airframe Business Team** (ABT): Ensures smooth, efficient, timely business operations of the HSR program by the development and implementation of sound business practices for Airframe Technology.

- **Propulsion Management Team** (PMT) Reviews status and provides leadership for Propulsion elements.

- **Propulsion Business Teams** (PBT): Ensures smooth, efficient, timely business operations of the HSR program by the development and implementation of sound business practices for Propulsion Technology.

- **Technology Management Team** (TMT): Responsible for approval of Level 2 project documents while providing technical oversight for technology development within a given technology area, and monthly technical reporting. TMT consists of line managers from the various industry partners and NASA centers.

- **Integrated Technology Development** (ITD) team: Responsible for the development and monitoring of project plans while providing day-to-day technical insight of tasks, and technical reporting to the TMT's. The ITD consists of senior individuals from a specific technical area.

Individual teams were made up of industry and NASA members, which varied in number depending upon the task at hand. The leadership of each team was not necessarily a NASA team member. Rather, the leadership role for most teams is decided upon by the individual team members themselves. Teams were given a great deal of flexibility to decide upon team process issues as long as consensus among team members could be reached.

One of the most important aspects of the teaming environment, has been the flexibility given to each team to determine their own processes. Within HSR lies a great deal of diversity from team to team. Not only is the nature of work different, but also the team processes that allow members to make decisions or discuss issues are different. Teams were given the autonomy to decide the team processes as long as consensus was reached. For some teams, that meant rotating leadership from time to time, while other teams voluntarily employed ad-hoc teams to get help on key issues. Furthermore teams were given some autonomy to resolve money, scope, and schedule issues within the team. Given the complexity of the program, this could have been a major issue. However rules were set up to avoid chaos from breaking out within the program. One of the guidelines set by program management was that decisions could be made within a team as long as the implications of a decision did not effect another team in any way. In such a case, the other teams within the organizational structure would have to be consulted. To keep control of costs and schedule, program management also developed guidelines for decisions as shown in Table 3:

Table 3: NASA/Industry Team Authority Levels (NASA Office of Aeronautics, 1996)

	Authority level	
Team Levels	**Reprogramming of Funds**	**Milestone Changes**
AMT and PMT	Unlimited authority as long as Level I milestones are not effected.	Approve changes to Level II milestones.
TMT	Up to $1M or 15% of guidelines (whichever is less).	Approve changes to Level III milestones.
ITD	Up to $500K or 15% of guidelines (whichever is less).	Approve changes to Level IV milestones.

These guidelines gave the teams the autonomy they needed to get the work done without program management micromanaging every step of the way. As Wally explained: "Each time we try to push it [decision making] to the lowest level. . . We try to make it an efficient operation. We don't want a cast of thousands. We don't want a ton of teams. We want the minimum amount to get the job done, and we want you to have the latitude in terms of money, and in terms of scope to do your work."

Tools for Managing the Future

Measuring for Success

Early on in the planning stage of HSR, assessing the progress of the technology development for the entire program was a particularly intriguing challenge. McDonnell Douglas Aerospace offered a proposal to this challenge: metrics. Although not new to aeronautics, metrics was unique here because they were being applied to a technology development program. With the nature of the program being one of technology advancement and eventual integration of these technologies into a final aircraft, changes within the program may not have been obvious to management. The purpose of these metrics was clearly defined by McDonnell Douglas:

> " During a program's conceptual phase, when many promising technologies are being identified and explored, the end-results of a specific technology development effort are difficult to forecast. Technology breakthroughs and

failures will occur. The nature and frequency of these occurrences are challenging to predict with any degree of certainty. Therefore, one aspect of technology development program management should be to acknowledge the presence of uncertainty, measure it, and if possible, reduce the risk to an acceptable level. In order to assess the relative cost/benefits of investments in the Phase II technology areas as well as to measure progress towards the Phase II technology goals, some measures of merit must be defined both at the individual technology level and the vehicle level. These measures of merit, or *metrics*, should be identified, tracked, and integrated using a process-based approach to ensure consistency in treatment among the metrics and over time. . . MDC (McDonnell Douglas Corporation) views the primary function of this process as a decision-tool to furnish the decision maker with information on the consequences of programmatic decisions. It is by no means meant to serve as an oracle or a substitute for sound business and technical reasoning, nor is it designed to account for the myriad policy issues associated with allocating development funds to specific technology areas. It is simply meant to give some additional insight into how technology area funding allocation decisions might influence the environmental acceptability and economic viability of the HSCT vehicle." (McDonnell Douglas Aerospace, 1994)

From the beginning ITD teams picked their own metrics with advice from the Technology Integration team. Some of these metrics would be rolled up (see figure 7) into more general metrics while other metrics remained at the ITD level. These metrics by no means were perfect the first time around; however through the commitment of management and team members metrics have evolved during the program to where there are approximately seventy metrics used by HSR team members. For management, the rolled up metrics provided key information to assess the overall progress of the program using probabilistic methods to incorporate risk and uncertainty. In order for metrics to be successful, the ITD team members who provided data for the metrics had to see the benefit in order for measurement to be truly effective. The team members had to see that the data was going to benefit the program, the individual team, or both. For the ITD teams, tracking progress for the individual development of technology becomes essential. Progress for these teams does not necessarily mean achieving the initially projected goal (figure 8). In HSR, progress could be defined as reducing the error band around the initial projected goal and monitoring its effect on programmatic metrics. By reducing the error band, risk and uncertainty are diminished which provides HSR with the necessary information to make decisions.

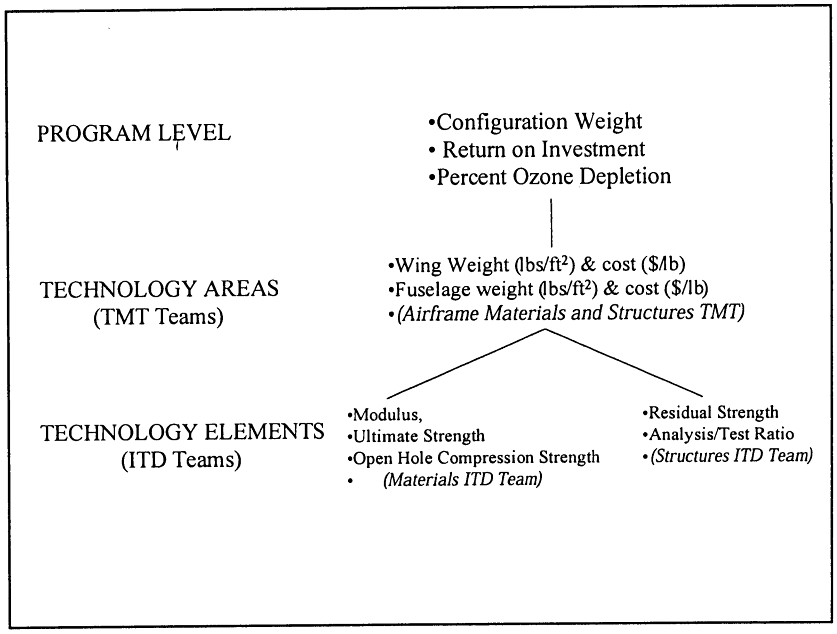

Figure 7: Sample Metrics Used by Various Teams in HSR

The Uncertain Environment

HSR program management had to also deal with budgetary uncertainties which is inherent in most projects and programs. Early on, program management created tools to cope with this problem. Throughout the year, program management met to create a list that addressed these two scenarios:

- If HSR had more money, where would HSR apply it in the program?
- IF HSR had less money, where would it be taken away within the program?

Therefore, when NASA decided to change the funding profile of the program during a particular period, program management had already agreed up front what would happen as a result of the funding changes. By making a list up front, they were prepared for any dramatic change, and knew exactly how it would effect the program.

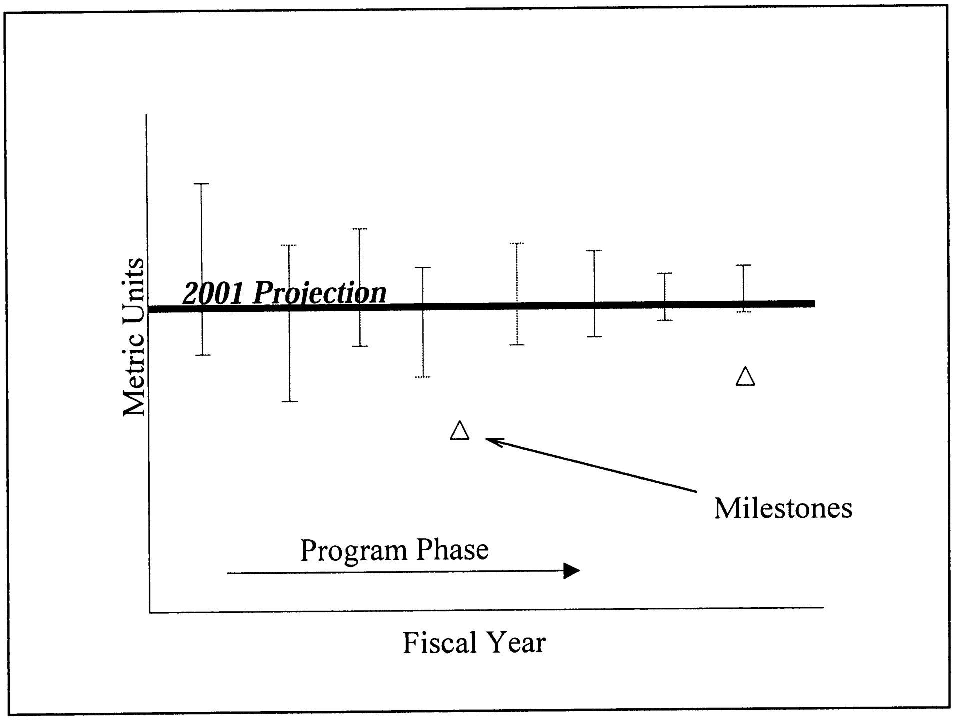

Figure 8: Sample Metrics Chart

Another important aspect to the HSR program has been the reporting mechanism used by the teams in the form of Planning and Control Documents or Work Plans (PCD's are used in ITD's in Airframe, while Work Plans are used by ITD's in Propulsion). These documents serve dual purposes: to plan for future work and to document costs, schedule, statement of work, resources, exit criteria, etc. In producing these documents, ITD teams develop a better understanding of the work processes within their own team as Steve Rizzi explained "the value [of PCD's or Work Plans] is going through the process of planning." By working on the PCD's, ITD members understand the whole problem in terms of cost, schedule, scope and technical performance. Since HSR is a long-term program, employee attrition is a problem that teams must deal with. To help new employees transition into the program, these plans serve to provide vital information of the past, present, and future of each team.

As part of the PCD's and Work Plans, exit criteria have played a vital role in delivering only the technology that is necessary for the HSCT aircraft. With technology development, often times projects run the risk of over optimizing technical performance of products at the expense of cost, scope, or schedule. But with exit criteria, as the name implies, a task is accomplished once the exit criteria are met, even if the deliverable can be improved upon. Each team is held accountable for meeting these exit criteria. Although it is nice to have the additional technology, HSR is about developing the technology for a HSCT, and not about doing research for research sake. Since the team members are the ones doing the work, HSR made sure that each team participated in designing the exit criteria for each deliverable. Team members had to buy into the exit criteria, and by allowing them to participate, they also had a better understanding of the exit criteria, since they were the ones developing it.

These reporting processes and tools were by no means perfect the first time around, and are still in continual evolution. Program management understood this. One problem that many teams in Propulsion had to deal with was the change process for updating Work Plans. As one of the requirements for the contracting arrangement within HSR, plans required updating on a yearly basis; however the approval process for updating the plan required nearly a year. Propulsion Technology teams recognized this as a stumbling block for getting the work done and they wanted to see that changed. This problem required the development of a new change process, so Joe Shaw, HSR Propulsion Office Director, decided that dedicating someone within HSR would be the only way to effectively change the process. Joe would ask Ed Graber, initially the Critical Propulsion Components (CPC) Manager, to help him out. As a result, Ed would leave his post as the CPC Manager, and dedicate his efforts towards improving not only the plan change process, but also other areas within HSR. Joe's dedication to the program and to helping the employees was clear to Mary Marks, "Joe's job is to make our jobs easier."

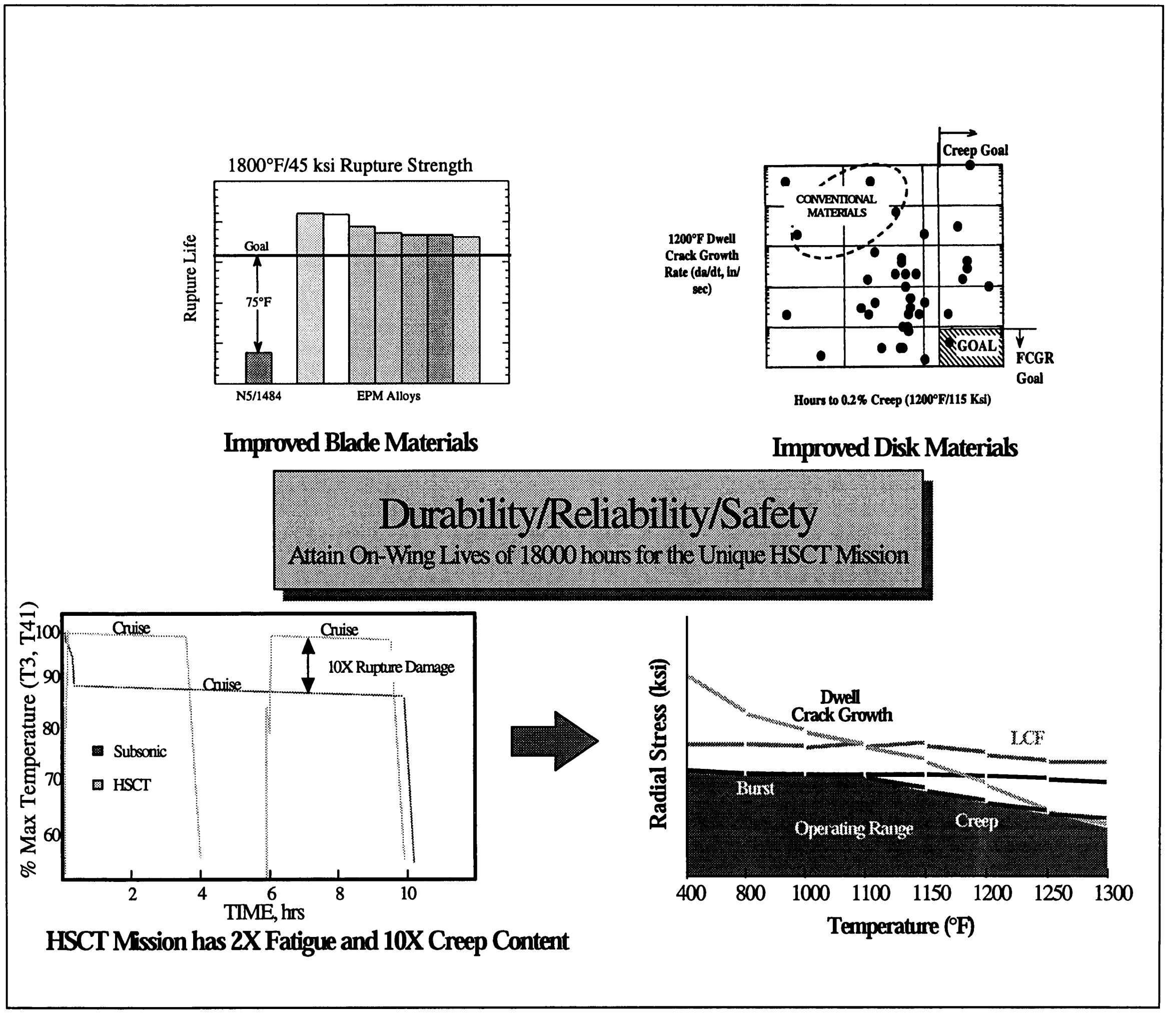

Figure 9: Material Requirements for HSCT Mission (Courtesy of General Electric)

Looking Out for the Environment

After the cancellation of the SST by Congress in the early seventies, partly due to environmental concerns, program management made sure that environmental compatibility was a priority not just an accessory to the program. Program management decided to deal with environmental issues early in the program through the initiation of various studies in Phase I. From Phase I, various environmental models (such as atmospheric models, sonic boom impact models, etc.) were refined, and a better understanding of the possible effects of a HSCT on the environment were better understood. Once Phase II was underway, program management brought the environmental stakeholders from Phase I into Phase II, and designated an entire team to focus on dealing with environmental issues.

Concerned with such things as ozone depletion, airport noise standards, radiation exposure, sonic boom, etc. HSR would have to involve the environmental stakeholders directly in the process of developing the technology for the HSCT. One example of the environmental impact on the HSR Program was sonic boom. Early on in the HSR program life cycle, several studies had been conducted to determine the boom levels that might be acceptable to future noise regulations. However, it was decided that no matter what the boom characteristics were, the noise level would be unacceptable for civilian areas. It became clear that the plane would not be able to fly over land, rather supersonic speeds would only be achieved over water. Even with supersonic speeds over water, other environmental issues dealing with sonic boom needed to be addressed. An environmental impact team continues to be in constant contact with many of the major environmental stakeholders such as the Federal Aviation Administration, the International Civil Aviation Organization, and the National Oceanic and Atmospheric Administration. This has allowed HSR to be proactive in the environmental field, and to remain informed on any future laws that may effect the program. The environmental impact team members participate in other team meetings within Airframe or Propulsion whenever environmental input is necessary. These environmental issues were integrated into the program to the point where they have an input on the HSCT metrics, design, and mission as Wally explains,

> "One thing we've done this time around from the 60's time period, is to bring those environmental issues and concerns into the program, to bring those people who are knowledgeable and capable of helping us understand them and solve them, into the program now, so that we are not just working technology that's going to make a dollar. But we are also being cognizant of the environmental concerns, and then (asking) how do you still make a dollar without destroying your own planet in the process. And that's what we are going.... when we got into developing the technology was to try to see if we could see I'll call it lick the sonic boom problem. And this is where you really kind of run into the laws of physics with sonic boom. . . You can design an airplane that has low boom. . . a really low boom. But the problem with it is it doesn't become commercially viable because it is such a long, long, long needle nose type fuselage you can't get people in there. So what you have is you don't have payload. So when you start trading down on payload, then you find you're back to having a boom problem. And you can mitigate the boom, you can soften the boom, but you really can't do away with it. Now it could be that there will be areas where you might have dedicated corridors and if that's the case then you might be able to fly over some areas and generate a boom. What we're saying is we don't want to have to count on that in the program. . . We're going to say you're not going to do that, then what does that lead you to as an economically viable airplane. If you get the other, that's a windfall, but we don't want to develop the technology based on promises, based on certifications, that you're going to get to something and someone's going to say gee I don't know whether we'll change a law, and by that I mean we know that

from the noise standpoint, we can't be any noisier than the subsonic fleet is now. So we're going to have to meet all those noise standards, and by the time this airplane comes in, those airplanes are going to improve. So therefore, we better set goals that are below what we're seeing so that we can drive toward that so that we don't have to develop something, get out there and hope that you're going to change a law allowing us to be outside the current standard...the then current standard..."

Summary of Key Practices: It's the Airplane Stupid!

The HSR Program has evolved since its inception in 1995 (Phase II) in order to meet its technical goals, its budget, and its schedule. Being the first focused NASA aeronautics program was a conscious decision by senior management in an attempt to bring the structure and discipline of project management to a research/technology effort. As a result, much of the program's success to date can be attributed to a **clear vision and focus**:

> *Developing the technology for a supersonic transport which travels Mach 2.4, carries 300 passengers, flies 5000+ miles, and which is both environmentally compatible, and economically viable.*

Not only is this focus and vision clear, but it is also something that most can relate to. People understand the implications of the program, and the potential impact on their lives in the future. As a result, HSR members are motivated to help HSR achieve its goals. Furthermore, this focus was supported by metrics and exit criteria, which were intended to bring attention to the technology development as it effects the entire airplane.

Partnering with industry was extremely important since it is industry who will eventually be the customer of the technology development. By **involving the customer** in the program, NASA and industry are able to ensure that the deliverables they produce focus on the specific needs of industry. Only industry can understand what it will take to bring a complete HSCT online, and through the **partnering relationship** with NASA, NASA is able to give exactly what industry requires.

Program management has realized that the processes within the program are not perfect, rather they have promoted a culture of **continuous improvement**, as Joe summarized, "We are ALWAYS looking for improvement". Throughout its life cycle several efforts have been made to improve team processes, metrics reporting, and even the change process for Work Plans. Utilizing surveys, and dedicating members to deal with improvement have helped HSR evolve into what it has become today. HSR team members feel committed to helping the program improve, as David Utah explained:

> ". . . in the very beginning we had face to face meetings and then after the face to face meetings we had to write the one or two page monthly progress reports. . . we did that for about six months to about a year. And then finally our program manager said that we are spending so much time reporting that we aren't getting the work done. And they (program managers [EPM]) came to us and asked how can we do it better? They

took it upon themselves to change. Now, the monthly progress reports are less time consuming."

One of the drawbacks of partnering with industry, is the lack of collocation of team members. Dealing with this problem has not been an easy task for HSR team members. **Building trust** within teams and across teams has helped HSR accomplish team and program goals. Institutionalizing regular meetings while **employing technology** such as teleconferencing, videoconferencing, and the Internet, have helped HSR members deal with non-collocation. However, collocating teams occasionally was necessary to build this trust and develop personal relationships among team members which can be difficult even with technological support.

In a large-scale partnering relationship between NASA and industry, **consensus management** has been successful in involving both NASA and industry members to help accomplish its technical goals. This management approach has several advantages:

1. The benefit of a diverse knowledge base to help solve complex problems.
2. Efforts are better coordinated among industry and NASA participants through better information sharing
3. Team members learn from each others experiences and are able to share technical experience and ideas
4. The ability to take advantage of resources from several NASA and industry facilities

With consensus management in place, HSR implemented extensive use of teams. Although this by no means is unique to any program or project, HSR made sure that the teams had the proper infrastructure to support that teaming arrangement. Program management **empowered each team** by giving them the formal authority to change resources, and scope within certain guidelines. Furthermore, with a formal organizational structure designed around systems and subsystems, teams were able to understand the implication of their work upon other teams.

Another important aspect to the success of consensus management within the program has been the implementation of **training and development** early on in the program. With an innovative approach to teaming, HSR team members required the training to understand the processes involved in consensus, and to insure that everybody had the same ideas of what consensus was all about.

To give all the teams the information they required, the teams had **the tools they required** to get their job done. For most teams within HSR, **metrics** have brought the technology development efforts together, since there are a variety of metrics that are rolled up into system metrics. These metrics also provide status on progress which gives HSR management vital information of where problems may exist now, and in the future. Dealing with a technology development program, risk and uncertainty are inherent, but having metrics and other tools which incorporate uncertainty and risk have made management decision making a lot easier. Even though developing these tools and metrics for some teams has been challenging, improvement efforts have all helped teams deal with the situation.

Planning at the ITD team level has been captured in the **Planning and Control Documents and Work Plans**, which, as a whole, represent the total HSR Program technical plan at the most detailed level. Embedded within these plans, **exit criteria** define when the research and development results are satisfactory to prevent over optimizing the technology and to prevent any additional resources from being wasted.

Economic viability and environmental compatibility are essential before any HSCT is produced by industry. The HSR program had to deal with these two problems directly. Partnering with industry, NASA was able to have input from industry on the economic requirements to make HSCT viable. HSCT could also have a variety of environmental implications, but by involving **environmental stakeholders**, and **setting stringent environmental goals**, HSR will be in a position to meet the environmental regulations of tomorrow.

Case Summary

The HSR Program appears to be well on its way to meeting the objectives it set out to achieve for the year of 2002. From industry's and NASA's perspective, the partnership has benefited both sides, where each member has been able to learn a great deal from one another, strengthening the relationship between NASA and industry. Throughout the program, people have had to overcome a great deal of challenges within the program, and have learned from their experiences as part of a team. Even among traditional competitors, the collaborative work that teams have been able to accomplish has been a trademark to this program, as Joe Shaw explained:

> "We have a lot to be proud of in this program, the technical accomplishments, the management approach, the challenges, yeah, we haven't done it all right, but I think we've tried to do a lot things right, a lot of things better. We've taken some more futuristic and positive approach to things."

The program can already point to technological successes such as the development of a combustor that is capable of meeting emission goals and the development of materials that are able to withstand the high engine temperatures for extended periods of time. Developing the technology for an HSCT has created a great deal of excitement inside and outside the HSR Program. Much of excitement can be attributed to the common vision that HSR team members share, which will ultimately push the aeronautics envelope to another level. The HSR Program has demonstrated that utilizing sound management approaches that focus on the airplane as a system, while using technology to deal with such things as geographic dispersion, uncertainty, risk, etc., can help a program become successful.

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