The High-Speed Research Program is directed at critical environmental compatibility issues and establishment of a foundation for subsequent decisions on future High-Speed Civil Transport technology and development programs.
AIR TRANSPORTATION GROWTH

Worldwide air travel demand has tripled in the past 20 years, to a current level of approximately 1000 billion revenue-passenger-miles per year. A further growth to 2 1/2 times that value is expected over the next 20 years.

The worldwide large transport market is estimated at an average $20 billion per year through the remainder of this century, growing to more than twice that annual figure over the first quarter of the 21st century. U.S. employment in the transport aircraft manufacturing industry now totals a quarter of a million workers.

Long-range international travel, particularly that related to the rapidly maturing Pacific Rim commerce and trade centers, is the fastest growing sector of the projected market -- and the sector in which the benefits of high-speed transit are most obvious.
HIGH-SPEED RESEARCH PROGRAM

AIR TRANSPORTATION GROWTH

ANNUAL REVENUE PASSENGER MILES (BILLIONS)

ACTUAL GROWTH 7.2%/YR

PROJECTED AT 4%/YR

TOTAL

DOMESTIC

INTERNATIONAL

AIRCRAFT MARKET (LARGE TRANSPORTS)

YEAR


1000 2000 3000 4000 5000 6000

1990 2000

5300 AIRCRAFT

$265 BILLION

SUBSONIC

$1.5 TRILLION

SUBSONIC & SUPERSONIC
PRODUCTIVITY

The air transportation system, in less than 70 years -- one human life span-- has evolved from a fleet of several dozen flimsy 2000- to 5000-pound biplanes carrying 5 to 15 people at 80 miles per hour, to thousands of jet aircraft weighing on the order of a half-million pounds or more, some carrying more than 500 passengers and flying at over 550 miles per hour.

These increases in passenger capacity and speed have resulted in a steady growth in productivity, providing constantly improved service to the travelling public and the world of commerce.
EARLY HIGH-SPEED TRANSPORT DEVELOPMENTS

In the 1960s, attempts were made in Europe and in the U.S. to achieve even greater growth in productivity by developing supersonic transports capable of cruising at twice the speed of sound or more.

The American effort was abandoned in 1971 because of environmental concerns, economic uncertainties, and objections to government-funded prototype development. The Concorde development was continued by the French and British governments. Sixteen of these aircraft were built, and fourteen were placed in airline service.

Concorde represents a remarkable technical accomplishment. It has proven that supersonic transportation is feasible and can be comfortable, reliable, and safe. It has also provided 20 years of valuable design, development, and operational experience.

As a product of 30-year-old technology, however, Concorde has inadequate range and payload performance for economic viability and, although it has attracted a segment of first-class trans-Atlantic travelers willing to pay premium fares, it has not been a financial success. Moreover, it does not satisfy current concepts of environmental acceptability.
HIGH-SPEED RESEARCH PROGRAM

EARLY HIGH-SPEED TRANSPORT DEVELOPMENTS
CURRENT OUTLOOK

Results of NASA and industry research conducted over the years since the cancellation of the U.S. SST and the introduction of the Concorde has provided confidence that the technology can be developed for a future environmentally acceptable and economically viable high-speed civil transport. However, considerable research and eventual validation efforts are still required.

It is envisioned that the new aircraft would carry three times the Concorde passenger load over twice the distance, at less than one-seventh the cost per passenger-mile.

During the past three years, NASA and the industry have conducted a series of high-speed civil transport studies. The results indicate that a substantial market for such an airplane will exist early in the next century, if it

- meets acceptable standards of airport noise and sonic boom levels,
- has no harmful effect on the atmosphere, and
- is economically competitive with new-generation long-haul subsonic transports.
# HIGH-SPEED RESEARCH PROGRAM

## CURRENT OUTLOOK

<table>
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<tr>
<th>CONCORDE</th>
<th>HSCT</th>
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<tr>
<td>3000 RANGE (n. mi.)</td>
<td>5000-6500</td>
</tr>
<tr>
<td>100 PAYLOAD (passengers)</td>
<td>250-300</td>
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<tr>
<td>400,000 WEIGHT (lb.)</td>
<td>750,000</td>
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<tr>
<td>EXEMPT COMMUNITY NOISE STANDARD</td>
<td>FAR 36 - STAGE III</td>
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<tr>
<td>PREMIUM FARE LEVELS</td>
<td>STANDARD</td>
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</table>

![Concorde and HSCT Diagrams]
RESEARCH OBJECTIVE

The White House Office of Science and Technology (OSTP) reports of 1985 and 1987 identified national aeronautical R&D goals directed at maintenance of U.S. aeronautical preeminence into the next century, and presented an action plan for achievement of the goals.

The goals address three areas of aeronautics -- subsonics, supersonics, and transatmospherics. The supersonics goal calls for development of technology for efficient, long-distance supersonic cruise for both future military aircraft and trans-Pacific-range supersonic transports.

Consistent with this goal, and in view of the world market potential and international competition, the development of an updated technology base for high-speed civil transports -- with top priority and emphasis on the environmental barrier issues -- is an important and timely national research objective.

The NASA High-Speed Research Program is a direct response to meeting this national objective. It is an essential step which must be taken prior to initiating more focused government/industry technology development efforts that could lead to future high-speed civil transports.
HSCT EVOLUTION

The High Speed Research Program (HSRP) does not imply commitment to High-Speed Civil Transport (HSCT) aircraft development. Its purpose is twofold:

- to determine whether the potential environmental barriers to HSCT development can be overcome; and

- to develop a technical basis for establishing -- and for meeting -- acceptable HSCT environmental standards

Assuming that HSRP progress shows sufficient promise of success, and that further technical and economic studies confirm the importance of HSCT to the transportation system and the national economy, a cooperative NASA/industry focused technology development effort could be considered as the next step that would complete a foundation for much more costly subsequent airframe and engine development and production, which would depend on industry investment.
HIGH-SPEED RESEARCH PROGRAM

HSCT EVOLUTION

INDUSTRY
AIRFRAME/ENGINE
DEVELOPMENT

NASA/INDUSTRY
HSCT TECHNOLOGY
DEVELOPMENT
PROGRAM

NASA
HIGH-SPEED
RESEARCH PROGRAM

APPLICABLE ONGOING AERONAUTICS R & T

PROGRAM GOALS

The goals of the High-Speed Research Program are focused on three major environmental issues: atmospheric effects, airport community noise, and sonic boom. These issues are basic concerns that require better understanding before further efforts are planned.

The possibility that HSCT engine emissions might cause depletion of the stratospheric ozone layer must be explored thoroughly and resolved before serious consideration can be given to development of a high-speed civil transport. Atmospheric models must be perfected and exercised to predict the effects of high-altitude aircraft emissions and to develop a technical basis for establishment of suitable standards. Simultaneously, propulsion research toward reduction of engine emissions to the lowest possible level must be conducted and the results subjected to critical evaluation using the atmospheric models.

Public acceptance of the HSCT will also depend on its ability to meet noise level standards, currently assumed to be the FAR 36 Stage III levels now applied to newly designed subsonic transports. Research is required to assure reliable prediction of HSCT airport and community noise and evaluation of new noise reduction technologies. The research must also examine the feasibility of still further HSCT noise reduction which may be required in the future.

In addition, the High-Speed Research Program must establish either that supersonic flight over land with acceptably low levels of sonic boom can be assured or that design for subsonic cruise over land, if necessary, will not unduly compromise overall HSCT economy.
HIGH-SPEED RESEARCH PROGRAM

PROGRAM GOALS

• STRATOSPHERIC OZONE
  DEVELOP PREDICTIONS OF HSCT OZONE EFFECTS
  DETERMINE FEASIBLE NOX REDUCTION LEVELS
  PROVIDE TECHNICAL BASIS FOR ACCEPTABILITY CRITERIA

• AIRPORT COMMUNITY NOISE
  DETERMINE FEASIBILITY OF ECONOMICAL COMPLIANCE WITH FAR 36-III

• SONIC BOOM
  DEVELOP HSCT SONIC BOOM PREDICTIONS
  DETERMINE FEASIBLE SONIC BOOM REDUCTION LEVELS
  PROVIDE TECHNICAL BASIS FOR ACCEPTABILITY CRITERIA
The program content emphasizes the environmental issues associated with High-Speed Civil Transport. Assessment of atmospheric effects of aircraft operation is closely coordinated with system studies which serve as a necessary tool for understanding the effects of the individual and integrated technologies on overall environmental compatibility, as well as the economic viability of the conceptual aircraft. Combustor research and technology effort directed at reduced emissions is accompanied by research on propulsion source noise reduction.

Investigations on perceived noise at the ground include consideration of the effects of aircraft operational characteristics, with emphasis on takeoff climb capability. In the sonic boom reduction research, studies of low-boom aircraft configurations are coordinated with investigations of subjective response to boom overpressures. Supersonic laminar flow control is emphasized because of its synergistic beneficial effect on emissions, noise, and sonic boom through aircraft weight reduction.

In the following discussions, the rationale and specific elements for each program area are defined. An “Approach” discussion describes how the research will be performed and integrated. Finally, major program milestones are identified.
HIGH-SPEED RESEARCH PROGRAM

PROGRAM CONTENT

• ATMOSPHERIC EFFECTS
  - ATMOSPHERIC STUDIES
  - SYSTEM STUDIES

• EMISSIONS AND SOURCE NOISE
  - EMISSIONS REDUCTION
  - PROPULSION NOISE REDUCTION

• COMMUNITY NOISE AND SONIC BOOM
  - COMMUNITY NOISE REDUCTION
    AND HIGH-LIFT RESEARCH
  - SONIC BOOM
  - SUPERSONIC LAMINAR FLOW CONTROL
ATMOSPHERIC EFFECTS

Worldwide scientific attention is being directed at the effects of man-made pollutants on the Earth's upper atmosphere, with particular attention to protection of the stratospheric ozone layer. As a major U.S. participant in this effort, NASA reports regularly to the Congress and to concerned agencies on the status of upper atmospheric research and on scientific assessment of potential effects of human activities.

The atmosphere is changing, as demonstrated by the discovery of the Antarctic ozone hole. Man-made chemicals are depleting the ozone layer, and international agreements have been reached to reduce the use of chlorofluorocarbons (CFCs) and bromine compounds. Studies have shown that nitrogen oxides (NOx) and other engine emissions from aircraft operating in the stratosphere have the potential of further altering the global ozone and possibly the stratospheric circulation and climate.

The HSRP places primary emphasis on the understanding and assessment of atmospheric effects. Atmospheric assessment will be guided by prominent members of the international atmospheric science community coordinated by leaders of the NASA Upper Atmosphere Research Program. An advisory group including university and environmental agency scientists has been established to recommend and evaluate the research on atmospheric impact of potential future aircraft fleets.

The research will include the application of sophisticated atmospheric chemistry and dynamics models to analyze the dispersion and effects of the emissions, and their long-term influence on the atmosphere.
HIGH-SPEED RESEARCH PROGRAM

ATMOSPHERIC EFFECTS

OCT 15, 1987     DAY 288

SOUTH POLAR PLOT

NIMBUS-7: TOMS
TOTAL OZONE
NASA/GSFC
The atmospheric assessment effort consists of a hierarchy of theoretical models, laboratory experiments, and field measurements used in combination to improve the assessment of aircraft stratospheric impact by reducing the large uncertainties in current global models.

Existing atmospheric models and data bases utilized in evaluating ozone depletion effects of surface-released pollutants such as CFCs will be updated, refined, and adapted for the assessment of high-speed aircraft effects.

Interim assessments will be conducted initially using preliminary emissions estimates, assumed variations of emission parameters, and results of previous studies conducted during the 1970s. As results of the emissions reduction technology program and the systems studies become available they will be used as atmospheric model inputs.

Field experiments critical to improvement and validation of the assessment models -- e.g., measurement of the distribution of aircraft emission particles along projected HSCT flight corridors -- will be defined and conducted.

Fleet assessments of projected HSCT transports will be made periodically and reviewed critically with respect to uncertainty reduction and remaining uncertainties. Initially confined to consideration of projected aircraft fleet emissions in a "pure" atmosphere, the assessments will progress to evaluation in combination with increasing levels of other pollutants and the influence of other climate and solar effects.
ATMOSPHERIC EFFECTS

INPUTS, MODELS
- 2-D CHEMISTRY MODELS
- 3-D DISTRIBUTION MODELS
- "SPECIAL" MODELS
- PLUMES, AEROSOLS
- LAB STUDIES (CHEMISTRY)

ASSESSMENT ELEMENTS

GLOBAL ASSESSMENT MODELS

INTERIM ASSESSMENTS

TECHNOLOGY EFFORTS

INSTRUMENT DEVELOPMENT

FIELD EXPERIMENTS

IMPROVED GLOBAL ASSESSMENT MODELS

FLEET ASSESSMENTS
ATMOSPHERIC EFFECTS APPROACH

The investigation of the possible effects of High-Speed Civil Transport operations on the upper atmosphere will draw directly on the expertise of scientists who have been conducting similar, more general studies for NASA and other organizations. The initial effort will emphasize improvement of atmospheric models to provide better predictions of aircraft emissions effects on the global atmosphere. Improvement approaches will include incorporating the results of laboratory experiments, such as measurement of the effects of heterogeneous chemistry under conditions of enhanced NOx.

Global models will be analyzed to define flight experiments needed in order to reduce prediction uncertainties, and necessary instrumentation will be developed. Measurements of atmospheric properties will be made from aircraft directly in the proposed flight corridors and other locations that could be affected by emissions. Chemical tracers may be used to determine the dispersion and mixing characteristics, and to provide experimental verification for theoretical models. Flight experiments will include measurements of the distribution and dispersion of engine emissions and chemical perturbations within projected stratospheric flight corridors. Results of the experiments will be used to establish model validity and to guide further model modifications.

Scenarios defining a range of HSCT operations and emissions will be developed for preliminary assessments. Parametric and sensitivity studies will be conducted to determine the effects of significant variables. As more reliable data on aircraft emissions and operations become available from the technology and systems study activities, they will be used as inputs for more refined assessments. Two-dimensional global models will be used to predict ozone perturbations due to the aircraft emissions. Three-dimensional models will be used to predict the global distribution of emissions. The most current models will be exercised periodically to assess the technology sensitivities and update fleet scenarios. A final assessment will be made at the end of the program to quantify any key uncertainties remaining in the predictions.
### ATMOSPHERIC EFFECTS

#### High-Speed Research Program

#### Approach

|---------|---------|---------|---------|---------|---------|

#### Analysis & Prediction Methods Development
- Basic research on atmospheric effects
- Develop theory & models
- Develop analysis methodologies
- Laboratory studies on chemical reactions under perturbed conditions

#### Supporting Experiments
- Develop and test aircraft instrumentation
- Detect exhaust plume chemical perturbations
- Measure emissions & dispersion along flight corridors
- Verify theoretical models

#### Assessment of Atmospheric Effects
- Define HSCT scenarios
- Parametric and sensitivity studies
- Global assessment (fleet effects on ozone, stratospheric circulation, climate)
ATMOSPHERIC EFFECTS MILESTONES

The most critical milestones for the High-Speed Research Program are those which will reduce the uncertainty in basic understanding of the upper atmosphere's reaction to aircraft emissions. Milestones have been established for each of the three elements and key events are summarized as follows:

**FY1990**  
Preliminary definition of NOₓ and H₂O emissions from aircraft as a function of latitude and altitude

Application of 2-D global models with current, gas-phase chemistry

**FY 1991**  
Evaluate accuracy and uncertainty in global assessment from research with 3-D global models and detailed heterogeneous chemistry

**FY 1993**  
Use measurements, results of lab experiments and specialized chemistry models to improve simulation of 2-D and 3-D dispersion in lower stratosphere

**FY 1994**  
Determine, from flight experiments, chemical perturbations in stratospheric flight corridors

**FY 1995**  
Evaluate accuracy of models with data from flight and other measurements (e.g., satellite) and complete assessment of remaining uncertainties
# ATMOSPHERIC EFFECTS

## HIGH-SPEED RESEARCH PROGRAM

### MILESTONES

|---------|---------|---------|---------|---------|---------|

#### ANALYSIS AND PREDICTION METHODS DEVELOPMENT

- **Δ** 2-D GLOBAL MODELS WITH GAS-PHASE CHEMISTRY
- **Δ** EVALUATE UNCERTAINTY IN GLOBAL MODELS
- **Δ** LAB MEASUREMENTS OF RATES FOR GAS PHASE REACTIONS IN BACKGROUND STRATOSPHERE
- **Δ** IMPROVE GLOBAL MODELS WITH EXPERIMENTAL DATA
- **Δ** LAB MEASUREMENTS OF KEY REACTION RATES UNDER PERTURBED CONDITIONS OF FLIGHT CORRIDORS
- **Δ** EVALUATE MODEL ACCURACY WITH DATA FROM FIELD CAMPAIGNS

#### SUPPORTING EXPERIMENTS

- **Δ** DEFINE INSTRUMENTATION REQUIREMENTS AND BEGIN DEVELOPMENT
- **Δ** INITIAL FLIGHTS TO TEST MODELS AND MEASURE CLIMATOLOGY OF NOx AND H20 IN PROJECTED FLIGHT CORRIDORS
- **Δ** DEFINE NEW INSTRUMENTATION FOR SECOND FLIGHT PROGRAM
- **Δ** SECOND FLIGHT PROGRAM TO MEASURE CHEMICAL PERTURBATIONS IN FLIGHT CORRIDORS

#### ASSESSMENT OF ATMOSPHERIC EFFECTS

- **Δ** PRELIM.DEFINITION OF EMISSIONS DISPERSION WITH 2-D MODELS AND GAS-PHASE CHEMISTRY
- **Δ** COMPLETE FLEET SCENARIOS WITH FULL 3-D AND SEASONAL EMISSIONS
- **Δ** 2-D GLOBAL EMISSIONS ASSESSMENT WITH GAS-PHASE AND AEROSOL CHEMISTRY
- **Δ** 2-D/3-D GLOBAL ASSESSMENT INCLUDING PERTURBATIONS TO OZONE, STRATOSPHERIC CIRCULATION AND CLIMATE
- **Δ** COMPLETE ASSESSMENT OF PREDICTION UNCERTAINTIES
SYSTEM STUDIES

System studies provide the basis for evaluating and guiding the technology efforts. In particular, the interplay between environmental and economic considerations can be investigated.

• For example, meaningful assessment of atmospheric effects requires realistic definition of the size, weight, numbers, and operating characteristics of projected HSCT vehicles. It also requires estimates of details such as fuel burned, engine exhaust temperatures, and operating altitudes, latitudes, and longitudes.

• Similar systems information is required for determination of noise and sonic boom characteristics.

• System studies will develop these essential inputs and will also be used to evaluate the effects of technology advances on environmental compatibility and on aircraft performance and economics, including fleet size, revenue, and fare premium requirements.
HIGH-SPEED RESEARCH PROGRAM

SYSTEM STUDIES

ANNUAL FUEL BURN FOR EMISSIONS ASSESSMENT

TOGW (1000 lb)

SIDELINE NOISE (EPNdB)

EFFECT OF ENGINE SIZE

TOGW (1000 lb)

ENVIRONMENTAL COMPATIBILITY

ECONOMIC VIABILITY

DISCOUNT COACH

COACH

BUSINESS

FIRST

TOTAL FLEET SIZE

CONCORDE 2000 2015

ANNUAL SEAT MILES (MILLIONS)

FARE PREMIUM (%)
The principal elements of the studies are design analysis programs and computational tools that allow rapid configuration conceptual design closure, system integration, evaluation of technology sensitivities and benefits, determination of cost benefits for advanced technology applications, and assessment of environmental impact. As indicated by the alternate paths for use of the studies results, vehicle considerations can, in turn, influence the specifications for environmental constraints.

Data bases in each of the technical discipline areas will be maintained and will be updated constantly as technology advances are developed and validated. The data will be utilized in iterative conceptual configuration studies and systems analysis, the results of which will identify critical technology needs and define the benefits of various technology advances.

Aircraft vehicle system technology integration studies will consider the effects of aircraft size, speed and route on sonic boom and related human acceptability; the estimated life cycle costs for airline application of candidate laminar flow control (LFC) devices; the practical low speed aerodynamic characteristics to be assumed in community noise calculations; and finally the overall costs and effectiveness of technology applied to meet environmental and other system requirements.
SYSTEM STUDIES

VEHICLE CONSIDERATIONS
- ENGINE
- AIRFRAME
- OPERATIONS

ENVIRONMENTAL CONSIDERATIONS
- EMISSIONS
- NOISE
- SONIC BOOM

ELEMENTS

• ASSESS ENVIRONMENTAL COMPATIBILITY
• EVALUATE ECONOMIC VIABILITY
• IDENTIFY KEY TECHNOLOGIES

• CONCEPTUAL DESIGN
• INTEGRATED SYSTEM ANALYSIS

OUTPUT
- AIRCRAFT SIZE
- PERFORMANCE
- ECONOMICS

• ABILITY TO MEET CONSTRAINTS
SYSTEM STUDIES APPROACH

Previous studies have determined that large improvements in propulsion system efficiency across the speed range are critical to achieving economic viability, and that challenging reductions in emissions and noise must be achieved without compromising engine efficiency or reliability. Relevant component technologies will be integrated in the systems studies with a number of innovative propulsion cycle concepts, and benefits and shortcomings evaluated. Initial selection of engine cycles will be based on the earlier High-Speed Civil Transport studies. The cycles shown here will be included as will others to be identified in related propulsion research.

A series of baseline aircraft concepts will be developed and technologies under study applied to assess the overall effectiveness of the vehicle system for environmental compatibility and economic viability. Aircraft operational procedures and flight paths that enhance environmental compatibility will also be studied.

Aircraft performance sensitivity to changes in propulsion system, aerodynamic shaping, high lift systems and other technologies directly included in the program will be determined. The possible benefits from other programs investigating related technologies such as structures and controls will also be assessed in the system studies.

Economic analyses will be conducted to evaluate the technology options in practical airline operations scenarios. Existing market studies will be utilized to estimate required fleet sizes and revenue requirements, including the effects of technology on environmental compatibility as well as on the necessity for fare premiums to sustain profitable HSCT airline operations.
SYSTEM STUDIES

HIGH-SPEED RESEARCH PROGRAM

APPROACH

SENSITIVITY ASSESSMENT:
- ENVIRONMENT
- ECONOMICS
- TECHNOLOGY


PROPULSION CYCLE ANALYSIS & TECHNOLOGY INTEGRATION
- ENGINE CYCLES
  - DOUBLE BYPASS
  - VARIABLE STREAM CONTROL
  - TURBINE BYPASS
- COMPONENT TECHNOLOGIES
  - COMBUSTORS
  - NOZZLES
  - NOx ADDITIVES
  - INLETS
- TANDEM FAN
- OTHERS

VEHICLE SYSTEMS TECHNOLOGY INTEGRATION
- PROPULSION SYSTEM
  - EMISSIONS
  - COMMUNITY NOISE
  - EFFICIENCY
- AERODYNAMICS
  - SONIC BOOM
  - HIGH-LIFT
  - LAMINAR FLOW CONTROL
- STRUCTURE
  - COMPOSITES
  - ADVANCED METALLICS
- OPERATIONAL METHODS
  - SPEED
  - ALTITUDE
  - TAKEOFF PROCEDURE

ECONOMIC AND ENVIRONMENTAL COMPATIBILITY ANALYSES
- MARKET
  - PROJECTIONS
  - STIMULATION
- REVENUE REQUIREMENTS
  - RETURN ON INVESTMENT
  - FARE PREMIUM
- FLEET SIZE
  - ROUTE STRUCTURE
  - AIRCRAFT SIZE/RANGE
- ENVIRONMENT
  - ATMOSPHERE
  - NOISE
SYSTEM STUDIES MILESTONES

System studies will continue throughout the program, on flexible schedules related to the development of technology in this and other programs and the need to assess the possible resulting benefits to reference aircraft systems. In this manner, the studies will also provide guidance to ongoing technology efforts. Critical milestones include:

**FY 1990**
- Initial assessment of additives for NOx reduction and noise suppression concepts

**FY 1991**
- LFC concept selection for use in LFC flight experiment

**FY 1992**
- Select best engines
- Definition of low-noise aerodynamics for assessment of effects on noise reduction

**FY 1994**
- Incorporate multi-discipline technology advances in propulsion analysis models

**FY 1995**
- Final technology and economic assessments

Economic analyses will be conducted periodically throughout the program to ensure that configurations being considered are practical from an airline perspective. Existing computer codes will be modified for high-speed aircraft application and baseline configurations evaluated as technology updates are completed.
# SYSTEM STUDIES

**HIGH-SPEED RESEARCH PROGRAM**

## MILESTONES

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### PROPULSION CYCLE ANALYSIS & TECHNOLOGY INTEGRATION

- **FY 1990**
  - Initial Engine Selection
  - Assess Initial NOx Reduction Additives and Noise Suppression Concepts

- **FY 1991**
  - Select Best Engines

- **FY 1992**
  - Update Noise Codes Using Test Data

- **FY 1993**
  - Advanced Technology Analytical Models

- **FY 1994**
  - Integrated Data Set for Atmospheric Assessment

### VEHICLE SYSTEMS TECHNOLOGY INTEGRATION

- **FY 1990**
  - Select Low-Boom Configurations

- **FY 1991**
  - Select Low-Cost LFC Concept

- **FY 1992**
  - Define Low-Noise Aerodynamics

- **FY 1993**
  - Integrate Boom Annoyance Criteria

- **FY 1994**
  - Complete Technology Assessment

### ECONOMIC AND ENVIRONMENTAL COMPATIBILITY ANALYSES

- **FY 1990**
  - Update Codes and Models

- **FY 1991**
  - Initial Baseline Configurations

- **FY 1992**
  - Assess Configuration Economics

- **FY 1993**
  - Final Baseline Configurations

- **FY 1994**
  - Assess Configuration Economics
EMISSIONS REDUCTION

The engine emissions of primary concern are nitrogen oxides (NOx) which, through a series of known catalytic reactions, could adversely impact the earth’s protective ozone layer. Although continuing atmospheric studies are needed to fully understand and quantify the levels that would yield no damage, it is clear that technology development focused on reducing NOx emissions is paramount before U.S. industry could commit to a high-speed transport development program. Fortunately, prior emissions reduction programs such as the Department of Energy sponsored research for stationary gas-turbine powerplants indicate that reduction to levels in the range of 3 to 8 grams of NOx per kilogram of fuel burned is possible with advanced combustor design approaches. Further NOx reduction and potential elimination may also be achievable through secondary means such as downstream (post-combustion) injection of chemical reactants.

Successful development of low-NOx combustor technology for supersonic transport engines poses a significant set of challenges. The first relates to the need for substantial fuel efficiency gains to achieve viable aircraft performance and economics. The gains dictate considerable increases in the engine’s combustor pressure and temperature environment, which accentuates the potential for NOx formation; e.g. the NOx level could double or triple relative to Concorde-type technology, if not specifically controlled. This requires a departure from current combustor designs using high-temperature primary zones (near stoichiometric conditions), toward advanced designs based on fully pre-mixed or two-stage approaches that constrain peak temperatures to very near the average combustor exit temperature. With most development and operational experience of these approaches limited to ground-based applications, the advanced designs must also continue to meet unique aircraft-engine operating requirements such as rapid power transients and altitude relighting. The planned program aggressively pursues solutions to all of these challenges.
HIGH-SPEED RESEARCH PROGRAM

EMISSIONS REDUCTION

EMISSIONS INDEX

gm NOx
kg fuel

ENGINE FUEL EFFICIENCY GAIN - %

CURRENT COMBUSTOR TECHNOLOGY

ADVANCED LOW-EMISSIONS TECHNOLOGY

ADVANCED COMBUSTOR TECHNOLOGY

CONCORDE
EMISSIONS REDUCTION ELEMENTS

Three inter-related and complementary elements form the foundation of the emission reduction technology development:

Analysis and Prediction Codes - Advancements in detailed computational analysis are providing increasingly better insight to complex flow processes at the controlling physics level. The improved understanding offered by these evolving tools will be applied throughout the program in the analysis, screening and definition of NOx reduction concepts and combustor configurations.

Combustion Concept Experiments - Focussed research in controlled laboratory conditions to identify and measure key flow field parameters with specialized instrumentation will help provide the underlying basis for advanced concepts and continued improvement in computational tools. Planned experimentation areas include rapid fuel vaporization and fuel-air mixing, fuel-lean and -rich combustion chemical kinetics, flashback criteria and avoidance, and post-combustion NOx destruction additives.

Advanced Component Configurations - Practical ("engine-level") combustor configurations applying these low-emission fundamentals will be defined, fabricated and developed through analysis and testing at the sub-component and component level. Two candidates -- the lean pre-mixed, pre-vaporized and rich-burn, quick-quench, lean-burn -- offer much promise but require substantial efforts to progress from the current "idea-stage" to operating component hardware.

Both predicted and measured combustion product constituents resulting from these activities will be used in conjunction with the system studies for the atmospheric assessment previously discussed.
EMISSIONS REDUCTION

ANALYSIS & PREDICTION CODES
- 2-D & 3-D AERO
- CHEMICAL KINETICS
- COMBUSTION PRODUCTS PREDICTION
- FUEL INJECTION
- HEAT TRANSFER

ELEMENTS

COMBUSTION EXPERIMENTS
- FUEL VAPORIZATION & FUEL-AIR MIXING
- FLAME TUBE WITH ADV. DIAGNOSTICS
- NOx DESTRUCTION ADDITIVES

ADV. COMBUSTOR CONFIGURATIONS
- LEAN PRE-MIXED/PRE-VAPORIZED
- RICH-BURN/QUICK-QUENCH/LEAN-BURN

LOW-EMISSIONS COMBUSTOR RIG DEMONSTRATIONS

NOx INDEX (EI)

FUEL-AIR EQUIVALENCE RATIO

LEAN
RICH

18
EMISSIONS REDUCTION MILESTONES

Key milestones have been established in each of the three elements to cross-check related progress and to facilitate mid-course planning adjustments, if warranted. Major benchmarks during the technology development process are:

**FY 1991**  
Flame tube level experiments completed to establish technology capability and critical factors for achieving 3-8 emissions index (EI) at simulated supersonic cruise conditions.

**FY 1992/93**  
Laboratory combustion experiments completed

- 2-D and 3-D aero/chemistry NOx prediction codes refined
- Sub-component technology base evolved

**FY 1994**  
2-stage and/or variable geometry combustor integration of low-NOx concepts completed with 15-20 EI demonstrated in “engine-level” combustor rig

**FY 1995**  
Final “engine-level” combustor rig demonstration completed to verify successful 3-8 EI technology transfer to practical application
EMISSIONS REDUCTION

MILESTONES

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<td>Δ CODE UPDATE BASED ON EXPERIMENTS</td>
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<td>Δ PREDICTION VERIFICATION WITH TEST DATA</td>
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COMBUSTION CONCEPT EXPERIMENTS

| Δ NOx DESTRUCTION ADDITIVES |
| Δ FLAME TUBE NOx FORMATION/CONTROL |
| Δ MIXING AND VAPORIZATION; LEAN AND RICH COMBUSTION |

LOW-EMISSION COMPONENT CONFIGURATION DEFINITION AND DEVELOPMENT

| Δ CONCEPT ASSESSMENT/SCREENING |
| Δ CONCEPTS SELECTED FOR COMBUSTOR DEVELOPMENT |
| Δ COMBUSTOR RIG DEMO'S (15-20 EI) (3-8 EI) |
NOISE REDUCTION

Aircraft noise and its propagation in the airport vicinity and to surrounding communities has been, and will continue to be, a subject of significant public concern and associated legislation. Aircraft community noise regulations are defined by Federal Air Regulation, Part 36 (FAR 36) and currently require Stage III noise levels for aircraft certified after 1975. Although the Concorde operates at levels significantly in excess of Stage III because of special exemption, future high-speed transports must be able to achieve a "friendly neighbor status" by meeting these standards.

Technology development for supersonic transport noise reduction has been nearly dormant since the termination of the Supersonic Cruise Research (SCR) / Variable Cycle Engine (VCE) program in 1981. General advances in acoustics understanding and vehicle aerodynamics since then, as well as the advent of supercomputer-based analysis capabilities, offer much promise in extending the gains made during that program.

While the propulsion system is the dominant noise source requiring alleviation, aircraft operation also plays an integral role in overall noise levels near airports. The vehicle lift and drag characteristics, in addition to setting the engine thrust requirements, also determine the climb-out-path and thus, the distance over which the noise can attenuate before reaching ground level. The HSRP focuses on technology improvements in both of these key areas. The propulsion source noise reduction efforts are discussed in the following section. Perceived noise reduction, including the effects of improved operations based on advanced high-lift aerodynamics technology, is covered under "Community Noise Reduction".

HIGH-SPEED RESEARCH PROGRAM

NOISE REDUCTION

- PROPULSION NOISE REDUCTION
  - SUPPRESSION CONCEPTS
  - VARIABLE CYCLE ENGINES

- SYSTEM NOISE REDUCTION
  - ENGINE/AIRFRAME INTEGRATION
  - HIGH-LIFT AIRCRAFT AERODYNAMICS (AIRPORT OPERATIONS)

ADVANCED TECHNOLOGY

125
120
115
110
105
100

SIDELINE NOISE EPNdB


YEAR

FAR 36 STAGE II

SCR/VCE PROGRAM

CONCORDE

FAR 36 STAGE III
PROPULSION NOISE REDUCTION ELEMENTS

Three inter-related and complementary activities form the primary elements of the propulsion noise reduction technology development:

**Analysis and Prediction Codes** - Advanced computational analysis has become an increasingly important tool in the understanding of complex flow fields at the controlling physics level and their effect on higher-level parameters of concern; in this case the noise levels generated by engine rotating and stationary components, and exhaust-jet plume.

**Aero/Acoustic Concept Experiments** - The underlying basis for advanced concepts and validation of computational tools will be investigated under controlled laboratory conditions using specialized instrumentation to isolate and measure key flow field parameters. Fundamental experiments are planned in the areas of nozzle geometry, jet plume mixing, shock generation and interaction, and potential active control mechanisms.

**Advanced Component Configurations** - Engine inlet and exhaust nozzle configurations that apply the attractive concepts in a practical application (i.e. acceptable mechanical complexity and added weight) will be defined, fabricated and tested, both statically and with simulated flight effects, in part-scale models to quantify noise reduction vs. performance tradeoffs.

These activities will be closely coordinated with the System Studies portion of the program since the components coupling with variable cycle engine concepts and integration with the airframe all affect Stage III compliance.
PROPULSION NOISE REDUCTION

ELEMENTS

ANALYSIS & PREDICTION CODES
- 2-D & 3-D TIME DEPENDENT AERODYNAMIC CODES
- JET NOISE MODELING
- INLET & TURBOMACHINERY NOISE MODELING
- SOURCE NOISE INPUT CODES FOR SYSTEM PREDICTION

AERO/ACOUSTIC CONCEPT EXPERIMENTS
- NOZZLE GEOMETRY
- ENHANCED MIXING
- SHOCK INTERACTION & CONTROL

ADVANCED NOZZLE CONFIGURATIONS
- INVERTED VELOCITY PROFILE
- EJECTOR
- SUBSONIC CRUISE/PRIMARY TAKEOFF

NOISE vs. PERFORMANCE COMPONENT EVALUATIONS

- THRUST
- NOISE PNLdB

22
PROPULSION NOISE REDUCTION APPROACH

The approach to the noise reduction technology development employs an interactive combination of analytical and experimental capabilities to formulate, investigate, and ultimately validate advanced concepts in practical component configurations:

• The analysis codes will be used to provide early screening assessments, and to help define laboratory experiments and diagnostic measurements, for proposed noise reduction concepts. They will also be applied to evaluate the effectiveness of the concepts when combined in realistic component configurations.

• The concept experiments and diagnostic measurements will be conducted early in the program to create a strong fundamental knowledge base from which new component configurations, as well as modification enhancements to existing candidates, can be formulated. In addition, these activities will provide valuable feedback to improve the flow modeling and prediction accuracies of the codes.

• Fabrication and development testing of part-scale inlet and exhaust component models will verify the concepts in realistic hardware applications under simulated operating conditions. Acoustic and performance measurements from these activities will expand the data base for code prediction comparison, and also may uncover further areas for supporting fundamental experiments.

NASA, U.S. industry, and university expertise and facilities will be pooled throughout this process to ensure that the most promising critical component technology and the highest-payoff configurations are developed and verified.
APPROACH

NOISE ANALYSIS & PREDICTION CODE DEVELOPMENT
- 2-D & 3-D NOZZLE/INLET AERODYNAMICS
- JET NOISE MODELING
- TURBOMACHINERY NOISE MODELING
- SYSTEM NOISE PREDICTION INPUT

AERO/ACOUSTIC CONCEPT EXPERIMENTS
- GEOMETRY EFFECTS
- RAPID MIXING
- SHOCK INTERACTION
- ACTIVE CONTROL

LOW-NOISE COMPONENT CONFIGURATION DEFINITION & DEVELOPMENT
- ANALYTICAL ASSESSMENT WITH CODES
- SMALL-SCALE MODEL TEST SCREENING
- PART-SCALE COMPONENT ACOUSTIC & PERFORMANCE VERIFICATION TESTS
PROPULSION NOISE REDUCTION MILESTONES

Key milestones have been established in each of the three elements to track related progress and to ease mid-course planning adjustments, if needed. Major benchmarks during the technology development process are:

**FY 1992**  
Initial aero/acoustic concept experiments and scale-model component configuration testing completed, permitting first assessment of Stage III compliance

**FY 1993**  
Analysis and prediction code update based on completed testing

**FY 1994**  
Selection of final component configurations for part-scale development testing

**FY 1995**  
Part-scale component tests, with and without forward flight effects, completed and used to verify aerothermodynamic performance and Stage III noise predictions
PROPULSION NOISE REDUCTION
HIGH-SPEED RESEARCH PROGRAM

MILESTONES

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**NOISE ANALYSIS AND PREDICTION CODE DEVELOPMENT**

- FY 1990: Initial 2-D and 3-D analysis codes
- FY 1991: Code update based on experiments
- FY 1994: Prediction verification with tests

**AERO/ACOUSTIC CONCEPT EXPERIMENTS**

- FY 1990: Nozzle geometry effects on plume mixing
- FY 1991: Porous plug shock management
- FY 1992: Contoured 2-D shock management
- FY 1993: Inverted velocity profile
- FY 1994: Active control feasibility

**LOW-NOISE COMPONENT CONFIGURATION DEFINITION AND DEVELOPMENT**

- FY 1990: Concept analytical assessment/screening
- FY 1991: Candidate scale-model tests
- FY 1992: Engine cycle/nozzle definitions
- FY 1993: Performance/noise verification test
COMMUNITY NOISE REDUCTION ELEMENTS

The noise heard on the ground as an aircraft flies overhead is not only a function of the propulsion system, but also dependent on the aircraft flight path and atmospheric propagation characteristics. In particular, a wing with good takeoff lift performance will help reduce observed noise by quickly carrying the offending engines to high altitudes.

Using noise source models developed in the propulsion noise research, with particular emphasis on takeoff conditions, the Community Noise research will include the following elements:

- Update of atmospheric propagation models.

- Investigation of innovative flight operations to minimize perceived noise, particularly utilization of high lift aerodynamics.

- Prediction of noise footprints (i.e., the ground area subjected to threshold or greater noise levels of interest such as FAR 36, Stage III) for assessment of overall acoustic performance.
COMMUNITY NOISE REDUCTION

HIGH-LIFT AERODYNAMICS

ATMOSPHERIC PROPAGATION

ELEMENTS

FLIGHT OPERATIONS

REDUCTIONS IN NOISE FOOTPRINTS

Advanced High Lift

Current Technology

Runway

Downrange

HSCT 5.1 mi²

Airport

Concorde 74.8 mi²
COMMUNITY NOISE REDUCTION APPROACH

Major advances have occurred recently in the capability to predict the complex vortical flows associated with highly swept wings operating at high angles of attack. The resulting high-lift aerodynamic techniques will be coupled with noise predictions for the advanced engine concepts being evaluated in the HSRP. Community noise computer codes will be modified to incorporate new modules that reflect advances such as active and passive jet noise suppression, and various nozzle geometries and exit velocity profiles.

Component and model-scale tests will be conducted to provide input to the predictive techniques and to help verify the accuracy of the completed analyses. These experiments will address the far-field community noise and the engine/airframe performance integration, as well as the high-lift devices that augment basic wing performance. Tradeoffs of operational procedures will then be conducted to develop new low-noise/high-lift systems for HSCT aircraft.

Concept verification in the HSRP will include a suitable combination of analysis and experiment.
COMMUNITY NOISE REDUCTION
HIGH-SPEED RESEARCH PROGRAM

APPROACH

|---------|---------|---------|---------|---------|---------|

PREDICTIVE METHODOLOGY
- SUPERSONIC AIRCRAFT NOISE
- NONLINEAR WING THEORY
- ENROUTE NOISE COUPLING

SUPPORTING EXPERIMENTS
- HIGH-LIFT SYSTEMS
- LOW NOISE/HIGH-LIFT SYSTEMS

CONCEPT VERIFICATION
- ENGINE/AIRFRAME INTEGRATION
- LOW NOISE/HIGHLY SWEPT WINGS
# COMMUNITY NOISE REDUCTION MILESTONES

Key milestones have been established to track progress and to facilitate mid-course program adjustments. Major benchmarks during the program are:

<table>
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<tr>
<th>Year</th>
<th>Milestone</th>
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<tbody>
<tr>
<td><strong>FY 1991</strong></td>
<td>Development of supersonic jet noise model and identification of candidate high-lift systems</td>
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<tr>
<td><strong>FY 1993</strong></td>
<td>Initial HSCT system noise prediction code is available</td>
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<tr>
<td><strong>FY 1994</strong></td>
<td>Low-noise, high-lift concepts are evaluated through supporting experiments</td>
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<tr>
<td><strong>FY 1995</strong></td>
<td>Conduct wind tunnel verification test program on low-noise aircraft including integrated high-lift system concept</td>
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COMMUNITY NOISE REDUCTION

MILESTONES

|---------|---------|---------|---------|---------|---------|

**PREDICTIVE METHODOLOGY**

- FY 1990: Develop Supersonic Noise Code
- FY 1991: Complete Advanced High-Lift Wing Code
- FY 1992: Couple Noise and High-Lift Codes
- FY 1993: Validated Method Available

**SUPPORTING EXPERIMENTS**

- FY 1990: High-Lift Systems, Small Scale
- FY 1991: Low-Noise High-Lift Concepts
- FY 1992: Advanced Airfoil/Flap Systems

**CONCEPT VERIFICATION**

- FY 1990: Verify Noise Code
- FY 1991: Low-Noise Aircraft Wind Tunnel Test
SONIC BOOM

Sonic boom is the result of a pressure disturbance caused by an aircraft flying at supersonic speeds. The aircraft advances faster than the disturbance, which can only travel at the speed of sound. In supersonic cruise, the disturbance propagates in a conical region behind the aircraft. The intersection of this region with the ground defines a “footprint” where the sonic boom will be experienced. A plot of the pressure change experienced on the ground is generally described as a sharp increase when the initial shock from the aircraft nose is experienced, a linear decrease to below normal pressure, then another shock from the rear of the aircraft restoring normal pressure.

For some routes the ability to fly at supersonic speeds over land as well as over water would greatly enhance the time benefit to the passenger. It would also increase productivity and economic viability.

There are no reliable guidelines on what sonic boom noise levels might be acceptable for flight over land. In addition to the magnitude, the detailed shape of the pressure wave can influence the perception, and therefore the annoyance, of sonic boom noise. Configuration trades must be made to define design approaches permitting the most perceived noise reduction for the minimum cost in vehicle efficiency.

The goals for the sonic boom reduction research are to: a) establish acceptability criteria, b) develop predictive methodology for minimum boom concepts, and c) verify prediction capability.
HIGH-SPEED RESEARCH PROGRAM

SONIC BOOM

PRESSURE DISTURBANCE

PRESSURE CHANGE (\(\Delta p\)) AT GROUND

\[ \Delta p \]

DISTANCE OR TIME
SONIC BOOM REDUCTION ELEMENTS

**Human Response Criteria:** The economic viability of supersonic transports would be significantly enhanced if they produced "acceptable" sonic booms. This element, therefore, seeks to determine what level of sonic boom would be acceptable to the general populace. It would also quantify the potential benefits of sonic boom shaping and determine the response of buildings and other structures.

**Prediction:** Achieving a low boom configuration first requires an accurate capability to predict the near-field disturbances about a complete aircraft. Computational analyses will be developed to address potential HSCT geometries and flight conditions and extended to evaluate low-boom concepts.

**Propagation:** The near-field results will be extrapolated to the far field, including all atmospheric properties necessary to accurately predict the sonic boom observed on the ground. This element will also be used to ensure the viability of low-boom concepts developed with the near-field codes above.

**Concept Verification:** Experiments will be utilized to verify the prediction/minimization codes and to better understand the detailed effects of geometry changes.
The effort to minimize sonic boom impact involves a synergistic approach, combining advances in the understanding of human and structural response to booms with modifications to aircraft geometry to reduce annoyance.

Very little is known about the subjective response to the annoyance of sonic booms or how buildings and other structures respond to the related impulses. Sophisticated technical, statistical and psychological means will be used to measure response characteristics. The acceptability criteria developed here will be used to guide the design of low-boom concepts and to evaluate those designs with analysis and experiments. Assessment of far-field propagation effects will ensure that the benefits of low-boom concepts are not reduced by the atmosphere.

Verification of the low-boom concepts and design methodology will be accomplished experimentally with simulation of the annoyance for human response, wind tunnel tests of aircraft performance and possible flight tests involving current supersonic aircraft.
**SONIC BOOM REDUCTION**

**HIGH-SPEED RESEARCH PROGRAM**

**APPROACH**

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<td><strong>ACCEPTABILITY CRITERIA</strong></td>
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**SONIC BOOM PREDICTION AND MINIMIZATION**

- NEAR FIELD PREDICTIONS
- DESIGN STUDIES
- LOW-BOOM CONCEPTS

**FAR-FIELD PROPAGATION EFFECTS**

- ATMOSPHERIC EFFECTS
- COUPLE TO PREDICTIVE TECHNIQUE

**CONFIGURATION MINIMIZATION AND VERIFICATION**

- IDENTIFY LOW-BOOM CONCEPTS
- FINAL DESIGN VERIFICATION
- MODEL SCALE DEMONSTRATION
SONIC BOOM REDUCTION MILESTONES

Key milestones have been established to facilitate program monitoring and control. Major benchmarks during the program are:

**FY 1990**  Preliminary assessment of human response to sonic boom is determined

**FY 1992/93**  Sonic boom prediction capability is developed and far field propagation effects investigated

**FY 1994**  Conduct low-boom optimization studies

**FY 1995**  Methodology and propagation effects verified by flight test
SONIC BOOM REDUCTION

MILESTONES

|---------|---------|---------|---------|---------|---------|

**HUMAN RESPONSE CRITERIA**

- Subjective Assessment
- Interim Criteria
- Subjective Assessment
- Final Criteria

**PREDICTION AND MINIMIZATION**

- Near Field Code
- Design Studies
- Far Field Code
- Experimental Correlation
- Optimization Studies

**FAR-FIELD PROPAGATION EFFECTS**

- Atmospheric Variation Model
- Couple with Prediction Code

**CONFIGURATION MINIMIZATION AND VERIFICATION**

- Wind Tunnel Tests
- Wind Tunnel Tests
- Flight Tests
SUPERSONIC LAMINAR FLOW CONTROL

The previously discussed program topics address direct reduction of emissions, noise and sonic boom. A less direct but extremely important means for reduction of these environmental problems is to reduce the weight of the aircraft, which in turn results in a lower boom level and in smaller engines that produce less emissions and noise. Advanced structures and materials for lower weight that have a broad range of vehicle applications are being addressed in other NASA programs and are considered in the System Studies element of the HSRP. Another means of significant weight reduction is laminar flow control, a technology that requires special attention for supersonic cruise application.

The achievement of drag reduction is critically important for high-speed civil transports because of the inherently small payload fraction for such vehicles which makes any reduction in fuel requirement especially beneficial, as additional revenue producing passengers can then be carried. Laminar flow control offers a major potential for minimizing overall drag by directly reducing the friction drag component, which is a third or more of the total aircraft drag, and indirectly reducing shock wave drag by lowering aircraft weight since less fuel and smaller engines would be required to overcome drag forces. In a similar synergistic manner, benefits will accrue with respect to sonic boom, aerodynamic heating, and aircraft speed and range.

Theoretical estimates of the benefits for achieving laminar flow control through pressure gradient control (i.e., natural laminar flow) and suction indicate that a significant increase in lift-to-drag ratio can be obtained. Even with penalties associated with suction system weight and engine power extraction, recent analyses have predicted 6.5% or greater reductions in takeoff gross weight for typical high-speed civil transports, an amount comparable to the aircraft’s payload.
HIGH-SPEED RESEARCH PROGRAM

SUPERSONIC LAMINAR FLOW CONTROL

TURBULENT BASELINE:
680,000 LB TAKEOFF GROSS WEIGHT (299,000 LB FUEL)
5000 NMI RANGE
PROJECTED YEAR 2000 TECHNOLOGIES

M = 2.4

LFC RESULTS:
CRUISE DRAG BENEFIT: 8.0% REDUCTION

PENALTIES:
• 8500 LB SYSTEM WEIGHT
• 1200 HP FROM ENGINES TO OPERATE

NET BENEFIT:
• 45,000 LB (6.5%) REDUCTION IN GROSS WEIGHT
• 33,100 LB (11.1%) REDUCTION IN FUEL WEIGHT

LAMINAR FLOW WITH SUCTION

NATURAL LAMINAR FLOW
SUPERSONIC LAMINAR FLOW CONTROL ELEMENTS

Three inter-related and complementary activities comprise the principal elements of the HSRP's Supersonic Laminar Flow Control (SLFC) technology development:

**Prediction**: As in all other areas of aerodynamics, modern computational fluid dynamic techniques are to be applied. These include nonlinear aerodynamic wing flowfield codes, three-dimensional stability analyses and laminar-to-turbulent transition prediction. The related necessary understanding of fluid physics will be assisted by fundamental experiments.

**Environmental Disturbance Measurement**: Critical experiments will be conducted in low-disturbance wind tunnels and with flight instruments to evaluate and model the influence of contamination on transition, document the effect of roughness and waviness, and develop an understanding of the influence on transition of the suction holes and their coupling with free-stream disturbances. These results will contribute to the design of the flight tests and analysis of the resulting data.

**Flight Tests**: Because of difficulty in simulation of vehicle scale and atmospheric conditions, flight tests of wings incorporating SLFC will be conducted with a modified F-16XL aircraft and will be the primary focus of this element, providing a comprehensive data base for validation of design methodologies being developed in the program.

These activities will be closely coordinated with the System Studies portion of the program to ensure the practicality of the SLFC concepts being investigated.
SUPERSONIC LAMINAR FLOW CONTROL
HIGH-SPEED RESEARCH PROGRAM

ELEMENTS

ENVIRONMENTAL DISTURBANCE MEASUREMENT

PREDICTION

FLIGHT TESTS
SUPersonic laminar flow control approach

The approach to development of supersonic laminar flow control technology will use a combination of fundamental experiments, predictive techniques and flight tests to understand the physical mechanisms adequately to assemble an effective design methodology.

Fundamental experiments will utilize special facilities such as a low disturbance wind tunnel and high-altitude research aircraft to obtain a basic understanding of flow response to ambient disturbances as well as aircraft shape. This information will be used to improve the prediction of laminar-to-turbulent transition, which will then be verified by additional experiments.

The application of advanced computational tools will provide the capability to design the maximum extent of laminar flow. A capability to predict transition will allow the development of effective control devices and to plan flight experiments.

In turn, measurements of ambient atmospheric disturbances will be used both to guide the development of prediction methodology and in the design of flight tests to verify the methodology. A series of flight tests will be conducted during the program to allow an iterative development and verification of the design tools.
## SUPersonic Laminar Flow control

**High-Speed Research Program**

### Approach

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<td><strong>Fundamental Experiments</strong></td>
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<td>- Receptivity Experiments</td>
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<td>- Laminar Control Devices</td>
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<td><strong>Transition Prediction</strong></td>
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<td>- 3-D Nonlinear Codes</td>
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<td>- Stability Analyses</td>
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<td>- Calibrate Design Tools</td>
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<td><strong>Environmental Disturbance Measurements</strong></td>
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<td><strong>Flight Experiments</strong></td>
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<tr>
<td>- Transition Measurements</td>
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<tr>
<td>- Flow Control Devices</td>
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**SUPersonic Laminar Flow Control Milestones**

Key milestones have been established in each of the elements to track related progress and to ease mid-course planning adjustments, if needed. Major benchmarks during the technology development process are:

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<th>Year</th>
<th>Milestones</th>
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<tr>
<td><strong>FY 1990</strong></td>
<td>First flight experiments with transition glove</td>
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<tr>
<td><strong>FY 1991</strong></td>
<td>First experiments on boundary layer disturbances sensitivity</td>
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<td>Flight measurements of environmental disturbances</td>
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<tr>
<td><strong>FY 1992</strong></td>
<td>Flight tests of modified glove with leading-edge suction</td>
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<td>Transition prediction capability for 3-D supersonic flow</td>
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<tr>
<td><strong>FY 1994/95</strong></td>
<td>Flight tests of the suction glove and evaluation of alternative laminar flow control devices</td>
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</table>
MILESTONES

**FUNDAMENTAL EXPERIMENTS**
- FY 1990: Boundary Layer Response Experiments
- FY 1991: Correlate with Theory
- FY 1992: Assess Control Devices

**TRANSITION PREDICTION**
- FY 1993: Develop Advanced Nonlinear Code
- FY 1994: Design Tools Available

**ENVIRONMENTAL DISTURBANCES**
- FY 1995: Develop Flight Sensor
- FY 1996: Measure Atmospheric Disturbances

**FLIGHT EXPERIMENTS**
- FY 1997: Conduct Baseline Transition Glove Test
- FY 1998: Conduct Leading-Edge Suction Transition Test
- FY 1999: Initial LFC Tests
- FY 2000: Complete LFC Tests
MILESTONE SUMMARY

As noted in the introduction, the purpose of the High-Speed Research Program is to investigate the environmental compatibility and economic viability of High-Speed Civil Transport.

The program has been subdivided into three principal elements that address the issues of atmospheric effects and emissions, noise, and sonic boom. Interim milestones have been scheduled to assess the status of our knowledge and the progress of technology development. The general course will be to first understand basic phenomena, prepare computer models or other design tools, and finally to verify these tools with experiments. Midcourse corrections will occur as required.
## HIGH-SPEED RESEARCH PROGRAM

### MILESTONE SUMMARY

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<thead>
<tr>
<th>ELEMENTS</th>
<th>FY</th>
<th>GOALS</th>
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<tr>
<td><strong>ATMOSPHERIC EFFECTS</strong></td>
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<td><strong>ASSESS EFFECTS OF HSCT FLEET ON ATMOSPHERE</strong></td>
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<td><strong>PROVIDE BASIS FOR EVALUATING AND GUIDING TECHNOLOGY</strong></td>
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<td><strong>EMISSIONS AND SOURCE NOISE</strong></td>
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<td><strong>DEVELOP TECHNOLOGY FOR ACCEPTABLE REDUCTION OF EMISSIONS AND NOISE</strong></td>
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<tr>
<td><strong>EMISSIONS AND SOURCE NOISE</strong></td>
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<td><strong>COMMUNITY NOISE / HIGH LIFT</strong></td>
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<td></td>
<td><strong>VERIFY COMPLIANCE WITH FAR 36 STAGE III NOISE LEVELS</strong></td>
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<td><strong>ASSESS LOW BOOM CONCEPTS</strong></td>
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<td><strong>DEVELOP SLFC TECHNOLOGY</strong></td>
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PROGRAM SUMMARY

A successful conclusion of the program will demonstrate that economic and technically promising bases exist for:

- Flight in the upper atmosphere without environmental degradation
- Satisfaction of the current noise regulations, and
- Supersonic flight overland or efficient subsonic flight to satisfy sonic boom restrictions

Achievement of these goals will allow a confident initiation of a cooperative NASA/industry focused technology development program that, in turn, would complete a foundation for eventual industry development of a High-Speed Civil Transport.
HIGH-SPEED RESEARCH PROGRAM

PROGRAM SUMMARY

A SUCCESSFUL CONCLUSION OF THE INTERRELATED RESEARCH EFFORTS WILL DEMONSTRATE:

EMISSIONS
- Feasibility of 90% NOx Reduction to EI = 3 to 8
- Validity of HSCT Ozone Effect Predictions
- Acceptability of Emission Levels

AIRPORT COMMUNITY NOISE
- Feasibility of Economically Viable Compliance with FAR 36-III

SONIC BOOM
- Feasibility of Acceptable Supersonic Overflight or Economic Viability Assuming Subsonic Overflight Restriction

READINESS FOR INITIATION OF HIGH-LEVERAGE TECHNOLOGY DEVELOPMENT PROGRAM
RESOURCE SUMMARY

The budget resources for the High-Speed Research Program are allocated by technical discipline. Investigations of the effects of projected aircraft operations on the upper atmosphere will be conducted by scientists who have been associated with NASA's previous more general research in this area. The related emissions studies will be conducted in a cooperative manner by engineers responsible for aircraft engine combustor technology. Likewise, airport community noise, sonic boom and supersonic laminar flow control investigations will be conducted by researchers who have continuing responsibility for those basic aircraft technologies. The Systems Studies element of the High-Speed Research Program will continue the work begun in the previous High-Speed Civil Transport Studies.

The funding plan reflects the emphasis on environmental matters. As discussed earlier, HSRP is the first phase of a long-range plan to prepare a foundation for industry HSCT development. The indicated funding growth reflects the normal budgetary trend of a new program that requires early study and procurement activity, followed by hardware acquisition and testing, and ending with less expensive data analysis activities.
## HIGH-SPEED RESEARCH PROGRAM

### RESOURCE SUMMARY

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