AN ADVANCED CONCEPT THAT PROMISES ECOLOGICAL AND ECONOMIC VIABILITY

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SUMMARY

Economical and ecologically acceptable supersonic travel throughout the world can be a reality in the 1990's. The actuality of supersonic commercial service being provided by Concorde is demonstrating to the world the advantages offered by supersonic travel for both business and recreation. Public acceptance will gradually and persistently stimulate interest to proceed with a second generation design that meets updated economic and ecological standards. This paper identifies an advanced technology supersonic cruise vehicle, developed under the NASA SCAR program, that could be available for commercial service in the 1990's. It is estimated that this concept could operate profitably on world-wide routes with a revenue structure based upon economy fares. This airplane will meet all present day ecological requirements regarding noise and emissions.

INTRODUCTION

The National Supersonic Transport Program was canceled in 1971 after a considerable investment of the national resources, both material and human. The major factors which contributed to the program demise were the ecological and economic deficiencies due to marginal range-payload characteristics. In the same time period, attractive subsonic wide-body aircraft were being introduced into the long-haul aircraft market. At the close of the program, it was clear to both Government and industry that significant improvements in supersonic technology were required to make a second generation aircraft economically viable and ecologically acceptable.

In 1972, the National Aeronautics and Space Administration (NASA) initiated an Advanced Supersonic Technology (AST) program. The intent of the program was, and still is (in the form of the SCAR program), to give the industry of the country the technology data base needed to proceed with development of a second generation supersonic cruise vehicle, when that decision is made.

TECHNOLOGY - WHY?

At the present time, it is not proper to ask "Why a civil supersonic cruise vehicle?" but rather "Why technology studies?"

For the past several years, NASA Langley Research Center has been pursuing a Supersonic Cruise Aircraft Research (SCAR) program to provide sound technical bases for future civil and military supersonic vehicles. Under NASA sponsorship, various engine and airframe companies have been conducting technology assessment or impact studies to identify and assign priorities to important research and development programs and provide guidance and support to see that the critical needs are implemented. This program has provided industry with funds to perform contract studies, and has defined a flagpole around which industry could gather its own privately funded supersonic technology studies and research. An integrated program approach, as illustrated in Figure 1, has been formed because of this stimulus. Without an integration team monitoring the various on-going programs and assessing the technology impact, guidance for updating programs or identifying new programs would be missing. The all important technology and economic feedback would also be missing. In earlier aircraft development programs, these kinds of advancements in the various technologies were largely stimulated by general NASA research and military aircraft studies, contracts, and development.

The present SCAR impact studies have drawn together inputs from NASA research efforts, industry independent research and development (IRAD), FAA/SST follow-on tasks, and various Climatic Impact Assessment Program (CIAP) and airline inputs. Such studies provide the only valid means of assessing the worth of the discrete technical advances resulting from the research and technology programs. Such efforts are beneficial in reducing risk and building experienced design teams necessary to permit successful program expansion from the research and technology phase to a development/production program at a later date. It should also be noted that these studies give emphasis to the need for experimental programs and correlation of results with parallel theoretical programs.

TECHNOLOGY - WHEN?

The point in time when technology readiness must be established depends upon what degree of technology advancement is required, what funding support is to be made available to establish these advances, when the airplane that results from these technology improvements can be made available, and finally, and most importantly, when the marketplace is in a position to accept and successfully employ this new advanced technology airplane.

Early introduction of a Supersonic Cruise Vehicle (SCV) into the marketplace does not seem likely at this time because of the current economic status of the airline industry, its need to replace aging subsonic long range equipment with new quiet fuel-efficient replacements, and the political adversity to new aircraft designs that are claimed to threaten the ecological well-being of all citizenry.

The 1980's are most likely to be the era of the subsonic transport derivative (Figure 2). In the middle 1980's, airlines will be replacing 727-100's, 707's and DC-8's. The projected economic viability of the airline industry will not be able to support two aircraft programs such as subsonic derivatives and a supersonic cruise vehicle. Airline management must opt for the derivative aircraft first.

Time is therefore available to perform further SCV technology studies. With adequate funding, this time can be used to develop much improved airframes and propulsion systems, and demonstrate their viability as well. This program would establish for this country a supersonic airplane technology readiness status by mid 1980 that would permit low-risk development of economic and ecologically viable commercial supersonic cruise vehicles and superior advanced supersonic military tactical and long range cruise aircraft.

SCV DESIGN OBJECTIVES

A successful second generation SCV must properly meet market needs in terms of range and size. To insure economic viability, the design should emphasize the smallest aircraft size possible, cruise speeds commensurate with best possible utilization, and payload fractions at least twice that of Concorde. Lockheed marketing studies performed in 1973, with market projections carried out to the year 2000, suggested that the most attractive designs adopt trans-Atlantic range with approximately a 300-passenger payload capability. Such a concept benefits from small airplane size, with resultant improvements in development/production costs and operating expenses. A later growth version of the concept appears as a logical follow-on derivative that would provide nonstop trans-Pacific operation. A modest payload growth to 11 - 12 percent appears reasonable (Figure 3).

Cruise speed studies suggest operation at Mach 2.5, with the capability of achieving these speeds under representative high-altitude, hot-day operations.

Range

The Lockheed concept has been designed to achieve a zero-wind, hot-day range of 7400 km (4000 nautical miles). This goal provides a design concept that can achieve world-wide operations as shown in Figure 4. The aircraft can readily accommodate the North Atlantic with nonstop operation. The aircraft will be practical for North-South American operations. It can operate satisfactorily in the Pacific using Honolulu as a stopover for east/west flights. Nonstop Pacific operation requires a range of 8900 km (4800 nautical miles); an aircraft with this capability would increase gross mass approximately 68,000 kg (150,000 lb) and be more costly for most service operations. It may be possible to develop this size airplane as a later growth version of the basic 7400 km (4000 nautical mile) design.

Speed

Task III of the NASA-Lockheed technology assessment study carefully examined cruise speed options. TWA added airline experience by assisting in a separate Lockheed-funded cruise speed study. Figure 5 reveals that Mach numbers greater than 2 permit four flights per day across the Atlantic with reasonable allowances made for turnaround time. The studies indicated that increasing speed offered greater potential with regard to utilization and scheduling flexibility.

Beyond Mach 2.5, temperature effects prohibit use of practical composite materials (Figure 6). SCV's must use polymide type composites. The epoxy versions being developed for subsonic aircraft cannot be employed for elevated temperature SCV application because of structural deficiencies brought on by moisture absorption.

Capacity

During the Lockheed economic studies conducted in Task II of the SCAR studies, the question of payload size was studied. The results, shown in Figure 7, indicate an economic plateau around 300 passengers. Below this number, return on investment (ROI) decreases due to increasing direct operating cost (DOC). Above this number the forecast traffic potential is not great enough to sustain utilization and would result in decreased flight frequency.

SCV MAJOR CONCERNS

The aforementioned design goals must be realized while fully recognizing the demands of other vital issues: cost, risk, noise, emissions (Figure 8). Performance advances can be obtained by two methods: improved flight efficiency in terms of lift-to-drag ratio and fuel consumption; and reduced airplane mass fractions, defined as the ratio of operating mass empty (OME) to takeoff gross mass (TOGM). Using today's technology an aircraft sized to 7400 km (4000 nautical miles) is not competitive. Mass and size need to be reduced in order to reduce development costs, facility costs, first costs, and support costs. The reduced size aircraft also reduces noise and emissions. To minimize risk, the aircraft must reflect simplicity in design wherever possible. A simple aircraft design reduces unknowns.

Technology advancements required to produce a viable supersonic cruise concept must encompass all the related disciplines of propulsion, aerodynamics, structures, and controls.

PROPULSION

Lockheed considers the propulsion technology as one of the most important areas that can benefit from research and development. Propulsion technology encompasses long-lead-time, high-risk items. This technology offers improvements in fuel economy and economics along with reductions in noise and emissions. Propulsion involves not only the engine but inlet, nozzle, and propulsion/airframe integration.

Advanced Engines

Throughout the SCAR program, attention has been given to engine cycle studies. Lockheed has maintained a continuous exchange with the two engine manufacturers involved in the SCAR program: the Pratt and Whitney Aircraft Company and the General Electric Company. Many advanced engine cycles have been studied since 1973 as indicated in Figure 9. The number of cycles have been narrowed down from eight in 1973 to two in 1976. Turbojets, various-bypass-ratio turbofans, and various combinations of forward, rear, and dual-valved variable cycle engines (VCE) have been investigated. The two most promising cycles that have emerged are a medium-bypass-ratio turbofan, designated as a variable stream control engine (VSCE), and a double-bypass, dual-cycle engine. The valve concepts look complex with marginal benefits.

Performance results from these cycle development efforts are compared in Figure 10 with the 1971 SST engine. The best turbojet and fan are compared along with three VCE concepts. Only small supersonic cruise fuel consumption benefits are offered by the more modern engines. The 1971 SST turbojet engine reflects near optimum cruise efficiency, whereas the modern engines reflect recognition of noise constraints which limit operating temperatures and require tailored exhaust profiles.

Subsonic fuel consumption for the SCAR engines are improved due to better off-design airflow schedules that result in less spillage and boattail drag. Large payoffs have come in improved engine mass due to advanced materials and lowered operating temperatures. The fan cycle offers the most attractive options to date due to its light mass and superior subsonic fuel consumption.

Noise

The critical airport noise problem for an SCV is jet exhaust noise. This problem, while not relevant for current subsonic transport design, is a major problem for Concorde. The SCAR studies have revealed four new potential schemes for relieving the jet noise problem. These schemes are shown in Figure 11 along with the mechanical suppressor which was available for first generation SST's. The shaded areas of the figure suggest areas of uncertainty for the various noise reduction methods. The mechanical suppressor, while offering the largest reduction potential, is the least attractive because of maintenance, stowage, and loss of nozzle efficiency. The coannular effect looks very attractive but to date has only been verified using small scale models. Full scale forward flight effects are required.

Optimization of the flight profile is a noise reduction method that is additive to the other schemes. Lift-to-drag ratio refinements brought about from high lift refinements, powered lift, and wing shape modifications, can be used to improve take-off and climb performance. Active controls can be employed for flight profile management.

Jet noise shielding provided by an above-wing engine installation appears to offer a new noise relief prospect.

Two airframe-engine arrangements that may offer this jet noise shielding potential are shown in Figure 12. The over-under engine arrangement could provide flyover noise benefits of 3 to 5 EPNdB while the acoustical staggered engine arrangement could provide sideline noise benefits of up to 3 EPNdB. The experimental results obtained from two recent independent test programs are summarized in Figure 13. The twin jet noise studies indicate a 3 EPNdB noise reduction beneath the path of the aircraft as compared to the noise levels 90 degrees to the plane of the twin jets. This data was obtained from University of Tennessee tests (Ref. 1) at relatively low jet velocities. General Electric Company data (unpublished) at higher jet velocities indicate noise reduction levels of 5 EPNdB.

Wing shielding benefit studies were made jointly by Lockheed and NASA to examine the use of wing structure as the shielding medium. A photograph of the configuration is shown in Figure 14. The effort stressed use of engines on top of the wing positioned to obtain noise shielding in combination with upper surface blowing to achieve aerodynamic improvements. The shielding benefits proved to be small. Erosion and corrosion problems plus sonic fatigue problems appear to be sizeable. Therefore the concept is not considered to be attractive.

Advanced Inlets

A serious propulsion need exists to develop advanced technology inlets to match and integrate with the development of advanced cycles. The B-70 and YF-12 are the only mixed compression inlets designed and built for supersonic aircraft. Both of these inlets incorporate technology of the 1960's.

The major areas of needed effort for advanced engine inlet technology are presented in Figure 15. Advanced control technology being developed today will allow for digital integrated propulsion controls for the inlet, engine, and nozzle package. The need for self-starting capability of the inlet must be verified. Inlet hardware commonality and simplicity have to be design goals for inlets even if designed for slightly different local Mach numbers at the inlet face.

An example of inlet airflow matching between inlet and engine for the General Electric double-bypass, dual-cycle engine is shown in Figure 16. Corrected airflow is plotted versus Mach number. The dashed lines indicate the initial SCAR inlet design using axisymmetrical inlets with translating centerbodies. These inlets are of the 1960 technology type. The final design features 2-D inlets with articulated centerbodies which allow for large throat area for transonic operation. All of the inlets are designed to have identical corrected airflow at cruise.

It should be noted that the over-wing inlet, due to its larger local Mach number, must have a 14 percent larger capture area at cruise to deliver the same corrected airflow to the engine. However, because of the airflow flexibility of the new proposed engines, the engines need only have different engine/inlet controls in order to be adaptable to either below-wing or over-wing installations. The mass increase of the larger over-wing inlet is offset by the ability of the inlet to supply increased transonic airflow resulting in a 25 percent thrust increase transonically with a corresponding 7 percent reduction in fuel consumption. These benefits offset partially the mass and friction drag penalties paid for the larger inlet.

Engine Location

SCV engine integration with the airframe is a complex design task that affects performance, flying quality, maintenance, and noise characteristics. A comprehensive engine location study was undertaken to identify the airplane performance, mass, and noise characteristics of several engine location arrangements (Figure 17). This study included over-the-wing, tail-mounted, and fuselage-mounted engines. Configurations incorporating three engines, T-tails, staggered engines, and canards were examined. Two configurations evolved which had superior performance characteristics: the over-under engine arrangement and the more conventional four-engines-under wing arrangement.

The over-under engine installation offers some unique characteristics that warrant more detailed investigation (Figure 18). High lift enhancement results from increased flap span. Inlet unstart isolation is provided by wing structural shielding. Mass reduction is created by a more efficient engine support structure. Vertical tail size is reduced due to movement inboard of the critical engine-out moment arm. Flyover noise reduction is produced by jet noise shielding.

Concerns were expressed regarding engine/inlet airflow matching, hardware commonality for inlet and engine, and above-wing engine-out incremental forces and moments. These concerns were the basis for high speed wind tunnel tests. The tests examined the supersonic characteristics of an engine mounted over the wing as shown in Figure 19. No problems were revealed. Aerodynamic disturbances of inlet unstart for over-wing mounted engines were reduced over that for a conventional four-engines-under-wing arrangement, since the critical engine was further inboard and experienced reduced local dynamic pressure over the top of the wing. Favorable sidewash at the vertical tail was generated by the inlet flow disturbance.

AERODYNAMICS

An SCV concept must be configured to favor cruise efficiency. In recognition of this, much wind tunnel testing and analysis, together with analytic tools employing elaborate computer programs, have been developed over the years by both NASA and industry. A respectable data base regarding the importance and understanding of wing planform shape, equivalent body shape and fineness ratio, drag-due-to-lift minimization using twist and camber, and trim drag alleviation has been amassed. Further work is in progress in these areas. Nacelle-airframe integration, elements of which have already been discussed, also forms an important part of this current activity.

A critical problem with all aircraft designed for efficient high speed operation relates to the flight characteristics that these swept wing, slender body aircraft generate at subsonic speeds, and during take-off and landing operations. The design challenge is to seek out design features and refinements that improve these deficiencies.

For these reasons, Lockheed has spent much of its SCAR aerodynamic efforts on low speed studies, wind tunnel tests, and analysis. A photograph of the low speed model is shown in Figure 20.

Wing Development

The first generation SST developed by Lockheed during the FAA/SST program of the 1960's featured a low wing loading, double delta planform, tailless concept. The philosophy of this design was to aerodynamically eliminate aerodynamic center movement due to Mach number change (double delta planform); eliminate cruise trim drag with proper wing shape and center of gravity location to enhance cruise L/D (tailless configuration); and utilize a large wing area to permit higher altitude, lower sonic boom cruise operations, and at the same time allow operations in the terminal area without need for high lift devices. Fundamentally, the concept stressed simplicity.

Technology advancements made since that time suggest that alternatives to that design philosophy may offer attractive potential. In addition, different, and in some cases, more demanding design requirements are imposed by today's scenario. Noise is a more critical consideration and forces the aerodynamicist to develop better subsonic lift-drag ratio levels for airport operation. Vortex lift cannot be relied upon because of attendant vortex drag and resultant low levels of L/D. Camber lift and the L/D benefits of high lift flaps must be utilized.

The added complexity of high lift devices is measurably offset by the benefits in wing mass savings, achieved because the high lift devices permit adoption of a higher design wing loading (smaller wing). The wing mass savings has a significant favorable impact on design range or gross mass for a given range. The best wing loading for achieving maximum payload range characteristics is always higher than the wing loading desired for airport performance needs. All subsonic transports in operation today adopt wing loadings that favor cruise performance, and adopt high lift devices to tailor the wing aerodynamic characteristics to provide good airport performance characteristics. A similar philosophy applied to an SCV therefore seems like an attractive prospect.

Figure 21 depicts the major considerations affecting wing area selection for a given payload range supersonic cruise airplane. The incremental range gain with decreasing wing area shows the benefit for cruise operation at wing loadings for best cruise efficiency. A 1970 technology design wing area is identified. The range benefit obtainable from improved lift augmentation is indicated by the 199X objective wing size.

Takeoff field length and approach speed sensitivity to reduced wing area are shown in the side plots. These figures serve to indicate the need for advancements in high lift required to achieve satisfactory speeds and field lengths, when taking the high wing loading option.

High Lift Assessment

Lift enhancement is made difficult by the very features which are responsible for its high cruise efficiency - leading edge sweep and reduced span. Large wing leading edge sweep angles are desired so that the leading edge falls behind the Mach line in cruise. This geometry relationship produces benefits in cruise L/D, and allows for rounded wing leading edge shapes that benefit low speed L/D. Trailing edge sweep also improves supersonic L/D levels. Hence for best supersonic cruise efficiency, the highly swept arrow wing offers the greatest potential.

Extreme sweep, combined with low span, offers very poor low speed aerodynamic characteristics, and requires auxiliary means for achieving desired levels of performance. One potential solution to the problem is to adopt the variable sweep wing design concept - configure a wing with an inboard pivot that will allow for rotation of an outer wing panel, so as to reduce its sweep and increase wing span for low speed operations. This novel design idea was thoroughly explored in the FAA/SST program of the 60's, and was abandoned because of extreme design complexity and mass bogies.

Use of a fixed wing with supersonic leading edge sweep offers some relief to the low speed problem, but the benefits do not totally eliminate the need for auxiliary geometry changes. The exception to this would be use of large wing areas (the Lockheed approach of the 1960's).

The present Lockheed philosophy is to recognize the need for high lift devices (Figure 22), and accept the challenge that these auxiliary flaps be developed so as to provide satisfactory low speed aerodynamic characteristics while adopting the most efficient high speed wing shape - the arrow wing.

The development task that needs to be done can and should include the following considerations:

> Angle of attack - high values produce more lift, but also more vortex drag, worsen flight station visibility, and require a longer landing gear.
>
> Active controls - offer the potential for using relaxed static stability as a means for alleviating the trim drag normally associated with flap deflection (it should be noted that the notch of the arrow wing also helps alleviate flaps-down trim problems, since the flap is located in a more forward location than would be the case with an unnotched planform).
>
> Powered lift - the high thrust-weight ratio of the SCV suggests the use of vectored thrust, or engine bleed air for BLC, as a further means for achieving lift for takeoff.
>
> Folding wing tips - can be employed to provide tip extensions for low speed operation, and retract during normal flight regimes.

Figure 23 illustrates how flaps and relaxed static stability help improve the low speed characteristics. The flaps generate camber lift producing an increased lift at constant angle of attack. The flaps also generate additional nose down pitching moment. However, the trim requirement needs are alleviated by moving the center of gravity aft. Tail loads are not needed for trim but, as indicated, the aircraft will operate with a negative static margin. Results from NASA and Lockheed low speed wind tunnel tests indicate that a trimmed approach lift coefficient compatible with the wing loading desired for best payload and range can be attained at an acceptable angle of attack. These data show that the incremental pitching moment coefficient from the trailing edge flaps requires a relaxation of inherent static stability requirements by about 6-8 percent. Relaxed Static Stability (RSS) is predicated on the continued development of necessary active control stability augmentation systems.

Additional lift enhancement is proposed for the Lockheed SCAR baseline configuration by means of folding wing tips (Figure 24). During cruise these panels are vertical, adding to the directional stability. At low speed, when the trailing edge flaps are extended, the wing tips are redeployed horizontally. Wind tunnel tests verify that the added span improves the lift curve slope so that at approach angle of attack, a supplemental lift increment of approximately 10 percent can be realized by reasonably sized tip extensions.

The use of powered lift to enhance arrow wing lift characteristics has received serious attention. One application, using upper surface blowing as a means for supplementing flap lift, was discussed early in connection with Figure 14. Other means studied were vectored thrust and BLC. Analytic studies and large scale NASA wind tunnel tests have been carried out. Lockheed assisted in the data analysis of these tests.

Findings are summarized in Figure 25. Shown is the thrust increase needed to provide added lift, as a function of the reduction in approach speed permitted by the lift increment, assuming fixed approach attitude. Compared are the relationships using simple flap deflection, flaps with hinge line chordwise blowing, and thrust vectoring by means of tilting exhaust nozzles. The figure shows that in the range of flap effectiveness linearity ($\delta_f = 0^\circ$-30°), use of powered lift requires greater levels of approach thrust to achieve a given decrement in approach speed. Greater thrust means higher approach noise. Therefore, these results do not suggest any advantage for powered lift. However, the potential of this idea has not yet been fully explored, and further study of powered lift appears to be warranted.

STRUCTURES

Advances in aircraft structures offer significant potential when applied to supersonic cruise vehicles, with the prospect that the "1960 all-titanium structure" vehicle mass can be decreased by ten percent. This will be achievable because of new developments in materials, controls technology, manufacturing processes, and analytic methods.

As part of the NASA SCAR activities, Lockheed performed a one year structural design contract study of an arrow wing planform SCV. This program exercised the latest computer aided analytic techniques and advanced materials options, and studied numerous structural design concepts. Design criteria, design conditions, stress allowables, loads, structural arrangements, masses, aeroelastic characteristics, and flutter behavior were all established during this detailed study. Results are presented in Reference 2.

Materials

A new structural advancement receiving great attention at present is the prospect of using new composite materials to replace metal alloys. These composites are formed from filaments of metal or carbon imbedded in a formable matrix. The orientation of the fibers can be arranged to produce any desired structural property with regard to load intensity and direction. Strength/mass properties exceed conventional metal alloys. Therefore, these new materials have the potential of offering lighter, more efficient structures for advanced aircraft.

Figures 26 and 27 show Lockheed aircraft that are being used to obtain flight service experience with these new materials. The L-1011 is being used to examine epoxy type composites in support of the NASA ACEE program. The YF-12 shown is a NASA research vehicle operated by Dryden Research Center, and is being used to obtain real world high temperature advanced materials characteristics in the actual flight environment of future SCV concepts.

Adoption of these new materials for commercial transport application will require an extensive, time consuming, development program. Current projections are shown in Figure 28. Most emphasis is being directed towards the epoxy subsonic aircraft type materials. Adoption of the high temperature materials for SCV use will require accelerated program activity, if these new materials are to see extensive application in basic structures.

Projected benefits of high temperature composites in reducing SCV size are shown in Figure 29. Using 1985 technology, take-off gross mass decreases 6 percent over 1980 technology, reducing the aircraft cost by $8 million (based on a production run of 300 aircraft).

Manufacturing Technology

A very significant technology emerging from the SCAR program is new manufacturing techniques such as high temperature forming (superplastic forming) and no-draft forming (Figure 30). These techniques significantly impact fabrication cost by eliminating machining operations, and by providing large structural assemblies with fewer detailed parts. Figure 31 shows a typical cost comparison to indicate the savings of using the no-draft precision forging method. Ninety percent less material is used with the total cost reduced by 75 percent. This real-world component, a titanium tail bumper forging used on the L-1011, is shown in Figure 32. Further applications and development will offer even greater opportunities to save mass and reduce production costs for 1990 airplanes.

Analytic Methods

Many new analytic methods have emerged since the first generation SST program (Figure 33). The benefits from these new analytic methods include accelerated design processes, more efficient structure, greater accuracy, improved correlation of theory and experimental tests, all at reduced cost. The structural design iteration process requires involved analyses and many technical disciplines (Figure 34). The ability to use computer programs which are properly interfaced and combined with computer graphics, measurably helps to improve response time and accuracy of results.

Shown in Figure 35 is a typical arrow wing structural model used for analysis. A computer derived map of temperature contours for one particular design condition is presented in Figure 36. A graphic representation of static deformation of the wing is shown in Figure 37.

CONTROLS

The most promising advanced technology that will see early implementation on future subsonic transport aircraft will involve use of advanced controls. These advances will pave the way for extensive application on SCV's in the 1990's. This belief is highlighted by the milestone chart of Figure 38. Certified use of active controls for load relief on the L-1011 is projected by 1982.

Potential active controls benefits are illustrated in Figure 39. Throttle management, programmed flaps, and relaxed stability will produce better climb profiles, less trim drag, and resulting noise relief. Maneuver load control, gust load alleviation, elastic mode suppression, and relaxed stability are means for mass savings that will be developed in the 1980's on subsonic aircraft. Flight station ride quality and envelope limiting are safety items needed for long-body aircraft. Relaxed stability, fuel management, and inlet controls will improve performance by reducing trim drag and improving engine performance.

The projected impact of active controls on take-off gross mass is presented in Figure 40. The benefits are the result of analyses performed using the arrow wing structure studies results presented in Ref. 2. The benefits shown may appear to be small. However, it should be appreciated that the mass savings indicated follow benefits already realized by propulsion, aerodynamics, and materials advanced technology.

CONCEPT DEVELOPMENT

A vital need of the SCAR program has been to assess technology advances to indicate the impact, relative benefit, and research priorities for the various emerging improvements. The following paragraphs describe a potential 1990 SCV design that adopts the technology advances discussed in previous paragraphs.

Figure 41 presents a summary of the advanced technology items that were adopted. An advanced turbofan is employed in an over-under engine arrangement. Potential noise relief options are envisioned as allowing the engine to be sized for maximum payload and range while meeting noise standards. The wing can be optimized for cruise while being tailored to meet low speed needs by use of a high lift system combined with relaxed static stability. New materials and fabrication techniques are employed along with active controls.

To meet the 290 passenger, 7400 km (4000 n. mi.) design requirement using 1970 technology would require a 385,500 kg (850,000 lbm) aircraft, as shown in Figure 42. Advanced technology reduces take-off gross mass by 117,000 kg (260,000 lbm). The mass reduction is distributed between the various technologies of propulsion, aerodynamics, and structures. The cross-hatched area indicates potential attainable with more optimistic advancements.

Concept Description

The concept, shown in Figure 43, is 89.5 m (294 ft) long with a 36.4 m (119.5 ft) wing span.

A summary of the concept characteristics is shown in Figure 44. The takeoff gross mass is 268,500 kg (592,000 lbm) with a payload fraction of 9 percent or 26,300 kg (58,000 lbm). The engine airflow size at take-off is 270 kg/s (600 lbm/sec). This is approximately the same engine size as employed by today's wide-body transports. The approach speed is 81 m/s (158 knots). The wing area of 624 m^2 (6720 ft^2) corresponds to a wing loading of 430 kg/m^2 (88 PSF) at takeoff. FAR part 36 noise levels are met.

Payload-range characteristics are shown in Figure 45. The 26,300 kg (58,000 lbm) payload reflects only passengers and their baggage with no provisions for cargo. The total fuel load is approximately 136,000 kg (300,000 lbm) with the reserve fuel being 70 percent of the payload. The aircraft requires a 3350 m (11,000 foot) takeoff field length on a hot day and a 3050 m (10,000 foot) landing field length.

Figure 46 compares the advanced SCV concept with the first generation Lockheed L-2000 design. The concept has increased range and carries more passengers at a slightly slower speed. It employs a smaller wing, and has a longer fuselage to accommodate the increased payload. There is no projected improvement in sonic boom. The masses are about the same.

Operating Costs

Prediction of real operating economics for a 1990 aircraft is impossible to do reliably. However, some meaningful trends are illustrated in Figure 47. Total operating cost (TOC) is plotted as a function of seat cost using 1973 dollars and 8.7¢/liter (33¢/gallon) fuel cost. An SCV will have higher cost per seat than for subsonic transports - it is a more technology intense airplane. The operating cost will be higher because of increased fuel requirements, increased engine maintenance, and lack of cargo revenue. However, Lockheed studies indicate the possiblity of an attractive realization of return on investment (ROI) even if the operating costs are 10 - 20 percent higher than the subsonics. What is presumed is that SCV's will provide all one-class passenger accommodations, that is, first class supersonic service with fare levels between present day tourist and first class rates.

CONCLUDING REMARKS

Technology accomplishments that strongly benefit economics have been identified (Figure 48). Small wing size, composite materials, and active controls provide improved performance with a smaller airframe-engine combination. Advanced manufacturing techniques and refined analytic tools show promise of providing lower development and fabrication costs.

The technology accomplishments that benefit ecology are presented in Figure 49 Engine cycle development and coannular noise relief have led to a light mass, reduced exhaust velocity turbofan. Jet and structural shielding benefits support the use of the over-under engine concept.

Future SCAR effort should follow the guidelines indicated in Figure 50. In propulsion, a scaled engine demonstrator is needed to verify predicted cycle characteristics. In-flight noise relief tests are critical and need more priority. Inlet research is needed to keep pace with cycle development. In aerodynamics, more wind tunnel testing is needed to verify emerging analytical methods. In structures, development of materials and manufacturing techniques should be accelerated. Large scale hardware programs should be implemented.

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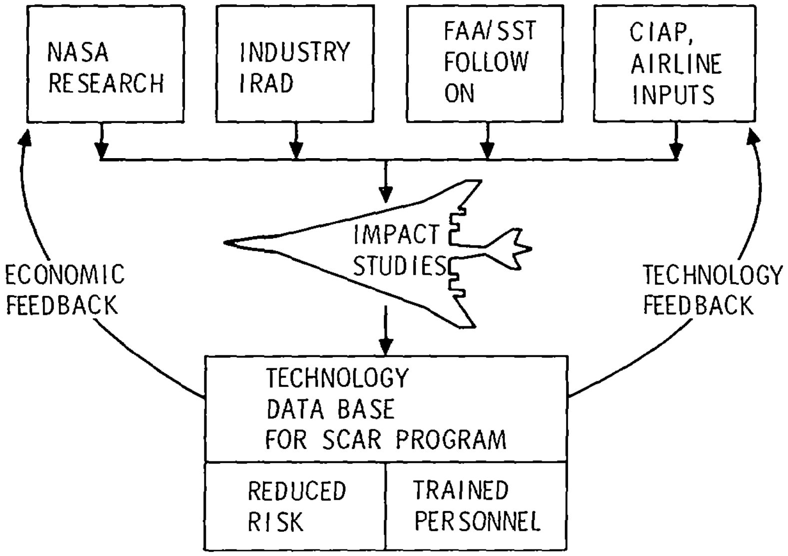

Figure 1.- Technology - why?

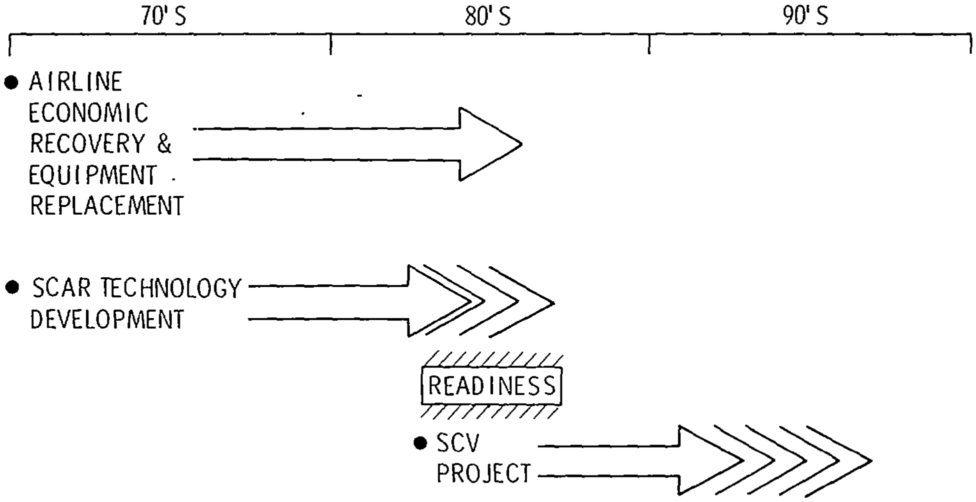

Figure 2.- Technology - when?

	INITIAL PRODUCTION	GROWTH DERIVATIVES
RANGE	TRANS-ATLANTIC	TRANS-PACIFIC (GROSS MASS STRETCH)
SPEED	2.55 ±	2.55 ±
PAYLOAD	9%	11%

Figure 3.- Performance philosophy.

4000 N.MI. PROVIDES OPERATIONAL SERVICE BETWEEN THE FOLLOWING CITY PAIRS:

	GREAT CIRCLE DISTANCE	
	km	(N.MI.)
NEW YORK – LIMA	6945	(3750)
ANCHORAGE – COPENHAGEN	6936	(3745)
NEW YORK – ROME	6862	(3705)
HONOLULU – TOKYO	6188	(3341)
TOKYO – ANCHORAGE	5563	(3004)
ANCHORAGE – NEW YORK	5430	(2932)

Figure 4.- Range.

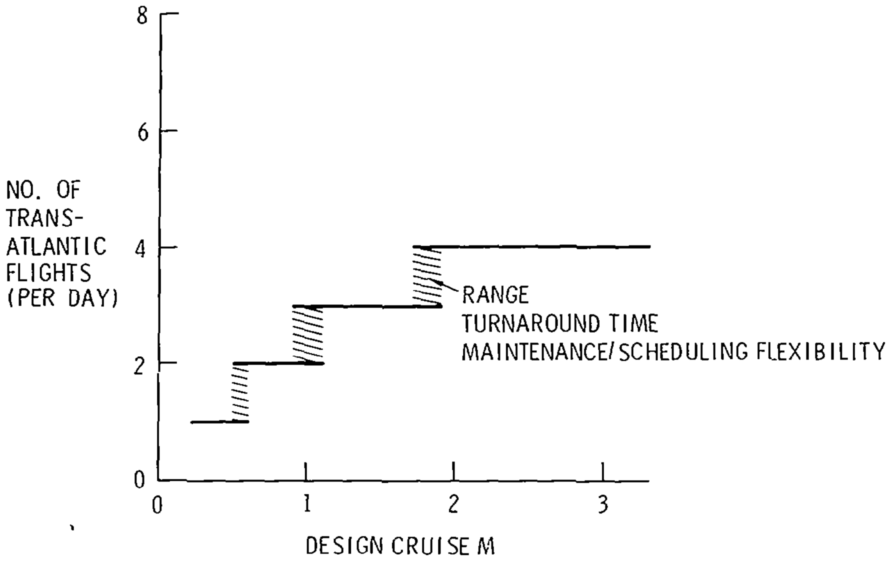

Figure 5.- Speed - scheduling impact.

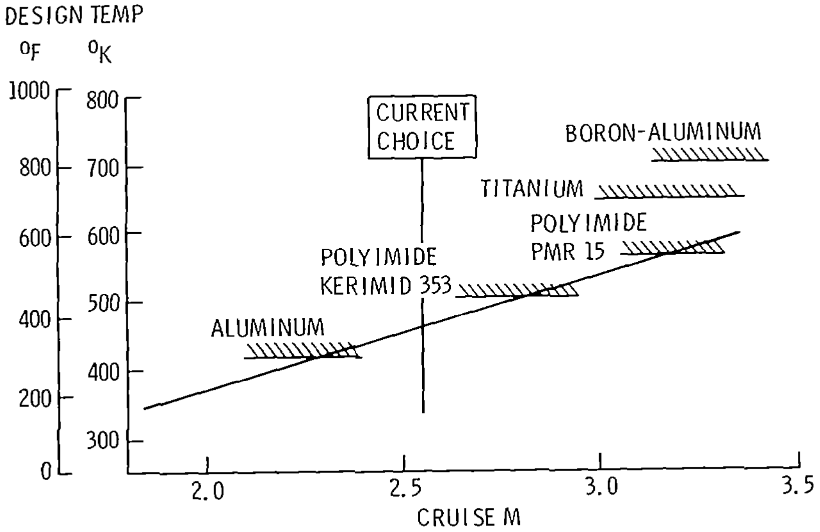

Figure 6.- Speed - materials impact.

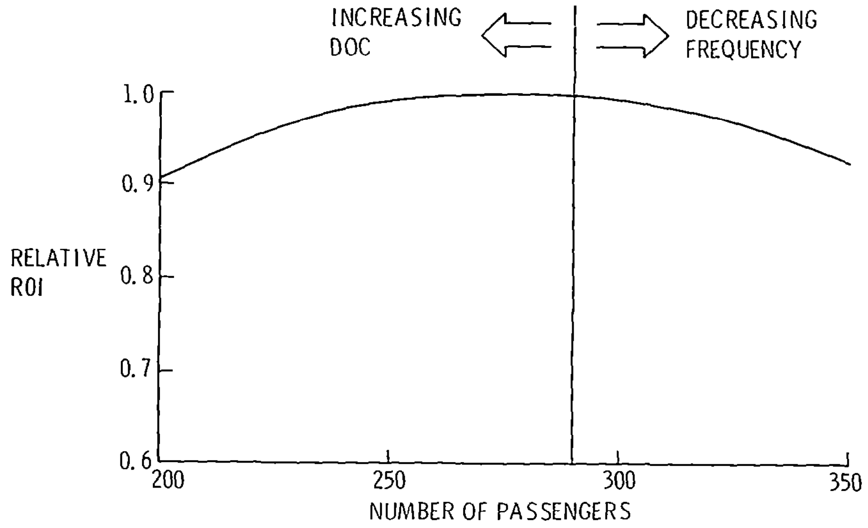

Figure 7.- Capacity.

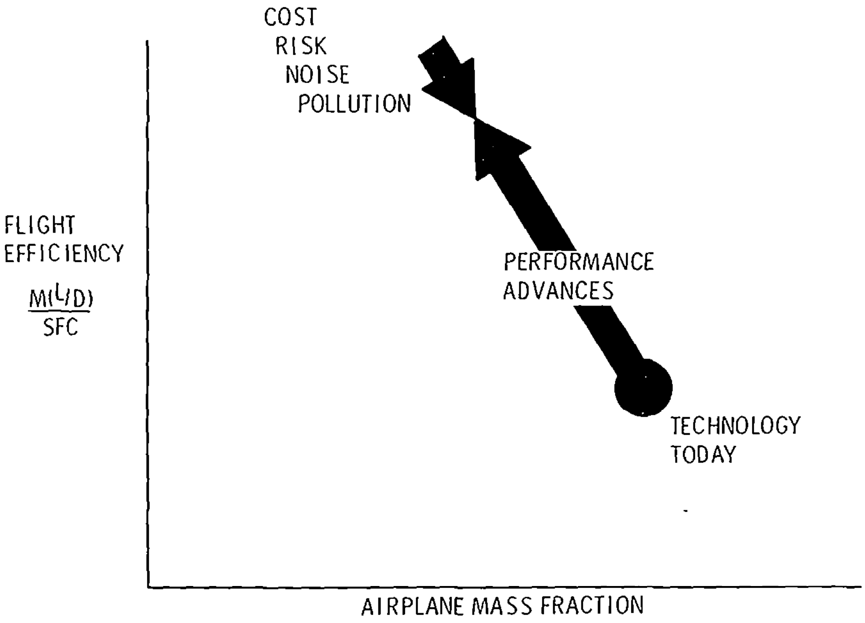

Figure 8.- SCV major concerns.

1973	1974	1975	1976
● MINI-B/P TJ	● LOW BPR A/B TJ	● LOW BPR A/B TJ (NEAR TERM)	
● LOW BPR VSCE	● MED BPR VSCE	● MED BPR VSCE	● MED BPR VSCE
● MED BPR VSCE	● MED BPR VSCE (IMP BURNER)	● DBL BYPASS DUAL CYCLE VCE	● DBL BYPASS DUAL CYCLE VCE
● HIGH BPR DBTF	● HIGH BPR DBTF	● REAR VALVE VCE	
● LOW BPR MIXED A/B TF	● SGL VALVE VCE		
● SGL VALVE VCE	● DBL BYPASS DUAL CYCLE VCE		
● DBL VALVE VCE	● REAR VALVE VCE		
● DBL VALVE VCE MIXED FLOW			

Figure 9.- Advanced engines.

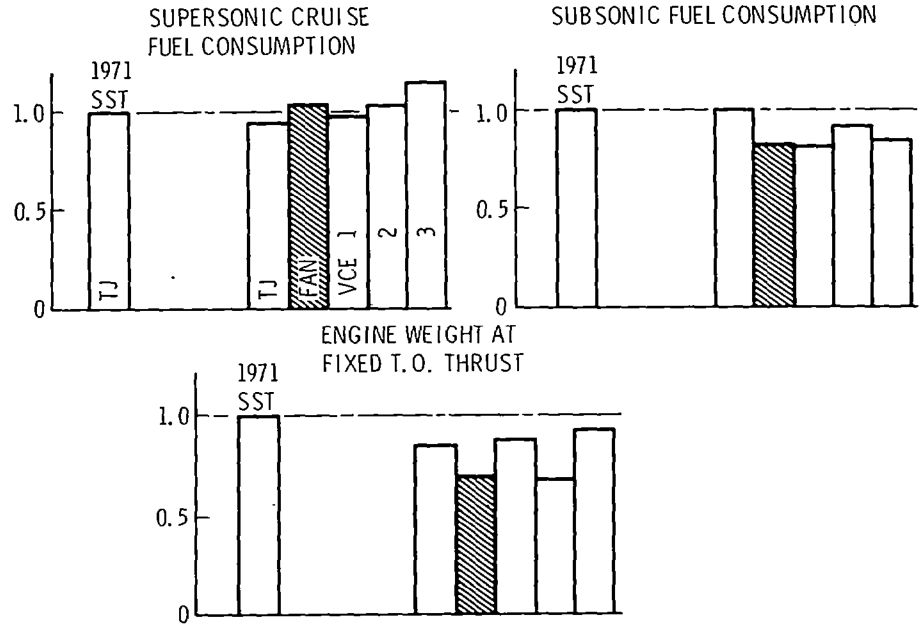

Figure 10.- Engine cycle comparisons.

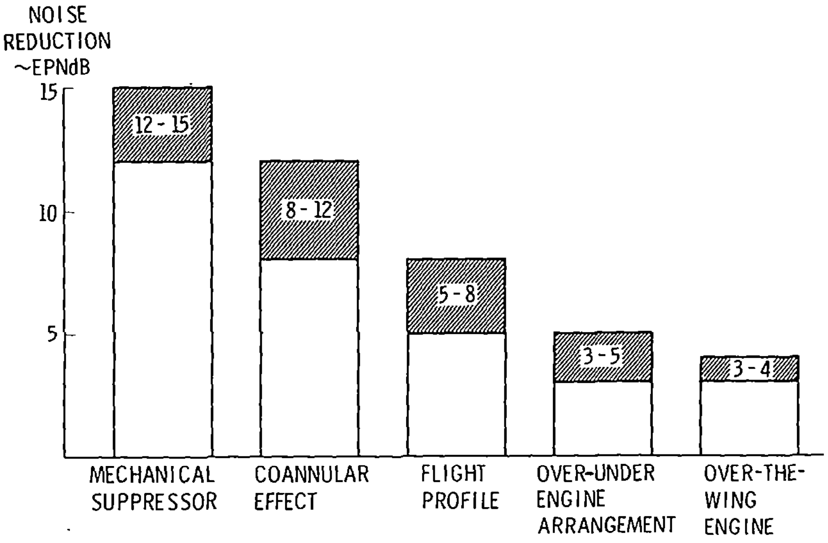

Figure 11.- Noise reduction potential.

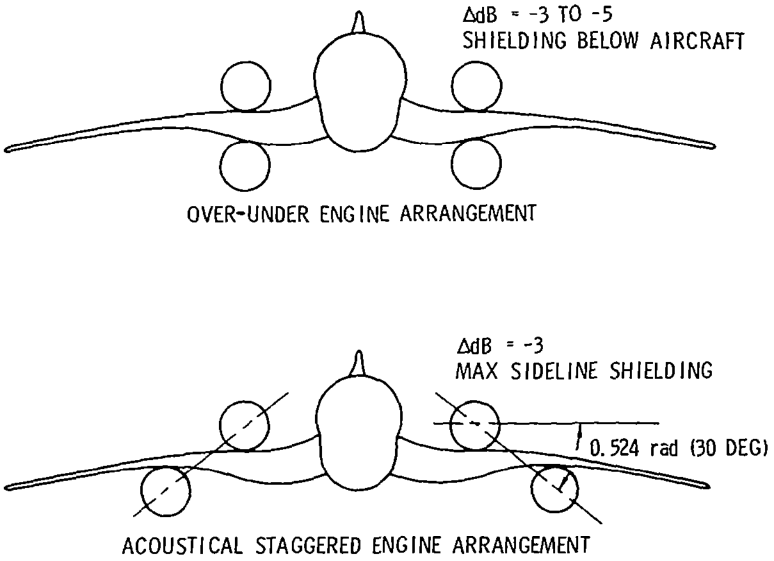

Figure 12.- Engine arrangement shielding benefits.

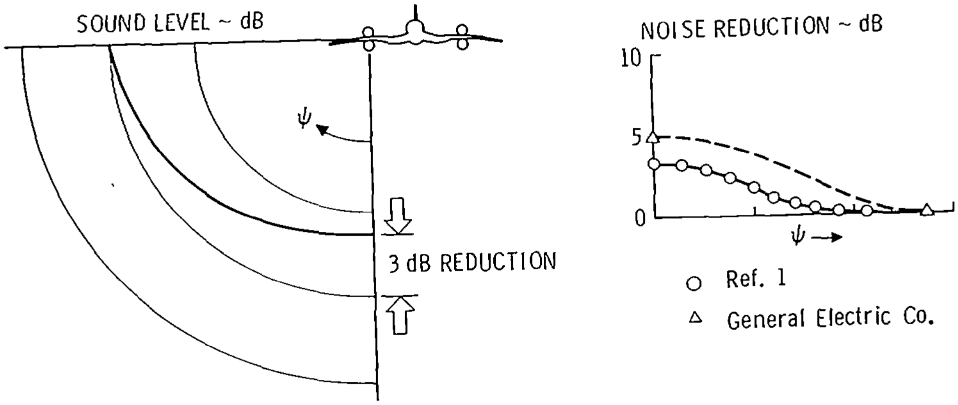

Figure 13.- Twin jet noise studies.

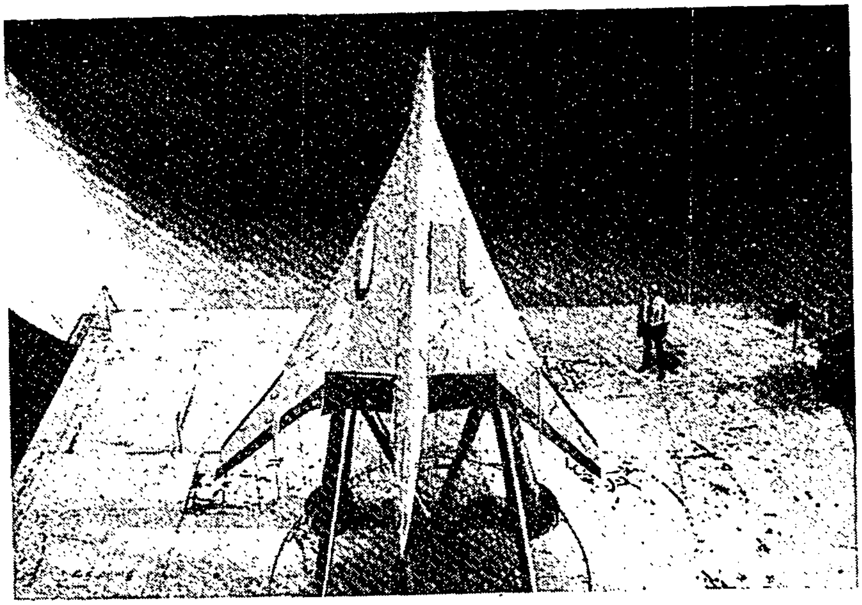

Figure 14.- Over-the-wing shielding benefits.

- ENGINE/INLET AIRFLOW MATCHING FOR MAXIMUM PROPULSION SYSTEM PERFORMANCE
- VARIABLE PERFORMANCE/STABILITY TRADEOFF
- DIGITAL INTEGRATED PROPULSION CONTROLS
- SELF-STARTING CAPABILITY
- ENGINE/INLET COMPATIBILITY
- HARDWARE COMMONALITY AND SIMPLICITY

Figure 15.- Advanced engine inlets.

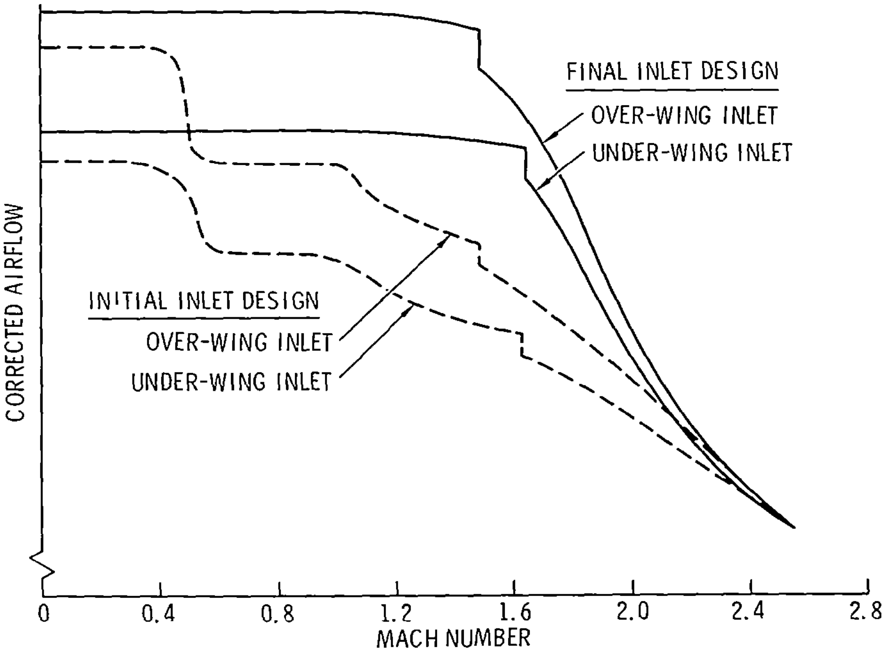

Figure 16.- Inlet airflow optimization.

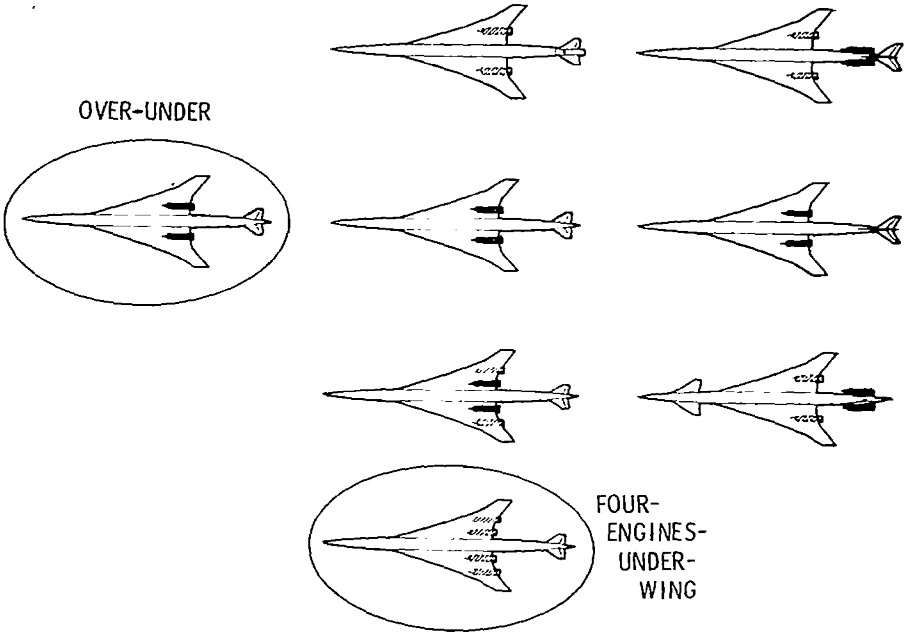

Figure 17.- Engine location study.

- HIGH LIFT ENHANCEMENT
- INLET UNSTART ISOLATION
- WEIGHT REDUCTION
  - ENGINE SUPPORT STRUCTURE
  - VERTICAL TAIL
- FLYOVER NOISE REDUCTION
- INSTALLATION CONSIDERATIONS
  - ENGINE/INLET AIRFLOW MATCHING
  - HARDWARE COMMONALITY
  - INCREMENTAL FORCES AND MOMENTS

Figure 18.- Over-under engine installation.

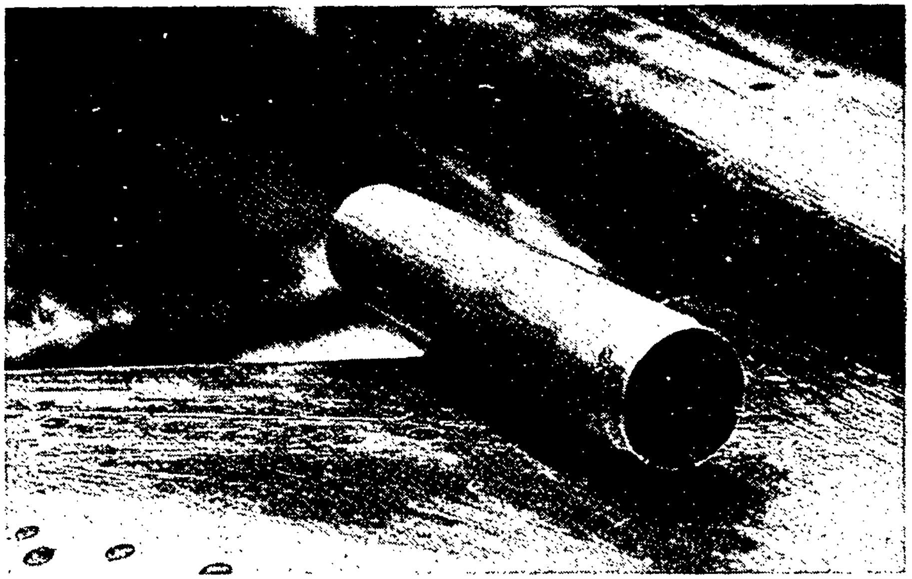

Figure 19.- Inlet unstart test.

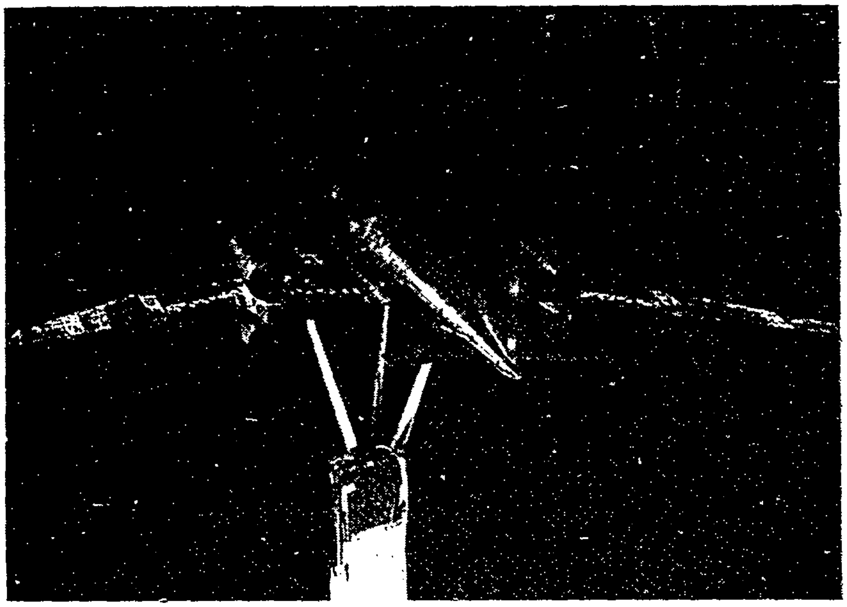

Figure 20.- High lift development model.

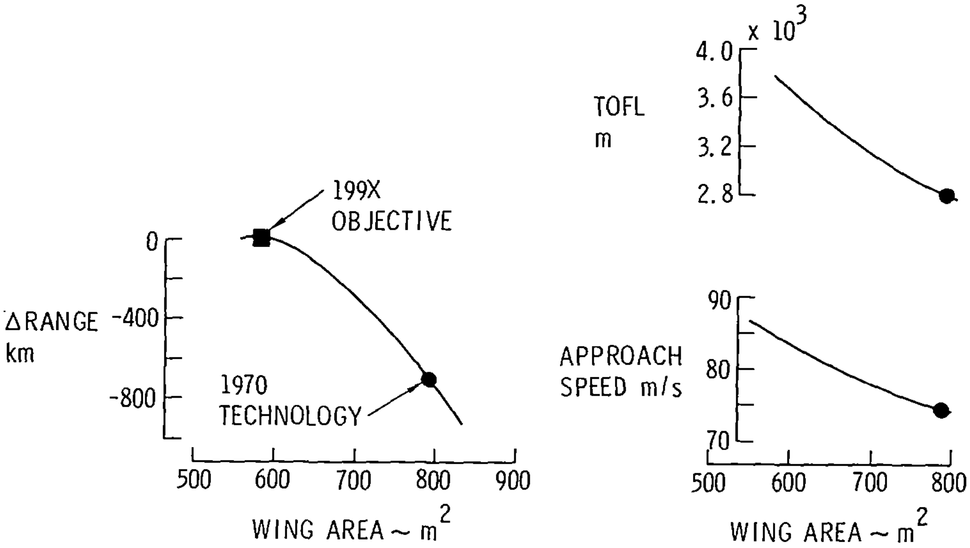

Figure 21.- Wing area selection.

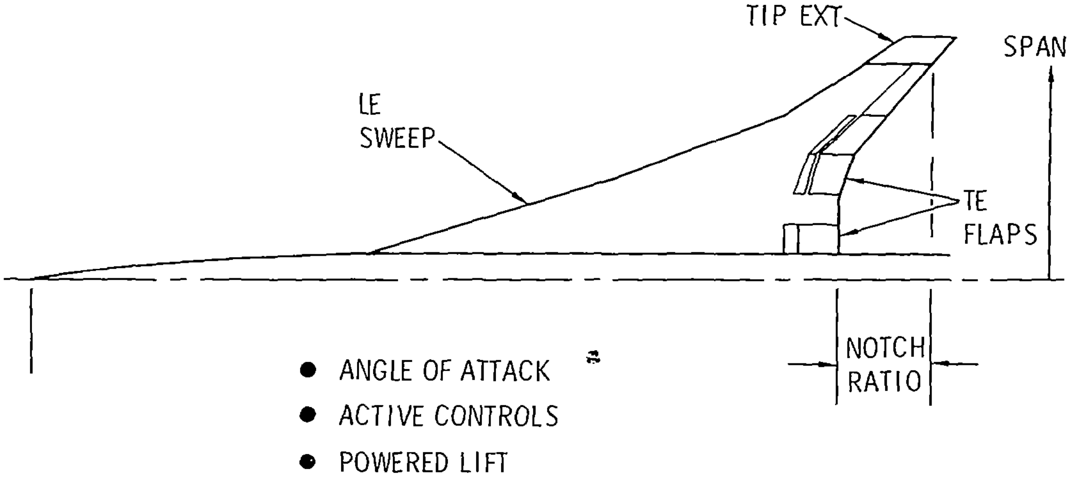

Figure 22.- Low speed lift enhancement.

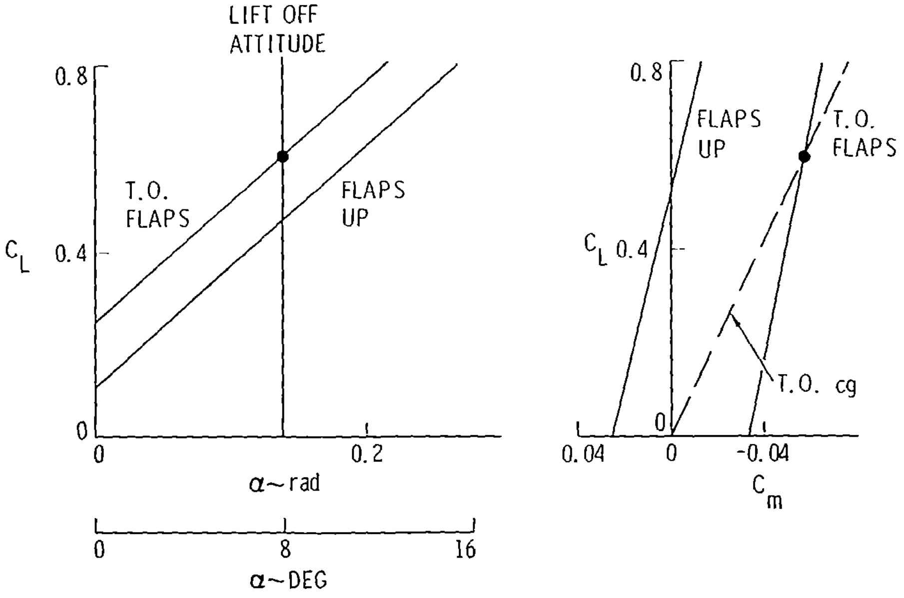

Figure 23.- Benefits of flaps and RSS.

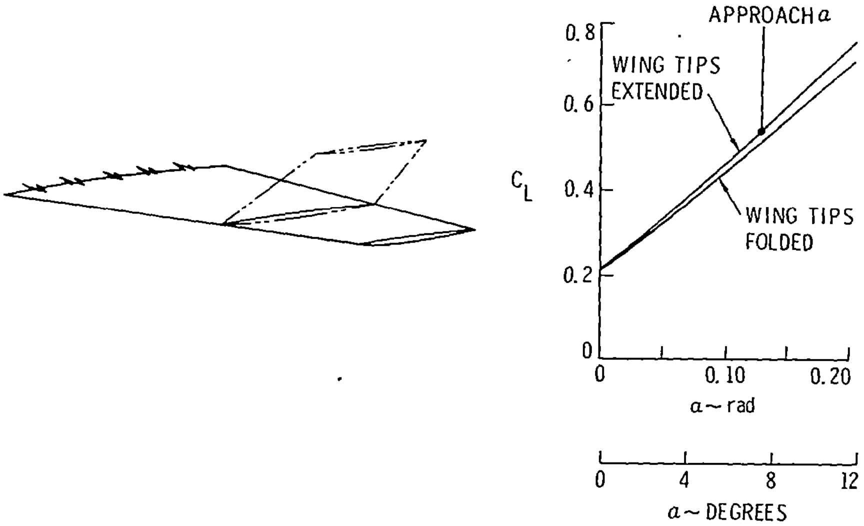

Figure 24.- Folding wing tips.

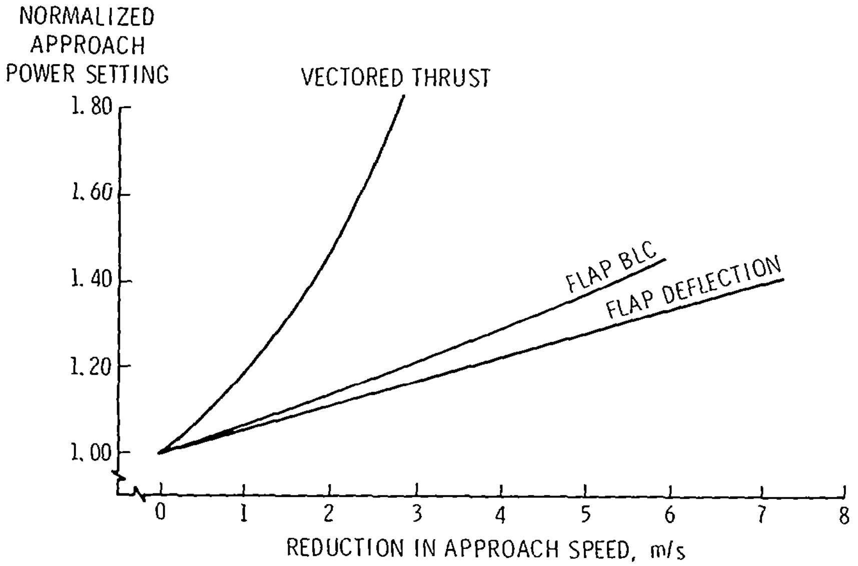

Figure 25.- Powered lift.

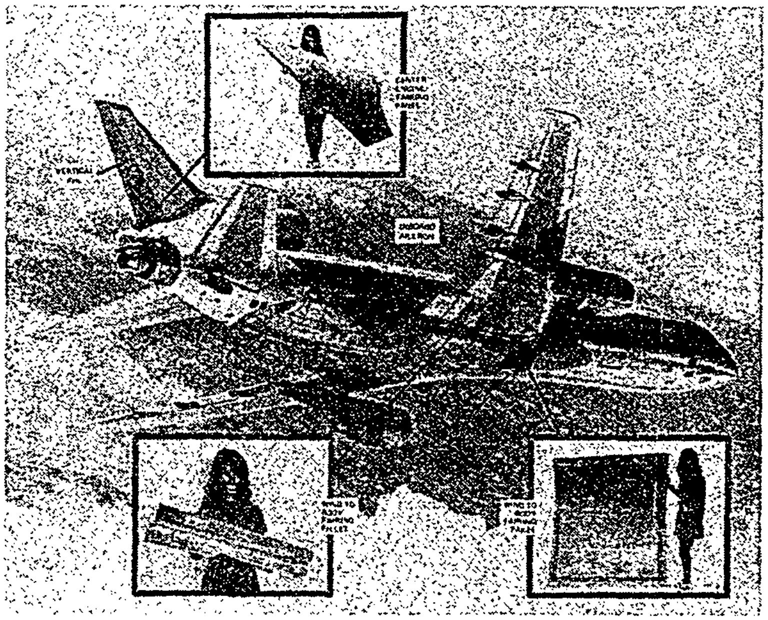

Figure 26.- Advanced material development.

Figure 27.- YF-12 panel tests.

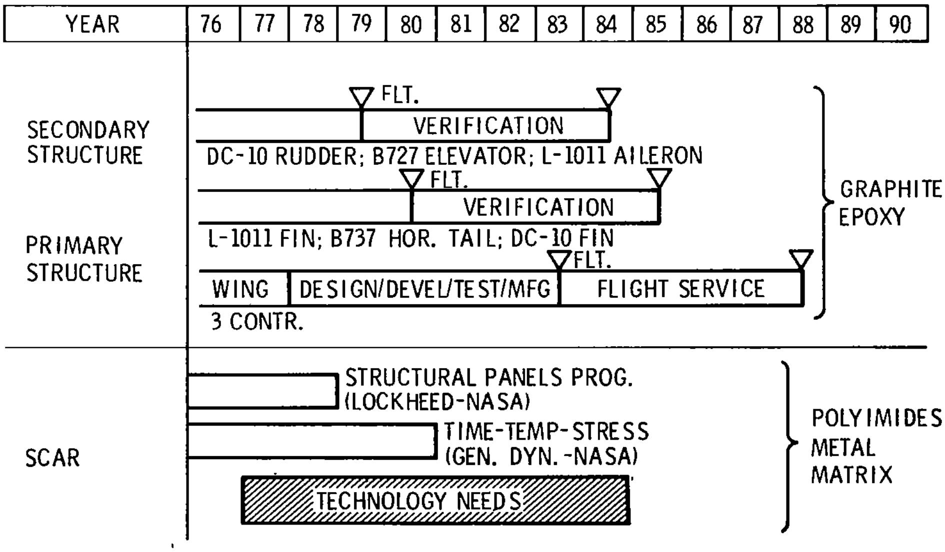

Figure 28.- Advanced composites technology schedule.

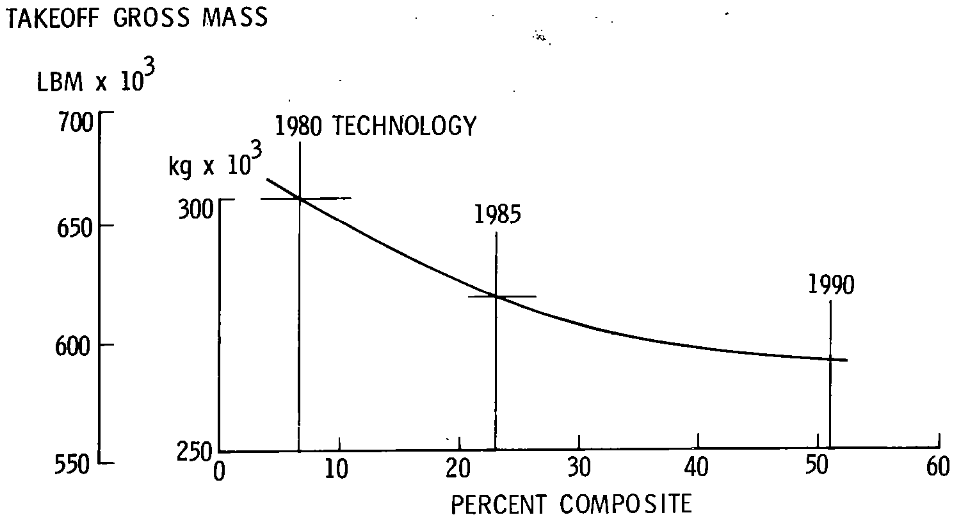

Figure 29.- Composite materials impact.

NEW TECHNIQUES

- LOW-COST—NO-DRAFT PRECISION TITANIUM FORGING
- SUPERPLASTIC FORMING

PAYOFF

- ELIMINATES MACHINING
- MINIMIZES NUMBER OF PARTS
- REDUCES MASS AND COST

Figure 30.- Advanced manufacturing technology.

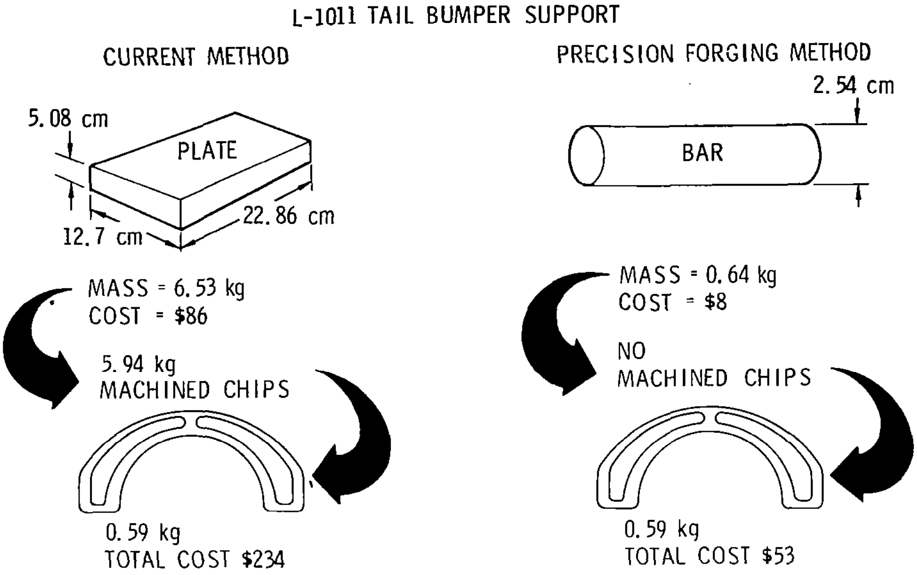

Figure 31.- Low-cost—no-draft precision titanium forging.

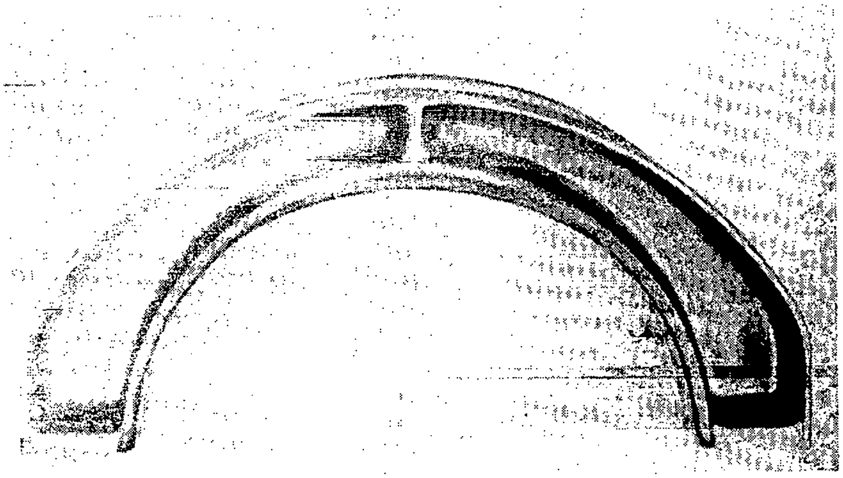

Figure 32.- Titanium manufacturing.

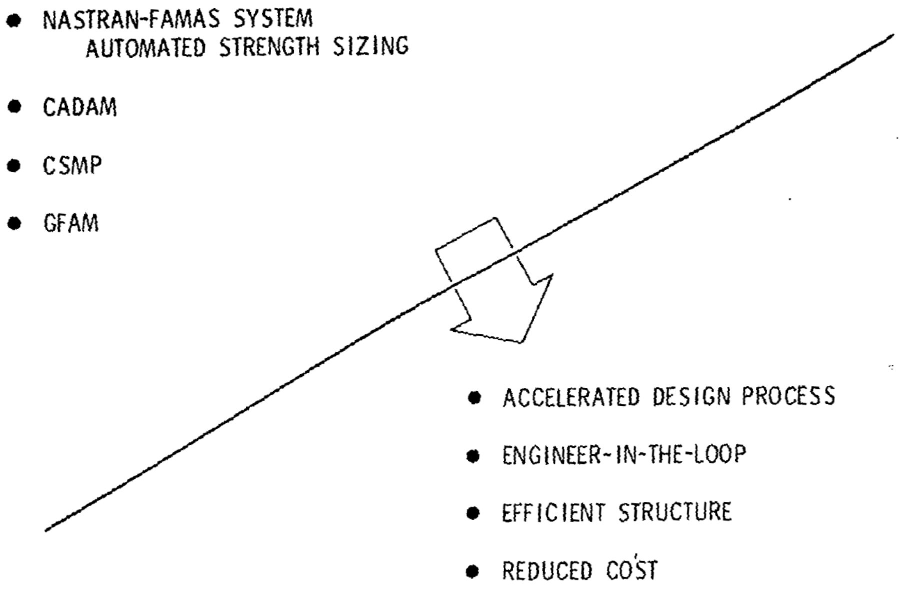

Figure 33.- New analytic methods.

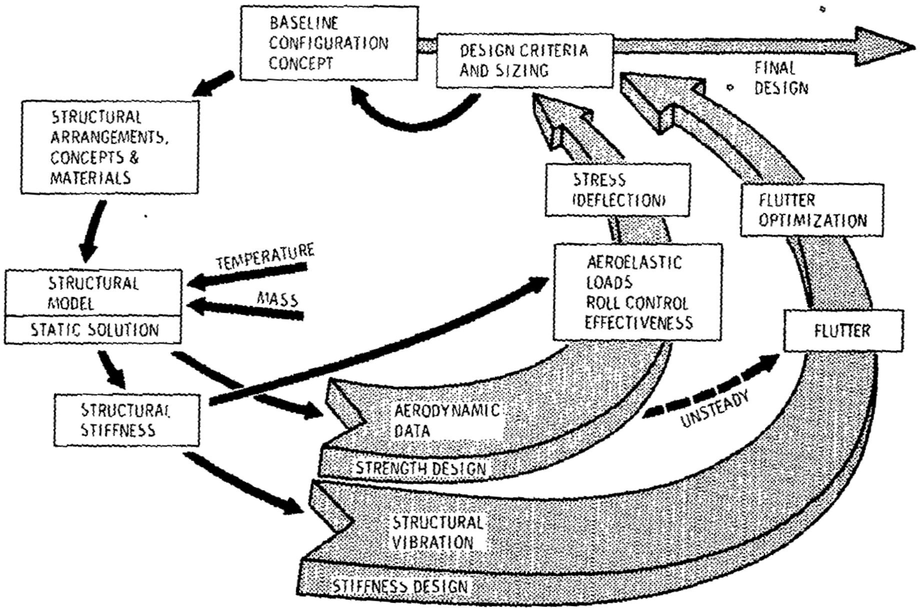

Figure 34.- Structural design methodology.

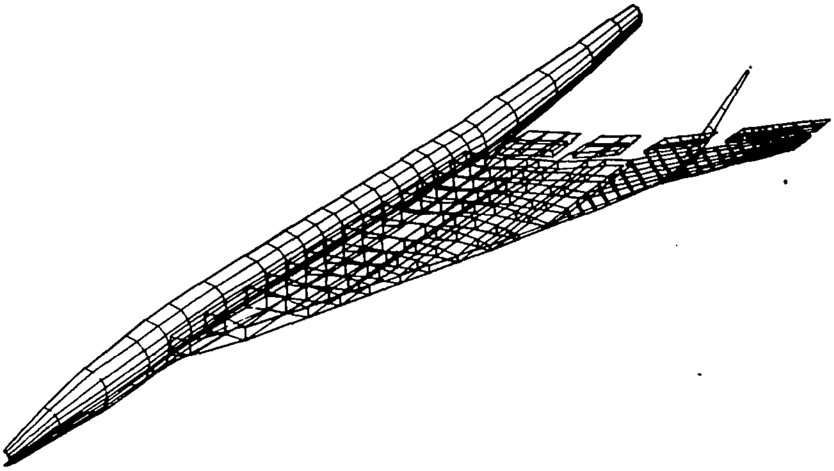

Figure 35.- Finite element structural model.

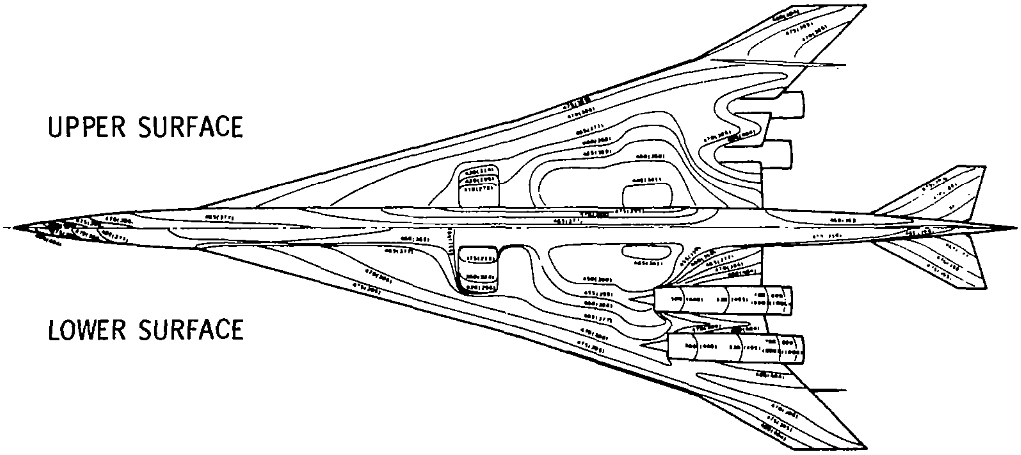

Figure 36.- Temperature contours.

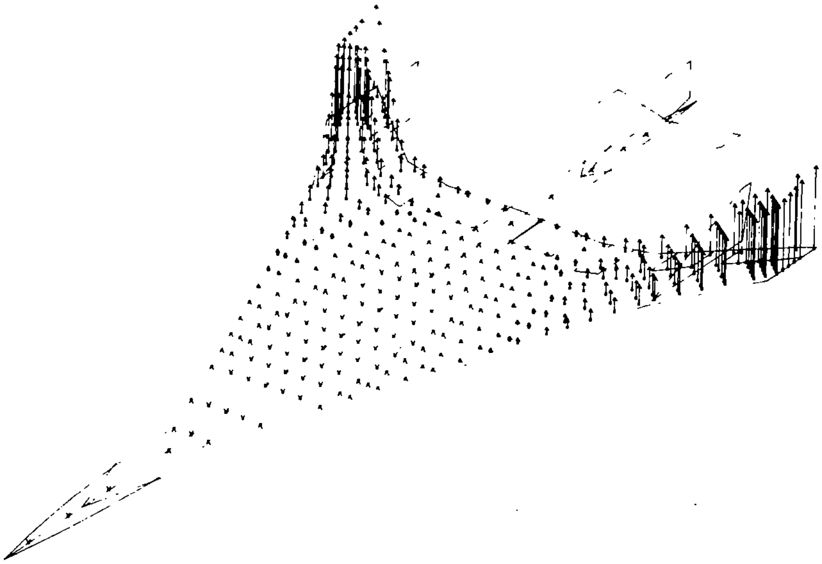

Figure 37.- Static aeroelasticity.

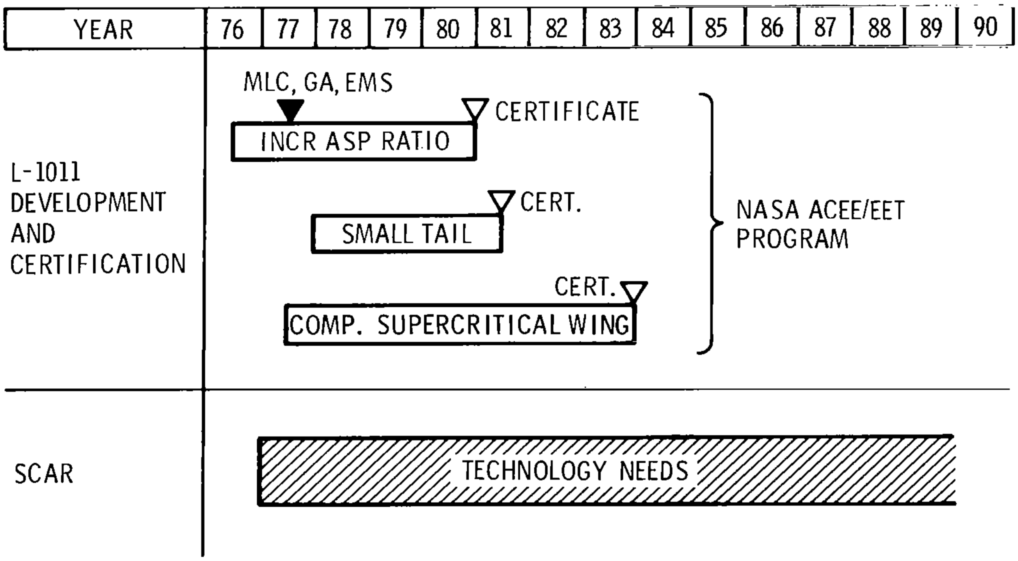

Figure 38.- Advanced controls technology development schedule.

NOISE RELIEF

- THROTTLE MANAGEMENT
- FLAP PROGRAMMING
- RELAXED STABILITY

MASS SAVINGS

- MANEUVER LOAD CONTROL
- GUST ALLEVIATION
- ELASTIC MODE SUPPRESSION
- RELAXED STABILITY

SAFETY

- FLIGHT STATION RIDE QUALITY
- ENVELOPE LIMITING

PERFORMANCE

- RELAXED STABILITY
- FUEL MANAGEMENT
- INLET CONTROLS

Figure 39.- Active controls benefits.

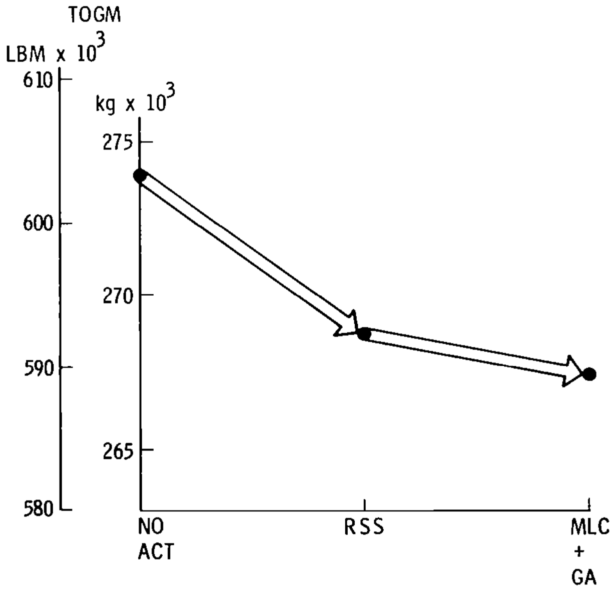

Figure 40.- Impact of active controls.

PROPULSION

- ADVANCED TURBOFAN ENGINE
- OVER-UNDER ENGINE ARRANGEMENT
- ADVANCED COMBUSTOR DESIGN
- TAILORED EXHAUST PROFILE
- SMALL ENGINE SIZE

AERODYNAMICS

- MODIFIED ARROW-WING PLANFORM
- SMALL WING AREA
- HIGH LIFT SYSTEM (FLAPS + AFT TAIL)
- RELAXED STATIC STABILITY

STRUCTURES

- POLYIMIDE TYPE COMPOSITES
- ADVANCED MANUFACTURING APPLICATIONS
- ACTIVE-CONTROLS

Figure 41.- Features.

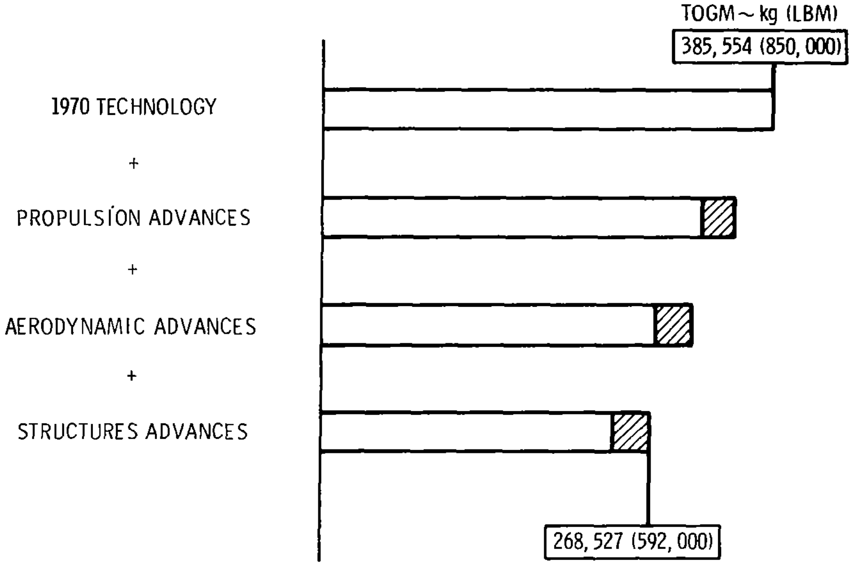

Figure 42.- Technology impact.

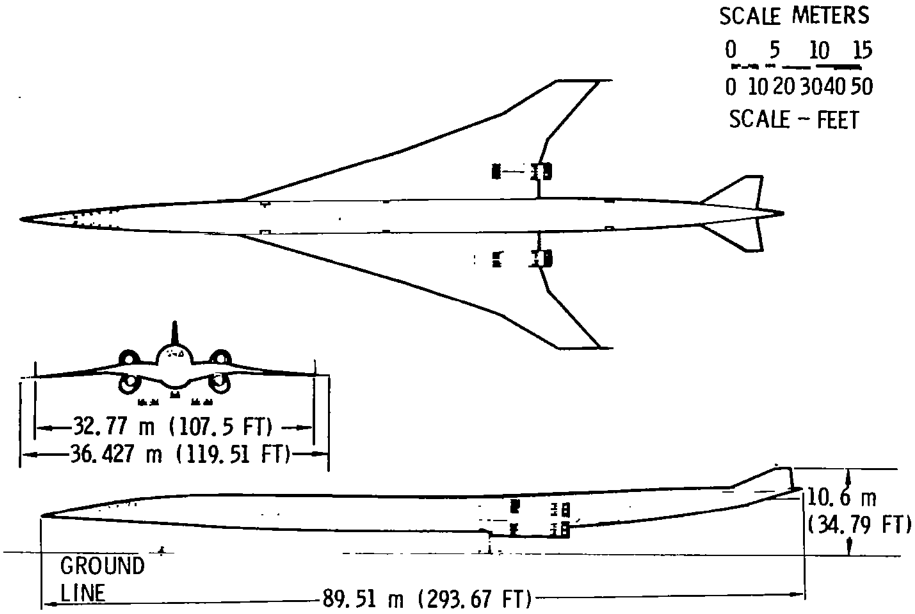

Figure 43.- SCV concept.

TOGM	268 527 kg	PAYLOAD	26 308 kg
OEM	106 594 kg	RANGE	7 593 km
CRUISE M	2.55	TOFL	3 353 m
ENGINE AIRFLOW	272.2 kg/s	APPROACH SPEED	81.3 m/s
WING AREA	624.3 m^2	NOISE	FAR 36 TO 36-3

Figure 44.- Characteristics summary.

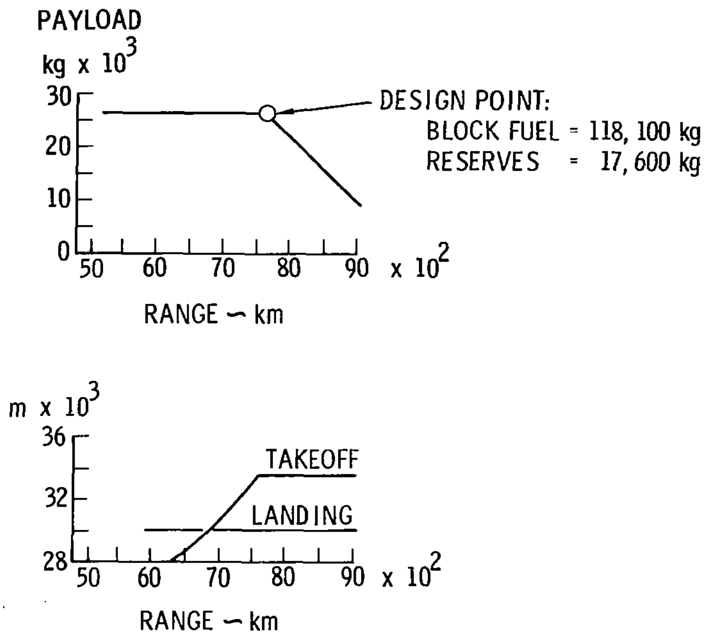

Figure 45.- Payload-range characteristics.

	L-2000-II ADVANCED SCV	L-2000-I	L-2000-II ADVANCED SCV	L-2000-I
RANGE	4100 N MI	3400 N MI	7593 km	6297 km
PASSENGERS	290	258		
CRUISE SPEED (MACH)	2.55	2.70		
WING AREA	6720 SQ FT	8486 SQ FT	624.3 m^2	788.4 m^2
LENGTH	294 FT	273 FT	89.6 m	83.2 m
TOGM	592,000 LBM	590,000 LBM	268,527 kg	267,619 kg
OEM	235,000 LBM	235,500 LBM	106,594 kg	106,821 kg
SONIC BOOM	1.7 PSF	1.7 PSF	81.4 N/m^2	81.4 N/m^2

Figure 46.- Characteristics comparison.

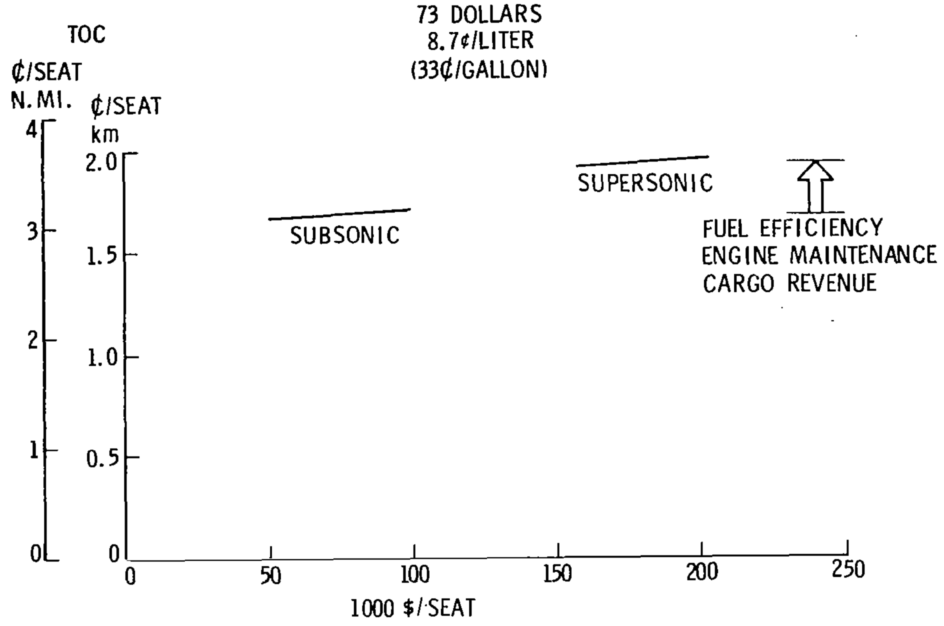

Figure 47.- Economics.

SMALL WING - HIGH LIFT DEVELOPMENT COMPOSITE MATERIALS ACTIVE CONTROLS	IMPROVED PERFORMANCE WITH SMALLER AIRFRAME-ENGINE
MANUFACTURING TECHNIQUES REFINED ANALYTIC TOOLS	LOWER DEVELOPMENT AND FABRICATION COSTS

Figure 48.- SCAR technology accomplishments - economics.

NOISE

ENGINE CYCLE DEVELOPMENT COANNULAR NOISE RELIEF	LIGHT WEIGHT, REDUCED EXHAUST VELOCITY, TURBOFAN
JET SHIELDING STRUCTURAL SHIELDING	OVER-UNDER ENGINE CONCEPT

EMISSIONS

COMBUSTOR DESIGN

Figure 49.- SCAR technology accomplishments - ecology.

PROPULSION

- SCALED ENGINE DEMONSTRATOR
- INFLIGHT NOISE RELIEF TESTS
- INLET RESEARCH

AERODYNAMICS

- CONTINUED HIGH LIFT DEVELOPMENT
- ADVANCED CONTROL DEVELOPMENT
- VEHICLE SIMULATION

STRUCTURES

- ACCELERATED DEVELOPMENT OF MATERIALS AND MANUFACTURING TECHNIQUES
- LARGE SCALE HARDWARE PROGRAMS

Figure 50.- Technology development priorities.