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Compilation and Review of Supersonic Business Jet Studies from 1963 through 1995

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ABSTRACT

This document provides a compilation of all known supersonic business jet studies/activities conducted from 1963 through 1995 by university, industry and the NASA. First, an overview is provided which chronologically displays all known supersonic business jet studies/activities conducted by universities, industry, and the NASA along with the key features of the study vehicles relative to configuration, planform, operation parameters, and the source of study. This is followed by a brief description of each study along with some comments on the study. Mention will be made as to whether the studies addressed cost, market needs, and the environmental issues of airport-community noise, sonic boom, and ozone.

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INTRODUCTION

The eventual introduction of an environmentally acceptable and economically successful supersonic transport into world-wide commercial service is not to be denied. So too with equally successful and acceptable supersonic business jet. Interest in supersonic business jets, also referred to as executive or corporate jets, began in the early 1960's. Since that time, a number of studies have been conducted by universities, industries and the National Aeronautics and Space Administration (NASA). These efforts are cyclic in nature and appear to have some correlation with each of the major government efforts relating to commercial supersonic transports. This can be expected, since many of the supersonic business jet studies depended upon, and made considerable use of, an extensive data base developed in the U. S. National SST Program in the late 1960's and 1970's, the NASA Supersonic Cruise Research Program (SCR) in the late 1970's and early 1980's, and the NASA Industry High-Speed Research effort. It is expected that studies of supersonic business jets will continue into the future and it is important that any future studies benefit from the lessons learned on past supersonic business jet study efforts. It is significant for the NASA, in particular, to be aware of what has gone on in the past and to be in a position to respond to future supersonic business jet proposals seeking NASA's involvement in cooperative programs aimed at the development of a supersonic business jet.

It is interesting to note that most of the supersonic business jet activities presented in this compilation are quire lacking in citing references to previous supersonic business jet studies. This could be expected in the case of the very early university efforts because little information on the subject existed in the literature and what information that was available was government and/or industry controlled. The more recent supersonic business jet studies, however, may not have made reference to previous studies, either because they were not aware of their existence, did not have access to the information because of data restriction, or felt that previous activities were not required in their studies.

The purpose of this document is to provide a compilation of all known supersonic business jet studies/activities conducted from 1963 through 1995 by universities, industries, and NASA. First, an overview is provided chronologically displaying all known supersonic business jet studies/ activities with the key features of the study relative to configuration, planform, operating parameters and the source of the study. A brief description of each study and comments follow. Mention will be made whether the studies addressed cost, market needs, and the environmental issues of airport-community noise, sonic boom and ozone.

CHRONOLOGY OF SUPERSONIC BUSINESS JET STUDIES/ACTIVITIES

Interest in supersonic business jets began in the early 1960's. Since that time a number of studies have been conducted by universities, industries and NASA. A chronology of these activities are presented in figure 1. Over the past three decades (fig. 1) there has been a total of 22 activities on the subject of supersonic business jets. Of this total, 6 are university directed (designated U-1 through (U-6), 8 are industry directed (designated I-1 through I-8) and 8 are NASA directed (designated N-1 through N-8). It is interesting to note that, for this compilation, the earliest attention to supersonic business jets was reflected by Professor K. D. Wood of the University of Colorado in 1963 (N-1), the last effort is reflected in the 1995 work of R. Greene and A. R.. Seebass of the

Aeronautics Systems Corporation and University of Colorado, respectively (I-8). Another observation to note from figure 1 is that the university studies were conducted in the 1960 time period and not again until the early 1990's. Although there were signs of industry interest in supersonic business jets in the late 1960's and early 1990's, it was not until 1981 and 1988 that Fairchild/ Swearingen (I-3) and Gulfstream/sukhoi (I-5 and I-6), respectively, delved into serious research. NASA, however, put considerable effort into supersonic business jet studies beginning late in 1977 and ending in 1986. Although a number of these studies addressed market issues, only two were designed primarily as market surveys (indicated by the "blacked-in" symbols I-4 and N-4 on fig. 1). A University study (U-5) dealt primarily with supersonic business jet propulsion.

In the 1985-86 tie frame, the AIAA Aircraft Design Committee consisting of university, industry, and government members, sponsored a student design competition for a Supersonic Executive Jet. Information and documentation regarding this AIAA activity is apparently no longer available, and, thus, is not included in this compilation.

Table I has been prepared to provide additional insight into the studies/activities shown in figure 1. Shown in Table I, chronologically, are the dates of 22 supersonic business jet activities along with an indication of the source of the effort, key features of the study vehicles relative to configuration/planform and operating parameters. Note that the vehicles were designed to accommodate from 6 to 16 passengers and crew, cruise at Mach numbers of 1.5 to 3.0, fly from about 2500 to 5000 nautical miles and have take-off gross weight from 8,400 to 134,000 pounds. A majority of the vehicles had arrow or cranked arrow-wing planforms but others incorporated delta wings, an unswept trapezoidal, and, of course, variable sweep. The number of power plants varied from 2 to 4 and fuselage lengths ranged from 40 to 135 feet. Cabin heights selected in these studies ranged from 4.0 feet to stand-up head room of 6.2 feet.

Additional characteristics of the vehicles and environmental issues addressed in 20 of the 22 supersonic business jet studies are listed in Table II. This information includes the type of engine cycle, cruise altitudes and L/D's, and airplane wing loading. These last three columns in Table II indicate whether the three key environmental issues of ozone (O), airport-community noise (AN) and sonic boom (SB) were addressed in the study, whether noise estimates were provided, and if estimates of the sonic boom ground overpressures (Δp) at cruise were made.

Propulsion systems selected for the various studies included non-afterburning, partial and full afterburning turbojets, and variable-cycle engines. The earlier studies utilized existing power plants, whereas later studies selected projected engine cycles. All of the industry studies considered existing/modified near-term propulsion systems. Cruise altitudes range from as low as about 45,000 feet to as high as about 74,000 feet, vehicles with wing loadings of from about 48 lbs/ft^2 to 100 lbs/ft^2 are included and airplane L/D's of about 4.7 to slightly greater than 7.5 were estimated.

Essentially all of the studies were aware and mentioned at least one or more of the three major environmental issues including ozone, noise and sonic boom. Only 4 of 22 studies included noise estimates, 10 of the 22 studies listed cruise overpressures, and none of the studies provided information regarding emissions. It is interesting to note the cruise Δp's of about 1.0 lb/ft^2 or less are projected for a majority of these study vehicles. In fact, a level of 0.4 lb/ft^2 is projected for the most recent study (I-8) via a boom minimized airplane designed for overland flight.

Figures 2, 3 and 4 provide an indication of the configuration planforms of the supersonic business jets studies under the universities, industries and NASA efforts, respectively. The University of Colorado study case of 1963 considered a delta or trapezoidal fixed-wing configuration (fig. 2a). Georgia Tech’s 1967 effort (fig. 2c) considered two fixed wing configurations, a delta wing planform and unswept trapezoidal wing planform. The same year the Catholic University (fig. 2b) studies a variable-sweep planform somewhat similar to the then Boeing US-SST wing planform. The 1990 joint sponsored NASA/USRA University Advanced Design Program saw Purdue select two configurations from a number of responses to the universities RPF for a supersonic business jet, including an arrow-wing and a variable (fig 2d). A similarly sponsored NASA/USRA 1993 study saw Case Western Reserve select a delta wing with subsonic leading edges (fig. 2e). The majority of the university studies located the power plants under the wing with the exception of the Catholic University variable-sweep configuration (fig. 2b) where engines were located underneath the horizontal tail and the Purdue three-engine arrangement (fig. 2d) with one engine mounted on the vertical tail.

The industry study configuration of CASA (fig. 3a) selected a delta-ogive planform. Boeing’s unpublished 1971 study (not shown) involved a delta wing arrangement. All of the 1981 to 1985 Fairchild/Sweringen study configurations (fig. 3b), including their own baseline, the Douglas, British Aerospace, and Lockheed inputs were of arrow-wing planform. Gulfstream and Gulfstream/Sukoi, 1988 through 1990, considered a delta-ogive and cranked arrow-wing planform (figs. 3c and 3d, respectively). The most recent study by the Aeronautical Systems Corporation (fig. 3e) indicated that they selected the F-16XL cranked arrow-wing planform (not shown in ref. I-8). On these industry studies, engine placement ranged from underwing, the vertical tail third engine of the two configurations having three engines, to the above fuselage arrangement of the Lockheed (W. Hawkins) configuration.

With the exception of the 1984 Kentron variable sweep configuration (fig. 4f), all other NASA-funded studies (fig. 4) selected arrow-wing planforms. Engine placement varied from tail-mounted to underwing arrangements, with the Rockwell MMIPS propulsion systems having its inlet above the fuselage (fig. 4c).

Interestingly, of all of the configurations addressed in these studies, only four utilized forward canard surfaces: the University of Colorado concept (fig. 2a), the British Aerospace and Lockheed concepts (fig. 3b) and the Gulfstream/Sukhoi design (fig. 3d).

BRIEF DESCRIPTION OF, AND COMMENTS ON STUDIES

The material in this section provides a brief description of the universities, industries and NASA supersonic business jet studies cited in this report. Includes, when available, are the report abstracts with information and comments reflecting study philosophy, design constraints, ground rules, etc., influencing the study in its depth of detail.

University Studies

Six university studies on supersonic business jets, beginning in 1963, have been identified with the latest study taking place in 1993. These studies include the University of Colorado in 1963 (U-1), Georgia Tech in 1967 (U-2), Catholic University in late 1967 (U-3), Purdue University in 1990 (U-4), the University of Loughborough in 1992 (U-5), and Case Western Reserve University in 1993 (U-6).

Study (U-1) was published in a chapter of an aerospace vehicle design handbook; study (U-2) was published in an SAE paper; study (U-3) was brief article in AW&ST; study (U-4) was published in a NASA/USRA conference report; study (U-5) propulsion for supersonic business jets is a Masters Thesis; and study (U-6) is a published paper in a NASA/USRA conference report and a NASA contractor report. It should be noted that, with one exception, none of the documents contains a reference to supersonic business jet activities reported in this paper. The Georgia Tech Study (U-2) does reference the work of K. D. Wood at Colorado University; the only other study at the time was the industry study paper out of CASA (Spain) in 1965 (I-1).

(U-1) University of Colorado (1963). - “Layout Design of Supersonic Airplanes and Wing Missiles,” Chapter I-3 in Aircraft Design, Vol. 1. The text book by Professor K. D. Wood entitled “Aerospace Vehicle Design,” Vol. 1, “Aircraft Design,” was first published in 1934 and since then has excited, encouraged, and educated a great many students. In 1963 he challenged students to address the task of designing a 2-engine, 8400 pounds, Mach 3, 4 passenger supersonic business jet having a transatlantic range of 3500 nautical miles. The resulting vehicle (fig. 1a) was influenced by the F-108, XB-70 and Avro CF-105 configurations in featuring either a delta or trapezoidal planform and a canard. Although the 4-foot high fuselage quarters were quite cramped, the assumption was made that the flight would rarely be over 90 minutes long. In the interest of low drag, retractable periscopes were used in place of a cockpit canopy. An estimation of 3000 gallons of fuel would be required for the mission. At the time, an L/D of 6.5 was considered the highest ever recorded in flight; their vehicle had an L/D of 4.7. The very low design take-off gross weight and fuel load reflects the optimism in engine efficiency and structural design especially for a Mach 3 vehicle. Mention is made that sonic boom complaints may limit the usefulness of supersonic business jets by confining them to over water flights. No mention is made of the ozone and airport noise problems.

(U-2) Georgia Tech (1967). - “Preliminary Studies of a Supersonic Business Jet,” SAE paper 670246. The abstract reads: “This paper discusses two possible designs, an upswept trapezoidal wing model and an essentially delta wing model for a 10 passenger Mach 2.2 Supersonic Business Jet. The studies are quite preliminary in nature and the result of team efforts in two different Senior Aerospace Vehicle Design courses at the Georgia Institute of Technology. The philosophy of the course and the selection of this particular aircraft as a project design are touched upon briefly.

The body of the paper compares two designs and discusses in an elementary manner their aerodynamic performance, engines, and propulsion system; some of the design details; and probably noise level including the sonic boom problem. They are not considered solution aircraft, but the designs are believed to be fairly representative of what the resulting aircraft would resemble.

The work is continuing through recycling and optimization of the performance by” computer techniques.”

The author states in his introduction that “This project study started as a purely academic one in the Senior Aerospace Vehicle Design course. The requirements were simply that the project would be of interest, educate, and motivate the student, yet not too difficult or far out.” These students had worked on a supersonic transport during the previous four years and the problem with availability of information (at least company classified) was a serious one. The author also stated that “the large transport was difficult to handle as a student project and began to get out of range of the feel of the students.” Selection of the supersonic business jet was an attempt to overcome the difficulties faced during the supersonic transport study and would provide an excellent senior student project.

The technical requirements were to design a Mach 2.2 - 2.3 supersonic business jet to carry 10 passengers plus a crew of 2 for 3000 nautical miles with FAA fuel reserves and operate out of airports with 5000 to 6000 foot runways. The students were aware that they could not ignore the environmental concerns of ozone, sonic boom and airport community noise. Recall that the introduction of the FAR-36 Stage-2 noise rule did not exist until December 1969. Although these environmental issues were mentioned (the author noted that the ozone problem was new to him), only the sonic boom was discussed using NASA data. A concern was expressed relative to the interior cabin noise due to the close proximity of the engines to the fuselage/cabin in the “Miss August” configuration.

The delta wing “Viper” (see fig. 2c) was compared to the F-111A and B-58 while the unswept trapezoidal wing “Miss August” was compared to Jet Star and Gulfstream II. Acknowledgements are given to General Dynamics, Grumman, Lockheed Georgia, and Delta Airlines for their help and cooperation in this study.

(U-3) Catholic University (1967) “ Variable-Geometry Business Jet Studies.” - The only information available on this study is the review provided by AW&ST, May 1, 1967. Contacts with the university were not successful in locating anyone who could recall whether a copy of the study existed in their library. Since the AW&ST write-up is brief, it is included as follows:

> “Washington - A small variable-geometry supersonic aircraft for business or airline training use, has been studied as preliminary design by students at Catholic University Department of Space Science and Applied Physics here.
>
> Initial studies indicate that such an aircraft might have economic advantages over a conventional straight or delta-wing design. One of these would be similar to the Boeing supersonic transport design, which would enable it to be used as a relatively inexpensive flight trainer.
>
> Wing design also is expected to reduce fuel consumption during subsonic operations and provide some noise relief.

> The aircraft design during the studies is 85-feet long, has a 57.5 wingspan with the wings extended, and a 38-foot span with wing swept. Height is 21 feet and the four engines in dual pods under the wings, have approximately 82-inch runway clearance. The engines used in the study are General Electric GE1/J1B with a high pressure ratio fan and partial afterburner system. Thrust rating was approximately 8500 pounds per engine at sea level without afterburner and 3200 pounds per engine at altitude. With afterburning, sea level thrust per engine could exceed 15,000 pounds.
>
> Take-off gross weight has been calculated at 63,000 pounds, approximately 41,000 pounds is fuel. the major portion of the fuel supply is carried in the aft fuselage and the remainder in the fixed section of the wing and the vertical fin. An automatic fuel transfer system would be used for center-of-gravity trim.
>
> The fuel supply is estimated to give a range of 3300 nautical miles plus a 10-minute reserve. Of this distance, 2800 nautical miles would be flown at Mach 2.0. The cruise speed was chosen to permit the structure to remain well below the critical temperature speed for conventional aluminum structure of approximately Mach 2.25.
>
> Payload at gross weight is 2500 pounds, including nine passengers, two crewmen and baggage.
>
> The passenger cabin would be approximately 15-feet long, 65 inches long, 65 inches wide and 58 inches high. Seat width would be 25 inches on a 36-inch pitch.
>
> The wing would sweep to 65 degrees, compared with 72 degrees for the Boeing supersonic transport. Lift coefficients for all phases of flight were derived from Boeing studies. The wing sweep mechanism is powered by the aircraft's primary hydraulic system.
>
> Takeoff and landing distances to clear a 50-foot obstacle were calculated at 5200 and 5000 feet, respectively.
>
> Cost figures are very preliminary and were worked out on the basis of military aircraft experience. Cost per pound of gross weight was roughly computed to fall in the $65-$85 range.

<u>(U-4) Purdue University (1990). </u>- "Design of a High Speed Business Transport," NASA CR 187041, pp. 321-324. The abstract reads:

"The design of a High Speed Business Transport (HSBT) was considered by the Aeronautical Design Class during the academic year 1989 to 1990. The project was chosen to offer an opportunity to develop user friendliness for some computer codes such as WAVE DRAG, supplied by NASA/Langley, and to experiment with several design lessons developed by Dr. John McMasters and his colleagues at Boeing. Central to these design lessons was an appeal to marketing and feasibility consideration. There was an emphasis upon simplified analytical activity. Two designs stood out among all the rest because of the depth of thought and consideration of alternatives. One design, the Aurora, used a fixed wing design to satisfy the design mission; the Viero used a swept wing configuration to overcome problems related to supersonic flight. A summary of each of these two designs is given."

The authors indicate that their two designs were in response to the RFP to develop a passenger business transport that could fly supersonically to foreign business regions. Recent discussions between the author and Dr. Terry Weisshaar of Purdue University, who generated the RFP and was also the Class Advisor, indicated that the 10 study teams submitted proposals in response to the RFP. He selected the two reported herein (U-4). He stated that there are University reports containing all the details generated on these two studies and the RFP came about as a result of the Gulfstream/Sukhoi activities.

Neither Mach number nor range were specified by the RFP; initially, the choice of number of passengers was also undefined. The "Aurora" design is a three-engine arrow-wing transpacific vehicle carrying 8 passengers at Mach 2.2 over a range of 4980 nautical miles. The second design, the "Viero," is a four-engine variable-sweep transpacific vehicle carrying 9 passengers at Mach 2.5 over a range of 4750 nautical miles. The Aurora team consisted of 7 students and the Viero team had 5 students.

In addition to using the NASA/Langley Wave Drag Program, the two design teams made use of the NASA/Langley Flight Optimization System (FLOPS). It is interest to note that both design teams were required to address marketing and cost factors, but nothing is mentioned in their NASA contractor report paper about the environmental issues of ozone, airport-community noise and sonic boom. In fact, there are no references or acknowledgements in the report. Professor Terry Weisshaar indicated to the author that all three environmental issues were made known to the design teams and that a library search was made for previous supersonic business jet studies. Finally, it should be kept in mind that this study was jointly funded by the NASA/USRA University Design Program bringing NASA engineers, students, and faculty from U.S. engineering schools together by integrating future NASA space/aeronautics engineering design projects into the university curriculum.

<u>(U-5) Loughborough University (1992).</u> - "Conceptual Design Study of a Variable Cycle Engine for a Supersonic Business Jet," M.S. Thesis Report No. ETN-93-93486 (available from AIAA Technical library). The abstract reads:

"The aim of this project was to produce an engine cycle for both subsonic and supersonic flight conditions that could be produced by the variation of bypass ratio. The basic aircraft and flight profiles are defined followed by the initial conditions of the engine. The starting point, the take-off, subsonic cruise and supersonic cruise engine cycles are studies. For each of these conditions, carpet plots are produced for a range of bypass ratios, turbine entry temperatures, and engine pressure rations. A selection is made of the most suitable engine cycle for the supersonic condition. Their compatibility was then studied. The results indicated that the two engine cycles were compatible and therefore could be produced by the same engine by the variation of the bypass ratio. The effect of the engine cycle selection of the dimensions of the engine are examined and a schematic diagram of the engine layout is produced. Methods of varying the engine cycle are discussed and compared with the results of this study. There are certain aspects of the engine design which are not entirely satisfactory. Methods by which the design might be improved are discussed."

Although this report dealt primarily with a supersonic business jet propulsion system, it is interesting to note in the abstract, no mention is made regarding the environmental issues of ozone, airport-community noise (although the abstract does allude to jet velocity restrictions at takeoff), or sonic boom. Even though these three issues are airplane-related problems, a propulsion study should identify with them.

(U-6) Case Western Reserve University (1993). - "Tesseract Supersonic Business Transport," NASA CR-195118 and NASA CR-192072. The abstract reads:

"This year, the senior level Aerospace Design class at Case Western Reserve University developed a conceptual design of a supersonic business transport. Due to the growing trade between Asia and the United States, a transpacific range has been chosen for the aircraft. A Mach number of 2.2 was chosen, too, because it provides reasonable block times and allows the use of a large range of material without a need for active cooling. A payload of 2500 pounds has been assumed corresponding to a complement of nine passengers and crew, plus some light cargo.

With these general requirements set, the class was broken down into three groups. The aerodynamics of the aircraft were the responsibility of the first group. The second developed the propulsion system. The efforts of both the aerodynamic and propulsion groups were monitored and reviewed for weight consideration and structural feasibility by the third group. Integration of the design required considerable interaction between the groups in the final stages. The fuselage length of the final conceptual design was 107 feet, while the diameter of the fuselage was 7.6 feet. The delta wing design consisted of an aspect ratio of 1.9 with a wing span of 47.75 feet and a mid-chord length of 61.0 feet. A SNECMA MCV 99 variable-cycle engine design was chosen for this aircraft."

In this study, the class was quick to note that historically, the most efficient cruise for jet aircraft occurs at velocities higher than those that would generate the maximum L/D. A variety of wing planforms were considered and included forward swept and "eccentric" wings but these were discarded to the lack of a suitable data base. The delta planform with subsonic with subsonic leading edges was chosen because of the existence and availability of wing performance theory. It is of significance to note that the design team conducted a finite element analysis on the wing and fuselage using the software GIFTS, a computer program obtained through the University of Arizona. The original design specified a three engine configuration based on engine-out criteria; however, both the weight concern and problems involved in mounting an engine to the centerline of the aircraft (e.g., boundary layer removal, foreign object damage, and accessibility) drove them to a two-engine under-wing configuration.

The environmental issues of ozone, airport-community noise, and sonic boom were not mentioned in either NASA contractor report. They did, however, mention that the selection of turbofan engines would have reduced velocities at lower speeds, and therefore, lower noise.

There are no references to previous supersonic business jet studies, in particular, no reference is made to the Purdue University NASA/USRA study of 1990 (U-5). This is particularly disturbing since the Case Western Reserve supersonic business jet study is also a NASA/{USRA supported activity. Contact was made with Mr. Art Glassman of NASA/Lewis Research Center now retired, who was involved in this Case Western Reserve University study) relative to the environmental issues and referencing of previous supersonic business jet studies. He indicated that although those three environmental issues were most likely related to the student design groups, the scope of the study did not allow them to address these issues in any detail.

It should be pointed out again that the purpose of the NASA/USRA Advanced Aeronautics Design Program was to offer opportunities for study of design problems with emphasis on the systems approach. It appears that a systems approach must include environmental issues.

Industry Studies

A total of eight (8) industry studies on supersonic business jets have been identified beginning in 1965 with the last activity taking place in 1995. These studies include CASA, Spain, in 1965 (I-1), Boeing in 1971 (I-2), Fairchild/Sweringen in 1981-85 (I-3), Business & Commercial Aviation in 1987 (I-4), Gulfstream Aerospace in 1988 (I-5), Gulfstream-Sukhoi in 1988-90 (I-6), Sukhoi in 1993 (I-7) and Aeronautical Systems Corporation in 1995 (I-8).

Study (I-1) appears in a Spain Ingenieria Aeronautica & Astronautica; Study (I-2) is an unpublished Boeing report written in the mid-1970’s that NASA/Langley was familiar with; Study (I-3) is an unpublished Fairchild/Sweringen Technical Feasibility Review with involvement of, and inputs from, Douglas, Lockheed, British Aerospace, Rolls Royce, General Electric and consultants. Study (I-4) is a preliminary copy of the Business and Commercial Aviation (B/CA) supersonic business jet market survey; Study (I-5 is an AW&ST article on Gulfstream’s supersonic business jet development; Study (I-6) is reflected in four AW&ST articles and articles in Aerospace America and ICAO Journal on the Gulfstream/Sukhoi partnership; Study (I-7) is an AW&ST article on Sukhoi’s plans for a supersonic business jet after Gulfsteam dropout from the joint venture; and Study (I-8) is Aeronautical Systems Corporation paper presented at a NASA/Langley conference.

<u>(I-1) CASA-Spain (1964). </u>- “Supersonic Business Airplane,” Spain Ingenieria Aeronautica & Astronautica. This study begins by posing the question “Is it time to think about a supersonic business airplane?” The author also points out that many of the studies performed on supersonic transports will be applicable to the supersonic business jet; however, the supersonic business jet presents peculiarities that will be analyzed in the article. The introduction discusses airspace utilization in the United States by airlines, military aircraft, and general aviation, looks at the history of light airplane sales and suggests some routes for a supersonic business jet. The author addressed the general conditions (Mach number, range, weight, and payload) for this class of airplane; examined its aerodynamic possibilities (L/D,M L/D, C_{DO}, etc.) stating that an essential condition for any SST, regardless of size, is to maintain supersonic cruise for a considerable portion of its flight); discussed optimum dimensions (it is pointed out that although one could think of this supersonic business jet as a scaled down version of an SST in regard to weights and surfaces, the passengers, unfortunately, do not scale) and other performances, and selects and ana-

lyzed, in design book fashion, a possible configuration (a 12-passenger Mach 2.2 fixed-wing airplane of 3000 nautical miles range with a TOGW of 44,000 pounds). Engines considered included the GE J-79 and J-75, P&W J-57 and TF-30, RR Avon 300, and SNECMA Atar 9. Two GE J-79's were selected for the study vehicle.

In the Final Considerations section, the author notes that this study (that is without references) is nothing but a demonstrative introduction of the possibility of realizing a supersonic business jet and that many other important aspects are left untreated (sonic booms, temperatures, materials, etc.). A price of $100,000 per ton of take-off weight was assumed in the estimate for such an airplane. He concludes, however, "that it is possible in the near future for the business man to travel at supersonic speeds in his own airplane and outside the margin of the regular airlines."

(I-2) Boeing Company (1971). - "...of a 10-passenger Delta Wing Aircraft..." Unpublished Boeing Document. Reference is made to this study in the Introduction of NASA TM 74055, Sept. 1977 (N-1) as follows: "In 1971, Boeing conducted a study (which is unpublished) of a 10-passenger delta-wing aircraft that resulted in a 4778 Km (2580 n.mi) range, 46,947 Kg (103,500 lbm) gross weight with a take-off field length of 1615 meters (5300 feet)."

(I-3) Fairchild/Swearingen (1981-1985). - "Supersonic Executive Transport - Technical Feasibility Review," June 4, 1982 (unpublished). From 1981 to 1985, Fairchild/Swearingen put forth a concerted effort toward establishing the feasibility of a supersonic executive transport. During the early stages of the study, they arranged to have other airframe and engine manufacturers, along with other consultants, assist in this feasibility study. McDonald-Douglas, Lockheed-California and British Aerospace Corporation (BAe) from the airframe side, and General Electric and Rolls-Royce from the propulsion side were included in the studies.

On June 4, 1982, a technical feasibility review was hosted by Fairchild/Swearingen and included overviews of each of the four vehicle configurations (Fairchild, Douglas, British Aerospace and Lockheed) shown in figure 3. The key objectives of the study were to meet Stage-3 noise requirements, an IFR range of at least 4000 nautical miles, operate from runways 7500 feet or less, have cabin comfort equal, or better than Gulfsteam G-III, have practical subsonic cruise capability above 40,000 feet, and have maintenance procedures and intervals competitive with present corporate aircraft.

The British Aerospace Corporation provided some interesting responses/comments/next steps to the Fairchild/Sweringen study regarding their (BAe) study design incorporating a modified version of the Concorde Olympus 593 engine. Some worry was expressed at long over water flights of a two-engine aircraft. BAe concluded that at this preliminary stage, nothing surfaced to cast doubt on the feasibility of the supersonic executive transport project.

There were a number of concerns expressed by the consultants regarding the technical feasibility of the project relative to attaining Stage-3 noise levels, acceptance of overland sonic booms, two-engine vehicles over water, use of older technology Concorde engine and weight control.

(I-4) Business & Commercial Aviation (1987). - "Supersonic Business Jet Survey," presented to NBAA Seminar in New Orleans. The title of the seminar was "Future Business Travel and Its

Impact on Corporate Aviation." The supersonic business jet market survey conducted by B/CA is the second of only two known to be made over the last three decades during which the 22 supersonic business jet studies were conducted. The first market survey (N-4) by W. Barry Enterprises, was conducted in 1981. Mr. John W. Olcott, President of B/CA, indicated that his paper entitled "Supersonic business jet Survey" is not longer available.

Mr. Alcott points out in his letter that, although there were numerous questions (some 25) associated with the survey in which there were 273 respondents, most of the concerns focussed on only a few areas. These included questions on the technologies to be utilized, airport performance, and efficiency of subsonic flight. Airport noise and sonic boom were frequent concerns as well as passenger comfort and safety (emissions were not specifically mentioned); can the ATC system handle a supersonic business jet, and will existing regulations present political barriers to its efficient use? Some respondents felt that a Mach 0.95 airplane having a 6000 nautical mile range would satisfy the need for traveling to the Pacific Rim Countries while others felt resources should be directed toward enhancing the present subsonic business jet community. It is of interest to note the response to Question 1 of the survey that asked if there would be an interest in a supersonic business jet if one was available. The response was about 60 percent "yes" and 40 percent "no." Question 16 of the survey asked responders to describe their job function. About 41 percent were company aviation department managers or chief pilots, 20 percent were company line pilots or co-pilots and 21 percent company officers (partners, president, vice president, etc.).

<u>(I-5) Gulfstream Aerospace (1988).</u> - Gulfstream studies of a supersonic business aircraft began in early 1988, as indicated in the AW&ST article of September 12, 1988. Although a cranked delta wing planform was illustrated in this article, it is apparent that a number of wing planforms were under consideration and the L/d's attainable for a number of configurations were examined.

In continuing their feasibility study, the sonic boom was investigated for one of the more promising high L/D configurations, the delta wing reference planform. Optimization of the configuration for low boom was then examined and a cruise overpressure for the 100,000 pound, M 1.5 airplane was reduced from about 1.0 lb/ft^2 to about 0.6 lb/ft^2 . The resulting configuration was the 125-foot long ogive-delta, shown in figure 3c. The study indicated that the area distribution for minimum boom is different from that required for minimum wave drag. The configuration for minimum boom had a significant drag penalty.

Although Gulfstream envisioned a vehicle having transatlantic range (overwater flights), the sonic boom study suggests that overland flights at supersonic speeds my also be permitted if very low overpressures can be demonstrated. The boom study was considered preliminary but preparations were being made to conduct a considerably more detailed study of an efficient low-boom supersonic business jet configuration. If Gulfstream decided to proceed further on design effort, use would be made of WAVEDRAG with CADAM Mach-plane cuts to permit refinement of the shape of fuselage and fairings. Use would also be made of computational aero-modeling and analysis with PANAIR supersonic code to attain more accurate estimates of drag, boom signatures, aero derivatives and loads.

<u>(I-6) Gulfstream Aerospace/Sukhoi (1989-1991).</u> - During the 1987-1988 time period, both Gulfstream and Sukhoi were actively involved in feasibility studies of supersonic business jets and

both organizations were seeking joint partnerships. Sukhoi first announced their desire for an international partner in the SU-51 business jet studies in a June 5, 1989, AW&ST article (ref. I-6). As a direct result of this article, the Sukhoi-Gulfstream agreement was reported in an AW&ST article “Sukhoi, Gulfstream to Study Supersonic Business jet,” June 26, 1989 (ref. I-6). Rolls-Royce and Gulfstream, who had been close partners for many years, were also included in the joint discussions as was the Myasishehev Design Bureau, relative to acceptable engines. At that time, the Sukhoi study configuration had a cranked double-delta planform and Gulfstream a delta planform (see figs. 3c and 3d). Both were two-engine vehicles.

In a December 18, 1989, the AW&ST article (also in ref. I-6) reported that FAA certification of the proposed Sukhoi/Gulfstream supersonic business transport was a distinct possibility. Under the current planning, the Soviets would build the airframe, Gulfstream would apply systems, and engines would be built by both Rolls-Royce and Lyulka, the Soviet engine design bureau. The joint project was reported as being discussed at the Gorbachev level and that the questions of technology transfer, bilateral agreements, would require Department of Defense (DoD) and Department of Commerce (DoC) and the Congress (Foreign Relations Committee).

A very informative article entitled “Sukhoi and Gulfstream Go Supersonic” (ref.I-6) published in the April 1990 issue of the AIAA Aerospace America, points out the need to address the environmental issues of ozone depletion due to nitrogen oxides and overland sonic booms. While Gulfstream was doing market studies, Sukhoi was proposing wind tunnel tests of various configurations.

In 1990, the July 2 issue of AW&ST (ref. I-6) reported that the Soviets formed a company called Aero Conversion (made up of Sukhoi and Lyulka) to plan the Gulfstream-Sukhoi supersonic business jet program. During this time period, Gulfstream's informal marketing study with corporate chief pilots indicated that the cabin need not accommodate up to 18 passengers, rather 6 to 8 passengers is maximum load on most flights. A three-engine configuration having winglets and a forward canard is shown to be the newest arrangement (fig. 3d).

A paper in the August 1991 ICAO Journal by H. S. Bruner of Gulfstream entitled “SSBJ: A Technological Challenge,” (ref. I-6) provides a very interesting and informative overview of the Gulfstream-Sukhoi 4000 mile range, Mach 2, supersonic business jet effort. The author notes that the Concorde required 12 years to be developed and certified, thus, it is absolutely necessary to do the supersonic business jet right the first time. He also notes that L/D’s of 8.8 forecasted for SST’s cannot be expected for supersonic business jets, primarily because of its lower fineness ratio (passengers cannot be scaled down). In addition, historical weight data shows that heavy aircraft are capable of having lower empty weight fractions than lighter aircraft. The issue of airport noise is discussed and the variable-cycle engine and/or ejector-mixer nozzles are possible solutions but will never match the noise levels of present day turbofans. Sonic boom is cited as the most urgent technological requirements of today; the supersonic business jet must be able to fly overland and it is reasonable to assume there is some level of sonic boom that is acceptable. He states that the FAA, NASA, industry and academia must join forces and find a technical political solution to this problem.

In his summary he states that their studies indicate that present technology is "inadequate" to satisfy all of the performance requirements and yet meet the weight requirements.

(I-7) Sukhoi (1993). - "Sukhoi Goes Supersonic." The only information available on this study is the review provided by AW&ST, September 20, 1993, p. 41. Since the AW&ST write-up is brief it is included as follows:

> "Russia's Sukhoi Design Bureau has revived its supersonic business jet development program with $25 million from Russian industrial developers.
>
> The new financing will drastically increase our development work on a supersonic business aircraft." Mikhail Simonov, Sukhoi general designer and chief executive officer, said.
>
> Sukhoi is trying to lure Gulfstream Aerospace back into the supersonic business jet (SSBJ) program. But Sukhoi believes it now has enough funding to simultaneously advance the effort and look for a new partner if Gulfstream declines. Gulfstream cited cost and technology concerns when it dropped out of a joint SSBJ venture with Sukhoi in 1992 (AW&ST Sept. 14, 1992, p. 93).
>
> Simonov said the new financing will enable Sukhoi to continue SSBJ design work to a pre-prototype stage where the company will then initiate international marketing.
>
> Sukhoi will continue to pursue the 4600-nautical mile range, S-21 106,000 pounds gross weight aircraft design that could carry about 10 passengers at Mach 2.
>
> Simonov declined to name the new investor group"

It is obvious that the Gulfstream pullout had a significant effect on the future outlook for the Sukhoi supersonic business jet development program.

(I-8) Aeronautical Systems Corporation (1995). - A Corporate Supersonic Transport," to appear in a soon to be published NASA conference document. A draft version (I-8) was provided to NASA Langley.

This paper is the last supersonic jet study addressed in this compilation and was presented at the NASA/Langley Symposium "Transportation Beyond 2000: Engineering for the Future," Sept. 26-28, 1995. The authors state that "this paper derives from a carefully considered study of the possibility of a corporate supersonic transport, conducted largely by the first author. It presents the non proprietary aspects of a possible Corporate Supersonic Transport (CST). Such a CST could begin service as early as 2000. This project will require considerable technical assistance from NASA. Over a 10-year production period, this aircraft could accrue some $15 billion in sales with perhaps 40 percent of this amount being export sales"

It further stated that “The authors describe here, in brief, the strategies for developing a commercially successful CST, describe the potential market for such a business aircraft and the technology selected for its development. They then describe such an aircraft and delineate some missions for it.

The principle “show stopper” would seem to be the FAA certification of such an aircraft. The development of noise certification specifications for take-off, and possible supersonic flight overland routes are crucial to launching such an aircraft.

The authors conclude by suggesting some important roles for NASA in the development and eventual success of such an aircraft and note that the roles NASA should play were well delineated by aircraft category nearly 15 years ago. As civil supersonic aircraft go, the CST is ”smaller, faster, cheaper.”

The vehicle being considered (fig. 3e) is a 66,000 pound aircraft that would carry 8-10 passengers over a 3350-nautical mile range at Mach 1.8. As will be noted from figure 3e, only a profile of the vehicle is provided. It is stated that this vehicle would have a cranked arrow-wing planform similar to the F-16XL and will have a natural flow wing design and sonic boom shaping. Materials will be current technology and the propulsion system considered is the Allied Signal F 125-GA-100. Cruise sonic boom overpressures are projected to be slightly less than 0.5 lb/ft^2.

NASA Studies

A total of eight NASA/Langley studies on supersonic business jets have been identified beginning in 1977 and ending in 1986. These include NASA/Langley in 1977 (N-1), Boeing Study in 1977 (N-2), Rockwell in 1979-1980 (N-3), W. Barry Smith Enterprises in 1981 (N-4) and the four Kentron studies in 1981 (N-5, 1983 (N-6), 1984 (N-7) and 1986 (N-8).

Study (N-1) is a NASA Technical Memorandum; Study (N-2) is a NASA Contractor Report; Study (N-3) consists of a contract briefing package, a paper in the NASA SCR Conference, and a final Contractor Report; Study (N-4) is an unpublished marketing report; and Studies (N-5, N-6, N-7 and N-8) are NASA Contractor Reports (CR’s).

With the exception of the Boeing Study (N-2) and Marketing Study (N-4) both of which contain no references, the other six NASA studies made some reference to previous supersonic business jet studies. Only the NASA/Langley Study (N-1) referenced the two 1967 University Studies (U-2 and U-3) and the unpublished Boeing study (I-2). All of the Kentron studies made reference only to (N-1) or (N-4, N-5 and N-6).

(N-1) NASA/Langley (1977). - “A Preliminary Study of the Performance and Characteristics of a Supersonic Executive Aircraft,” NASA TM X-74055. The abstract reads”

“A preliminary design study has been conducted to determine the impact of advanced supersonic technologies on the performance and characteristics of a supersonic executive aircraft. Four configurations with different engine locations and wing/body blending were studied with an advanced non-afterburning turbojet engine. One configuration incorporated an advanced General

Electric variable-cycle engine and two-dimensional inlet with internal ducting. A Mach 2.2 design Douglas scaled arrow wing was used throughout this study with Learjet 35 accommodations (8 passengers).

All four configurations with turbojet engines met the performance goals of 6926 km (3200 n.mi.) range, 1981 meters (6500 feet) take-off field length and 77 meters per second (150 knots) approach speed. The noise levels of turbojet configuration studies are excessive. However, a turbojet with a mechanical suppressor was not studied. The variable-cycle engine configuration is deficient in range by 555 km (300 n.mi.) but nearly meets subsonic noise rules (FAR 36-1977 edition) if co-annular noise relief is assumed. All configurations are in the 33,566 to 36,287 kg (74,000 to 80,000 lbm) take-off gross weight when incorporating current titanium manufacturing technology."

The objective of this study, conducted by NASA/Langley and Vought Corporation, Hampton Technical Center, was to determine the impact of advanced SCAR technologies on the performance and characteristics of a supersonic executive jet. Special emphasis was placed on terminal area noise and take-off performance. The Mach 2.2 design constraint was chosen because of the availability of high-speed wind tunnel data and models, and an anticipated low-speed experimental database. Figure 4a illustrates the four configurations included in the study.

Four basic configurations were evaluated: a clean wing version with aft fuselage-mounted nacelles (SSXET) baseline, a similar concept with the nacelles mounted under the wing (SSX JETI), a blended wing body version with aft fuselage nacelles (SSXJET II) and an aft fuselage integrated engine installation with underwing two-dimensional inlets (SSXJET III).

It was pointed out that arrow-wing planform with subsonic leading were selected for all four configurations because it offers several advantages over a delta-wing planform used on the Concorde and the TU-144. The planform of the wing essentially determines the drag-due-to-lift as well as the wave-drag of the wing.   The SSXJET II T design was aimed to reduce the cross-sectional area and did provide a slight improvement in wave drag but at the expense of limiting access to the crew compartment, thus isolating the passengers. A similar tandem arrangement was considered in the Georgia Tech Study (U-2) and was rejected because of access disadvantage.

Sonic boom and airport noise are addressed but no mention is made regarding the ozone problem. The "first cut" sonic boom prediction method was used to estimate the boom overpressures during climb and the beginning and end of cruise. Although no attempt has been made to optimize the designs for minimum sonic boom, it was suggested that such an optimization could result in a vehicle with boom levels acceptable for overland flight.

Take-off, climbout and approach noise were addressed in detail using the NASA/Langley ANOPP and the respectable experimental noise database generated by General Electric (GE) and Pratt & Whitney (P&W) during the NASA SCAR engine cycle activities (inverted flow T.F.'s co-annular jet exhausts, etc.). All meet the State-2 noise rule (1969) but do not met the current Stage-3 noise rule (1978). Interestingly, a plea was made that the FAR-3 noise rule be modified to not impose stricter noise limits on two-engine aircraft than on four-engine aircraft and to allow thrust cutbacks at lower altitudes.

Finally, the author states that while the performance results are encouraging, some uncertainties exist mainly in the prediction of aerodynamic characteristics and can be resolved only by extensive wind tunnel tests through the Mach range.

(N-2) Boeing Company (1977). - "Supersonic Cruise Research Airplane Study," NASA CR 145212. The abstract reads:

"This report presents the results of a study to determine the feasibility of using a sub-scale research airplane to replace the need for a larger second generation SST prototype.

The study addresses the engine as well as the total airplane. Questions of manufacturing technology, airplane cost prediction confidence, and the technical areas of aero elastics, flight controls, noise, systems, structures, weights and propulsion, including the variable-cycle engine, are discussed. The General Electric Company participated in the study by assessing the development aspects of the variable-cycle engine and defining a flight worthy engine to be used on the airplane."

The vehicle considered in this study (see fig. 4b) had a TOGW of 56,000 pounds, an arrow-wing planform, two engines, a crew of two, is 93.5 feet long, a cabin height of 4.5 feet, and can fly at Mach 2.4 for 3250 nautical miles. Although this study vehicle cannot be classified as a supersonic business jet, it does contain considerable information relative to technology assessment, and manufacturing and cost estimating assessment. In addition, its aerodynamic, structural, and propulsion performance may also provide considerable insight into the design studies of the supersonic business jet.

Before leaving the discussion of this Boeing study, it is of significance to note some of the unique possibilities for the supersonic research vehicle. The aircraft utilized two of the then new GE F-404 low bypass afterburning turbofan engines and would have refueling capabilities. It would also have a mechanical variable-camber wing leading edge to enhance low speed aerodynamics. Plans were to demonstrate advanced operating procedures relative to airport community noise, measure airframe noise, establish the near-field sonic noise environment, and suggested that the vehicle may be used in sonic boom psychoacoustic studies. With some configuration modification, the research airplane could be used to investigate boom minimization techniques.

(N-3) Rockwell (1979). - "Supersonic Cruise Vehicle Research Business Jet," NASA CP-2108, Nov. 1979, pp. 935-949. The summary reads:

"A comparison study of a GE-21 variable-cycle propulsion system with a Multimode Integrated Propulsion System (MMIPS) was conducted while installed in small M = 2.7 supersonic cruise vehicles with military and business jet possibilities. The 1984 state-of-the-art vehicles were sized to the same transatlantic range, takeoff distance, and sideline noise. The results indicate the MMIPS would result in a heavier vehicle with better subsonic cruise performance. The MMIPS arrangement with one fan engine and two satellite turbojet engines could not be appropriate for a small supersonic business jet because of design integration penalties and lack of redundancy."

The aircraft were designed for a transatlantic range of 5926 km (3200 n.mi.) at a cruise Mach number of 2.7.

The aircraft were size to the same range, constrained to a 2591 m (8500 ft.) balanced field length and then compared at the same sideline noise level.

The MMIPS was found to be the heavier propulsion system although it had superior performance except in the supersonic cruise leg. The single inlet requirement for MMPIS when installed in a small vehicle was a major penalty."

This study to develop a research vehicle (fig. 4c) had objectives quite similar to the Boeing research/demonstrator vehicle (N-2) just discussed. The Rockwell vehicle, however, was designed to carry 8-10 passengers and possibly have a military application (stealthy supercruise fighter and/or bomber with internal stores). In the area of structures, the use of the state-of-the-art SPF/DB (superplastic forming/diffusion bonding) and FRATS (fiber reinforced titanium structures) was applied. In aerodynamics, it was wing-body blending and advanced high-lift designs and sonic boom minimization but the prime technology area of this study was propulsion and the resulting comparison of a GE-21 VCE system and MMIPS.

The MMIPS system consisted of a prime turbofan engine with its bypass air feeding to one or more turbojets (satellite engines) for supersonic cruise or bypassed around for take-off or subsonic cruise. For this study, a 1 x 2 MMIPS was arranged since the bypass ratio of 2.0 for the F-101 engine necessitated two-core satellites.

A second objective was to meet State-3 noise levels making the vehicle environmentally acceptable. Noise estimates for various take-off trajectories are included. Stage-2 sideline noise is met but 2-4 EPNdB are required for Stage 3. Sonic boom minimization through vehicle shaping was also suggested. No mention is made of the ozone concern.

(N-4) W. Barry Smith Enterprises, Inc. (1981). - "Market Considerations affecting Product Definition for a Supersonic Business Jet, unpublished. An abstract is not provided, however, the Introduction reflects the nature of the study and is included as follows:

"Incorporating into one document the accumulated knowledge of 35 years experience in marketing business jets is a challenging task. When you stop to consider all the parameters that become involved in the process of acquiring a new business jet, the list seems without end. An item as mundane as which type hydraulic fluid to use...very available Skydrol with its intrinsically corrosive features versus the not-so-available Military Spec fluid that will meet the Part 25 flame standards...is typical of the detailed concerns that require a response.

To assure that all major elements that affect the cost and marketability of a supersonic business jet have been identified, we have reviewed detailed type specifications and standard equipment lists for selected aircraft on a paragraph-by-paragraph basis.

In so doing, the authors of this report have restricted themselves to addressing only those key elements of the proposed configuration defining minimum acceptable performance and large equipment and certification standards having a pronounced impact when defining the ultimate characteristics of the research vehicle under study.

The unpublished report (N-4) represents Phase I of a three-phase marketing investigation into the commercial possibilities for a supersonic business jet derived from a small supersonic cruise research vehicle (Rockwell study N-3) designed to demonstrate that an economically acceptable Advanced Supersonic Transport (AST) can be built using 1984 state-of-the-art technology. Phase I objective was to identify market factors (needs) affecting a supersonic business jet and stress areas of conflict between the baseline design and market needs (with the advent of the termination of the NASA/SCR (Supersonic Cruise Research) Program in 1981). Phases II and III of this marketing study were not funded. This was the first of only two market survey studies conducted over the 30-year span of the 22 supersonic business jet studies contained in the present report. The second study (I-4) was made in 1987 by B/CA.

The topics included in this unpublished Phase I Market Study (N-4) addressed a market overview, passenger cabin size, interior weight allowance, general aircraft features, performance specifications, pricing and projected questions. Baseline design characteristics suggested by this study were Mach 2.7, 3200 nautical miles, 8 passengers, 8500 feet take-off field length, and 160 knots approach speed. Environmental issues included airport-community noise (target was FAR-36 Stage-3 noise levels) and sonic boom (target of $\Delta p = 0.5$ lbs/ft.^{2} at cruise) but not the ozone issue. the "project questions" reflected some interesting responses. For example, the interior noise should be low. A cabin height of at lease 65 inches is desired. Is ozone treatment contemplated for the air conditioning system? Can the windows be made larger than on Concorde?

<u>(N-5) Kentron (1981)</u>. - "Conceptual Development Studies for a Mach 2.7 Supersonic Cruise Business Jet," NASA CR-165705. The abstract reads:

"A significant body of information now available in published literature encouraged the development of a revised and improved version of an advanced supersonic cruise business jet aircraft concept. The objective of this study was to determine the impact of applying these advanced technologies on the performance and characteristics of this type vehicle. The study aircraft was configured for a maximum cruise Mach number of 2.7. Performance analysis was conducted at Mach 2.62 cruise on a standard plus 8°C day condition for a 5926 km (3200 n.mi.) range with a payload of 8 passengers plus baggage. Superplastic formed/diffusion bonded primary structure was assumed and resulted in a maximum gross weight of 284,686 N (64,000 lbf). A scaled version of the General Electric (GE21/J11-B14 engine is used for propulsion. This paper presents those portions of the study conducted by the Hampton Technical Center of Kentron International, Incorporated."

Since the previous NASA Study (N-1) in 1977, the additional design analyses that ensued along with improvements in engine technology prompted this study. For this study, the Mach 2.7 AST-105 arrow-wing planform, adjusted to a wing loading of about 69 lbs/ft^2 at the TOGW of 64,000 pounds (fig. 4d), replaced the Mach 2.2 scaled wing planform geometry of the Douglas Mach 2.2 SST concept used in study (N-1). Particular emphasis was placed on airframe weight reduction through the use of 1980 level SPF/DB titanium technology (Study N-1 used 1976 technology).

The computer program (ESBULL) developed by Kentron was used for estimating mass properties and extensive use was made of he NASA-developed Aircraft Sizing and Performance (ASP).

Of the three environmental issues, only sonic boom is discussed. Noise is mentioned only in the discussion of the baseline GE 21/J11-B14 variable-cycle turbofan study engine where it is noted that the exhaust system consists of an annular C-D plug nozzle with translating shroud sized for inherent sound suppression. No mention is made of any acoustic lining within the shroud which will definitely be required to attain the required noise suppression. Boom levels were estimated using the simplified procedure, however, equivalent cross-section areas were used to establish the characteristic shape factor. The author states that the cruise overpressures, varying from 1.0 lb/ft^2 at start of cruise to 0.7 lb/ft^2 at end of cruise, are severe enough to prohibit overland operations.

(N-6) Kentron (1983). - "Effects of Advanced Technology and a Fuel Efficient Engine on a Supersonic Cruise Executive Jet With a Small Cabin." NASA CR-172190. The abstract reads:

"An analytical study of a supersonic-cruise, executive, jet aircraft has indicated the effects of using advanced technology. the twin-engine, arrow-wing was configured with a cabin of minimum practical size to hold on pilot, 8 passengers and their baggage. The primary difference between this configuration and that of a previous report were the reduction in cabin size and the use of ore fuel-efficient engines. Both conceptual vehicles are capable of performing the same mission. the current vehicle has a range of 3350 nautical miles at Mach 2.3 cruise and 2700 nautical miles at Mach 0.9. the concept description includes configuration definition, aerodynamic and propulsion-system characteristics, and mass properties.

The performance analyses are documented for intercontinental flight profiles. In the latter case, a reduction of sonic boom overpressure from 1.3 to 1.0 pounds per square foot was achieved by varying the flight profile slightly from that for optimum performance.'

The two previous NASA studies, (N-1) and (N-5), applied concepts and technologies of the Supersonic Cruise Research (SCR) Program to 8 passengers, 3200 nautical miles, arrow-wing configurations of supersonic business jets. Study (N-1) using 1976 state-of-the-art titanium technology resulted in a vehicle TOGW of 74,000 to 80,000 pounds. Study (N-5) using state-of-the-art technologies of 1980 resulted in a 64,000 pound vehicle that exceeded the range requirements. This latter vehicle (N-5) serves as a baseline for the present (N-6) study but without the wing fins. A drooped nose feature for take-off and landing were retained. Modifications to enhance the performance of this present vehicle (fig. 4e) were to incorporate a fuel efficient turbofan engine and reduce cabin size as much as practical. This latter task took the form of a single pilot and reducing seat size, pitch and clearances. A single pilot was chosen based on the assumption that automated controls would reduce pilot work load during flight, and that a single pilot could be certified for intercontinental and transcontinental supersonic operation.

Of the three environmental issues, only sonic boom is discussed. Noise is only mentioned in discussions of the Boeing 701S turbine bypass turbojet and it is noted that the exhaust system utilizes a thermal acoustic shield for sound suppression. Estimates of sonic boom overpressure levels were made using the simplified method but rather than using simple shape-factor charts, equivalent cross-section areas of volume and lift were used to provide the characteristic shape-factor curve. A statement is made that the combination of low wing loading and high cruise altitude of this aircraft pose no sonic boom problem on a New York to Los Angeles mission.

Extensive use was made of the Kentron developed Flight Optimization System (FLOPS) described in the Appendix of this report (N-6). this vehicle design came in at a ramp weight of 51,000 pounds.

(N-7) Kentron (1984). - "Application of Near-Term Technology to a Mach 2.0 Variable-Sweep Wing, Supersonic Executive jet" NASA CR-172321. The abstract reads:

"An analytic study has been conducted to assess the impact of variable-sweep-wing technology with relaxed static stability requirements on a supersonic-cruise executive jet with transatlantic range. The baseline vehicle utilized modified, current-technology engines and titanium structures produced with superplastic forming and diffusion bonding; this vehicle meets study requirements for both supersonic-cruise and low-speed characteristics.

The baseline concept has a ramp weight of 64,00 pounds with a crew of two and 8 passengers. Its Mach 2.0 cruise range is nearly 3500 nautical miles; its Mach 0.9 cruise range is over 5000 nautical miles. Take-off, landing, and balanced field length requirements were calculated for a composite variant and all are less than 5000 feet."

The authors point out that early civil variable sweep supersonic designs were adversely affected by the need to maintain static longitudinal stability through the operating envelope. At the time of this study, variable sweep appeared more feasible due to developments in stability and control techniques. This fact, coupled with improved technologies in structures, materials, and propulsion systems suggested that the variable-sweep configuration (fig.4f) planform be revisited. The fixed-wing concepts of studies (N-5 and (N-6) are designed to meet requirements very similar to this variable wing study. Studies (N-5) and (N-6) has a "drooped visor nose" providing 15- degree angle of vision below the horizontal, whereas this variable sweep vehicle had only nose camber that provided 6 degrees of forward down vision. Elimination of the visor nose saved 250-300 pounds of structural and operating mechanism weight. In addition, the variable-sweep vehicle shows a range of over 5000 nautical miles at Mach 0.9 as compared to the two fixed-wing aircraft having subsonic ranges of about 2700 nautical miles and 3800 nautical miles. The message from this variable-sweep planform study, utilizing advanced technologies, is the same as was found on earlier variable-sweep investigations; that is, a penalty is paid for carrying around two wings rather than one.

Of the three environmental issues, only sonic boom was discussed. A statement is made that although noise analyses were not performed in the preliminary design effort, low power settings, low speeds, high-lift coefficients, and high L/D's should provide a relatively benign airport noise environment (the aircraft would be over 5400 feet altitude at the 3 nautical-mile community noise measurement point). Boom levels were estimated using the simplified process; however, equivalent cross-sectional areas were used to establish the characteristic shape factor rather then simple shape-factor charts. The effect of boom alleviation flight profiles on sonic boom and range are presented.

In this study, the recently developed Kentron Flight Optimization Systems (FLOPS) was used throughout.

(N-8) Kentron (1986). - "Effects of Emerging Technology on a Convertible business/Interceptor, Supersonic Cruise jet," NASA CR-178097. The abstract reads:

"This study was initiated to assess the feasibility of an eight-passenger, supersonic-cruise long-range business jet aircrft that could be converted into a military missile carrying interceptor. The baseline passenger version has a flight crew of two with cabin space for four rows of two-passenger seats plus baggage and a lavatory room in the aft cabin. The ramp weight is 61,600 pounds with an internal fuel capacity of 30,904 pounds. Utilizing an improved version of a current technology low-bypass ratio turbofan engine, range is 3622 nautical miles at Mach 2.0 cruise and standard day operating conditions. Balanced field take-off distance is 6600 feet and landing distance is 5170 feet at 44,737 pounds. The passenger section from aft of the flight crew station to the aft pressure bulkhead in the cabin was modified for the interceptor version. Bomb-bay type doors were added and volume is sufficient for four advanced air-to-air missiles mounted on a rotary launcher. Missile volume was based on a Phoenix type missile with a weight of 910 pounds per missile for a total payload weight of 3640 pounds. Structural and equipment weights were adjusted and resulted in a ramp-weight of 63,246 pounds with a fuel load of 30,938 pounds. Based on a typical intercept mission flight profile, the resulting radius is 1609 nautical miles at a cruise Mach number of 2.0"

One of the main constraints established for this study was that the external geometry of the concept would be retained so the aerodynamics performance would be the same for both missions. The results of two previous NASA/Kentron studies (N-5 and N-6) were one of the driving features in initiating this study, this baseline configuration (fig. 4g) being similar to studies (N-5) and (N-6). In fact, the wing planform differs over the wing outermost panel which was extended. A drooped (visor) nose is incorporated for improved pilot vision during take-off and landing. The recently developed Kentron Flight Optimization System (FLOPS) was also utilized in this study

Of the three environmental issues, only sonic boom was discussed. Boom levels were estimated using the simplified process, however, equivalent cross-section area due to volume and lift combined to provide characteristic shape factor. The effect of various boom alleviation profiles on both boom level and fuel consumption are shown in a fashion similar to study (N-7).

SUMMARY REMARKS

A literature search has been made regarding Supersonic Business Jet (SBJ) studies/activities conducted from 1963 through 1995 by universities, industries and government. It was found that there are at least 22 activities on the subject of Supersonic Business (executive, corporate) Jets; 6 by university, 8 by industry and 8 by NASA. The earliest attention to supersonic business jets was a 1963 design problem posed by the University of Colorado; the last effort was reflected in the 1995 paper by the Aeronautical Systems Corporation. University studies were conducted in the early 1960's and not again until the early 1990's. Although there were signs of industry interest in the Supersonic Business jet in the late 1960's and 1970's, it was not until 1981 and 1988 that

Fairchild/Swearingen and Gulfstream/Sukhoi, respectively, delved into it seriously. NASA's efforts begin in 1977 and ended in 1986. Even though a number of these 22 studies addressed market issues, only two were designed primarily as market surveys.

Study vehicles were designed to cruise at Mach numbers ranging from 1.5 to 3.0, be able to fly 2500 nautical miles to 5000 nautical miles, to accommodate 6 to 14 passengers and crew, and have take-off weights from 8400 to 134,000 pounds. Cruise altitudes ranged from 44,000 feet to about 74,000 feet. A majority of the vehicles had arrow or cranked arrow wing planforms but others incorporated delta, unswept trapezoidal, and variable sweep wings. Most vehicles were designed with two engines, however, other designs utilized 3 and 4 engines. Fuselage lengths ranged from 40 feet to 135 feet and cabin heights of from 4.0 to 6.2 feet.

Essentially all of the studies mentioned, or were aware of, at least one of the three environmental issues which include ozone, aircraft noise and sonic boom. However, only four studies included noise estimates, ten listed cruise overpressures, and none provided information regarding emissions. All of the industry and noise studies realized the necessity to comply with the 1978 Stage 3 subsonic airplane noise rule even though there is currently no noise rule for civil supersonic airplanes. In addition, they are also aware of the current rule restricting overland supersonic flight because of the sonic boom even though cruise overpressures of about 1.0 lb/ft, and in one case 0.4 lb/ft, would be experienced. Only one of the configurations is to be deliberately shaped for minimum cruise boom.

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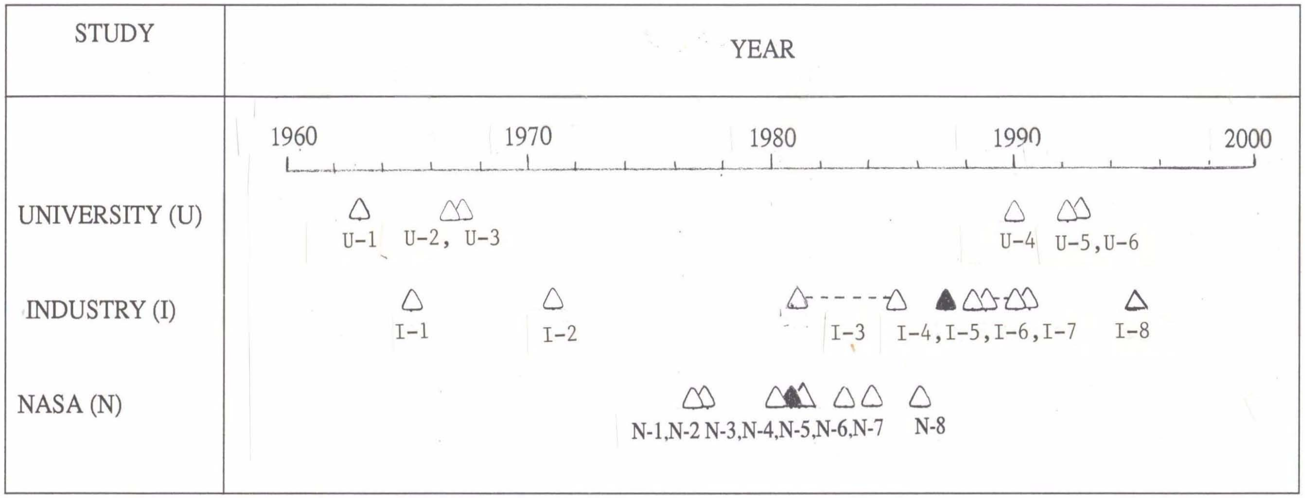
TABLE I. CHRONOLOGICAL LISTING OF SUPERSONIC BUSINESS JET STUDIES INCLUDING STUDY SOURCE AND VEHICLE CHARACTERISTICS

DATE	STUDY	SOURCE	MACH NO.	RANGE (n.mi)	TOGW (lb)	PAX + CREW	WING PLANFORM	NO. ENG.	NO. CONFIGS STUDIED	FUSELAGE LENGTH (ft)	CABIN HEIGHT (ft)	COMMENTS
1963	U-1	U.Colorado	3.0	3500	8400	4 + 2	Trapazoidal	2	1	40.0	4.0	
1965	I-1	Casa Spain	2.0	3000	44 000	12+2	Delta-ogive	2	1	83.6	5.1	
1967	U-2	Georgia Tech	2.2	3000	70 000 68 900	10 + 2	Delta unswept trapaz.	4 2	2	89.7 85.0	6.0	Business Jet or Airline Trainer
1967	U-3	Catholic Univ.	2.0	3300	63 000	9 + 2	Variable sweep	4	1	85	4.8	Also an inexpensive Flight Trainer
1971	I-2	Boeing	-	2580	103 500	10 + 2	Delta	-	-	-	-	Unpublished
1977	N-1	NASA LaRC	2.2	3200	74 000 80 000	8 + 2	Arrow	2	4	103 - 107	5.7	
1977	N-2	Boeing	2.4	3250	56 000	0 + 2	Arrow	2	1	93.5	4.5	Research vehicle
1980	N-3	Rockwell	2.7	3200	93 600	8/10 + 2	Arrow	2,3,4	1	96	5.4	MMIPS engine concept
1981	N-4	W.BarrySmith Assoc.	2.7	3200	-	8 + 2	-	-	-	-	5.4	Market survey
1981 1985	I-3	Fairchild/ Sweringen	2.0 2.2	4000+	100 000 134 000	8 + 3 14 + 2	Arrow Cranked arrow	2,3,4	4	100 128	6.0	Includes inputs from BAe,DAC,LAC
1981	N-5	Kentron	2.7	3200	64 000	8 + 2	Arrow	2	1	103	5.8	
1983	N-6	Kentron	2.3	3350	51 000	8 + 1	Arrow	2	1	103	4.8	
1984	N-7	Kentron	2.0	3500	64 500	8 + 2	Variable sweep	2	1	107	5.3	
1986	N-8	Kentron	2.0	3622	61 600	8 + 2	Arrow	2	2	103	5.7	Business jet + missile carrier- launcher
1987	I-4	Bus&Com. Aviation	2.0	4000+	-	-	-	-	-	103	5.7	Market Survey
1988	I-5	Gulfstream	1.5	Trans-Atlantic	100 000	8 + 2	Delta Ogive	4	1	125	6.0	Primarily sonic boom study
1988 1990	I-6	Gulfstream/ Sukhoi	1.5-2.0	4000+	80 000	10/12+2	Cranked delta arrow	3-4	2,3,4	100	6.0+	
1990	U-4	Purdue Univ.	2.2 2.5	4980 4750	104 500 128 348	8 + 2 9 + 2	Arrow Variable sweep	3 4	2	110 135	5.5 6.1	
1992	U-5	Univ. of Loughborough	-	-	-	-	-	-	-	-	-	Propulsion study
1993	I-7	Sukhoi	2.0	4600	106 000	10 + 2	Cranked arrow	2	1	114	6.0+	
1993	U-6	Case Western Research Univ.	2.2	5000	107 000	7 + 2	Delta	2	1	107	6.2	
1995	I-8	Aero Systems Corp.	1.8	3350	66 000	8/10+2	Cranked arrow	4	1	91	6.01	Includes market analysis

TABLE II.- ADDITIONAL CHARACTERISTICS OF THE VEHICLES AND ENVIRONMENTAL ISSUES ADDRESSED IN SUPERSONIC BUSINESS JET STUDIES

Date	Study	Source	Mach No.	Range (n.mi.)	TOGW (lb)	Propulsion System	Cruise Altitude (ft)		Cruise L/D		Wing Loading lbs/sq.ft	Environmental Issues Mentioned	Noise Estimates	Cruise Δp_o lbs/sq.ft
							Begin	End	Begin	End				
1963	U-1	U. Colorado	3.0	3500	8400	PW JT-12A-20 TJA/B	65000		4.7		80	SB	-	-
1965	I-1	CASA, Spain	2.0	3000	44000	G.E. J-79 TJ/AB	50000- 60000		5.8		48.4	SB	-	-
1967	U-2	Georgia Tech	2.2	3000	70 000 68 900	PW JT-11 B-4 non A/B TJ	60 000	60 000	6.5 6.5		61.3 91.9	O,AN,SB	-	1.5
1967	U-3	Catholic Univ	2.0	3300	63 000	GE 1/J1B Partial A/B TJ	-	-	-	-	-	AN	-	-
1971	I-2	Boeing	-	2580	103 500	-	-	-	-	-	-	-	-	-
1977	N-1	NASA LaRC	2.2	3200	74 000 80 000	•Non A/B TJ • GE 20/J11-B10 VCE TF	55 000	65 000	5.43 to 6.27	-	70-81	AN,SB	Yes	1.0
1977	N-2	Boeing	2.4	3250	56 000	GE 404 (mod) Low BP/AB	54 000 - 64 000		-	-	75.5	AN, SB	Yes	-
1980	N-3	Rockwell	2.7	3200	93 600	•MMIP(TJ/TF •GE 21 VCE	63 000 58 000	71 000 66 000	~ 7.5		89.0	AN,SB	Yes	-
1981	N-4	W. Barry Smith Asso.	2.7	3200	-	-	-	-	-	-		AN, SB	Stage 3 Goal	0.5
1981-85	I-3	Fairchild/Sweringen	2.0 2.2	4000+	100 000 134 000	Non A/B Olympus 59 T.J.	60 000 - 63 000		7.5		70.1	AN,SB	Yes	1.3
1981	N-5	Kentron	2.7	3200	64 000	GE 21/J11-B14 Var.Cycle T.F.	64 975	73 624	6.87	6.54	69.0	SB	-	0.9
1983	N-6	Kentron	2.3	3350	51 000	Boeing 701S TBP - T.J.	62 444	65 000	7.27	6.40	62.9	AN,SB	-	0.9
1984	N-7	Kentron	2.0	3500	64 500	Low BPR TF & Turbine bypass T.J.	47 970	58 098	6.32	6.31	87.9	AN,SB	-	1.0
1986	N-8	Kentron	2.0	3622	61 600	Low BPR TF	52 973	58 204	7.18	6.24	63.0	SB	-	0.9
1988	I-5	Gulfstream	1.5	-	100 000	-	51 000	65 000	7.5+		50.0	SB	-	0.6
1988-90	I-6	Gulfstream/Sukhoi	1.5-2.0	4000+	80 000	Lyulka AL-36 Rolls-Royce	50 000 - 60 000					O, AN,SB	-	-
1990	U-4	Purdue Univ.	2.2 2.5	4980 4750	104 500 128 348	Non A/B T.J.	-	-	7.07 6.3		90.0	-	-	-
1993	I-7	Sukhoi	2.0	4600	106 000	Lyulka AL-36 Non A/B	57 000		-	-	-	-	-	-
1993	U-6	Case Western Res	2.2	5000	107 000	Snecma MCV 99 Var.Cycle	55 000	65 000	~ 7.0		100	O,AN	-	
1995	I-8	Aero Systems Corp.	1.8	3350	66 000	Allied Signal F125-GA-100 ACFF	44 000	47 000	-	-	-	AN,SB	-	0.4

O = Ozone AN = Airport Noise SB = Sonic Boom

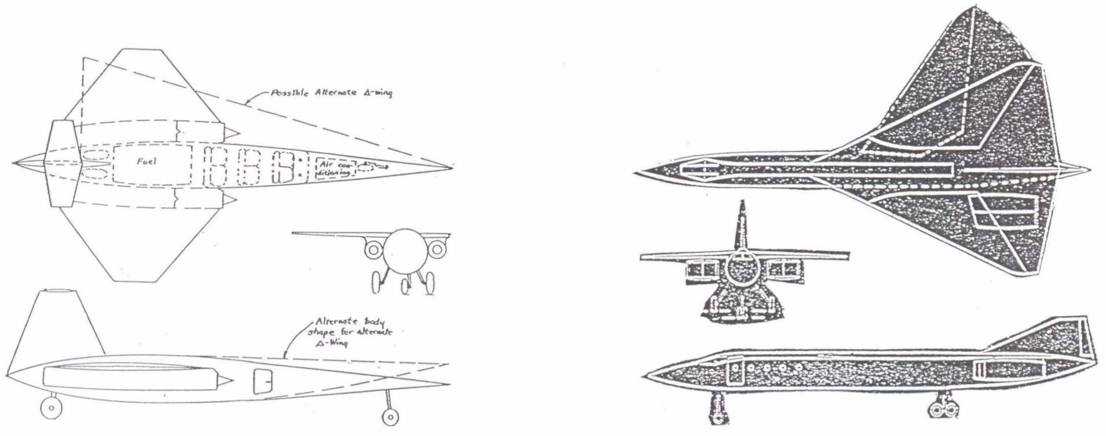


UNIVERSITY STUDIES	
U-1	UNIVERSITY OF COLORADO
U-2	GEORGIA TECH
U-3	CATHOLIC UNIVERSITY
U-4	PURDUE UNIVERSITY
U-5	UNIVERSITY OF LOUGHBOROUGH
U-6	CASE WESTERN RESERVE UNIVERSITY

INDUSTRY STUDIES	
I-1	CASA (Spain)
I-2	BOEING CO.
I-3	FAIRCHILD/SWEARINGEN
I-4	BUSINESS & COMMERCIAL AVIATION
I-5	GULFSTREAM
I-6	GULSTREAM/SUKHOI
I-7	SUKHOI
I-8	AERONAUTICAL SYSTEMS CORP.

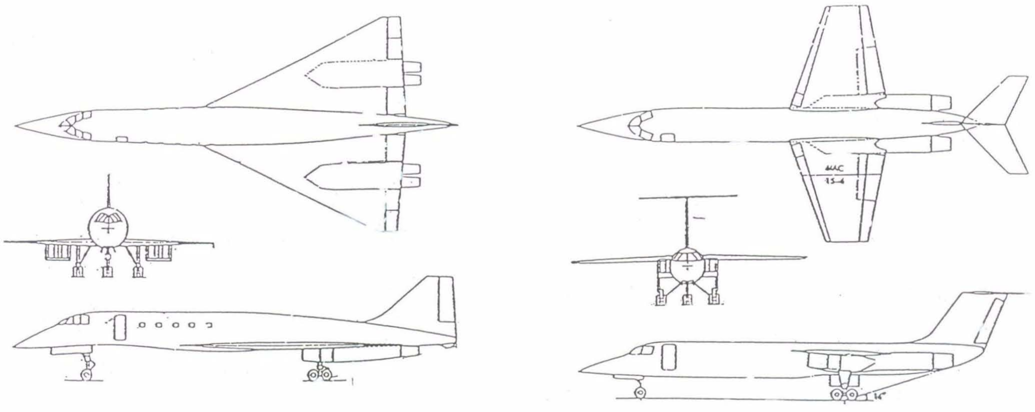
NASA STUDIES	
N-1	NASA LaRC
N-2	BOEING CO.
N-3	ROCKWELL
N-4	W.BARRY SMITH ENTERPRIZES
N-5	KENTRON
N-6	KENTRON
N-7	KENTRON
N-8	KENTRON

Figure 1. - Chronology of Supersonic Business Jet Studies.



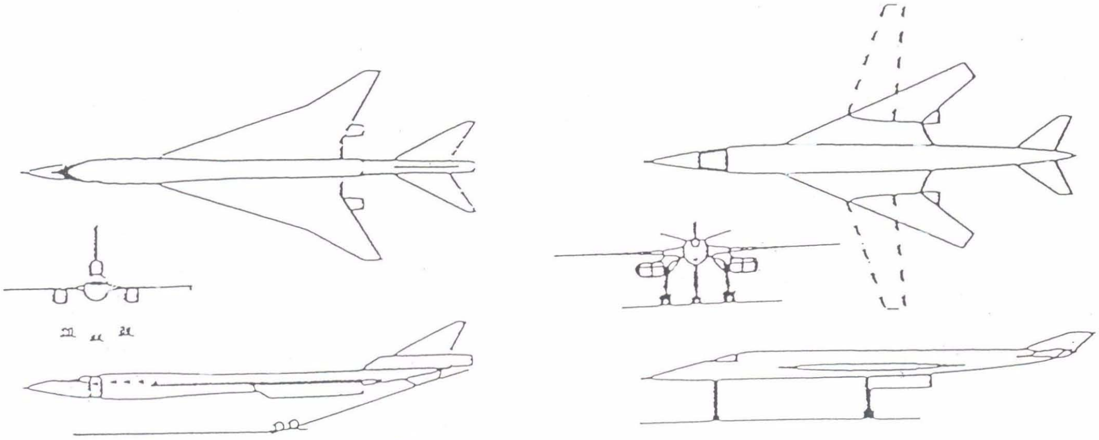
(a) U-1 University Colorado 1963

(b) U-3 Catholic University 1967

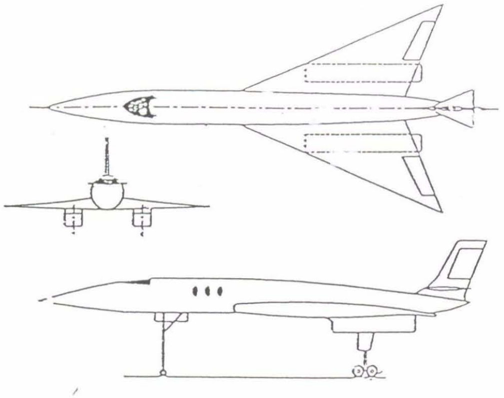


(c) U-2 Georgia Tech 1967

Figure 2. - Supersonic Business Jet Configurations - University Studies.

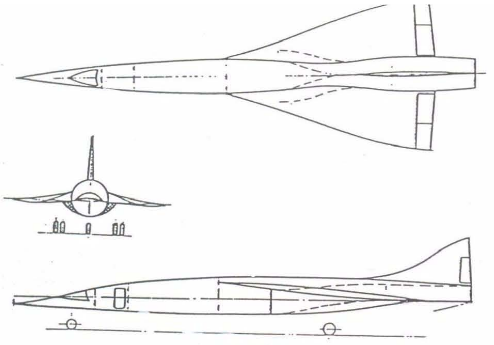


(d) U-4 Purdue University. 1990

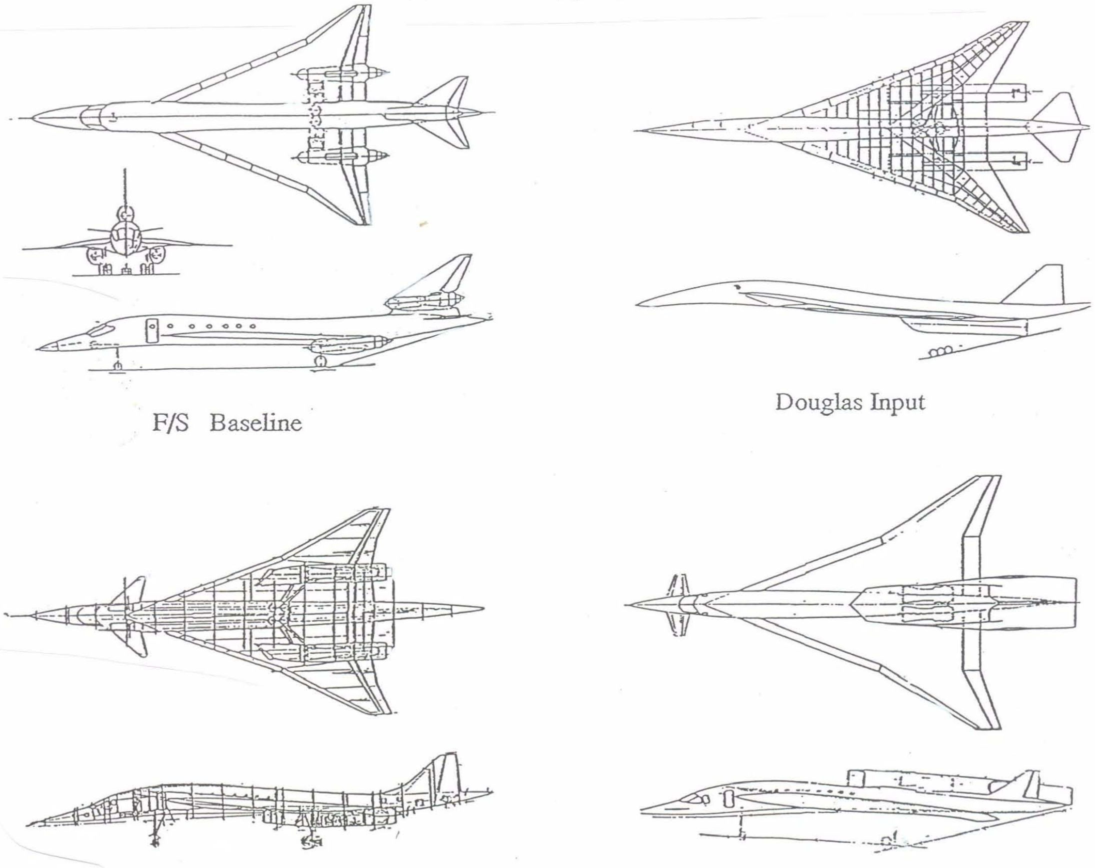


(e) U-6 Case Western Res. Univ. 1993

Figure 2. - Concluded.



(a) I-1 CASA (Spain) 1965



F/S Baseline

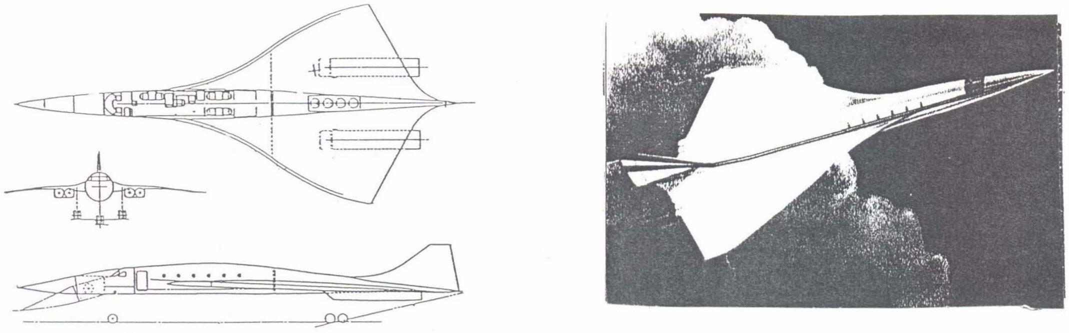
Douglas Input

British Aerospace Input

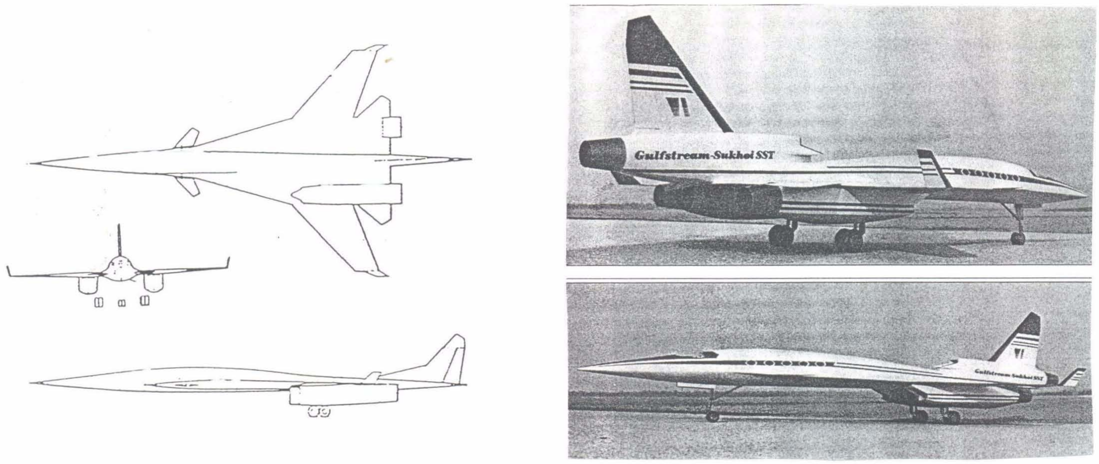
Lockheed (W. Hawkins) input

(b) I-3 FAIRCHILD/SWEARINGEN 1981-1985

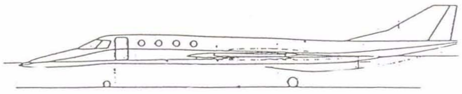
Figure 3. - Supersonic Business Jet Configurations - Industry Studies.



(c) I-5 GULFSTREAM 1988

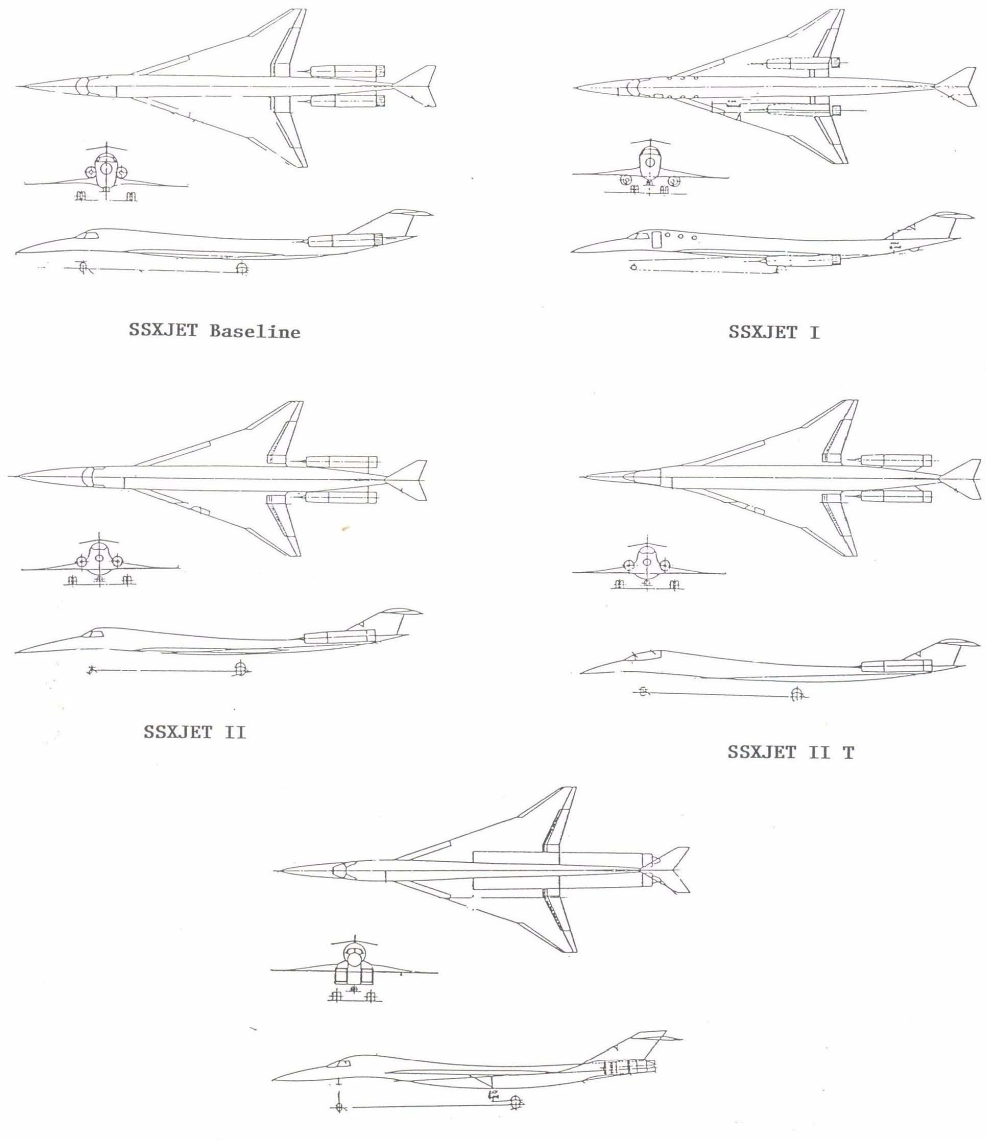


(d) I-6 GULFSTREAM/SUKHOI 1988-1990



(e) I-8 AERO. SYSTEMS CORP. 1995

Figure 3. - Concluded



SSXJET Baseline

SSXJET I

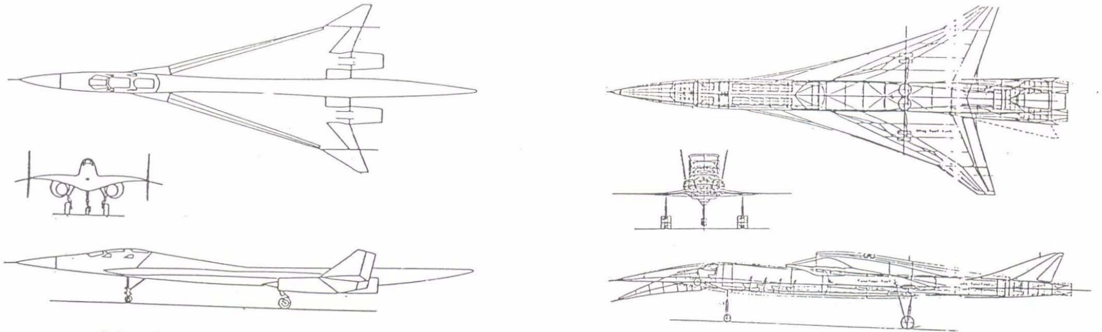
SSXJET II

SSXJET II T

SSXJET III

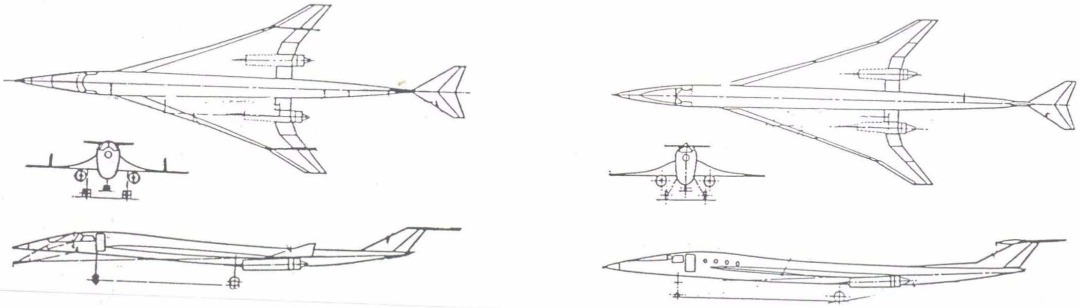
(a) N-1 NASA Langley 1977

Figure 4. - Supersonic Business Jet Configurations - NASA Studies.



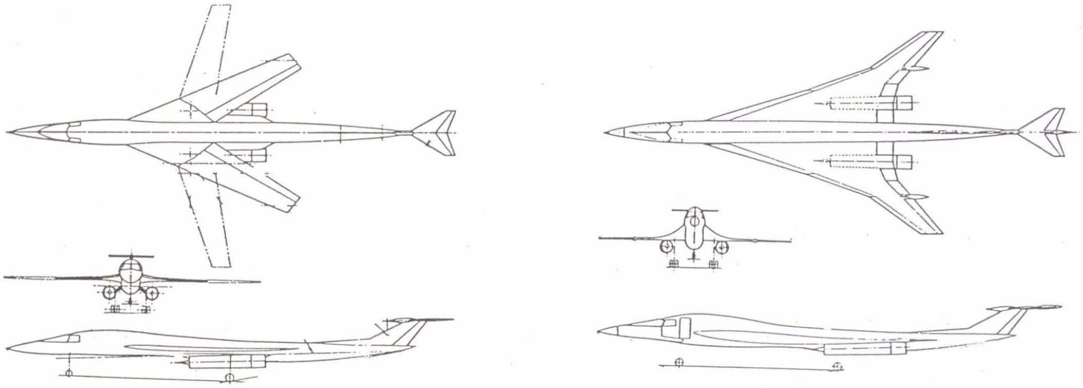
(b) N-2 BOEING 1977

(c) N-3 ROCKWELL 1980



(d) N-5 KENTRON 1981

(e) N-6 KENTRON 1983



(f) N-7 KENTRON 1984

(g) N-8 KENTRON 1986

Figure 4. - Concluded

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14. ABSTRACT

This document provides a compilation of all known supersonic business jet studies/activities conducted from 1963 through 1995 by university, industry and the NASA. First, an overview is provided which chronologically displays all known supersonic business jet studies/activities conducted by universities, industry, and the NASA along with the key features of the study vehicles relative to configuration, planform, operation parameters, and the source of study. This is followed by a brief description of each study along with some comments on the study. Mention will be made as to whether the studies addressed cost, market needs, and the environmental issues of airport-community noise, sonic boom, and ozone.

15. SUBJECT TERMS
Supersonic; Business jet; Sonic boom; Community noise; Ozone

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