Overviews of Japanese Study Activities for The Second Generation SST

ICAS-94-1.2.1

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Abstract

Since 1989, the "Feasibility Study for Future SST/HST" has being performed by the Committee in the Society of Japanese Aerospace Companies, Inc. (SJAC). The study results obtained so far and related activities in Japan are briefed. The Committee has tentatively defined the baseline airplane specifications for assessing the technological subject to be tackled. Small scale technology developments undertaken by Japanese industry and governmental laboratory cover all disciplinary field of aircraft technology. Studies related to environmental concerns and social impacts from SST operation are touched.

Introduction

An outlook over the 21st century indicates that air traffic passenger demand will likely exceed 2 billion per year by 2010 and will increase throughout the century because of a foreseen growth in world economy. Especially, demand in the Pan-Pacific long range route will grow as twice in rate as the world average, due to the dramatic growth of the economy recently witnessed in the Far East and Asia.

To cope with the above mentioned situation, it will be inevitable that enhancement of world air transportation systems through the employment of much faster and more efficient aircraft such as SST/HST for long range routes must take place.

Results of Japanese preliminary study conducted up to 1988 by SJAC showed that the progress after Concorde and additional breakthrough in aircraft technology could make out the future SST/HST feasible in economical viability and environmental acceptability in early stage of the 21st century.

Since 1989, SJAC has been conducting a "Feasibility Study for Future SST/HST" covering (1) market prospect and analysis for identifying airplane requirements, (2) engineering analysis and evaluations of technologies to be attained for actual realization and (3) environmental assessment on worldwide operation of the SST.

The study has been closely coordinated with other national research projects such as the "R&D of Propulsion Systems for Super/Hyper-sonic Transport" and "R&D of High Performance Materials for Severe Environments" which have focused on more basic research for long-term demands of HST and Space Plane.

SUNAKAWA, Megumi: Chairman of the Committee
IWAKI, Takeo: Coordinator of the Committee

The basic principle of the "Study" is that Japan should positively take part in the international cooperative program of development and production for the 2nd generation SST and contribute to the program with her high economic and technological abilities. To this end, the requirements from Japanese airlines, who will be major customers of the SST, should be clarified and the relevant technologies characteristic to Japanese airplane industries need to be defined.

This paper will mainly focus on the 2nd generation SST (Mach 2-3 class) tackled in the "Feasibility Study"[1] and briefly touch on the related activities performed by Japanese industry and governmental laboratory.

I Airplane Specification and Concept Design

1) Airplane Requirements

The SST will serve on international long range routes in world air network to reduce travel hours and it should suit to the subject market demands. We have studied the marketability of various airplane specifications varying number of seats, cruising Mach numbers and range capabilities as well as evaluating the program's viability with anticipated costs of development and production.[2, 3, 4]

As a result, we have found that the 2nd generation SST needs to have a capacity as meny as 300 passenger seats. Figure 1 shows feasible area map of cruising Mach number and range performance, with the assumption that overland supersonic flight will not be allowed because of sonic boom.

Case A presents the area where development and production cost are plausibly estimated in the line of current technology trends, whereas

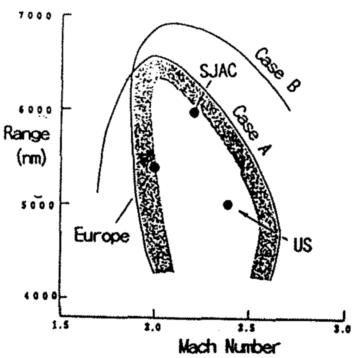

Fig. 1 Area Map of Mach Number and Range

Case B is another one where the favorable triggering of tourist needs can be expected and improved cost risks will result from aggressive new technology. Which scenario to choose depends on the way of evaluation and expectation onto the rewards for the efforts made. European requirements seem to favour the optimum point of Case A, while the US appears to select the optimum combinations in Case B.

The following specifications are presumed by the "Study" Committee as tentative bases.

- Cruising Mach number = 2.2
- Range performance = 11,100 km (6,000 nm)

The range performance has a satisfactory level required for direct flight from Japan to Europe via East Siberia. (Route 1 or 5 in Fig. 2) It falls within the range attainable by future technological improvement to achieve 12,000 km (6,500 nm) needed for direct flights from Japan to the East Coast of US, and strongly desired by Japanese airlines.

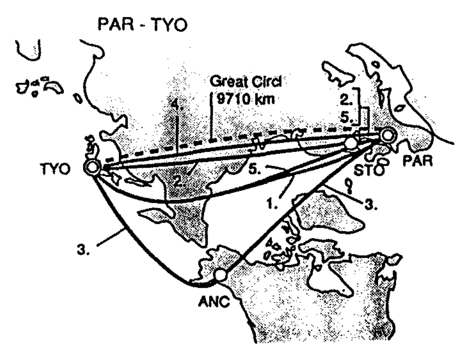

Fig. 2 Routes between Tokyo and Europe

The Mach number incidentally equals the average of those by the US and Europe. It can meet both the scenarios of Case A and Case B and comes from the evaluation of heat-resistant materials described in I-5).

2) Baseline Specifications and Configurations[16]

On highly advanced airplane like the SST whose full scale development is expected to start around the year 2000, various innovative technologies so far developed and demonstrated will be employed.

One of major subjects of the study is to predict and evaluate the technological progress in each field of a) aerodynamics for improving the lift-drag ratio at supersonic cruise, b) heat-resistant materials and structures for ensuring the airworthiness against aerodynamic heating, still satisfying a severe weight saving demands, c) the engine for realizing low fuel consumption and high compatibility to environmental needs, and d) the systems, avionics, and component technologies to enhance reliability and efficiency.

A CAD (computer aided design) program incorporating the above predictions and evaluations has been developed and maintained with technological findings to update airplane configurations and assess the aspects of technology to be developed. Figure 3 shows the baseline specifications and configurations generated by the CAD so as to satisfy the airplane requirements previously settled.

3) Engine Specifications and Airplane Size[15]

Maximum take-off weight of the airplane, which is closely related to development and production costs and seriously affects the viability of program, must be kept as low as possible. The engine technology for reducing fuel consumption is important because the weight of fuel will take 60% of the maximum take-off weight.

High bypass ratio engine of low fuel consumption during cruise, enjoyed by current subsonic jetliners, cannot be used to supersonic cruise which require high specific thrust and low additive drag of airintake. To maintain the present low noise at airports attained by high bypass engine is another serious problem for supersonic transports, sincea low bypass ratio inevitably increases exhaust gas velocity and hence noise.

For overcoming these conflicting requirements between low speed operations and high speed cruise, many 'Variable Cycle Engine' concepts have been proposed and studied so far. These have likely emerged to two typical types; the one is the SBE(Single-Bypass Engine) favored mainly by the US engine consortium and the other is the TDF(Tandem Fan Engine) proposed by the European consortium who recently announced a new MTF(Mid Tandem Fan) concept as their baseline. The former carries a new

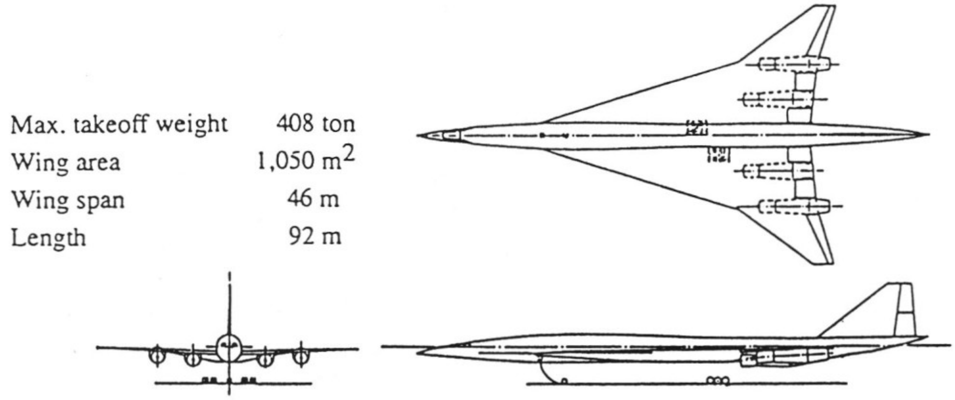

Fig. 3 Baseline Specifications and Configurations

technology still to be developed for an ejector nozzle that can effectively reduce the jet noise and the latter has developing elements for both an efficient air intake and a reliable mechanism for switching air passages.

Figure 4 presents a results of airplane sizing analysis with the CAD program, a comparison of optimized specifications of SSTs installing above-mentioned engines fulfilling the same mission requirements. Future technological advancement of both type of engines may affect the results.

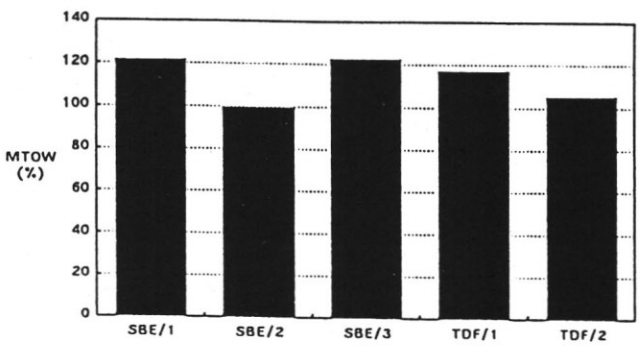

Fig. 4 Maximum Take-Off Weight of SSTs

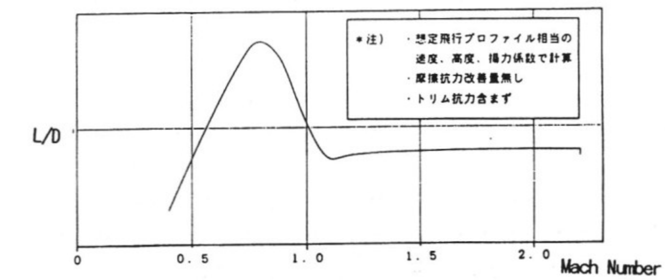

Fig. 5 Lift-Drag Ratio of Baseline Configuration

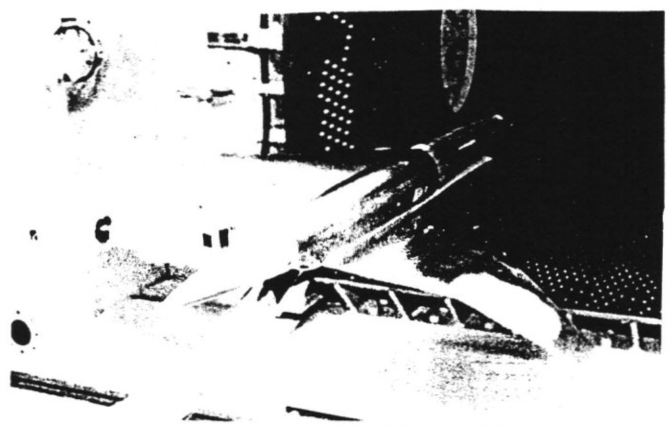

Fig. 6 Transonic Wind Tunnel Test

4) Aerodynamic Performance[5, 7, 9]

Shown in Fig. 5 is the lift-drag ratio of the baseline configuration estimated from the results of subsonic, transonic and supersonic wind tunnel tests. (Fig. 6) It predicts the airplane can achieve a ratio of 8.2 at Mach 2 cruising, which is far superior to 7.3 of Concorde and meets the target value set in the CAD data base.

We realize that further effort have to be made to improve the lift-drag ratio at transonic and low speed operation, as well as during supersonic cruise. To this end, innovative aerodynamic design concept such as 'Warp Wing' and LFC (Laminar Flow Control) technology should be studied to optimize wing shape.

An another configuration with horizontal tail incorporated with high lift devices such as 'vortex flap' concept has been studied and tested in a low speed wind tunnel using a small-scaled model. The test result showed promising possibility for design freedom and configuration selection. However, the Reynolds number effect of low speed aerodynamics should be confirmed in further tests with a larger-scaled model.

5) Composite Structure[8]

Figure 7 summarizes the technology assessment of the current and future trend of heat-resistant materials to be applied to Mach 2 ~3 class SST which will be deliverable around the year 2005. The selection of 2.2 as the baseline

Mach number and employment of the polymer-type composite as the baseline structural materials were based on this assessment.

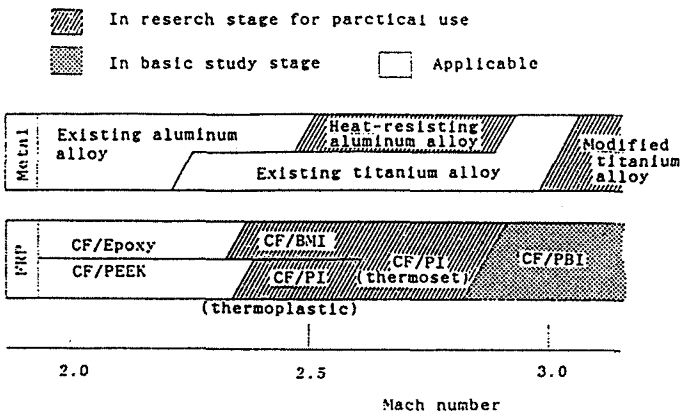

Fig. 7 New Materials for 2nd Generation SST

The concept design study in the following structural parts was substantially reviewed for investigating subjects specific to SST:

- general parts of main wing, fuselage, tail and nacelles,
- high-strength parts such as landing gear mounts and wing body junction,
- high-temperature parts of leading edge of wings and nose of fuselage,

The study made the following points clear:

a) Composite materials can reduce the structural weight by 20 to 30%.

b) Composite materials are superior to metals when subjected to stress due to aerodynamic heating,

c) Metals such as titanium will be applied to important parts which are subject to high loading,

d) Data accumulation of new composite materials is required for establishing design criteria to assure safety and durability of parts,

The structural data base in the CAD is elaborated to assess the effect of materials selection for structure. The baseline specifications and configuration shown in Fig. 3 assume that advanced composite materials are applied to the main airframe structure, excluding high-strength components such as wing body junction and high temperature leading edges, etc.

6) Heat Control and Other Systems

The SST flying at Mach 2.2 will be surrounded with air average temperature of 120 ℃ caused by aerodynamic heating. This makes heat control systems for air-conditioning and oil cooling unable to rely on outside air as their heat sink. Consequently, new heat-control systems utilizing loaded fuel as the only heat sink are needed to ensure comfort in cabin and cockpit and the temperature level of oil. The systems have to maintain the fuel temperature below allowable level throughout the flight, although onboard fuel itself is heated from tank walls. The tentative system specifications and elements to be developed for related system technology including the fuel system were defined.

Subjects for new system technologies such as advanced flight control integrated with FBW/FBL, new flight management/operational systems compatible to FANS (Future Air Navigation System) and an artificial vision system to avoid nose nose deflection mechanism, was also studied.

II Technological Development

Many evolutions counted with in the CAD data base should be developed and validated in each disciplinary field of aircraft technology. These technological evolutions affordable to the SST current level of safety, reliability as well as operational economy in severer flight conditions characterized by shock wave drag and aerodynamic heating, will be spun-off to subsonic airplane and lead innovation of air transportation systems in the 21st Century. This is a basic recognition upon which the advanced countries undertake technological development projects, the US initiated HSRP (High Speed Research Program) as big as 2 billion dollors.

The following reviews technological development activities in Japan, covering the "Feasibility Study" by SJAC and NAL's "Special Cooperative Research with Industry on High Speed Aircraft" as well as industry's in-house elaborations. Some of them have been presented at AIAA Design and Systems Conferences since 1991.

1) Aerodynamic Technology

For improving aerodynamic performance of the 2nd generation SST, it is necessary to collect considerable aerodynamic data on low-speed, transonic and supersonic flight conditions. The CFD technology has been remarkably advancing in recent years, overcoming the restrictions of tests in existing wind tunnels and is almost ready for sophisticated aerodynamic design use. The high level of Japan's supercomputer technology promises that Japan can substantially contribute to the SST development in the field of aerodynamic technology with her extended CFD ability. Figure 8 demonstrates the

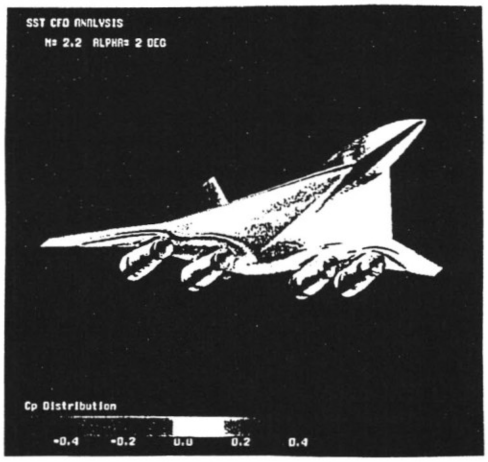

Fig. 8 Detail Flow Field with CFD

applicability of CFD analysis with the Euler equation to show the details of aerodynamic flow field on the wing and nacelles.

Laminar flow control technology either passive (NLF: Natural Laminar Flow) or active (LFC: Laminar Flow Control) is expected to increase the lift-drag ratio of coming SST to 10 and more. Figure 9 samples a testing in a low turbulence tunnel in industry's in-house research related to LFC technology. The subject have also been tackled by NAL's "Special Cooperative Research Program".

Other aerodynamic researches below have been pursued in industries' in-house program.

- Optimizing Study of Aerodynamic Configuration of SST,
- Research on the Aerodynamic Configuration for Low Sonic Boom,

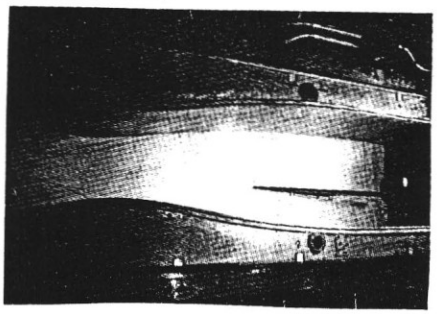

Fig. 9 LFC Test in Low Turblence Wind Tunnel

2) New Material and Structure

With the recognitions described in I-5) of the "Study" results, following technological issues have being undertaken in industry's in-house researches and NAL's "Special Cooperative Research Program"

- Aerodynamic Tailoring of SST Main Wing Using Composite Materials, [12]
- Flutter of the Composite Fuselage Outer Panel,
- Design Tolerance of Composite Panel Buckling,
- Junction Technology of Thermoplastic Composite Materials, (Fig. 10)
- Heat-Resistant Composite Materials for Supersonic Aircraft, (Fig. 11)
- Processing Method of Thermosetting Structural Materials for Supersonic Aircraft,
- Research on the Processing Procedure of Titanium Alloy,

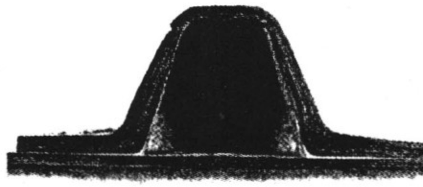

Fig. 10 Composite Stringer

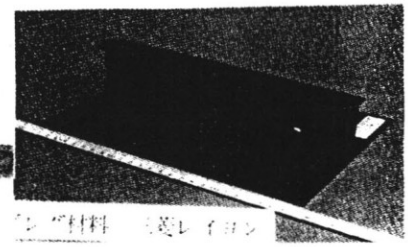

Fig. 11 Composite Frame

3) Fuel Efficient and Environment-Adaptive Engine

Major issues related to the acceptability of SST are likely to focus on its engine ; SST should meet the noise criteria at least equal to subsonic aircraft, and its engine will be required to have a NO_x exhaust level as low as negligible influence on the ozone layer. Accordingly the feasibility of SST largely depends on new engine technologies which can achieve the adaptability to these environmental requirement as well as low fuel consumption, as described in I-3).

The technological goals of cycle efficiency and turbine temperature targeted in "R&D of Propulsion Systems for Super/Hyper-sonic Transport" were reflected upon in the cycle optimization of SBE and TDF study on airplane sizing in the previous section. And "R&D of High Performance Materials for Severe Environment" covers innovative materials applicable to SST engines. It is convinced that coming SST engines will utilize the technological achievement of these two national research projects.

Related industry's in-house research items are as follows;

- Research on the Adaptability Characteristics of High Performance Supersonic Air-Intake,
- Switching Mechanism of the Variable Bypass and Fan Flow Passage,
- Ultra-High Temperature-Resistant Materials Applicable to Engine Components,

4) Heat Management and New Systems Technology

Concorde had led the upgrading of technology in commercial transport when it inaugurated hydraulic system of 4,000 psi and the FBW concept to its flight cntrol system. The practical FBL control systems with higher hydraulic pressure which have to be met in the 2nd generation SSTs will surely lead to the way of evolution in systems for commercial aircraft of the 21st century.

Foreseen advances in avionics show the possible use of artificial vision systems which assure flight safety and provide pilots with precise information and simulated views, thus eliminating the nose down systems of Concorde which impose additional weight and complexity.

Significant improvement in reliability of flight operation systems and sophisticated navigation systems may reduce the weight of reserved fuel presently estimated more than the payload, and can improve the economy of SST to a large extent. There is no doubt Japan's excellent avionics technology will be able to contribute to the development of innovative flight deck for the SST.

III Environmental Concerns

International consensus for environmental acceptance to SST operation should be established before full launch of the airplane development anticipated around the year 2000. ICAO CAEP has started regulatory work for noise and emission, where SJAC has been contributing through ICCAIA.

For ozone problem, a professor at the University of Tokyo, a member of the "Study" committee, has been invited to Scientific Advisory Panel of AEA program of NASA.

1) Community Noise

The engineering studies described in I -3) were performed on the assumption that the coming SST should comply to ICAO Annex 16 Chapter 3 which was consented as a guideline at ICAO CAEP-2, 1991. The working group of the "Study" committee recognizes the above-mentioned guideline is based on subsonic aircraft now in service, and a new rule for coming SST should be established as ICAO regulation.

The committee has also been investigating noise in climbing stage which might have effect on ground.

2) Sonic Boom[14]

Supersonic overland flight will improve the operational economy of SST, eventhough the flight routes were limited to restricted corridors. It is worth to challenge the reduction of sonic booms on one hand and try to evaluate acceptability on the other hand.

The working group of the "Study" committee have conducted simulation test with anechoic chamber (Fig. 12) and in progress, have established test technique to evaluating waveform of 'N' shape. They have found PLdB has the best correlation to human feeling and initial rising time in 'N' wave is markedly related to human annoyance. Specially designed test chamber has been just completed and will be utilized to take more detailed data for low boom configuration acceptable to make supersonic overland flight.

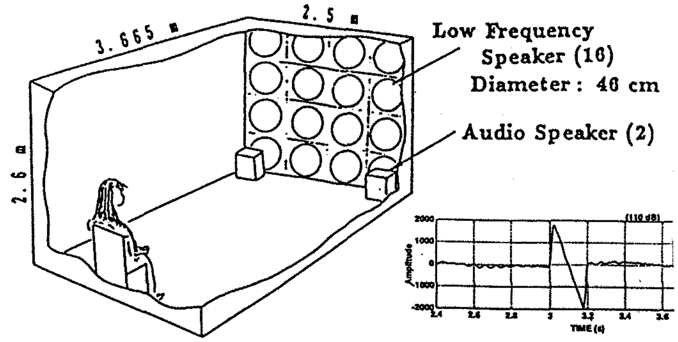

Fig. 12 Sonic Boom Simulation Test

3) Ozone Layer[11]

One-dimensional and two-dimensional chemistry transport models have been developed for assessing the potential impact of aircraft emission on stratospheric ozone to give technological requirements for SST.

Recent studies have revealed that the heterogeneous chemical reactions on the surface of stratospheric sulfate aerosols play a significant role in stratospheric ozone chemistry. Calculations with models confirmed the points. The total ozone change in 2010 based on the assumed operational scenario (SST market share 50 %, emission index 5) is estimated less than 1 % as shown in Fig. 13.

These results of the studies have been presented at NASA workshops.

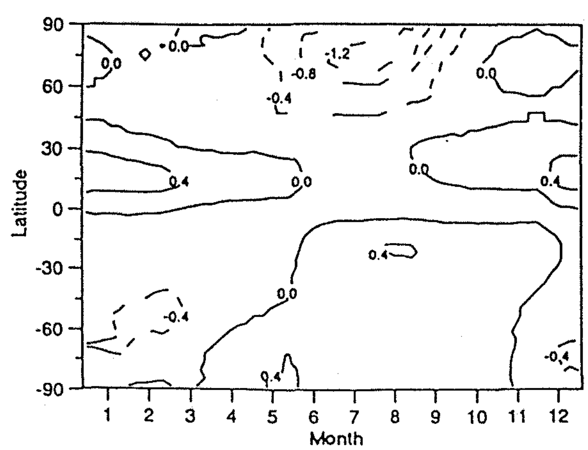

Fig. 13 Estimation of Influence to Ozone Layer

IV Impact of SST Operation to Economy

Considering the prospects for social and economic impact resulting from SST operation, a quantitative analysis was performed to figure out the stimulation potential to the Japanese economy in 2020 when the airplane will go round.

The reduction of travel hours will expand the sphere and improve the productivity of industry's business trip and stir up tourism, personal visit and international associations.

Productivity in trade with East Asia, such as Hongkong, Shingapore and Indonesia, will be raised to the high level of domestic trade in Japan when one day business trips to these area are realized. The productibity of current 2-3 day business trips to Asia will be extended to the trade with the US, Europe and Australia currently taking more than 4 days. The Japanese manufacturing industry will enjoy high efficiecy of business trip by close connection for manufacturing goods and boost their yield.

Past experiences in constructing new airports and extending the Shinkansen (bullet train) network in Japan have shown the stimulation to traffic demands is one and a half times. The excess with SST in Japanese oversea traveller will add another output to the related industry of the country, whereas the money spent by excessive foreign visiters will help the Japanese economy.

Above three influencial advantages in economic potentials of SST operation were analyzed with 1992 statistics concerning the relevant Japanese industries and figured out the benefits to be 3,800 billion yen per year which amounts almost 1% of the Japanese GNP. When the above percentage figure is applied to the world's economy with economic logic, the benefit in global GNP favored by worldwide operation of SST will be accounted to be 250 billion US$ per year, which means the anticipated investment for developing the airplane will be drawn back in one year.

V Concluding Remarks

Public transportation systems in Japan with air and the Shinkansen (bullet train) network allow one day domestic trips and bolster up the excellent performance of the nation's social economy and civil welfare. The 2nd generation SST rendering worldwide travel one-day trips will contribute to the prosperity and progress of the world's social life in the 21st century.

It goes without saying that Japan, with her economical potential and technological background, is expected her appropriate contribution to the development of SST and cooperation among countries in high-tech areas of the program will be of great significance.

Acknowlegements

The authors wish to express their thanks to the member of the "Feasibility Study for Future SST/HST" Committee in SJAC and Ministry of International Trade and Industry of Japan for permission to publish this paper. They also appreciate the cooperations given by Mr. T. Uchida, JADC and Mr. Y. Naramoto, IADF in reviewing the paper.

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