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Japan's Supersonic Technology and Business Jet Perspectives

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Abstract. In order to open the next generation supersonic era, SSBJ (Supersonic Business Jet) is being tried to design as a technical and industrial challenge in Japan. The accumulated technical fruits obtained from the series of R&D programs including NEXST, D-SEND, HYPR/ESPR and other related projects are intentionally applied. Those accomplishments are suitable for solving the critical issues such as noise, sonic-boom, fuel economy and thus the community acceptance for supersonics realization. Design trial of the supersonic business jet is under way by a Japanese team with evaluation of the affordability and applicability of the technical achievements accumulated from those Japanese research projects.

Nomenclature

C_L	=	lift coefficient
C_D	=	drag coefficient
D	=	drag
FN	=	thrust
H	=	altitude
L	=	lift
p	=	pressure, sound pressure
R	=	range
SFC	=	specific fuel consumption

I. Introduction

Many aeronautical people have a dream of re-realization of supersonic transports. However the fuel economy, community noise and sonic boom are the critical problems which should be solved for a new birth of the next generation's supersonic jet. Japan is making effort on the technological development for those subjects with a certain number of research projects. For instance, JAXA, Japanese national aerospace R&D agency, performed NEXST Project [1][2] as well as D-SEND Project [3], with the flight experiment for demonstration of the newly developed technologies such as the advanced CFD-based aerodynamic design with the inverse method, and METI (Ministry of Economy, Trade and Industry) promoted HYPR Project [4] for the supersonic and hypersonic propulsion technologies in the last decade. On the other hand, the world economical movement is changing rapidly and requirements of fluent business communication and timely decision making are so keen. In those circumferences, high speed and convenient tools of human mobility should be necessary for the current and future business and political people. It must be the time to consider reopening the door of supersonic speed by utilizing the recent achievements of the R&D for lowering CO_2 emission, sonic-boom and community noise. We think that the supersonic business jet (SSBJ) could be the first runner for the new supersonic era. Recently, several enterprises including NASA of USA, one of Russia and private companies are promoting the SSBJ research or development programs considering near future SSBJ market [5][6]. A team for the future supersonics in Japan was formed with the Japanese aircraft manufacturers, JAXA and academia to make a trial to design the SSBJ in order to define an affordable concept, to evaluate the new technologies and to study about the airplane market. This paper describes the major new technologies developed in the R&T projects of Japan, market concerns and critical consideration for a system concept of the near future SSBJ.

II. Japanese Technological Achievement for Supersonics

A. Aerodynamics

From 1997 to 2007, JAXA performed NEXST project in order to develop the advanced aerodynamic design technology for low-drag aerodynamics mainly by introducing the natural laminar flow wing (NLF) technology and also by the CFD based computer aided design technology with inverse calculation method, which makes

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the design process automatic to realize a desired performances [1][2]. Figure 1 shows the 3 main aerodynamic technologies developed in the project. The demonstration airplane, called NEXST-1, was developed by JAXA in cooperation with the aircraft manufacturing companies of Japan. The length of the experimental airplane was 10m to simulate about 1/10 scale of the targeted future transports. More than 800 points of measurement were installed for gathering the data of surface pressure, temperature, heat transfer and structural phenomena for boundary layer transition on the surfaces, aerodynamic coefficients and the basic flight conditions of the airplane.

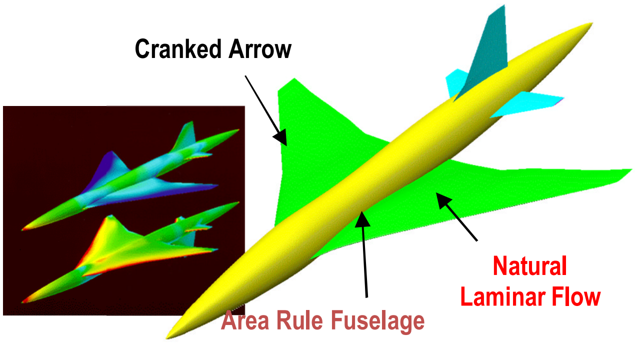

Fig.1 Aerodynamic technologies developed by the project and Pressure contours by CFD

The successful flight was performed in the Woomera testing range in South Australia in November 2005. That test campaign was carried out by full international collaboration between Japanese project team and Australian support team. Figure 2 shows a view of the successful launch of the experimental airplane "NEXST-1" with the solid rocket booster firing, which was also developed in the project. The data has been obtained through 15min flight at the altitude of 18,000m and 10,000 for different Reynolds numbers respectively.


Fig.2 Launch of the NEXST-1 Demonstrator (Oct. 2005)

Figure 3 shows the demonstrated natural laminar flow (NLF) region on the wing surfaces by analyzing the measured data of the experimental flight. It is verified that more than 30% area of the wing upper surface could be laminar as shown as the shaded area in the figure at flight Mach number 2.0. It must also be said that the NLF technology application could make the business jets with remarkable low supersonic drag and high performance. The technology of integration with cranked arrow wing and area ruled fuselage for drag reduction has been also developed and demonstrated.

Figure 4 shows the lift/drag ratio (C_L/C_D) derived from the NEXST-1 flight, compared with the calculation in 2 cases of boundary layer conditions. Good agreement between experiment and calculation is indicated. Those technologies have been developed with supercomputer based CFD with the inverse and optimized methods. Those results and accomplishments such as CL/CD, the boundary layer data, the surface pressure distributions and so forth, were arranged as the unique database by JAXA to dedicate to real applications and scientific studies [7].

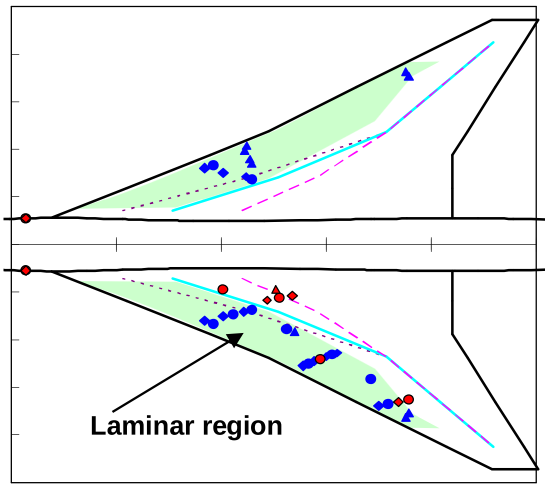

Fig.3 Demonstrated Laminar region on the wing upper surface

B. Structures

Structure and material technologies are strategically important for Japanese industry. Japanese composite technologies including both of CFRP and CMC are the competitive ones for the aerospace systems. The composite structures of the main wing and fuselage of B787 and Japanese F-2 are the successful applications typically. The composite structure is one of the important technologies for light weight SSBJs.

C. Sonic-Boom

Sonic-boom is one of the most critical issues for public acceptance of the next generation supersonics. There is the target oriented discussion in ICAO for the sonic boom regulation underway. JAXA together with NASA is participating in the ICAO Committee with providing the current research data. Sonic boom study is carried out on several subjects including evaluation of the human acceptability of boom intensity level and mitigation of the boom pressure. The sonic boom level evaluation was tested by a boom simulator. Figure 5 shows a typical result of the tests to obtain a certain criteria for the sonic boom level produced by SST or SSBJ [8]. The result shows that 95% of the testees could accept if the sound pressure is less than 80(dB), and 89(dB) for 50% ones. As for mitigation of sonic boom, improvement of the airplane aerodynamic shape is being studied in JAXA. JAXA's D-SEND project (Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) [3] is being executed with the model drop from the balloons to verify the mitigation technology. Fig.6 is the result of the first drop test performed in Sweden last year [9][10]. D-SEND #1 used the conical shaped test objects shown in the same figure. A certain cross sectional distribution can make its sonic boom week by reducing the peek value of sudden pressure rise. JAXA's Low-Boom Model shows a half of the peek pressure of N-wave model at Mach number of about 1.4. In 2013, JAXA will carry out the second drop test at the same test range with the winged model (D-SEND#2), which realizes closer simulation to the airplane shape with the lift association. Applying this technolgy, sonic boom will be reduced signifficantly, so that the market value of the airplane should be remarkably increased.

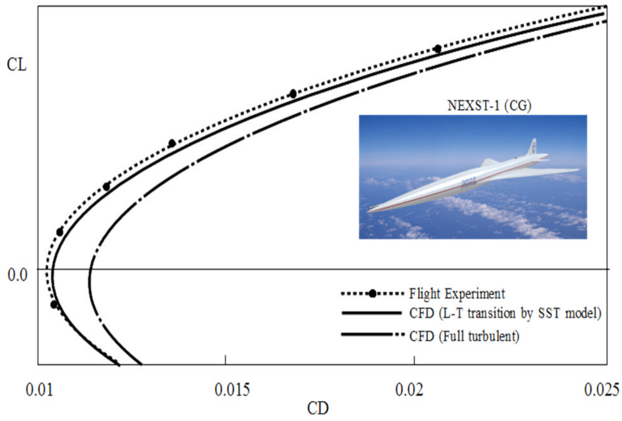

Fig.4 Lift/Drag ratio CL/CD obtained from the NEXST-1 flight (M-2.0)

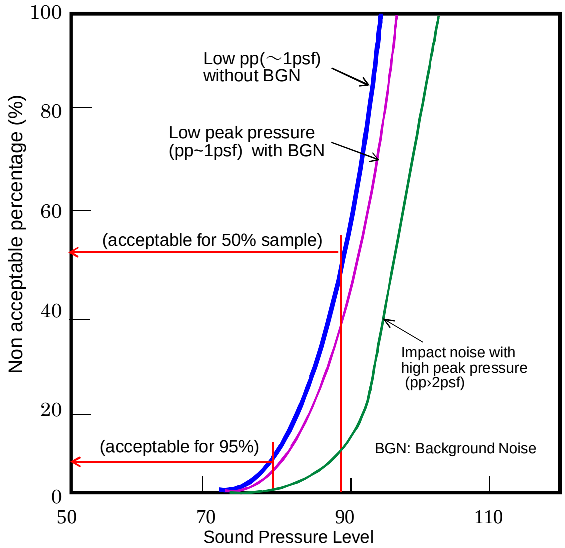

Fig. 5 Tested result on the sonic-boom acceptability[6]

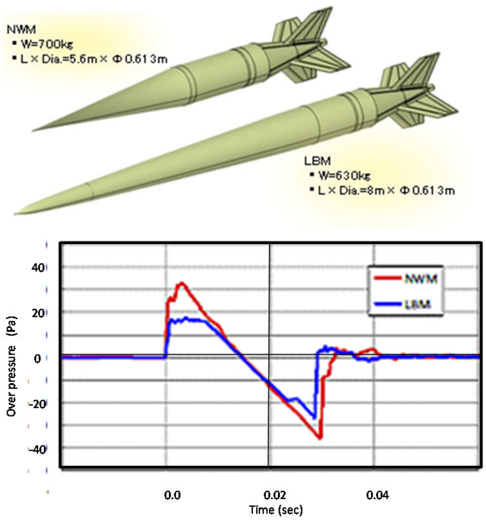

Fig.6 Result of the drop tests of D-SEND1

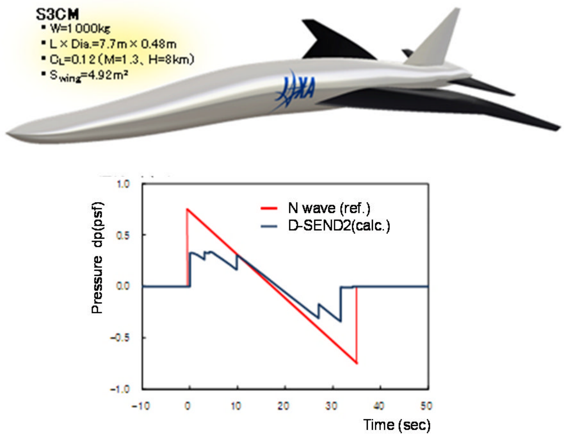

Fig. 7 D-END2 configuration and expected pressure indication on the land

D. Propulsion

The supersonic propulsion system needs several key technologies, such as lowering the community noise, increasing the efficiency at the cruise condition, weight reduction and so forth. Some of them require variable configurations in the propulsion system. Japanese HYPR project (1990-2003) promoted by METI and cooperated with JAXA (at that time it was NAL.), executed to develop the demonstrator engine for Mach 5 turbo-ramjet engine system, together with Mach 2.5 low bypass turbofan ESPR engine[4]. Foreign enterprises such as GE, P&W, RR and SNECMA participated into the project. Figure 8 shows the cross sectional view of the ESPR engine with the mixer-ejector noise reduction nozzle. The sea level static thrust of the engine is about 5tons. The noise tests of the ESPR engine with the M-E nozzle were carried out in US and noise reduction performance has been demonstrated [11]. The data for necessary length to its diameter derived from ESPR tests is shown in Figure 9. There are still remaining technical subjects for much more affordable noise reduction system in terms of weight, size, and simplicity.

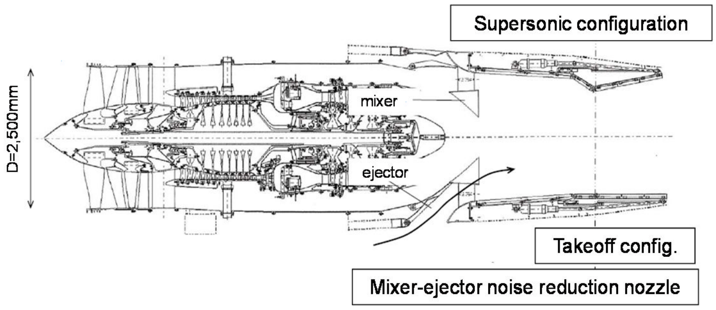

Fig.8 ESPR M2.5 demonstrator engine developed in HYPR project

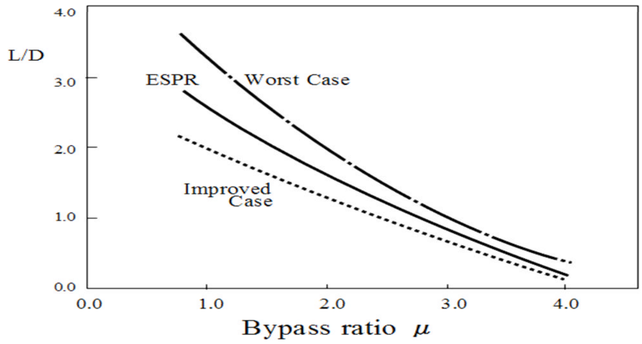

Fig.9 Necessary length/diameter ratio of the mixer-ejector nozzle for ESPR

E. Others

Maximum lift during take-off is very important for the total fuel efficiency and aircraft concept. The configurations of leading-edge and trailing-edge flaps are studied aerodynamically for maximizing the lift. Again, CFD has been applied for optimization of the flap system operation.

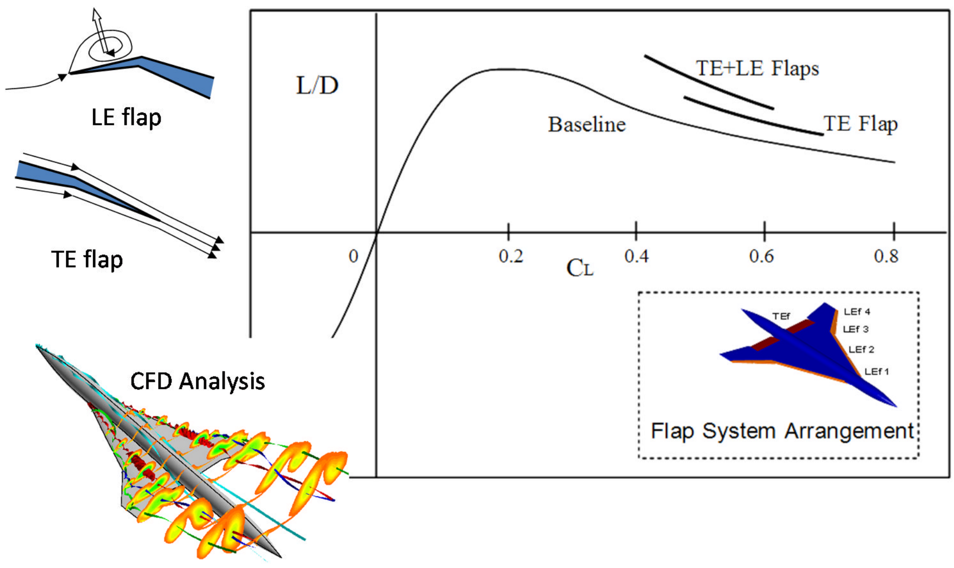

Fig.10 Flap operation in landing phase optimized by CFD

Figure10 is the typical result of lift variation for some combined operation of 5 flaps (TE1, LE1, LE2, LE3, LE4) [12]. This shows significant improvement of the lift by optimized combination of the deflection angles during the take-off phase of the SST. There must be other factors including flap locations, flap chord, flap cross sectional and plan shapes and so on. The research is continued in Japan by the cooperative group with academia and research institutes.

III. Market Reality

Resent market dynamics of the business jet and general aviation seem to be very active and prospective. Higher speed for convenience and mobility, flexible operation for various purposes and styles of utilization are required even it is subsonic. As for the world economics, the growth in Asian countries is very remarkable recently. And also the political events and the cultural exchanges between the countries in this area could increase. Those things suggest that demands of the human mobility and goods transport inside this area will increase rapidly. So, the future demand of air transport including business jet operation shall be much increased in this region. On the other hand, the large supersonic transports, such as 100 seater or larger, require very high level technologies to overcome the adequate regulations for the community noise and the sonic boom intensity, and also to achieve affordable fuel efficiency which are critical for their realization, which means it takes time. On the contrary, SSBJ, which is much lighter and smaller than the transports, may have very positive opportunity to the market entry within a decade.

Figure 11 shows the possible air-route as the market of the supersonic business jet. Typically, it is said east and south-east Asia countries and regions including Japan are very promising regions for SSBJ market. If the low boom technology will not be sufficient for the overland regulation, there are many over the ocean route there. Even though, the low boom technology is obviously meaningful for the product value. Mach around 1.6 brings very effective time utilization for the international business activities with one day round trip to the major cities in Asia located within 3,000 to 4,000nm radius from the major cities of Japan. As a result of our market study, the market capacity exceeds 350 aircraft in this region for 10 years.

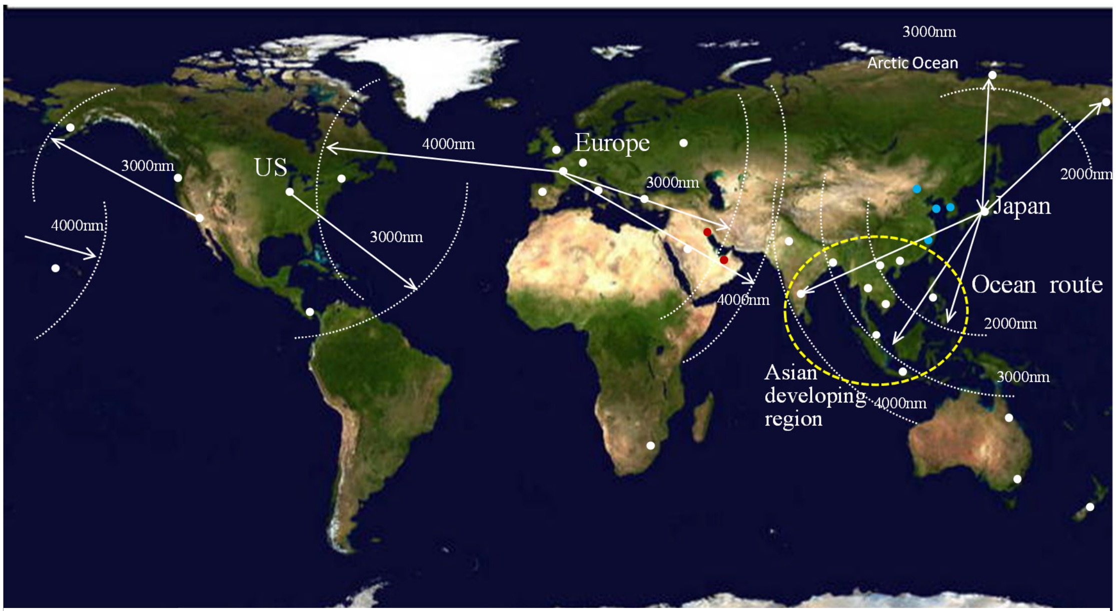

Fig. 11 Possible air routes for SSBJ (5.000 to 7,000 km range) in the near future, the market perspective.

IV. Design trial of SSBJ (Super Sky Access Partner)

A. System study[13] [14]

The researches on the supersonic aircraft systems are being carried out in JAXA and aircraft manufacturing companies together with JADC (Japan Aircraft Development Corporation). The system study for SST or SSBJ has been done for evaluation of the developed technologies, clarification of the technical subjects to be studied and so forth. Figure 12 shows a reference concept of SSBJ with variable wing system obtained from the system studies [13]. The advantage of this concept is in the low speed performance and community noise feature, but the variable geometry mechanism and control technology need highly critical technologies.

B. Design trial for 4 to 12 seat SSBJ

(Conceptual design specification) In Japan a trial design team for SSBJ conceptual design has been formed with the members from the aircraft manufacturing companies, JAXA, academia and SKY Aerospace institute. For present, the team is making a

Fig.12 A reference concept of variable geometry SSBJ

design trial of SSBJ conceptually with applying the technological achievement mainly obtained through the previous mentioned projects executed in Japan. The design trial is aiming at foreseeing possibility of chance for challenge to SST/SSBJ development in Japan. Based on the preliminary market study done by the team, the specifications of SSBJ summarized in Table 1 have been defined as the design target for the present. The cruise Mach number is 1.6, the target range is over 3,000nm (5,500km), and the existing turbofan engines will be installed. It can be divided into two sizes of aircraft in which the medium size one (SSBJ-M type) is with 6 to 12 seats, and the small size SSBJ-S has 4 to 8 seats. Those specifications are considered mainly to match the Asian market, but of course, some consideration has been done about its adaptation to the market of North America.

(Cruise performance) In order to achieve sufficient cruise performances with high lift to drag ratio and light enough weight necessary for the range and/or payload capacity. The advanced natural laminar flow wing and integration of warp and area rule are to be introduced with the CFD based computerized design technology. The external compression air-intakes with multi-shock system are being designed applying the JAXA's data base and the nacelles are being designed for low aerodynamic drag. The advanced high lift devices will be adopted, but if the natural laminar flow wing is considered, the leading edge flap may not be installed. As common knowledge, the performance compromise among the airframe factors such as the cruise L/D, weight, maximum lift, wing loading, and the jet engine factors of SFC, thrust, jet noise is fundamental thing for design, and so, the team always seeks the maximum total performance for SSBJ with the existing engines. Figure 13 is a typical process for performance improvement for achieving the target range R with several possible measures such as the engine SFC and cruise L/D. As the data of the existing subsonic BJ and their statistical trend curves are also shown in the figure [15], it can be seen that SSBJs are much heavier than subsonic ones caused by the fuel weight.

(Sonic boom consideration) Since the low boom feature is important for market value of SSBJ, the accomplishment of JAXA's research will be applied to define the nose shape and the location of the engine installation. Technology for intensity mitigation of the second concentrated shock wave mainly generated by the body tale is also very important subject for design. If the low boom technology developed in JAXA will be successfully applied, the 4-seat aircraft (SSBJ-S type) ought to produce only 0.3psf pressure rise which is about one sixth of that of Concorde (2psf). For community noise reduction, the mixer-ejector nozzle could be installed and engine location is also considered as it expected jet noise shielding effect appears.

(Others) The advanced flight system including the flight deck will be adopted to adapt the next generation global airspace system, such as NextGen by US and SESAR by Europe as well as CARATS from Japan. Business jet cabin should be special. Comfort for transport and utility for working or meeting are to be considered. Introducing the current car technology would be suitable.

(Conceptual image) Figure 14 shows the image of interim result of SSBJ-M conceptual design. The advanced technologies to be applied to the aircraft are also shown in the figure. Upper fuselage engine installation and rlated tail configuration, low boom nose and tail

Table 1 Super Sky Access Partner (SSAP) specifications

Items	specification
Concept	Supersonic Business Jet
Seats	4-12 seats with 2 crews
Cruis Mach Mo	Mach 0.9 (12,000m) to 1.6 (15,000m)
Range R	5,500+km (3,000+nm)
Propulsion	2 low bypass turbofan engines SLS thrust 3 to 10 ton Cruise thrust 1 to 3 ton SFC 1.1 - (M1.6) Noise ICAO Chapt.4-
Community Noise	ICAO Chapter4−
Emission	ICAO Regulations/Standards
Sonic boom	as low as possible (<0.3psf for S)

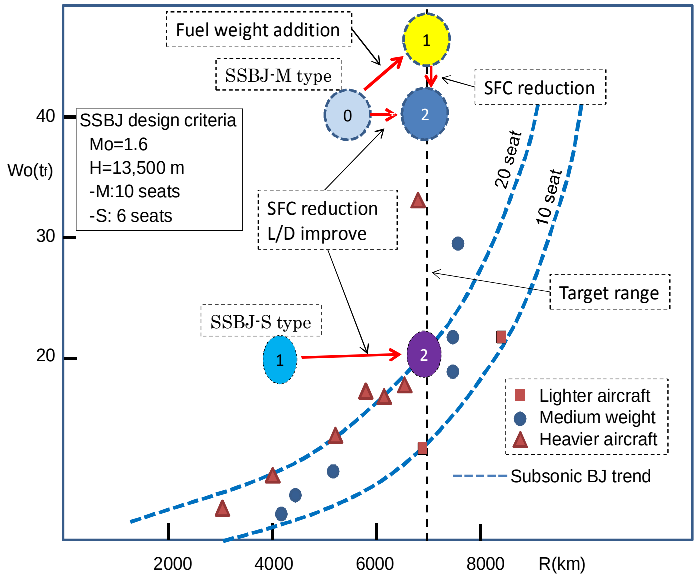

Fig. 13 Improvement trial for range of SSBJ (comparison with Subsonic BJ)

shapes, advanced high performnce wing plan form, and others will be adopted and will make the aircraft fly efficiently and comfortably. As descrived, this is just the first stage of the design of SSBJ, as trial conceptual design and the collaborative work will continue to design more affordable and valuable SSBJ as "Super Sky Access Partner."

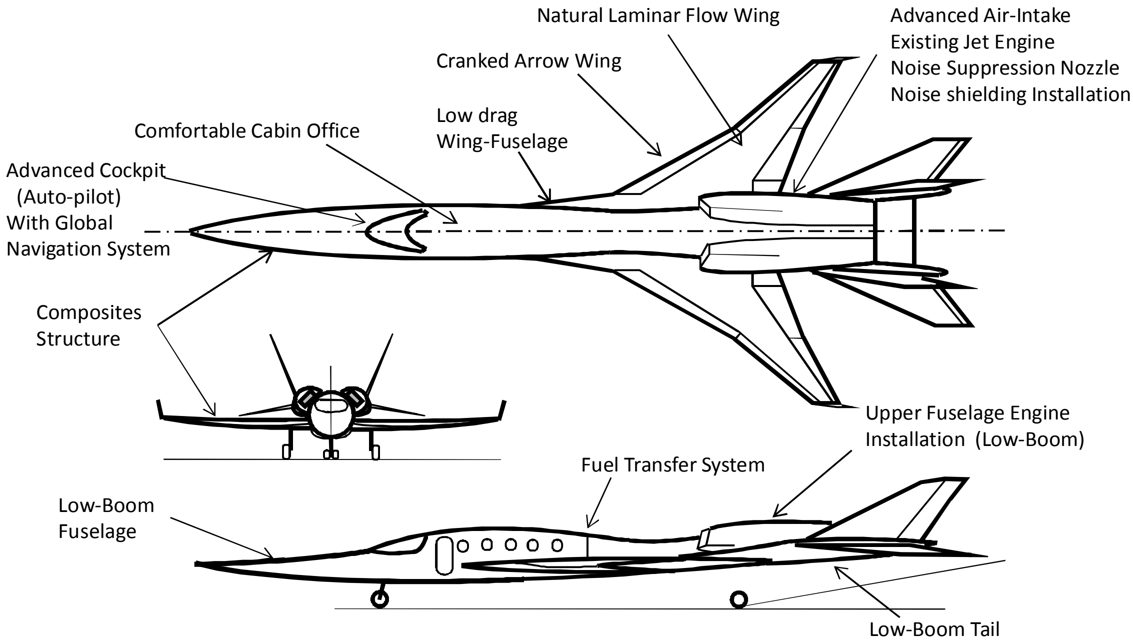

Fig.14 SSBJ concept (Super Sky Access Partner) and adopted new technologies

V. Conclusion and Acknowledgement

Japanese aerospace industry is now facing at a chance for upgrading them stand point. The aircraft market and technological base would be adequate for prospect. Supersonic airplane may be promising and challenging target for the future. But there are several keen technological subjects such as sonic boom, fuel economy and noise which should be overcome for its realization. It may be the time for challenge onto the supersonics not as the large transport but as the SSBJ. Japanese team began to perform conceptual design with the base of Japanese new technologies. The international collaboration may be necessary in the actual development.

This paper presents number of the research results provided by JAXA and aerospace manufacturers. Author wishes to express sincere gratitude to the corresponding researchers and engineers in those companies. Author also expresses thanks to the members in the SSBJ design team for their design efforts and discussions.

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