National Experimental Supersonic Transport Project

Takeshi Ohnuki, Keiichi Hirako, Kimio Sakata
Japan Aerospace Exploration Agency

Keywords: *Supersonic, Flight Experiment, UAV, CFD, Aerodynamic Design Technology*

Abstract

National Experimental Supersonic Transport (NEXST) Project was commenced in 1997 by National Aerospace Laboratory (NAL), which merged into Japan Aerospace Exploration Agency (JAXA) in 2003. Development and flight experiment of scaled supersonic aircraft is a core of this project which aims at the establishment of the aerodynamic design technology using Computational Fluid Dynamics (CFD) method. The airplane configuration is designed using the inverse method. This method is developed by NAL and produces a wing shape to realize the given pressure distribution. The airplane is 11.5m long, 4.7m wide, and 2,000kg weight. It is a non-powered vehicle and launched with solid rocket booster. The flight experiment was conducted successfully in Woomera Test Range in South Australia and the results show that the flight data has a good agreement with the predicted characteristics.

1 Introduction

Back in the 1990s, both the US and Europe used to have respectively research and development program for the next generation supersonic transport. Japan had also supersonic research program then and finally commenced the NEXST project in 1997(Figure 1) [1]. The only supersonic civil transport in the world, the Concorde, was to retire in early 2000s, actually did in 2003, research and development was internationally promoted to overcome several technical difficulties toward the Concorde successor. NEXST project aims technological research and development for the next generation supersonic transport with special emphasis on technological objectives where Japan has advanced skills.

The NEXST project comprises of two areas - one is basic research on the key technologies for the future supersonic transport and the other is development and flight tests of unmanned scaled airplanes. As for the flight experiment, the CFD based aerodynamic design technology was planned to be verified, and for this purpose, two types of vehicles were originally planned, non-powered (NEXST-1) and jet-powered (NEXST-2) airplanes. Unfortunately, the NEXST-2 plan was canceled in 2003 but NEXST-1 made a success flight last year.

Overview on the NEXST-1 project will be introduced and some results from the flight test will be discussed in this paper.

2 NEXST-1 Experimental System

2.1 NEXST-1 Airplane

The experimental airplane is an unmanned scaled vehicle with 11.5m in length, 4.7m in span, and weighs about 2,000kg (Figure 2). The structural material is basically aluminum alloy. The design point is at Mach Number 2.0 and altitude 15,000 meters. As the airplane does not have thrust power or landing gear it was planned to launch with a solid rocket booster and land with the aid of several stages of parachute and airbags.

The airplane configuration was designed using CFD technique, especially the wing was

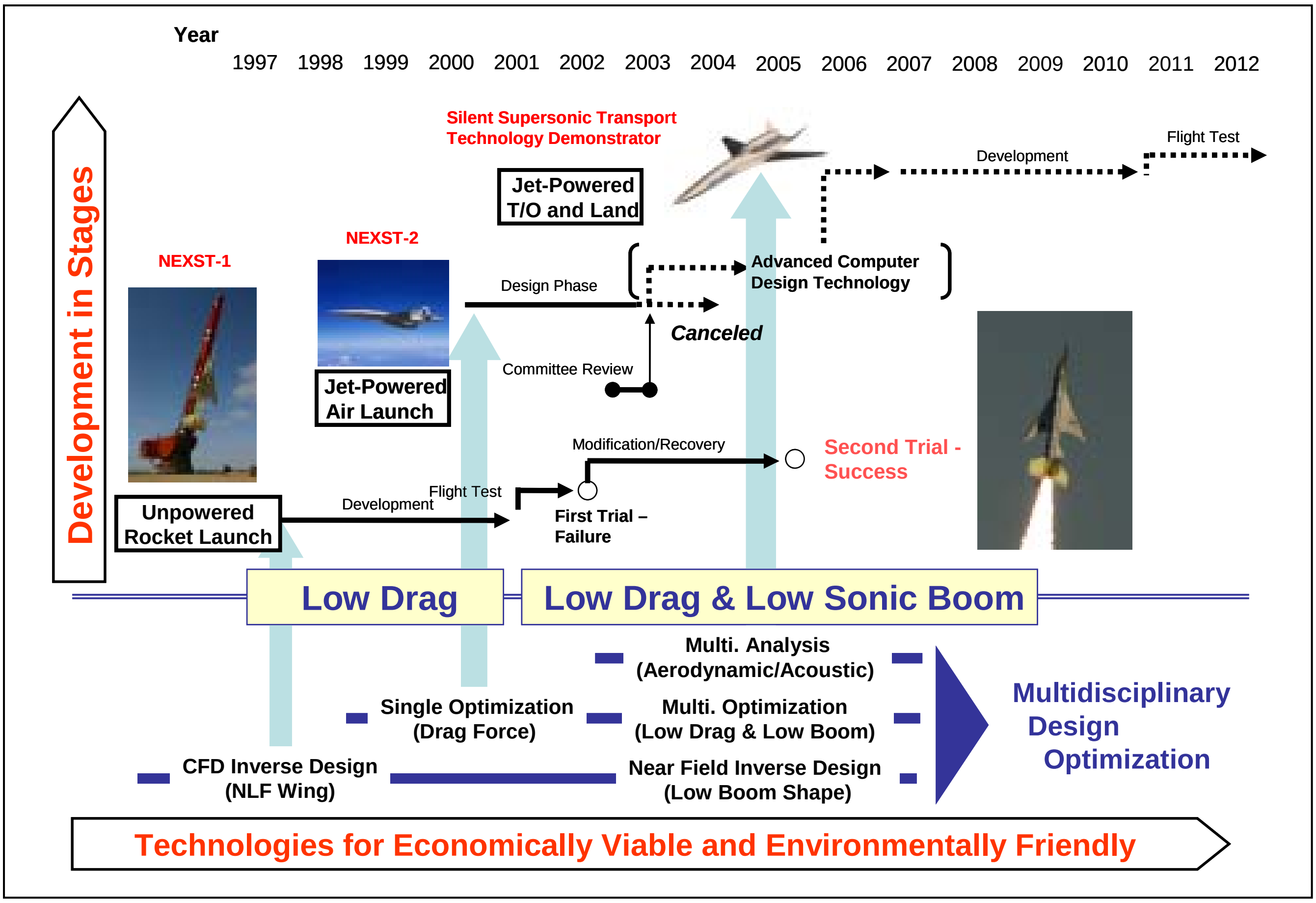


Fig.1 Supersonic Research and Development Project in JAXA

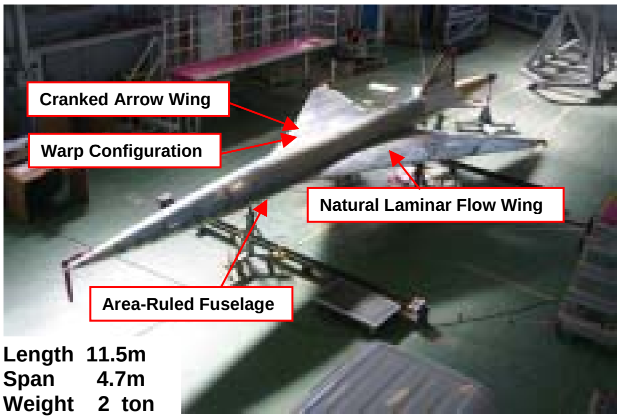


Fig.2 Airplane Configuration

designed using the inverse method giving the preferable pressure distribution to delay the boundary layer transition as far as possible[2].

This inverse technique was developed and also the preferable pressure distribution for the supersonic Natural Laminar Flow (NLF) wing was designed by NAL. Some other aerodynamic concepts were applied to minimize the aerodynamic drag such as the warp technology for the wing twist, the cranked arrow wing plan form, and the supersonic area rule for the fuselage shape.

A large number of sensors were installed to acquire data such as aerodynamic pressure, the boundary layer characteristics, temperature, and structure strain. The boundary layer

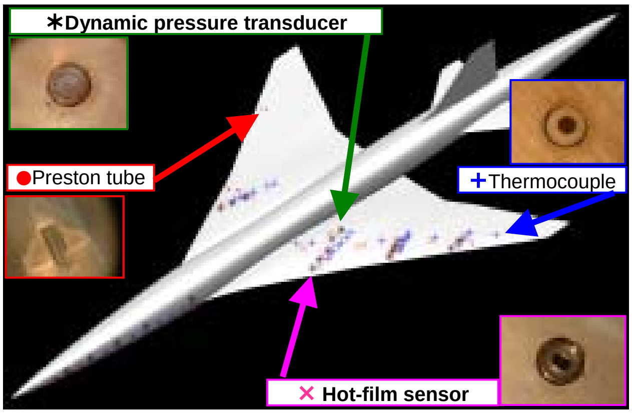


Fig.3 Location of Aerodynamic Sensors

characteristics on the surface was measured using four kinds of sensors, i.e. hot-film sensors, dynamic pressure sensors, thermocouples, and Preston tubes (Figure 3).

2.2 Solid Rocket Booster and Launch Configuration

As no engines are installed on the airplane, a solid rocket booster was adopted to make the airplane fly at supersonic speed. The solid rocket booster used for the launch is a modified version of SB-735, the side rocket booster of Japanese satellite launcher M3SII. This booster measures 10.0 meters in length, with a diameter of 0.735 meters. The launch mass is 5720kg and burn-out mass is 2230 kg. It has front and rear connection and separation mechanisms for airplane attachment. The launch configuration is shown in Figure 4. This view represents the orientation just prior to separation and note that the configuration is inverted on the launcher rail (Figure 5).

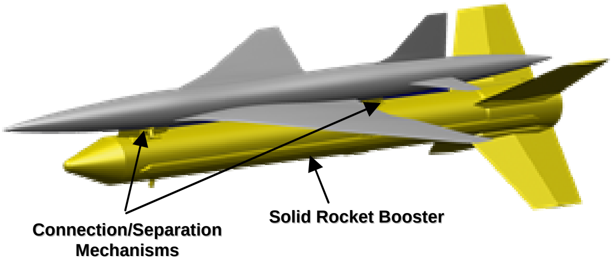


Fig.4 Launch Configuration

Fig.5 Airplane/Booster on Launcher

2.3 Flight Plan and Woomera Test Range

The flight experiment was proceeded in Woomera Test Range in South Australia (Figure 6). It has extremely large and less populated area, 127,000km^2, and a good infrastructure for various kinds of flight tests. Australian Department of Defence has a well established organization for supporting non-Defence users.

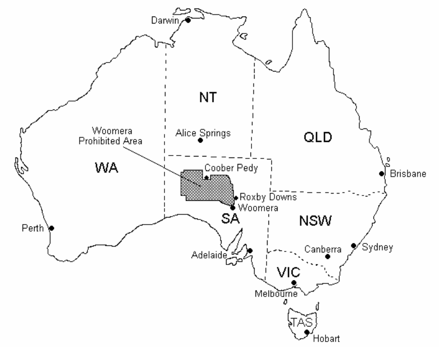


Fig.6 Woomera Test Range

Figure 7 shows the flight plan. The airplane with the booster is launched at 65 degrees of elevation angle and after burn out of the booster, the airplane is separated from the booster. The airplane changes its angle of attack at Mach Number 2.0 between 18.5km and 19.5km altitude in Test Phase 1. The airplane makes Mach Number 2.0 flight again in lower altitude in Test Phase 2 to collect data with higher Reynolds Number. Finishing the test phases the airplane makes a U-turn to head for designated retrieval point. The airplane lands with the aid of parachute and air bags.

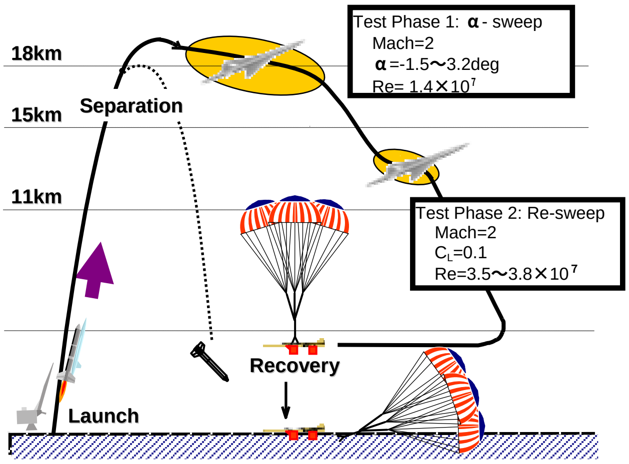


Fig.7 Outline of Flight Plan

The sequence is controlled autonomous by onboard computers - Autopilot on the booster in the boosted phase and Flight Control Computer on the airplane after separation.

3 Results from Flight Experiment

3.1 Flight Trial

The flight trial was conducted on 10 October 2005. Figures 8 to 10 show some scenes from the trial. Figure 8 shows the lift off, Figure 9 the airplane in flight, and Figure 10 the airplane after landed. All of the system of the airplane and the booster worked perfectly as designed and the airplane including the onboard data recorder was retrieved safely. A large array of aerodynamic data was acquired and not a single data was dead. The flight trajectory is shown in Figure 11. Top left shows side view and bottom left plan view of the flight trajectory. Top right and bottom right show time history of altitude and Mach Number, respectively. The total flight time was about 15 minutes.

Fig.8 Lift off

Fig.9 In Flight

Fig.10 After Landing

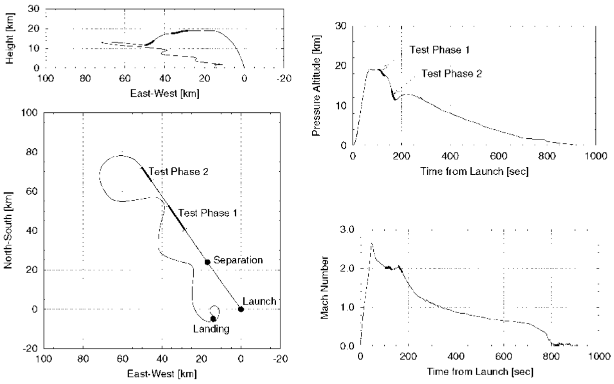


Fig.11 Flight Trajectory

Figure 12 shows time history of the lift coefficient during Test Phases 1 and 2. Time indicates from lift off. The airplane changed its angle of attack at six stages from -1.5 degrees to 3.2 degrees in Test Phase 1 and kept at about 1.6 degrees giving designed lift coefficient (0.1) at Test Phase 2. Mach Number during these phases were maintained between 2.0 plus/minus 0.05 and can be assumed to be equal to 2.0. The Reynolds number based on the mean aerodynamic chord was between 12.4 and 36.9 million during these two phases.

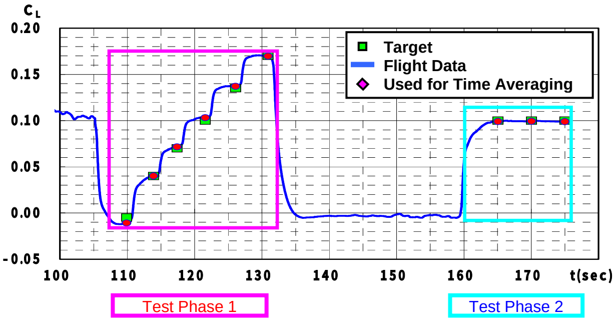


Fig.12 Test Phases 1 and 2

3.2 Aerodynamic Forces

The lift-drag characteristics at Mach Number 2.0 is shown in Figure 13. Solid line indicates CFD prediction and small circles from flight test. The dotted line corresponds to a horizontally moved curve of the solid one. This difference is 6 counts (=0.0006). This figure shows that the profile of the drag polar curve corresponds with each other though minimum drag on the flight result is different from the CFD results. In general, the profile of drag polar curve depends on the wing plan form and lift at the minimum drag condition depends on warp configuration. Therefore this results of the same drag polar curves and the same lift at minimum drag means that the design of the wing plan form is verified and warped design concept was confirmed.

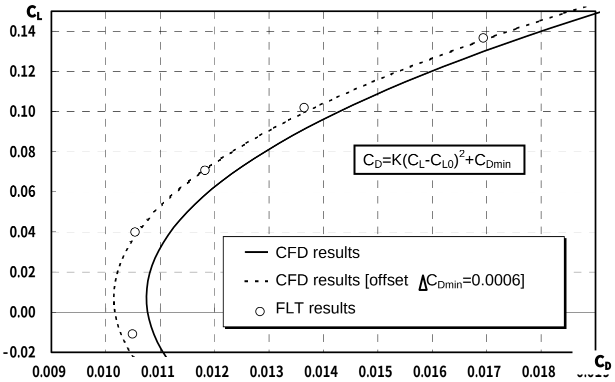
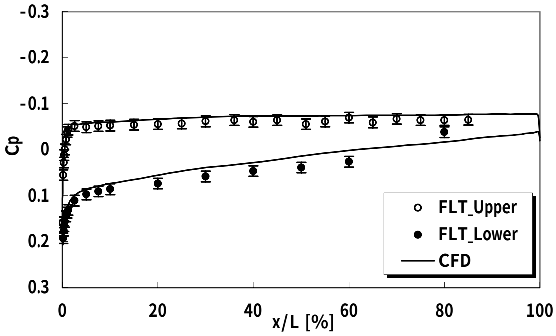


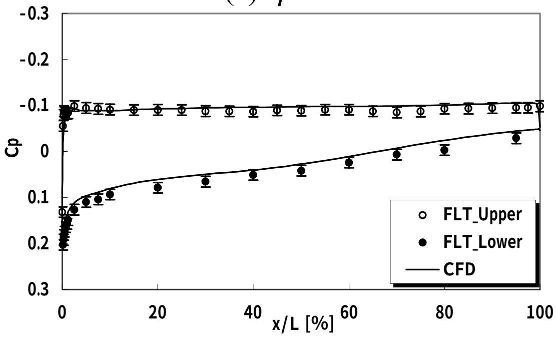
Fig.13 Polar Curve at Mach Number 2.0

3.3 Pressure Distribution

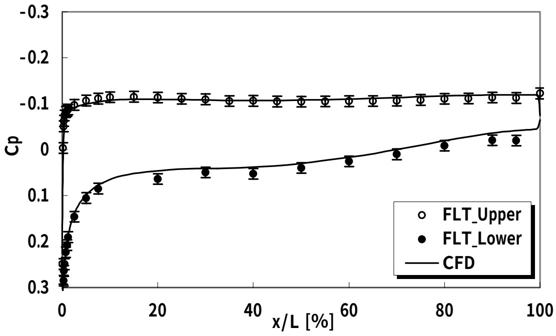
Figure 14 shows pressure coefficient C_P distributions at the design point (M=2.0, α=1.59deg., Re=13.8million) at the several span wise stations[3]. 'η' indicates non-dimensionalized span wise location with η=0 at root and η=1 at tip. The error-bars on the C_P distributions are the uncertainty of the pressure measurement system (ΔC_P=0.0115). C_P distributions by CFD analysis are also plotted. The agreement between flight tests and CFD analysis is very good.



(a) η=0.3



(b) η=0.5



(c) η=0.7

Fig.14 Pressure Distribution at Design Point
(M=2.0, α=1.59deg, Re=13.8million)

3.3 Boundary Layer Transition

Figure 15 shows the boundary layer transition location on the wing upper surface detected by hot-film sensors and dynamic pressure sensors[4]. Small dots indicate locations of those sensors and the color corresponds the condition of the boundary layer - blue indicates laminar and/or transition and red turbulent. Light blue line shows transition position assumed with these flight data. While the boundary layer soon makes its transition at the off-design condition, it keeps laminar condition up to at most 40% chord location at the design condition. The results of the pressure distribution and location of boundary layer transition show that (1) the CFD inverse design technology is verified and (2) the design of the preferable pressure distribution for supersonic NLF is confirmed in this flight tests.

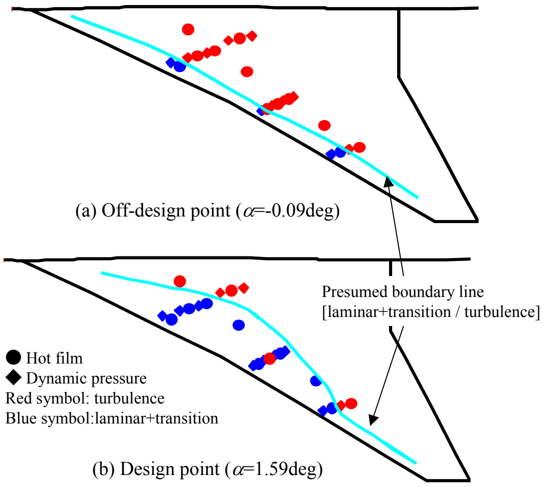


Fig.15 Boundary Layer Transition at the Design and off-Design Points

4 Future Plan

As shown in Figure 1, the next project, Silent Supersonic Technology Demonstrator, is being planed[5]. Unmanned vehicle will be developed and tested in flight for validation of technology for the aerodynamic drag reduction and the sonic boom mitigation.

Acknowledgments

This achievement of NEXST-1 Project is indebted to its contractors, Mitsubishi Heavy Industries, Ltd., Kawasaki Heavy Industries, Ltd., Fuji Heavy Industries, Ltd., and IHI Aerospace Co., Ltd. The authors greatly acknowledge the support from these sources.

References

[1] Sakata, K. Supersonic Experimental Airplane (NEXST) for Next Generation SST Technology - Development and Flight Test Plan for the Unmanned Scaled Supersonic Glider-. *AIAA Aerospace Sciences Meeting and Exhibit*, Reno, AIAA Paper 2002-0527, 2002.

[2] Yoshida, K. and Makino, Y. Aerodynamic Design of Unmanned and Scaled Supersonic Experimental Airplane in Japan. *ECCOMAS 2004*, Finland, 2004.

[3] Kwak, D.-Y. and Yoshida, K. Flight Test Measurements of Surface Pressure on Unmanned Scaled Supersonic Experimental Airplane. *AIAA Applied Aerodynamics Conference*, San Francisco, AIAA Paper 2006-3483, 2006.

[4] Tokugawa, N. and Yoshida, K. Transition Detection on Supersonic Natural Laminar Flow Wing in the Flight. *AIAA Applied Aerodynamics Conference*, San Francisco, AIAA Paper 2006-3165, 2006.

[5] Murakami, A. Silent Supersonic Technology Demonstration Program. *ICAS 2006*, Hamburg, ICAS 2006-1.4.2, 2006.