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LOW-SONIC-BOOM CONCEPT DEMONSTRATION IN SILENT SUPERSONIC RESEARCH PROGRAM AT JAXA

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Abstract. *JAXA's supersonic research program named S-cube for future supersonic airliners with economically viable and environmentally friendly characteristics and the flight test project named D-SEND for demonstrating the advanced low-boom design concepts are introduced. In the first phase of the project(D-SEND#1), two axisymmetrical models were dropped back to back from a stratospheric balloon and the sonic-booms generated from both models were measured both on the ground and at about 1km above the ground in order to validate JAXA's sonic-boom measurement system and to make sure the possibility of demonstrating low-boom concepts with the 8m-long scaled model in the second phase of the project(D-SEND#2). The D-SEND#2 airplane is an unmanned low-boom scaled airplane which is considered to be a 16% scale model of a 50-passenger small size supersonic transport regarded as a technology reference aircraft of the S-cube program. Some low-boom design concepts such as a non-axisymmetrical low-boom nose, a low-drag/low-boom wing geometry, a lifting aft-fuselage, and reverse-cambered horizontal tails which are applied to the D-SEND#2 airplane will be demonstrated in the drop test.*

Keywords: *Supersonic Transport, Sonic Boom, Low Boom Demonstration*

1. INTRODUCTION

Japan Aerospace Exploration Agency(JAXA) has been promoting the Silent SuperSonic(S-cube) research program for future supersonic airliners with economically viable and environmentally friendly characteristics since 2006. In this program, the flight test project named D-SEND(Drop test for Simplified Evaluation of Non-symmetrically Distributed sonic boom) is planned in order to demonstrate the advanced low-boom design concepts. The project comprises two experimental phases. In the first phase of the project(D-SEND#1), two axisymmetrical models named NWM(N-Wave Model) and LBM(Low-Boom Model) are dropped back to back from a stratospheric balloon and the sonic-booms generated from both models are measured both on the ground and at about 1km above the ground as shown in Figure 1. The objectives of the D-SEND#1 tests are to validate JAXA's sonic-boom measurement system and to make sure the possibility of demonstrating low-boom concepts with the 8m-long scaled model. In the second phase of the project(D-SEND#2), an unmanned low-boom scaled airplane named S3CM(Silent SuperSonic Concept Model) will be dropped in the same way as in the D-SEND#1 as shown in Figure 2. The S3CM is designed to demonstrate some low-boom design concepts such as a non-axisymmetrical low-boom nose, a low-drag/low-boom wing geometry, a lifting aft-fuselage, and reverse-cambered horizontal tails. The airplane is considered to be a 16% scale model of a 50-passenger small size supersonic transport shown in Figure 3 which is regarded as a Technology Reference Aircraft(TRA) of the S-cube program. In this paper, the S-cube program and its TRA study are introduced together with the status of the D-SEND project.

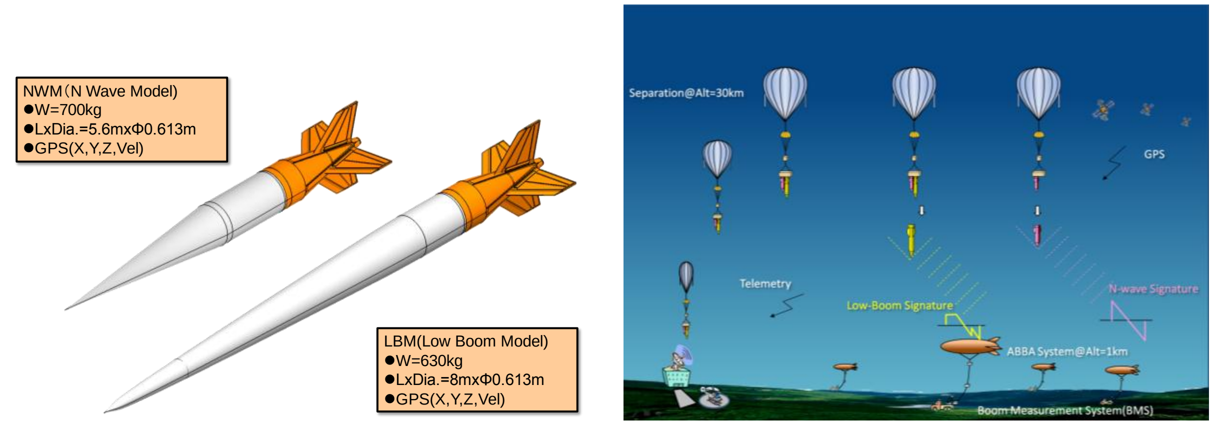

Figure 1. D-SEND#1 models and drop test image.

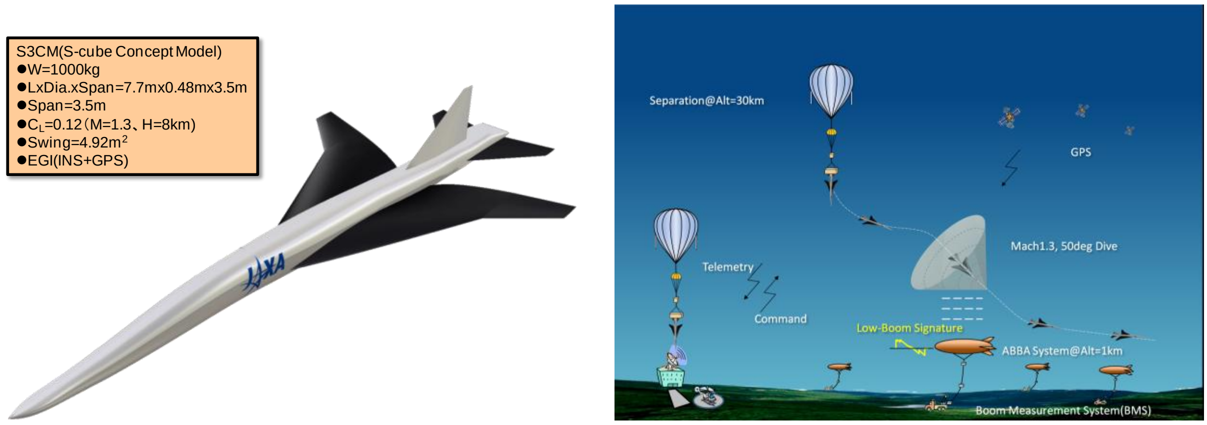

Figure 2. D-SEND#2 model and flight test image.


Figure 3. Technology reference aircraft in the S3 program.

2. S-CUBE RESEARCH PROGRAM

In the S-cube program, a conceptual study of the TRA is conducted in which the technological targets are set as shown in Table 1 and its baseline configuration is designed with the specification shown in Table 2. In order to estimate its performance, a wind-tunnel model was built and tested at JAXA's 1mx1m supersonic wind tunnel as shown in Figure 4. The test results show that the technological target of L/D>8 can be achieved though some data corrections for friction drag estimation, model support interference, and airframe/nacelle interference still have to be considered.

Table 1. Technological targets of the S-cube TRA

Sonic boom	$\Delta p < 25$Pa (0.5psf) (Half of Concorde technological level)
Airport noise	ICAO Ch.4
Performance	L/D > 8
Structural weight	15% reduction (compared to Concorde technological level)

Table 2. Specification of the S-cube TRA

Passenger	36 to 50
Mach number	1.6
Range	3500 nm
Max. TO weight	70 ton
Engine	2 (15 ton/engine)

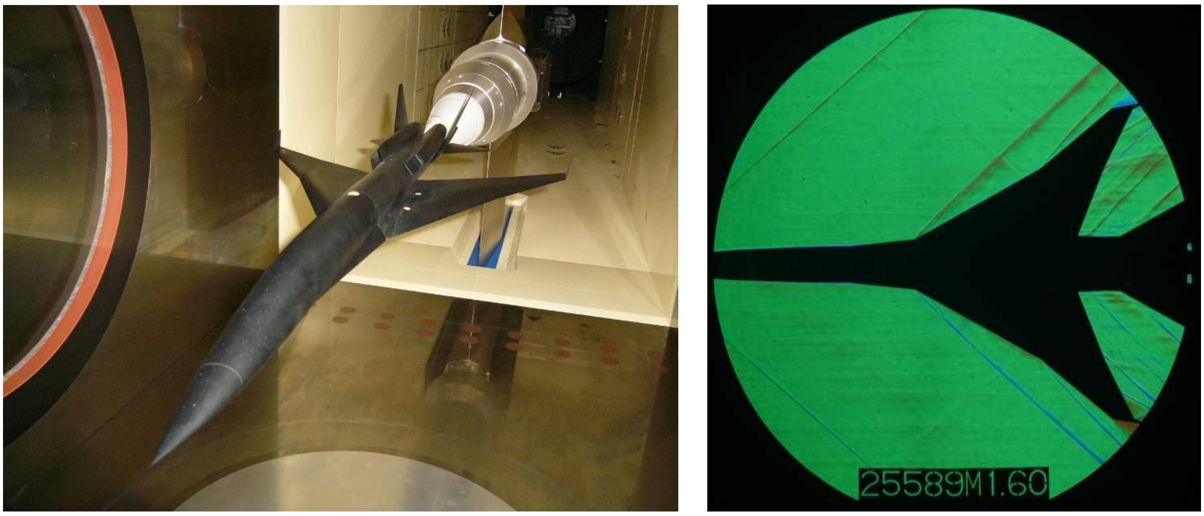

Figure 4. Technology reference aircraft in the S3 program.

Then the multi-objective design optimization tool is applied to the baseline configuration for low-boom design. Three configurations shown in Figure 5 are designed at trim condition in this design process. Some low-drag/low-boom concepts such as warped wing, blunt nose, and lifting aft-fuselage are adopted for these configurations. Their sonic-boom signatures predicted with the panel method combined with the aging modification[1] and the Thomas method[2] show that the technological target of Δp<0.5psf can be achieved though no engine nacelle is considered in this low-boom design. The sonic-boom characteristics of these configurations are validated with their near-field pressure signature measurement at H/L=2.0 shown in Figure 6. The test data shows qualitative agreement with the prediction while some discrepancies are shown in the aft-part of the signatures.

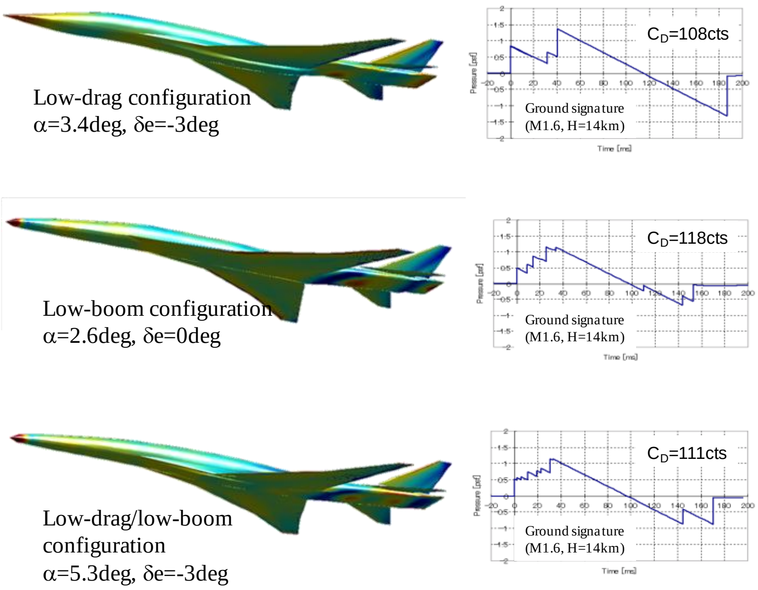

Figure 5. Low-drag/low-boom multi-objective shape design of the TRA.

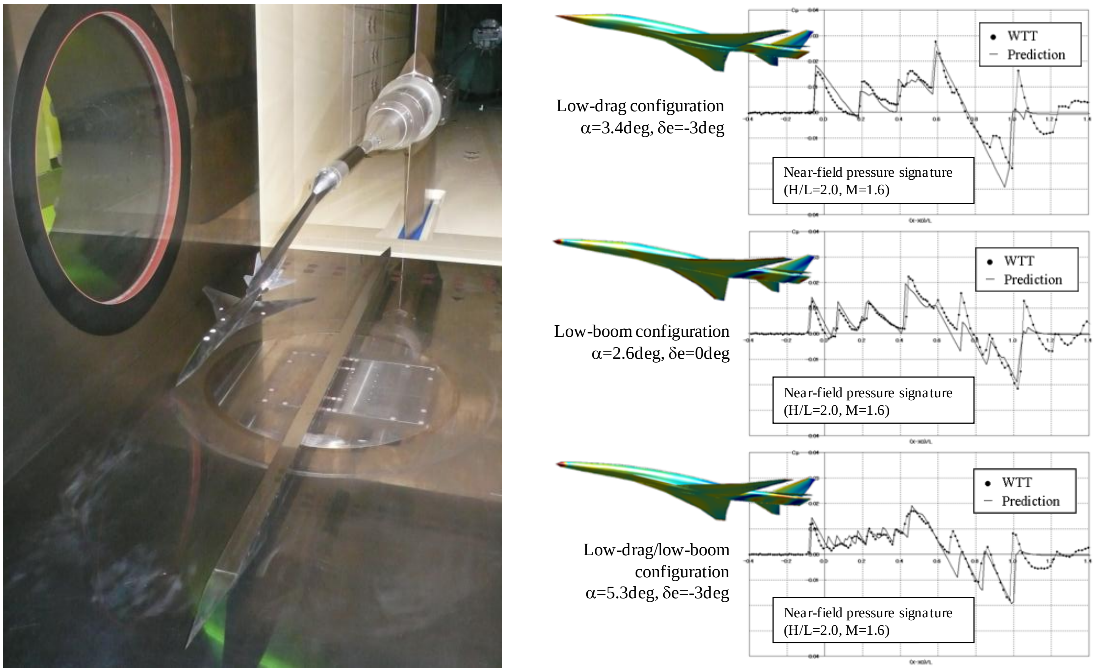

Figure 6. Low sonic boom design validation test at JAXA 1mx1m supersonic wind tunnel.

2. D-SEND PROJECT

The D-SEND#1 drop tests were conducted twice at Sweden in May 7th and 16th, 2011. The test results showed that JAXA's sonic-boom measurement system could accurately measure the sonic-boom pressure signatures of scaled models with small pressure peaks and short duration time shown in Figure 7. In the first test, the models were separated at 21km and the measured sonic-booms were generated at about Mach 1.42 which is almost the same as the design Mach number of D-SEND#1. In the second test, the models were separated at 27km and the measured sonic-booms were generated at about Mach 1.57. In both tests, the measured sonic-booms of the LBM showed the flat-top type low sonic-boom characteristics and their pressure peaks were about halves of those of the NWM. This test results suggested that the low-boom concept demonstration with a scaled model like the S3CM would be possible. The measured sonic-booms are utilized to validate JAXA's sonic-boom prediction tools including the CFD with structured/unstructured overset grids technique[3] for accurate prediction of near-field pressure signatures and the sonic-boom propagation analysis based on Burgers' equation[4] considering the atmospheric absorption effects as shown in Figure 8.

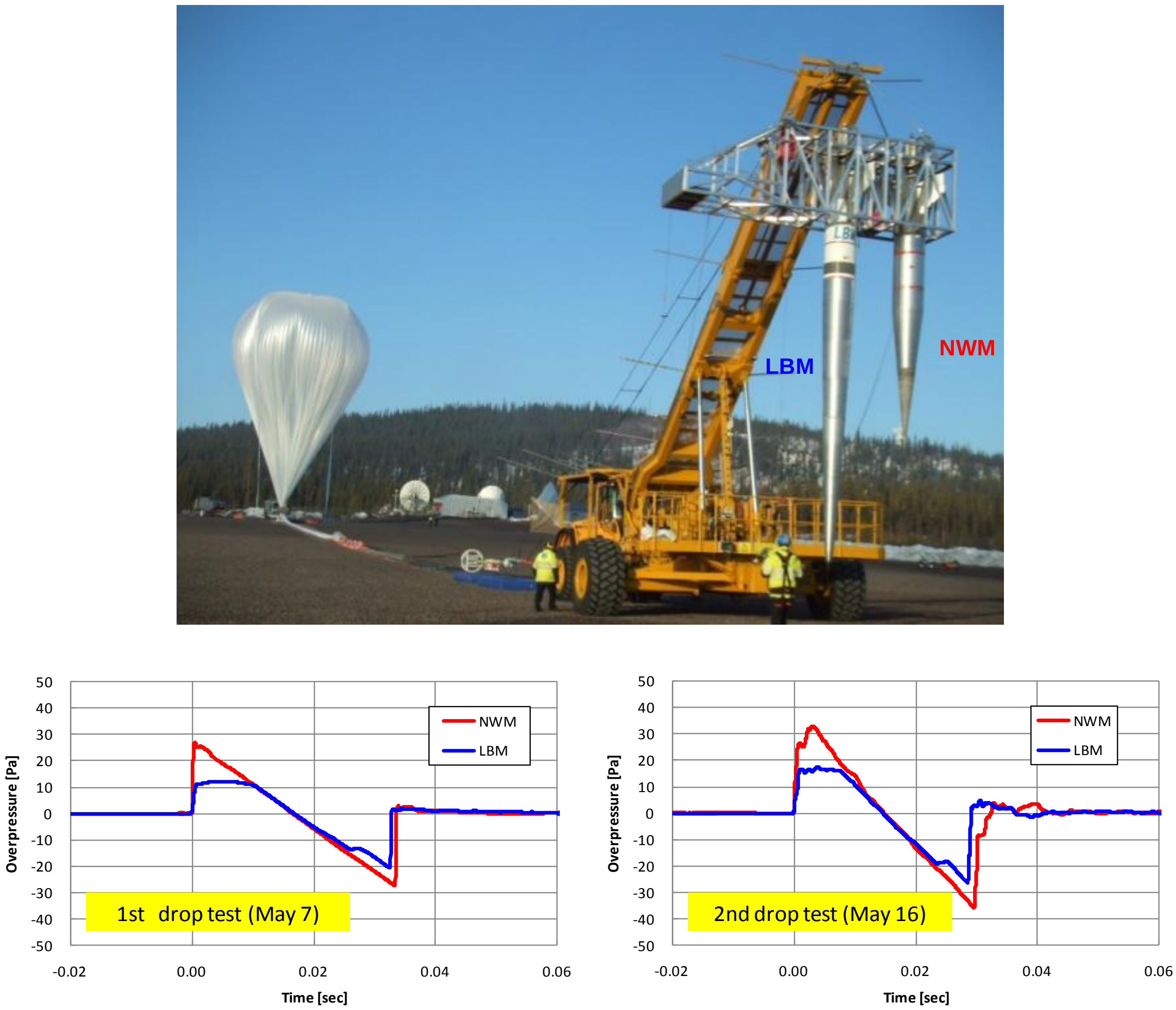

Figure 7. D-SEND#1 drop test in 2011.

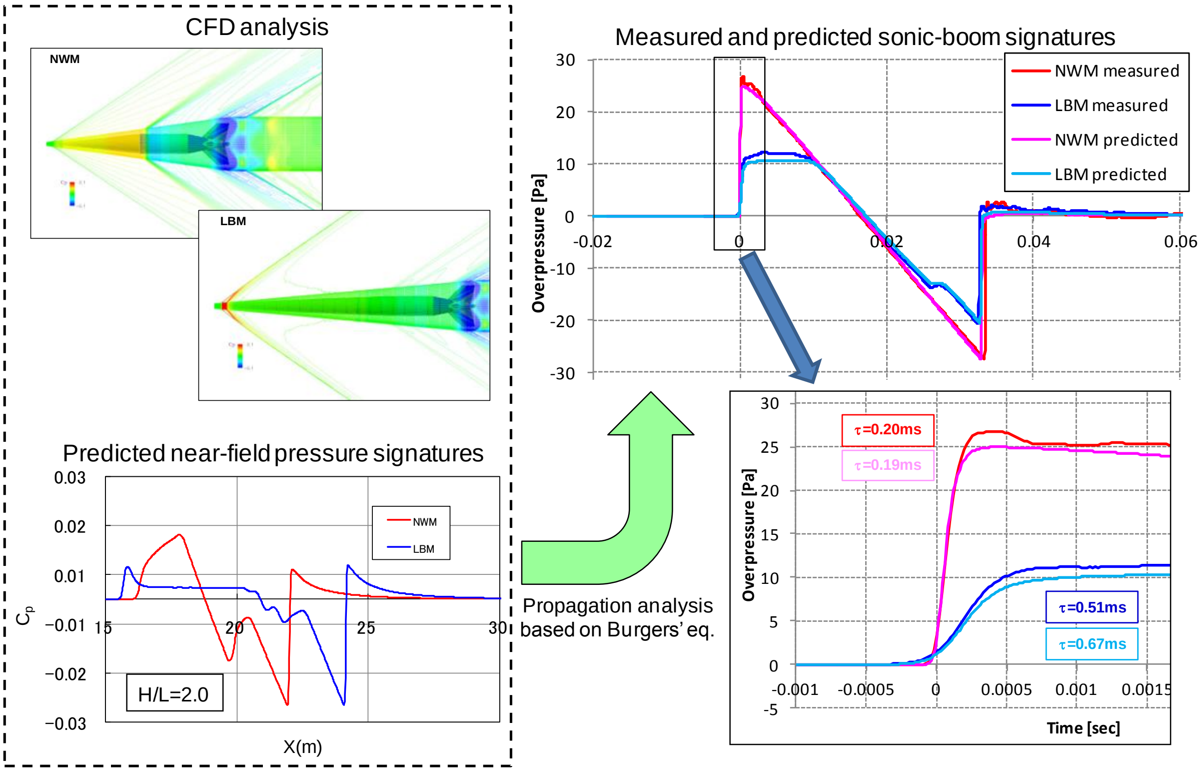

Figure 8. Sonic boom prediction tool validation with the D-SEND#1 results.

The D-SEND#2 project is now in the final phase of the detailed design of the S3CM and will proceed to its fabrication toward the drop test in 2013. Some low-boom design concepts such as a non-axisymmetrical low-boom nose, a low-drag/low-boom wing geometry, a lifting aft-fuselage, and reverse-cambered horizontal tails have been applied to the S3CM airplane. The airplane is designed for low-drag and low-boom using the multi-objective GA optimization tool. The Kriging surface surrogate model is used in the optimization based on some sampling points at which the aerodynamic performance and sonic-boom characteristics are evaluated by a single structured grid Euler CFD analysis with Thomas method. Figure 9 shows the CFD result at design Mach number of 1.3 and predicted near-field pressure signature below the airplane at H/L=2.0. The design Mach number of the S3CM is determined to minimize the sonic-boom propagation distance so that its height to length ratio(H/L) becomes similar to that of the TRA real size airliner. For the same purpose, the S3CM is planned to dive above the sonic-boom measurement location at lowest altitude determined from the dynamic pressure restriction. Figure 10 shows the comparison of the predicted sonic-boom signatures of the S3CM airplane and supposed real size airplane extrapolated from the same near-field pressure signature shown in Figure 9. While the signature interval of the S3CM is much shorter than that of the real size airplane, these signatures show similar low sonic-boom pressure signatures which are characterized by a flat-top shape in the front part and double shocks in the rear part. Both signatures are shown with each reference N-shaped signatures predicted by the First-cut method[5] based on the Whitham theory[6]. Considering the measured sonic-boom signatures of the LBM in the D-SEND#1 drop test shown in Figure 7, it seems to be possible to observe the low sonic-boom signature characteristics of the S3CM in the D-SEND#2 flight test. The low sonic-boom design of the S3CM is planned to be validated by measuring near-field pressure signatures in some wind-tunnel tests before the D-SEND#2 flight test.

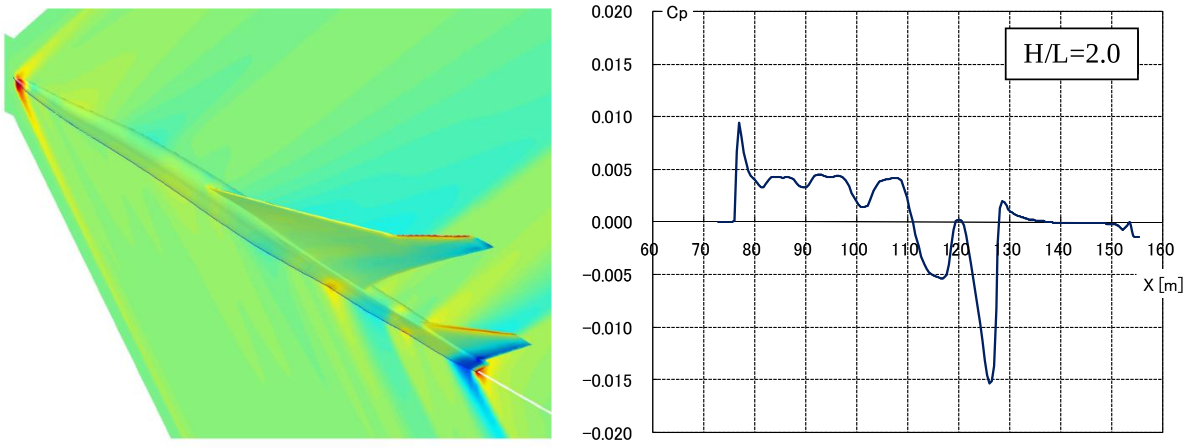

Figure 9. Near-field pressure signature prediction of the S3CM with Euler CFD analysis.

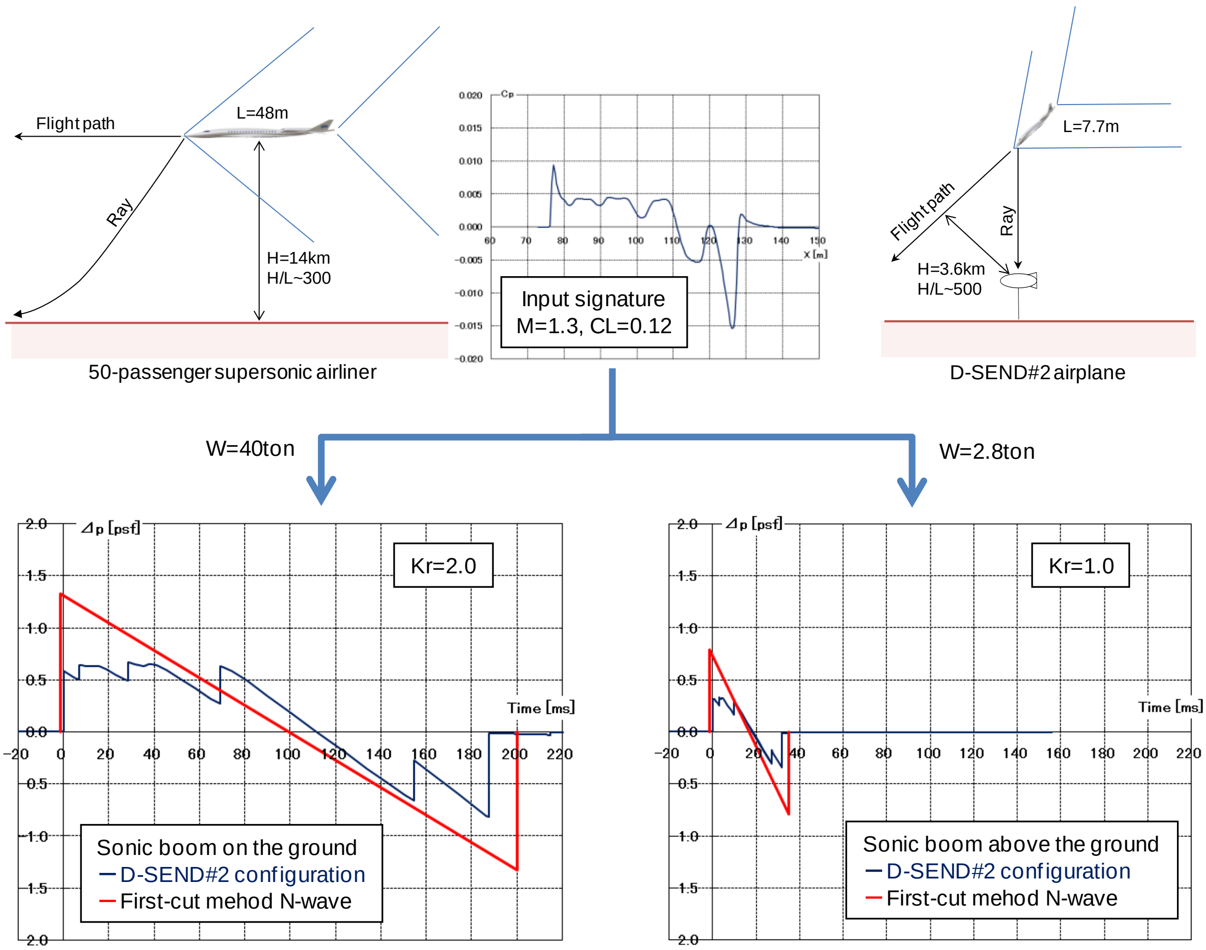

Figure 10. Comparison of the predicted sonic-booms for a real and scaled airplane.

4. CONCLUSION

JAXA's S-cube supersonic research program and D-SEND project for demonstrating the low-boom design concepts are introduced. The concept design of a 50-passenger small size supersonic transport is conducted in the S-cube program regarded as a technology reference aircraft and some low sonic-boom design concepts are planned to be validated in the D-

SEND project. In the D-SEND#1 drop tests, JAXA's sonic-boom measurement system was validated for low sonic-boom signature measurement and the possibility of demonstrating low-boom concepts with the 8m-long scaled model in the D-SEND#2 test is shown by the data. The D-SEND#2 test is planned in 2013 at Sweden.

Acknowledgements

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