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D-SEND#2 - FLIGHT TESTS FOR LOW SONIC BOOM DESIGN TECHNOLOGY

Kenji Yoshida
Masahisa Honda

Aeronautical Technology Directorate
Japan Aerospace Exploration Agency

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○ D-SEND#1 — *two drop tests (2011): **success***

○ **D-SEND#2** — *1st flight test (2013): **failure***

2. D-SEND#2 2nd Flight Test (24 July, 2015): *success*

- *Principal test results → Goal of S3 program*

Concluding Remarks

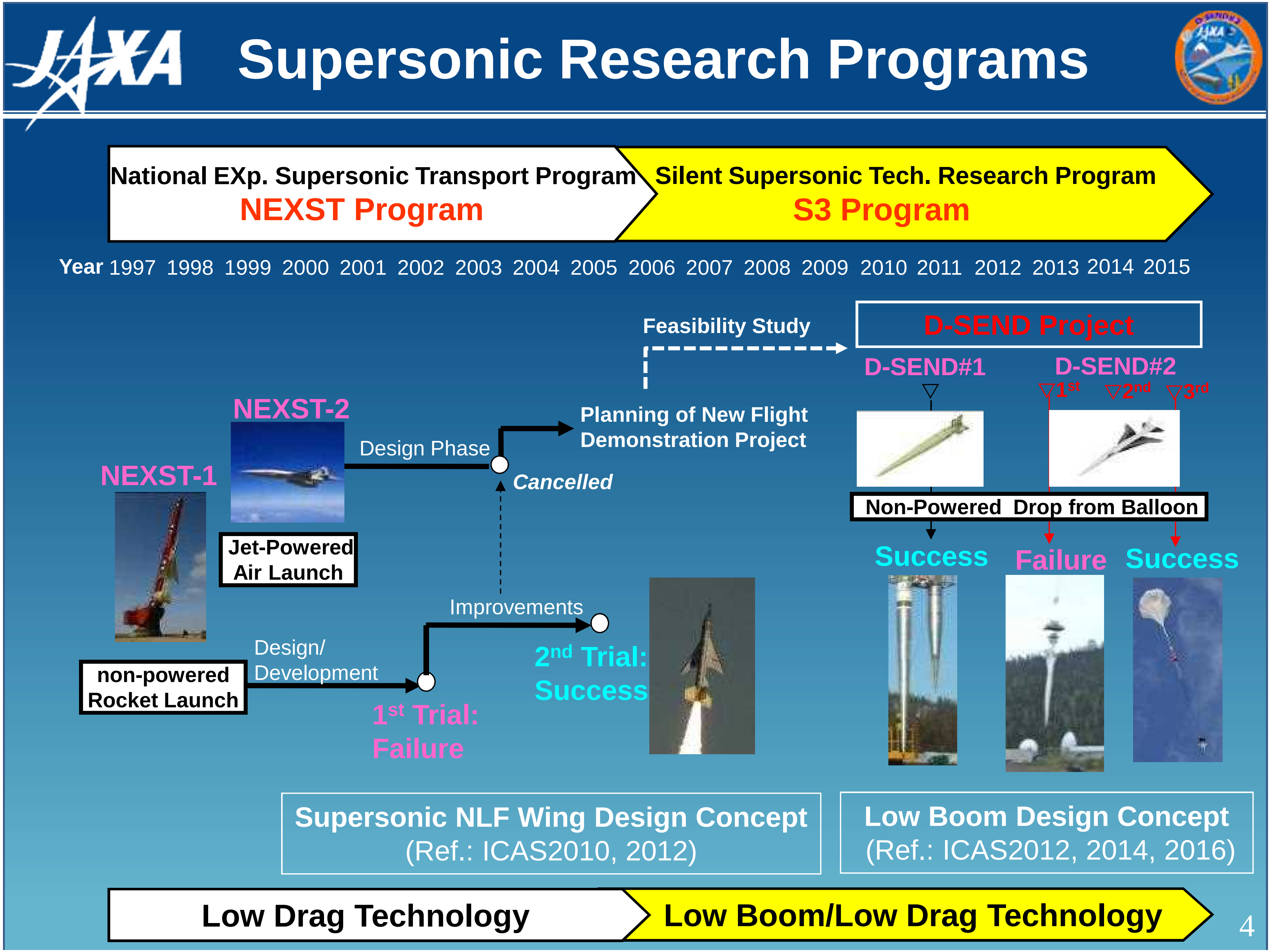
Background

To address the technological challenges to create a next generation SST beyond Concorde, JAXA focused on the following R&D areas:

Economically Viable	Environmentally Acceptable
Drag Reduction (Supersonic Cruise)	Low Sonic Boom
NEXST Project (1997-2005)	D-SEND Project (2010-2015)

Flight Test Demonstration Project

Weight Reduction	Low Noise (Take-off/Landing)
S3 Program (2006-2015)	*S3 Program (2006-2015)*



Supersonic Research Programs
National EXp. Supersonic Transport Program
NEXST Program
Silent Supersonic Tech. Research Program
S3 Program
Year 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Feasibility Study
D-SEND Project
D-SEND#1
D-SEND#2
▽1st ▽2nd ▽3rd
NEXST-2
NEXST-1
Design Phase
Planning of New Flight Demonstration Project
Cancelled
Non-Powered Drop from Balloon
Jet-Powered Air Launch
Success
Failure
Success
Improvements
Design/ Development
non-powered Rocket Launch
2nd Trial: Success
1st Trial: Failure
Supersonic NLF Wing Design Concept
(Ref.: ICAS2010, 2012)
Low Boom Design Concept
(Ref.: ICAS2012, 2014, 2016)
Low Drag Technology
Low Boom/Low Drag Technology
4

Overview of NEXST Program

National EXperimental Supersonic Transport (NEXST) program

Technical Target Aircraft : Larger SST than Concorde

【Specifications of Target Aircraft】

- Cruise Mach: 2.0
- Length: 91 m
- Wing Area: 836 m^2
- Max. Weight: 360 t
- Pax: 300
- Range: 11,000km

【Specifications of NEXST-1(11% scale)】

- Flight Mach: 2.0
- Length: 11.5 m
  (adding parachute space)
- Wing Area: 10 m^2
- Max. Weight: 2 t

Objective

To develop a CFD-based aerodynamic design method including new drag reduction concepts

NEXST-1 Design Concepts

[Design Point]
M=2, C_L=0.1@H=18km

〔11% scale of a large SST (300pax)〕
Length: 11.5m, Span: 4.72m, Weight: 2000kg

Surface roughness target: 0.3μm

Natural Laminar Flow (NLF) Wing
to reduce friction drag

Cranked Arrow Planform
to reduce lift-dependent drag

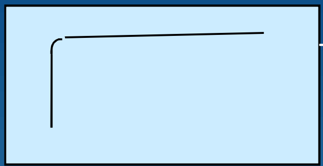
Area-ruled Body
to reduce wave drag due to volume

Warped Wing
to reduce lift-dependent drag

NEXST-1 Design Procedure

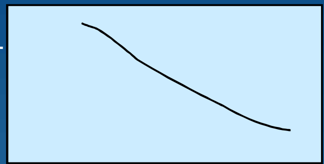
CFD-based Inverse Design Flow

Cp,upper

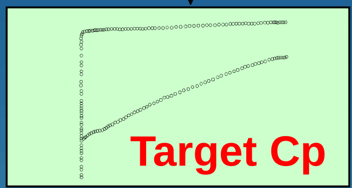


Ideal Cp
for NLF

$\Delta Cp \equiv Cp_{lower} - Cp_{upper}$



Ideal load
by warp design



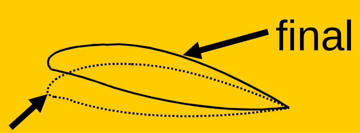
Initial configuration using a warped wing and area-ruled body concepts

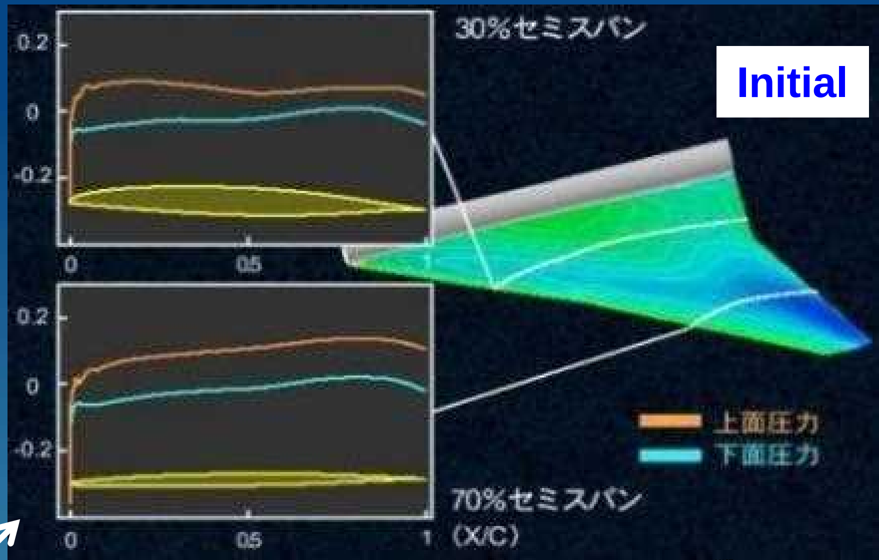
successive
approach

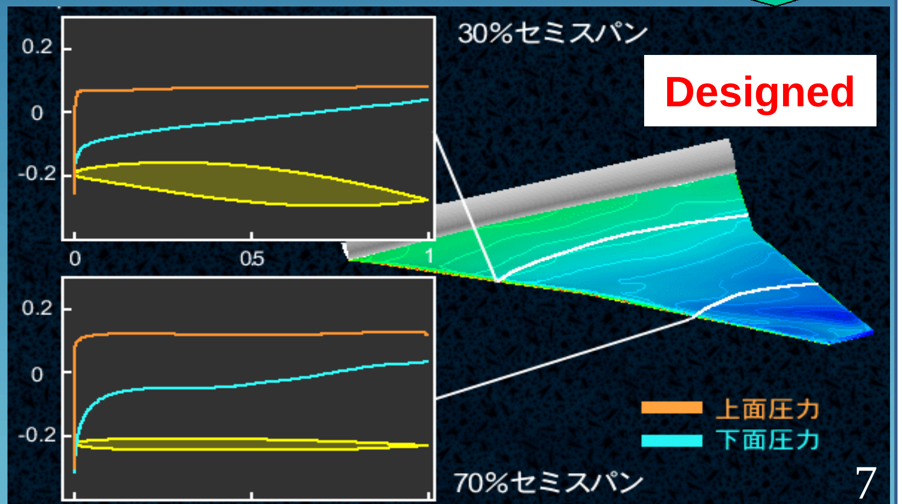
①Computation by CFD
②Estimate Cp-difference
③Modification of shape

convergence

Designed airfoil geometry

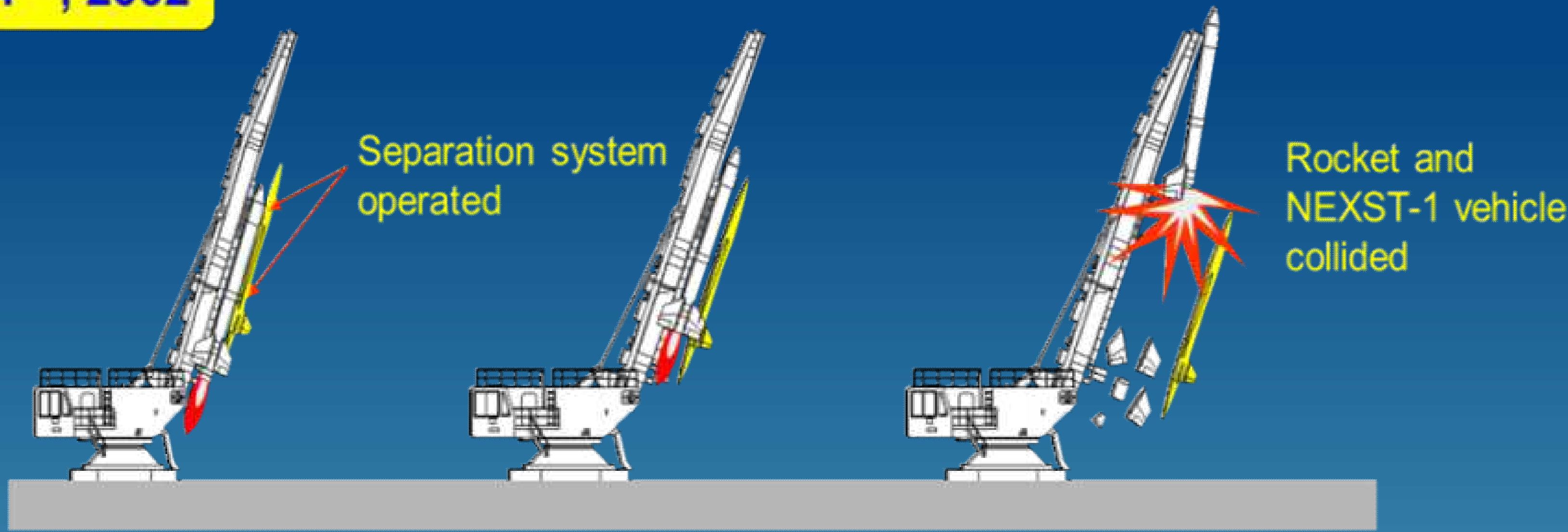


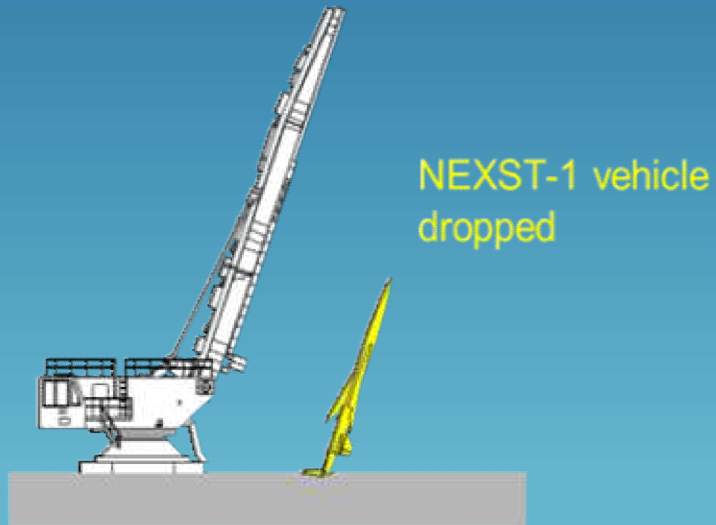




NEXST-1 1st Flight Test

July 14th, 2002





Main Cause of the Failure

Shock of ignition

↓

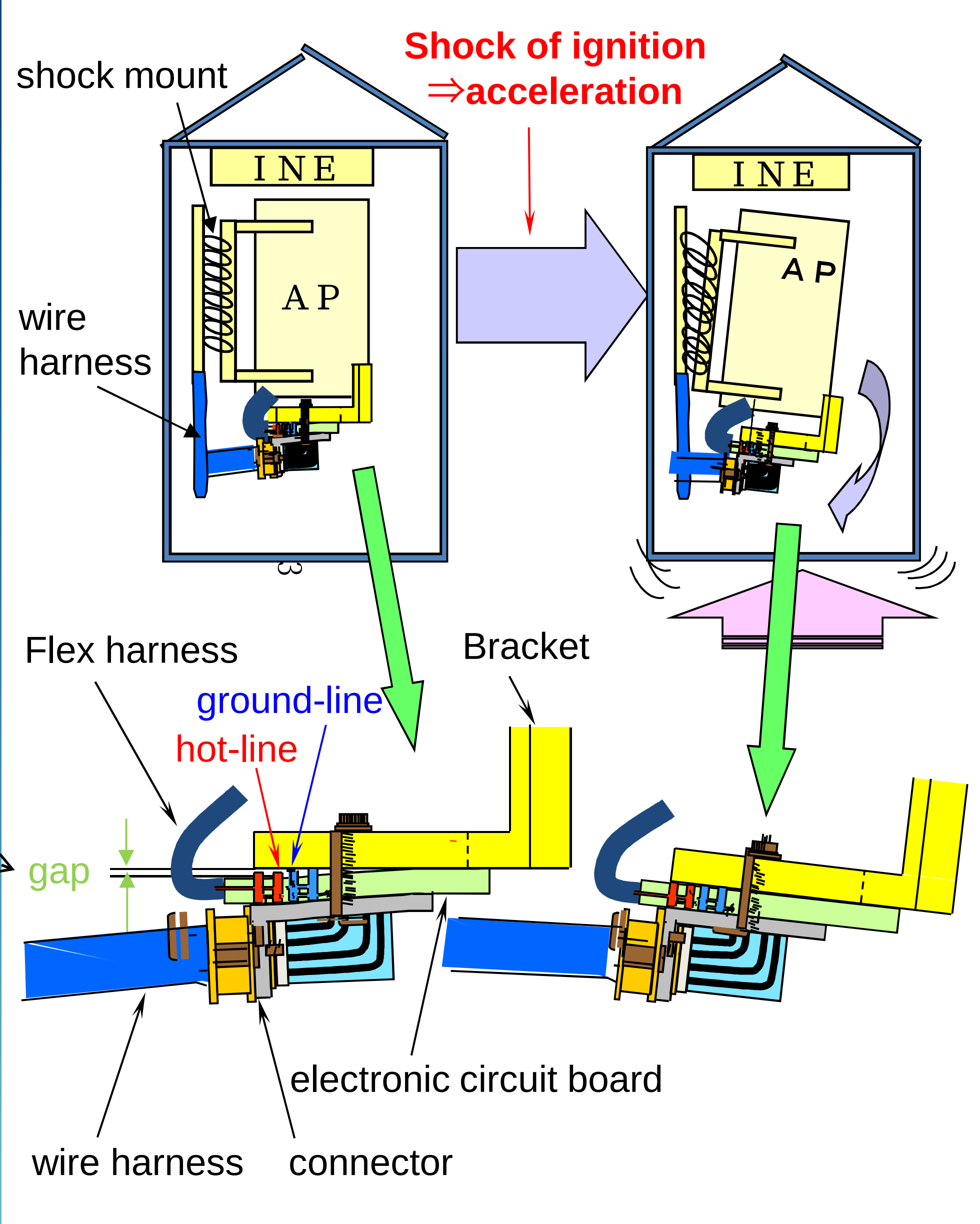
Gap※ was kept.

※) between board and harness

↑

Successful vibration test

(But, AP axis was oriented horizontally)



No vibration test vertically

Spring deformed by weight of AP

↓

Shock of ignition

↓

Gap※ was lost.

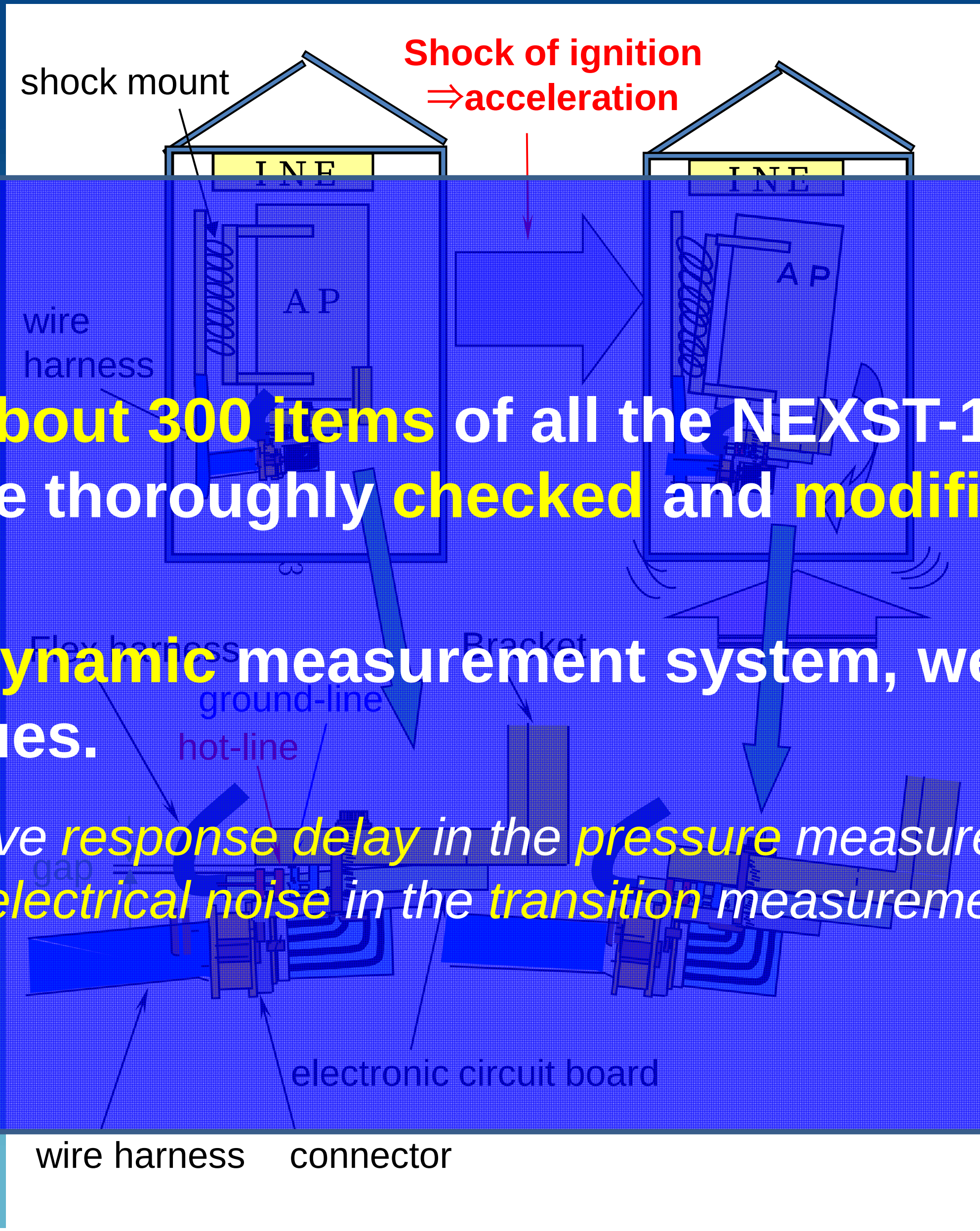
↓

Electrical short

↓

separation signal

Main Cause of the Failure



Shock of ignition

Gap※ was kept.

※) ... harness

Successful vibration test

(But, AP axis was oriented horizontally)

No vibration test vertically

Spring deformed by weight of AP

Shock of ignition

Gap※ was lost.

Electrical short

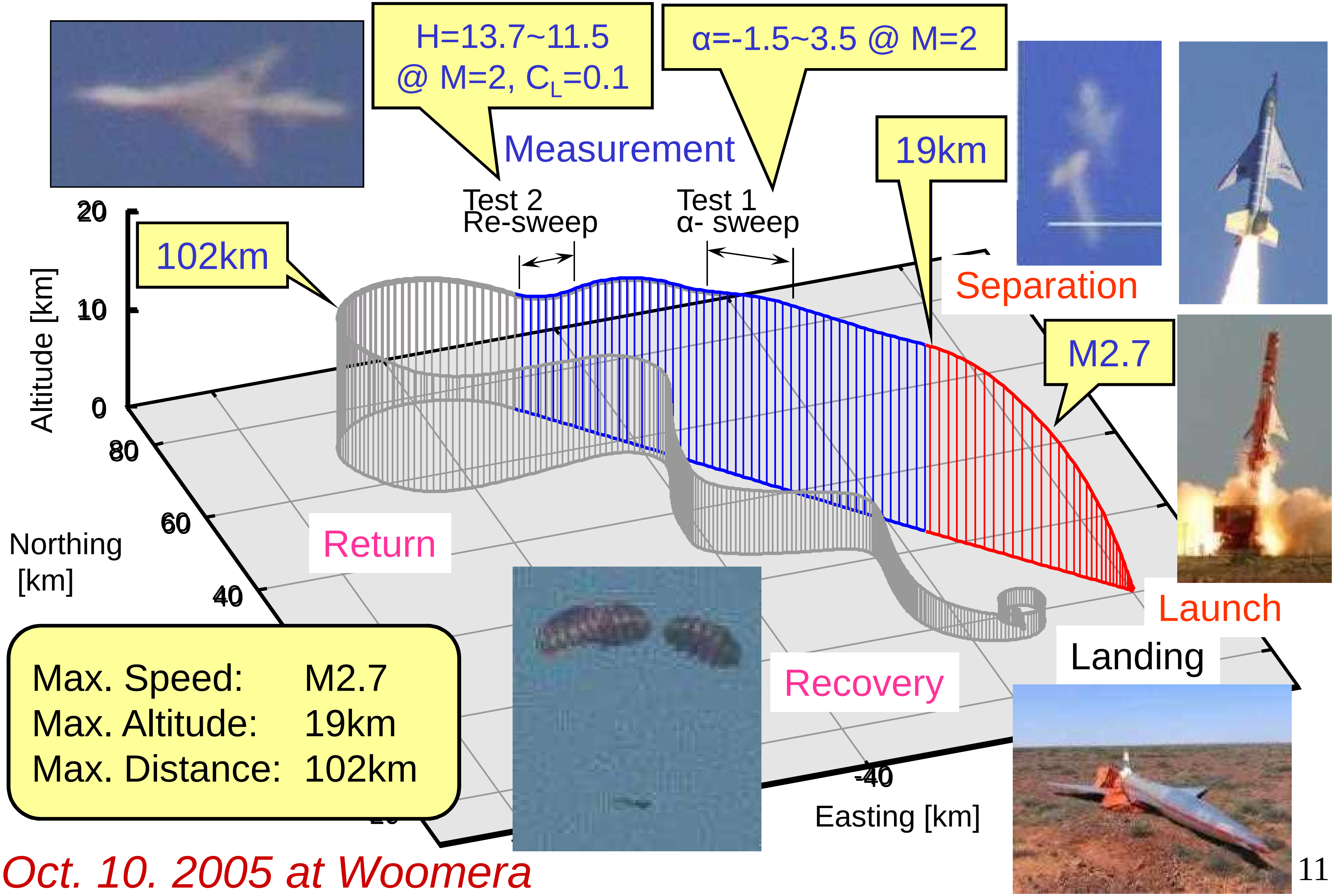
separation signal

- **After that, about 300 items of all the NEXST-1 vehicle system were thoroughly checked and modified.**
- **In the aerodynamic measurement system, we also found two big issues.**

  (1) An excessive response delay in the pressure measurement system

  (2) Too much electrical noise in the transition measurement system

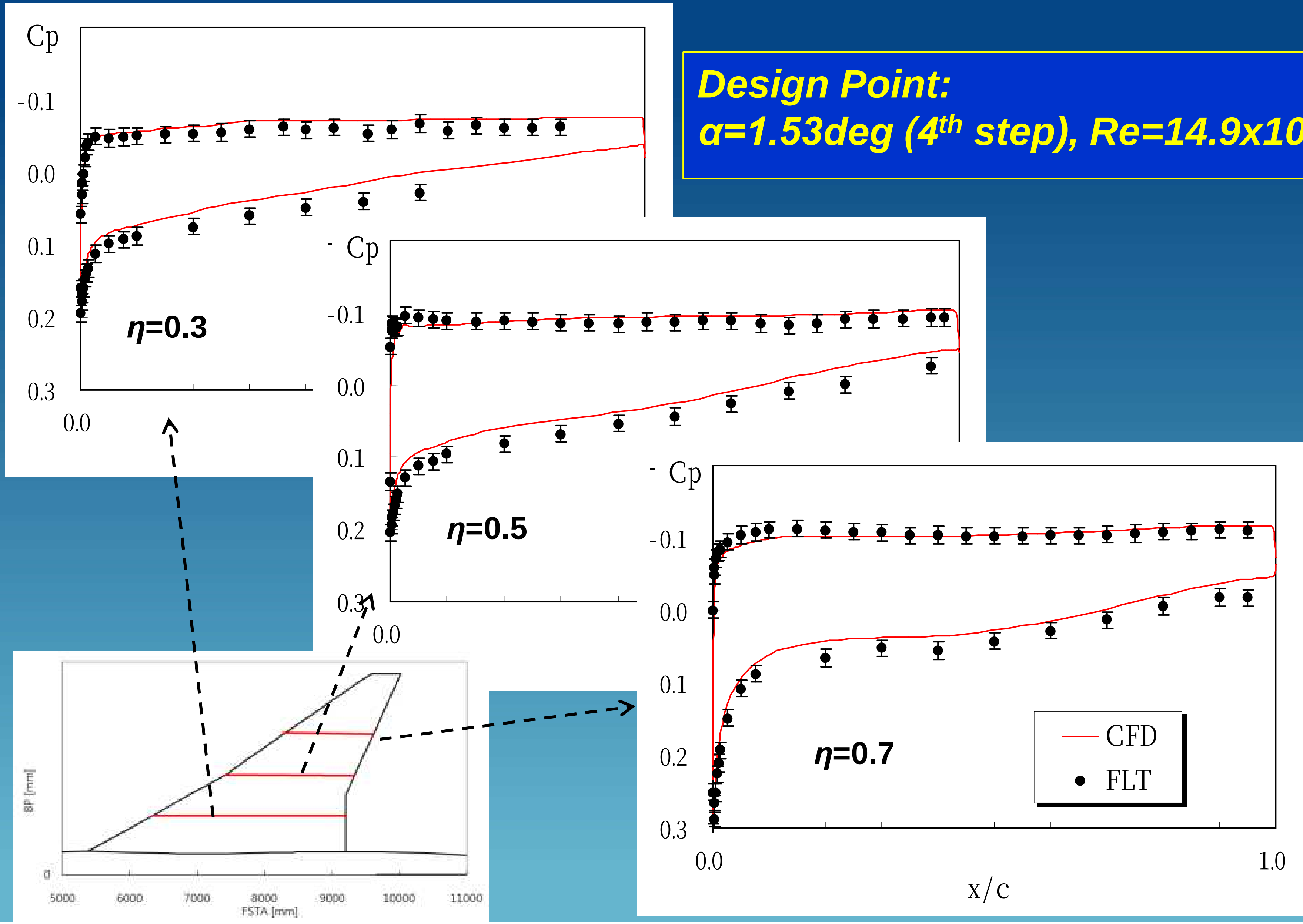
NEXST-1 Flight Test Trajectory



Oct. 10. 2005 at Woomera

Flight Test Results : Pressure Data

Design Point:
α=1.53deg (4th step), Re=14.9x10⁶)



Flight Test Results : Transition Data

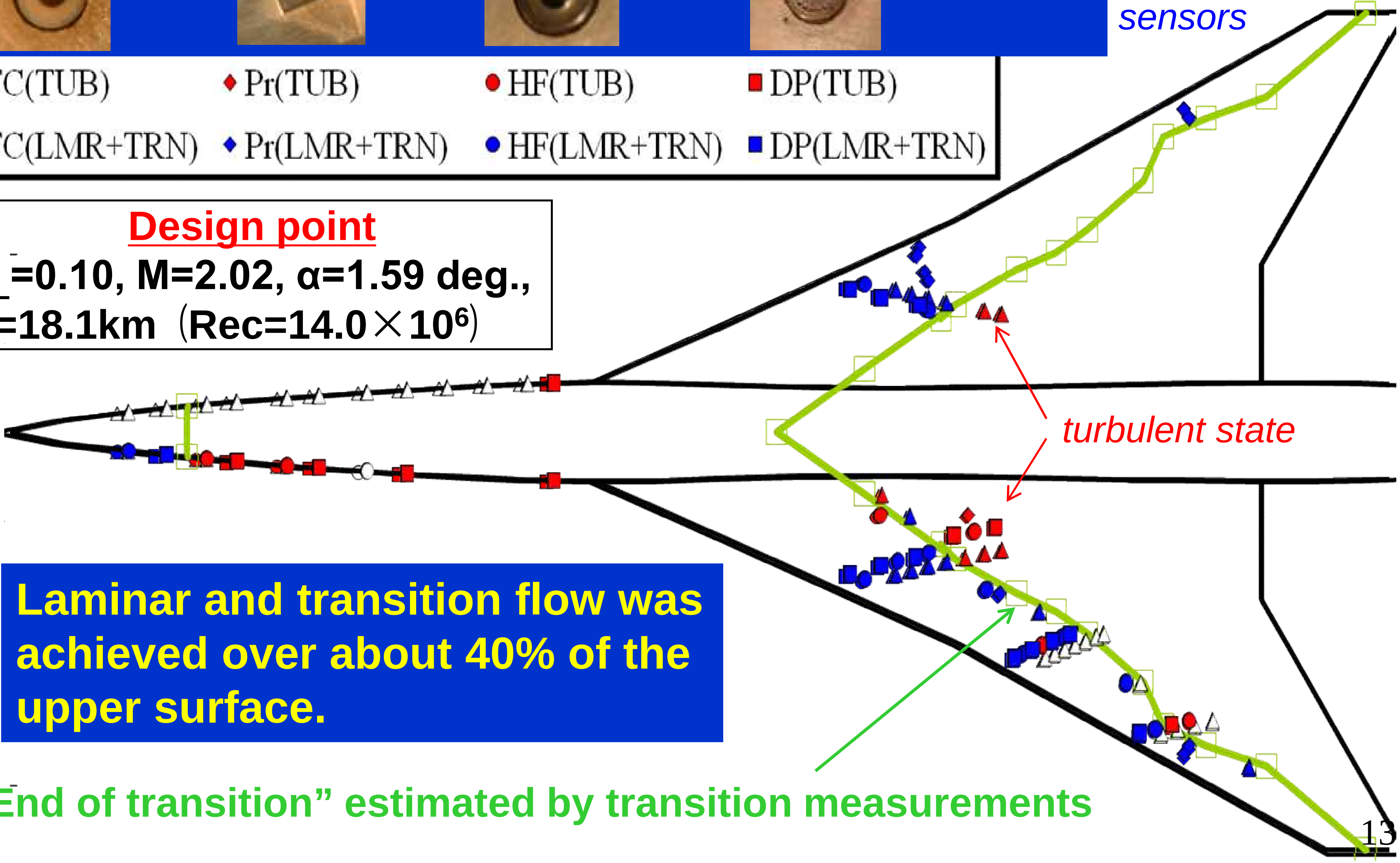
Transition detection sensors

▲ TC(TUB) ◆ Pr(TUB) ● HF(TUB) ■ DP(TUB)

▲ TC(LMR+TRN) ◆ Pr(LMR+TRN) ● HF(LMR+TRN) ■ DP(LMR+TRN)

Design point

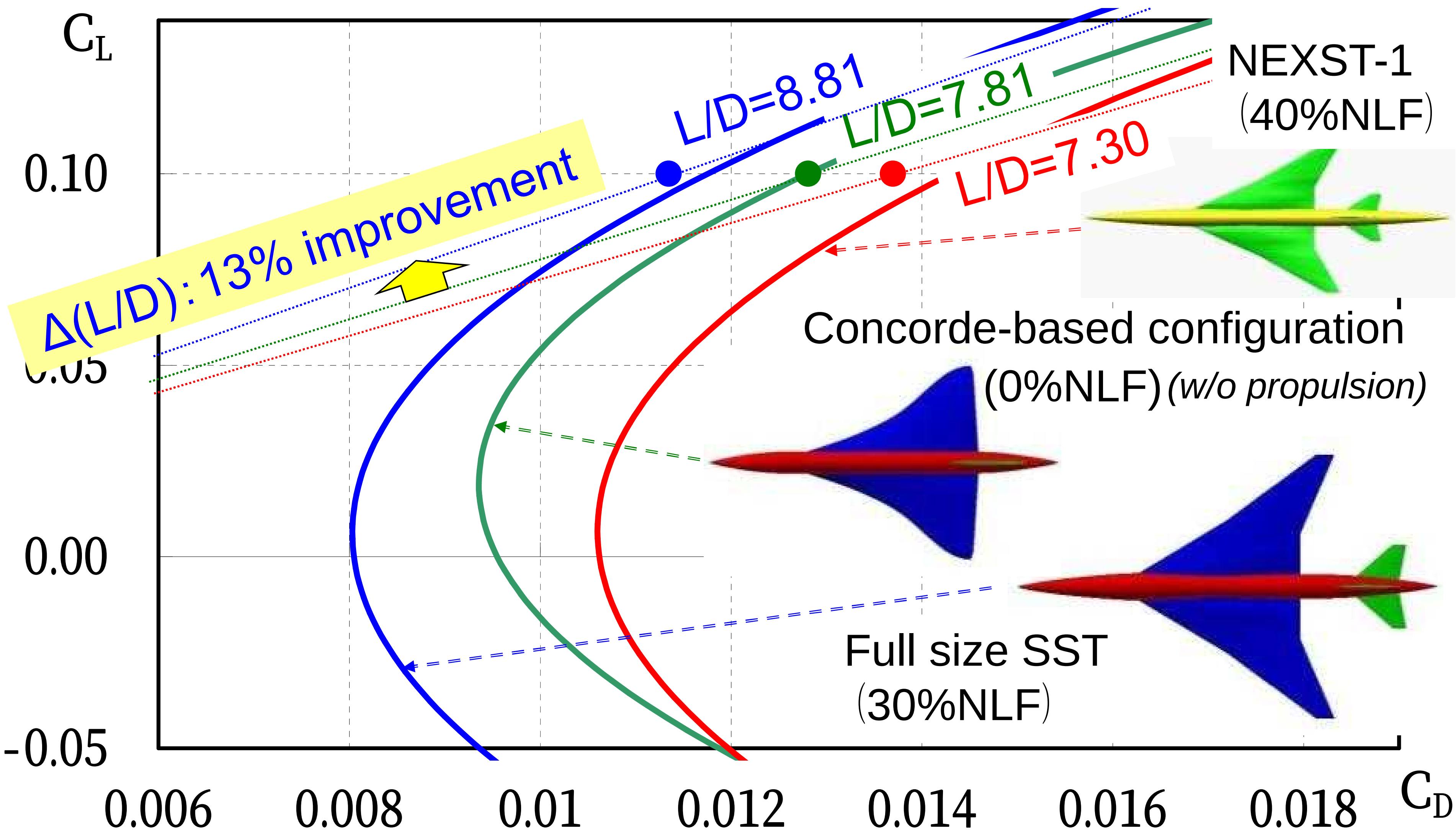
C_L=0.10, M=2.02, α=1.59 deg., H=18.1km (Rec=14.0×10^6)



Laminar and transition flow was achieved over about 40% of the upper surface.

"End of transition" estimated by transition measurements

NEXST-1 : Effect on a Large SST

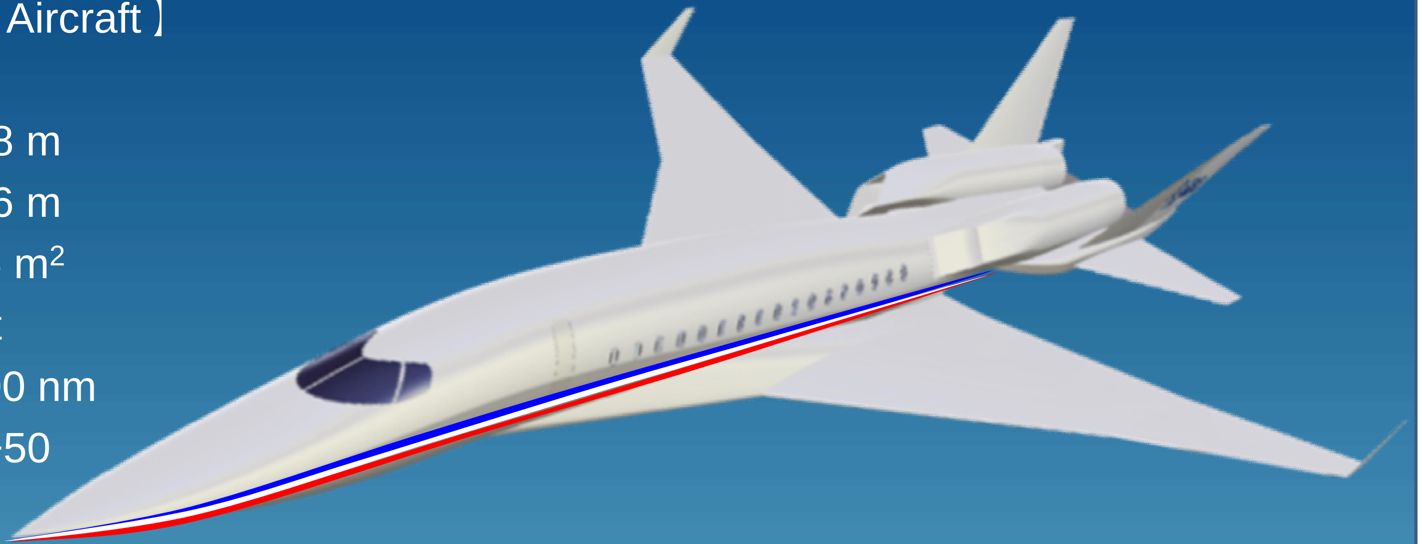


Overview of S3 Program

Silent SuperSonic Technology Research (S3) program

Technical Target Aircraft : Smaller SST than Concorde

【Specifications of Target Aircraft】
- Cruise Mach : 1.6
- Fuselage Length : 47.8 m
- Wing Span : 23.6 m
- Wing Area : 175 m^2
- Max. Weight : 70 t
- Range : 3500 nm
- Pax. : 36~50



Objective

To research & develop some technologies to achieve these target values

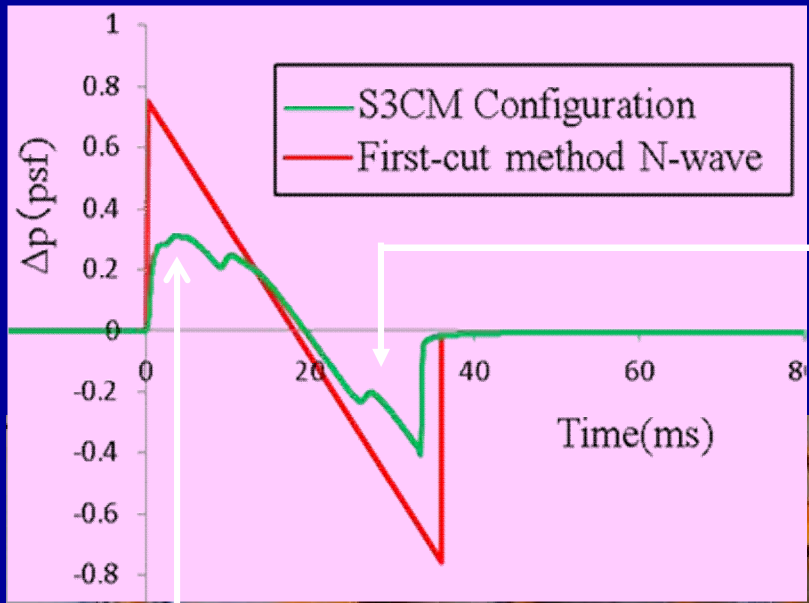
Technical Challenges	Target Values
Sonic Boom Reduction	**< 25% intensity of Concorde's boom**
L/D Improvement	> 8 @ cruise
Structural Weight Reduction	15% ref. to Concorde tech.
Noise Reduction	meet to Chap.4 with margin

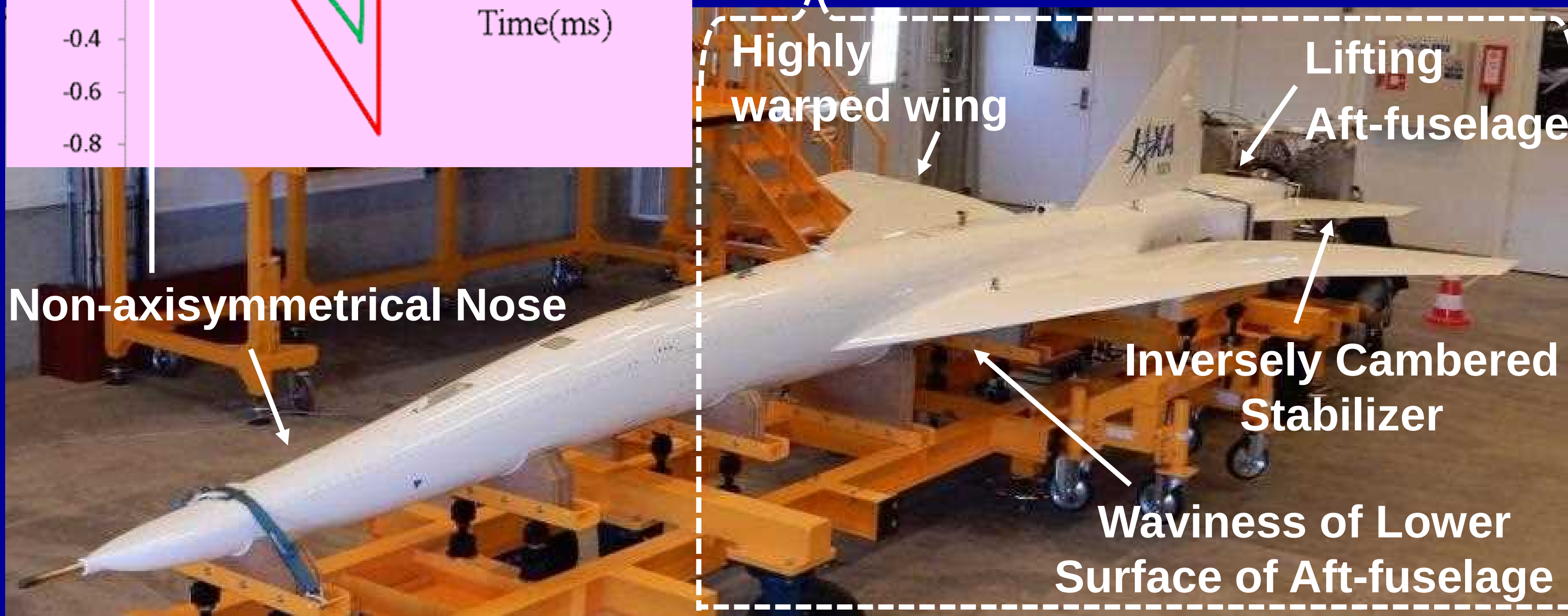
JAXA's low-boom design concepts

S3 Concept Model (S3CM)

[Design Point]
M=1.3, C_L=0.12

Weight	1000kg
Wing Area	4.891m^2
MAC	1.912m
Wing Span	3.510m
Length	7.913m





Challenge on Low Boom Design

◆Current low boom design theory can create an aircraft design that has low front and rear overpressures, but it can not keep the trim condition.

◆As a first step, the front boom reduction was demonstrated in the SSBD program in the US, 2003 (※).

◆JAXA created new design concepts to reduce both front and rear overpressures keeping the trim condition completely.

◆D-SEND#2 flight test was planned to demonstrate the concepts.

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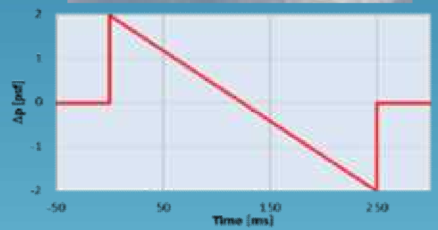
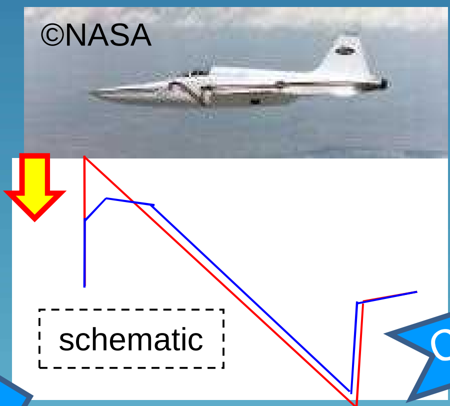


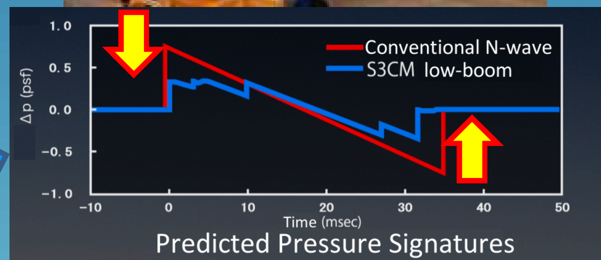
Concorde

Challenge



※**NASA SSBD** (2003)
(Front boom reduction)

Challenge



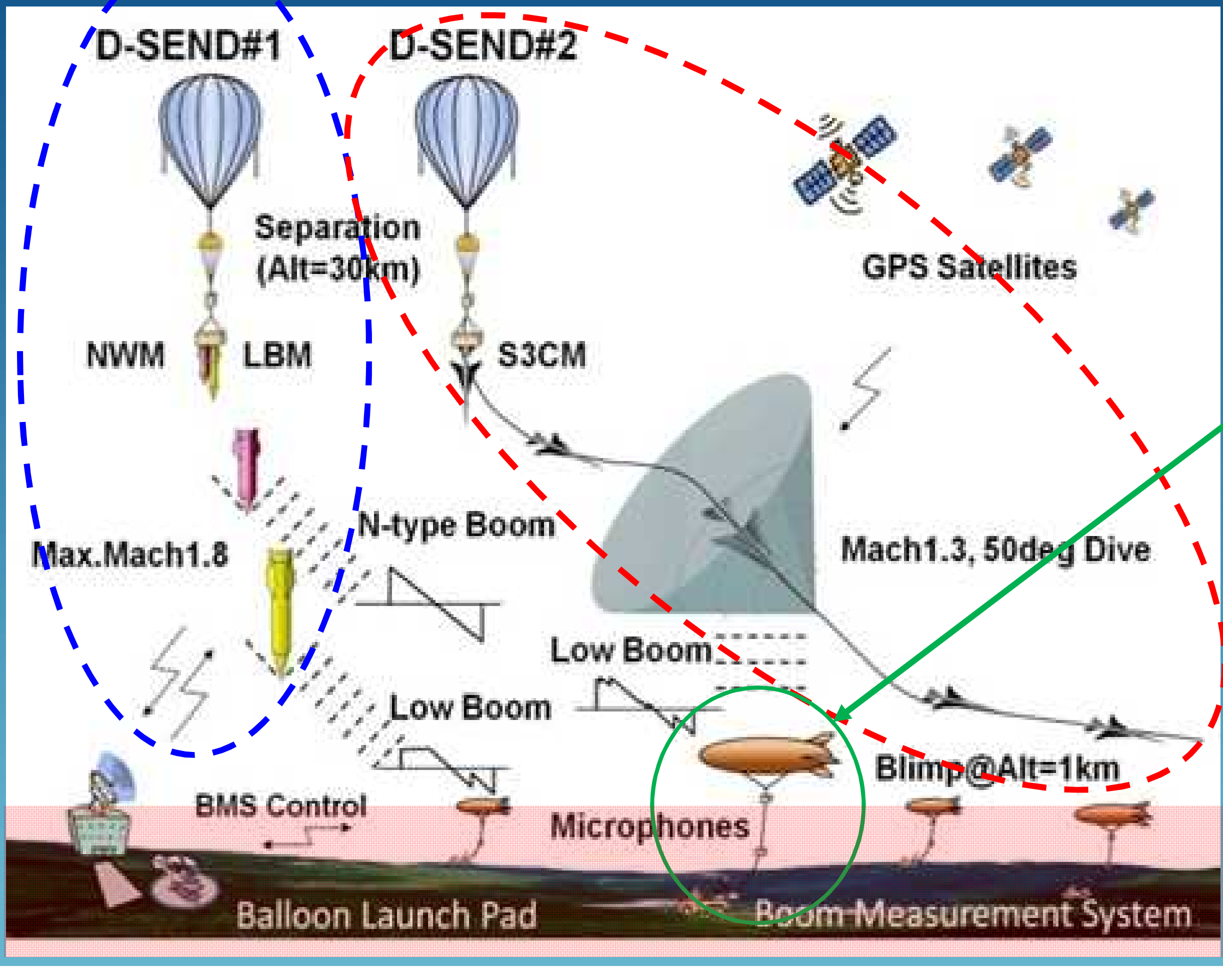
D-SEND#2
Both front and rear boom reduction at trim condition

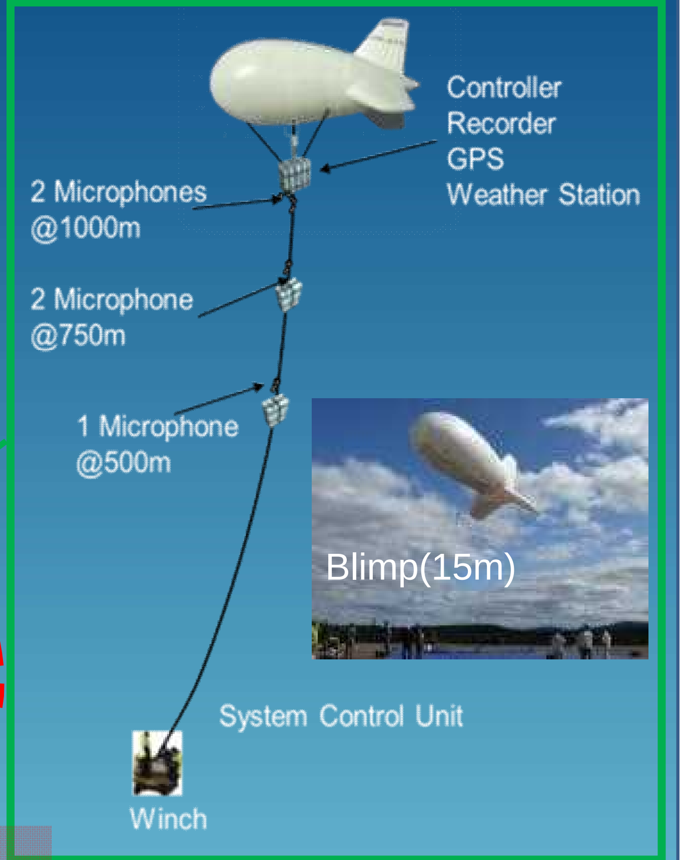
D-SEND Project (2010-2015)

Drop test for **S**implified **E**valuation of **N**on-symmetrically **D**istributed sonic boom

(1) D-SEND#1: To establish airborne sonic boom measurement system (BMS)

(2) D-SEND#2: To validate JAXA's low-boom design concepts





← **atmospheric turbulence**

History of D-SEND#2 Flight Tests

2013					2014												2015												2016		
8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3

Month

1st CPN

1st Flight Test

at Esrange in Sweden

Failure

Analysis of failure

Improvements

- Small stability margin
- Insufficient Aero. Model

2nd CPN

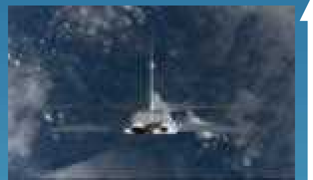
CD trial

No weather cond.

Discussion of significance & technical value

3rd CPN

2nd Flight Test



Modifications

- New ideas to increase the possibility of FLT test

Success

Analysis of FLT data

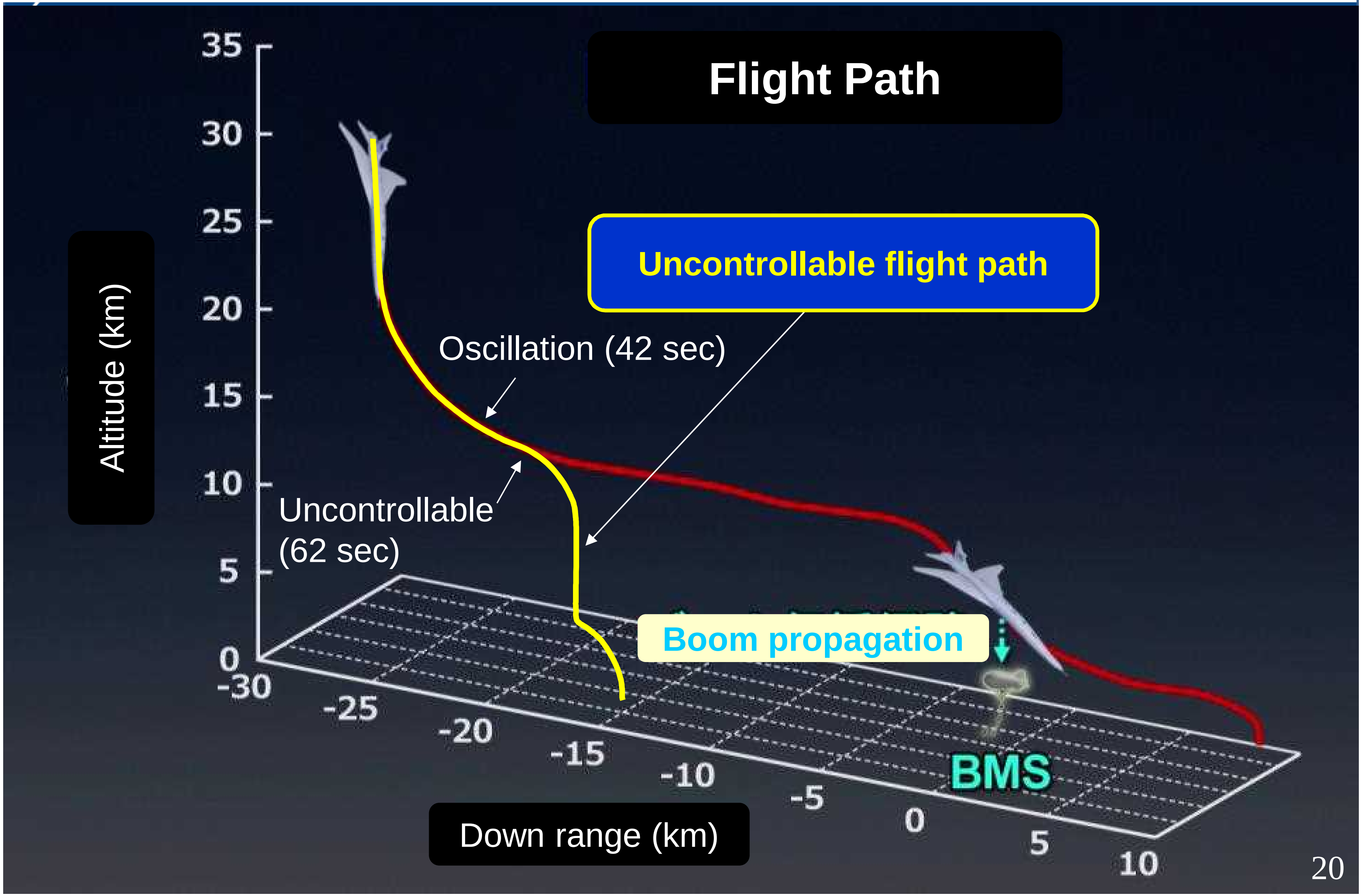
SSTG

Discussions

ICAO/ CAEP10

Flight Demonstration of Low Boom Design Concepts

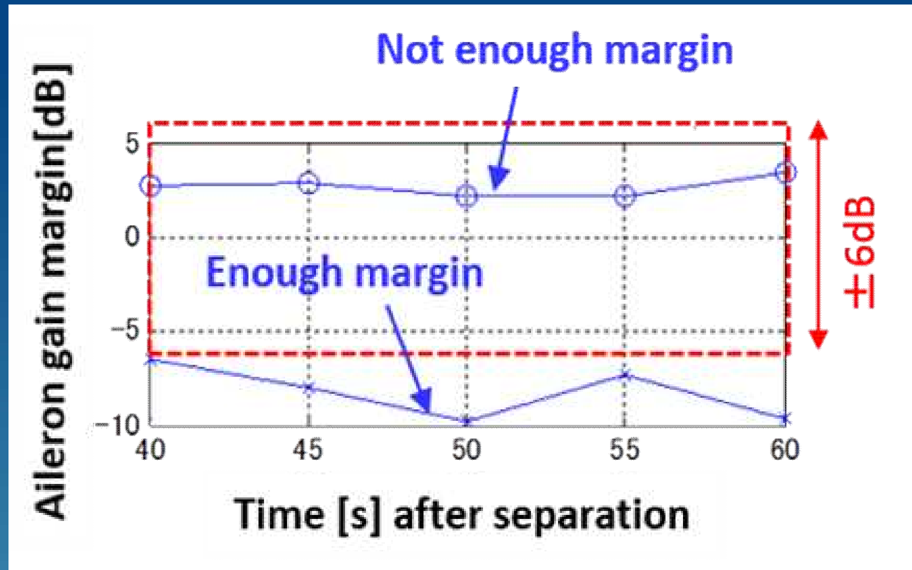
1st Campaign (16 August, 2013)



Main Causes of the Failure

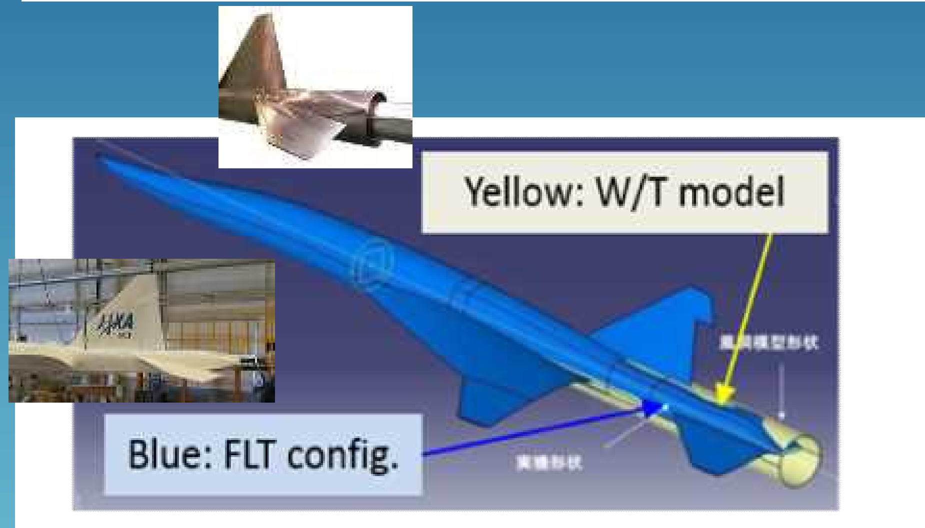
Main cause 1

- There was not enough stability margin in attitude control.
  ⇒ The aileron control gain margin was +2dB, which was smaller than the usual margin of +6dB.



Main cause 2

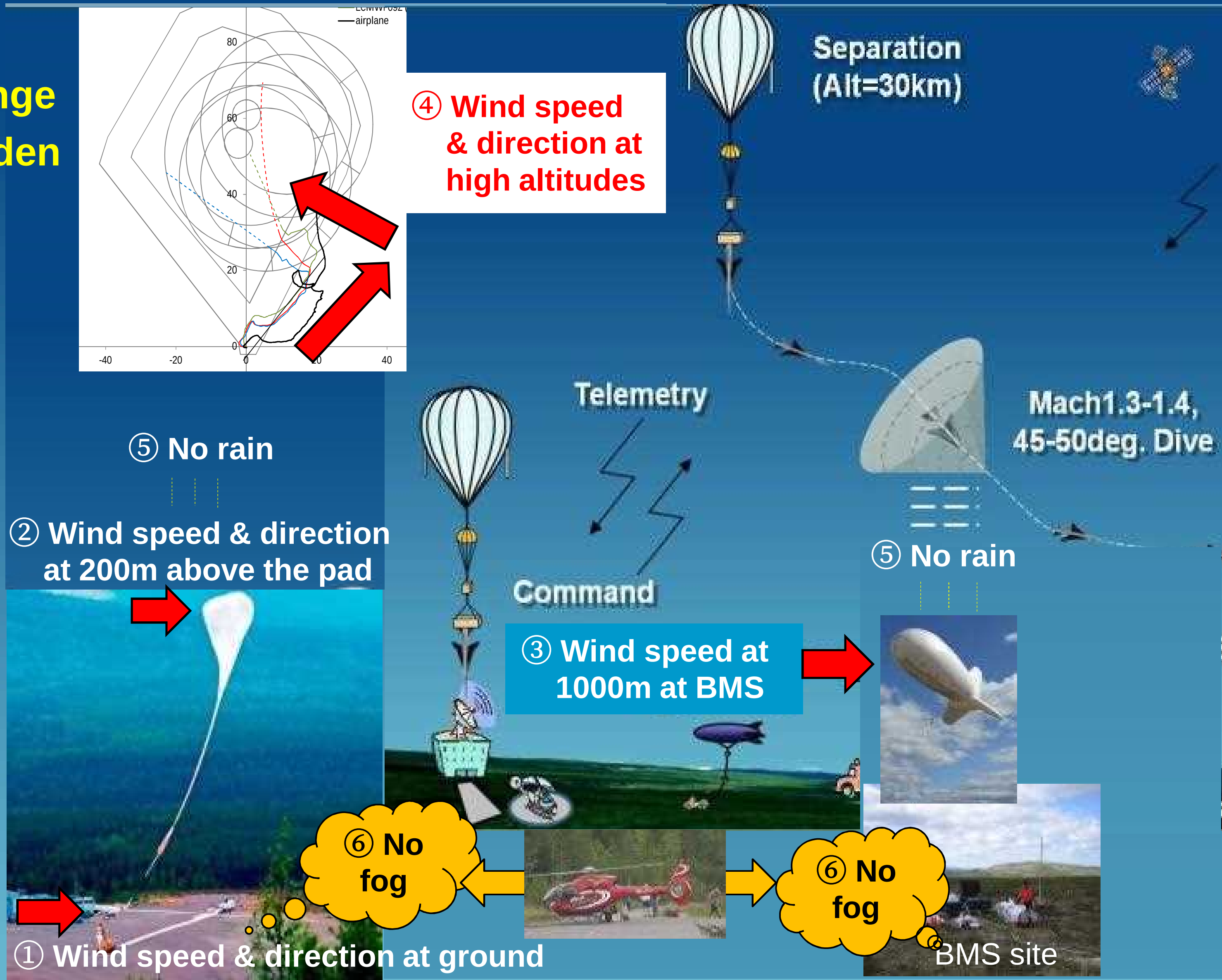
- Lateral aerodynamic characteristics used by the OFP had some errors.
  ⇒ They were mainly based on insufficient correction for the W/T model support-sting.



Comparison of flight configuration and W/T model

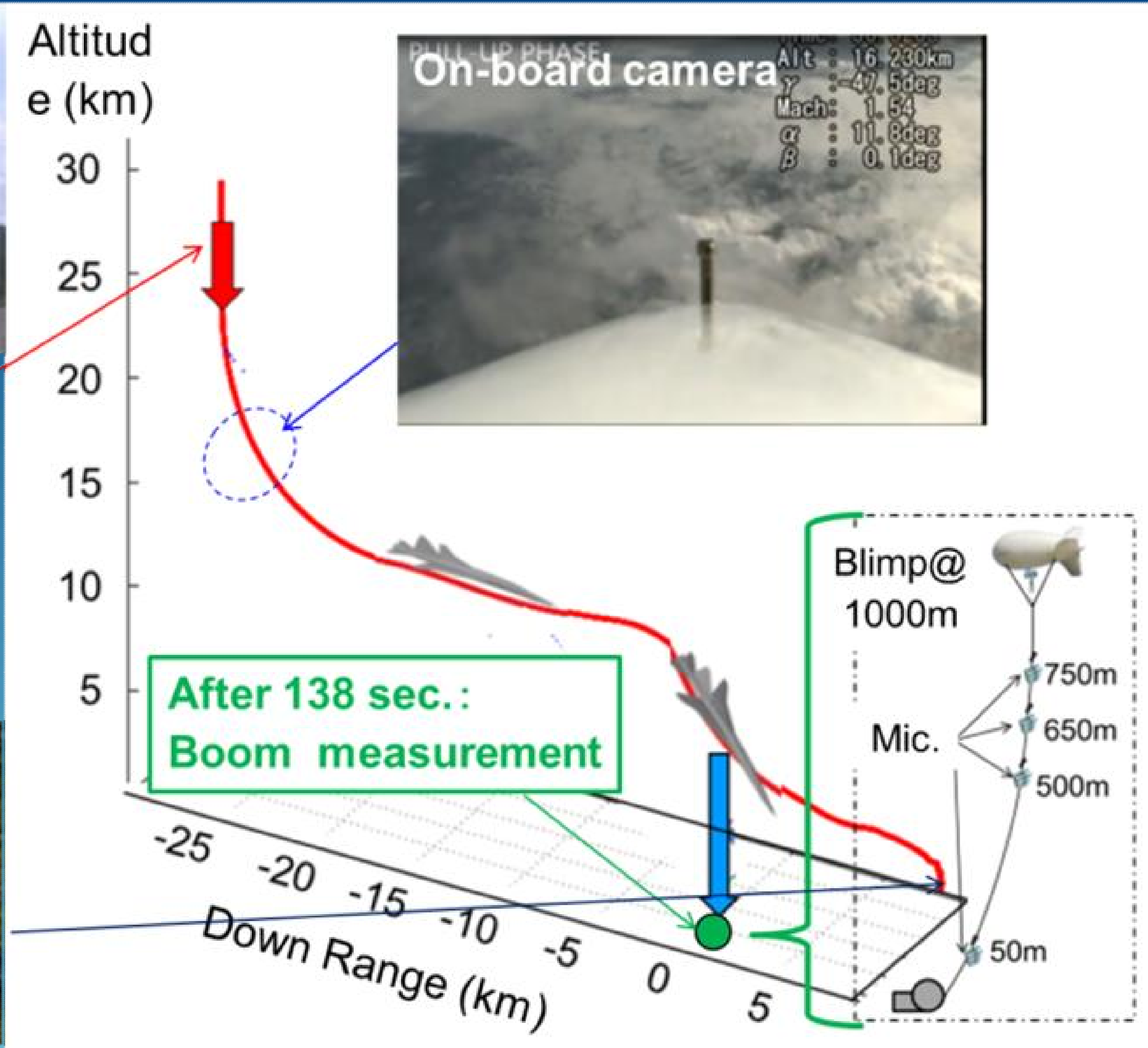
Weather Conditions for Flight

at Esrange
in Sweden

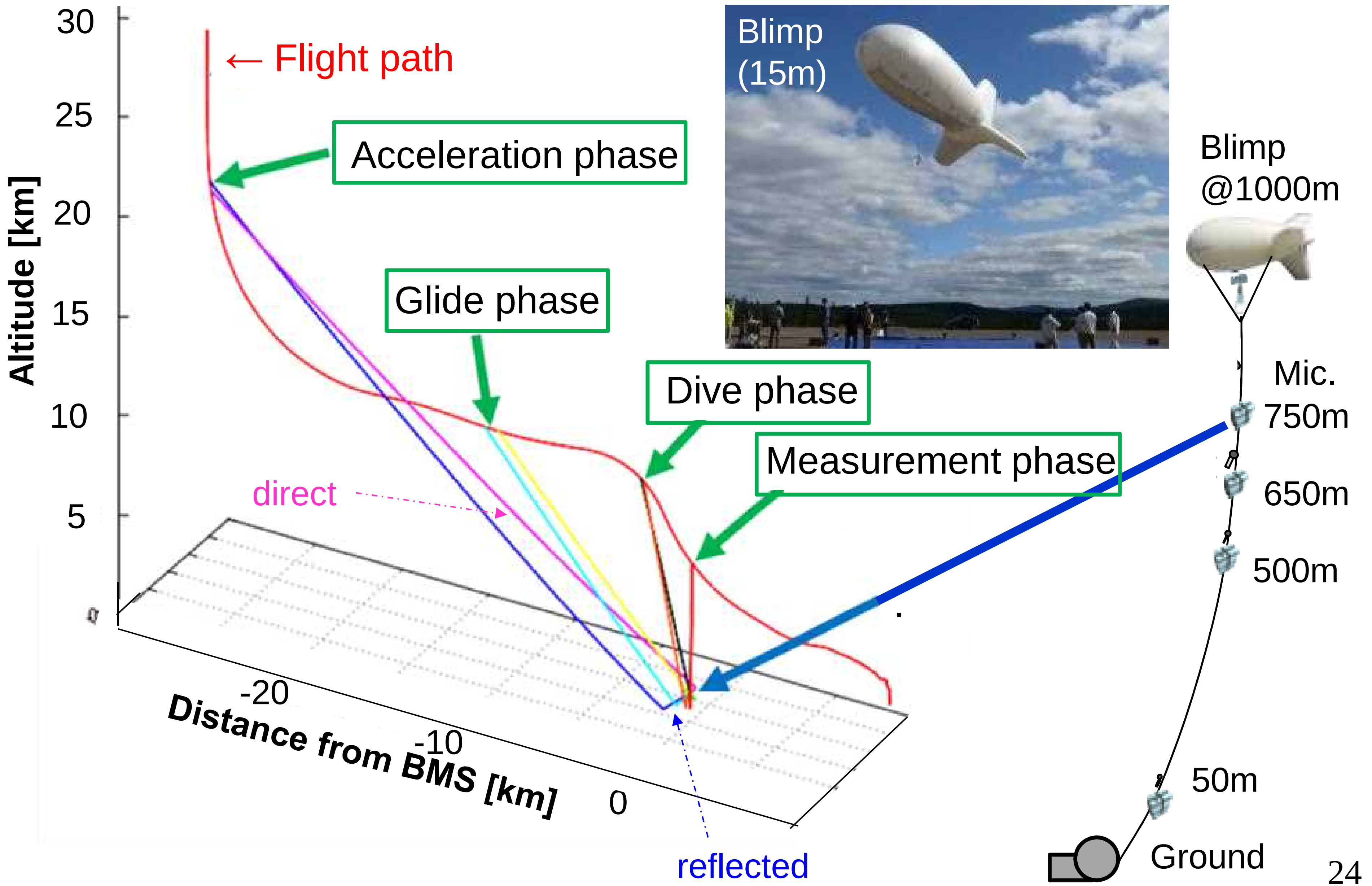


Overview of D-SEND#2 Flight Test

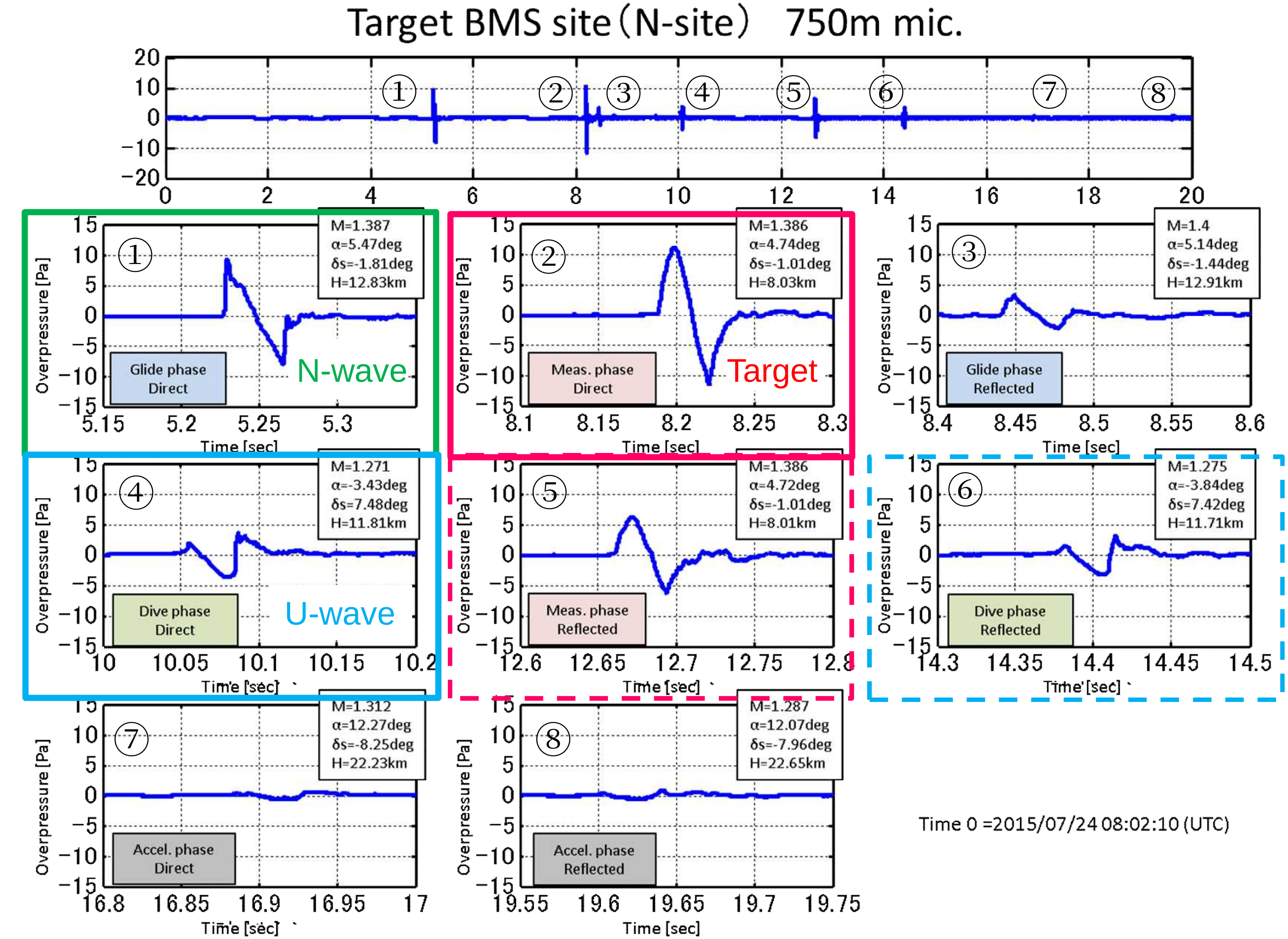
Sonic Boom measurements were successful at Esrange in Sweden.



D-SEND#2 Flight Test Results (1/5)

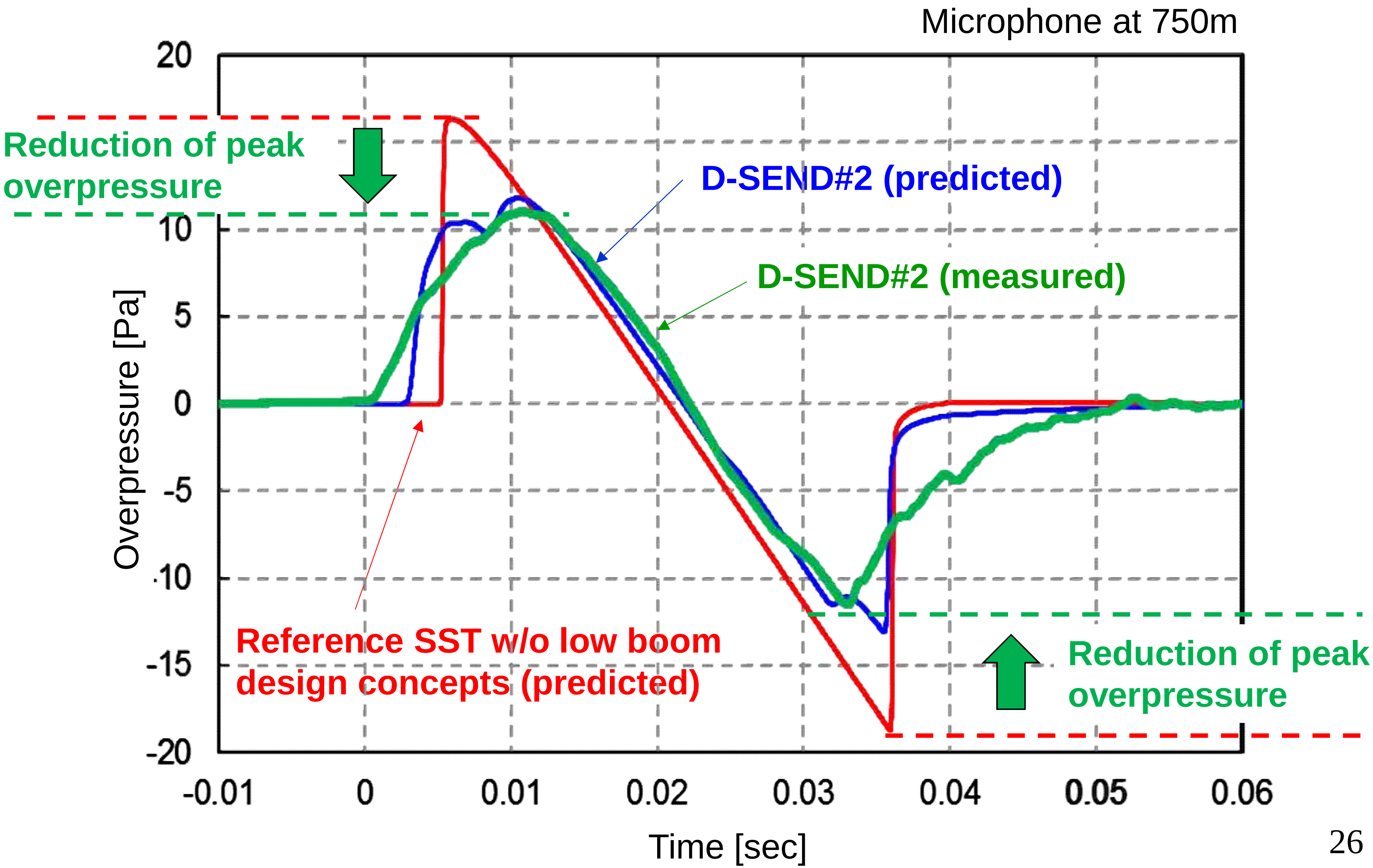


D-SEND#2 Flight Test Results (2/5)



Time 0 =2015/07/24 08:02:10 (UTC)

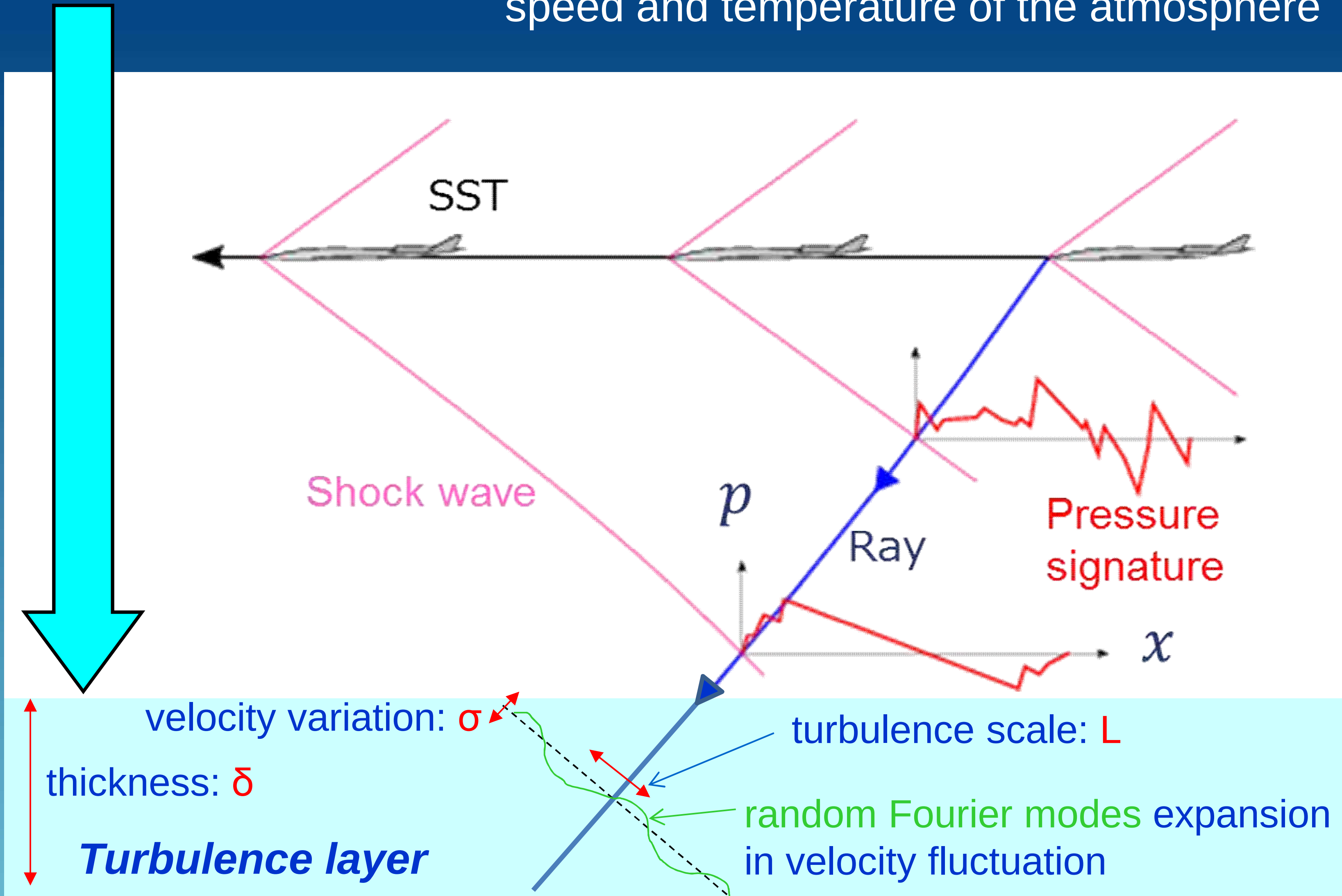
D-SEND#2 Flight Test Results (3/5)



D-SEND#2 Flight Test Results (4/5)

Atmospheric turbulence

Both time and space-wise fluctuations in aerial speed and temperature of the atmosphere



D-SEND#2 Flight Test Results (4/5)

Atmospheric turbulence

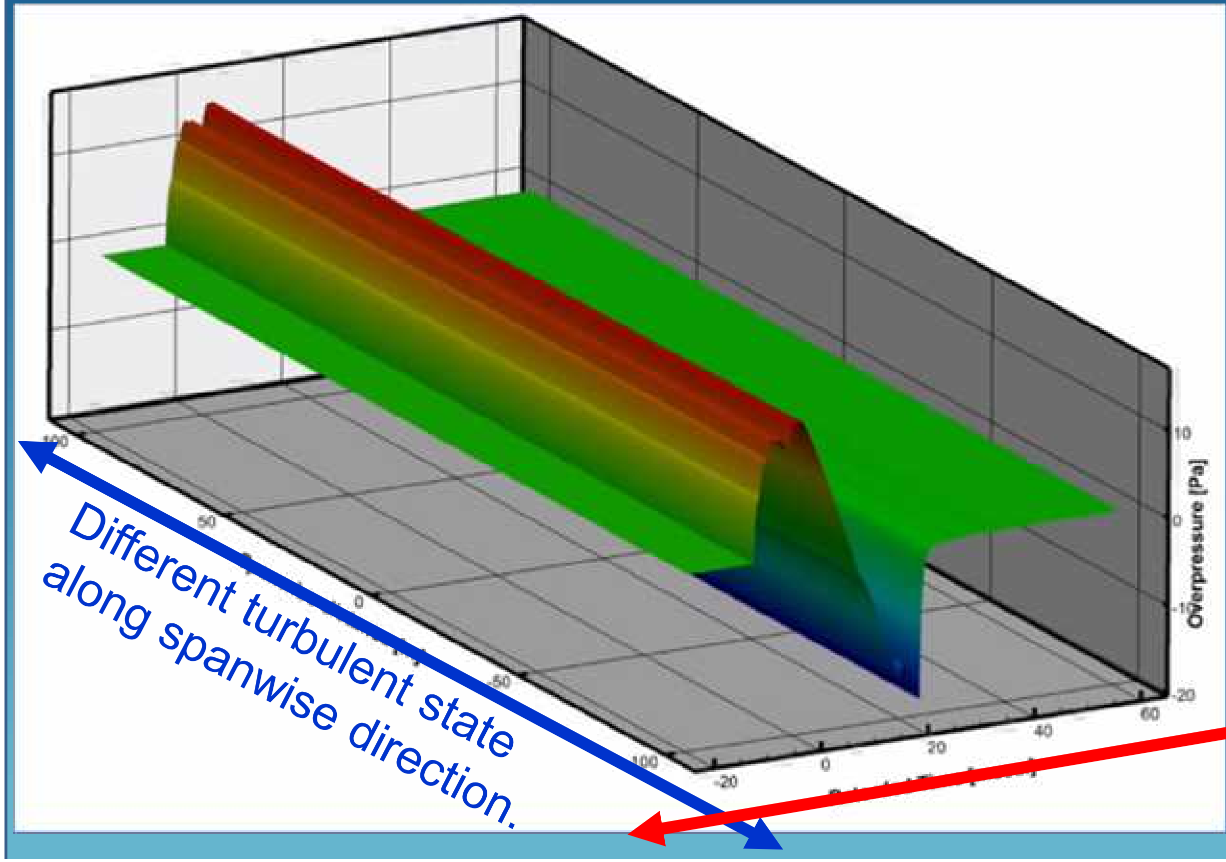
Both time and space-wise fluctuations in aerial speed and temperature of the atmosphere

○ Major parameters of the turbulence model estimated using observation data

① velocity variance [σ=1m/s]

② turbulence scale [L=30m]

③ thickness of turbulence layer [δ=3.5km]



Low boom signatures at measurement phase

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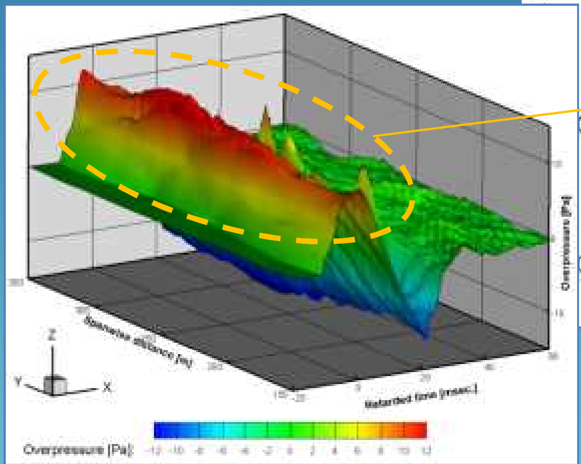
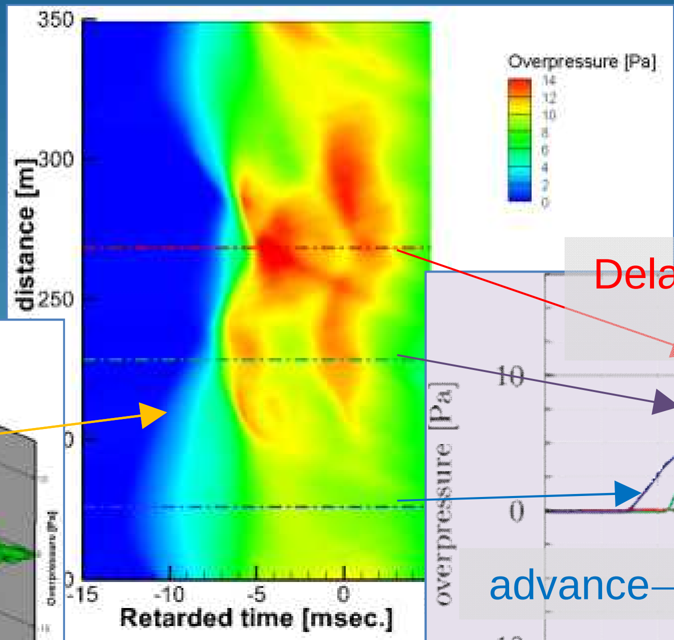
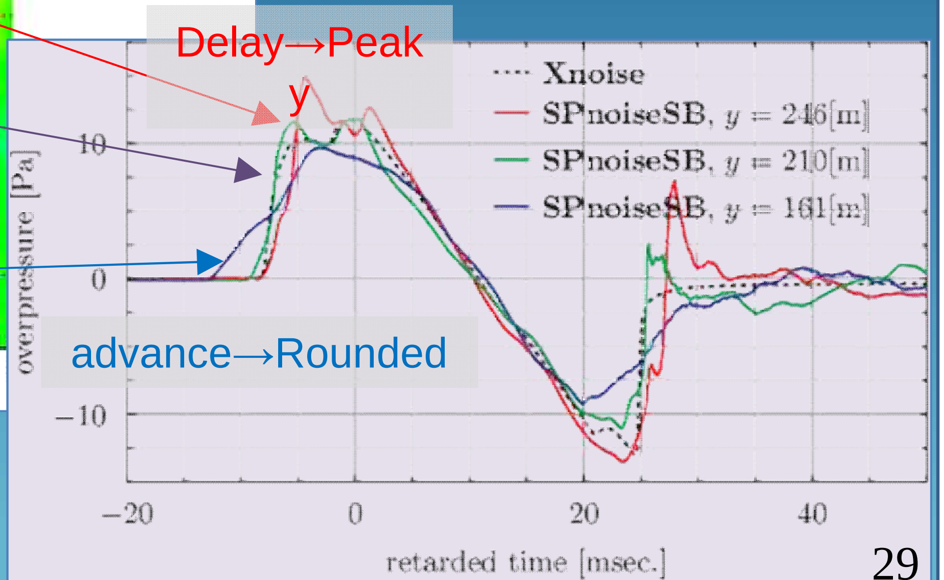
Low boom signatures at measurement phase







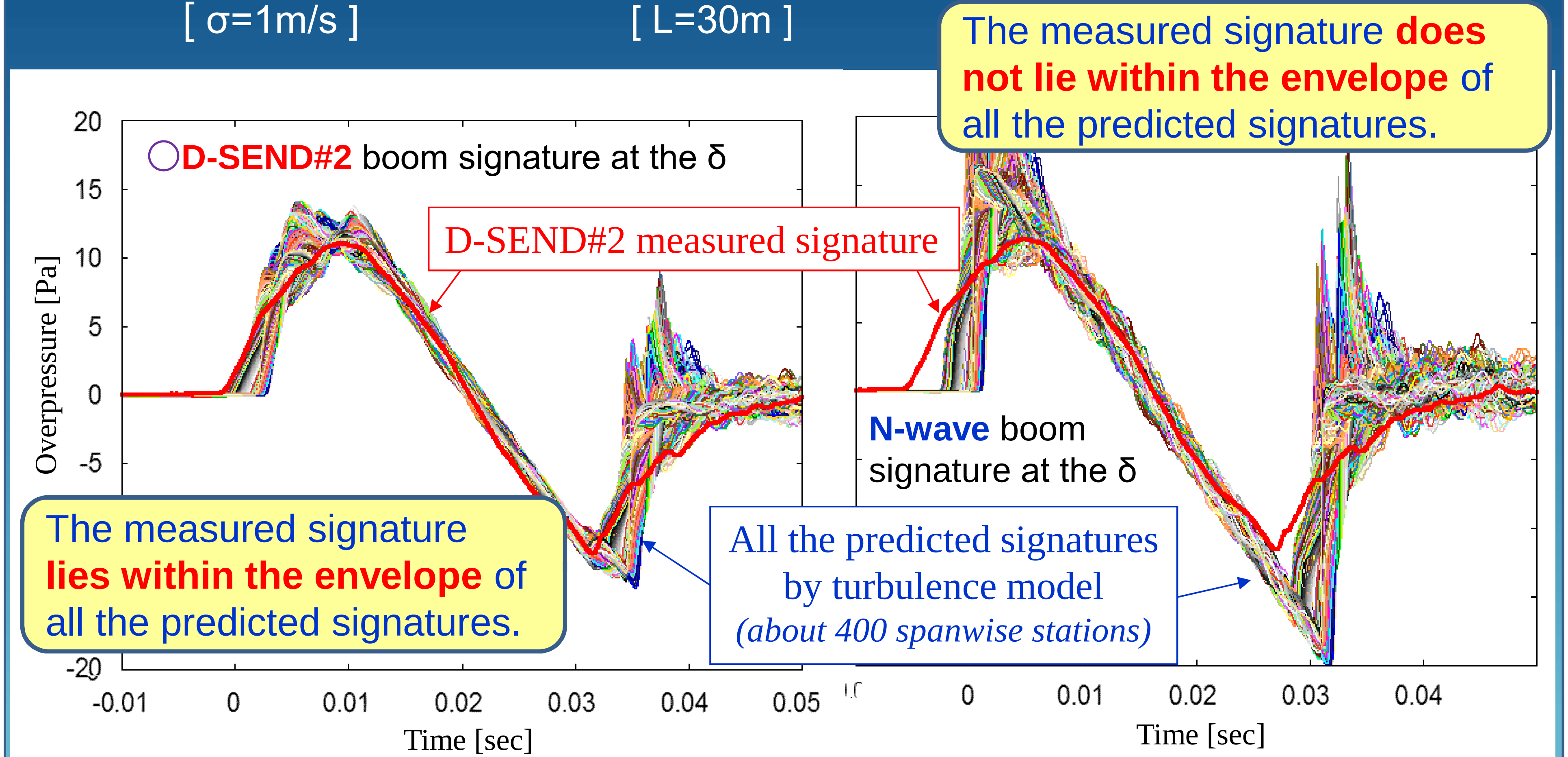
D-SEND#2 Flight Test Results (4/5)

Atmospheric turbulence

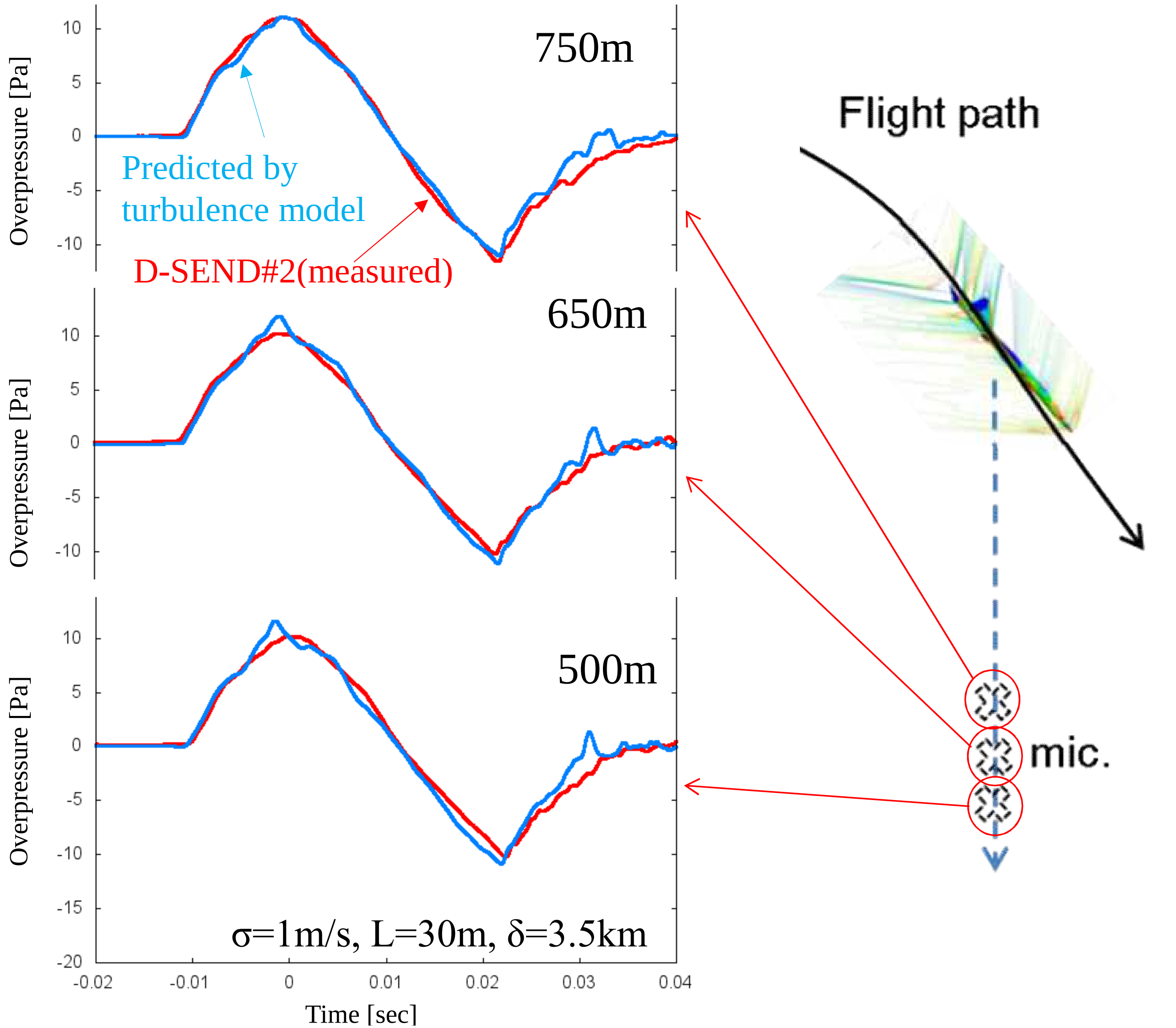
Both time and space-wise fluctuations in aerial speed and temperature of the atmosphere

○ Major parameters of the turbulence model estimated using observation data

① velocity variance [σ=1m/s] ② turbulence scale [L=30m] ③ thickness of turbulence layer



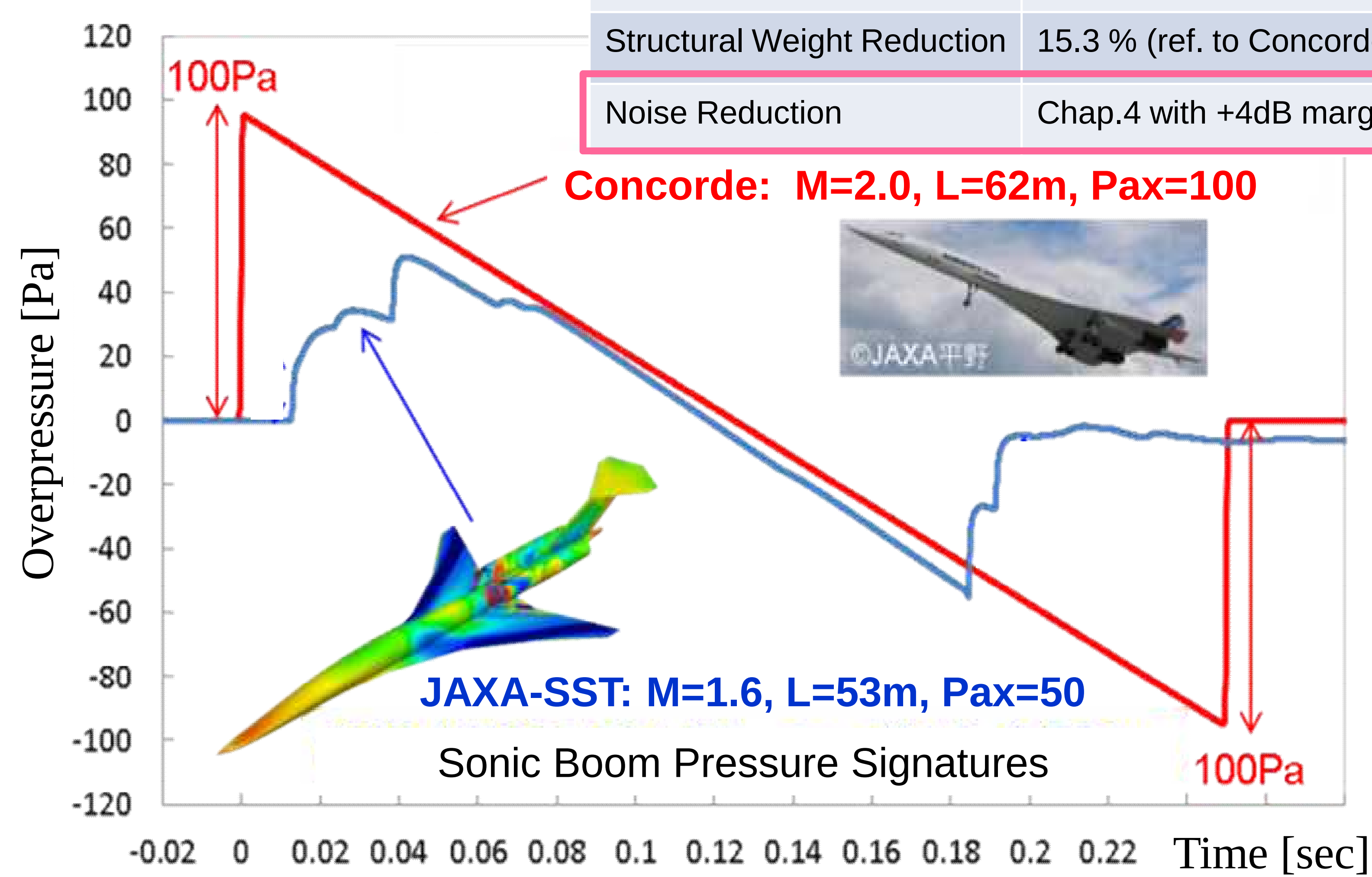
D-SEND#2 Flight Test Results (5/5)



Principal Results of S3 Program

A conceptual design configuration satisfied the 4 targets.

Technical Challenges	Results for targets
Sonic Boom Reduction	**22Pa < 25Pa (=25% of the boom by Concorde)**
L/D Improvement	8.1 @ M=1.6 cruise
Structural Weight Reduction	15.3 % (ref. to Concorde tech.)
Noise Reduction	Chap.4 with +4dB margin



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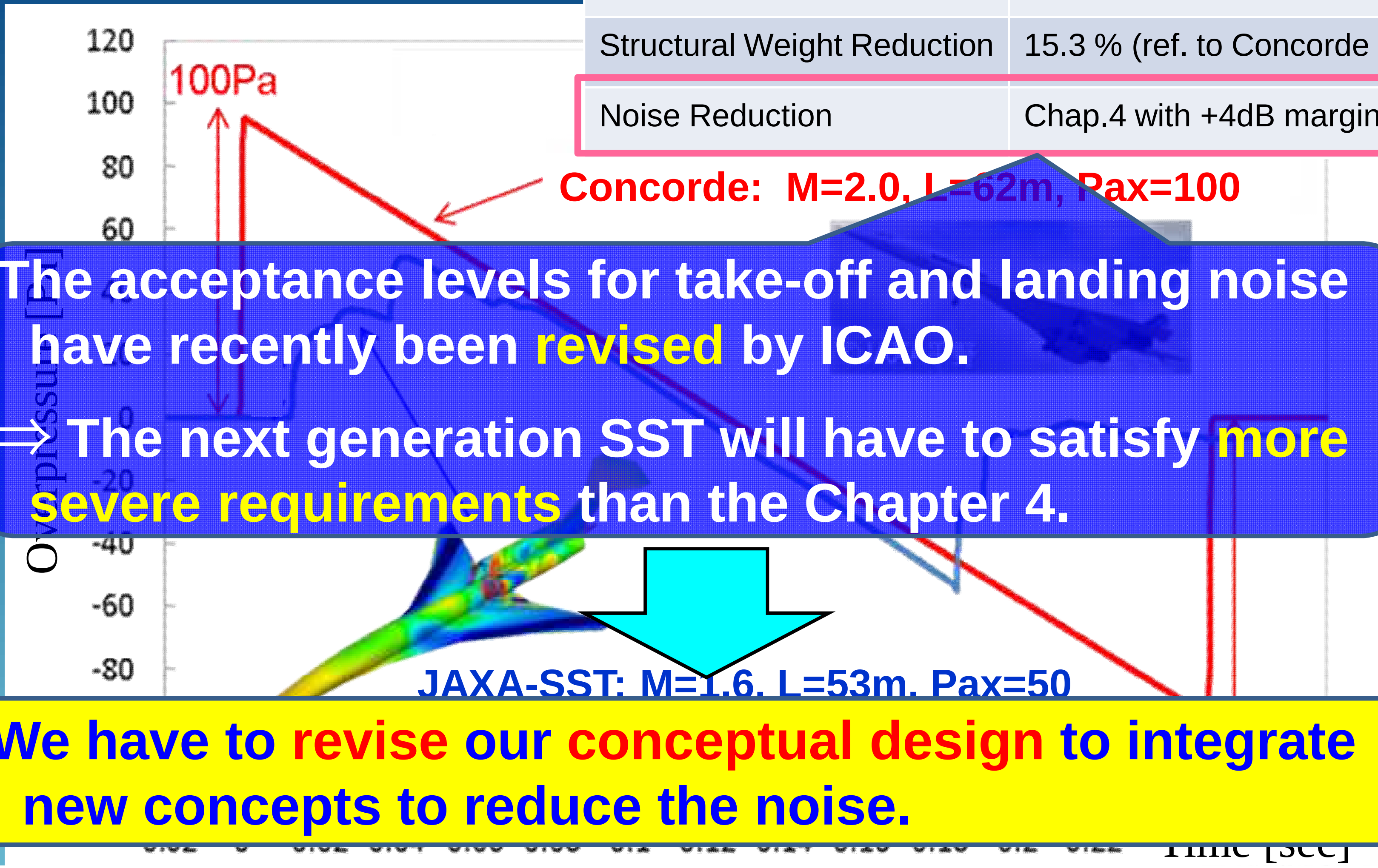


The acceptance levels for take-off and landing noise have recently been revised by ICAO.

⇒ The next generation SST will have to satisfy more severe requirements than the Chapter 4.

We have to revise our conceptual design to integrate new concepts to reduce the noise.

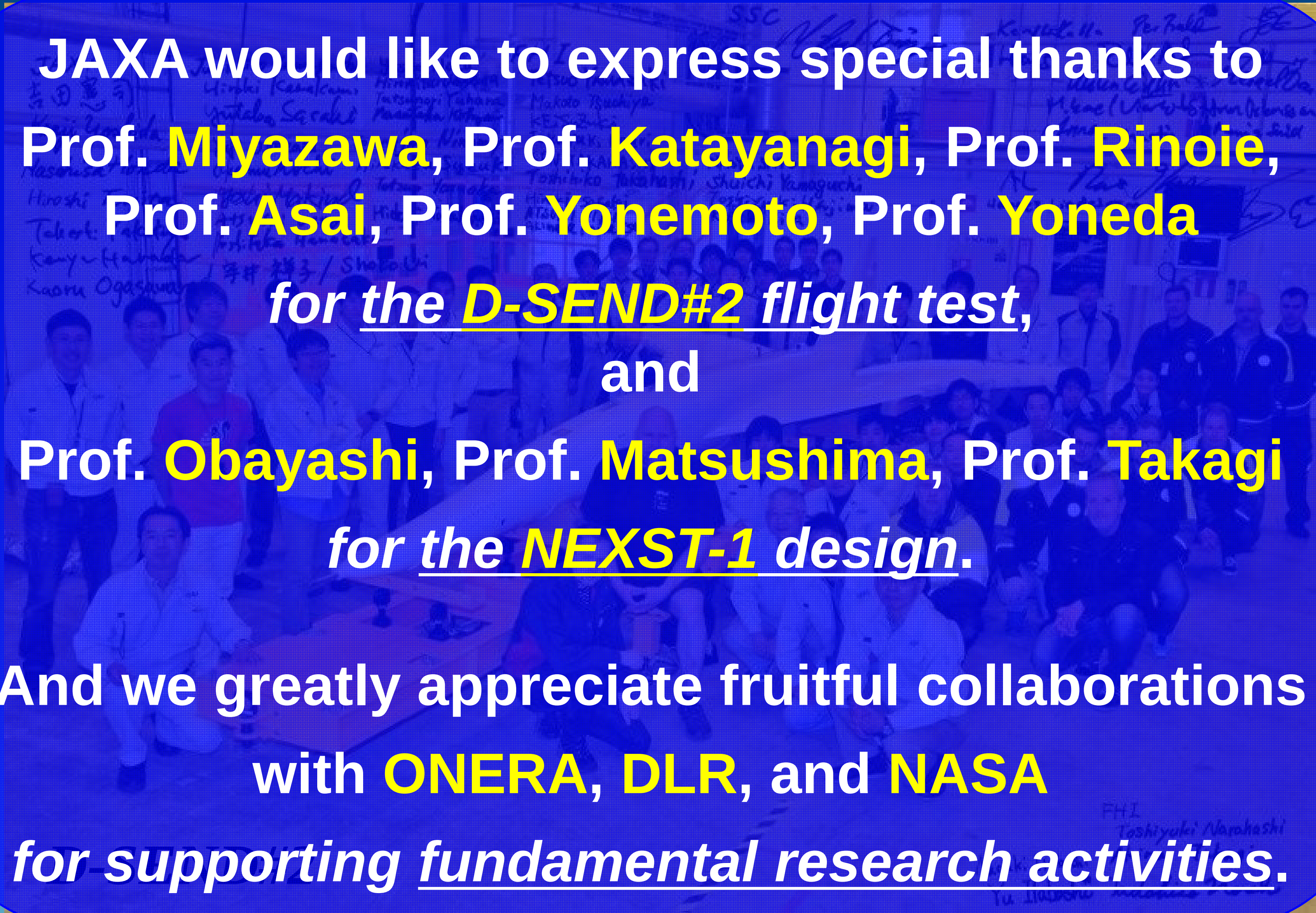
Concluding Remarks

The D-SEND#2 flight test was successfully conducted on July 24, 2015.
JAXA's low boom design concepts were validated in the flight test considering the atmospheric turbulence effect.

Consequently, JAXA was able to design a conceptual configuration that satisfied the technical target values.

In order to clear the path toward a future SST, JAXA will advance research activities including international collaborations and continue technical contributions to the discussion of ICAO.

Thank you for your kind attention!



JAXA would like to express special thanks to

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***for the D-SEND#2 flight test*,**

and

Prof. Obayashi, Prof. Matsushima, Prof. Takagi

***for the NEXST-1 design*.**

And we greatly appreciate fruitful collaborations with ONERA, DLR, and NASA

***for supporting fundamental research activities*.**

Thank you for your kind attention!