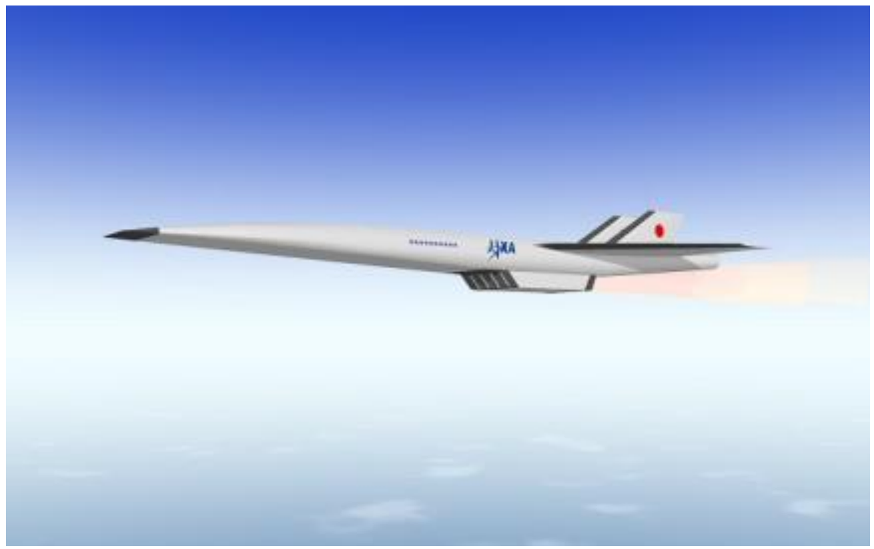
Aero-thermodynamic design of JAXA's hypersonic passenger aircraft



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Japan Aerospace Exploration Agency

1st International Symposium: "Hypersonic flight: from 100.000 to 400.000 ft"
Rome, Italy
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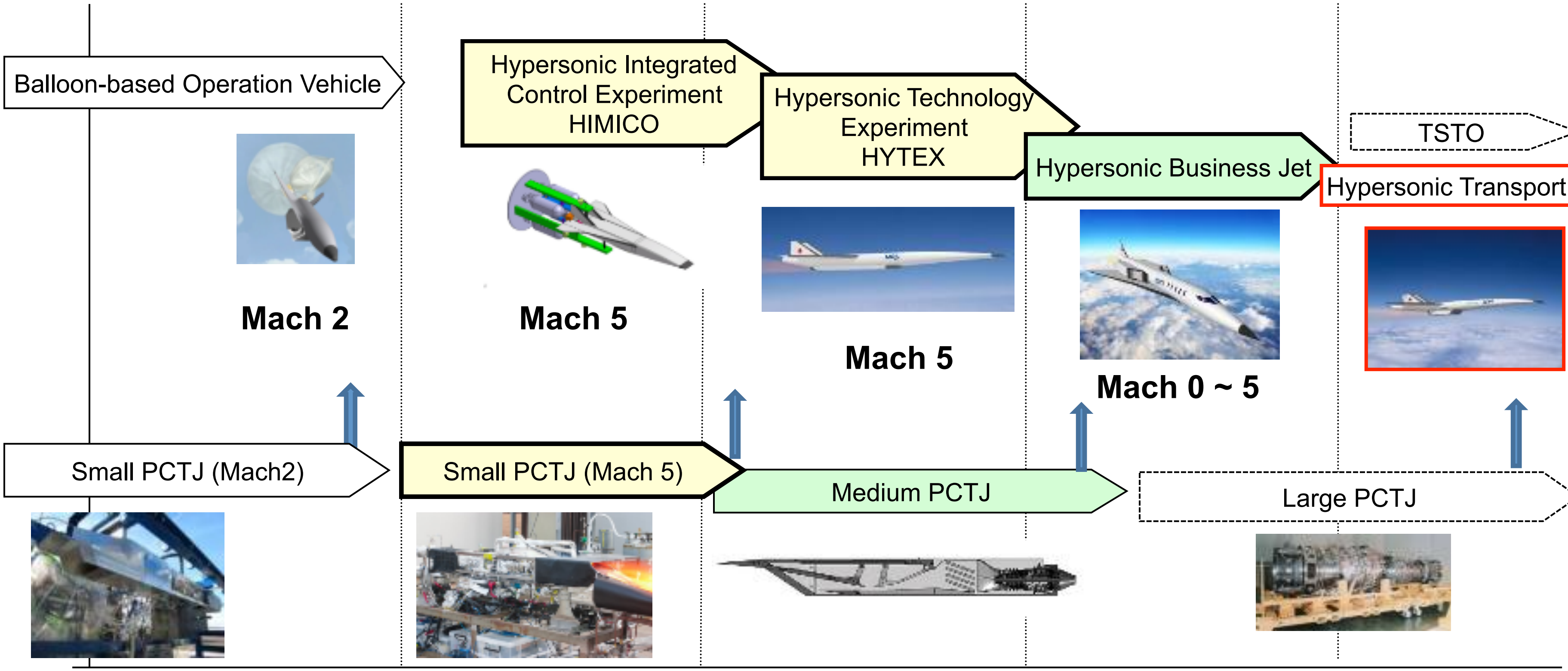
3. Hikari project (Europe-Japan Collaboration)
    - Brief introduction of Hikari's results
        - ✓ Evaluation of hypersonic engine performance

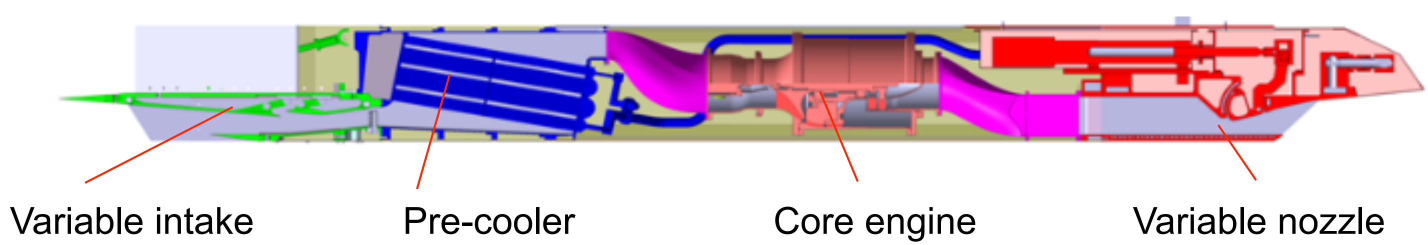
4. Summary

1. Hypersonic research at JAXA

➢ Hypersonic research at JAXA



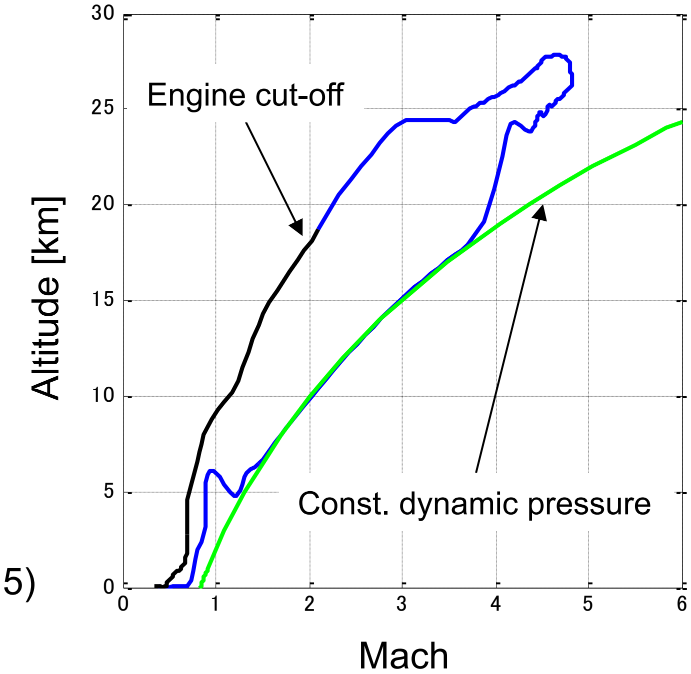
JAXA's R&D Roadmap on Hypersonic Transport Aircraft

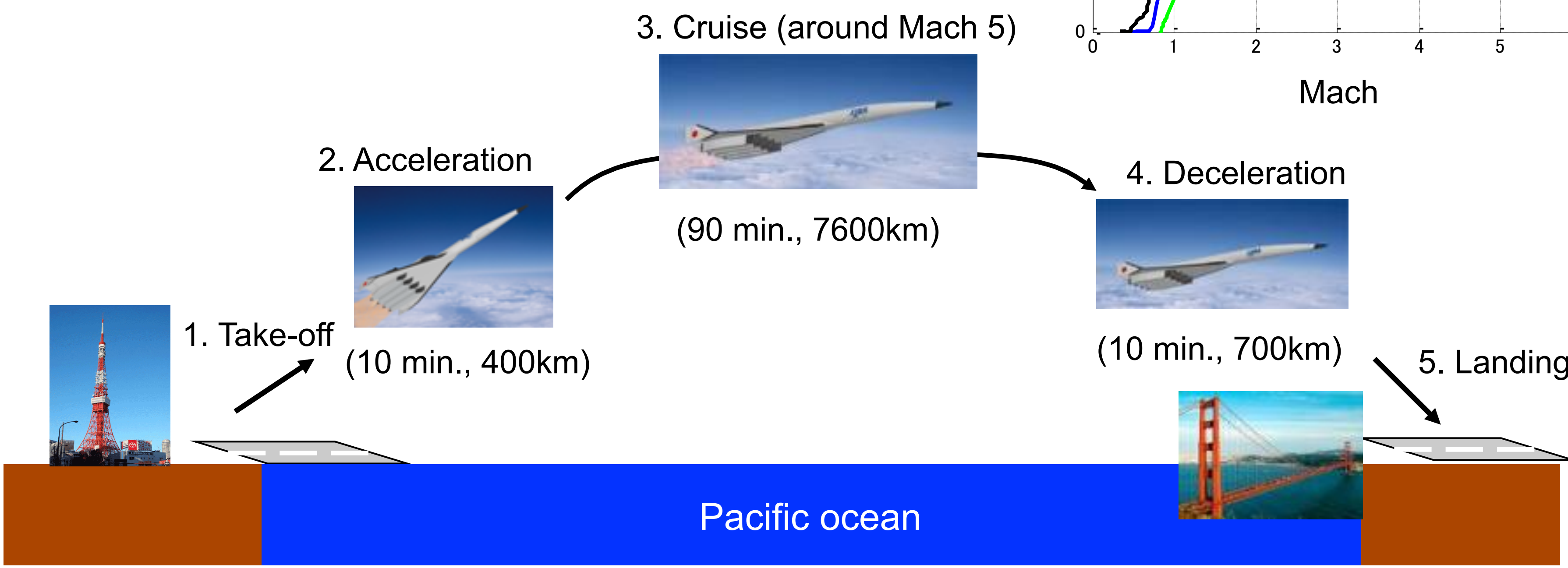


Pre-Cooled TurboJet Engine (PCTJ)

1. Hypersonic research at JAXA

- Hypersonic transport
  - 100 passengers
  - Mach 5 / Altitude 25 km
  - 2 hours from Tokyo to Los Angeles
  - Use existing airports

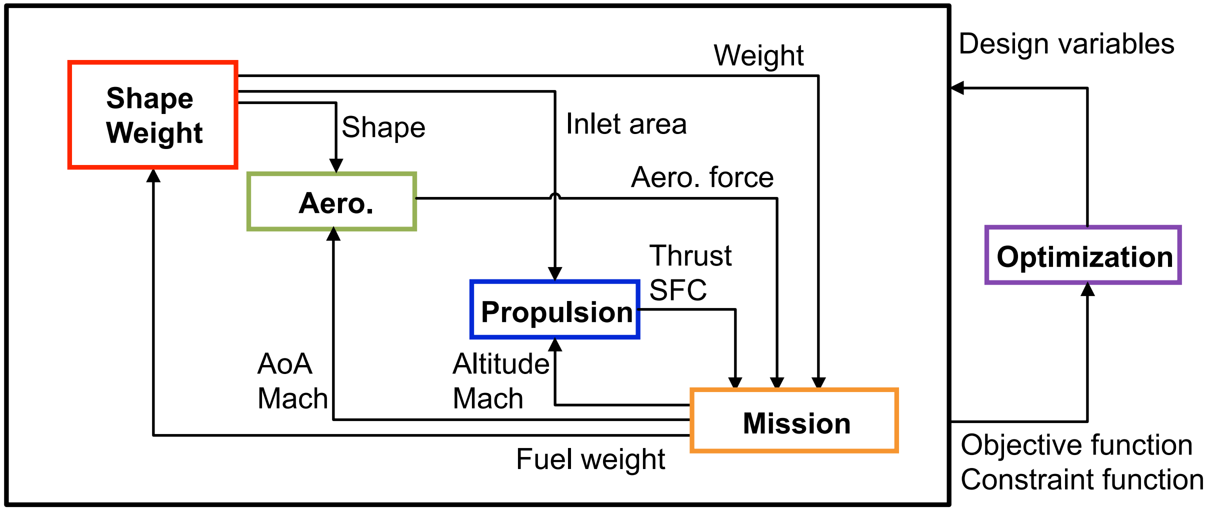


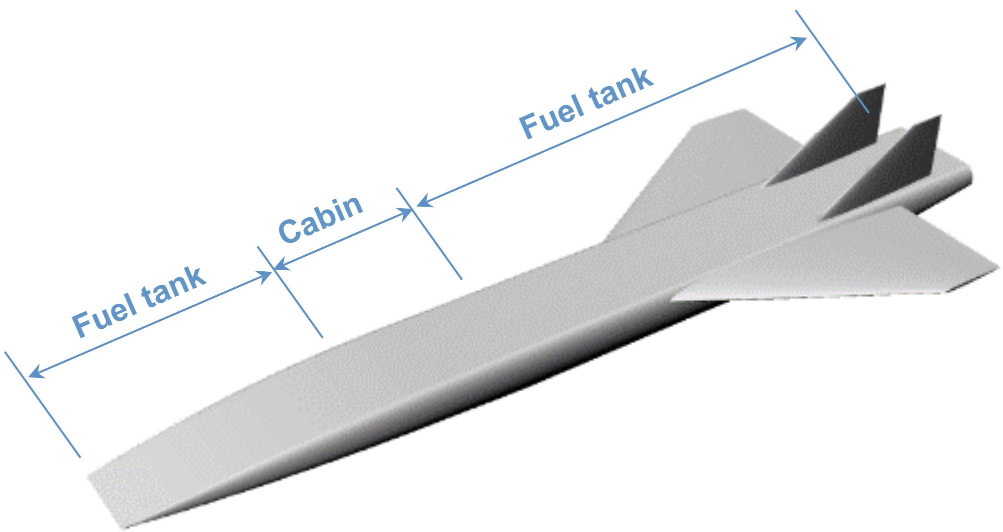


Mission profile

Baseline configuration

- Multidisciplinary design optimization





Baseline configuration

Baseline specifications	
MTOW	370 ton
Dry Weight	190 ton
Fuel Weight	180 ton
Length	87 m
Span	35 m
Wing Area	770 m^2
Engine	PCTJ
Thrust (SLS)	44 ton X 4

2. Aero-thermodynamic design

- Evaluation of Aerodynamic heating rate
  - In MDO, aero. heating was not taken into account.
  - TPS weight was estimated using empirical relation.
    - HASA, NASA-Contractor Report 182226
  - ⇨ CFD and wind tunnel test (WTT) were conducted to evaluate aero. heating.

WTT

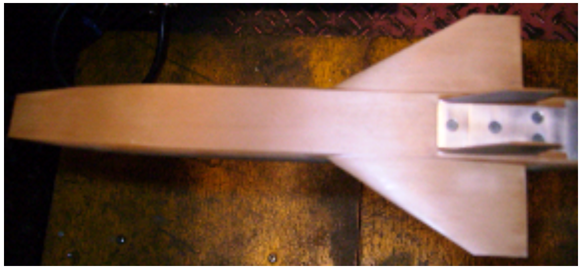
Validation

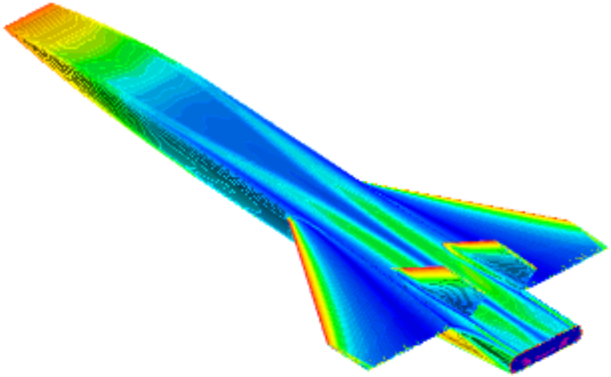
CFD
(WTT condition)

(Flight condition)

Aero. heating

TPS
design

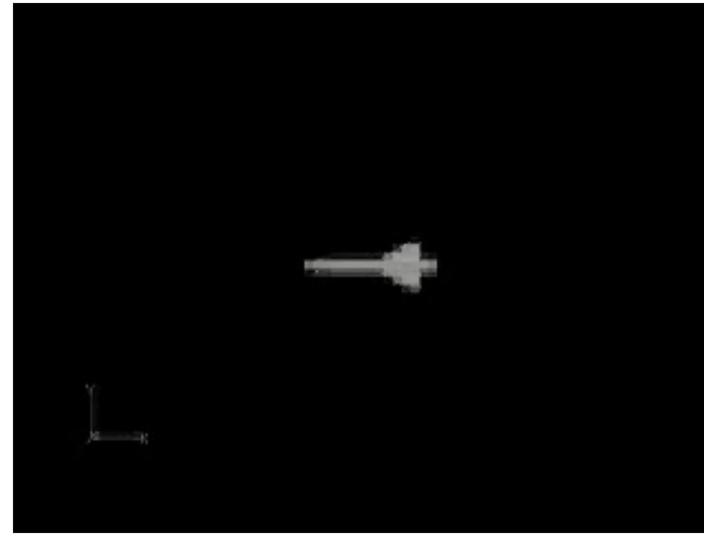




2. Aero-thermodynamic design

CFD analysis

- Navier-Stokes analysis
  - JAXA's UPACS code
    - Equation: RANS
    - Flux discretization: AUSMDV (3rd order)
    - Turbulent model: Spalart-Allmaras
    - Number of points: 15 million



  - Flow condition:
    - Wind tunnel condition
      - T0 = 700 [K], M = 5, AoA = 5 [deg]
      - Re = 1.7×10^6 (P0=1.0 [MPa]), Laminar
      - Re = 7.1×10^6 (P0=1.5 [MPa]), Turbulent
      - Tw = 303 [K], Isothermal wall

      ⇒ Validation

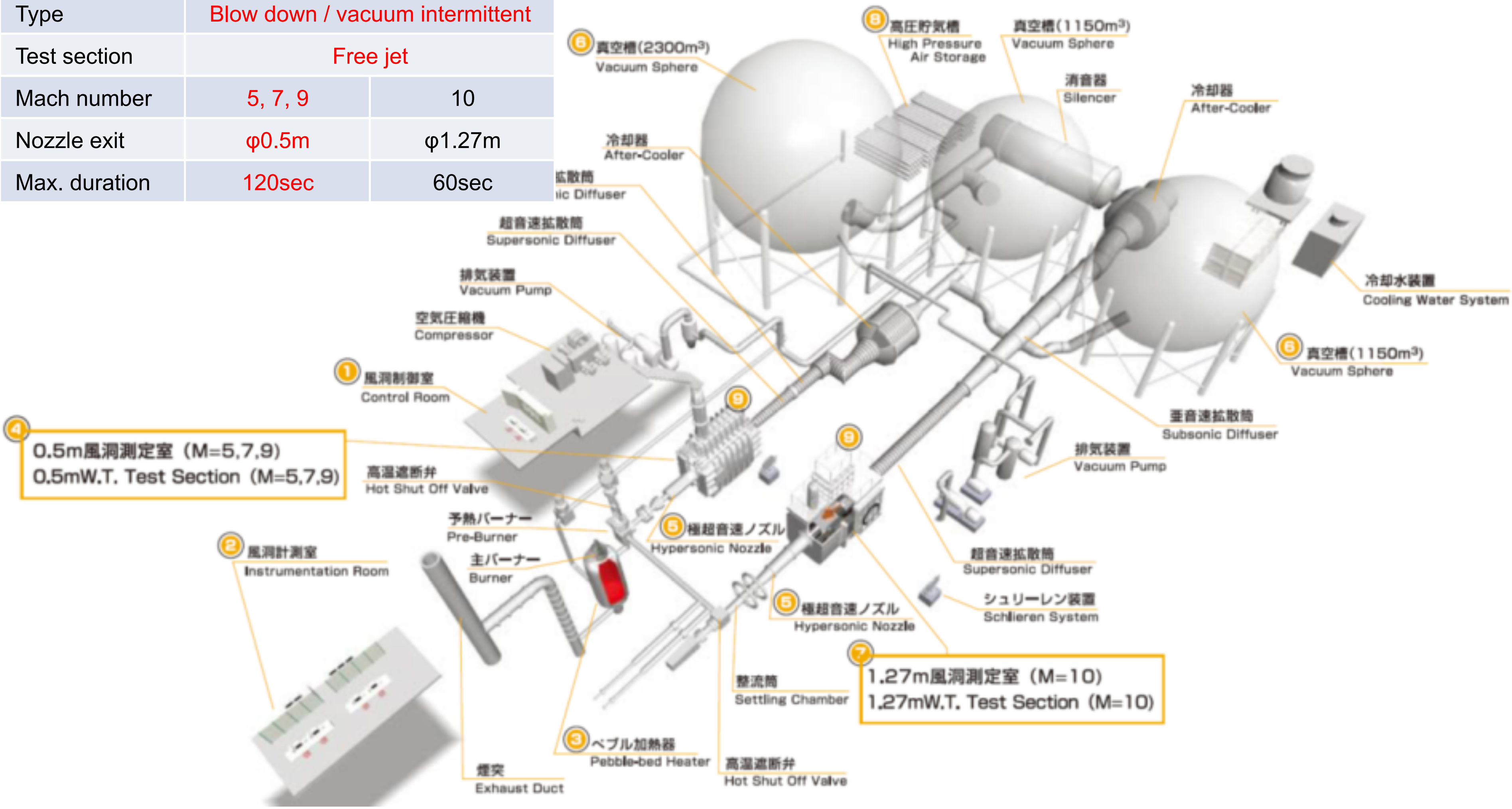
    - Flight condition
      - h = 24.2 [km], M = 5, AoA = 5 [deg]
      - Re = 4.0×10^8, Turbulent
      - Tw = 823 [K], Isothermal wall

      ⇒ TPS design

➢ Wind tunnel test

– JAXA HWT1

	HWT1	HWT2
Type	Blow down / vacuum intermittent	
Test section	Free jet	
Mach number	5, 7, 9	10
Nozzle exit	φ0.5m	φ1.27m
Max. duration	120sec	60sec



2. Aero-thermodynamic design

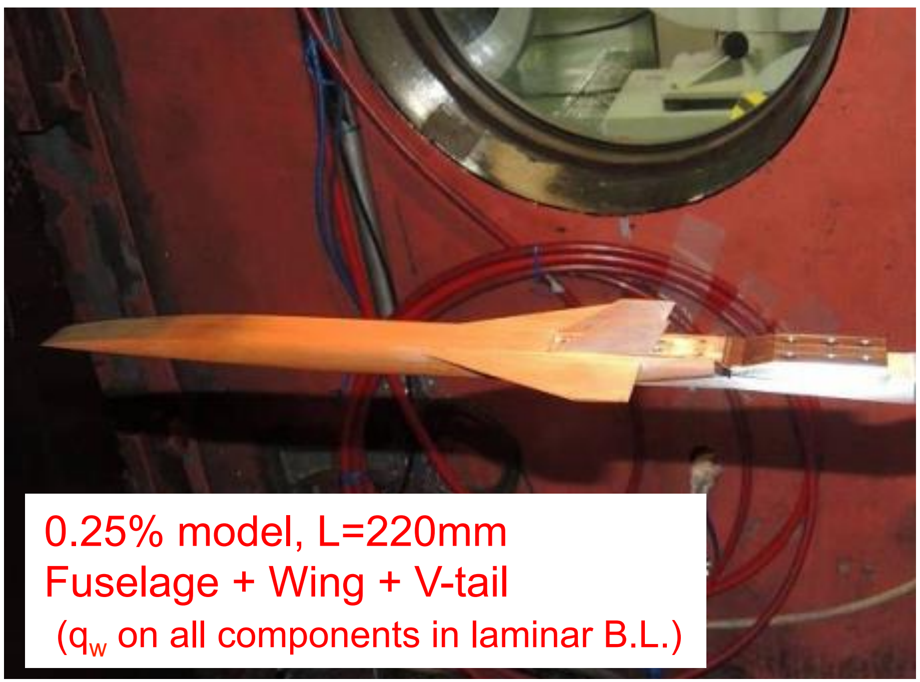
- Wind tunnel test
  - Wind tunnel model

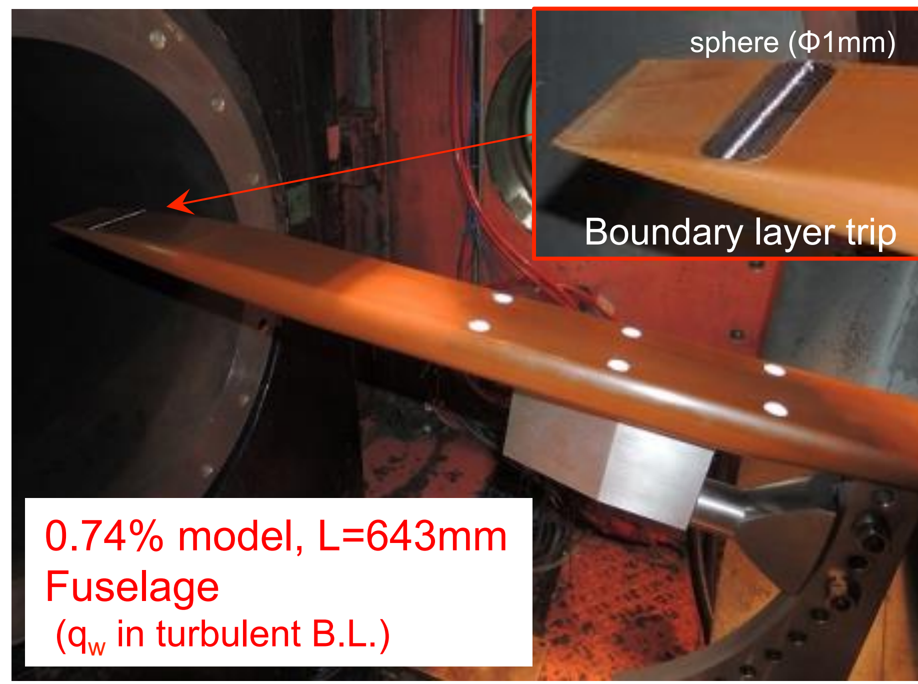
	0.25% model	0.74% fuselage model
Material	Vespel (polyimide plastic)	
M, AoA	M = 5, AoA = 5 [deg]	
P0, T0	1.0 [Mpa], 700 [K]	1.5 [MPa], 700 [K]
Re	1.7×10^6, Laminar	7.1×10^6, Turbulent
Measurement	Temperature (IR thermography)	

Temperature

semi-infinite,
1D heat equation

Aerodynamic heating

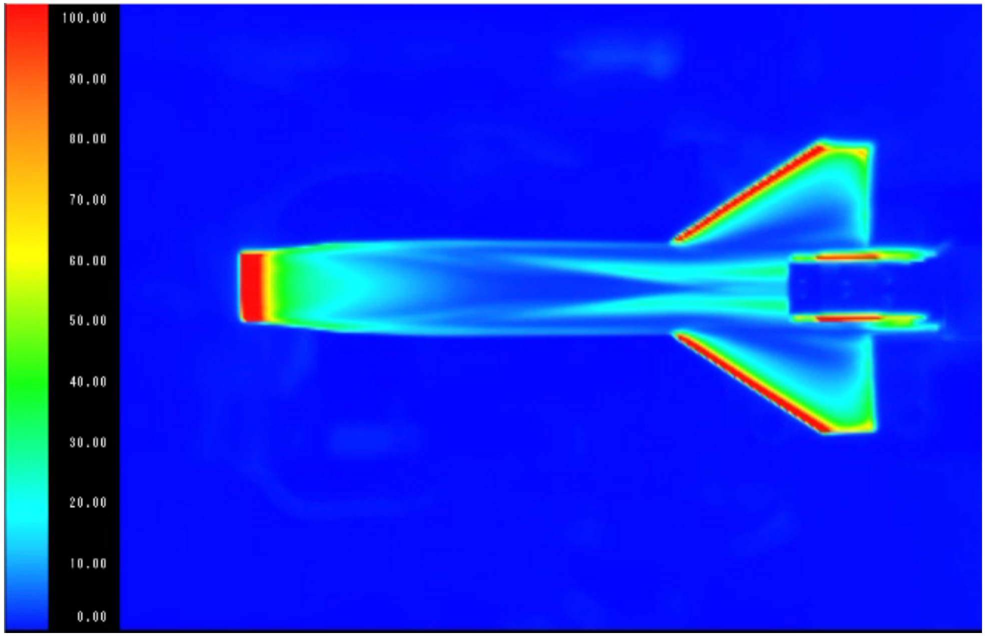


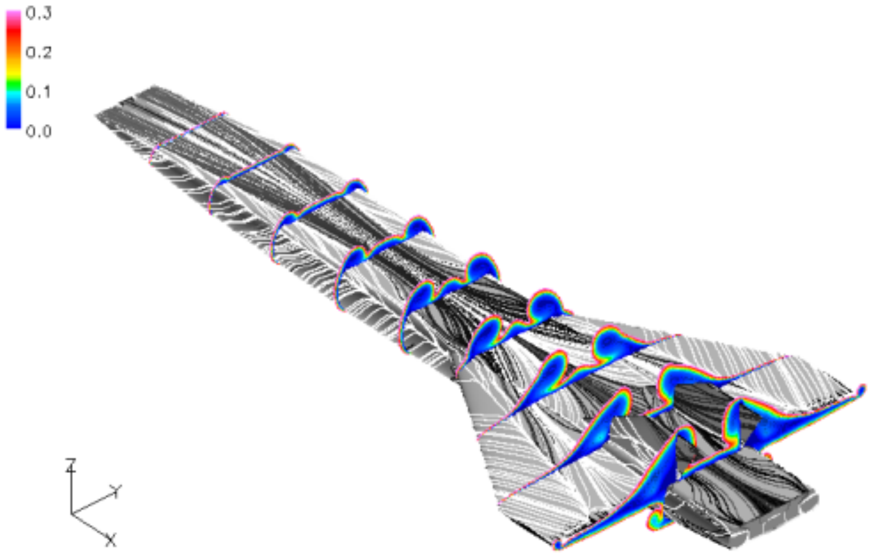


Wind tunnel model

2. Aero-thermodynamic design

- Result of WTT
  - Result of 0.25% model (Laminar boundary layer)
    - Wind tunnel test



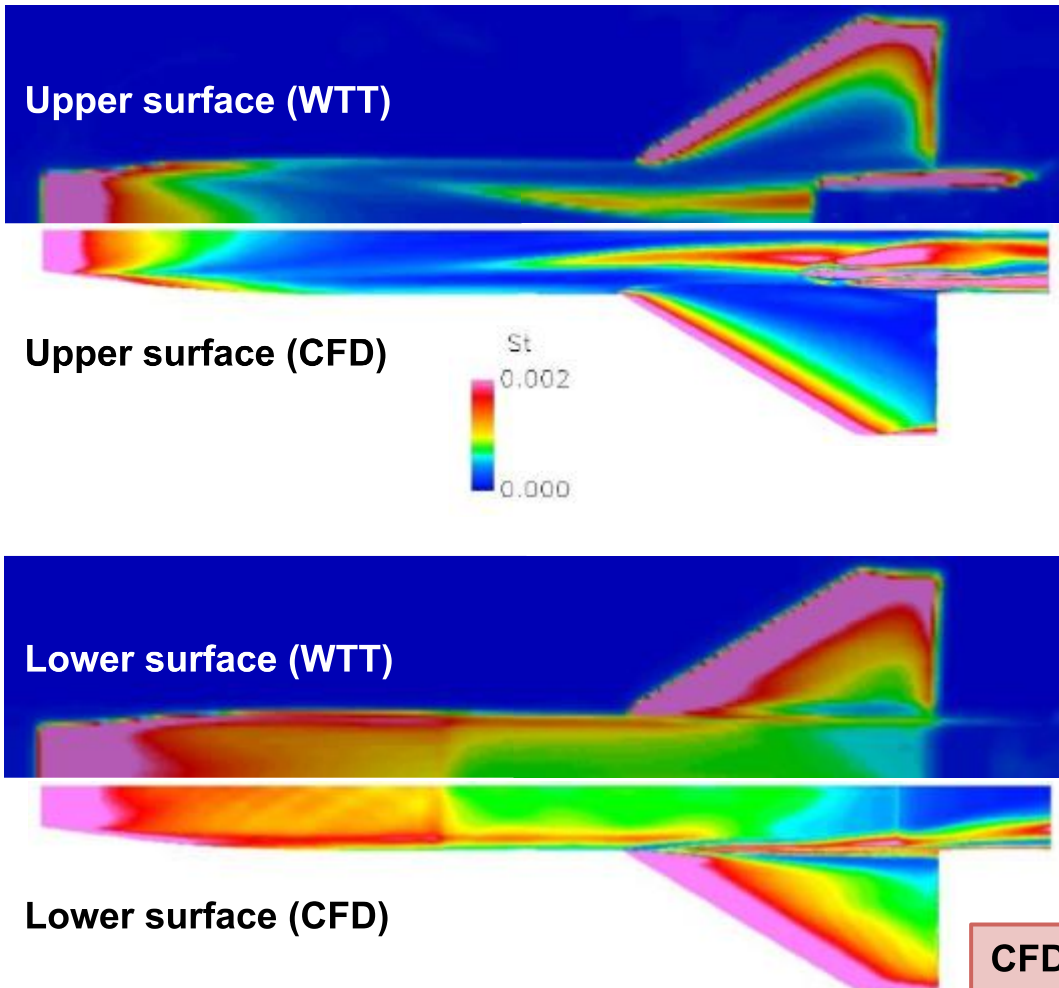


Aerodynamic heating
(M = 5, AoA = 5 [deg], Upper surface)

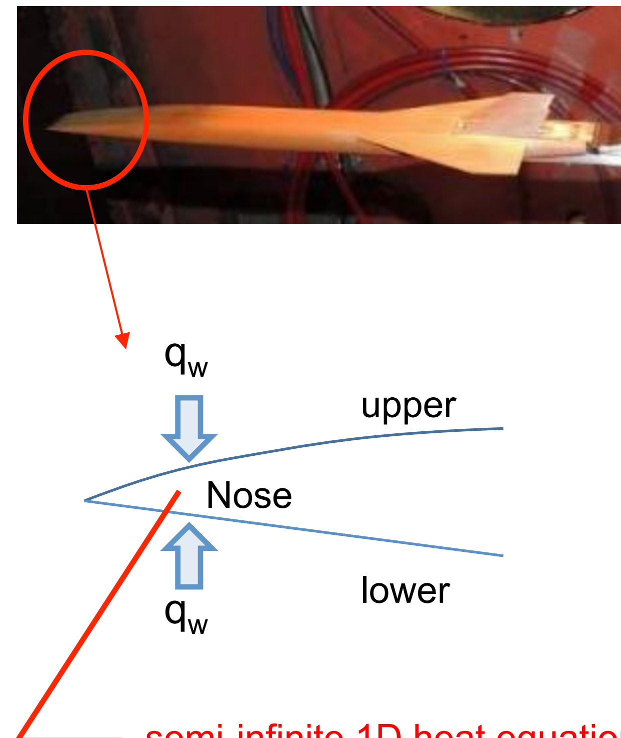
Aerodynamic heating on all components was measured.
Large aerodynamic heating due to separated vortex was observed.

2. Aero-thermodynamic design

- Comparison between CFD and WTT
  - Result of 0.25% model (Laminar boundary layer)



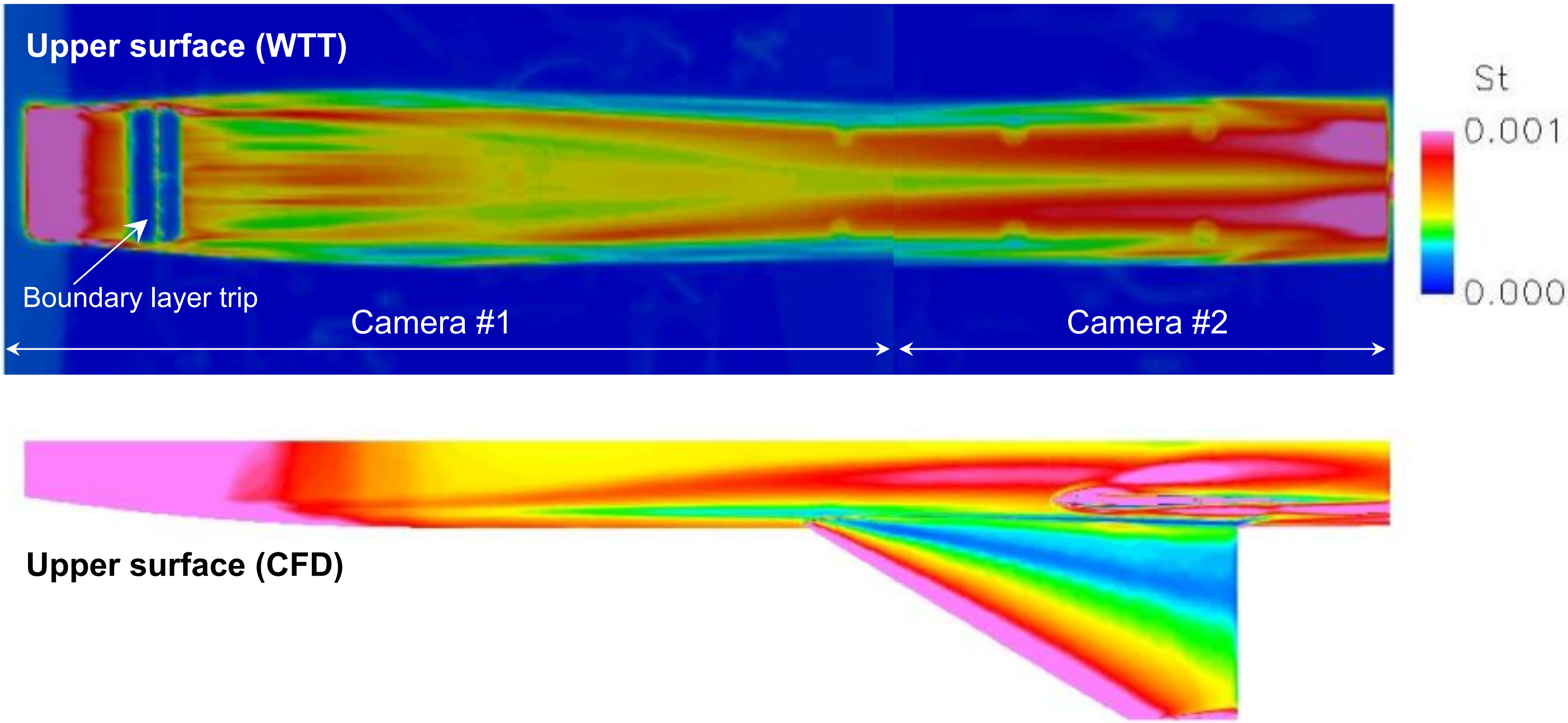
Distribution of Stanton number at AoA=5deg.



semi-infinite,1D heat equation is not correct.
⇨ Overestimation in WTT

CFD agrees with wind tunnel test qualitatively except in region where thickness of model is thin.

- Comparison between CFD and WTT
  - Result of 0.74% fuselage model (Turbulent boundary layer)

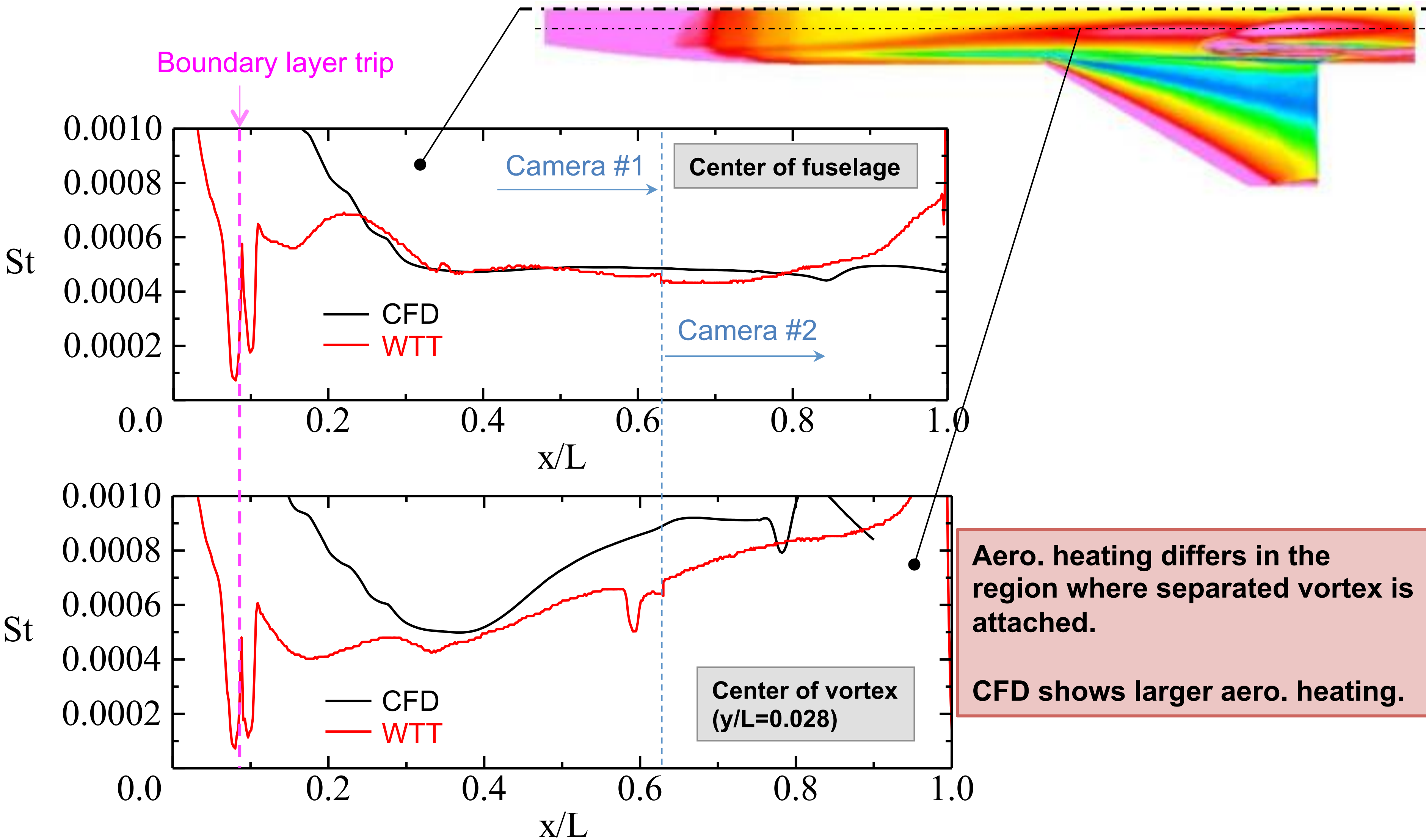


Distribution of Stanton number at AoA=5deg.

Boundary layer transition was observed behind boundary layer trip.
High aero. heating due to separated vortex was observed also in turbulent B.L.

2. Aero-thermodynamic design

- Comparison between CFD and WTT
  - Result of 0.74% fuselage model (Turbulent boundary layer)

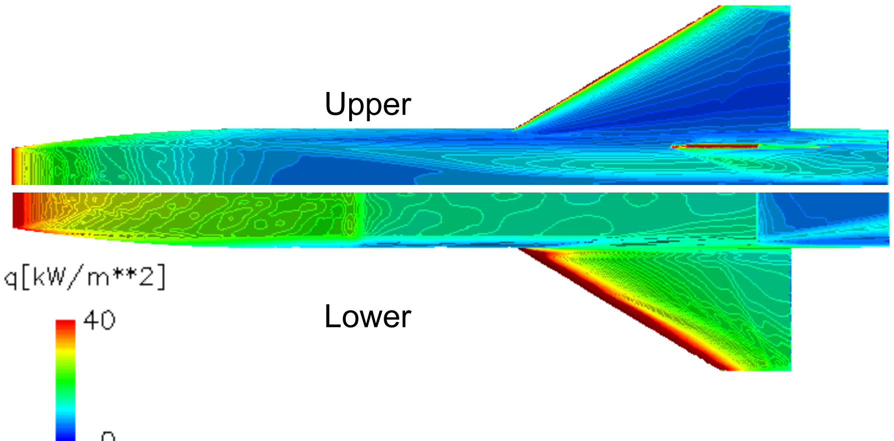


Aero. heating differs in the region where separated vortex is attached.

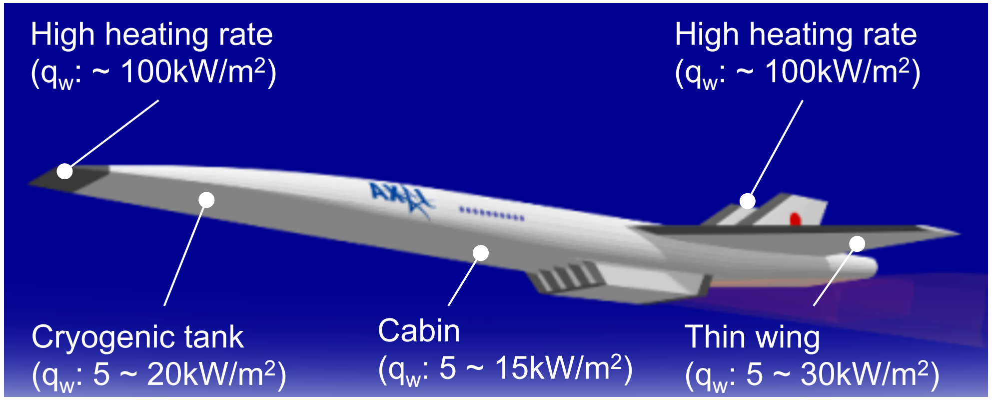
CFD shows larger aero. heating.

2. Aero-thermodynamic design

➢ TPS design based on CFD result



CFD result at flight condition



Super alloy (Inconel) honeycomb should be applied in the region where aerodynamic heating is large (e.g., nose and leading edge).

Ti multi-wall can be applied in the region where qw is about 20kW/m^2.

◆ Summary

- ✓ Results of wind tunnel test and CFD agreed qualitatively.
- ✓ CFD showed larger aerodynamic heating in the region where separated vortex is attached.
  - ⇨ Different turbulent model should be tested in the future.
- ✓ TPS was designed based on aerodynamic heating obtained by CFD.
  - ⇨ TPS material was selected.

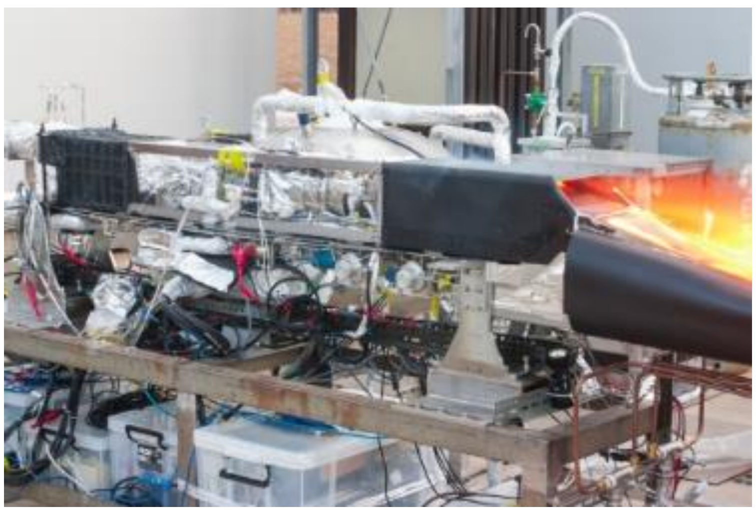
3. Hikari project

Europe-Japan "HIKARI" Collaboration

Objectives: Market analysis, Environmental Impact Assessment, Aircraft Systems Study, Propulsion, Common R&D Roadmap

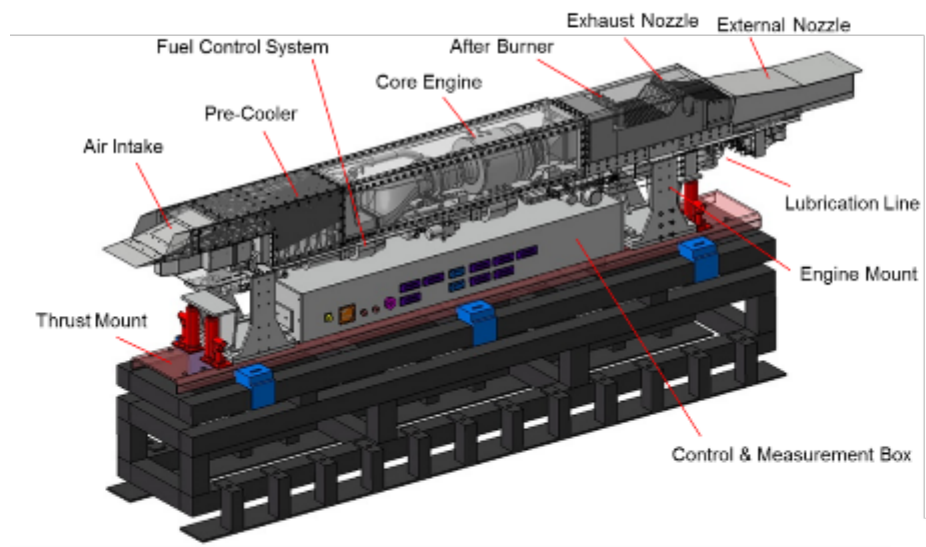
Task of JAXA: Performance evaluation of Hypersonic Pre-Cooled Turbojet Engine

Status: Mach 4 experiment has been successfully conducted. Performance map will be provided to research partners in August.



Mach 4 Direct Connect Test

-High Temperature Structure
-Mach 4 Operation



Mach 4 Wind Tunnel Test

-Starting Sequence
-Heat Structure of Variable Mechanism

Hypersonic Pre-Cooled Turbojet Engine (JAXA)

4. Summary

- Hypersonic passenger aircraft was studied using MDO technique.
  - Baseline was defined.

- Aerodynamic heating rate was evaluated by both CFD and WTT.
  - CFD and WTT showed qualitative agreement.
  - TPS was designed based on aerodynamic heating rate obtained by CFD.

- Results from Hikari project was briefly introduced.

- Future works:
  - Plan for experimental vehicle with small PCTJ flying at Mach 5.