ICAS Emerging Technology Forum 2019

Digital Transformation in Aerospace

ISSAC (Integrated Simulation System for Aerospace Vehicles)
- Toward Digital Flight with High-Fidelity Numerical Simulation -

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Talk Contents

- JAXA aeronautics and its activities
- What is ISSAC ? Overview of ISSAC from CPS viewpoint
- ISSAC current work and results
- Conclusions and future plan

ISSAC

JAXA ATD Missions

1. Contribute to enhancing Japanese aviation industry's global competitiveness
2. Contribute to realizing secure society through enhanced air transportation safety
3. Contribute to creating future air transportation breakthrough

Accordingly, JAXA ATD implements three R&D programs based on Japanese government's R&D plans in response to social needs, while also engaging in research for science and basic technologies that support the three programs and the sustainable R&D of future aviation technologies

JAXA ATD R&D Activity Diagram

Enhancing global competitiveness

ECAT

Environment-Conscious Aircraft Technology Program

Aviation safety / Secure society

STAR

Safety Technology for Aviation and Disaster-Relief Program

Technology innovation

Sky Frontier

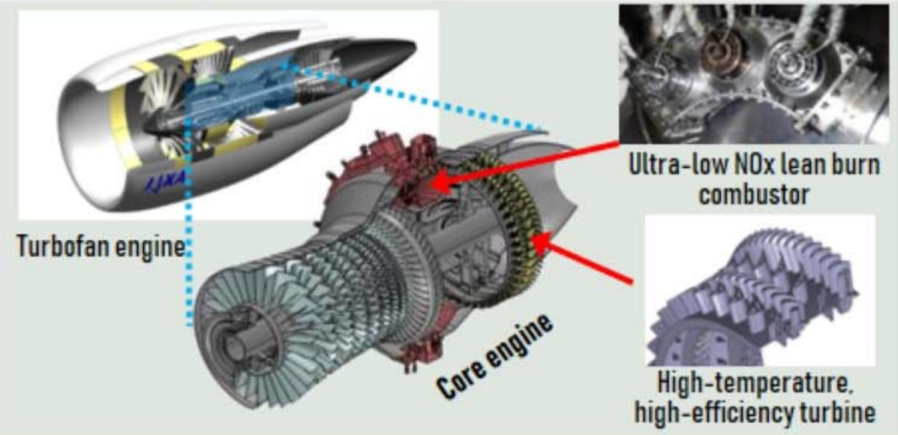
Sky Frontier Program

Science & Basic Tech

Aeronautical Science and Basic Technology Research

JAXA ATD ECAT/STAR/SF Programs' R&D

Core engine technology demonstration



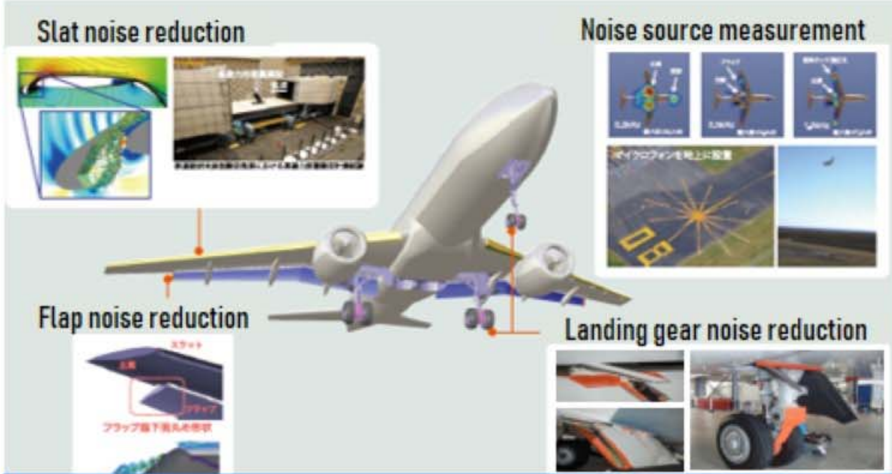
Realize world-leading environmental performance with advanced combustor and new material turbine technologies

Turbulence accident prevention

Turbulence information display   Boeing ecoDemonstrator 2018

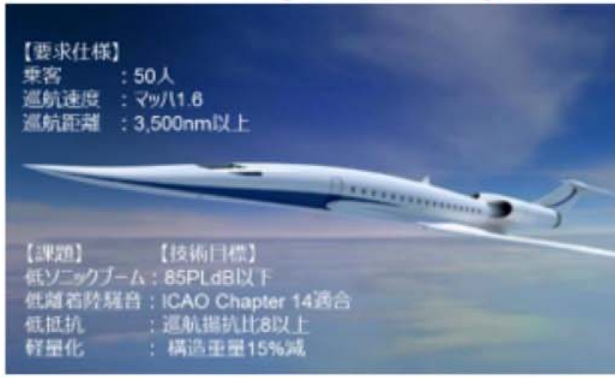
Reduce turbulence related accidents by developing a clear-air turbulence detection system that uses LIDAR laser beams

Airframe noise reduction



Demonstrate feasibility of low-airframe-noise design technologies promising significant additional noise reduction

Low-boom supersonic flight



Low-boom design concept flight demo at Esrange 2015

Contribute to the realization of overland low-boom supersonic flight by developing its key technologies

JAXA ATD Technology Transfer

Integrated aircraft operation system for disaster relief (D-NET)

- Enables efficient real-time management of resource allocation and mission planning during disaster response operations via digital communication, optimizing the application of available assets
- Put into operation for the first time in 2014 by the Fire and Disaster Management Agency, the system is equipped on all fire-fighting and disaster-relief helicopters throughout Japan since 2017. Contributed to increased efficiency in disaster-relief activities following major earthquakes and floods in recent years in Japan.

Portable system (commercialized in 2015)

Validation & evaluation at disaster drill

Airport Low-level Wind INformation provider (ALWIN)

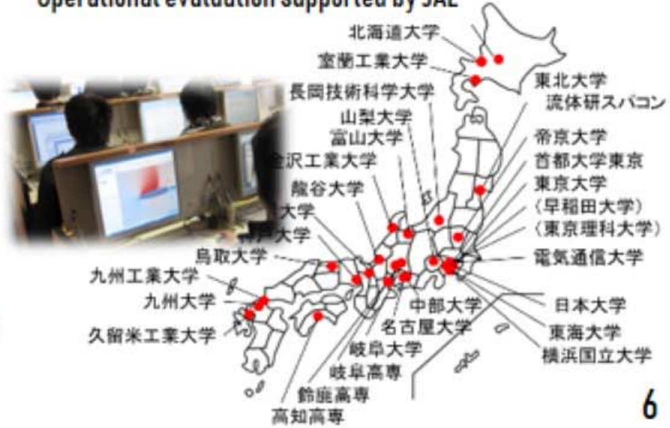
- Jointly developed by the Japan Meteorological Agency (JMA) & JAXA
- Transmits detailed and precise wind profiles on final approach paths in real-time, helping pilots and operators monitor sudden changes in winds
- Became operational at Haneda & Narita International Airports in Apr. 2017

Operational evaluation supported by JAL

Fast CFD aerodynamic analysis software FaSTAR† - Fast Unstructured CFD Code -

- World's fastest CFD aerodynamic analysis software, shortening the computation time of flow about an entire aircraft from 1 day to 2 minutes
- Used by 26 universities & 4 technical colleges for educational/research purposes as well as by industry like MHI

† FaST Aerodynamic Routines



JAXA ATD Open Innovation

Next-generation aeronautical innovation hub center (Established Apr. 2015)

- **Bridges research and society/industry**: needs-based themes
- **Open innovation**: Gathering of experts and knowledge from a wide range of technical areas
- **Creates high-impact outputs**: Research output with high social impact

WEATHER-Eye consortium

- Established in Jan. 2016 as a platform to develop technologies that can **prevent aircraft accidents caused by special weather (snow & ice, lightning, volcanic ash, etc.)**
- Promotes cross-sectoral and multidisciplinary collaboration amongst research institutions, manufacturers, and universities from various backgrounds (weather, civil engineering, paint, sensors, etc.) as well as users (airlines). Current membership: **22 organizations**

2nd WEATHER-Eye open forum (Nov. 2017)

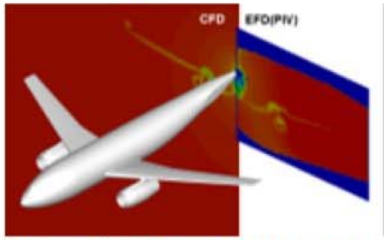
ÉCLAIR* consortium

- Established in July 2017 to realize "**emission-free aircraft**" that can significantly reduce CO2 emission from air transportation
- Serves as an open-innovation platform where Japan's cutting-edge electric and aviation technology stakeholders can collaborate. Current membership: **43 organizations**

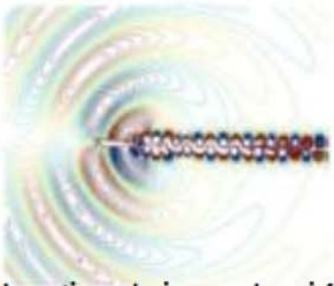
* Electrification ChaLlenge for AIRcraft (ECLAIR) consortium

JAXA ATD S&BT R&D & Facilities

Aerodynamics

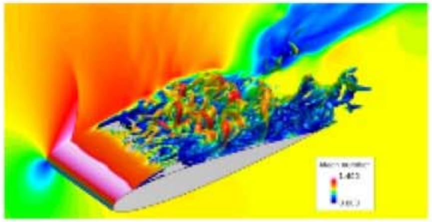


Comparison between EFD and CFD

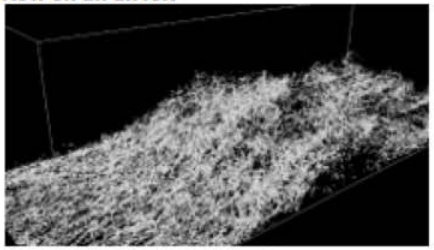


Acoustic analysis around an airfoil

Numerical simulation

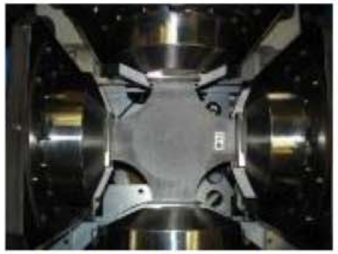


Detached eddy simulation of buffeting flow on an airfoil



Direct numerical simulation of a turbulent boundary layer with separation

Structure



Biaxial load test system

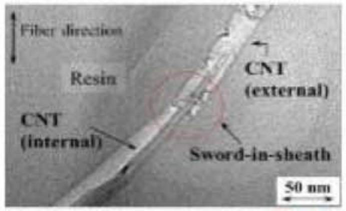
Multi-axis vibration evaluating system

Flight simulator

Aircraft

Helicopter

Composite material



TEM micrograph of composite(20 ply).

Wind tunnel (11 in total)

6.5mx5.5m low-speed

2mx2m transonic

1mx1m supersonic

1.27m hypersonic

Experimental aircraft

Hisho (2012)

MuPAL-α (1988)

BK117-C2 (2013)

JAXA ATD Motto

Provide with "solid" technologies that impact society

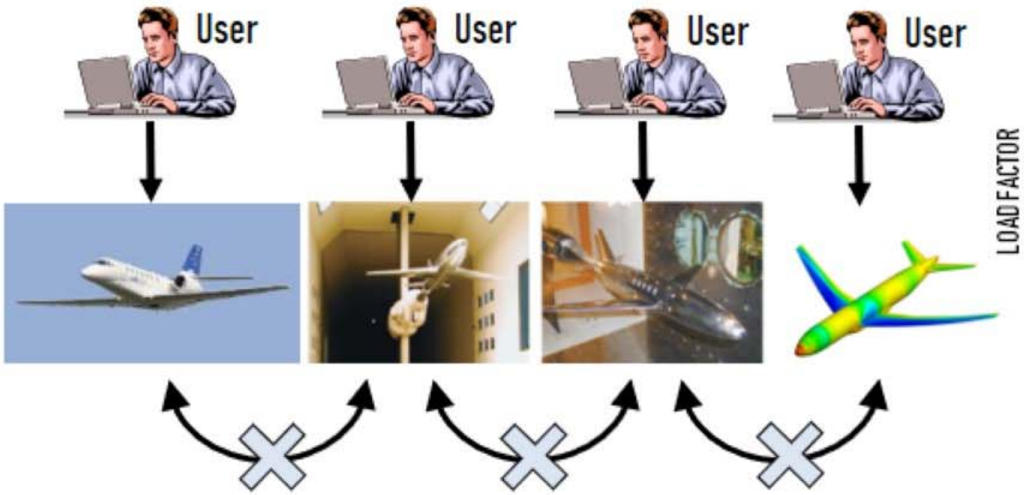
Transfer effective/practical technologies to society & industry

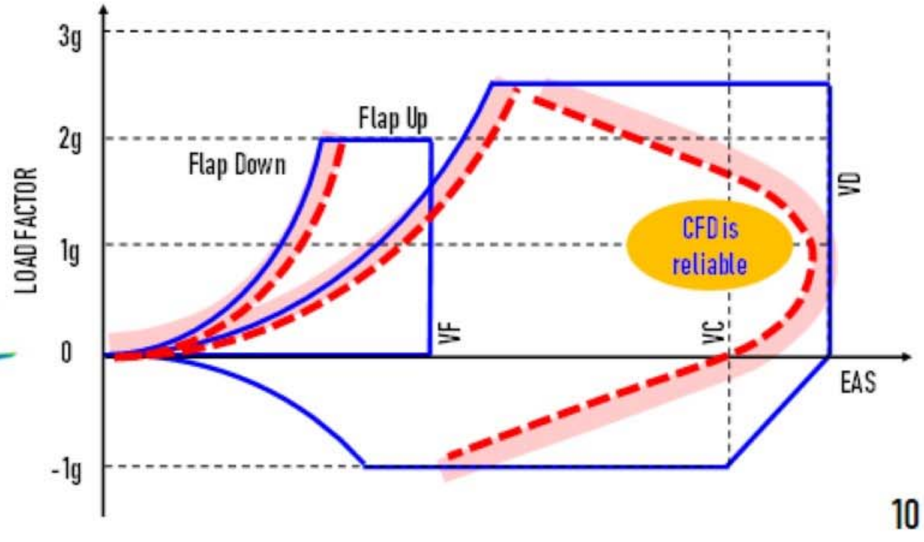
Produce future technologies that "wow" the public

Enhance efforts to sow the seeds of next-generation technologies

Issues for JAXA ATD, Aviation industry

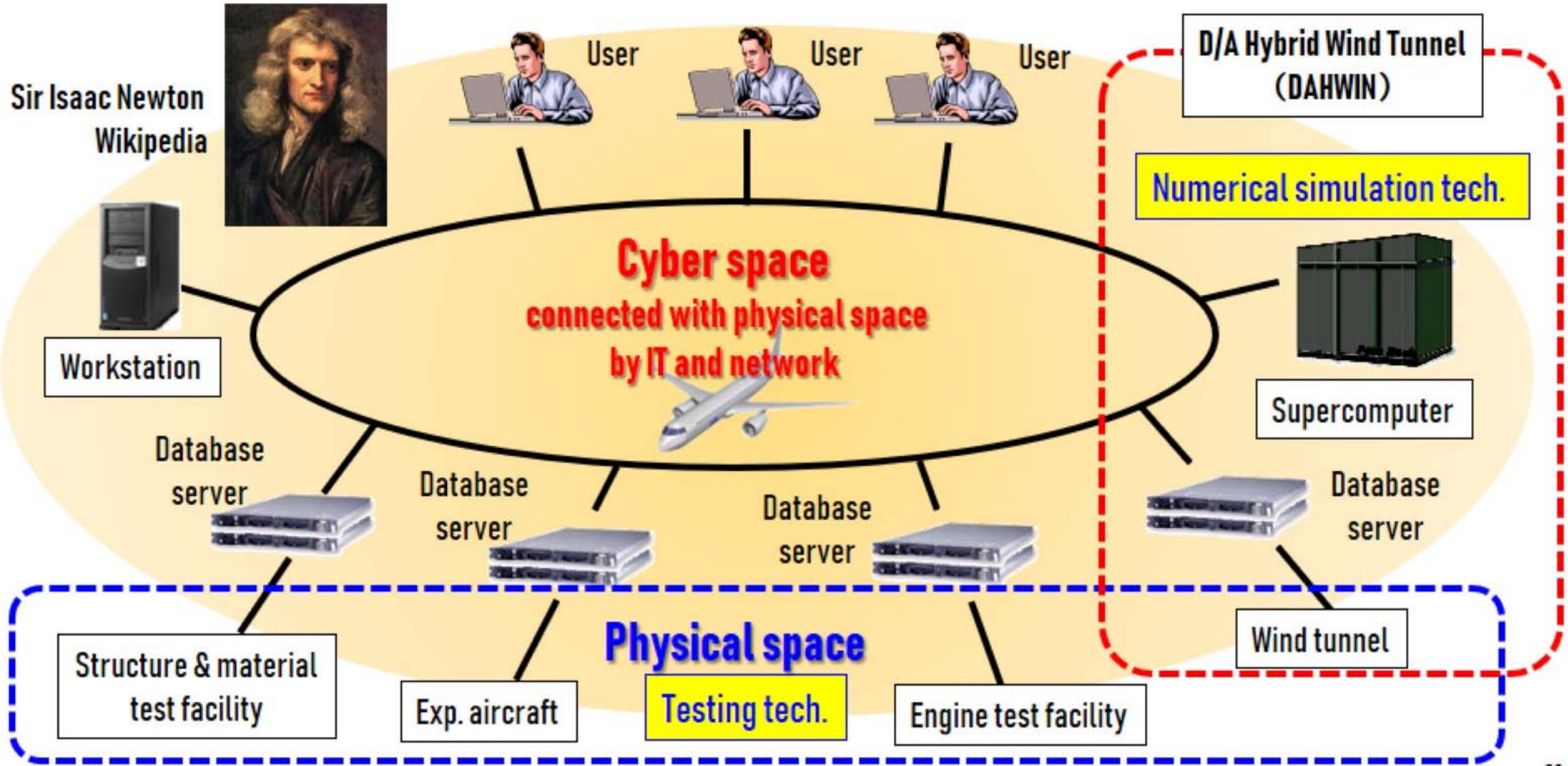
- Traditionally less communication and interaction between research fields as aerodynamics, structure, control, etc. Problems to be solved today mostly multidisciplinary or multi-physics
- CFD greatly advanced to date, though its usage still limited to the cruise condition or design point . Extended application to the entire flight envelope required
- The commercial aircraft development worldwide highly competitive because its market expected to be doubled in the next 20 years. Severe for Japanese aircraft companies compared to those in EU and US due to the lack of experience in aircraft design and less accumulated data/know-how. In order to overcome this, essential to establish technologies for acquiring data/know-how, and enabling rapid and streamlined aircraft development.



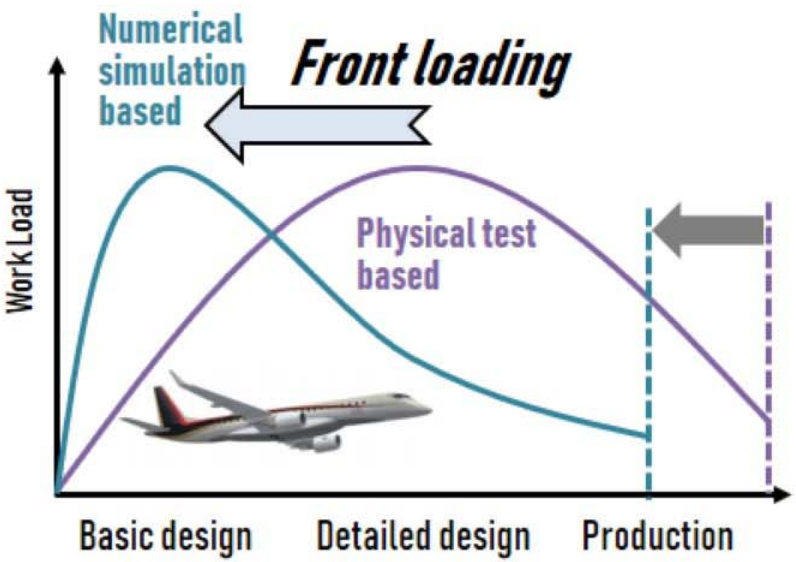


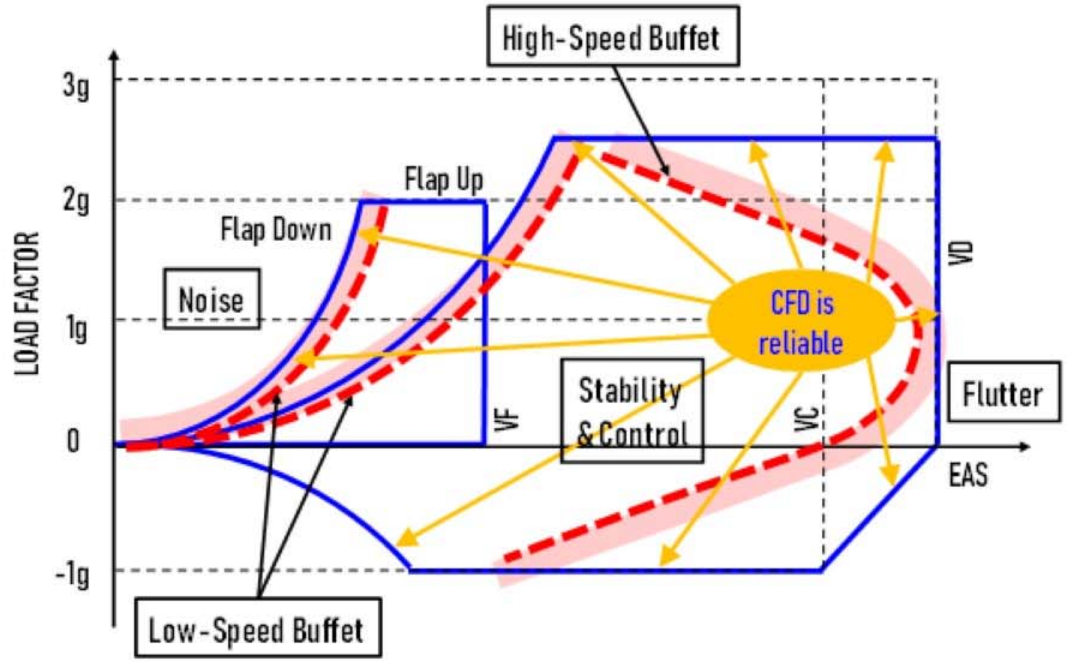
ISSAC (Integrated Simulation System for Aerospace Vehicles)

Launched a four-year (2018-21) project called ISSAC to develop an **integrated simulation-based system** in which the **high-fidelity numerical simulations** and the existing **facilities** such as wind tunnels, experimental aircraft are **integrated in the cyber-physical space** with the support of IT/NW technologies



- **Objectives**
  - To contribute the realization of accelerated development of aircraft at lower cost and risk by shifting front loading with high-fidelity numerical simulation
  - Particularly to extend the role of the numerical simulation to entire flight envelope, ultimately leading to 'digital flight' in the future

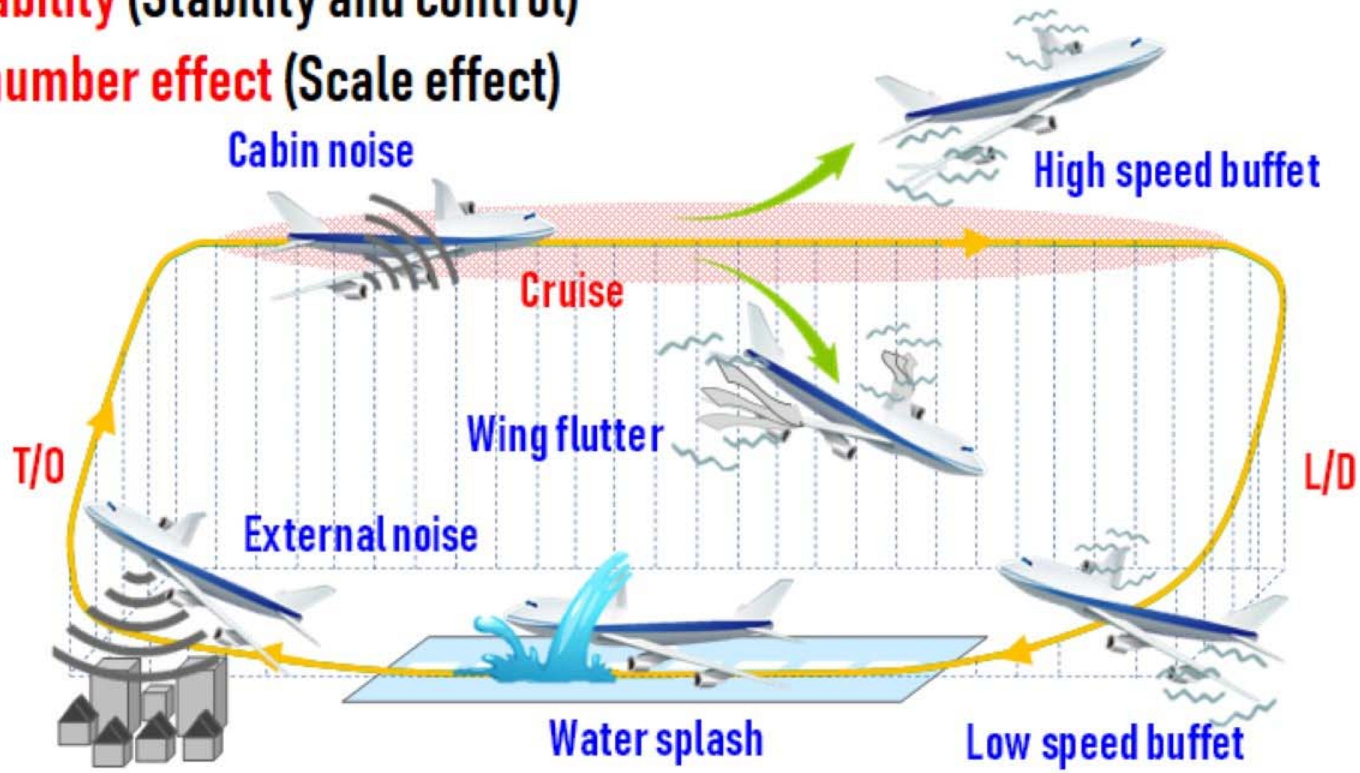




ISSAC

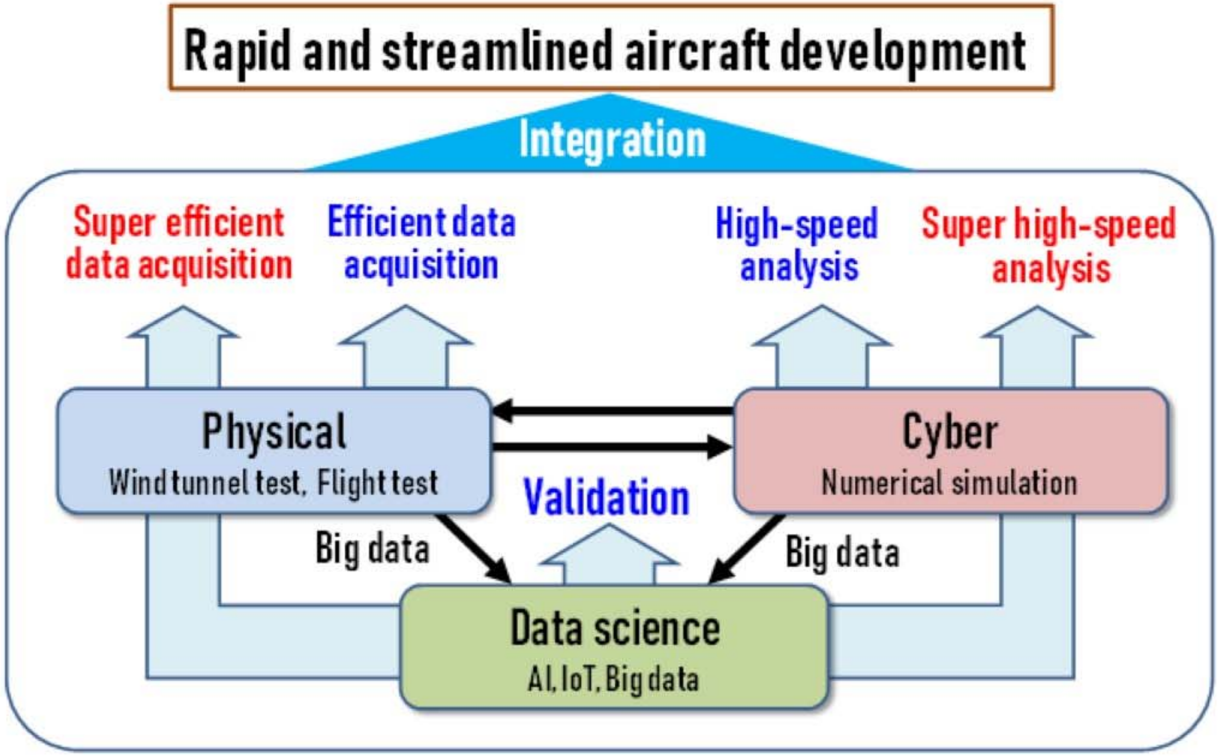
ISSAC

- **Key technological problems – Multidisciplinary, Multiphysics**
  1. High speed/Low speed buffet (Unsteady aerodynamics)
  2. Wing flutter (Aeroelasticity)
  3. Cabin/External noise (Aeroacoustics)
  4. Water splash on wet runaway (Multiphase flow)
  5. Maneuverability (Stability and control)
  6. Reynolds number effect (Scale effect)

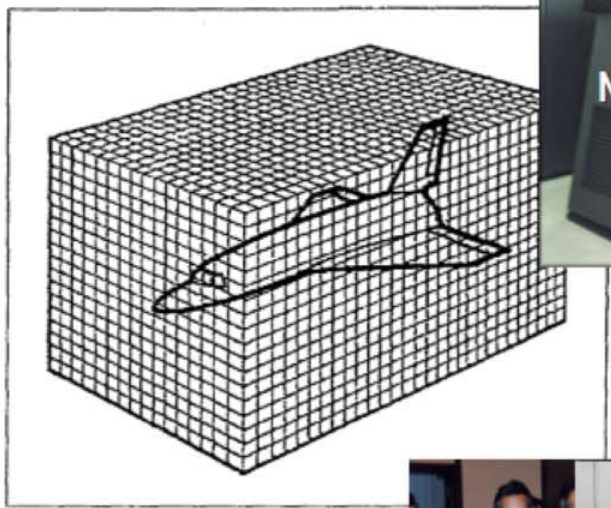


ISSAC

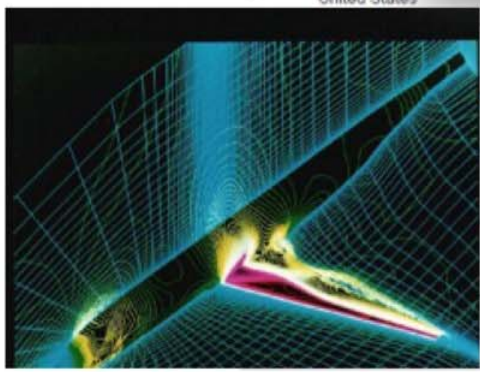
- **Concept of the integration**
  - Two concepts of the "integration" in ISSAC. One is the integration of **technological fields** e.g. aerodynamics, structure and flight dynamics. The other is that of **scientific methodologies** e.g. numerical simulation, wind tunnel/flight test and data science

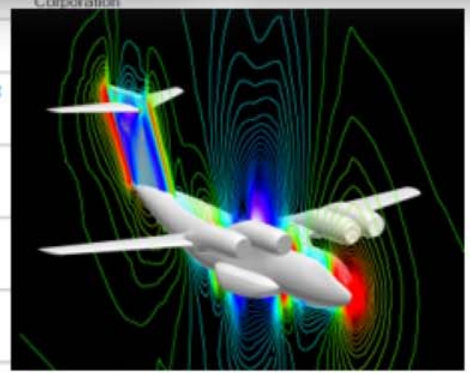


- In 1987, proposed the Numerical Wind Tunnel idea of replacing wind tunnel testing with numerical simulations by high speed computer. Developed a parallel vector supercomputer with Fujitsu and introduced it in 1992 by naming the system itself Numerical Wind Tunnel
- Achieved the world fastest computational speed in 1993 for the 3D RANS CFD simulations for complicated aerospace geometries
- Showed a large potential of the numerical simulation to the future usage



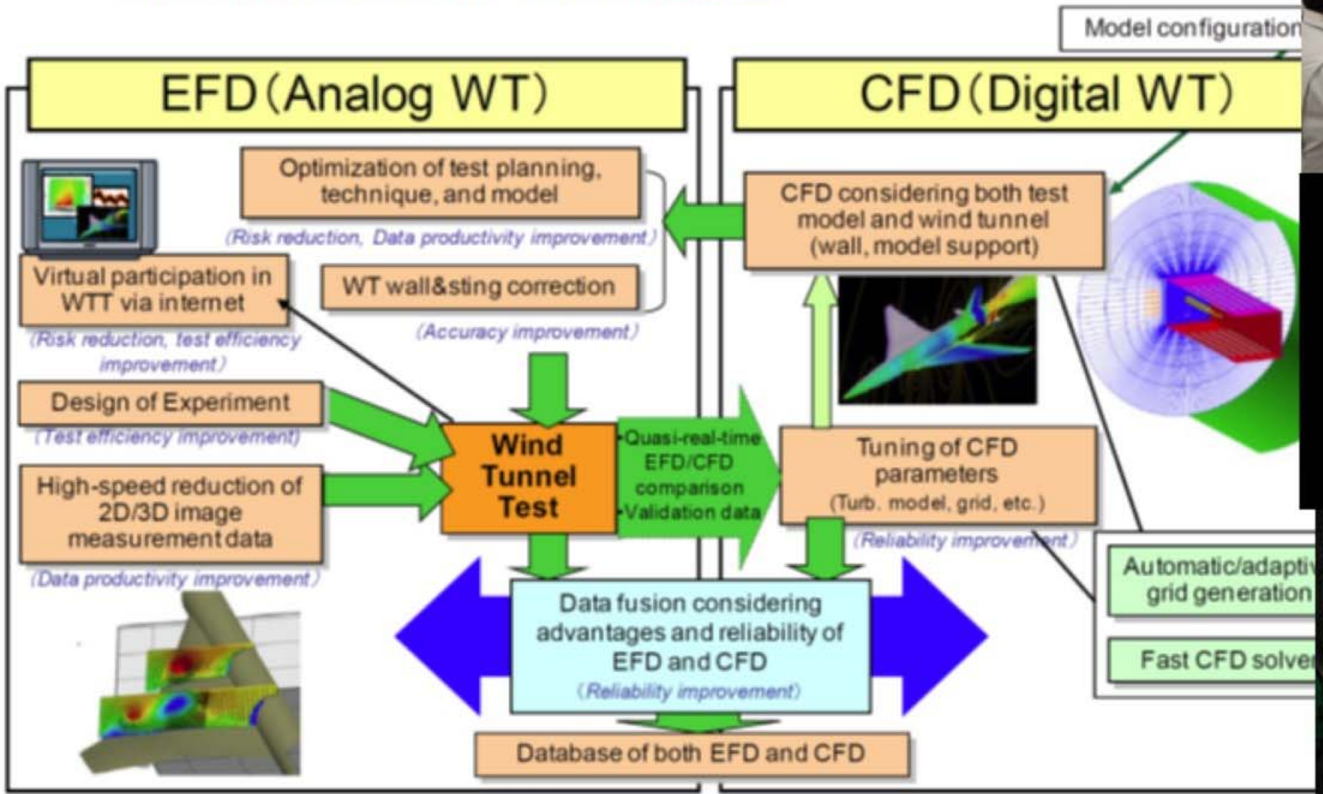
数値風洞の概念的説明を物理空間で行
を曲線格子系で覆い，格子点上で流れの
することにより格子点上での流れ場を





Past History #2, Digital/Analog Hybrid Wind Tunnel: DAHWIN

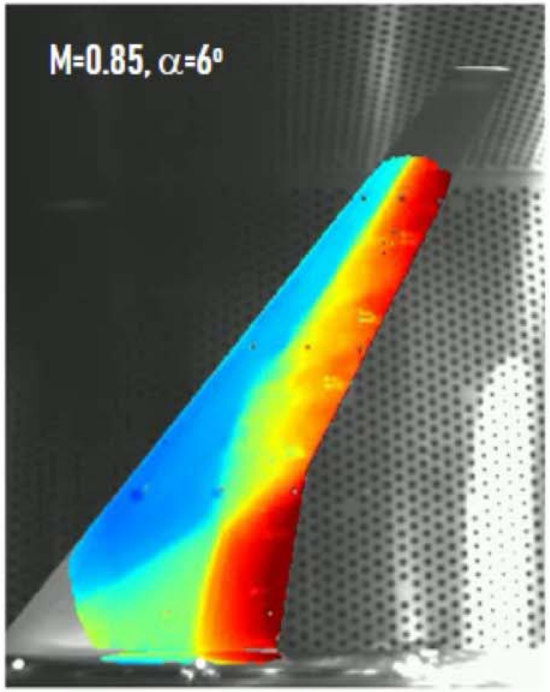
- Developed the Digital/Analog Hybrid Wind Tunnel called DAHWIN from 2008 to 2012
- Aiming at improving efficiency, accuracy, and credibility of aerodynamic characteristics evaluation in aerospace vehicle through mutual support of EFD (Experimental Fluid Dynamics, Analog WT) and CFD (Computational Fluid Dynamics, Digital WT)
- Hexahedra-based automatic mesh generation tool: ***HexaGrid***
  Fast unstructured CFD solver: ***FaSTAR***

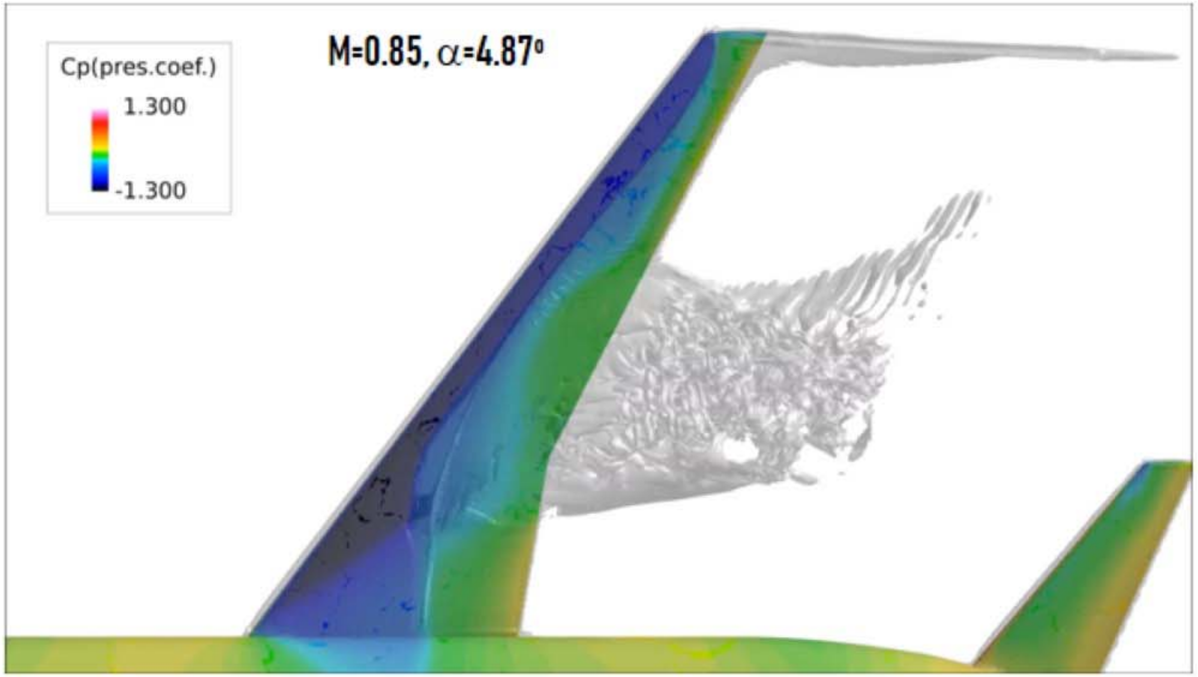


1. High Speed Buffet

Unsteady PSP*1 measurement in JAXA transonic wind tunnel

High-fidelity DES*2 simulation by fast CFD solver FaSTAR





Pressure fluctuation on the NASA-CRM main wing

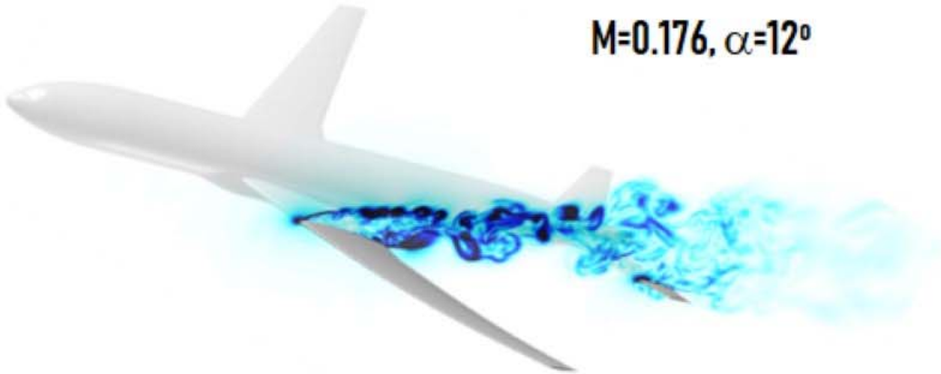
- Computed spanwise propagation of buffet cells qualitatively in good agreement with measured one
- Further improvement of the simulation is expected by applying embedded LES*3

*1 PSP: Pressure Sensitive Paint, *2 DES: Detached Eddy Simulation, *3 LES: Large Eddy Simulation

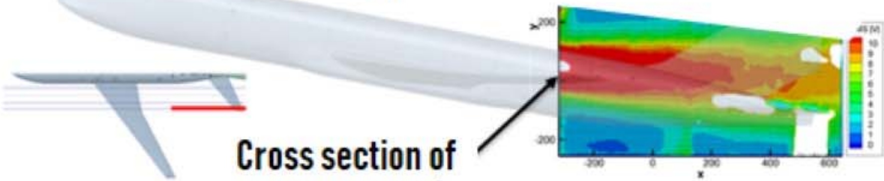
1. Low Speed Buffet

High-fidelity DES simulation by fast CFD solver FaSTAR

M=0.176, α=12°



α=12.25deg

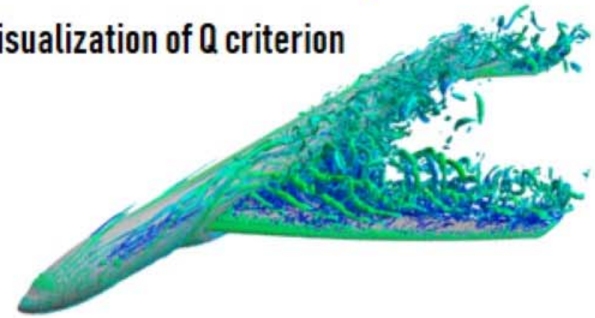


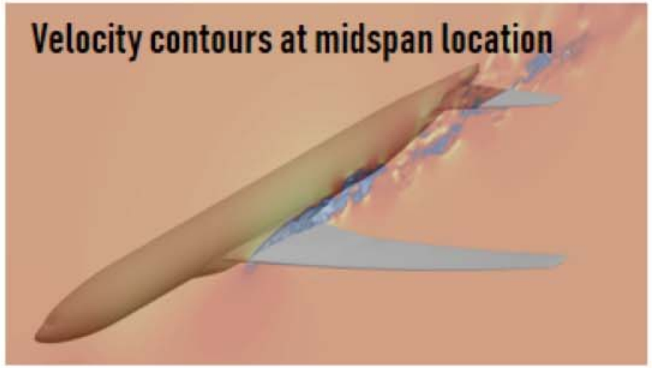
Cross section of measurement

PIV*2 measurement for NASA-CRM model

Much faster simulation by LBM*1 method

Visualization of Q criterion





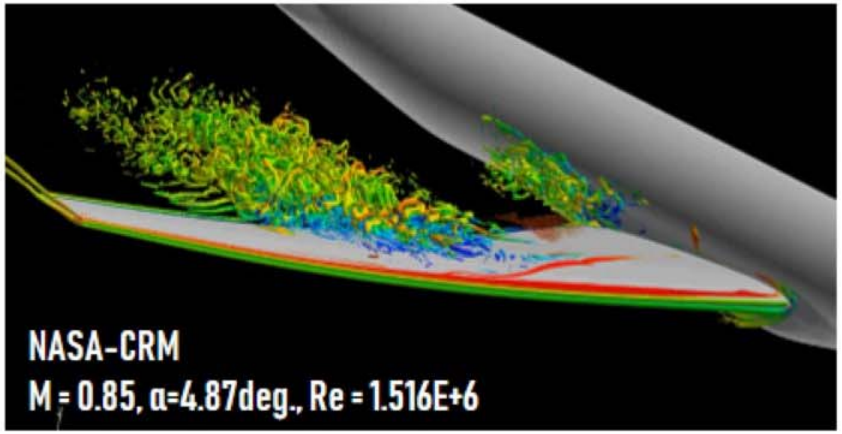
*1 LBM: Lattice Boltzmann Method

*2 PIV: Particle Image Velocimetry

- Low speed buffet phenomena, i.e. separated flow from main wing interacts with tail one, can be captured by DES simulation (left above) and PIV measurement (left below)
- Much faster LBM solver than DES is expected because the DES simulation of low speed buffet requires enormous grid points and very long computation time

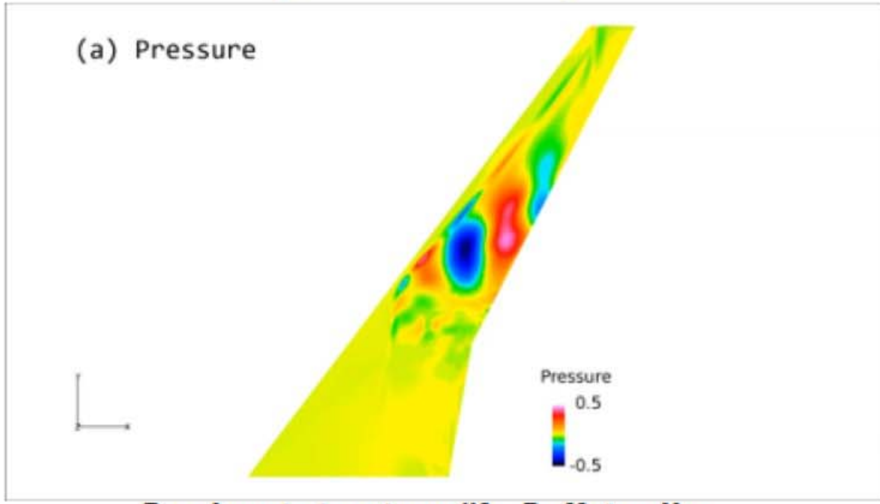
1. Data Mining for High Speed Buffet

Data mining to extract dominant flow structures from huge 3D unsteady data

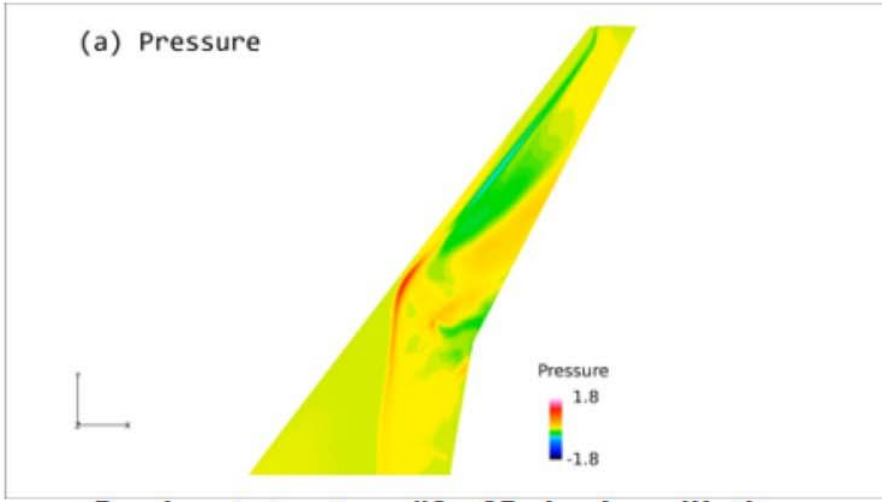


- DMD[*1] analysis and compressive sensing analysis to clarify 3D unsteady flow structures of high speed buffet on a swept wing
- Two dominant flow structures and their unsteady behaviors. One 'buffet cell' that only appear on the swept wings. The other well known 2D shock oscillations

[*1] DMD: Dynamic Mode Decomposition



Dominant structure #1 - Buffet cells



Dominant structure #2 - 2D shock oscillations

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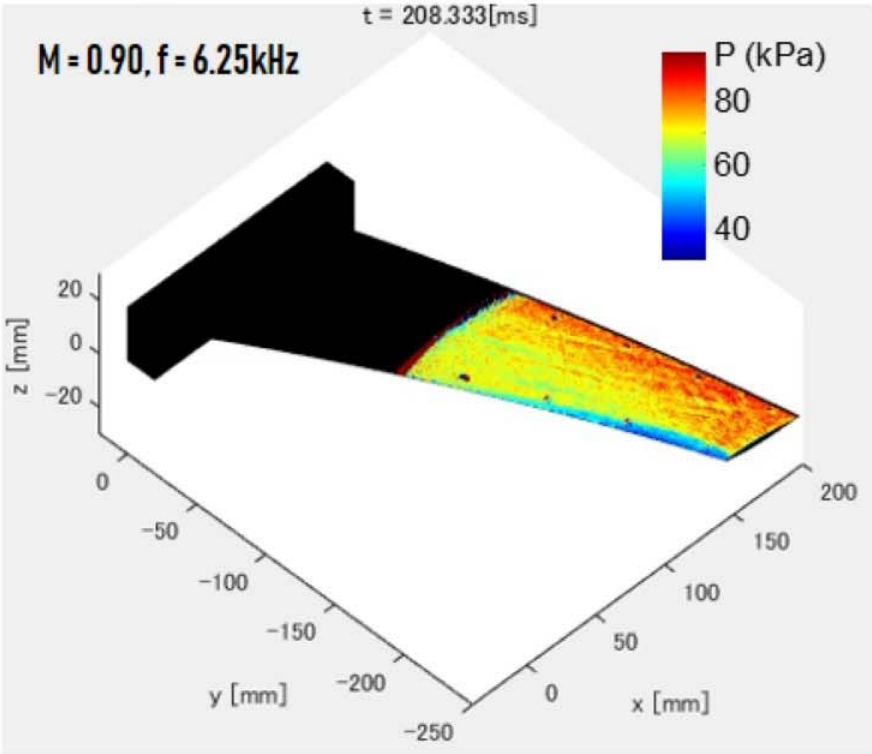
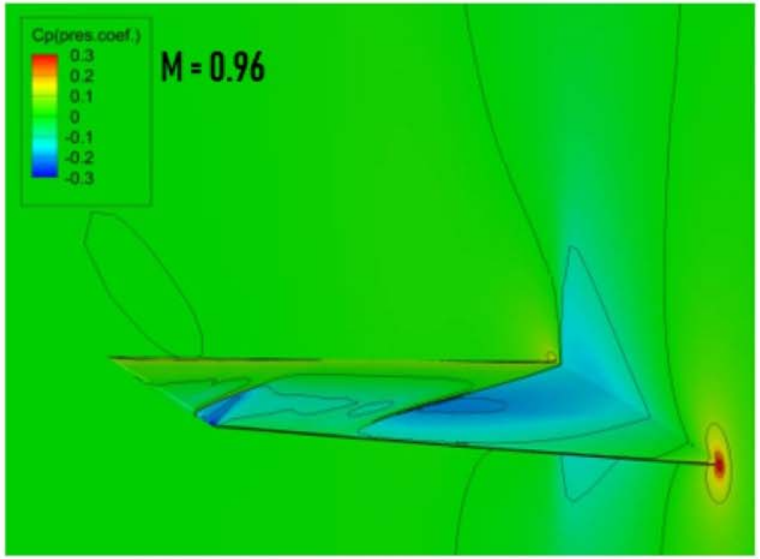
Simultaneous measurement of aerodynamic and structural data using unsteady PSP and MDM*[1]

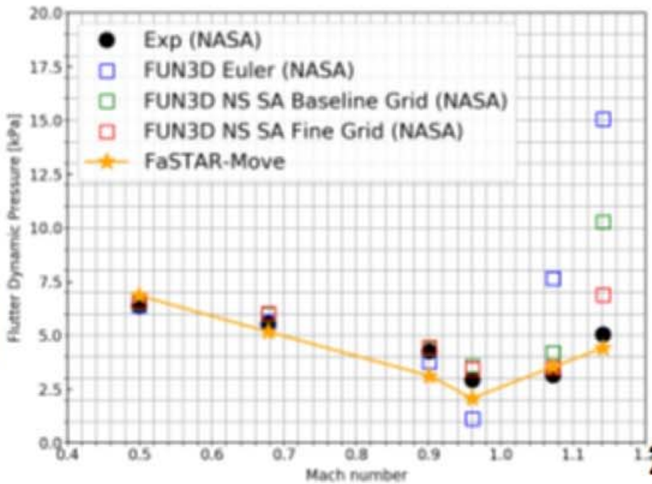


Measurement of thin airfoil flutter model

High-accuracy aeroelastic CFD/CSM coupled simulation with FaSTAR-Move



Analysis of AGARD445.6 model



•Predicted flutter boundary agrees well with exp. data ☞

*[1] MDM: Model Deformation Measurement

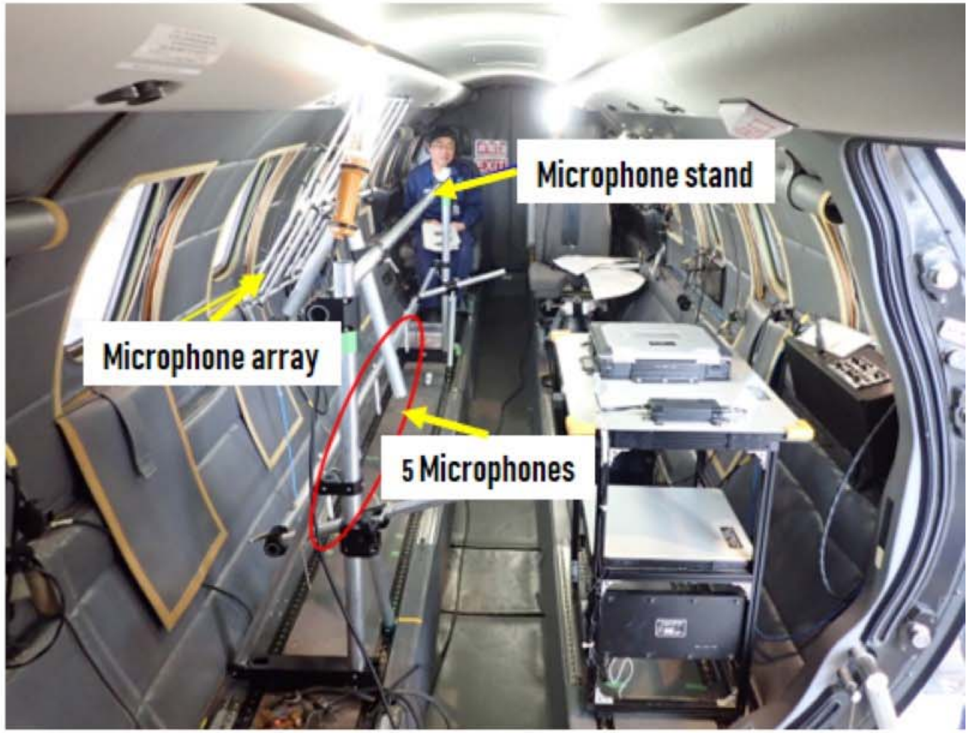
3. Cabin Noise

Flight test by experimental aircraft 'Hisho'

Objective: Data acquisition of cabin noise
Equipment: NAH*1
Microphones
Acoustic impedance meter
Altitude: 23,000ft/35,000ft (7,000m/10,700m)
Mach#: 0.65/0.72
Period: July 16, '19 - Aug 2, '19

'Hisho'

*1 NAH: Near-field Acoustical Holography
(Noise source identification technique that makes it possible to reconstruct and extract all the information of the sound field radiated by sources)



NAH system installed in 'Hisho'

Measurement of acoustic impedance on the ceiling panel

3. Cabin Noise

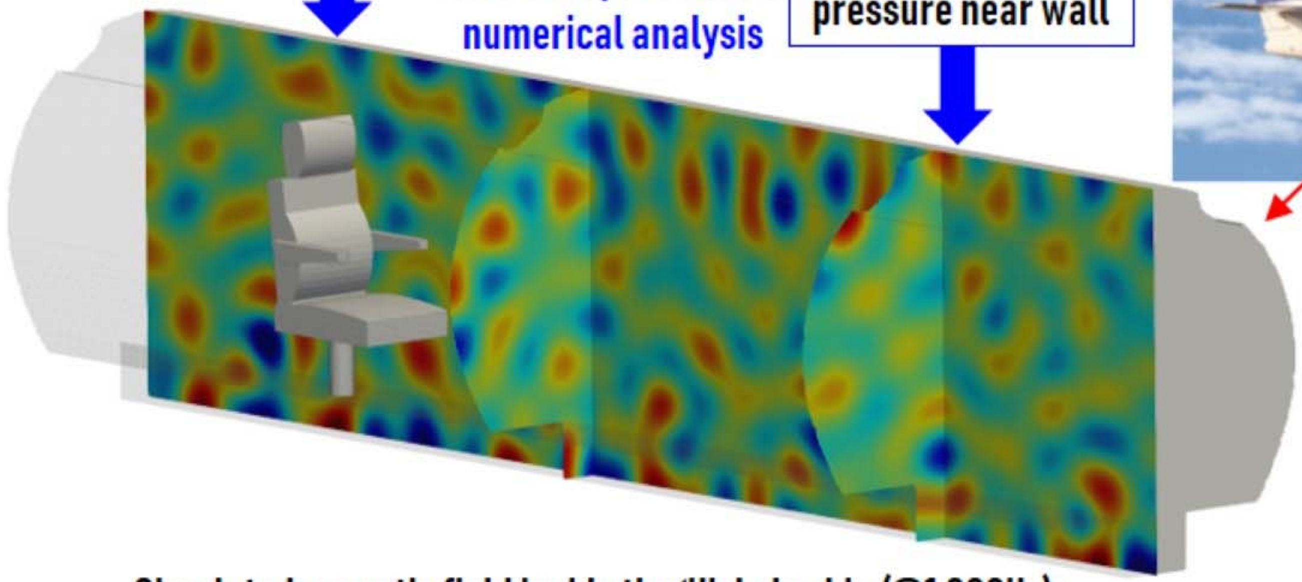
Cabin noise simulation by FDTD[*1] method

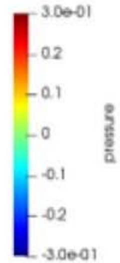
[*1] FDTD: Finite-Difference Time Domain

Measured acoustic impedance

Used as input data for numerical analysis

Measured acoustic pressure near wall





Simulated acoustic field inside the 'Hisho' cabin (@1,000Hz)

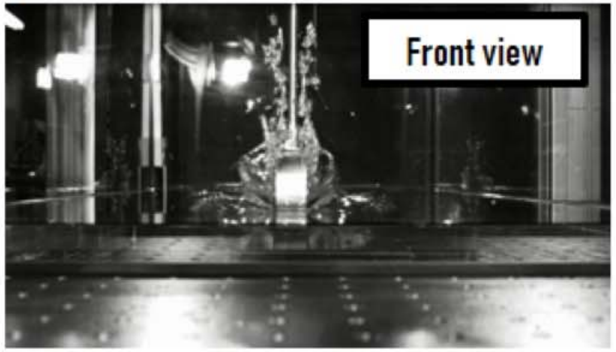
- Preliminary simulation of cabin noise performed by imposing the acoustic pressure and impedance data measured at the flight test as the boundary condition
- Transmitted sound in wide frequency range and in wide space predicted by FDTD method

4. Water Splash on Wet Runway

Water splash measurement

- Differential spray patterns due to speed and shape of moving object observed
- Data to validate the numerical simulation obtained

【Simplified test】 Aluminum cylinder: ϕ50mm,, Speed: 2m/s, Water depth: 10mm



【Quasi full scale test】 Small aircraft tire: ϕ300mm, Speed: 12m/s, Water depth: 10mm

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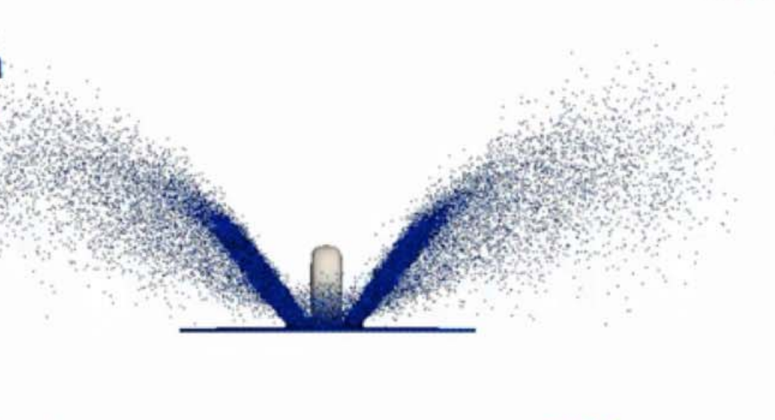
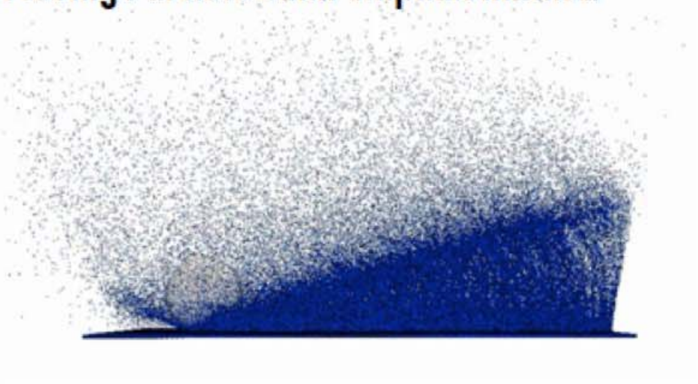
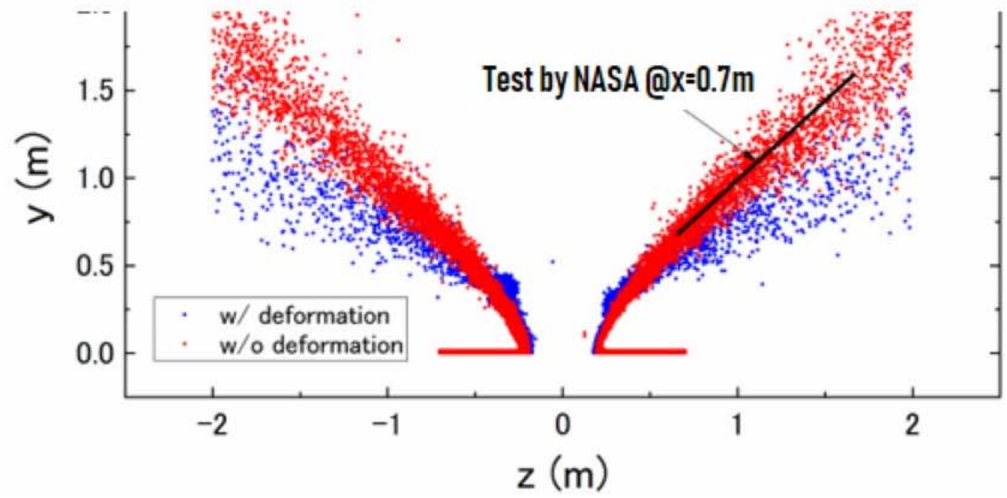
Water splash simulation by MPS*1 method

*1 MPS: Moving Particle Semi-implicit method

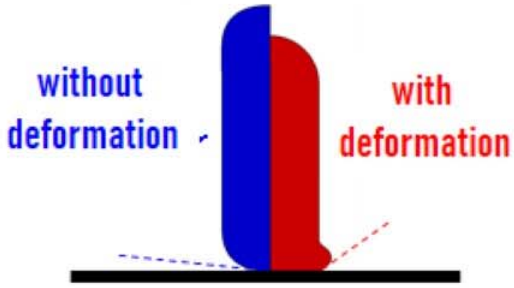
Tire dim. 0.445 m
Speed 8.3 m/s
Water depth 16 mm







Water splash distribution 0.7m downstream from the tire center



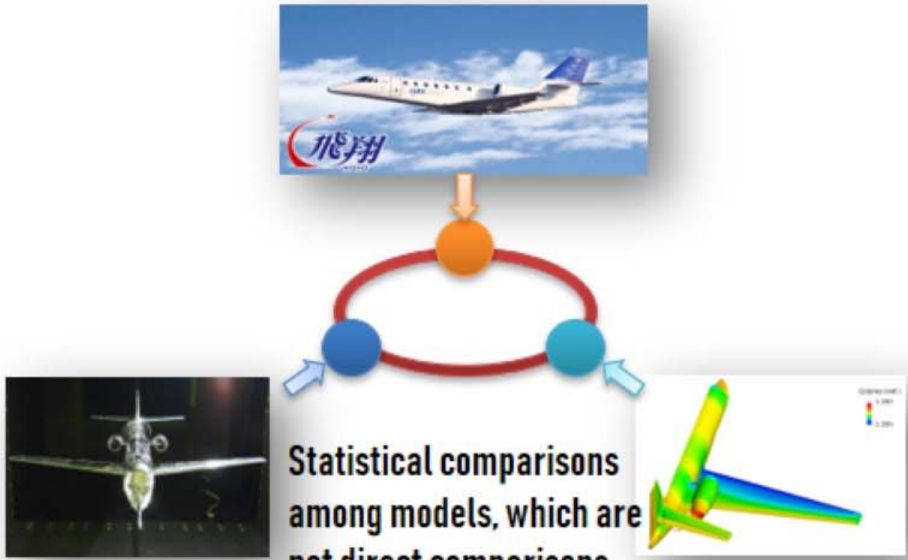
Cross section of the tire

- Consideration of the tire deformation important for accurate prediction

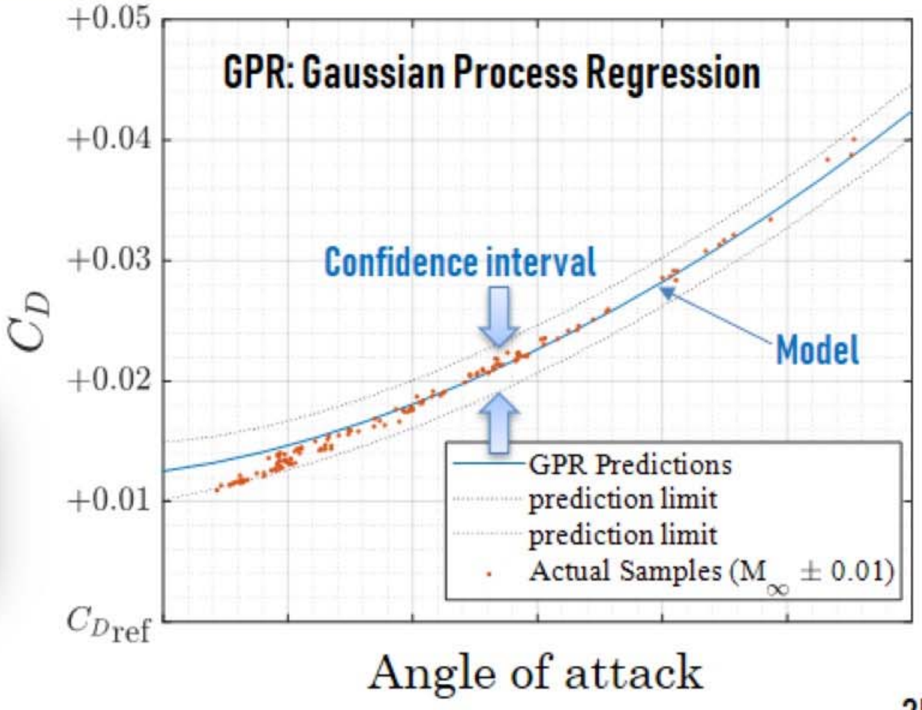
5. S&C Modeling and Evaluation

【Objective】Obtain CFD validation method with flight test and wind tunnel test through not by point-comparisons but by statistical evaluations of aerodynamic model built from each data source

【Research topics】
- Effective and efficient acquisition of aerodynamic flight test data for the validation of numerical simulation
- Statistical comparison techniques between measured (flight test and wind tunnel test) and computed results
- Techniques for building aerodynamic models suited for statistical evaluations



Statistical comparisons among models, which are not direct comparisons among points



ISSAC

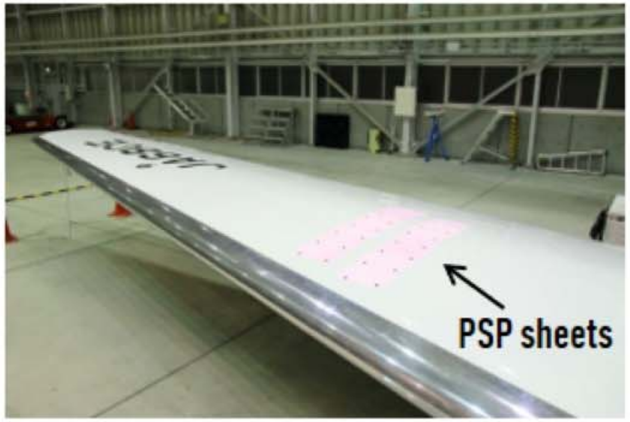
6. Reynolds Number Effect

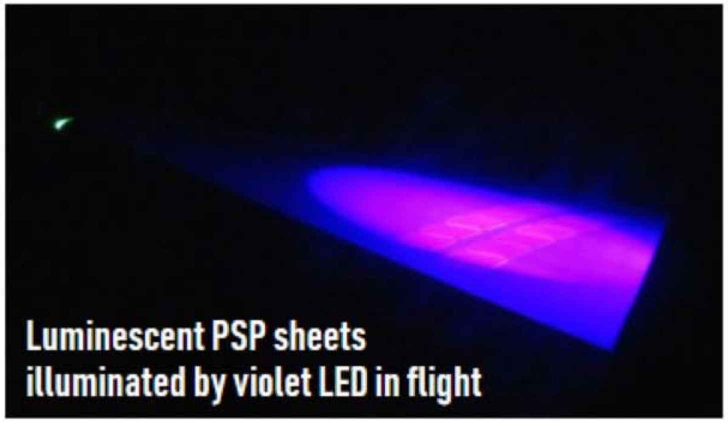
【Objective】

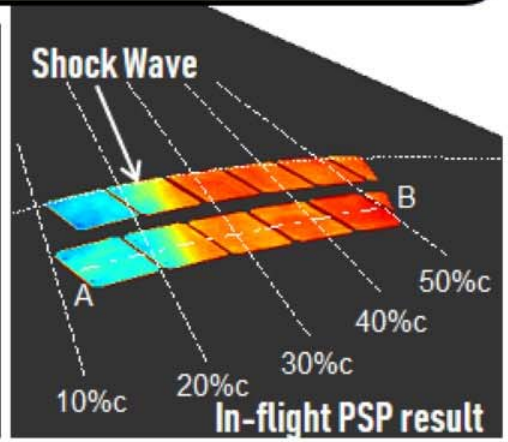
Establish various fundamental technologies to understand and estimate the Reynolds number effect

【Research topics】

- Shock-wave location visualization and quantitative pressure measurement using in-flight PSP measurement
- Measurement technique in pressurized high Reynolds number wind tunnel
- Analysis method of boundary layer transition

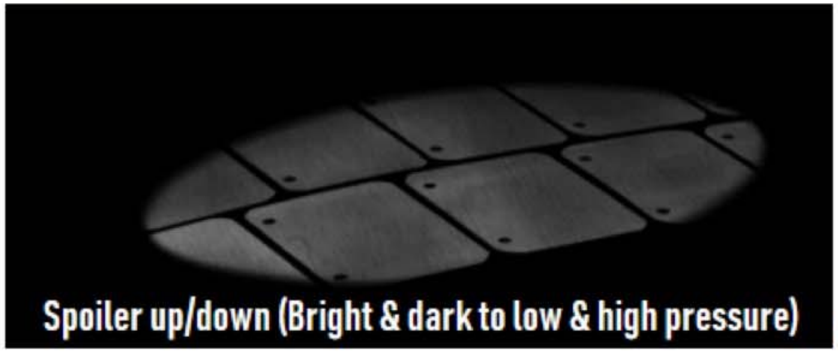






Visualization of shock wave location by in-flight PSP

- Flight data acquisition by in-flight PSP technique
- Upgrading from visualization to quantitative pressure measurement



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Measurement-Physical & Simulation-Cyber Summary

	High speed buffet	Low speed buffet	Wing flutter	Cabin noise	External noise	Water splash
Measurement (Physical)	Unsteady PSP*1	Unsteady PSP, PIV*5	Unsteady PSP, MDM*7	NAH*8	Microphone array	LLS*10
Simulation (Cyber)	FaSTAR (DES*2)	FaSTAR (DES), LBM*6	FaSTAR-Move	FDTD*9	Wave eq. of velo potential	MPS*11
Data mining, Optimization	DMD*3, POD*4, Compressive sensing		Harmonee			

*1 PSP:	Pressure Sensitive Paint
*2 DES:	Detached Eddy Simulation
*3 DMD:	Dynamic Mode Decomposition
*4 POD:	Proper Orthogonal Decomposition
*5 PIV:	Particle Image Velocimetry
*6 LBM:	Lattice Boltzmann Method
*7 MDM:	Model Deformation Measurement
*8 NAH:	Near-field Acoustical Holography
*9 FDTD:	Finite-Difference Time Domain
*10 LLS:	Laser Light Sheet
*11 MPS:	Moving Particle Semi-implicit method

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ISSAC Platform

Multidisciplinary building-block platform called ISSAC-PLATZ (Platform for Look-Ahead-design Technical Zone of ISSAC) based on cyber/physical simulators and an integrated database

C-Sim (Cyber simulator)
- Manage numerical simulation tools and computing resources including supercomputer

P-Sim (Physical simulator)
- Manage testing resources and measurement software as well as various testing know-how

Integrated database
- Accumulate and search for numerical simulation results, experimental data

Computing resources
Supercomputer

ISSAC-PLATZ
(Cyber Physical System)
Accumulated technologies and knowledges

Test facilities
Wind tunnels
Exp. aircrafts

Information providers

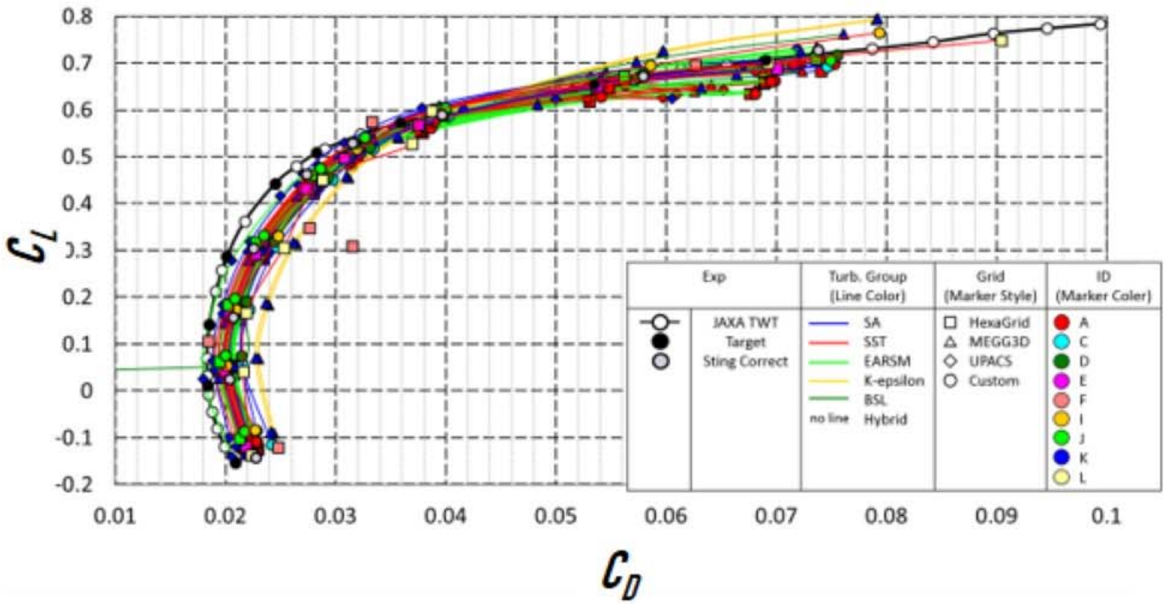
One-stop portal
- Usage acceptance, Information provision
- Communication b/w users

Users

ISSAC

APC (Aerodynamic Prediction Challenge) Workshop

- Promoting since 2015 in order to vitalize the simulation community as well as get involved the CPS-related stakeholders
- Experimental data provided by JAXA
- A wide variety of researchers in universities, industries, research institutes, and software vendors compete on the performance of their simulation capability



Comparison of C_L-C_D curve of NASA CRM model by all participants

ISSAC

Conclusions, Future plan

- A CPS like system named ISSAC to help the simulation capability extend to the full flight envelope and eventually enable a rapid and streamlined aircraft development in cyber space i.e. digital flight is presented

- The R/D progresses of the key technologies in ISSAC are shown

- The first phase of ISSAC will be completed in FY2021. Then, the system will be constructed on the ISSAC-PLATZ with the various software tools and data on. The second phase is planed for three-years FY2022-24 where the system tests and V&V/improvement will be made.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