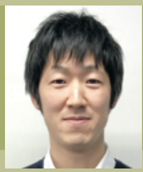
Aerospace Engineering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Aeronautical Engineering
Computational Aerodynamics

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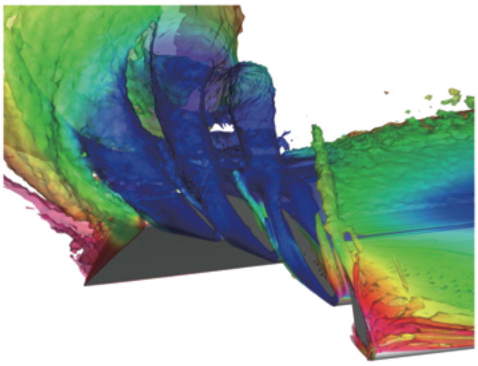
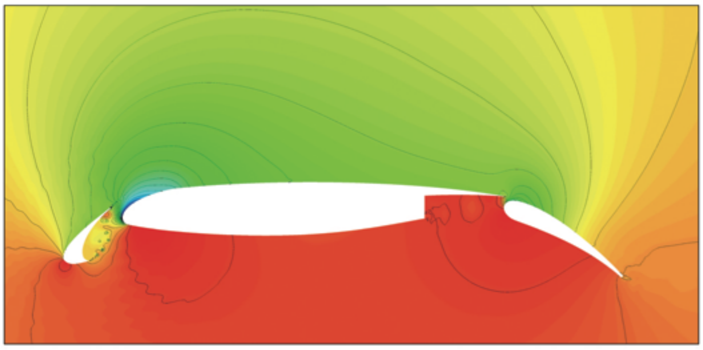


Numerical calculation around a multi-slotted morphing wing using unstructured grid method (visualization of vortices by Q value)



Numerical calculation around a 30P30N wing section using a Reynolds stress model (pressure contours)

Study of computational aerodynamics methods for dealing flow field around aerospace vehicles

Computational aerodynamics requires geometrical flexibility for handling complex aircraft shapes, accurate aerodynamic prediction capability, and high computational efficiency that can be used extensively at the design site. These requirements have been realized at a high level by the development of unstructured grid methods with excellent geometrical flexbility, second-order accurate finite volume methods, various turbulence models, and implicit relaxation techniques represented by the LU-SGS method. These contribute to a significant reduction in wind tunnel test cases and development costs. However, with regard to boundary layer separation and laminar-turbulent transition phenomena, accurate prediction of phenomena is possible by numerical calculation, unless a highly accurate numerical calculation method that requires a large amount of computational resources is used. In this laboratory, we aim to construct a laminar-turbulent flow transition model that can be used at a practical calculation cost, and to establish an unstructured grid method that can perform highly accurate fluid calculations around complex shapes at a lower cost.

Development of kinetic energy and entropy preserving (KEEP) scheme for unstructured grid method

In order to perform turbulent numerical simulations accurately, a stable and non-dissipative numerical scheme is essential. In recent years, a “kinetic energy and entropy preserving (KEEP) scheme” has been proposed for the structured grid method. We are aiming to extend the KEEP scheme to an unstructured grid method to realize highly accurate turbulent flow simualtions around complex geometries.

Study of implicit methods suitable for unsteady flow simulations

When the LU-SGS implicit method is applied to unsteady flow fields, weak wave propagation is dissipated due to its strong smoothing effect even if the number of internal iterations is sufficient. On the other hand, an explicit method such as the Runge-Kutta method suitable for unsteady flow simulations has low computational efficiency due to strict stability limit. We are studying implicit methods which are suitable for simulations of unsteady flows and efficient on large-scale parallel computers.

Development of laminar-turbulent transition model based on the Directed Percolation model

Since laminar flow and turbulent flow have very different flow characteristics, it is very important to predict the laminar-turbulent transition by numerical simulations accurately. However, the transition phenomena have not been fully understood yet, and thus existing transition models highly rely on empirical correlations. Also, few models take flow anisotropy into account. In this study, we aim to construct a transition model that can be applied to anisotropic flow fields based on the Directed Percolation model.

Application of computational aerodynamics methods to various practical problems

By applying the developed computational aerodynamics method to various problems in engineering and science, we are predicting and elucidating new phenomena and further improving the computational methods. Such examples include optimization of a vortex generator that suppresses boundary layer separation by generating longitudinal vortices, thermal protection of a capsule represented by HAYABUSA in hypersonic flow field of atmospheric entry, and accretion disk flows in astrophysics.

Aerospace Engineering
Department of Aerospace Engineering

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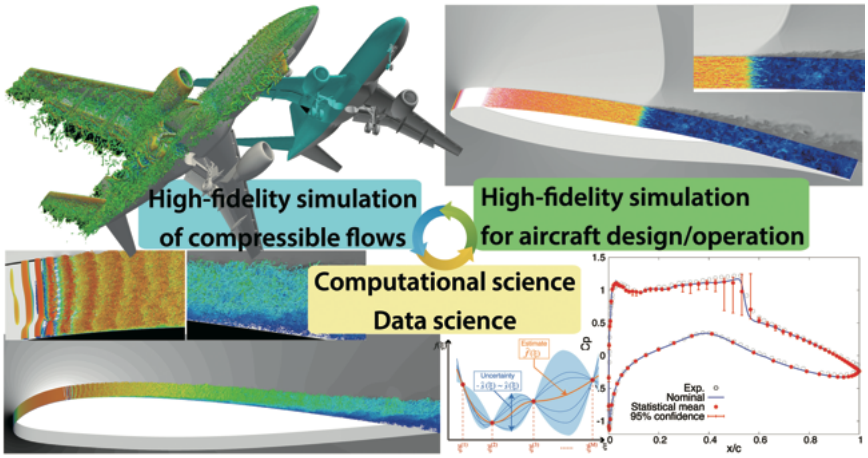

Compressible flow physics and computational engineering in Kawai Laboratory

Compressible flow physics and computational engineering

Our research draws from theoretical analysis, computational physics, data science, and high-performance computing to develop novel high-fidelity numerical simulation techniques for uncovering the fundamental flow physics underlying complex compressible, multi-scale and multi-physics flows in aerospace engineering and also for next-generation aircraft aerodynamic design tools. Our research interests broadly include in the fields of fluid mechanics, with an emphasis on compressible flow, turbulence, shock waves, mixing and combustion, high-fidelity numerical methods, physical modeling, machine learning, and uncertainty quantification.

Flow physics and high-fidelity numerical methods

Compressible turbulent flows are crucial phenomena in many engineering and scientific problems. However, there are many remaining challenges in numerical methods to be used to study the detailed physics of the turbulent flows. Our research develops high-fidelity numerical methods based on computational physics to uncover the flow physics underlying complex compressible turbulent flows with shock waves, contact surfaces, material interfaces, and flame surfaces in aerospace engineering.

Physical modeling of high Reynolds number flows

The state-of-the-art high-fidelity numerical simulations have received increased attention in recent years to study flow physics. Its applications, however, are far from the real aircraft flight conditions at high Reynolds number because of the high computational costs to resolve near-wall turbulence. Our research proposes and develops near-wall turbulence modelings to make the high-fidelity simulation applicable to real aircraft aerodynamic design problems at high Reynolds numbers.

Aerodynamic prediction over whole flight envelope

Our research develops high-fidelity numerical methodology as a next-generation aerodynamic design tool to innovate aircraft design and operation. The critical issue is to predict the aerodynamics across whole flight envelope, including the boundary of the flight envelope, such as transonic buffet and stall phenomena, at flight high Reynolds numbers. The high-fidelity methodology is built based on our achievements and extended for the massive-parallel exascale supercomputer environment.

Computational physics and data-driven science

Because of the complexity of flow nature, universal physical laws for many compressible turbulent phenomena are not known, and thus, it is often challenging to develop a physics-based model and also to understand its physical laws. Our research combines computational physics with data-driven science, with an emphasis on machine learning and uncertainty quantification, to develop data-driven modeling of the complex flow phenomena and also to understand the underlying physical laws.

Aerospace Engineering
Aeronautical Engineering


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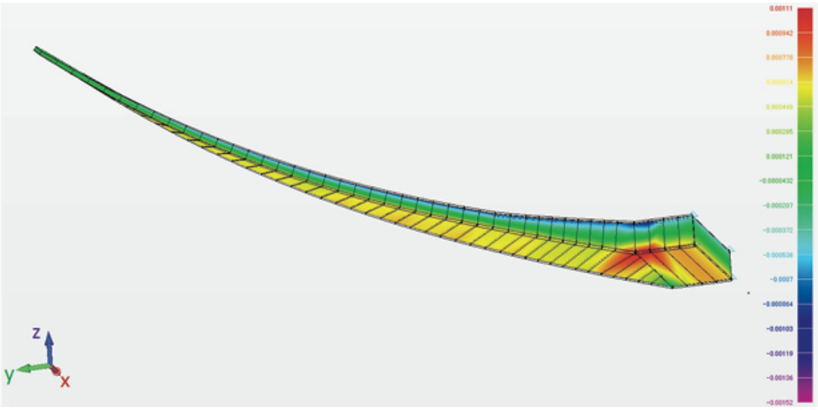
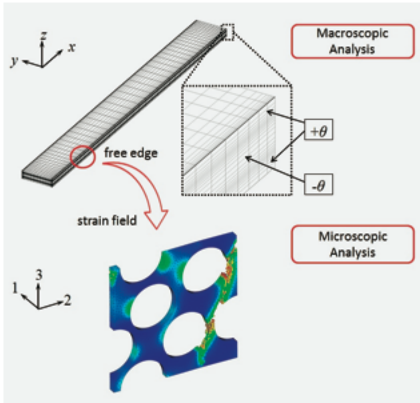
Smart Systems for Materials and Structures

http://www.plum.mech.tohoku.ac.jp/toppage.html



Structural analysis of composite aircraft wing



Multiscale modeling of damage in composite materials

Numerical simulations for advanced composite materials

Fiber-reinforced plastics, which are lighter and stronger than conventional metal materials, can improve fuel economy and reduce CO_2 emissions when used in the structural elements of aircraft, automobiles, and other transport equipment. Since 2012, practical application of these materials has steadily expanded, exemplified by the Boeing 787, which uses fiber-reinforced plastics for the majority of its structural materials. However, because fiber-reinforced plastics are difficult to manufacture and have a complex material structure, there are still many problems to solve. Our laboratory uses numerical simulations to investigate the characteristics of fiber-reinforced plastics and improve their performance. Our numerical simulations cover a wide range mechanics at a wide range of scales.

Optimization of the structural design of wings made of carbon fiber-reinforced plastic through coupled analysis of fluids, structures, and materials

In recent years, carbon fiber-reinforced plastics have increasingly been applied to the structural elements of aircraft. However, current designs do not take full advantage of the performance of these materials. Our goal is therefore to optimize the design of these structural elements by using coupled analysis of fluids, structures, and materials to clarify points of uncertainty, which are then incorporated into the design variables of genetic algorithms that are executed to discover multi-purpose optimizations.

Multi-scale modeling of initial damage to carbon fiber-reinforced plastic laminates

A unique strain field is known to occur between the layers at the free ends of carbon fiber-reinforced plastic laminates, leading to initial cracking. The load strain when the initial crack occurs is an important design criterion, so accurate initial damage prediction is required. Our goal is therefore to predict initial damage with good accuracy by means of multi-scale analysis. Macroscopic analysis is used to predict the strain field, and microscopic analysis is used to predict the progression of the damage.

Computer-aided design of multi-purpose materials for cross-linked polymers

A new discipline called Material Informatics is attracting attention as an innovative approach to materials development, which has traditionally relied on experience and trial and error. However, for polymer materials with complex cross-linked structures, almost no practical applications have yet been found. Our laboratory, in contrast, aims to design materials from the molecular level, using molecular dynamics approaches and self-organizing maps to propose promising candidates for new materials.

Development of numerical analysis methods for computer-assisted virtual testing of aircraft components made of composite materials

In recent years, computer-assisted virtual testing, which uses numerical analysis in place of certain certification tests, has been attracting attention as a way to reduce the cost of type certification testing of aircraft components made of composite materials. Our laboratory uses finite element and particle-based approaches to develop highly accurate methods of evaluating the damage tolerance and energy absorption characteristics of composite aircraft components in various situations (including emergencies) all the way from the manufacturing and processing stages to the usage stage.

Aerospace Engineering
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Smart Systems for Materials and Structures

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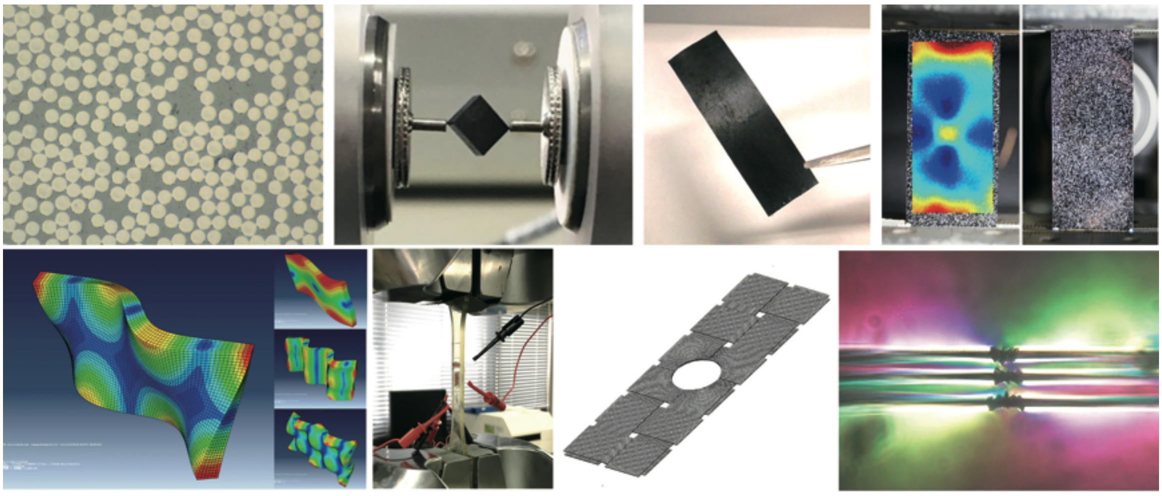

Experimental and Computational Micromechanics on Advanced Composite Materials

The Yamamoto group is working in several areas of advanced composite materials research including (i) tensile strength prediction of unidirectional CFRP composites, (ii) determination of full elastic constants using resonant ultrasound spectroscopy (RUS) technique, (iii) evaluation of fatigue crack growth properties for CFRP laminates, (iv) high-throughput screening on carbon nanotube nanostructures (v) statistical analysis of multiple cracking behavior of brittle thin films. We aim to understand the structure-properties relationship in such materials based on experimental and computational nano- and micromechanics.

Tensile Strength Prediction of Unidirectional CFRP Composites

Tensile strength of unidirectional CFRP materials are predicting by performing multi-fiber fragmentation experiments in combination with a spring element model simulation that considers the surface stress concentration on fibers caused by a fracture site in an adjacent fiber. Possible mechanisms by which additional stress concentration is generated on an intact fiber surface are analyzing numerically using the finite element method.

Determination of Full Elastic Constants of Carbon Fiber

The full elastic constants of a carbon fiber in a unidirectional CFRP composite are investigating by implementing a resonant ultrasound spectroscopy (RUS) technique. The effectiveness of the proposed method is confirmed by comparing the experimental results and those obtained by Eshelby-Mori-Tanaka theory. The determination technique could be applicable to randomly oriented discontinuous fibers, as well as biomaterials and nanomaterials.

Multiple Cracking Analysis for Brittle Thin Films

The progress of multiple cracking in a diamond-like carbon deposited onto a polyethylene terephthalate (PET) substrate is evaluating using Monte Carlo simulation in combination with tensile-loading experiments. The finite element analysis has been conducted to calculate the stress distributions in film fragments and was used in the simulation. The simulation predicted successfully the crack density and the distribution of fragment lengths during the progress of multiple cracking.

Fatigue Crack Growth Properties for CFRP Laminates

Attention has been focused on CFRP in which short carbon fibers are randomly dispersed in a thermoplastic resin. In order to develop a reliable CFRTP materials, in addition to clarifying the damage mechanism and deformation behavior, it is necessary to establish a prediction method to help with design and security. Furthermore, we aim to develop a strength prediction method by applying it to finite element analysis.

Aerospace Engineering

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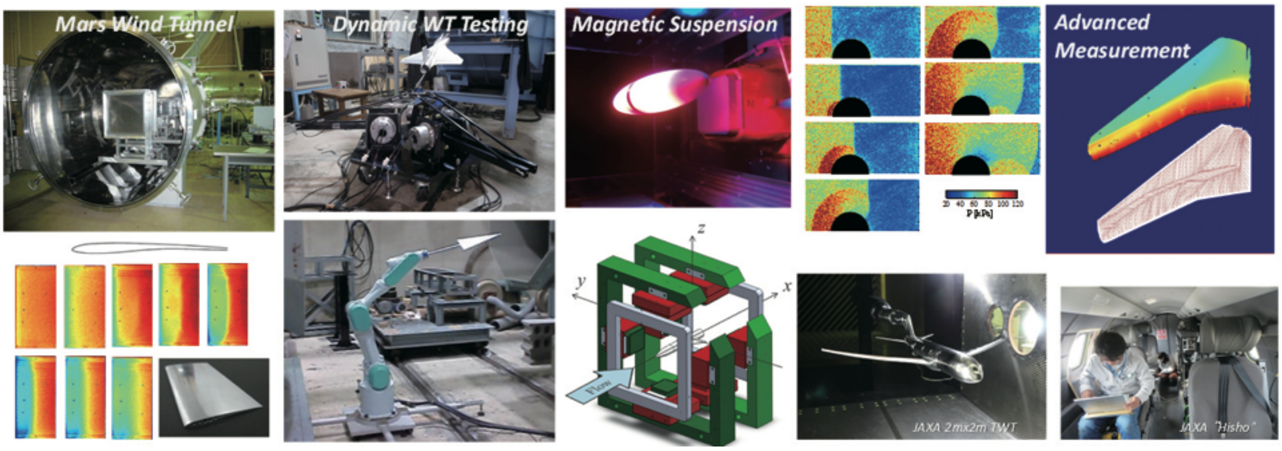

Unique experimental technologies in our lab (Our lab is jointly operated with Nonomura Lab)

Pursuing the Future of Flight - Challenge of Experimental Aerodynamics

More than a hundred years have passed since Wright Brothers' first flight, and a new evolution of the aircraft is progressing. Our laboratory is engaged in research to realize the aircraft of various uses, from eco-friendly airplanes to airplanes for planetary exploration. In particular, we emphasize the approach from experimental aerodynamics (EFD), aiming to improve aerodynamic design by clarifying fluid phenomena related to flight by the means of “wind tunnel experiments”. Wind tunnel technology that simulates real air flow, surface-flow measurement technology using molecules, dynamic wind tunnel experiments using a magnetic suspension and balance system.

Creating Flow - From Insect Flight to Hypersonic Flight

Wind tunnel experiments using scale models and research on similar laws are indispensable for developing aircraft and spacecraft. Our laboratory conducts wind tunnel experiments in various speed ranges from the speed at which insects fly to the speed at which a reentry capsule enters the atmosphere. In order to realize a Mars airplane, the world's unique “Mars Wind Tunnel (MWT)” was developed, and aerodynamic performance of wings at low density and high speed is being investigated.

Sensing Flow - Development of Advanced Flow Diagnostics

To date, sensors have mainly been electronic. Such sensors can only measure the quantities at discrete points, making it difficult to understand the complex flow field around an aircraft. In our laboratory, we are researching flow imaging technologies using various functional molecules such as “pressure-sensitive paint (PSP)”, “temperature-sensitive paint (TSP)” and “global luminescent oil film (GLOF)”. In particular, we are currently focusing on measuring time-varying flows.

Manipulating Flow - Research on Flow Control Devices

Safety is the most important factor in aircraft operation. We are trying to simulate dangerous situation that cannot be done by flight test by wind tunnel experiment. The latest technologies that support this kind of research are a high-speed parallel-link robot (HEXA) and a magnetic suspension and balance system (MSBS). Using these devices, we are conducting research on various devices that control dynamic aerodynamic forces, visualize flow fields, and control airplane's stability.

Challenge to Real Flight – Knowing the Reality by Flight

As part of collaboration with JAXA, our laboratory is working on education and research program on aerospace frontiers. Students boarded a JAXA's experimental aircraft and participated in an experiment to measure the pressure distribution and structural deformation of the wing during flight. All reality is condensed in the flight test. We would like to establish such an environment that allows universities to contribute to aircraft development through flight tests.

Aerospace Engineering

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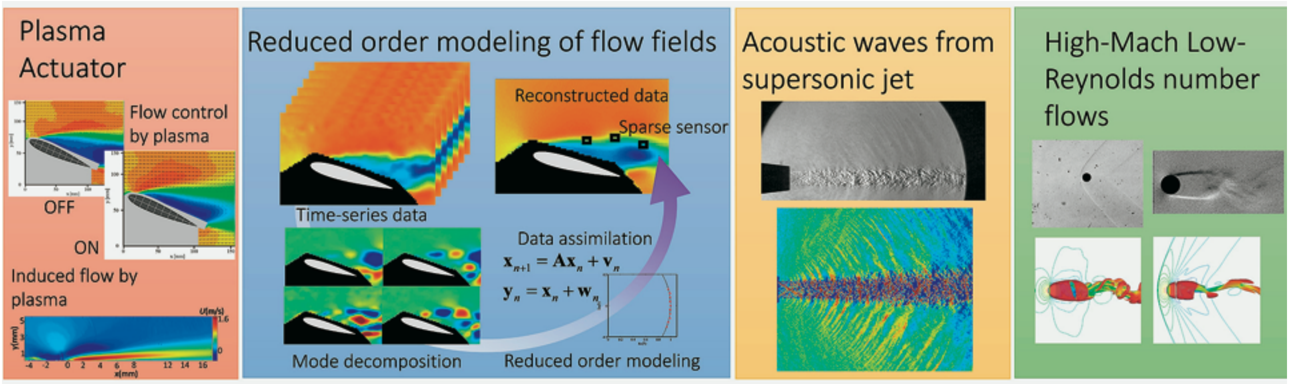

Advanced Measurement of Aerodynamic Problems and Optimal Flaw Control Based on it

Our laboratory conducts research to deepen comprehension of new aerodynamic and fluid control technologies for the development of new generation aircraft. First, using experimental aerodynamics (EFD) as a tool, we aim to obtain detailed information on fluid fields using advanced measurement techniques such as particle image velocimetry and pressure-sensitive paint. Next, based on the detailed information obtained here, we build a model that can easily express fluid phenomena, and aim to optimize the fluid field based on the obtained model. For flow control, we will utilize plasma actuators that control the flow by dielectric barrier discharge, which has been attracting attention in recent years. Based on aerodynamic experiments that handle real flows, we will conduct world-class research on “advanced measurement”, “modeling” and “control” of flows. This laboratory is managed with Asai Lab.

Reduced-order medeling of fluid field using advanced measurement and construction of an observer

In order to perform optimal control of aerodynamics, it is necessary to observe the state of the flow field time-by-time. In general, the flow fields around aeronautical vehicles are very complex, and computational fluid dynamics analysis requires enormous computational costs that require tens of millions to hundreds of millions of grid points. In this research, we will reduce the number of fluid fields expressed by a few tens of small quantities, and use a sparse sensor placed appropriately to realize state observations from moment to moment.

Next generation fluid control using plasma actuator

Dielectric barrier discharge plasma actuators are attracting attention because of their simple mechanism and quick response. In this laboratory, we try to improve the performance of fluid machinaries through flow control and understand its physical mechanism, with a focus on separation control using a plasma actuator. Targeting the flow around wind turbines and airfoils, we aim to greatly improve the performance of fluid machinaries.

Advanced measurement of supersonic jets and aeroacoustic waves generated from them

Acoustic waves generated from supersonic jets exhausted from supersonic aircraft and rocket engines are very intensive, and it is important to predict and mitigate them from an environmental point of view and to prevent equipment from breaking due to vibration. In this study, we will visualize the fluid and acoustic fields of supersonic jets with advanced measurements and clarify the generation mechanism of acoustic waves. Now, the flow fields of clustered supersonic jets are investigated.

Measurement and analysis of low Reynolds number and high Mach number flow

Supersonic jets exhausted from rocket engines contain micron-sized alumina particles, resulting in a solid-gas mixed phase flow in which supersonic solid particles and gases are mixed. In order to analyze and understand such a flow field, it is necessary to comprehend the force acting on the particle, but the flow field of high Mach number and low Reynolds number has not been well discussed. In this laboratory, we will investigate this type of flow through experiments and numerical analysis.

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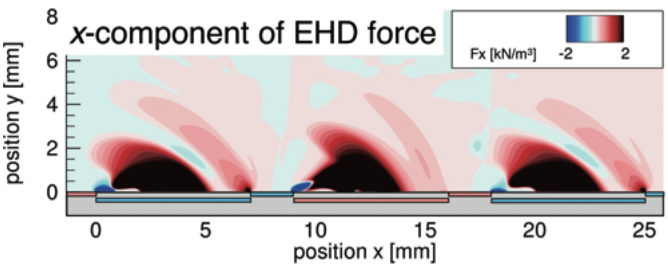
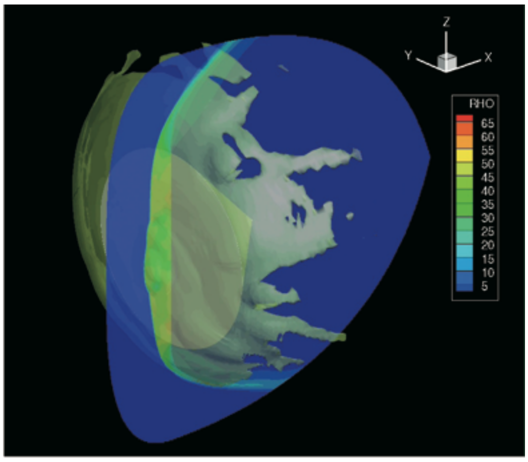


Electrohydrodynamic force generation by multi-electrode plasma actuators



Bow-shock instability around cone-base shaped object (density contours)

Physics and Applications of High-Temperature Gasdynamics

For propulsion and flow-control techniques, understanding in non-equilibrium high-temperature gasdynamics is required because a high-speed flow referred as hypersonic flow is usually accompanied by high-temperature gases in thermochemical non-equilibrium. Since such a high-speed flow is in general produced by locally instantaneous energy deposition or energy liberation and then mostly activates electromagnetic interactions, numerical simulations are indispensable for the understanding of the physics therein. In this laboratory, the numerical models have been developed, and new propulsion and flow-control techniques have been proposed based on the simulations.

Flow Control by Plasma Actuator

Plasma actuator using dielectric barrier discharge has been investigated as a flow-control techniques. Discharge dependencies of the plasma actuator were numerically predicted on electrode configuration and input voltage waveform, and a new type of the plasma actuator was experimentally demonstrated, which can be operated by a low-voltage power supply with a thin dielectric and multiplied electrodes, suggesting microfabrication of the electrodes may result in a higher performance.

Prediction of High-Temperature Shock Layer aroud Hypersonic Vehicle

Hypersonic objects such as re-entry capsule and vehicle equipped with scramjet engine are accompanied by a high-temperature shock layer ahead of them, in which the atmospheric gas is in thermochemical non-equilibrium. Aiming to accurate prediction of aerodynamic heating on the surface, a sophisticated thermochemical model has been developed by comparing with measured data. Laminar-turbulent transition in boundary layer is also investigated, which increases the convective heating.

Fundamental Physics of Supersonic Flow

In this laboratory, fundamental physics in various supersonic flows is a subject to be investigated. Sophisticated numerical simulations such as three-dimensional fluid simulation and molecular dynamics simulation are conducted for clarifying instabilities of shock wave found in core-collapse supernova explosion or ahead of a supersonic blunt body, catalytic recombination at re-entry vehicle surface, and shock wave propagation in a laser-ablated solid material.

Development and Applications of Numerical Solver for Radiation Hydrodynamics

A flow with high-temperature gases or plasmas exhibits so-called radiation hydrodynamics in which photon emission and absorption by atomic and molecular state transition and radiative transfer tightly interact with the flow dynamics. For accurate analysis of such a flow, new numerical schemes have been developed with practical models. Applications of short-wavelength radiation source produced by a plasma are also investigated by using the developed numerical schemes.

Aerospace Engineering
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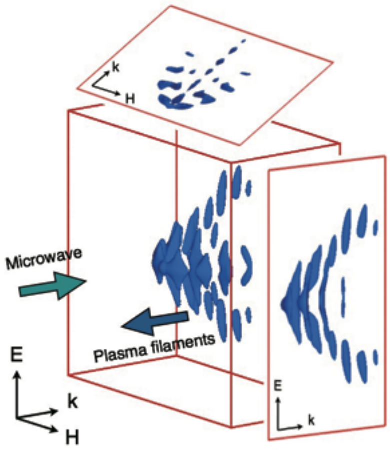
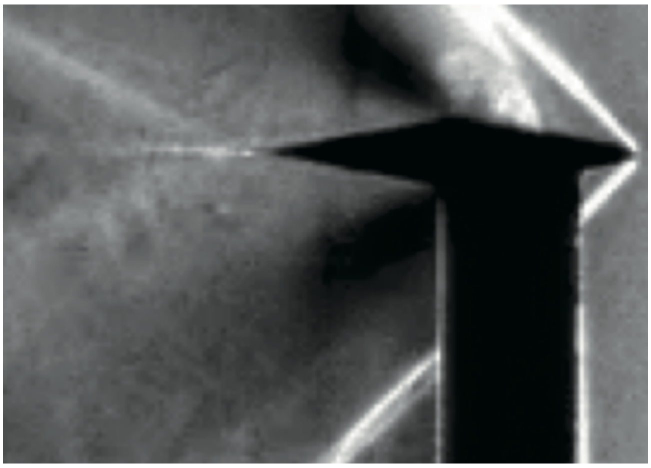


Plasma structure during microwave discharge



Schlieren image of supersonic wing

Construction of Aerospace Technology Based on Ionized High-speed Flow

We are trying to construct an innovative aerospace system using an ionizaed high-speed flow to achieve a next-generation space mission and high-speed flight on the earth. An energy is deposited to air or gas fuel to create an ionized gas that reacts to an external electromagnetic field. Novel technologies for rocket launch, space propulsion, and supersonic flight can be established using this ionized gas has because the high-speed flow is induced around an aerospace vehicle by applying the external field to the discharge gas. We are conducting numerical simulation and experiment to evaluate aerodynamic and thrust performances of aerospace system developed by us.

Launch by Microwave Rocket

Launching of a microwave rocket is conducted by irradiating an intense microwave from the earth to rocket. In this system, a launching cost is drastically decreased because transmittion of a propulsive energy from the earth removes an on-board fuel. A numerical simulation was conducted to reprosuce plasma and shock wave structures inside the microwave rocket. New concept to improve the thrust performance was proposed using external magnetic field and in-tube acceleration technilogy.

Traveling Magnetic Field Plasma Thruster

It is necessary to develop a new plasma thruster having long life time to achieve long-term space missions like a deep space exploration. We are focusing on a traveling magnetic field thruster as a novel electrodeless plasma thruster. In this system, a plasma inside the thruster nozzle is accelerated by applying a traveling external magnetic field. We are conducting a numerical simulation based on particle model for plasma transport and reaciton to understand the plasma behavier.

Space Traveling System by Magnetic Sail

It is necessary to improve specific impulse and thrust of a space propulsion system to decrease a term of space missions. High specific impulse and high thrust can be avhieved simultaneously when a magnetic sail system, which obtains a propulsive force by receiving solar wind, is established. We are doing a numerical simulaiton based on particle modeling for a plasma transport to capture an interaction between solar wind and magnetic field created by a vehicle.

Supersonic Flow Control by Repetitive Laser Pulses

Improving an aerodynamic performance of a supersonic wing is required to achieve a supersonic transport for commercial use. We are developing an innovative supersonic flight system based on repetitive laser pulses. An interaction between a laser-induced shock wave and flowfield around the supersonic wing is numerically reproduced by solving the Navier-Stokes equations. We are conducting a supersonic wind-tunnel experiment to evaluate the aerodynamic performance of the supersonic wing.

Aerospace Engineering
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Space Exploration

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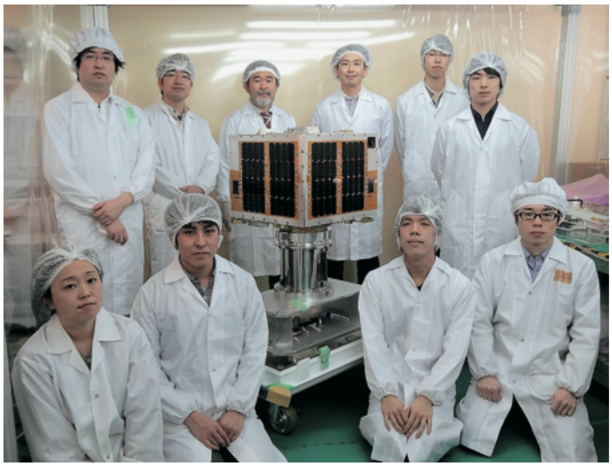
Moonraker-PFM: a lunar rover prototype



RISING-2: a 50kg-class microsatellite for Earth observation

Space Robotics, Lunar/Planetary Exploration and Micro-Satellites

In our laboratory, we are studying the dynamics and control of space robots for in-orbit missions and for lunar/planetary exploration. We investigate the mechanics and dynamics of robotic systems for a harsh and unique space environment and apply our expertise into mechanical designs and control algorithms. We are also deeply involved in Japan's space flight missions conducted by JAXA, such as “Orihime/Hikoboshi”, “Hayabusa”, and “Hayabusa 2”. We are also working on the development of university-based small satellites, and have a number of achievements. We hope our lunar rover and micro-satellite technologies will contribute to expand future space activities.

Space Free-Flying Robots for Orbital Debris Removal

We are studying the dynamics and control of on-orbit servicing robots for capturing malfunctioning or end-of-life satellites to reduce the potential sources of space debris. We investigate the capturing strategy with a special interest in impact dynamics and contact force control, which is particularly important when dealing with a rotating or tumbling target. In our laboratory, we are conducting practical research with simulated microgravity experiments using an air-floating testbed.

Spacecraft Development for Earth and Planetary Missions

We are developing micro-satellites and space probes for scientific research and technology demonstration. Since our first micro-satellite, "RISING" launched in 2009, we developed and operated 10 spacecraft in space, including "RISING-2", "DIWATA-1", "DIWATA-2", "RISESAT" for the Earth observation and "MINERVA-II2" for Japanese HAYABUSA-2 mission in these 10 years. DIWATA-1 and 2 are marked as a successful case of international collaboration with the government of the Philippines.

Mobile Robots for Lunar/Planetary Exploration

We are studying the mechanics and motion control of mobile robots that travel over natural rough terrains and soft soil environments such as the surface of the Moon. Based on a deep understanding of soil and wheel traction mechanics, we develop smart path-planning algorithms and navigation control systems. We are also working on innovative mobility designs that enable access to challenging terrains such as cliffs and vertical holes, or microgravity surface of small planetary bodies.

Toward Innovative Space Development to Expnd Humanity

Our laboratory participated in the Google Lunar XPRIZE challenge that aims privately-financed lunar exploration missions and developed successful prototype rover models, which were validated in the field test campaigns in analog sites of the Moon. We continue our endeavor toward innovative space flight missions with our micro-satellite technology and lunar rover technology to open up future space business opportunities.

Aerospace Engineering
Aerospace Engineering

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Space Systems
Space Exploration

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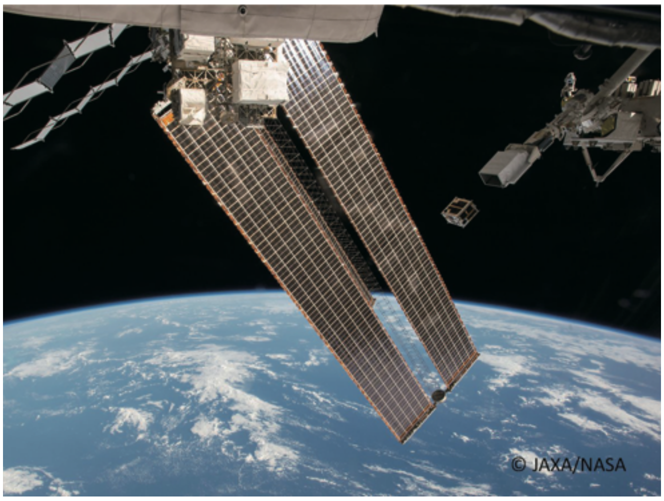


Development and Verification Environment of Micro-satellites

Deployment of Micro-satellite DIWATA-1 from the International Space Station

R&D of Micro-satellite Systems and Advanced Space Technologies

Our laboratory is doing research about dynamics and control of micro-satellites as well as the advanced space technologies for future utilization of small space systems. The focus of the research is the determination and control technologies of spacecraft orbit and attitude, which is required for global Earth observation and environmental monitoring. This lab is collaboratively working with Yoshida laboratory and so far demonstrated 50-kg-class micro-satellites such as: RISING-2, DIWATA-1, RISESAT, and ALE-1 and some CubeSats. RISESAT recently successfully demonstrated high-resolusion multi-spectral Earth observation technologies for the first time in the world.

We demonstrate Micro-satellite Technoilogies in Space!

Our Lab has been demonstrating advanced space technologies in space through the real-life 50-kg-class micro-satellite projects such as RISING-2, DIWATA-1, RISESAT, and ALE-1. These satellites are operated by laboratory members via Tohoku University's ground station located in Sendai. We will continuously contribute to orbit demonstrations of advances space technologies.

Simulation Technologies Reveal Spacecraft Dynamics!

We are also conducting researches about ground simulation and verification technologies for the study of micro-satellites' dynamics and control. The attitude control performance and robustness of the satellite on-board computer can be evaluated in the hardware-in-the-loop simulation environment. A floating motion table with 3 degrees of freedom is used to examine spacecraft dyncamis in the laboratory environment.

Advanced Space Technloogies for Space Utilization

A diverse range of key-technologies are investigated as collaborative researches between industrial partners. These include accurate attitude determination sensors, thin-film deployment de-orbit mechanism, optical communication instruments, small mobile optical ground station, etc. Also, our labotaroty collaborates with international partners in terms of research and development of micro-satellite technologies, as well as education of international students.

Micro-satellites Chenge the World!

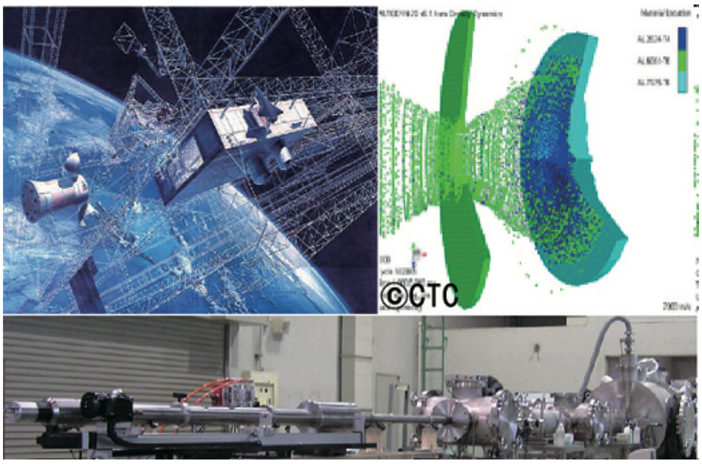
Micro-satellites can be developed very rapidly in low-cost, and can be applied to a wide range of application fields. Espacially micro-satellite constellation can realize continuous situational monitoring and communications. Through collabotarive operations with larger satellites, micro-satellites have a large potential of improving our living standard on Earth. The goal of our laboratory is to etablish advanced misro-satellite technologies for the improvement of our daily life.

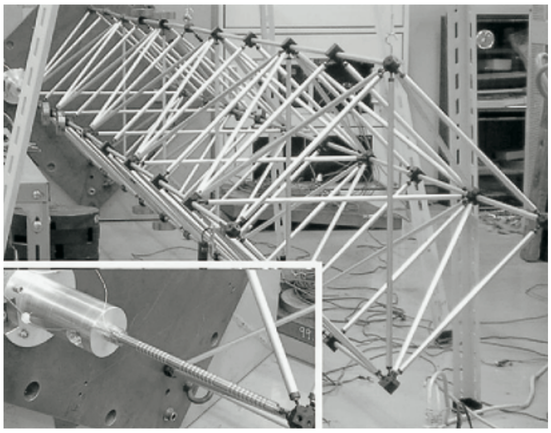
Prof.
Kanjuro MAKIHARA

Makihara Laboratory

Astronautical Engineering Space Structures

http://web.tohoku.ac.jp/makihara/index.htm





Space truss structure simulating a part of space station

Top-left: Next-generation space station, Top-right: Lunar observation base using moon craters Bottom: Hypervelocity impact experiments conducted in JAXA

Vibration Control, Noise Control, Shock Control of Space Structures

We have developed vibration control, acoustic control, and shock control for space structures such as space stations, lunar bases, and artificial satellites. In space, sufficient power supply is not expected. Thus, an innovative method is required to suppress structural vibration using a self-powered control device. Our laboratory focuses on a truss structure that forms a structural member for next-generation space stations. We have installed a truss structure in our laboratory, which is employed for proof experiments.

・Self-powered vibration control for large space structures (Enumerated items are example research subjects)
・Proof experiment using space truss structures
・Shock attenuation of artificial satellites during launch period
・Noise reduction of rocket fairings

Energy-Harvesting Using Smart Structures

We cannot solely rely on solar power generation on the moon because night time occurs for up to 14 days. Therefore, energy harvesting from vibration sources should be explored. We are developing an energy harvester that is utilized not only in space structures but also in airplanes and automobiles.

・Energy-harvesting using smart space structures
・Development of autonomous digital harvesters

Experiments for Space-Debris Impacts

The impact of space debris and meteorites is a serious issue for space structures. We have implemented measures to mitigate hypervelocity impact in collaboration with JAXA. We are investigating the use of a conductive tether system for debris removal.

・Protection of space station against space debris
・Impact-proof tether systems for debris removal

Modeling for Variable Morphing Wings

Next-generation aircraft are expected to have a variable wing (morphing wing) to achieve fuel efficiency and compactness. We integrated three fields (fluid, structure, and control) to establish a coupling model for variable wings.

・Mars-airplane with folding wings
・Modeling of variable morphing wings

Dynamics Analysis for Aerospace Structures

For future aerospace structures, an innovative structural analysis is necessary, which differs from conventional frameworks. We conduct pioneering research for future space development.

・Attitude analysis of mass-varying spacecraft
・Shape control of large deployable antennas

Aerospace Engineering
Graduate School of Information Sciences
Department of Computer and Mathematical Sciences

Yamamoto/ Miyazawa Laboratory

Prof.
Satoru Yamamoto

Assist.Prof.
Hironori Miyazawa

Mathematical Modeling and Computation

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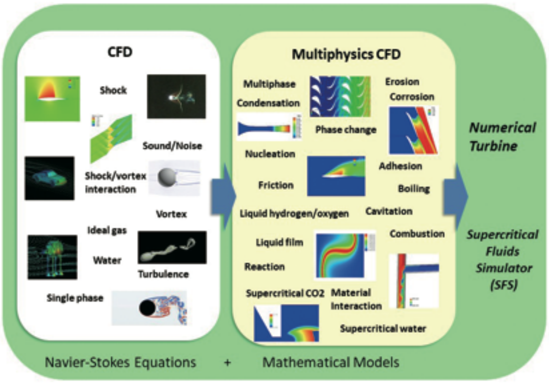
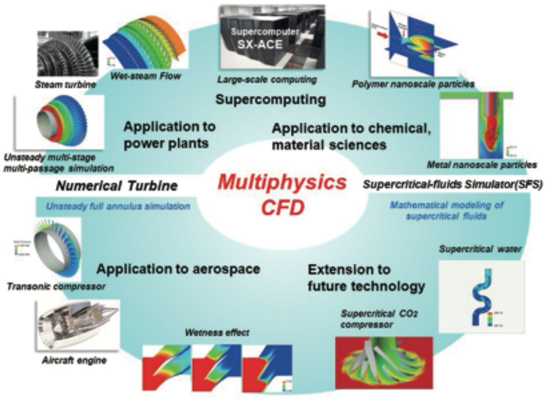


Multiphysics flow problems to be solved by Multiphysics CFD



Numerical Turbine and Supercritical-fluid Simulator (SFS) based on Multiphysics CFD

Multiphysics CFD for High-Performance and High-Reliable Fluid Machines

Our laboratory conducts Mathematical Modeling and Computation (MMC). We now explore Multiphysics CFD (MCFD) as a research field of MMC expanded from Computational Fluid Dynamics (CFD). MCFD solves additional mathematical models governing problems of physics, chemistry, and so on with Navier-Stokes equations. We promote two research projects: Numerical Turbine(NT) and Supercritical-fluids Simulator (SFS). NT achieves large-scale computations of moist-air and wet-steam flows in full annulus gas and steam turbines. SFS realizes the simulation of complex flows with arbitrary substances. NT and SFS are utilized for collaborative researches with industries.

Numerical Turbine and the Supercomputing

More than 90% of the electricity is generated from gas and steam turbines in Japan. This situation will be continued in future, even though reusable energies are developed. Numerical Turbine (NT) is a MCFD application for simulating multi-stage full-annulus flows in the turbines. Then, large-scale computations using supercomputers are executed. We now conduct collaborative researches using NT with industires and universities to develop high-performance and high-reliable turbines.

Supercritical-fluid Simulator (SFS)

We are developing a MCFD application named Supercritical-fluid Simulater (SFS) with associate professor Furusawa. SFS can simulate flows of aribitrary substance, such as water, carbon dioxide, methane, and so on, in not only gas and liquid state but also supercritical state considering phase change. Currently, we apply SFS to the simulations of supercritical-fluid flows of water, carbon dioxide and kerosine crossing critical point. The detail is explained in the page by Furusawa.

Large-scale moist-air flow simulation in aircraft engine

We apply NT to large-scale computations of moist-air flows through a fan and a compressor supposing those in aircraft engines and industry gas turbines. We clarified that moist air is certainly effective on the flows and affects the performance. Our interesting is how the moist air infulences to unsteady flows through multi-stage full-annulus stator and rotor blade rows in the fan and compressor. We have already custamized NT for the large-scale computation.

Degital Twin of Turbomacinery based on Numerical Turbine

Industry 4.0 leads fully automated maintenance, repair, and overhaul (MRO): cyber-physical systems. The shape change of stator and rotor blades caused by a long-time operation in turbomachinery is one of the primary issues considered for the scheduling of MRO. We now apply NT to the flows in an actual turbine at a power plant as the collaborative research with an electeic power company to optimize the scheduling. FInal target is to develop a Degital Twin based on NT.

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Furusawa Laboratory

Assoc.Prof.
Takashi Furusawa

Mathematical Modeling and Computation

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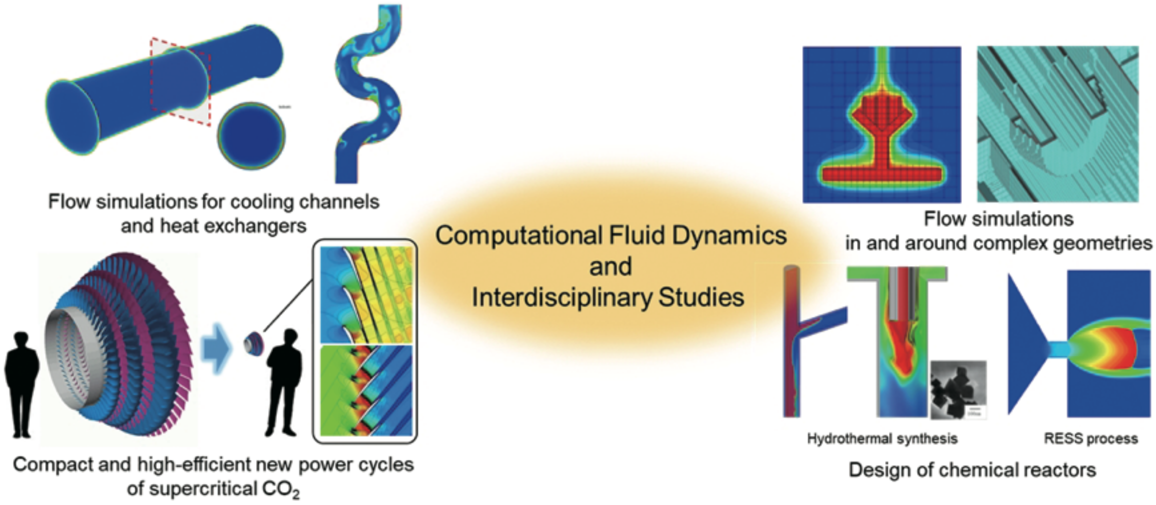

Numerical Methods and Interdisciplinary Studies for Multiphysics Flows

Our laboratory conducts interdisciplinary studies for multiphysics flows such as heat exchangers, cooling pipes, chemical reactors, turbines, and compressors. We have developed numerical methods and mathematical models for chemical reactions, particle formations, nonequilibrium condensations for many kind of industrial applications. The mathematical models are directly coupled with "Supercritical Fluids Simulator" and "Numerical Turbine" collaborating with Yamamoto/Miyazawa Lab. Our final goal is contribution for the sustainable society by the interdisciplinary study and numerical simulation achieving highly-efficient power cycle and green chemistry.

Supercritical Fluid Flows in Next-Gen Power Cycles

Carbon dioxide (CO2) is employed as a working fluid in supercritical Brayton cycles. Supercritical CO2 has several advantages in the compression and heating processes. We have reconstructed the numerical method for supercritical CO2 flows with the equation of state for real gas and the nonequilibrium condensation model. We investigate supercritical CO2 flows in radial compressor and some other components in this system.

Multiphysics Flow Simulation for Cooling Channels

Hydrocarbon fuel decomposes by the endothermic thermal cracking at high temperature. The additional cooling by the endothermic reaction in the propulsion system for aerospace planes reduces the heat of the engine wall. Typical hydrocarbon fuels consist of many components like alkanes and cycloalkanes. We have developed the numerical methods and the mathematical models for hydrocarbon fuels flows with thermal cracking process.

Design Support by CFD for Chemical Reactors

Supercritical H2O and CO2 is well used for nano-particle generation such as Rapid Expansion of Supercritical Solution (RESS) process and Supercritical Hydrothermal synthesis. In these processes, The solute in fluids precipitates as nono-particles in chemical reactors. Particle size, yield, and quality depend on the design of chemical reactors. We support flow-path design in chemical reactors using our numerical methods and particle formation models.

Mathematical Modeling in Supercritical Conditions

Mathematical models for chemical reactions, particle formations, and condensations are crucial for the accurate prediction of multiphysics flows in supercritical conditions. Supercritical fluids have the drastic change of thermophysical properties near the critical point. We develop new mathematical models considering the thermophysical properties for various industrial applications.

Aerospace Engineering
Computer and Mathematical Sciences, Graduate School of Information Sciences

Kobayashi/Sato Laboratory


Prof. Hiroaki Kobayashi
Assist.Prof. Masayuki Sato

Computer Architecture

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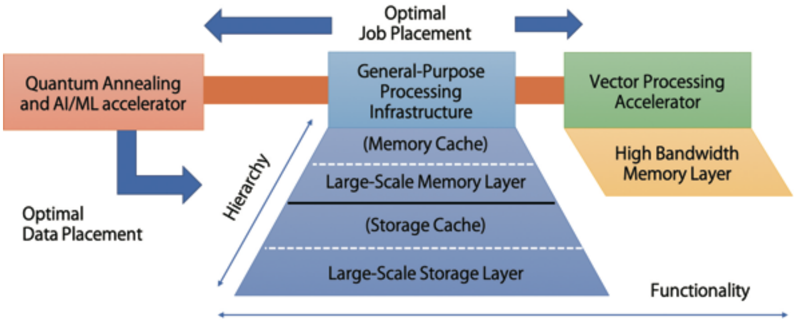
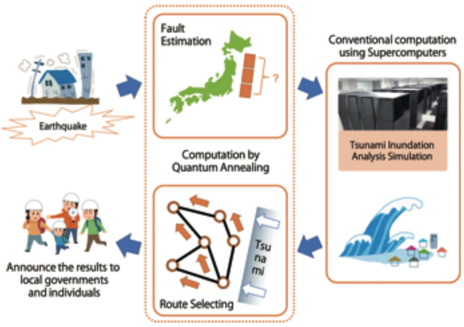


Hybrid conventional-QA-AI/ML computing environment



A real-time tsunami inundation simulation with routing assistance for evacuation

Next-Generation Computer Architectures and their Applications

Our laboratory aims at establishing fundamental hardware technologies for next-generation computing systems and developing high-performance applications and their optimization technologies. We are also interested in computer architectures in the Post-Moore era and their applications. Our interests include new information processing technologies such as quantum annealing and artificial intelligence. They can solve problems that conventional architectures could not solve in a practical time. Moreover, we are researching applications that can exploit the potentials of the new architectures and their deployments as high-performance infrastructures.

Quantum Annealing Assisted Supercomputing Systems

Conventional computing systems cannot solve combinatorial problems in a reasonable time. However, quantum annealing (QA) can effectively solve these problems by using the quantum effect. This research focuses on the integration of QA technologies into the conventional computing system as a single system image, and development and deployment of their killer applications: a real-time tsunami inundation simulation with routing assistance for evacuation.

High Performance Computing Supported by Machine Learning

Due to the power limitations of computers and the demands for big data processing, machine learning (ML) has attracted attention, in which computers learn various problems and their answers from a significantly large amount of data. Our laboratory is conducting researches on the integration of these emerging ML technologies into conventional computing systems, and development and deployment of their killer applications: a system to predict turbine faults.

Code Optimization to Exploit Potentials of Processors

Processors have changed their structures and increased their variations based on technology trends. However, as the complexity and variations of the processor structure increase, it becomes difficult to exploit the performance of the processors for applications. This research adapts applications to the processors to obtain the high performance by optimizing and tuning the application codes for each processor based on the evaluation results of the latest processors.

High-Performance and Low-Power Computer Architecture

Computers have significantly increased their performances based on the advances in integration technologies. On the other hand, due to the power wall and the memory wall, computers should process a larger amount of data with a lower power. Our laboratory focuses on hardware technologies to maximize the performance per watt, such as vector processing mechanisms, memory systems that can adaptively provide resources to applications, and non-volatile cache memories.

Aerospace Engineering

Graduate School of Information Sciences/Cyberscience Center

Takizawa Laboratory

Prof.
Hiroyuki Takizawa

High Performance Computing Laboratory

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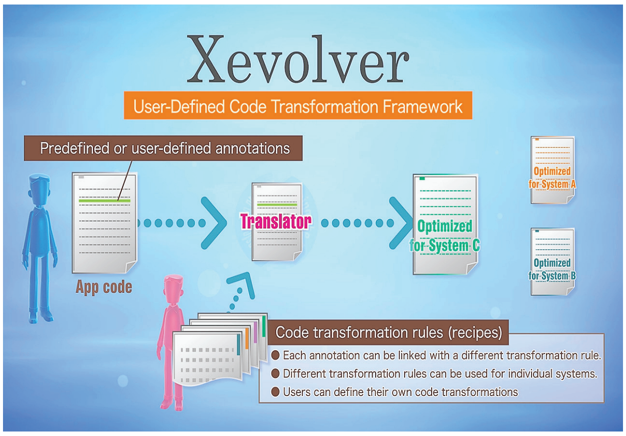
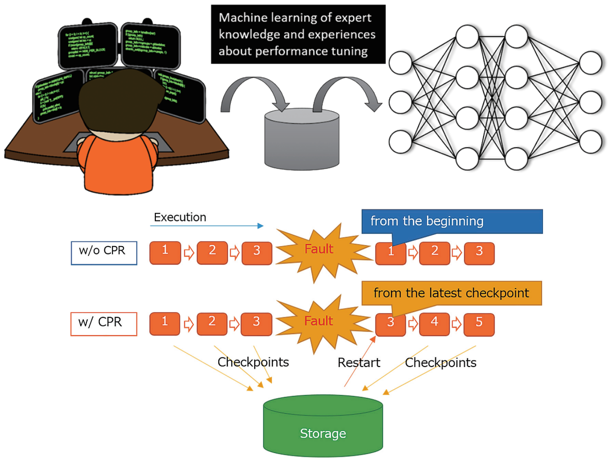


Performance-aware programming in an upcoming extreme-scale computing era



Check-pointing mechanism for periodically saving the system state

Shaping the future supercomptuing technologies and their applications

This laboratory focuses its research on shaping next-generation supercomputing technologies that are practical and indispensable for advancing the state-of-the-art science and technology, and also for supporting innovations in engineering. Especially, as future supercomputing systems will be larger and more complicated, we mainly work on developing novel system software and programming technologies to effectively exploit the system performance. For example, we are exploring an effective way to partially automate the supercomputing software development, and also to replace it with machine learning technologies. We also discuss future supercomputing system architectures and their building blocks at various levels by collaborating with Egawa laboratory and Kobayashi-Sato laboratory.

"Smart" software automatically tuning its parameters for individual system configurations

To achieve high performance on a hybrid computing system of different kinds of processors, a program needs to be specialized to the particular system configuration, by adjusting various parameters and also assigning the right processor to the right task. To reduce the burden of such system-specific programming, we are developing smart software technologies so that a user program is capable of automatically adapting to individual system configurations.

Supercomputer programming aided by machine learning

Machine learning technologies are now emerging very quickly. It might be difficult even for the latest machine learning technologies to fully automate performance-aware, supercomputer programming that has been achieved only by human experts with deeply considering individual system configurations. However, we believe the programming process could partially be automated by machine learning. Therefore, we are exploiting effective ways of using machine learning for performance-aware programming.

Hardware-software co-design for improving power and energy efficiencies

General-purpose processors are designed to execute any programs, and thus their hardware design could be redundant if they are always used only for specific purposes. By limiting the purposes, there is a potential to reduce redundant hardware resources and thereby power consumption of the processor without losing the performance. Therefore, we are considering hardware and software at the same time to design power/energy-efficient processors.

A fault-tolerant system that can keep working even if some of its components are broken

Since a supercomputing system consists of a huge number of components, failures could happen in the whole system at a relatively high frequency even if the failure rate of each component is low. If a program has to start from the beginning whenever a failure happens, the computation time until the failure is wasteful, and moreover the program may not be able to finish in practical time if failures happen too frequently. Therefore, we are considering the fault-tolerance mechanisms for a system to keep working upon failures.

Aerospace Engineering
Graduate School of Information Sciences/Cyberscience Center

Egawa Laboratory

Assoc.Prof.
Ryusuke Egawa

High Performance Computing Laboratory

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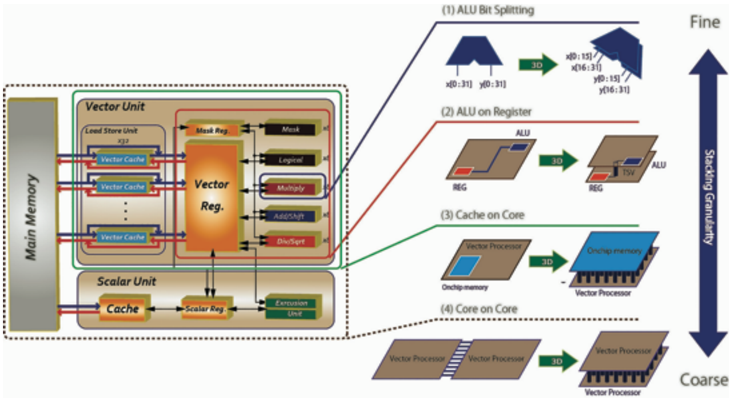
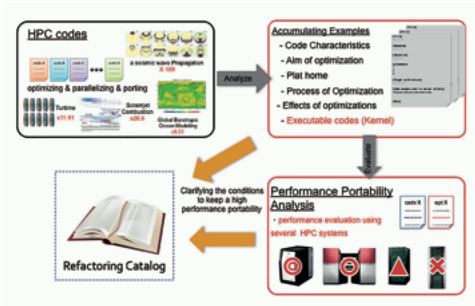


5.5D Green Micro Architecture



HPC Refactoring Catalog

Toward Energy-efficint Supercomputing System

Our research group is working on the design and development of high-performance computing (HPC) systems that will support future advances in computational sciences from the viewpoint of computer architecture and hardware/software co-design. Since future HPC systems need to have high energy efficiency as well as high computational performance, a significant reduction in power consumption is mandatory. To this end, the research topics in our laboratory cover, microprocessor design with innovative technologies, development of program optimization technologies, the database for keeping performance portability, and HPC, AI, and IoT convergence technologies.

5.5D Green Microarchitecure

To achieve energy-efficient computing in post-Moores' era, we are working on the development of future microprocessors that can maximize effective performance and power efficiency by using 2.5D and 3D stacking technologies and innovative devices. Currently, we are focusing on memory subsystems of microprocessors which targetting on high-performance computing and image processing/coding.

Challenge for keeping high-performance portability

Recently, it is getting difficult to exploit the potential of HPC systems due to their complexity and variety. These drastic changes of the HPC systems force HPC programmers to further spend enormous effort to develop, maintain, and migrate their codes to the future systems. To overcome this situation, we are developing a database named "HPC refactoring catalog" for maintaining performance portability of HPC applications.

Efficient Operation of HPC systems

Since the supercomputer is used simultaneously by multiple users, a large number of jobs are executed. However, if the job scheduling on the supercomputer does not perform efficiently, system throughput and power efficiency might be degraded. In this topic, we are predicting job execution time by machine learning and efficiently allocating computational resources by a quantum computer. Recently, we also explore innovation at the convergence of HPC, AI, and IoT.

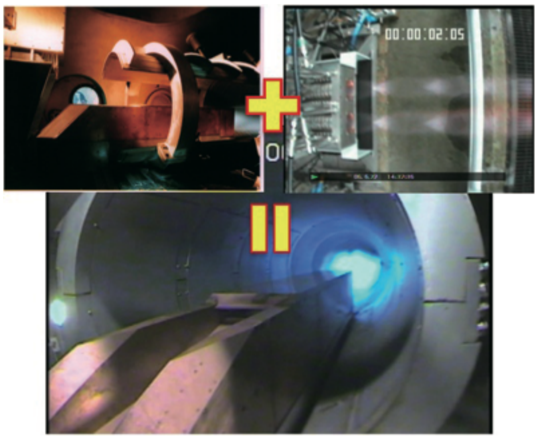
Accelerating Real Applications

In order to exploit the potential of supercomputers, it is indispensable to optimize the code considering the hardware configuration and the characteristics of system software. We are promoting research and development on code optimization technology that can accelerate real applications based on clinical approach and findings through the operation of supercomputers at the Cyberscience Center.

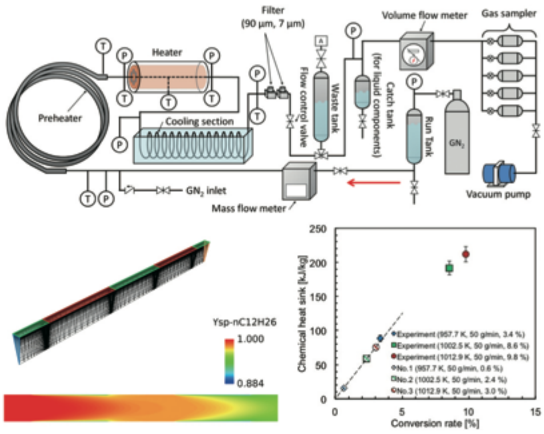
Tomioka Laboratory

Visiting Prof.
Sadatake Tomioka

JAXA Cooperative Laboratory,
Next Generation Space Transportation System



Scramjet engine + Rocket engine = RBCC engine



Cooliwng test apparatus (upper) and comparison with CFD (lower)

Study on Propulsion System for Reusable Launch Vehicle

System studies on high efficiency propulsion system vital to realize reusable launch vehicle are underway. Combination of rocket engines with hypersonic air-breathing engines is targeted to reduce on-board oxygen consumptiom, as well as high efficiency rocket engine technology. Major issues are;

* System analysis as launch vehicle,
* Studies on altitude compensation nozzle, especially on interaction between nozzle flow and outer flow,
* Studies on wide range operative rocket engine with hydro-carbon fuel, including injection and cooling,
* Performance prediction of Rocket-Based Combined Cycle engines.

Combustion and Its Control within Highspeed Reactive FLow

Studies on ramjet/scramjet (Supersonic Combustion ramjet) engines are expected to reduce onboard oxygen consumption of reusable launch vehicle. Major issues are;

* Studies on high-speed combustion phenomena including dual-mode operation
* ombustion control technique to optimize heat release region for best performance in accordance with airspeed,
* Combustion enhancement of hydrocarbon fuel at low-speed flight regime.

Researches on vital components of hypersoic airbreathing engine

Researches on hypersonic engine components are underway. Currently, cooling system is targeted as hydrocarbon fuel suitable for small scale demonstrator has poor cooling capability. Improvement of the cooling capability by thermal decomposition of hydrocarbon fuel is investigated both experimentally and numerically (received student award in 2018). Fluid dynamics, especially instability, within the cooling system is also targeted.

Optical Diagnostics on Combustion Phenomena

Observation of combustion phenomena within high-pressure, high-temperature rocket combustion chamber as well as within high-speed scramjet combustor is a hard task. Optical diagnostic techniques, especially quantitative measurement using laser diagnostics are pursued such as;

* Temperature measurement using Laser Induced Fluorescence Spectroscopy,
* Density measurements of species using Tunable Diode Laser Absorption Spectroscopy.

Aerospace Engineering
Institute of Fluid Science

Obayashi/Yakeno Laboratory

Prof.
Shigeru Obayashi

Assist.Prof.
Aiko Yakeno

Aerospace Fluid Engineering Laboratory

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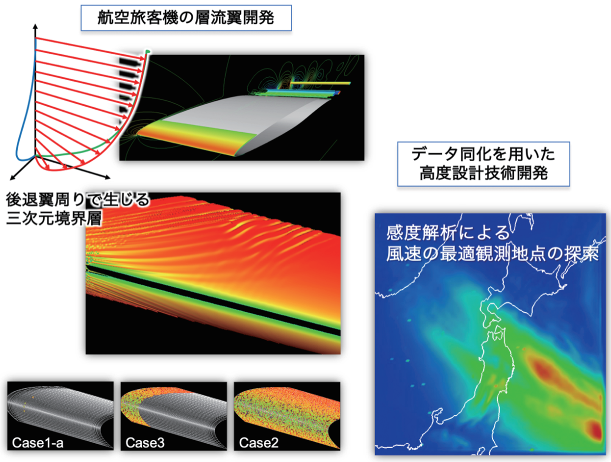
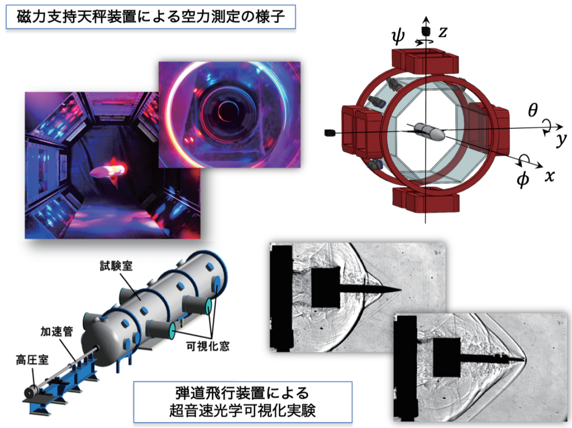


Examples of computational results



Aerodynamic experiment by magnetic force balance system (MSBS) and supersonic visualization experiment by using ballistic range

Advanced computational aerospace fluid engineering

Advanced computational challenges to solve various engineering issues related to flow nonlinear phenomena, such as turbulence transition, flow separation, and wake vortex interference. We are developing data-assimilation techniques with data obtained with the wind tunnel experiment and the flow simulation, to solve problems of an aircraft at the actual flight condition. Additionally, high-resolution direct numerical computation, linear flow instability, and turbulence structure extraction are employed for investigations.

Laminarization around a arcraft swept wing

Friction drag due to the flow viscosity is considerable when an aircraft operates, approximately half of the total one. Laminar and turbulent states are coexisting around an aircraft wing. If we delay a transition to turbulence by some techniques, and if we maintain the laminar flow, the viscous drag can be reduced. Therefore, we are developing superior laminar flow wing, by using large-scale parallel direct numerical computation by a supercomputer, and data-driven methods to evaluate flow instability.

Development of data-assimilation technique

We are developing data assimilation technology aiming for the sophistication of CAE. We are now conducting research to predict uncertainty phenomena quickly such as turbulence in the atmospheric boundary layer, which is a problem when operating an aircraft, to control at real-time.

Aerodynamic measurement by the magnetic force supporting balance system (MSBS)

In order to measure the aerodynamic characteristics of flying objects, we are developing a magnetically supported balance device (MSBS) that floats the model in the air by magnetic force and controls the attitude in order to avoid the influence of the model's mechanical support. We have constructed a highly responsive system for unsteady motion and supersonic flight. Currently, we are using them to evaluate the aerodynamic characteristics of actual shapes, such as low-thinness ratio cylinders and throwing for athletics.

Supersonic aerodynamic experiment by ballistic range

The ballistic flight device can perform high-speed free flight, and high-speed collision experiments from transonic speeds up to 7 [km/s]. The problem with supersonic aircraft is the deterioration of fuel economy caused by sonic boom and wave drag, but one of the solutions is double-wing, which has been developed. We have acquired knowledge for the development of the supersonic aircraft, such as confirming the trend of changes in shock wave shape due to changes in the blade tip thickness.

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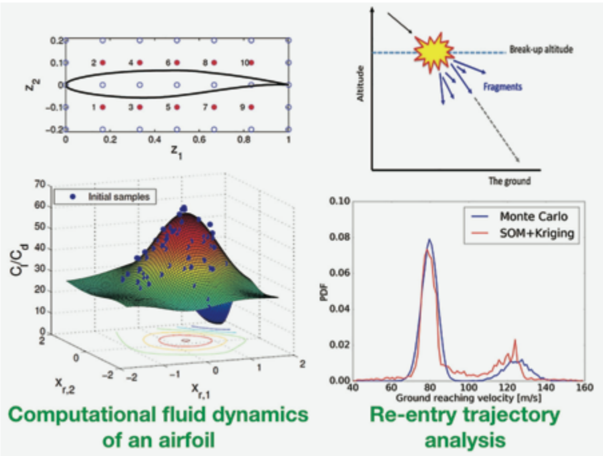
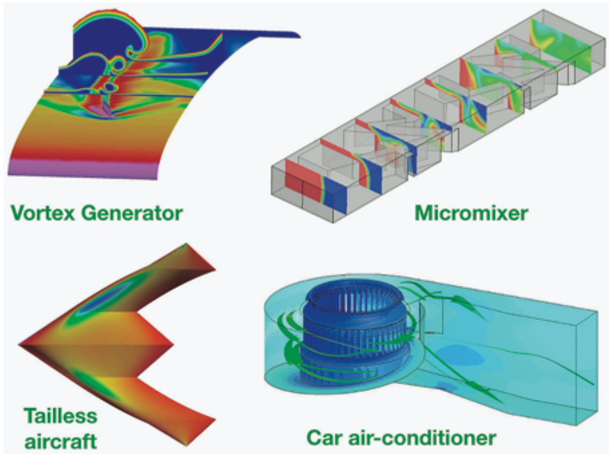


Examples of uncertainty quantification



Examples of multi-objective design exploration

Uncertainty Quantification in Flow Analysis and Design

Real-world flow phenomena are caused by various “uncertain” physical factors. Numerical analyses to simulate flow phenomena are often simplified without considering such uncertainties, and these results often disagree with the real-world phenomena. Hence, we aim to help exact understanding of complex flow phenomena by modeling uncertainties that appear in a real world, introducing the uncertainty model into flow analysis, and quantifying behavior of physical quantities against the uncertainties. In addition, we aim to create engineering products, which are robust for practical use, by introducing the uncertainty model into design process.

Multi-Objective Design Exploration of Fluid Machineries

We have been proposing “multi-objective design exploration,” which is based on evolutionary computation and data mining, as an approach to create innovative design regardless of designer’s knowledge and experiences, and applying this approach to the design of fluid machineries such as aircraft and automobile. This approach is useful for discovery of new design knowledge by finding various optimal design candidates and extracting characteristic information from the candidates.

Evolutionary Computation to Search for Optimal Solutions

Real-world design is formulated as the optimization problem with many shape and performance parameters. In such a problem, it is difficult to manually find optimal shapes that achieve the best in terms of all performances. Therefore, we are developing an original algorithm of “evolutionary computation,” which mimics biological evolution for efficient solution search, and utilizing the algorithm to solve the real-world large-scale design problem.

Surrogate Model to Estimate Optimal Solutions

In actual engineering design, it is desirable to reduce a turn-around time until a design candidate satisfying pre-specified design requirements is obtained. For this purpose it is necessary to estimate performance for various shapes promptly. Therefore, we are developing an original “surrogate model” to represent a complex response of the performance to the change in the shape, and utilizing the model to establish a real-time design process.

Simulation and Optimization of an Air Conditioning Unit

In Tohoku University, we have established a collaborative research division with a domestic car parts supplier, and are doing research on fundamental technologies expected for development of an electric vehicle. We aim to develop a compact and low-load air conditioning unit for the electric vehicle by high-fidelity computational thermo-fluid dynamics simulation together with design optimization.

Aerospace Engineering
Institute of Fluid Science

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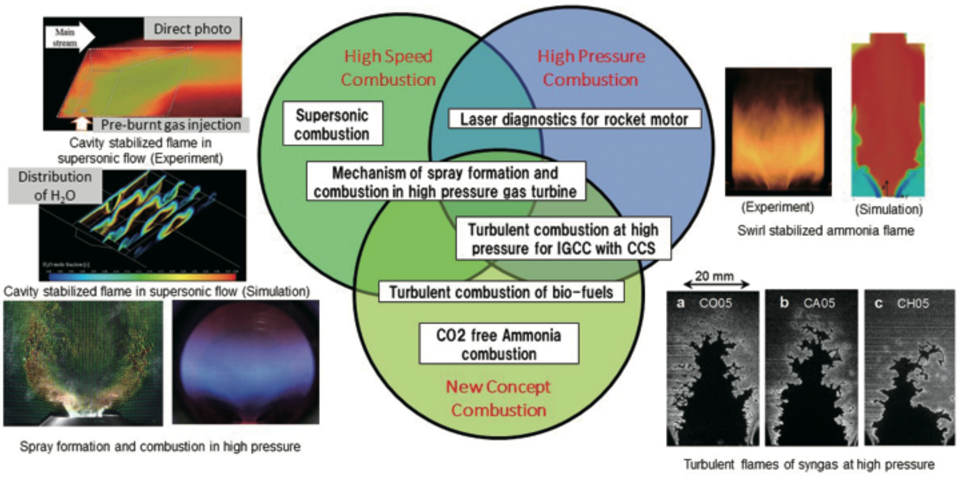


Combustion technology in aerospace, environment, and energy sectors

Combustion is a complex phenomenon composed of multi-dimensional dynamics of temperature, concentration, velocity and chemical reactions. Advanced combustion technologies are essential to solve the environmental and energy issues. Our laboratory focuses on investigation of combustion phenomena, development of diagnostics, and analytical methods of flames. Projects on turbulent combustion at high pressure and high temperature, heterogeneous combustion in fuel spray for jet engines, controlling supersonic combustion, as well as new fuel combustion for reducing greenhouse gas emissions, are in progress.

High pressure turbulent combustion

Turbulent combustion researarch at high pressure and high temperature is essential not only for improving thermal efficiency of internal combustion engines but also for promoting scientific understanding of complex combustion phenomena. The mechanism of turbulent combustion in such extreme conditions are investigated using advanced laser diagnostic technologies and numerical simulations for development of highly efficient energy systems.

Combustion in supersonic air flows and its control

Research of gas mixing, combustion, and interaction of shock wave in supersonic air flow is essential for the development of next-generation supersonic combustion ramjet engine (SCRAM Jet Engine). In our laboratory, planer laser induced fluorescence for OH (OH-PLIF) and numerical simulation are performed to investigate the effects of the incident shock wave on the mixing and flame holding as well as interaction between a cavity flame-folder and pylons placed upstream of the cavity.

Carbon-free ammonia combustion phenomena

Recently, ammonia has been considered not only as a hydrogen energy carrier but also as a potential carbon-free fuel. However, its flame characteristics are not fully understood. In our laboratory, characteristics of ammonia combustion are investigated based on experiments as well as numerical simulations using detailed chemistry. Flame stabilization mechanism and turbulent combustion are also studied to apply the ammonia combustion to gas turbine power generation.

Fuel spray formation and combustion at high pressure

Gas turbines for aircraft and power generation are operated at high pressure. To realize a gas turbine combustor with very stable operation over a wide range of conditions, characteristics of spray formation and combustion should be clarified in detail. In our laboratory, spray formation and combustion phenomena are investigated using laser diagnostics (PDPA, PIV) and high-speed flame observations to develop high performance jet engines.

Aerospace Engineering
Institute of Fluid Science

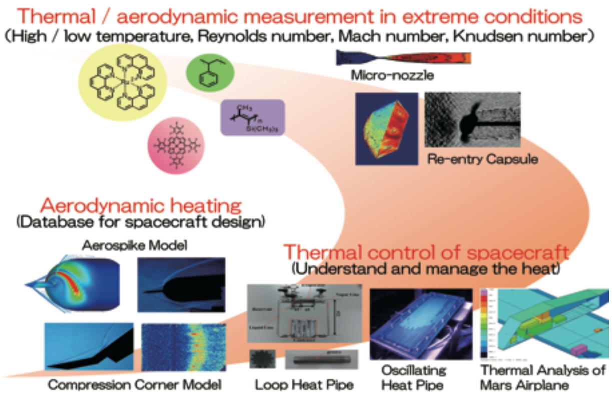
Nagai/Fujita Laboratory

Prof.
Hiroki Nagai

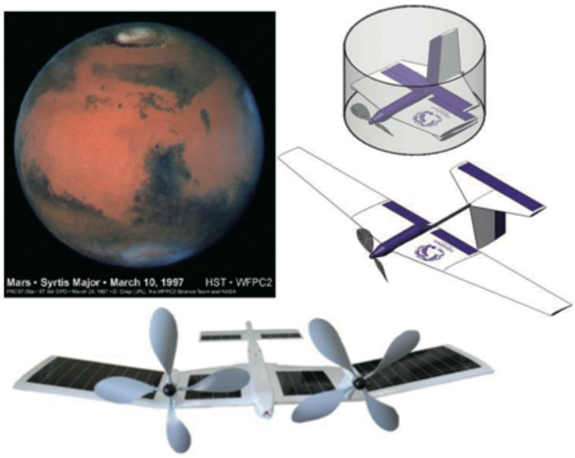
Assist.Prof.
Koji Fujita

Spacecraft Thermal and Fluid Systems Laboratory

http://www.ifs.tohoku.ac.jp/space/index-e.html



Study of thermal fluid phenomena for next-generation spacecraft



Mars airplane conceptual picture

Study of thermal fluid phenomena for next-generation spacecraft

The elucidation of the thermal and aerodynamic characteristics for re-entry vehicle is essential for the development of next-generation space transportation systems. In this research, we are conducting a study of the aerodynamic heating estimation methods using molecular sensors, and research and development of thermofluid measurement methods that can measure extreme environmental fields such as high temperatures (over 1000 ℃) and cryogenic temperatures. Our laboratory also has studied Loop Heat Pipes (LHP) and Oscillating Heat Pipes (OHP), Two-Phase Mechanically Pumped Loop System for spacecraft thermal control.

Study of aerodynamics and heating for re-entry vehicle

The next-generation spacecraft is required to be small, light, and economical, so accurate prediction of aerodynamic heating is required. In this research, we are studying a measurement method that can estimate aerodynamic heating with high accuracy using Temperature-Sensitive Paint (TSP). At the same time, we aim to build a database for spacecraft design by integrating with CFD.

Development of thermal control devices for spacecraft

Our laboratory has studied thermal control devices (LHP, OHP, Mechanical Pump Loop) using the vapor-liquid two-phase flow. In particular, LHP/OHP has no mechanical part and do not need the electrical power, so it is expected to be installed in a deep-space spacecraft with limited resources as a lightweight and space-saving non-power heat transport device. We aim to propose a power-saving and highly efficient spacecraft thermal control system that combines these.

Study of new planetary exploration system using aircraft

Currently, we are researching and developing Mars airplanes that conduct exploration while flying in the Martian atmosphere. Flight demonstration tests will be conducted in the vicinity of an altitude of 35 km on the earth, which has an equivalent flight environment to that of Mars. We will demonstrate its feasibility through the flight test ahead of the world. We aim to propose a new planetary exploration system ("Planetary Locomotion") using aircrafts.

Study of membrane wing for planetary exploration

The wing of a Mars exploration airplane is required to satisfy not only high aerodynamic performances but also various performances such as lightness, storage/deployability, and gust resistance. We are focusing on flexible membrane wings such as the wing of insects and bats. Especially the studies include the elucidation of the interaction between low Reynolds number flow and a flexible membrane, and control of the flow field using a membrane-like advanced actuator.

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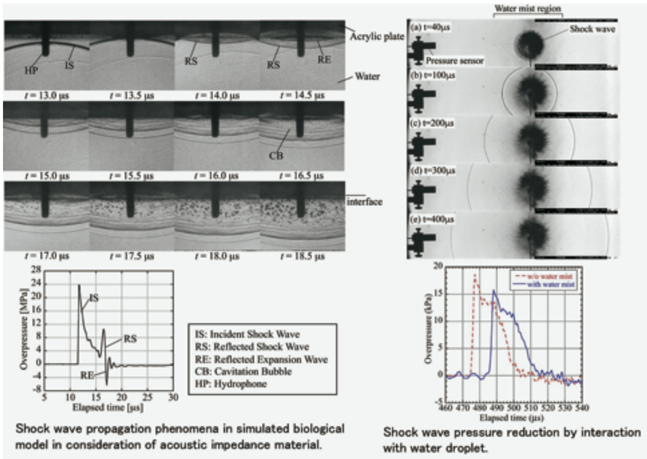
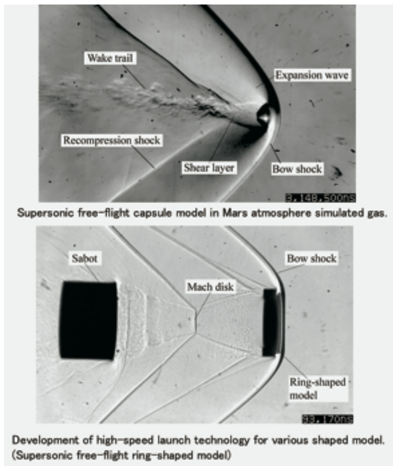


Study on shock wave attenuation and pressure active control



Supersonic free-flight projectile test by using ballistic range

Elucidation of complex shock propagation and its interdisciplinary application

Shock wave phenomena associated with various research field such as aerospace engineering, material engineering, medical and biomedical engineering, and geophysics, is significant problem. The complex shock wave laboratory investigates complex propagation phenomena of shock wave in gas-liquid-solid three-phase for understanding a fundamental mechanism of shock wave phenomena and its interdisciplinary application.

Study on shock wave propagation for human body tissue protection

We focus on acoustic impedance value, investigates to shock wave propagation and interaction phenomena in simulated biological model in consideration of acoustic impedance for understanding of shock wave tissue damage mechanism. We aim establishment of human body tissue protection method from shock wave by using the obtained knowledge about shock wave propagation phenomena such as local elevation of pressure and negative-pressure region related to cavitation bubble generation.

Shock wave attenuation phenommena by shock interaction

We investigate experimentally and numerically shock wave attenuation phenomena due to shock wave interaction with water droplet, a rough surface and irregular shape, etc. These achievements are expected to understand mechanism of a serious influent reduction caused by shock wave to artificial construction and human body, and to estabish the reduction method.

Establishment of shock wave pressure active control

We aim establishment of shock wave pressure active control method by using shock wave reflection phenomena with various materials with different acoustic impedance and shock wave enhancement phenomena due to shock wave interaction in a closed space in the condition of air and underwatwer. These achievements are expected to develop new device for industrial application by using controlled shock wave pressure.

Study on supersonic free-flight for aerodynamics

We investigate experimentally aerodynamic properties for supersonic free-flight model, its generated shock wave and flow fields regarding development of the silent supersonic transport and Mars entry capsule by using ballistic range. And we focus on a development of supersonic launching method for various complex shaped models and their quantitative and qualitative new measurement.

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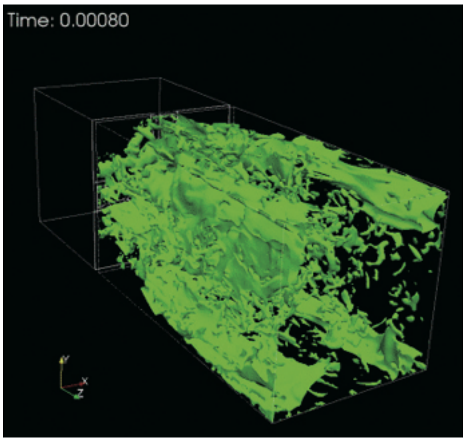
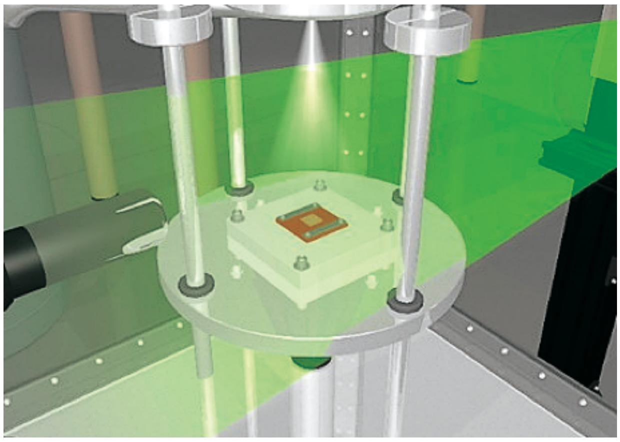


Coupled fluid-structure computing for hydrogen leakage phenomena of high pressure tank with crack propagation



High-precision PIA laser integrated measurement of fine solid-nitrogen particulate spray flow

Creation of multiscale interdisciplinary multiphase flow energy system

Our laboratory is focusing in the development of innovative multiphase fluid dynamic methods based on the multiscale integration of massively parallel supercomputing and advanced measurements, and research related to creation of environmentally conscious energy systems. Furthermore, we promote basic research for the creation of risk management science and associated new multiphase flow system directly linked to sustainable energy represented by a high-density hydrogen storage technology. Particularly, we are focusing on chemical-free, pure water free, dry type semiconductor wafer cleaning system using cryogenic fine solid high-speed spray flow.

Denelopment of high density hydrogen energy carrier

This computational study provides useful information for predicting dynamic crack propagation mainly caused by hydrogen embrittlement of aged pressure vessels accompany with leaked hydrogen-air mixing as an important part of assessing hydrogen as an energy vector. The present study was conducted by using a hybrid of the coupled particle and Euler methods.

Supercomputing for Tsunami and Flood Damage Mitigation

The mitigation procedure of hydrodynamic energy caused by tsunami or flood is predicted by supercomputing to contribute the structural designing or land-use planning of coastal area. First, we aim to develop Multiphase Fluid-Structure Interaction (MFSI) computing by constructing a numerical model that considers multiphase hydrodynamic treatment on the interaction between megafloat and tsunami, obstackles and flood.

Non-aqueous semiconductor cleaning technology using fine solid particulate spray

We are focusing in different field integration research and development such as creation of environmentally conscious type nano-cleaning technology using reactive multiphase fluid that is a thoroughly chemical-free, pure water free, dry type semiconductor wafer cleaning system using cryogenic micro-nano-solid high-speed spray flow, and also focusing on removal-reusing technology for solar cells and ITO membranes for conducting organic polymer (including indium oxide tin).

Development of new physical cleaning method using cavitation bubbles in megasonic field

Numerical analysis of non-spherical oscillating bubbles in a megasonic field has been investigated and clarified that it is possible to analyze the translational motion of bubbles due to the primary Bjerknes force and the non-spherical collapse of bubbles when collapsing near the wall surface. Furthermore clarified that the particle removal mechanism and non-spherical multiple bubble dynamics in megasonic cleaning.

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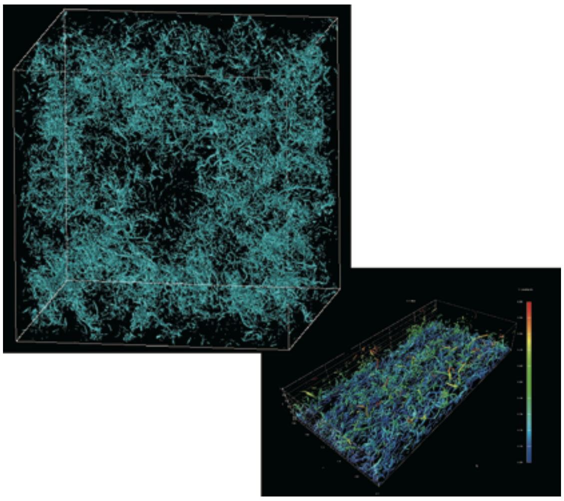
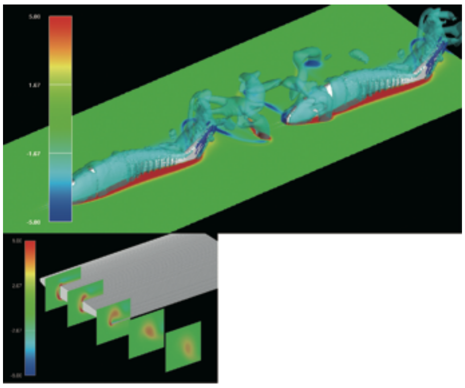


Direct Numerical Simulation of Turbulent Flows



Vortex Formation in Wake of Swimming Fish and at Wing Tip

Study of Complex Flow Phenomena by Large-Scale Numerical Simulation

We are studying complex flow phenomena by large-scale numerical simulation with high accuracy. The flows which we encounter in the nature and engineering applications often involve complex geometry and deforming objects which are difficult to deal with by traditional body-fitted grid systems. We develop and improve the volume penalization (VP) method, which is one of the immersed boundary methods, to analyze such flows. So far we have developed a new method for direct numerical simulation of aeroacoustic noise that can be used for complex and deformable geometry. Application of this method is in progress.

Theoretical & Numerical Hydrodynamic Stability Analysis

Stability is one of the fundamental properties of flows which is useful for their understanding and control. We study stability of vortices and other flows by theory and numerical analysis. We have found the curvature instability of vortices and necessary and sufficient conditions of parallel shear flows based on the variational principle. Currently we are interested in the effects of rotation and stratification on vortices aiming at applications in the atmosphere and the ocean.

Vortex Dynamics

It is important to understand the vortex motion for clarifying the dynamics of flow phenomena. We are studying every aspect of vortex dynamics including formation process, nonlinear dynamics and routes to turbulence in order to clarify the roles of vortical structures in flow phenomena in general. We have studied formation of strong vortices, hydrodynamic properties of swimming fish and formation process and the structure of wingtip vortices.

Study of Turbulence and Development of Turbulence Models

Most of the flows we encounter in nature and engineering are turbulent. We are studying statistical properties of turbulence, which is one of the long-standing important problems in fluid dynamics. We study dynamical analysis of statistical properties of vortical structures in isotropic turbulence and develop new turbulence models using machine learning.

Formation of vortices & dynamics in geophysical fluids

Strong vortices in atmosphere like hurricanes and tornados are subjected to density stratification and planetary rotation. We are studying formation and dynamics of these vortices. One of the recent results is discovery of strato-hyperbolic instability due to hyperbolic instability and phase shift by internal gravity waves. Formation of giant vortices on Jupiter and their growth are also studied by numerical simulation.

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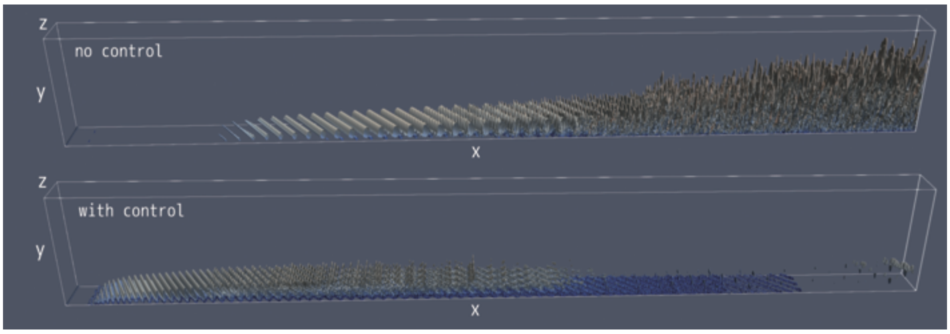
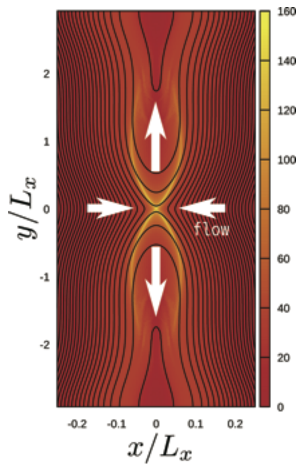


Control of boundary layer transition by wall roughness



Explosive magnetic reconnection

Clarification and control of flow phenomena based on stability theory

Flow phenomena observed in fluids and plasmas are getting reproduced in more detail by recent high-accuracy and large-scale numerical simulations. On the other hand, it becomes also important to extract new physical laws or mathematical models from vast amount of numerical data. The stability analysis is historically a powerful means to understand laminar-turbulent transition, vortical structure formation/breakdown and so on. Our goal is to predict and control flow dynamics by taking advantage of both stability theory and numerical simulation.

Boundary layer transition control by wall roughness

On widely-used swept wings of aircrafts, the boundary layer flow becomes three-dimensional and its instability leads to turbulent transition. By suppressing or delaying this transition somehow, the viscous drag on aircrafts as well as the fuel cost is expected to be reduced. We are seeking a feasible method for suppressing the instability by placing artificial roughness on the wing surface. Direct numerical simulation is useful for elucidating the transition process.

Stability analysis of parallel/rotating shear flows

Rigorously understanding stability of parallel/rotating shear flows is not only fundamental to classical fluid mechanics but also informative as a simplified case of more complicated flows. In addition, the effects of density stratification, centrifugal force and magnetic field are no longer straightforward to understand phenomenologically. We are mathematically analysing stability conditions of such various flows.

Explosive magnetic reconnection in collisionless plasma

Magnetic reconnection is an instability that causes solar flares, magnetospheric substorms and magnetically-confined plasma collapses. The longstanding question in plasma physics is why magnetic reconnection occurs so fast in nature. We are focusing on an explosively accelerating phase of magnetic reconnection numerically and proposing a theoretical model for understanding its physical mechanism.

Self-organized state sustained by helicity injection

In conductive fluids such as plasmas, magnetic helicity is a well-conserved quantity that measures how much the magnetic field lines are entangled and twisted. Therefore, magnetohydrodynamic relaxation is expected to occur toward the minimum energy state under the constraint that the helicity is nearly constant. We aim for prediction and control of such self-organized state which is continuously sustained by a helicity injection.