RESEARCH INTRODUCTION

Resolving spacecraft and aircraft sound issues through numerical analysis

Creating a comfortable space for artificial satellite

A launch vehicle's job is to transport cargo (payloads), such as artificial satellites, into space. The payload is put into place, wrapped with the fairing to protect it from air resistance, to get ready for take-off. Resounding a spectacular roar, it soars straight into space. (Fig. 1)

The roar spreads to its surroundings, even to the launch vehicle immediately after launch, and transmits into the fairing, reaching the artificial satellite. You might think that an artificial satellite is not affected by noise. In fact, that is not the case. Sound is air vibrations, in other words, "waves". Depending on the frequency of those waves, there is concern that they may adversely affect the artificial satellite. There are frequencies that easily resonate according to the size of the object. Musical instruments use such frequencies to play a clear tone; however, equipment on board artificial satellites will vibrate violently depending on the frequency and, in the worst case, break. We are advancing research aimed at establishing a numerical analysis method for accurately determining what sound transmits into the fairing and whether it reaches the artificial satellite.

Fig. 1: Launch vehicle soaring into space with a resounding roar

Sound is divided into the long-wavelength "low-frequency range", short-wavelength "high-frequency range" and the "mid-frequency range", which is in the middle. An analysis method for the high-frequency range has already been established and is being used to develop launch vehicles and artificial satellites, even by JAXA. At the low-frequency range, these can be determined with high precision through an analysis method called the "finite element method (FEM)". However, a valid analysis method for the mid-frequency range has not yet been established.

Hybrid analysis method

What we have our eyes on as a method for analyzing

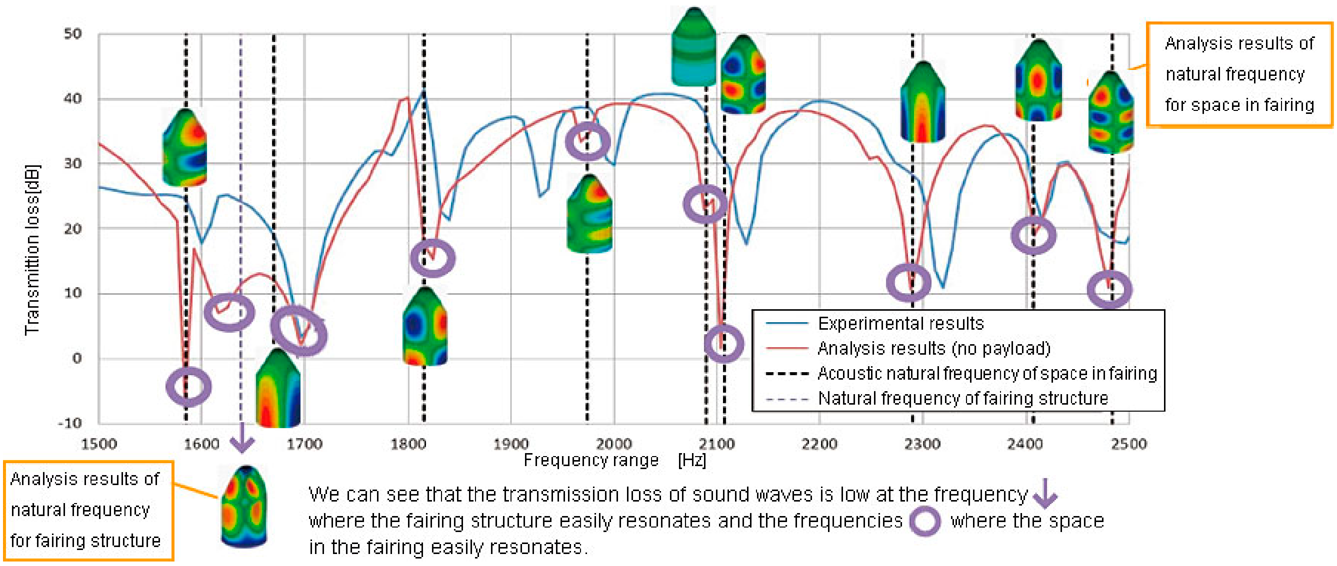


Fig. 2: Comparison of results for sound transmission into the fairing

the mid-frequency band with high precision is the "wave-based method (WBM)". WBM is a method for determining sound transmission by denoting the various behaviors of sound traveling through space as functions (wave functions) and using an equation created by superimposing those functions. With WBM, the transmission of sound from the low-frequency range to mid-frequency range can be determined with high precision. However, it cannot be applied to an analysis of the "phenomenon where sound transmits through solid structures like the fairing". Therefore, we are advancing research to establish an analysis method by applying the "hybrid finite element wave-based method (HF-WBM)", which, with the structural FEM, analyzes the "phenomenon where sound transmits through the fairing" and, with WBM, analyzes the "propagation of sound in the fairing".

In order to verify HF-WBM, we set up a fairing model in an anechoic chamber and performed tests to study sound penetration. By comparing these results with the analysis results, we were able to confirm that the analyses could be performed accurately. (Fig. 2)

Also focusing on development of future launch vehicles

What we ultimately wish to determine is the effect of sound on the artificial satellite in the fairing. Therefore, in addition to testing a rectangular aluminum model, which simulates an artificial satellite, in the fairing model, we are also continuing work on the analysis. (Fig. 3)

An actual artificial satellite has quite a complex shape. With WBM, it is necessary to divide the space to be analyzed into areas of an appropriate size. However, if not all of the divided areas are convex, the feature cannot be analyzed (fig. 4A). Therefore, currently we are tackling research and development of the more advanced HF-WBM, which analyzes a limited space around the satellite with acoustic FEM (fig. 4B).

If an HF-WBM analysis method can be established, it will be possible to design a fairing so that artificial satellites will not easily be affected by sound. In addition, we believe this could be applied to vehicles, such as aircraft, boats and trucks, that have a similar problem.

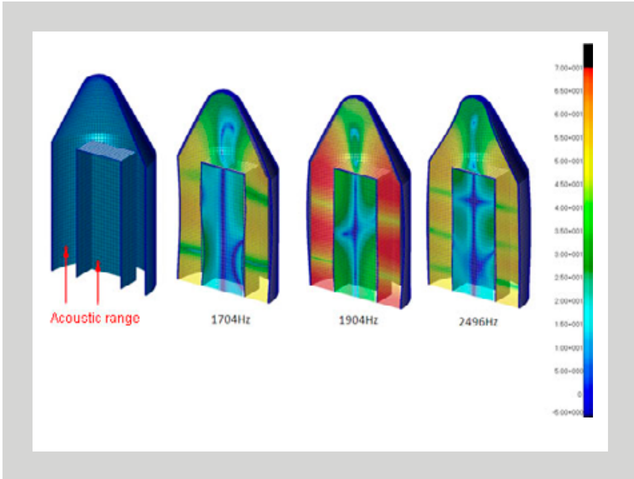
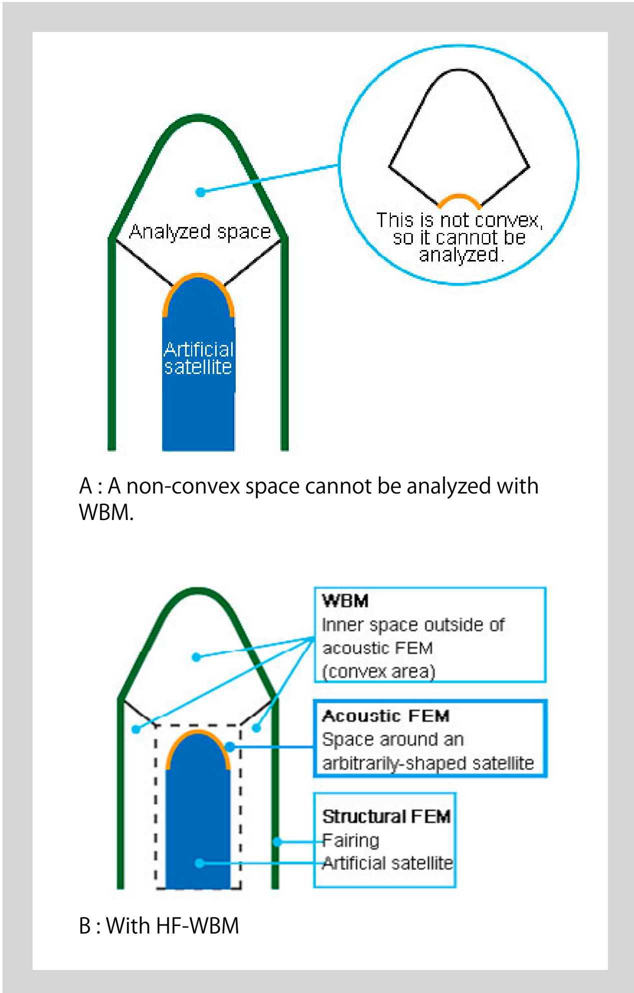


Fig. 3: Sample analysis of model with payload



A : A non-convex space cannot be analyzed with WBM.

B : With HF-WBM

Fig. 4: HF-WBM

Bringing the world closer

If one were to go by boat to the other side of the wide Pacific Ocean, to the west coast of the United States, it would take over ten days. However, by airplane, it is a leap in about 8 hours. Traveling at a high speed-80% to 90% the speed of sound (Mach 0.8 to 0.9)-at an altitude of 10,000 m, where there is little air resistance, shortens the time. We want to go far distances in shorter and shorter time! In order to satisfy that demand, we can only "make aircraft speeds faster" .

Until 2003, a civil transport called the Concorde flew between Europe and the United States. It flew at twice the speed of sound (Mach 2) at a high altitude of 18,000 m, but it had the problem that it could not fly at supersonic speeds over land because of the "sonic boom" that was certain to occur when it traveled at a speed exceeding the speed of sound.

Previously, we mentioned that sound is air vibrations, in other words, waves. For normal sound, the vibrations of the air are extremely small, but when moving at a speed greater than the speed of sound, the air in front is compressed to the fullest extent, and a "shock wave" , a wave with a very large compression ratio, occurs. If that wave propagates through the air to arrive at our ears, it becomes a large sound called a sonic boom (fig. 5).

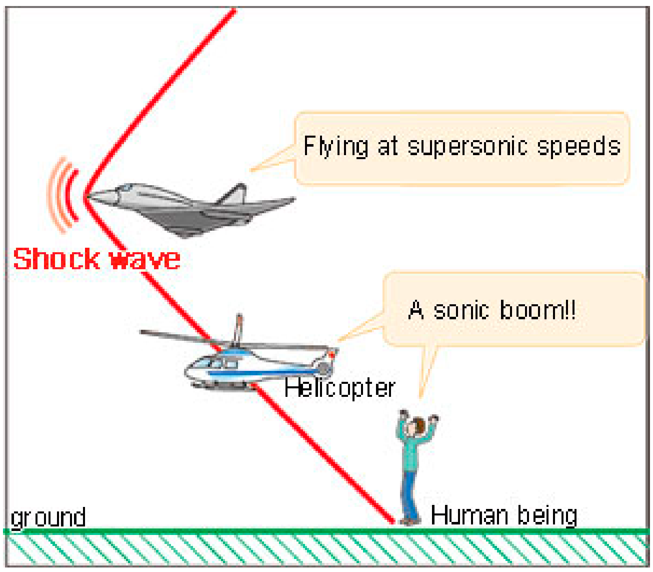
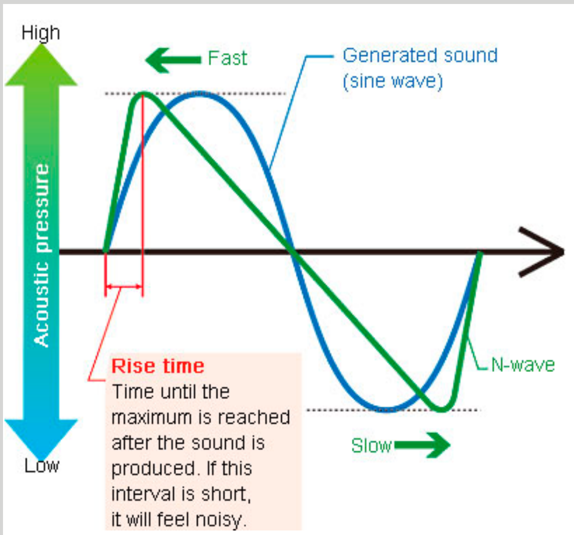


Fig. 5: Sonic boom

Verifying a sonic boom

When analyzing sound, it is necessary to consider the "geometric attenuation effects" , where sound spreads spatially while gradually becoming weaker, and the "environmental changes during propagation" , where pressure or temperature changes with altitude. For sound with an extremely high acoustic pressure, we must also consider the "non-linear effects" (fig. 6), where the wave propagates faster as the acoustic pressure increases. Until now, we have taken these into account when analyzing sonic booms.

However, with conventional analysis methods, we could not take into account the "attenuation effects" due to thermal viscosity and vibrational relaxation. Therefore, we established a new analysis method that uses an equation where attenuation effects can be taken into account. As



Sound advances faster as the acoustic pressure increases. Since the air in front of an aircraft flying extremely fast, like a supersonic aircraft, is very strongly compressed, the acoustic pressure difference (size of vibrations) of the sound emanating from it becomes larger. As a result, the initial wave form changes gradually and becomes a very harsh and loud sound, called an "N-type" , when it reaches the ground.

Fig. 6: Non-linear effects

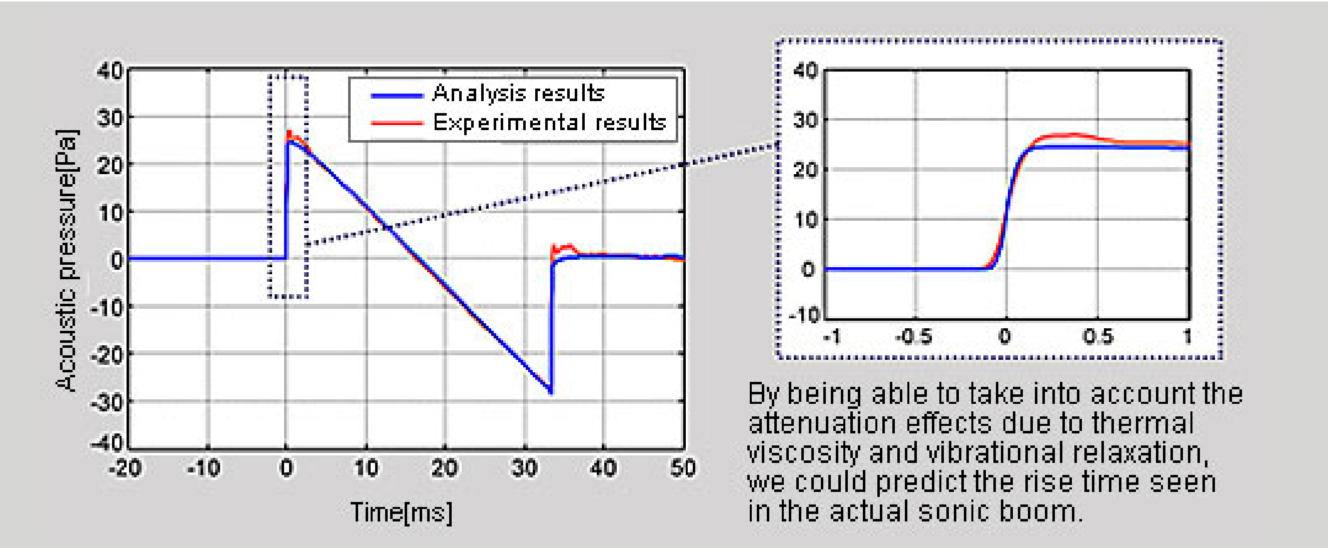


Fig. 7: Comparison of sonic boom analysis and experimental results

a result, the "rise" time seen in an actual sonic boom was captured (fig. 7).

"Focus booms" generated when accelerating and turning

Supersonic aircraft do not simply continue flying straight while maintaining a constant speed. They must take a variety of flight configurations, such as acceleration, deceleration and turning, according to their operation. It is known that supersonic aircraft turning or accelerating generate a sound louder than a sonic boom, called a "focus boom" . The analysis method to predict focus booms is at the research stage; however, we have already succeeded in devising a prediction tool and recreated booms a number of times stronger than normal. (Fig. 8)

If noise during actual operation could be analyzed, it would certainly be helpful in the development of new aircraft in addition to being helpful for creating standards allowing supersonic aircraft to fly the world' s skies. Therefore, we are verifying whether or not actual focus booms can be recreated with analyses.

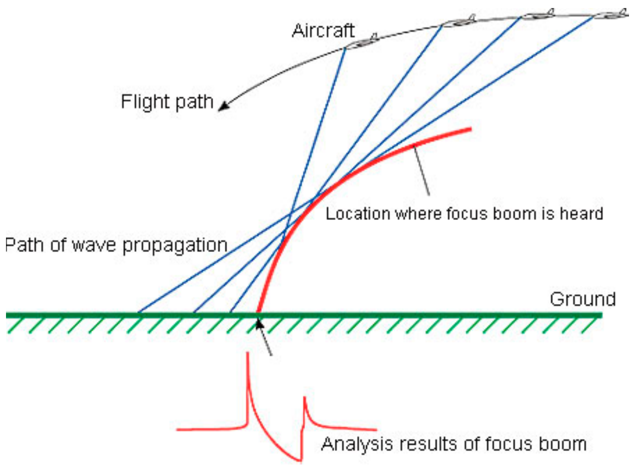
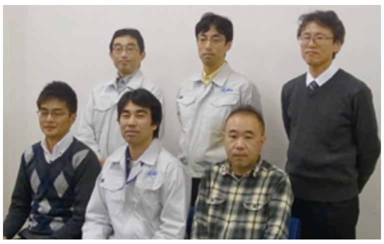


Fig. 8: Principle of a focus boom



[Numerical Analysis Group]

(From top left) Takashi Aoyama, Takashi Takahashi, Masafumi Yamamoto
(From bottom left) Masashi Kanamori, Atsushi Hashimoto, Hidekazu Kaneda

Heroes behind the scene

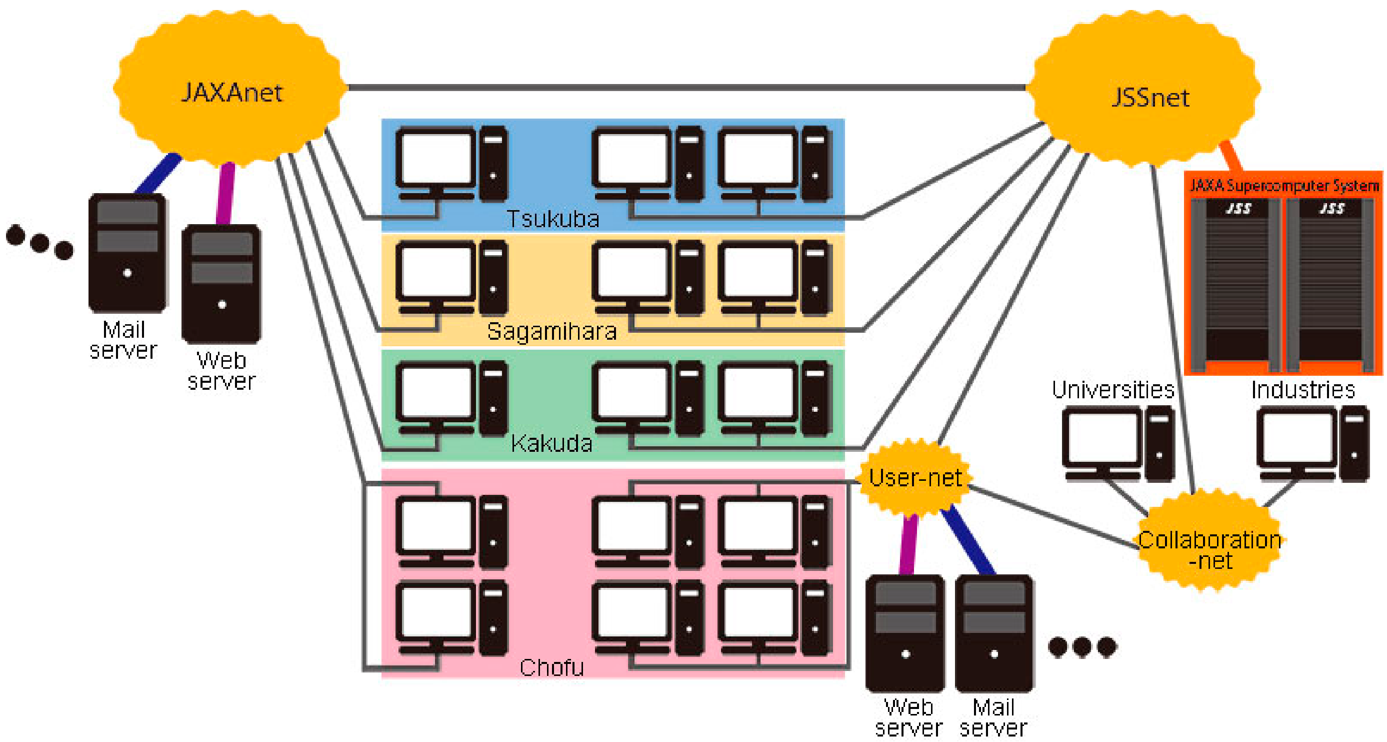
Creating a network environment depending on the objective

We routinely and casually use computers. In fact, this one cannot send mail or browse web pages. We need to use a “server” , which is a computer with high-processing capabilities to provide e-mail sending/receiving functions and functions for accessing web pages. The server is accessed via a network. The computers at JAXA are connected to a network called “JAXAnet”. Not only e-mail and web browsing, but various business operations are performed by accessing the server via this network.

However, the server and network efficiency required to conduct research and development differs from that for business operations. For example, it includes a network connection to the supercomputer “JAXA Supercomputer System (JSS)” for various aerospace-related numerical simulations. Therefore, a network specialized in research and development is being maintained and utilized: the “Chofu Project Network (Chofu Pnet)” , centered around the Chofu Aerospace Center, where JSS is located.

Supporting smooth research and development

Chofu Pnet is being maintained and operated by the “server management group” and “network management



All business operations on computers are conducted via JAXAnet. Other than that, there is “Chofu Pnet” , which is specialized in research. A network environment is being maintained that can easily be used by researchers and developers at not only Chofu Aerospace Center but also at Tsukuba Space Center (Tsukuba), the Institute of Space and Astronautical Science (Sagamihara) and the Kakuda Space Center (Kakuda).

Fig: JAXA network environment

group" in addition to the "help desk" consultation service. All new server setups, network connection requests as well as failure inquiries first go through the help desk.

Based on the received request, the server management group sets up or manages servers necessary for research and development.

Building a network for accessing the server is the job of the network management group. Chofu Pnet is made up of three networks. One is "JSSnet" for JAXA researchers and developers to use JSS from their personal computers. JSS is used not only within JAXA but also by universities and industries conducting aerospace research and development. The second is "Collaboration-net" , which connects other external organizations with JSS. The third is "User-net" , which was constructed when researchers and developers within JAXA wanted to accelerate the exchange between JSSnet and Collaboration-net. Connecting these networks and routinely maintaining the state of the connected network is the job of the network management group. This is the organization that continuously monitors each network and immediately responds when failures occur in order to maintain smooth connections.

Interview

Rika Ito Takehiko Okui
Naoyuki Fujita

Okui : Since JSS is a large-scale computer system, there are various technical issues that do not occur in a common system. In addition, there are many users with specialized applications, each requiring a different solution. I get a sense of satisfaction from resolving such challenges.

Ito : While working in a research position, I am engaged in server management. Precisely because I am in a position to get a better sense of the needs of researchers as users, I try as much as possible to reflect the essential requirements of users. The requests may be difficult, but it makes me very happy when users are satisfied, and I feel good about achieving it.

Fujita : As coordinator of Chofu Pnet, I feel that it is very rewarding to construct an infrastructure helpful to research and development. Not only JAXA employees, but people of various positions, such as commissioned or temporary, are working in this section. The sights of the closely related JAXAnet and JSS help desk training jointly, everyone confronting a single job, and one team working together to complete it have been my secret joys these days.

Chofu Pnet group
and JAXAnet Chofu area supervisors