

Smooth Passage for an Artificial Satellite - Combustion Test Title -

Necessity of Next Term Solid Rocket

In September 2006, the "M-V (Mu (μ)-Five)," a rocket developed by the Institute of Space and Astronautical Science, one of the predecessor organizations of JAXA, was launched for the last time. The curtains fell, ending several momentous years for the M-V.

The M-V was one of the largest and most high-performance multistage solid rockets in the world. Over its years of service, it conveyed many astronomical satellites and planetary exploration spacecrafts into space. Now, however, the demand is shifting towards highly mobile, lower-cost, and smaller rockets for the frequent deployment of smaller satellites. Frequently achieving results, demonstrating prior art and human resource development capabilities are now a subject of close focus, and highly frequent launches of small-type launching systems will be required to cope with the current demands in aerospace.

To respond, our team is promoting the research and development of the "Next-Term Solid Rocket (Fig. 1)." Our aim is to apply the technology cultivated over the half



Fig.1 Image of the Next-Term Solid Rocket

century leading up to M-V to the development of a simple launching system using the features of a solid rocket to the maximum possible extent, for application to small-type satellite missions.

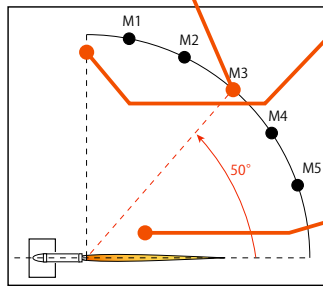
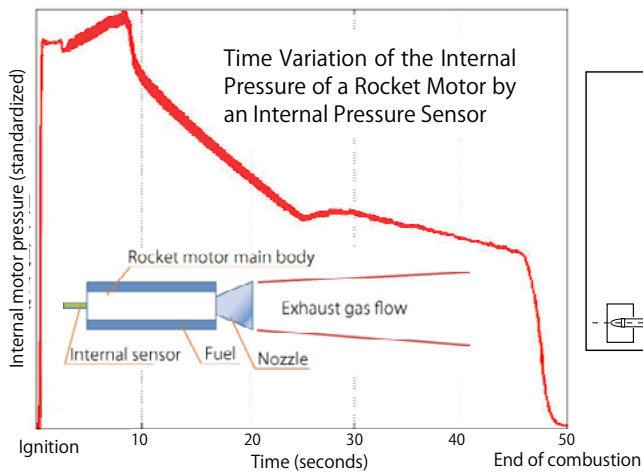
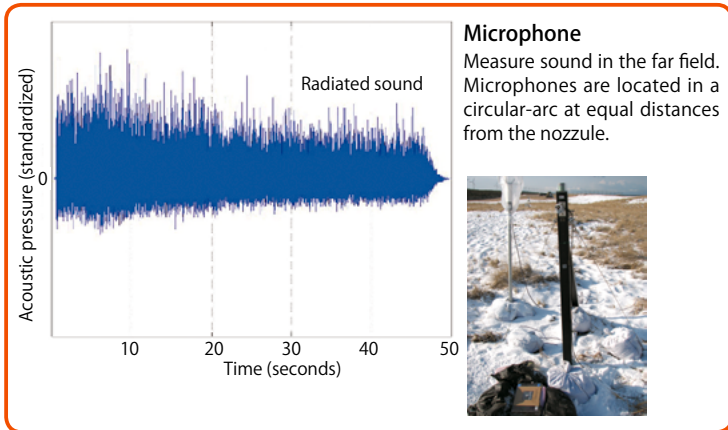
Designing the Launch Complex

One of the elements to consider when arranging the launch complex for the next-term solid rocket is "acoustic vibration." The booming roar propagating in the air during a launch reaches the fairing and shakes the artificial satellites and other payloads stowed inside the rocket. The sound generated during a launch depends largely on the shape of the space launch complex where the rocket is installed and the launch actually takes place. By designing the shape of the space launch complex in specific ways, our researchers therefore expected to reduce the acoustic vibration during the launch. The space launch complex has been designed based on the experiences of tests and launches, and its adequacy has been verified by combustion tests with scale models of rockets and space launch complexes. Higher performance is now being achieved with "computational fluid dynamics (CFD)," an analysis method to determine the state of air flow and soundscape, etc. The applicability of CFD as a design tool for space launch complexes is growing.

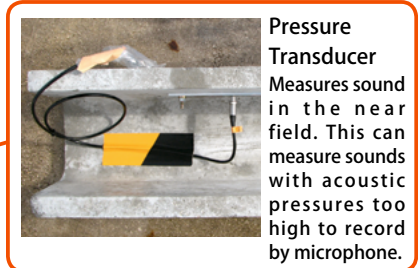
Verification Data Obtaining Test

An indispensable first step, in judging whether or not CFD can be applied as an effective design tool for the development of a space launch complex, is to verify/compare data obtained from the tests. Accordingly, we performed a combustion test on a solid rocket motor * 1 to obtain data required for the verification/ comparison, etc. from 2007 to 2008.

We used three solid rocket motors of different types and sizes as specimens (the NAL-735, M-24, and KMV1). The combustion test was performed with the rocket motor installed horizontally. We measured mainly the "sound in the far field," as well as the "sound in the near field" and the "source of sound release" to investigate the transmission of the sound generated from the jet before reflection onto



Microphone Array
Measure the source of sound release. The optimum array is manufactured for each test.



Specimen
NAL-735
M-24 (2nd stage of M-V)
KM-V1 (M-V kick motor)

The test was performed in a "free jet" state without interfering items in front of the jet (arranged by installing the rocket horizontally)^(*)

(*) The test on M-24 was performed by installing a deflector to change the direction of the jet.

Fig.2 An Example of Acoustic Measurement Results obtained by a Combustion Test (Specimen: NAL-735)

the deflector (free jet) (Fig. 2). Additionally, we measured items relating to sound propagation, such as air flow, temperature, etc. After analysis, the data obtained are used to improve a semi-empirical model, verify the CFD analysis (refer to P.03), and ultimately complete a design tool for the development of the space launch complex.

During the tests, we also measured various fundamental

data required for rocket development, such as data to evaluate the performance of solid rocket motor, etc. In the future we plan to perform tests periodically to obtain fundamental data for designing the space launch complex and data for maintaining and improving solid rocket motor technologies.



[Members of M-24 Combustion Test]

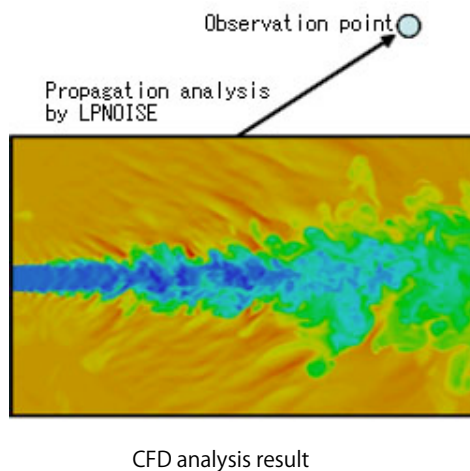
Researchers from the Jet Engine Technology Research Center of the Aerospace Research and Development Directorate participated in the test as the main members of the Acoustic Team.

Comfortable Voyage for an Artificial Satellite - Numerical Analysis -

Numerical Analysis of the Sound Generated from Rocket Jets

The Engineering and Digital Innovation Center (JEDI Center) at JAXA specializes in numerical simulations and other computing-engineering technologies. The JEDI Center uses its computing-engineering techniques to streamline and improve the operations and reliability of spacecraft for the aerospace projects in which JAXA plays a central role.

This article will explain how numerical simulation is being used to design the launch complex for the next-generation rocket such as introduced on Page 1. Fig. 1 is a visual depiction of the sound (sound pressure) generated from a rocket jet. The image was generated from the results of CFD, an analysis method for numerical simulation. We use CFD to generate detailed visual representations of various types of flow in the atmosphere, including the sound wave. Yet to do so, we must devote a great deal of time to calculate the complicated jet flow. The process is too computing-intensive to actually apply for projects. To design the actual launch complex in our current project, we are applying CFD only to the analysis of region around jet, where the flow fluctuations are significant. Then, the sound propagation is analyzed by an acoustic code based



An acoustic analysis at the far field points can be conducted by an analysis tool (LPNOISE: now being developed by the Numerical Analysis Group) using the CFD analysis results on specified surfaces (for example, the cylindrical surface covering a jet). The LPNOISE calculation is very efficient compared with a direct CFD calculation including observation points. LPNOISE is validated by comparing with the experimental data at several observation points.

Fig. 1: Comparison between the analytical result and experimental data for rocket-generated sound

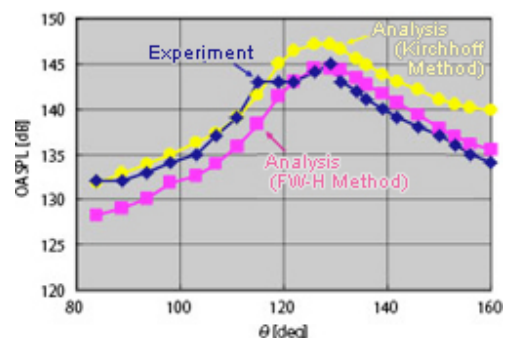
on the wave equation using the results of CFD. Through this approach, we determine the propagation of sound by assuming that the fluid in the far field remains stationary or uniform.

This method has been applied in the prediction of helicopter noise, etc. The role of the Numerical Analysis Group of Aerospace Research and Development Directorate is to develop new analysis methods to be applied in the various kinds of project.

A Step to Understand the Acoustic Environment in Fairing

The booming roar propagated directly by the jet or by the turbulent air reaches the fairing carrying the artificial satellite and vibrates the satellite. A key step to mitigate this phenomenon is to learn how the propagated sound is transmitted through the fairing, and how it vibrates the satellite. We have been developing a set of analytical tools to investigate this process (See issue No.20 of "Sora to Sora").

We have developed a new tool to analyze sound transmission in three dimensions and have been simulating the transmission of a plane sound-wave through a dome-shaped structure which models a rocket fairing (Fig. 2). Though the modeled wall is thicker than an actual fairing in



Comparison between the analytical result and experimental value at multiple observation points

Numerical Analysis of Acoustic Vibration during Rocket Launch

this calculation, we can clearly grasp how the propagated sound is transmitted into the dome and how the sound generated by the vibration of the dome propagates to the outward region.

Experiment on Sound Transmission

To improve the prediction capability of our numerical tool, we must validate it by comparing with experiment. In a collaborative research project with Nagoya University, we have recently carried out tests to quantify the transmission of the plane sound-wave through a plate.

Fig. 3 shows the results of the experiment and the numerical analysis. Every structure has a frequency (natural frequency) at which it easily vibrates, and the sound easily transmits at this frequency. Through our research, we have confirmed that the drop of transmission loss^(*) appears not only through the experiment but also by our new analysis method.

To reduce the sound vibration of the satellite, a sound-absorbing material is attached to the inside of the fairing. To take into account this sound-absorbing material in the analysis, we plan to carry out a test with a series of plates

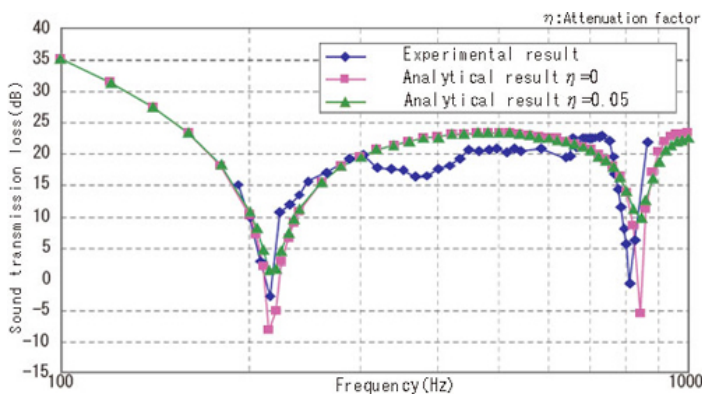


Fig.3 Comparison of sound transmission loss between analytical and experimental results

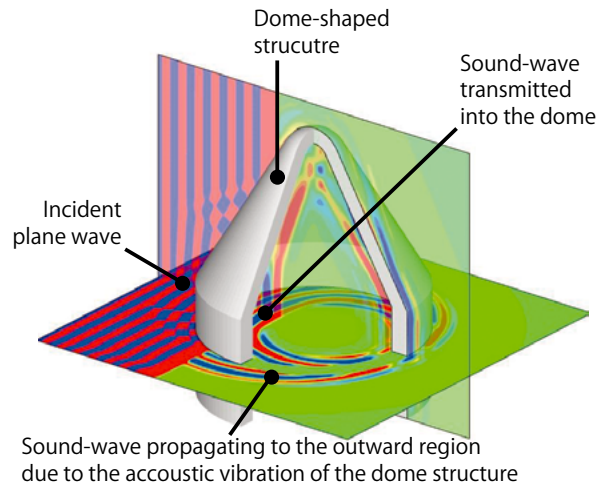
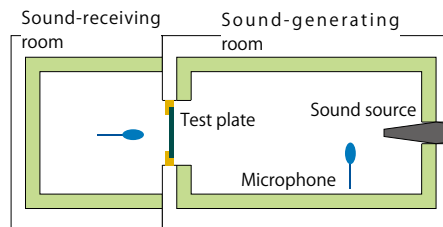


Fig.2 Sound transmission through a dome structure modeled as rocket fairing.

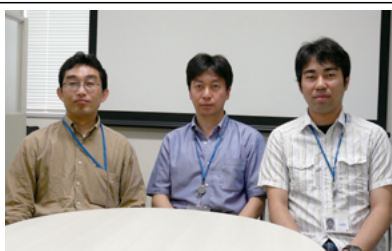
with sound-absorbing material in this fiscal year.

(*) Sound transmission loss: ratio of the intensity of the transmitted sound to that of the incident sound. The higher value of this ratio means the larger sound loss.



Experimental equipment

There are two rooms, a "Sound-Generating Room" and a "Sound-Receiving Room", and a test plate (aluminum plate) is fixed between them. The magnitude of the transmitted sound is quantified by measuring the sound on both sides of the plate. Sound-absorbing material is installed on the walls of both the sound-generating room and sound-receiving room to avoid the sound reflection from the walls.



[Numerical Analysis Group]

(from left) Takashi Aoyama, Keiichi Murakami, Atsushi Hashimo

Sound propagation

Sound is generated by vibrating matter. Let's assume, for example, that the air pressure in a specific place is changed in relation to the atmospheric pressure. When this happens, the air vibrates to restore the pressure difference (sound pressure) to its original state. This vibration takes the form of a wave which travels through the air. When this wave reaches our ears, we perceive it as a sound (Fig. 1). Sound travels through various substances, as well as air. When a rocket is launched, the sound waves emitted from the combusting flow (jet) travel through the air to a fairing. Once they reach the fairing, they travel through the walls of the fairing and continue to vibrate even through the artificial satellite housed inside (refer to page 3).

A sound travels through a substance at different speeds, depending on the hardness (modulus of elasticity) and weight (density) of the substance. It travels through the air near the ground at about 340 m/s. The speed of its travel also depends on the temperature. In most substances, sound travels faster at higher temperatures. In air of lower density and colder temperatures, sound therefore travels more slowly. At 10,000 m, the cruising altitude of a large passenger airplane, sound travels at about 300 m/s.

But what happens when an aircraft flies faster than the sound it produces (when

the plane breaks the sound barrier)?

Let's assume that a sound is generated at point A (Fig. 2). When point A is standing still, the sound is propagated evenly through the surrounding space (I). If the sound source moves at a certain speed, the sound propagation changes (II). When the sound source moves faster than the speed of sound, in other words, at a supersonic speed, the sound generated will not travel farther than the sound source. The sound stays in a cone, the so-called Mach cone, even in the area trailing the sound source (III) (*). At this moment, a high-pressure air wall called a shock wave is generated in front of point A. When this shock wave reaches the ground, it creates a huge impulse noise (sonic boom). If an air flow blasts out faster than the speed of sound, for example, when a jet blasts out from the rocket nozzle, the phenomenon generates an impulse noise called jet noise.

Jet impulses are inevitably accompanied by air flows in aerospace. JAXA is researching technologies for quiet supersonic transport and the phenomenon of supersonic flow in the hopes of establishing a technique to analyze sonic booms and other forms of impulse noise.

(*) Because the sound source moves, the sound can actually be heard at the moment it enters the Mach cone.

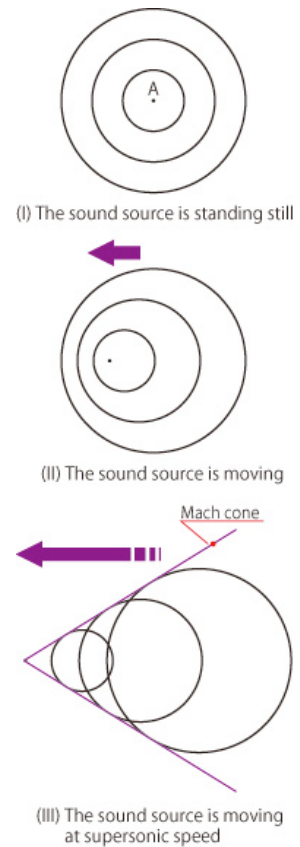


Fig.2 Supersonic sound

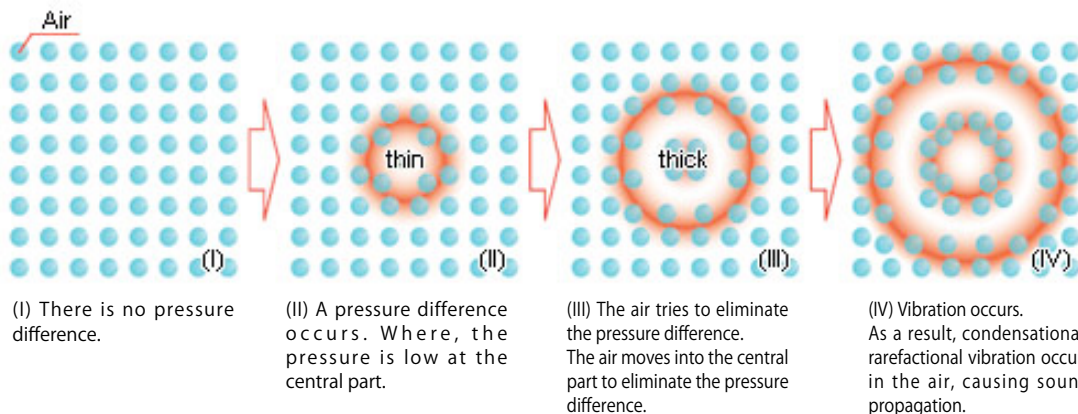


Fig.1 Expansion of sound. A "thin" portion where the pressure is low (the air is rare) and a "thick" portion where the pressure is high (the air is thick) alternate and vibrate. This is how a sound wave propagates.