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P02

小型超音速飛行実験機燃料タンク向け加圧ガス巻きこみ抑制技術に関する研究
（スロッシング抑制技術の開発）

Study on Pressurized Gas Entrainment Suppression Technology for Small-scale Supersonic Flight Experiment Aircraft Fuel Tanks
(Development of Sloshing Suppression Technology)

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1. Introduction

The Aerospace Plane Research Center in Muroran Institute of Technology is development the small-scale supersonic flight experiment aircraft as a flying test bed for a technical demonstration in high-speed flight environment. In the small-scale supersonic flight experiment aircraft, the liquid supplying system for bioethanol (BE) and liquid oxygen (LOX) by nitrogen pressurant has been studied. However, sloshing in expected to occur in this liquid fuel tank by the acceleration during flight. It is feared that the risk of adverse effects on the attitude control of the aircraft and the propulsion system by the inclusion of pressurized gas in the supplied fuel increase due to sloshing.

The purpose of this paper is to research and develop a sloshing suppression device in the aircraft fuel tank and evaluate its performance.

2. The sloshing suppression device

Figure 1 shows a structure of the sloshing suppression device. Cylindrical geometry is used for the structure of the sloshing suppression device. By using a cylindrical geometry in the structure of the suppression mechanism, damping due to viscous stress increases outside the cylindrical geometry due to the increased contact area between the liquid fuel and the solid wall. Inside the cylindrical geometry, the ring baffle concept, which is a common method of suppressing transverse sloshing[1)], is applied to suppress it.

Sloshing can be controlled both inside and outside the cylindrical shape, reducing sloshing throughout the

tank.

The use of metal mesh on the cylindrical side walls prevents sloshing while preventing liquid accumulation inside the mechanism. This is because the surface tension of the liquid forms a liquid film on the metal mesh, which can be regarded as a pseudo solid wall.

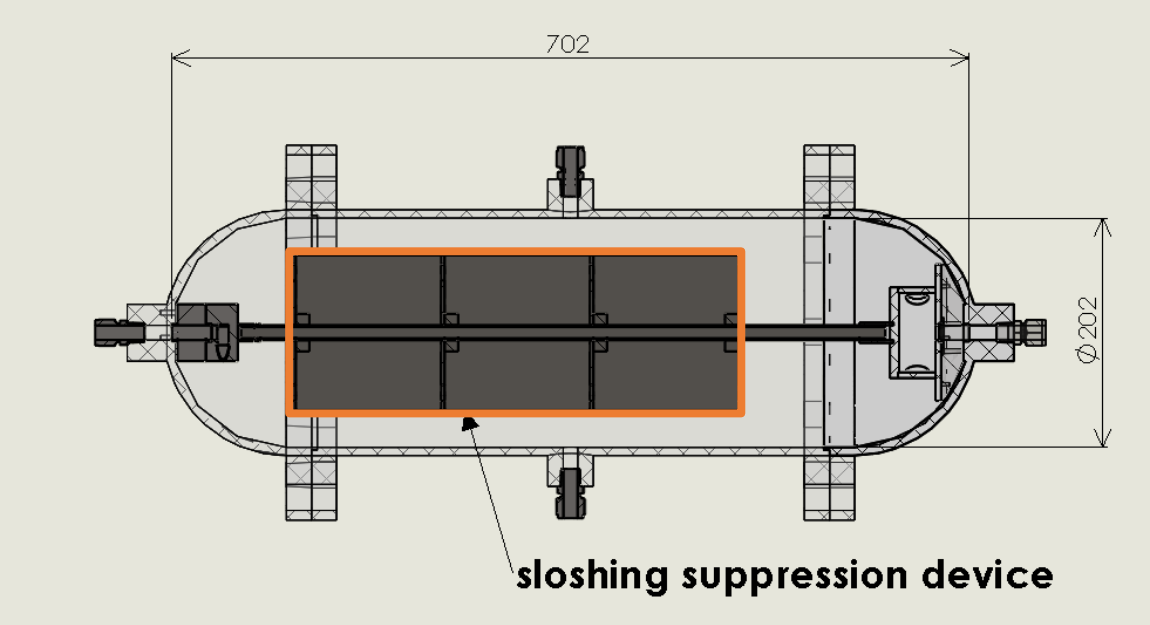


Figure 1. Installation of the sloshing suppression device.

3. Experimental Method

To compare the liquid behavior of the newly designed sloshing suppression device when the entire experimental setup, including the full-scale model tank, is subjected to instantaneous acceleration in the pitch direction using a crane to evaluate the performance of the device. The liquid to be observed is water coloured with food colouring, and the liquid volume is 80%, 50% and 20%, with 80% of the liquid remaining immediately after the start of liquid discharge, 50% when the liquid level drops to the center of the tank and 20% when the liquid level is near the end of discharge. A new cylindrical suppression device and a disc-shaped suppression device were developed for the suppression device mounted inside the tank, and a performance comparison was carried out between a case with and without these two suppression devices. The structures of the cylindrical and disc-shaped suppression devices are shown in **Figures 2 and 3** respectively. **Figure 4** shows the appearance of the fabricated experimental apparatus.

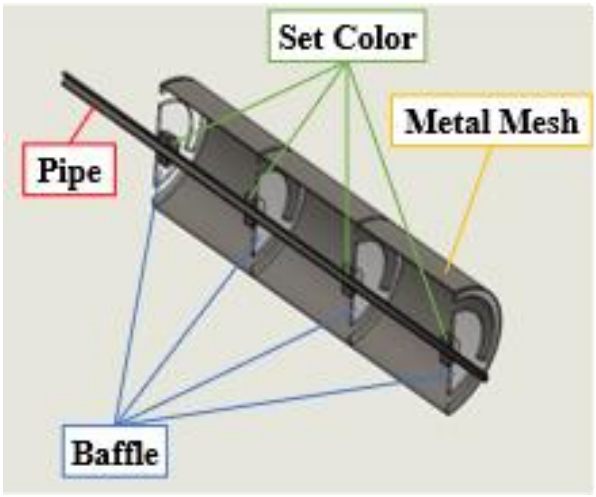


Figure 2. The structure of the cylindrical suppression device.

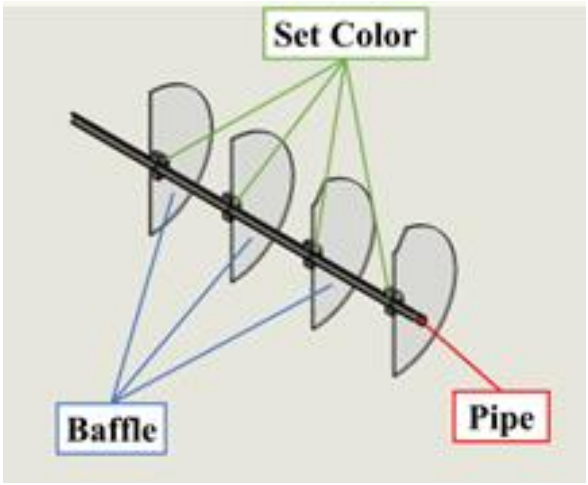


Figure 3. The structure of the disk-shaped suppression device.

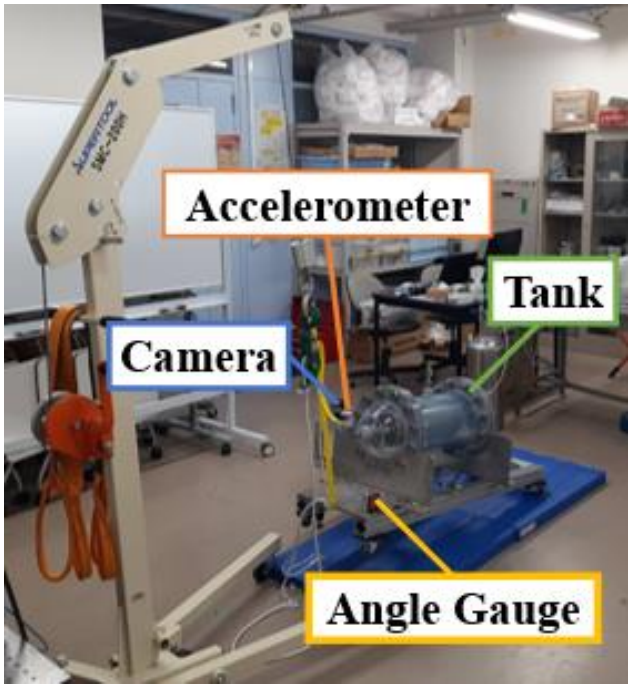


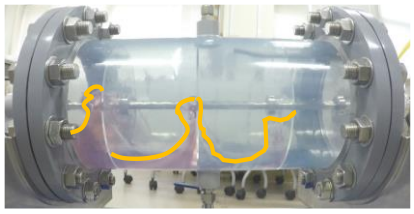
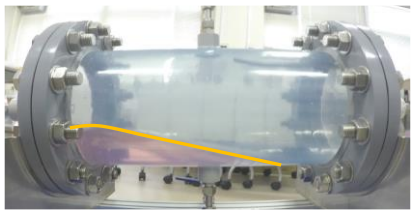
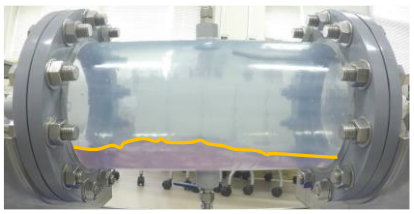
Figure 4. Experimental apparatus with full-scale model tank.

4. Experimental result and discussion

Table 1 shows the vibration test results. In Number 1 (20% liquid volume, 0.40 sec after the start of drop), the liquid did not behave in a splashing manner as in the case of the disk-shaped suppression device in the

case of the cylindrical suppression device and in the case of no suppression device, and it can be said that sloshing was suppressed. In Number 2 (20% liquid volume, 1.47 sec after the start of the drop), sloshing was suppressed by the cylindrical suppression device because the turbulence of the liquid surface was small, as in the case of the disk-shaped suppression device and the case of no suppression device.

Table 1. Image of the results of vibration tests on full-scale model tank.

Device \ Number	1 20% liquid volume, 0.40 sec after the start of drop	2 20% liquid volume, 1.47 sec after the start of drop
The cylindrical sloshing suppression device		
The disk-shaped sloshing suppression device		
Without sloshing suppression device		

Figures 5, 6 and 7 show the time variation of the liquid level height at the right end of the cylindrical part of the model tank at 50% liquid volume when a cylindrical suppression device is installed, when a disc-shaped suppression device is installed and when no suppression device is installed, respectively. The liquid level height was recorded using the image processing software ImageJ[2)].

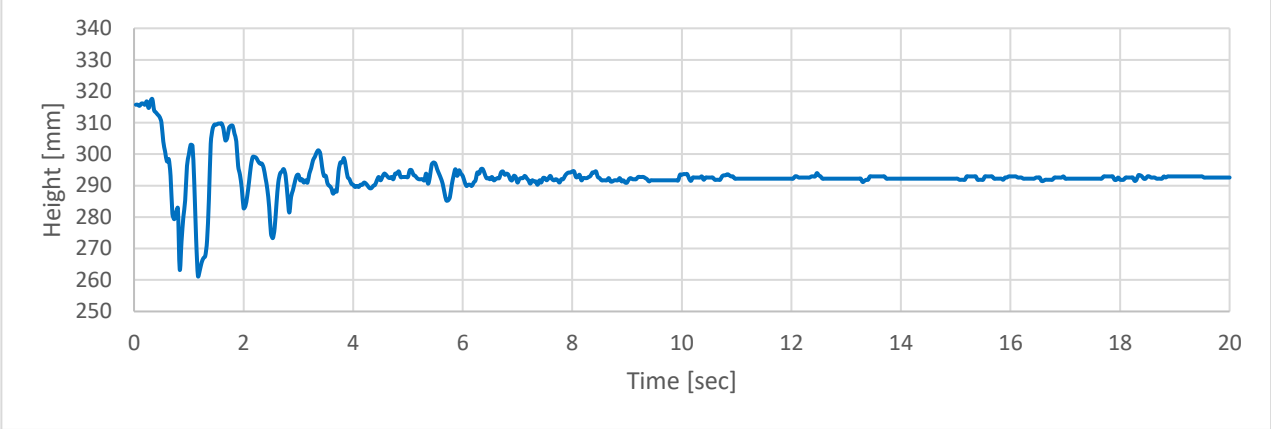


Figure 5. The change in liquid level height when the cylindrical suppression device is in place at 50% liquid volume.

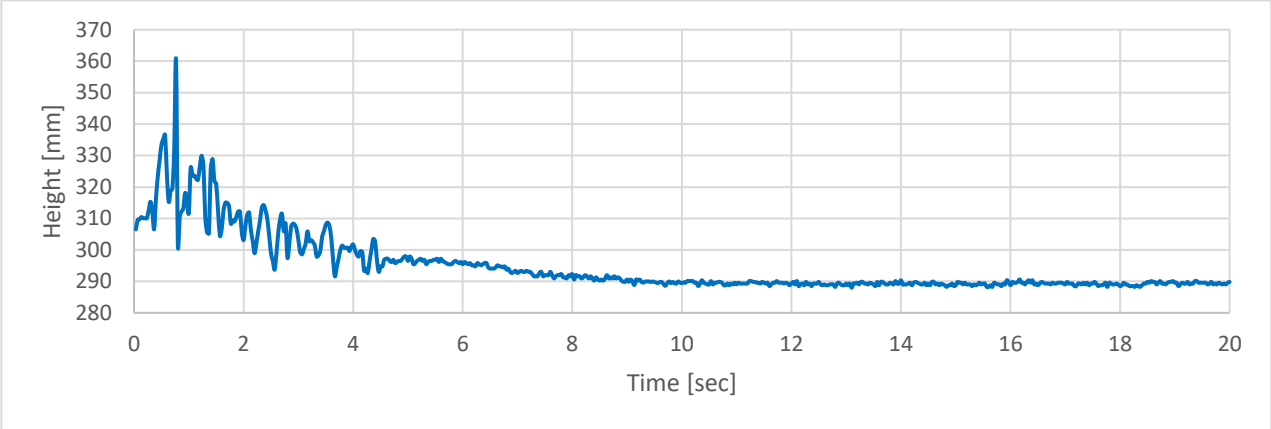


Figure 6. The change in liquid level height when the disk-shaped suppression device is in place at 50% liquid volume.

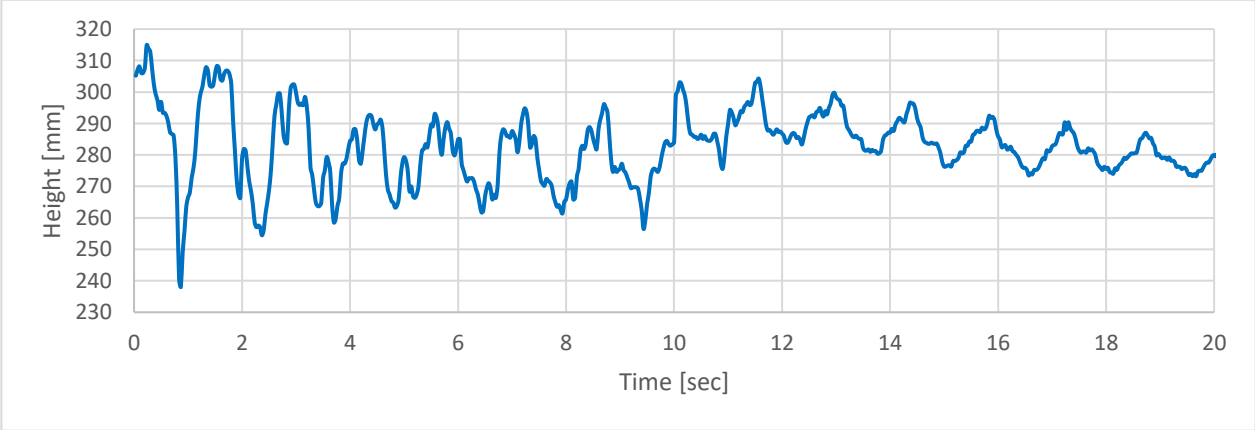


Figure 7. The change in liquid level height when no suppression device is in place at 50% liquid volume.

The results show that a cylindrical suppression device has a higher damping effect than a no suppression device. A comparison between the cylindrical suppression device and the disc-shaped suppression device shows that there is no significant difference in the damping effect between the two. **Table 2** summarizes the results of the experiments so far.

Table 2. Summary of experimental results in full-scale model tank.

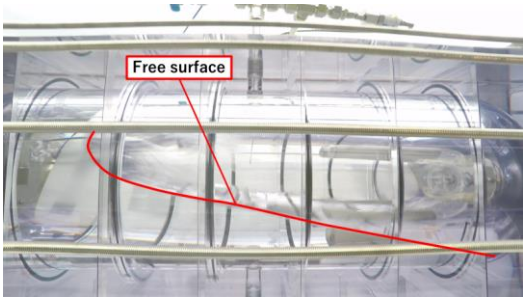
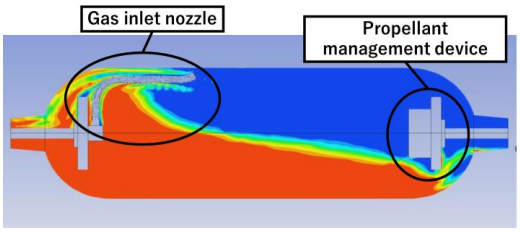
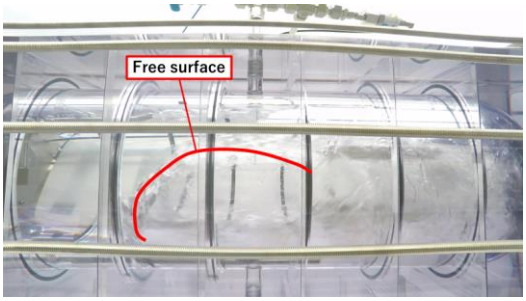
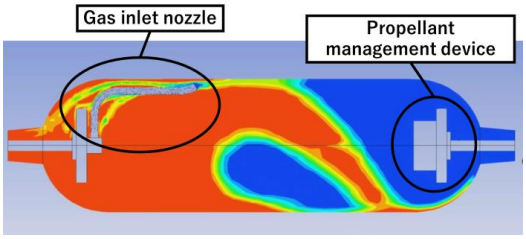
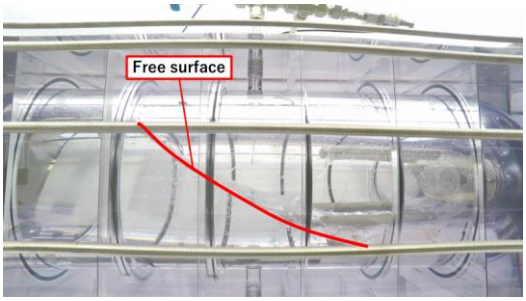
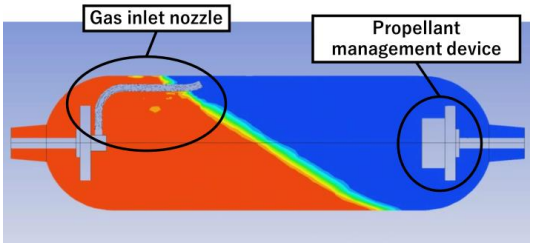
Device	Effectiveness in reducing liquid level behavior.	Attenuation effect.
The cylindrical suppression device	○	○
The disk-shaped suppression device	○	×
Without suppression device	×	○

Based on the above results, it is considered that the cylindrical shape is a promising shape for a sloshing suppression mechanism, judging from the overall suppression and damping effects of changes in the liquid level behavior of the liquid in the tank.

5. Optimization of the sloshing suppression device

Prior to the structural optimization of the sloshing suppression device using computational fluid dynamics (CFD) analysis in three dimensions, a three-dimensional analysis of the flow behavior without the sloshing suppression device is analyzed. Acceleration data measured at the High-Speed Test Track at the Shiraoi Engine Test Field of the Muroran Institute of Technology are introduced to predict the fluid behavior under continuous acceleration by analysis. **Table 3** shows a comparison between the actual video footage and the analysis results. As shown in the above results, the prediction of flow behavior during acceleration was reasonable.

Table 3. Comparison of filmed images and analysis results.

Elapsed time since start of acceleration.	Filmed image.	Analytical results.
0.23 sec		
0.5 sec		
2 sec		

6. Conclusion

In this study, a sloshing suppression device mounted inside the fuel tank of a small-scale supersonic flight experiment aircraft was developed to develop a fuel sloshing suppression technology. A cylindrical suppression device was devised and tested, and the suppression effect was investigated by comparing the liquid behavior between the case without a suppression device and the case with a disc-shaped suppression device by means of vibration tests. As a result, it was confirmed that the change in the behavior of the liquid was slower when a cylindrical suppression device was installed than when no suppression device was installed or when a disc-shaped suppression device was installed. It was also confirmed that the cylindrical

suppression device had a higher damping effect than the case without the suppression device, and the same level of damping effect as the disc-shaped suppression device. Based on the above results and judging from the overall suppression of changes in liquid behavior and the damping effect, the cylindrical-shaped suppression device is considered to be promising as a sloshing suppression technology. CFD analysis in three dimensions was used to predict the fluid behavior during acceleration when the suppression device is not installed.

In the future, it is necessary to establish a technique for predicting flow behavior during deceleration when the suppression device is not mounted, to evaluate the performance of the cylindrical suppression device using a High-Speed Test Track and to optimize the geometry using CFD analysis.

Reference

1) Keiji KOMATSU, *Sloshing Liquid level fluctuations and tank vibrations*, 1st ed., Morikita Publishing Co., Ltd. (2015)

2) https://fiji.sc/ (referenced on September 1st)