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## P11

# 小型超音速飛行実験機向け推薬供給システムに関する研究（ガス巻き込み抑制機構の性能検証）

# Study on Propellant Supply System for Small-scale Supersonic Flight Experiment Vehicle

# (Performance Evaluation of Gas Entrainment Suppression Mechanism)

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## 1. Introduction

The Aerospace Plane Research Center in Muroran Institute of Technology is developing the small-scale supersonic flight experiment vehicle as a flying test bed for technical demonstration in high speed flight environment. In the small-scale supersonic flight experiment vehicle, liquid supplying system for Bioethanol and LOX by pressurant gas has been studied. However, sloshing is 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 propellant management device (PMD) which suppresses gas entrainment in an aircraft fuel tank and evaluate its performance. In this study, we analyzed fluid behavior in the PMD during liquid drainage and reselected the mesh. After that, a liquid discharge experiment using a simulated propellant was carried out in a full-scale model tank, and performance verification was performed to see if gas entrainment could be suppressed at a flow rate equivalent to the actual flight model.

## 2. Theory

**Fig. 1** shows a structure of the PMD. The PMD is installed on the liquid outlet. Suppression mechanism of pressurant gas entrainment uses surface tension of liquid [1)]. A metal mesh is attached to the fuel supply pipe at the position marked with red in **Fig. 1**. Next, the suppression mechanism of gas entrainment by the metal mesh is shown [2)]. When the mesh gets wet, a liquid film is formed by the surface tension of the liquid, and this liquid film can prevent invasion of gas. The pressure at which the liquid film breaks due to the gas penetration is called the bubble point pressure. Bubble point pressure is expressed by the following equation (1).

$$P_{BP}=\frac{2\sigma}{d/2} \tag{1}$$

$P_{BP}$ is the bubble point pressure, $\sigma$ is the surface tension of the liquid, and $d$ is the mesh diameter. When the following conditions are met, theoretically gas entrainment can be prevented.

$$P_{BP} > \Delta P \tag{2}$$

$$\Delta P = P_t - P \tag{3}$$

$P_t$ is the tank pressure, and P is the nozzle pressure on the PMD.

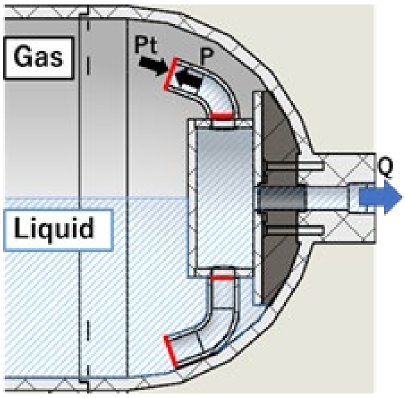


**Fig. 1** Installation of propellant management device

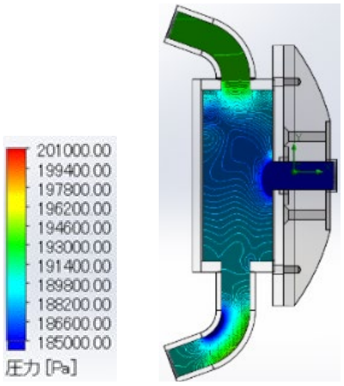


**Fig. 2** Analytical results

## 3. Selection of mesh diameter

Based on the above theory, we analyze the fluid behavior in the PMD and measure the bubble point pressure when the liquid is discharged.

### 3.1. Analysis of the fluid behavior in the PMD

We conduct pressure analysis of PMD. The analysis is considered the case where liquid is discharged at a flow rate of 0.6 L/s, design value for the actual flight model. The pressure difference $\Delta P$ applied to the liquid film calculate from the analytical results. The analysis was performed for PMD with nozzle inner diameters of 13 mm, 16 mm, 20 mm, and 25 mm. **Fig. 2** shows the pressure distribution in the PMD with a nozzle inner diameter of 13 mm. In addition, the results of the analysis are summarized in **Table 1**. From the following results, the pressure difference $\Delta P$ when the liquid was discharged from the PMD with the nozzle inner diameters 13 mm was 5996 Pa.

**Table 1** Analytical results

| Nozzle inner diameter [mm] | $\Delta P$[Pa] |
|---|---|
| 13 | 5996 |
| 16 | 3188 |
| 20 | 2582 |
| 25 | 1722 |

### 3.2. Bubble point pressure measurement test

The bubble point pressure measurement test method is to bond a mesh to a transparent pipe, supply water to the pipe, and measure the height h at which the liquid film can be retained. The bubble point pressure $P_{BP}$ is calculated using the following equation (4). **Fig. 3** shows overview diagram of the test.

$$P_{BP} = \rho g h \tag{4}$$

$\rho$ is the density of the liquid, $g$ is the gravitational acceleration, and h is the height from the mesh to the liquid surface. The bubble point pressure of three kinds of mesh is measured. **Table 2** summarizes the test results. In addition, **Fig. 3** shows the test results of a mesh with a mesh diameter of 4 μm. The water surface is represented by a red line.

From the results of the test, the liquid level height $h$ in the test of a mesh with a mesh diameter of 4 μm is 0.63 m. Since $P_{BP}$ is calculated to be 6163Pa from equation (4). It is shown that equation (2) is satisfied by using the mesh of 4 μm in diameter.

**Table 2** Bubble point test results

| Mesh | Test results | |
|---|---|---|
| Pore diameter [μm] | Height [m] | Bubble point pressure [Pa] |
| 15 | 0.27 | 2641 |
| 5 | 0.49 | 4793 |
| 4 | 0.63 | 6163 |

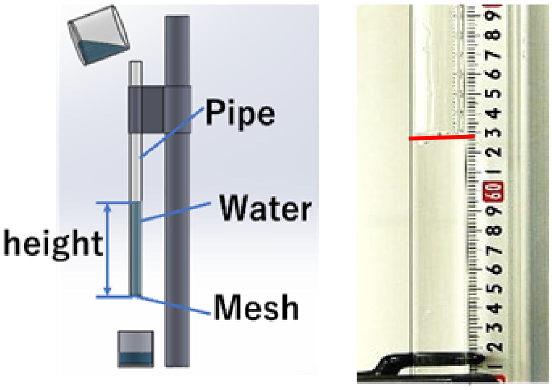


**Fig. 3** Test piece for bubble point test

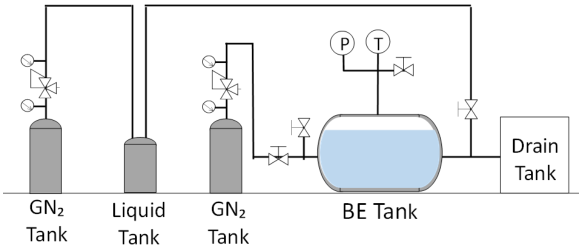


**Fig. 4** Piping system Configuration of the liquid discharge experiment

## 4. Liquid discharge experiment method

**Fig. 4** shows the piping diagram of this experiment. The $GN_2$ pressurizes the model tank and discharges the liquid by opening the valve installed at the tank outlet. The measurement items were tank internal pressure, tank internal temperature, and weight of discharged liquid in the drain tank. The discharge flow rate was calculated from the amount of liquid discharged from the tank and the time required for discharge.

As shown in **Fig. 5**, PMD is installed on the liquid outlet. The PMD is constructed by combining the pyrex® glass nozzle and cylinder made of transparent acrylic resin to visualize the flow inside. The picture of the PMD is shown in **Fig. 6**. In this experiment, the tank internal pressure is increased to 0.2MPa or 0.3MPa, and the flow rate is adjusted by a valve to confirm whether gas entrainment can be suppressed. The PMD is originally provided with a mesh at the tip of the upper and lower nozzles to suppress gas entrainment without being affected by sloshing and to supply fuel. However, since the reselected mesh has a large pressure loss, the pressure in the PMD decreases, and gas entrainment occurs, it is difficult to discharge the liquid at the target flow rate. Therefore, in this experiment, the mesh is mounted only on the upper nozzle that faces the gas phase when liquid is discharged, and the performance of the suppression mechanism of gas entrainment is evaluated. The liquid used distilled water.

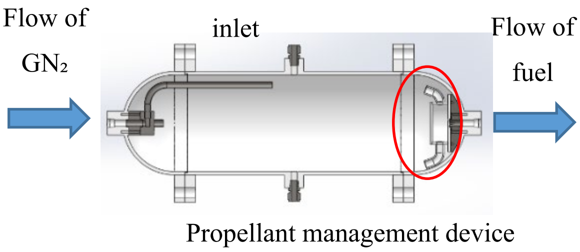
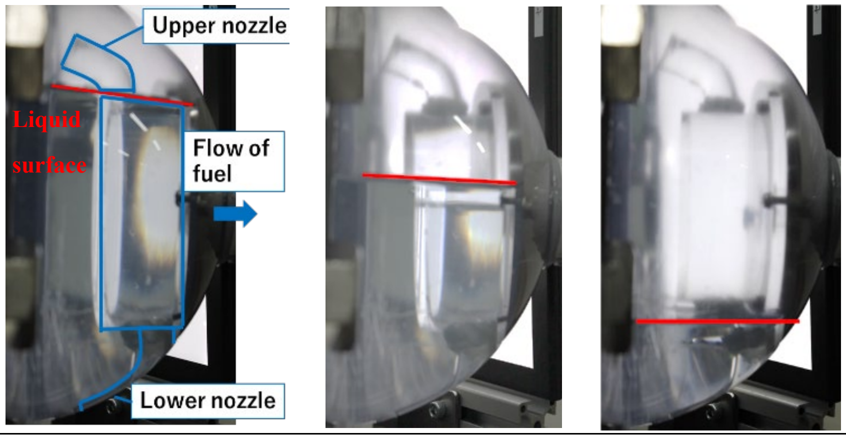


**Fig. 5** BE tank

**Fig. 6** The propellant management device

## 5. Results

At a pressure of 0.2 MPa, fully open the downstream valve and perform a liquid discharge experiment. The flow rate was 0.47 L/s, and it was confirmed that liquid was discharged without gas entrainment until the water surface in the tank reached the lower nozzle of the PMD. However, even though the valve was fully opened, the design flow rate of 0.6 L/s was not reached. Since the flow rate can be increased with the tank pressure, the pressurization value is set to 0.3 MPa and a liquid discharge experiment is conducted. The results are shown in **Fig. 7**. It was found that gas entrainment was suppressed from the start of liquid discharge until the liquid level in the tank reached the lower nozzle, and liquid discharge was completed in the targeted discharged flow rate of 0.6L/s. On the other hand in the experiment with meshes in both nozzles, a gas phase was generated in the upper nozzle. According to the results, it is thought that the cause is the pressure loss due to the mesh. In an actual flight model, both nozzles use with mesh attached, so it is necessary to consider improvement measures so that gas entrainment can be suppressed with the mesh attached



11s 19s 31s

**Fig. 7** Liquid drainage experiment results

## 6. Conclusion

In this study, mesh was re-selected based on the results of analysis and bubble point pressure measurement tests in order to establish a mechanism for suppressing pressurized gas entrainment in the small supersonic flight experimental aircraft fuel tank. The mesh was mounted only on the upper nozzle, and the results of the liquid discharge experiment conducted showed that gas entrainment could be suppressed at a flow rate of 0.6 L/s equivalent to the actual flight model. In contrast, as a problem, when both nozzles have a mesh, a gas phase may occur in the upper nozzle due to the pressure loss of the mesh. Therefore, future guidance was obtained that it is necessary to improve the gas entrainment control with mesh installed on both sides. As a future improvement necessary to establish the PMD, the shape of the PMD is changed to use a mesh with small pressure loss.

## References

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