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# 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（液体捕捉機構に関する検討）

# Study on Propellant Supply System for Small-scale Supersonic Flight Experiment Vehicle (Study on the Propellant Management Device)

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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. The our conventional PMD could not satisfy the performance required in the flight model use because of the pressure loss by the mesh installed to order to suppress the gas entrainment. In this study, PMD was reexamined from experiment and analysis.

## 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. The 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.

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

$$\Delta P = (P_t - P) + P_m \tag{3}$$

$P_t$ is the tank pressure, $P_m$ is the pressure loss of the mesh, and $P$ is the pressure in the nozzle. Fig.1 shows a specific position.

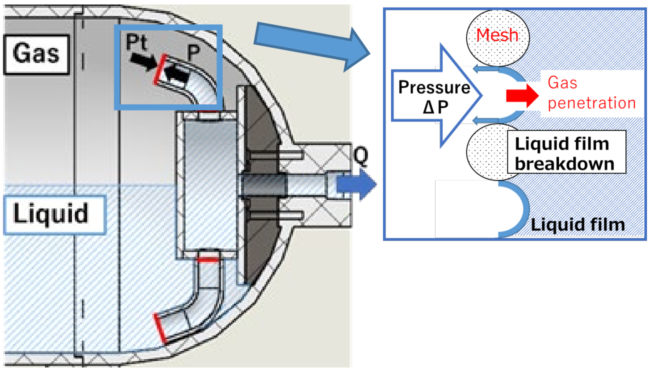

Fig.1 Installation of propellant management device

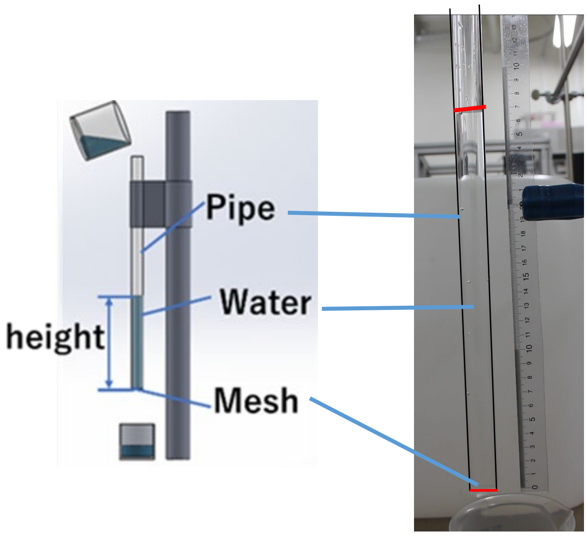

Fig.2 Test piece for bubble point test

## 3. Examination of PMD shape

Based on this theory, the fluid behavior in the PMD was analyzed and the bubble point pressure when the liquid was discharged was calculated. The pressure drop through the mesh was calculated. In addition, the PMD shape which can satisfy the required performance of the flight model is reexamined by considering the pressure loss by the mesh.

### 3.1. Bubble point pressure measurement test

The bubble point pressure measurement test uses a transparent pipe with a mesh on one side. A schematic diagram of the experimental apparatus is shown in Fig.2. In the experimental method, the mesh part of the pipe is placed downward, and the height $h$ which can hold the liquid film is measured by supplying water from above. The bubble point pressure $P_{BP}$ is calculated using the following equation (4). Fig.2 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 pressures of three kinds of mesh are measured. Table 1 summarizes the test results. From the results of the test, the liquid level height h in the test of a mesh with a mesh diameter of 15μm is 0.27m. Since $P_{BP}$ is calculated to be 2641Pa from equation (4). It is found that the bubble point pressure increases as the mesh diameter decreases.

**Table 1** 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 |

### 3.2. Pressure loss through mesh

The mesh is so fine that pressure loss occurs as the fluid passes through it. The pressure loss is calculated using equation (5).

$$\Delta P_m = \alpha\mu u + \beta\rho u^2 \tag{5}$$

$$u = \frac{L}{6A} \tag{6}$$

$\Delta P_m$ is the pressure loss, $u$ is the flow velocity, $\mu$ is the viscosity, $\rho$ is the density, $L$ is the flow rate and $A$ is the surface area of the mesh. Then, $\alpha$ is the viscous resistance coefficient, and $\beta$ is the inertia resistance coefficient, and the value depends on the mesh. Figure 3 shows the relationship between the surface area of the mesh and the pressure loss when using a mesh with a diameter of 15μm.

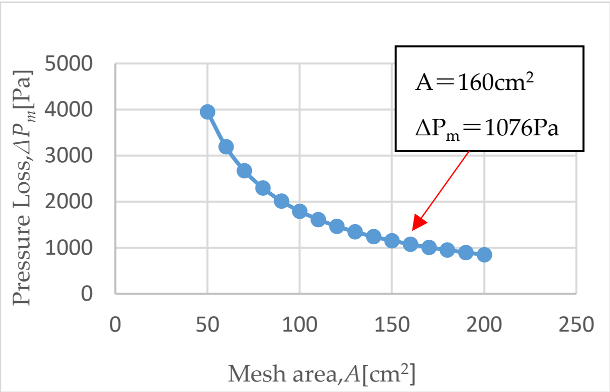


Fig.3 Changes in mesh surface area and pressure loss

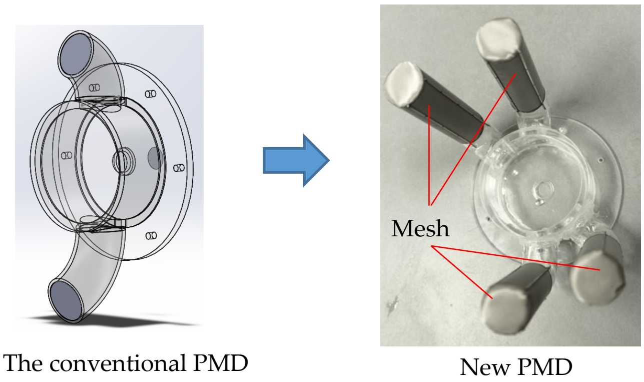


Fig.4 The propellant management device

If the surface area of the mesh is 160cm$^2$ from Fig.3, the pressure loss when passing through the mesh is 1076Pa. The conventional PMD shape and the new PMD shape are shown in Fig.4. In order to secure the surface area of the mesh, the nozzle of the internal device was changed from one upper and one lower nozzle to two upper and two lower nozzles. In addition, the mesh shape is changed from circular to cylindrical for the same reason.

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

We obtain pressure distribution in the PMD by the numerical analysis. Figure 5 shows analytical result when the discharged flow rate is 0.6L/s, design value for the actual flight model. From the analytical results, the pressure difference $P_t - P$ when the liquid was discharged from the PMD with a nozzle inner diameter of 25mm was 864Pa, and the pressure difference $\Delta P$ including the pressure loss of the mesh was 1940Pa.

From the above results, if a mesh having a mesh diameter of 15μm is used and the PMD shape shown in Fig.4 is used, the equation (2) is satisfied.

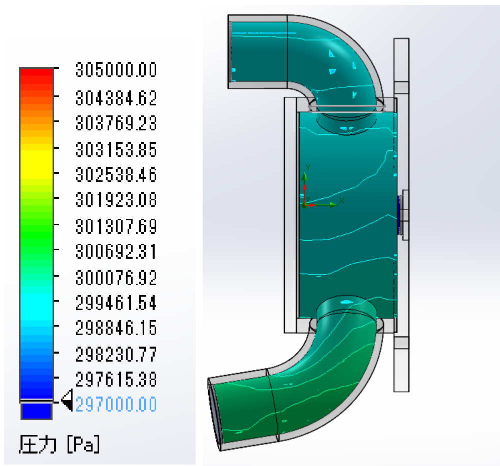


Fig.5 Analytical results

## 4. Future experiment schedule

Performance evaluation experiment of PMD to be carried out in future is described.

In order to evaluate the performance of PMD, a liquid discharge experiment using a model tank was carried out. Fig.6 shows the piping diagram of this experiment. The $GN_2$ pressurizes the model tank and the liquid is discharged by opening the valve install at the tank outlet. The measurement items were tank internal pressure, tank internal temperature, and flow rate. The tank used in the experiment is made of transparent polyvinyl chloride for internal visualization, and is a full-size model tank of about 700mm in overall length. As shown in Fig.7 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.4. In this experiment, the tank internal pressure is raised to 0.3MPa, and it is confirmed whether the gas entrainment can be suppressed by adjusting the flow rate with a valve. The liquid uses distilled water.

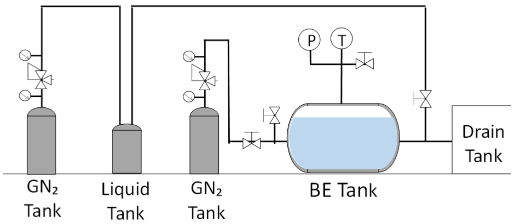


Fig.6 Piping system Configuration of the liquid discharge experiment

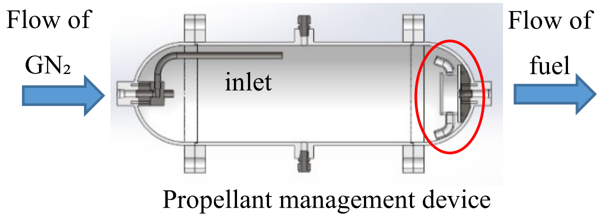


Fig.7 BE tank

And, the evaluation of PMD in the condition in which the acceleration acts like the flight model is also considered. We will use the high-speed track facility of the Aerospace Systems Research Center. This equipment is high-speed running track test equipment (Total length 300 m, maximum speed 400 km/h, acceleration 10 G) which can carry out high-speed and high-acceleration environmental test of the hardware component. A clustered hybrid rocket is used as the main propulsion system, and a water braking system is employed to ensure deceleration by entering the water channel. This equipment is used to evaluate the performance of PMD in an accelerated environment. Fig.8 shows the piping diagram of the experiment.

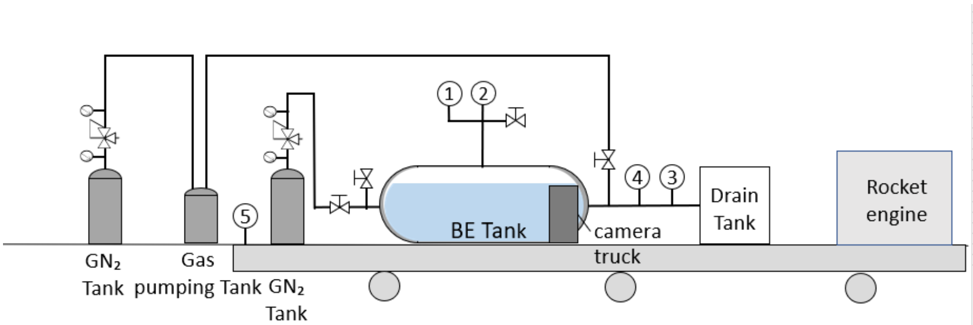


Fig.8 The piping diagram of the experiment.

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