2009-a-05

Progress Report on Preliminary Design of the LE-X Components

By Makoto KOJIMA[1], Hideo SUNAKAWA[1], Akihide KUROSU[1], Koichi OKITA[1]
Akira OGAWARA[2], Tadaoki ONGA[2]

[1] *Space Transportation Directorate, Japan Aerospace Exploration Agency*
[2] *MHI Nagoya Guidance & Propulsion System Works, Japan*

JAXA is planning to develop the next booster engine called LE-X with higher reliability and at significantly reduced cost. The LE-X is under study for the future expendable launcher (post H-2A) with enhanced reliability and at reduced cost. We aimed to achieve significant cost reduction by drastic simplification of the components and innovation of the manufacturing process. In 2007, we had optimized the engine baseline configuration. We examined components designs which have potentially achieved cost-cutting targets. This paper reports the progress of the component design. The key design of each component described. At the present, it appears that preliminary design of the LE-X components is successfully conducted. Feasibility of the components designs and the manufacturing process was confirmed.

Key Words: Liquid Rocket Engine, LE-X, component

1. Introduction

JAXA is planning to develop the next booster engine called LE-X with higher reliability and at significantly reduced cost. The LE-X is under study for the future expendable launcher (post H-2A) with enhanced reliability and at reduced cost. Early-stage feasibility study of LE-X engine system and fundamental studies of LE-X components had been completed by 2006. In 2007, the engine baseline configuration had been optimized from the aspect of cost reduction activities. Figure 1, 2 shows LE-X engine base configuration schematic diagram and 3D layout model. Significant cost reduction will be achieved by drastic simplification of the components and innovation of the manufacturing process. In 2008, the components designs which have potentially achieved cost-cutting targets have been examined. This paper reports the progress of the components design. The key design of each component described as follows.

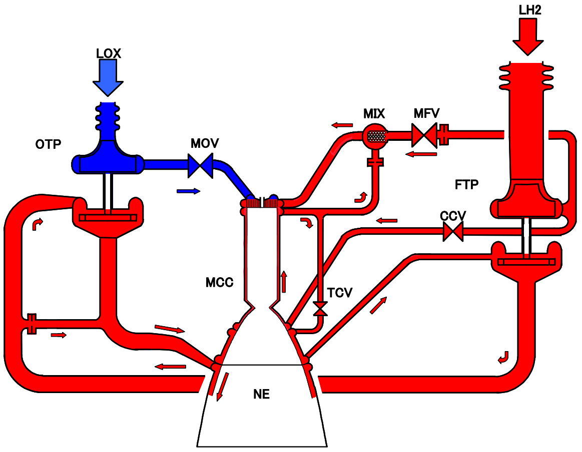

Fig.1 LE-X engine schematic diagram

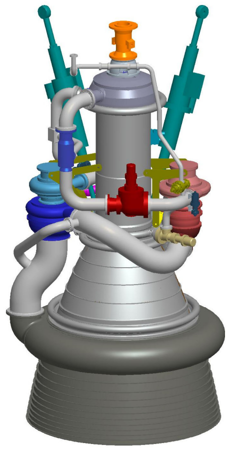

Fig.2 3D engine layout model

2. Engine cost analysis

To be competitive rockets and engines, it will be important to reduce costs. First of all, cost of Japanese traditional rocket engine was analyzed. And the result indicated that reducing components and manufacturing process proved to be effective. So we decided to simplify the engine system.

On the other hand, we analyzed manufacturers' cost of the main combustion chamber, injector and nozzle. As a result, it developed that simplification of manufacturing method proved to be effective. So we consider the adoption of simplified manufacturing method to LE-X each component.

3. The Main Combustion Chamber (MCC)

3.1. Simplification of manufacturing for MCC

MCC is the heaviest component of the LE-X and the main driver for the engine gross cost.

Pratt & Whitney Rocketdyne (PWR)’s hot isostatic pressure (HIP) bonding technology was selected as the candidate to fabricate combustion chamber at significantly low cost. This technique, which has potentially low cost fabrication advantages compared to traditional Japanese combustion chamber fabrication technique, involves the brazing of a coolant liner and outer jacket. In 2007, material properties test after typical HIP brazing thermal cycle and flat panel bonding test demonstration were carried out. As a consequence, HIP bonding process of OMC copper alloy was successfully demonstrated. In 2008, we conducted further material properties tests to examine effects of HIP and heat treatment about OMC. Furthermore, tensile tests of brazing part were conducted to examine mechanical characteristic. Additionally, we conducted fabrication tests at near full scale by flow forming method.

3.2. Prototype deign approach for MCC

Based on result of MCC design in 2007, we assessed trade-off among materials for coolant liner, outer jacket and manifolds. We evaluated weight, cost, strength, life and manufacturability of FE-based superalloy and stainless alloy as candidate for outer jacket. Specific engine design was conducted with selected material as follow.

The results of above fabrication tests were reflected in design for coolant channel and wall thickness of coolant liner. Then, based on results of FEM analysis, thickness of pressure vessel part was decided. We changed manifold shape to uniformize pressure distribution, based on CFD analysis.

On the other hand, as reliability assessment, we assessed failure mode and risks using FMEA for MCC. Design changes were conducted to mitigate these risks for selected critical parts.

Figure 3 illustrates latest combustion chamber assy of prototype LE-X.

About lower MCC, Further specific design will be conducted to fix design for prototype engine MCC.

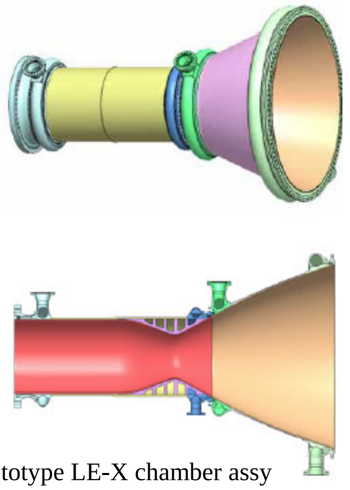

Fig.3 Prototype LE-X chamber assy

4. Injector

4.1. Eliminating LOX inlet manifold

Eliminating the LOX inlet manifold can effectively reduce the production cost of the LE-X injector. CFD simulation was conducted to estimate the effect of LOX inlet manifold elimination. The velocity bias could be seen around inlet orifice of LOX elements. The velocity bias potentially affects engine system in terms of combustion instability, mixture-ratio bias, regenerative cooling condition, and combustion efficiency. We figured out the several solutions that terms described below to reduce the velocity bias.

- To form LOX inlet port in tapered shape.
- To increase distances of LOX inlet port to inlet orifice of the LOX elements by increasing volume of dome.
- To turn LOX inlet angle at small.

The unmodified model is shown in Fig.4. The modified model is shown in Fig.5. CFD simulation of these models was conducted to estimate the effect of the solution. The results are shown in Fig.6-10. These show that the solution reduce the velocity bias, flow rate bias and static pressure bias to the same level as established model which has LOX inlet manifold.

Subscale water flow test was performed to investigate the effect of the solution. To estimate the velocity bias, flow rate in each LOX post was measured. Then the velocity in LOX dome was measured by visualization of tracer flow. The result of the measurement was compared with that of the CFD simulation. As shown in Fig.11-13, it was confirmed that the solution reduce flow rate bias to the same level as established model which has LOX inlet manifold. However, there is flow rate distribution difference between experimental results and CFD results under certain conditions. It seemed that the main factors of the difference were turbulence model, computational grid and boundary conditions for the CFD simulation. And, for the modified model, it was confirmed that reducing flow bias in experimental result and CFD result. So, we decided to begin the primary design of the prototype engine’s injector based on these results.

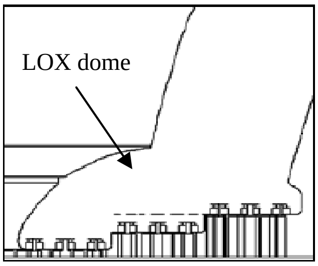

Fig.4 Unmodified model

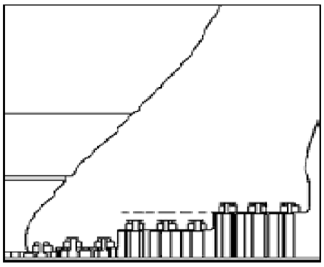

Fig.5 modified model

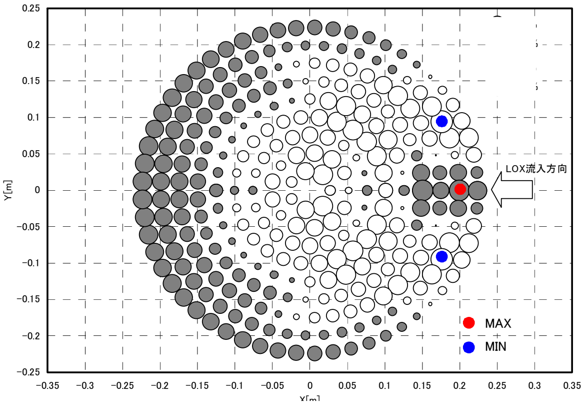

Fig.6 Flow rate bias at unmodified model

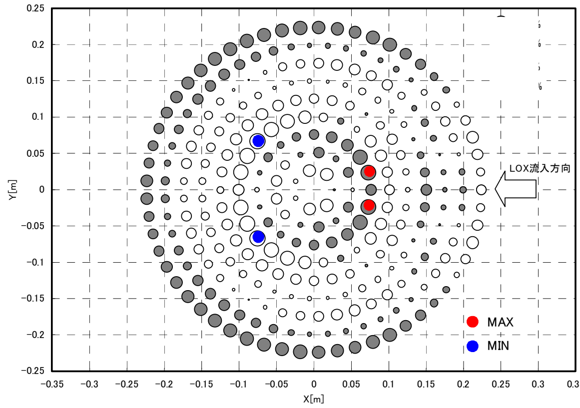

Fig.7 Flow rate bias at modified model

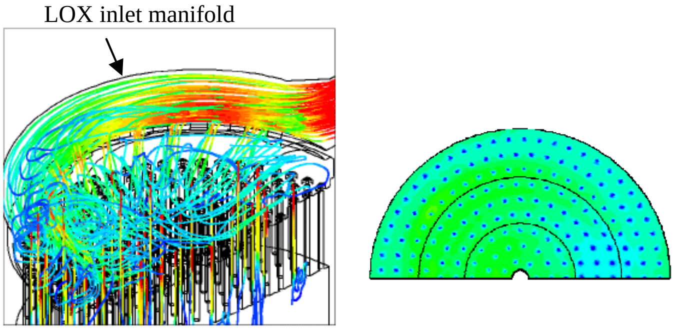

Fig.8 Velocity distribution(left), static pressure distribution (right) at established model with LOX inlet manifold

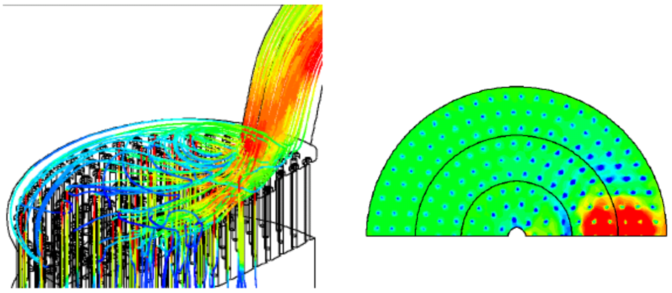

Fig.9 Velocity distribution(left), static pressure distribution (right) at unmodified model

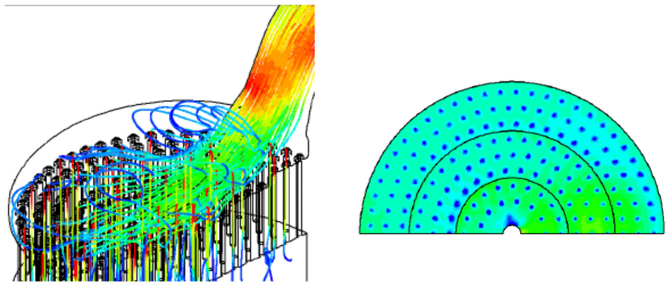

Fig.10 Velocity distribution(left), static pressure distribution (right) at modified model

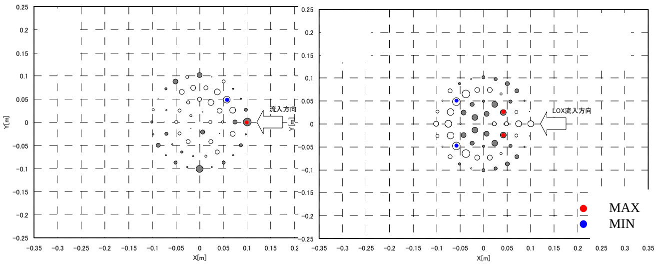

Fig.11 Flow rate distribution experimental result(left), CFD result(right) at established model with LOX inlet manifold

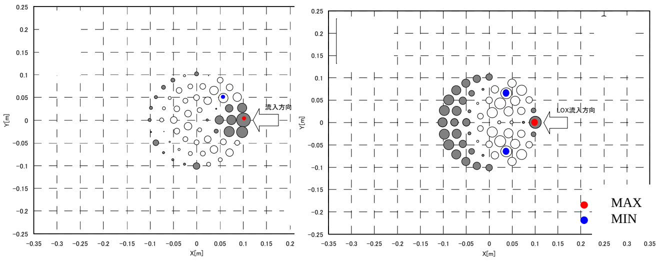

Fig.12 Flow rate distribution experimental result(left), CFD result(right) at unmodified model

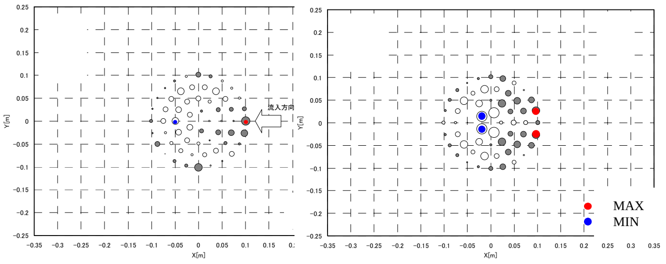

Fig.13 Flow rate distribution experimental result(left), CFD result(right) at modified model

4.2. Prototype design approach of injector

Prototype injector was designed in the aspect of combustion instability, structural intensity and static pressure distribution on a trial basis. Acoustic analysis was conducted to assess combustion instability. Structural eigenvalue analysis was conducted for injection elements to avoid resonance with MCC. Main injection elements were modified to meet the required pressure drop and injection velocity ratio. It was confirmed that structural design of the injector was validated with FEM analysis. CFD analysis was performed to estimate the distribution of LH2 velocity and static pressure as shown in Fig.14.

Figure 17 illustrates the injector of prototype LE-X. To compare the injector of prototype with established injector and unmodified injector, Figure 15 and 16 illustrate these injectors.

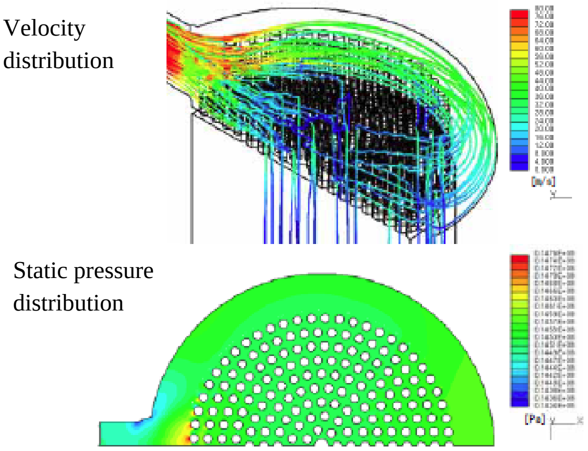

Fig.14 CFD results of velocity distribution and static pressure distribution for LH2

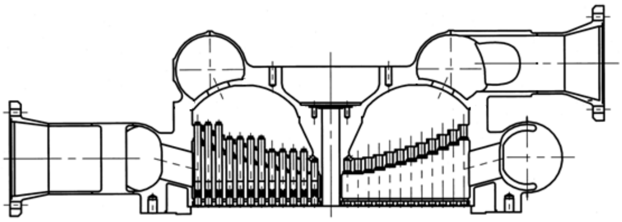

Fig.15 Injector of established model

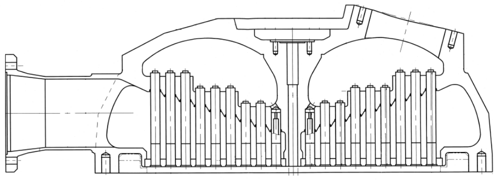

Fig.16 Injector of unmodified model

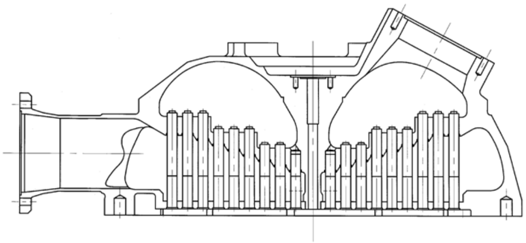

Fig.17 Injector of prototype LE-X

5. Nozzle

5.1. Spin forming process

From the cost prediction of the LE-X engine nozzle, machining process for single sheet metallic nozzle is mainly the cost driver for nozzle fabrication. A spin forming process, which has been adopted to manufacture the propellant tank-dome of H-2B launch vehicle, has a potential to realize significant cost reduction, compared to the conventional machining process. The subscale manufacturing test for the LE-X engine nozzle was conducted to confirm manufacturing condition. Figure 18,19 shows the experimental apparatus and test specimens. The test clarified the impact of roller motion numbers, direction and speed of the spinning pass on dimensional accuracy. Fig.20 showed effect of spinning pass pattern. Based on these results, the manufacturing conditions were determined. Additionally, we conducted material properties tests to examine effects of spin forming and heat treatment. As a result, no significant strength reduction was recognized. So, we decide to move to near full scale test phase.

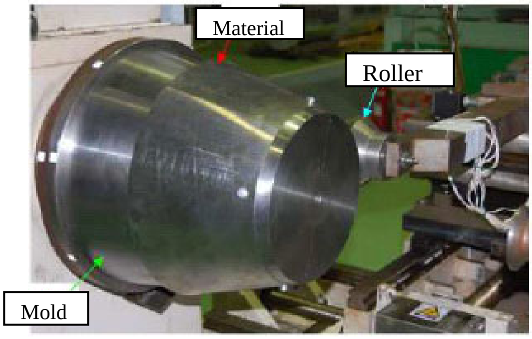

Fig.18 Experimental apparatus of subscale spin forming test

Fig.19 Test specimens by spin forming

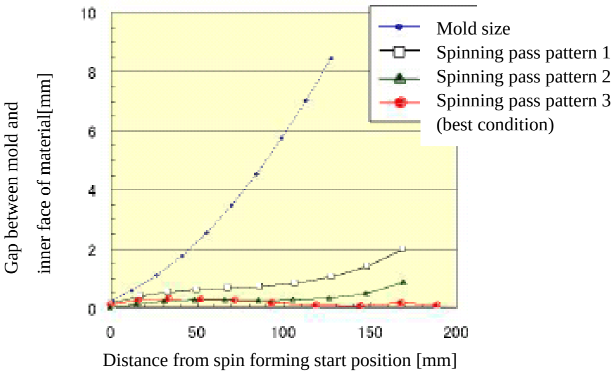

Fig.20 Effect of spinning pass pattern on dimensional accuracy

5.2. Powder metallurgy

To reduce manufacturing cost, we have considered the adoption of powder metallurgy. Metal Injection Molding (MIM) which was one of the powder metallurgy technique was selected as manufacturing method for film cooling gas nozzle(Fig. 21) to meet the required dimensional accuracy.

Material properties tests were carried out to select material for the film cooling gas nozzle. As an example, some of the experimental results of INCO625 are shown in Fig.22. Almost all of the material properties which includes yield stress, ultimate stress, Young's modulus, linear expansion coefficient and heat conductivity of INCO625 by MIM were in agreement with that of forging and casting INCO625. However, certain the material properties which includes elongation, reduction of area, low cycle fatigue strength and fracture toughness of INCO625 by MIM were much lower than that of forging and casting INCO625. It is considered that inadequate molding conditions cause the material defect. So, it is necessary to improve the molding conditions.

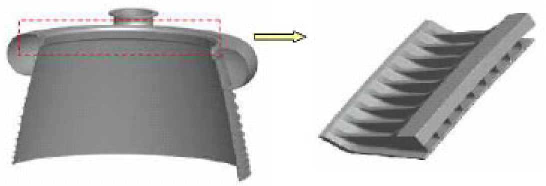

Fig.21 Film cooling gas nozzle

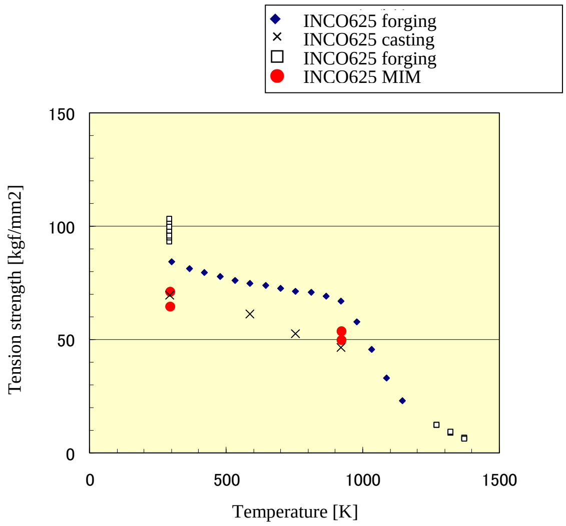

Fig.22 Tension strength of INCO625

6. Valves

The LE-X is planned to have the ability of adjusting thrust and mixture ratio in the engine operation. MOV (Main Oxidizer valve) and TCV (Thrust Control Valve) of the LE-X are designed to be driven by electric actuator and be able to control propellant flow rate continuously, monitoring the signal of some sensors such as chamber pressure, for adjusting its thrust and mixture ratio. This automatic control of thrust and mixture ratio will reduce the engine performance dispersion and number of acceptance hot firing tests before launch, which leads to less cost and more payload weights.

In 2008, the conceptual designs of the LE-X electric valves are fixed using QFD, FMEA, etc. To confirm the feasibility of the conceptual design, feasibility tests at full scale using LE-7A MOV flow part was conducted at ambient and liquid nitrogen temperatures. From the test results, we will evaluate control, heat transfer characteristics of the valve system. The seal (frictional, leak) and control (response) characteristics are in agreement with analysis results. In contrast, the heat transfer characteristic doesn't agree with the analysis results, temperature of the actuator I/F part is lower than that by the analysis. Fig.23 shows measuring points and the results are shown in Fig.24. Accordingly, it is necessary to improve analysis accuracy and design.

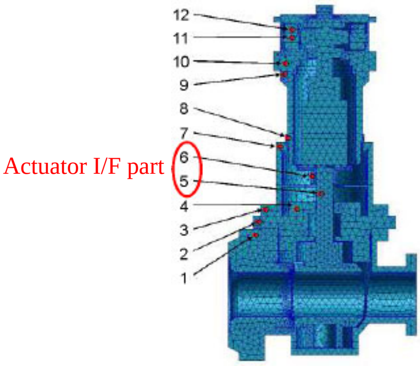

Fig.23 Measuring points of temperature

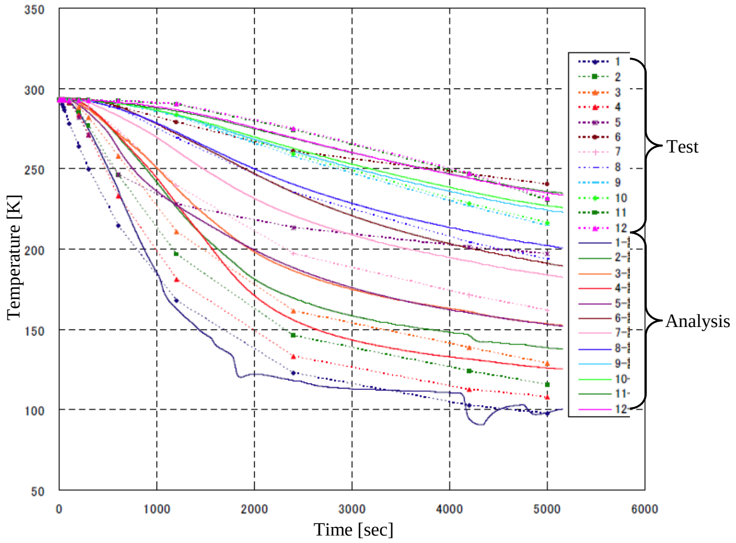

Fig.24 Temperatures of each point in the valve test

7. Conclusion

At the present, it appears that preliminary design of the LE-X components is successfully conducted. Feasibility of the components designs and the manufacturing process was confirmed.

References

1) Sunakawa, H., Kurosu, A., Okita, K., Sakai, W., Maeda, S. and Ogawara, A.: Automatic Thrust and Mixture Ratio Control of LE-X, AIAA2008-4666, 2008.

2) Kurosu, A., Sunakawa, H., Yamanishi, N., Okita, K., Ogawara, A., Onga, T., "LE- X - Japanese Next Liquid Booster Engine-" AIAA2008-4665, 2008