CURRENT STATUS OF ROCKET DEVELOPMENTS IN UNIVERSITIES -COLLABORATIVE ROCKET LAUNCH IN ALASKA AND DEVELOPMENT OF HYBRID ROCKET-

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Abstract
A space educational program in Tokai University Shonan campus (TUS) was established in 1995 for a purpose of the space science and engineering education. We have mainly two space programs, the one is sounding rocket experiment collaboration with University of Alaska Fairbanks (UAF) and the other program is development and launch of small hybrid rockets.

In January 2000 and March 2002, two collaborative sounding rockets were launched from the launch site in Alaska and all of handmade instruments were successfully carried to the apogees of 79 km and 89km high, respectively. Tokai students made two fluxgate magnetometers and analogue sun sensor, and Alaska students made accelerometers, telemeters, recovery system and so on. The third student sounding rocket is going to launch on March in 2006. In 2001, the first Tokai hybrid rocket was launched at Alaska and Tokai students carried accelerometer, bolometric altimeter and flight computer on the payload. After then, we could have launching experiments at Hokkaido and at Akita in Japan and Tokai five hybrid rockets were launched during 2004-2005.

The Tokai space education program provides students with the opportunity for hands on experience to design, to construct, to test sounding rocket payloads and hybrid rockets by use of low cost devices, and to analyze acquisition data after launches. This program has proven to be very effective in providing students with practical, real-world engineering design experience and this also allows students to participate in all phases of a sounding rocket mission. Also students learn scientific knowledge, engineering technique and system management through experiences of cooperative teamwork, presentations and collaborations.

In this paper, we introduce the space education program in Tokai and discuss advantages and some problems in promotion of the education.

1. Introduction
The student space educational project is very successful in providing interdisciplinary research opportunities for undergraduate and graduate students, and in allowing these students to interact with the steady flow of scientists and engineers. The space project provides students with
opportunities for hands-on experience with design, construction, testing and launch of rockets and payloads. For scientific research and engineering techniques, the project develops low cost, student designed instruments to investigate geophysical phenomena and rocket performance, and provides frequent launch opportunities to maintain the technology base and transfer specialized knowledge from practicing aerospace professionals to students. Many of students, who range from freshman to graduate students, are using their participation in this project to fulfill some aspect of their academic program. The students participating in this project become familiar with all aspects of a rocket mission while become resident experts in some specific aspect of the project. The goal of the program is to provide the students with an opportunity to apply their technical education to the solution of real-world engineering design problems. Equally important to the technical aspects of this program are the practical experiences gained in working as part of an interdisciplinary design team in an environment similar to what the students will encounter in industry. The director serves as the primary faculty advisor and manager of this ongoing program.

2. Space education program in Tokai University

We established the Tokai Student Rocket Project (TSRP)\textsuperscript{1}) team that was a similar space education program to that of UAF in 1995. The student rocket program in UAF was created to better integrate this unique aerospace resource into the academic program. Tokai first project is a collaborative hands-on rocket launch that is a sounding experiment at Alaska. Students of both universities design and make their sensor instruments each other and test them. They get together and construct a payload section at UAF. After NASA’s examination, the collaborative student rocket is launched. Two Japan/US student rockets launched in 2000 and in 2002\textsuperscript{2}).

Another Tokai project is handmade hybrid rocket launch of which the first rocket was launched at Alaska in 2001. The first Tokai hybrid rocket reached to the altitude of 300m high. Tokai students carried accelerometer, bolometric altimeter and flight computer on the payload. After then, 5 hybrid rockets were launched during 2004-2005 at Hokkaido and at Akita in Japan. In 2002, TSRP team participated in the University Space Engineering Consortium (UNISEC)\textsuperscript{3}) that is a NPO gathering by handmade space engineering groups in Japan.

Approximately 70 student participants, who range from freshman to graduate students, are independently working and studying interdisciplinary research and extensive techniques after their classes every day. TSRP is composed of a couple of working groups, such as sensor team, mechanical team and hybrid engine team under the student management office. The Faculty director and advisors serve helps of this ongoing program, management, public affair and funding. Tokai students have high motivation and they also work some outreach activities like space classes and demonstration lectures for children and high school students.

2.1 Collaboration with Alaskan students
Profs. S. Akasofu and J. Hawkins, the director of the Alaska Space Grant Program (ASGP)\(^5\) of UAF, invited us to join the rocket launch collaboration in 1994. UAF is the only one university to have a rocket launch site, Poker Flat Research Range (PFRR)\(^5\) in the world. The rocket booster was supplied and launch technology was helped by NASA, but all of other works should be done only by students themselves.

Tokai 7 students visited UAF in March of 1996 at first and discussing some of the various team projects. The purpose of the second visit, in August 1996, was to get to know the other team and to discuss areas of potential collaborations. Each Tokai member presented his/her ongoing work and UAF members presented their area of the rocket project. These resulted in the Tokai designing, and fabricating a magnetometer, and their performing wind tunnel tests on scale models designed and built at UAF. Prof. Hawkins visited 3 times to TUS during 1995-2001 and had lecture meetings to encourage the TSRP to become more involved by taking on more projects. From 1996 to 2005, a total of above 65 Tokai students and professors have visited Alaska and a total of 10 UAF students and professors have visited Japan to have many rocket meetings\(^6\).\(^7\).

Both students held many workshops and shared techniques from 1996 each other. Alaska students designed and constructed rocket nose cone and other bus instruments and Tokai students designed and constructed fluxgate magnetometers and sun sensors for detecting rocket attitudes during the flight. Tokai students visited Alaska during their summer and spring holidays by their own traveling expenses and all instruments are integrated into a payload segment and are all-around tested before launch at UAF. Both students usually discuss rocket design and exchange their documents by internet mails.

In January 2000, the first collaborate rocket, TR-1\(^8\) of that the motor was supplied by NASA, was launched at midnight from the PFRR and all of payloads were successfully carried to the apogee of 79 km high. Tokai students carried a fluxgate magnetometer for detecting rocket attitudes and the detailed attitude performance of the Orion rocket was first determined.

The second collaborative rocket, SRP-4\(^9\) was successfully launched at daytime in March 2002. The initial conceptual design for the payload includes instruments that will measure plasma density variations of the D-region of the ionosphere, perturbations in the geomagnetic field and turbulence in the stratosphere. In this experiment, Toyama Prefectural University first joined us and measured plasma density variations. The length and the weight of SRP-4 are 5.4m and 500kg, respectively with an Orion engine and the apogee of 89 km high. Figure 1 shows the configuration and onboard instruments. Figure 2 shows an attitudinal performance of the SRP-4 rocket by Tokai magnetometer and sun sensor data.

The next collaborative sounding rocket, SRP-5\(^10\) is scheduled to launch in 2006. The aim of the student rocket is to measure the stratosphere ozone density and electron temperature. Tokai student team is constructing an Ultra Violet (UV) sensor, a digital sun sensor and a magnetometer for detecting the altitudinal profile of Ozone density in Arctic region. The payload weight will be 50 kg and altitudinal apogee will be 100 km high.
2.2 Hybrid rocket project in Tokai University

Hybrid rocket propulsion has been drawn much attention in recent years. This propulsion system is highly safe compared with other chemical systems, because only an inert solid fuel grain is stored in the combustion chamber and also its burning is insensitive to a crack or unbonds of the fuel grain. In addition, hybrid rocket propulsion is not mature technology unlike solid or liquid propulsion. From these viewpoints, fundamental research on hybrid propulsion and development of small-sized hybrid rockets give good opportunities to space education in university.

After the launch of the first Tokai hybrid rocket (H#1) in Alaska, original Tokai hybrid program started with the development of non-explosive separation system and static firing tests of a micro hybrid engine, which will be described somewhat in detail later.

In March 2004, two hybrid rockets (H#2, 3) with the same configuration except payloads were successfully launched\(^{(1)}\). A schematic view of H#3 (10cm in diameter, 2.1m in length and 7.0kg in total weight) is presented in Fig. 3. The main purposes of the experiments were to obtain the data on flight characteristics of the rockets and to confirm normal operation of the non-explosive original separation system. The separation system worked well, but the recovery of H#3 failed because a wooden plate which fixed the string of parachute was crushed by a large shock at the parachute opening.

In March 2005, a hybrid rocket (H#4) was launched in Hokkaido up to the altitude of about 400m. The rocket configuration was almost the same as those of H#2, 3. However, a new hybrid engine using a wax fuel and GFRP fins were incorporated. The launch by a N\(_2\)O/wax hybrid engine was the first in Japan. The fin material was manufactured by holding glass fiber clothes in polyester resin matrix. The payloads were two three-axis accelerometers, a barometric altimeter, a digital camera, and a telemetry system. The non-explosive separation mechanism acted normally and recovery of the rocket was successful without any damage.

In August 2005, two hybrid rockets (H#5, 6) were launched at Noshiro. Since the launching site was rather narrow, altitude of the rockets was lowered below 300m for ensuring safety. The one
launch (H#5) aimed for un-experienced undergraduate students to be skilled in launching operation and hand-crafted electronic devices. The main objectives of the other launch (H#6) were to verify both an improved hybrid engine and a handmade electronic device for the non-explosive separation system.

2.2.1. Non-explosive separation system

So far, several kinds of separation mechanisms have been used in space technology, most of which employ an explosive. Although a separation mechanism with a pyrotechnic device has a big merit, it has to be treated very carefully to avoid any accidental operation. Therefore, a non-explosive separation system seems to be much suited particularly when unskilled students are involved. A new separation mechanism without any explosive was proposed and has been improved by students. A schematic illustration of this mechanism is shown in Fig. 4.

The separation force (1kN at present) is produced by the repulsion of three separation springs, which is not a new idea of course. The points are how to hold the springs shrink before operation and how to release the holding as quickly as possible at the operation. This problem was resolved by using both an air cylinder and an assembled nut with a cylindrical nut cover. A nut is divided into three pieces before assembling, so that it does not work without the cover. The mechanism is set up under the state that both separation springs and pullback springs are appropriately shrink respectively. The air pressure in the cylinder (0.7MPa) pushes up the nut cover against the force of pullback springs. When the compressed air is exhausted outside by opening the electromagnetic valve, the force of pullback springs removes rapidly the nut cover and thereby the force of separation springs can eject the upper movable plate at a certain initial speed. The speed of ejection can be easily changed by adjusting the force of separation springs. Although any part of the mechanism is commercially available, the above idea is original. The operation of this mechanism is highly reliable if properly adjusted. This mechanism was used so far for five launches including CAMUI rocket of Hokkaido University, and all separations resulted in success. It should be noted that this separation mechanism is inexpensive even if many times tests are repeated.

![Fig.3 An illustrative view of Tokai hybrid rocket H#3.](image1)

![Fig.4 The non-explosive separation mechanism developed in Tokai.](image2)
2.2.2. Development of \( \text{N}_2\text{O}/\text{wax} \) hybrid engine

In a narrow sense, hybrid propulsion system employs liquid oxidizer and solid fuel grain. Although various combinations of solid fuels and liquid oxidizers can be considered, most common is the combination of a polymer fuel such as plastics, rubber and cryogenic liquid oxygen. However, when this combination is selected, fuel regression rate becomes typically less than one-third that of solid propellants. In order to improve the regression rate to a great extent, some special method is needed\(^{12} \). Recently, paraffin wax draw an attention abroad as a solid fuel with much higher regression rate compared with the above conventional fuels\(^{13} \).

In our university, fundamental research on hybrid propulsion system started with designing and assembling a small-sized hybrid engine of 20N thrust class (micro hybrid engine) and its firing test facilities. Gaseous oxygen or nitrous oxide has been used as an oxidizer, and many kinds of solid fuels have been widely tested. This micro hybrid engine shown in Fig. 5 was proved to be very useful in that it is highly safe and suited for un-experienced students to be skilled in hybrid engine operation. Considering the obtained results generally, the combination of liquid nitrous oxide (\( \text{LN}_2\text{O} \)) as an oxidizer and wax as a solid fuel was finally chosen as the most appropriate hybrid system for our research and development program. It should be noted that although the performance of \( \text{LN}_2\text{O}/\text{wax} \) propulsion system is rather low, replacement of \( \text{LN}_2\text{O} \) by liquid oxygen can easily improve it.

A \( \text{LN}_2\text{O}/\text{wax} \) hybrid engine of 300N thrust class was newly developed and tested, which can be applied to launch a similar sized rocket as H\#2,3 up to the altitude of 500m. A schematic of this combustion chamber is presented in Fig. 6. Since this engine uses nitrous oxide as a liquid oxidizer, a gas-pressurized feed system can be employed, which makes the system much simpler. A typical example of the static firing test is presented in Fig. 7. The average thrust is approximately 320N and burn time is 2.2sec. Appreciable low frequency pressure and thrust oscillations are seen during the whole burning time. Since this type oscillation is likely to appear when liquid oxidizer is used, its reduction is required\(^{14} \). The motor case of flight type engine was made of aluminum alloy with a graphite nozzle. Total mass of the engine is 1.9 kg including liquid nitrous oxide of 440 cm\(^3 \). In spite of a few problems to be improved further, this engine was installed to the rocket H\#4 and operated normally.

![Fig.5 Firing test apparatus of micro hybrid engine.](image)

![Fig.6 A schematic of the combustion chamber of \( \text{LN}_2\text{O}/\text{wax} \) hybrid engine.](image)
In order to improve the adhesion and brittleness of wax fuel, some attempts have been carried out. One of them is the holding of fine wax powders in synthetic rubber (HTPB). A test engine developed based on this idea (mixture ratio of 3) was used for launching H#6 rocket after successful static firing tests. However, investigation of the recovered engine revealed that mixing of wax powder and HTPB polymer was not enough. The quality control of the fuel grain remains as an important problem.

Fig. 7 A typical firing test result of N$_2$O/Wax hybrid engine.

Fig. 8 Flight characteristics of H#6 by accelerometers and altimeter.

2.2.3. Payload instruments on hybrid rockets

In order to determine the flight characteristics of a launched hybrid rocket, two methods have been used. The one is the data acquisition of onboard measuring instruments and the other is optical observation from the ground. Some of the basic instruments such as accelerometer, magnetometer, altimeter, electronic gyro, flight computer and onboard camera have been installed to each rocket for this purpose since H#1. From H#4 in 2005, telemetry system has also been installed to transmit the measured data to the ground station. This rocket H#4 carried two three-axis accelerometers. The
measured data of one accelerometer was transmitted to the ground station with success during 2.3 seconds after lift off, but any meaningful signal could not be captured afterwards. The cause may be due to the interference with a radio wave emitted from a nearby radar site. The data obtained by the two accelerometers agreed well with each other. This means that reliability of the accelerometer is good.

Figure 8 shows the flight characteristics of H#6 as an example. The velocity and altitude of the rocket were calculated from the accelerometer data. The time of separation signal and the altitude at the separation coincide rather well with the ground observation data, respectively.

Although an electronic timer was often employed to create the separation signal, it was proven by H#6 that use of the measured data by an onboard barometric altimeter and an accelerometer, both of them were made by students themselves, was quite effective to achieve the separation near the apogee point.

3. Summary

It is desirable recent trends that many universities and colleges promote to practice their unique hands-on educational program on space engineering. The objects of space educational program are the below.

(1) The program provides students with a practical experience of their hand made instruments and a launching chance of rocket within a couple of years for training future space engineers.
(2) Their constructing structure and payload of rocket should be made by use of devices on the market and save a cost.
(3) Students learn knowledge and technology about space science, electronics, measurement, and so on, through a payload design, construction, test, tracking and data analysis.
(4) Students also learn from their experience for public affair, presentation, management, making a documentation and cultural exchange by an each other information.
(5) The program should give students dreams and hopes for their future space sciences.

We, educators know many advantages to direct students. Students answer their advantages for education as below.

(1) Their most motivational reason is dream, hand-on work and acquisition of skill.
(2) Students obtain technical skill and knowledge, ability of presentation and discussion, and get the hang of teamwork, public affair and management.
(3) They know the importance of cooperation with other university students and it motivated by collaboration.

There are many problems on education for hand-on student projects as below.
(1) It is difficult to get the fund to promote the project, especially, on traveling expenses.
(2) We strongly wish to be able to use any public facilities, like rocket launch site and test
facilities for students.
(3) More educators and staff for helping projects are required, and organization and program for education are also improved.
(4) It is difficult to keep succession on technique, knowledge or skill and to stay balance project promotion that is to respect student autonomy and to control student heading direction.

In conclusion, it is not to mention that hands-on space education brings an immediate great result on student motivation.¹⁵)

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References
1) Web site; http://tsrp ea.u-tokai.ac.jp/
3) Web site; http://www.unisec.jp/
4) Web site; http://www.uaf.edu/asgp/asrp/srp.htm
5) Web site; http://www.pfrr.alaska.edu/
6) F.Tohyama; Collaborate student rocket project with University of Alaska (in Japanese), Proceedings of Annual Conference of Japan Society of Mechanical Engineers (V), 667-668, 2000.