THE LAMBDA-4S ROCKET

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Abst

Lambda-4S is an all solid-propellant four stage rocket having two sub-boosters strapped on its first stage.

Basing on the Lambda-3H, that is a three stage high altitude sounding rocket developed by the University of Tokyo, and attaching an attitude control system and a spherical fourth stage motor atop its third stage, Lambda-4S was planned primarily as a sounding rocket capable of attaining a peak altitude of several thousand kilometers.

Since that the configuration of Lambda-4S was almost similar to that of Mu-4S, which was being developed as a satellite launcher by the University of Tokyo, Lambda-4S's had been used as the simulation test vehicles of Mu-4S for the purpose of studying satellite launch technology since 1966.

After several modifications since the first test flight of Lambda-4S in 1966, the Lambda-4S-5 was launched on February 11th, 1970, from Kagoshima Space Center, and successfully put the Japan's first satellite "OHSUMI" (1970 11A) into an orbit. The Lambda-4S-5 had a maximum diameter of 73.5 centimeters, was 16.5 meters long and weighed 9.4 tons. The weight of "OHSUMI" was 23.8 kilograms including the weight of burnt-out fourth stage motor. The orbit attained was 337 kilometers high at perigee, 5,151 kilometers at apogee and was inclined 31.1 degrees to the equator. The period was 144.5 minutes.

I. Introduction

The Lambda-4S is a four stage rocket, employing solid propellant for its all stages. First three stages are similar to those of the Lambda-3H rocket that is a sounding rocket developed in 1966 and is capable of attaining a peak altitude of two thousand kilometers. Attaching the fourth stage atop the third stage of the Lambda-3H, the Lambda-4S was designed, at first, for the purpose of space probe missions in an altitude of five to six thousand kilometers. However, the Lambda-4S had been used for the purpose of studying the satellite launch technologies such as attitude control, tracking, and so forth. These technologies were necessary as the basis of the Mu-4S that had been being developed as a scientific satellite launcher. Since that the configuration and the velocity characteristics of the Lambda-4S were quite like those of the Mu-4S, the Lambda-4S was conveniently used as a simulated test vehicle of the Mu-4S.

First three test flights of the Lambda-4S were made in September and December, 1966, and April, 1967. The results indicated that some improvement must be made to achieve better separations between stages. After one and a half year studies, the Lambda-4T, that was a sub-orbital test vehicle having the fourth stage motor partially loaded with propellant, was successfully launched in the beginning of September, 1969. The Lambda-4T showed that the effect of the improvement

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was quite remarkable, but, unfortunately, the followed launching the Lambda-4S-4 was unsuccessful due to the collision of the sep third stage motor to the upper stage that took place about sixty seconds after the separation. This collision was due to a very acceleration of an order of 0.01 to 0.001G caused by the residual thrust remained after the motor burn-out. Attaching retromotors the third stage motor, that total impulse was large enough to ca out the acceleration caused by the residual thrust, the Lambda-4 was launched on 11th of February, 1970, and successfully put the Japan's first artificial satellite "OHSUMI" into an orbit.

II. Description of the Vehicle

The configuration of the Lambda-4S rocket is shown in Fig. The dimension, weight, mean thrust and burning duration of each s are summarized in Table 1.

1) The First Stage: The first stage motor employs a solid prope of the polyurethane. It has a diameter of 735 millimeters and is about 8.4 meters long. The first stage motor gives a mean thrust 37 tons for a duration of 28.8 seconds.

Two sub-boosters are strapped on the first stage motor and a more 26 ton thrust to the thrust of the core motor. The increase acceleration during the sub-boosters are burning makes the vehicl less sensitive to the wind dispersion. These sub-boosters are to jettisoned soon after their burn-out.

The first stage motor is separated from the second stage by of a shaped charge encircling the transition section that connect first and the second stages.

2) The Second Stage: The second stage motor is also of the poly urethane and it has the same diameter with that of the first stag motor, while the length is almost one-third. The thrust generate this stage is 11.75 tons and the duration of burning is 38.4 seco

A pair of spin-up motors are mounted atop the second stage m that spin up the vehicle to a spinning rate of 2.5 rps prior to t ignition of the second stage. This spinning motion of the vehicle makes up for a shortage of the stability during the later period second stage burning where the aerodynamic stabilization by means the tail fins becomes less effective. The tail fins of the secon stage are canted to 0.4 degrees in order to reduce the damping in

The second stage motor is connected to the upper stage by mea of three sets of separation nuts. Three coil springs are employe give a relative separation velocity of 1 m/sec at the time of sepa tion.

3) The Third Stage: The third stage motor has a diameter of 504 millimeters and is 2.5 meters long. The polybutadien propellant i employed for this motor that gives a mean thrust of 6.58 tons for duration of 27 seconds.

The third stage motor is connected to the attitude control sy section by means of four sets of separation nuts. Four coil sprin employed gives a relative separation velocity of 1.75 m/sec. Besi the coil springs, four retromotors having a total impulse of 220 k sec are mounted atop the third stage motor in order to decelerate third stage motor after its separation. The nozzles of the retro- motors are directed up and 22 degrees outward in order to make the flame of the retromotors have little thermal and gasdynamic effect the upper stage. Four second delay is provided between the igniti of the retromotors and the separation in order to assure a separat distance of at least 2.5 meters at the time of the ignition of the retromotors.

4) The Attitude Control System and The Instrument Sections: Atop the third stage motor are connected the attitude control system and the instrument sections.

The attitude control system employed for the Lambda-4S is shown in Fig. 2. It is substantially the same one with that of the Mu-4S, excepting the thrust level of the hydrogen-peroxide control jets. The thrust level is same for each of eight control jets and is 300 grams.

The attitude reference is provided by a two-degree of freedom gyroscope mounted on a spin-table that is despun against the spinning motion of the vehicle. The attitude is controlled with reference to the gyroscope in a bang-bang way to the local horizontal at the peak of predicted third stage trajectory.

The spinning motion of the vehicle that is succeeded from the second stage must be removed prior to initiate the attitude control. A pair of despin-motors are mounted atop the instrument section for this purpose. The despin-motor has two nozzles that extend to opposite directions. One nozzle is closed by a lid at first and the plume flowing through other nozzle generates despinning torque. At the time when the spinning rate decreases to almost zero, the lid is jettisoned resulting that the flow of the plume in both directions terminates the despinning torque.

A pair of respin-motors are mounted also atop the instrument section that give a spin of 3 rps after the attitude control maneuver is over.

Other instruments included in the instrument section in the case of the Lambda-4S-5 were, two FM-PM telemetry transmitters operating at 295.0 MHz and 296.2 MHz, a radar transponder at 1,680 MHz, a command receiver at 410 MHz, accelerometers, thermometers, a geomagnetic attitude meter with sun sensor, a separation distance meter by means of radio isotope, timers, and so forth.

5) The Fourth Stage: The fourth stage motor has a shape of sphere alike the case of the Mu-4S. The motor case is made of titanium alloy of 1.6 millimeters thick and has a diameter of 480 millimeters. The propellant employed is the polybutadien and the fourth stage motor generates a mean thrust of 0.81 tons for a duration of 31.5 seconds. The configuration of the fourth stage is shown in Fig. 3.

The fourth stage is connected to the instrument section at the flange of its nozzle by means of four pins. The pins are pulled away using pyrotechnique one second before the separation and a small amount of charge is employed to push forth the fourth stage.

The fourth stage payload in the case of the Lambda-4S-5 included a four channel FM-PM telemetry transmitter operating at 295.6 MHz, a beacon transmitter at 136.16 MHz, a pilot transmitter at 296.7 MHz, thermometers, accelerometers and a silver-zinc battery. The battery had a capacity of 30 hour continuous operation. These instruments are mounted atop the fourth stage motor and was covered by a truncated circular cone instrument cover. The total weight of the payload was 8.89 kilograms.

III. Flight Time Sequence

The Table 2 shows the planned time sequence and the flight characteristics of the Lambda-4S.

A large increase in the velocity is attained in the fourth stage. The velocity increase in the fourth stage reaches almost to a half of the total velocity attainable. This large increase in the velocity is due to an excellent mass ratio of the fourth stage spherical motor.

The sequence of the events of the Lambda-4S is indicated in Fig. 4. The flight of the Lambda-4S is made in almost a similar way as the Mu-4S. After the separation of the first stage motor, the ignition of the spin motors gives 2.5 rps spinning to the vehicle and the second stage motor is ingited. The jettisoning of the heat shroud that co the fourth stage takes place after the second stage burn-out soon before the separation of the second stage motor. The third stage f with a spin succeeded from the second stage.

The third stage motor is separated twenty seconds after its bu out. The retromotors have delay igniters of a delay time of six seconds. The delay igniters are ignited two seconds prior to the separation so as to provide four second delay between the ignition retromotors and the separation.

At the end of attitude control maneuver, the mode change in th operation of the attitude control system takes place. A pair of ro control jets are turned into continuous operation and gradually spi up the fourth stage to a spin rate of 0.5 rps in thirty seconds. T the ignition of respin motors gives additional 3 rps spin. The gra spin-up by means of the roll control jets makes it possible to avoi the disturbance that might be introduced due to a possible unbalanc the thrust of the respin motors.

The timer that controls the sequence is set to ignite the fourt stage at an expected time when the third stage reaches to the peak the undispersed trajectory. The time of the ignition of the fourth stage can be shifted by a radio command sent from the ground. The best time to ignite the fourth stage is determined according to the actual trajectory of the third stage that is measured by radars.

IV. Launch of The Lambda-4S-5

The Lambda-4S-5 was launched from the Kagoshima Space Center, University of Tokyo, at 13:25 JST on 11th of February, 1970. The launch elevation angle was 63 degrees, which was decided considering the dispersion due to wind. The Lambda-4S-5 ready for launch is sho in Fig. 5. The fourth stage of the Lambda-4S-5 attached atop the instrument section is shown in Fig. 6.

The fourth stage of the Lambda-4S-5 became the Japan's first artificial satellite "OHSUMI" after burn-out. Ohsumi is the histori name of the district where the Kagoshima Space Center is located. T international designation for the satellite "OHSUMI" is 1970 11A. I orbital elements are summarized in Table 3. The total weight of the satellite "OHSUMI" was 23.8 kilograms including the burn-out motor weight of 15 kilograms.

The satellite "OHSUMI" was expected that it would have a batter life of 30 hours. The telemetry data at the time of the first revol tion indicated that the temperature of the on-board instruments had risen to 68°C. This high rise in the temperature was due to that the heat stored in the fourth stage motor after the burn-out was much larger than estimated. The operation of the satellite "OHSUMI" cease after spending fifteen to sixteen hours in the orbit because that the battery had been weakened due to this high temperature.

V. Conclusion

The purpose of the Lambda-4S to demonstrate the feasibility of satellite launching as a simulation study vehicle for the development of the Mu-4S was accomplished by the success of the Lambda-4S-5. Eve though the way to reach the final success was not flat but very preci itous, the results and the experiences obtained through the experimen of the Lambda-4S were quite fruitful for the development of the Mu-4S

The next step of the Lambda-4S is to modify it in order to study the technology of guidance by means of installing secondary fluid injection thrust vector control systems in the lower stages. This ty of Lambda-4S will be called as Lambda-4SC and the first test flight o the Lambda-4SC will be made in August, 1971. The results obtained through the experiments of the Lambda-4SC will be reflected to the design of the Mu-4SC that is an improved version of the Mu-4S.

The staff of the Institute of Space and Aeronautical Science,

University of Tokyo and the author wish to express their appreciation to the members of many companies who have contributed to the development of the Lambda-4S rocket and to the successful launching of "OHSUMI". Also, they wish to express their deep thanks to National Aeronautics and Space Administration of the United States of America, Radio Research Laboratory of Ministry of Post and Telecommunications, National Space Development Agency of Japan and the Tokyo Astronomical Observatory for their kind cooperations to the tracking of "OHSUMI".

Table 1. Specification of the Lambda-4S-5

Total length: 16.522 meters
Total weight: 9.399 tons

	1st stage	sub-boosters	2nd stage	3rd stage	4th stage
Diameter (m)	0.735	0.310	0.735	0.504	0.480
Length (m)	8.38	5.77	3.93	2.96*	1.00
Weight (t)	4.97	1.01**	2.47	0.83	0.11
Thrust (t)	37.0	2.60**	11.75	6.58	0.81
Thrust Duration (s)	28.8	7.4	38.4	27.0	31.5

* including attitude control system and instrument sections
** total of two sub-boosters

Table 2. Time Sequence of the Lambda-4S-5
Launch elevation angle: 64 degrees

Time (sec)	Event	Height (km)	Velocity (km/s)
0	1st stage ignition	0.0	0.00
7.4	sub-boosters burn-out	1.5	0.45
8	sub-boosters separation	1.8	
29	1st stage motor burn-out	15	0.98
32	1st stage motor separation	17	
34	spin-motors ignition	19	
37	2nd stage motor ignition	21	
75.4	2nd stage motor burn-out	58	2.59
98	jettisoning heat shroud	87	
100	2nd stage motor separation	90	
103	3rd stage motor ignition	93	
130	3rd stage motor burn-out	141	4.60
150	3rd stage motor separation	182	
154	retromotors ignition		
160	despin-motors ignition	203	
161	initiating attitude control	205	
232	attitude control mode change		
262	respin-motors ignition	372	
477	4th stage motor ignition	525	
509	4th stage motor burn-out	525	8.13*

* absolute velocity

Table 3. Orbital Elements of "OHSUMI(1970 11A)"

ISAS, Univ. of Tokyo

Semi-major axis	9122.1446	km
Eccentricity	0.263855	
Time of Perigee Passage*	545.4813	sec
Right Ascension of Ascending Node	245.2937	deg
Argument of Perigee	115.7124	deg
Inclination	31.1130	deg
Nodal Regression	-2.81626	deg/day
Orbit Precession	4.38307	deg/day
Period	144.51281	min
Height of Perigee	337.061	km
Height of Apogee	5150.908	km

* time after lift-off

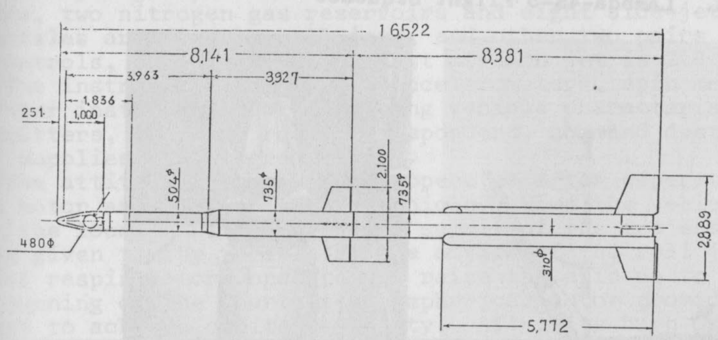

Figure 1. The Lambda-4S-5

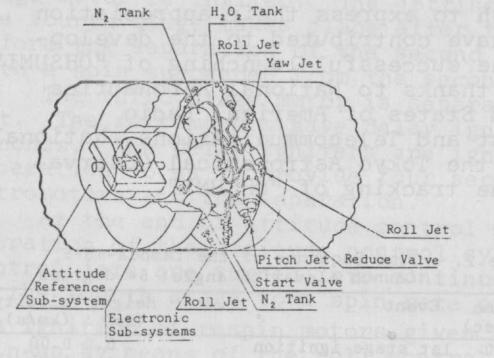

Figure 2. Attitude Control System

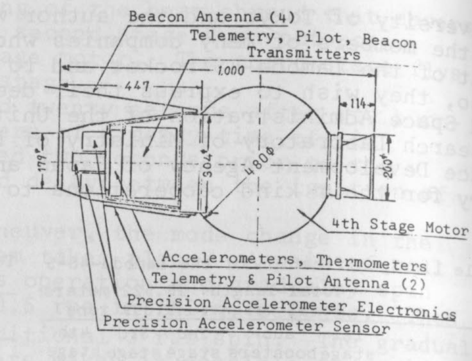

Figure 3. The Fourth Stage of Lambda-4S-5

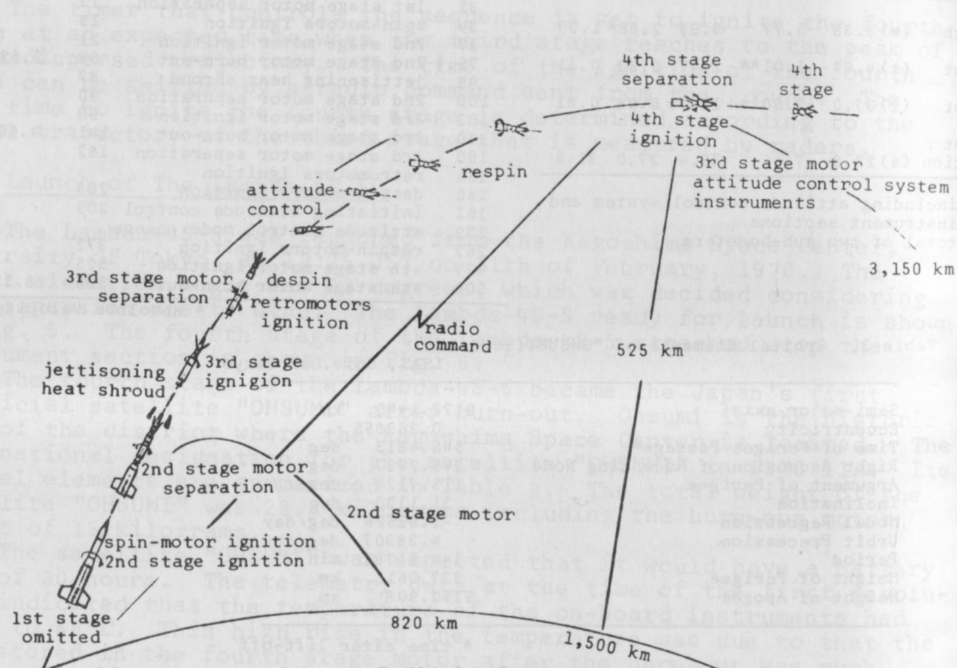

Figure 4. Lambda-4S-5 Flight Sequence

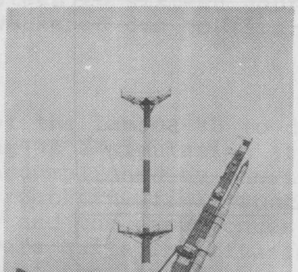

Figure 5. The Lambda-4S-5

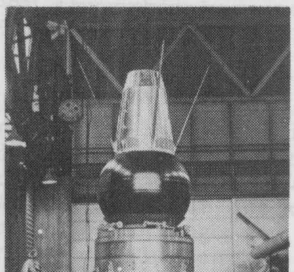

Figure 6. The Fourth Stage of the Lambda-4S-5