Kappa and Lambda: Japan's first steps into space

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**** DRAFT: Needs better images, fact checking ***

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1 Kappa: Japan's first space rocket

Japan is now one of the world's leading space powers, with interplanetary probes like the Hayabusa asteroid mission, space vehicles like the Kibo space station module and the HTV robot cargo ship, and orbiting astronomical observatories such as Hinode and Suzaku. The roots of this program are in the work of Hideo Itokawa (1912-1999) at the Institute of Industrial Science (Seisangijutsu Kenkyujyo) of the University of Tokyo (Tokyo daigaku or Todai), who began testing small rockets in 1954 [1].

The IIS was located in Todai's Chiba campus (CONFIRM?). The Tokyo rocket group formed a separate institute in 1964, the *Ucyu Koku Kenkyujyo* (CONFIRM?) or Institute of Space and Aeronautical Science (ISAS), based on the University's Komaba campus in Tokyo's south central Meguro ward. ISAS was reformed as a national institute in 1981, and renamed as the 'Institute of Space and Astronautical Science', *Ucyu Kagaku Kenkyujyo* and in 1989 the institute moved out of Toyko to the suburb of Samigahara.

The ISAS rockets were developed together with ISAS's industrial partner, Nissan Motors, which built solid rocket motors at Ogikubo in Tokyo's . The Ogikubo plant was the Fuji Seimitsu Kogyo Co. from 1950 to 1961; the Prince Motor Co from 1961 to 1966; Nissan Motor Co from 1966 to 2000; and IHI Aerospace starting in 2000 [2],[3].

1.1 The Kappa-8 rocket

Japan's first exoatmospheric sounding rocket was the Kappa, developed by the Institute of Industrial Science at the University of Tokyo. Early Kappa-1, Kappa-4 and Kappa-6 endoatmospheric rockets were followed by Kappa-8, a true space rocket. The two-stage vehicle featured a 42-cm K420B booster stage, test-flown as Kappa-7, together with a K250-class upper stage which was derived from the Kappa 6, and reached altitudes of 200 km. With its first launch on 1960 July 11 from the Itokawa team's rocket range at Akita, Japan became a spacefaring nation - the eighth country to launch a rocket above the atmosphere since the historic 1942 suborbital flight of Werner von Braun's notorious A-4 missile.

In a series of flights from Akita, Kappa-8 was mainly used to study the ionosphere, with research led by K. Hirao from the Radio Research Laboratory at Ibaraki (now the Communications Research Lab). Hirao later joined ISAS to lead its ionospheric program. K-8-7 and K-8-9 also carried photometers to study upper-atmosphere airglow. The Kappa-8 was a remarkably successful rocket for its day, although the last Akita launch in May 1962 was a failure, part of the booster breaking off in the first second of flight. The rocket reached a height of 115 meters and then the second stage ignited, flying into a sandbank and exploding, causing minor damage to some houses near the range [5].

Kappa-8 launches from Akita

Flight	Date (GMT)	Apo/km	Notes	Experimenters
K-8-1	1960 Jul 11 0424	150	Test flight	
K-8-2	1960 Jul 17 0411	182	Test flight	Hirao (Tokyo) and RRL
K-8-3	1960 Sep 22 0632	200	Ionosphere	Hirao (Tokyo) and RRL
K-8-4	1960 Sep 26 1125	185	Ionosphere	Hirao (Tokyo) and RRL
K-8-5	1961 Mar 27 0408	172	Ionosphere	Hirao (Tokyo) and RRL
K-8-6	1961 Apr 18 1227	150	Ionosphere	Nakamura (TAO) and Tokyo U.
K-8-7	1961 Jul 21 0242	158	Atmos./Ion.	Hirao (Tokyo) and Oya (Kyoto)
K-8-8	1961 Oct 24 0359	200	Ionosphere	Hirao (Tokyo)
K-8-9	1961 Oct 30 1113	175	Atmos./Ion	Hirao (Tokyo), Huruhata
K-8-10	1962 May 24 1050	0	Ionosphere	Miyazaki (RRL)

1.2 The Kappa-6H and the Sigma-4

Two one-off test flights further developed Japan's capabilities - the Kappa-6H, which reached 70 km on 1960 Sep 29 and deployed a grenade to measure upper atmosphere winds; and on 1961 Jun 18, the Sigma-4 'rockoon'. In the Sigma-4 flight, emulating an approach pioneered by US scientists in the 1950s, a single-stage Kappa-4 rocket, K-4-2, was lifted into the upper atmosphere on a balloon, then released and ignited. The launch reached an apogee of 105 km [4] and was carried out from Obuchi in the Aomori district, northeast of the normal Akita range.

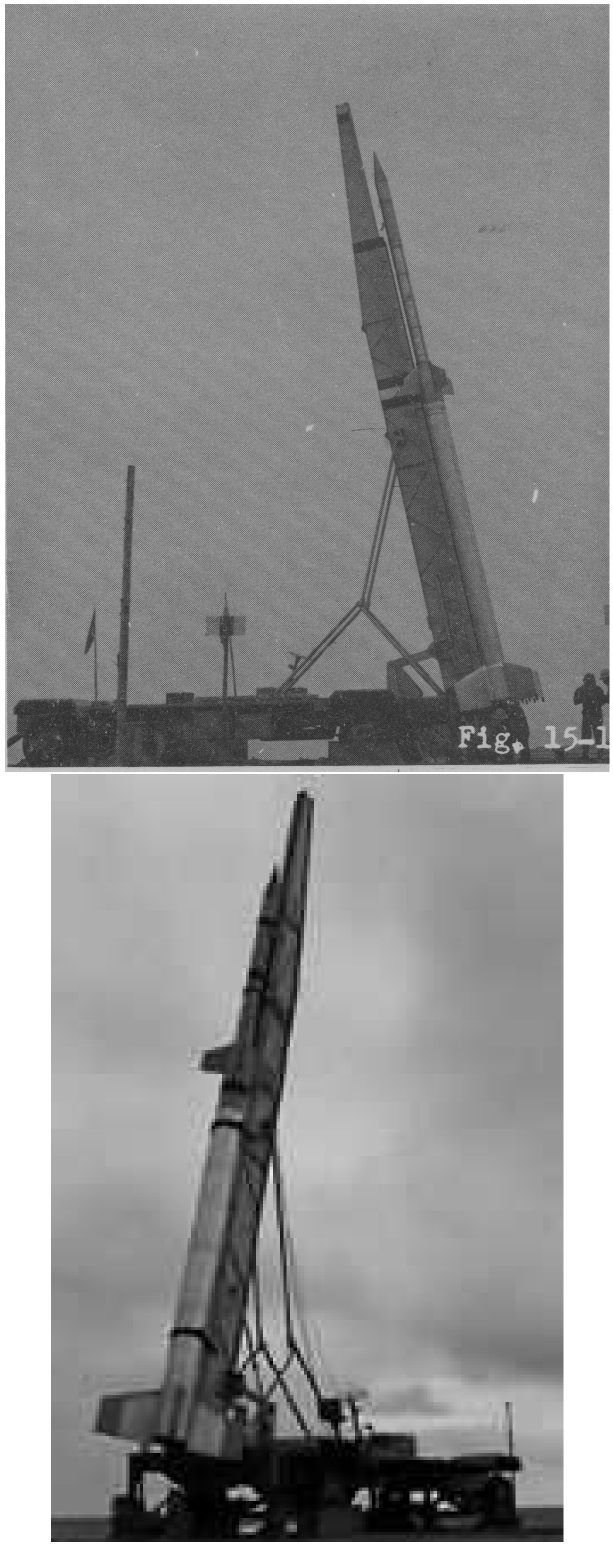


Figure 1: Kappa-8 rocket

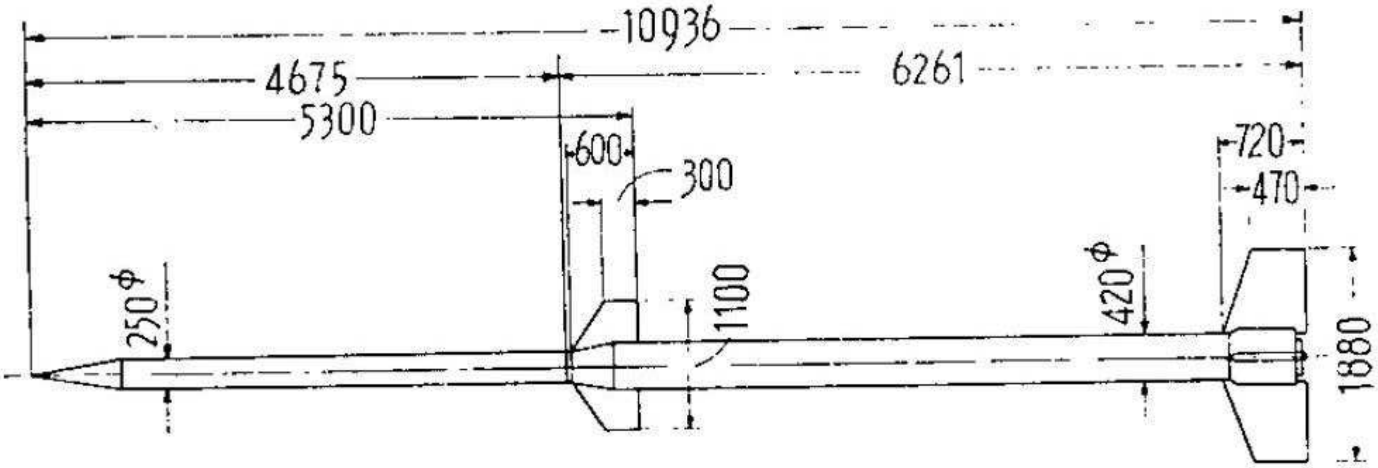


Figure 2: Diagram of vehicle K-8-10

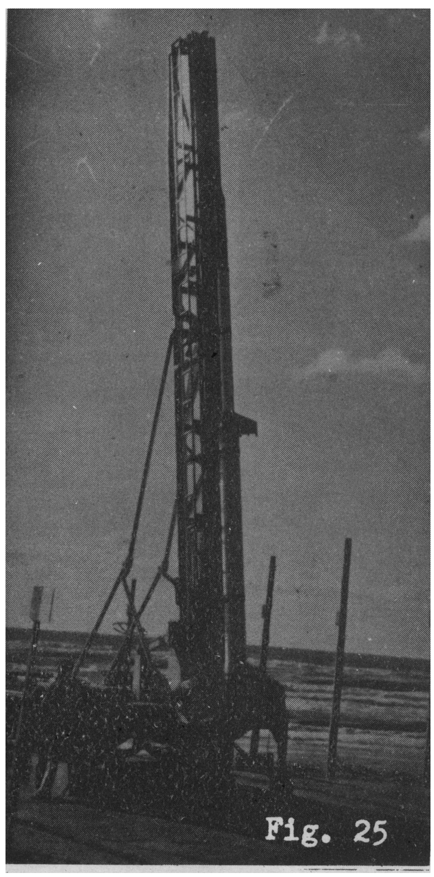
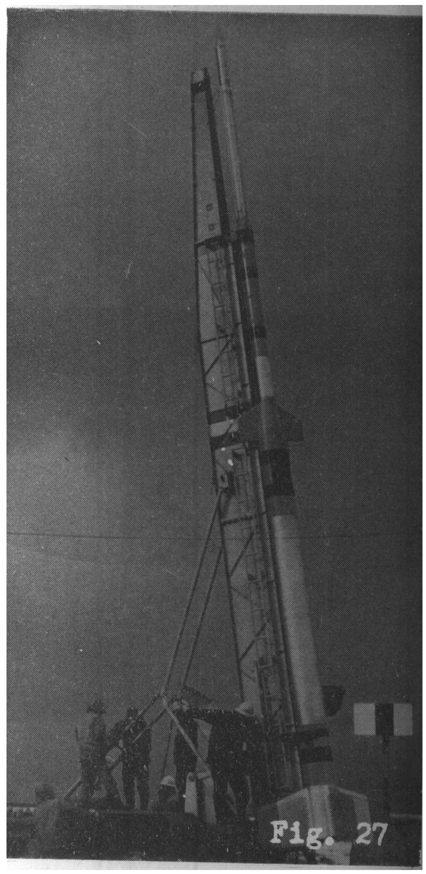


Figure 3: Kappa-6H on the launch pad at Akita.

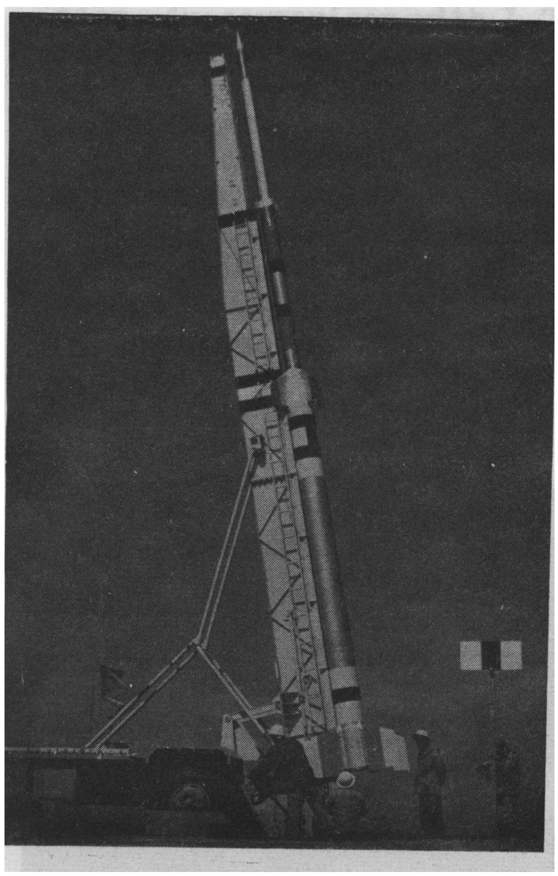
1.3 The Kappa-9L

Soon after the success of Kappa-8, the Tokyo team developed its first three-stage rocket, the Kappa-9L. This had the same 420-mm K420 booster stage as Kappa-8, and a slightly shorted 250-mm second stage apparently identical to the Kappa-6, topped with a final 150-mm stage similar to the Kappa-6H upper stage. This combination had only two flights, in which it demonstrated the ability to reach over 300 km in altitude. The second flight carried a 17 kg payload with instruments to measure the ionospheric electron density and temperature.

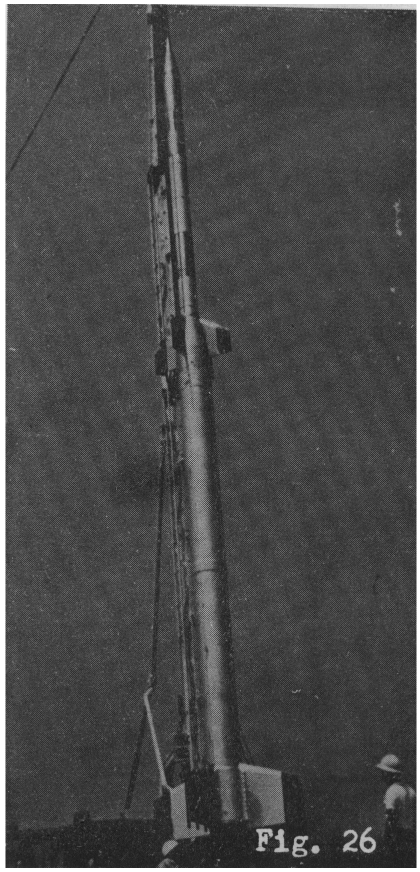


Kappa-9L launches

Flight	Date (GMT)	Apo/km	Notes	Experimenters
K-9L-1	1961 Apr 1 0325	350	Test flight	
K-9L-2	1961 Dec 26 0505	343	Test flight	Ichimaya (ISAS)



1.4 The Kappa-8L



In August 1962 the future ISAS team inaugurated the new Japanese launch site at Kagoshima (now the Uchinoura space center) with a low-altitude AT-150 test rocket followed by the first launch of the Kappa-8L. Despite the similar name, the 8L was a much smaller rocket than the Kappa-8 and was an improved version of the Kappa-6H. Its first stage was the Kappa-6H, comparable to the second stage of K-8 with a 25-cm diameter, and the upper stage had only a 15-cm diameter. The 8L was built partly as a practice run for the development of the Kappa-9M. The rocket was mostly used for atmospheric studies, including sodium vapor releases to measure wind speeds.

Kappa-8L launches

Flight	Date (GMT)	Apo/km	Notes	Experimenters
K-8L-1	1962 Aug 23 0715	173	Test flight	
K-8L-2	1963 Dec 12 0850	103	Atmosphere	
K-8L-3	1964 Apr 1 0310	100?	Atmosphere	
K-8L-4	1964 Jul 26 0907	124	Atmosphere	
K-8L-5	1964 Jul 26 1051	112	Atmosphere	Saito (TAO)
K-8L-7	1964 Nov 2 0903	156	Atmosphere	Huruhata (TAO)
K-8L-8	1964 Nov 10 0205	145	Ionosphere	Okumoto (Osaka)
K-8L-6	1964 Nov 12 0305	100?	Atmosphere	Okumoto (Osaka)
K-8L-9	1965 Oct 6 0400	141	Atmosphere	Aoyama (Tokai)
K-8L-10	1966 Aug 11 1205	130	Atmosphere	Kimura (Tokyo)
K-8L-11	1966 Oct 18 0917	150	Atmosphere	Kimura (Tokyo)
K-8L-12	1966 Dec 10 0200	147	Atm/Ionos/Solar	Tohmatsu (ISAS)

1.5 Follow-on launches of the Kappa-8

The Kappa-8 was also used at the new Kagoshima site and continued in sporadic use until 1970. K-8-11 tested a geomagnetic attitude control sensor and carried a cosmic ray detector and a radio noise detector [5] The K-8-15 mission in 1969 deployed a large antenna wire to measure electric fields and used a resonance impedance probe (known in Japan as a gyro-plasma probe) to quantify the electron density [6]. The K-8-16 released a sodium cloud to measure upper-level winds, and measured electron densities [7].

Three Kappa-8 missions were also used in a collaborative effort with Indonesia's LAPAN space agency in 1965. Confusingly the flights were given "K-8(L)" designations (L for LAPAN), but were the full Kappa-8 model and should not be confused with the smaller K-8L rocket variant. The SK-8-3 flight used grenades to determine upper-level wind conditions [8], while SK-8-4 [9] was an ionospheric flight. An earlier flight is cited in UPI wire stories for Aug 8, 1965, but details seem garbled (an apogee of 197 miles seems unlikely - perhaps 197 km is correct). Prof. Itokawa himself was at the launches; ten Kappa rockets were taken to Indonesia, but I have only evidence for three being fired. Decades later, Indonesia began firing rockets of very similar dimensions and capability in its RX-250 program, which probably had at least some design heritage from the Kappa-8(L).

Kappa-8 launches from Kagoshima				
Flight	Date (GMT)	Apo/km	Notes	Experimenters
K-8-11	1962 Dec 18 0503	202	Cosmic rays	Takakura (TAO)
K-8-12	1965 Jul 16 1050	160	Atmos/Ionos	Nakamura (Tokyo)
K-8-13	1966 Apr 20 1205	155	Plasma/Ionos	Kimura (Tokyo)
K-8-14	1966 Oct 20 0220	191	Ionos/Solar UV	Aoyama (Tokai)
K-8-15	1969 Jan 9 0740	188	Ionosphere	Aoyama (Tokai)
K-8-16	1970 Sep 2 1014	174	Atmos/Ionos	Namakura (Tokyo)
Kappa-8 launches from Indonesia				
K-8(L) SK-8-1?	1965 Aug 7	200?	Atmosphere	?
K-8(L) SK-8-4	1965 Aug 11 0135	190	Atmos,Ionos	Kusumanto, Baiquni (LAPAN)
K-8(L) SK-8-3	1965 Aug 17 0005	200?	Atmosphere	Karjoto, Pringgd. (LAPAN)

1.6 The Kappa-9M, a scientific mainstay

For a quarter of a century the Kappa-9M rocket was almost synonymous with Japanese space science research. By far the most productive of the Kappa variants, its 80 flights resulted in many published papers in a variety of fields. The two-stage Kappa-9M was an upgrade of Kappa-8, replacing the first stage K420 motor a high power K420H version; the 250mm K250 second stage was a stretched version of the Kappa-8 upper stage. The first flight only reached 58 km when the upper stage failed to ignite, but proved the basic design, and subsequent missions were reliable.

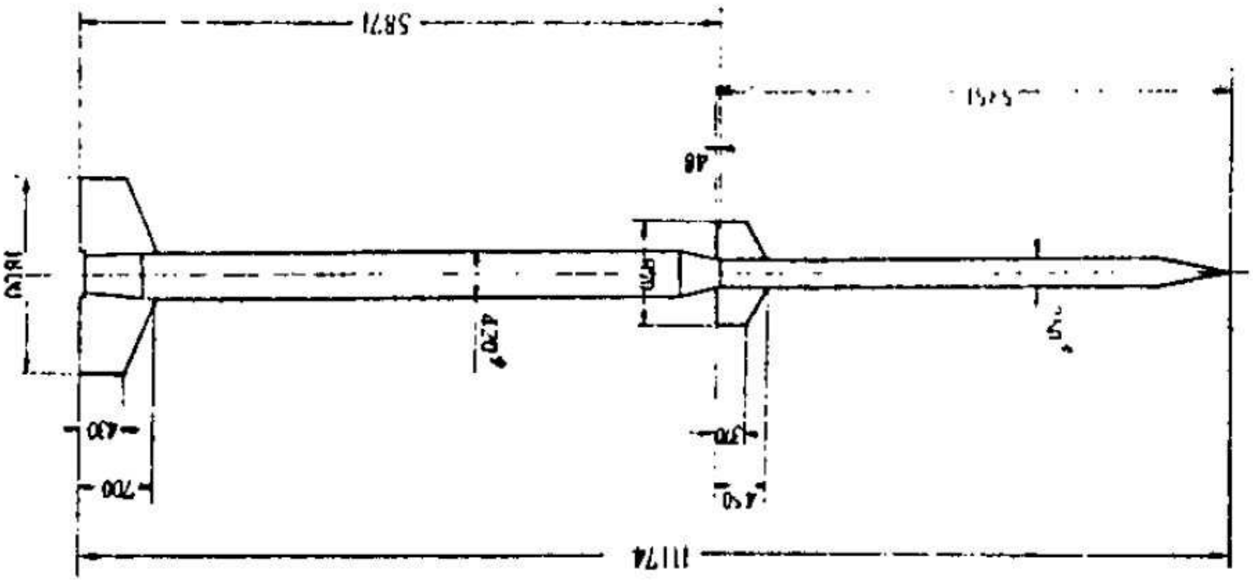


Figure 4: K-9M-28 and 29

Kappa-9M launches - 1962-1974					
Flight	Date (GMT)	Apo/km	Notes	Experimenters	Ref
K-9M-1	1962 Nov 25 0201	58	Ionosphere	Hirao (Tokyo)	
K-9M-2	1963 May 20 0209	345	Ionosphere	Takakura (TAO)	
K-9M-5	1964 Jul 29 1007	300?	Cosmic rays		
K-9M-4	1964 Nov 5 0301	356	Ionosphere		
K-9M-3	1965 Jan 22 0514	350	Ionosphere?		
K-9M-7	1965 Feb 6 0501	325	Ionosphere	Oshio (Osaka)	
K-9M-6	1965 Feb 6 1002	335	Solar RF	Tsuchiya (TAO)	
K-9M-8	1965 Mar 25 1121	320	Atmos/Ionos	Tanabe,Hiruhata (TAO)	[11]
K-9M-9	1965 Mar 27 0501	335	Ionosphere	Tohmatsu (Tokyo)	[12]
K-9M-10	1965 Mar 28 0701	349	Ionosphere	Yabuzaki (Kyoto)	
K-9M-12	1965 Jul 26 1201	350	Astronomy	Matsuoka,Tanabe (ISAS,TAO)	[13]
K-9M-13	1965 Jul 27 0310	317	Ionosphere	Aoyama (Tokai), Oya (Kyoto)	[14]
K-9M-14	1965 Oct 4 0300	299	Ionosphere	Oya (Kyoto)	
K-9M-16	1965 Dec 13 0620	318	Ionos/Atmos	Oshio (Osaka)	[65]
K-9M-17	1965 Dec 18 0600	316	Ionosphere	Yamaguchi (Nagoya)	
K-9M-15	1966 Mar 20 1215	300	Astron?/Atmos.	Shiro,Tanabe (RRL/TAO)	[11]
K-9M-18	1966 Jul 17 0210	326	Ionos/Solar	Tohmatsu (Tokai)	
K-9M-11	1966 Aug 3 0200	328	Atmosphere?		[10]
K-9M-19	1966 Aug 10 1237	330	Ionos/Atmos	Kimura (Kyoto)	[16], [11]
K-9M-20	1966 Oct 20 0825	353	Ionosphere	Oya,Tohmatsu (Kyoto,Tokyo)	[18],[17]
K-9M-21	1966 Dec 5 0200	326	Ionos/Solar	Tohmatsu (Kyoto)	[18]
K-9M-22	1967 Jan 31 0205	327	Ionos/Solar Radio	Yamaguchi (Nagoya)	
K-9M-25	1969 Jan 8 0210	343	Ionos/Cos.Rays	Kimura (Tokyo)	[6]
K-9M-24	1969 Jan 19 1200	340	Atmos/Ionos	Tanabe (TAO)	[6]
K-9M-23	1969 Feb 13 0205	310	Ionos/Solar	Higashino (Osaka)	
K-9M-27	1969 Aug 7 1215	340	Ionos/Astronomy	Kitamura (Osaka), Oda (ISAS)	[20]
K-9M-26	1969 Aug 24 0804	341	Ionosphere	Kamada,Hayakawa (Nagoya)	[21]
K-9M-28	1970 Jan 25 0500	369	Ionos/Atmos	Oyama,Suitsu (ISAS,RRL)	[19]
K-9M-29	1970 Jan 27 1020	357	Ionosphere	Hirao,Matsumoto (ISAS, Kyoto)	
K-9M-32	1970 Sep 27 0642	346	Ionosphere		
K-9M-30	1971 Jan 16 0715	357	Ionosphere		
K-9M-35	1971 Jan 23 1320	338	Ionosphere	Mastumoto (Kyoto)	
K-9M-34	1971 Jan 24 0200	328	Astronomy		
K-9M-31	1971 Aug 18 1200	330	Astronomy	Miyamoto,Oda (ISAS, Osaka)	[22]
K-9M-36	1971 Aug 25 0540	0?	Ionosphere		
K-9M-33	1971 Aug 26 1035	340	Ionosphere		
K-9M-37	1972 Jan 23 1122	340	Ionosphere		
K-9M-39	1972 Feb 18 0928	310	Ionosphere		
K-9M-38	1972 Feb 22 0600	352	Atmos/Ionos	Tohmatsu (Tokyo)	[23]
K-9M-40	1972 Sep 20 0500	326	Ionosphere	Mukai (ISAS)	[24]
K-9M-41	1973 Jan 19 0900	330	Ionosphere	Matsumoto (Kyoto)	[25]
K-9M-42	1973 Feb 23 0938	306	Ionosphere		
K-9M-43	1973 Aug 21 0700	355	Ionosphere		
K-9M-44	1973 Aug 27 1200	341	Astronomy	Hayakawa (Nagoya)	[26]
K-9M-45	1974 Jan 16 0200	360	Ionos/Solar	Hirao (ISAS)	[27],[31]
K-9M-46	1974 Sep 16 1540	336	Ionosphere		
K-9M-47	1974 Sep 19 0200	328	Ionosphere		
K-9M-48	1974 Sep 20 1132	348	Ionos/Solar	Kubo, Hirao (ISAS)	[28]

Kappa-9M launches - 1975-1988					
Flight	Date (GMT)	Apo/km	Notes	Experimenters	Ref
K-9M-49	1975 Jan 17 0935	363	Atmos/Ionos		
K-9M-50	1975 Jan 23 1105	353	Astronomy	Iwanami et al (Nagoya)	[29]
K-9M-53	1975 Aug 26 1040	351	Ionosphere		
K-9M-51	1975 Sep 2 1200	311	Ionosphere		
K-9M-52	1975 Sep 23 1200	336	Astronomy		
K-9M-54	1976 Jan 16 2100	367	Magnetospheric	Hirao (ISAS)	[30]
K-9M-57	1976 Aug 30 1955	288	Ionosphere	Kawashima (ISAS)	
K-9M-55	1976 Sep 16 0200	359	Ionosphere	Hirao (ISAS)	[27],[31]
K-9M-56	1976 Sep 18 1000	300?	Ionosphere		
K-9M-58	1977 Jan 16 1245	324	Astronomy/Ionos	Hayakawa (Nagoya)	[32]
K-9M-59	1977 Sep 3 1000	376	Ionos/Solar	Obayashi, Watanabe, Ogawa	
K-9M-62	1978 Jan 22 0200	369	Ionos/Solar		[27]
K-9M-61	1978 Jan 27 1100	292	Atmos/Ionos		
K-9M-60	1978 Feb 26 1100	340	Astronomy		
K-9M-64	1978 Aug 20 1130	319	Astronomy	Noguchi (Nagoya)	[33]
K-9M-65	1979 Jan 16 2050	353	Atmos/Ionos		
K-9M-66	1979 Jan 21 0906	336	Atmos/Ionos		
K-9M-67	1979 Aug 18 0700	365	Ionosphere	Minami (Osaka), Hirao (ISAS)	[27][34]
K-9M-68	1979 Sep 11 0100	353	Ionosphere		
K-9M-69	1980 Jan 16 0300	328	Tether	Kawashima (ISAS)/Utah State	[35]
K-9M-70	1980 Sep 2 1040	230	Atmos/Ionos		
K-9M-71	1980 Sep 4 1245	308	Atmosphere	Nakamura (ISAS)	
K-9M-73	1982 Jan 15 0920	303	Ionosphere		
K-9M-72	1982 Feb 13 0200	328	Ionosphere		
K-9M-74	1982 Feb 18 1240	315	Astronomy		
K-9M-75	1982 Sep 13 1230	320	Astronomy	Matsumoto (Nagoya)	[36]
K-9M-76	1983 Jan 14 2040	349	Atmos/Ionos	Amemiya (RIKEN),Tanabe	[27]
K-9M-77	1984 Jan 13 1930	317	Astronomy	Matsumoto (Nagoya)	[37]
K-9M-78	1985 Sep 14 1440	297	Astronomy	Matsumoto (Nagoya), Lange (Berkeley)	[38]
K-9M-79	1986 Jan 31 0800	319	Ionosphere	Kaya? (ISAS)	
K-9M-80	1987 Feb 22 1500	317	Astronomy	Matsumoto (Nagoya), Lange (Berkeley)	[39]
K-9M-81	1988 Jan 25 0200	359	Ionosphere	Oyama (ISAS), Piel (U. Bochum)	[45]

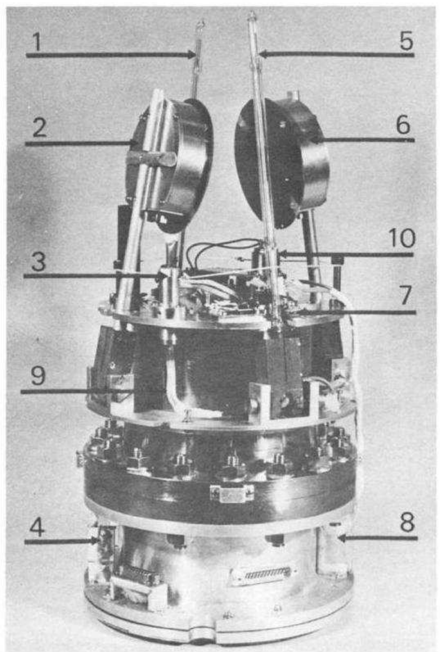
1.6.1 Ionospheric missions

The Kyoto group including H. Oya carried out flights of the gyro-plasma probe and Langmuir probe to study the altitude variation of electron density on flights 13, 19, 20 and 21 [14],[18], [16].

A strong ionospheric research program was carried out by ISAS scientists including Kunio Hirao and Koh-ichiro Oyama [17]. They discovered a layer of unexpectedly hot electrons about 105 km above the Earth during wintertime. Several flights from K-9M-45 to K-9M-76 flew Langmuir probes to measure the energy distribution of ionospheric electrons [31],[27]. K-9M-40 flew an electron spectrometer to study the distribution of electron kinetic energies [24].

M. Hayakawa at Nagoya studied very-low-frequency radio waves using the K-9M-26 payload [21].

Two missions, K-9M-35 and K-9M-41, used electric fields to generate VLF (very low frequency) plasma waves in the ionosphere and measure their properties [25], a precursor to later work using electron beams to actively probe the ionosphere.



[redacted] SENSORS INSTALLED ON THE PAYLOAD HEAD OF THE ROCKET K-9M-45.
1. D.c. Langmuir probe which is not described in this paper. 2. Electron temperature probe (Low sensitivity). 3. Guillotine for the probe deployment. 4. Relays for the probe deployment and glass tube cutter. 5. Langmuir probe for energy distribution measurement. 6. Electron temperature probe (High sensitivity). 7. Cutter for glass-tube removing. 8. Batteries for guillotine and cutter driving. 9. Sensor chamber of photoelectron energy analyzer. 10. Inlet of photoelectron energy analyzer.

Figure 5: K-9M-45 payload

Flight 67 carreid a retarding potential analyser to measure the ion temperature [34]. The K-9M-79 flight in 1986 test-flew two instruments for the EXOS-D (Akebono) satellite, an ion mass spectrometer and antennae to study auroral kilometric radiation.

1.6.2 Atmospheric studies

K-9M-9 carried photometers built by Tokyo University's geophysics department [12] to study the dayglow, spectral-line emission from oxygen and nitrogen in the upper atmosphere, while K-9M-8, K-9M-15 and K-9M-19 flew a similar payload from the Tokyo Astronomical Observatory to study the nighttime airglow [11].

Flight 11 [10] carried a television camera, possibly to return cloud cover images.

Flight 16 [65], [?] and Flight 38 [23] carried on an ozone measurement program using photometers to detect absorption of solar ultraviolet light by the atmosphere. Flight 59 had spectrometers to improve the resolution of the ozone experiment, and studied the emissions of atomic nitrogen and nitrous oxide.

1.6.3 The space tether mission

In 1980, K-9M-69 flew the first space tether payload experiment, TPE-1, a joint project between ISAS and the Utah State University [35]

The radiation and fields in space vary not only from place to place but also from one moment to the next even at one place, and as a rocket flies through the Earth's magnetosphere it is difficult to be sure whether the changes it sees are due to its changes in location or to the passage of time. Many earlier rocket missions, beginning with NASA flights in the early 1960s, had featured 'mother-daughter' payloads in which a small package was released to fly some distance away from the main experiment, allowing the scientists to distinguish the spatial and temporal effects, but until now the daughter had flown freely and quickly reached large distances from the mother. On K-9M-69 the 100-meter tethered payload retained a thin physical connection between the two, and allowed the electrical potential difference between them to be accurately measured.

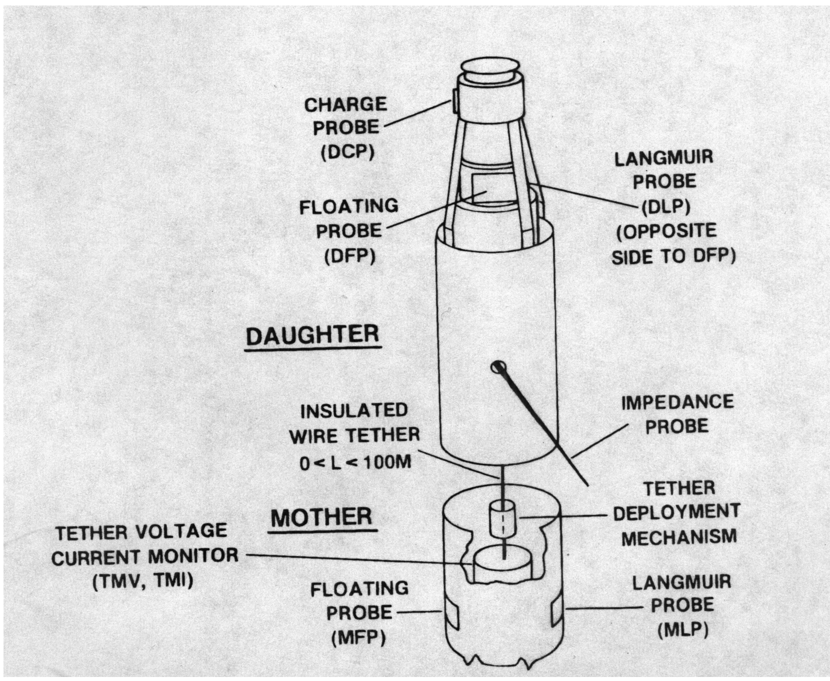


Figure 6: TPE-1 tether experiment on K-9M-69

A second Japanese tether mission flew on an S-520 rocket the next year but was less successful. The tether technique would later be used for a variety of purposes, and was the focus of two Space Shuttle missions in the 1990s as well as some highly successful NASA experiments on Delta rockets.

1.6.4 Astronomical studies

A group of researchers at Nagoya University led Japan's rocket-based astronomy program in the 1970s and 1980s, probing the sky in X-rays, the near infrared, and the submillimeter waveband, parts of the electromagnetic spectrum that the Earth's atmosphere shrouds from ground-based observers. The X-ray program supplemented one carried out with Britain's Leicester University using American rockets in the LEINAX (Leicester-Nagoya X-ray) program.

Satio Hayakawa of Nagoya flew an X-ray proportional counter detector on the K-9M-12 in 1965, only three years after Riccardo Giacconi's discovery of extrasolar X-ray sources [13].

Hayakawa led an investigation of time-variable soft X-ray sources [26] on K-9M-44, which carried a proportional counter detector payload with an area of 440 sq. cm. Flight K-9M-50 in 1975 carried a set of six X-ray proportional counters with a total area of 750 square cm, to map the diffuse soft X-ray emission from the Milky Way. The Nagoya experiment returned 400 seconds of data. [29].

Missions K-9M-58 and K-9M-64, flown in 1977-1978, carried an 8-cm infrared telescope to study star formation in the galactic plane. It extended previous balloon-based observations by reaching out to 4.5 microns wavelength, which is absorbed by the Earth's atmosphere [32],[33]. The research was carried out by Kunio Noguchi, Satio Hayakawa, Toshio Matsumoto and others.

Measurements of the ultraviolet spectrum of the Sun were attempted on the K-9M-23 flight and later continued on Kappa-10 missions.

A group at ISAS under M. Oda, together with S. Miyamoto of Osaka University flew a series of experiments in 1969-71 to measure X-rays from the binary star Sco X-1 [20],[22] on K-9M-27 and K-9M-31. Oda had spent time at MIT, where he invented the modulation collimator instrument, and in turn he brought American expertise in the field back to Japan. Some of this work was done as part of a collaboration with U. R. Rao of the Physical Research Lab in Ahmedabad, India.

1.6.5 Searching for the very first stars - a personal adventure

In 1982 and 1984, the Nagoya group under Toshio Matsumoto flew a small liquid-nitrogen-cooled infrared telescope on K-9M-77 to study background light from the universe at near-infrared wavelengths. If such light were detected, it might originate from distant stars and galaxies early in the history of the universe. The missions were successful, but the results were inconclusive [36],[37].

In 1985 and 1987, Prof. Matsumoto collaborated with Andrew Lange of the University of California at Berkeley on a project to measure a better-known faint radiation glow that bathes the universe - the three-degree-Kelvin cosmic microwave background, discovered in 1965 by Penzias and Wilson and recognized as crucial evidence for the Big Bang theory. The K-9M-78 and K-9M-80 rockets carried instruments that were able to measure this glow at shorter wavelengths of light than had ever been done before, the so-called 'submillimeter band', using a telescope cooled by liquid helium to less than 1.5 degrees above absolute zero. The measurements would be made at 481, 709 and 1160 microns wavelength. The first flight tested the radiometer but the cover failed to open so no measurements of the sky were obtained [38]. After improvements, the second flight of the experiment returned an astonishing result [?] - in addition to the famous three-degree-Kelvin 'black body' radiation, there was an additional and powerful extra glow at higher temperatures - in all, about 20 percent unexpected extra energy.

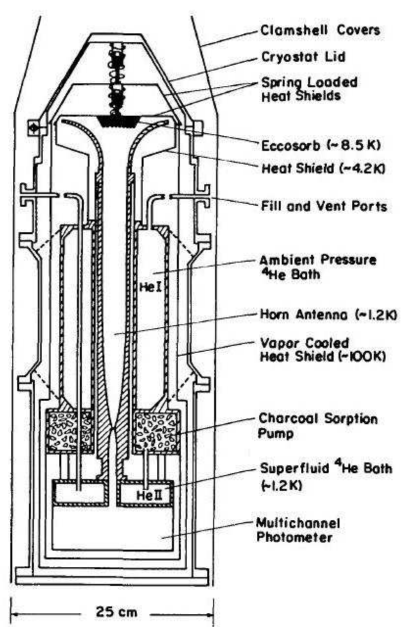


Figure 7: Submillimeter telescope on K-9M-80

This was particularly exciting for the present author, as my first published paper [40], with Cambridge cosmologist Bernard Carr and his Japanese collaborator H. Sato, had predicted the possibility of the near-infrared glow that the K-9M-75/77 missions had seen, and the more detailed analysis done as part of my thesis [41] calculated that much of the glow could show up in the submillimeter instead, anticipating the effect seen by K-9M-80. I was gratified to see that the Nagoya group cited my work in their papers. My colleagues Fred Adams, Katy Freese, Janna Levin and I sprung into action to interpret the K-9M results in terms of our models, and published a paper [**?**] explaining how the submillimeter light could arise from the glow of the first generation of stars, shortly after the Big Bang, seen dimly through a fog of dust made by the creation of the first heavy elements, possibly in those same stars, and shifted in wavelength due to the expansion of the universe. We were able to report that if the rocket results were correct, the famous 'dark matter' problem might be partly due to the black holes left over from these first stars. However, we were acutely aware of the extreme experimental difficulties of the ambitious Matsumoto-Lange experiment, and not over-astonished when shortly afterwards the spectacular data from NASA's Cosmic Background Explorer (COBE) satellite showed that the extra glow just wasn't there - winning a Nobel for John Mather in the process [43]. It turned out that the telescope on board K-9M had observed the glow from its own booster's rocket exhaust, confusing the sensitive instrument. But in the long run the mission had a good effect, stimulating us to think hard about the role of cosmic dust in the early universe, teaching us how to do better cosmological rocket experiments, and making the COBE results even more interesting, rather than just what we'd always expected to see.

1.6.6 K-9M-81: The final flight

The final Kappa-9M flew in January 1988 and returned to its scientific roots, studying the ionosphere. The Cooperative Resonance Cone Experiment (COREX) detector was developed by A. Piel of the Rühr-Universität Bochum in Germany in collaboration with K. Oyama of ISAS, A Morioka of Tohoku University and H. Thiemann of the Freiberg PTS institute, and was designed to masure the directional distribution of electron velocities in the ionosphere [44]. The flight was successful, reaching an apogee of 360 km, and confirmed the ability of the resonance cone instrument to measure electron temperatures, although the analysis suggested that the rocket's flight affected the local plasma environment, complicating interpretation of the data. [45].

1.7 Kappa-10

1.7.1 The standard Kappa-10

The Kappa-10 was a logical evolution of the Kappa-9M, with the thin second stage replaced by a shortened version of the K420H first stage, called the K420(1/3). The 10 was used for occasional missions for which the 9M was inadequate, especially for astronomical payloads, and was eventually retired in 1980. K-10-8 introduced a new lightweight fiberglass-plastic second stage, only 75 kg empty instead of 102 kg, and carried a 133 kg payload [47].

Mission K-10-3 used early photon-counting detectors flown by K. Yamashita of Nagoya to measure the ultraviolet flux from bright stars in the 1060-1480 Angstrom band [46].

Flight K-10-4 carried a 23-cm telescope with a lead-sulfide near-infrared detector developed by the Nagoya group to map the zodiacal light, caused by sunlight scattering of micron-size dust grains orbiting the Sun [48], [49]. It also flew a Langmuir probe to measure electron densities in the ionosphere [6].

Flights K-10-6 and K-10-9 carried an ultraviolet spectrometer to study the absolute brightness of the Sun [50],[51]. The experiment was carried out by Keizo Nishi of the Tokyo Astronomical Observatory (now the National Astronomical Observatory of Japan's Mitaka campus). K-10-9 also carried the X-ray experiment for further studies of Sco X-1 [22].

[I have been unable to find published papers describing the later Kappa-10 astronomy flights: K-10-11, 13 and 14].

The Kappa-10S flight				
Flight	Date (GMT)	Apo/km	Notes	Experimenters
K-10S-1	1965 Aug 28 0202	742	Ionosphere	Hirao (ISAS)
Standard Kappa-10 launches				
K-10-1	1965 Nov 8 0505	228	Ionosphere	
K-10-2	1966 Dec 10 1130	253	Atmos/Solar UV	Tanabe (TAO)
K-10-3	1967 Mar 7 1100	248	UV Astronomy	Tanabe (TAO), Yamas.(Nagoya)
K-10-4	1969 Jan 14 1000	229	Astronomy	Hayakawa (Nagoya)
K-10-5	1969 Sep 6 1135	247	Ionos, Astron.	Nakamura (Tokai)
K-10-7	1971 Aug 20 1210	274	Astronomy	
K-10-6	1971 Sep 1 0210	228	Solar UV	Nishi (TAO)
K-10-8	1972 Sep 12 1110	259	Astronomy	
K-10-9	1973 Feb 19 0022	236	Solar UV	Nishi (TAO)
K-10-10	1973 Sep 22 0920	242	Astronomy	Sasaki (Tokyo)
K-10-11	1975 Sep 24 0500	196	Astronomy	
K-10-12	1976 Jan 18 0520	350	Ionosphere	Chayashi (ISAS)
K-10-13	1977 Sep 14 1222	204	Astronomy	
K-10-14	1980 Aug 26 1140	219	Astronomy	
Technology launches				
K-10C-1	1969 Jan 12 0510	229	Atmos/Solar UV	Tohmatsu (Tokyo)
K-10C-2	1969 Sep 26	300?	Test flight	
K-10C-3	1970 Sep 13	300	Test flight	
PT-420-01	1969 Feb 13	100?	Test flight	

1.7.2 The high-apogee Kappa-10S

Although there was only one launch of the Kappa-10S, it is worth mentioning as it achieved the highest apogee by far of the Kappa series. The three-stage 10S was a significant step on the way to a Japanese orbital capability, as it tested the apogee motor technology to be used in Japan's first satellite launch vehicle, the Lambda-4S. The third stage spherical motor was a scaled-down version of the orbital vehicle's fourth stage. In addition to the motor, the rocket carried an electron temperature probe [52].

1.7.3 The Kappa-10C test vehicle

Kappa-10C, used in 1969-70, is a poorly-documented rocket that was used to develop the thrust vector control technology used in the later Mu satellite launch vehicles. The first 10C flight carried the ozone experiment used earlier on K-9M-16 and -21 [65] but later missions seem to have been strictly technology tests. The 10C was succeeded by the even more mysterious Lambda-4SC which continued devlopment of the technology in parallel with the orbital launches of the Mu-3C. Anyone with details of the Lambda-4SC flights is encouraged to contact the author.

1.8 After Kappa

In parallel with the Kappa flights, ISAS flew the small S-160 and S-300 rockets for technology experiments. In the 1970s this series was extended with the S-210JA used by the National Institute of Polar Research at their Syowa base in Antarctica. By the 1980s the S rocket family had grown to include the larger S-310 and S-520 rockets, which gradually supplanted Kappa for scientific suborbital and technological flights. Meanwhile, much scientific work had moved from sounding rockets to satellites, and those payloads were delivered to orbit by the direct technological descendants of Kappa - the Lambda 4S orbital rocket (1966-70) and the Mu-3/4 series of satellite launch vehicles (1970-1995). Independently, a parallel series of rockets developed by the Science and Technology Agency led to NASDA's TR-1 microgravity sounding rocket and, together with licensed American technology, laid the foundations for JAXA's N and H series of launch vehicles.

Kappa is largely forgotten now, but the small ISAS rockets played a key role in the development of Japanese orbital capability during the 1960s and Japan's space science expertise during the 1970s.

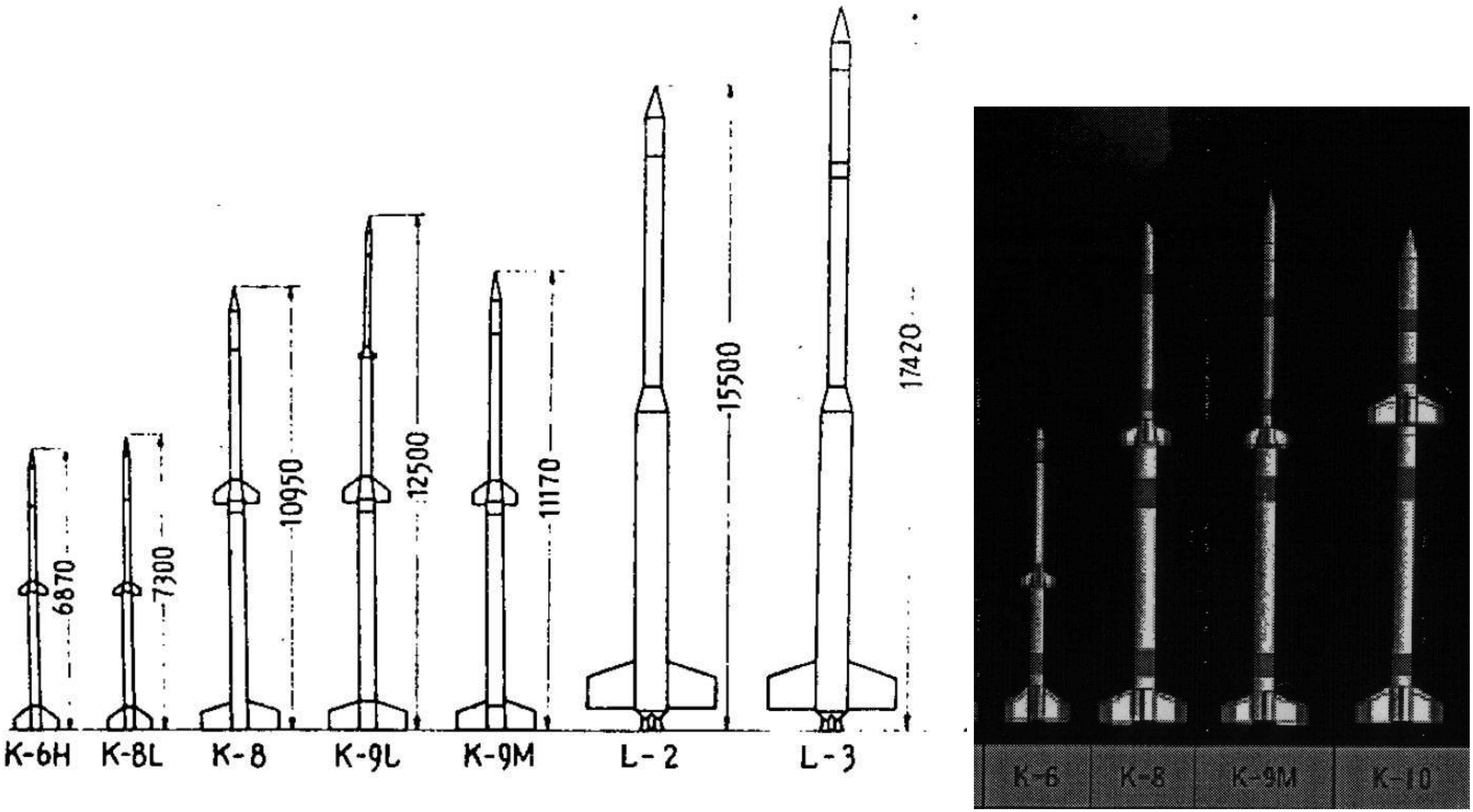


Figure 8: Kappa rocket family, including K-8L and K-9L (left, from TT-F-303) and K-10 (right, from a 1980s ISAS pamphlet). It is hard to find all the Kappa variants compared in a single figure.

1.9 Summary tables

Kappa variants for suborbital spaceflight

Vehicle	Kappa-6H	Sigma-4	Kappa-8	Kappa-8L	Kappa-9L	Kappa-9M	Kappa-10S	Kappa-10	Kappa-10C
In use	1960	1961	1960-70	1962-66	1961	1962-88	1965	1965-80	1969-70
Overall									
Length	6.9	5.9	10.9	7.3	12.5	11.1	10.0?	9.8	10.0?
Mass/t	0.3	0.2	1.5	0.3	1.6	1.5	1.8?	1.8	1.8?
Stage 1									
Motor name/kg	(K250-6H)	(K4-B)	K420	(K250-6H)	K420	K420H	K420H	K420H	K420H
Mass full/kg	300?	150?	1200?	300	1200?	1200?	1200?	1145	1200?
Mass empty/kg	50?	20?	200?	50?	200?	200?	300?	337	300?
Length/m	3.6	3.3	5.8	3.6	5.8	5.8	5.8	5.8	5.8
Diameter/m	0.25	0.33	0.42	0.25	0.42	0.42	0.42	0.42	0.42
Thrust/kN	34?	105.0	110.0	34?	110.0	110.0	110.0	110.0	110.0
Burn time/s	7.2	3.0	17.0	7.2	17.0	17.0	17.0	17.0	17.0
Stage 2									
Motor name	K150	(K130-4)	(K250-8)	K160	(K250-6)	K250	K420(1/3)	K420(1/3)	K420(1/3)
Mass full/kg	100?	40?	300?	100?	200?	300?	413?	413/386	413?
Mass empty/kg	10?	20?	50?	20?	40?	50?	102?	102/76	102?
Length/m	3.5	2.7	3.1	2.4	2.3	4.6	2.2	2.2	2.2
Diameter/m	0.15	0.13	0.25	0.16	0.25	0.25	0.42	0.42	0.42
Thrust/kN	19.0	10.0	34	?	34	43	45	45	45
Burn time/s	15.8	3.0	9.7	5.3	9.3	7.6	?	?	?
Stage 3									
Motor name					K150		K10S		
Mass full/kg					100?		100?		
Mass empty/kg					10?		10?		
Length/m					3.5		0.5?		
Diameter/m					0.15		0.30		
Thrust/kN					19.0		?		
Burn time/s					15.8		?		
Payload									
Typical Mass/kg			60	25	25	60		130?	
Typical Apogee/km	70	105	200	150	350	350	742	250	300

2 The Lambda rocket series

Japan's early work in space with 420-mm Kappa sounding rockets was a stepping stone to a more ambitious program of orbital launches. By the early 1960s ISAS was already planning the Mu launch vehicle, with a diameter of 1.4 metres, which would be able to send a useful scientific satellite into space. Static testing for the 0.74-meter Lambda solid motor was underway by 1961 [54]. An ISAS team under Prof. T. Nomura [53] decided to accelerate the race to orbit with an intermediate technology demonstration, the Lambda-4S. This 735-mm diameter solid rocket would have the capability to orbit a minimal test payload.

As part of the development program, a series of two and three stage versions of Lambda were flown, and became some of the most powerful suborbital scientific sounding rockets ever used. The eventual success of the orbital Lambda-4S came after a series of failures, as ISAS became neither the first nor the last space agency to discover that satellite launches are significantly harder to pull off than suborbital flights.

2.1 Lambda-2 and Lambda-3

Static tests of the 410-kN-thrust L735 motor proved ISAS's ability to build the big first stage. In all Lambda flights, two SB-310 strapon boosters were used together with this main stage. A version of the Kappa-8 420mm stage was used as the second stage, and in the Lambda-3 version another, truncated version of the 420mm stage made up the third stage.

The first Lambda-2 flight in August 1963 failed, but the second flight reached an apogee of 410 km and returned data on the ionosphere [56].

Lambda-3 had three flights, all successful and reaching of order 1000 km apogees to return scientific data on the ionosphere and the universe. L-3-1 was flown during the International Year of the Quiet Sun as part of Japan's contribution to that international research program [57]. On this test flight the nose cone remained attached and sensors protruded through the side wall of the fairing. The L-3-2 mission detected plasma waves in the ionosphere. The L-3-3 flight [58] was Japan's entry into X-ray astronomy, a field in which it would eventually rise to world prominence. The rocket carried a sodium iodide scintillator for measuring 'hard' X-rays with energies in the 5 to 20 keV range. The investigators measured the spectrum of the X-ray background; they also tried to detect the Crab Nebula but could only set an upper limit to its flux.

Lambda-2 launches				
Flight	Date (GMT)	Apo/km	Notes	Experimenters
L-2-1	1963 Aug 24 0200	51	Ionosphere, failed	
L-2-2	1963 Dec 11 0500	410	Ionosphere	Kimura (Tokyo)
Lambda-3 launches				
L-3-1	1964 Jul 11 0202	857	Ionosphere	Aoyama (Tokai)
L-3-2	1965 Jan 31 0501	1040	Ionosphere	Ota,Oshio (Tokai)
L-3-3	1965 Mar 18 1007	1085	Astronomy	Hayakawa (Nagoya)

2.2 Lambda-3H

A 1/3-length version of the first stage, the L735(1/3), was pressed into service as a second stage for the next upgrade, called Lambda-3H. This proved the lower stages of the orbital vehicle and was later used as a sounding rocket. Unusually, the Lambda 3 and 3H rockets also carried experiments attached to the second stage, which probed a lower altitude range. The third stage payload was around 95-100 kg, and the second stage payload around 130-170 kg.

Most of the L-3H flights were successful, although L-3H-1's second stage failed to spin up correctly, and L-3H-4 is recorded as a failure (whether of the rocket or payload is not clear).

The first mission extended the work of L-3-3 and successfully measured the X-ray flux from the Crab supernova remnant [59] using counters mounted on the second stage. The L-3H-3 flight's second stage payload [67] continued the X-ray work, studying the spectrum of the background and the time variability of Sco X-1. L-3H-5, observing in the 0.2-10 keV range with proportional counters on the second stage, discovered a new soft X-ray source [61], [62]. The L-3H-8 second stage payload featured sodium iodide scintillators to extend the observations to higher energy X-rays, up to 10-40 keV [60].

The second flight carried a swept-frequency impedance probe for ionospheric measurements [64] and ozone photometers [65]. L-3H-6 in 1970 continued the ionospheric work [55], deploying whip antennas 1.6m long. L-3H-7 studied trapped electrons as a function of altitude [63]. The final mission in 1977 carried a wide array of ionospheric experiments with particle and electron detectors, airglow photometers, and plasma wave studies.

Figure 9: L-3H-1

Lambda-3H launches

Flight	Date (GMT)	St 2 Apo	St 3 Apo/km	Notes	Experimenters
L-3H-1	1966 Mar 5 0450	355	1829	Astronomy	Hayakawa (Nagoya)
L-3H-2	1966 Jul 23 0635	340	1800	Ionos/Atmos	Fugono (RRL), Oya (Kyoto), Higash
L-3H-3	1967 Feb 6 0210	427	2150	Astronomy, Ionos.	Matsuoka (ISAS), Hayakawa (Nagoya
L-3H-4	1969 Jan 16		1800?	Ionosphere (failure)	
L-3H-6	1970 Jan 21 0210		1848	Ionosphere	Obayashi (ISAS)
L-3H-5	1970 Sep 19 1130	336	2017	Astronomy	Hayakawa (Nagoya)
L-3H-7	1971 Sep 3 1200		1718	Astronomy/Ionos	ISAS, Hayakawa (Nagoya)
L-3H-8	1974 Jan 22 1100	330	1571	Astronomy/Ionos	Hayakawa (Nagoya)
L-3H-9	1977 Aug 16 1115	302	1294	Atmos/Ionos	various

2.3 Lambda-4S orbital attempts

The Lambda-4S orbital vehicle added a spherical apogee motor to the existing Lambda-3H. Fired in a lower elevation trajectory, the third stage reached a 400 km apogee, at which point the 4th stage fired to place the satellite in orbit. At least, that was the theory [66]. Of five satellite attempts, only the final one succeeded. The 9 kg payload attached to the 15 kg empty fourth stage of Lambda-4S-5 was named Ohsumi after a local district. Its Feb 1970 launch beat the Chinese by two months to make Japan the first East Asian orbital power. Ohsumi was a 0.45m long 0.30m diameter truncated cone containing an accelerometer, a thermometer and a telemetry beacon, attached to the 0.48m diameter rocket motor for an overall size of 1.0 meters long and a total in-orbit mass of 24 kg.

The launch event sequence for the successful L-4S-5 mission is given below, with the slightly different times for the earlier unsuccessful flights in parentheses.

The Lambda-4S launch profile (L-4S-5)

Time (min:sec)	Event	Altitude km	Inertial Velocity km/s
0:07	SB-310 booster burnout		
0:08	SB-310 separation		
0:29	L735 burnout		
0:30	L735 separation	17	
0:37	L735(1/3) ignition		
1:15 (1:09)	L735(1/3) burnout, coast	58	2.6
1:38 (1:48)	Nose fairing separation	87	
1:40 (1:50)	L735(1/3) separation		
1:43 (1:52)	L500 ignition	93	
2:10 (2:14)	L500 burnout, coast	141	4.6
2:30 (2:17)	L500 separation		
	Despin		
7:57 (7:15)	L480S ignition	520?	3.81
8:29 (7:47)	L480S burnout	525	8.13

2.3.1 L-4S-1: the first try

After two successful Lambda-3H launches, L-4S-1 carried the L480S kick motor for the first time. But two minutes after launch one of the four explosive bolts joining the second and third stages failed to fire, sending the third stage off course a few hundred kilometers above the Sea of Japan. Although the fourth stage successfully ignited for 15 seconds, it was unable to save L-4S-1 from its downward plunge. Nevertheless this first flight of the L-4S rocket did allow many of its systems and design features to be verified.

Figure 10: L-4S-1

2.3.2 L-4S-2: almost there

On Japan's second launch attempt, everything went perfectly until third stage separation- then things fell apart. The rocket, spinning rapidly for stability, needed to reduce its rotation rate for fourth stage ignition but the despin motor worked only partly and broke the kick motor igniter. Completing a suborbital flight, the fourth stage followed the third back down to the ocean from its circa 500 km apogee.

Figure 11: L-4S-2

2.3.3 L-4S-3: third stage failure

L-4S-3 was laucnhed on 1967 Apr 13 and probably reached about 300 km in altitude. One minute and 50 seconds after launch the second stage separated on schedule, but two seconds later the planned L500 third stage motor ignition did not occur, and the vehicle fell back to Earth. Following this failure, Hideo Itokawa resigned as head of the Japanese space program. It would be over two years before the ISAS group made another orbital attempt.

Figure 12: L-4S-3

2.3.4 L-4T-1: a near miss

Following earlier failures, on 1969 Sep 3 ISAS tried a test flight with a lighter fourth stage carrying less propellant - only a 60 percent load. According to the JAXA web site, residual thrust from the third stage caused it to collide with the fourth stage after separation and disturbed the trajectory, but even so 1.82 km/s was added to the velocity, sending the payload to a roughly -2500 x 500 km trajectory with impact in the Pacific. It was thought that if a full propellant load had been carried, L-4T-1 would have made orbit.

Figure 13: L-4T-1

2.3.5 L-4S-4: another stage 3/4 collision

Only 19 days after the L-4T-1 flight, ISAS tried again with a fully loaded Lambda-4S. Once again the rocket's first three stages burned correctly and put the fourth stage on course to a 500-km apogee, but again the third stage continued thrusting slightly after separation, and 60 seconds later it hit the fourth stage and knocked it out of alignment. The fourth stage continued its coast to apogee but then ignition came with the rocket pointing in the wrong direction and the payload fell in the ocean.

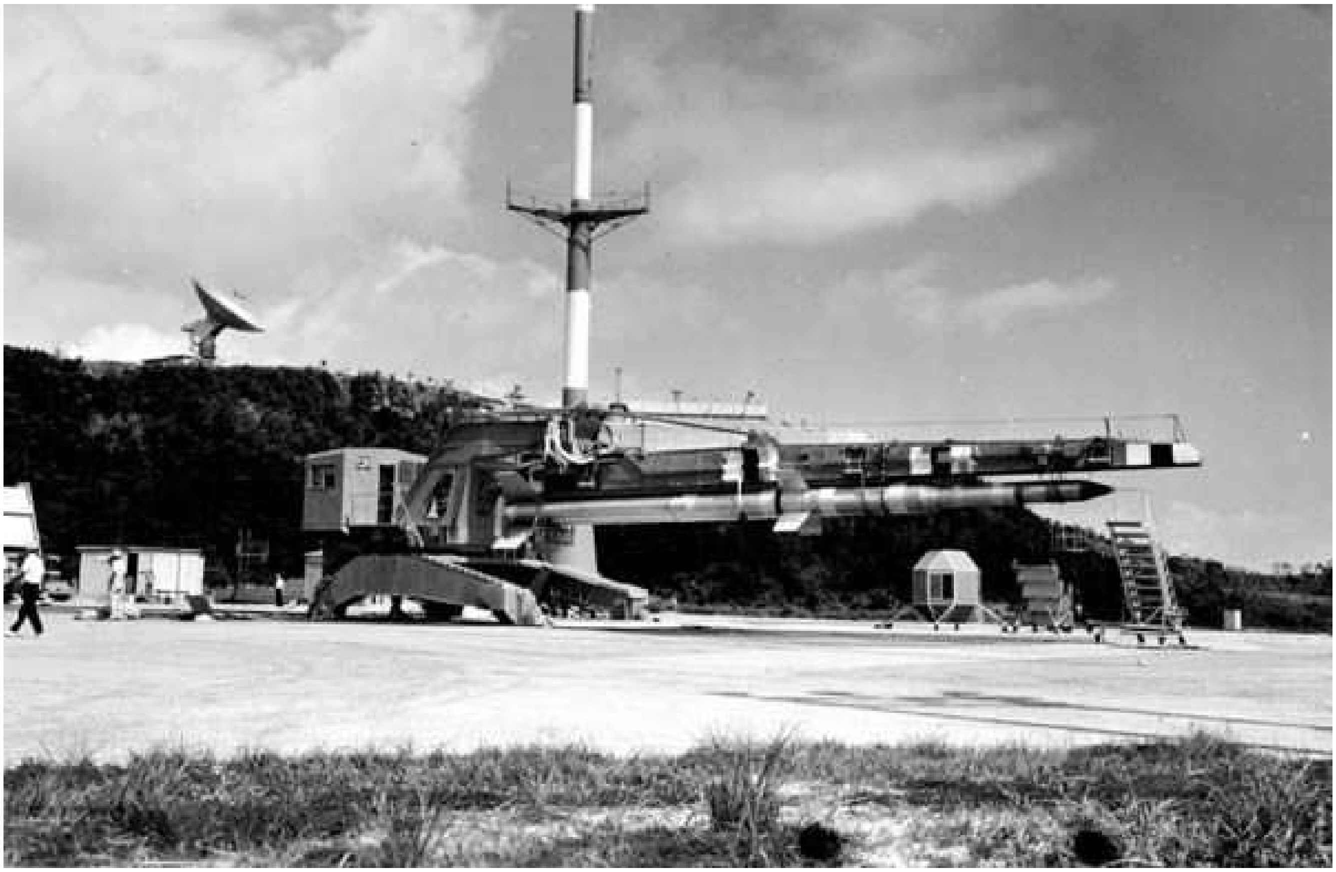


Figure 14: L-4S-4

2.3.6 L-4S-5: success at last

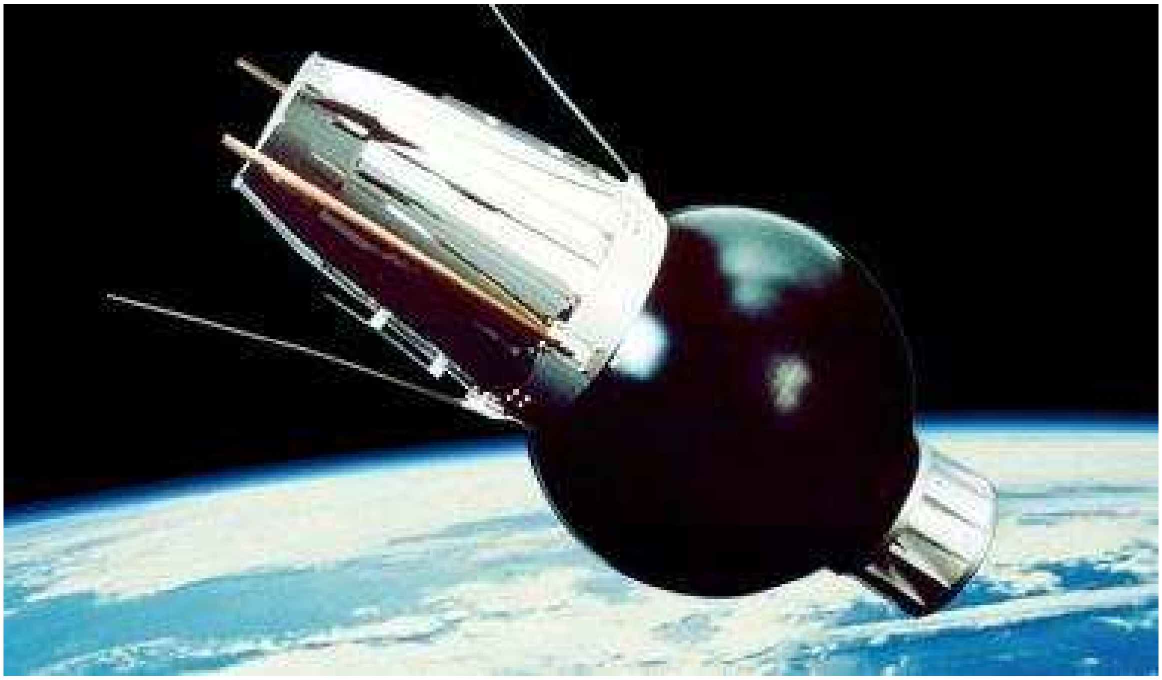


Figure 15: L-4S-5 Ohsumi satellite

The first Japanese satellite reached orbit at 0433 UTC on 1970 Feb 11. After third stage separation at 0427 UTC, Ohsumi coasted to an altitude of 525 km on a suborbital trajectory (its nominal perigee at this point was -5400 km, well inside the Earth). The 32-second motor burn accelerated the satellite to an orbit which was 340 km at perigee, 5138 km at apogee, in a plane inclined 31.1 degrees to the Earth's equator. The battery-powered transmitter sent back signals for 16 hours, after which the defunct satellite continued to orbit the Earth silently. At each perigee, the thin tendrils of the Earth's outer atmosphere slowed the satellite slightly, reducing its apogee, and by one year after launch it was in a 335 x 5030 km orbit - a loss of 100 km in apogee height but almost no change in perigee. It was not until 2002 that the perigee dropped significantly - an orbit of 297 x 1178 km by Apr 2002 - and finally in July 2003 Ohsumi was in a low circular orbit and dropping fast, to 186 x 225 km on Jul 31, 157 x 173 km on its last tracked orbit a day later. Its fiery reentry on 2003 Aug 1 was little noticed, as Japanese space watchers focussed on the successful ion drive journey of Hayabusa, the preparations for the sixth launch of the massive H-IIA rocket, and the upcoming merger of the ISAS and NASDA space agencies to form a unified Japanese space agency, JAXA.

Figure 16: L-4S-5

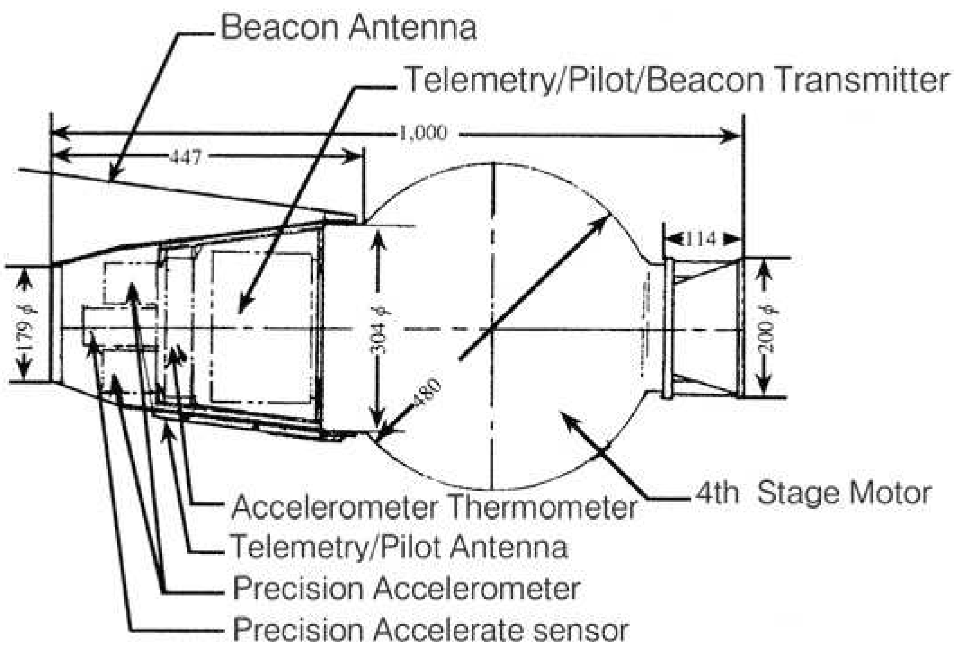


Figure 17: L-4S-5 Ohsumi satellite

2.4 The mysterious Lambda-4SC

Following the triumph of Ohsumi, four more suborbital Lambda vehicles were flown between 1971 and 1976 in a test of secondary-injection thrust vector control (SITVC) for the Mu-3C rocket, which used this capability on its second stage. Radio guidance technology was also tested by the missions [69]. The first flight was only a partial success, while the others appear to have been counted as successful.

Very little has been revealed in English-language publications on these mysterious Lambda-4SC flights, which presumably used up remaining flight articles from the orbital program. The '4' in the designation Lambda-4SC implies that all four stages were used, but the mission profile is a mystery. Did they reach high apogees of over 2000 km like the Lambda-3H flights? Were they used for reentry experiments with the upper stages firing downward? Were some of the upper stages dummies, and the flights only to very low altitudes of 100 km or even less? It is to be hoped that Japanese historical researchers can find the answer in the ISAS archives.

Lambda-4S launches				
Flight	Date (GMT)	Apo/km	Notes	Experimenters
L-4S-1	1966 Sep 26 0258	400		
L-4S-2	1966 Dec 20 0220	400		
L-4S-3	1967 Apr 13 0240	200	[68]	
L-4T-1	1969 Sep 3	400	Test flight	
L-4S-4	1969 Sep 22 0210	400		
L-4S-5	1970 Feb 11 0425		Ohsumi	
Lambda-4SC launches				
L-4SC-1	1971 Aug 20	?	Test flight	
L-4SC-2	1973 Jan 28	?	Test flight	
L-4SC-3	1974 Aug 20	?	Test flight	
L-4SC-4	1976 Aug 30	?	Test flight	

2.5 Summary tables

Lambda variants				
Vehicle	Lambda-2	Lambda-3	Lambda-3H	Lambda-4S, 4T, 4SC
In use	1963	1964-65	1966-1977	1966-1976
Overall				
Length	15.5	17.4	16.5	16.5
Mass/t	6.3	7.0	8.2	9.4
Strap-on Boosters				
Motor name/kg	SB-310	SB-310	SB-310	SB-310
Mass full/kg	502	502	502	502
Mass empty/kg	190	190	190	190
Length/m	5.8	5.8	5.8	5.8
Diameter/m	0.31	0.31	0.31	0.31
Thrust/kN	95.0	95.0	95.0	95.0
Isp/s	220.0	220.0	220.0	220.0
Burn time/s	7.4	7.4	7.4	7.4
Stage 1				
Motor name/kg	L735	L735	L735	L735
Mass full/kg	5000?	4977	4977	4977
Mass empty/kg	1000?	1090	1090	1090
Length/m	8.4	8.4	8.4	8.4
Diameter/m	0.74	0.74	0.74	0.74
Thrust/kN	410.0	410.0	410.0	410.0
Burn time/s	28.8	28.8	28.8	28.8
Stage 2 (mass includes fairing)				
Motor name	K420?	K420?	L735(1/3)	L735(1/3)
Mass full/kg	1430	1800	2474.5	2474.5
Mass empty/kg	300?	300?	619	619
Length/m	8.7	11.0	4.1	4.1
Diameter/m	0.42	0.42	0.74	0.74 (0.77)
Thrust/kN	110.0	110.0	118	118
Isp			242.9	242.9
Burn time/s	17	17	38.4	38.4
Stage 3				
Motor name		K420?	L500	L500
Mass full/kg		520	832	832
Mass empty/kg		?	285	285
Length/m		4.8	3.0	3.0
Diameter/m		0.42	0.50	0.50 (0.55?)
Thrust/kN		110?	69.0	69.0
Isp			249.3	249.3
Burn time/s		?	27.0	27.0
Stage 4				
Motor name				L480S
Mass full/kg				102
Mass empty/kg				15.1
Length/m				0.5
Diameter/m				0.48
Thrust/kN				7.8
Isp				254.0
Burn time/s				31.5
Payload				
Typical Mass/kg	250	100		8.4
Typical Apogee/km	410	1100	2000	400

Note: the figures in this table differ from those in http://www.isas.jaxa.jp/e/enterp/rockets/vehicles/l-4s/index.shtml because the JAXA table gives cumulative masses - e.g. the mass given for stage 2 includes the stage 3 and stage 4 and payload masses too. Here we give masses for the individual components.

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References

[1] ISAS, Japanese Space History, http://www.isas.jaxa.jp/e/japanistory/index.shtml (accessed 2010 Nov 16).

[2] Matogawa, Y., The Pencil Rocket Story, http://www.jaxa.jp/article/interview/sp1/index.html (accessed 2010 Nov 16).

[3] http://www.ihi.co.jp/ia/en/company/about.html, accessed 2010 Nov 17.

[4] Hirao, O. and Okamoto, S., 1962, 3rd Sympo. on International Space Technology and Science, 262.

[5] Itogawa et al, 1963, Survey of Japanese Space Program, NASA Technical Translation TT-F-303.

[6] Space Research 10, 707.

[7] Nakamura, J., 13th Symposium on International Space Technology and Science, p 1505.

[8] Karjoto, 1968, Space Research 8, 1080.

[9] Kusumanto et al 1968, Space Research 8, 346.

[10] New York Times, Aug 4, 1966.

[11] Huruhata M. and Nakamura T., 1968, Space Research 8, 699.

[12] Nagata T, Tohmatsu T and Ogawa T, 1965, Plan. Space Sci. 13, 1273.

[13] Hayakawa S, Matsuoka M and Sugimoto D, 1966, Space Science Reviews 5, 109.

[14] Oya, H. and Oyabashi, T., 1967, Space Research 7, 480.

[15] Ohsho, 1968, Space Research 8, 639.

[16] Kimura I., Nishina R and Maeda K., 1968, Space Research 8, 305.

[17] Hirao K. and Oya H., 1969, Space Research 9, 262.

[18] Oya, H. and Obayashi, T. 1968, Space Research 8, 332.

[19] Nagata T, Tohmatsu T and Ogawa T., 1971, Space Research 11, 829.

[20] Kitamura T. et al 1971, Space Research 11, 1367.

[21] Hayakawa, M., 1974, Plan.Space Sci. 22, 638.

[22] Miyamoto S et al 1978, Astron. Astrophys. 65, 329.

[23] Tohmatsu T, Ogawa T and Watanabe T, 1974, Space Research XIV, 176.

[24] Mukai T. and Hirao K., 1973, J. Geophys. Research 78, 8395.

[25] Miyatake S., Matsumoto H. and Kimura, I., 1974, Space Research XIV, 369.

[26] Hayakawa, S et al 1976, Astrophys. Space Sci. 42, 169.

[27] Amemiya H, Oyama K and Hirao K, 1985, Plan.Space Sci. 33, 875.

[28] Kubo H, Mukai T and Hirao K, 1976, Space Research XVI, 497.

[29] Iwanami H, et al 1979, Ap. Space Sci. 61, 217.

[30] Mukai T, Kondo Y and Hirao K, 1979, Plan. Space Sci. 27, 31.

[31] Oyama, K., and Hirao K., 1979, Plan. Space Sci. 27, 183.

[32] Hayakawa, S. et al 1978, Pub Astron. Soc. Japan 30, 369.

[33] Noguchi K, Hayakawa S and Matsumoto T, 1981, Pub. Astron. Soc. Japan 33, 583.

[34] Minami S, Tsutsumi S and Takeya Y, 1982, Rev. Sci Instrum. 53, 1709.

[35] Williamson, P.R. et al, in Grandal, B., ed., Artifical particle beams in space plasma studies, NATO Advanced Study Institute Series B79, 1982, p. 645.

[36] Matsumoto T, et al 1982, Adv. Space Res. 3, 469.

[37] Matsumoto T, et al 1988, Astrophysical Journal, 332, 575.

[38] Lange, A et al. 1987, Applied Optics 26, 401.

[39] Matsumoto T, et al 1988, Astrophysical Journal, 329, 567.

[40] Carr B, McDowell J, and Sato H, 1983, Nature 306, 666

[41] McDowell, J.C., 1986, Monthly Notices of the Royal Astronomical Scoeity, 223, 763.

[42] Adams, F, McDowell J, Freese K and Levin J, 1989, Astrophysical Journal 344, 24.

[43] Mather, J.C. et al, 1990, Astrophysical Journal Letters, 354, 37.

[44] Piel, A. et al 1988, Adv. Space Res. 8, 143.

[45] Rohde, V et al, 1993, J. Geophys. Research 98, A11, 19163.

[46] Yamashita, K., 1968, Astrophys. Space Sci 2, 4.

[47] Uemura et al, Intl. Symposium on Space Technology and Science, 10, 268.

[48] Nishimura, T., 1973, Pub. Astron. Soc. Japan 25, 375.

[49] Hayakawa S, Matsumoto T and Nishimura T, 1970, Space Research 10, 248.

[50] Nishi 1973, Solar Physics 33, 23.

[51] Nishi 1975, Solar Physics 42, 37.

[52] Hirao K and Miyazaki S, 1966, Intl. Symposium on Space Technology and Science 6, 703.

[53] Harvey, B: The Japanese and Indian Space Programmes, Two Roads Into Space. (Springer-Praxis, 2000).

[54] Missiles and Rockets, Nov 13 1961, p 38.

[55] Obayashi, T. and Ejiri, M., 1971, Space Research 11, 1067.

[56] Maeda K, Oyabashi T and Kimura I, 1965, Space Research 5, 1071.

[57] Hirao, K, et al 1966, J. Radio Research Labs., 13, No. 66, p 75.

[58] Hayakawa S., Matsuoka M. and Yamashita K, 1968, Space Research 8, 68.

[59] Hayakawa S. et al, 1967, Space Research 7, 1306.

[60] Fukuda Y. et al, 1975, Astrophys. Space Sci. 32, L1.

[61] Hayakawa, S. et al, 1971, Nature Physical Science 231, 76,

[62] Hayakawa, S. et al, 1972, Astrophys. Space Sci. 17, 30.

[63] Hayakawa, S. et al 1973, J. Geophys. Research 78, 2341.

[64] Oya H., and Obayashi T., 1968, Space Research 8, 339.

[65] Nagata T., Tohmatsu T. and Tsuruta H., 1968, Space Research 8, 639.

[66] Nomura, T., International Symposium on Space Technology and Science 9, 563.

[67] Matsuoka, M., et al 1969, Astropyys. Space Sci. 4, 44.

[68] Asahi Shimbun, Apr 13, 1967, page 3 (1).

[69] Tamaki, F., International Symposium on Space Technology and Science 10, 13.