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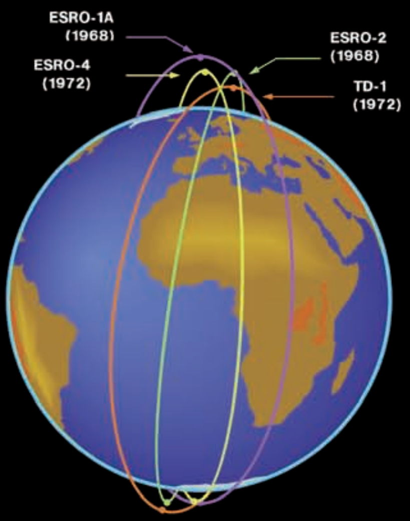
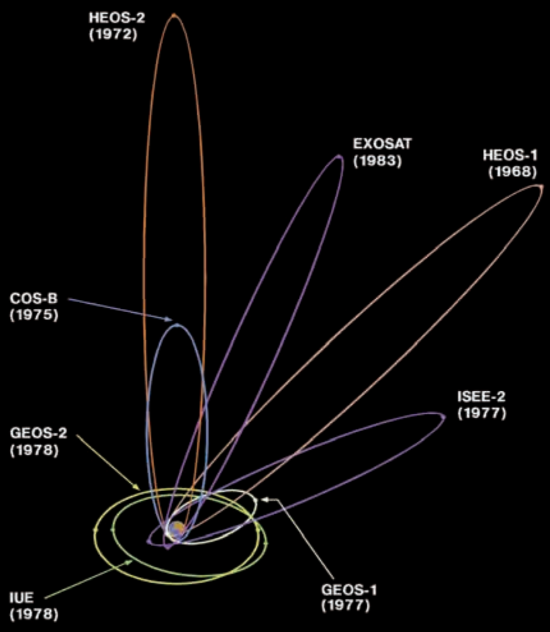
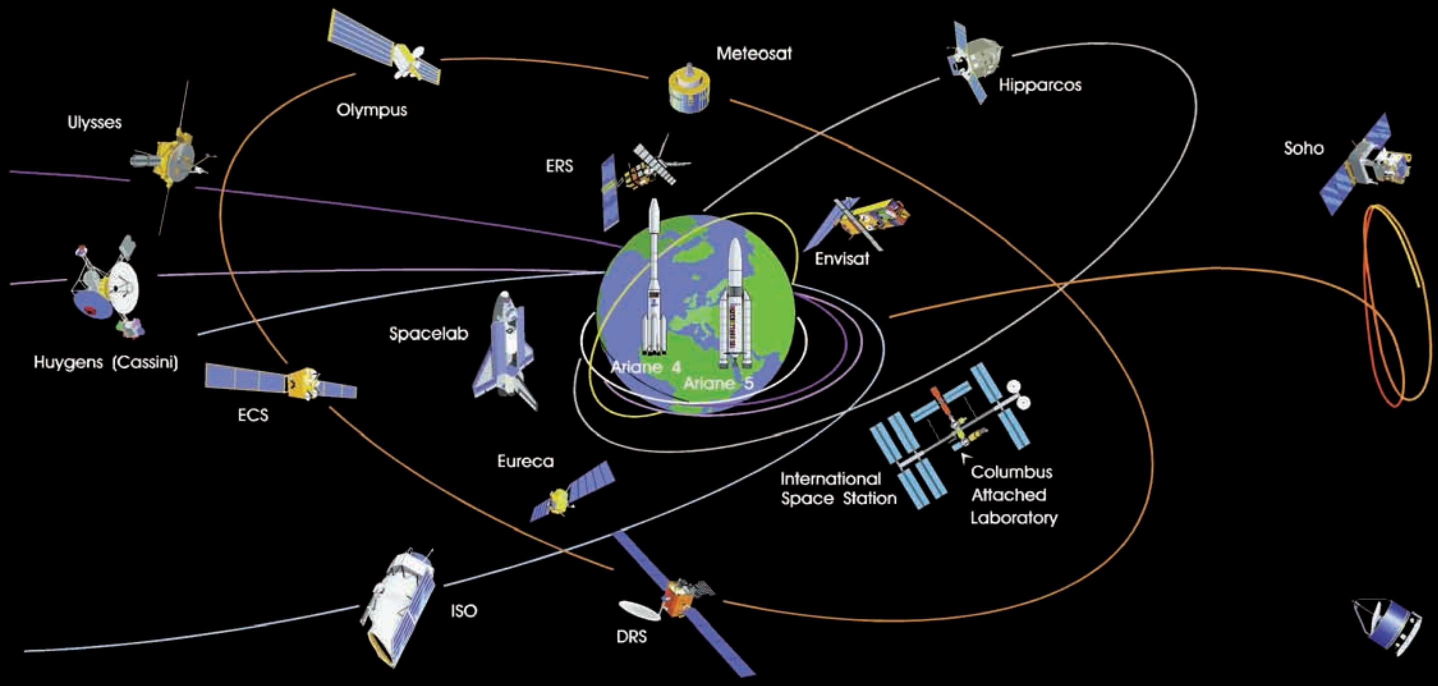
by
Günther Seibert







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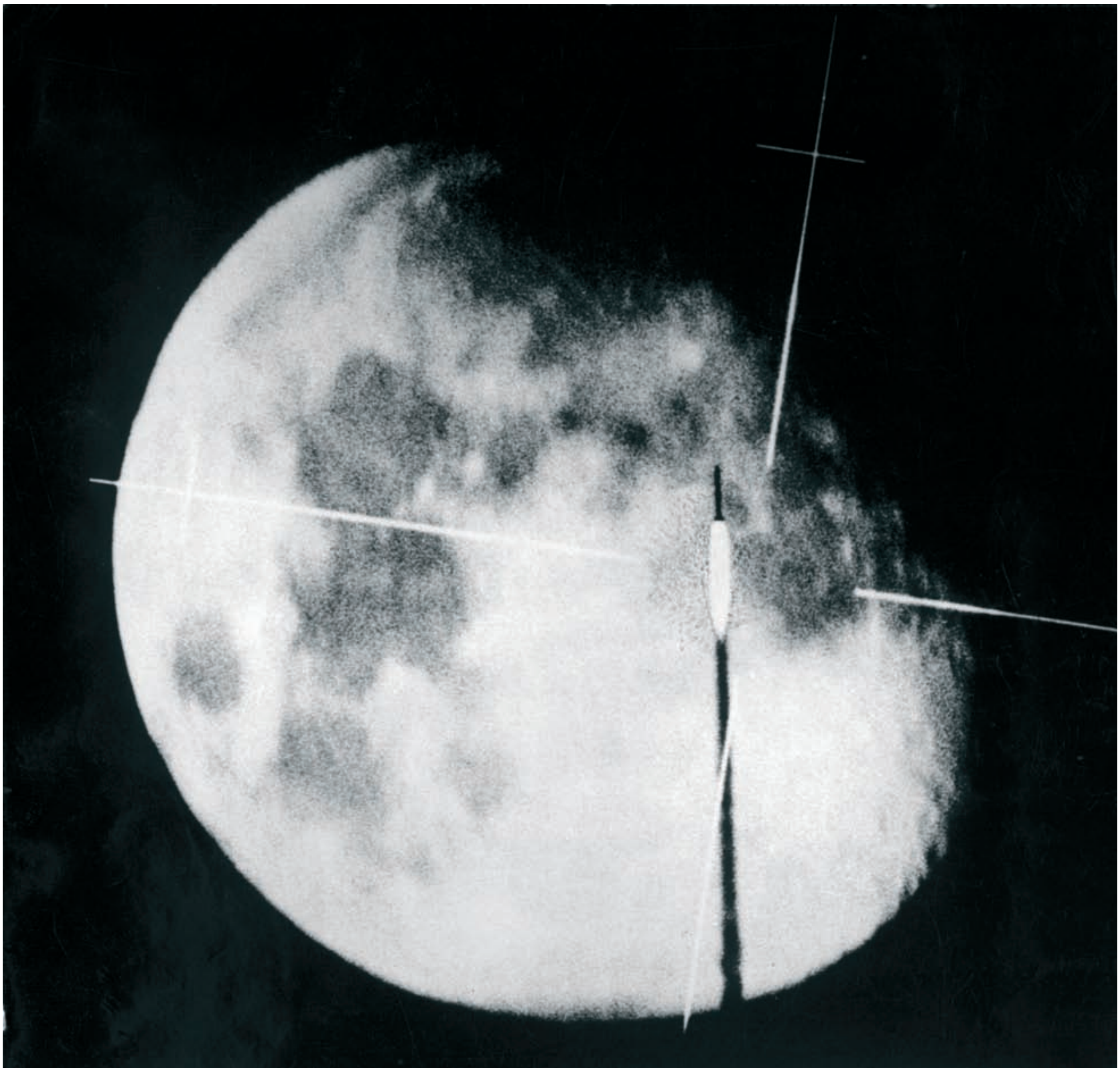
Rationale for Recapitulating the History of European Sounding-Rocket Activities

In January 2006, Mr Marius Le Fèvre, former Director of ESA's Space Research and Technology Centre (ESTEC), wrote to ESA's Director General to inform him that the French space agency CNES, the Institut Français de l'Histoire de l'Espace, and the Association Amicale des Anciens du CNES had decided to hold a sounding-rocket Workshop (Atélier fusées sondes) to compile information on sounding rockets, and thus demonstrate the historically unique role they have played in the setting-up of French space research activities and the creation of a space industry. The letter further explained that it was intended to produce a document on this subject and to arrange a related Colloquium in Toulouse in the first half of 2007.

Mr Le Fèvre, as Workshop Chairman, asked in his letter that certain former staff of the original European Space Research Organisation (ESRO) and the European Space Agency (ESA) who had been involved in or had witnessed ESRO's early sounding-rocket programme should be involved in steering the working group's deliberations and provide inputs, documentation, images, etc.

Dr. Daniel Sacotte, ESA's Director of Human Spaceflight, Microgravity and Exploration (D/HME) and Dr. Martin Zell, Head of that Directorate's Research Operations Department, proposed that Dr. Günther Seibert, former Head of its Microgravity and ISS Utilisation Department, should take over this task. This proposal was made because Dr. Seibert had worked from 1969 to 1973 as Satellite Manager of the ESRO-IV project. That polar-orbiting atmospheric research satellite included a number of experiments that were also performed in parallel as sounding-rocket experiments. This required scientific, operational and schedule cooperation between ESRO's Sounding-Rocket Division and the ESRO-IV project. From mid-1973 onwards, Günther Seibert was involved in the preparation and implementation of Spacelab utilisation. In performing this task, he started to prepare for and to set up what would become ESA's Microgravity Research Programme, 25% of which (in budget terms) included - and today still includes - sounding-rocket activities, such as Texus, Maser and Maxus flights launched from the Esrange launch centre near Kiruna in the north of Sweden.

In the 1980s and 1990s, the microgravity sounding-rocket flights of ESA, the German Aerospace Centre (DLR) and the Swedish Space Corporation (SSC) represented the most important activity at Esrange.



A Skylark sounding rocket passing in front of the Moon after launch from the Salto di Quirra range in Sardinia

1. Scope

This report first describes the history of rocket development before and during the Second World War and their use as sounding rockets in Europe, the USA and the USSR, and then outlines the technical, operational and scientific features of sounding rockets. The major European national sounding-rocket activities and those of ESRO from the early 1960s to the early 1970s are then described, a period when sounding rockets represented an important part of space research. Over that time span, several hundred sounding rockets (up to 500 per year around 1970) were launched worldwide each year.

This report does not present detailed scientific results obtained with the help of those sounding-rocket flights, or detailed technical descriptions of the payloads or the sounding rockets themselves. Instead it gives a historical overview of the evolution of the use, benefits and importance of sounding rockets, which provided access to space for scientific experiments for the first time. Sounding rockets also gave rise to the first worldwide cooperation between scientists and space-research institutes.

During the 1960s to 1990s, sounding rockets provided inexpensive management schooling for space scientists active in several space research disciplines around the World. Those managers later became the key space scientists, when more sophisticated space research used complex satellites to study the Universe. Sounding-rocket activities had a similarly beneficial effect on the creation of a space industry.

When ESRO decided to concentrate from 1972 onwards on scientific and applications satellites, and on the development of the Ariane launcher and the Spacelab laboratory, and to discontinue its own sounding-rocket programme, a second phase of European national sounding-rocket activities – devoted to space science – proceeded. However, the first European national-level sounding-rocket programme, that of France, was terminated in the middle of the 1970s, whereas most of the other ESRO/ESA Member States continued their national flight activities. Sounding-rocket flights are still ongoing today, but since the 1990s the content and scale of global activity in the space sciences has begun to shrink.

In the second half of the 1970s, a new sounding-rocket user discipline emerged, namely the use of the free-flying phase of sounding-rocket flights for research in the materials and life sciences under microgravity conditions. This new mode of applications was used for short-duration microgravity experiments in fields such as fluid physics, materials sciences and biology, as well as to perform Spacelab and International Space Station (ISS) precursor experiments.

Launch of a V2 rocket from Blizna in Poland in 1944

2. Historical Background

In many areas of daily life, such as:

- global communications and information transfer
- weather, climate and environmental observation and forecasting
- remote-sensing/observation of the Universe and the surface of the Earth
- navigation of air, route and ship traffic
- human spaceflight,

the utilisation of space systems has become routine.

Just half a century ago, humankind began to expand its horizons by conducting missions to explore the near-Earth-orbit environment of space. This started with sounding rockets and small scientific satellites designed to investigate *in-situ* the Earth's atmosphere and ionosphere, which were at that time totally unexplored regions. In addition, the first observations of the Sun and stars using instruments carried by sounding rockets operating at altitudes above the atmosphere were carried out.

The launch of the first satellite, Sputnik, on 4 October 1957 by the USSR prompted the start of a space race between the two superpowers, the USA and the USSR, which culminated with the US space programme's landing of the first human being on the Moon on 21 July 1969.

Today, space research/applications and rocket/spaceflight technology, along with nuclear-energy exploitation and the mastering of advanced data processing/handling, belong to those leading-edge areas of technology that have opened up new technical, economic and sociological opportunities, and without which a modern, industrialised country can no longer advance. Spaceflight, rocket/space technology and associated research have now established and proved themselves to be a valid means of improving our quality of life; they are being relied upon to contribute to the preservation of an inhabitable Earth and the long-term survival of the human race. This extraordinary accomplishment of the human mind over the last 50-60 years has had a more profound influence on our way of life and work patterns than the public at large realises.

Rockets remain today a fundamental element of every spaceflight programme, because they make the transportation of instruments and human exploration in terrestrial orbit above the atmosphere and also further away from our home planet possible.

The use of rockets as sounding rockets for the space sciences was at its most intense around 1957/58, with activity flourishing around during the International Geophysical Year and extending into the early 1980s, but still continues to this day.

2.1 Rocket history and pioneers

The early history of rocket development is closely connected with military applications. After the invention of gunpowder (black powder) in the 13th Century by the Chinese, they used gunpowder-driven rockets for fireworks during celebrations, but also as military 'fire lances' in their battles with the Mongols. Via India and Arab countries, early military use of solid-fuel rockets reached Europe and the USA and they were used, for example, in battle by Napoleon (1803-1814) and in the British-American War (1812-1814).

The idea of civil/scientific use of rockets to explore space emerged only towards the end of the 19th and the beginning of the 20th Centuries, when spaceflight pioneers like the mathematics and physics teachers Konstantin Tsiolkowski in Russia and Hermann Oberth (author of *The Rocket into Planetary Space*) in Germany proved theoretically that it actually was possible to escape the Earth and its atmosphere. They developed independently the theoretical fundamentals of rocket flight into space and proposed to use liquid propellants (e.g. with liquid oxygen as one constituent) as an alternative to the less precisely performing solid-propellant rockets being used at that time by the military. Tsiolkowski set out the multi-stage principle, with several rockets attached together, and put forward a fully feasible design for a rocket combustion chamber catering for two types of liquid propellant. He was considered to be a dreamer in his own country and therefore had neither the public nor government support for bringing his ideas to fruition.

It was Hermann Oberth who claimed that it should be possible to build rockets which, by exploiting the Earth's gravitational field, could be turned into artificial satellites of the Earth and even leave its gravity field altogether to continue their journey into outer space. His books included *Rakete zu den Planetenräumen* (1923) and *Wege zur Raumschiffahrt* (1929), the latter entering the standard canon of work on rocket travel. The French spaceflight scientist Robert Esnault-Peltérie wrote what he called his 'bible of astronautics'. Oberth received the French *Prix International d'Astronautique* for his efforts. His theories are still fundamental to modern space travel and he is recognised worldwide as the father of spaceflight.

The first experiments with liquid-propellant rockets were performed by the American physicist R.H. Goddard in the period 1926-29. He also filed a patent for a solid-fuel, multi-stage rocket. He designed and tested a new nozzle which drastically improved the rocket's performance. Goddard is today often considered the father of space rockets.

Thanks entirely to Oberth and Goddard, spaceflight left the realm of the imagination and speculation.

In this context, the French spaceflight visionary Jules Verne (1826-1903) should also be mentioned. He predicted and described many spaceflight missions (*De la Terre à la Lune*, 1874) and rocket-technology developments many decades before they came about.

The utopian and imaginative science-fiction films of Fritz Lang in the late 1920s on this subject also provided many ideas for spaceflight ventures, which were later put into practice by space engineers and technicians.

In the late 1920s, the rocket spaceflight idea attracted enthusiasts worldwide, especially in Germany, France, the USA, the USSR and the United Kingdom. In these countries, national and international societies for spaceflight or astronautics were set up, with mission studies and experimental tests being carried out. For example:

- In Germany, the Verein für Raumschiffahrt was founded in 1927.

- In the USA, the American Interplanetary Society was founded in 1931, and was renamed the American Rocket Society in 1934.

- In France, Henri Melot had already worked on rocket engines for airplanes back in 1916. In the late 1920s, Esnault-Peltérie performed rocket-theory work and prompted the experimental tests of J.I. Barré in 1931 using different propellant combinations. In 1941, Barré designed the first French liquid-propellant rocket, which was 3.15 m long, had a mass of 100 kg at launch, produced 1000 kg of thrust, reached an altitude of 15 km and travelled a distance of 60 km. Due to World War II, this rocket performed its successful maiden flight only in 1945.

- In the United Kingdom, the British Interplanetary Society (BIS) was founded in 1933 and attracted spaceflight enthusiasts from many other countries, including France's Robert Esnault-Peltérie. An English statute dating back to 1875 prohibited the carrying-out of experiments using explosives. However, the Society supported the first study of a manned flight to the Moon. The BIS-proposed lunar spacecraft had the following features: 1000 t dry mass, 2500 small solid-propellant rocket thrusters connected together, 900 t of fuel, 32 m length, and was to be launched from a 3800 m-high mountain in Bolivia or Peru in an eastward direction in order to exploit the Earth's rotation and the lower air resistance during launch.

- In Moscow, Russian spaceflight pioneers organised the first International Exhibition on Space Navigation back in 1927.

All of these foundations, exhibitions, publications and science-fiction films on spaceflight ventures, etc. promoted the spirit of spaceflight among the public and prompted new ideas, studies and laboratory tests on such aspects, for example, as the use of liquid propellants for rockets and the efficiency of propellant combinations, the use of electric propulsion and the use of aerodynamic friction to decelerate spacecraft during atmospheric re-entry.

2.2 Rocket development in Germany from 1930 to 1945

In contrast to the somewhat slow progress made on rocket development in the USA, the USSR, France and the United Kingdom, a scientific/cultural movement and environment emerged in the late 1920s in Germany which produced an enthusiasm for high technology, whereby the group of space-rocket enthusiasts led by Klaus Riedel (inventor of the liquid-propellant combustion chamber), Walter Thiel and later Wernher von Braun, obtained the greatest governmental support for establishing a rocket research and development programme of enormous scale (Thiel died during the bombing of Peenemünde in 1943).

This originally civil, space-rocket initiative by enthusiastic pioneers was turned – after the seizure of power by the Nazis in 1933 – into a political instrument to advance the capabilities of military rockets in order to exercise the military threat and to use large rockets as a weapon of war. In 1936, the German army took over the financing and moved the German rocket experts and technicians to a rocket base near Peenemünde overlooking the Baltic Sea. Von Braun became the central character in the German V2 rocket-development programme. Oberth was pushed aside and had to be content with watching the experiments from a small office in Peenemünde and noting that his theories had proved to be sound. (The V1 was not actually a rocket, but a guided winged bomb, which flew at 200 to 2000 m altitude and had a maximum speed of 665 km/hour).

Von Braun put together a very large team (6000 rocket scientists/engineers and technicians plus some 13 000 unskilled workers) from 1936 onwards in Peenemünde.

The R&D rocket programme was funded by support equivalent today to €4 billion from the armaments office (*Heereswaffenamt*). This programme was by far the most expensive weapons development activity carried out under Hitler's regime (1933-45). The result was the production of a series of rocket types denoted A1 though A4 (A standing for Aggregate). The single-stage liquid-propellant A4 was later renamed the V2, which stood for *Vergeltungswaffe* (retaliation weapon). The V2, the first test flight of which took place in October 1942, had the following technical performance characteristics:

Table 2-1. V2/A4 technical characteristics

Length:	14.2 m
Diameter:	1.65 m
Dry mass:	13 t
Propellant mass:	9 t
Payload mass:	1 t
Propellant type:	ethyl/water plus liquid-oxygen mixture
Thrust:	25 000 kg
Range:	330 km
Altitude:	190 km

The V2 was the first rocket to fly into space. It was the precursor of the generation of large rockets developed later.

Although some 5700 V2s were manufactured, fortunately only about 3200 were fired during the period September 1944 to March 1945 (mainly targeting Antwerp, the Allies' primary European harbour, and London). However, in the beginning, many launch failures occurred. German V2 records show that of the first 1000 successful V2 firings performed over the period 8 September 1944 to 26 November 1944, a total of 298 hit targets in England, 629 hit Belgian territory and Maastricht, and 73 hit the Paris suburbs and northern France (Lille, Tourcoing, etc). The Belgian city of Antwerp, used by the Allies as a supply port, was the most frequent target of V2 firings: 556 V2s hit the city over this short period.

As is well-documented in the French AAAF account *La France a-t-elle hérité de Peenemünde?* written by Jacques Villain, the President of the *Commission Histoire de l'AAAF*, the V2 attacks on France began on 8 September 1944 and ended on 5 October 1944. This stands in contrast to the V2 bombardment of England, which continued with several V2s per day until 18 March 1945. In this context, it should be recalled that the German military authorities had originally announced that the V2 would be used to attack England instead of crossing the Channel with troops. However, the Allies landed earlier (at the beginning of June 1944) along the Normandy coast, so the rocket-firing facilities erected there were never used for V2s. This was the reason why the main launch range and liquid-oxygen production plants for V2 rockets targeting England became Wizeres near Watten on the North Sea coast and the Somme Valley in France. The V2 rockets targeting Paris were mainly fired from launch sites in the Ardennes.

In January 1945, shortly before the closure of Peenemünde in the following month, the upgraded-version of the A4, the A4B, which had a range of 750 km, was flight-tested.

In February 1945, the 13 t of Peenemünde technical documentation together with the nucleus of the von Braun team were transferred to central Germany, and later to the south. This documentation included rocket designs up to the A10, a multi-stage intercontinental rocket, which later served as the basis for the American Atlas rocket, which was used as a satellite carrier and intercontinental missile. The Germans called the A10 their 'American rocket', because it was designed to cross the Atlantic to target the USA.

2.3 The Peenemünde rocket centre

The Peenemünde rocket centre located on Germany's Baltic coast was the think-tank of German rocket-engine development, qualification and flight-testing. Not only were the V2 and its improved versions (A4B to A10) designed, developed and tested there, but also rocket engines for fighter aircraft, though their technical execution was continued only after the war, in the USA, the USSR and the United Kingdom. Sea-launch rocket systems were also designed (e.g. for launches from submarines).

The use of the V2 as a sounding rocket

The Peenemünde rocket centre worked together with many (some 50) subcontractors and research institutes in Germany and Austria, which specialised in various technical areas of rocket design. They studied rocket aerodynamics and high-performance materials, for example.

The use of the V2 for atmospheric measurements and ionospheric research was first proposed by the Physics of the Stratosphere Institute in Friedrichshafen, led by Profs. Regener and Ehmert. There exist secret minutes (dated 8 July 1942) of a meeting between von Braun and this Institute, which stress that physical measurements of the density, pressure, temperature and composition of the atmosphere at various altitudes were urgently needed in order to improve rocket-trajectory calculations. The V2 *Regener Tonne* payload developed by the Institute for research flights from Peenemünde was flown several times from March 1944 onwards. This payload was ejected from the V2 during flight and landed by parachute. It included UV spectrometers, barometers and facilities to take air samples at different altitudes. The priority given to the

V2 as a war missile, pushed by the German army authorities, led to a postponement of the use of the V2 as a scientific sounding rocket. Only after the War was the V2 used again as a sounding rocket, being launched from White Sands in New Mexico (USA), from where V2s were being launched by the team led by von Braun.

Von Braun and Dornberger jointly wrote a book in the spring of 1945 showing the value of the V2 rocket for atmospheric research (i.e. as a sounding rocket) and for space research; they described their vision of flying to the Moon and to the planets and mentioned as an intermediate step the establishment of a space station in low Earth orbit. In order to avoid problems with the Nazi regime, they had the book published only after the end of the War. In this context, it should be recalled that von Braun was imprisoned by the SS, being accused of thinking more about rocket-based space exploration than about military missiles. Thanks to the intervention of General Dornberger, von Braun, Riedel and Göttrup were released after just a few days.

After the first British bombing attack on Peenemünde in April 1943, during which 600 rocket personnel were killed, dispersion of the group of rocket experts to different places started. V2 series production activities were placed under the responsibility of the SS and moved to the mining areas of Nordhausen in central Germany. There, prisoners of war and inmates of the Dora concentration camp were forced to work underground under terrible inhuman conditions, where some 20 000 of them died.

When the Red Army conquered Peenemünde on 5 May 1945, they found it deserted and destroyed. The German military authorities had moved the key rocket experts and their documentation to the south where, in mines near the Austrian/German border at Lake Traunstein, a new rocket centre was to be created. The SS had given the order to execute von Braun and his team should they have to surrender. However, with the help of General Dornberger, this was avoided.

Von Braun and his closest collaborators had planned (and managed) to surrender to the American army, and not to the Soviets, British or French; they saw in wealthy America by far the best chance of pursuing and exploiting their ideas about rocket development for spaceflight purposes.

At the end of the War, frenzied competition between the Allies took place with the objective of capturing German rocket experts, seizing technical documentation and capturing not-yet-destroyed V2 rockets. Each country built up its own corresponding V2 setup. Each obtained complete V2 rockets and components such as engines, combustion chambers, turbopumps, gyroscopes, gas generators, nozzles, tubes, valves, electromagnetic and pneumatic systems, electronic components, etc.

The USA’s war booty

A Special Mission V2 unit of the American army was the most successful participant in this competition.

The V2 production site was located near Nordhausen, an area (Thuringe) of Germany which was first provisionally occupied by American troops, but which was later – according to the Yalta Agreement between the War Allies – to become part of the Soviet occupation zone. During this short and transient ‘American’ period, a specialised US raid in a 10-day crash action dismantled more than 100 V2 rockets and transported them by train to Antwerp for shipment to the USA. In contrast to Peenemünde, the Nordhausen facilities had not been completely destroyed when the German army had to give up this area.

The American Special Mission V2 unit captured von Braun and 350 of his closest collaborators (more followed later), found the 13 t of Peenemünde technical documentation and about 100 V2 rockets, and took them to New Mexico. Von Braun himself was considered to be the most important prisoner of war World War II, and later became the father of the American lunar Saturn-V rocket. The first V2 launches in the USA took place from White Sands (New Mexico) between 10 May and 9 July 1946, when five V2’s reached altitudes of more than 100 km.

In New Mexico, the von Braun team participated in the development of the first two-stage sounding rocket, which in February 1949 reached an altitude of 400 km. In 1950, the team was moved to Huntsville, where it was integrated into the Redstone Arsenal US Army centre. By 1955, some 760 German rocket experts were still working in Huntsville. There, a new follow-on model of the V2 was developed which, on 5 May 1961, took Alan Shepard on a ballistic trajectory into space. Further follow-on developments were the intermediate-range Jupiter launcher, and later the Saturn.

The USSR's war booty

Most of the rocket technicians (3500) from the Peenemünde centre were transferred as POWs to the USSR. However, a small proportion of them were first engaged by the Soviet army under the command of Col. Sergej Koroljow to rebuild the partially destroyed V2 production facilities in Nordhausen. This task was accomplished by late 1945, when the V2 test facilities were also again operational. In October 1946, the Soviets decided to dismantle all V2 facilities in Nordhausen in order to transport them to the USSR, i.e. to Kapustin Jar 200 km east of Stalingrad, from where many of the Kosmos satellites were later launched.

A team of about 200 German rocket-guidance experts, led by H. Göttrup, were brought to Baikonur in Kazakhstan in late 1946 to test/improve (1947-50) the V2s captured by the Red Army. On 30 October 1946, the first improved V2 was launched from Soviet territory in Kazakhstan. This first Soviet V2 achieved a range of 350 km and was considered later by historians as the starting point of the Soviet-American space race. The German rocket experts were subsequently employed to support the development of the Soviet SS-6 intercontinental missile, which was used in 1957 to launch Sputnik.

As in the USA, in 1946 the Soviet government assigned the highest priority to the development of intercontinental missiles. Based on the V2s, by 1950 the Soviets had developed the T-1 rocket, which used liquid oxygen as one of its propellants. It had a range of 800-900 km, with a payload capacity of 1.2 t. The Soviet army obtained this rocket under the name 'Pobeda' (meaning victory). In contrast to the Americans, who developed new and more powerful rockets, the Soviets applied the principle of clustering together several existing rocket engines.

In contrast to American and French arms development policy, which integrated the Peenemünde rocket experts into their own teams, the Soviets wanted to take over the German rocket know-how and technology, but did not want to involve the Germans themselves too closely in the follow-on development work.

In 1955 most of the German rocket technicians left the USSR, where they had still felt like prisoners of war.

France's war booty

In France, by May 1945 the Groupe Operationnel des Projectiles Autopropulsés (GOPA) had been set up under the auspices of the government's Direction des Etudes et Fabrication d'Armement (DEFA) with the task of compiling and studying as much V2 hardware and documentation as possible and hiring Peenemünde rocket experts.

About 90 German rocket-engine experts from Peenemünde, led by Heinz Bringer (rocket-motor expert), Otto Müller (guidance expert) and Helmut Habermann (electronics expert), were brought to France to collaborate with French scientists on liquid-propellant rockets at the newly (1946) created Laboratoire de Recherches Balistiques et Aerodynamiques (LRBA) in Vernon. The development of the first version of the Veronique rocket started there in 1949, resulting in 1952 in a liquid-propelled rocket 6.5 m long, with a dry mass of 1150 kg, a payload capacity of 60 kg and an altitude capability of 65 km. This first version was still very similar to the V2's sister rocket Wasserfall, which had also been developed at Peenemünde in 1941 for the German Air Force. The Veronique was regularly launched from the French military centre at Colomb-Béchar/Hammaguir in the Sahara (today Algeria) from 1952 onwards. It was the first liquid- propelled rocket built in Europe to be used for space research. By 1954, a more powerful version (the AGI) had been developed for use during the International Geophysical Year of 1957/1958. This French sounding rocket was used from March 1959 until February 1969 and reached an apogee of 220 km. A further-improved version of Veronique, the 61M, was launched from June 1964 until 1970, first from Hammaguir and then from Kourou. By 1958, Veronique had been replaced by the *Pierres précieuses* family of rockets from the company Sereb, which included the Agate, Rubis, Topaze, Saphir, Emeraude, and finally the Diamant. In 1970, Sereb merged with Nord-Aviation and Sud-Aviation to become Aérospatiale.

Besides the LRBA in Vernon, the French military authorities created an aerodynamics design office in the city of Emmendingen in southwest Germany, for which a large number (more than 30) of Peenemünde experts were hired. One of them was a key individual of the highest technical reputation in this field, Helmut Weiss, who had worked immediately after the War for the British Ministry of Supply (MOSEC). This office designed the wind tunnel for Vernon, based on that at Peenemünde.

In the early 1950s, the French army created a Franco/German working group led by Prof. K. Rawer in Freiburg (Germany) with the objective of performing studies of the ionosphere using sounding rockets. From 1956 onwards, this group was supported financially by the German government and became one of the Fraunhofer Institutes.

The LRBA also contributed substantially to the construction of the engine for the French Diamant rocket, the first stage for which was derived from the V2.

Another German team of about 50 rocket-engine experts worked under Prof. Eugen Sänger for the French Air Ministry on rocket-powered jet planes. Sänger had developed the first hypersonic aircraft and tested it in wind tunnels in 1943. He returned to Germany in 1953 to become Director of the Jet Engine Physics Institute in Stuttgart.

The United Kingdom's war booty

From the beginning of World War II, the Nazi propaganda machine spread news of Germany's development of a novel 'wonder' weapon to be used against England. The British government was worried and its intelligence service received a high-priority order to gather information on this novel weapon. The first extremely useful piece of V2-related information that the British government obtained was a comprehensive and detailed description of German armaments development work, in the form of a letter delivered in November 1939 to the British Embassy in Oslo. This letter from a German scientist, a Nazi-opponent and pacifist, contained a detailed description of the Peenemünde rocket centre and the planned development of rocket types A1 to A4 (V2). Hans Kummarow was assassinated together with his family more than three years later (in 1943) as a member of a German anti-Hitler resistance organisation. Those pursuing him had not been aware that he was the author of the letter delivered to the British Embassy in Oslo.

A second very important V2-related piece of information emerged from a misguided test rocket, which landed by mistake in Sweden in 1943. The surviving V2 hardware from this flight was immediately taken to England in a small plane, where a thorough technical analysis made the British authorities certain that this very powerful rocket represented a great danger to the security of the population of southern England. The response of the British military authorities was the heavy bombardment of Peenemünde by the Royal Air Force on 18 August 1943. This devastating bombardment not only killed some 600 rocket experts, but also resulted in the destruction of the technical facilities, leading to a major delay in V2 qualification and testing.

In March 1944, Prime Minister Churchill gave the order for the British Secret Service to kidnap von Braun and bring him to London. However, as this proved not to be feasible in practice, it was later changed to an order to recover a fully-functional V2 rocket and bring it to England. By chance, this order was fulfilled in mid-1944, after a V2 test rocket launched from Peenemünde landed on the banks of the river Bug in Poland. From there – having been professionally dismantled by the Polish resistance – it was transported by a roundabout route to London. The ensuing technical analysis yielded information about the propellants (including the liquid oxygen used in the oxidation process), the rocket's enormous flight capability in terms of range and payload, the materials used in its construction, etc.

Since, among all the Allies, the United Kingdom had suffered most from the V2 bombings, the British military was the most eager at the end of the War to take over the V2 launch ranges and the V2 hardware in Holland and West Germany (e.g. a launch base on the Rhine near Koblenz was found to be fully functional when British troops arrived). With the consent of General Eisenhower, the V2 hardware that the troops recovered was, on the initiative and under the supervision of British Commander Joan Bernard, taken to Cuxhaven on the German North-Sea coast. It was her idea to reintegrate a number of V2 rockets and launch them for demonstration purposes from the German V2 range near Cuxhaven. This operation, which was supported by all of the Allies, was named 'Operation Backfire'. It was executed with the help of 85 rocket experts from the von Braun team, who were brought to Cuxhaven for several months especially for the purpose from Southern Germany and Austria. In addition, 400 German V2 launch experts, who had worked first at Peenemünde and later at Cuxhaven under Peenemünde V2 launch chief Kurt Debus, and who were now prisoners of war, were engaged for Operation Backfire. As a result of that Operation, three V2 launches were successfully performed between 2 and 14 October 1945. Rocket experts from all of the Allies, international scientists and the press were invited to attend this event. Among the observers were the subsequent JPL Director W. Pickering, Prof. Theodore von Karman, a US/Hungarian rocket expert, plus Soviet Colonels and rocket experts Glushkov, Pobedonostev and Koroljow. A number of selected British and French military rocket experts also attended the Backfire V2 launches. All participants received a complete set of V2 technical and operational information, including a V2 set-up and assembly instruction manual.

After Operation Backfire, the German rocket experts who had come from the von Braun team in the south of Germany returned, and most of them were offered employment in the USA. Von Braun himself had already been taken to the USA in September 1945 by the US Army. Soon afterwards, K. Debus became the Director of Cape Canaveral, a post he retained until the end of the Apollo Programme in the early 1970s.

In the early post-War years, there was neither a strategy nor funding in the United Kingdom for any new rocket-development work.

A group of liquid-propellant combustion-chamber experts who had worked at Peenemünde under Walter Riedel moved to the United Kingdom, where there was practically no experience in this important field of rocket technology. This group participated in the development of the British military rocket Blue Streak, which was later to become the basis for the first stage of ELDO's large Europa rocket. In addition, this team was involved in the development of the British Black Arrow rocket, on which the first UK satellite Prospero was launched in 1971. Blue Streak was developed by Hawker-Siddeley Dynamics in Stevenage for the British Ministry of Aviation. The boosters for Blue Streak were produced by the British company Rolls Royce under licence from the American company Rocketdyne.

General Remarks on Rocket Development in Germany

Today, rocket experts are convinced that the Peenemünde team of von Braun developed the technological basis for the progress with civil and military rockets achieved in the second half of the 20th Century.

After World War II, von Braun became the father of the huge American Saturn-V rocket, which enabled the first human to land on the Moon in 1969.

Fortunately, the V2 rocket came too late at the end of World War II and still had a low firing accuracy, so that its military impact was limited.

According to an assessment made in 1945 by a group of American scientists (called together by Albert Einstein) for the US government, the rocket technology R&D between 1929 and 1945 had given Germany a ten-year lead over the rest of the World.
After the end of World War II, the core of von Braun's team of rocket experts documented their know-how and about 100 V2 rockets were transferred to the USA. Another even larger group of Peenemünde rocket engineers and technicians was taken to the USSR, and smaller groups to France and the United Kingdom.

Winston Churchill wrote in his memoirs (published in 1953) concerning the rocket-development activities of Nazi Germany that it was lucky that the Germans had devoted their greatest efforts to the rockets and not to the development of bombs. In 1945, the Allies imposed on Germany the obligation to refrain from all military development activity – including rocket development – in the future.

Credit: Jan Olav Anderson

Aurora Borealis in the neighbourhood of Andenes in Norway

3. Birth of the Space Age: Use of Sounding Rockets for Atmospheric Research and the Launch of Sputnik

As early as 1947 in the USA, and in the mid-1950s in Europe, a few rockets based on the V2 were used as sounding rockets to study unexplored features of the upper atmosphere and near- Earth orbit. However, all rocket development until the mid-1950s was predominantly aimed at serving military purposes.

This changed in the period from July 1957 to end-1958, designated the International Geophysical Year (IGY), which saw a definite breakthrough in the use of rocket technology for civilian purposes. The IGY was devoted to global atmospheric research. The idea came from American geophysicists, the most prominent of whom at the time, Sidney Chapman, became the chairman of a huge IGY international research programme, which involved setting up a large number of measuring stations in the central Arctic regions and Antarctica. Measurement points were installed on lightships, ice floes and oceanic islands. Tens of thousands of researchers worked to collect data.

The organisation of the IGY and its scientific programme were influenced to a certain extent by the large solar flare that was observed on 23 February 1956, and which caused very high absorption of VHF-band radio waves over the Earth's polar caps (at geomagnetic latitude 60°N). This was the first time that this phenomenon had been reported and the subsequent observations showed that large solar flares were generally followed by radio-wave absorption combined with aurora. The absorption was thought to be caused by bursts of proton and electron radiation from the Sun. The proton flux and its energy spectrum and electron density in the ionosphere would therefore need to be measured *in-situ* using rocket-borne equipment. Knowledge of the cosmic radiation was supposed to contribute to understanding the effects of absorption on radio communication in the polar regions. Radio blackouts were feared by air, sea and land traffic alike.

The IGY prompted the launch of some 200 sounding rockets worldwide. The vehicles used were derived from military rockets, or else military rockets were used but under a different name. These were very different in respect of their technical capabilities, ranging from payloads of a few kg (e.g. the Canadian Black Brant 4A could lift 4 kg payloads to 185 km altitude) to 200 kg (e.g. the French Veronique 61M could lift 200 kg to 220 km altitude). The number of different types of sounding rockets used annually for scientific purposes increased in the 1960s/early 1970s to about 90.

The start of space-science activities employing sounding rockets was facilitated in Europe by the fact that in the 1960s the USA was very generous, often supplying sounding rockets and their launch services free-of-charge to the national space authorities of countries that were members of NATO.

Even the creation of ESRO's first scientific programme profited from this generous American assistance. Its first two small satellites, ESRO-I and II, were launched with Scout rockets free of charge by NASA.

The unexpected launch of Sputnik on 5 October 1957 accelerated space research and spaceflight ideas throughout the whole World, and had 'shock effect' in the USA. Two months later, the USSR launched Sputnik-2 with the dog Leika onboard.

The USA realised that they had been overtaken in the space race and this had evidently taken place in secret. A storm of self-criticism swept across the country concerning everything connected with its ability to handle high-technology development. The education system in particular was subjected to extensive reforms over the following years. There, and in the West in general, the 'Sputnik defeat' contributed to a heavy concentration on technical/scientific training for the younger generation. This reappraisal process in the USA culminated in the decision to implement the Apollo Programme, designed to take astronauts to the Moon and back before 1970. The Cold War thus advanced into space, with the ensuing competition that was to be the basis for space policies and programmes through to the end of the 1980s, when the Iron Curtain came down and a few years later the Communist system and the entire USSR collapsed.

The urgent recovery action by the USA in response to the shock effect of Sputnik led to the launch of the first American satellite, Explorer-1, on 31 January 1958. In October 1958, NASA was founded by the US Government with the objective of focusing all US space efforts. Also that October, the International Council of Scientific Unions (ICSU) founded COSPAR, the Committee on Space Research.

In the period July 1958 to March 1959, the Italian physicist Edoardo Amaldi expressed in letters to some 70 prominent European scientists (e.g. Auger, Massey, Van der Hulst, Hultqvist, etc.) his conviction that it was time to set up a European Space Research Organisation (ESRO), in order not to fall behind the USA and the USSR in space research and technology. The European scientists stipulated that ESRO should be free of any military involvement and influence, and should have only peaceful purposes.

Prof. Eduardo Amaldi together with Professor Pierre Auger (Noble Prize winner, Chairman of the French *Comité de Recherche Spatiale*) achieved the setting-up of ESRO's precursor body GEERS (*Groupe d'Etude Européenne pour la cooperation dans le domain des Recherches Spatiales*) in June 1960. GEERS defined a scientific programme for the future ESRO, which consisted of a series of sounding-rocket flights and low-Earth-orbit small-satellite missions. GEERS was replaced by COPERS, the *Comité Préparatoire pour la Recherche Spatiale*, which was charged with the task of defining an organisational framework for ESRO and ELDO.

In COPERS, the structure of ESRO was agreed to consist of a Headquarters in Paris, ESTEC in Noordwijk (NL), ESOC in Darmstadt (D), ESRIN in Frascati (I), and Esrange in Kiruna (S).

When ESRO was finally established by its Member States, Esrange was provided with a sounding-rocket launch facility for the study of polar aurora and the upper atmosphere. ESRO also used national sounding-rocket bases in Salto di Quirra (Sardinia), Andøya (Norway), Isle de Levant (France) and a base in Greece.

At a COPERS meeting in 1961, the ESRO budget for the first eight years was agreed, amounting to FF 1500 million.

The ESRO Agreement signed on 14 June 1962 did not actually come into force until 20 March 1964. The founding Member States were Belgium, Denmark, France, Germany, Italy, The Netherlands, Spain, Sweden, Switzerland and the United Kingdom. Prof. Auger was appointed as ESRO's first Director General.

3.1 Technical and operational features of sounding rockets

Before providing further details of the history and objectives of sounding-rocket activities in Europe, a basic definition of what constitutes a sounding rocket needs to be established. A sounding rocket is a projectile that is launched into the upper atmosphere to reach an altitude of between 40 and 2000 km. Sounding rockets are of special interest for atmospheric research at altitudes that cannot be reached by balloons (max. 40 km) and the low-Earth-orbit (LEO) satellites that need to operate beyond about 200 km to avoid re-entry due to residual atmospheric friction.

A sounding-rocket engine consists of one or more stages, filled with solid or liquid propellant. The main difference between a solid-propellant and a liquid-propellant engine is that the solid grain burns without it being possible to interrupt the thrust, whereas the thrust of liquid-propellant engines can be modulated, interrupted or re-ignited. However, liquid propellant is normally corrosive; therefore, if a launch has to be postponed or cancelled, the liquid-propellant stage has to be drained and flushed out.

The payloads of sounding rockets are normally installed on top and protected during launch by a fairing.

ESRO/ESA and European national sounding-rocket programmes have predominantly used the rocket families offered by:

- France: Centaure, Dragon, Belier and Veronique
- United Kingdom : Skylark, Skua and Petrel
- USA: Arcas, Nike-Apache, Javeline 3 and Aries/Castor 4B
- Canada: Black Brant 3A, 4B, 5C (and other later versions).

The technical characteristics of selected sounding rockets are summarised in Table 3-1.

The technical capabilities of the various sounding rockets are very different. The payload mass-carrying capability varies between Skua and Aries/Castor by a factor of up to 100, whereas the achievable apogee altitudes vary by a factor of 5 to 10.

A yardstick often applied for measuring the technical capability of sounding rockets used for atmospheric and ionospheric studies is the product of payload mass times the maximum altitude achievable. Such studies are over time requiring increasingly sophisticated experimental equipment and higher altitudes, so that the sounding rockets used in the later decades of the 20th Century needed higher performances.

Small sounding rockets like the Skua (7.5 kg payload) and Petrel (20 kg) are often used for routine measurements in the fields of meteorology and atmospheric data collection.

The sounding-rocket flight programmes in microgravity research fields such as materials research, fluid physics and biology call for long free-fall phases at altitudes above 100 km. Therefore, in the Texus, Maser and Maxus programmes, the high-capability SR Skylark 7, Black Brant 5B and Castor 4B were used, which allow payload masses of 370 kg (Skylark 7 and Black Brant 5B) and 800 kg (Castor 4B) and microgravity periods of 6 and 12 minutes, respectively.

Table 3-1. Technical features of selected sounding rockets used by ESRO and national space agencies in Europe in the 1960s/1970s

Rocket type	Nominal apogee (km)	Nominal payload mass (kg)	Dry mass (kg)	Max. accel. level (g)	No. of stages
Skua	95	7.5	42	55	2
Petrel	120	20	98	60	2
Bellier III	109	60	387	10.5	1
Centaure types :					
- Centaure IIB	146	60	317	17	2
- Centaure III	170	60	327	17	2
Dragon IIB	440	75	321	16	2
Dragon III	520	70	324	15	2
Skylark Types:					
- Raven VI/Cuckoo	125	150	1060	25	2
- Raven VI/Goldfinch	210	200	1217	35	2
Veronique 61M	240	200	1950	14	1 liquid

3.2 Scientific features of sounding rockets

There are two major fields of investigation – space science and microgravity research (physics and life sciences experimentation under microgravity/weightlessness conditions) – in which sounding rockets are used as carriers of scientific instruments.

(a) Space science

The most important innovation provided by sounding rockets for space-science activities was related to the fact that the study of many atmospheric and ionosphere phenomena requires measurements taken through the vertical cross-section of the atmosphere and the ionosphere.

Secondly, they enabled measurement-taking above 40 km, i.e. the maximum altitude attainable by balloon-borne instruments, and below altitudes at which stable satellite orbits can be achieved, i.e. 200 km. The region between these two altitudes, containing the scientifically interesting D, E and F-layers of the ionosphere (70-200 km), could therefore at that time be investigated only by performing *in-situ* experiments using rocket-borne instruments.

Thirdly, sounding rockets offer excellent opportunities for testing ideas, scientific theories and the operational performance of instruments prior to their eventual use on satellites.

Fourthly, sounding rockets are an excellent means of taking measurements at very short notice of transient phenomena such as aurora (photometry), radiation and magnetic-field properties in low Earth orbit (LEO) shortly after solar eruptions/flares. Strong solar flares are accompanied by the emission of high-velocity protons, which reach the Earth's atmosphere within 15 to 30 minutes. These solar protons penetrate deep into the atmosphere and produce strong ionisation phenomena (known as polar-cap absorption). These phenomena are inevitably accompanied by disruption and even blackouts of short-wave radio communications.

The quiet ionosphere can be studied at high, medium or low geographical latitudes, but the very interesting study of the disrupted ionosphere can best be carried out in the auroral zones (65°-70° geomagnetic latitude), because the solar particles responsible for the disturbances are drawn towards the poles by the Earth's magnetic field. On descending into the Earth's atmosphere at an altitude of 100 km, these particles undergo collisions, are slowed down/stopped and thereby produce disruptions in the form of magnetic storms and aurora.

In general, it can be said that sounding rockets have been best-suited for *in-situ* studies at altitudes between 40 and 200 km of:

upper atmosphere features such as
- wind, pressure, temperature, neutral chemical composition, albedo, planetary radiation, etc.

ionosphere features such as
- electric currents, electron and ion densities, propagation of radio waves, magnetic-field disturbances, etc.

The long-lasting scientific interest in ionospheric research is related to evolving research objectives over recent decades.

In the *period 1957 – 1970*, interaction particles responsible for optical aurora and neutral and ionised species in the D and E-layers of the ionosphere received primary attention. Then, measurements of spectra of incoming particles and of optical aurora and X-ray emissions were added, in order to study energy dissipation in detail. Knowledge of the effects of energy dissipation was needed to understand the ion chemistry and the energy distribution of low-energy plasma. Further studies include problems related to the magnetosphere, including coupling with the auroral ionosphere, the physics of the auroral arc, auroral substorms and the acceleration and precipitation of auroral particles.

In the *period 1971 – 1990*, attention focused more on the study of the upper ionosphere (the F-region) because auroral phenomena had become better understood. This required larger sounding rockets in order to reach higher altitudes, as well as more sophisticated payloads. Over this period, instruments able to measure electrical fields and waves were flown as sounding-rocket payloads. Out of this work grew the idea of studying the energy transfer between the various constituents of the system, either by heating the lower ionosphere via powerful transmitters on the ground or by emitting an artificial electron beam from the rocket. This approach called for separable – mother/daughter – payloads in order to remove the sensors from the region of the beam-emitting vehicle.

Around 1980, interest turned to studies of the coupling between the neutral atmosphere and the ionospheric plasma. This led to a series of campaigns with the specific aim of studying this relationship. During this period, complementary ground-based measurements using radar – (EISCAT, PRE, STARE) – and lidars took on increasing importance in sounding-rocket research.

In the *period 1991 to today*, sounding-rocket research continues on gravity waves and turbulences. In addition, intensive studies of the altitude region around the mesopause (80-90 km) have been performed. At these heights, the temperature drops to about 100 K during the summer, making this region the coldest in the Earth's atmosphere. Associated with the drop in temperature are occurrences of noctilucent clouds and polar mesospheric summer echoes. The latter are extremely strong radar echoes in the VHF and UHF bands. Further studies are continuing on pulsating aurora and magnetosphere/ionosphere interaction.

The second main space science area of interest in the early phase of sounding-rocket flights was astrophysics/astronomy. Studies of X-ray radiation and the measurement of the ultraviolet, visible and infrared light spectra of the Sun (including measurements during solar eclipses) and stars were made from points above the atmosphere, i.e. radiation that is largely absorbed by the atmosphere and which – apart from the small visible region – cannot therefore reach the Earth's surface.

Sounding rockets were first used by American scientists to measure solar particle radiation, terrestrial trapped radiation (Van Allen belts) and galactic radiation.

(b) Sounding rockets for materials and life-sciences research under microgravity conditions

In the microgravity sciences such as materials science, fluid physics (including combustion research) and biology, sounding rockets are used as short-duration flight opportunities, which provide up to 12 minutes of microgravity at levels better than 1/10 000g. The microgravity levels achievable with sounding rockets compare favourably with those of manned orbital systems and are determined by the drag of the residual atmosphere above 100 km altitude.

During the ascent phase, a sounding rocket is spin-stabilised about its longitudinal axis. After rocket-motor separation and de-spinning, the coasting (or microgravity) phase is reached at 100 km. Depending on the type of rocket used, this 'free-fall' phase can last up to 12 minutes (Maxus-Castor 4B). During re-entry into the atmosphere, drag forces increase gradually and the free-fall conditions no longer prevail.

Parachutes are deployed at an altitude of about 5 km to return the payload without mechanical damage. Using the Skylark 7 and Black Brant 5B rockets (used by the DLR, SSC and ESA for Texus and Maser flights over the last 25 years), the maximum acceleration rises to 12g during lift-off and 30g during the re-entry phase.

The apogees of Texus and Maser flights reached about 250 km, and those of Maxus flights about 800 km.

Sounding rockets have been used in Europe for microgravity research since 1977 and today ESA, DLR and Sweden still carry out such programmes. Sounding rockets were/are used in these research fields not only as precursor experiments for Spacelab and ISS experiments or for the verification of proper performance of technical designs in low gravity; they also provide several sub-disciplines with results that constitute a high scientific return in themselves. This is especially the case for short-duration experimenting to investigate combustion behaviours in low-gravity conditions, and for various fields of fluids science and the solidification of metallic melts.

The interest shown by materials scientists/physicists and life scientists in the significance and importance of the effects of gravity during the solidification and the processing of fluids on the one hand and on living systems (gravitational biology and medicine) on the other, has led from the beginning of the space age to the execution of short-duration experiments using sounding rockets and drop towers.

The microgravity research community has very much appreciated:
- the short lead-time of sounding-rocket experiments between conception and execution
- the application of lower safety standards (e.g. no high-reliability parts, unmanned vehicle)
- lower hardware costs due to standardised components/subsystems and greater feasibility of in-house instrument development.

Although the duration of the free-fall conditions provided by sounding rockets is rather short, this type of experimentation in microgravity has contributed significantly to the advances made in these research fields.

Launch of a Centaur II sounding rocket from Esrange (S)

4. Beginning of National Sounding-Rocket Programmes

4.1. Activities worldwide in the 1960s

After the impetus given to sounding-rocket activities by the International Geophysical Year (1957/58), many countries started to derive sounding rockets from already-developed military rocket hardware. At that time, from an economic point of view, this was the only way to obtain sounding rockets for scientific and meteorological purposes. No research institute had the financial means to develop new types of dedicated sounding rockets.

Data on global sounding-rocket flight activities were compiled centrally by the US National Space Science Data Center (NSSDC) at Goddard Spaceflight Center. However, these data were not complete for all years. The data for the two years 1963-64 and for 1968 were extensive and were used to provide an overview of the extent of worldwide sounding-rocket activities in the 1960s. At the global and European level, the late 1960s/early 1970s can be considered the period of greatest sounding-rocket activity worldwide, although the intensity of activity varied widely across the individual sponsoring countries/agencies. For example, by 1972 the ESRO sounding-rocket programme and by 1976 the French national programmes had been terminated, whereas those of the USA, the USSR, Canada, the United Kingdom, Germany, Spain and the Asiatic countries were still growing at this point and then stayed at the same level for many years to come.

The NSSDC data provide answers to such questions as:

(a) Which countries/agencies were sponsoring sounding-rocket launches?
(b) Where did they launch their rockets from?
(c) What types of experiment have been flown?
(d) What instrument technologies have been used?
(e) What was the altitude coverage?

As far as (a) is concerned, Table 4-1 shows the number of launches in 1963/64 and 1968 by country. The numbers illustrate the main features of the geographical distribution and the priorities assigned by sponsoring countries, and the evolution over time of a particular country's sounding-rocket activity, e.g. the contrasting trends for France and Sweden on the one hand, and Germany on the other. The motivation for reducing national sounding-rocket activities was quite different for France and Sweden.

Instead of continuing with its national sounding-rocket flights, France established a large balloon programme to carry heavy space-science instruments up to 40 km above the Earth's surface for long-duration observations. Sweden decided in the second half of the 1960s to fly its sounding-rocket experiments within the ESRO programme (using Esrange near Kiruna), but later revived its national flight activities after 1972 when ESRO terminated its programme.

Table 4-1. Breakdown of launches by sponsoring country for 1963/64 and 1968

Country/Agency	No. of launches 1963/64	No. of launches 1968
America:		
- Argentina	-	17
- Canada	-	23
- USA	153	183
Asia:		
- India	-	12
- Japan	-	2
- Pakistan	-	3
Europe:		
- Denmark/Norway	6	5
- France	38	16
- Germany	1	38
- Spain	4	15
- Sweden	8	1
- United Kingdom	11	32
- ESRO	3	20
USSR:	-	52
Total:	224	419

The very dominant role of the USA in 1963/64 (68% of all flights) was reduced to 44% in 1968. In just a few years, the number of annual launches increased almost four-fold. The altitude coverage during both periods showed a peak in the 100-200 km range (see Table 4-2).

Table 4-2. Proportion of flights covering different apogee altitude ranges

	1963/64	1968
Above 400 km	5%	3%
300-400 km	2%	3%
200-300 km	16%	14%
100-200 km	69%	65%
Below 100 km	8%	15%

The global distribution of sounding-rocket launch ranges is indicated in Table 4-3. Owing to the French rocket launches from the Sahara and the British and ESRO launches from Woomera, this table also includes launch sites in Africa and Australia.

The interpretation of this data must take into account the fact that certain sponsoring countries spread their sounding-rocket launch activities over different continents and geographical latitudes (e.g. France, Germany, UK, USA).

Table 4-3. Launch-range locations/number of launches

Launch range	No. of launches 1963/64	No. of launches 1968
Africa:		
- Hammaguir/Algeria	30	-
- Regane/Algeria	3	-
Asia:		
- Kagoshina/Japan	-	3
- Sonmiani/Pakistan	3	3
- Thumba/India	-	11
America:		
- Wallops Islands/USA	63	50
- White Sands/USA	21	41
- Eglin/USA	1	10
- 6 other US launch ranges	1	22
- Chamical/Argentina	2	8
- Mar Chiquita/Argentina	-	9
- Ascension Island	8	-
- Natal/Brazil	-	6
- Fort Churchill	29	67
- Kourou/French Guiana	-	5
Australia:		
- Woomera	11	10
Europe:		
- Ile du Levant/France	4	1
- Landes/France	-	5
- Vik/Iceland	2	-
- Salto di Quirra/Italy	2	7
- Andøya/Norway	3	9
- Arenosillo/Spain	4	17
- Krongärd/Sweden	12	-
- Kiruna/Sweden	-	23
- South Uist/UK	-	22
USSR:		
- Kheisha Islands	-	15
- Miscellaneous ranges	16	24
Total (Volgograd/USSR not known)	214	394

In addition to these 30 or so launch sites spread around the World, there are another ten less equipped ranges from which sounding rockets can be launched using mobile facilities providing all the necessary operational equipment. DLR’s MORABA mobile rocket base consists of a team of 30-50 engineers/technicians, which conducts sounding-rocket (and balloon) launches and flight operations, providing such services as:

- rocket-motor launch preparation
- radar tracking
- telemetry
- recovery operations
- flight analysis
- data processing
- project coordination.

Since April 1967, under the national sounding-rocket programme started by Germany in 1963, MORABA has launched, or supported the launch of, several hundred sounding rockets from 15 different sites for DLR and ESRO/ESA.

Breakdown of activities by space-science discipline
For each of the two periods (1963/63 and 1968), 644 sounding-rocket experiments were analysed. The corresponding space-science disciplines are given as percentages in Table 4-4.

Table 4-4. Breakdown of experiments by scientific discipline

Scientific discipline	% experiments 1963/64	% experiments 1968
Atmospheric physics	32%	48%
Ionospheric research	32%	22%
Solar physics	11%	4%
Energetic particles	6%	8%
Aurora & airglow	6%	7%
Astronomy	4%	7%
Planetology	2%	3%
Magnetic fields	1%	3%
Test and other objectives (for example, communication)	6%	-
Total no. experiments as %	100%, 644 experiments	100%, 644 exp.

The scientific equipment flown by these sounding rockets consisted *inter alia* of the following instruments/sensors/mechanical systems: cameras, chemical release systems, falling spheres, Geiger Müller counters, grenades, ionisation chambers, impedance probes, ion traps, Langmuir probes, magnetometers, mass-spectrometers, micrometeorite detectors, various photometers, propagation measurement facilities, radio-frequency receivers, scintillation counters, telescopes, etc.

4.2 Early French activities

As already mentioned in Chapter 2, the first French sounding-rocket test flights started back in 1951 with Veronique, which included technical features derived from the V2. These early fights were carried out from the French military base near Hammaguir in southwest Algeria, which was then still French territory. At that point in time, the military authorities were responsible for all rocket-development activities and operations. During this same period, the French military authorities developed their nuclear *force de frappe* strike force, of which strategic missiles represented an important element.

The scientific sounding-rocket activities were considerably increased during the International Geophysical Year (June 1957 to December 1958).

The Laboratoire de Recherches Balistiques et Aerodynamiques (LRBA) set up in 1946 in Vernon contributed greatly to the development of Veronique, the first sounding rocket in Europe. The first version N (total of ten) had a length of 6.5 m, a launch mass of 1 t, a thrust of 40 kN and could lift payloads of 60 kg to an altitude of 70 km. The version used during the IGY already had a guidance system and could reached 210 km altitude with a 60 kg payload.

In the period between its first flight in May 1952 from Hammaguir and 1973 when the last one was fired, about 83 Veronique sounding rockets were launched. The last and most powerful version - the 61 M - was able to launch a 100 kg payload to 325 km altitude.

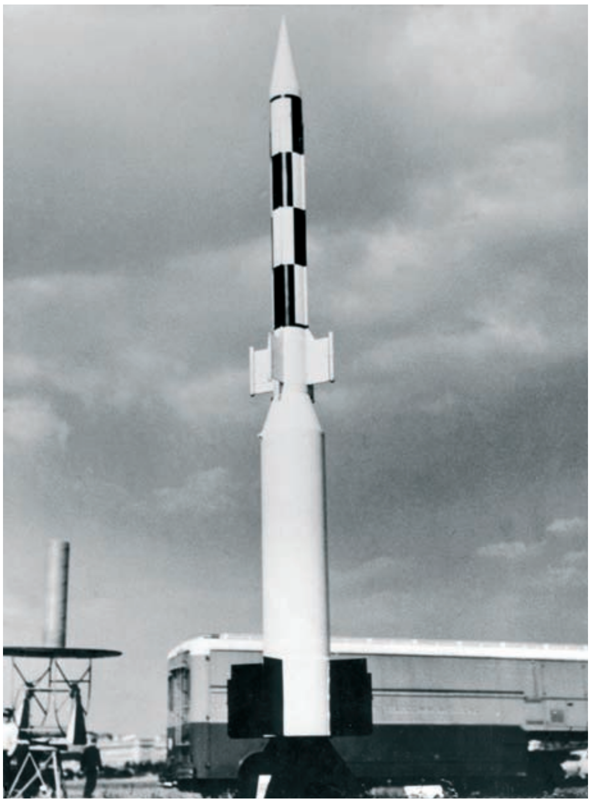
The LRBA was also responsible for coming up with the name ‘Veronique’, which was derived from VERnon electrONIQUE. In the 1960s, the laboratory developed and improved various new rocket motors for the Vesta sounding rocket (141 kN) and the Vexin motor (283 kN), which was used as the first stage for the French Diamant A rocket, which first flew in 1965.

Later, in1970, the laboratory used a mixture of nitrogen peroxide and UDHM (a derivate of hydrazine) as propellant. This resulted in the development of even more powerful rocket motors such as the Valois (344 kN) and Viking (617 kN). Viking was used for Ariane-1 and later for Arianes-2, 3 and 4. Ariane-1 used five Viking engines: a cluster of four to build the first stage and the fifth as the second stage. The names of all these different engines start with a ‘V’ for Vernon.

The first European country to do so, France established a national space agency (CNES) in May 1962. This had been recommended by the Comité des Recherches Spatiales set up in January 1959, of which Prof. Auger became the first Chairman. One of CNES’s first tasks was to coordinate the launching of sounding rockets. CNES engineers and technicians soon learnt to master this new research tool and the scientists at the various research institutes learnt to build space hardware that could survive in the harsh environment in which sounding rockets operated. CNES soon extended its flight activities to launch bases in Norway (Andøya), Sardinia, Spain, India, South America (Argentina) and the Antarctic. This was when France started its coordinated exploration of space, i.e. first with sounding rockets and later extended with satellites.

By the end of 1962, France had developed for its programme two families of sounding rockets:
- solid-grain propellant rockets: Bélier, Centaure and Dragon
- liquid-propellant rockets: the Veronique family (later also Vesta).

The first years of the French national sounding-rocket programme saw a flight rate of 20-30/ year, which decreased in the 1970s. In 1974/75, the French government reoriented its space policy and terminated its national sounding-rocket programme in 1976, after having launched nearly 300 rockets carrying French scientific and meteorological payloads.



A Dragon sounding rocket on its mobile launch table

A separate list, scanned from an old document in the ESRO archives, is available as Annex 1 to Chapter 4.2. It records about 180 French national sounding-rocket flights launched during the period 15 October 1962 to April 1969 and provides information on the following:
- type of rocket used (eight, with Centaure, Veronique and Dragon making up 90%)
- dates of launches
- launch ranges (14 used, but 63% used Hammaguir)
- altitude reached (15 to 2035 km range covered, but 77% explored the 100-200 km range)
- flight objectives (type of experiment or routine measurement)
- scientist and/or institution responsible for payload
- flight result (e.g. 49 total failures recorded).

A further separate shortlist of eight French sounding-rocket experiments, flown in the framework of ESRO's programme covering 1964-72, was also found in the ESRO archives (see Annex 2 to Chapter 4.2).

Over the period 1962-69, the French national programme used, for civil/scientific purposes, eight different types of sounding rocket, delivering the following levels of performance:

Sounding rocket	Max. apogee	Payload mass	% used
Centaure	195 km	30 kg	47%
Veronique	325 km	100 kg	23%
Dragon	460 km	60 kg	20%
Bélier	85 km	30 kg	3%

The other types were Vesta, Titus, Tacite and Rubis. Together, their share amounts to 7% of the scientific sounding rockets flown.

Regarding the scientific disciplines covered by the French national programme, the following breakdown was found:

Atmospheric physics (vapour trail, neutral composition /density, temperature, pressure)	28%
Ionosphere (wave propagation, ion/electron densities and composition)	24%
Magnetic field (geomagnetic and electric fields)	13%
Solar physics (IR, UV and X-rays)	13%
Astronomy(radio, UV, X- and gamma-ray astronomy)	10%
Energetic particles (terrestrially trapped radiation, particle precipitation)	5%
Biology (microgravity effects on living organisms)	4%
Planetology (including zodiacal light)	3%

After the termination of the French national sounding-rocket programme in 1976, only sounding-rocket activities involving international cooperation continued. French scientists contributed to launches jointly carried out with the USSR from the Heyss Islands in the Arctic and from the Kerguelen Islands. French groups also participated with Germany in the Porcupine programme, which was devoted to the study of auroral plasma, with Sweden and with the USA (ten joint flights).

With the phasing-out of the French national programme, most sounding-rocket installations such as those at the Guiana Space Centre were closed down. In the mid-70s that Centre was still being used for rocket campaigns for meteorological sensor inter-comparison and for the Exametnet programme, under which temperature and wind measurements were performed up to 80 km altitude. This programme employed Super Arcas rockets from French Guiana.

Towards the late 1970s, Ariane activities took priority at the Space Centre and made sounding-rocket activities there no longer practicable.

French experiments performed under the ESRO programme 1964-1972

The number of French sounding-rocket experiments performed over the period 1964-72 under the ESRO programme was rather limited, because of the existence of the extensive national programme. The following French experiments were launched by ESRO:

Year	Sounding-rocket type and no.	Range	Payl. no.	Expt. Group	Research area
1964	Centaure (1)	Ile du Levant	C02	IAP	Airglow with photometers
1967	Skylark (2)	Sardinia	S19	IAP	Pressure measurements
1968	Centaure (2)	Kiruna	C45	SAV	Sodium cloud / temperatures
1969	Centaure (2)	Kiruna	C51	FGR	Scattered light measurement
	Centaure (2)	Kiruna	C62	CPL	Auroral electrons & protons
	Centaure (1)	Kiruna	C39	TU	Auroral photometer
1970	Centaure (2)	Kiruna	C48	CEN	X-ray (1.5-3 KeV)
	Skylark (2)	Kiruna	S67	TU	Auroral photometer

* For 1971/72, no data concerning French experiments were found in the ESA archives.

The abbreviations for experimenter groups refer to the following:

CEN:	Centre d'Étude Nucleaires, Saclay
CPL:	Cosmic Physics Laboratory, Meudon
FGR:	Franco/German Research Institute St. Louis, Alsace
IAP:	Institute of Atmospheric Physics
SAV:	Service d'Aéronomie, Verriere
TU:	Toulouse University

In order to make progress with their research, these groups normally made use of all flight opportunities that were offered, i.e. national, ESRO and international cooperation.

Some archived scientific/technical details of the above sounding-rocket experiments are summarised below:

A. *The Luminescence nocturne* experiment conducted by a Paris astrophysics institute (IAP) team (led by Prof. E. Vassy) was an airglow investigation with the objective of measuring nightglow at 5577 and 6300 A above 100 km altitude in the direction of the spin axis of the rocket and perpendicular to that direction. It used three photomultipliers. However, the first experiment conducted failed, due to a malfunction in the photomultiplier amplifier.
The IAP team performed several other sounding-rocket investigations, such as:
- measurement of ions and their masses above 100 km altitude with the help of a mass-spectrometer
- measurement of the vertical distribution of ozone during night-time up to 60-70 km altitude using short-wavelength light emitted at regular intervals

- a further experiment (RN 104) by Dr. Atzei of the IAP team was flown by ESA in October 1967. It measured the vertical distribution of pressure, temperature and density at altitudes between 20 and 90 km. Pressure was measured at the surface of the rocket and at the stagnation point using a gauge
- the IAP team also performed studies of meteoric aerosols above 80 km altitude.

B. The experiment by the CEN Saclay group, led by Prof. J. Labeyrie, had the objective of performing X-ray spectroscopy from space. For this task, the group used proportional counters with an auto-coincidence facility to eliminate particular radiation.

The group also performed other sounding-rocket experiments such as:
- spectrometry of gamma-rays in space, for which scintillation spectrographs were used: a photomultiplier collected gamma-ray scintillations from sodium-iodide (NaI) crystals and from a plastic scintillation counter
- measurement of the intensity of solar X-ray spectra during a solar-flare event: for this, a proportional counter was used, which provided 100 channels for amplitude analysis.

C. The experiment by a team from Toulouse University, led by Prof. F. Cambou, had the objective of performing spectroscopy of auroral protons and determining their contribution to auroral phenomena. The protons' energy distribution throughout the rocket trajectory was measured using solid lithium detectors, as was magnetic deflection.

A further experiment conducted by the University group involved measuring the intensity of the 3914 A nitrogen line and the hydrogen line in an aurora with the help of two photomultipliers and filters centred on these two lines.

D. An experiment by a research team from the Cosmic Physics Laboratory at Meudon, led by Prof. J.E. Blamont, took measurements of local temperatures in the upper atmosphere by observing vibration and rotational spectra of aluminium oxide, ejected by an explosion of TNT carried by a rocket.

Franco - American Cooperation

Rocket type	Altitude	Range/year	Research centre/objectives
2 Aerobee 150	280 km	Wallops Island / Oct. 1963	CNET, Ionosphere irregularities via parallel VLF field strength and local
2 Aerobee 150	280 km	Wallops Island / Sept. 1965	Electron density measurements
2 Dragon 2 Centaure	400 km 190 km	Hammaguir, Algeria / 4 in April 1964	CNES & Goddard Space Flight Center, Charged particles & neutral gas temp.
1 Aerobee 150	280 km	White Sands / Nov. 1964	CNRS: One of several experiments providing special sample surfaces to collect and analyse extraterrestrial dust particles as part of the Luster project
1 Aerobee 150	280 km	White Sands / Nov. 1965	
1 Aerobee 150	280 km	White Sands / June 1967	

4.3 Early activities by Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and United Kingdom

4.3.1 National sounding-rocket/balloon programmes and the Esrange Special Project

The first period of coordinated European effort in the field of sounding rockets lasted from 1964 to 1972, when ESRO operated its first programme. The content and features are described in Chapter 5. However, all the founding ESRO Member States, plus Norway and Austria, which only became ESA Member States in the 1980s, had previously or simultaneously started up national or bi-lateral sounding-rocket activities. These national activities are summarised below in separate subchapters for each country. The French national programme has already been summarised in some detail in Chapter 4.2.

These additional national sounding-rocket activities vary from country to country. Some were predominantly space-science-oriented, such as those of the United Kingdom, Germany and France. Others like those of Sweden and Norway provided launch services in addition to national experiments, thanks to their ideal geographical location and climatic conditions. Spain, in cooperation with the USA and Germany, concentrated on the routine collection of meteorological data with sounding rockets launched from its territory.

Preference for launching sounding rockets for ionospheric studies from northern Sweden/Norway
Although sounding-rocket experiments proposed by research groups in ESRO Member States covered almost the whole spectrum of space sciences, particular interest was shown in experiments that can only be carried out in the auroral zone. Such experiments cover not only the study of auroral particles and auroral photometry, but also certain aspects of solar-particle behaviour, magnetic-field properties, etc., which are in many ways interrelated with high-latitude phenomena. These studies are of great significance, because their results lead to a better understanding of the interaction between the Earth’s atmosphere and solar phenomena.

The quiet ionosphere can of course be studied at high, medium and low latitudes, but studies under disturbed conditions can best be carried out in the auroral region, since the solar particles responsible for the disturbances are drawn towards the poles by the Earth’s magnetic field. About 100 km up, these particles undergo collisions, are slowed down or stopped, and thereby produce disturbance effects such as magnetic storms and aurora. The configuration of the Earth’s magnetic field and the region where solar particles interact with the atmosphere is such that the most intense auroral effects occur at geomagnetic latitudes of about 65° to 70°. This is exactly the latitude range in which Esrange/Kiruna (Sweden) and Andøya/Andenes (Norway) are located.

In addition to auroral studies, there are several other phenomena that occur only at polar latitudes. The most important of these are solar-proton radiation events, which occur at times of strong solar flares. These flares are accompanied by the emission of high-velocity protons, which reach the Earth within 15 to 30 minutes. They penetrate deep into the atmosphere and produce strong ionisation phenomena over the entire polar-cap region. These phenomena are known as polar-cap absorption events and normally extend to a geomagnetic latitude of about 65° and are inevitably accompanied by blackouts of short-wave radio communications.

Esrange Special Project

When the ESRO Council decided to terminate the Organisation’s sounding-rocket programme on 30 June 1972, a second phase of European collaboration on rocket activities began that July, for which the Esrange Special Project (ESP) was established in December 1971. At that point, ESRO transferred its ownership of the Esrange launch base near Kiruna to Sweden. However, the Norwegian Andøya launch base was also included in the Special Project - via a special Swedish/Norwegian Agreement. Coordinated European sounding-rocket research at high latitudes could thereby be continued after ESRO’s activities had ended.

The main building at Esrange, near Kiruna (S)

Initially, eight European countries - Belgium, France, Germany, The Netherlands, Norway, Sweden, Switzerland and the United Kingdom - participated under the ESP Cooperation Agreement over the first five-year period. The Project still operates today, but with fewer participating states, as Belgium left the ESP in 1977, and The Netherlands and the United Kingdom in 1980.

The ESP's objective is to provide sounding-rocket and balloon launch services from Esrange and Andøya. Under the Project, sounding-rocket payload planning and development are carried out by the national organisations of the participating states, which fund their use of the ranges by yearly contributions to ESP and via campaign fees depending on the duration of individual launch campaigns.

Under the ESP, every other year a sounding-rocket and balloon Symposium is held with the support of ESA. During these Symposia, ESP operational and scientific activities are presented and the future trends and planning of sounding-rocket and balloon activities are discussed. The Proceedings of these Symposia are published by ESA.

The Esrange Special Project is still a valid activity today; however, its content was somewhat revised in 2004 and its name changed to the Esrange and Andøya Special Project. The EASP Member States have made long-term commitments, so the Scandinavian ranges will be available at least until 2010.

4.3.2 Early Belgian sounding-rocket/balloon activities

Today, most of Belgium's space-related activities are executed within the framework of its participation in ESA's standard science, applications and infrastructure programmes. During the ESRO period, and even today, the two most active Belgian groups as regards space science were/are the following:
- Institut d'Aeronomie Spatiale de Belgique, Brussels (IAS)
- Institut d'Astrophysique de l'Université de Liège (IAUL).

The IAS has, since the early 1960s, conducted several balloon flights and two sounding-rocket experiments in 1969 under the ESRO programme; whereas the IAUL has participated in a large number (20) of ESRO sounding-rocket programme flights and has performed some rocket experiments bilaterally with French scientists under the French national programme.

The Belgian sounding-rocket experiments mainly concerned auroral UV measurements using spectrometers and compositional photometry of auroral phenomena.

In cooperation with the American Ionosphere Research Laboratory at the Pennsylvania State University, the IAS conducted a programme to measure nitrous oxide, from which the D-layer of the ionosphere originates.

Belgium participated until 1977 in the Esrange Special Project.

4.3.3 Early Danish sounding-rocket activities

Denmark did not participate in the Esrange Special Project, but scientists from the Danish Space Research Institute (DSRI) flew a Faraday-rotation experiment and a few experiments in the field of ionosphere physics, particles and VLF noise, about 20 times over the period 1964 to 1972. In addition, some limited national sounding-rocket-based activity was performed in cooperation with Norway and the USA.

The DSRI's Department for Plasma and Space Physics launched its own sounding rockets from the Søndre Strømfjord base on the west side of Greenland. This base, set up in 1971, was managed and temporarily used by the Danish Meteorological Institute with the support of Danish Army and Air Force personnel. This rocket launch base in Greenland was equipped with mobile launch facilities for Nike, Petrel, and Black Brant sounding-rocket flights.

4.3.4 Early French sounding-rocket activities

French national sounding-rocket activities were described in some detail in Chapter 4.2 above, and so only a few additional remarks will be added here.

The French national sounding-rocket programme for astronomy and magnetospheric research ended in 1976. Thereafter, the only activities that continued were those involving international cooperation, such as cooperative launches with USSR teams carried out from the Heyss and Kergueulen Islands.

In the late 1970s, the sounding-rocket installations at CNES's Guiana Space Centre were closed down in order to avoid interfering with the impending new Ariane launch activities.

4.3.5 Early German sounding-rocket activities

In Germany, the Federal Ministry of Research and Technology has sponsored, via the DLR (Deutsches Zentrum für Luft- und Raumfahrt), a large-scale national sounding-rocket programme since 1963. Numerous German scientific groups have been selected, coordinated, funded and technically supported by:
- DLR Cologne/Bonn for the planning, management and administration of industrial/university contracts for payload development and rocket service systems
- the DLR Operations Centre in Munich-Oberpfaffenhofen for launch and operational services.

Initially, in the 1960s, German scientific groups had opportunities to participate in three different sounding-rocket programmes:
- bilateral cooperation with other rocket-launching countries such as the USA, France, Spain, Sweden and Norway

- ESRO's sounding-rocket programme
- national launches, starting in 1963, and performed since 1967 by the Mobile Raketen Basis (MORABA), a Department of the DLR Operations Centre specialised in providing mobile launch support for sounding-rocket/balloon launch campaigns all over the World.

MORABA, consisting of a team of about 30-50 staff, has for about 40 years been one of the World's most experienced and best-equipped sounding-rocket/balloon launching organisations.

Germany's national programme used predominantly the ranges at Esrange, Andøya, El Arensillo and Natal. The activities performed by MORABA under national and partly bilateral sounding-rocket/balloon campaigns are the following:
- campaign operations
- rocket-motor flight preparation
- radar tracking
- telemetry/telecommand coverage (TM/TC)
- rocket/payload recovery operations
- sounding-rocket/balloon flight analysis
- project coordination
- flight-system provision and operation (service systems for TM/TC and video transmission, recovery systems, rate- and attitude-control systems)
- payload and rocket data processing
- balloon launches.

After the termination of ESRO's sounding-rocket activities in 1972, Germany's national activities were increased and organised into various categories, i.e. topic-based research programmes for the in-depth study of specific scientific problems, such as the:

- Aeronomy programme known as the Western Winter Anomaly Campaign, an integrated sounding-rocket, balloon and ground observation campaign involving 22 German research groups. Under this campaign, 47 sounding rockets and 23 balloons were launched, mainly from the El Arensillo and Andøya ranges.
- Astronomy campaign, during which in the period 1973 to 1977 twelve sounding rockets (Skylark, Black Brant and Aries) were launched from El Arensillo, Woomera and White Sands. This campaign addressed X-ray sources (e.g. Crab Nebula and galactic X-ray sources), UV star photometry and UV measurements of the Sun.
- International Magnetosphere Study (IMS), including in the period 1976-1978 a campaign called Porcupine involving the launching of four large Aries sounding rockets from Esrange and four Skylark-12's from Andøya. This activity was coordinated with electromagnetic-field measurements performed by two geostationary satellites (GEOS and ATS-F).

Similar science campaigns under which sounding-rocket experiments were performed followed in the 1980s and 1990s in the field of ionospheric research.

In the first 35 years (1963-1998) of the German national sounding-rocket programme, some 300 flights were launched. About 40% of them were from Esrange/Kiruna and 20% from Andøya/Norway. This strong German programme contributed to the stability and survival of the Scandinavian launch bases. Other large European countries like France and the United Kingdom predominantly used their own launch ranges.

Furthermore, German scientific groups participated in many sounding-rocket flights launched by other countries, such as the USA, France, Spain, the United Kingdom, Sweden, Norway, Switzerland, the USSR, India, etc. The number of these joint flights is estimated to be at least twice that of national launches. For example, in 1968 the number of cooperative, national and ESRO-launched sounding-rocket flights with German experiments onboard was as follows:

Cooperative:	23
German national:	8
ESRO launches with German experiments:	7

This breakdown underlines the importance of international scientific cooperation as far as sounding-rocket activities are concerned. In the view of the scientists, the pooling of resources in specific research fields or campaigns provides a greater overall output than uncoordinated individual research.

As far as the share of funding of sounding-rocket activities is concerned, a figure was published in a paper by Prof. Gerhard Haerendel in the German scientific journal *Raumfahrtforschung*, No. 1/1976, in which he states that the share of sounding-rocket activities in the five-year period 1973 to 1977 amounted to 50% of the Federal Republic of Germany' space-science budget.

The main research institutions/universities generating German space-science sounding-rocket experiments were the following:

- Max Planck Institut für Extraterrestrische Physik, Garching
- Max Planck Institut für Aeronomie, Lindau
- Max Planck Institut für Kernphysik, Heidelberg
- Arbeitsgruppe Physik und Weltraumforschung, Freiburg
- Physikalisches Institut der Universität Bonn
- Institut für Geophysik und Meteorologie, TU Braunschweig
- Ionosphären-Institut, Breisach
- Universität Bochum
- Universität Heidelberg
- Universität Kiel
- Universität München
- Universität Tübingen
- Franco-German Research Institute St. Louis/Alsace.

First use of sounding rockets for research under microgravity conditions in Europe

In the second half of the 1970s, Germany started the use of Skylark 7 sounding rockets in Europe for research under microgravity conditions (initially fluid physics and materials sciences, and since 1985 life sciences also). These flights were known as Texus missions, this being the German abbreviation for *Technologische Experimente unter Schwerelosigkeit*. The Texus initiative was to a certain extent prompted by the need to perform precursor experiments for Spacelab missions. In the 1980s, ESA included sounding-rocket flights for research under microgravity conditions in its Microgravity Research Programme, in order to make flight opportunities available for scientists from all of its Member States. ESA used Texus/Skylark, Maser/Black Brant and Maxus/Castor 4B vehicles.

Also, Sweden, from where all German and ESA microgravity research-dedicated flights were launched, started a similar smaller-scale programme of its own in the 1980s. It used Black Brant sounding rockets for this new activity, and called it the Maser programme.

Preparation of the payload for the first Texus flight from Esrange in December 1977

4.3.6 Early Italian sounding-rocket activities

In Italy, space research is overseen by the Committee for Space Research (CRS), which is an advisory body of the National Research Council (CNR). The Secretariat for Space Activities (SAS) of that Council is the executive body for all its sponsored space programmes.

After ESRO terminated its programme, Italian national sounding-rocket activities were terminated earlier than those of the other larger ESRO/ESA Member States. The reasons for this might have been that auroral research was not possible from the sounding-rocket base in Sardinia and that solar/celestial astronomical studies were more effectively performed by satellite experiments.

However, the extension of the well-equipped military rocket base at Salto di Quirra on the island of Sardinia to provide, from 1960 onwards, for civil scientific sounding-rocket launches also, resulted in a large number (140) of national launches in the 1960s. In 1961/1962, eight cooperative US/Italian campaigns were carried out using American Nike-Cajun and Nike-ASP rockets. These cooperative flights were used to release sodium vapour at altitudes of 80 to 200 km into the upper atmosphere. The illumination of these vapour clouds was used to measure upper-atmosphere winds via ground photography.

Italy's national sounding-rocket activities peaked in 1963/1964 when 119 rockets (mainly Arcas, Robin-Sonda and Marquardt 200/C rockets) were launched to altitudes of between 60 and 280 km.

Under the ESRO sounding-rocket programme, about 40 Italian experiments were flown in the period 1966 to 1972 from the ranges in Sardinia, Kiruna and Woomera. These experiments had various scientific objec-

Preparation of a Centaure sounding rocket for launch from Salto di Quirra in Sardinia (I) in July 1965 tives, including:

- measurement of low-energy photon fluxes
- measurement of celestial gamma-rays
- study of neutron albedo
- measurement of the intensity of X-ray sources in the southern hemisphere.

The main Italian research institutes involved in these national, cooperative and ESRO-operated sounding-rocket flights were:

- Astronomical Observatory of Rome
- Physics Institute of the University of Bari
- Physics Institute of the University of Bologna
- Physics Institute of the University of Milan
- Physics Institute of the University of Turin.

Italy did not participate in the Esrange Special Project established by eight European countries in 1972 when the ESRO programme was terminated.

Since 1972, hardly any launches from Sardinia have been reported. However, Italy also operated the San Marco equatorial range in Kenya, from which for example Scout rockets were launched from time to time.

4.3.7 Early Dutch sounding-rocket activities

Space research in the Netherlands started in 1961 with the creation of the Committee for Geophysics and Space Research (GROC), at the Royal Netherlands Academy of Arts and Sciences. GROC was in charge of coordinating, stimulating and funding scientific space-research activities.

Experimental Dutch space research started in 1965 with sounding-rocket experiments flown under the ESRO programme and atmospheric balloons, and shifted to satellite activities after the termination of ESRO's programme in 1972.

There was no programme of national launches in the Netherlands and in 1972 the Dutch authorities first decided to join the ESP for 5 years, and then later for another 3 years until 1980.

A few sounding-rocket experiments in the field of soft X-rays were flown in 1978 within the framework of Dutch/American cooperation between the Space Research Laboratory of Utrecht and Stanford University.

Another international joint effort in the field of soft X-rays from stars in the energy range 100 eV to 15 keV was carried out in 1976 by the University of Leiden and the Japanese University of Nagoya.

In the period 1965 - 1971, about 30 Dutch sounding-rocket experiments were flown within the ESRO programme. These experiments addressed mainly the following scientific objectives:

- solar X-rays measured by X-ray spectrometers and heliographs carried by sounding rockets launched by ESRO from Sardinia, Greece, Esrange/Kiruna and Andøya/Norway
- cosmic-ray studies using rocket-borne Geiger Müller counters and proton spectrometers.

The following Dutch research institutes were involved in these experiments:

- Space Research Laboratory at the University of Utrecht
- Cosmic-Ray Working Group at the University of Leiden
- Department of Space Research at the University of Groningen
- Satellite Geodesy Working Group at the Technical University of Delft.

Dutch sounding-rocket experiment activities started up again in the late 1980s under the ESA Microgravity

Research Programme, which included regular launches from Esrange. This Optional Programme was approved in 1982 and the Netherlands immediately participated in it (as it still does today).

4.3.8 Early Norwegian sounding-rocket activities

Although Norway was never an ESRO Member State and joined ESA only in 1987, it was Norway that started ionospheric research back in 1928, when the World's first auroral observatory was established in Tromsö, north of the Arctic Circle.

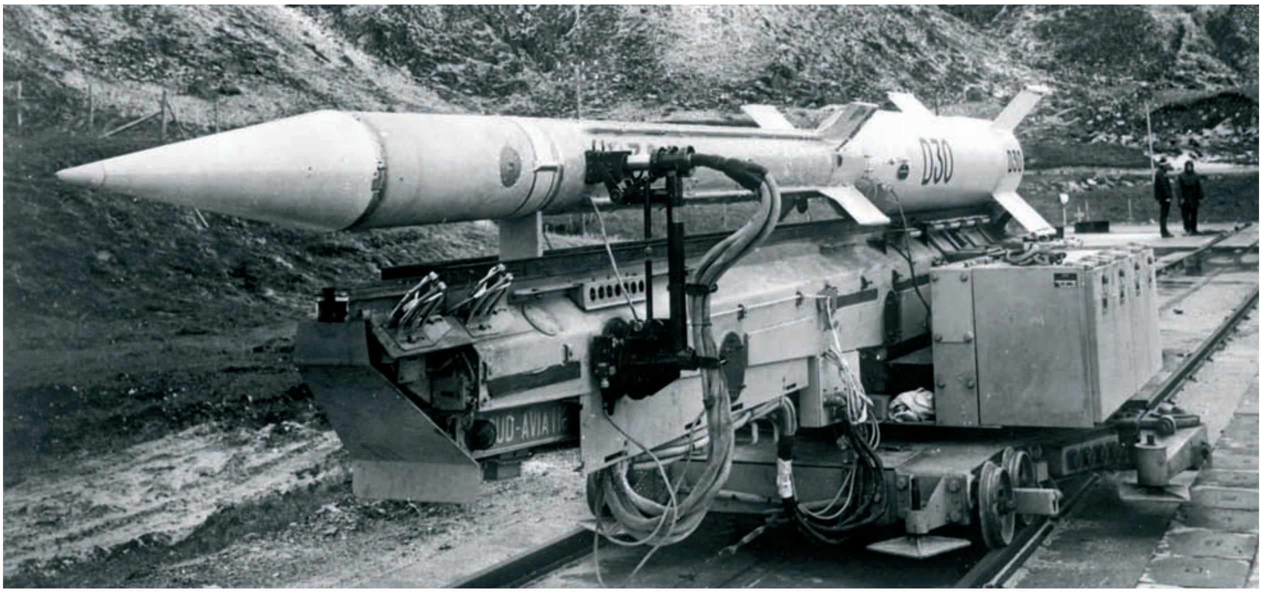
This observatory conducted the first ground-based ionospheric and radio-wave-propagation studies, because long-distance radio communications were suffering blackouts during solar storms, when strong auroral events occurred. These ionosphere-related studies were supported and reinforced in 1932/1933 during the International Polar Year, when research groups from the USA, Canada, Germany and the United Kingdom cooperated with the Norwegians with the objective of understanding the physics of the ionosphere, which seemed to reflect or absorb long-distance radio waves depending on its changing physical properties.

During the Second World War, the German occupation forces continued these studies and established two new ionospheric data centres in Tromsö and near Oslo, in order to support long-distance radio systems for their navy and air force communications during the war. Shortly after the Second World War, the Cold War started between the USA and the USSR and space technology became an important factor.

Norway joined Nato for security reasons, because it had a common border with the USSR in the Arctic region and internationally-agreed joint administration of the Spitzbergen Islands, where more Soviet miners lived than Norwegians.

The Soviets were keen to ensure that Norway remained as neutral as possible during the Cold War. The prevailing climate of suspicion was one of the reasons why Norway hesitated to join ESA when it was set up in 1973. At this time, both the Americans and the Soviets considered ionospheric research and radio-wave communication to be of strategic importance, all the more so as intercontinental ballistic missiles armed with atomic warheads were planned to cross the Norwegian part of the Arctic Sea in any military conflict.

Besides the military interest in understanding disturbances to radio communications, the changing properties of the ionosphere and the associated communication blackouts were also of economic importance for Norway's shipping and fishing industries. Owing to the strategic importance of the polar region, Nato



Transport of a Dragon sounding rocket from the assembly hall to the launch pad at Andøya in 1967

The Andøya facilities, photographed in the 1970s

equipped the Norwegian ionospheric laboratory with the most modern electronic instruments and built an airport at Andøya on the island of Andenes. Located on the coast of the North Atlantic/Arctic Sea, Andøya is well-suited to being a sounding-rocket launch site in the auroral belt (see sub-chapter 4.3.1 for further advantages of sounding-rocket bases in the polar region).

In 1962, the first sounding-rocket campaign was carried out from Andøya in the framework of cooperation between Norway, the USA and Denmark. The US Air Force provided the rockets for this campaign (4 Nike-Cajuns). In the subsequent years, to date almost 300 scientific sounding rockets, more than 400 small meteorological rockets and about 200 test flights of new or improved rocket types have been launched from there. Most of the science missions were launched by the Norwegians in the framework of cooperation agreements with other countries. Norway has always supported international cooperation for peaceful activities.

Both bases - the one near Kiruna in Sweden and the one at Andøya in Norway - are ideally located in geographical terms, being slightly north of the Arctic Circle where auroral phenomena can be studied best. The Kiruna base offers on-land recovery, an advantage for payloads that have to be returned to a ground laboratory. However, the almost-unpopulated sounding-rocket impact area north of Kiruna is limited in size and extent, so that the larger rockets needed to be equipped with guidance systems.

Andøya offers splash-down recovery in an almost unlimited area of the Arctic Ocean. However, the launching of rockets with high dispersion was considered too risky because of the close proximity of the city of Andenes.

When the ESRO precursor-organisation COPERS had to select the site where ESRO would erect its Esrange sounding-rocket launch base, it set up a working group for this task. The scientific, technical, security, political and economic advantages/disadvantages of both sites (including ease of travel and housing) are described in great detail in *Making Sense of Space: The History of Norwegian Space Activities*, edited/published in 1994 by John Peter Collet.

In the end, Kiruna was chosen to establish Esrange. However, ESRO itself, its Member States and the USA still used Andøya whenever there was a scientific/technical advantage for a specific sounding-rocket mission to do so. Germany's national space programme, for example, has used Andøya more than 60 times.

Esrange was inaugurated in 1966 and its ownership was transferred to the Swedish authorities in July 1972.

While at that point in time coordinated European sounding-rocket activities continued under the Esrange Special Project, Norway was not yet able to join the ESP as a Member State, but Andøya was included in the Project under a separate special Swedish/Norwegian add-on agreement as its second launch base. Norway has participated to date in all meetings of the ESP Programme Advisory Committee (PAC) and has contributed to ESP funding.

Norway considered the choice of Kiruna as a setback, but was to a certain extent compensated by ESA, which installed satellite receiving stations for its space-science programme at Spitzbergen and Tromsö, operated by Norwegian personnel.

84 sounding-rocket launches that took place during the first five-year period of the ESP Agreement (1972-1977), 49 of which were launched from Andøya and 35 from Esrange/Kiruna. The Andøya base was initially better suited (safer due to the larger impact area) for the new heavy-lift rocket types like Aries, which was able to launch 500 kg payloads to altitudes of over 500 km, and Skylark 12, which launched 100 kg payloads to 900 km altitudes. Later, the Swedish Space Corporation, in cooperation with the rocket builders, developed special guidance systems for these large rockets, so that launches from Kiruna with land recovery became possible.

4.3.9 Early Spanish sounding-rocket activities

In Spain, the government entrusted the coordination and financing of space research to the Comision Nacional de Investigacion del Espacio (CONIE). INTA is its technical centre for the support and execution of space projects. It operates the El Arenosillo sounding-rocket launch range southeast of Huelva, from where rockets are fired over the Atlantic.

Spanish sounding-rocket activities started in 1966. By early 1969, 61 launches with Spanish participation had already taken place, mainly for conducting meteorological measurements:

- 5 national launches using Skua 1 rockets for temperature and wind measurements in the stratosphere at altitudes ranging between 50 and 68 km

- 39 cooperative INTA-NASA launches with 30 Judi and 4 Nike-Cajun rockets to perform stratospheric wind measurements using radar tracking, interferometers and acoustic Doppler measurements, with the latter made possible by Nike-Cajun rocket grenade explosions

- 17 cooperative INTA-German (Max Planck Institute) launches of Skua II rockets for wind measurements in the ionosphere at altitudes of between 70 and 100 km.

The INTA/NASA joint meteorological sounding-rocket programme was reinforced in 1977 when 60 Super Lokis were launched from El Arenosillo.

By mid-1969, Spain had developed its own sounding rocket, the INTA 100 and the INTA 300, the first of which was able to carry a payload of 18 kg to 150 km altitude.

The scientific launches using Skua, Centaure, Nike-Cajun and Nike-Apache rockets were extended to study the minor constituents of the D-layer of the ionosphere.

Spain pursued a strong programme of joint sounding-rocket activities, but participated in neither the ESRO flights nor the Esrange Special Project.

4.3.10 Early Swedish sounding-rocket activities

Sweden began its first space-research-oriented activities in 1959. It had at the time, when European space programmes, structures and organisation were being discussed, the right individuals in scientific, technical and political circles, sharing a vision of the future importance of space activities. These key individuals were able to recognise the unique geographical situation of the most northern part of Sweden, which is favourable for conducting space physics and applications experiments with the help of sounding rockets.

The history of Swedish space activities is well described by space pioneer Jan Stiernstedt in *Sweden in Space*, published in Swedish in 1997 and translated into English by ESA in 2001 (ESA SP-1248). Stiernstedt was not a scientist, but held very important positions in the Swedish government and in the Ministry of Education and Culture. He was deeply involved in and contributed to the creation of national and European (ESRO/ESA) space structures from the early 1960s until the end of the 1980s. From summer 1964 onwards, he served for a total of 25 years as chief Swedish delegate on the ESRO and ESA Councils.

A second book on Swedish and European space history was also first published in Swedish in 1996 by the space scientist Prof. Bengt Hultqvist, the first Director (1956-1994) of the Kiruna Geophysical Observatory (KGO). This book was also translated into English by ESA in 2003 (ESA SP-1269).

Hultqvist was the initiator, and became the founding father, of the Kiruna sounding-rocket centre, which later became Esrange. He secured backing from the right political and scientific dignitaries in his country for his ideas. As an expert in the fields of atmospheric physics and ionospheric research, he was able to formulate convincing scientific/technical arguments in favour of locating a sounding-rocket launch base near to a research centre. He and his colleagues persuaded Swedish political decision-makers to play a neutral European hand, rather than orient national space research too much towards the USA. This attitude, along with the scientific environment on offer, was certainly one of the main reasons that prompted COPERS, the ESRO precursor organisation, to select the proposed site near Kiruna as a European sounding-rocket launch base.

The Swedish politicians having responsibilities in this regard had well understood that the establishment of Esrange near Kiruna was not only very important for national space science, but also for the economy of the entire Kiruna region. From Sweden's membership of CERN, the politicians had learnt that neighbouring countries Switzerland, France and Italy had been able to reap greater benefits from their membership of that Organisation than Sweden, due to their proximity to the facilities. In addition, Swedish politicians responsible for research had more clearly understood than other Europeans the overall importance of space technology and research for advances in high-tech industry, communications, Earth observation from space and scientific research.

Therefore, Sweden linked its possible membership of ESRO to a decision to select Kiruna as an ESRO sounding-rocket launch base. The decision in favour of Kiruna was taken by COPERS on 7 March 1964.

National Swedish sounding-rocket activities had already started in August 1961, i.e. long before Esrange became operational. The first launch in Sweden was performed from Kronogärd, where an interim launch facility had been erected for the first five years until Esrange was inaugurated in September 1966. The first launch from Esrange took place on 20 November 1966.

Swedish space-science groups participated successfully in the ESRO sounding-rocket programme (the selection of experiments always took place after competition at European level) as well as in the national programme, which was almost exclusively arranged on a bilateral or multilateral cooperative basis. The most important element of these bilateral cooperative activities was the Sweden/NASA launch programme in the period 1961 to 1965. In the context of the latter, four cooperative launches were performed from White Sands in New Mexico (1961-1963) and one from Wallops Island on America's Atlantic coast (1964). In 1965, four Swedish launches were also carried out from Norway's Andøya base.

Night launch of a Nike-Apache sounding rocket from Esrange in August 1969

Swedish scientific groups flew a total of 68 sounding-rocket experiments from Kronogärd or Kiruna over the period 1961 to 1971 under the national/bilateral programme, and 27 experiments under the ESRO programme. The scientific profile of these 95 Swedish experiments was as follows:

Atmospheric physics:	43%
Ionospheric research:	21%
Energetic particles:	28%
Micrometeorites:	8%

The Swedish scientific groups involved in this first phase of sounding-rocket activities were as follows:

Kiruna Geophysical Observatory	35 experiments
Institute of Meteorology, University of Stockholm	31 experiments
Uppsala Ionospheric Observatory	11 experiments
Lund Observatory, University of Lund	9 experiments
Plasma Physics Department, Royal Institute of Technology, Stockholm	5 experiments
Physics Department, University of Lund	4 experiments
Total:	**95 experiments**

A second phase of Swedish activities at national level started after ESA had transferred the ownership of Esrange to Sweden on 1 July 1972. Since that time, the Swedish Board for Space Activities (SBSA), later renamed the Swedish National Space Board, has been responsible for all government-funded space activities in the country and for the supervision of international sounding-rocket launches from Swedish territory. The technical execution of the various space programmes is entrusted by SBSA to the Swedish Space Corporation (SSC), a state-owned company.

The SSC also took on the managerial and operational responsibility for all sounding-rocket launches from Esrange.

Over the first five-year period (1972-1977) of the ESP Arrangement, 17 Swedish sounding-rocket experiments were flown from Esrange. Launch activities continue to this day.

However, interest in launching atmospheric/ionospheric research sounding rockets has declined in the last two decades. Over this period, the emphasis of the Esrange sounding-rocket activities has shifted slowly from space science towards research under microgravity conditions. In this new research field, which started in 1977 with the first sounding-rocket launch of Germany's Texus programme and increased in the 1980s with launches carried out under ESA's Microgravity Research Programme and the Swedish microgravity programme, larger sounding rockets such as Skylark 7 and Black Brant (both housing 350 kg payloads) and Castor 4B (almost 800 kg) predominate. For this new type of sounding-rocket activity, which is mainly devoted to materials science, fluid physics, combustion and biology under microgravity conditions, a new laboratory infrastructure for experiment preparation and post-flight analysis has been set up at Esrange.

4.3.11 Early Swiss sounding-rocket activities

For the duration of the ESRO sounding-rocket programme, Switzerland had no separate national sounding-rocket launch activities.

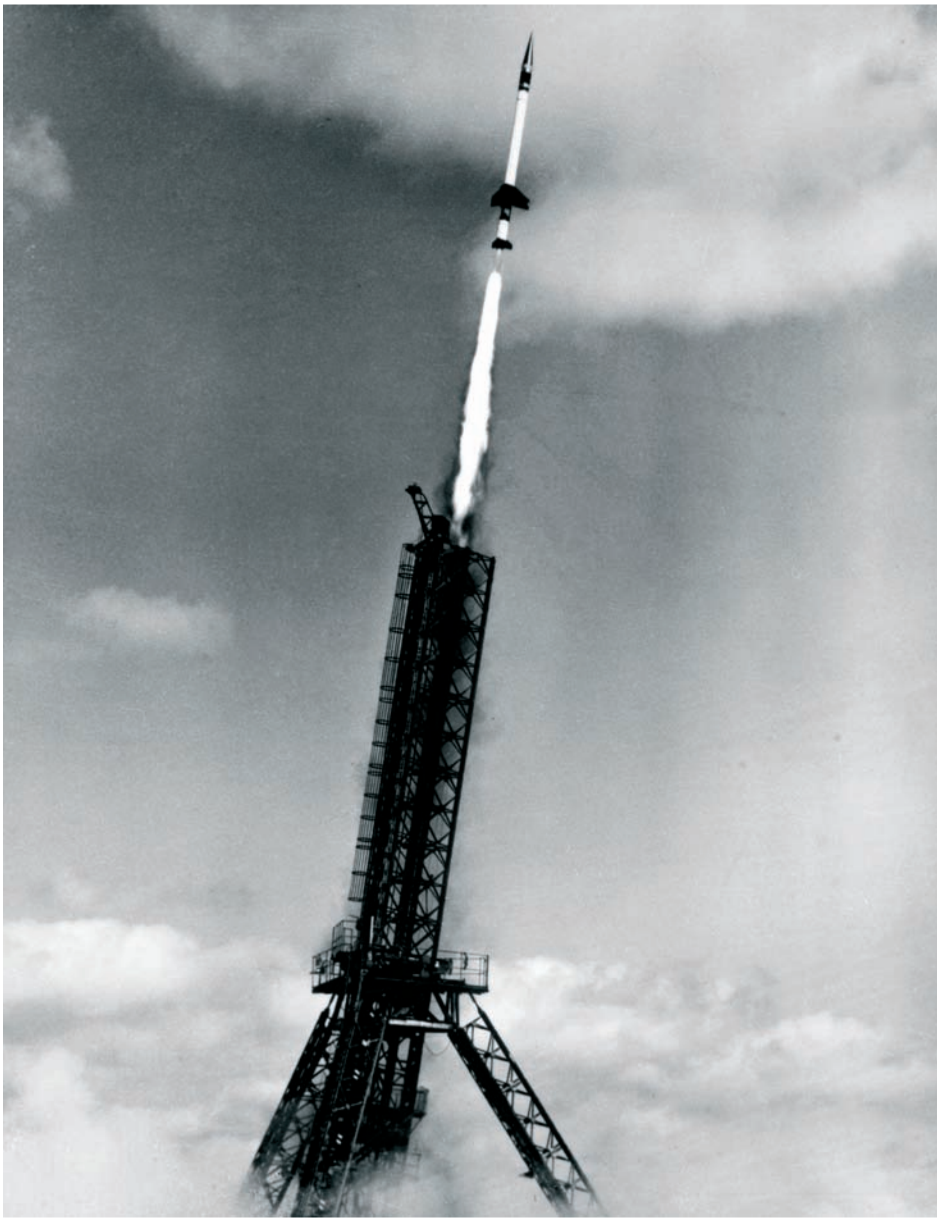
Under the ESRO programme, the first two pairs of Swiss experiments were developed by the Physikalisches Institut der Universität Bern. They were flown on ESRO Skylark flights in:

- January/February 1970 from Esrange/Kiruna: neutral and ion mass-spectrometer
- November 1970 from Salto di Quirra/Sardina: upper atmosphere ion mass-spectrometer.

Since 1972, Switzerland has been an active participant in the Esrange Special Project, and the science group at the University of Bern has, in cooperation with groups from Germany (Max-Planck-Institut für Kernphysik, Heidelberg) and the USA, implemented a programme of two flights per year in the field of mass-spectroscopy of the upper atmosphere. This sounding-rocket activity was coordinated for a certain period with measurements made by the Bern University team using ESA's GEOS satellite.

4.3.12 Early United Kingdom sounding-rocket activities

In the 1960s, the United Kingdom had the largest programme of sounding-rocket activities (national plus involvement in ESRO programme) of all the ESRO Member States. The UK national programme was comparable to that of France in terms of numbers of launches and in that it used predominantly - like France - national launch bases and domestic technology.



Launch of a Skylark sounding rocket from Woomera in South Australia

The UK space-science community made more use than any other Member State of the opportunities provided by the ESRO programme. The UK had started as early as 1957 launching British Skylark rockets with payloads of about 100 kg to altitudes of up to 300 km from the Woomera launch base in Australia.

With the development and application of sounding-rocket attitude stabilisation and control/guidance systems, the UK's interest in Woomera shifted steadily towards astrophysical research, because Woomera's location in northern Australia makes it well-suited to Galactic Centre studies. When the high-latitude and well-equipped Esrange launch site at Kiruna became available in late 1966, UK science groups were very keen to perform geophysical experiments on auroral phenomena and related Earth magnetic-field studies from this Arctic location.

Besides the Skylark rockets, the smaller British Petrel rocket (11 kg payload capability up to altitudes of 160 km) was used to conduct campaigns from the British island of South Uist, one of the Hebrides Islands in the Atlantic. Other launch bases used by the UK programme were those of Thumba (India), Sommiani (Pakistan) and Andøya (Norway). In addition, the UK used an even smaller and less expensive rocket, the Skua II, which had a payload-carrying capability of only 2.5 kg to altitudes of up to 100 km. Whereas the Skylark rocket was spin-stabilised and offered a Sun-pointing, field-pointing and star-pointing capability, the two smaller rockets had only spin-stabilisation of 8-6 rps (Petrel) and 14 rps (Skua II). Both smaller rockets had the additional disadvantage of very high acceleration levels of about 60g, whereas the maximum acceleration of Skylark at launch was only 12g. In addition, Skylark was the only British rocket for which a parachute-based land-recovery system had been developed by national industry.

The records show that just over the period 1961-1968, the number of UK experiments exceeded 400. The split between nationally-flown sounding rockets and experiments flown via ESRO was as follows:

UK programme:	127 launches, 333 experiments
ESRO programme:	45 launches, 75 experiments

The rockets used for the 127 national launches were:

- 103 Skylarks from Woomera
- 11 Petrel and 13 Skua II from South Uist.

In the five following years (1969-1974), the size of the national programme was slightly scaled down to the following annual launch rates:

- 10 to 12 Skylark rockets launched from Woomera, carrying stabilised payloads with predominantly astronomical experiments (average: 3/year)
- 30 Petrel rockets launched from South Uist (20/year), Esrange/Kiruna (5/year) and 5 other launches per year from various ranges.

The experiments flown by the Petrel rockets covered research in the fields of atmospheric physics, ionospheric research and particle physics.

In addition to the purely national flights, the UK Science Research Council (SRC) made bilateral cooperation arrangements with a number of countries, predominantly the USA and Commonwealth countries.

As far as the breakdown of UK experiments by scientific discipline is concerned, the World Data Centre's Rocket Discipline Code Division shows the following picture for 1968, a typical year:

Scientific discipline	ESRO-flown UK experiments	Nationally-flown UK experiments	Total number UK experiments
Atmospheric physics	4	3	7
Ionospheric research	6	32	38
Energetic particles	-	3	3
Geomagnetic fields	1	1	2
Solar physics	1	10	11
UV and X-ray astronomy	4	2	6
Total:	16	51	67

This table clearly shows the predominance of ionospheric experiments performed by the UK science groups.

In 1972, the UK joined the Esrange Special Project for the first five-year period. Thereafter, however, the UK space authorities decided to extend their ESP membership only until 1980.

In the UK, the responsibility for formulating, funding and executing scientific research lies with the Science Research Council through its Astronomy, Space and Radio Board (ASRB). The ASRB is advised by several scientific committees on the allocation of funds to research groups and central facilities.

During the 1970s, the UK sounding-rocket programme was managed by the SRC's Appleton Laboratory.

After 1977, national sounding-rocket activities were cut back significantly, with only a few launches being carried out from time to time using surplus rocket/experiment hardware.

Sounding-rocket payload including impedance- and Langmuir-probe experiments, shown here with their booms deployed, being readied for launch from Sardinia in September 1967

5. ESRO's First Sounding-Rocket Programme (1964-72) Devoted to Space Science

Even before the formal setting-up of ESRO in 1964, the predecessor organisation COPERS (see Chapter 3) had already decided from the outset that an international sounding-rocket programme and a scientific-satellite programme should become the two pillars of the first eight years of ESRO activity.

Initially, the sounding-rocket programme was four times larger in annual budget terms than the satellite programme. This situation was reversed, however, in the early 1970s,when the ESRO Council decided on 14 July 1971 to terminate its sounding-rocket activities in 1972 and to extend the scope of the European (i.e. ESRO) space programme from 1973 onwards with the start-up of new application satellites (telecommunications, Earth observation) programmes, the development of the Ariane launcher, and the construction of the Spacelab laboratory, Europe's contribution to the US Space Shuttle programme. This fundamental change in European space policy was associated with the transformation of ESRO into ESA, the European Space Agency.

The ESRO Council's decision to terminate ESRO/ESA sounding-rocket activities did not call into question the value of such activities, but reflected the Member States' desire to reduce the financial envelope of the Mandatory Programme, of which the Science programme constitutes the largest component. The sounding-rocket programme was selected for termination within ESA because this move was considered to cause the least damage, taking into account the fact that all of the larger Member States, such as France, the United Kingdom and Germany, as well as Sweden and Norway, could continue their existing national programmes.

The initial motivation for starting a large-scale sounding-rocket programme within ESRO in 1964 had been to foster scientific cooperation between space scientists from all ESRO Member States and to share and optimise the scientific results of sounding-rocket experiments. The ESRO programme was designed to be complementary to, rather than compete with, the various national programmes, several of which had already existed before ESRO was formally set up.

The ESRO policy of starting with sounding-rocket activities was based on exploiting two major advantages of rockets compared to satellites:

(a) relatively short payload development and integration times, due to the lower safety and reliability requirements, and

(b) considerably lower project costs at Agency and national laboratory level, because the personnel and administrative efforts associated with payload development, integration and flight operations were seen to be much lower than for satellite missions.

Sounding-rocket activities allowed the continuation and extension of laboratory-type experimentation and made it possible - in contrast to satellite experimentation - to take higher risks during payload and rocket subsystem development and to apply new technologies. Sounding rockets provided the ideal transition stage from scientific laboratory working methods to later satellite experimentation. Sounding-rocket payload development served as an educational tool for learning how to build scientific equipment that could survive the harsh launch environment (several 10's of g) experienced by sounding-rocket payloads and small satellites.

In addition, sounding-rocket and scientific-satellite activities were complementary, so that sounding rockets were used in the following domains where satellites/balloons could not be used or would be a much more expensive alternative:

Beginning of an era: sounding-rocket nose cones in the first ESRO offices in Delft (NL) in 1964

- Research at altitudes between 40 and 200 km.
- Measurement of vertical profiles of characteristics of the ionosphere's D, E or F-layers during the rocket ascent phase.
- Investigations for which the measurement technologies require that the relative payload instrument/ environment velocities are lower than those achievable with orbiting satellites (e.g. mass-spectrometry of complex molecules, electrical fields, etc.).
- Study of unpredictable transient events such as aurora appearances in the upper atmosphere of polar regions, i.e. sounding rockets were used predominantly for short-term observation of the transient phenomena associated with magnetic storms, solar flares and for radiation measurements, e.g. during eclipses, etc. In this context, it is important to recall that the timing of a sounding-rocket launch can be chosen to coincide with the occurrence of transient events, whereas a satellite - once launched - must follow its pre-selected orbit and may not be in the right place at the right time. The shorter observation period available during sounding-rocket flights is offset by the lower costs and shorter preparation times of the experiments, in addition to the ability to recover film cassettes or collect trays.
- Development and calibration of scientific instruments destined for subsequent satellite launches.
- Development of spaceflight-related technical capabilities such as Sun and star pointers, three-axis-stabilised attitude-control systems, telemetry and telecommand systems, transmitters to relay data and pictures back to the ground, power-conditioning systems, thermal-control systems, i.e. development, testing and qualification of all the major technical constituents of a satellite except for the solar arrays.

General conclusion regarding the contribution and benefits of sounding-rocket programmes to the creation of European space activities:

The significance of sounding-rocket activities for the establishing of European-level space programmes can hardly be overestimated, because ESRO itself, the existing scientific laboratories and interested industrial firms all gained invaluable experience by establishing a solid technological base on which ESA's present scientific and applications-oriented missions are grounded.

Its sounding-rocket activity enabled ESRO to demonstrate the European capability to put space science and applications experiments into space and get results back on the ground.

The European companies and/or their successors such as BAe, SNIAS/Sud Aviation/Aerospatiale, Dornier/EADS, CASA, Air Italia/Alenia, Saab, etc., which were involved in early sounding-rocket payload and rocket-subsystem development and integration activities, are still major European space players today. The same is the case for the prominent space-science institutes (see Table 5.6 below), key scientists and their successors.

5.1 Some ESRO sounding-rocket programme statistics (1964-72)

The first two sounding-rocket payloads for an ESRO programme were selected in October 1963 and were provided by the following laboratories:
- Institute d'Astrophysique de Liège (Dr. Rosen)
- Max Planck Institut für Extraterrestrische Physik, Munich-Garching (Prof. Lüst).

The two experiments had the objective of releasing substances such as ammonia and barium into the ionosphere and studying photo-decomposition, diffusion characteristics and wind velocities in the ionosphere from the ground. The first launch campaign took place in late June/early July 1964 from the Italian military Salto di Quirra rocket range in Sardinia, where an existing launch tower had been modified to accommodate Skylark rockets using Cuckoo boosters.

The second ESRO launch campaign took place in October 1964 from the French rocket-launching base on Ile de Levant in the south of France, using a Centaure rocket, which for the first time in Europe carried a telemetry system.

Under the ESRO programme, 184 sounding rockets were launched in the period 1964-72. The ESRO programme employed eight different types of rockets, with the British Skylark and French Centaure rockets being the most frequently used (see Table 5-1):

Table 5-1. Sounding rockets used by ESRO in the period 1964-74 (source: ESA BR-60)

Rocket type	Country of origin	No. of launches
Skylark	United Kingdom	83
Centaure	France	64
Skua	United Kingdom	15
Arcas	USA	14
Dragon	France	4
Belier	France	2
Petrel	United Kingdom	1
Zenit	Switzerland/Germany	1

Annual launches of ESRO sounding rockets and their success rates were published by ESA in ESA BR-60 (by D. Eaton) in 1989 (see Table 5-2):

Table 5-2. ESRO sounding-rocket launches by year

Year	No. of launches	Success rates in %
1964	3	100%
1965	8	38%
1966	27	52%
1967	18	67%
1968	20	80%
1969	26	77%
1970	26	85%
1971	43	86%*
1972	12	93%

* Excluding the 15 standard meteorology soundings.

By far the largest numbers of ESRO sounding rockets were launched from Esrange near Kiruna (Sweden) and from the Salto di Quirra range on Sardinia. A large proportion of the rockets launched from Sardinia were equipped with Sun- or star-pointing facilities. In addition, the range in Sardinia was used for mid-latitude atmospheric studies. The ranges on the Ile de Levant and on the Island of Karystos (Greece) were used for special campaigns (e.g. solar eclipses), whereas Andøya, the rocket range in Norway, was used for large rockets such as Dragon, which could not be launched from Esrange. The Woomera range in Australia was used for launches of star-pointing rockets designed to observe the southern sky.

Transport of a Centaure sounding rocket to the launch site at Karystos in Greece in May 1966 and the subsequent launch

The numbers, country of origin (Table 5-3) and objectives of the experiments flown under the ESRO programme are well-documented in ESRO publications SP-76 to SP-80 for the years 1964 to 1970. However, no publications were to be found in the archives of ESA or the Swedish Space Corporation for the years 1971 and 1972. This is probably due to the fact that in 1971, as already stated, the ESRO Council decided to terminate rocket activities in 1972 and the associated sounding-rocket team was disbanded in 1972/1973.

Table 5-3. Annual numbers/country of origin of sounding-rocket experiments flown by ESRO

Origin of experiment	Number of experiments							Total no.
Country	1964	1965	1966	1967	1968	1969	1970	
Belgium	1	-	2	-	1	4	(3)	11
Denmark	-	-	5	3	2	1	(0)	11
France	1	-	-	2	2	5	(1)	10
Germany	1	4	5	7	5	9	(21)	52
Italy	-	-	-	1	1	2	(1)	5
Netherlands	-	1	3	3	2	2	(3)	14
Spain	-	-	-	-	-	-	(1)	1
Sweden	-	-	1	2	6	4	(4)	18
Switzerland	-	-	-	-	-	-	(2)	2
United Kingdom	-	5	13	13	14	8	(25)	78
ESRO/ESLAB	-	-	-	-	1	2	(-)	3
Total	3	10	29	31	34	37	61	205

( ) refers to data drawn not from official ESRO publications, but from archived internal reports.

With regard to the figures given in Table 5.3, it has to be recalled that almost all of the ESRO Member States conducted, in addition to the experiments listed here, either national or bilateral sounding-rocket launches, in most cases with NASA. The total number of scientific sounding-rocket experiments per ESRO Member State carried out in the period 1964 to 1974 was published in ESRO SP-97, and is shown together with the corresponding research areas in Table 5-4.

B:	20	(ATM, ION, STAR)
CH:	7	(ATM, ION)
D:	95	(ATM, ION, SUN, STAR, PLASMA)
DK:	32	(ATM, Propagation)
E:	3	(ATM, STAR)
F:	20	(ATM, ION, SUN, PLASMA)
I:	10	(STAR, PLASMA)
NL:	18	(ION, SUN)
S:	26	(ATM, ION)
UK:	163	(ATM, ION, SUN, STAR, PLASMA)
Total:	394	scientific experiments

Table 5-4. Total number (national + ESRO) of scientific (i.e. excluding technology and meteorology) sounding-rocket experiments and their research area by Member State (1964-74)

The results and merits of the ESRO sounding-rocket programme cannot be measured solely in terms of the numbers of rockets and experiments flown. For many scientific groups in Europe, sounding rockets represented their first contact with space-based experiments. There was remarkable progress in many scientific laboratories between the time of their first sounding-rocket experiment and their first involvement in advanced satellite experiments a few years later.

Of the order of 40 scientific groups were active under ESRO's sounding-rocket programme. This clearly played an important role in building up strong European-level space-research communities, which - for several decades - and still today, together with their American counterparts, are leading the global space-science effort.

The ESRO sounding-rocket programme was, especially for scientists in the smaller Member States, the only opportunity on offer to participate in space-science activities. Also, scientists from non-ESRO Member States such as Austria cooperated with Scandinavian sounding-rocket programmes. Norway also participated in these ESRO activities, having in addition embarked on a programme of its own.

Whereas the larger ESRO Member States - Germany, France and the United Kingdom - covered a wide range but for financial reasons not all fields of research (see Table 5.5, based on ESRO SP-97), there was a tendency for the smaller and the southern countries to concentrate on astrophysics. The Scandinavian countries have a long tradition of experimentation associated with auroral phenomena.

ESRO, as a European-level organisation, was the natural choice for the development of pointing devices, because this need was expressed over time by more and more investigators and because the testing of these devices required costly checkout equipment. In addition, the task of payload integration was taken over by ESRO, because not all Member States had gained the necessary experience in the preparation and testing (e.g. electromagnetic compatibility) of complex payloads.

An important lesson learnt during sounding-rocket experimentation was the growing conviction of the research community that cooperation was the only way to arrive at optimum solutions for multi-experiment payloads. Towards the end of the ESRO programme, the payloads were much more sophisticated in terms of instrument development, mechanical/electrical/thermal testing and data analysis than in the mid-1960s.

Table 5-5. Experience gained by various Member States in different sounding-rocket research fields

Field of research	Larger MS			Smaller + southern MS						Scandinavian MS		
	D	F	UK	(A)	B	CH	E	I	NL	DK	(N)	SWE
Ionosphere / radio	+	-	+	+	-	-	+	+	-	+	+	+
Plasma problems	+	+	+	+	-	-	-	+	-	-	+	+
Electric/magnetic fields	+	+	+	-	-	-	-	+	-	+	+	+
Auroral electrons /protons	+	+	+	+	-	-	-	-	-	+	+	+
Barium release	+	-	+	-	-	-	-	-	-	+	-	-
Aurora photometry	-	+	-	-	+	-	-	-	+	-	+	-
Atmospheric photometry	+	-	-	-	+	-	-	-	-	-	-	-
Ion mass-spectrometer	+	-	-	-	-	+	-	-	-	-	+	-
Atm. mass-spectrometer	+	-	-	-	-	+	-	-	-	-	-	-
Solar physics	+	+	+	-	-	-	+	-	+	-	-	-
Stellar ultraviolet	+	+	+	-	-	+	-	-	+	-	-	-
Stellar X-ray	-	+	+	-	-	-	-	+	+	-	-	-

Table 5-6. Major national research institutes in the Member States involved in ESRO sounding-rocket activities (1964-72)

Belgium:	Astrophysical Institute, University of Liège	(IAUL)
	Institut d'Aéronomie Spatiale de Belgique	(IAS)
Denmark:	Danish Space Research Institute	(DSI)
	Danish Meteorology Institute	(DMI)
France:	Centre d'Etude Nucleaire , Saclay	(CEN)
	Cosmic Physics Laboratory, Meudon	(CPL)
	Franco-German Research Institute, St. Louis –Alsace	(FGR)
	Institute of Atmospheric Physics Paris	(IAP)
	Service d'Aéronomie, Verrière	(SAV)
	Toulouse University	(TU)
Germany:	Ionosphere Institute, Breisach	(I I B)
	Max Planck Institut für Extraterrestrische Physik, Garching	(MPG)
	Max Planck Institut Heidelberg	(MPH)
	Max Planck Institut Lindau	(MPL)
	Physics Institute, University of Bonn	(PIB)
	University of Heidelberg	(UH)
	University of Kiel	(UK)
	University of Munich	(UM)
	University of Tübingen	(UT)
Italy:	Astronomical Observatory Rome	(AOR)
	Physics Institute Bologna	(PIB)
	Physics Institute Milan	(PIM)
The Netherlands:	Space Research Laboratory Utrecht	(SRL)
	Utrecht Observatory	(UO)
	Cosmic Ray WG, University of Leiden	(CRL)
	Department of Space Research, University of Groningen	(SRG)
Sweden:	Geophysics Observatory Kiruna	(GOK)
	Royal Institute of Technology Stockholm	(RIT)
	Institute of Meteorology Stockholm	(IMS)
	Uppsala Ionosphere Observatory	(UIO)
	University of Lund	(UL)
Switzerland:	University of Bern	(UB)
United Kingdom:	Astrophysics Research Unit Culham	(CUL)
	Meteorological Office Bracknell	(MOB)
	Mullard Space Science Laboratory	(MSSL)
	Queen's University of Belfast	(QUB)
	Radio and Space Research Station Slough	(RSRS)
	University of Birmingham	(UB)
	University College of Wales, Aberystwyth	(UCW)
	University College London	(UCL)
	University of Leiceister	(UL)
	University of Sheffield	(US)
	University of Southampton	(USN)
	Imperial College London	(ICL)
	Royal Observatory Edinburgh	(ROE)

Overview of the Texus and Maxus experiment modules

6. Sounding-Rocket Programmes Devoted to Research under Microgravity Conditions

The use of sounding rockets for research in the fields of materials and fluid science, life sciences and fundamental physics has already been briefly addressed in Chapters 3.2, 4.3.5, 4.3.7 and 4.3.10. Over the last 30 years, the use of sounding rockets for research under microgravity conditions has developed into a major and essential component of the overall European sounding-rocket activities. All of these microgravity-related flights are carried out from Esrange, and some further details will be given in this chapter.

SPAR programme

The very first time that sounding rockets were used for microgravity experiments was in the mid-1970s, when NASA started its Space Processing Applications Rocket (SPAR) programme. SPAR used Black Brant Vc rockets, which were spin-stabilised about their longitudinal axis using spin-up motors and slanted external fins. After de-spinning and motor separation, the coasting phase starts. At altitudes above 100 km, where the aerodynamic forces are sufficiently low, residual accelerations of less than 1/10000 g are reached for 4 minutes and 20 seconds. During re-entry into the atmosphere, the drag forces gradually increase and ‘free-fall’ conditions no longer prevail at altitudes below 100 km. Parachutes are deployed at altitudes of about 5 km to return the payload without major mechanical damage. These SPAR flight opportunities were used by a few European scientists on a cooperative basis with NASA.

Texus programme

In 1976, Germany’s national Texus sounding-rocket programme was started and it continues to this day. Texus (*Technologische Experimente unter Schwerelosigkeit*) used British Skylark 7 rockets, which provided about 6 minutes of microgravity. Only recently, in 2005, the Skylark ceased to be commercially available, so that from Texus 42 onwards (November 2005) the Skylark 7 has been replaced by the Brazilian VSB-30 rocket.

In 1982, ESA started to use Texus as a short-duration flight opportunity for Spacelab precursor experiments by selected European researchers in the materials and fluid sciences fields, and later also for biology experiments in microgravity. The Texus experiments soon proved that sounding rockets are a powerful tool and a cost-effective means for preparing and developing the operationally more complex and more expensive experiments performed in orbiting laboratories.

The two-stage solid-propellant Skylark 7 rockets carried a scientific payload consisting of 250 kg of experiment hardware, made up of three to four autonomous experiment modules, each with its own power supply and data-handling system. The Texus payload concept provides a high degree of flexibility, as well as easy testing and maintenance/refurbishment of modules for re-use at moderate cost.

Maser programme

Since 1987, the Swedish National Space Board has offered to fly ESA microgravity experiments under the Swedish Maser (Materials Science Experiment Rocket) programme, managed by the Swedish Space Corporation (SSC). Maser has practically the same technical capabilities as Texus, but instead of the Skylark 7 it used a Canadian Black Brant rocket, until Maser 5 in April 1992. From Maser 6 onwards, this programme also used Skylark 7 rocket motors, and with Maser 10 on 2 May 2005 it launched the last existing Skylark 7. Maser 11 in 2008 will be launched by the Brazilian VSB-30.

The Maser 7 launch from Esrange (S) on 3 May 1996

In 1987, ESA's Microgravity Research Programme welcomed this extension to two industrial sounding-rocket service providers, for two reasons:

- In 1986, the Shuttle Challenger accident had taken place and Shuttle/Spacelab operations were grounded for several years to come, so ESA decided to double its sounding-rocket flight activities in order to satisfy microgravity user-community demand at least with a sufficient number of short-duration flight opportunities.

- In 1987, DLR transferred the management of the Texus programme to ERNO (today part of EADS), which offered Texus flights to paying customers on a commercial basis.

Maxus programme

Over time, microgravity experiments on sounding rockets had become more and more sophisticated and a considerable percentage of them were requiring longer microgravity periods. This and the demand for a larger mass capability had the consequence that ERNO and the SSC - after conducting market research on

The Maxus 5 sounding rocket on the launch pad at Esrange (S) on 31 March 2003

existing rocket motors - developed, under a joint industrial venture, the large Maxus sounding rocket, for which ESA became the sole customer. Under its Microgravity Research Programme, the Agency offered the relevant European research community every second or third year a Maxus flight opportunity of 12-13 min duration for a purely scientific payload of 480 kg. The Maxus programme was based on the considerable flight experience with the Texus and Maser projects, and the name was derived from MAser-teXUS.

ERNO took care of the payload service system, the scientific payload and the motor development/adaptation, i.e. the conversion of the existing Castor IV A motor - used by the US Thiokol Corporation as a strap-on booster to the US launch vehicle Delta II - into a single-stage motor with steerable nozzle for sounding rockets. The flex nozzle had to be added to guide the vehicle, and the maximum acceleration had to be reduced to 13 g. A shroud had to be developed to carry the whole vehicle on the launch stool and to accommodate the fin assembly. The overall Maxus launch mass was 12.4 t.

The SSC was responsible for the rocket systems, upgrading of the Esrange station and safety operations, the launch pad, upgraded launch stool and mobile tower, as well as mission operations. The Maxus guidance and control system was a newly developed item built by the Swedish company Saab Ericsson Space.

The service systems, mounted on the top of the payload, consist of the telemetry module and the high-altitude parachute-recovery system with 1000 kg capability, with a two-stage system deploying the drogue and main parachutes derived from the Texus recovery system. To protect the Maxus payload against heat loads during the re-entry into the Earth's atmosphere, all external structures are coated with zirconium oxide. On its aft end, the payload has a re-entry cone, which can take the heat loads and reduces the landing shock on impact with the ground. By spinning up the payload one tries to reduce the re-entry speed of more than 3300 m/s to about 150 m/s.

Mini -Texus programme

In addition to the demand for longer-duration sounding-rocket flight opportunities on Maxus, there was a need for shorter, inexpensive flight opportunities providing of the order of 3-4 min long periods of microgravity. DLR developed, via industry (ERNO), the 'Mini-Texus' sounding-rocket flight opportunities for this purpose. Mini-Texus was always launched in combination with a Texus or Maxus mission within the same launch campaign in order to minimise costs. ESA also participated in Mini-Texus from 1992 until 1998.

ESA exploitation of various sounding-rocket types

A breakdown of ESA's use of the four sounding-rocket programmes Texus, Maser, Maxus and Mini-Texus, is given in Table 6-1:

Table 6-1. Characteristics and degree of ESA's use of various European sounding-rocket types

	Texus/ Skylark 7 Black Brant	Maser/Skylark 7 and	Maxus Castor 4B	Mini-Texus Nike/Orion	New Rocket VBS-30 for Texus-Maser
Payload mass	370 kg	370 kg	800 kg	160 kg	400 kg
Sci. payload mass	250 kg	250 kg	480 kg	100 kg	270 kg
Microgravity time	6 min	6 min	12-13 min	3-4 min	6-7 min
No. expt. modules	3-4	3-4	4-5	1-2	3-4
Average % use by ESA experiments	49%	33%	14%	4%	-
No. of flights	43 (1977-2006)	10 (87-2005)	7 (1992-2006)	6 (1992- 98)	(start 2006)

The Maser 10 flight conducted on 2 May 2005 used the last Skylark 7 rocket.

From November 2005 onwards, the Brazilian VBS-30 rocket has been used for Texus and Maser. This replacement for Skylark 7 and Black Brant was developed and qualified following close collaboration between MORABA/DLR and the Brazilian aerospace organisations CTA and IAE. As can be seen from Table 6.1, the technical capabilities of the VBS-30 are slightly higher than those of the Skylark 7 and the Black Brant used for Maser.

Very-long-duration Russian sounding-rocket flight opportunity using Wolna rocket

The sounding-rocket activities of the USSR/Russia are not addressed in this report, because they were part of their secret military rocket activities, the research results of which were not published.

In the context of various types of sounding rocket used by European space programmes, it can be mentioned that in June 1995, the ‘thermal convection’ experiment module of Bremen’s microgravity research-related institute ZARM was flown by DLR on a Russian Wolna carrier (SS-N-18). This rocket was launched from a submarine in the Barents Sea and the payload recovered in the region of Kamchatka, 5600 km from where it had been launched and after reaching an apogee of 1250 km. The period of microgravity lasted 20 minutes. However, this type of very long-duration sounding-rocket test flight using a Russian military rocket was not repeated or further exploited by DLR. The desired longer period of low g-level was achieved, but the establishment of the necessary laboratory ground infrastructure proved too difficult and expensive, taking into account that the launch area and the landing site lie several thousands of kilometres apart in the Arctic. There was also no possibility of real-time interaction with the payload during flight, such interaction having become a standard feature of European sounding-rocket missions since 1983.

Scientific results of research conducted using sounding rockets

Although sounding rockets provide relatively brief periods of free fall, they have contributed significantly to the advancement of microgravity research. The high level of continuity, constant refinement of experiment techniques and diagnostic tools, and the expansion in the types of sounding rockets resulted in substantial contributions being made to progress in the life sciences and physical sciences under microgravity conditions.

As one example of the excellent results achieved with sounding rockets, the field of critical-point research should be mentioned here. D.A. Beysens summarised the results in this field in a chapter of *A World without Gravity: Research in Space for Health and Industrial Processes* (ESA SP-1251). There, it is stated that experimentation in microgravity with fluids and liquid mixtures near the critical point has led to breakthroughs in:

- the determination of critical, universal power laws
- the behaviour of specific-heat and adsorption properties near a solid wall
- a unified view of phase separation with industrial and biological applications
- discovery of a new, very fast heat-transport mechanism known as the ‘piston effect’.

For this work, which drew largely on sounding-rocket experiments conducted using the Critical Point Experiment Module developed by ERNO (providing temperature control to 0.1 mK), in 1985 Beysens was awarded the French Ancel prize for condensed-matter physics.

In the other microgravity research disciplines, excellent results have also been achieved thanks to sounding-rocket experimentation by German and other European scientists. These are summarised in the ESA-issued Proceedings of the Sounding Rocket and Balloon Symposia, held every other year since 1973 (see Chapter 8, Sources and References).

Launch of Maxus 5 from Esrange (S) on 1 April 2003

7. Research in Space and Industrial Space Activities Prompted by Sounding-Rocket Flights

In the 1950s, sounding rockets enabled European scientists for the first time to perform experiments in the upper atmosphere and the ionosphere, as well as solar and astrophysics studies with payloads carried by sounding rockets above the Earth's atmosphere. When, a few years later, the first small satellites were built and launched, the space-science community quickly recognised the advantages and disadvantages of experimentation using sounding rockets, notably:

- short development and turn-around times of such projects, which was very important in order to complete university theses within reasonable time spans
- less demanding requirements regarding flight-hardware reliability and safety compared with experiment hardware on satellites and manned missions
- lower costs for experiment flight-hardware development
- sounding rockets were recognised as being a unique tool for performing in-situ experiments at altitudes between the maximum achievable with balloons (40 km) and the perigee of stable satellite orbits (200 km)
- the short observation time (minutes) was the major disadvantage, compared with satellites (years), for the study of long-duration phenomena
- the great flexibility of sounding rockets as regards launch time made them an ideal means of studying transient phenomena such as aurora appearances.

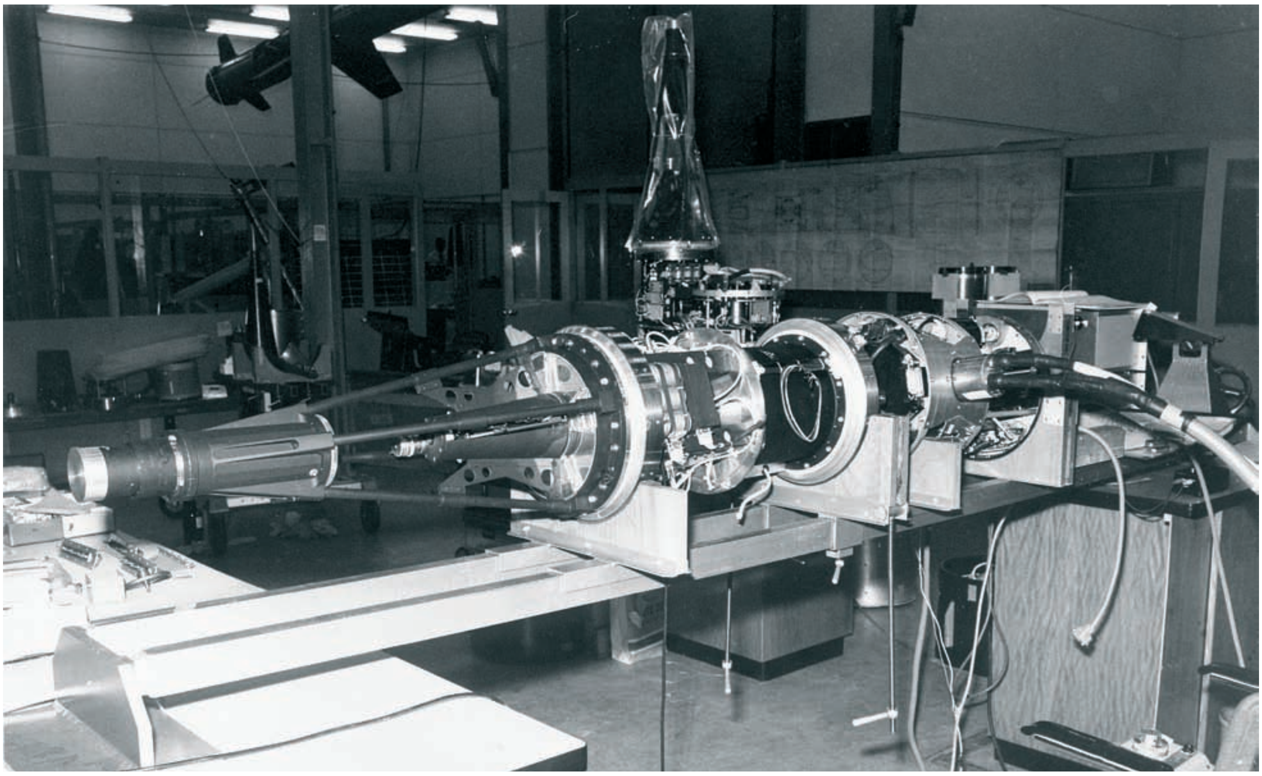
The performance of scientific experiments on both sounding rockets and satellites led to an unprecedented expansion of international cooperation, because such cooperation enabled the use of more complete sets of measuring instruments to achieve particular scientific objectives and better use of the special skills of specific research teams.

The sounding-rocket programme had the advantage of quick successes, compared with satellite projects. A further very important aspect favoured scientific cooperation. In Europe, the main launch sites were located in northern Scandinavia. There, young European research teams performed joint field experiments and spent many long nights together in that polar setting. This created a meaningful bond between scientists of different nationalities.

As can be seen from ESRO's sounding-rocket programme, enormous technical progress was made over a short period within a matter of years. It started with the launch of very simple gas-cloud experiments using metal compounds released by sounding rockets and observed from the ground. This ESRO activity was concluded some eight years later with very complex Sun- and star-pointing payloads incorporating three-axis-stabilised attitude-control systems, telemetry and telecommand capabilities, and payload-recovery systems. The launch success rate improved from 38% in 1965 to 93% in 1972, a time span that included 44 consecutive completely successful sounding-rocket launches during one three-year period (1969-1972).

Although the ESRO sounding-rocket programme was wound up for sound policy reasons, those activities undeniably made an extremely valuable and significant contribution to space-science development, cooperation and history at ESRO/ESA, to the national space programmes of the various European countries participating, and to initiating space-related work in European industry.

Whereas the USA and the USSR by the early 1950s had already used military rocket technology for peaceful scientific measurements to obtain information about the Earth's upper atmosphere constituents and dynamics and solar radiation, Europe joined the field quickly around the late 1950s/early 1960s with national sounding-rocket programmes in France, Germany, the United Kingdom and Scandinavia, and also at European level coordinated by ESRO.



The first ESRO star-pointing payload undergoing flight-clearance testing

It was those successful sounding-rocket projects that contributed to putting Europe firmly on the map as a serious space-science community globally speaking. In the 1960s, sounding-rocket experimentation prompted scientific and technical cooperation among more than 40 European groups interested in space research. That cooperation covered areas ranging from instrument development, mechanical and thermal testing, to participation in launch campaigns, joint data analysis and publication of results.

Many of the scientific and technical instruments/methods developed at research institutes or by industry for sounding rockets were drawn upon sooner or later when flying instruments on satellites. Examples, besides the payload instruments themselves, include:

- Sun and star sensors used in three-axis-stabilised attitude-control systems
- advanced telemetry and telecommand systems, including high-gain antennas, to relay data and pictures back to the ground
- power control and conditioning systems apart from solar arrays
- deployable mechanisms such as booms, shutters, etc.
- active and passive thermal-control systems.

In addition, the research objectives set for sounding rockets and for the first generation of satellites had common or complementary elements, as Table 7-1 shows:

Satellite	Research objective	Launch date	Re-entry date	Carrier
ESRO-2	Cosmic rays, solar X-rays	17/05/1968	9/05/1971	Scout
ESRO-1A	Polar ionosphere, aurora	2/10/1968	26/06/1970	Scout
HEOS-1	Interplanet. magnetic field/solar wind	5/12 1968	18/10/1975	Thor Delta
ESRA-1B	Polar ionosphere and light	1/10/1969	23/11/1969	Scout
HEOS -2	Polar magnetosphere/solar wind	31/01/1972	2/08/1974	Delta
TD-1	UV-, X-ray, gamma astronomy	12/03/1972	4/05/1974	Thor Delta
ESRO-4	Atmosphere, ionosphere, solar partic.	22/11/1972	15/04/1974	Scout

Similar technology transfers and commonalities of scientific objectives featured later on in the 1980s and 1990s in the microgravity research field. The techniques and research facilities developed for sounding rockets - such as furnaces for metallurgy and solidification studies, semiconductor crystallisation, fluid-physics modules, facilities for critical point research, combustion modules, liquid-bridge configurations for convection studies in microgravity, facilities for investigation of the gravity perception of plant cells and unicellular organisms - were first developed for sounding rockets and afterwards transformed or adapted for use in facilities for conducting similar research on the Shuttle/Spacelab.

In addition, sounding rockets serve to this day as the main carrier for precursor experiments for the International Space Station (ISS) and for instrument verification, qualification and calibration prior to deploying such experiment facilities and instruments for long-duration research onboard the ISS.

Another very important scientific aspect in the space life and physical sciences is the demonstration of the relevance of microgravity to certain proposed experiments on sounding rockets prior to final ISS experiment selection. Experience has shown that existing theories used to predict results and behaviours are often incorrect and need to be adapted or even replaced.

Taking into account these scientific and technical aspects, it can be stated that sounding-rocket programmes have proved to be a very useful workhorse for many areas of the physical and biological sciences, with the exception of human physiology and medical research.

European industry very soon recognised the learning potential and importance of sounding-rocket payload development, assembly, integration and testing for subsequent satellite projects. At the start of the ESRO (also the CNES and DLR) sounding-rocket programme, this type of work was done in-house. However, after a few years, about 70% of the development work had already been delegated to industrial contractors such as, in ESRO’s case, BAe, Dornier, CASA, Sud Aviation and Saab Ericsson, i.e. to companies that are still to this day (themselves or their successors) active in the space business.

Of course, following the early days of European space activities using sounding rockets and small satellites, technological methods/innovations such as component soldering, onboard recorders, and data archiving on microfiche were later replaced by integrated circuits, solid-state memory with large storage capabilities, computer-aided circuit design and archives accessible via the Internet.

Despite all of this technological progress, sounding-rocket experimentation never became obsolete, either when small scientific satellites started to be launched in large numbers in the late 1960s to early 1970s, or today when we are ready to perform research on and from the ISS. Sounding rockets are still used to test ideas, instruments and scientific theories prior to eventual use/application on satellites. The much lower costs, shorter lead-times and actual execution times of sounding-rocket experiments, the learning potential for young scientists, etc. are and will remain major advantages compared with experimentation on conventional satellites or in space laboratories.

8. Sources and References

Before listing related publications and unpublished reports/articles consulted, it should be noted that the list is not exhaustive; in particular, for the three-year period 1970 to 1972 of the ESRO sounding-rocket programme, the normally-compiled annual ESRO/ESA SP special reports were to be found neither in the archives of ESA, nor Esrange nor DLR. For the years 1964/1965 to 1969, the ESRO annual reports were compiled (by Y.P.G. Guérin, a member of the ESRO sounding-rocket team) retroactively over the period November 1972 to May 1974, and were found. Because the ESRO sounding-rocket programme was terminated on 30 June 1972 and the ESRO team was disbanded in 1972/73, the annual reports (ESRO SPs) for the period 1970 to 1972 were probably never compiled.

Lists of national sounding-rocket flights in European countries exist for the 1960s, but in some of these programme lists also there are gaps from 1970 to 1972. The lists of French national sounding-rocket launches and payloads were drawn up by P.R. Jacquot (CNES, Atélier Fusées Sondes). This list is complete for the period 1959 to 1978.

In addition, a complete list of all sounding-rocket launches carried out from Esrange's setting-up in Kiruna in 1966 through to today was received via J.G. Englund. This chronological list provides information on the rocket types and performance (altitude, launch date and institution(s) involved). However, it contains little information on the payloads' scientific objectives or technical characteristics - just the payload number is provided.

Furthermore, S. Grahn (SSC) has provided a list (in Swedish) of all of that country's national sounding-rocket launches from 1961 to 2005. This list gives the launch date and time, rocket type, supplier and launch range used, altitude reached, payload mass, telemetry frequency used and hints at the scientific objectives.

A similar list of German sounding-rocket activities was obtained from the German mobile rocket base (MORABA) team. This shows all rockets launched by the team since it started operations in 1967. It includes all national flights, launch dates, scientific institutions involved, rocket types and ranges used.

The Norwegian Space Centre's book *Making Sense of Space*, edited by Peter J. Collett, and published by the Scandinavian University Press in 1995 on the occasion of the 30th anniversary of the Space Activity Division of NSC's precursor organisation the NTNF, includes a list of all sounding rockets and scientific balloons launched by Norway throughout the World, plus those of other countries launched (in cooperation with Norway) from Andøya. The list covers the period 1962 to 1995, provides information on launch dates, rocket configurations and any recoveries, the abbreviations of the Norwegian institutions involved, outlines the mission objectives, and gives the payload numbers.

Generally-speaking, most of the above-mentioned and below-referenced lists exist only as a single hard-copy in library archives (e.g. at ESA) and are not available on loan. A paper copy of all lists can be made available on request (to G. Seibert) and delivered as an annex to this report. Due to their often poor legibility, these old lists cannot be scanned to obtain readable electronic copies.

The situation regarding ESA sources of information improves drastically from 1973 onwards to today, i.e. from when the Esrange Special Project became operational. Every other year, a symposium is organised by ESP's Programme Advisory Committee. All the Proceedings of these PAC symposia from 1973 to 2005 are available either from the ESA archives, in ESA's libraries or from ESA's Publication Division at ESTEC.

These Proceedings start in general with the national reports of the ESP participating countries on their sounding-rocket and balloon activities, supplemented by papers on the corresponding programmes of non-European countries (e.g. USA, Japan, Brazil). They continue with selected scientific papers in various space-science and microgravity research fields. In addition, papers on new techniques and instruments and invited speakers' presentations are included.

17 sets of Proceedings (1973 to 2005) entitled *Andøya and Esrange Special Project Concerning the Launching of Sounding Rockets* have been published by ESA's Publication Division in its Special Publications series, a few months after the Symposia have taken place. These Proceedings alone amount to more than 10 000 pages of programmatic, scientific and technical information on European sounding-rocket and balloon activities between 1973 and 2005.

8.1 List of ESRO publications

The ESRO publications are available either as SPs (Special Publications) or as SNs (Scientific Notes):

1. *Development, Launch and In-flight Performance of ESRO Sounding Rocket Payloads, Vol. I: Payloads launched in 1964-1965*, compiled by Y.P.G. Guerin, ESRO SP-76, November 1972.
2. *Ibid, Vol. II: Payloads launched in 1966*, ESRO SP-77, June 1973.
3. *Ibid, Vol. III : Payloads launched in 1967*, ESRO SP-78, November 1973.
4. *Ibid, Vol. IV: Payloads launched in 1968*, ESRO SP-79, February 1974.
5. *Ibid, Vol. V: Payloads launched in 1969*, ESRO SP-80, May 1974.
6. *Solar Eclipse of 20 July 1966, Centaure Sounding Rocket Experiments*, W. Graaf, ESLAB, ESRO SN-56, May 1966.
7. *European Sounding-Rocket and Related Research at High Latitudes*, ESRO SP-97, November 1973, Proc. 1st ESA-ESP/PAC Symposium, Spätind, Norway, 2-6 April 1973.
8. *Ibid, with Emphasis on the International Magnetospheric Study* (IMS), ESRO SP-107, February 1975, Proc. 2nd ESA Symposium, Örenas Slott, Sweden, 9-12 September 1974.

9-23. *Proceedings of the 3rd to 17th 'ESA Symposia on Sounding-Rocket and Balloon Programmes:*

9. *3rd ESA Symposium*, 3-7 May 1976, Schoss Elmau, Germany, ESA SP-115.
10. *4th ESA Symposium*, 24-29 April 1978, Ajaccio, France, ESA SP-135.
11. *5th ESA Symposium*, 14-18 April 1980, Bournemouth, UK, ESA SP-152.
12. *6th ESA Symposium*, 11-15 April 1983, Interlaken, Switzerland, ESA SP-183.
13. *7th ESA Symposium*, 5-11 May 1985, Loën, Norway, ESA SP-229.
14. *8th ESA Symposium*, 17-23 May 1987, at Sunne, Sweden, ESA SP-270.
15. *9th ESA Symposium*, 3-7 April 1989, Lahnstein, Germany, ESA SP-291.
16. *10th ESA Symposium*, 27-31 May 1991, Mandelieu-Cannes, France, ESA SP-317.
17. *11th ESA Symposium*, 24-28 May 1993, Montreux, Switzerland, ESA SP- 355.
18. *12th ESA Symposium*, 29 May-1st June 1995, Lillehammar, Norway, ESA SP- 370.
19. *13th ESA Symposium*, 26-29 May 1997, Öland, Sweden, ESA SP-397.
20. *14th ESA Symposium*, 31 May-2 June 1999, Potsdam, Germany, ESA SP-437.
21. *15th ESA Symposium*, 28-31 May 2001, Biarritz, France, ESA SP-471.
22. *16th ESA Symposium*, 2-5 June 2003, St. Gallen, Switzerland, ESA SP-530.
23. *17th ESA Symposium*, 30 May-2 June 2005, Sandefjord, Norway, ESA SP-590.

In addition to these 17 ESA Symposia Proceedings, the following 4 ESA SP's have been published:

24. *Proc. Cluster Dayside Polar Cusp Workshop* (Svalbard, September 1991), ESA SP- 330.
25. *Flight Experiment Hardware for Sounding Rockets: Materials and Fluid Science*, ESA SP- 1116.
26. *Summary Review of Sounding-Rocket Experiments in Fluid and Materials Science*, ESA SP-1132:
    - *Volume 1: Texus 1-20 and Maser 1 and 2*
    - *Volume 2: Texus 21-24 and Maser 3*
    - *Volume 3: Texus 25-27 and Maser 4*
    - *Volume 4: Texus 28-30 and Maser 5 and Maxus 1*
27. *Life-Science Experiments on Sounding Rockets 1985-94: Texus 11-32, Maser 3-6 and Maxus 1.*

28. In 1969, ESRO established an internal working group to carry out a sounding-rocket policy study for a sounding-rocket programme review of launch rate and facility growth, turnaround times, national programmes and ESRO programme efficiency (document without annex found in ESA archive).

29. *Survey of European sounding-rocket and scientific-balloon programmes*, ESRO paper of 15 April 1975. This contains national reports for B, D, NL, S, CH, E, DK and F (property of Esrange library).

30. In 1978, the SSC performed a study under ESA contract to define a proposal for potential sounding-rocket activities for the following decade (i.e. the 1980s) with a view to defining how Spacelab utilisation and sounding-rocket activities could be coordinated. The final report dated 4 April 1978 (no. 333/77/F/ HGE/SC) is entitled *Sounding-Rocket Activity in Europe in the 1980s.*

31. *From small beginnings……The Story of ESRO's Sounding Rocket Programme*, D. Eaton, ESA BR-60. This brochure was published in September 1989 on the occasion of the 25th Anniversary of the launch of the first ESRO sounding rocket.

32. *The ESRO Sounding-Rocket Launching Range in Kiruna*, ESRO Bulletin No. 4, 1966.

8.2 Non-ESA/ESRO sounding-rocket-related publications

The above list of ESA publications in the form of Proceedings of Symposia includes, besides national programme reviews, a large number of scientific review papers and individual publications. All of these reviews and publications include lists of references, which together amount to many hundreds and so cannot be reproduced here. However, some examples of selected non-ESRO/ESA publications that cover past sounding-rocket activities include:

33. *'Stand und Ergebnisse des deutschen Höhenforschungsprogramms'*, G. Haerendel, Raumfahrtforschung Heft 1/1976

34. *'La France a-t-elle hérité de Peenemünde'*, F. Villani, Président de la Commission Histoire de l'AAAF, Octobre 1992

35. *'Base de Lancement pour Fusées- Sondes de Kiruna (Suede)'*, internal ESRO working paper by J. B. Lagarde, issued on 7 November 1968 (Ref. 8028/JBL/JO)

The following works on European space programmes were consulted for information on sounding rocket activities:

36. *Raumfahrt in Deutschland: Forschung - Entwicklung - Ziele 1976'*, Werner Büdeler, ECON Verlag, ISBN 3-430-11593-0

37. *Geschichte der Raumfahrt*, Werner Büdeler, 1979/1982 Siegloch Edition, ISBN 82-00 22692-1

38. *Making Sense of Space: The History of Norwegian Space Activities*, edited by John Peter Collett (Scandinavian University Press, Oslo: 1995), ISBN 82-00-22692-1

39. *Sweden in Space, Swedish Space Activities 1959 -1972*, Jan Stiernstedt, originally published in Swedish by the Swedish National Space Board in 1997, translated by ESA and published in 2001 as ESA SP-1248

40. *Space Science and me*, Bengt Hultqvist, originally published in Swedish in 1997 by the Swedish Academy of Sciences, translated by ESA and published in 2003 as ESA SP-1269

41. *Geschichte der deutschen Raumfahrtpolitik 1923-2002*, Nikolas Reinke, Forschungsinstitut der Deutschen Gesellschaft für Auswärtige Politik, R. Oldenburg Verlag, München 2004

9. Acknowledgements

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Enthusiastic support was received by Peter Preu and Maria Roth from DLR/Bonn who provided archive material from the DLR library. Mr Peter Turner, Head of MORABA, DLR München-Oberpfaffenhofen, provided a list of German sounding-rocket missions launched from that base.

Warm thanks go also to Marie-Angèle Lemoine of the ESA's Information Documentation Service at the ESA Head Office library in Paris for making available a large number of 'back-number' reports from the ESA archives. I would also like to thank Wolfgang Herfs (ESTEC) for assembling the Proceedings of sounding-rocket symposia published by ESA Publications Division and for checking this manuscript. Anthony Blend of ESA's Translation Division helped put the English of this document into proper shape.