5 SOUNDING ROCKETS

This section is aimed at providing new and experienced users with basic information regarding the utilisation of Sounding Rockets for microgravity experiments.

5.1 Introduction to Sounding Rockets

5.1.1 What Are Sounding Rockets?

Sounding rockets have been utilised for scientific research since the late 1950s and were originally implemented in Meteorological and Upper Atmosphere studies. ESA has been using this type of platform to carry out low gravity experimentation since 1982. These rockets take their name from the nautical term "to sound," which means to take measurements, and are made up of essentially 3 major parts, i.e. a single or two-stage solid-fuel propulsion system, the service systems (rate control, telemetry module, recovery system) and the scientific payload (the section that carries the instruments to conduct experiments). Sounding rockets are sub-orbital carriers, which means that they do not go into orbit around the Earth. The rockets follow a parabolic trajectory from launch to landing, which, for the case of the rockets used by ESA, provide between 3 to 13 minutes of low gravity environment.

5.1.2 What Do Sounding Rockets Offer?

Sounding rockets offer users the following:

- 3 to 13 minutes of low gravity;
- A weightless environment with levels $\leq 10^{-4}$ g_0;
- Quick access (a payload usually flies between 1-2 years after experiment approval);
- A regular flight schedule (1-2 ESA funded missions per year);
- Direct involvement of the users in developing the hardware, and in the preparation and execution of the experiment;
- Minimum safety constraints for the experiments;
- Extensive use of interactive experiment operation ("telescience") from the launch site or from remote sites via ISDN lines;
- Possibility of late experiment installation ("late access" – up to 1 hour before launch) and fast sample retrieval after the flight ("early retrieval" – typically within 1 hour after launch);
- Comprehensive user infrastructure at Esrange launch site in Kiruna, Sweden (e.g. laboratories, accommodation);
- Availability of a large number of flight proven experiment modules for different scientific disciplines.

5.1.3 Why Use Sounding Rockets?

Sounding Rockets are excellent platforms for the performance of independent investigations, preparatory experiments for the ISS and other long duration flight opportunities, and for in-flight verification of scientific innovations, especially in cases where no prior microgravity experience exists. They enhance the possibility to obtain valuable scientific return from longer duration missions. These platforms are cost efficient and are ideal for testing new instrumentation. From a scientific point of view, sounding rockets provide the opportunity to carry out research over a wide range of disciplines in materials science, fluid physics, combustion, fundamental physics and biology.

5.1.4 Principal Characteristics of Sounding Rockets Used by ESA

In Europe there are 4 different sounding rocket projects for microgravity research offered by industry to any paying customer. Normally these missions are used by ESA and the German Space Agency (DLR), but in the past they have also been used by Japanese companies. The main characteristics of the four projects are summarised in the table below.

Table 5-1: Main characteristics of sounding rockets used by ESA

PROJECT	MANAGED BY	MICRO-G TIME (min)	NUMBER OF EXPERIMENT MODULES	PAYLOAD DIAMETER (cm)	SCIENTIFIC PAYLOAD LENGTH (m)	SCIENTIFIC PAYLOAD MASS (kg)	SPIN RATE (Hz)
MiniTexus	EADS-ST, Bremen (D)	3-4	1-2	43.8	1	100	5
Texus	EADS-ST, Bremen (D)	6	4	43.8	3.4	260	3-4
Maser	SSC, Solna (S)	6	4	43.8	3.4	260	3-4
Maxus	EADS-ST and SSC	12.5	5	64.0	3.8	480	≤ 0.5

5.1.4.1 MiniTEXUS

The German MiniTEXUS short duration sounding rocket programme was initiated in 1993. Of the 6 MiniTexus missions that have been carried out up to June 2005, ESA has participated in 4. Up to now the MiniTEXUS has used a two-stage solid propellant vehicle made up of a Nike first stage and an Orion second stage, offering approximately 3 minutes of microgravity time.
In future, the MiniTEXUS could be launched by the Brazilian single stage solid propellant VS30 rocket motor.

Table 5-2 summarises the major characteristics and features of the MiniTEXUS sounding rocket.

Table 5-2: MiniTEXUS sounding rocket characteristics

PARAMETER	VALUE/CHARACTERISTIC
Overall Length	10 m
Scientific payload diameter	0.43 m
Scientific payload length	1 m
Total Payload module mass	160 kg
Scientific hardware mass	100 – 120 kg
Microgravity time	3 minutes
Apogee	140 km
Microgravity level achieved	$\leq 10^{-4}\ g_0$
Analogue video channels	≤ 2
Analogue telemetry channels	128
Digital telemetry channels	120
First stage type	Nike
1st stage propellant type	Solid
1st stage nominal thrust	217 000 N
Peak acceleration	21g
1st stage burn time	3.2 sec
Second stage type	Orion
2nd stage propellant type	Solid
2nd stage nominal thrust	13000 N
Peak acceleration	14g
2nd stage burn time	32 sec

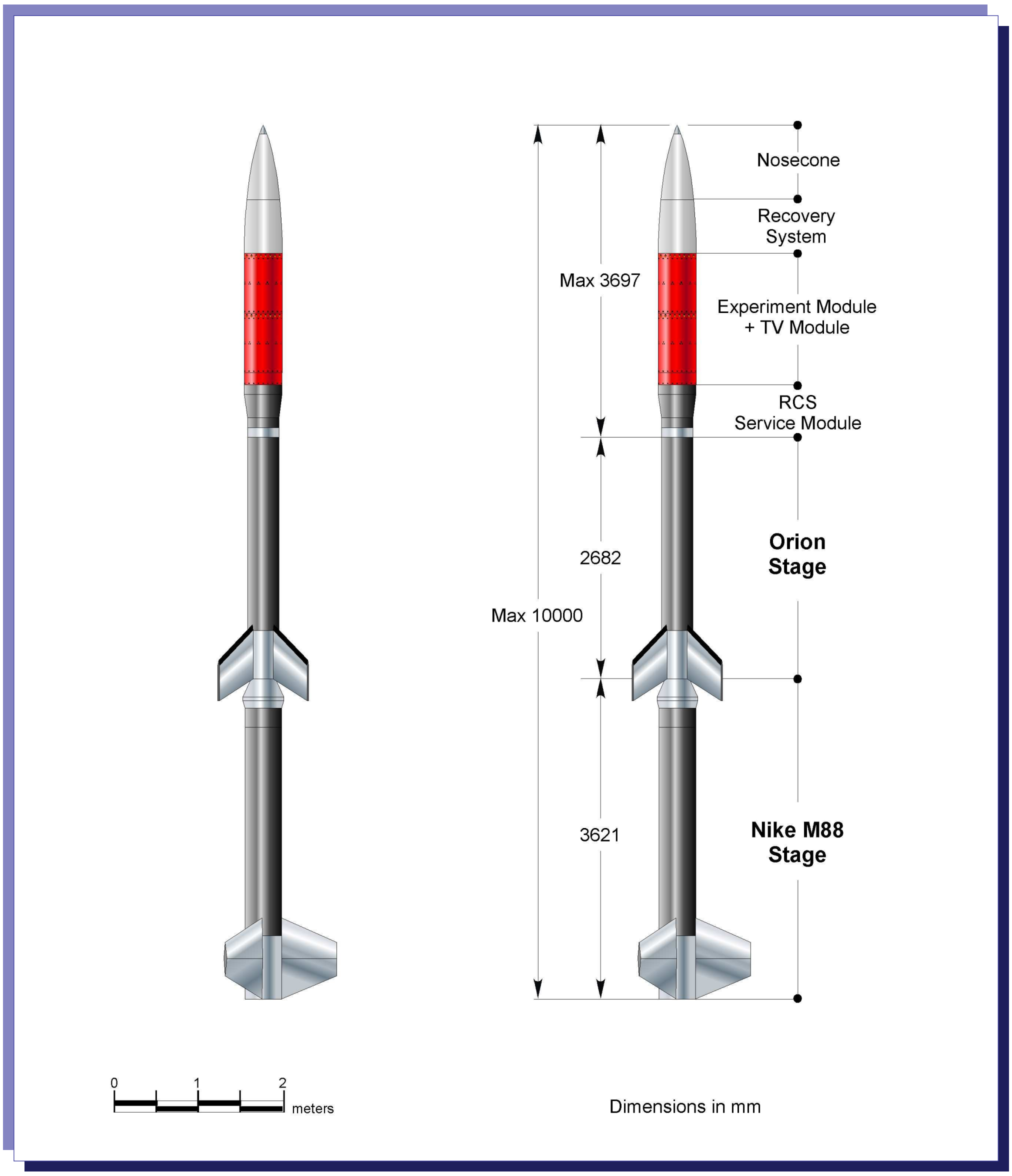

Figure 5-1: MiniTEXUS sounding rocket

5.1.4.2 TEXUS

The TEXUS Sounding Rocket Programme (Technologische EXperimente Unter Schwerelosigkeit) was initiated in 1976 by the German Ministry for Research and Development, as a preparatory programme for the first Spacelab mission in 1983. The first TEXUS mission was successfully launched from Esrange, Kiruna on 13 December 1977. ESA's first experiment flew on the German Texus 6 mission in 1982. Since then ESA has flown 77 experiments up to the TEXUS 40 mission (April 2003). Skylark VII two-stage solid fuel launchers (first stage: Goldfinch IID, second stage: Raven XI) manufactured by British Aerospace, were usually employed in the TEXUS programme. The mission related tasks, (such as the provision of the rocket motor, the service systems and the launch service) are covered by an industrial consortium led by EADS-ST (Bremen, Germany). As from TEXUS EML-1, scheduled for launch in November 2005, the Brazilian two-stage solid propellant VSB30 rocket motor will be used for TEXUS and MASER missions. This rocket motor has a performance that is slightly superior to the Skylark 7.
Table 5-3 summarises the major characteristics and features of the TEXUS sounding rocket.

Table 5-3: TEXUS sounding rocket characteristics

PARAMETER	VALUE/CHARACTERISTIC
Overall Length	13 m
Scientific payload diameter	0.43 m
Max. scientific payload length	3.4 m
Total Payload module mass	~370 kg
Scientific hardware mass	260 kg
Microgravity time	~6 minutes
Apogee	260 km
Microgravity level achieved	$\leq 10^{-4}\ g_0$
First stage Type	Goldfinch IID
1st stage propellant type	Solid
1st stage Nominal thrust	189 000 N
Peak acceleration	10g
First stage burn time	3.7 sec
Coast phase after 1st stage burn out	2.5 s with negative acceleration
Second stage type	Raven XI
2nd stage propellant type	Solid
2nd stage nominal thrust	83 000 N
Peak acceleration	7.5g
2nd stage burn time	39 sec
Analogue video channels	2-6
Analogue telemetry channels	192
Digital telemetry channels	180
Spin rate	3-4 Hz
Digital video downlink	Available on request

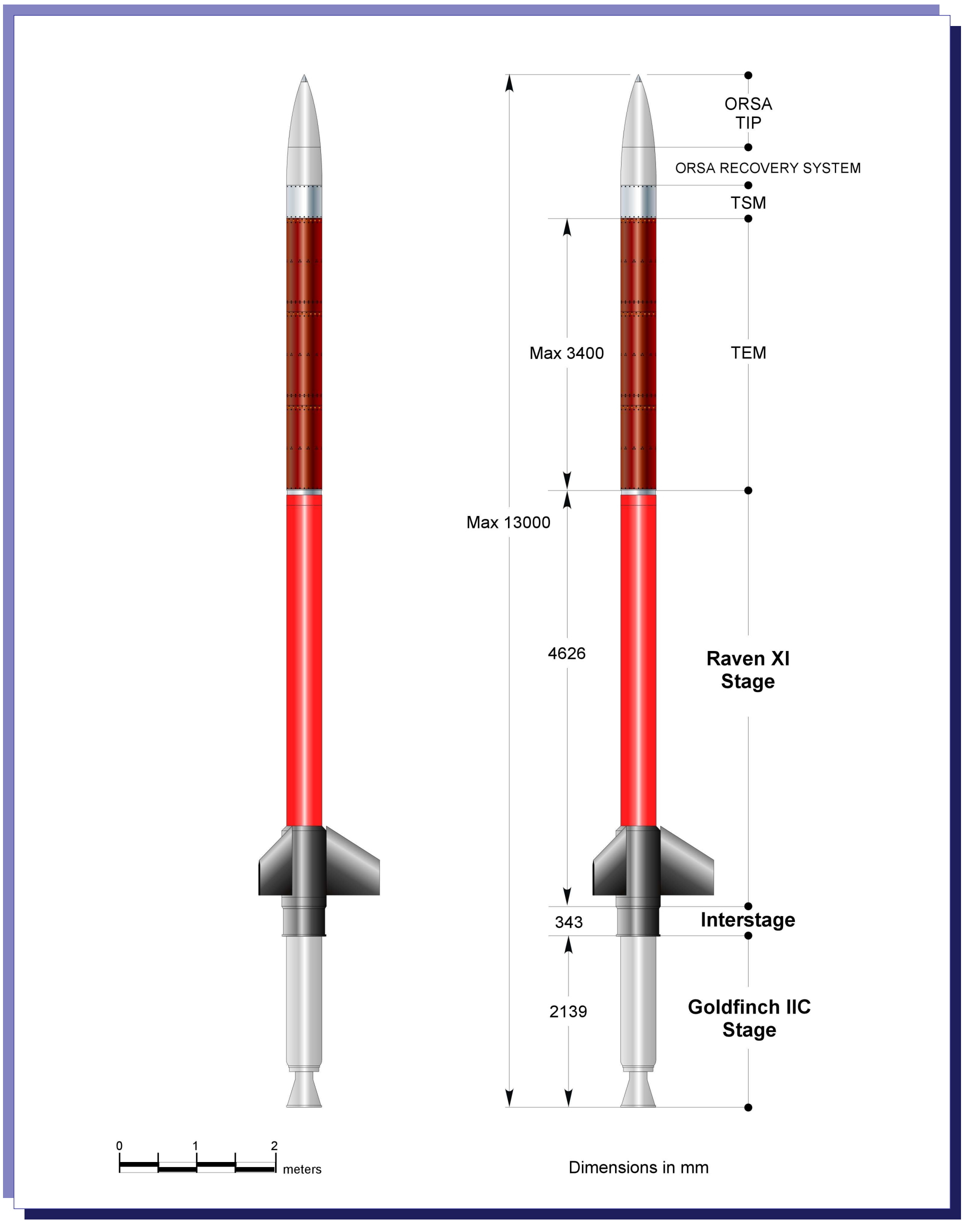

Figure 5-2: TEXUS sounding rocket

5.1.4.3 MASER

In 1986 Sweden began its own sounding rocket programme called MASER (MAterial Science Experiment Rocket). The first successful launch – MASER 1 – took place at Esrange in March 1987. ESA has participated in all 10 MASER missions, and missions 6 – 10 have been funded 100 % by ESA. The MASER missions are managed by the Swedish Space Corporation (SSC). From MASER 6 to MASER 10, two-stage Skylark VII rocket motors have been used, while from MASER 11 onwards it is planned to use the Brazilian two-stage solid propellant VSB30 rocket motor.
Table 5-4 summarises the major characteristics and features of the MASER sounding rocket.

Table 5-4: MASER sounding rocket characteristics

PARAMETER	VALUE/CHARACTERISTIC
Overall Length	13 m
Scientific payload diameter	0.43 m
Scientific payload length	3.4 m
Total Payload module mass	~370 kg
Scientific hardware mass	260 kg
Microgravity time	~6 minutes
Apogee	260 km
Microgravity level achieved	$\leq 10^{-4}$ g_0
First stage Type	Goldfinch IID
1st stage propellant type	Solid
1st stage Nominal thrust	189 000 N
Peak acceleration	10g
First stage burn time	3.7 sec
Coast phase after first stage burn out	2.5 s with negative acceleration
Second stage type	Raven XI
2nd stage propellant type	Solid
2nd stage nominal thrust	83 000 N
Peak acceleration	7.5g
2nd stage burn time	39 sec
Spin rate	3-4 Hz
Analogue video channels	2-6
Digital video downlink	Available

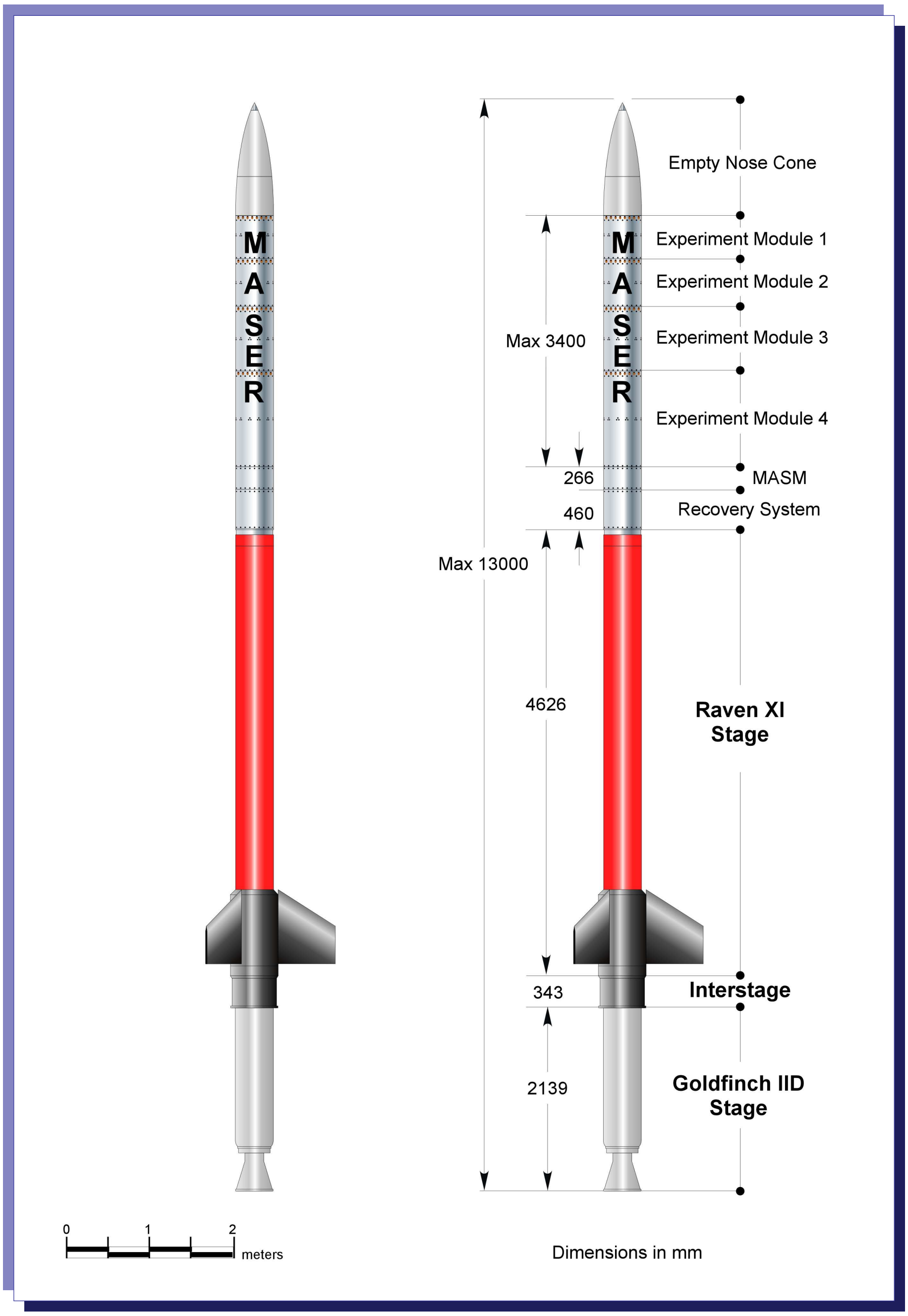

Figure 5-3: MASER rocket

5.1.4.4 MAXUS

The European long duration sounding rocket programme MAXUS was initiated in 1990. Due to a failure, however, the first successful launch from Esrange took place in November 1992. The mission related tasks, (such as the provision of the rocket motor, the rocket systems, the service systems and the launch service) are covered by an industrial joint venture formed by EADS-ST (based in Bremen, Germany) and the Swedish Space Corporation – SSC (Sweden). The MAXUS programme offers 12-13 minutes of microgravity time for experiments. All 6 MAXUS missions flown up to mid-2005 have been funded 100 % by ESA. The following table summarises the major characteristics and features of the MAXUS sounding rocket.

Table 5-5: MAXUS sounding rocket characteristics

PARAMETER	VALUE/CHARACTERISTIC
Overall Length	16.2 m
Max. Diameter	1 m
Scientific payload diameter	0.64 m
Scientific payload length	3.8 m
Gross launch mass	12 300 kg
Total Payload mass	800 kg
Scientific hardware mass	480 kg
Microgravity time	12 minutes 30 seconds
Apogee	705 km
Microgravity level achieved	$\leq 10^{-4}$ g_0
Analogue video channels	2-6
Digital video downlink	Available on request
Analogue telemetry channels	384
Digital telemetry channels	360
Motor	Morton Thiokol Castor IVB
Propulsion module diameter	1 m
Propulsion module length	9.2 m
Propellant type	Solid
Vacuum thrust	430 318 N
Peak acceleration	13g
Burn time	64 sec
Spin rate	$\leq$ 0.5 Hz

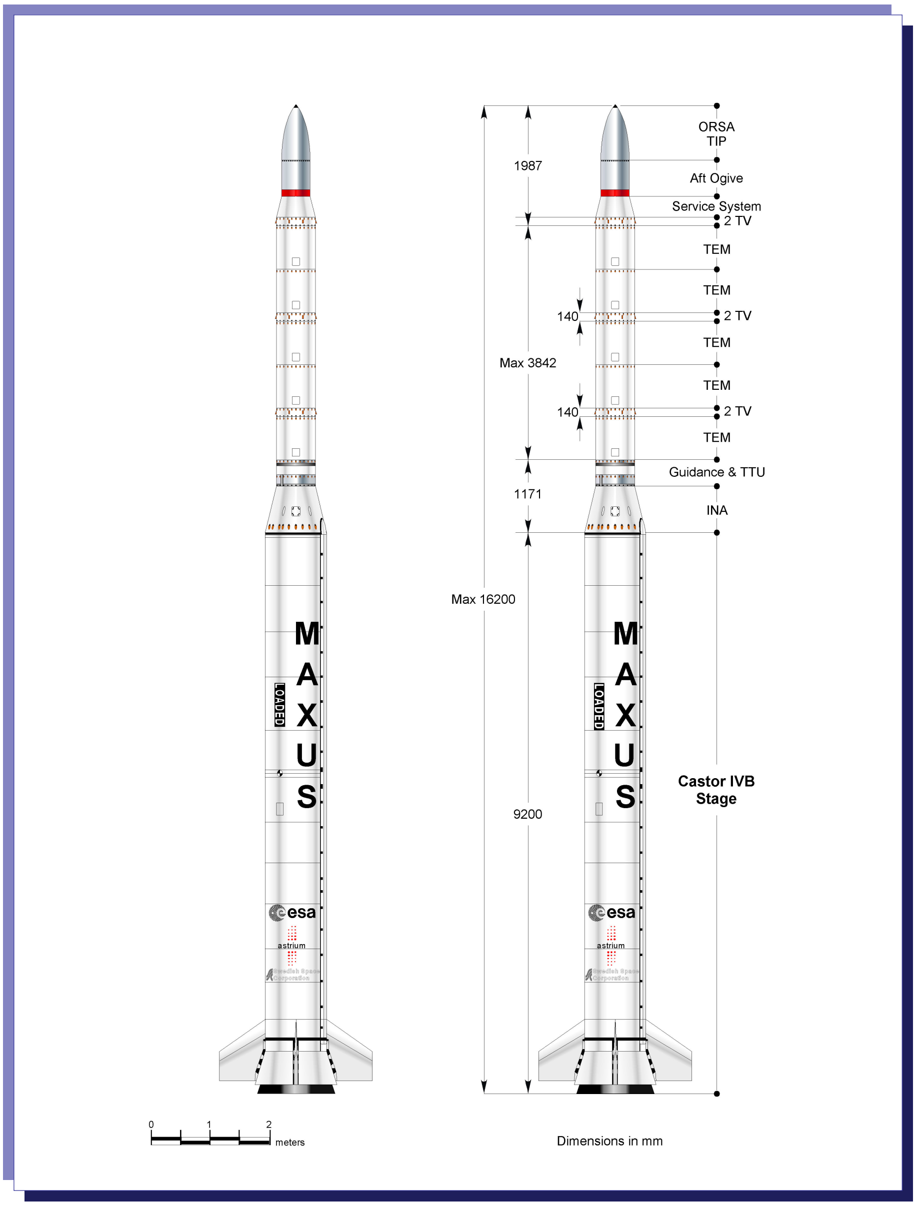

Figure 5-4: MAXUS Sounding Rocket

5.1.5 Sounding Rocket Mission Profiles

The sounding rockets used by ESA (i.e. MiniTEXUS, TEXUS, MAXUS and MASER) are all launched from the Esrange launch site east of Kiruna, northern Sweden (67°54' N, 21°05' E). All these rockets follow a steep parabolic trajectory with similar sequences of events occurring at different altitudes and times.
Figure 5-5 shows the typical altitudes achieved during the flight of the 4 different sounding rockets compared to Shuttle and ISS, and the subsequent tables and figures summarise the flight sequences for each individual launcher. The values reported may vary from mission to mission, depending mainly on the total payload mass. During ascent, for flight stabilisation, the TEXUS, MiniTEXUS and MASER rockets spin around the longitudinal axis at a rate between 3 – 5 Hz. After the second stage burnout a yo-yo despin system is activated to decrease the spin rate to about 0.1 Hz. Then the motor is separated from the payload and a Rate Control System with nitrogen thrusters is activated. If any of the angular motion rates (pitch, yaw, roll) exceed a given threshold, the corresponding thruster is activated until the rate decreases below the threshold. On MAXUS, which uses a non-spinning rocket, no yo-yo despin system is needed and only the Rate Control System is used to stabilise the payload, and to spin it up shortly before re-entry.

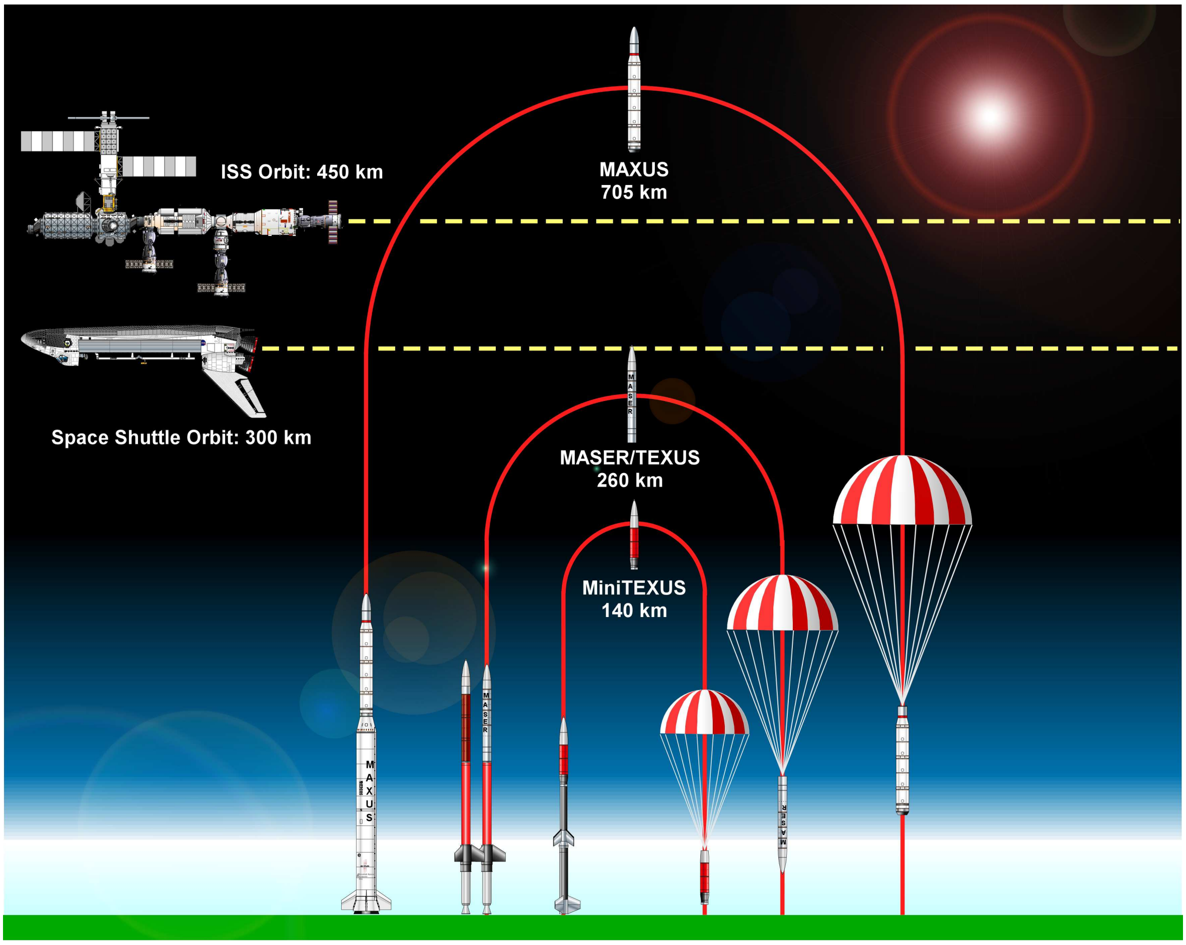

Figure 5-5: ESA sponsored sounding rocket maximum altitudes compared to Shuttle and ISS

5.1.5.1 MiniTEXUS

The following table provides data relative to the main events during a mission trajectory of the MiniTEXUS for missions 1-6. As was stated previously in 5.1.4.1, future (if any) MiniTEXUS launchers will use a different rocket motor, meaning that the data provided in Table 5-6 will change. The information below is provided purely for historical reasons and reference purposes.

Table 5-6: MiniTEXUS principal mission events

EVENT	TIME FROM LAUNCH (s)	ALTITUDE (km)	GRAVITY LEVEL (g)
Launch: Ignition first stage	0	0	
First stage burnout	3.7	1	20
Ignition second stage	6.5		14
Second stage burnout	35		1
Yo-yo despin	66		
Nose cone ejected	68		
Motor/Payload separation	70 (spin rate approx. 6.5 rpm)		
Start of microgravity	100		$<10^{-4}$
Payload apogee	180	140	$<10^{-4}$
End of microgravity	260		$<10^{-4}$
Start of re-entry phase	~270 (max. velocity 1.3 km/s)		6 (maximum)
Spin-up command	~280		
Heat shield released	420		
Drogue parachute released	421		
Main parachute deployed	450		
Landing	1044	0	
Payload retrieval	3600-7200	0	

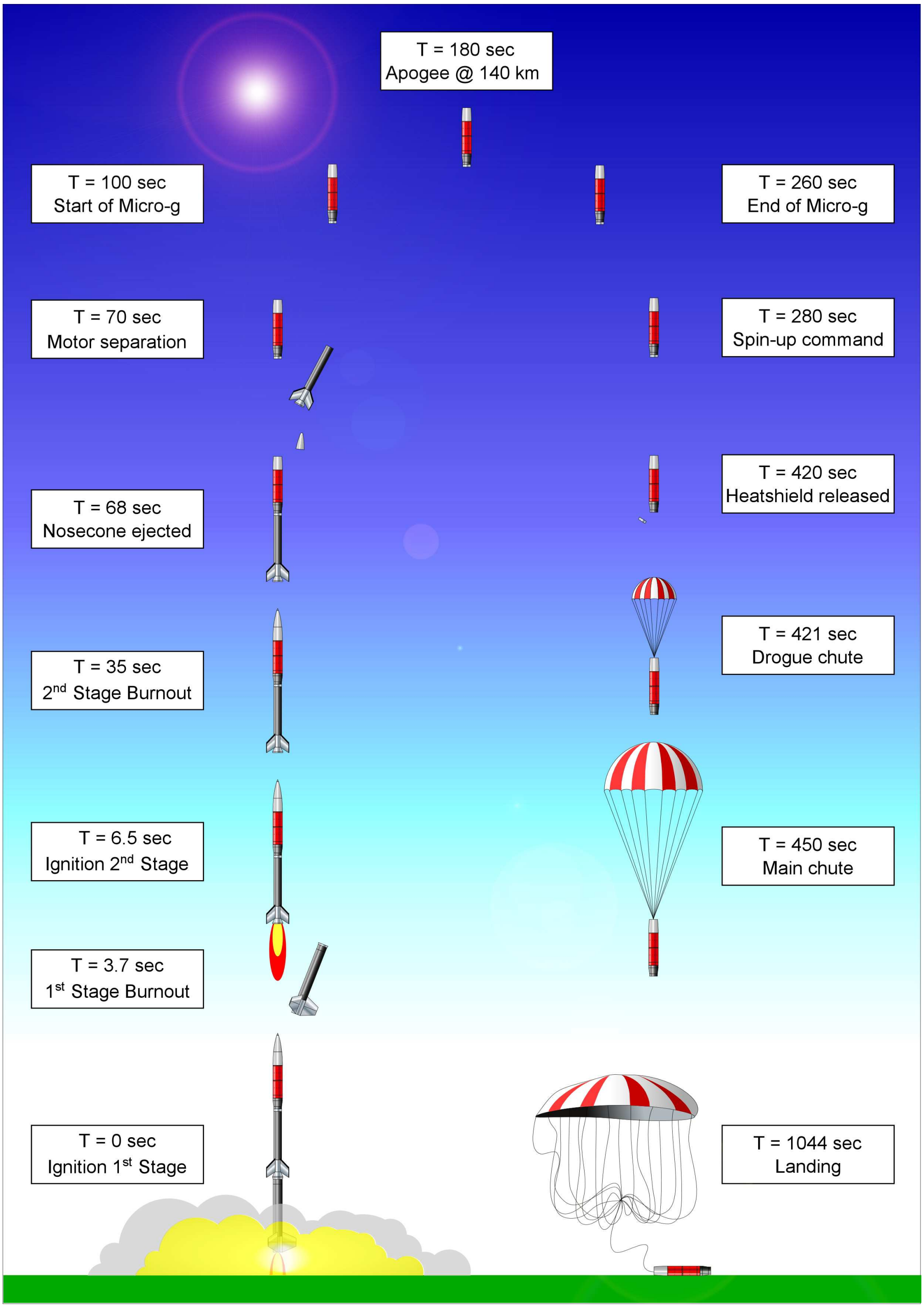

Figure 5-6: MiniTEXUS Flight Profile and major events

5.1.5.2 TEXUS and MASER

Table 5-7: TEXUS and MASER principal mission events

EVENT	TIME FROM LAUNCH (s)	ALTITUDE (km)	GRAVITY LEVEL (g)
Launch: Ignition first stage	0	0.3	
First stage burnout	3.7		10
First stage separation	5.5	1.4	0.002
Ignition second stage	6.5	1.55	Up to 7.5
Burnout second stage	45	49	
Nose cone ejected	55	68	
Yo-Yo despin activated	56	69.9	
Yo-Yo despin completed	57.5	72.7	4×10^{-3}
Motor/payload separation	59	75.4	
Rate Control System (RCS) activation/ start of microgravity period	75	100	$<10^{-4}$
Apogee	260	260	$<10^{-4}$
End of microgravity period	440	100	$<10^{-4}$
Start of re-entry	490 (max. velocity 2 km/s; max. outer skin temp. 180 °C)	30	50 (peak)
Beacon activated	540		
Heat shield released	570		
Drogue parachute deployed	578		
Main parachute released	590		
Payload retrieval	3600-7200	0	

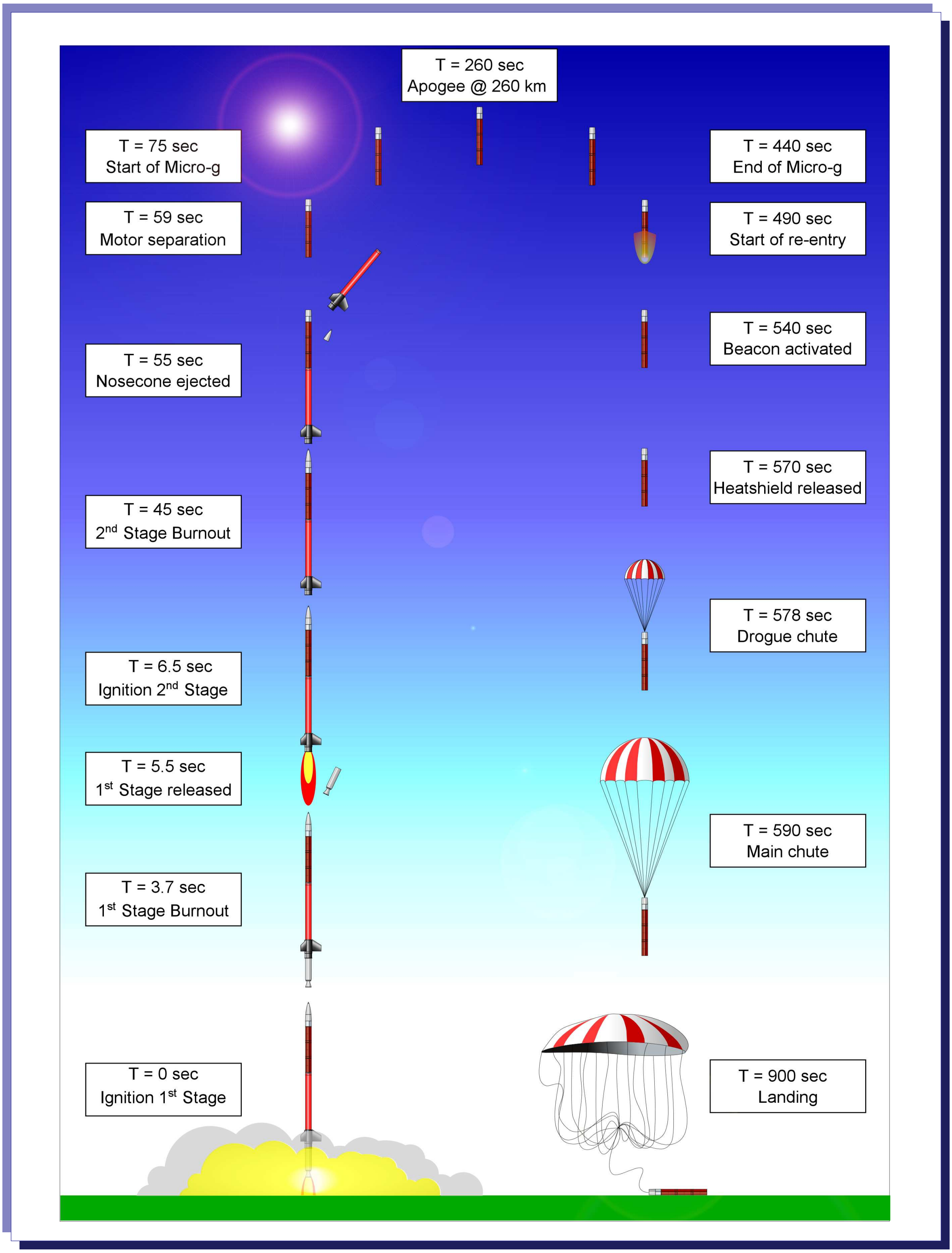

Figure 5-7: TEXUS and MASER Flight Profile and major events

5.1.5.3 MAXUS

Table 5-8: MAXUS principal mission events

EVENT	TIME FROM LAUNCH (s)	ALTITUDE (km)	GRAVITY LEVEL (g)
Launch: Ignition of single stage	0	0	
Burnout	64	75	~13 at T+60 sec
Nose tip released	68		
Motor/Payload separation	86 (spin rate ≤ 0.5 Hz)	100	
Rate Control System (RCS) activation	86	103	$<10^{-4}$
Start of microgravity period	96	110	$<10^{-4}$
Apogee	460	705	$<10^{-4}$
End of microgravity period	836	100	$<10^{-4}$
Spin-up command	847		
Start re-entry period	855 (max. velocity 4.5 km/s; max. outer skin temperature 250 °C)		40 (peak)
Beacon activated	870		
Heat shield released	945		
Drogue parachute disreefed	952		
Main parachute released	960		
Payload retrieval	4500-5400	0	

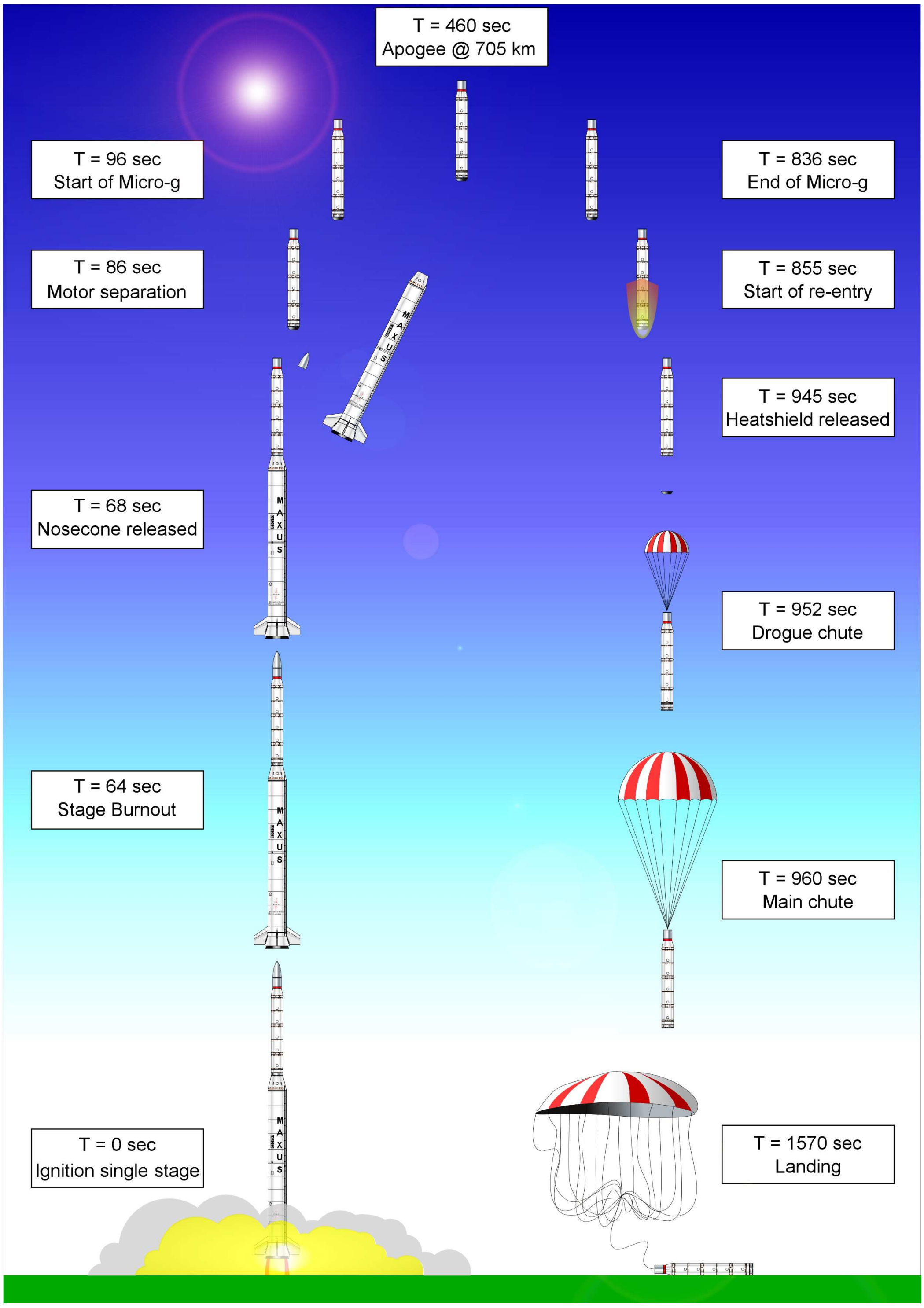

Figure 5-8: MAXUS Flight Profile and major events

5.1.6 Launch and Landing Site

The Esrange launch site (67° 54' N, 21° 04' E) is located in northern Sweden 200 km above the Arctic Circle and 43 km east of the town of Kiruna. The European Space Research Organisation (ESRO) established Esrange in 1966 mainly as a launch facility both for sounding rockets and stratospheric balloons. In 1972 the ownership of Esrange was transferred to the Swedish Space Corporation (SSC). Access to Kiruna is very good with two daily flights to and from Stockholm. The range covers an area of 20 km^2 and has the following infrastructure:

The Main Building area located in the Vittangi river valley, comprising the Main Building, the Telecom building, Hotel Albert, Hotel Herbert, Hotel Dagobert, Hotel Dilbert and garages. Close to the main building area is the area for balloon launches including two buildings for operations control and payload preparation. Further east is the launching area for rockets, which includes a blockhouse, rocket and payload preparation halls, chemical laboratories and launch pads. The rocket storage is located another kilometre further east, while one kilometre south of the launch tower there is a mobile radar station belonging to DLR. The satellite receiving station, and a GPS reference station are situated on top of a hill 2 km southwest of the Main Building.

The rocket impact area (Figure 5-9) is located north of Esrange in the Swedish tundra region. This area is divided into three zones, A, B, and C, with a total area of 5,600 km^2. Zone A, the impact area for boosters, can be extended when rockets with long-range boosters are launched. Zones B and C are impact areas for second and third stages as well as payloads. Zone C is not accessible during the period May 1 - September 15. The nominal impact point normally chosen is situated 75 km north of the launch pads.

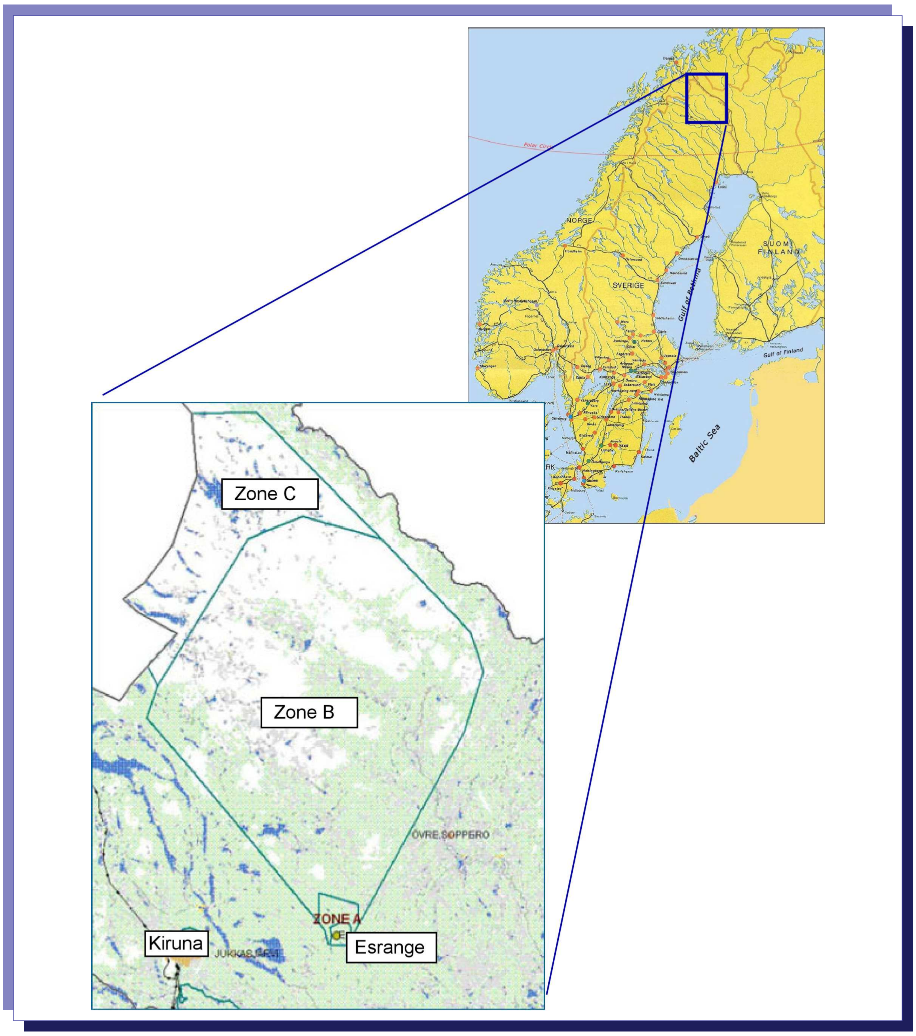

Figure 5-9: Impact areas for rockets launched from Esrange (Image: SSC)

5.2 Physical Environment

5.2.1 Acceleration Levels

For microgravity experimentation sounding rockets offer one of the best environments in terms of time and quality of microgravity. The acceleration levels to which these rockets are subjected reach approximately 10-13g (i.e. 10 to 13 times the gravitational acceleration measured at sea level) during the ascent phase, then drop to less than 10^{-4} g during the microgravity phase and are then (for a very few seconds) subjected to very short peak accelerations of more than 20g during the re-entry phase.

Figure 5-10 shows the acceleration levels, as multiples of ‘g’, measured along the flight-path axis during the early ascent phase of the MAXUS 5 mission, as a function of the mission elapsed time (seconds). The maximum value of approximately 13 g is a typical value for MAXUS missions.

Figure 5-11 displays the acceleration levels (in milli g) measured during the microgravity phase of the MAXUS 3 mission (i.e. between 100 and 840 seconds after launch). From this figure it can be noted that, on average, the absolute value of the microgravity levels during this phase can be typically less than 0.04 milli-g, i.e. < $4x10^{-5}$ g.

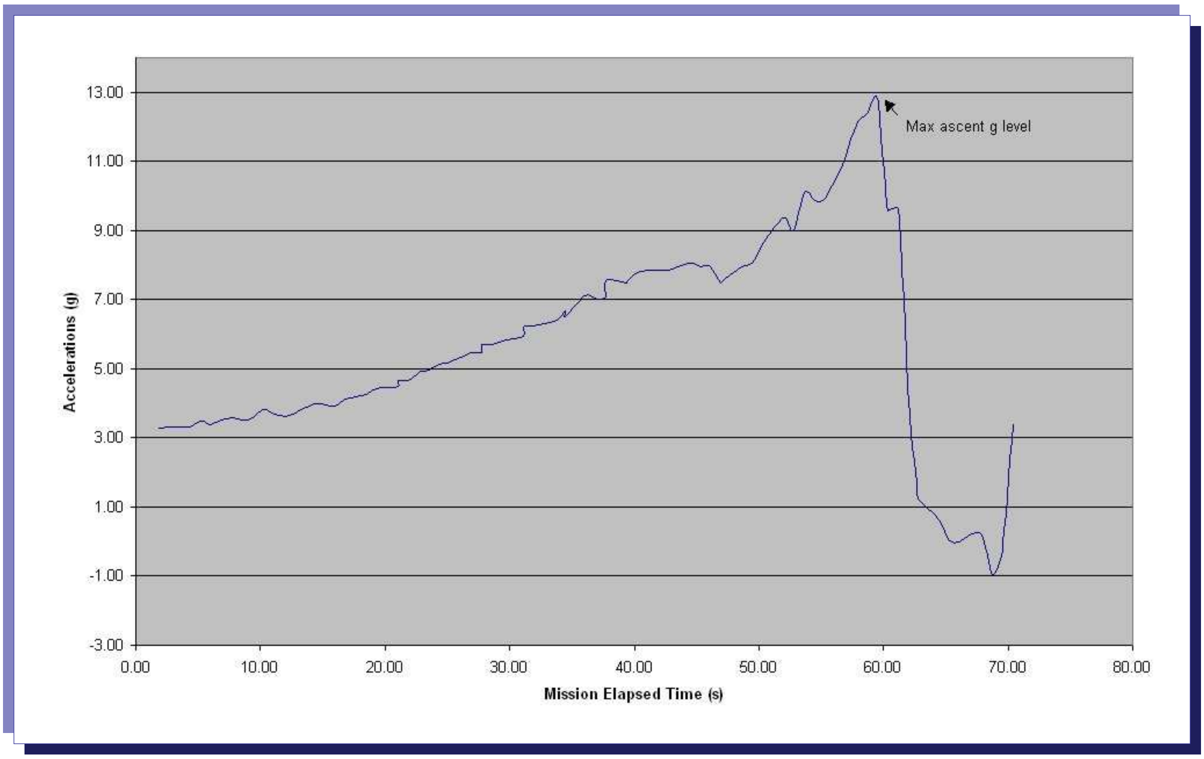

Figure 5-10: Acceleration (g levels) measured along the flight-path axis during the ascent phase of the MAXUS 5 mission

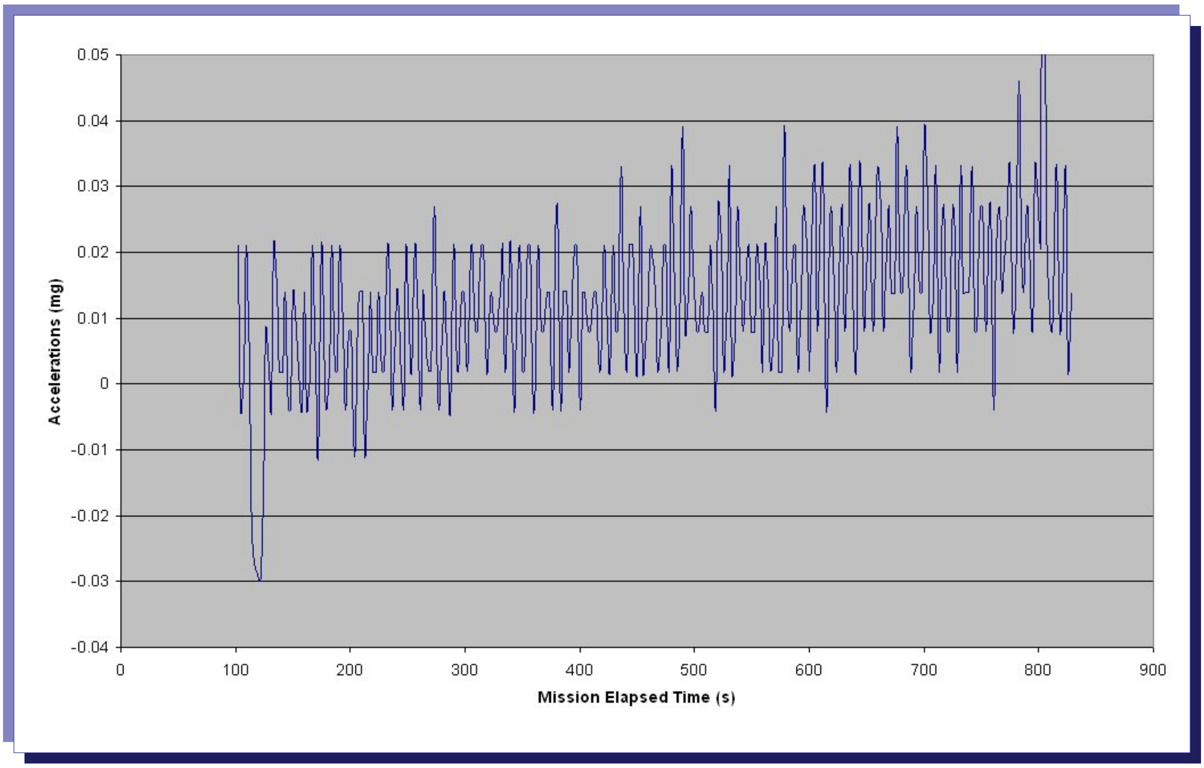

Figure 5-11: Acceleration (milli g) measured along the flight-path axis during the microgravity phase of the MAXUS 3 mission

5.2.2 Thermal Environment

The payload thermal environment is kept under control during the pre-launch phase. The sounding rocket housing air temperature before launch is usually around 18 °C with a range of ± 5 °C. Measurements performed during the ascent phase of the sounding rockets launched from Esrange, have shown that the payload module outer structure reaches a maximum temperature of approximately 130 °C for MASER and TEXUS missions and 170 °C for MAXUS missions. Upon re-entry the outer structures are heated up to about 160 °C for MASER and TEXUS and 270 °C for MAXUS. The experiment design must take care that in particular the temperature increase during ascent does not badly affect the performance of the experiment. During the countdown, temperature sensitive experiments can be connected to a remotely controlled external liquid loop.

After impact of the payloads on the ground the experiment modules are subjected to snow and cold air for a period of up to 2 hours. The seasonal temperatures in the periods when sounding rocket campaigns take place (usually October-November, March-May) are typically sub-zero, and range typically between –30 °C and 0 °C.

5.3 Scientific Research Suitable for Sounding Rockets

The following blocks (Figure 5-12) highlight the various scientific fields for which sounding rockets have proven to be a suitable platform. It is important to note, however, that these fields are based on the data from current and past research carried out on sounding rockets, and should therefore NOT be considered exhaustive. Furthermore, the lists include areas that require further study in future research, identified by scientists contacted during a sounding rocket study carried out on behalf of ESA in 2001. Scientists should view the fields presented below as a guideline, but are encouraged to propose new research areas, as long as their experiments can be executed within sounding rocket flight limitations.

FUNDAMENTAL PHYSICS

Complex plasmas and dust particle physics

Cold atoms and quantum fluids
- Critical phenomena
- Energy transport

BIOLOGY

Plant Physiology
- Gravitropism/graviperception

Cell and developmental biology
- Gravitaxis/gravikinesis
- Graviperception
- Signal transduction pathways
- Cytoskeleton
- Gene expression
- Metabolism
- Self organisation of molecules
- Evolutionary biology
- Reproduction
- Normal development functions
- Cell morphology
- Unicellular organisms
- Multicellular organisms
- Endocrinology

Biotechnology
- Protein crystal growth
- Electrophoresis
- Electrofusion

FLUID AND COMBUSTION PHYSICS

Combustion
- Premixed gas flames
- Gaseous diffusion flames
- Flame spreading
- Combustion synthesis
- Liquid fuel sprays and droplets
- Fuel particles and dust clouds
- Smouldering combustion

Structure and dynamics of fluids & multiphase systems
- Multi-phase flow and heat transfer
- Bubble/Drop nucleation
- Boiling with/without electric field
- Colloids
- Magneto-rheological fluids
- Foams
- Granular systems
- Fluid spreading
- Wetting phenomena
- Critical point studies
- Liquid drop dynamics
- Gas bubble dynamics
- Capillarity
- Magneto/electro hydrodynamics
- Surface driven bulk flows

MATERIALS SCIENCE

Thermophysical properties
- Thermophysical properties of melts

New materials, products and processes
- Solutal diffusion in metals and alloys
- Composites
- Solidification interfaces in metals and alloys
- Multiphase and multicomponent solidification
- Reaction kinetics in glasses and ceramics
- Phase separation in glasses and ceramics
- Nucleation in glasses and ceramics
- Crystal growth from solution & melt
- Vapour crystal growth
- Semiconductors
- Undercooling
- Metallic foams
- Zeolites

Figure 5-12: Research fields carried out on Sounding Rockets, based on past experiments

5.4 Payload Accommodation

The design concept of payloads flown on ESA-sponsored sounding rocket missions is based on re-usable autonomous experiment modules. The scientific payloads are made up of combinations of experiment modules, assembled together with the service systems necessary for in-flight support (i.e. telemetry, rate control, recovery). Use of these modules assures maximum integration and operational flexibility and the minimum number of interface connections between experiments and the service module. Under this arrangement, basic experiment resources are decentralised, and standardised as support subsystems and components (i.e. module structure, batteries and power supply, etc.). Experiment modules flying on MiniTEXUS, TEXUS and MASER are accommodated within a 438 mm diameter cylindrical payload envelope on a one- or two-platform structure. This layout groups experiment services (power supply and electronics) in the lower part of the module, under the experiment-dedicated equipment (e.g. experiment chamber, furnace, diagnostics, etc.) assembled on the upper platform. The modules for the MAXUS programme have a diameter of 640 mm and are in most cases assembled on a single platform, the service components being grouped around the experiment facilities. This approach of assembling autonomous modules, provides users great flexibility in meeting experiment and mission requirements, it facilitates testing at module level and has proven to be a cost-effective solution in all phases of the programme. Within the framework of its Microgravity Programme, ESA has funded the development of many sounding rocket experiment modules for a broad spectrum of scientific investigations. Users can select and utilise an already developed experiment module, requesting (if necessary) suitable modifications to be made. The following section provides users with an overview of ESA-owned modules that have already been developed and flown.

5.4.1 ESA Experiment Modules

5.4.1.1 Materials Sciences

Table 5-9: Materials Sciences Experiment Modules

MODULE NAME	MISSIONS FLOWN	SUITABLE FIELDS OF RESEARCH	MAIN CHARACTERISTICS AND FEATURES
LPE (Liquid Phase Epitaxy)	*Maser 7* (May 1996)	❑ Epitaxial growth of SiC	❑ High temperature vacuum furnace with graphite heaters ❑ 1800 °C ≤ T_{max} ≤ 2000 °C ❑ Mass = 63 kg ❑ Module length = 406 mm
TEM 01-4	*Texus 32* (May 1994)	❑ Isothermal melting and solidification	❑ Two isothermal furnaces with resistance heaters ❑ T_{max} = 1600 °C ❑ Sample dimensions: diameter = 18 mm, length = 50 mm ❑ Heated length = 65 mm ❑ Isothermal condition = ± 5 °C depending on sample ❑ Gradient = 10-40 °C/cm depending on sample ❑ Module height = 350 mm ❑ Payload outer cylinder diameter = 438 mm ❑ Experiment mounting platform diameter = 403 mm ❑ Mass = 32 kg
TEM 02-5M	*Maxus 4, Maxus 6* (April 2001, November 2004)	❑ Floating zone crystal growth ❑ Vibration and rotating magnetic fields influence on Marangoni convection	❑ Two monoellipsoidal mirror-furnaces with one CCD camera each ❑ T_{max} = 1600 °C ❑ Lamp power, pulling speed and rotation rate adjustable by telecommand ❑ Sample dimensions: diameter = 10 mm, length = 80 mm ❑ Max. translation length = 50 mm ❑ Translation speed = 1 – 10 mm/min ❑ Rotation speed = 1 – 10 rpm ❑ Typical gradient = 40 °C/cm ❑ Module height = 950 mm ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Temperature measurement in the melt with remotely adjustable pyrometers (temperature range 400 – 1800 °C) ❑ Sample vibration system with 70 Hz and 100 to 150 µm amplitude ❑ Rotating magnetic field with 50 Hz and 7 mT at the sample location ❑ Mass = 165 kg

TEM 06-26M	*Maxus 4, Maxus 5* (April 2001, April 2003)	❑ Crystallisation of zeolites from solution	❑ 10 furnaces each housing 3 cartridges capable of containing 1cm^3 of suspensions at 30 bar ❑ Heating temperatures typically between 145 and 165 °C ❑ Water cooling system for quenching ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Mass = 85 kg ❑ Module length = 523 mm
JET	*Maser 8* (May 1999)	❑ Jet growth motion of urotropine crystals in aerosols	❑ Temperature controlled experiment chamber of 1.5 ml volume, connected to 2 compartments with reagent gas and a particle injection device ❑ Optical system with 4 CCD cameras for 3D particle tracking velocimetry (PTV) ❑ Mass = 54 kg ❑ Module length = 661 mm
TEM 01-1M	*Maxus 6* (November 2004)	❑ Unconstrained eutectic solidification of ternary alloys	❑ 4 identical furnaces with 2 zone resistance heaters ❑ Maximum temperature = 600 °C ❑ Water spray cooling of the inconel cartridges ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Module length = 464 mm ❑ Module mass = 62.5 kg

5.4.1.2 Fluid Sciences

Table 5-10: Fluid Sciences Experiment Modules

MODULE NAME	MISSIONS FLOWN	SUITABLE FIELDS OF RESEARCH	MAIN CHARACTERISTICS AND FEATURES
GABRIEL (Gravity Assessment for Boiling Research and Investigation with ELectric field)	*Maser 7, Maser 8* (May 1996, May 1999)	❑ Pool boiling with electric field	❑ Two chambers for boiling experiments with high voltage electrodes and one CCD camera each ❑ Mass = 57 kg ❑ Module length = 661 mm
INEXMAM (INteractive EXperiment on MArangoni Migration)	*Maser 6, Texus 34, Maxus 5* (November 1993, March 1996, April 2003)	❑ Marangoni migration	❑ Block-shaped experiment cell with 3 windows ❑ Heaters on two opposite sides to establish a temperature gradient ❑ Video observation from 2 sides ❑ Mass = 69 kg (TEXUS), 89 kg (MAXUS) ❑ Module length = 968 mm (TEXUS), 601 mm (MAXUS)
WSM (Wet Satellite Module)	*Maser 5* (April 1992)	❑ Liquid motion in rotating annular tank	❑ Module made up of small satellite with its own telemetry and transmitter to be ejected from the payload aft end after motor separation ❑ Experiment consists of an annular tank with a momentum wheel and a set of 9 accelerometers ❑ Mass = 42 kg ❑ Module length = 520 mm
SME (Solutal Marangoni Effect)	*Maser 5, Maser 6* (April 1992, November 1993)	❑ Solutal Marangoni effect	❑ Two cubic experiment cells (70 x 70 x 70 mm) each with a fluid detonation and pressure compensation system and windows on 4 sides ❑ Each cell equipped with an injection needle which can be brought into the liquid matrix to form a droplet of a second liquid (2 to 6 mm diameter) ❑ Observation by 2 CCD cameras in directions perpendicular to each other ❑ Mass = 56 kg ❑ Module length = 602 mm
TEM 04-2	*Texus 27, Texus 28* (November 1990, November 1991)	❑ Continuous flow electrophoresis	❑ Electrophoresis equipment with AC (50 Hz) and DC (up to 200 V) voltage applicable between electrodes ❑ Light sheet perpendicular to the flow and video observation (CCD camera) under 45° with respect to the light sheet plane ❑ Separation cell dimensions = 230 x 60 x 15 mm ❑ Rectangular flow section = 60 x 3 mm ❑ Payload outer cylinder diameter = 438 mm ❑ Experiment mounting platform diameter = 403 mm ❑ Module height = 901 mm ❑ Mass = 72 kg

TEM 06-9	*Texus 10, Texus 12, Texus 18, Texus 23, Texus 33* (May 1984, June 1985, May 1988, November 1989, November 1994)	❑ Long liquid columns	❑ Plateau tank configuration for liquid bridges of diameter = 30 mm and length = 100 mm with video observation ❑ Laser light sheet less than 0.2 mm in thickness ❑ Mass = 44 –58 kg ❑ Module height = 679 mm ❑ Payload outer cylinder diameter = 438 mm ❑ Experiment mounting platform diameter = 403 mm
TEM 06-10	*Texus 11, Texus 13, Texus 25* (April 1985, April 1986, May 1990)	❑ Phase separation near the critical point of binary mixtures ❑ Heat and mass transport phenomena in supercritical CO_2	❑ 3-stage thermostat with temperature stability of better than ± 0.5 mK, controllable in steps of 1 mK ❑ Video observation ❑ Mass = 43 kg ❑ Module height = 567 mm ❑ Payload outer cylinder diameter = 438 mm ❑ Experiment mounting platform diameter = 403 mm
TEM 06-12	*Texus 17, Texus 23, Texus 31* (May 1988, November 1989, November 1993)	❑ Coagulation of suspensions/ dispersions/ colloids	❑ Ten experiment units each with magnetic stirring, ultrasonic homogenisation, optical transmission measurement system ❑ Mass = 33 kg ❑ Module height = 412 mm ❑ Payload outer cylinder diameter = 438 mm ❑ Experiment mounting platform diameter = 403 mm
TEM 06-17	*Texus 21, Texus 31* (April 1989, November 1993)	❑ Marangoni-Bénard instabilities	❑ Two independently controlled experiment units in which a free silicon oil surface can be established ❑ Heating from below ❑ Each container with video observation (CCD cameras) and light sheet through the silicon layer, parallel to the surface ❑ Mass = 58 kg ❑ Module height = 743 mm ❑ Payload outer cylinder diameter = 438 mm ❑ Experiment mounting platform diameter = 403 mm
TEM NOR	*Minitexus 2* (May 1994)	❑ Boiling in Freon due to a sudden pressure decrease	❑ Temperature and pressure controlled experiment chamber with observation via 2 CCD cameras ❑ Mass = 43 kg
DYLCO	*Maxus 2* (November 1995)	❑ Dynamic behaviour of liquids in corners and edges	❑ 12 rotating experiment cuvettes with filling systems observed by 2 CCD cameras, synchronised with the illumination arrays ❑ Each cuvette has an octagonal outer shape and a rhombic inner shape ❑ Each cell is equipped with an independent filling unit consisting of a motor-driven piston ❑ Mass = 68 kg ❑ Module length = 440 mm

MEO (Maxus experiment on Electro-phoretic Orientation)	*Maxus 1b* (November 1992)	❑ Electrophoretic orientation of macromolecules	❑ 6 experiment cells in a rotating cell exchange mechanism ❑ Linear dichroism measurement system ❑ Electrical field up to 1 kV ❑ Mass = 59 kg ❑ Module length = 361 mm
TEM 04-2M	*Maxus 2, Maxus 3* (November 1995, November 1998)	❑ High resolution separation by continuous flow electrophoresis ❑ Electro-hydrodynamic sample distortion during electrophoresis	❑ Electrophoresis unit with 500 V DC and sample collection in 59 channels ❑ Light sheet perpendicular to the flow ❑ Video observation under 45° with respect to the light sheet plane ❑ Mass = 106 kg ❑ Module height = 786 mm
TEM 06-4M	*Maxus 1b, Maxus 3, Maxus 4* (November 1992, November 1998, April 2001)	❑ Marangoni convection in a floating zone (liquid bridge) ❑ Heat flux studies	❑ Liquid bridge configuration with Peltier controlled pistons ❑ Liquid bridge diameter = 20 mm ❑ Liquid bridge length up to 25 mm ❑ 2 light sheets (one 0.3 mm thick) with different wavelengths ❑ Observation by 2 CCD cameras and 1 infrared camera ❑ Insertable thermocouple comb and thermal flux measurement in lower piston ❑ Mass = 49.5 kg ❑ Module height = 370 mm ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm
TEM 06-17M	*Maxus 2* (November 1995)	❑ Marangoni-Bénard instabilities and multilayer experiments	❑ 3 independently controlled experiment units: 2 containers in which a free silicon oil surface can be established (heating from below), one of them with a light sheet perpendicular to the layer and both with one CCD camera, plus one multilayer set-up for 3 fluid layers separated by 2 sliders ❑ 2 light sheets perpendicular to each other in the multilayer unit. Observation by 2 CCD cameras ❑ Module height = 707 mm ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Mass = 104 kg
TEM 06-27M	*Maxus 4* (April 2001)	❑ Multi-roll instability of thermocapillary flow and transition to oscillatory flow in long floating zones	❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Possibility of studying long liquid bridges with aspect ratio A>4 (A=length/radius) and remotely controlled bridge length ❑ Temperatures in bridge measured by 5-thermocouple comb. Each thermocouple is 0.7 mm thin. ❑ Flow field visualised by tracer particles illuminated by two perpendicular laser light sheets and observed by three CCD cameras at different angles ❑ Mass = 49 kg ❑ Module length = 702 mm

TRUE (Thermal Radiations in Unsteady conditions Experiment)	*Maser 8, Maser 10* (May 1999, May 2005)	❑ Thermal radiation forces	❑ 6 temperature controlled measurement units with a force sensor based on an electromagnetic galvanometer with a resolution of ± 0.01 dyne ❑ Mass = 55.7 kg ❑ Module length = 550 mm
TEM FER	*MiniTexus 5* (February 1998)	❑ Fluid-like behaviour of granular materials submitted to vibrations ❑ Parametric instabilities of a spherical liquid-vapour interface submitted to vibrations	❑ Two 3-stage thermostats with temperature stability better than ± 0.5 mK, controllable in steps of 1 mK ❑ Video observation via CCD cameras ❑ Both the thermostats and the CCD cameras are mounted on an acceleration system with variable frequency and amplitude which can achieve up to 35g ❑ Mass = 94 kg ❑ Module length = 975 mm
TEM FER 2M	*Maxus 5* (April 2003)	❑ Vibration phenomena in inhomogeneous media	❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ See TEM FER ❑ Mass = 95 kg ❑ Module length = 738 mm
CYRENE 2	*Maser 9* (March 2002)	❑ Convective boiling and condensation in microgravity	❑ Module height = 900 mm ❑ Mass = 65 kg ❑ The module comprises one Ammonia loop with an evaporator and a cooling system. ❑ The cooling system consists of a water loop with five condensers. ❑ The Ammonia is pumped through the closed loop and is evaporated and thereafter cooled and condensed. ❑ Pressure drops can be measured
ITEL	*Maser 9, Maser 10* (March 2002, May 2005)	❑ Interfacial turbulence in evaporating liquids (ethanol)	❑ Module height = 750 mm ❑ Mass = 68.5 kg ❑ The experiment volume is circular and has a liquid volume of 14 ml, a free liquid surface of Ø15 mm and a liquid depth of 6 mm. ❑ The thermal control is passive during flight and uses an external liquid loop during countdown ❑ The cell is pressure tight and incorporates ten thermocouples, a pressure sensor, liquid inlet, and a nearly laminar nitrogen flow parallel to the liquid surface ❑ The evaporation rate of the liquid is controlled by regulating pressure of the gas phase ❑ The temperature variations in the liquid volume are observed by an interferometric optical tomography system to get a 3-D temperature field. A Schlieren optical system is used to control the flatness of the liquid surface.
CDIC	*Maser 10* (May 2005)	❑ Chemically driven interface convection	❑ The module contains 4 independently controlled experiment units mounted on 2 decks ❑ 2 experiment cells are observed by a shadowgraph optic, the other 2 by means of an interferometer ❑ Each cell has its own filling system consisting of two motor driven syringes ❑ Mass = 85.7 kg ❑ Module length = 1100 mm

5.4.1.3 Life Sciences

Table 5-11: Life Sciences Experiment Modules

MODULE NAME	MISSIONS FLOWN	SUITABLE FIELDS OF RESEARCH	MAIN CHARACTERISTICS AND FEATURES
CIS (Cells In Space)	*Maser3, Maser 4, Maser 5, Maser 6, Maser 7, Maser 9* (April 1989, March 1990, April 1992, November 1993, May 1996, March 2002)	❑ Cell growth and behaviour in microgravity ❑ Regulation of cell growth and differentiation ❑ Cell fusion ❑ Cytoskeleton, extracellular matrix and genetic expression ❑ Thyroid cells ❑ Signal transduction and genetic expression of T-lymphocytes ❑ Suspended cell clusters	❑ Module consisting of 2-4 sub-modules, which can accommodate 2-3 different experiments with a rather large number of samples ❑ 12-18 temperature controlled experiment 'cans' in which the individual experiment units ('LIDIA') are housed ❑ In-flight 1g centrifuges and ground reference set-up available ❑ Thermal control provided between 15 and 40 °C, with an accuracy of ±0.2 °C ❑ Mass = 62-117 kg
EMEC (Effect of Microgravity on Enzyme Catalysis)	*Maser 7* (May 1996)	❑ Enzyme catalysis	❑ 16 experiment chambers of 1.2 ml volume, each with injection system and optical transmission measurement in the UV range (324 nm) ❑ Ground reference unit with 16 equally equipped experiment units ❑ Mass = 59 kg ❑ Module length = 677 mm
TEM 06-5MZ	*Maxus 2* (November 1995)	❑ Cell biology	❑ Module consists of a significant number of temperature controlled experiment units based on sets of interconnected syringes for 2 or 3 activations and an in-flight 1g centrifuge ❑ Module height = 626 mm ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Mass = 103 kg
TEM 06-5RO1M	*Maxus 2* (November 1995)	❑ Spatial orientation of cells	❑ Rotary experiment deck with tuneable frequency to achieve up to 1g inside the samples ❑ 2 identical temperature-controlled experiment units with video observation via microscope optics ❑ Mass = 55 kg ❑ Module height = 401 mm
TEM 06-RO1M	*Maxus 5* (April 2003)	❑ Gravisensitivity and graviperception mechanisms of plant cells	❑ Module consisting of 12 temperature controlled cuvettes placed on a rotating platform in different radial positions ❑ Visualisation via 2 video-microscopes ❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Mass = 75 kg ❑ Module length = 614 mm

BIG (BIological Gravisensitivity module)	*Maxus 3, Maxus 5* (November 1998, April 2003)	❑ Influence of gravity on morphological structures in microtubules	❑ Temperature controlled experiment compartment with a significant number of samples, part of which is installed on an in-flight 1g centrifuge ❑ Observation by 2 CCD cameras ❑ Module height = 601 mm ❑ Mass = 100 kg
TEM 06-5RO2M	*Maxus 3* (November 1998)	❑ Mechanism of gravitactic signal perception and signal transduction of unicellular flagellates	❑ Payload outer cylinder diameter = 640 mm ❑ Experiment mounting platform diameter = 590 mm ❑ Module consists of two identical experiment chambers placed on a rotating table (centrifuge) in order to introduce an artificial gravitational field ❑ Each of the experiment chambers can be rotated by 360 degrees around its symmetry axis, to avoid sedimentation of the cells during launch ❑ Cells loaded with fluorescent microscopes (Calcium Crimson, Molecular Probes) ❑ Visualisation via an image-intensifier camera attached to a microscope, at g-levels varying between 10^{-4} g and 1g ❑ Mass = 67.5 kg ❑ Module length = 547 mm
BIM	*Maser 10* (May 2005)	❑ Role of microgravity on Actin metabolism in mammalian cells ❑ Influence of microgravity on the activation of NF-kappa B	❑ 16 plungerbox experiment units as microgravity samples ❑ 16 plungerbox units as in-flight 1g reference samples ❑ Ground control set-up with 16 plungerbox experiment units ❑ All 32 flight units are mounted on a temperature controlled late access sled for late installation in the payload ❑ Mass = 48.8 kg ❑ Module length = 506 mm

5.4.1.4 Combustion

Table 5-12: Combustion Experiment Modules

MODULE NAME	MISSIONS FLOWN	SUITABLE FIELDS OF RESEARCH	MAIN CHARACTERISTICS AND FEATURES
TEM SEN	*MiniTexus 3, MiniTexus 6, Texus 38* (May 1995, November 1998, April 2000)	❑ Flame spreading over solid fuels in a laminar flow ❑ Forced convection in combustion processes	❑ Module comprises a combustion chamber with a laminar gas flow (different speeds and gas composition) ❑ The diagnostic tools comprise up to 3 CCD cameras, an IR camera, light sheet illumination, a PIV system, and thermocouples ❑ TEM SEN also contains a sample exchange mechanism as well as a soot collection system ❑ Module height = 1594 mm ❑ Mass = 115 kg
TEM EVA	*Texus 38* (April 2000)	❑ Droplet evaporation	❑ Capability to generate droplets of 1 mm diameter between two syringes and to fix their attachment to a 85 µm wire ❑ The wire with the droplet and the observation system is moved upward until the droplet is positioned in the centre of a pressure chamber with 50 bar and 400-600 °C ❑ Mass = 69 kg ❑ Module length = 860 mm

5.4.1.5 Fundamental Physics

Table 5-13: Fundamental Physics Experiment Modules

MODULE NAME	MISSIONS FLOWN	SUITABLE FIELDS OF RESEARCH	MAIN CHARACTERISTICS AND FEATURES
CODAG (COsmic Dust AGgregation)	*Maser 8* (May 1999)	❑ Dust particle physics	❑ Vacuum chamber with dust injection device ❑ 3D observation by 2 microscopes perpendicular to each other mounted on a scan table and viewed by 2 fast digital CCD cameras (fov 50 x 50 mm) ❑ Light scattering ring with 22 analyser blocks ❑ Module height = 681 mm ❑ Module diameter = 438 mm ❑ Mass = 57 kg

5.5 Available Flight Resources

The payload service systems are designed in a modular style similar to that selected for experiments. This approach offers the following advantages:

- Assures maximum flexibility of payload assembly to meet centre of gravity requirements;
- Ease of integration with experiment modules by means of standard interfaces;
- Ease of servicing, maintenance and checkout;
- Modifications to individual services can be implemented with minimum impact on other flight systems;
- Maximum commonality between the different flight systems.

5.5.1 Service Module

Typically, the Service Module (TSM) consists of the Telemetry System (TM), the Telecommand System (TC), the Rate Control System (RCS) and the acceleration sensing assembly.

5.5.1.1 Telemetry System

The Telemetry System multiplexes and transmits experiment and housekeeping data from the experiment modules and the in-flight service systems to the ground. In general, for each experiment module the following are available for telemetry:

- *Analogue channels*: 32 to 64, 0 – 5 V
- *Digital channels*: 36, 12 bit

5.5.1.2 Telecommand System

A total of 40 telecommand channels are available for experiment operation. Update (refresh) interval = 50 msec.

5.5.1.3 Rate Control System (RCS)

The function of the RCS is to keep evolving body rates of the payload in all 3 axes below predetermined limits of 0.1°/sec and 1.5°/sec. This is achieved by applying opposite thrust to the disturbance vectors by means of cold gas thrusters. The quality of the microgravity environment is determined by this system. Rate gyros provide input signals to the system. The acquisition of the rate control system occurs after separation from the launch vehicle and despin by the yo-yo system (only for MiniTEXUS, TEXUS and MASER).

5.5.1.4 Acceleration Measurement

The acceleration measurement system typically has the following measuring ranges:

- *Coarse measurement (accelerometers)*: ± 75 g, resolution 3.66 x 10^{-2} g
- *Fine measurement (microgravity sensors)*: ± 12.8 x 10^{-3} g, resolution 6.25 x 10^{-6} g

5.5.2 TV Module

The TV module for analogue video transmission comprises 2 TV transmitters. It can be integrated into the payload as required. Typically, 1 to 2 TV modules are accommodated in various areas along the scientific payload. Analogue video transmissions to the ground are usually in the S-band at 10W nominal RF power.
Each TV module is equipped with 4 antennas and an antenna switching system to ensure that for the transmission to the ground station the antenna with the highest link margin is used.

5.5.3 MAXUS Rocket Systems

For a MAXUS mission besides the above described payload service systems the so-called Rocket Systems are also needed. They consist of the Telemetry and Tracking Unit (TTU), the Guidance Control System (GCS) and the conical Interstage Adapter (INA).

5.5.3.1 Interstage Adapter (INA)

The conical Interstage Adapter (INA), developed by SSC (Sweden), is the connecting hardware between the Castor IVb rocket motor with a diameter of 1018 mm and the payload with a diameter of 640 mm. It provides the power for the stirring mechanism of the rocket nozzle, it activates the self destruct system of the rocket motor upon telecommand from the ground, it contains a radar transponder for the radar tracking of the motor and it accommodates the separation system that separates the payload from the motor after burn out.

5.5.3.2 Telemetry and Tracking Unit (TTU)

The TTU, developed by SSC (Sweden), is mounted on top of the INA. Its lower end is shaped as a re-entry cone which functions as a heat shield during the re-entry phase and as a shock absorber upon the payload’s impact on the ground. The TTU contains a video camcorder that records the separation of motor and payload. It further accommodates a telemetry system to downlink the rocket motor data, the GCS data and the GPS data, and to receive telecommands from the ground station.

5.5.3.3 Guidance Control System (GCS)

The GCS, supplied by SAAB Ericsson Space (Sweden), is located on top of the TTU. Its task is to control the deflection of the rocket motor nozzle in order to stabilise and navigate the vehicle along the calculated trajectory so to reduce the dispersion of the impact point. This is achieved by means of an inertial platform with rate gyros.

5.5.4 Recovery System

Except for MASER 1-3 and 6-10, which used aft-end recovery systems, the recovery system for a microgravity sounding rocket mission is located in the nose cone of the payload. Under normal conditions it enables the recovery of the payload without any major damage. This is important since many investigators, besides the downlinked telemetry and video data of their experiments, also need their samples back for detailed investigations in their home institutes. If a digital video system is used, this also applies to the uncompressed video images of the experiments as they are stored onboard. Another big advantage of recovering the payload is that the service systems and experiment modules can be re-used after refurbishment. This leads to a considerable cost saving.

5.5.5 External Temperature Control

A number of experiments require active regulation of temperature prior to launch. Some metallurgy experiments require the sample to be molten at the start of microgravity operations, while biology experiments frequently require thermal conditioning of the sample to support biological activity. Ground-based water-cooling loops are available where needed, the supply disconnecting from the module at launch. Cooling can be maintained during ascent either by means of Peltier elements or by making use of the thermal capacity of the experiment module.

5.6 Ground Support Facilities

5.6.1 Main Building

The Main Building has four storeys with a total floor area of 3930 m^2. In the basement there is storage for consumables. It also contains mechanical, electrical and carpentry workshops. For staff and guests there is a sauna and showers. The ground floor houses offices for Esrange administration and technical facilities, a reception desk, a switchboard (which on working days is staffed from 8:00 to 16:00, and on countdown days until the end of operations), a canteen, two conference rooms for 15 and 30 people, and a lounge. The first floor has offices for operational staff, the operations centre for sounding rockets and rooms for timing, telemetry and scientific instruments (Scientific Centre). In an annex on the same floor there are offices and guest rooms. The top floor (second floor) has a large conference room for about 80 people, and offices. The Main Building area also includes accommodation buildings with 96 single rooms (of different standards), showers and kitchens.

5.6.2 Launching Area

The launching area is located in an area about 1 km east of the Main Building. All operations that are required from storage to preparation, assembly, integration, testing and launch of sounding rockets with complex payloads are performed in this area. During countdowns the road to the area is closed by a gate, and only authorised personnel are allowed to work in the launching area. To pass the gate a badge is needed, which can be obtained from the safety officer in charge.

5.6.2.1 Offices

Three offices are available to users (i.e. industry and scientists). They are situated in the laboratory annex in close connection to the payload assembly hall. Each office is equipped with standard furniture, telephone and Internet access. When entering Esrange, each campaign participant receives a personal code for his/her official phone calls, and another code for private calls. By means of these codes each telephone at the range can be used. There is also a small common space and toilets in this area. Near the main entrance there is a well-equipped kitchen and a TV-room for convenience.

5.6.2.2 Payload Assembly Hall

The payload assembly hall has a floor area of 10.5 m by 20 m and a height of 3.9 m, except for the central portion, which has a higher ceiling to allow vertical assembly of longer payloads. A single rail electric gantry crane is installed for payload handling. If required, the area can be divided into sections by means of movable screen-walls. The area is equipped with workbenches with electric power outlets.
Single phase and 3-phase power and also two cold water supplies are available. The main access door to the hall is 4.08 m high and 3.81 m wide.

5.6.2.3 Laboratories

Apart from standard tools and instruments, a variety of equipment for laboratory work, is available for use. Four laboratories are available for advanced biological work. They are all equipped with gas, warm and cold water, fume hoods, laminar airflow cabinets (horizontal or vertical), refrigerators, deep freezers, and lockable cupboards to store poisonous materials. One electronic laboratory is reserved for the launch crew. The laboratory equipment available to users includes:

- A high-temperature 3-litre oven. Thermostat controlled up to 1200 °C ± 1 °C;
- A vacuum medium-temperature 130 litre oven 1 mbar thermostat controlled up to 250 °C (LeyboldHeraeus VT5050EK);
- An oil-diffusion pump, 10^{-6} mbar (Edwards diffstak CR100/300M);
- A turbomolecular pump, 10^{-6} mbar (Balzer TSU170);

- An ultrasonic cleaner, 5.5 litre (Bransonic 32);
- Three 50 litre containers for liquid nitrogen;
- Three 100 litre containers for liquid helium (Alfax RS101);
- One 250 litre container for liquid helium;
- A weighing-scale 0-1200 g capacity, with 0.1 mg resolution (Satorius 1206 MP);
- A stereo-zoom microscope. Magnification 30x to 210x. Reflected light and camera adapter with 35 mm Contax camera (F:1.7), Bausch & Lomb Stereo Zoom;
- Microscope Nikon, Diophot + accessories;
- Microscope Nikon, SMZ-2B, 2 pcs;
- Microscope Nikon, SMZ-2T;
- Schott coldlight source, KL 1500, 3 pcs;
- Centrifuge Hettich Universal K2S + accessories;
- Deepfreeze Colora, UF85-110T;
- Autoclave Denley BA 852;
- Magnetic Stirrer Nuova II, SP 18420-26;
- Vortex mixer Eckli 600;
- Distillation apparatus Schott 2481100;
- Water demineralisation Seradest S750/5200;
- Transportbox Veba electronics, #378 37 °C;
- Transportbox Veba electronics, #379 37 °C;
- Transportbox Veba electronics, #833 4-22 °C;
- Transportbox Veba electronics, #832 4-22 °C;
- Transportbox Veba electronics, #828;
- Accu charger;
- Accu 12 V/65AH, 2 pcs;
- Nikon 801 + AF Nikon 50 mm;
- Cleaner for laboratory glassware, Miele G 7733 automatic;
- Conductometer, Knick type 600;
- Electronic precision balance, range 3000 g, resolution 0.01 g, PAG Oerlicon, Precisa 3000 C;
- Microscope illumination, Volpi type Intralux 5000;
- Incubator, Memmert type BE 60;
- Large shaker, GFL type 3020;
- Magnetic stirrer, IKA-Werk type Ikamag RCT;
- pH-meter, Knick type 646;
- Pipetting guide, Technomara type Pipetboy;
- Reagent glass shaker, Heidolph type Reax 2000;
- Shaking water bath, Julabo type SW-20 C;
- Steam sterilizer, Heuss u. Partner, type Varioklar 400 E;
- Refrigerated centrifuge, Heraeus, type Omnifuge 2.0 RS;
- Refrigerated centrifuge, Sigma, type Sigma 3 K-1;
- Ultracentrifuge, Kontron Instruments, type TGA 55;
- Water bath, GFL type 1013;
- Water bath, Memmert type WU 600;
- Intralux 5000 cold light source.

5.6.2.4 Workshop

One small mechanical workshop is available.

5.6.2.5 User's Blockhouse

To accommodate the large amount of ground control equipment, mainly used for microgravity payloads, a dedicated blockhouse is available. It's roof and walls are reinforced to the same standards as the main blockhouse. The floor area is 8.0 m by 7.5 m.

5.6.2.6 Storage

A cold storage, 10 m by 16 m, is situated 50 m south of the payload assembly hall main entrance. It is used for long term storage of launch support equipment, and temporary storage of user's equipment.

5.6.3 Scientific Centre

The Scientific Centre in the Main Building is the centre for scientific observations. During a sounding rocket mission, the telemetry and video data from the experiment modules are displayed in the Scientific Centre to enable the scientists to follow their experiments.

5.6.3.1 Telemetry

The telemetry station is very flexible and can be quickly adjusted for different missions. Several telemetry links can be maintained simultaneously. RF downlinks in P, S, or L-band can be used. For the telemetry and analogue video downlink of microgravity missions only the S-band is used. Equipment for demodulation and recording of PCM, FM and TV signals is included in the station. Signal decommutation and conditioning for quick look information is also performed. Flight data are presented in real time or post-flight, using several different media and formats. For microgravity sounding rocket missions, besides the Esrange TM station, also the DLR telemetry station is used for redundancy.

5.6.4 Telescience

Besides manipulating onboard experiments during flights from the blockhouse at Esrange it is also possible to do so from remote laboratories all over the world. Data, TV-video signals and telecommands can be transferred between Esrange and remote sites by terrestrial telecommunication links or broadband satellite links, which enables the real-time telescience.
The following figure (Figure 5-13) shows a generic ground segment layout for a sounding rocket campaign.

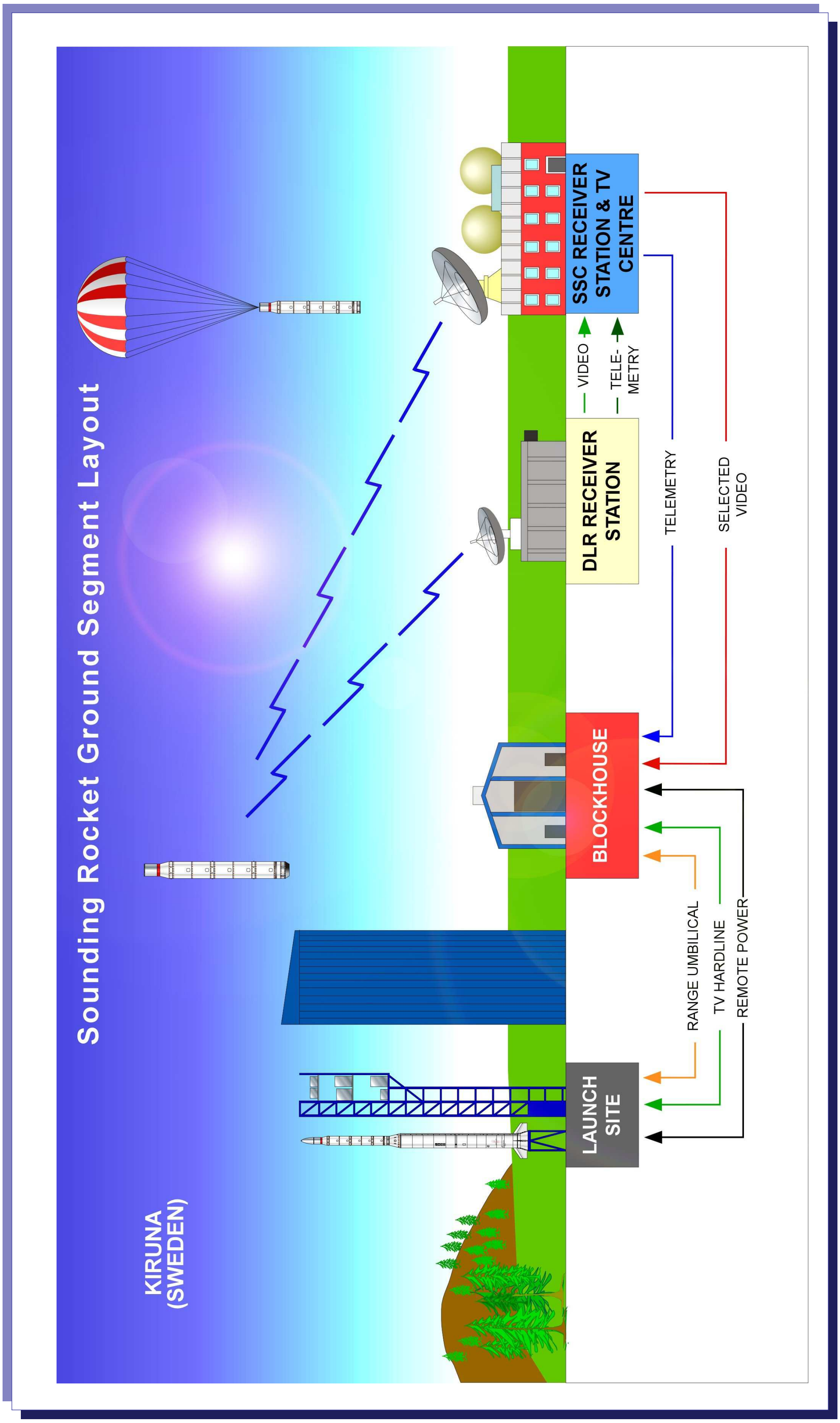

Figure 5-13: Generic Sounding Rocket campaign ground segment layout

5.6.5 TV Centre

Two stations receive the transmitted TV signals from the sounding rockets. Each analogue TV channel is received in two polarisation directions and distributed to the TV centre in the Main Building. An operator chooses the best signals for recording and further distribution to the Blockhouse and the Scientific Centre. S-VHS video recorders are used for recording. The TV centre is a property of EADS-ST (Germany) and can, when the necessary agreements have been made, be used for TV selection and distribution if needed.

5.6.6 Late Access/Early Retrieval

In conjunction with the on-site laboratories, biologists, as well as other users with experiments that have to be prepared late in the countdown cycle, can take advantage of insertable “late access” assemblies to delay integration of the samples into the payload up to 1 hour before launch. This is achieved by inserting the late access unit into the experiment module through a hatch in the outer structure. This approach also makes it possible to extract late access units from the payload at the landing site, so that they can be returned to Esrange by a special helicopter and handed over to the experimenter before the payload is brought back to the range.

5.6.7 Recovery of Payloads

Recovery of payloads is standard procedure at the range. The impact area makes Esrange very suitable for all kinds of flights where recovery is necessary. The open landscape allows smooth payload landing contributing to a minimum of impact damage. To ensure a quick and successful recovery, all microgravity payloads are equipped with proper homing devices (e.g. beacons, GPS transmitters). All other parts, without beacons, such as motor cases, nosecones, etc., are recovered as soon as they have been located. The helicopter support from pilots well acquainted with payload recovery in this uninhabited region of Scandinavia makes it possible to maintain a very high probability for fast and successful recovery.

5.6.8 Accommodation at Esrange

There are 4 hotel facilities at the Esrange site offering a total of 96 single rooms at very reasonable rates. With the distance to Kiruna being roughly 40 km this is very practical for most visitors. Also, there is a restaurant at Esrange, which is generally open for breakfast, lunch and dinner during campaigns.

For more information regarding accommodation, recreation, climate and travel, users are advised to consult the Esrange web site at the following URL:

http://www.ssc.se/esrange/index.html

Also, users can contact Esrange by sending an e-mail to the following address:

info@esrange.ssc.se

5.7 Legal Aspects

In general, Swedish laws and safety regulations apply to activities at Esrange. The Work Environment Act contains the basic provisions concerning occupational safety and health questions in Sweden. This act is a general act of law, which is backed up by special rules and regulations in different fields. The specific safety rules and regulations that apply for work at Esrange are defined in the "Esrange Safety Manual (ESM)", which is available on site at Esrange.

Toxic substances, infectious or living biological materials, or animals/organisms that shall be brought to Esrange as either sample material or for experiment preparation, have to be permitted by the relevant Swedish authorities.

5.8 Safety

5.8.1 Safety Organisation

The safety organisation at Esrange is based on the following main functions:

- The General Manager for Esrange Division is responsible for implementing the range safety policies and criteria;
- The Head of Operations and Safety is responsible for conducting the operations in accordance with the ESM;
- During operations, the responsibilities are delegated to personnel conducting the actual operational tasks;
- The Head of Launch Team is responsible for all handling of explosives at Esrange. He is also responsible for ground safety in the launch areas during countdown and build-up of a campaign.

5.8.2 Operations and Scientific Centre

Signs with the text "No Access" are placed above the doors to the Operations Centre and Scientific Centre. When these signs are illuminated, only authorised personnel have access.

5.8.3 Dangerous Material

Dangerous material is defined as all material containing micro-organic, explosive, pyrotechnic, poisonous, infectious, corrosive, or radioactive materials. When an investigator intends to use dangerous materials, for his/her experiment, this must be notified to Esrange well in advance. The same applies if living cells or animals shall be used for the experiment.

5.8.4 Experiment Module Safety

The module responsible shall establish a list of hazardous and living materials to be used in the module during flight and flight preparations, and shall communicate it to Esrange at the first Project Meeting and this information should also accompany the module.

5.9 Payload Life-Cycle and Major Milestones

The payload life cycle varies from experiment to experiment, and depends strongly on the complexity of the hardware as well as the channel through which access has been obtained to fly on a sounding rocket mission. For experiments approved following submission of a proposal in answer to an Announcement of Opportunity (AO), the time from experiment approval (following the review process) to assignment of a flight can vary from 6 to 36 months. The period that elapses from the moment that an experiment is assigned to a specific campaign to the start of the campaign ranges from 12 to 24 months. For the example provided below, the time from proposal approval to flight assignment will be taken as 6 months.

Figure 5-14 below, represents a typical timeline with major milestones of an experiment for a sounding rocket campaign. The user must keep in mind that, although the tasks displayed in the timeline are standard, the periods are based on a generic case, and will differ, as described above, from experiment to experiment. The timeline is given in terms of months with respect to the launch (L).

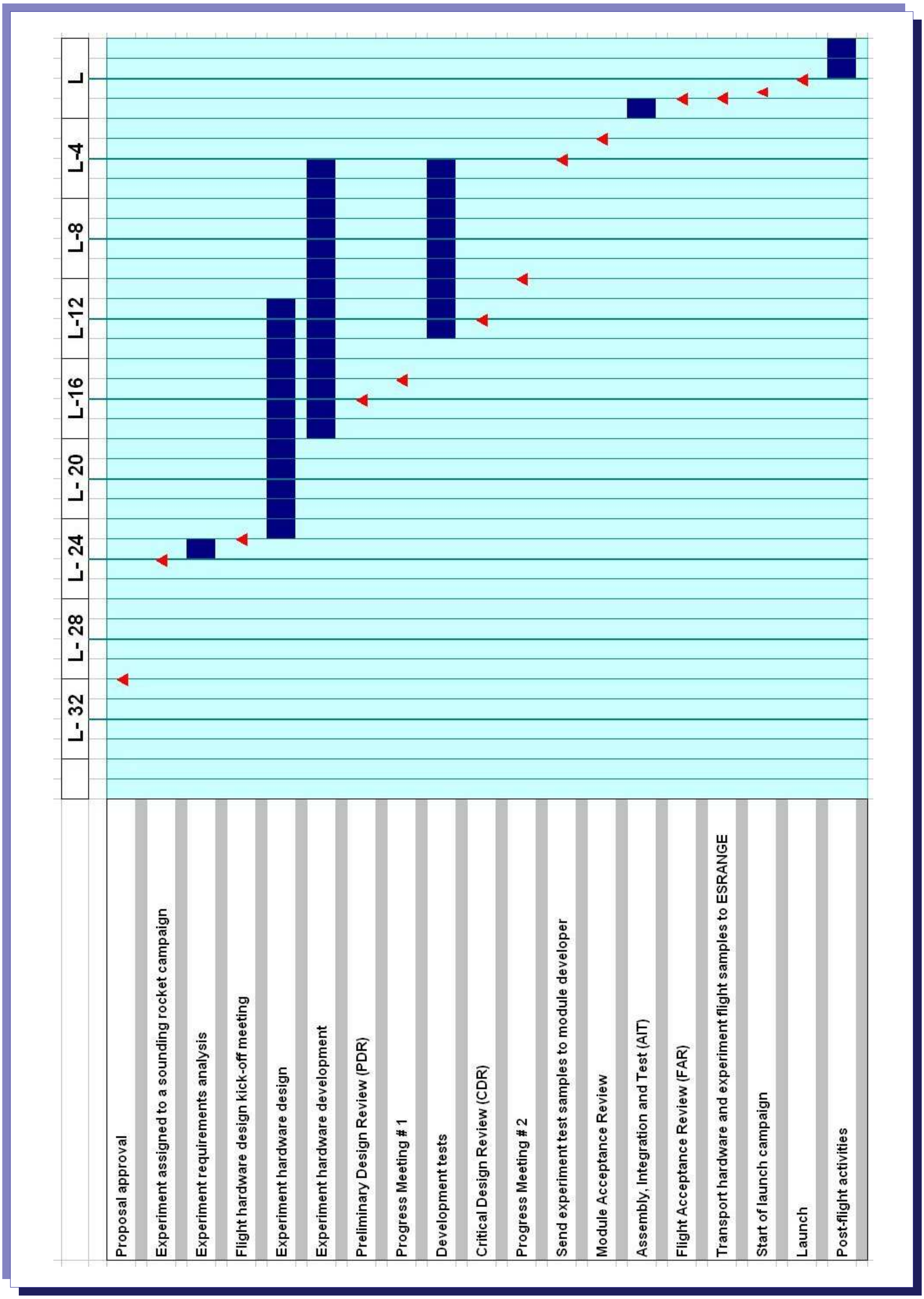

Figure 5-14: Typical timeline for an experiment on a sounding rocket flight campaign

5.10 Payload Assembly, Integration and Test (AIT)

The payload system AIT is performed at EADS Ottobrunn (Germany) for (Mini-) TEXUS and MAXUS, and at Packforsk in Kista (Sweden) for MASER, and starts, typically, 5 weeks before the planned start of the launch campaign. At the start of the AIT all flight hardware (experiment modules and service systems) must have successfully passed their Acceptance Reviews. Upon completion of the AIT, the Flight Acceptance Review is held.

5.10.1 Experiment Module Status at Delivery

Before entering the payload system AIT, each experiment module should have successfully passed the Module Acceptance Test and the Module Acceptance Review. As a minimum requirement it is suggested that the affiliation responsible for the module, conduct the following qualification/acceptance tests:

- Electrical/functional tests;
- Vibration tests;
- Vacuum and thermal tests;
- Flight simulation test.

5.10.2 Module Incoming Inspection

All modules delivered to the payload AIT will undergo mechanical and electrical interfaces inspection upon delivery.

5.10.3 Payload Assembly and Interface Tests

The experiment modules will, in due order, be integrated to the payload. All interfaces are checked and tested systematically during the assembly.

5.10.3.1 Mechanical Interface Test

The mechanical joints are checked by mounting the module to the interfacing modules. Orientation of umbilicals, feed-through harness, venting holes, etc. are checked.

5.10.3.2 Electrical Interface Test

The electrical interface test verifies the compatibility of the interfaces and the functioning of the related hardware. Interface compatibility for dangerous signals, protection automatisms and voltage regulations are checked systematically during assembly. Details have to be defined for every individual module/subsystem. The test is performed by the module manufacturer under supervision of the prime contractor.

5.10.4 Payload System Tests

The main system tests include the following:

5.10.4.1 Module Checkout

The module is connected to the telemetry system and all channels used are checked with the module power on and in experiment mode.

5.10.4.2 Mass Properties and Balancing

The mass properties of the payload are measured. The following measurements are performed:

- Payload mass;
- Centre of gravity;
- Spin balance;
- Moments of inertia.

If necessary the payload is balanced by adding ballast.

5.10.4.3 Spin Test

The payload is rotated with a constant spin rate of 5 rps for 2 minutes to verify the spin balancing.

5.10.4.4 System Electrical Test 1 and EMI-Check

These tests are performed with all flight hardware electrics working and (as far as possible) in their flight configuration. Telemetry transmission is carried out via the antennas or via cable. All signals will be recorded at the telemetry ground station. The modules and service systems will be monitored and controlled from their EGSE's.

5.10.4.5 Vibration Test

The payload will undergo vibration testing in the x, y and z directions, with each axis following the a, b, c sequence defined below.

a. *Low level sine sweep*

The payload is vibrated with sine sweep to identify resonances.

- *Frequency*: 5-2000 Hz
- *Amplitude*: 0.25g
- *Sweep*: 2 octave/min
- *No. of sweep*: 1 up

b. *Random vibration*

The input levels in all 3 axes will be:

- For 20-1000 Hz frequencies: 0.01 – 0.1 g^2/Hz, increasing with 1.8 dB/oct
- For 1000-2000 Hz frequencies: 0.1 g^2/Hz
- Total RMS: 5.9 for MAXUS, 5.6 for TEXUS, MASER

The duration of the random input will be 60 seconds in each direction.

c. *Low level sine sweep*

In order to check if any changes have occurred the sine sweep test is repeated.

5.10.4.6 System Electrical Test 2

After the vibration test an electrical function test is performed. Each module responsible decides which tests to carry out. However, a complete telemetry system test must be included before disassembling the payload.

5.10.4.7 Flight Simulation Test

After successful results in the various tests, the payload is ready for a flight simulation test (FST). Each module is monitored and controlled by the module ground support equipment. When all modules are running nominally, a complete countdown and flight sequence is performed. During the test all telemetry signals are recorded in the telemetry ground station.

5.11 Operational Cycle of a Sounding Rocket Campaign

The following provides a general outline of the major events that take place during the operational cycle of a sounding rocket campaign. Scientists should use this as a reference and should keep in mind that the list below may vary from mission to mission. ("L" refers to the time of launch of the sounding rocket).

Table 5-14: Major events in a sounding rocket campaign operational cycle

TIME	EVENT
L – 14 days	Users travel to and arrive at the Esrange launch site near Kiruna, Sweden.
L – 13 days	Unpacking and checking of flight hardware delivered to Esrange prior to arrival of users
L – 12 to L – 6 days	Preparatory activities relative to the experiment modules
L – 12 to L – 6 days	Preparatory activities relative to the service system
L – 7 to L – 6 days	Range compatibility tests
L – 6 days	Payload bench tests
L – 5 days	Payload integration
L – 4 days	Payload RF-test and flight simulation test
L –3 days	Payload installation at launcher
L –3 days	Blockhouse preparation
L –2 days	Overall RF-Test and final payload check
L – 1 day	Practice countdown
L – 4 hours	Begin 1st Hot Countdown
L – 45 minutes	Recovery helicopters sent out to report on weather and impact area
L	Launch of sounding rocket
L + 1 hour	Payload retrieval
L + 1 day	Postflight activities and transport preparation
L + 2 days	Departure of payload teams

The following figure (Figure 5-15) summarises the sequence of events during a sounding rocket campaign.

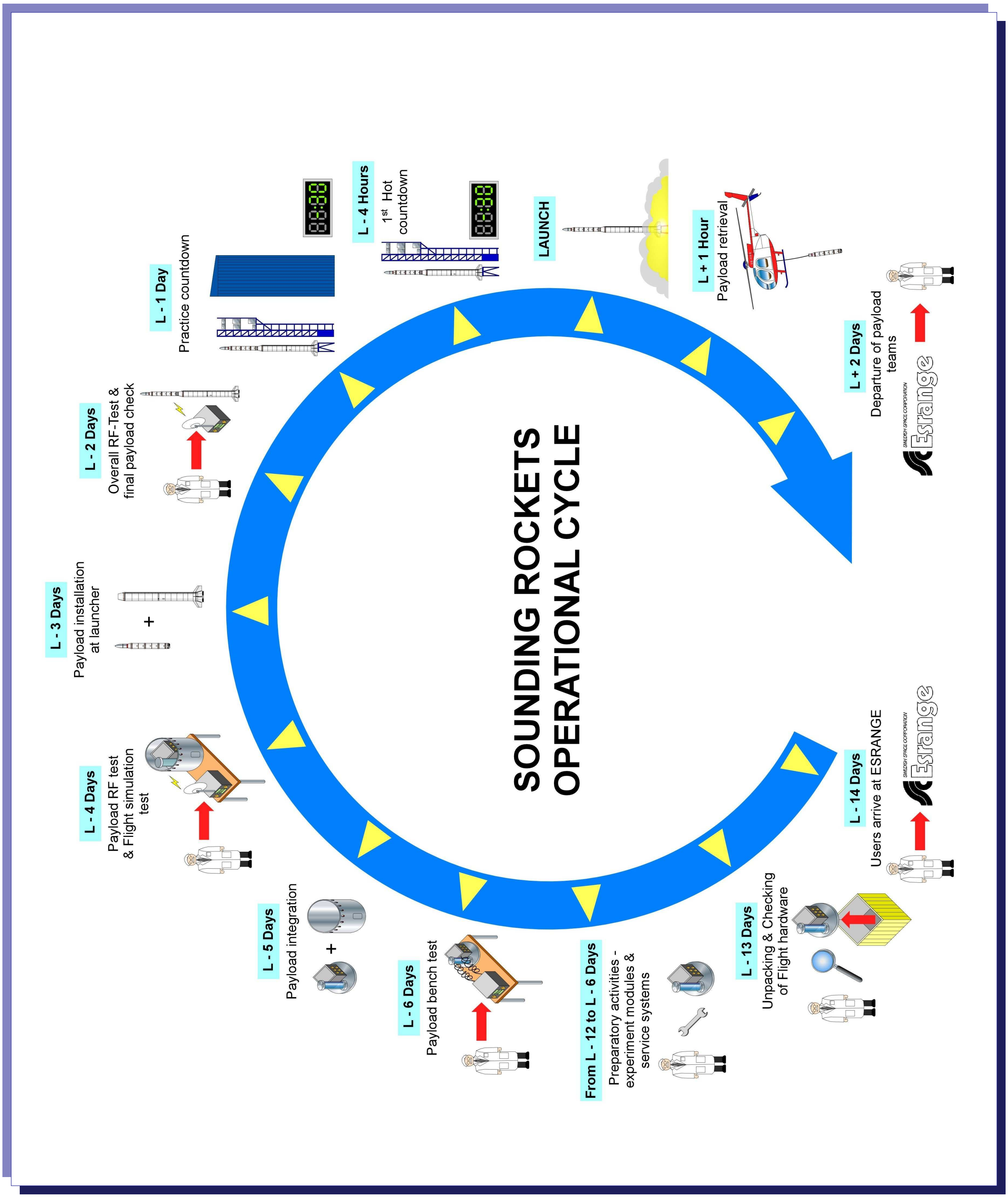

Figure 5-15: Sounding rocket campaign operational cycle

5.12 References

1. Erasmus Experiment Archive (EEA): http://www.spaceflight.esa.int/eea
2. Erasmus User Information Centre Internet Pages: http://www.spaceflight.esa.int/users/
3. “MASER User Manual”, Edition 2, rev. 1, Swedish Space Corporation, Sweden, February 1992
4. Esrange internet pages: http://www.ssc.se/esrange/index.htm
5. ”Microgravity Sounding Rocket Missions”, Issue 1, DASA, Bremen, Germany, August 1995.
6. “Summary Review of Sounding Rocket Experiments in Fluid Science and Material Sciences”, ESA SP-1132 Volumes 1-4, February 1991 – October 1994.
7. “Facilities for Microgravity Investigations in Physical Sciences supported by ESA”, ESA SP-1116 (Rev. 2), March 1995.
8. “Life Sciences Experiments Performed on Sounding Rockets (1985-1994)”, ESA SP-1206, April 1997.
9. “A world without gravity”, G. Seibert et al., ESA SP-1251, June 2001.
10. “Proceedings of the 13th ESA Symposium on European Rocket and Balloon Programmes and related research”, ESA SP-397, Öland, Sweden, 26-29 May 1997.
11. “Proceedings of the 14th ESA Symposium on European Rocket and Balloon Programmes and related research”, ESA SP-437, Potsdam, Germany, 31 May-3 June 1999.
12. “Proceedings of the 15th ESA Symposium on European Rocket and Balloon Programmes and related research”, ESA SP-471, Biarritz, France, 28-31 May 2001.
13. “Proceedings of the 16th ESA Symposium on European Rocket and Balloon Programmes and related research”, ESA SP-530, Sankt Gallen, Switzerland, 2-5 June 2003.