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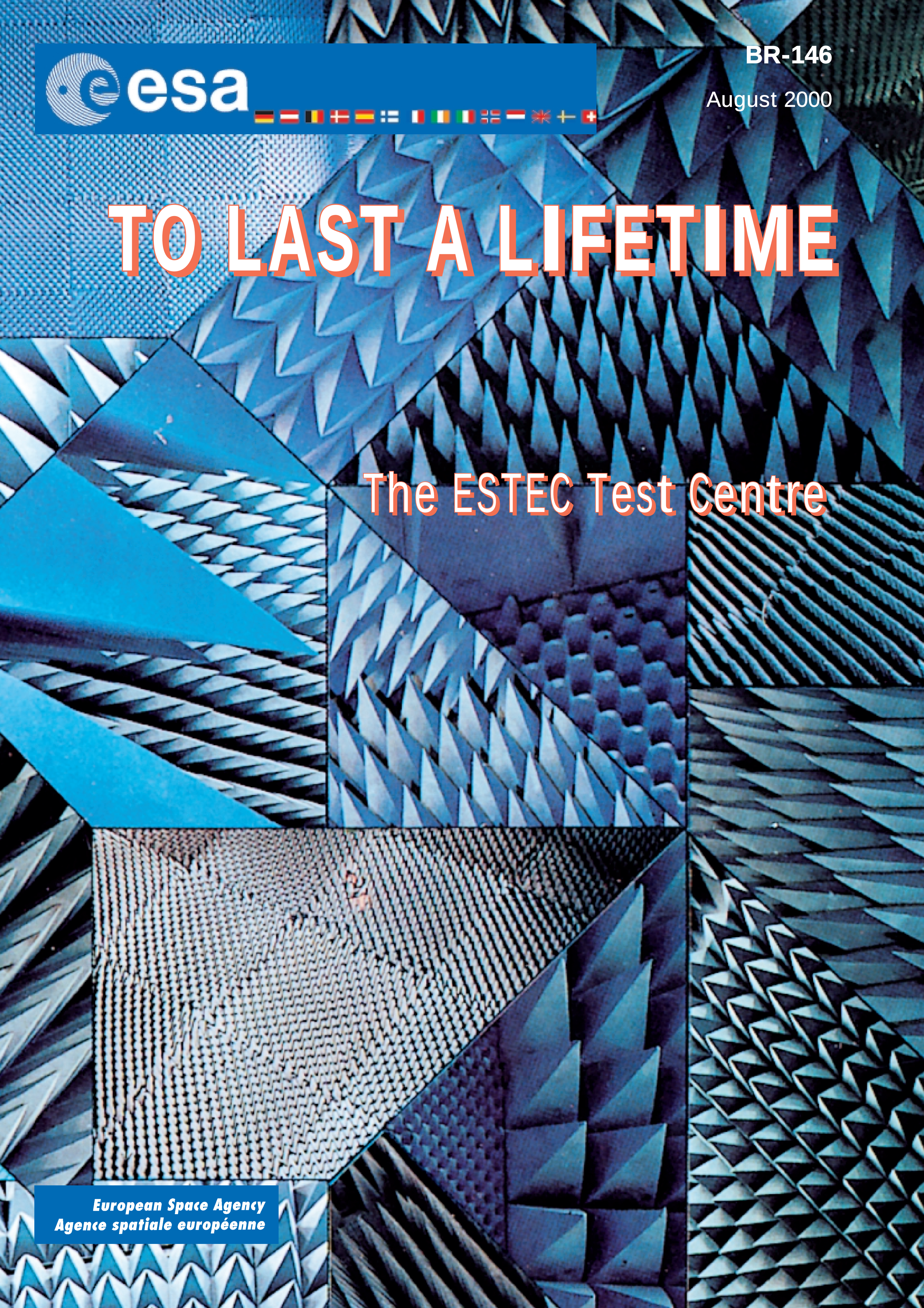
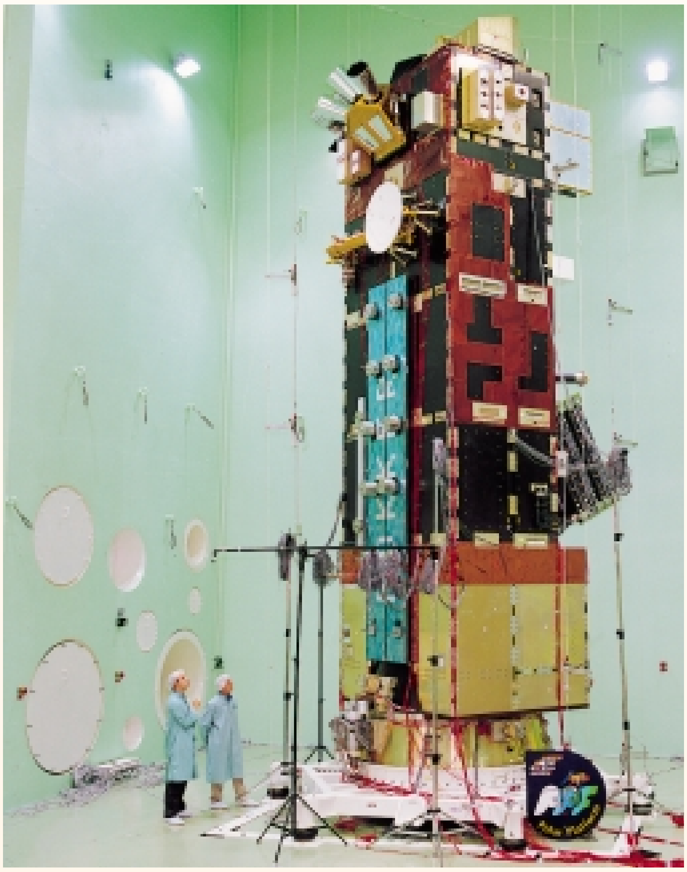


TO LAST A LIFETIME

The ESTEC Test Centre

European Space Agency
Agence spatiale européenne



PPF/ENVISAT - STM in the LEAF Acoustic Facility

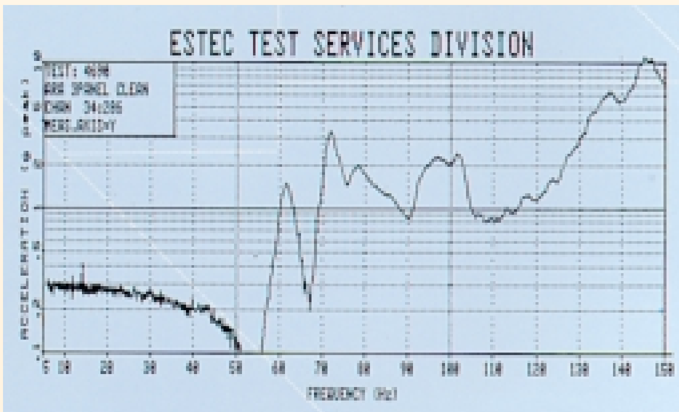
TO LAST A LIFETIME

Whatever the mission, be it manned or unmanned, for scientific research, applications or space transportation, a spacecraft and its payload must be able to withstand, first of all, the extreme stresses caused by the mechanical vibrations and the acoustic noise which occur during the launch phase, and, once in orbit, the rigours of the space environment – in particular, the effects of solar radiation and the vacuum conditions of space – over a period which may vary from two to three years to up to ten years or more. There is only one way of making use of this: every single element of the vehicle and the instruments it is carrying must be proved spaceworthy and must, therefore, be tested on Earth under conditions simulating, as closely as possible, those it will meet in space. ESA's Test Centre does just that.

Occupying a complete building on the premises of the European Space Research and Technology Centre (ESTEC) in the Netherlands, the Test Centre comprises a number of indispensable test facilities together with the associated supporting elements, such as check-out rooms, as well as office and meeting areas for the users of the facilities. It has been designed in such a way that a spacecraft can move smoothly from one facility to another thus eliminating the need to reconfigure the spacecraft between tests and so reducing the risk of damaging it through repeated handling: a very economical system, both time- and money-wise.

Yet another advantage for the customer is the fact that the Test Centre can call upon a vast range of support from other areas in ESTEC – an astrophysicist, say, from the Space Science Department, experienced engineers from the Directorate of Technical and Operational Support… whatever the problem, there will always be somebody on site able to suggest ways and means of overcoming it.

Vibration testing of ERS-1 scientific instruments



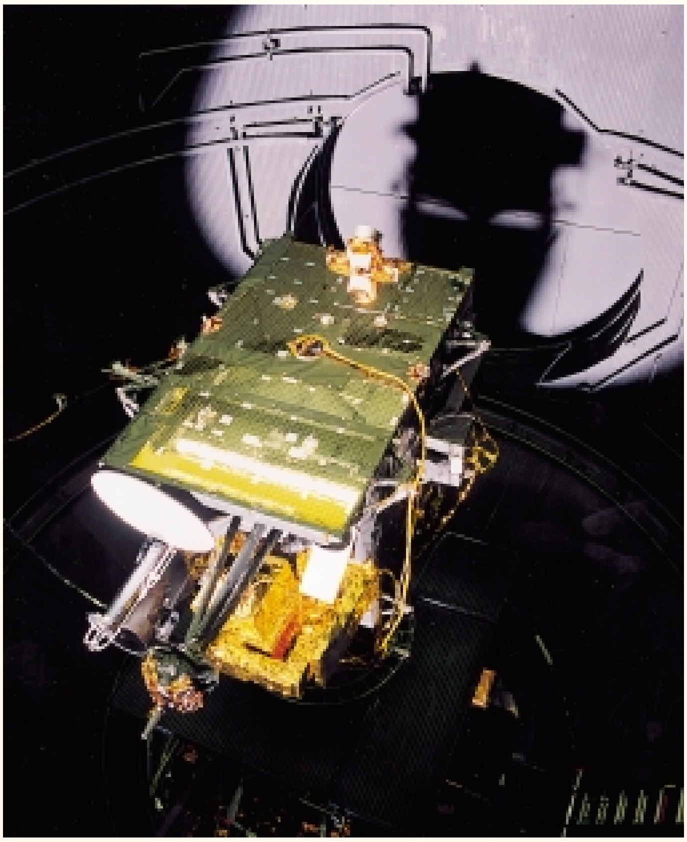
Vibration plot

With the increase in the size and complexity of spacecraft and their payloads over the last two decades, the need for bigger and more sophisticated environmental test facilities has also grown. The staff of ESA's Test Centre have met these new challenges and have ensured that ESTEC remains one of the foremost spacecraft test centres in the world.

So successful have they been that ESA Member States can but consider they have had an excellent return for their investments. For over thirty years – since 1965 to be precise – not only has a long line of ESA projects undergone stringent testing at ESTEC but many non-ESA spacecraft have also benefited from the know-how and expertise available within ESA's Test Services. The fact that all these spacecraft have successfully carried out their many and varied missions, most of them for much longer periods than originally foreseen – to quote but one example, ESA's scientific spacecraft Cos-B, which was originally scheduled to operate for two years, more than tripled its lifetime and functioned for well over six years – is indeed proof that the Test Services too have accomplished their mission: to ensure that the vehicles launched into space can, and do, function over relatively long periods in a very hostile environment.

ESA feels justifiably proud of its achievements in this field. Together with its other partners within the Coordinated European Test Facilities framework – Intespace in Toulouse (France), IABG* in Ottobrunn (Germany) and CSL ** in Liège (Belgium) – it plays an important part in maintaining Europe's position at the forefront of space research.

* Industrieanlagen-Betriebsgesellschaft
** Centre Spatial de Liège



Artemis undergoing solar simulation tests in the Large Space Simulator

The loaded test floor

THE TEST FACILITIES

One of the most spectacular facilities on site is the Large Space Simulator or LSS. As its name indicates, the LSS simulates the vacuum, cryogenic temperature, and solar radiation conditions of space. Designed to test large spacecraft, it is undoubtedly the foremost installation of its kind in the world today.

Amongst the most demanding of tests a spacecraft undergoes are the mechanical and acoustic tests that simulate the launch environment. There are various electrodynamic and hydraulic shakers on the site at ESTEC able to generate the vibrations experienced during launch, with state-of-the-art instrumentation to analyse the structural behaviour of the hardware. For the acoustic qualification of space articles, the large European Acoustic Facility, or LEAF, with a volume of some 1600 m^3 is available at ESTEC. Realistic noise spectra, corresponding to those experienced during “lift-off” and the atmospheric flight of the launch phase, can be generated in this huge facility.

The facilities also include a ‘family’ of machines for the determination of the physical properties, and several vacuum test chambers designed to simulate the different vacuum and thermal conditions to which a spacecraft will be exposed during launch and in orbit.

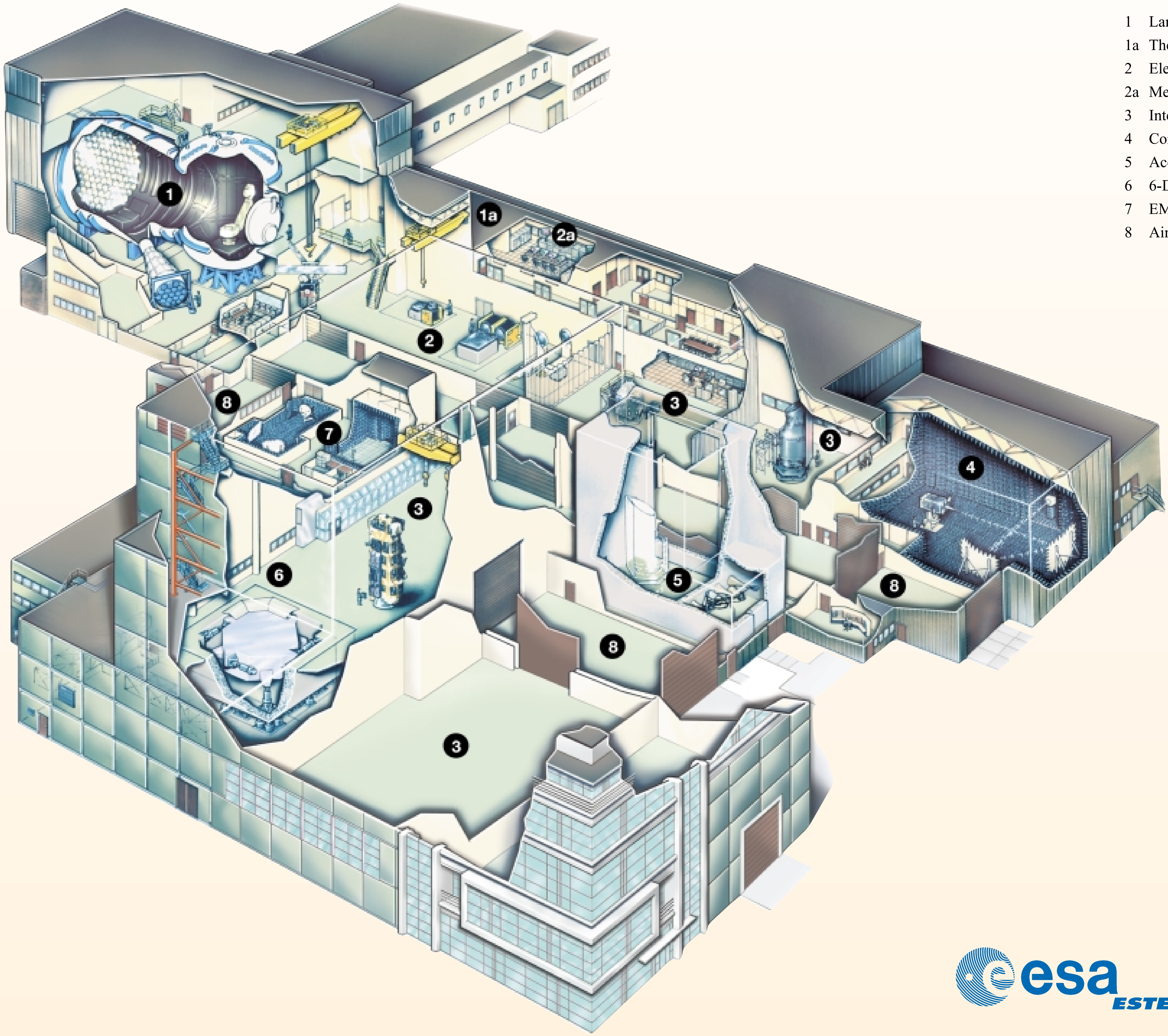
The electro-magnetic radiating characteristics of communication payloads are measured in the Compact Payload Test Range (CPTR), in the frequency of 1.5 GHz to 40 GHz.

Yet another essential test facility on site is the Electro-Magnetic Compatibility Chamber (EMC) which checks, on the one hand, whether a spacecraft and its payload will be able to withstand the electromagnetic environment of space and, on the other hand, whether each element is electromagnetically compatible, that is, it is not liable to cause interference vis-à-vis other elements.

The Data Handling Systems used to interpret the results of the thermal, mechanical and acoustic tests, are one of the key elements of the Test Centre. The Data Handling Systems first scan the hundreds of sensors placed on the test subject, then convert the electrical signals into engineering data showing the performance of the spacecraft or experiment during a test and, finally, analyse the results of the tests and produce reports tailored to the customer needs.

No description of the Test Centre would be complete without some mention being made of the Clean Rooms which ensure that all satellite operations are performed in the appropriate environment. At ESTEC, all test and integration areas are temperature and humidity controlled and satisfy the severe cleanliness requirements for satellites.

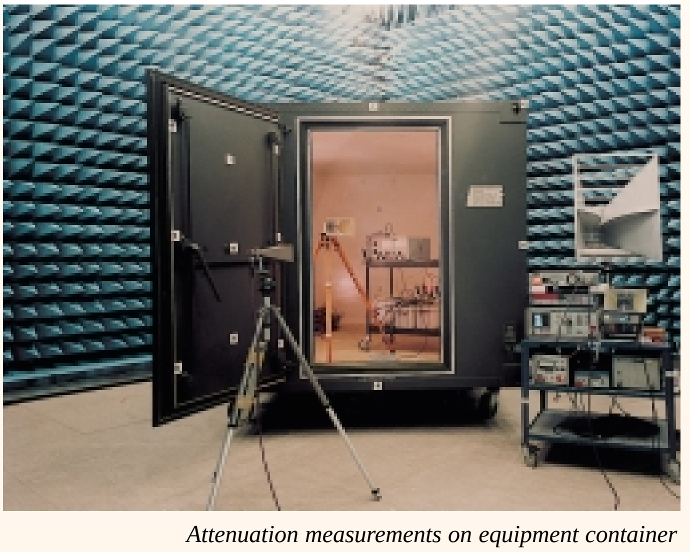
These brief descriptions cover the main elements of ESA’s Test Centre; more detailed descriptions of each group of facilities is contained in the folders opposite. A wide range of other facilities and instruments are, of course, available, which it would be too long and fastidious to describe here.



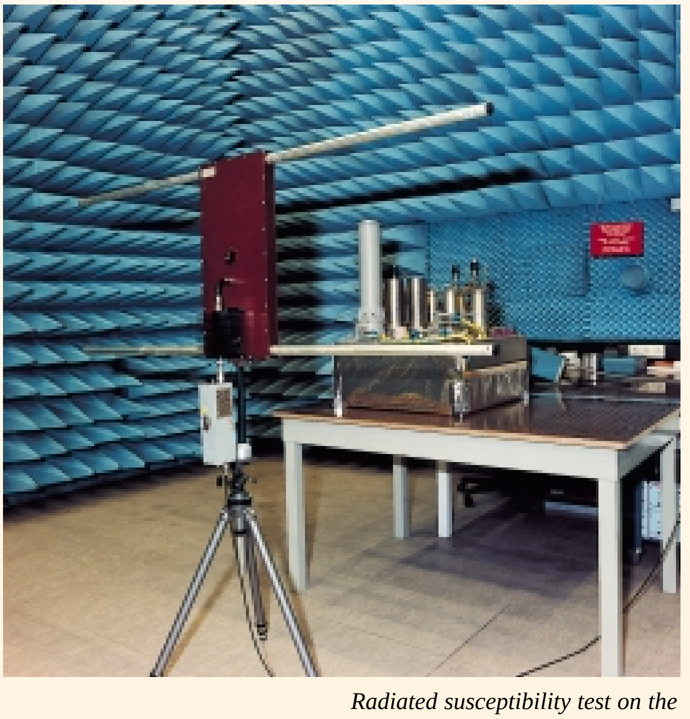
1 Large Space Simulator (LSS)
1a Thermal Data Handling
2 Electrodynamic Vibrators
2a Mechanical Data Handling
3 Integration Halls
4 Compact Payload Test Range (CPTR)
5 Acoustic Test Facility (LEAF)
6 6-DOF Hydraulic Shaker (HYDRA)
7 EMC Facilities
8 Airlocks

esa
ESTEC - TEST CENTRE

THE ELECTROMAGNETIC AND ELECTROSTATIC TEST FACILITY



Attenuation measurements on equipment container



Radiated susceptibility test on the Eureca Multi-Furnace Assembly

Electromagnetic compatibility verification measurements are designed to ensure both:

– the compatibility of a system to operate in a specific environment which is subject to electromagnetic interference caused by radio frequency or electrical noise from many sources; and,
– the mutual compatibility of different units operating within the same system, for example, a satellite.

It is essential to ensure that the electrical and electronic equipment within a spacecraft functions correctly. It could indeed be fatal if, when switching on an experiment for example, other payload systems, such as the telemetry or other telecommunication links, were disturbed or even disrupted.

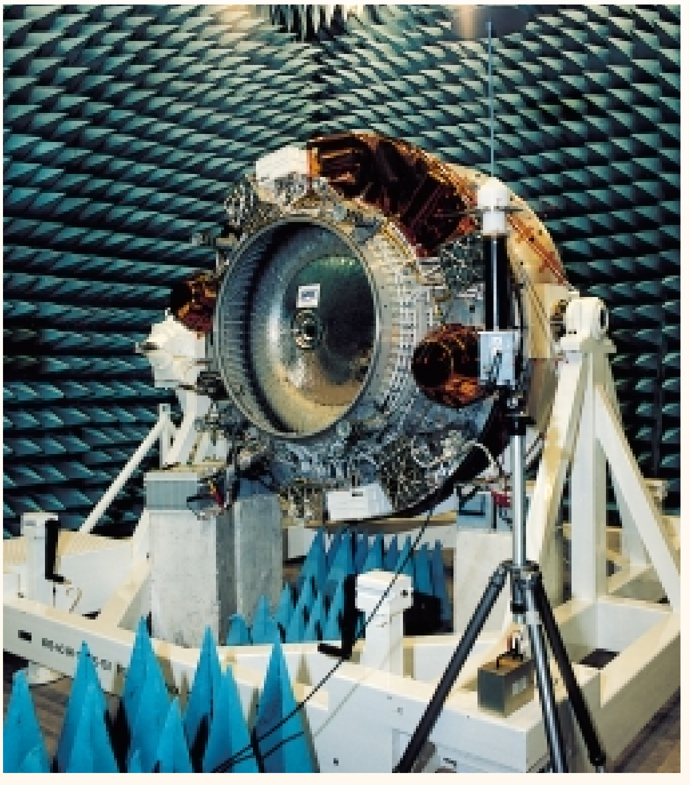
Another source of interference, and a very capricious one at that, is electrostatic discharge. Electrostatic charges accumulating on conducting or non-conducting surfaces can cause high potentials and subsequent discharges which may damage electronic circuits and lead to serious malfunctions.

The Test Chamber

The ESTEC Test Chamber consists of a shielded enclosure with continuously conducting metal walls, floors and ceilings. The walls and ceiling are lined with an absorbent, anechoic material designed to attenuate the reflected electromagnetic energy.

There are two control rooms attached to the facility. The EMC test equipment is operated from one, and the unit or system being tested from the other.

The design of the facility, based on 30 years of experience, incorporates a number of unique characteristics which ensure that tests are carried out in the most effective and economical way possible. These include the use of fibre optics for communications and for susceptibility monitoring.



Radiated Emission test on IRIS-ISS

Principal parameters of the EMC test chamber

Size:	LxWxH = 7.1x6.1x5 m
Access door:	WxH = 3.5 x 4.5 m
Max floor load:	1450 kg/m
Airlock:	Via building Fh (non-controlled area)
Conditions:	Cleanliness class 10 000 Humidity 40 %-55% Temperature 20-24°C Pressure 610-775 mmHG
Fire protection:	Siemens HALON protection system
Attenuation:	Magnetic field: 20 dB - 50 Hz/90 dB-15 kHz Electric field: 140 dB - 1 kHz/140 dB 50 MHz Plane wave: 130 dB - 50 MHz/100 dB - 40 GHz
Measurements:	Radiated emission: 20 Hz - 40 GHz Conducted emission: 0.1 Hz - 100 MHz Modulation: CW-FM-Pulse Time domain: up to 500 MHz Electrostatic discharge - direct/indirect

The test programmes are fully automated and are conducted in both the frequency and the time domains. A dedicated data acquisition system controls each step of a test programme thus providing maximum security to the test subject. Test data, collected through antennae, current and voltage probes, are plotted separately, with a clear identification between narrow-band signals and broad-band coherent and incoherent noise.

The facility is particularly well adapted to carry out electrostatic discharge tests on spacecraft and to verify the effects of the discharges. A high voltage unit, generating up to 30 kV, is used for this purpose. A separate multi-channel data acquisition and measurement system is used to verify the effects of electrostatic discharges on the test subject. The system, which has an overall dynamic range of 160 dB, includes active sensors for measurements of the magnetic and electric fields and of the surface current.

Emission and Susceptibility Testing

All emission tests in the frequency and time domain are fully automated. That is, they are computer-controlled with online data reduction, narrow and broad-band identification, together with all evaluated data and are corrected for probe factors etc.

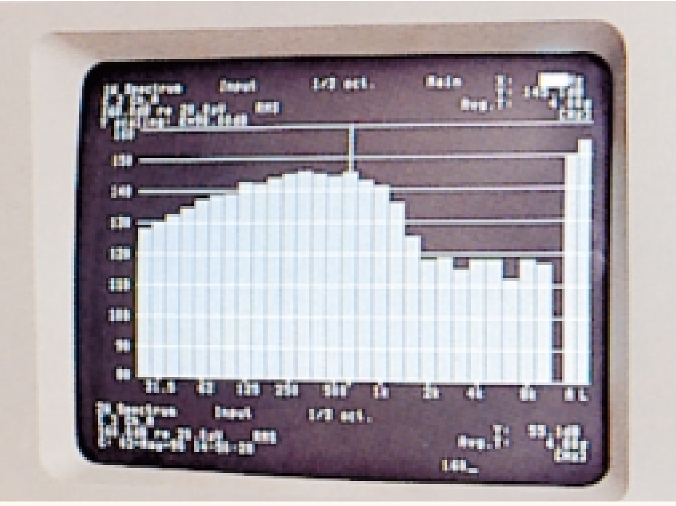
Output data is stored and plotted. A printout is available of all values measured in numeric order together with the levels compared with the relevant specification.

Time domain measurements are also an integrated part of the test activities. A bus-controlled oscilloscope is used for this purpose.

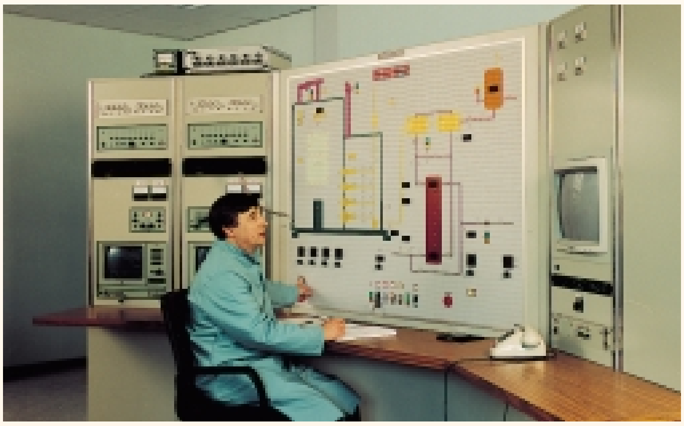
Susceptibility testing is also fully automated. This avoids the problems of manual operation where the operator has to control the frequency with one hand, the amplitude with the other, and, at the same time, check the modulation, the overload of the amplifiers, etc. All these control and check functions are handled by the computerised system controller. This provides an accurate and fully corrected measurement, calibrated on the spot at each frequency step. Above all, the measurements can be made any number of times without the slightest deviation.

Both electrostatic discharge and susceptibility tests can be carried out on large ground stations or computers to detect bonding faults and ground loops which can considerably cut back on expensive facility time.

THE LARGE EUROPEAN ACOUSTIC FACILITY



Noise generation analysis as it appears on the control console



The LEAF control console

Part of the LEAF reverberant chamber showing the horn outlets: lower left, the 25 Hz cut-off horn, upper right, the 80 Hz horn, lower right the 35 Hz horn, and just visible to the right of the technician, the 160 Hz horn

Acoustic noise tests form an integral part of the verification process of space hardware. The qualification and acceptance of spacecraft and their payloads by acoustic noise tests assure that no damage will occur to these structures during the launch phase. The simulation of realistic spectral noise pressure levels, comparable to those generated by the launcher engines and by the air flow passing along the fairing during the atmospheric flight, is therefore the main objective to be borne in mind when considering the layout of an acoustic test facility.

The Large European Acoustic Facility (LEAF) provides the required environmental performance and offers a great variety of selectable noise levels and spectral shapes as well as test sequences and durations in order to meet different user requirements. The related infrastructure supports efficient test preparations, fast operations and flexibility thanks to the state-of-the art instrumentation used for performance monitoring.

The noise generation system consists of four different horns with cut-off frequencies of respectively 25 Hz 35 Hz, 80 Hz and 160 Hz and of three high-frequency generators. An overall noise level of 154.5 dBL can be achieved; provisions have been implemented to extend the level to 158.5 dBL. The facility has been specially built to prevent noise break-outs in order to avoid any disturbance in adjacent facilities. Furthermore, the acoustic chamber rests on springs to prevent propagation of vibration to the structure of the building. With a mass of 2000 ton, the chamber is very well suited for modal survey of large structures.

The instrumentation of the acoustic facility includes a microphone mounting system which allows an easy distribution of up to 16 microphones in appropriate locations around the test article. The large number of suspension points distributed throughout the chamber offers considerable flexibility for spacecraft suspension.

The LEAF is totally remote-controlled and safeguarded from a control room with the aid of a programmable logic controller. The concept of the facility assures the safe operation of all subsystems and also protects the test article against excessive noise levels and test durations. The mechanical test data are interfaced to a dedicated mechanical data handling computer which provides a detailed recording of parameter and test conditions, including test data acquisition and evaluation ensuring efficient on-line test analysis.

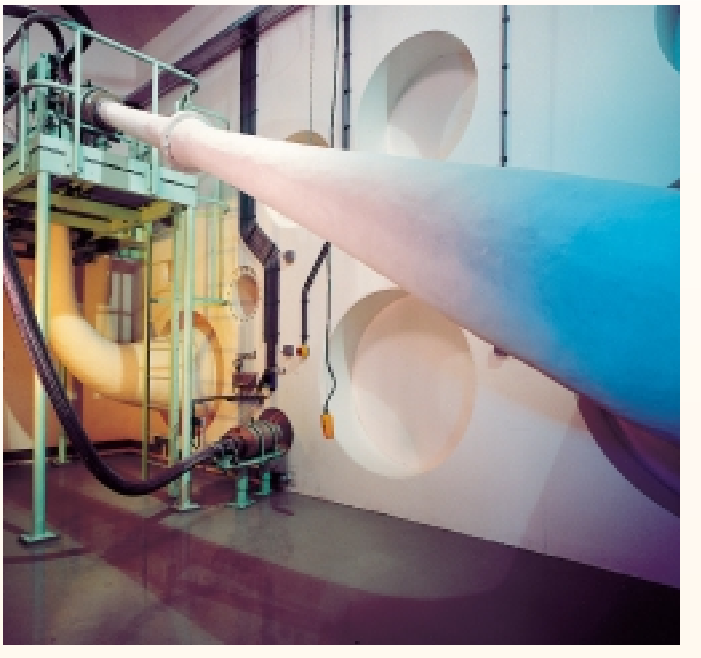
Since the acoustic noise in the LEAF is generated by pressurised gaseous nitrogen, the risk of test article contamination is excluded.

Main parameters of acoustic reverberent chamber

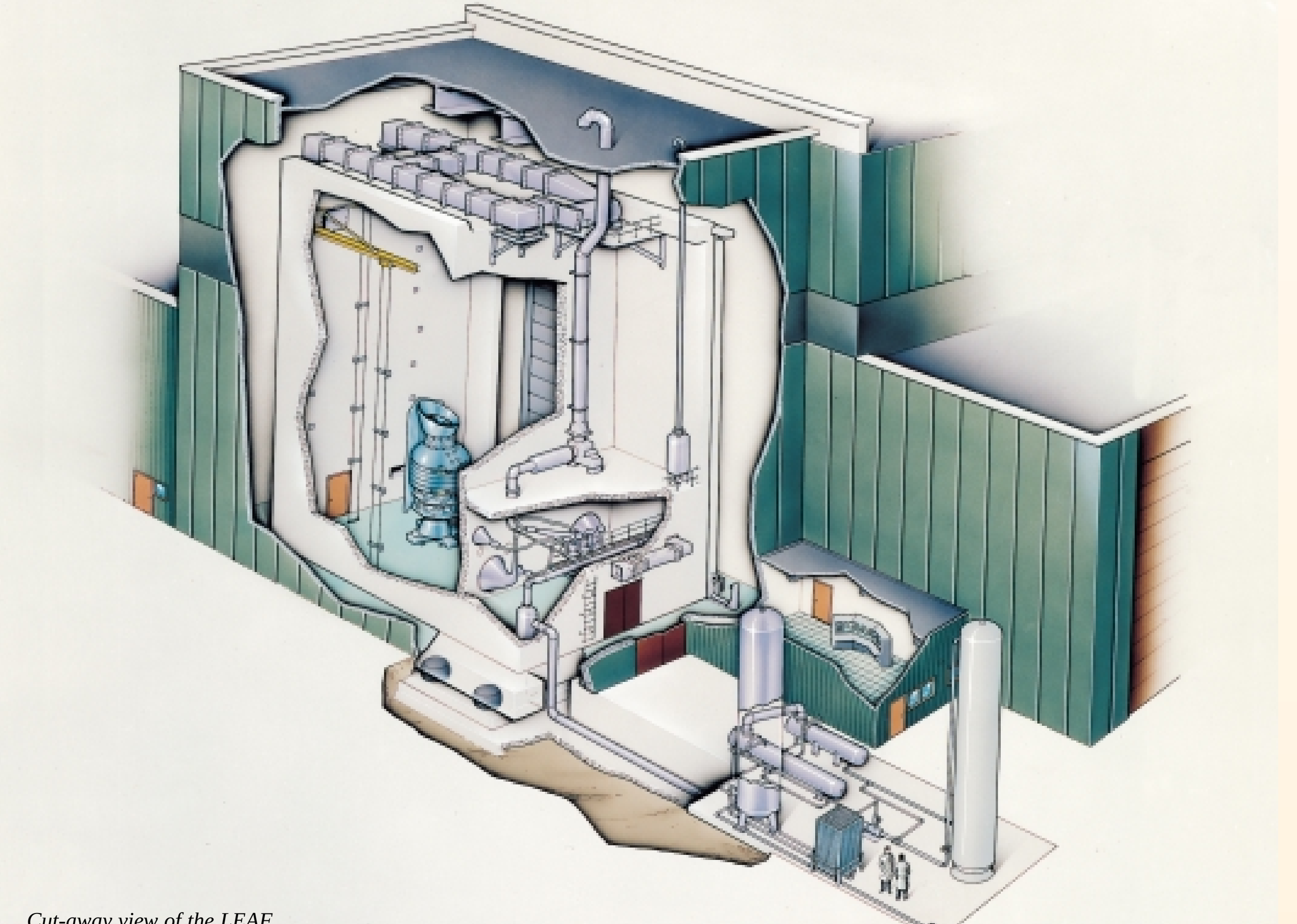
Chamber Volume	: 1624 m^3
Chamber Dimensions	: 9 m × 11 m × 16.4 m (width × length × height)
Main Door Access	: 7 m × 16.4 m (width × height)
Suspension Points	: 9 points of 80 kN load capacity 35 points of 15 kN load capacity
Max. Crane Load	: 160 kN
Cleanliness	: Class 100 000
Temperature Range	: 20° ±2°C (during test)

Centre Frequency (Hz)	Sound Pressure Level (dBL)	
31.5	136.5	specified octave band pressure levels in empty chamber at 154.5 dBL
63	141.5	
125	147.5	
250	150.5	
500	147.5	
1000	144.5	
2000	137.5	
4000	131.5	
8000	125.5	

Overall Sound Pressure Level Range	: 125 dBL — 154.5 dBL
Field Homogenity in Test Volume	: ±2 dBL
Control Tolerance of Sound Field	: ±1.5 dBL overall
Noise Measurement	: 16 microphones
Data Acquisition	: 250 accelerometers, and 50 strain gauges

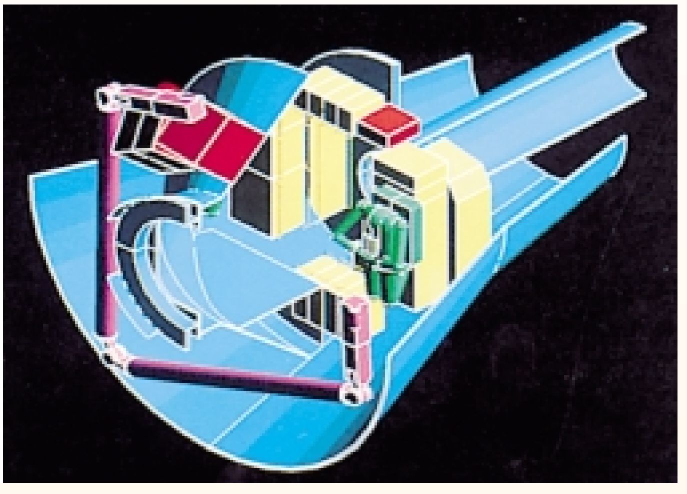


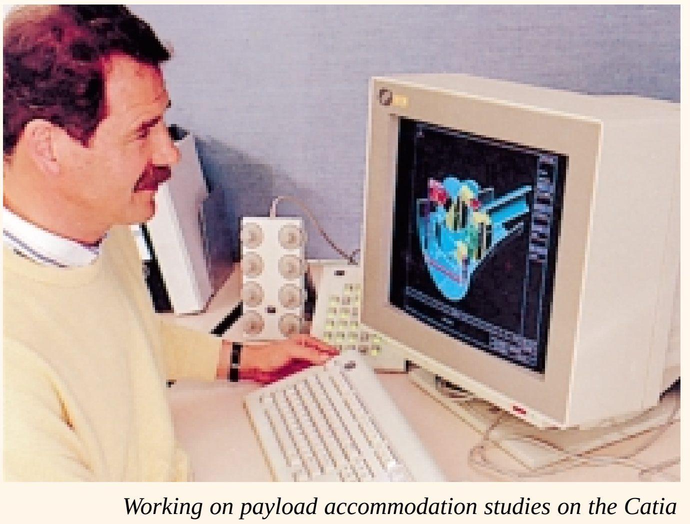
LEAF horn room with the 25 Hz (foreground) and 35 Hz (background) cut-off horns



Cut-away view of the LEAF

THE ENGINEERING SERVICES





Working on payload accommodation studies on the Catia system and (above) a close-up of the screen

A view of the Mechanical Workshop

The Engineering Services Section provides assistance and support to the ESA project teams as well as to the European space industry and to national space programmes in ESA Member States.

ESTEC's Engineering Services also play an important role in ensuring the smooth running of the Test Division. Their task is to provide high-quality engineering support, including the provision of special tools and equipment, very often at short notice, and in particular when:
– unforeseen problems arise during testing which need immediate engineering action, and
– very specialised, high precision requirements come to light.

Support of this kind can only be provided by an in-house unit with a highly specialised, experienced and flexible staff.

The Engineering Services comprise the following main sectors or areas of specialisation:
– mechanical engineering,
– electronic engineering,
– electronic instrument maintenance and calibration,
– metrology.

Mechanical Engineering

With its design office and mechanical workshop, the Mechanical Engineering sector provides test-specific support and equipment as well as special flight hardware if required, in the fields of general mechanical and structural design and construction, vacuum, cryogenic, thermal and optical technology.

Besides conventional design work, the design office operates 6 CAD workstations where the design system CATIA (3D) is installed. This CAD system is frequently used in the European aerospace industry, thus offering the possibility of extended work file exchange. The well equipped workshop covers mechanical manufacturing from fine mechanics to structures for flight units.

Electronic Engineering

This sector is specialised in the design of analog and digital circuitry at sub-system and unit levels. Its activities include breadboarding of design-critical areas to ascertain feasibility and ensure component selection, the preparation of system diagrams and electronic circuit boards, as well as the design, manufacture and assembly of printed circuit boards and the assembly, integration and harnessing of electronic and electromechanical units.

Analog and digital design is carried out by means of CAE systems, which offer the possibility of verifying by simulation the performance of the conceived circuitry before implementation and which, at the same time, ensures traceability of the development process. In many cases, this leads to the simplification of the breadboard phase, and maximises flexibility.

A cleanroom for flight hardware assembly and inspection is an integral part of this sector.

Electronic Instrument Maintenance and Calibration (Laboratory Equipment Pool)

Besides managing all electronic measurement equipment in common use at ESTEC and ensuring the regular maintenance and calibration of instruments, the equipment pool also plays a key role in the maintenance of electrical and time standards which are of particular importance in view of the very stringent quality control requirements for space equipment. The pool is recognised and certified by the Dutch Calibration Organisation and is equipped with transportable reference standards, periodically certified by the Dutch National Standards Laboratory.

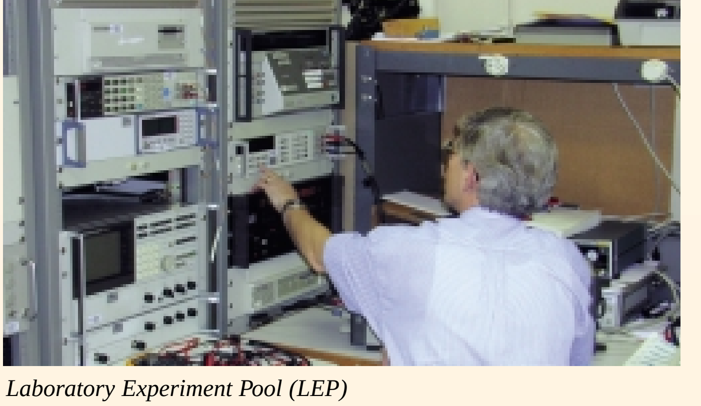
Metrology

Equipped with high precision measuring equipment, this sector, besides calibrating mechanical and optical measuring equipment, also provides support both in-house and to industry for the installation of complex test structures. It can be called upon by the project teams to carry out mechanical interface verifications and to provide specialised alignment equipment. It not only gives advice on spacecraft alignment methods but also applies and tests them and evaluates the results. It is equipped with a large class 100 000 clean room to handle large equipment. Its standards are recognised and certified by the Dutch National Standards Laboratory.

Cleanroom for flight hardware assembly and inspection

Electronic Laboratory

The metrology laboratory



Laboratory Experiment Pool (LEP)

THE HYDRA MULTI-AXIS SHAKER

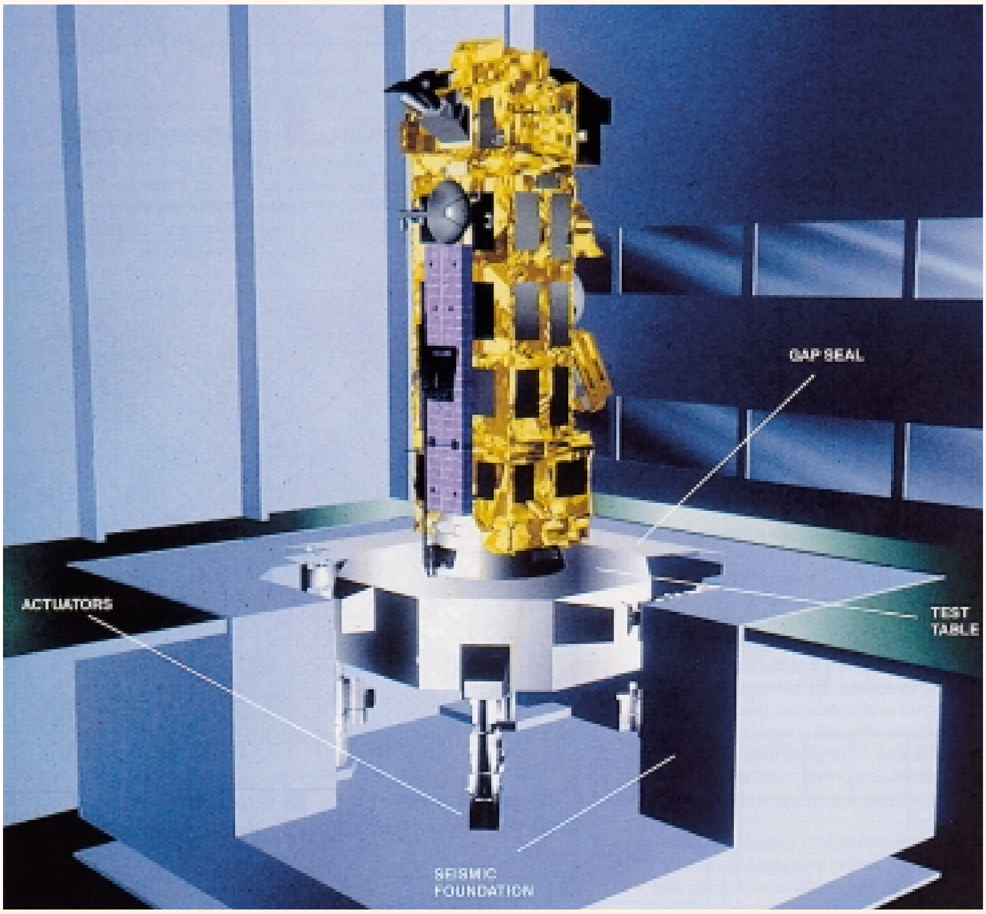
A powerful tool for vibration testing at ESTEC

Tool for structural qualification

Considerable effort has been expended during the last decade in studying the possibilities for dynamic structure qualification and system acceptance of Ariane-4 and Ariane-5 payloads. These investigations have fed through into the concept for the HYDRA hydraulic shaker, which is distinguished by the following main features compared with conventional electrodynamic shakers:

– extended shaker forces and stroke
– extended frequency range below 5 Hz
– operation in 6 degrees of freedom (DOF)
– improved test operations and safety.

It has the potential for tests with realistic flight-load representation by 6 DOF transient excitation.



Artist's impression of the operational configuration

Operational aspects

The 6 DOF hydraulic shaker allows the specimen to be tested along both the vertical and the lateral axes with a single test set-up. It is therefore no longer necessary to dismount, re-locate and re-instrument the payload for the different excitation directions. This not only reduces the effort involved in handling and in instrumentation, with consequent reductions in test duration and risk, but it also provides flexibility in the sequencing of tests. In particular, x-, y- and z-signature tests can be performed without particular effort before and after each single-axis test run.

The aspects of the HYDRA configuration of particular interest to the customer are illustrated in the figure on the left. The large octagonal test table has a span of 5.5 m and is flush with the test floor. It facilitates the mounting of heavy and/or geometrically large specimens (e.g. appendages such as solar arrays). The complexity and mass of test-specific mechanical support equipment and adapters can be reduced with this configuration.

The shaker is located adjacent to both the control room and the area for the customer's satellite check-out equipment, which fosters good communication and working links between the user teams and the test operations staff. All shaker equipment and supplies are located in the basement of the building, mechanically isolated from the clean test area (class 100.000 Fed. Std. 209).

Cleanliness and safety

Detailed product assurance analyses during HYDRA's design have led to a well thought out strategy for providing optimum protection for the test item against contamination and over-testing. The safety system is of the utmost importance, due to the presence of moving masses with high inertia and the large installed hydraulic power. The control system protects the specimen against all potential failures identified in various safety analyses, by initiating a "soft facility shutdown".

The gap between the aluminium test table and the test floor is closed by a flexible seal (gap seal). This provides mechanical separation of the clean test area from the hydraulic equipment (actuators, bearings, valves, etc.) located below the table (see figure).

Dynamic performance

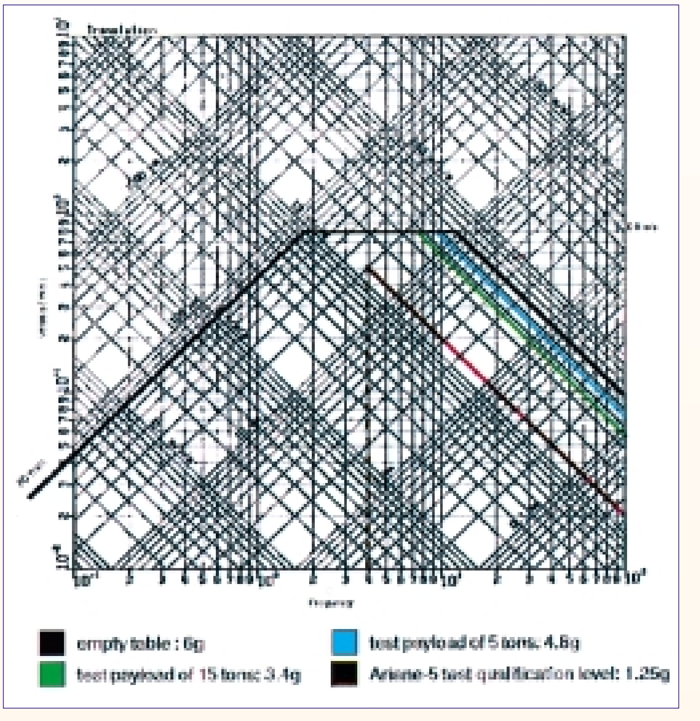
Some of the main dynamic characteristics of the HYDRA facility are shown in the accompanying performance diagrams (right), which indicate the test table excitation limits for different payload masses.

The Ariane-5 qualification levels for sinusoidal vibration tests are indicated in the diagrams and demonstrate that adequate margins exist even for very heavy payloads. Also, low level excitation at 0.05 g up to 15 Hz and 0.1 g up to 100 Hz is possible with adequate accuracy.

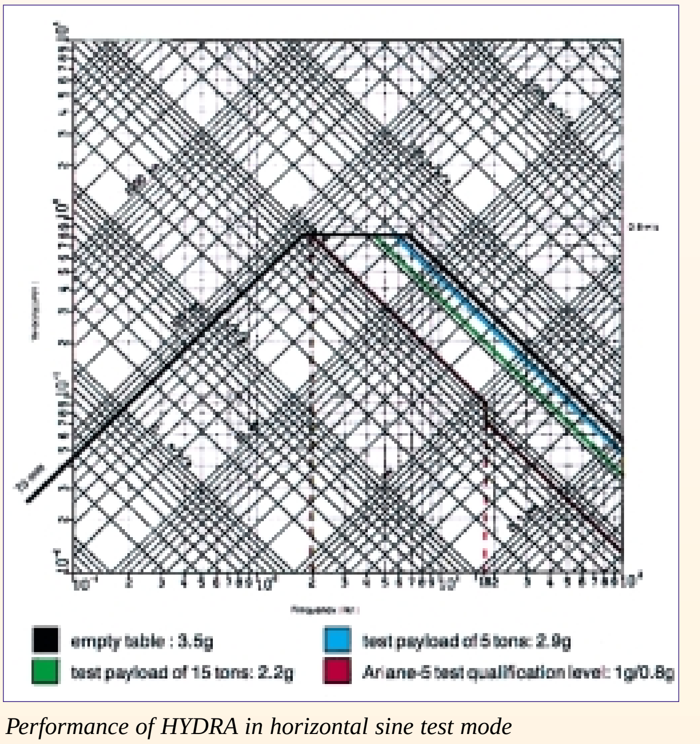
Realistic flight-load simulation (transient testing)

A future goal is the introduction of a test method that reflects a more realistic representation of the launch environment. It has been concluded that the simulation of the multidirectional transients at the interface of launcher and spacecraft produces the most realistic structural responses, unlike traditional sine or random tests, which lead to unrealistic responses and therefore involve an inherent risk of over- or under-testing.

Consequently, HYDRA has been designed to perform sinusoidal testing as well as to generate 6 DOF transients. The latter test mode can be implemented as soon as satellite programmes are ready to apply this new test method.

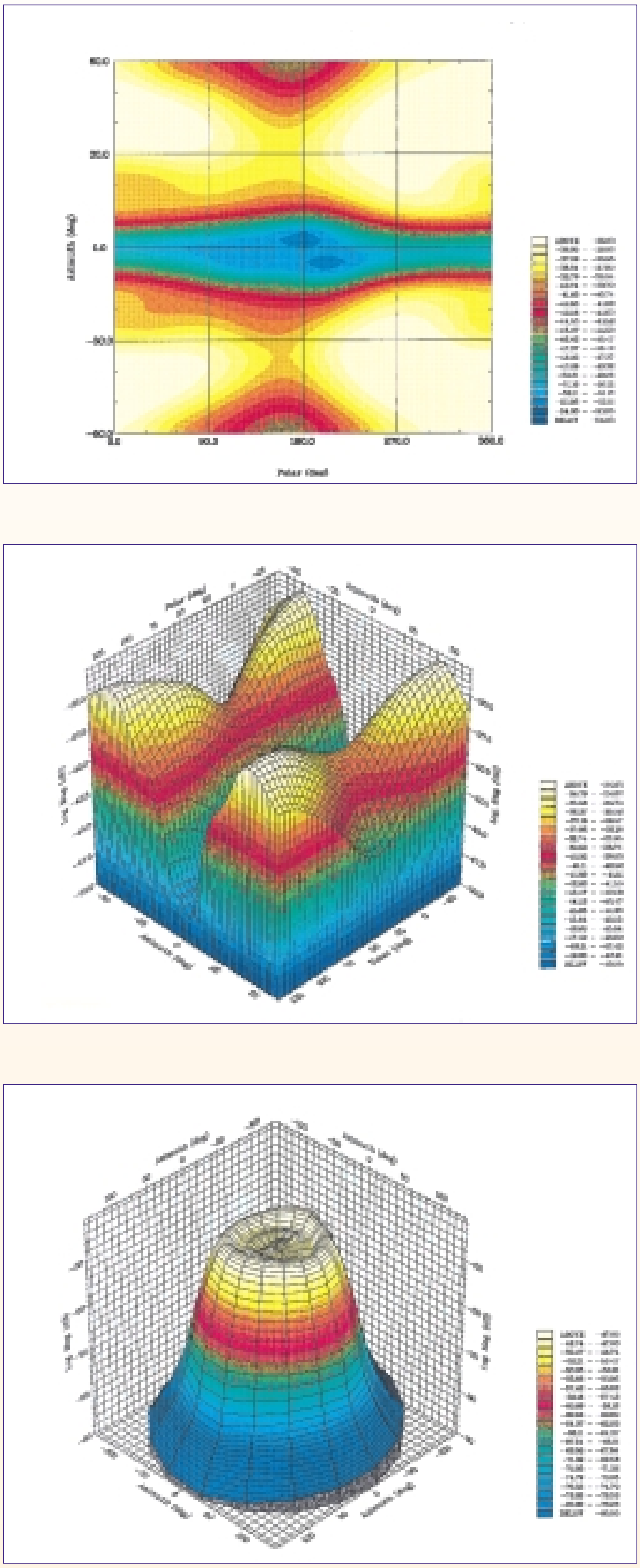


Performance of HYDRA in vertical sine test mode



Performance of HYDRA in horizontal sine test mode

COMPACT PAYLOAD TEST RANGE



Three examples of different printouts from antenna radiation patterns

Radiating payload measurements are used to verify the in-orbit performance of complex radiating systems so as to eliminate the uncertainties caused by predicting performance from the measurement of different units forming part of the system.

In addition, other critical system parameters, not normally verifiable by means of tests, such as EIRP, PFD, beam steering, link budgets etc, can be measured on the integrated system.

One of the main features of the Compact Payload Test Range (CPTR) is its low cross-polar performance allowing accurate measurements to be made of communications payloads employing frequency re-use.

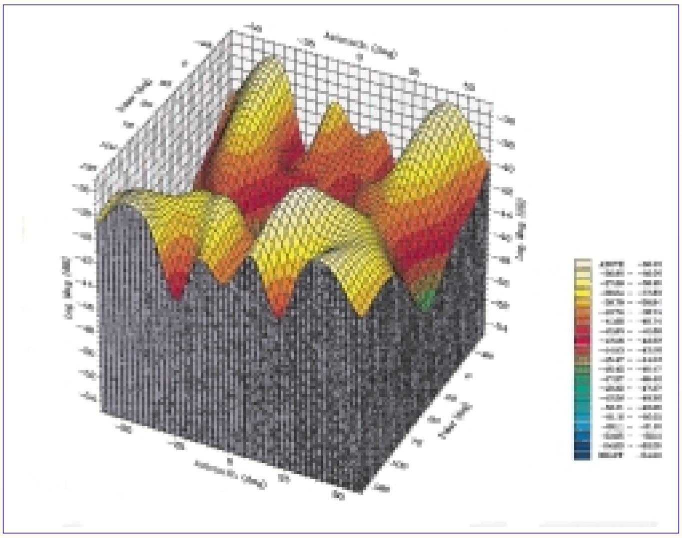
The Compact Payload Test Range at ESTEC, operational since late 1990, consists of a shielded anechoic chamber with a feed scanner room, an attached control room and a test preparation area.

The chamber itself and its main loading door are large enough to take a complete spacecraft of today’s generation, compatible with an Ariane 4 payload.

The equipment needed to operate the positioners and acquire the test data is located in the control room. The instrumentation required to operate the system under test is placed in the test preparation area and connected, via feedthroughs, into the CPTR.

The facility is designed to ensure that tests are carried out in the most effective and economical way. The test programmes are fully automated with test result presentation available in a variety of formats. The data acquisition system controls each step in the test programme and provides maximum security for the test object. Test data can be presented in the form of radiation pattern cuts (2-D plots), contour plots (3-D plots) and projections (3-D plots).

An important feature of the CPTR is the fact that feed horns can be placed at different locations in the focal plane, thus causing the boresight (or axis) to deviate from normal. This means that, by placing horns at a variety of positions in the focal plane, the performance of an Earth station transmitting, for example, via the satellite to a ground station or an air terminal at different locations on the Earth’s surface, can be verified. The range performance also lends itself to the measurement of the performance of scanning and active arrays. Here the beam is scanned electronically and sensors in the focal plane verify the correct dynamic behaviour of the system. Finally, because the chamber is shielded, it can also be used to carry out a range of electromagnetic compatibility measurements.



Antenna radiation pattern

Electrical characteristics

Overall size	l6x10x25 m
Inside size	10.9x9.6x24.5 m
Plane Wave Zone	7x5x5 m
Frequency Range	1.5 to 40 GHz
Amplitude Ripple	±0.2 dB
Phase Ripple	±4°
Taper	0.4 dB

Environmental characteristics

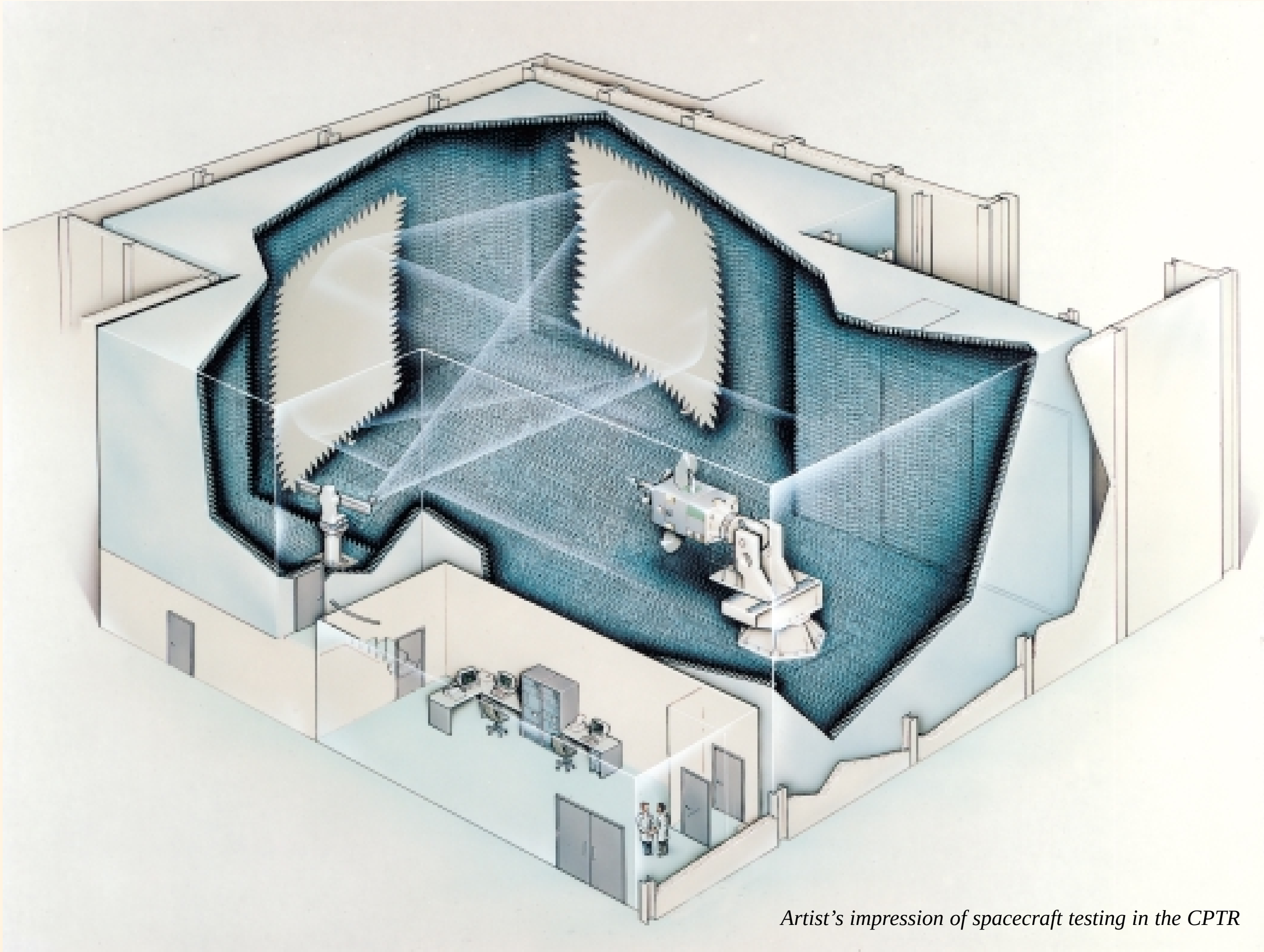
Cleanliness Class	100.000
Temperature	20°C ± 2°
Humidity	50% ± 10%

Positioners

Test Positioner - Load Capacity	6000 kg

Reflectors

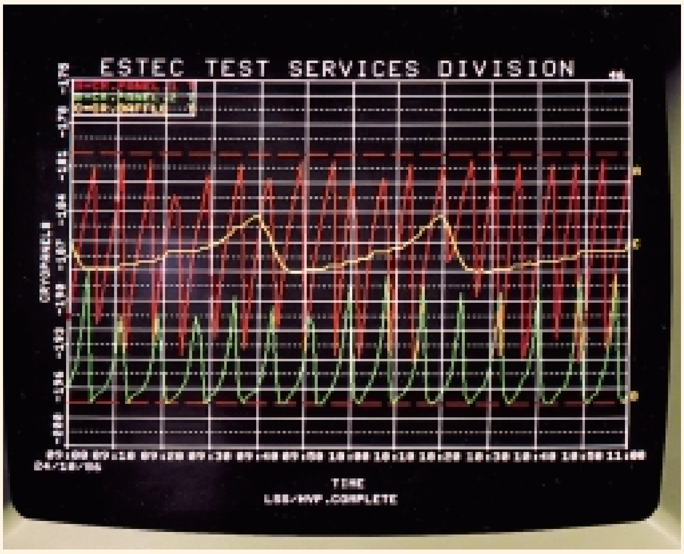
Subreflector Dimensions	9.2x8.0 m
Reflector Dimensions	l0.5x7.5 m
Surface accuracy	70 microns (peak to peak)



Artist's impression of spacecraft testing in the CPTR

THE DATA HANDLING FACILITIES

Some curves showing Large Space Simulator performance data



Plot showing the regulation of the Large Space Simulator cryogenic pumping system

The Test Facilities Data Handling systems provide a set of excellent tools to monitor and analyse the behaviour of satellites and their payloads during vibration, shock, acoustic, thermal balance, thermal vacuum and infra-red radiation tests.

These Data Handling facilities are characterised by:

- *Extreme flexibility*. Each test requires a unique set of data acquisition, reduction and presentation capabilities. The Test Facilities Data Handling systems meet these requirements fully; they can accept almost any specifications for test configurations and requirements and, if necessary, alter them at the last minute or even during the tests themselves.

- *Data presentations*. To be able to follow and monitor the performance of a satellite or a payload in real time throughout the duration of a test sequence, it is essential to have flexible, fast and appropriate methods of data presentation. The Data Handling Facilities, including Dyna Works, present data in graphical or tabular form, on colour CRT's and printers. Data presentation layouts are tailored to the needs of each individual user and can be re-defined at any moment during a test. Sensor values, in engineering units, and derived values, in graphical or tabular form are updated as new data is acquired.

The Data Handling Facility consists of three independent systems:

– the Thermal Data Handling system, dedicated to handling data from the test subject during thermal testing;
– the Facility Data Handling system, dedicated to data handling for thermal test facility control; and,
– the Mechanical Data Handling system, which handles test subject data during vibration, acoustic and mechanical tests.

Computers, signal conditioning and acquisition systems of the Mechanical Data Handling system

Facility data handling for the Large Space Simulator

The Thermal Data Handling System

The Thermal Data Handling system can provide data acquisition, reduction and presentation for several test facilities at the same time during:
– thermal balance tests;
– thermal vacuum tests;
– infra-red radiation tests, and
– photogrammetry measurements.

The safety of test subjects is assured by the generation of messages and alarm signals when sensor- or derived values exceed pre-defined limits or slopes. Warning messages and signals are also issued on the basis of extrapolated values.

Early warning capabilities, integrated in the system to detect and analyse deviations from nominal conditions at the earliest possible moment, ensure a safe and reliable operation of the facility at all times.

Spacecraft sensor information can also be included in the early warning capability and warning signals sent back to satellite check-out stations, thus providing an additional safety factor for the test subject.

The reliability of the data handling system is assured by:
– a dual sensor measurement system;
– a high degree of redundancy in peripheral equipment; and,
– continuous monitoring of tasks under software control.

Data presentations, on graphic colour monitors, terminals and printers are available in the customer areas on the test floor, in the satellite check-out area, the facility control areas, the data handling areas and, if need be, anywhere else either inside or outside ESTEC through the public telephone network.

The Facility Data Handling System

The Facility Data Handling system provides data handling support to assist and monitor the operation of all ESTEC's thermal facilities. Its design criteria are, however, specifically geared to the needs of the Large Space Simulator (LSS).

By monitoring detailed facility parameters, both the test operation team and the customer are provided with fast, reliable, up-to-date and accurate information on the test environment and the performance of the facility itself.

Data are acquired directly from temperature, pressure, flow, solar intensity sensors, etc., as well as through digital communication links with the four LSS subsystem control systems. Detailed data on the performance of the facility – valve positions, control modes, interlocks, drive and feedback signals, for example – acquired from the subsystem controllers ensure that reliable information is immediately available to enable the assessment of performance and of any possible deviations.

The Mechanical Data Handling System

The Mechanical Data Handling system provides data acquisition, reduction and presentation for vibration, acoustic and shock tests.

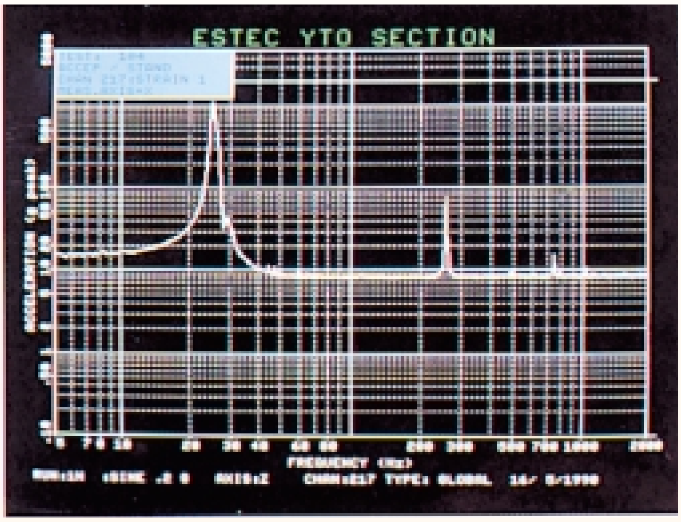
Transducer data, delivered by various types of sensor (accelerometers, deformation gauges, microphones, etc.) are acquired, partially recorded onto an analog recording system and analysed by:
– a general purpose computer system;
– four dedicated signal analyser computer systems, and
– structural dynamics analyser software.

A list of main data reduction capabilities, on a channel by channel basis, is given below:
– transfer and coherence functions;
– auto- and cross-correlations;
– Fourier transformations in real time;
– convolutions;
– shock analysis.

Fast reduction and presentation of data from numerous transducers is provided for:
– global and filtered accelerations;
– phase;
– power spectrum densities;
– rms versus time;
– 1 and 1/3 octave analyses;
– root mean square calculations, and
– real and imaginary parts.

This type of data is displayed on colour CRT's and plotted on paper at high speed. Data from all the transducers are analysed on-line during tests and are available for presentation shortly after the run is over.

Several data presentation options are available. It is, for example, possible to present the data from up to five transducers on one graph, to present graphs in three dimensions, graphs showing the difference between the data from two transducers, etc., as well as phase graphs related to a freely-selectable reference transducer. Data can also be presented in tabular form. Whatever the option chosen, the results are fully documented with test, run and transducer information.



A typical vibration response curve


Partial view of the Mechanical Data Handling system


Thermal Data Handling: TDH Control Room

Main performance characteristics of the Mechanical Data Handling System

Number of acceleration transducers:	max. 252
Number of deformation gauges:	max. 36
Number of microphones	6
Sinusoidal mode bandwidth:	2-2000 Hz
Random mode bandwidth	10-2500 Hz
Acoustic analysis bandwidth:	10-12 000 Hz
Plotting speed:	12 graphs/min
Digital data storage capacity	300 runs

Main performance characteristics of the Thermal Data Handling System

Analog measurement capacity (temperatures, pressurs, etc.	max. 1032 sensors
Digital measurement capacity (status, position, etc.)	max. 128 sensors
Derived data capacity (averages, differences, etc.)	max. 456 parameters
Conversion methods to EU or derivation methods:	unlimited
Alarm messages and signals generated on reaching:	low, high delta and extrapolated limits
Online storage capacity for sensors and derived values:	20 000 000 values

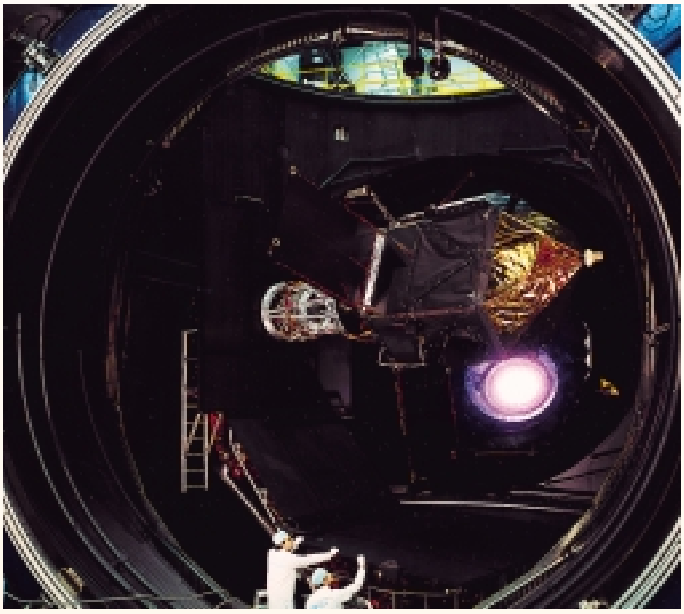
General data presentation formats

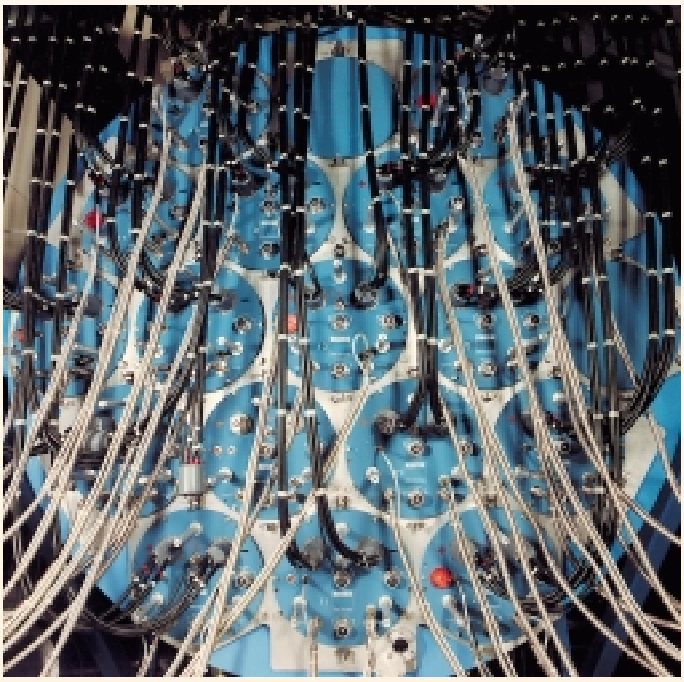
– tabular	scan versus time; average; equilibrium search; equilibrium prediction; alarm summary.
– graphical	max. 63 sensors in 3 columns per screen, DynaWorks
– digital	magnetic tape, DAT, CD-ROM, 1/4” cartridge
Number of devices where data presentation can take place simultaneously	max. 25

Main performance characteristics of the Facility Data Handling System

		Used by LSS
Analog measurement capacity (temperatures, pressures, etc.):	max. 368 sensors	368
Digital measurement capacity (status, interlocks, etc.):	max. 4816 sensors	700
Derived data capacity (averages, differences):	max. 831 parameters	200
On-line storage capacity for sensors and derived values:	max. 20 000 000 values	
Alarm/warning messages and signals generated on reaching:	low, warning-low, warning-high, high, delta and extrapolated limits	

THE LARGE SPACE SIMULATOR


Hipparcos spacecraft on the LSS motion simulator


Lamp modules

Efficient test preparation, fast operations, reproducible test parameters and ‘user-friendly’ data presentations were the basic specifications for the Large Space Simulator (LSS); the design of the facility also took into consideration past experience and recent trends in test requirements.

The LSS provides close simulation of in-orbit environmental conditions thus ensuring the optimisation of the design and verification of spacecraft and payload hard- and software. Thanks to the exceptional test volume available, it is an excellent tool for testing large payloads.

The specific design features and excellent performance characteristics of the facility mean that a number of tests can be carried out under high vacuum conditions, including:

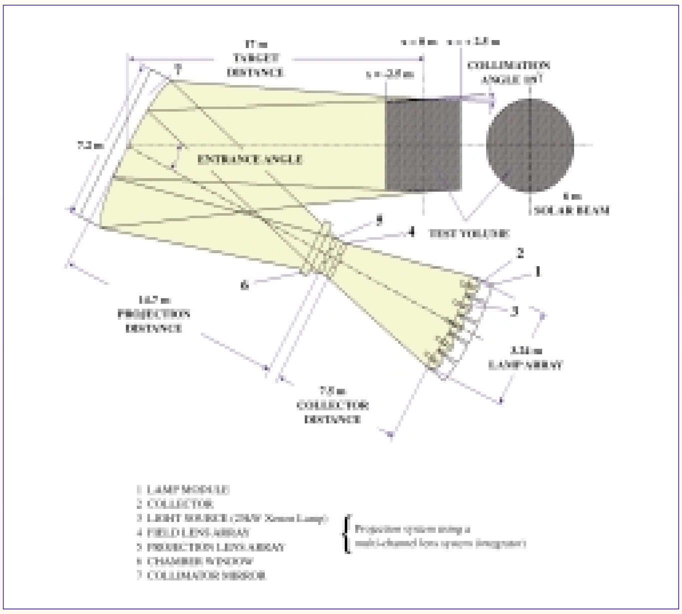
Thermal tests:
– solar simulation;
– infrared radiation;
– vacuum temperature cycling.

Mechanical tests:
– deployment of large structures;
– dynamic balancing;
– photogrammetry for deformation measurements.

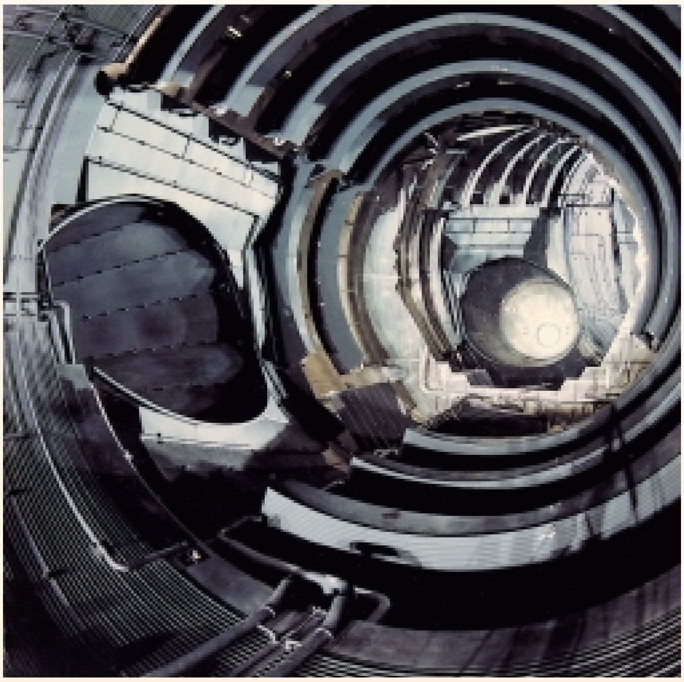
Subsystem monitoring and control are based on state-of-the-art technology and offer remarkable flexibility in selecting test mode combinations and sequences tailored to user requirements.

On-line computer-aided reporting on the performance of the facility itself provides a complete and detailed documentation of parameters and conditions during test activities, not only for the benefit of operations and maintenance but also in support of quick and efficient test analysis.

Since it became operational, in 1986, the LSS has proved itself to be a unique facility which sets new standards in space simulation techniques. From the customer’s point of view, it has two main advantages: it is, as already mentioned, a ‘user-friendly’ system which provides real-time information on the test subject. Secondly, thanks to the state-of-the-art technology used in designing the facility, it can be run very economically, both from the point of view of operating costs and of consumables, and compares very favourably with smaller existing facilities.



The sun-simulator sub-system



View into the auxiliary chamber

THE CHAMBER

The LSS chamber, with an overall volume of 2150 m^3 consists of:

– *the main chamber,* a vertical cylinder, the top flange of which forms a removable lid for easy loading into the chamber. An additional 5 m door – with a man-door let into it for fast access – is also available on the lower, test-floor, level. The chamber contains a stable specimen support platform which, because it is insulated from both chamber and building movements, has a low mechanical noise level (less than 10^{-3} g), a point of significant importance for dynamic tests, optical calibrations and heat-pipe operations during heat balance phases. Numerous flanges and ports for instrumentation, observation and, in particular, for photogrammetric equipment are also available thus ensuring that deformation tests can be carried out on specimens during vacuum and thermal testing;

– *the auxiliary chamber,* a horizontal cylinder which provides a stable interface with the solar simulation optics and which contains the collimation mirror on a rigid support structure.

THE SHROUDS

Both main and auxiliary chamber are equipped with a number of stainless steel shrouds that are temperature controlled, using liquid or gaseous nitrogen, in a range from 100 to 353 K depending on the operational mode chosen.

The shrouds in both chambers can be independently controlled thus allowing various temperature combinations to be obtained.

THE SUN SIMULATOR SUBSYSTEM

The sun simulator provides a horizontal solar beam of 6 m in diameter with excellent uniformity and very high long- and short-term stability (<0.5%).

An intensity level of 1 solar constant (approximately 1360 Watts per square metre) can be achieved by operating 12 of the available 19 Xenon lamp modules at a nominal power of 20 kW per lamp. The sun simulator thus has a high degree of redundancy which means that tests can be carried out over long durations or at elevated intensities.

Should the need arise, the sun simulator could also be equipped with 32 kW lamps.

THE HIGH VACUUM SUBSYSTEM

The LSS is depressurised using both the Test Centre's central pumping system and a dedicated high vacuum system. The minimum vacuum obtained to date is 3×10^{-7} mbar using turbo-molecular pumps and an LHe cryo-pump. The chambers are repressurised using GN_2 to 100 mbar and then clean air to reach atmospheric pressure. The total repressurisation time can be varied from 4 to 24 hours depending on needs.

Independent cryo-panels, put into operation early in the chamber evacuation phase and reconditioned only during repressurisation, provide optimum protection against contamination for both the test object and the facility optics.

THE MOTION SIMULATOR

The customer can choose from two motion simulator configurations:
– the gimbal stand and
– the yoke configuration (see figures).

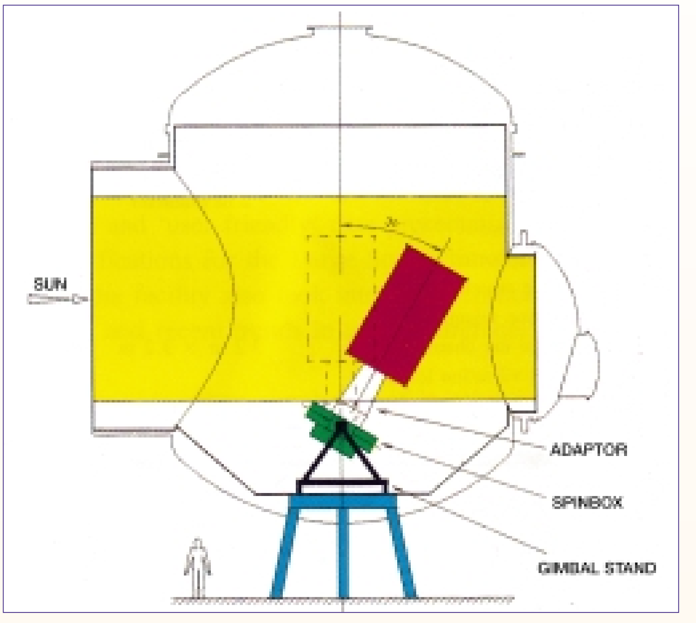
Thanks to the two-axis *yoke* configuration, a test article can be placed within the LSS in any position relative to the solar radiation axis. The drive systems and controls make it possible to simulate satellite motions in orbit within a large speed range and with high angular position accuracy. As is the case for the chambers, the motion simulator is equipped with thermally controlled shrouds.

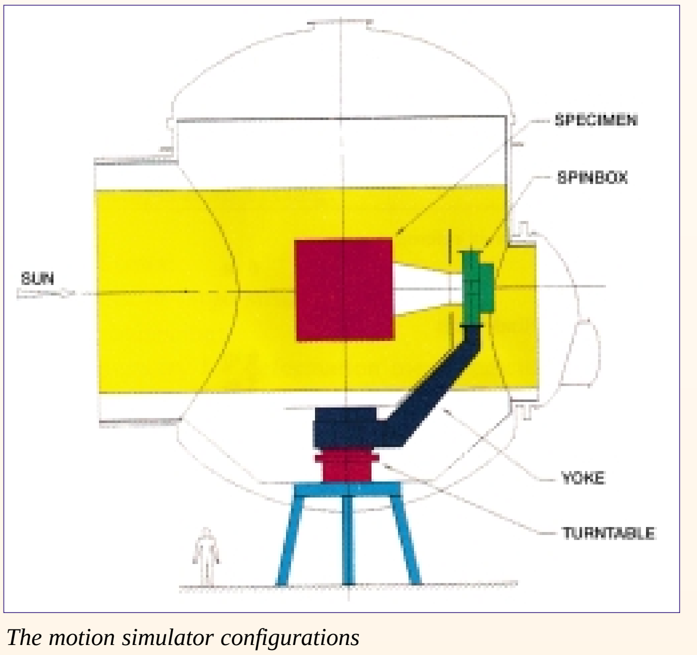
The motion simulator consists of:
– the turntable, which causes rotation around the vertical axis for the simulation of attitude motions;
– the spinbox, mounted on a yoke, which ensures spin motion around the horizontal axis.

The spinbox can also be mounted on a *gimbal* stand in order to provide spin motion around the vertical axis. The gimbal stand allows an inclination of the spin axis of up to $\pm 30^{\circ}$ from the vertical;
– the data and power transmission system for the exchange of electrical data and power between the rotating test object and the external check-out and data handling equipment.

DATA HANDLING

All control functions and readings (temperatures, process parameters, etc.) are collected from the various subsystems using programmable logic controllers. The data obtained are analysed and status outputs displayed on subsystem mimics and control indicators.
Data are also collected by a dedicated data handling computer for analysis and for detailed fault finding in case of failure.





The motion simulator configurations

Full details of the Test Centre Data Handling System can be found in the Data Handling folder.

LSS Main Contractors

Carl Zeiss (D)	Sun Simulator
Leybold-Heraeus (D)	Shrouds and nitrogen supply
Bignier Schmid-Laurent (F)	Chamber
IBB-Kondor Groep (NL)	Building
Comprimo (NL)	Engineering support
ESA/ESTEC (LSS Project Team)	Overall project management

Principal parameters of the chamber

Main chamber:	
— Diameter	10 m
— Overall height	15 m
— Material	AISI 304 SS
— Chamber access:	
• removable top lid	10 m diameter
• sliding side-door	5 m diameter
• man-door	2 m diameter
— Specimen supports:	
• platform (supported via an interface structure to a 90 tonne seismic block below the chamber)	3.2 m × 3.2 m
• mechanical vibration level of platform	$<10^{-3}$ g
• 3 suspension points in upper part of main chamber	1200 kg (max. load per point)
Auxiliary chamber:	
— Diameter	8 m to 11.5 m
— Overall length	14.5 m
— Material	AISI 304 SS
— Chamber access:	
• man-door to mirror	2 m diameter

Principal parameters of the sun simulator

Solar beam diameter in reference plane	6 m
Test volume (cylindrical):	
— diameter	6 m
— length	5 m
Collimation angle	1.9°
Uniformity (measured with a 2×2 cm sensor):	
— reference plane	±3%
— test volume	±4%
— spectrum	unfiltered Xenon light
Light sources:	
— type of lamp	high-pressure Xenon
— number of lamp modules	19
— lamp power	25 or 32 kW per lamp
— number of lamps for 1 solar constant	12 at approx. 20 kW
Optical elements:	
— collector optics	metallic elliptic mirrors
— transfer optics	integrator with 55 field and projection lenses
— collimation mirror	temperature controlled; 121 hexagonal segments; diameter: 7.2 m
— chamber window	HERASIL; diameter: 1080 mm

Principal parameters of the shrouds

Temperatures	<100 K in LN_2 mode; -160°C to $+80$°C in vacuum temperature cycling (VTC) mode
Clear diameter within main chamber	9.5 m
Surface	approx. 630 m^2
Mass to be cooled/heated	approx. 19 t
Cool-down/warm-up duration	±2 hours
Surface properties	
(Black paint type	$\alpha p > 0.95$
Chemglaze Z306	$\epsilon n > 0.9$

Principal parameters of the high vacuum subsystem

2 multivane pumps (used in the range between 1013 and 1.0 mbar)	2500 m^3/h each
3 Roots pumps (used in the range between 20 and 3×10^{-3} mbar)	3000 m^3/h each
2 cryo-panels (for condensing gases)	43 m^2 at 80 K (boil-off mode)
4 turbo-molecular pumps (to support chamber depressurisation to 1×10^{-4} mbar and to provide pumping capacity for He)	2000 l/sec each
1 LHe cryo-pump for N_2	300000 l/sec

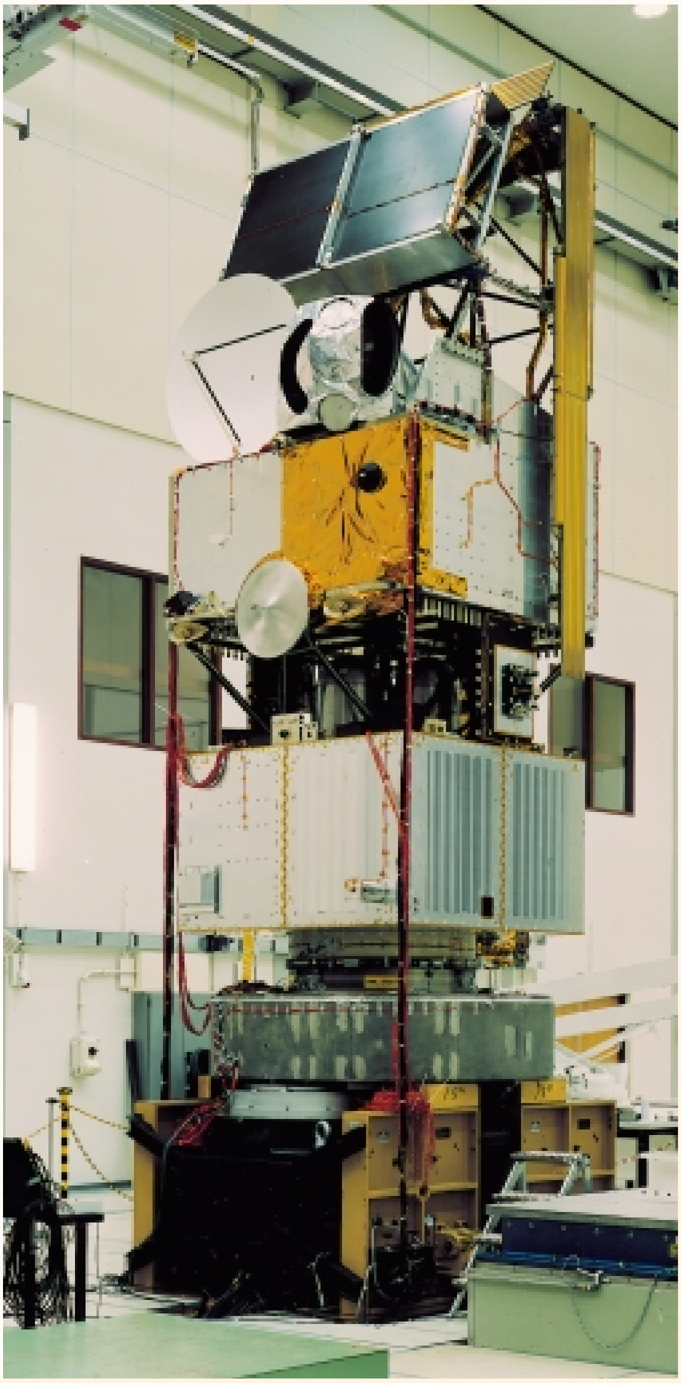
Main characteristics of the motion simulator

General:	
Specimen mass	Maximum 5000 kg (including adaptor)
Spinbox:	
Fast motion	velocity: 1-6 rev./m; accuracy: ±3% of selected speed
Slow motion	velocity: 1-24 rev. per day; position mode: 40°/m; positional accuracy: ±0.4% of selected value
Turntable:	
Rotation range	±90°
Rotation mode	velocity: 1-24 rev. per day; accuracy: ±1% of selected speed
Position mode	velocity: ±60°/m; accuracy: ±0.4% of selected speed

Data and Power Transmission:

	Channels
Thermocouple (Cu/Con)	4×144
Pt 100/Pt 500	114
5 amp	33
1 amp	144
UHF/VHF	80

THE MECHANICAL TEST FACILITIES



Structural model of the ERS-I spacecraft undergoing vibration tests on the electrodynamic multishaker in vertical direction

ESTEC's Mechanical Test Facilities comprise a series of electrodynamic shakers, a hydraulic shaker* and an acoustic chamber**, together with a number of physical properties machines, All are designed to verify the integrity of the structural design of spacecraft and their subsystems.

One of the major risks faced by a spacecraft stems from the high level of vibration to which it is submitted during launch. It is, therefore, essential to be able to test a spacecraft and its components under similar conditions in order to ensure that it will be able to withstand the launch and arrive, in orbit, in perfect condition. This type of test is carried out in the ESTEC vibration and acoustic test facilities.

Basically, two types of test are performed here:

– *design qualification tests*, usually carried out on the structural model during the spacecraft development phase in order to verify the mathematical model, by measuring:
  • resonant frequencies;
  • vibration modes;
  • magnification factors;
– *acceptance tests* on the flight model, to verify workmanship and to ensure that the equipment does indeed operate satisfactorily in its final configuration and will not degrade when subjected to the vibrations it will encounter during launch.

Three electrodynamic shakers are available:

– an 80 kN shaker used in vertical or horizontal configuration coupled to an auxiliary slip table;
– two 160 kN shakers which can either be used individually for testing subsystems or in multishaker configuration to enlarge the capacity of the facility. In the latter configuration, the two shakers are coupled to a dual head expander for tests in the vertical axis and to a large slip table for tests in horizontal direction.

The shakers are electrically powered with switching amplifiers and controlled using a digital vibration control system.

The multishaker facility, which has been operational since January 1985, can efficiently and safely test spacecraft with a mass of up to 6000 kg in vertical and 20000 kg in horizontal direction.

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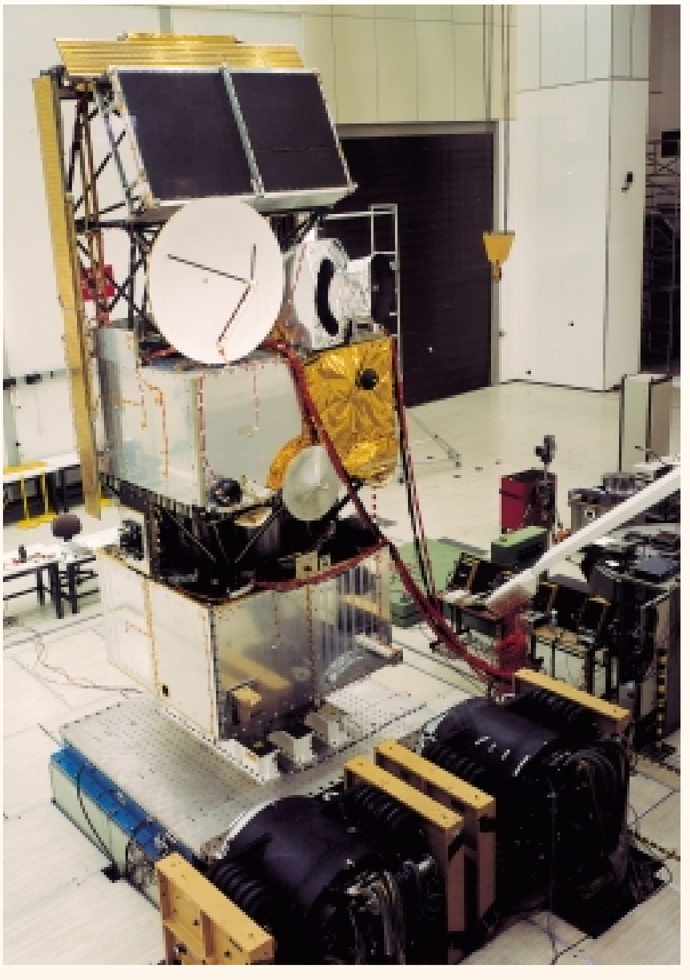
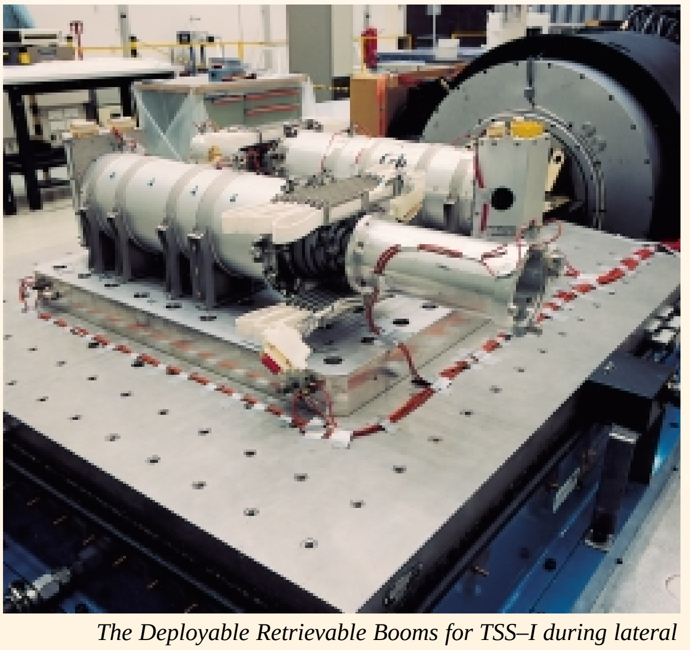
* see separate leaflet "The HYDRA MULTI-AXIS SHAKER"
** see separate leaflet "The European Acoustic Facility"

THE ELECTRODYNAMIC MULTISHAKER (2x160 kN)



Structural model of the ERS-I spacecraft undergoing lateral vibration tests on the electrodynamic multishaker



The Deployable Retrievable Booms for TSS–I during lateral vibration tests on the large slip table with single shaker, (80 kN)

Thanks to the high power of the shakers and to the numerous fixation interfaces available, the multishaker is particularly well–suited for testing very large, although lighter, structures such as solar panels, antennas, etc.

The multishaker system is mounted on a 550 ton seismic block supported by pneumatic springs so as to minimise reaction forces to the building. In the 320kN or multishaker mode, tests can be performed in both vertical and horizontal configurations, thus making it possible to simulate the effect of launch vibrations in the three orthogonal axes of the spacecraft.

In vertical configuration:

The vertical configuration is achieved by coupling the armatures of the shakers by means of a magnesium dual-head expander with an outside diameter of over 2 m; The total mass of the moving element is then 2000 kg. Guidance is provided by two large hydrostatic bearings. Special emphasis was put on the design of the alignment and guidance system of the multishaker assembly in order to avoid exceeding allowed tolerances on lateral displacement between stationary and moving parts. The dual-head expander is judiciously ribbed to provide a good rigidity/mass ratio and also to provide good transmission of the forces delivered by the two shakers. It is provided with an additional pneumatic load-compensation device which gives the assembly a dynamic load capacity of 6000 kg. The load is mechanically attached to the dual-head expander by means of Ml0 inserts arranged in a matrix pattern at 80 mm intervals, or by means of the M12 insert pattern of the shaker also reproduced on the surface of the dual-head expander.

In horizontal configuration:

The horizontal configuration is achieved by means of a slip table, a 40 mm thick magnesium plate, 3.5 m long by 3 m wide. This plate is guided by means of 81 hydrostatic T-film bearings. It is fixed to the armatures of the shakers by magnesium driver bars. In this configuration, the total mass of the moving element is 2000 kg. As is the case for the dual-head expander, the load is attached to the large slip table by means of the M10 insert matrix.

In single shaker(1x160 kN) configuration:

The two shakers composing the multishaker system can also be used in the 160 kN mode with one shaker in the vertical configuration.

To extend the interface capability of the 160 kN shaker in vertical configuration, a single-head expander, with an internal bearing and an outside diameter of 1108 mm can be fitted to the shaker armature. In this particular configuration, the total moving mass with the single-head expander is 370kg.

THE 80 kN INSTALLATION

The 80 kN installation is complementary to the large shaker system and is used to carry out vibration tests on small items such as electronic boxes, batteries, cameras, etc. in sine and random modes up to 2000 Hz.

The installation consists of:
– one 80 kN shaker used alone in vertical configuration for longitudinal tests;
– one slip table to which the shaker is coupled in horizontal configuration for lateral tests.

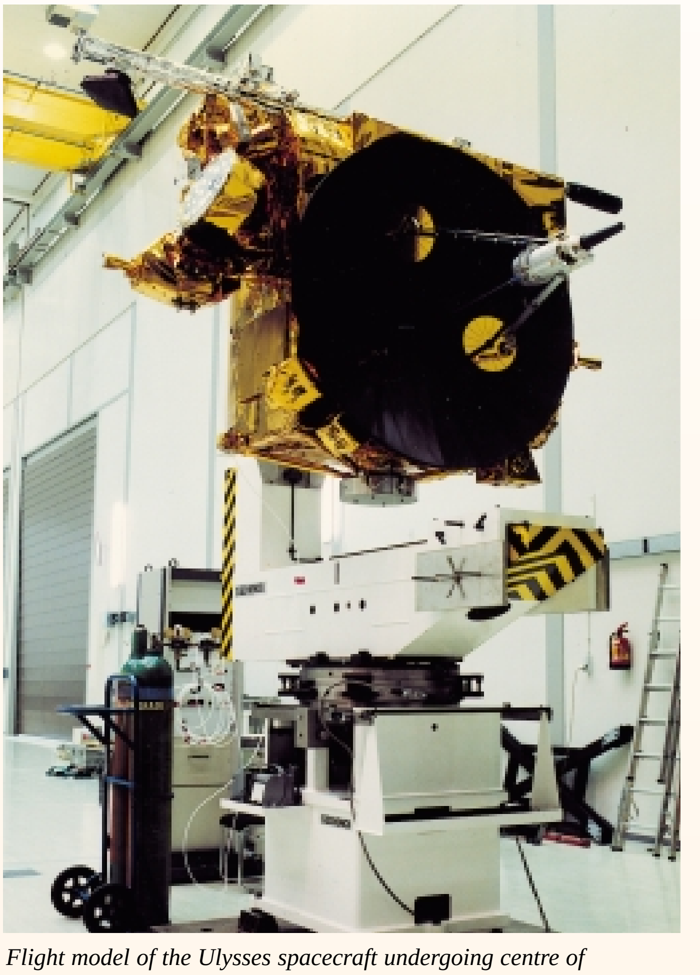
Test objects are attached to the facility by means of:
– special aluminium cube adapters for short duration vibration tests along the three axes with the shaker in vertical configuration;
– circular plates for both longitudinal tests with the shaker in the vertical position and for lateral tests with the slip table coupled to the shaker.

THE CONTROL SYSTEM

The safety of the test object is obviously a matter of prime importance for all test activities. As vibration tests are particularly demanding, every effort has been made to offer the maximum guarantees of safety. All shakers are controlled by a high-performance digital control console designed for easy programming of the various test modes and levels with high resolution. In combination with the remote control system and interlock circuitry, it controls all functions of both the power amplifiers and the shakers on the one hand and of the test specimen on the other. It provides timely information on any deviations from nominal conditions and ensures the immediate close-down of the system, in a predetermined and controlled manner, should the need arise, thus ensuring the protection of both the test object and the facility.

PHYSICAL PROPERTIES MACHINES

The Test Centre is also equipped with a series of machines for the accurate determination of the physical properties of spacecraft systems or sub-systems. These include:
– weight;
– centre of gravity;
– moment of inertia, and
– dynamic balancing.



Flight model of the Ulysses spacecraft undergoing centre of gravity determination tests

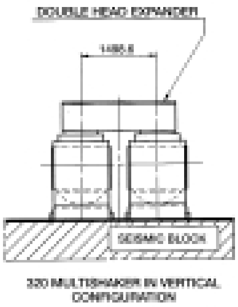
THE MECHANICAL DATA HANDLING SYSTEM

Data are acquired from accelerometers and strain gauges through the Test Centre's Mechanical Data Handling System. In addition to the standard plot presentation, modal analysis can be performed from test-run results using a computer modal software. This modal analysis technique is used to determine the dynamic characteristics of the structure from vibration test data, i.e. eigen frequencies and mode damping.

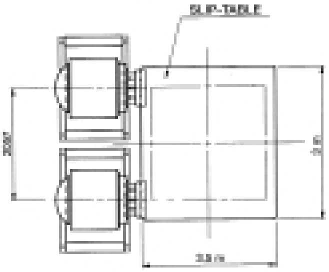
Realistic displays of animated mode shapes of the test structure can be produced on an isometric three-dimensional display.

(Further details on the Mechanical Data Handling System can be found in the Data Handling Facilities folder).

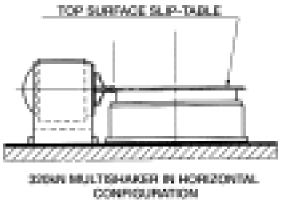
Multishaker configuration:
– vertical with the dual head expander, side view



– horizontal with the large slip table, top view



– horizontal with large slip table, side view



Main parameters of the 80 kN shaker

Nominal sine thrust	80 kN
Nominal RMS random thrust (20 to 2 000 Hz white noise)	75 kN limited to 30 g
Frequency range	3 to 2000 Hz
Maximum displacement (between overtravel switches)	38 mm p.p
Maximum velocity	2 m/s
Maximum acceleration (no load)	100 g
RMS noise level (no load)	≤ 0.05 g
Minimum level	dependent on test specimen
Axial resonance	2400 Hz

Main parameters of the single shaker configuration (160 kN)

Nominal maximum sine thrust	160 kN
Nominal RMS random thrust	155 kN (max. 30 g)
Frequency range	3 to 2000 Hz
Maximum displacement (between overtravel switches)	38 mm
Maximum velocity	2 m/s
Maximum no–load acceleration	100 g
RMS noise level (no load)	≤0.05 g
RMS noise level (loaded)	dependent on test specimen
Axial resonance	1659 Hz

Main parameters of the electrodynamic multishaker (320 kN)

Maximum thrust		
• sinusoidal		320 kN o.p.
• random		310 kN rms
Overtravel limit switches		50 mm p.p.
Displacement (maximum) in sine		20 mm p.p.
Maximum velocity		1.5 m/s
Maximum sine acceleration (bare test facility)		
• in vertical configuration		16 g
• in horizontal configuration		26 g
Minimum controllable level		0.1 g
RMS noise level (no load)		≤0.05 g rms
Frequency bandwidth		
• in sine		3–2000 Hz
• in random		10–2000 Hz
Maximum load	vertical	6000 kg
	horizontal	20000 kg
Maximum overturning moment		
• in vertical configuration		200 000 Nm
• in horizontal configuration		1 300 000 Nm
Cross–axis response (<100 Hz)		
• zero overturning moment		≤10%
• maximum overturning moment		≤10%
• except in vertical configuration		≤50%
Frequency resonances (bare test facility)		
• in vertical configuration		250 Hz
• in horizontal configuration		400 Hz
Interface dimensions		
• in vertical configuration		Ø2 m
• in horizontal configuration		3.5 m x 3 m
Interface fixation		M10 on a matrix 80 x 80 mm
Required flatness at interface for horizontal configuration		0.1 mm

On behalf of ESA, the Test Centre at ESTEC is operated by ETS B.V.
Information on the facilities and on the utilisation of the Test Centre can be obtained from:

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