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SYSTEM TEST APPROACH FOR THE SAX SATELLITE

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ABSTRACT

SAX satellite verification is based on a protoflight approach, in which only one system model is realized at flight standard level, taking into account the utilization of hardware already qualified for other space programs and the necessity to respect the schedule constraints for a scientific objective. In any case, this approach was tailored with some deviations in order to reduce risks inherent such a choice.

The protoflight approach was also pursued at subsystem/unit level in particular for those subsystems and units considered critical from the schedule point of view. Payload Instruments followed the same approach but complete spare units were developed to reduce the risks associated with such an approach.

The paper will deal first with the description of the model philosophy and then, at satellite level, it will present the testing approach and rationale for each model. Finally, a brief description of each test will be given, highlighting objectives, methodologies and test configurations. Moreover, for the major tests, problems encountered and solutions applied in establishing a correct approach are descibed.

INTRODUCTION

SAX is a satellite for X-Ray Astronomy. It is a major element of the overall basic Science Program of the Italian Space Agency (ASI) and is being developed with the contribution of the Netherlands Agency for Aerospace Programs (NIVR).

The scientific objectives of SAX, see Ref. 1, are to carry out systematic and comprehensive observations of celestial X-Ray sources over the 0.1 ÷ 300 KeV energy range with special emphasis on spectral and timing measurements.

The satellite will also monitor the X-Ray sky to investigate long-term source variability and to permit the localization and study of X-Ray transients.

Alenia Spazio is developing the satellite that is intended for launch at the end of 1993 (December) into a low (600 Km), near-equatorial orbit (inclination lower than 5 degrees) and with a lifetime of 24 months.

SAX, shown in Figure 1, is a three axis stabilized satellite with a total mass of 1400 kg and about 3.5 m high for 2.7 m of diameter. Power sources are two Ni-Cd batteries (30 Ah) during eclipse and two non sun-tracking deployable solar arrays and one body mounted solar panel during sun viewing. The maximum Telemetry bit rate is 917 KBPS on the stored data channel.

SAX uses on-board magnetometers for the AOCS that is utilized to align the Satellite with the Earth's magnetic field. The error allowed in the pointing accuracy due to the equipment magnetostatic emissions is of 5 deg.

The satellite can be subdivided into two main modules (Figure 2):

- Spacecraft (S/C) Module
- Payload (P/L) Module

The S/C Module is composed of a Service Module which accommodates the service subsystems like Power, Data Handling, Attitude Control, Reaction Control Subsystem and Telemetry & Telecommand and the Science Instrument electronic units. The Service Module is an aluminum sandwich panel structure with an inside corrugated cone interfacing with the Launch Vehicle (Atlas Centaur). Shear sandwich panels connecting the internal cone and the external panels complete the configuration giving the suitable stiffness to the Service Module.

The Payload Module is composed of a Payload support structure and a shade structure. The P/L support structure that accommodates the five Science Instruments consists of a carbon fiber optical bench and concentrator tubes. The shade structure is the Science Instrument enclosure and ensures the required fields of view for Instruments and AOCS sensors.

MODEL PHILOSOPHY

The overall Model philosophy is shown in Figure 3. At system level the model philosophy is basically a two model approach: Structural/Thermal Model and Protoflight Model.

The **Structural/Thermal Model** consists of a flight standard structure equipped with dummy units having representative mass and thermal power loading. Some units, like RCS valves and tank, are also built up in such a way as to permit the passage of a tracing gas for leakage testing the satellite. Harness subsystem mass is represented only in areas where the unit density is low and where its mass is meaningful. Thermal hardware will be flight standard as well but it will be partially integrated, mainly for blankets and heaters.

With the above configuration the Model will be subjected to a structural qualification test campaign. Then the Model will be refurbished into a Thermal configuration with the integration of the remaining thermal hardware and shadowing panels and will undergo Thermal Testing. This model will be used to attain the maximum confidence in the mechanical and thermal behaviour of the satellite.

Furthermore, the STM Model will be used to verify the validity of mechanical integration procedures, Mechanical Ground Support Equipment (MGSE), and for personnel training.

The S/C **Engineering Model** consists of a mock-up structure equipped with Engineering (EM) or Engineering/Qualification (EQM) Models of service subsystems. It will be used for a partial mechanical and electrical integration procedure validation, Units/Subsystems interface compatibility and performance (where possible) and Electrical Ground Support Equipment (EGSE) interface and performance validation. Before the above activities, the mock-up is used also to develop the harness subsystem routing.

The **Protoflight Model**, built to flight standard level, will undergo a complete acceptance test campaign (thermal/structural/electrical). A launcher adaptor interface test will be performed very early in the Protoflight Model activities at the end of the flight structure manufacturing. Moreover the Protoflight Model will be connected to the Ground Station in order to perform a data and frequency Compatibility Test. Such test, in a preliminary way, will also be performed as off line activity with S/C EM using a satellite Suitcase.

Even if this paper deals basically with the System test approach, it is worth giving information about testing at lower level in order to understand the choice made at system level better.

Spacecraft units following the EQM/FM approach are subjected to a complete qualification on EQM in terms of environmental, EMC, functional and performance tests while FM models are only tested for workmanship evaluation.

Some units following the EM/PFM approach are subjected to a pre-qualification test campaign which includes vibration, thermal testing in ambient, conducted EMC and functional testing. This in order to get as much confidence as possible on the performances of the units decreasing the risk of finding problems at PFM level, which are subjected to full qualification including environmental, EMC, performance testing. Duration of environmental testing is reduced in order not to overstress electronic units. Partial or complete development models are used, case by case, in order to increase confidence in the design.

P/L experiments follow a pure protoflight approach where only a model is built up to be qualified, accepted and flown.

Risks associated with this approach are reduced firstly by using a structural/thermal model of high representativeness, as Science Instruments are costituted by non-standard material and new processes, and secondly by having a complete spare Instrument to be used in case of PFM failure at any time.

Structural/thermal models are subjected to full vibration tests and in some cases also to thermal tests. Spares are subjected to full acceptance tests for workamship investigation. Also development models for the most critical components and subassemblies are manufactured and tested.

PFM models, as per S/C PFM units, are subjected to protoflight testing including environmental, with limited duration, functional/performance, EMC testing and scientific calibration. Details on lower level test approach can be found in Ref. 2 and 3.

SYSTEM TEST APPROACH

As summarized in the model philosophy, two models at system level are used to accomplish qualification and flight readiness. Moreover, other partial models are used including a partial EM model, limited to the S/C and with a mock-up structure, a suitcase and a Software Validation Facility (SVF). Each model has a well-defined aim whose rationale is herebelow described.

The **Structural/Thermal Model** is used for the following purposes:

* to qualify the structure subsystem and the thermal control subsystem
* to qualify the RCS subsystem, not testable at subsystem level, and verify leakage
* to validate the mathematical models of structure and thermal control subsystems
* to provide confirmation of unit environments and check amplification factors
* to verify alignment stability of the items of interest
* to verify functionality of mechanisms at system level
* to develop and amend procedures
* to check interfaces and performances of MGSE.

The S/C **Electrical Model**, with a mock-up structure, equipped with S/C electronic units, has the goal to:

* verify the S/C electrical design
* verify the electrical interfaces including the ones toward the P/L
* validate the on-board software
* develop and commission the test SW
* verify the conducted EMC performances
* verify the interfaces and the performances of the EGSE
* develop and amend the procedures
* familiarize and train the personnel.

In the process of increasing confidence in satellite performances, two other development tools are used:

* a **Suitcase** which performs a preliminary data and frequency compatibility test with the Ground Station
* a **Software Validation Facility** which performs compatibility tests among the on-board processors to check communication protocols, timing and signal interfaces.

For this last scope, a **FUnctional MOdel (FUMO)** of each processor was requested to subcontractors. The Suitcase is constituted by a Transponder, a Telecommand Decoding module, a Telemetry generation and coding module and a power supply module. The above models and tools led to a Protoflight Model with a minimum risk.

The **Protoflight Model** has the goal:

* to demonstrate the workmanship of the satellite and to gather the data required to ensure flight worthiness
* to demonstrate that no functional degradation will affect the required performance during its life
* to show that all performances are compliant with the contractual requirements
* to demonstrate the flight readiness.

TEST PROGRAM

The System Test program for SAX was accomplished by performing the tests outlined in the preceeding paragraphs and in compliance with the aim of each model. All major tests, except the centrifuge, will be performed at the ESA/ESTEC (European Space Technology Center) facility. The following test program will be performed, see Figure 4:

* Mass Properties Measurement and Balance Test (STM & PFM)
* Modal Survey Test (STM)
* Centrifuge Test (STM)
* Acoustic Test (STM & PFM)
* Sine and Random Vibration Tests (STM)
* Thermal Balance Test (STM)
* Alignment measurement (STM & PFM)
* Leak Test (STM & PFM)
* Deployment/Release Tests (STM & PFM)
* Electromagnetic Compatibility (PFM)
* DC Magnetic Field Measurement (PFM)
* System Validation Test (PFM)

Major test activities involving critical methodologies are described herein.

- **Mass Property Measurements** will be carried out with the objective to measure the physical characteristics (mass, center of gravity and moments of inertia) and balance the system statically and dinamically. Details are contained in Ref. 4.

- **Modal Survey** will be performed at Alenia Spazio premises, connecting the satellite STM through an interface flange to a seismic mass in a fixed-free boundary condition. The Modal Survey test will yield the definition of Eigenfrequencies, Eigenvectors, Modal Damping Factors and Generalized Masses in order to correlate the Finite Element Model (FEM) and refine it if necessary. First of all, a Mode Identification Process will start applying random forces with different input levels at each foresen location/orientation to check which one adequately excites primary modes up to 100 Hz. Levels will be varied until a satisfactory level to collect data is established. Moreover linearity checks at the above locations, using random excitations, and reciprocity checks will be performed. Then, with the multipoint random excitation technique, the mode characteristic measurement will be performed. Finally, the analysis of the acquired data will be performed and the individual modal parameters will be extracted by using the Polyreference Modal Parameter Estimation Method. This will permit the test data validation/correlation. Details are contained in Ref. 5.

- The **Acceleration Test (Centrifuge)** will be performed at Cesta premises in Bordeaux. This shall demonstrate the structure's capability to survive the quasi-static loads deriving from the launcher. The satellite will be installed into a centrifuge nacelle by means of an inclined adaptor to simulate the resulting load direction from axial and lateral dimensioning flight loads, acting simultaneously. The Nacelle is a cylindrical module attached to an arm rotating around an axis perpendicular to the ground. The choice of the centrifuge method for the static test was dictated by the necessity to minimize time consumption and optimize both the quality of the results and the hardware's integrity. In order to ensure a good coverage of the qualification load distribution, two test cases, which correspond to two different configurations (see Figure 5), will be tested, anyway saving time with respect to a traditional whiffle tree method. One configuration is with the complete satellite and the other without the shade structure to get a greater inclination inside the nacelle. Because of the limited tilting angle, the correct lateral loads could not be reached on each structural part. They will be compensated by increasing the axial loads and introducing dedicated compensation masses. In the centrifuge test, the static loads simulating the design ones can be applied continuously to the whole structure, reproducing the exact values in the areas of interest (Interface Ring and Optical Bench Interface) and allowing an "average loading" of the other parts (not exactly corresponding to the real situation). On the contrary, with the traditional static test it is possible to apply the exact load only to a limited number of points, without loading the whole structure. Ref. 6 containes the test requirements while the rationale on the establishing the correct configurations is given in Ref. 7.

- The **Acoustic Test** will be performed to demonstrate the capability of the satellite to withstand acoustic noise environment during launch phase. The satellite will be installed onto a suitable jig supported by elastic devices in order to avoid coupling with the ground. Adequate instrumentation will be placed internally and all around the satellite to measure the sound pressure field level. Before starting with the satellite testing, a reverberant chamber equalization will be performed, both at low level and at high level. Equalization performed without the satellite will allow to set up the acoustic test spectrum and to confirm the ability of the facility to meet the requirements. Details are contained in Ref. 8.

- The **Vibration Tests** consist of sine and random excitations at low and high frequencies respectively of the satellite STM (Ref. 9). They will verify the capability of structural hardware to whithstand dynamic loads due to lift-off. They will not be repeated on the Protoflight Model because random are covered quite enough by the acoustic test and sine due to the particular approach given at unit level. In fact most of the flight units are already subjected to sine vibration and the interfaces between units and structure are verified at STM level with the dummy interfaces being equal to the ones of the flight units. Details on this rationale are given in Ref. 10.

- The **Thermal Balance** test is performed on the STM model to demonstrate the validity of Thermal Control S/S design and to validate the Thermal Mathematical Model, which, after correlation with test results, will be used for flight predictions. Analysis has shown the worst case conditions to be the operative ones. So transfer phase will not be tested at all. The satellite will be placed on the Attitude Simulator of the Large Space Simulator (LSS) of ESTEC, via the Thermal Test Support Rig. As SAX is a low orbit satellite, influence of albedo and infrared Earth emission will be simulated through dedicated radiative plates installed all around the S/L. They shall be supported by a removable frame fixed to the Thermal Test Support Rig in order to follow the S/L in all the foreseen test configurations. Cases tested are the Winter Solstice (+30° Sun Aspect Angle (SAA)) which is the worst hot case for P/L, -30° SAA Winter Solstice as the worst hot case for Service Module, -45° SAA Summer Solstice as worst cold case for all the satellite, Summer Solstice Eclipse (transient), and a calibration case (see Figure 6). During the test, power supplies will be used to feed the Thermal Control S/S, the dummy units and the guard heaters. Details are contained in Ref. 11.

- The **Thermal Vacuum** test will be performed at Protoflight level, again in LSS. Its objective is to demonstrate the ability of the satellite to meet operation requirements in the space environment and also to detect any material, process and workmanship defects that could occur under thermal vacuum and thermal stress conditions. The test will consist of a cycle of 12 hrs at hot and cold temperature extremes in order to detect failures that become evident early in the test before the more time-consuming soaks. Then 72hr hot/cold soaks will be performed to find out weakneses that become evident only during prolongated periods of temperature and vacuum conditions. Another 12hr hot/cold cycle, in order to find out degradation that may have occurred in the preceding soaks, will be performed. At the end a final hot/cold exposure will be performed and used to correlate again and refine if necessary the TMM. Stabilization will normally be reached when temperatures of all thermocouples do not vary more than 3°/hr, but during of the last exposure, a stabilization of 1°/8 hrs will be considered because of the correlation purpose with TMM. Temperature transient will be adjusted to the performance of the most sensitive components which are the P/L instruments. In fact, a strong constraint is their thermal gradient which can not override the value of 1°/hr.

- The **Electromagnetic Compatibility** test performed at Protoflight level will be conducted to verify the EMC margin of the system and the compatibilty with the Launcher. Verification of the satellite will investigate integrated System EMC aspects, support any System EMC analysis, and provide final closure to any deviations.
  The EMC test concerns the conducted and radiated tests in E and H fields. At system level the ESD test will not be performed due to the low orbit of SAX.
  The conducted tests - conducted emission common mode (CECM) and the conducted susceptibility common mode (CSCM) - will be performed at Alenia Spazio premises because it is not necessary to perform the tests in an anechoic room.

  The CECM will measure the current emission appearing on signal lines to provide a baseline threshold to be used for margin susceptibility verification.
  The CSCM will be performed by injecting interference, 6 dB higher than emission levels, in the wire bundles, in the same position of the conducted tests. The radiated tests - radiated emission E-field (RE-E), radiated susceptibility E-field (RS-E) and radiated susceptibility H-field (RS-H) - will be performed at the ESA/ESTEC anechoic facility.
  The Satellite will be installed in the shielded anechoic chamber minimizing as much as possible hardline connections towards EGSE in order to ensure satellite simulation and monitoring.
  The RE-E field will be performed to verify that the emission levels are under the required levels in order to assess the compatibility with the launcher.
  The RS-E field will be performed by radiating electrical fields into the satellite to demonstrate both the internal compatibility and the Launcher compatibility. During the susceptibility tests it will be verified that the satellite will not exhibit malfunctions.
  RS-H-field will be carried out to verify that no malfunction occurs in the satellite when exposed to the radiated magnetic fields.
  The satellite will operate in the relevant operation modes and linked to the EGSE via the RF anechoic cap or umbilical hardline during all the above tests. Details are contained in Ref. 12.

- The **Magnetic Cleanliness** of the SAX satellite has been defined with the objective to minimize the magnetic contamination of the Satellite and to minimize the residual magnetic field, in particular in close proximity to the AOCS magnetometer sensor. The DC H-field radiated emission of the SAX S/L measured at the magnetometer location shall not exceed 125 dBpT.

  The verification of the requirement will be carried out both with a test at PFM level and with a dedicated analysis of the Solar array's contribution to the overall magnetic vector. The test will be performed at Alenia Spazio's facility, that does not permit to have magnetic cleanliness; i.e, Earth magnetic field compensation. For this reason, the test at System level will be performed with a subtraction technique in two steps. First, the magnetostatic field will be measured at S/L magnetometer location, with a test magnetometer that will have a resolution at least an order better than the measurement value.

  The Satellite will be completely integrated except for the Solar Array and in "on" condition. In this case, the measured B (tot) includes the effects of: the Earth's magnetic field, the stray and remnant fields generated by the Satellite and the environmental field. Second, the magnetostatic field due to the Earth's magnetic field only will be measured, with the same test magnetometer and in the same location as in the first step. In this case we get the Earth's magnetic field and the environmental field. Subtracting the value measured in the two steps above we get the actual field value to be verified.

The above approach is based on the following assumptions.
The Earth's magnetostatic field is identical during steps a. and b. of the test. From an engineering point of view, this is equivalent to having the same position of the test magnetometer in the two steps a. and b.. In order to reach this, an alignment activity will be performed. Moreover this is equivalent to having possible local fluctuations of the Earth's magnetic field that are negligible with respect to the requirement to test.
The above measurements imply the linearity of the test magnetometer in the range of interest.
In order to avoid an effect of the Integration Dolly on the magnetic ambient emissions, because the structural elements are build up of magnetic materials, a dedicated non-magnetic dolly will be utilized.

- The **System Validation Test** (SVT) between SAX and the Space and Ground Segments will be performed with the main objectives of:

  - confirming the Operative Control Center's (OCC) capability to support all functions necessary for conducting the Mission Operations;
  - validating of the complete communication chain between the OCC and the Satellite.

  This activity will be carried out through real telecommand from OCC to Satellite and by processing the actual Satellite telemetry at the OCC. The SVT will be performed in two different phases called SVT1 and SVT2, this both to reach a validation with a Ground Station as soon as possible and to verify after the environmental tests that the compatibility is still valid. The SVT1 will be performed at ALENIA premises after the functional tests on SAX: ISST and IST and the SVT2 will be performed at ESA/ESTEC premises as the last activity, before transporting SAX to the Launch pad.

  To perform the SVT1, part of the Ground Segment will be moved, with dedicated shelter, in Alenia, and in particular this will be the TT&C Section and the Station Computer Section (STC).
  During the test the S/L will be under the control of the EGSE through hardwired umbilical connection and the Ground Station communication to/from the Satellite will be performed through the RF S-Band link. The SVT2 will be carried out with the same configuration as for the SVT1. Moreover, a back-up test configuration will be carried out in case of the unavailability of the Ground Station at ESTEC due to schedule problems. This back-up foresees a simplified test set-up with only a few modules to allow communication with the Ground Station via RF.
  This test is previously performed using the Suitcase linked to the S-Band station and to the OCC computer. The Suitcase wil simulate the telemetry generation from the satellite and is capable of reacting to any command sent by the OCC computer.

CONCLUSIONS

The SAX satellite development and qualification approach was conceived with the objective of minimizing the schedule and the total project costs while maintaining program performances. It was established first by investigating the mission, in order to define the present or induced environments, and then by defining the project requirements to be verified.
From the above investigation, and considering the constraints imposed by the Customer, a Protoflight approach, with some tailored deviations, was derived. An accurate balance between project risks and costs is reflected in the chosen protoflight model philosophy.

At system level, two full models are used:

- a **Structural-Thermal model (STM)** in order to qualify the structure and thermal control design and
- a **Protoflight model (PFM)** to confirm requirement performances and to give evidence of the flight readiness.

Moreover, a partial mock-up, limited to the Spacecraft part, was used to verify electrical interfaces and performances and to validate EGSE interfaces before its use at PFM level.

At subsystem/unit level, only critical schedule-wise units were developed with protoflight approach.

Payload instruments used a pure Protoflight approach, that is, only a PFM unit was developed, tested and delivered for actual flight. The risk deriving from the above approach was considered and complete spare units were developed.

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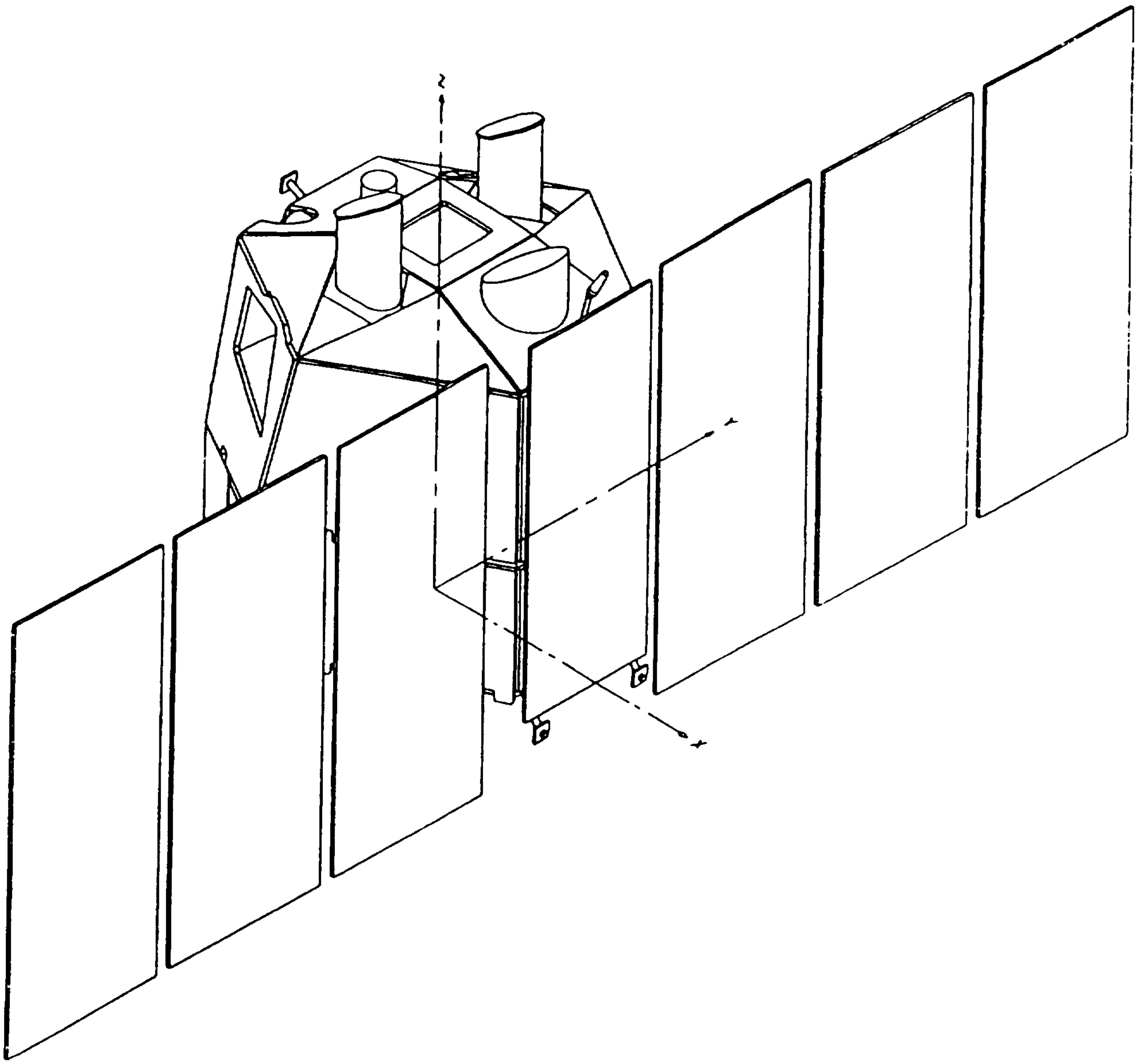


Fig. 1 - Satellite Overview

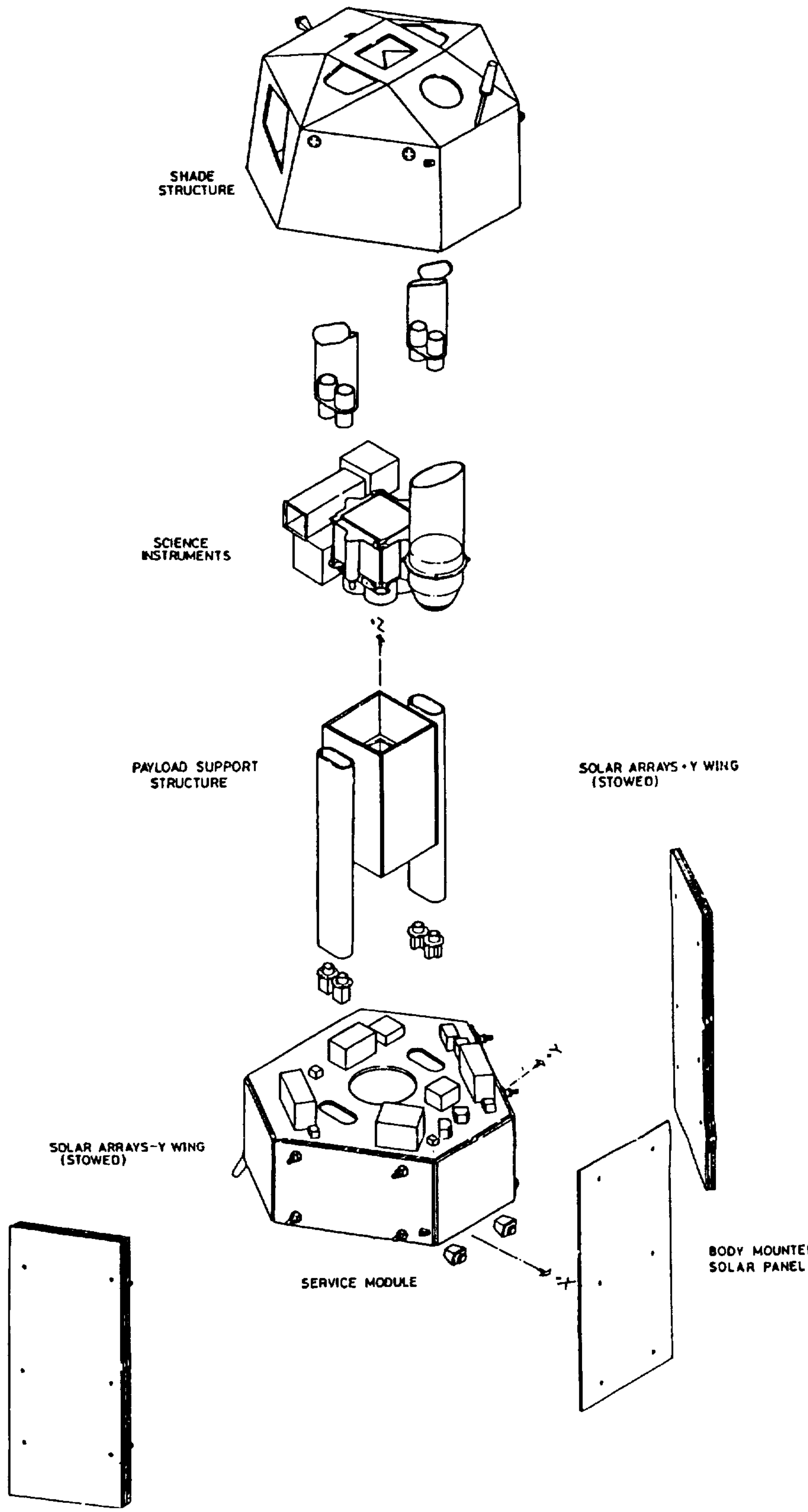


Fig. 2 - SAX Satellite Configuration

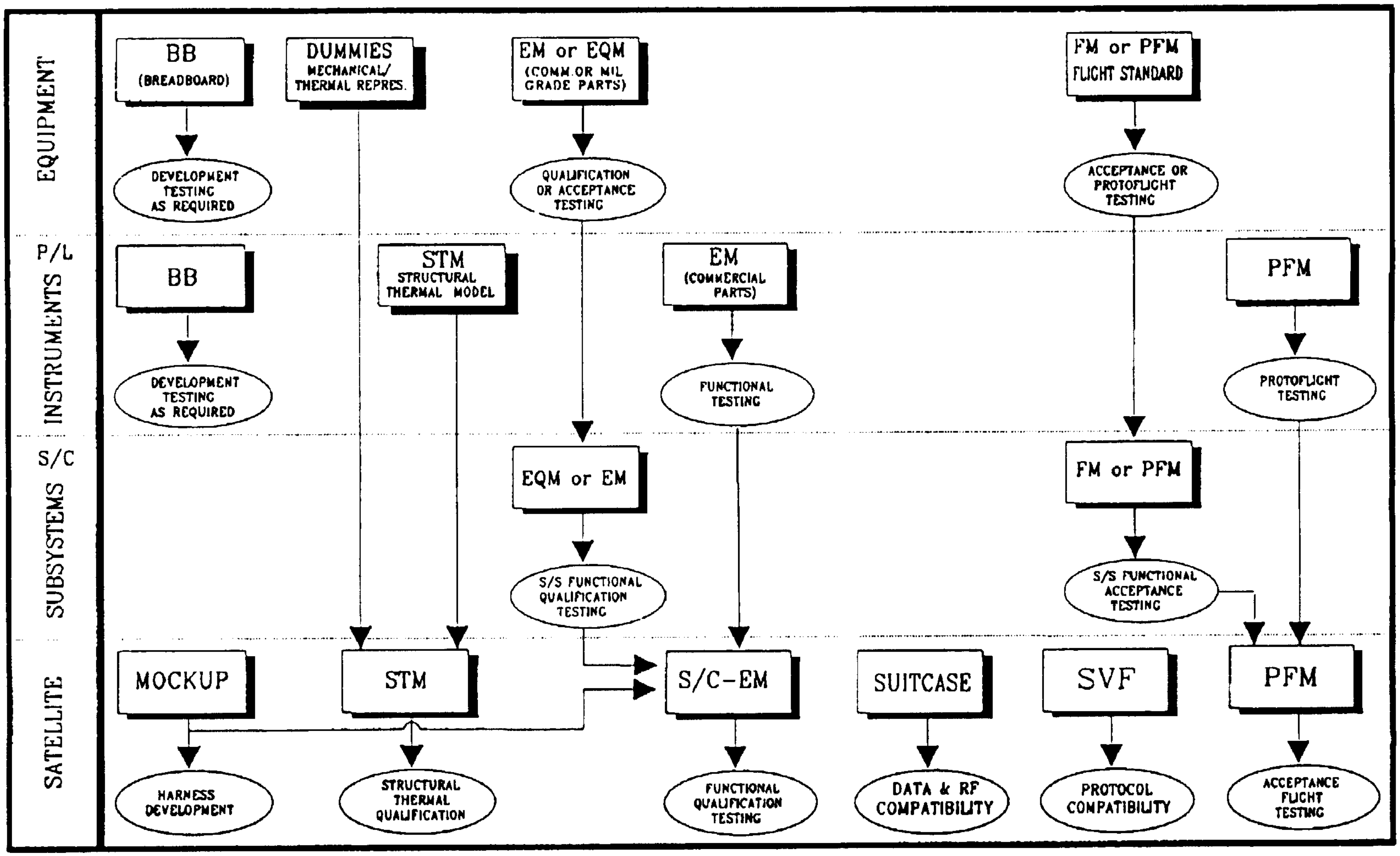
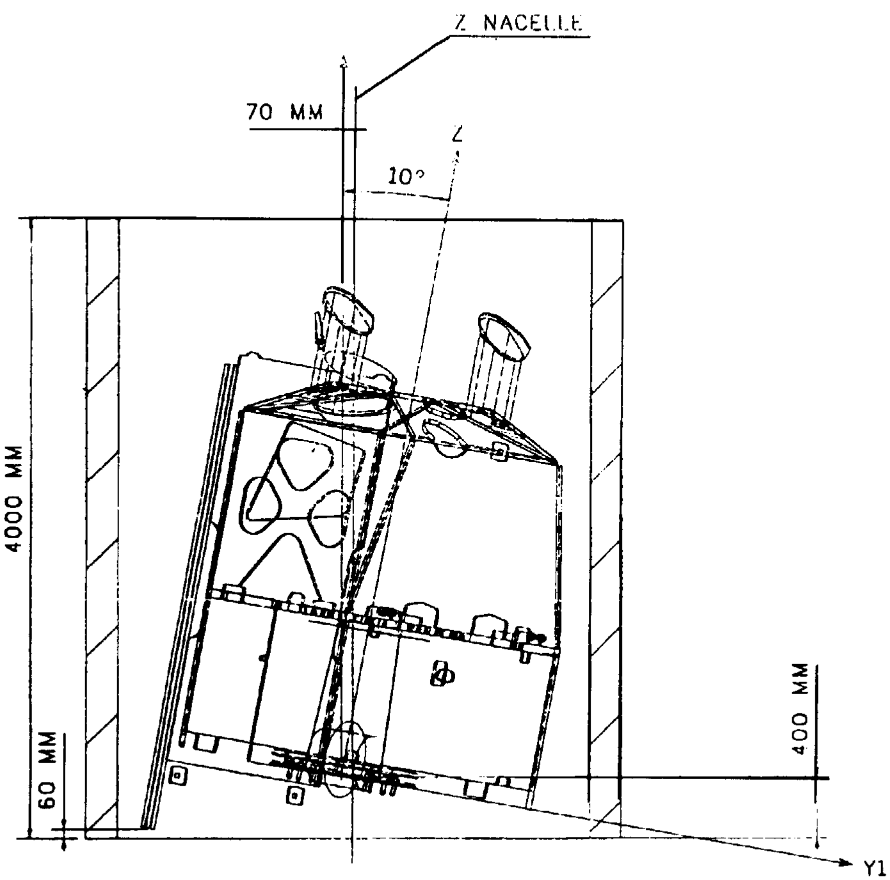


Fig. 3 - Model Philosophy

TYPE OF TEST	TEST DESCRIPTION	SAX SATELLITE MODELS STM	EM (S/C)	PFM
PHYSICAL PROPERTIES	Mass	X	- -	X
	MoI/CoG	X	- -	X
	Balancing	X	- -	X
STRUCTURAL TESTS	Modal Survey	X	- -	- -
	Acceleration	X	- -	- -
	Vibration	X	- -	- -
	Acoustic	X	- -	X
THERMAL TESTS	Thermal Balance	X	- -	- -
	Thermal Vacuum	- -	- -	X
ALIGNMENTS		X	- -	X
COMPATIBILITY	EMC/EMI	- -	- -	X
LEAK TESTS		X	- -	X
FUNCTIONAL PERFORMANCE TESTS	ISST	- -	X	X
	IST/ISC	- -	- -	X
DEPLOYMENT/RELEASE	Solar Array	X	- -	X
	C/S Shutter	X	- -	X
SPECIAL TESTS	P/L Calibration	- -	- -	X
	Ground Segment Comp.	- -	- -	X
	Match Mate Test	- -	- -	X
	Magnetic Field Measurement	- -	- -	X

Fig. 4 - Test Program



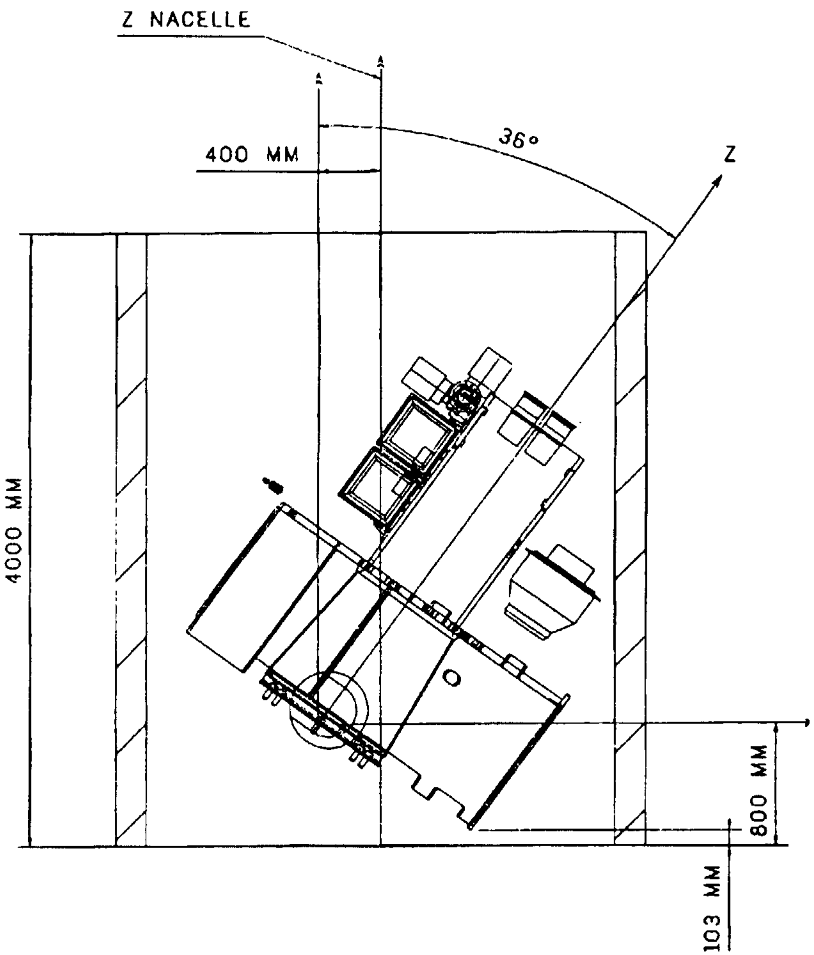


Fig. 5 - Centrifuge Test Configurations

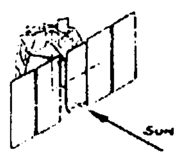
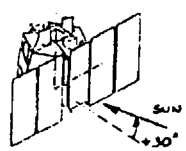
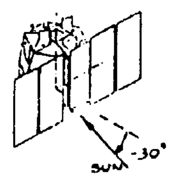
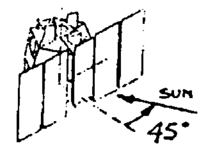
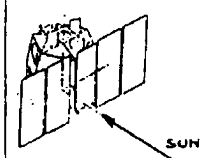
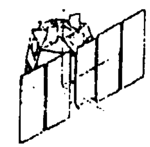
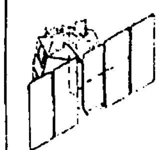
Task N°	1	2	3	4	5	6	7
Phase Description	Pump Down & Cooling Down	+ 30 ° SAA Winter Solstice	- 30 ° SAA Winter Solstice	+/- 45 ° SAA Summer Solstice	Summer Solstice Eclipse	Calibration Case	Chamber Recovery
Test Case	Reaching Test Cond.	Steady State	Steady States	Steady State	Transient	Steady State	Reaching Ambient C
Duration	12 Hrs	24 Hrs	24 Hrs	24 Hrs	5 Hrs	24 Hrs	12 Hrs
Spacecraft Orientation and Attitude							
spin rate	Fixed						
Solar Intensity	from 0 to 950 W/m^2	950 W/m^2	950 W/m^2	880 W/m^2	0 - 1320 W/m^2	0 W/m^2	0 W/m^2
Radiative Plates Power Dissipation	TBD	TBD	TBD	TBD	TBD	"	"
Chamber Vacuum	from ambient to 10^{-5} mbar	10^{-5} mbar or better					from 10^{-5} Torr to ambient
Shrouds Temp.	from ambient to 100° K	100 ° K					from 100° K to ambient
Comments		Hot Case for P/L	Hot Case for S/M	Cold Case for S/L	Verification of Transient Eclipse Performance		

Fig. 6 - Thermal Balance Test Cases