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MAQSAT-B2 FOR ARIANE FLIGHT L521

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1. ABSTRACT

This paper gives an overview on the MAQSAT-B2 test satellite launched in February 2005 for the successful second qualification flight of Ariane 5 ECA. Information is given also about the sister dummy payload MAQSAT-H2 originally planned also for this flight L521 but finally replaced by a paying customer.

2. PREVIOUS MAQSAT PROJECTS

Kayser-Threde's dummy satellites and structures program for Ariane 5 [1] started in 1997 when having been contracted by CNES for two dummy payloads for L502 after failure of the first launch of Ariane 5. The upper (H) payload was a 2.3 t dummy satellite representing the typical static and dynamic behaviour of a real satellite (see Fig. 1).

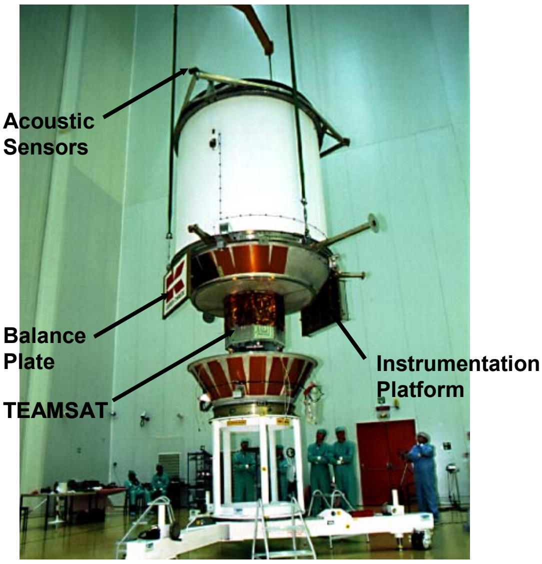

FIG 1. MAQSAT-H for Ariane 5 L502

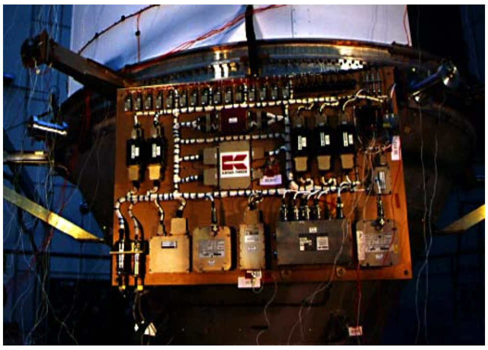

FIG 2. Instrumentation Platform of MAQSATH

The dummy was equipped with several sensors measuring the environmental loads during launch. An instrumentation plate (see Fig. 2) contained the complete electronic equipment inclusive battery package for an autonomous data transfer to ground. The lower (B) payload had a total mass of 1.6 t with now further functionality than only being a mass dummy (see Fig. 3).

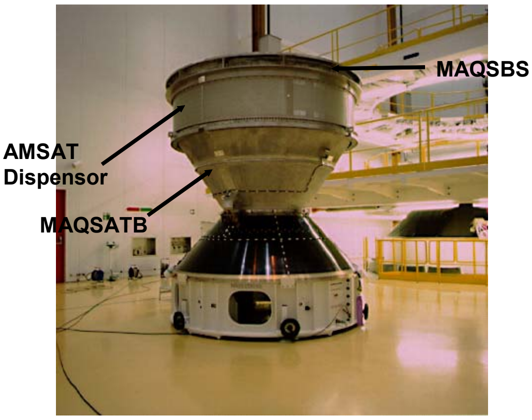

FIG 3. MAQSAT-B for Ariane 5 L502

The third dummy satellite was ordered by Arianespace for replacing a damaged paying customer on L503 being fully representative. This project has been realized in an extremely short time of 14 weeks. The 2.7 t MAQSAT-3 was launched in October 1998.

FIG 4. MAQSAT-3 for Ariane 5 L503

3. MAQSAT-B2 AND H2

3.1. Mission and Performance Requirements

The first qualification flight of the new Ariane 5 ECA failed in December 2002. For the second qualification flight it was decided to have two dummy satellites for a possible dual dummy launch configuration. It was clear from the beginning, that a respective instrumentation is required for the new MAQSATs for environmental measurements during lift-off. In addition to that the possibility of implementation of further experiments for technology verification had to be taken into account. Several ideas have been presented to ESA, CNES and Arianespace with a modular design concept by KT during spring/ summer 2003. In parallel a set of mission requirements have been defined and agreed with the above mentioned authorities. These requirements have been derived out of mission analyses performed by KT or based on experiences gained out of the former MAQSAT-H program. These mission requirements for L521 have been as follows

- Environmental measurement during lift-off and launch until ECA passivation
- Dynamic characterization using vibration, shock, acceleration and acoustic noise sensors
- Autonomous power system (own batteries)
- Autonomous telemetry system (own encoder, transmitter, antennas etc.)
- Radiation protection (GTO-trajectory)
- Design to required delivery time (use of available electronic equipment)
- No commanding via TC, therefore commanding:
  - before ignition: via EGSE
  - during launch: via Ariane dry loop commands
  - after A5 passivation: via MAQSAT timer
- Electrical architecture shall be based on experience of previous KT programmes like MAQSAT H, MAXUS/TEXUS and ROKVISS
- Data transmission simultaneously during launch until 3,5 h after T0
- Ground Station:
  Ariane ground stations („free“ access for Arianespace)
- Frequency:
  S-band, via Ariane-frequency 2218 MHz

During the definition phase it was decided to have MAQSAT-B2 being the lower passenger as a full representative test satellite carrying all equipment and experiments and to have MAQSAT-H2 as a back-up dummy satellite for the upper commercial passenger XTAR to secure the original goal of Ariane 5 ECA qualification. For the single dummies the following mechanical requirements have been defined:

MAQSAT-B2:

- representing a “typical” satellite (see Table 1)
- carrying experiments with one to be separated
- fully compatible to Ariane 5 standards & procedures
- no separation
- integration of +/- 300 kg trim masses

MAQSAT-H2:

- structural dummy satellite fully representing XTAR (main passenger) characteristics (see Table 1)
- to be separated
- possibility of very late exchange with XTAR
- integration of +/- 300 kg trim masses

H2		**Spec**	
		MIN	**MAX**
Mass	**kg**	3740	3760
CoG	**mm**	1435	1535
I_X	**kgm²**	1700	2300
I_Y / I_Z	**kgm²**	3825	5175
1st Lateral Mode	**Hz**	14.25	15.75
Effective Mass	**%**	55	60
1st Longitudinal Mode	**Hz**	35.15	38.85
Effective Mass	**%**	30	35

B2		**Specification**	
		MIN	**MAX**
Mass	**kg**	3490	3510
CoG	**mm**	1540	1740
I_X	**kgm²**		
I_Y / I_Z	**kgm²**		
1st Lateral Mode	**Hz**	> 15	
Effective Mass	**%**	> 50	
1st Longitudinal Mode	**Hz**	> 31	
Effective Mass	**%**	> 30	

TAB 1. Structural and dynamic requirements

Furthermore, the following ”safe” design requirements have been applied:

- MoS > 100%
- APEX-Factor 1.25
- Overflux < 10%

Finally a very stringent schedule was agreed to meet the overall L521 schedule constraints which has led to an extremely short and interacting development and MAIT phase. The final main milestones were:

22.09.03	Kick-Off / Release of LLI Procurement
06.10.03	PDR / Release of Manufacturing 1st Batch
24.11.03	CDR / Release of Manufacturing 2nd Batch
30.01.04	TRR MAQSAT-H2
26.02.04	TRR MAQSAT-B2
30.03.04	QRR

FIG 5: Ground Track of L521 out of MAQSAT-B2 mission analysis

Consequently, from Kick-Off to final acceptance of the hardware there was only a 5 months period to develop, design, realize and qualify two ≥ 3,5 t dummy satellites.

3.2. Mechanical Design of MAQSAT-H2 and B2

The final design of both dummy satellites was an output of a relatively complex optimization process. Besides fulfilling the direct performance requirements as outlined in the chapter before, there were a number of additional boundary conditions and constraints influencing the design concept, which have to be taken into account, e.g.:

- Making maximum use of existing MGSE
- Making maximum use of processes already qualified in previous MAQSAT and MFD programmes
- Use only short lead items (e.g. material, standard parts)
- Shipment constraints (e.g. envelope, size)
- Minimize effort for final integration at launch site
- Design to optimum MAI process

Finally, the mechanical design of MAQSAT-H2 and B2 was strongly adopted from previous design principles used for e.g. MAQSAT-3 and MFD [1], leading to a modular design out of plates and cylinders stacked together. Fig. 6 shows the design of MAQSAT-H2 identifying the main elements and trim masses. The design is characterized by a single raising cylinder with heavy plates at different levels and two MFD cylinder structures (MFD Flex) attached on the outer rim of the main plate. These cylinders have been introduced to comply with the 1st longitudinal mode requirements and the high static moment of inertia moments required.

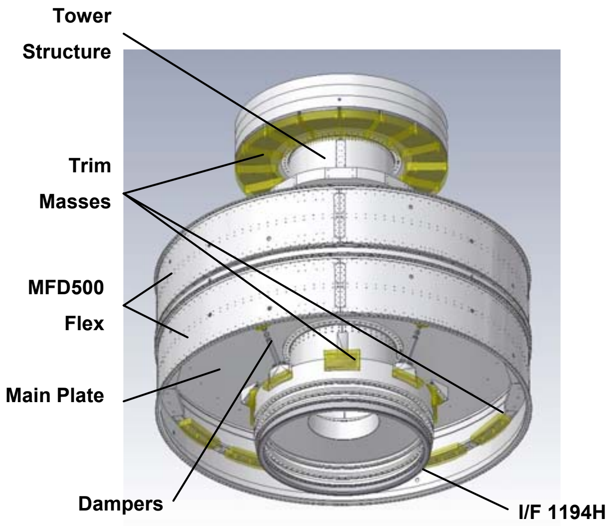

FIG 6. MAQSAT-H2 Mechanical Design

The final results out of the dynamic analysis have shown typical and clear to be identified first modes as presented in Fig. 7: the first lateral mode is a pure bending mode at 15,2 Hz with 52% effective mass, the first axial mode is an umbrella mode of the main plate at 35,2 Hz with 35% effective mass. The figures indicate also coloured areas of high stress. The final strength justification analysis for H2 has been performed by a dynamic load analysis due to the fact, that a pure static strength analysis was not sufficient.

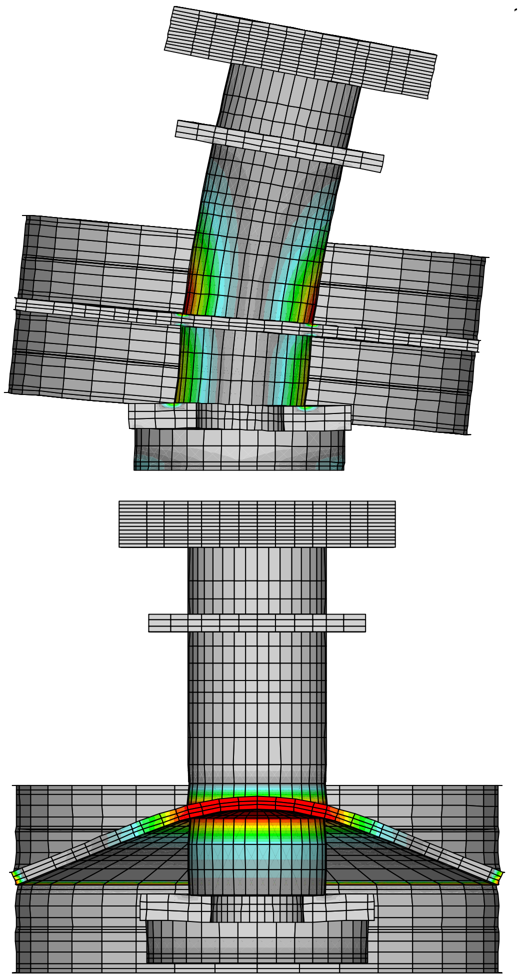

FIG 7. MAQSAT-H2 main eigenmodes lateral and axial

For MAQSAT-B2 the design of a single raising cylinder could not be kept due to the higher first eigenfrequencies required combined with high effective masses. Therefore,

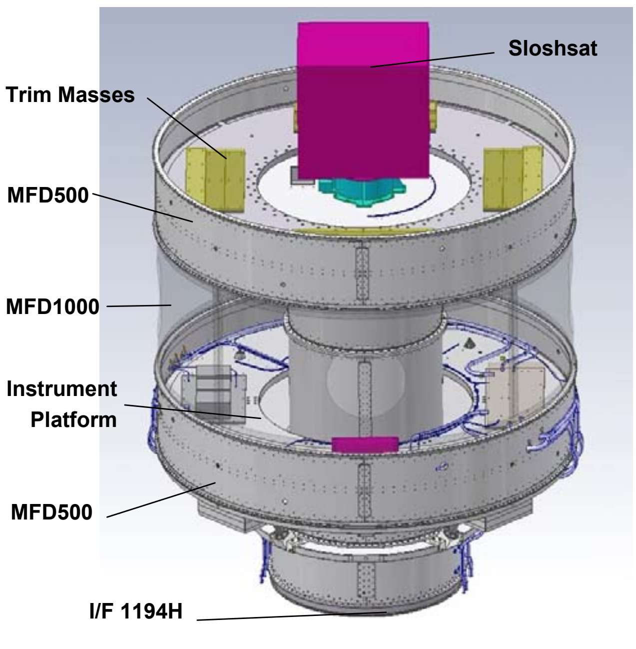

FIG 8. MAQSAT-B2 Mechanical Design

two raising cylinders have been used starting from the main plate. Another reason for that design was to be able to limit the respective environmental boundary conditions for SloshSat - the Dutch micro-satellite to be separated from B2 (contracted by ESTEC) - according to the Ariane 5 User Manual. The two MFD500 used in MAQSAT-B2 have been refurbished out of the previous MFD programme. The lower one has been modified to carry the complete electrical instrumentation and further experiments. To have access to the electrical equipment and experiments four large access holes have been introduced in the MFD1000.

Fig. 9 shows the predicted dynamic behaviour of the first eigenmodes of B2. The first lateral mode is again a pure bending mode now at 23,4 Hz with 46% effective mass, the first axial mode is again an umbrella mode of the main and upper plate at 54,1 Hz with 59% effective mass. Due to the very stiff design using two cylinders, the strength justification analysis for B2 could be performed by static analysis only.

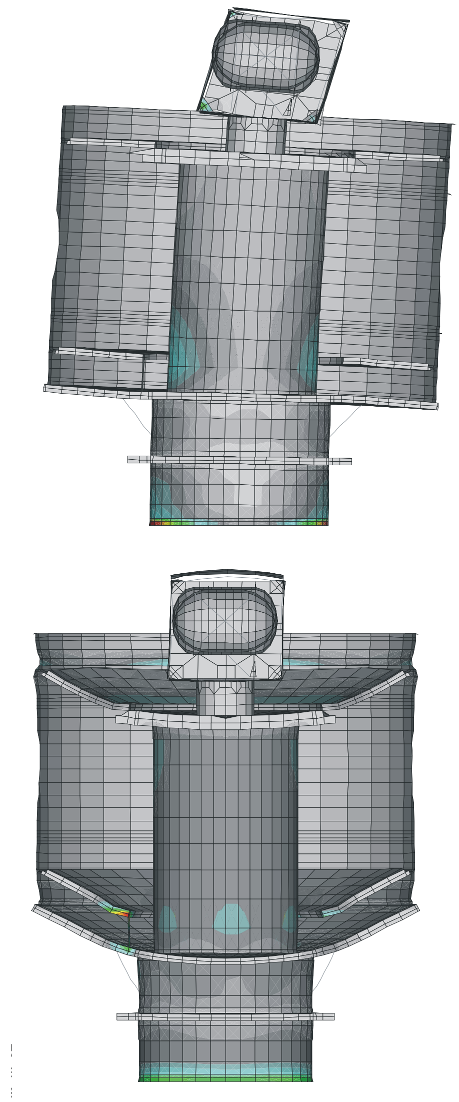

FIG 9. MAQSAT-B2 main eigenmodes lateral and axial

Both MAQSAT-H2 and B2 are an all-aluminium design. The cylinders are made out of a cylindrical shell riveted to an upper and lower I/F flange. The single plates are milled out of large aluminium plates. All parts providing an interface diameter of 2624 mm diameter are made out of two or more parts welded together (e.g. main plates and large I/F flanges). In addition to the dynamic requirements already outlined a specific damping behaviour was required. It was clear from the beginning that the necessary and representative damping cannot be achieved by pure structural damping (e.g. due to the number of rivet connections in the design) and additional means have to be introduced to the design. Therefore, four single damping elements on the basis of a strong wire mesh have been mounted connecting the MAQSAT's cylinder basis with the main plate.

Fig. 10 provides a top view of the instrument platform of MAQSAT-B2. The equipment has been positioned in such a way, that the static balance of the rotational symmetric design of MAQSAT-B2 is not affected. Besides the experiments and instrumentation additional acceleration sensors have been integrated to have a full set of in-flight data from MAQSAT-B2.

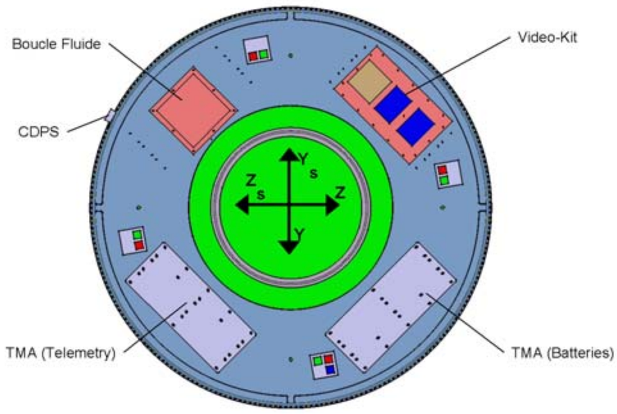

FIG 10. MAQSAT-B2 Instrument Platform with experiments top view

3.3. Electrical Architecture of TMA

The electrical system (SES) of MAQSAT-B2 has been defined and designed to be able to provide the complete necessary infrastructure to the experiments and to transmit the data from the experiments and sensors to ground using antennas installed on the outside of the fairing. The SES consists of the complete harness and the so-called TMA (Telemesure Assemblage) package which has been integrated by two separate decks on the Instrument Platform of MAQSAT-B2: a battery deck and an instrumentation deck.

The overall power need for the MAQSAT-B2 mission duration has been identified to 20 Ah which has been realized using 4 qualified Ariane 4 batteries. The instrumentation deck contained a Power Switching Module BMO-K, a Power Distribution Module PDM, a Command and Isolating Module CDI, an Encoder CMA 2000 and a Transmitter. The BMO-K was used for external / internal switching of the TMA and for providing battery power to the consumers. A Power Distribution Module PDM is used to connect the 4 batteries to the BMO-K and to provide house-keeping channels. The CDI was used to provide manual check-out functions during verification and assembly tests. The CMA 2000 is the encoder which provides voltage input and additional conditioner and filter functions for all sensor data inputs. Finally, the transmitter is used to provide RF link during flight for all data acquired with the CMA 2000. The complete system design and development of the TMA including software was under KT responsibility except the link budget itself which has been covered by Arianespace. The single parts and elements are mainly COTS products already qualified; only few of them had to be newly developed.

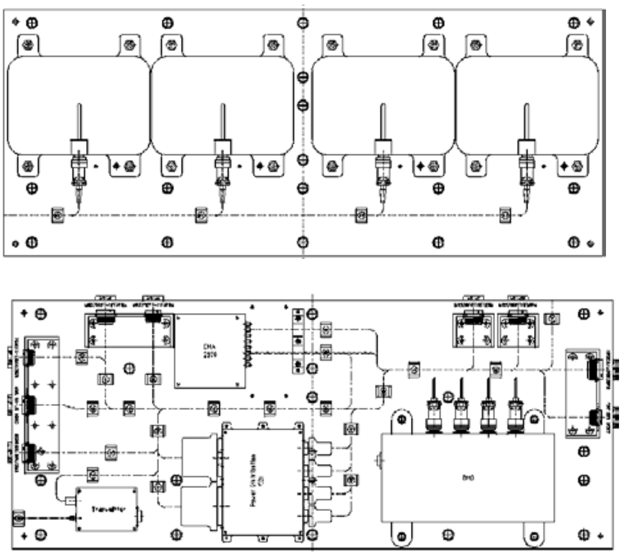

FIG 11. MAQSAT-B2 TMA, batteries deck (top) and telemetry deck (bottom)

3.4. Experiments on board of MAQSAT-B2

In the frame of the MAQSAT-B2 programme ESA has selected several experiments to be accommodated on MAQSAT-B2. These are as follows:

1. SloshSat, a Fluid Dynamics Experiments Satellite made by NLR under ESTEC contract (see Fig. 13)
2. Boucle Fluide, a Loop Heat Pipe Experiment by CNES
3. CDVP, a Vacuum Pressure Sensor (later cancelled)
4. DVCAM, a video kit by Dassault (see Fig. 12)
5. TQCM, a pollution sensor (later cancelled)
6. Set of environmental sensors on MAQSAT-B2 and Ariane 5 Payload Bay

FIG 12. DVCAM (with own batteries for power supply)

All experiments have been provided to Kayser-Threde for integration on MAQSAT-B2 and final qualification in the frame of the overall MAQSAT-B2 qualification program. Kayser-Threde was fully responsible for the experiment's interface definition process and integration.

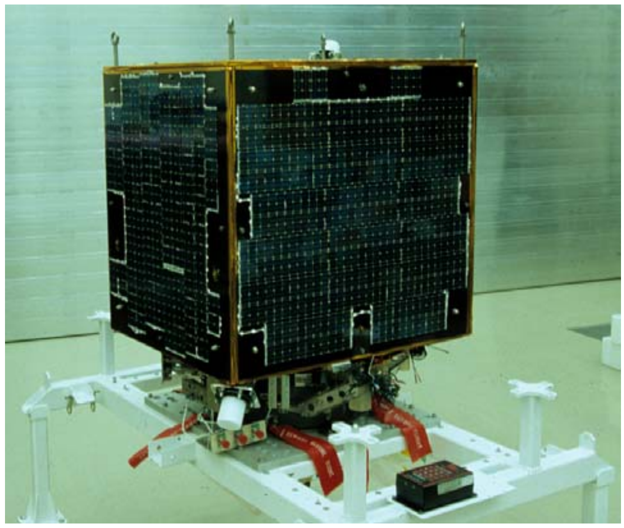

FIG 13. SloshSat including ESAJECT separation system

3.5. MAI Programme

Both MAQSATs have been fully integrated at IABG (close to Kayser-Threde) and close to its later used test facilities. The electrical equipment has been integrated at Kayser-Threde facilities including electrical implementation and connection of the experiments. MAQSAT-B2 after final assembly and integration is shown in Fig. 14.

FIG 14. MAQSAT-B2 fully integrated

Fig. 15 gives a bottom view of MAQSAT-B2 showing the four dampers attached between the lower plate and the main plate and some of the trim masses.

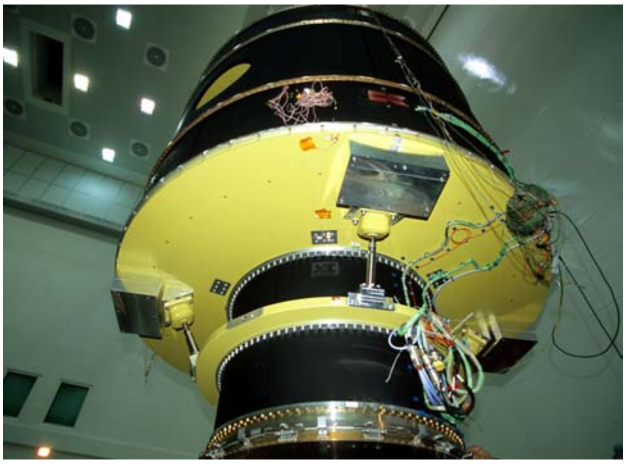

FIG 15. Bottom view of MAQSAT-B2

Fig. 16 shows the TMA telemetry kit attached to the instrument platform of the lower MFD500 seen through one of the access holes. Boucle Fluide was protected by an additional housing and isolation material due to thermal reasons as can be seen on Fig. 17.

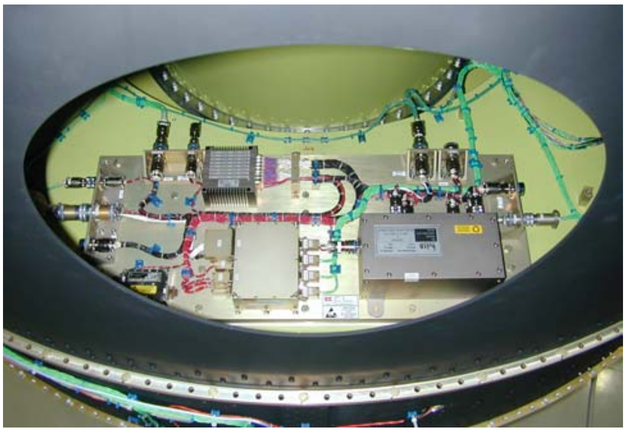

FIG 16. TMA telemetry integrated on instrument platform

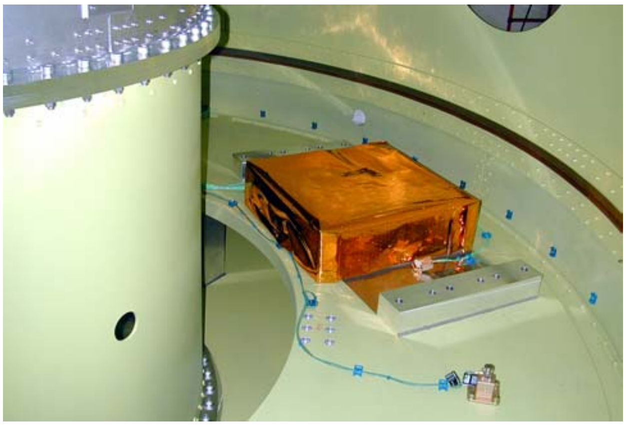

FIG 17. Boucle Fluide on the Instrument Platform

Fig. 18 shows a detail view of ESAJECT, the separation system for Micro-Satellites used for SloshSat, developed by VERHAERT under ESTEC contract.

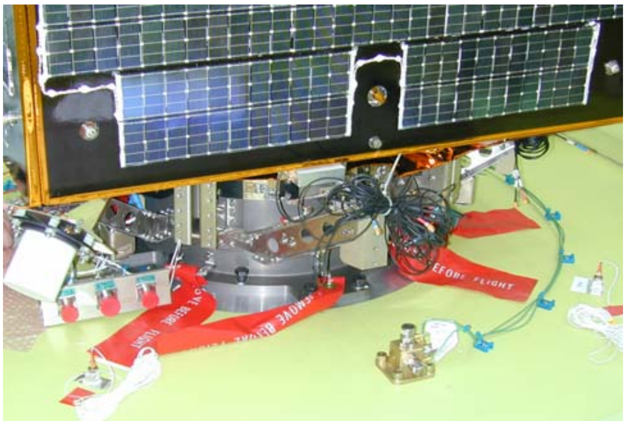

FIG 18. SloshSat and ESAJECT finally accommodated onto MAQSAT-B2

After full integration of the electrical equipment and experiments the harness has been integrated, routed and connected between the single units. Before entering the test campaign a first successful functional test of all components has been performed.

3.6. MAQSAT-H2/B2 Test Programme

A full set of Qualification/Acceptance tests has been performed, which were:

- EMC (see Fig. 19)
- Vibration (MAQSAT-B2 only, see Fig. 20)
- Acoustic (MAQSAT-B2 only, see Fig. 21)
- Modal Load (MAQSAT-H2 only, not performed with MAQSAT-B2, see Fig. 22)
- Shock (Shogun test MAQSAT-B2 only, see Fig. 23)
- Functional Performance (before and after each mechanical test)

FIG 19. EMC test of TMA and experiments

FIG 20. Vibration test of MAQSAT-B2

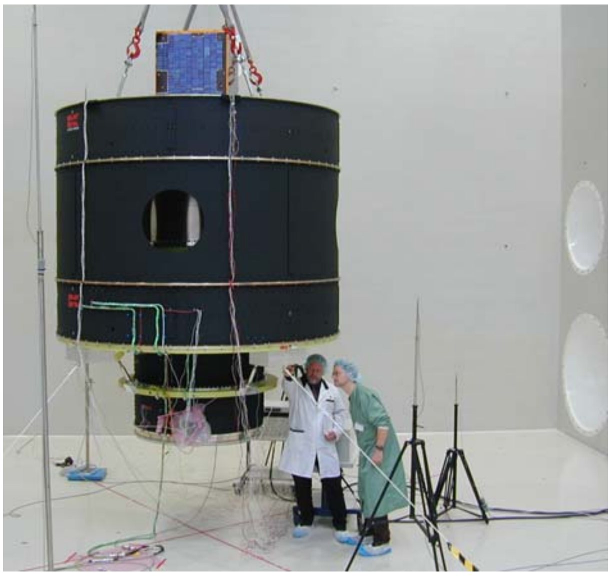

FIG 21. Acoustic test of MAQSAT-B2

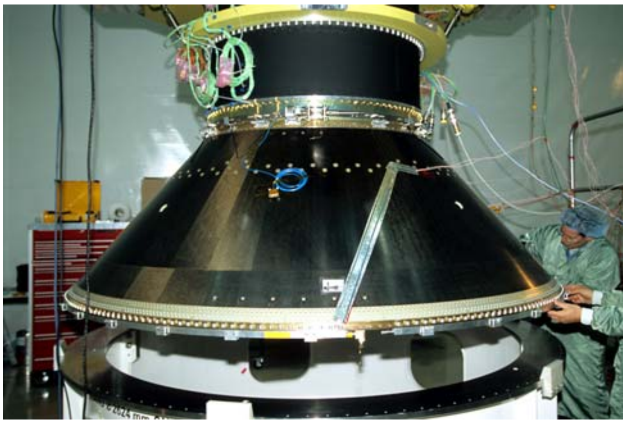

FIG 22. Shock test (Shogun) using ACU and clampband for representative clampband interfaces

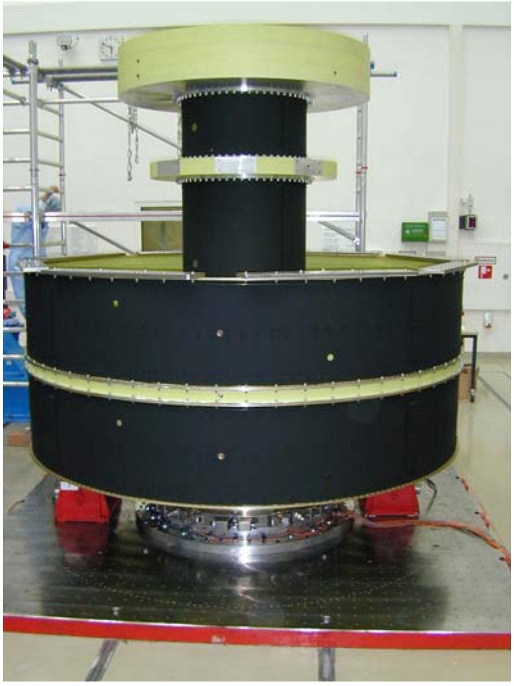

FIG 23. Modal load test of MAQSAT-H2

The Shogun test has been performed by Arianespace using a complete set of equipment for simulating representative interfaces. Also the separation system of ESAJECT has been tested. The tests have also been used to measure the shock environment at different levels inside MAQSAT-B2 induced by the clampband separation.

The modal load test of MAQSAT-H2 has been used also to identify the damping characteristics, which could be transferred to MAQSAT-B2 due to similar design. Finally a damping of more than 1% could be achieved which was in line with the respective requirements.

The qualification/acceptance test programme has been finalized successfully demonstrating the robust mechanical design of both MAQSATs and reliable electrical design of MAQSAT-B2. In addition the experiments have been qualified successfully. After acceptance by the customer, both MAQSATs have been packed using specific transport container and shipped to the launch site in Kourou, French Guyana.

3.7. Launch Campaign

The PRE-POC activities have been performed in August 2004. These activities comprised full preparation of MAQSAT-B2 for launcher integration, first tests with EGSE and launch pad facilities and again functional tests of the experiments. The final POC has been started 3 weeks before launch date; main task was the mating of MAQSAT-B2 with the launcher (see Fig. 26) including connection of all electrical interfaces.

FIG 24. Integration of MAQSAT-B2 to the launcher

L521 has been launched successfully on February 12th 2005. MAQSAT-B2 has performed its full defined program. All data could be transmitted to ground.

FIG 25. Launch of L521 with XTAR and MAQSAT-B2

One of the main results from the MAQSAT-B2 campaign was that the evaluation of the environmental in flight measurement by Arianespace has confirmed that the higher powered Ariane 5 ECA provides not a higher environment than specified in the Ariane 5 User Manual.

Finally, XTAR could be launched successfully into its final orbit and there was no need for an exchange with MAQSAT-H2. It is still stored in Kourou and investigations and proposals have been made for further use.

4. Summary and Outlook

The MAQSAT-B2 program has again demonstrated Kayser-Threde's flexibility in providing dummy satellites and structures with dedicated performances in a very short time and to full customer satisfaction. In addition an autonomous telemetry system has been developed, qualified and successful demonstrated as a system being able to manage and control experiments.

The success of this TMA has led to the development of a concept of a self-standing and autonomous platform as a piggy-back solution. It provides efficient access to space for experiments and/or in-orbit technology verification and is called KAP (Kayser-Threde Arianespace Platform) [2].

The KAP structure is based on the MFD design [1], a multipurpose fitting dummy for Ariane 5 payload trimming in terms of CoG and mass as well as used for shock damping having a diameter of 2624 mm and a height of 500 mm. KAP will be mounted to the launcher like a MFD between the payload adapter ACU and the launcher and will not be separated.

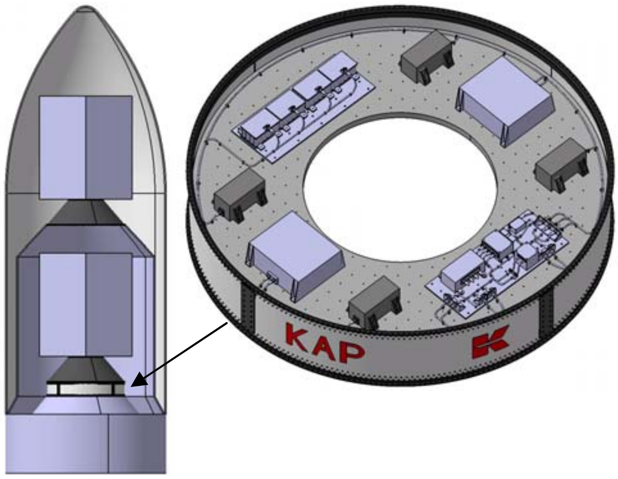

FIG 26. KAP (Kayser-Threde Arianespace Platform)

Two versions are under detailed development, one for Ariane 5 (which means KAP would fly on GTO) and one for the future VEGA (which means KAP would fly on LEO). As outlined in Tab. 2 the concept covers three different mission durations: 3 hours short mission (SM, only during launch), 3-days Medium Mission (MM, maximum use of battery power) and 1-year Long Mission (LM, using solar power). It is foreseen to have a demonstrator mission end of 2007.

5. Acknowledgment

For the MAQSAT-B2 project the authors and the complete KT project team express their thanks to all people on Arianespace, CNES and ESA side having supported the challenging project. The KAP Phase A study has been co-funded by DLR under contract no. 50JR0453 in the frame of its OOV-programme. Also for that project, Kayser-Threde wants to thank Arianespace and ESA for its contributions and interest in KAP as a possible future commercial payload platform on Ariane 5 and VEGA.

References

[1] C. Kaiser, E. Pfeiffer, C. Widani, W. Gambietz: *Ariane 5 Dummy Satellites and Structures*, 54th IAF Congress, Bremen, September 2003, Paper 16131

[2] Kaiser C., Pfeiffer E.: KAP and MAQSAT-B2 – an Experimental Platform for Ariane 5 evolved from the Test Satellite for L521, Proceedings of the 6th International Symposium on Launcher Technologies, Munich, Germany, 8.-11.11.2005

Name	Duration	Major Characteristics
KAP-SM	3 h (short mission)	Online data transfer with 15kbps, power via batteries, 120-220 kg payload at 600 kg total mass, 100W const. payload power, antennas attached outside of Ariane (e.g. on ACY), possibility of implementation of Ariane environmental sensors
KAP-MM	3 days (medium mission)	Data storage and data transfer during playback with 15kbps to GSOC Weilheim, power via batteries, 80-180 kg payload at 600 kg total mass, 25W average payload power
KAP-LM	1 year (long mission)	Data storage and data transfer during playback with 15kbps to GSOC Weilheim, power via solar generators, 80-180 kg payload at 600 kg total mass, 50W average payload power

TAB 2: Mission concepts for KAP, a future platform for technology in-orbit verification and small experimental payloads