The HUYGENS Testing Programme And Results.

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1 ABSTRACT

In respect to the mission profile of the HUYGENS Probe, the 7 years flight in a deep space environment and the descend into an atmospheric pressure region of the SATURN moon TITAN, two classical environmental test methods have to be combined. The thermal-vacuum test to simulate deep space environment and a thermal test under atmospheric pressure conditions to simulate the atmosphere of TITAN.

The paper will describe, how the thermal-vacuum facility 3m-TVA has been modified in order to be operated as a high-vacuum facility with standard requirements on pressure below 10^{-5} mbar, residual gas, contamination and cleanliness and a thermal chamber for low pressure above 100 mbar conditions at temperatures below 100 K.

With these test requirements it became necessary to design a thermal container , which can be independently operated at 100K within the thermal vacuum facility 3m-TVA. A very sophisticated pressure control equipment controlled the different pressure values of 900 mbar, 100 mbar and 10-5 mbar and simulated additionally the transient from 10-5 mbar to 900 mbar in respect to the theoretical pressure profile; the descend into the atmosphere of TITAN.

In order to avoid mechanical stresses the pressure differences between the inner volume of the HUYGENS Probe and the test volume the 3m-TVA chamber has been controlled continuously during test. The gas flow rate through the HUYGENS probe as an indication of the tightness of the Probe has been measured accordingly.

A dedicated data acquisition system has been operated to measure the several temperatures, power supply data, strain gauges and thermistors with highest requirements on accuracy and resolution.

The complete test set-up as an unique test facility of this size in Europe will be described and the results of the TITAN test and the facility performance data will be presented. The safety measures of the successfully facility operation will be discussed.

2 INTRODUCTION

2.1 Cassini / HUYGENS Mission Description

The CASSINI / HUYGENS mission is designed for the delivery of a combined Saturn orbiter and Titan atmospheric probe to the Saturnian system. The spacecraft will be injected into a 6.7-year Venus-Venus-Earth-Jupiter Gravity Assist trajectory to Saturn by a Titan 4/Centaur launch vehicle.

The HUYGENS Probe is the ESA provided element and the orbiter CASSINI is provided by NASA.

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The launch is scheduled for October 1997. The Titan atmospheric descent of the Probe is scheduled for November 2004.

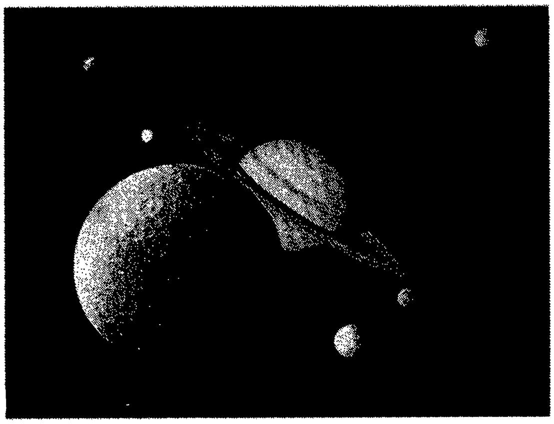

Figure 1 : Impression of SATURNIAN System

2.2 Description of HUYGENS Module

The HUYGENS Probe is in many respects different from a common satellite. Due to the entry conditions at Titan, units and experiments have to be shielded by the thermal protection system. The Probe design is arranged with an outside shield, the front shield and back cover, and an internal kernel, the descent module. The outside shield is released early in the descent sequence prior to the start of scientific measurements. The descent module descending through Titan's atmosphere houses the experiments and electrical units. Several parachutes are required in order to optimize the timelines defined by the scientific objectives.

The front shield diameter is 2.7m. The descent module diameter is 1.3m and its height is 0.64m. The descent module package is very dense in order to incorporate six experiments, all electrical units, the harness and the foam of the thermal subsystem.

2.3 Test Objectives and Test Flow

The overall test objectives include classical thermal, mechanical and electrical tests as well as scaled model wind tunnel tests, full scale helicopter drop tests and full scale stratospheric balloon drop tests.

The test plan presented here describes the thermal vacuum tests performed on system level only. The main objectives of these tests have been :

- Heat balance determination to verify the thermal mathematical model for cruise and coast thermal environment.
- Probe release from the Orbiter under simulated thermal conditions at the actual release including gravity compensation due to earth gravity during the test.
- Titan atmosphere simulation of the descent module thermal control under varying descent pressures.
- Space conditioning of the front shield and of the thermal MLI.

3 THERMAL TESTS

The Space Test Centre of IABG as one of four ESA coordinated Test Centres in Europe has operated two thermal test facilities for the designated thermal testing activities on the HUYGENS STPM Module. A complete overview of the test programme is given in /1/

3.1 Thermal Test Facilities

Both thermal test facilities consist of a horizontal cylindrical vessel and are equipped with a thermal shroud system to simulate the thermal environment in the temperature range of 100K to approx. 385K. The pumping system with several roughing pumps, refrigerator He-cryo pumps and turbomolecular pumps is designed to maintain a pressure below 10^{-5}mbar. Size and the irradiation equipment are characterizing the difference of the two facilities. In the following table 1 the main characteristics are listed.

Description	3m-TVA /2/	WSA / TVA
Dimensions	Diameter : 3.2m Length : 3.8m Volume : 50m^3	Diameter : 6.8m Length : 13m Volume : 500m^3
Irradiation System	Infrared Lamps: • I_{max} :8.5kW/m^2 • IR-radiation rig :3.4x2.3m^2 • Uniformity : ±10%	Off-Axis Solar Sim. • I_{max} :2000W/m^2 • Beam Dimensions : 3.6m diameter (3x4.5m) /3/ • Uniformity : ±4% • Spectrum : Xenon

Description	3m-TVA	WSA / TVA
Handling System	Overhead and bottom rails • M_{max} :1.2t	Motion Simulator (with L-Adapter) • M_{max} : 2.5t • Aspect angle: 0-360° • Spin: 0-10rpm • Levelling System : ±0.2°
Vacuum System	2 He-Cryopump S_{eff} :3*10^4 /s	6 He-Cryopumps S_{eff} :1.5*10^5 l/s
Thermal System	<100-400K	<100-385K

Table 1 : Characteristical Data Of Thermal Test Facilities

All test facilities are equipped with mass spectrometers and contamination sensors to determine and evaluate residual gas and contamination effects.

3.2 Thermal Tests in the WSA/TVA

Due to the baseline test philosophy to simulate conditions between the cruise and coast phase (in particular to simulate the solar radiation impact) the thermal balance test has to be carried-out in the large Space Simulation Facility WSA/TVA. In figure 2 the rear side of HUYGENS STPM, mounted on the L-Adapter of the Motion Simulator and facing the solar beam, can be seen.

The second thermal vacuum test, the „Spin-Ejection-Device"-Release Test, has been performed to demonstrate correct separation of the Probe from the Orbiter on system level. The separation and the corresponding shock has been performed respectively measured in a thermal vacuum environment after approx. 90 hours operation time.

3.3 Thermal Tests in the 3m-TVA

The third kind of test, the Space Conditioning Test, had the task to outgass the thermal MLI and the cover shield of the HUYGENS Probe. These tests have been performed at high temperatures at vacuum conditions. To avoid contaminations by the outgassing flight components, the complete set-up was installed in a protection tent. Contamination, RGA and TQCM

Figure 2 : HUYGENS STPM on L-Adapter

measurements accompanied the test. For more details see/**4**/.

The forth thermal test, the TITAN Test, which is described in more detail within this presentation, was to simulate the descent of the HUYGENS Probe into the atmosphere of TITAN in order to verify the thermal behavior of the HUYGENS Probe. The main technical challenges has been the simulation of the descent, from low pressure to high pressure regions as well as the combination of different pressure conditions at low temperatures within one test facility and test.

3.3.1 Test Requirements of TITAN Thermal Test

The main requirements for the HUYGENS Titan test are listed in table 2 and can be summarized as following:

- Control of pressure at different pressure levels at above 100mbar and combination with the high vacuum phase of 10^{-5} mbar at a temperature of 100K
- Simulation of the pressure increase during descent from a pressure of 10^{-5} mbar to 900mbar according to a theoretical pressure-time function
- Control of a pressure difference $\Delta P \leq \pm 5$mbar between inner volume of the probe and the chamber pressure to avoid mechanical stress caused by high pressure differences during chamber pressure changes

- Performance of gas flowrate measurement at a pressure of 900mbar and at temperatures of 100K and 300K to verify the thermal characteristic of the probe
- Measurement and recording of the test data

Description	Requirements
Pressure	• $\leq 10^{-5}$ mbar • 100mbar • 900mbar • transient simulation • $\Delta P \leq \pm 5$mbar • Accuracy : ±7%
Leakrate Measurement	• Accuracy : 10% • at P=900mbar/T=ambient • at P=900mbar/T=100K
Handling System	• Max.mass :approx. 200kg
Shroud Temperature	• $\leq$100K • Local deviation : ±4°C
Molecular Contamination	• $\leq 10^{-7}$ g/cm^2
Data Acquisition (Thermal Control)	• 42 thermocouples • 5 high precision sensors • 55 power supplies • 36 strain gauges

Table 2 : Requirements of the TITAN Thermal Test

In order to fulfill the requirements extensive modifications of the facility including, the development of a pressure control system and a thermal container became necessary.

3.3.1.1 The Thermal Container /5/

Due to the low required temperatures (T=100K) at low (p<10^{-5} mbar) and at high (p > 100mbar) pressure conditions a thermal container has to be designed, which operates as an inner shroud system within the 3m-TVA.

The task of this thermal container (see figure 3) is

1. to cool the test object, which is mounted or installed in its inner volume,
2. to reduce or to compensate the cooling of the vessel by heating the standard shroud system of the TV chamber against the gaseous convection,
3. to minimize the gas flow out of the inner volume of the thermal container into the volume of the TV chamber by a closed insulation of the thermal container with Mylar foil, however
4. to remain openings in order to pump the inner volume of the thermal container down to the low pressure ranges

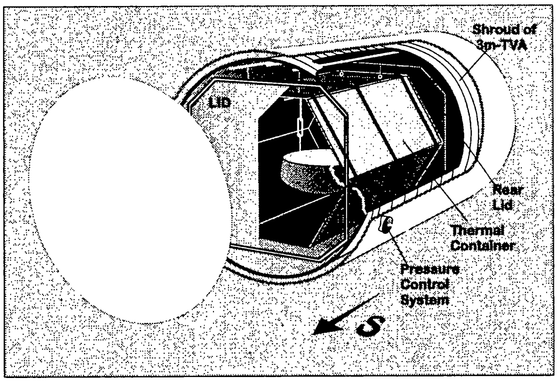

Figure 3 : Principal Test Setup in 3m-TVA

The main technical characteristics of the Thermal Container are summarized in the following

Dimensions

- Hexagonal shaped cylinder
- Length : 2700 mm
- Rmin: 850 mm
- Rmax : 1100mm
- Inner surface area : ≈25 m^2

Material

- Material : Aluminum
- Black paint $\alpha_s > 0.95$
  (Electrodag 501) $\varepsilon_N \geq 0.83$
- Insulation with Mylar foil 3 layers

(Exception : Upper shroud segment for pumping access , see figure 4)

LN2-Supply

- 4 sections (2cylinders/front and rear lid)
- Max. heat load : 30 kW
- LN2 consumption: 1100 l/h

Thermal Behaviour

- Cooling-down time to 100K : 1hour
- Warming-up time : 3hours
- Tmin : ≈ 100K

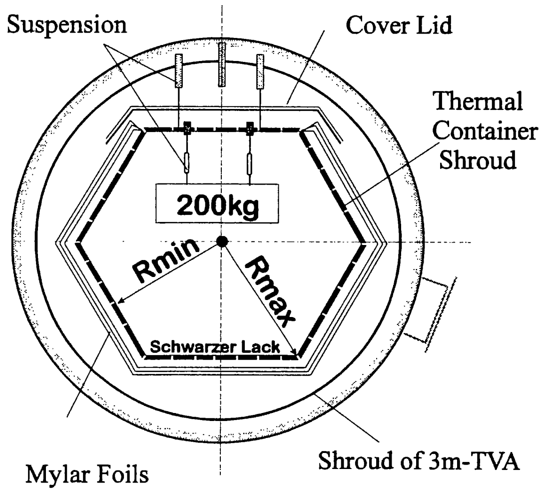

Figure 4 : Dimensions of Thermal Container

3.3.1.2 Pressure Control System

The tasks of the pressure control system have been

1. **to maintain precisely the different required pressure levels (P=100mbar to 900mbar),**

   This control system consist mainly of a pressure sensor, an electrical controlled valve to purge gaseous nitrogen into the chamber, a small roughing pump and a control equipment or routine on PC level. The concept is to evacuate continuously with the small roughing pump against the controlled purging with gaseous nitrogen. This system also allows the simulation of the transient (descent) phase from 10-5 mbar to 900 mbar due to theoretical pressure-time relation.

2. **to determine the gas flow through the probe at different temperatures,**

   In a closed loop an additional small pump has to pump the gas out of the HUYGENS Probe by maintaining a constant pressure difference. A flow meter has measured the respective gas flow.

3. **and to simulate the transient from low to high pressure regions.**

   To simulate the transient phase in the range of 10-5 mbar to 15 mbar (gas flow:. 10^{-3} mbarl/sec to 600mbarl/sec) and to stabilize the pressure at constant values the chamber pressure has been controlled by purging with N_2 via a manually operated variable gas leak valve (V2). In the range 15mbar to 900mbar (gas flow: approx. 600 mbarl/sec to 20 barl/sec) the pressure has been controlled by a servovalve (V1) (operated by a pressure control unit and a PC). A mechanical pump (P1) is installed to stabilize the chamber pressure (compensation of leaks N_2-purging of the test chamber). Chamber pressure , differential pressure ΔP and the pressure of the HUYGENS Probe have been measured via flexible tubes with high precision gauges.

In the following figure 5 the pressure control system can be seen.

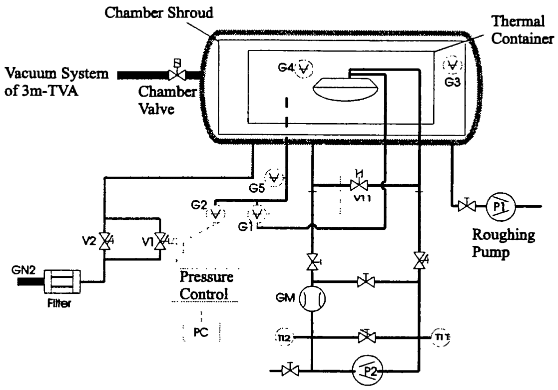

Figure 5 : Pressure Control System And Leakrate Measuring Setup

3.3.1.3 Modification of 3m-TVA Facility

In order to provide LN2/GN2 for the Thermal Container as well as LN2/GN2 for the shroud of the 3m-TVA for parallel operation a movable and independent LN2 supply system has been designed and adapted to the existing thermal supply system of the test facility. This setup allowed the operation

- of the Thermal Container
  - with LN2 in the different test phases
  - with GN2 in the recovery phase
- and of the 3m-TVA shroud with GN2 to control its temperature at approx.+40°C

3.3.1.4 Data Acquisition

Three dedicated Data Acquisition Systems / see **6** and **7**/ have been operated to measure, to record and to evaluate the test data.

The Mobile Acquisition Unit (MAU), the PILOT and the KEITHLY Measuring System have been developed and commissioned to measure about 250 thermo couples, high precision thermistors, several power supplies, test data (e.g. strain gauges) and facility data (e.g.pressure, flow). The main capabilities have been to provide the test data incl. „pseudo channels" on-line on several monitors to the test personnel.

3.3.2 Safety Considerations / **8** /

To increase safety and reliability of the system a HAZOP analysis has been carried out in order to detect weak points of the test setup and the several design and modification tasks.

Most of the „detected" discrepancies have been considered in the test operational or emergency procedure in order to prevent the possible cause. Technical improvements have been considered mainly

- to switch-off the liquid nitrogen supply after pressure increase above a max. allowed chamber pressure of 930mbar
- to heat external critical flanges to avoid gas leaks
- to control the max.chamber pressure and to implement an „high" alarm at 910mbar into the standard alarm system of the 3m-TVA operation control system
- to monitor oxygen concentration in air at the facility side.

The complete improved system (the technical part as well as the respective documentation) has been checked and verified in several pretests as part of the testing program.

3.3.3 Test Performance

After a preparation time of approx. 9 month the test has been performed with the following test phases and conditions:

Test Activity	**T [K]**	**P [mbar]**
Pump down and purging with GN2		
1.Gas Flow Measurement	300	900
2. Gas Flow Measurement	100	900
Steady state	100	900
3. Gas Flow Measurement	100	900
4. Gas Flow Measurement	300	900
Steady state	100	10^{-5}
Transient Phase	100	10^{-5} to 900
Steady State	100	100/300/50
5. Gas Flow Measurement	300	900
Recovery		

Table 3 : Test Flow

The TITAN test setup in the 3m-TVA facility can be seen in figure 6.

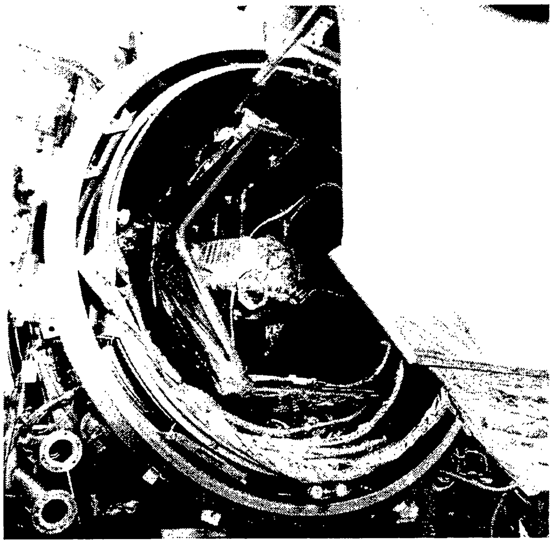

Figure 6 : Test Setup of TITAN Thermal Test

3.3.4 Test Results

After a testing time of about 167 hours the facility related results demonstrate the successful test performance.

- **Contamination**

  The contamination analysis has resulted in values below $3.8*10^{-8}$ g/cm^2, measured at different locations in and outside of the Thermal Container.

- **Chamber Pressure**

  The lowest pressure has been measured to approx. (3-6)x10^{-6} mbar in the volume of the thermal container. The pressure at the different levels (100 to 900 mbar) and within the pressure range 15 to 900 mbar in the transient phase had been controlled with a deviation from required value of maximum ±2mbar.

The transient has been performed

- manually between the pressure of 10-5 mbar and 15 mbar
- and with the pressure control system from 15 mbar to 900 mbar.

The deviation from specified theoretical specified values has been approximately

- ±40% (maximum) for the manual mode
- ≤±1% for the control mode

Figure 7 shows the pressure versus time of the transient simulation.

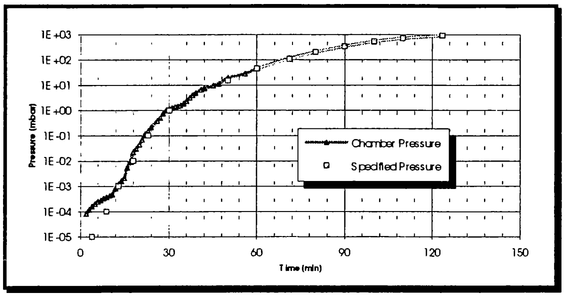

Figure 7 : Transient Phase

- **Differential Pressure ΔP**

The pressure difference between the HUYGENS probe and the test volume ΔP has never exceeded the specified value of ΔP = ± 5mbar. The most critical influences on the pressure difference have been the pressure changes during pumping and repressurization performances. In figure 8 the dependency from these activities can be seen.

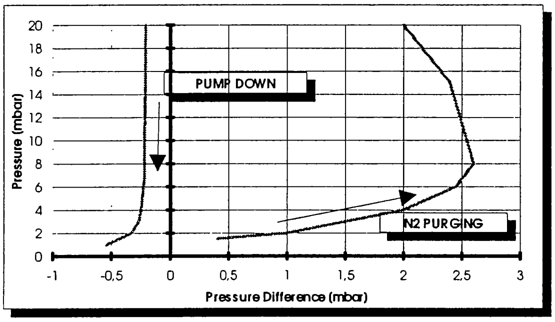

Figure 8 : ΔP During Pump Down And Purging

- **Temperature of Thermal Container**

The temperatures of the Thermal Container are depending on the different pressure conditions P. The respective meanvalues and their local deviations are summarized in table 4.

P [mbar]	T_{TC} [K]	ΔT_{TC} [K]
10^{-5}	94	±2
100	94	±2
900	98	±5

Table 4: Temperature of Thermal Container

Due to the thermally „free" opening of the upper segment of the Thermal Container the heat exchange by convection with the warm environment produces

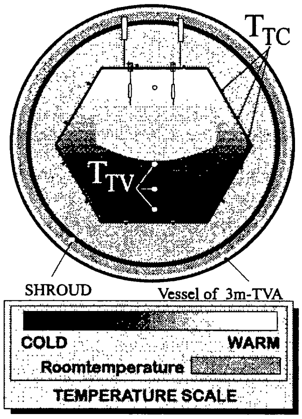

Figure 9: Isotherm Layers

a sort of isotherm layers with the lowest temperature at the deepest point and the highest temperature at the highest point of the Thermal Container (see figure 9). The indicated temperatures have been realized by operating the shroud of the 3m-TVA at temperatures of approx. +40°C.

- **Gas Flow Measurement**

During the TITAN Thermal Test the flowrate through the HUYGENS Probe has been measured with different adjustable constant pressure differences ΔP at a chamber pressure of P=900 mbar and at temperatures of the thermal container of T=100K and T=300K (see figure 10). In particular this measurement shows the good relation between prediction and measurement. The approximate linear function of the flow rate Q (see figure 13) with the pressure difference ΔP is in accordance to the theory /9/ (Q≈P*ΔP) at constant temperatures. For low temperatures the flow rate Q increases because of the inverse proportionality of the coefficient of viscosity to the temperature ($\eta \approx T^x$ or $Q \approx 1/T^x$). With a factor of x=0.79 for air (see / 9/) the factor for the flow rates between T=300K and T=100K is in the order of 2.4, which is in the same magnitude as measured.

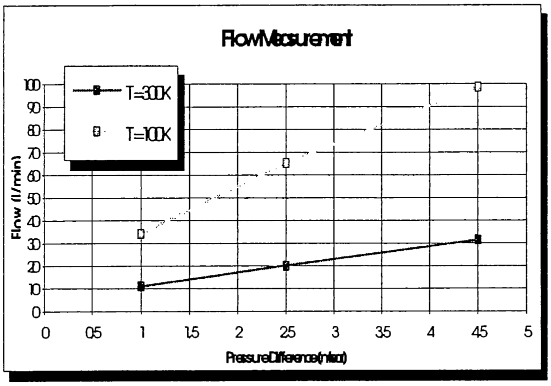

Figure 10 : Flow Measurement

4 CONCLUSIONS

As part of the overall environmental testing programme the HUYGENS Probe has been thermally tested in the thermal vacuum facilities of the Space Test Centre of IABG.

1. The Thermal Balance Test using solar radiation with common requirements has been performed in the large Space Simulation facility WSA/TVA.
2. The SED Release Test simulated the release of the HUYGENS Probe from the orbiter under thermal vacuum conditions. The preciseful implementation of a comprehensive test setup into the WSA/TVA and the interaction between all subsystems and industrial teams has been the challenge of the successful test program.
3. Space Conditioning Test were performed on HUYGENS Front Shield Subsystem and Multilayer Insulation. The tests were conducted using a specific „Thermal Contamination Tent" by which all the outgassing contaminants could be collected and quantified. Measurement results for the bake-out using mass spectrometry, IR-spectroscopy and quartz crystal microbalances are described in /4/.
4. The 3m-TVA, a medium size facility, has been used for the performance of the TITAN Thermal Test. With the design of the Thermal Container, a sophisticated pressure control system, the data acquisition system and the modification of the 3m-TVA facility a unique test facility and method has been developed and commissioned. The technical challenge has been the combination of high pressure and low pressure conditions at low temperatures within one test facility and test.

All testing activities have fully met the requirements without any major discrepancies.

5 ACKNOWLEDGMENT

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REFERENCES

/1/ J.Klein,

The HUYGENS Probe System Level Thermal Test

16th Aerospace Testing Seminar / Los Angelos, March 1996

/2/ H.E.Nuss, I.Streuff

„Leak Rate Measurements For Large Vacuum Chambers"

Vacuum/volume 46/numbers 8-10/p.845 to 848/1995

/3/ J.Klein

„Data Of A Rectangular Beam Solar Simulator"

Proceedings of the International Symposium on Environmental Testing for Space Programmes, 26-29 June 1990, ESA SP-304, p.139

/4/ H.E.Nuss, J.Reimann, A.Zwaal,

„Contamination Effects During Bake-Out Test of Subsystem Level Space Hardware"

3rd International Symposium on Environmental Testing for Space Programmes

ESTEC, 25-27 June,1997

/5/ J.Klein, H.E.Nuss

„Design And Manufacturing Of The Thermal Container“

IABG/B-TR W065, Project :HUYGENS, 1995

/6/ E.Görner

„PC-Based Data Handling Systems For Space Simulation Test Chambers at IABG“

3rd International Symposium on Environmental Testing for Space Programmes

ESTEC, 25-27 June,1997

/7/ J.Klein

„Modifikation einer Thermalvakuumanlage für Klimatests“

26.Jahrestagung der GUS, Pfinztal 12.-14.3.1997, p.8-1

/8/ J.Klein,

„Safety Measures For Testing Facilities“

2.nd International Symposium on Environmental Testing for Space Programmes

ESA WPP-066, October 1993

/9/ Scientific Foundations of Vacuum Technique

S. Dushman, J.M.Lafferty, John Wiley &Sons, Inc.

p.31-32, p.82