CARLO GAVAZZI

CARLO GAVAZZI SPACE SpA

AMS02-TCS

Tipo Doc.: *Doc.Type:*	REPORT			N° DRD: *DRD N°:*	NA
N° Doc.: *Doc. N°:*	**AMSTCS-RP-CGS-004**	Ediz.: *Issue:* **1**	Data: *Date:* **16-05-2008**	Pagina *Page* **1**	Di *Of* **54**
Titolo : *Title :*	THERMAL BEHAVIOUR OF GLUING BETWEEN ZENITH RADIATOR SKINS AND INTERNAL CONDENSER TUBES TEST REPORT				

	Nome & Funzione *Name & Function*	Firma *Signature*	Data *Date*
Preparato da: *Prepared by:*	Ruzza P.		16-05-08
Approvato da: *Approved by:*	X Molina M. Vettore C. Cremonesi L. Cinquepalmi C.		16/05/2008 16/05/08 16.05.08 16.05.08
Applicazione autorizzata da: *Application authorized by:*	Olivier M.		16/05/08
Customer / Higher Level Contractor			
Accettato da: *Accepted by:*			
Approvato da: *Approved by:*			

LISTA DI DISTRIBUZIONE *DISTRIBUTION LIST*	N	A	I
Interna / *Internal*			
Esterna / *External*			

N=Numero di copie A=Applicazione I=Informazione
N=Number of copy A=Application I=Information

Gestione documenti: *Data Management:* Firma / *Signature* Data / *Date* 16-5-08

File: AMSTCS-RP-CGS-004 Issue 1.doc

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA: Tutti i diritti sono riservati
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

REGISTRAZIONE DELLE MODIFICHE / *CHANGE RECORD*

EDIZIONE *ISSUE*	DATA *DATE*	AUTORIZZAZIONE *CHANGE AUTHORITY*	OGGETTO DELLA MODIFICA E SEZIONI AFFETTE *REASON FOR CHANGE AND AFFECTED SECTIONS*
1	16/05/08		First issue

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

LISTA DELLE PAGINE VALIDE / *LIST OF VALID PAGES*

PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*
1 - 54	1								

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

TABLE OF CONTENT

1. SCOPE 7

2. DOCUMENTS 7

2.1 APPLICABLE DOCUMENTS 7
2.2 REFERENCE DOCUMENTS 7

3. ACRONYMS 7

4. PARTICIPANTS REQUIRED 8

4.1 GENERAL 8
4.2 RESPONSIBILITY 8
4.3 QA WITNESS OF TEST AND SIGN-OFF 8
4.4 NON CONFORMANCE AND FAILURES 8
4.5 CALIBRATION REQUIREMENTS 8

5. TEST EQUIPMENT AND CONFIGURATION 9

5.1 GLUING THERMAL CONDUCTANCE TEST 9
5.2 DEEP COOLING IN LIQUID N_2 12
5.3 TEST SUCCESS CRITERIA 13

6. INSTRUMENTATION AND TEST EQUIPMENT 14

7. TEST PROCEDURE VARIATION SHEET 16

PROCEDURE VARIATION SHEET ref. N°: 17

8. TEST DATA SHEETS 18

8.1 DATA SHEETS FILLING UP 18

9. TEST DATA 20

9.1 SPECIMEN 1 21
9.1.1 SETUP 21
9.1.2 TEST 1AA 21
9.1.3 TEST 1AB 21
9.2 SPECIMEN 2 22
9.2.1 SETUP 22
9.2.2 TEST 2AA 22
9.2.3 TEST 2AB 22
9.3 SPECIMEN 3 23
9.3.1 SETUP 23
9.3.2 TEST 3AA 23
9.3.3 TEST 3AB 23
9.3.4 TEST 3BA 24
9.3.5 TEST 3BB 24
9.4 SPECIMEN 4 25
9.4.1 SETUP 25
9.4.2 TEST 4AA 25
9.4.3 TEST 4AB 25
9.4.4 TEST 4BA 26
9.4.5 TEST 4BB 26
9.5 SPECIMEN 5 27
9.5.1 SETUP 27
9.5.2 TEST 5AA 27
9.5.3 TEST 5AB 27

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.5.4 TEST 5BA 28
9.5.5 TEST 5BB 28
9.5.6 TEST 5CA 28
9.5.7 TEST 5CB 28
9.5.8 TEST 5EB 29
9.5.9 TEST 5JB 29
SPECIMEN 6 30
9.5.10 SETUP 30
9.5.11 TEST 6AA 30
9.5.12 TEST 6AB 30
9.5.13 TEST 6BA 31
9.5.14 TEST 6BB 31
9.5.15 TEST 6CA 31
9.5.16 TEST 6CB 31
9.5.17 TEST 6EB 32
9.5.18 TEST 6JB 32
9.6 SPECIMEN 7 33
9.6.1 SETUP 33
9.6.2 TEST 7AA 33
9.6.3 TEST 7AB 33
9.6.4 TEST 7BA 33
9.6.5 TEST 7BB 34
9.6.6 TEST 7JB 34
9.7 SPECIMEN 8 35
9.7.1 SETUP 35
9.7.2 TEST 8AA 35
9.7.3 TEST 8AB 35
9.7.4 TEST 8BA 35
9.7.5 TEST 8BB 35
9.7.6 TEST 8JB 36
9.8 SPECIMEN 9 37
9.8.1 SETUP 37
9.8.2 TEST 9AA 37
9.8.3 TEST 9AB 37
9.8.4 TEST 9BA 38
9.8.5 TEST 9BB 38
9.8.6 TEST 9JB 38
9.9 SPECIMEN 10 39
9.9.1 SETUP 39
9.9.2 TEST 10AA 39
9.9.3 TEST 10AB 39
9.9.4 TEST 10BA 40
9.9.5 TEST 10BB 40
9.9.6 TEST 10EB 40
9.9.7 TEST 10JB 40

10. TEST RESULTS 42

11. CONCLUSIONS 47

ANNEX A – GLUING PROCESS PROCEDURE 49

ANNEX B – MASTERBOND EP21TDC-2LO DATASHEET 51

ANNEX C – THERMOCOUPLES AND ELECTRIC RESISTANCES POSITION 53

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

LIST OF TABLES

Tab. 6-1 INSTRUMENT LIST 15
Tab. 10-1 Before cooling results 42
Tab. 10-2 After cooling results 44
Tab. 10-3 Test results 45

LIST OF FIGURES

Fig. 1 – Detail of gluing processes according to original (left) and upgraded (right) procedures 9
Fig. 2 – Detail of thermocouples position on the tube and the plate 10
Fig. 3 – Test specimen layout 10
Fig. 4 - Electrical scheme 11
Fig. 5 - Insulation 11
Fig. 6 – Test setup – flowmeter 12
Fig. 7 – Wood/polyurethane box with specimens inside the LN2 13
Fig. 8 – Specimen 6 detail before (left) and after (right) liquid nitrogen bath 43
Fig. 9 - Reference system used for positions 54

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

1. SCOPE

The scope of this document is to collect the thermal conductance test results for the gluing of specimens that represent the gluing between AMS-02 zenith radiator skins and the internal condenser tubes.
The main aim of the test is to measure the gluing thermal conductivity per unit length, and verify the stability of this measured value after a deep cooling at cryogenic temperature, provided by bathing the test samples in liquid N_2, at a temperature of -196°C (Cold Shock Test, in the following CSTest).

2. DOCUMENTS

2.1 APPLICABLE DOCUMENTS

AD	Document ID	Iss/Rev.	Date	Title
1	AMSTCS-PR-CGS-004	Issue 1	10/01/2008	Thermal behaviour of gluing between zenith radiator skins and internal condenser tubes test procedure

2.2 REFERENCE DOCUMENTS

RD	Document ID	Iss/Rev.	Date	Title
1	AMSTCS-MI-CGS-011	Issue 1	21/01/2008	Minute of meeting – Riunione per la valutazione dei risultati degli incollagggi
2	AMSTCS-MI-CGS-015	Issue 1	10/03/2008	Minute of meeting – Riunione per la definizione della produzione del radiatore Zenith di AMS

3. ACRONYMS

C.I. Configuration Item. Also called Part Number (P/N)
CGS Carlo Gavazzi Space
NA Not Applicable
P/N Part Number. Also called Configuration Item C.I.
PA Product Assurance
PVS Procedure Variation Sheet
QA Quality Assurance
S/N Serial Number
UUT Unit Under Test

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

4. PARTICIPANTS REQUIRED

4.1 GENERAL

All test will be performed under QA surveillance in accordance with, and following detailed procedure of applicable PA Plan. Start of the Test shall be notified to Prime Contractor and/or Customer as applicable.

4.2 RESPONSIBILITY

The technical responsibility for testing and test results is up to the Engineering department.

QA is responsible for ensuring that all the agreed procedures are carefully observed, that test equipment and instrumentation used during testing is calibrated and within validity date: that the test data sheets are recorded in the Test Report and signed by the operators and QA witnesses, that all non conforming condition and test results are properly documented and notified to the Prime Contractor, and that all requirements of applicable PA Plan, specification and Statement of Work pertaining to the acceptance tests, are fully satisfied.

4.3 QA WITNESS OF TEST AND SIGN-OFF

QA inspector, or its delegate, shall witness the tests described in this procedure in accordance to the requirement specified in the applicable PA Plans.

4.4 NON CONFORMANCE AND FAILURES

Any malfunction/defect which occurs during the test will be processed along the Non Conformance Procedure described in the applicable PA Plans.

4.5 CALIBRATION REQUIREMENTS

All instruments used for testing shall be calibrated.

Evidence of certification shall be provided by a label attached to the instruments itself, showing the calibration date, the expiring date and the signature of the operator.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

5. TEST EQUIPMENT AND CONFIGURATION

5.1 GLUING THERMAL CONDUCTANCE TEST

Tubes for specimens are supplied by Arotubi (Al 3003/3103 – internal diameter 3mm external diameter 4mm). Plates are supplied by Politecnico di Milano.
The glue used is MASTERBOND EP21TDC-2LO, a two component thermally conductive epoxy resin, widely used in aerospace applications (See ANNEX B for datasheets).
The whole gluing process has taken place (gluing and curing in a vacuum bag at room temperature at 20°C for 48 hours) at the facility of Politecnico di Milano.

Politecnico di Milano has provided CGS a detailed gluing/curing process procedure (approved by CGS before process), that is attached to this procedure (see ANNEX A).

After the supply and testing of the first 4 specimens (numbered from 1 to 4), some gluing defects have been observed, which have generated a loss of performance during the thermal test (begin the specimen gluing unable to withstand mechanical loads during setup preparation, and possibly thermo-elastic loads during CSTest). The de-bonding of the tube from the plate has been observed in some location, particularly in correspondence of the tube inlets and outlets on the plate. (see also next figures)

Because of this, in agreement with Politecnico di Milano, the gluing process procedure has been improved and a new gluing procedure has been issued (see RD1 and annex A).
6 new specimens (numbered from 5 to 10 have been glued with this updated procedure.
.
In the figure below some details of the gluing are shown. In the left picture specimen 2 (first gluing process used) is shown. In the right one, specimen 5 (modified gluing process used) is shown. Specimen 5 shows a more uniform gluing and no failure.

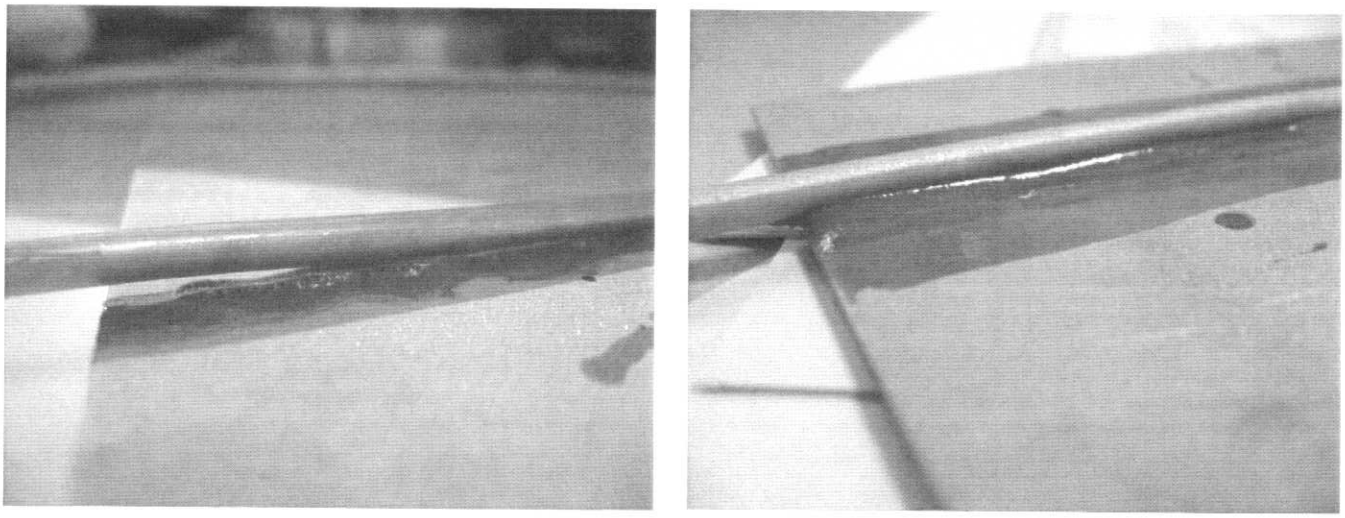


Fig. 1 – Detail of gluing processes according to original (left) and upgraded (right) procedures

The test equipment layout is shown in the figure below: electrical resistance and thermocouples positions are shown.
Ten pair of thermocouples (named T(2n)-T(2n+1)) are used to measure the difference of temperature between the tube and the plate. The two thermocouples have been positioned as close as possible to each other (see figure below), one on the tube surface and one on the plate. Thermocouples have been fixed to the plate and the tube using kapton adhesive tape.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

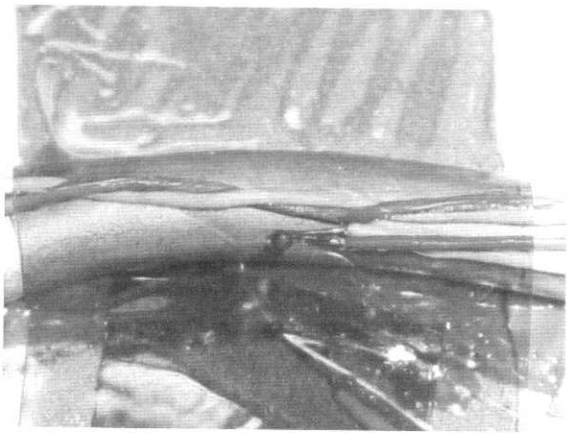


Fig. 2 – Detail of thermocouples position on the tube and the plate

Thermocouples have been positioned on the plates and the tubes following sketch on annex 3, but in some cases a little change of position has been foreseen in order to avoid the thermocouples to be placed where too much glue was present (which would have made the thermocouples being too much distant from the junction point with the tube).

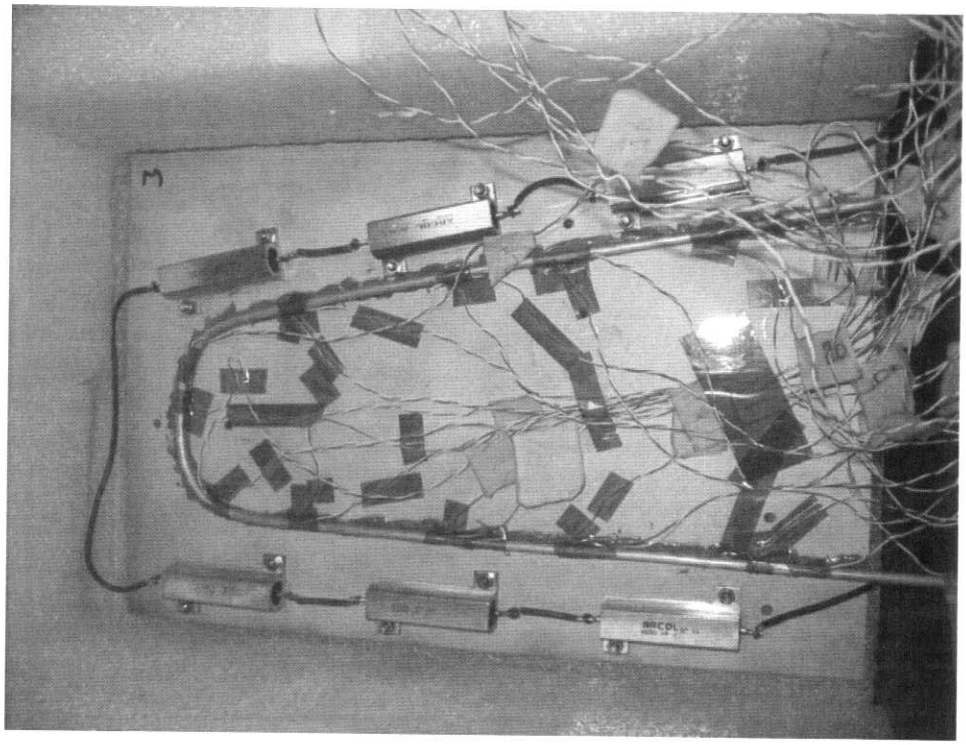


Fig. 3 – Test specimen layout

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

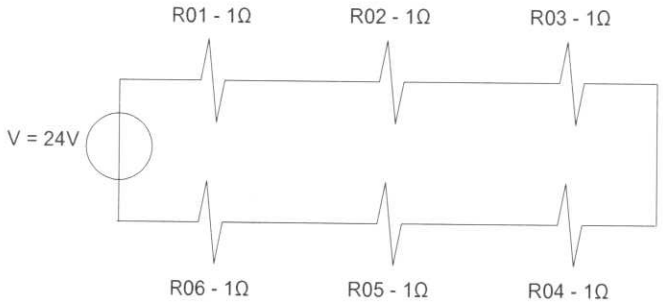


Fig. 4 - Electrical scheme

Two different test with a fixed power of approximately 12 and 24W* have been performed; electrical power has been provided by the 6 electric resistors sunk to the plate (See Fig. 4 for details), in turn heating water flowing at a constant mass flow rate in the tube from a temperature T_{in} to a temperature T_{out}. An insulation layer of polystyrene has been used to minimize heat losses to local environment. To ensure a good insulation from local environment a 50mm (at least) insulating has be used to cover the whole test equipment (see Fig. 5 for details).

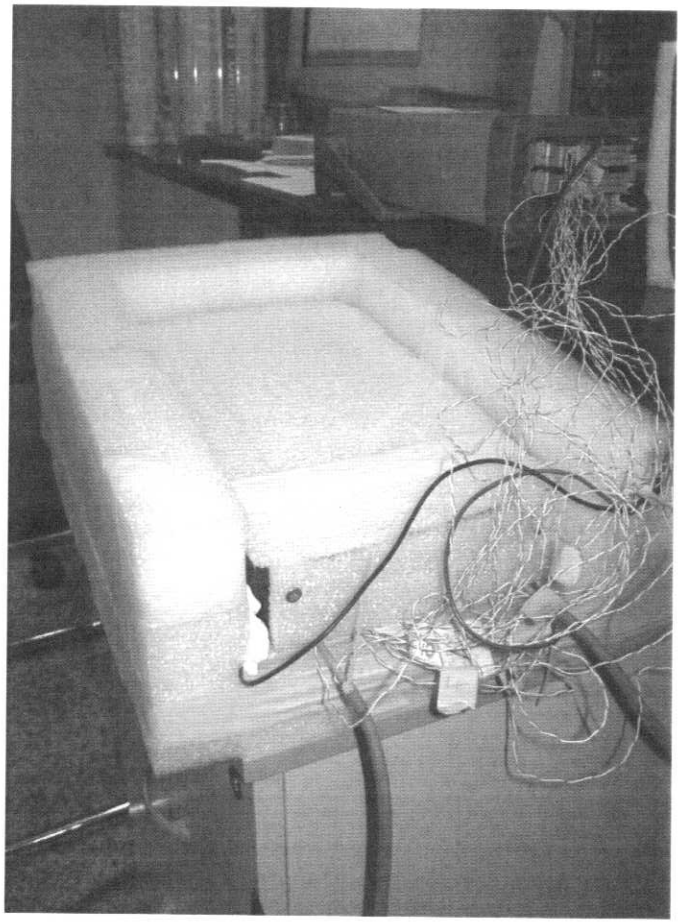


Fig. 5 - Insulation

Water flow in the tube is provided using a tank at a higher level of the plate. At tube exit a flow meter measure effective water flow rate, then a tube leads the water to an exhaust tank.

* 6 resistances of 1ohm 8.5V@1.4A=12W / 12.2@V-2.00A = 24W

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

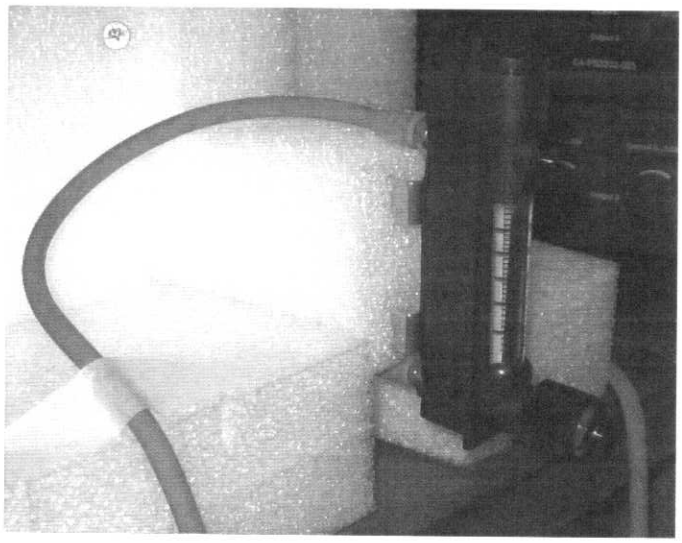


Fig. 6 – Test setup – flowmeter

The effective heat flux per unit length from base to the water flow (and so through the glue) is given by:

$$q_{ef} = \frac{\dot{m}Cp(T_{in} - T_{out})}{l_t}$$

Where $\dot{m}$ is the mass flow rate, Cp is the air specific heat, and l_t is the tube length. The thermocouple that measure Tin and Tout are placed respectively in the inlet and in the exhaust tube.
Thermal conductivity per unit length is given by:

$$k_g = \frac{q_{ef}}{\frac{1}{n}\sum_n (T_{2n+1} - T_{2n})}$$

Where the denominator is the average difference between plate and tube temperature (T_{2n} and T_{2n+1} are the temperature read from thermocouples respectively on the tube and on the plate). In order to verify the repeatability of the test 6 different measurement will be used.

5.2 DEEP COOLING IN LIQUID N_2

The deep cooling has been performed bathing the test samples in liquid N_2 for 8 hours.
A basin made by polyurethane foam and wood has been realized to provide the needed level of liquid N_2 for specimens bathing.
This phase has been taken place at Politecnico di Milano. Further details will be given when test results will be shown.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

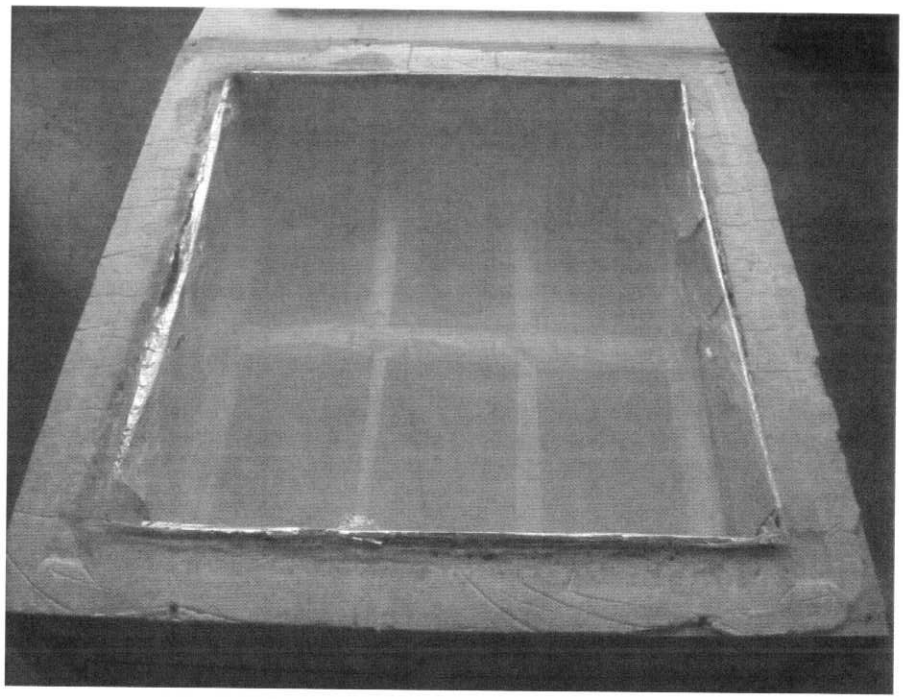


Fig. 7 – Wood/polyurethane box with specimens inside the LN2

Liquid N_2 is at a constant temperature of -196°C, so provided a 30% colder environment than the worst zenith radiator life condition (approximately -150°C during ISS power outage).

A constant control of the liquid N_2 level (and refill if needed) is needed because of the N_2 evaporation. A polystyrene float indicator is used to control the nitrogen level. During the test 1cm/hr evaporation rate has been observed.

5.3 TEST SUCCESS CRITERIA

The test will be consider successful when:

1- The test is correctly performed according to the step by step procedure in the following sections.
2- The measured average thermal conductance of each specimen does not fall below 5W/K per unit length (meter).
3- The specimen do not show any de-bonding or other degradation due to the liquid nitrogen bath
4- The specimen do not show any degradation when the thermal conductance per unit length is re-measured after the LN2 bath (apart from typical values scattering due to measurement uncertainties, of the order of 20%)

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

6. INSTRUMENTATION AND TEST EQUIPMENT

The complete list of the instrumentation used during the test shall be recorded in table 7.-1.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Tab. 6-1 INSTRUMENT LIST

N.	EQUIPMENT	MANUFACTURER	P/N	S/N	ACCURACY (*)	NEXT CAL. DATE	REMARKS
	Data logger	HP	34970A	US37008050		30/06/2009	
	Flow meter	KEI INSTRUMENTS	MR3L11BVBN	NA	±4% full scale	Purchase Date 12/2007	

(*) Where not specified the accuracy is as stated on the instrument manufacturer data sheet

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

7. TEST PROCEDURE VARIATION SHEET

In case that for any reason the test procedure has to be changed, the change shall be described in a Procedure Variation Sheet (PVS) as shown in the next page.

The PVS shall contain:

- Reference to the test procedure to be changed
- Reference to the relevant test, procedure page and paragraph
- Description of the change, possibly in the form was….is…..
- Reason for change
- Test Engineer, QA, Test conductor signatures and dates
- Customer signature and date (when required).

Each PVS shall be identified by a reference number provided in sequential order.

All the generated PVS shall be collected in a dedicated section of the Test Report.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

PROCEDURE VARIATION SHEET ref. N°:

Test Procedure Ref.:	Page Revised:	Paragraph Revised:

Description of Change:

Gluing procedure changed (see annex B for details) after first 4 specimens. 6 new specimens glued with updated procedure.

Added further LN2 bath and conductance measurement.

Reason for Change:

Debonding and gluing failure observed after first thermal test on the first 4 specimens

Performance decreasing have been observed, further investigation seems to be necessary

CONCURRENCE

Test Cond.	QA	System Eng.		Customer
Date 16-05-08	Date	Date		Date

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

8. TEST DATA SHEETS

The step-by-step procedure sheets are provided in the following pages.
For each test sample, the same procedure is to be redone after the deep cooling process, in order to compare the two results.

8.1 DATA SHEETS FILLING UP

The following fields of the data sheets:

- UUT DATA (including Model, Item, C.I., S/N)
- Measured value

shall be filled up during the test performances and shall be part of the Test Report together with photographs, sketches, etc. eventually useful to document the test execution/result.

Remarks field shall be used as a minimum to provide, where appropriate, reference to NCRs and PVS.

Test Report reference data shall be added in the relevant field.

Each data sheet (including the attachments) shall be certified by QA stamp and signature together with the Test Conductor signature and date.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

UUT DATA : **Model** **PFM** **Item** **THERMAL CONTROL SYSTEM ASSEMBLY** **C.I.** **TCS 10** **S/N** **FM01**

STEP n°	TEST SEQUENCE	EXPECTED VALUE	MEASURED VALUE	REMARKS
1.	**Thermal Conductivity test part I**			
1.1	Visual inspection of the test sample. Note if gluing failures are present.	No failures		See tables in the next pages with the information and measured values per each sample.
1.2	Install Thermocouples and resistances position as shown in annex 1.	OK		As above
1.3	Check thermocouples reading.	All OK		As above
1.4	Switch on electronic resistances and water flux.	V = 8.5V $\dot{m} \approx$ 100cc/min		As above
1.5	Check water flow rate is constant.	OK		As above
1.6	Wait for panel stabilization on all the sensors (stabilization criteria < 1°C/hr, observed for at least 30 minutes).	< 1°C/hr		As above
1.7	Record thermocouples reading.			As above
1.8	Repeat point 1.4 to 1.6 using a different power	V = 12V, I=2A $\dot{m} \approx$ 100cc/min		As above
1.9	Stop data acquisition and save data.	OK		As above
1.10	Switch off electronic resistances and water flux.	OFF		As above
1.11	Remove thermocouples and resistances.			As above
1.12	Repeat point 1.1 to 1.12 for all the test samples, recording the number of sample under test.			As above
2.	**Cold shock test**			
2.1 2.1	Bath the specimens for 8 hours in liquid N2. constantly check the LN2 level. Wait for the specimens to be at room temperature.			As above As above
3.	**Thermal Conductivity test part II**			
3.1	Repeat points 1.1 to 1.12.			As above

DATE:	TEST CONDUCTOR	QA	CUSTOMER

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9. TEST DATA

In the following section all test data for each specimen and test are presented. The following table summarized the performing test: each test is identified with an ID number like NXY where N is the specimen number, X identified the LN2 bath after which the test has been performed and Y identified the test performed (A = 12W applied, B = 24W applied).

Tab 9-1 - Tests performed

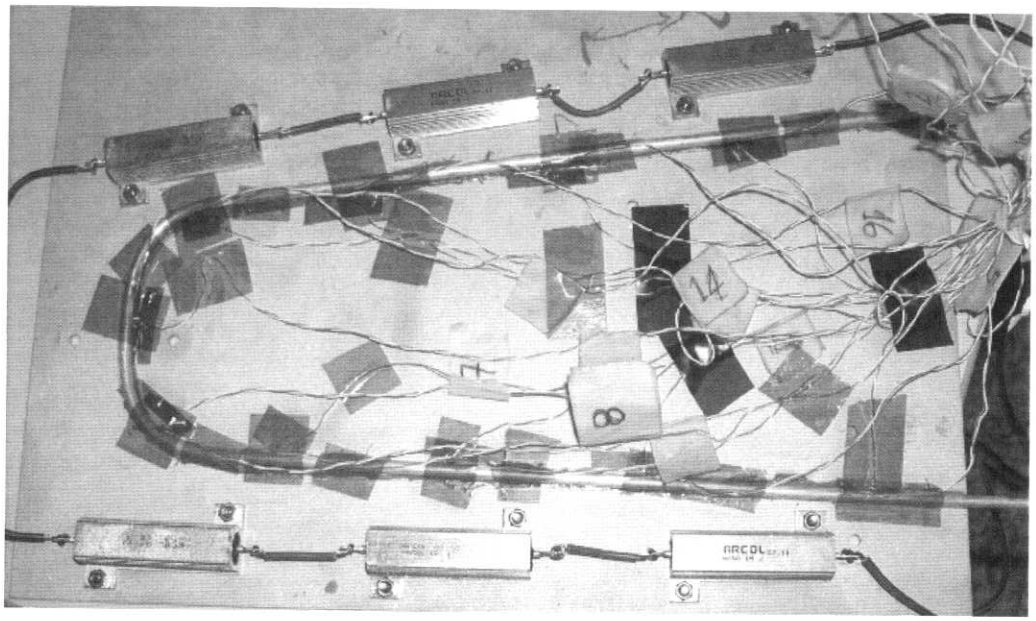
Specimen ID		A	B	C	D	E	F	G	H	I	J
		before LN2 bath	after 1st bath	after 2nd bath	after 3rd bath	after 4th bath	after 5th bath	after 6th bath	after 7th bath	after 8th bath	after 9th bath
1	LN2 bath duration	NA	-	-	-	-	-	-	-	-	-
	Type of test (A or B)	A B	- -	- -	- -	- -	- -	- -	- -	- -	- -
2	LN2 bath duration	NA	-	-	-	-	-	-	-	-	-
	Type of test (A or B)	A B		- -	- -	- -	- -	- -	- -	- -	- -
3	LN2 bath duration	NA	8hr	-	-	-	-	-	-	-	-
	Type of test (A or B)	A B	A B	- -	- -	- -	- -	- -	- -	- -	- -
4	LN2 bath duration	NA	8hr	-	-	-	-	-	-	-	-
	Type of test (A or B)	A B	A B	- -	- -	- -	- -	- -	- -	- -	- -
5	LN2 bath duration	NA	8hr	8hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
	Type of test (A or B)	A B	A B	A B	- -	B	- -	- -	- -	- -	- B
6	LN2 bath duration	NA	8hr	8hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
	Type of test (A or B)	A B	A B	A B	- -	B	- -	- -	- -	- -	- B
7	LN2 bath duration	NA	8hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
	Type of test (A or B)	A B	A B	- -	- -	- -	- -	- -	- -	- -	- B
8	LN2 bath duration	NA	8hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
	Type of test (A or B)	A B	A B	- -	- -	- -	- -	- -	- -	- -	- B
9	LN2 bath duration	NA	8hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
	Type of test (A or B)	A B	A B	- -	- -	- -	- -	- -	- -	- -	- B
10	LN2 bath duration	NA	8hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr	1hr
	Type of test (A or B)	A B	A B	- -	- -	- B	- -	- -	- -	- -	- B

For example test 5EB means the test B (24W) after 4th bath (1 hour long - column E) on specimen 5.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.1 SPECIMEN 1

9.1.1 SETUP



9.1.2 TEST 1AA

Water volume flow rate	100 cc/min
Electrical power – Voltage	8.48 V
Electrical power – Current	1.39 A

In Water Temperature	16.86°C
Out Water Temperature	18.46°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.24	21.85	21.46	21.65	21.65	21.04	21.49	20.96	20.58	20.56
Tube T [°C]	19.02	20.31	19.80	18.59	18.32	17.72	19.03	19.50	18.66	18.16

9.1.3 TEST 1AB

Water volume flow rate	180 cc/min
Electrical power – Voltage	12.2 V
Electrical power – Current	2.01 A

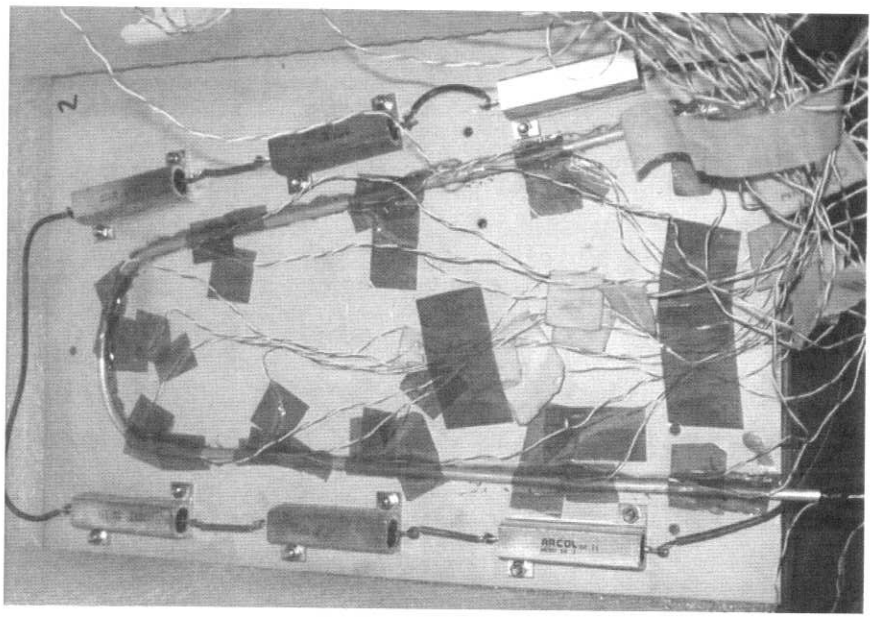
In Water Temperature	17.41°C
Out Water Temperature	18.85°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	26.49	25.58	24.84	24.50	24.44	23.43	24.63	24.01	23.49	22.96
Tube T [°C]	20.92	22.81	21.96	20.69	19.26	18.47	21.11	21.65	20.30	19.72

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.2 SPECIMEN 2

9.2.1 SETUP



9.2.2 TEST 2AA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.38 A

In Water Temperature	16.96°C
Out Water Temperature	18.62°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	21.11	21.09	21.12	21.27	20.85	20.24	20.47	20.21	19.80	19.86
Tube T [°C]	20.00	19.68	19.78	18.55	18.66	17.73	19.05	18.61	18.20	17.58

9.2.3 TEST 2AB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.4 V
Electrical power – Current	2.01 A

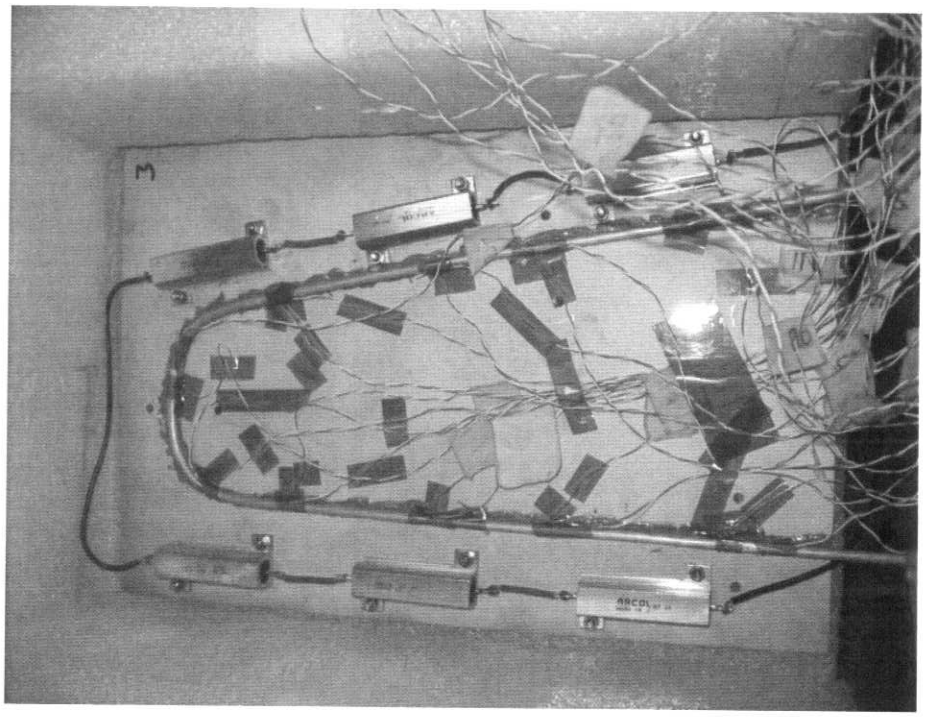
In Water Temperature	16.96°C
Out Water Temperature	19.98°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.96	26.38	26.78	27.66	27.28	25.84	26.32	25.26	24.42	25.01
Tube T [°C]	23.36	23.07	23.58	20.95	21.18	19.63	22.25	21.51	20.30	18.25

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.3 SPECIMEN 3

9.3.1 SETUP



9.3.2 TEST 3AA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.4 A

In Water Temperature	16.57°C
Out Water Temperature	18.20°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	21.22	21.42	21.11	20.98	21.05	19.90	20.14	20.18	19.74	19.89
Tube T [°C]	19.75	19.54	19.30	18.34	17.73	17.67	18.84	18.23	18.17	16.97

9.3.3 TEST 3AB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.4 V
Electrical power – Current	2.01 A

In Water Temperature	17.18°C
Out Water Temperature	20.21°C

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	28.46	29.32	28.02	28.08	28.65	26.67	27.13	26.89	25.98	26.37
Tube T [°C]	23.52	22.77	23.27	21.71	20.17	20.16	22.83	21.18	21.52	18.97

9.3.4 TEST 3BA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.39 A

In Water Temperature	18.90°C
Out Water Temperature	17.50°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.90	25.70	24.10	23.70	23.90	23.30	23.80	23.10	22.70	23.80
Tube T [°C]	20.00	20.50	20.80	19.50	18.70	18.70	19.60	19.70	19.40	18.30

9.3.5 TEST 3BB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.01 V
Electrical power – Current	2.0 A

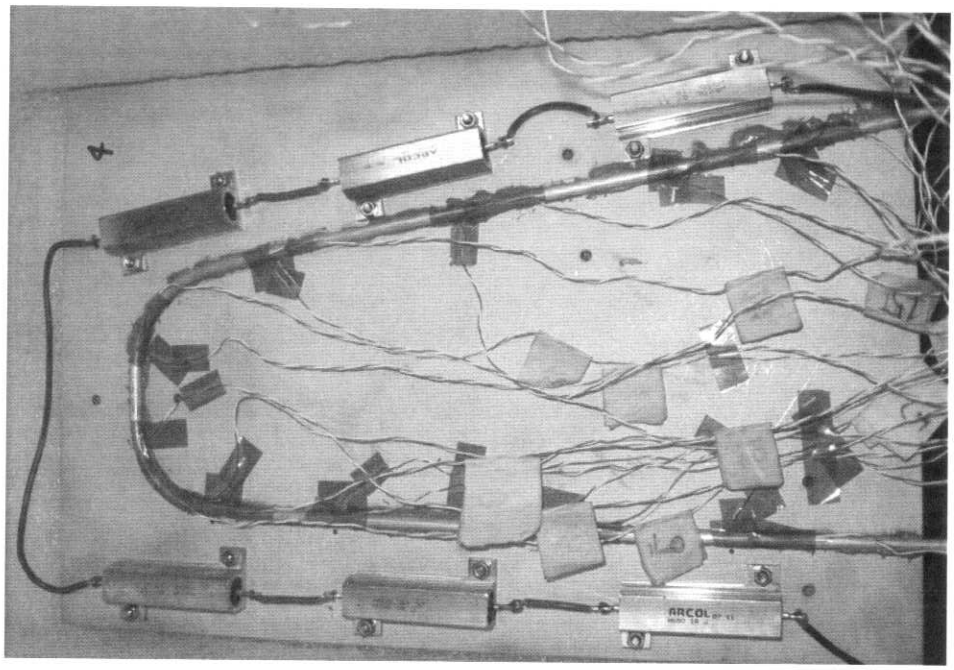
In Water Temperature	16.70°C
Out Water Temperature	19.50°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	33.10	32.80	30.00	29.10	29.70	28.70	29.60	28.20	27.60	30.00
Tube T [°C]	22.00	23.20	23.50	21.10	19.50	19.80	21.50	21.60	21.50	19.10

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.4 SPECIMEN 4

9.4.1 SETUP



9.4.2 TEST 4AA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.4 A

In Water Temperature	16.70°C
Out Water Temperature	18.85°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	20.91	20.82	21.14	21.14	20.48	20.55	21.56	20.60	19.17	18.86
Tube T [°C]	19.62	19.10	18.87	18.41	18.61	17.82	17.30	17.90	15.52	17.13

9.4.3 TEST 4AB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.4 V
Electrical power – Current	2.02 A

In Water Temperature	17.22°C
Out Water Temperature	20.29°C

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.87	25.08	25.91	26.08	24.84	25.07	27.32	25.34	22.62	22.05
Tube T [°C]	22.14	21.28	21.21	20.40	22.18	19.37	18.50	19.81	19.78	18.47

9.4.4 TEST 4BA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.4 A

In Water Temperature	17.20°C
Out Water Temperature	18.60°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.40	22.30	22.80	23.00	23.00	22.80	23.50	22.10	21.00	20.40
Tube T [°C]	20.20	20.60	19.40	19.60	18.20	18.00	18.70	19.40	18.30	17.90

9.4.5 TEST 4BB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.4 V
Electrical power – Current	2.03 A

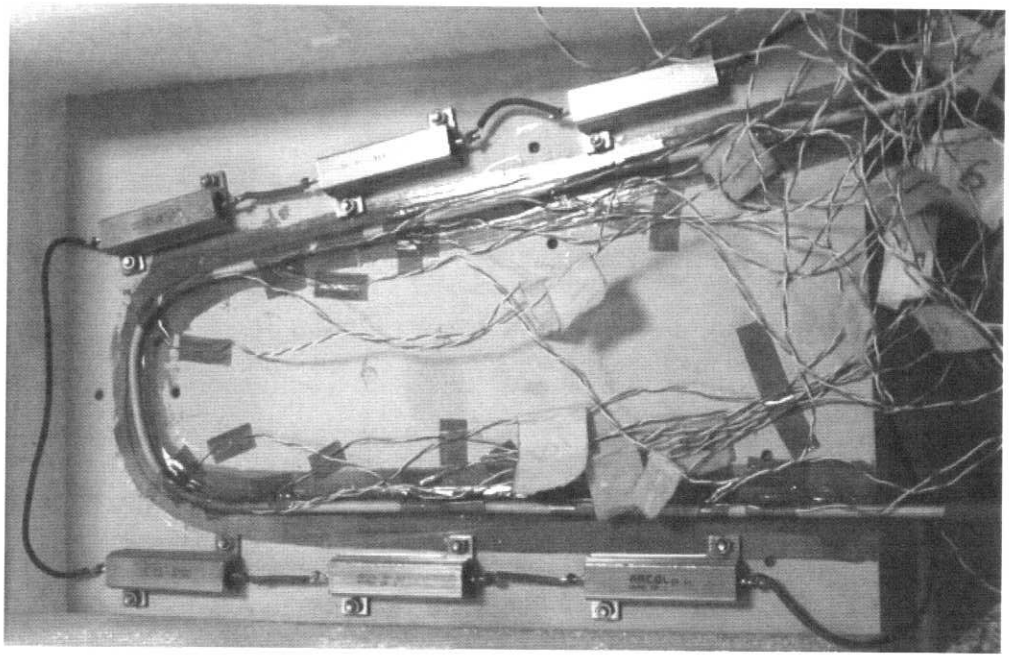
In Water Temperature	19.20°C
Out Water Temperature	16.30°C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	26.40	26.40	27.60	28.10	28.10	27.80	29.20	26.60	24.40	23.40
Tube T [°C]	22.00	23.20	20.80	21.50	18.80	18.40	19.90	21.20	19.20	18.40

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.5 SPECIMEN 5

9.5.1 SETUP



9.5.2 TEST 5AA

Water volume flow rate	130 cc/min
Electrical power – Voltage	8.48 V
Electrical power – Current	1.39 A

In Water Temperature	18.17 °C
Out Water Temperature	19.41 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	21.32	21.35	21.24	20.76	20.53	20.29	20.56	20.62	20.22	20.00
Tube T [°C]	20.47	20.11	20.13	19.65	19.73	*	19.62	19.38	18.98	18.35

9.5.3 TEST 5AB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.1 V
Electrical power – Current	1.99 A

In Water Temperature	17.86 °C
Out Water Temperature	20.60 °C

* thermocouple failure. No temperature available for this test

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.88	24.98	24.72	23.81	23.48	23.07	23.64	23.77	23.11	22.62
Tube T [°C]	23.12	22.39	22.51	21.52	21.82	*	21.73	21.35	20.53	19.18

9.5.4 TEST 5BA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.4 A

In Water Temperature	17.20 °C
Out Water Temperature	18.70 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	21.20	21.00	20.90	20.50	20.10	19.90	20.20	20.10	19.90	19.70
Tube T [°C]	20.20	19.60	19.50	19.00	18.80	18.00	19.00	18.60	18.30	17.50

9.5.5 TEST 5BB

Water volume flow rate	120 cc/min
Electrical power – Voltage	12.4 V
Electrical power – Current	2.03 A

In Water Temperature	17.51 °C
Out Water Temperature	20.12 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.49	25.47	25.27	24.55	24.00	23.57	24.13	24.02	23.72	23.31
Tube T [°C]	23.63	22.68	22.66	21.60	21.41	19.80	21.78	21.12	20.54	18.87

9.5.6 TEST 5CA

Water volume flow rate	130 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.4A

In Water Temperature	19.12 °C
Out Water Temperature	20.29 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.95	22.83	22.49	22.16	21.64	21.51	21.88	21.90	21.74	21.58
Tube T [°C]	21.55	21.16	21.06	20.29	20.17	19.67	20.67	20.35	19.93	19.36

9.5.7 TEST 5CB

Water volume flow rate	110 cc/min

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Electrical power – Voltage	12.4 V
Electrical power – Current	1.97 A

In Water Temperature	19.07 °C
Out Water Temperature	21.83 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	27.08	27.16	26.55	25.93	25.03	24.85	25.56	25.60	25.27	25.00
Tube T [°C]	24.41	23.80	23.64	22.21	22.22	21.09	23.09	22.55	21.71	20.53

9.5.8 TEST 5EB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.0V
Electrical power – Current	1.97 A

In Water Temperature	17.90 °C
Out Water Temperature	20.80 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.20	25.70	25.40	24.80	24.60	24.80	24.40	24.00	23.40	23.10
Tube T [°C]	22.90	22.20	22.40	21.60	21.30	21.30	21.90	21.50	20.10	18.70

9.5.9 TEST 5JB

Water volume flow rate	120 cc/min
Electrical power – Voltage	12.4 V
Electrical power – Current	2.03 A

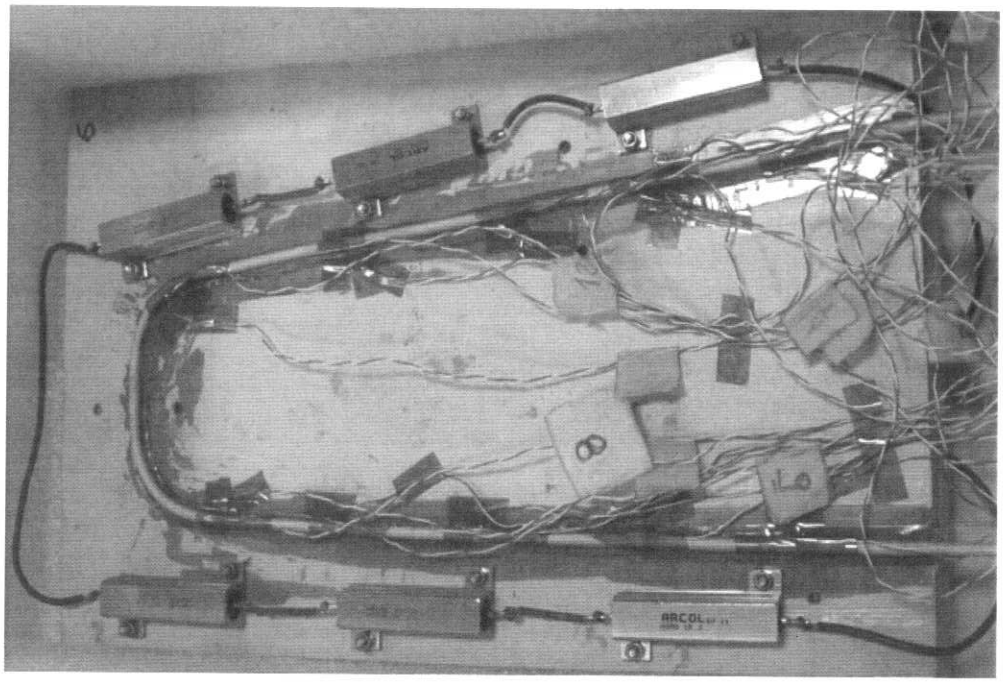
In Water Temperature	18.80 °C
Out Water Temperature	20.90 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.70	26.10	25.90	25.20	25.10	25.10	24.60	24.50	24.10	23.80
Tube T [°C]	23.30	22.60	23.00	22.20	22.00	21.70	22.10	21.60	20.80	19.30

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

SPECIMEN 6

9.5.10 SETUP



9.5.11 TEST 6AA

Water volume flow rate	100 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.39 A

In Water Temperature	17.72 °C
Out Water Temperature	19.52 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	21.23	21.01	20.98	20.57	20.71	20.44	20.38	20.13	19.81	19.34
Tube T [°C]	20.50	20.15	19.93	19.48	18.75	18.85	19.23	18.88	18.59	18.15

9.5.12 TEST 6AB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.1 V
Electrical power – Current	1.98 A

In Water Temperature	17.84 °C
Out Water Temperature	21.06 °C

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.78	24.76	24.77	24.08	24.47	23.99	23.89	23.37	22.75	21.84
Tube T [°C]	23.41	22.96	22.66	21.94	20.55	20.81	21.51	20.92	20.32	19.41

9.5.13 TEST 6BA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.35 A

In Water Temperature	17.24 °C
Out Water Temperature	18.61 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.40	22.30	22.80	23.00	23.00	22.80	23.50	22.10	21.00	20.40
Tube T [°C]	20.20	20.60	19.40	19.60	18.20	18.00	18.70	19.40	18.30	17.90

9.5.14 TEST 6BB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12 V
Electrical power – Current	1.95 A

In Water Temperature	17.12 °C
Out Water Temperature	20.37 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.33	24.48	24.81	24.66	24.68	24.95	24.37	24.07	22.82	21.58
Tube T [°C]	22.89	22.84	22.30	21.96	20.65	21.57	21.19	21.38	20.15	18.96

9.5.15 TEST 6CA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.35 A

In Water Temperature	18.12 °C
Out Water Temperature	19.77 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.06	22.03	21.96	21.76	21.91	21.88	21.51	21.32	20.77	20.47
Tube T [°C]	21.20	21.39	20.53	19.94	19.35	19.76	19.85	19.41	19.41	18.87

9.5.16 TEST 6CB

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Water volume flow rate	110 cc/min
Electrical power – Voltage	12 V
Electrical power – Current	1.93 A

In Water Temperature	18.32 °C
Out Water Temperature	21.57 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.67	25.95	25.93	25.66	26.10	26.16	25.45	25.13	24.17	23.52
Tube T [°C]	24.12	24.70	23.21	22.27	21.20	22.08	22.29	21.47	21.45	20.50

9.5.17 TEST 6EB

Water volume flow rate	120 cc/min
Electrical power – Voltage	11.6 V
Electrical power – Current	1.81 A

In Water Temperature	18.10 °C
Out Water Temperature	20.20 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.20	24.40	24.60	24.20	24.60	24.70	24.10	23.70	23.00	22.00
Tube T [°C]	22.50	22.80	22.30	21.30	20.80	21.00	21.60	20.70	20.10	18.90

9.5.18 TEST 6JB

Water volume flow rate	110 cc/min
Electrical power – Voltage	11.8 V
Electrical power – Current	1.86 A

In Water Temperature	19.00 °C
Out Water Temperature	21.60 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.60	25.90	26.00	25.90	26.10	26.20	25.40	24.80	24.40	23.60
Tube T [°C]	23.70	24.10	23.50	23.10	22.10	22.50	22.60	22.00	21.20	20.10

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.6 SPECIMEN 7

9.6.1 SETUP

No picture available

9.6.2 TEST 7AA

Water volume flow rate	80 cc/min
Electrical power – Voltage	8.6 V
Electrical power – Current	1.41 A

In Water Temperature	21.25 °C
Out Water Temperature	18.94 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.93	22.62	22.43	22.00	21.60	21.40	21.78	21.65	21.26	20.64
Tube T [°C]	22.25	21.89	21.41	20.74	20.56	19.84	20.86	20.50	20.10	19.35

9.6.3 TEST 7AB

Water volume flow rate	105 cc/min
Electrical power – Voltage	12.1 V
Electrical power – Current	1.99 A

In Water Temperature	21.13 °C
Out Water Temperature	17.58 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.74	24.46	24.26	23.65	22.92	22.63	23.46	23.28	22.51	21.47
Tube T [°C]	23.41	22.93	22.10	21.14	20.71	19.69	21.55	21.01	20.35	18.99

9.6.4 TEST 7BA

Water volume flow rate	cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.3 A

In Water Temperature	21.1 °C
Out Water Temperature	19.40 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	23.00	22.70	22.60	22.40	22.00	22.00	22.00	21.80	21.50	21.10
Tube T [°C]	22.30	22.10	21.60	21.20	20.80	20.90	20.90	20.60	20.30	19.80

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.6.5 TEST 7BB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12 V
Electrical power – Current	1.95 A

In Water Temperature	18.89 °C
Out Water Temperature	22.17 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.41	25.45	25.41	25.03	24.53	24.65	24.67	24.20	23.76	23.03
Tube T [°C]	24.19	24.15	23.61	22.94	22.20	22.61	22.56	21.90	21.46	20.62

9.6.6 TEST 7JB

Water volume flow rate	110 cc/min
Electrical power – Voltage	11.9 V
Electrical power – Current	1.87 A

In Water Temperature	19.30 °C
Out Water Temperature	21.80 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	26.20	26.30	26.50	26.10	25.90	25.60	25.70	25.00	24.40	23.50
Tube T [°C]	24.90	24.80	24.40	23.70	23.30	23.70	23.60	23.00	22.00	21.10

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.7 SPECIMEN 8

9.7.1 SETUP

No picture available

9.7.2 TEST 8AA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.38 A

In Water Temperature	19.16 °C
Out Water Temperature	17.42 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	20.95	20.64	20.47	20.02	19.62	19.33	19.86	19.71	19.41	18.94
Tube T [°C]	20.21	19.88	19.40	18.94	18.53	17.88	18.78	18.65	18.22	17.73

9.7.3 TEST 8AB

Water volume flow rate	105 cc/min
Electrical power – Voltage	12.2 V
Electrical power – Current	1.99 A

In Water Temperature	20.61 °C
Out Water Temperature	17.36 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.53	24.33	24.09	23.33	22.60	22.13	23.20	22.97	22.46	21.36
Tube T [°C]	23.06	22.58	21.89	21.13	20.49	19.18	21.07	20.83	19.93	18.94

9.7.4 TEST 8BA

Water volume flow rate	cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.3 A

In Water Temperature	17.80 °C
Out Water Temperature	18.94 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	20.98	20.84	20.69	20.35	19.91	19.65	19.75	19.86	19.56	19.12
Tube T [°C]	20.35	20.12	19.86	19.15	18.81	18.32	19.06	19.49	18.53	18.11

9.7.5 TEST 8BB

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Water volume flow rate	cc/min
Electrical power – Voltage	12.1 V
Electrical power – Current	1.9 A

In Water Temperature	17.57 °C
Out Water Temperature	19.87 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	23.83	23.91	23.76	23.28	22.62	22.22	22.79	22.74	22.17	21.17
Tube T [°C]	22.59	22.37	22.07	20.85	20.54	19.16	21.51	21.88	19.99	19.06

9.7.6 TEST 8JB

Water volume flow rate	cc/min
Electrical power – Voltage	12.0 V
Electrical power – Current	1.85 A

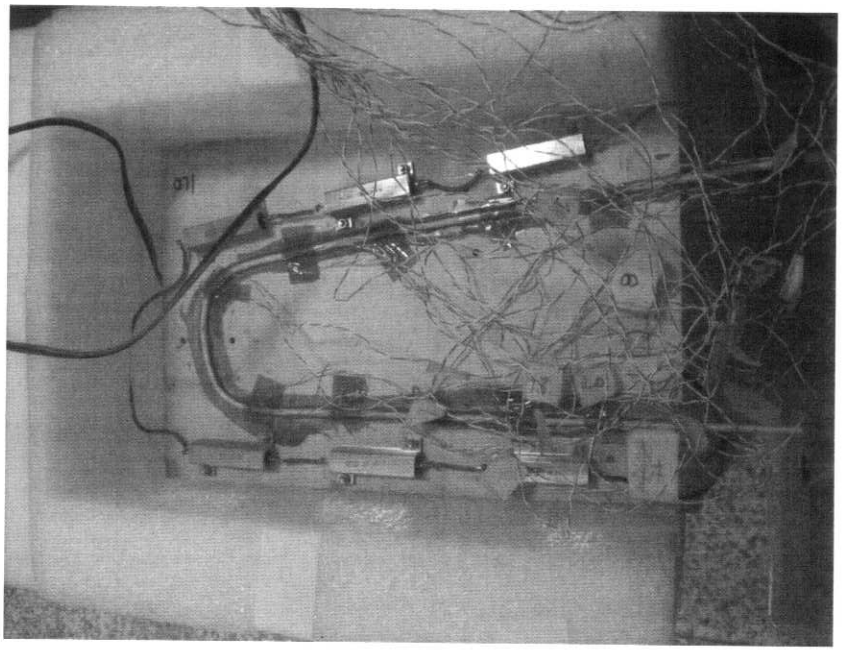
In Water Temperature	19.50 °C
Out Water Temperature	22.90 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	26.20	26.20	26.20	25.80	25.50	25.30	25.10	24.90	24.30	23.30
Tube T [°C]	24.90	24.70	24.30	23.80	23.10	22.50	23.20	22.40	21.70	20.90

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.8 SPECIMEN 9

9.8.1 SETUP



9.8.2 TEST 9AA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.38 A

In Water Temperature	17.91 °C
Out Water Temperature	19.75 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	21.38	21.15	20.99	20.53	20.39	20.09	20.35	20.33	19.85	19.68
Tube T [°C]	20.65	20.51	20.02	19.57	19.31	18.86	19.29	19.25	18.67	18.11

9.8.3 TEST 9AB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12.2 V
Electrical power – Current	1.99 A

In Water Temperature	16.69 °C
Out Water Temperature	19.95 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	23.22	23.18	23.06	22.33	22.31	21.76	22.30	22.39	21.44	21.15
Tube T [°C]	21.85	21.84	21.16	20.50	20.21	19.40	20.28	20.24	19.00	17.94

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.8.4 TEST 9BA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.3 A

In Water Temperature	16.32 °C
Out Water Temperature	17.96 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	19.89	19.64	19.57	19.23	19.10	18.77	18.85	18.92	18.69	18.72
Tube T [°C]	19.20	18.82	18.54	17.88	17.82	17.03	17.73	17.45	17.10	16.40

9.8.5 TEST 9BB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12 V
Electrical power – Current	1.95 A

In Water Temperature	16.99 °C
Out Water Temperature	19.93 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	23.42	23.24	23.23	22.70	22.56	22.03	22.22	22.35	22.02	22.11
Tube T [°C]	22.07	21.54	21.15	19.98	20.04	18.54	19.98	19.46	18.80	17.46

9.8.6 TEST 9JB

Water volume flow rate	110 cc/min
Electrical power – Voltage	11.7 V
Electrical power – Current	1.86 A

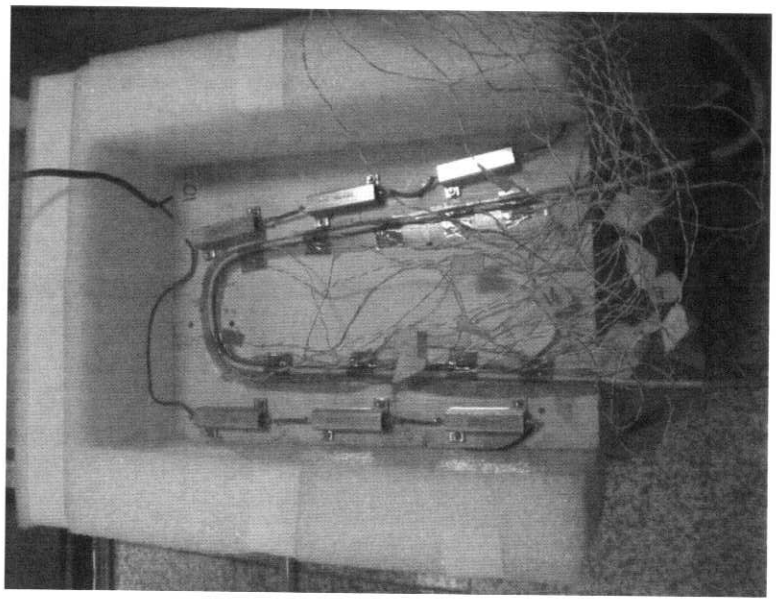
In Water Temperature	19.00 °C
Out Water Temperature	21.50 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.40	25.40	25.50	24.90	24.80	24.70	24.70	24.80	24.50	24.00
Tube T [°C]	23.70	23.60	22.90	22.00	22.10	21.90	22.10	22.10	21.20	19.90

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.9 SPECIMEN 10

9.9.1 SETUP



9.9.2 TEST 10AA

Water volume flow rate	90 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.34 A

In Water Temperature	16.55 °C
Out Water Temperature	18.66 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	19.89	19.83	19.78	19.62	19.04	19.38	19.27	19.00	18.66	18.16
Tube T [°C]	19.25	19.11	18.63	17.66	17.77	17.86	18.12	17.76	17.24	16.90

9.9.3 TEST 10AB

Water volume flow rate	100 cc/min
Electrical power – Voltage	12.1 V
Electrical power – Current	1.95 A

In Water Temperature	16.20 °C
Out Water Temperature	19.70 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	22.60	22.50	22.60	22.50	21.40	22.40	22.10	21.60	21.00	20.00
Tube T [°C]	21.30	21.10	20.10	18.70	18.70	19.20	19.90	19.20	18.20	17.50

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

9.9.4 TEST 10BA

Water volume flow rate	110 cc/min
Electrical power – Voltage	8.5 V
Electrical power – Current	1.3 A

In Water Temperature	16.70 °C
Out Water Temperature	18.26 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	20.18	19.89	19.95	19.87	19.83	19.69	19.46	19.27	18.90	18.31
Tube T [°C]	19.44	19.22	18.76	18.29	17.98	17.71	18.12	17.85	17.44	17.00

9.9.5 TEST 10BB

Water volume flow rate	110 cc/min
Electrical power – Voltage	12 V
Electrical power – Current	1.95 A

In Water Temperature	16.99 °C
Out Water Temperature	19.93 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	23.49	23.37	23.56	23.63	23.70	23.46	23.00	22.68	21.97	20.89
Tube T [°C]	22.14	21.95	21.27	20.63	20.04	19.56	20.49	19.94	19.14	18.26

9.9.6 TEST 10EB

Water volume flow rate	90 cc/min
Electrical power – Voltage	11.7 V
Electrical power – Current	1.81 A

In Water Temperature	18.60 °C
Out Water Temperature	21.70 °C

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	25.20	25.20	25.50	25.40	25.40	25.00	24.80	24.80	23.40	22.30
Tube T [°C]	23.80	23.90	23.20	22.30	21.90	21.50	22.70	21.70	20.60	19.80

9.9.7 TEST 10JB

Water volume flow rate	110 cc/min
Electrical power – Voltage	11.70 V
Electrical power – Current	1.86 A

In Water Temperature	19.00 °C
Out Water Temperature	21.50 °C

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

	T01-02	T03-04	T05-06	T07-08	T09-10	T11-12	T13-14	T15-16	T17-18	T19-20
Plate T [°C]	24.70	24.90	24.90	24.90	25.10	25.00	24.40	24.20	23.54	22.30
Tube T [°C]	23.20	23.00	22.50	21.40	21.20	21.00	21.80	21.30	20.30	19.40

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

10. TEST RESULTS

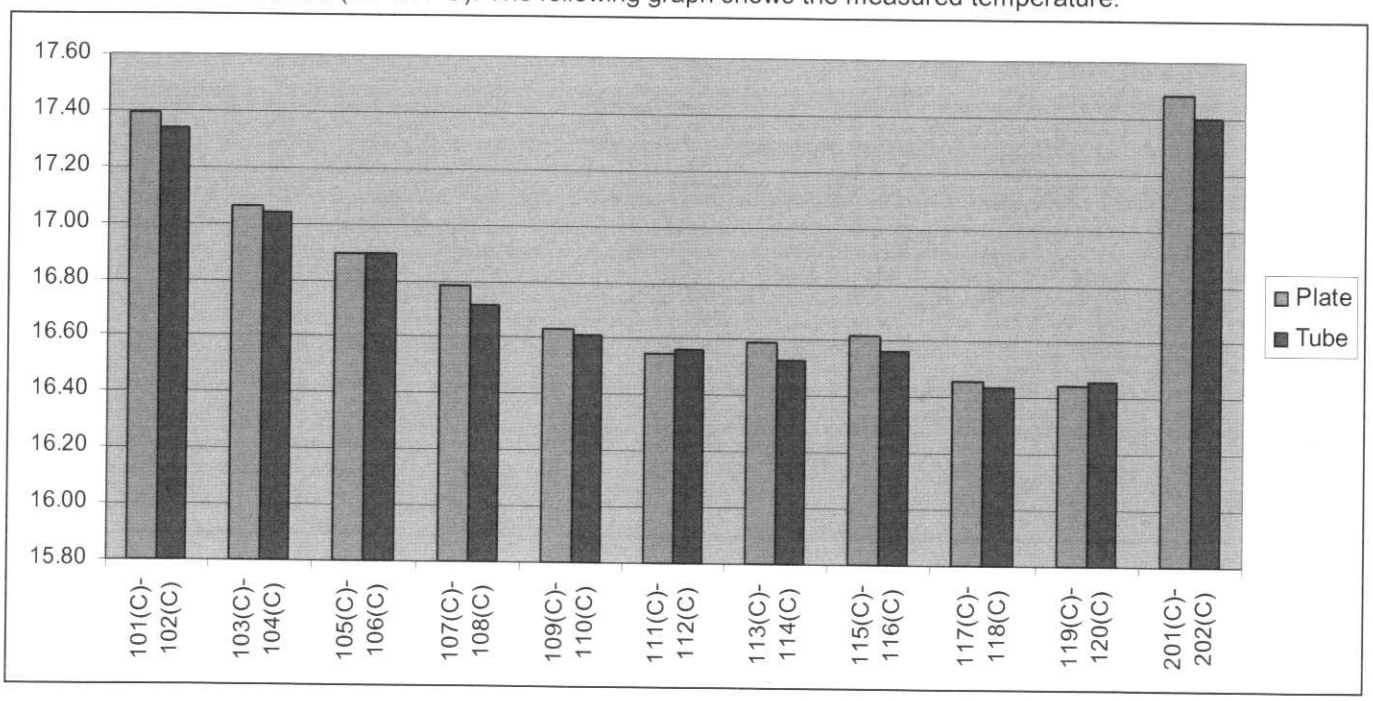
In this section the test results are summarized.
The following table presents the measured contact conductance per unit length for each specimen, before the liquid nitrogen bath.

Tab. 10-1 Before cooling results

# Specimen	TESTA - 12W			TESTB- 24W	
	K_g [W/K/m]	ΔK_g [W/K/m]		K_g [W/K/m]	ΔK_g [W/K/m]
Specimen 1	7.61	0.38		8.08	0.22
Specimen 2	10.64	0.53		7.51	0.38
Specimen 3	8.07	0.45		6.51	0.30
Specimen 4	8.03	0.5		8.54	0.39
Specimen 5	16.55	0.64		15.13	0.69
Specimen 6	17.30	0.87		16.98	0.77
Specimen 7	19.88	1.24		19.20	0.96
Specimen 8	19.80	0.94		18.98	0.86
Specimen 9	20.44	1.02		20.10	0.91
Specimen 10	17.90	0.99		16.41	0.82

As shown in the table, specimen from 5 to 10 have a better thermal conductance per unit length (more than double) than the first 4 specimen. The modification to the gluing process allows a significant performance improvement.

ΔK_g is the uncertainty due to the flow meter reading, that has a resolution of 10cc/min. an uncertainty of ±5cc/min has been assumed to calculate ΔK_g.
Thermocouples accuracy has been tested during the tests, measuring with each couple of thermocouples the temperature of some water in a glass at room temperature. No significant reading difference for each couple of sensors has been measured ($\Delta T<0.1°C$). The following graph shows the measured temperature.



Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Otherwise a significant temperature drift has been observed, but this do not affect thermal conductance measurement (based on the difference between each pair of near thermocouples). This drift is probably due to the temperature of the so called "reference junction", not constant inside the data-logger.

After the cooling of the specimen in liquid nitrogen no visible gluing failure has been observed. The figure below shows a gluing detail, before and after the nitrogen bath. No visible difference can be observed.

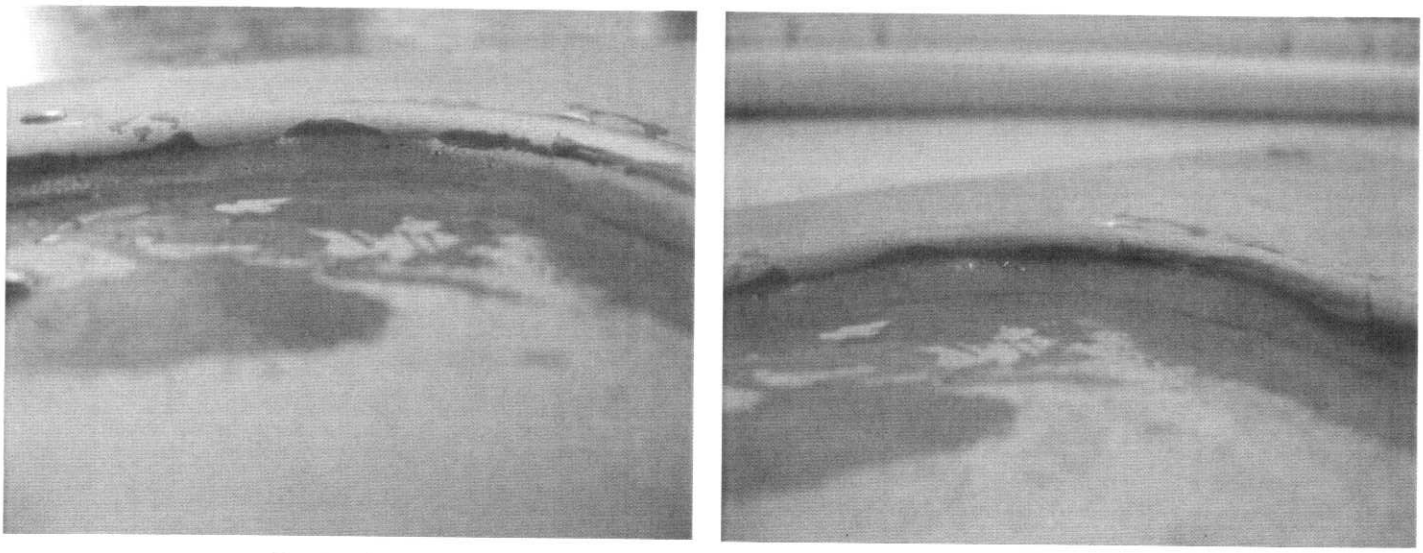


Fig. 8 – Specimen 6 detail before (left) and after (right) liquid nitrogen bath

Note that specimen from number 7 to 10 has been bathed only for about 1 hour, in order to analyze difference of performance degradation due to different "cooling history". The temperature profile for this cooling is shown in the following figure. In about 10 minutes the temperature falls from ambient temperature to about -193°C (close to LN2 evaporation temperature).

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

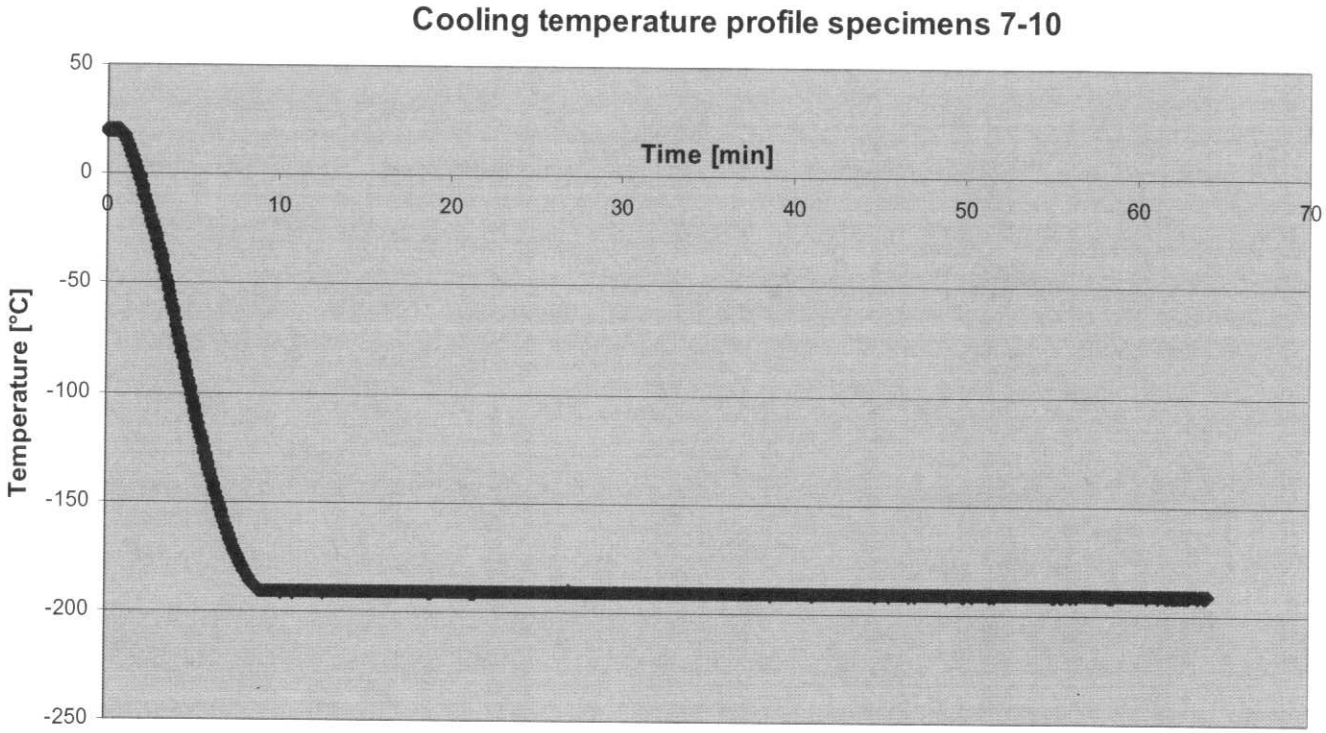


Fig 10-1 – Specimen 7-10 2nd cooling temperature profile - 1 hour cooling

The thermal conductance test has been repeated after the bathing only for the specimen that did not present evident debonding. For this reason specimens 1 and 2 have not been tested.

Tab. 10-2 After cooling results

# Specimen	TESTA - 12W			TESTB - 24W		
	K_g [W/K/m]	ΔK_g [W/K/m]		K_g [W/K/m]	ΔK_g [W/K/m]	Cooling duration
Specimen 1	debonded	-		-	-	-
Specimen 2	debonded	-		-	-	-
Specimen 3	4.36	0.18		4.54	0.19	8hr
Specimen 4	5.43	0.25		5.74	0.26	8hr
Specimen 5	12.79	0.58		12.41	0.52	8hr
Specimen 6	12.76	0.58		14.07	0.70	8hr
Specimen 7	18.65	0.93		19.22	0.96	1hr
Specimen 8	17.73	0.74		17.41	0.73	1hr
Specimen 9	17.09	0.78		16.79	0.76	1hr
Specimen 10	14.74	0.67		14.30	0.65	1hr

A performance degradation after the deep cooling in nitrogen has been measured. The table below shows a comparison between the measured thermal conductance per unit length before and after the cooling. In order to

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

compare performance before and after thermal cooling, the mean resulting values from test A and test B for each specimen, before and after cooling, have been faced up.
A mean degradation of 20% for specimens 5 and 6 (improved gluing procedure – 8 hours cooling) has been observed; A minor mean degradation (but very variable) has been observed instead for specimens from 7 to 10 (improved gluing – 1 hour cooling). Higher degradation has been measured in specimen 4 and 3 (not optimized gluing procedure – 8 hours cooling).

Tab. 10-3 Test results

specimen 3			***avg***				***avg***	***Difference***
TestA	*8.07*	*W/K/m*	**7.29**	TestA after LN2 bath	*4.36*	*W/K/m*	**4.45**	*-39%*
TestB	*6.51*	*W/K/m*		TestB after LN2 bath	*4.54*	*W/K/m*		
specimen 4								***Difference***
TestA	*8.03*	*W/K/m*	**8.29**	TestA after LN2 bath	*5.43*	*W/K/m*	**5.59**	*-33%*
TestB	*8.54*	*W/K/m*		TestB after LN2 bath	*5.74*	*W/K/m*		
specimen 5								***Difference***
TestA	*16.55*	*W/K/m*	**15.84**	TestA after LN2 bath	*12.79*	*W/K/m*	**12.60**	*-20%*
TestB	*15.13*	*W/K/m*		TestB after LN2 bath	*12.41*	*W/K/m*		
specimen 6								***Difference***
TestA	*17.3*	*W/K/m*	**17.14**	TestA after LN2 bath	*12.76*	*W/K/m*	**13.42**	*-22%*
TestB	*16.98*	*W/K/m*		TestB after LN2 bath	*14.07*	*W/K/m*		
specimen 7								***Difference***
TestA	*19.88*	*W/K/m*	**19.54**	TestA after LN2 bath	*18.65*	*W/K/m*	**18.93**	*-3%*
TestB	*19.20*	*W/K/m*		TestB after LN2 bath	*19.22*	*W/K/m*		
specimen 8								***Difference***
TestA	*19.80*	*W/K/m*	**19.39**	TestA after LN2 bath	*17.73*	*W/K/m*	**17.57**	*-9%*
TestB	*18.98*	*W/K/m*		TestB after LN2 bath	*17.41*	*W/K/m*		
specimen 9								***Difference***
TestA	*20.44*	*W/K/m*	**20.27**	TestA after LN2 bath	*17.09*	*W/K/m*	**16.94**	*-16%*
TestB	*20.10*	*W/K/m*		TestB after LN2 bath	*16.79*	*W/K/m*		
specimen 10								***Difference***
TestA	*15.91*	*W/K/m*	**16.16**	TestB after LN2 bath	*14.74*	*W/K/m*	**14.52**	*-10%*
TestB	*16.41*	*W/K/m*		TestB after LN2 bath	*14.30*	*W/K/m*		

The degradation is probably due to the different coefficient of thermal expansion of aluminium and of the used glue (Masterbond EP21TDC-2LO has a CTE of 90/100 in/in x10E-6°C aluminium 24 m/m x 10E-6°C). During the bath probably some non visible micro-debonding occurred, decreasing the contact thermal performance.

It's not completely understood if the duration of the exposure has a decisive impact on performance decreasing. Performance degradations are too scattered to definitely show a correspondence between the two variables.

Since this decreasing of performance has been noticed, in order to verify the behaviour of gluing after repeated exposure to cryogenic environment (as should happen during AMS-02 zenith radiator operative life), further liquid nitrogen bathes have been performed (each 1 hour long, except for 2nd bath on specimen 5 and 6, 8 hours long) on specimen number from 5 to 10 in order to make all the specimens to be thermally shocked 9 times (number of possible cooling down events due to ISS power outage).

.
The conductance measurement has not performed after each bath, in particular:

- Specimen 5 and 6 have been tested after 1st, 2nd, 4th and 9th bath;
- Specimen 10 has been tested after 1st, 4th and 9th bath;
- Specimen 7, 8 and 9 have been tested only after 1st and 9th bath.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Since in the previous tests almost the same results were recorded for TESTA and TEST2, only TEST2 (24W applied power) was performed on specimens after 4th and 9th bath.

As shown in the table below further degradations have been observed, but also after 9 bath in liquid nitrogen all the specimen have a conductance far above the minimum required value (5W/Km). For these test only the final value of conductance is shown (all test data such as temperatures and flow measurement are omitted).

Tab 10-1 - After different cooling history results

	before cooling	after 1st cooling	after 2nd cooling	after 4th cooling	after 9th cooling
specimen 5 [W/K/m]	15.84	12.60	10.73	11.78	9.3
specimen 6 [W/K/m]	17.14	13.42	12.20	10.66	11.47
specimen 7 [W/K/m]	19.54	18.93	NM*	NM*	14.4
specimen 8 [W/K/m]	19.39	17.57	NM*	NM*	16.7
specimen 9 [W/K/m]	20.27	16.94	NM*	NM*	12.82
specimen 10 [W/K/m]	16.16	14.52	NM*	12.67	12.1

The following graph summarize all the presented results; the red line represent the lower limit for thermal conductance. The uncertainty due to the flow-meter reading ΔK_g is also shown.

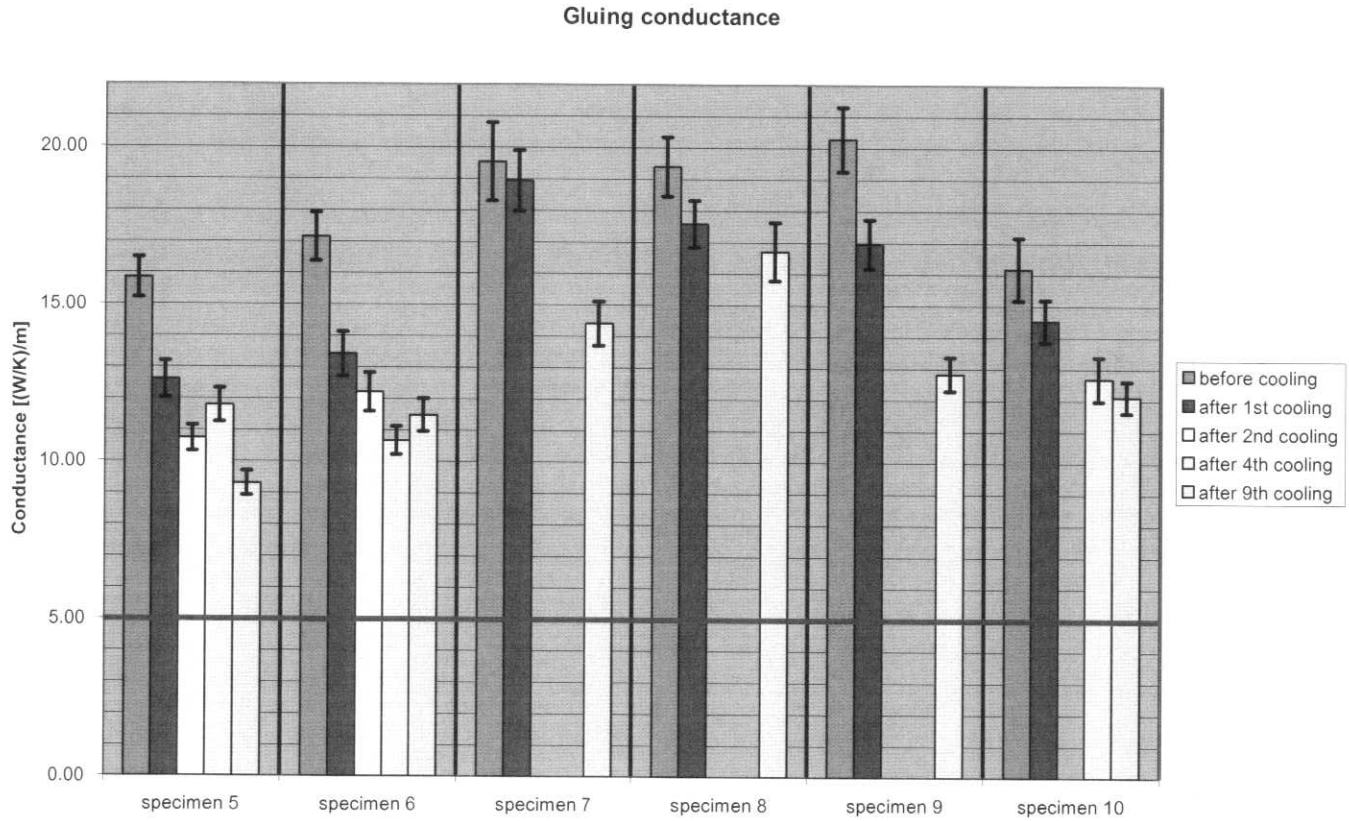


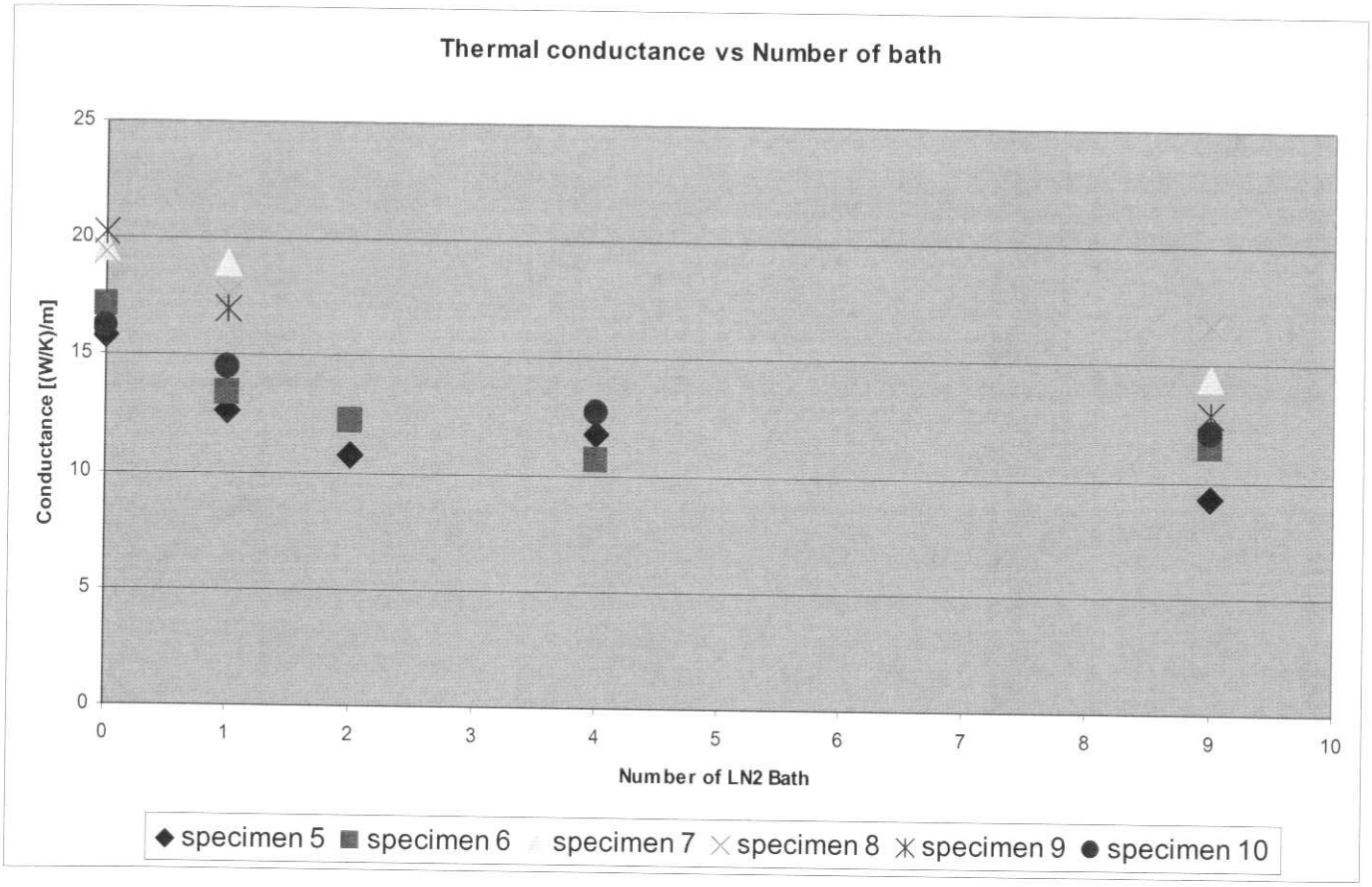
Fig 10-2 – Final results

* not measured

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

The strange behavior of conductance after 4th and 9th bath for specimen 5 and 6 is probably due to test uncertainty (especially flow meter reading).

The following graph also shows how the conductivity decrease with the increasing of the LN2 bath number.



11. CONCLUSIONS

Gluing procedure has a great impact not only on the bonding strength, but also on the thermal performance of the joint.

Gluing procedure used for the first 4 specimens, can not be considered a valid option for the gluing of the radiator FM: they have low thermal performance and after exposure at a cryogenic environment the performance fall near to the limit of 5W/K per unit length, that is considered the lowest limit for the radiator to work properly.

Instead gluing procedure used for the second set of 6 specimen instead permits better performance, not only in terms of mechanical strength (even if no mechanical tests have been performed, no debonding or visible failure have been observed) but also from a thermal point of view: the thermal conductance for unit length is far above the lower limit of 5W/K/m, also after a degradation due to several exposures at cryogenic environment.

After 9 repeated immersion in liquid nitrogen, thermal conductivity is – for specimens with improved gluing process - still higher than 5W/K/m that is consider to be the lower limit for AMS-02 zenith radiator application.

Gluing application is manual process and can give non repeatable results due to workmanship uncertainty. Some specimens show higher initial performance than others, and the same has been noticed for degradation. Anyway all the specimens tested have performance high above the minimum requirement.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Handling mechanical loads (due for example to transport or test set-up preparation), can also be a cause of the thermal performance degradation. Specimen 5 and 6 that have been tested – and therefore manipulated - 5 different times, show final performance that are lower than less tested specimens that have the same number of cooling cycles.

Using the modified gluing procedure, this technology assure good thermal conductance, as well as suitable mechanical properties for the application in AMS-02 zenith radiator.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

ANNEX A – GLUING PROCESS PROCEDURE

This annex contain the procedure (approved by CGS) used during the pretreatment/gluing/curing process at Politecnico di Milano.

1. **Tubes and plates production:**

   1.1. - Tubes modelling on a wood shape, realized as CGS sketch 30-AMS02TCS-000.00.01;
   1.2. - Aluminium Plate drilling to place the needed fixing tools and electrical resistances. Holes realized as attached CGS sketch.

2. **Tubes and plates surface treatment, specimen 1:**

   2.1. - Cleaning and Degreasing by acetone;
   2.2. - Plates sandblasting;
   2.3. - Tubes surface treatment by sandpaper, to increase surface roughness; take special care to not deform the tubes.
   2.4. - Cleaning by acetone.

3. **Glue mixing and application, specimen 1:**

   3.1. - Catalyser and resin mixing in a clean can, with a 1/3 weight ratio;
   3.2. - If air bubbles are observed, put the glue in vacuum for some minutes;
   3.3. - Application of a 0.2mm layer to both surface (tubes and plates) with a spatula.

4. **Curing, specimen 1:**

   4.1 - Tubes and plates joining by means of the provided fixing tools;
   4.2 - Vacuum bag realization on the joined parts to ensure a uniform contact between surfaces;
   4.3 - Vacuum maintaining in bag for 2-3 days at room temperature (20°C), or 3-4 hours at 65°C.

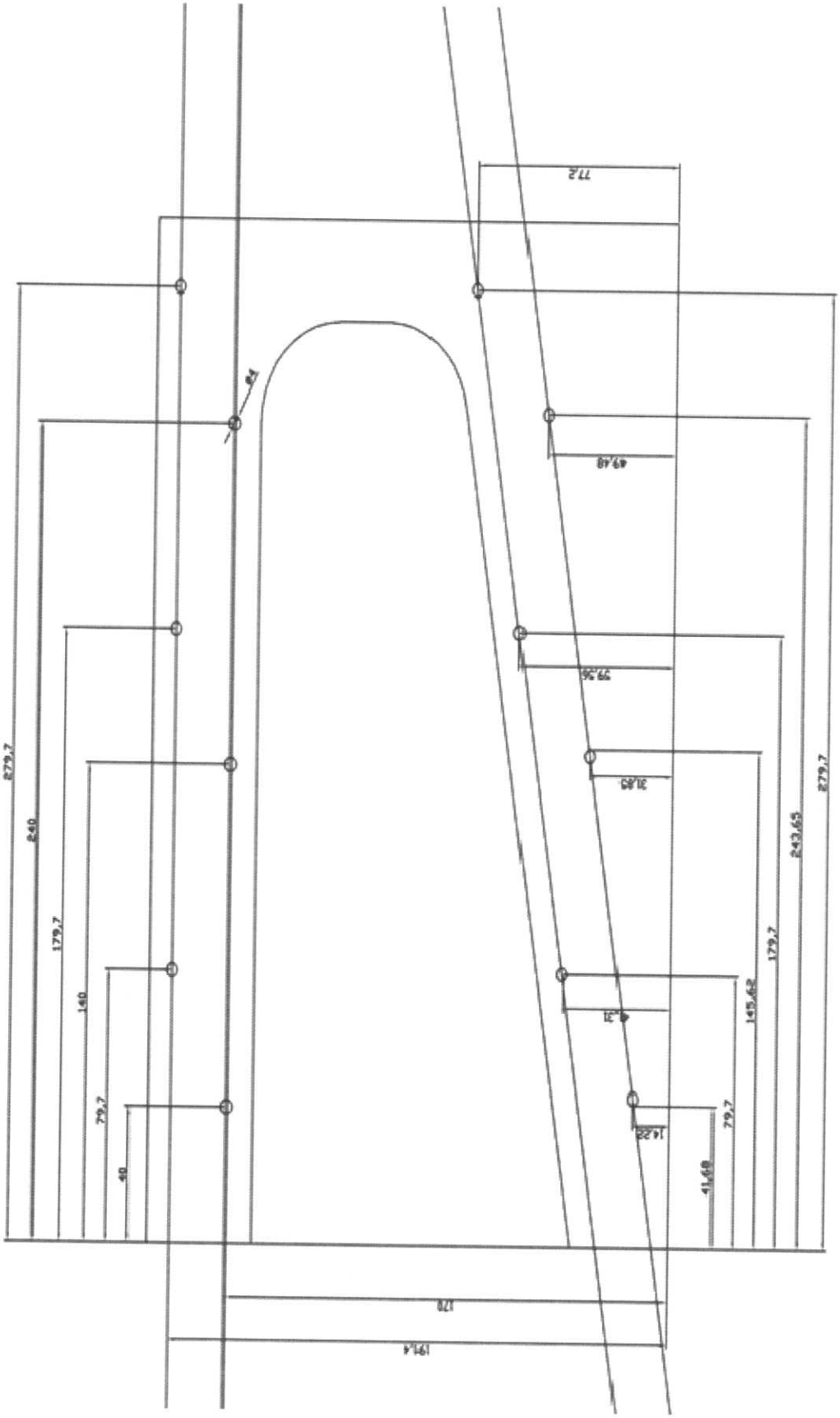
5. **Other specimens:**

   5.1 - Repeat from 2.1 to 4.3 for all specimens.

<u>New procedure changes (see RD1 for details)</u>

2.2 – visual control of plate planarity before and after the sandblasting process.
2.3 – tubes sandblasting;
3.3 – application of a 0.5mm thick x 10mm ca width layer of glue on the plate, with a shaped spatula.

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.



Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

ANNEX B – MASTERBOND EP21TDC-2LO DATASHEET

Technical Data Sheet

MASTER BOND POLYMER SYSTEM EP21TDC-2LO

Two Component, Low Outgassing Epoxy Resin Compound Featuring Flexibility and Thermal Conductivity For High Performance Bonding, Sealing, Coating, And Encapsulation. Cryogenically Servicable

Product Description

Master Bond Polymer System EP21TDC-2LO is a low outgassing two component highly flexible, thermally conductive epoxy resin compound for high performance bonding sealing, coating, and encapsulation. It is formulated to cure fully at ambient temperature or more quickly at elevated temperature with a convenient one to three mix ratio by weight. The cured compound exhibits high elongation and excellent toughness. As very little exotherm is developed during cure the Master Bond EP21TDC-2LO is suitable for potting and encapsulating thick as well as thin sectioned configurations. This epoxy resin compound exhibits superior tensile shear and peel strength for bonding and sealing applications. It adheres well to many different substrates including metals, glass, ceramics, rubber and plastics. The hardened composition is an excellent electrical insulator with outstanding resistance to chemicals including water, acids, bases and salts. The service temperature range is from 4°K to 250°F making it suitable for many cryogenic applications. Master Bond EP21TDC-2LO is widely used in the electronic, electrical, optical, fiberoptic, aerospace and other industries where low outgassing, flexibility, and thermal conductivity are desirable.

Product Advantages

- Convenient mixing: non critical one to three weight ratio
- Easy application: product spreads evenly and smoothly
- Versatile cure schedules: ambient temperature cures or fast elevated temperature cures as required
- High peel strength and elongation, excellent thermal shock and chemical resistance
- Superior bonding properties on similar and dissimilar substrates, superb impact resistance
- Excellent durability, high thermal conductivity combined with good electrical insulation properties.
- 100% reactive, no solvents, dilutes or volatiles emitted during cure or in service
- Cryogenically servicable; temperature range 4°K-250°F.
- Meets NASA low outgassing sepcifications.

Product Properties

- Mixing ratio, weight or volume, parts A to B 1/3
- Viscosity of mixed adhesive, 75°F, cps ..... paste
- Working life after mixing, 75°F, 100 gm mass, minutes ..... >90
- Cure schedule ambient temperatures, 75°F hrs ..... 48-72 hours
- Cure schedule ambient temperatures, 150°F hrs ..... 3-4 hours
- Tensile strength, psi, 75°F pli 1070
- Elongation, 75°F ..... >50
- Tensile shear strength, aluminum/aluminum, 75°F, psi ..... >980
- T-peel strength, 75°F pli ..... >15
- Hardness, shore D 25-30
- Water vapor permeability, gms/m2/24 hours ..... <0.5
- Moisture vapor transmission, gm/m2/24 hours ..... <0.5
- Volume resistivity, 75°F ohm cm ..... $>10^{12}$
- Thermal conductivity, BTU * in/ft^2 * hr * °F 9
- Thermal expansion coefficient, in/in x10^{-6}°C 90-100
- Service temperature range, ... 4K to 250°F
- Shelf Life, unopened containers @ RT 75°F ..... 6 months

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

Preparation of Compound for Casting or Bonding

Master Bond Polymer System EP21TDC-2LO is prepared for use by thoroughly mixing part A with part B in a one-to-three mix ratio by weight. Mixing should be done slowly to avoid entrapping air, stir until uniform. The working life of a 100 gm batch is in the order of 90 minutes. It can be substantially lengthened by using shallower mixing vessels or mixing smaller size batches. For bonding and sealing uses, matching surfaces should be carefully cleaned, degreased and dried to maximize bond strength. When bonding to metal surfaces, chemical etching should be employed when the bonded joints are to exhibit optimal environmental durability. Non-porous surfaces should be roughened with sandpaper or emery paper and solvent cleaned using acetone or xylene.

Compound Application and Assembly

Master Bond Polymer System EP21TDC-2LO can be conveniently cast or applied with a spatula, knife, trowel, etc. When bonding, enough (mixed) adhesive should be applied to obtain a final adhesive bond line thickness of 4-6 mils. This can be accomplished by coating each surface with an adhesive film of 2-3 mils thick. Porous surfaces may require somewhat more adhesive to fill the voids than non-porous ones. Thicker glue lines do not increase the strength of a joint but do not necessarily give inferior results as the EP21TDC-2LO compound does not contain any volatiles. The parts to be bonded should then be pressed together with just enough pressure to obtain and maintain intimate contact during cure.

Cure

Master Bond Polymer System EP21TDC-2LO can be cured at room temperature or at elevated temperatures as desired. At room temperature Master Bond Polymer System EP21TDC-2LO will cure in 2-3 days. Faster Cures can be realized at elevated temperatures, e.g. 3-4 hours at 150°F. Remove excess material promptly with a spatula before it hardens. Then wipe with rag and solvent such as isopropyl alcohol, toluene or acetone. Thinner sections of epoxy take longer to cure than thicker ones.

Handling and Storage

All epoxy resins should be used with good ventilation and skin contact should be minimized. The EP21TDC-2LO compound employs a low toxicity hardener. To remove resin or hardener from skin, use solvent, then wash with mild soap and water. If material enters the eyes, flood with water and consult a physician. Optimum storage is at or below 75°F in closed containers. No special storage conditions are necessary. Containers should however be kept closed when not in use to avoid contamination. Cleanup of spills and equipment can be achieved using acetone or xylene employing proper precautions of ventilation and flammability.

J8441500027

Master Bond Inc.

Adhesives, Sealants & Coatings • 154 Hobart Street • Hackensack, N.J. 07601-3922 • Tel: 201-343-8983
Internet Address: http://www.masterbond.com

→*Notice:* Master Bond believes the information on the data sheets are reliable and accurate as is technical advise provided by the company. Master Bond makes no warranties (expressly or implied) regarding the accuracy of the information, and assumes no liability regarding the handling and usage of this product.
D027

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

ANNEX C – THERMOCOUPLES AND ELECTRIC RESISTANCES POSITION

Approximate position of thermocouples and electric resistance.

Item	X position [mm]	Y position [mm]	Note
T01-02	50	160	T01 on the plate and T02 on the tube
T03-04	100	160	T03 on the plate and T04 on the tube
T05-06	150	160	T05 on the plate and T06 on the tube
T07-08	200	160	T07 on the plate and T08 on the tube
T09-10	250	160	T09 on the plate and T10 on the tube
T11-12	270	110	T11 on the plate and T12 on the tube
T13-14	220	75	T13 on the plate and T14 on the tube
T15-16	170	65	T15 on the plate and T16 on the tube
T17-18	120	55	T17 on the plate and T18 on the tube
T19-20	70	45	T19 on the plate and T20 on the tube
T21	N.A.	N.A.	At tube INLET, in water flow
T22	N.A.	N.A.	At tube OUTLET, in water flow
R01			Use the holes on the plates – on upper surface
R02			Use the holes on the plates – on upper surface
R03			Use the holes on the plates – on upper surface
R04			Use the holes on the plates – on upper surface
R05			Use the holes on the plates – on upper surface
R06			Use the holes on the plates – on upper surface

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.

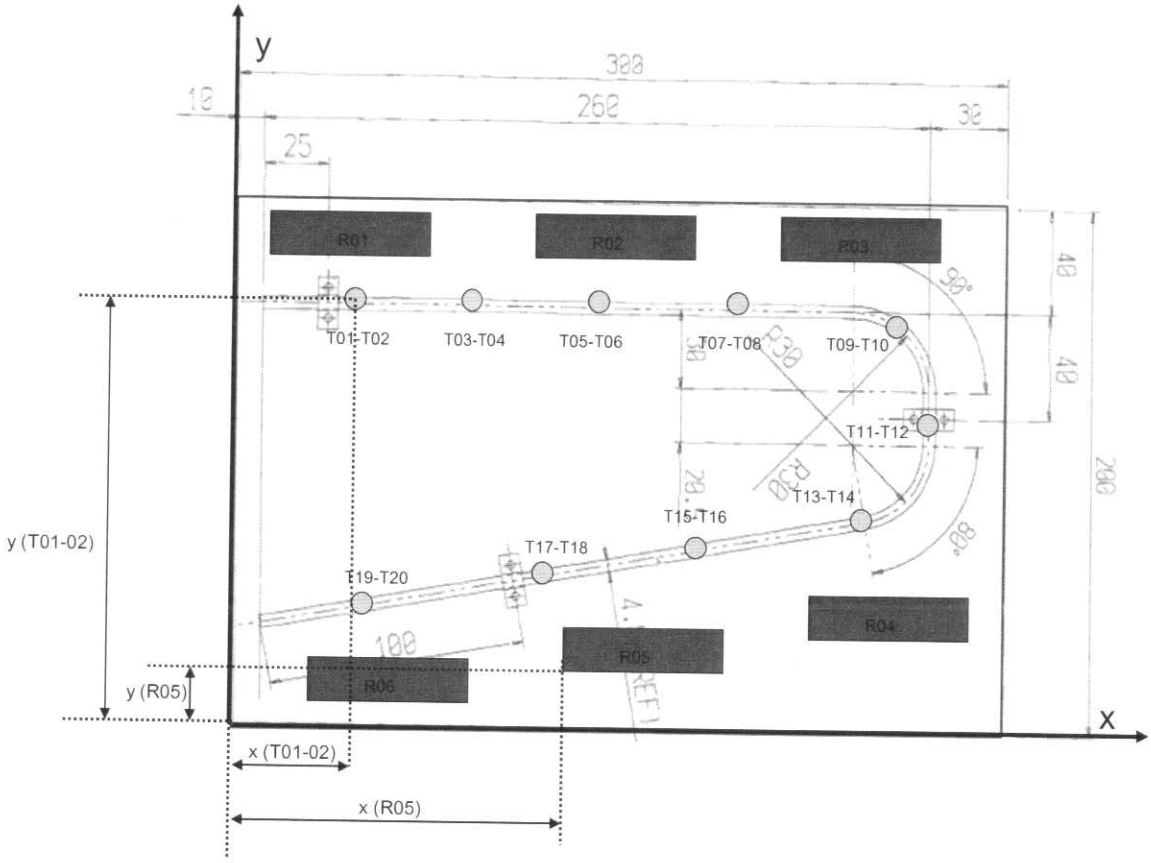


Fig. 9 - Reference system used for positions

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
All information contained in this document are property of CARLO GAVAZZI SPACE SpA. All right reserved.