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ENVIRONMENTAL TESTS OF THE ROBOT-X AIRFRAME (U)

by

S.G. Penzes, A.B. Markov,
A.E. Turner and B.G. Boulter*

Project No. 031SE

March 1987

* Boeing of Canada Ltd., Winnipeg, Manitoba

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ABSTRACT

// Environmental tests are described in which the ROBOT-X airframe was subjected to a wide range of ambient temperatures, from a minimum of −50°C to a maximum of +58°C. No unexpected problems were encountered. Valuable insight was gained into airframe thermal response under extreme ambient temperature conditions.//

ACKNOWLEDGEMENT

AETE support leading up to and throughout the week of testing was outstanding and included invaluable inputs and effort from the staff of the AETE environmental laboratory, the AETE Photo Section, and the CFB Cold Lake non-destructive testing facility. The efforts of Capt. R. Zuback, Sgt. J. Condron, Cpl. J. Kirkpatrick and Pte. B. Kennedy were particularly noteworthy and were instrumental in making the test series a logistical and technical success.

The timely instrumentation support of Mr. J. Vesso of Medicine Hat in the weeks prior to the trial were also essential to its successful completion and are gratefully acknowledged.

TABLE OF CONTENTS

Page

ABSTRACT ii
ACKNOWLEDGEMENT iii
TABLE OF CONTENTS iv
LIST OF TABLES v
LIST OF FIGURES vi

1. BACKGROUND 1

2. OBJECTIVES 2

3. INSTRUMENTATION 3

4. TEST PROCEDURES AND EVENTS 4

5. RESULTS AND OBSERVATIONS 7
   5.1 Comparison of Temperature Rise After Power-Up 9
   5.2 Environmental Evaluation of the ROBOT-X Structure .. 10
      5.2.1 Low Temperature Testing 11
      5.2.2 High Temperature Testing 12

6. SUMMARY AND RECOMMENDATIONS 13

TABLES
FIGURES

LIST OF TABLES

1. AIRFRAME CONFIGURATION
2. RECORDED DATA CHANNELS
3. HEAT SOURCES
4. RUN SUMMARY
5. SUMMARY OF ROBOT-X AVIONICS OPERATING TEMPERATURE RANGES
6. TEMPERATURE RISE IN CRITICAL AREAS
7. TEMPERATURE RISE IN AUTOPILOT AREAS

LIST OF FIGURES

1. ROBOT-X CONFIGURATION - TOP VIEW LOOKING DOWN

2. ROBOT-X CONFIGURATION - SIDE VIEW

3. ROBOT-X CONFIGURATION - AFT VIEW LOOKING FORWARD

4. ROBOT-X ENVIRONMENT ENVELOPE

5. ROBOT-X IN AETE ENVIRONMENTAL TEST CHAMBER

6. INSTRUMENTATION CONFIGURATION

7. AVIONICS BAY HEAT SOURCE NETWORK CONFIGURATION

8. DATA ACQUISITION EQUIPMENT AND INSTRUMENTATION

9a - 9c RUN NUMBER 1

10a - 10c RUN NUMBER 10

11a - 11c RUN NUMBER 14

12. LEFT CANARD X-RAY

13. RIGHT CANARD X-RAY

14. LEFT VERTICAL STABILIZER X-RAY

15. RIGHT VERTICAL STABILIZER X-RAY

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1. BACKGROUND

ROBOT-X is a rocket-boosted aerial target designed to simulate a variety of air threats for use in exercising air defence weapons systems. Its configuration is illustrated in Figures 1, 2 and 3. The airframe is made almost entirely of composite materials, with a length of 3.4 m and wing span of 2.4 m. Propulsion is by means of nineteen CRV-7 rocket motors, fired in pre-programmed stages. A wide variety of flight profiles may be achieved via the programmable microprocessor-based digital autopilot. The target is recovered by a parachute system. Flight tests conducted during 1986 have established the technical soundness of the ROBOT-X concept.

The ROBOT-X proof-of-concept program included extensive subsystem testing prior to the flight test program. One set of these tests involved subjecting the airframe to thermal extremes, in accordance with the ROBOT-X design environmental envelope shown in Figure 4. These tests were conducted at the Walk-In Temperature and Humidity (WITH) chamber at the Aerospace Engineering Test Establishment (AETE) at CFB Cold Lake.

Preliminary technical discussion with AETE staff took place in June 1984. These preliminary discussions identified a two phase program in the WITH chamber, as follows:

a) Phase 1 - investigation of the thermal inertia characteristics of the airframe and identification of airframe temperature related problems.

b) Phase 2 - fully integrated airframe/avionics temperature and humidity tests if found to be necessary based on flight test results.

The Phase 1 tests took place 10-15 March 1985. This report provides a summary of the objectives, test procedures, test instrumentation, test data and the resulting conclusions and recommendations.

2. OBJECTIVES

The primary objectives of the ROBOT-X AETE Phase 1 environmental tests were as follows:

a) To obtain quantitative data on the thermal characteristics of ROBOT-X airframe components that will house various avionics subsystems.

b) To identify airframe temperature related structural problems.

Secondary objectives included the following:

a) To evaluate the suitability of the WITH chamber for Phase 2 integrated airframe/avionics environmental tests.
b) To provide the DRES ROBOT-X project team with the opportunity to acquire background data and experience that will be required for the more complex Phase 2 tests, if the latter are required.

3. INSTRUMENTATION

The first flyable ROBOT-X airframe (S/N0001, Figure 5) delivered by Boeing of Canada Ltd. to DRES in January 1985 was instrumented at DRES with fourteen J-type thermocouples and with resistor networks to simulate the heat generation of the avionics subsystems. The configuration of this airframe is described in more detail in Table 1.

The thermocouple locations are defined in Table 2. Three of the thermocouples were externally mounted, one for test chamber ambient temperature, mounted on the right canard trailing edge and two external skin temperature thermocouples, one opposite the #10 thermocouple and the second acting as a rover whose location was defined by the test team as required. Two of the thermocouples were in the interface bay between the propulsion module and the forward fuselage, one in the auxiliary avionics bay, and the remaining eight in the avionics bay (Figure 6).

The heat source network characteristics are defined in Table 3 (see also Figure 7). The resistor networks were mounted on wooden blocks that were covered with aluminum foil to prevent local charring. A number of the heat sources were covered with metal covers so that a more representative distributed heat source resulted. The primary pitot-static probe was removed and the resulting opening in the nose used to run the instrumentation and source network wiring out of the vehicle (Figure 5).

In addition to the fourteen thermocouples, the voltage across and current drawn by the source networks were also monitored in order to provide accurate estimates of the power drawn at any given time. All sixteen channels were connected to an HP3497A data acquisition/ control unit configured for twenty analog-to-digital (A/D) channels and interfaced with an HP85 minicomputer using the HP-IB interface module. A second HP85 was available for analysis of test data concurrently with a test run. A Tektronix P6042 current probe was used as a test monitor and an HP power supply was used to provide 28VDC power to the heat dissipation networks. The data acquisition and power supply equipment as set-up at AETE are shown in Figure 8.

The DRES test team, consisting of two of the authors, travelled to AETE in a CFB Suffield crewcab and were essentially self-contained in terms of ROBOT-X instrumentation, data acquisition equipment and tools.

4. TEST PROCEDURES AND EVENTS

Prior to departure for AETE, the instrumented airframe and data acquisition system were set-up and operated at the Building 15 Test Complex at DRES in order to finalize the configuration of the heat source network, check the accuracy of the thermocouples, and debug any data acquisition hardware and software problems.

As a result of these preliminary tests, a number of heat source network changes were implemented. These included the addition of aluminum foil around the wooden blocks onto which the heat networks were mounted and the addition of metal covers around a number of these networks. The former change was as a result of charring of the wooden blocks due to the proximity of the hot resistors, and the latter in order to more representatively model the distributed nature of the real avionics components housings. This was particularly important in a number of areas where the heat sources where located very near the vehicle's external skin and acted too much as point or line sources.

In these preliminary tests, the proposed location of the X-band radar transponder in the upper auxiliary bay was also identified as a potential hot spot, to the degree that the structural integrity of the surrounding structure might be compromised. This network was thus isolated on a separate power line, allowing it to be shut down without turning off the other resistor networks.

Finally, the actuator servo heat source network was cut down to 25% of the peak power consumption value in order to be more representative of the average power consumed in a ROBOT-X flight.

After these preliminary tests, the airframe and all test equipment were disassembled, packaged and loaded onto a CFB Suffield crewcab and transported by the test crew to CFB Cold Lake on 10 March 1985. With the assistance of AETE staff, set-up of the airframe in the WITH chamber and the equipment in the AETE environmental laboratory took less than three hours on 11 March. AETE Photo Section personnel were called and took a series of pictures of the airframe and instrumentation. The first test runs took place on the afternoon of 11 March.

In general, two types of test runs were conducted. In the first type, the vehicle heat source network was turned on and temperatures were monitored until either the temperatures approached their equilibrium values or the most critical temperature reached +85°C. The latter limit had been established as being conservatively safe in not resulting in any permanent heat damage to exposed airframe structural components.

The second type of test run consisted of temperature monitoring without the heat sources being on after either a heat-on phase or after the WITH chamber ambient temperature had been changed.

As humidity testing was not part of this test series, no attempt was made to control the humidity of the test chamber. Airframe inspections were conducted when convenient.

A total of seventeen formal runs were conducted 11-15 March, and the data from each run was stored on an HP200 data cartridge.

Temperature return to equilibrium was monitored overnight on a number of runs. AETE fire safety considerations did not allow overnight cold and hot soaks, and therefore the heat sources and environmental chamber were always turned off during the overnight runs.

Quick-rep data reduction and analysis were conducted on all runs using the available HP reduction and analysis software. AETE staff also provided large format temperature versus scan number (time) plots for a number of critical channels and test runs. All of the results were logged and returned to DRES for further analysis.

The last run was completed on the morning of 15 March. AETE Photo Section personnel were called in to take pictures of a number of structural cracks that had developed during the tests. As well, the cracked components were x-rayed in the CFB Cold Lake nondestructive testing facility.

The airframe and test equipment were dismantled, packaged and loaded onto the crewcab. The DRES test crew returned to DRES on 16 March.

5. RESULTS AND OBSERVATIONS

A total of seventeen runs were recorded as summarized in Table 4. The humidity and pressure data in this table are based on CFB Cold Lake Met Section reports (pressure data are given as altimeter settings), and are provided as general reference information. No attempt was made to control or measure WITH chamber ambient humidity and pressure.

Representative data are presented graphically in Figures 9 through 11 inclusive. These runs (numbers 1, 10 and 14) were selected to illustrate the response of the system at room (20°C), cold (-40°C) and hot (40°C) temperatures. Figures 9 through 11 are presented graphically as three sets (e.g. 9a through to 9c inclusive), as follows:

Set a - Channels 1 through 8 inclusive.
Set b - Channels 2 and 9 through 14 inclusive.
Set c - Channels 2, 3, 7 and 9 (ambient chamber temperature and temperatures in critical hot areas).

The traces of channels 13 and 14 present air temperatures near the left and right side autopilot modules. The autopilot modules are the most restricted in terms of operating temperature environment (selected electronic components are specified for 0°C on the cold end and one, the ADF receiver, is specified to only 55°C on the hot end; see Table 5).

The traces of channels 5 and 6 present air temperatures in the interface avionics bay, in particular in the areas where the RISER and telemetry transmitter modules are located. The TM transmitter temperature range is quite large (-30°C to +71°C, Table 5) and the range for the RISER module is even larger (-55°C to 80°C).

The 'c' plots summarize temperatures in three critical hot areas, that is

Channel 3 - auxiliary avionics bay upper compartment air temperature,
Channel 7 - forward avionics bay bulkhead starboard air temperature,
Channel 9 - mid-avionics bay upper skin temperature (bottom of parachute bay).

One pair of thermocouples was configured to measure skin temperatures on opposite sides of the vehicle's structure. This pair consists of the number 1 (external skin temperature, bottom dead centre) and number 10 (mid-avionics bay internal bottom skin temperture) thermocouples. This pair has provided data that may, if required, be interpreted as a measure of the thermal conductivity of the vehicle's skin.

The remaining discussion on the results and observations associated with the Phase 1 tests will be organized as two subsections, one (Section 5.1) on a comparison of temperature rises after power-up and the second (Section 5.2) on the structural deficiencies that were identified during the tests.

5.1 Comparison of Temperature Rise After Power-Up

Table 6 compares the temperature rise in the three "hot" areas of the system, i.e. the auxiliary avionics bay upper compartment, the right forward bulkhead and the upper mid-avionics bay. The comparisons are made for scans 1, 10 and 20, corresponding, respectively, to time 0, 18 minutes and 38 minutes after the start of a run.

For each area the temperature rise over 10 samples and over 20 samples is roughly independent of ambient temperature. Significant differences are noted between the different areas, as might be expected due to the variation of the heat transfer mechanisms occurring inside the vehicle.

Table 7 gives an analogous comparison of temperatures in the left and right autopilot areas of the avionics bay. The right side autopilot temperatures, corresponding to the side containing the autopilot card cage, shows a greater temperature rise than the left side, with an approximately 10°C rise after 10 scans and 20°C after 20 scans.

A useful "rule of thumb" may then be seen to be that in the autopilot card cage area the temperature rises approximately 0.5°C per minute after start-up. This rule is roughly independent of temperature and applies for 40 minutes after power-up.

In ROBOT-X flights 2 (4 July 1986) and 3 (29 August 1986), possible autopilot card cage temperature problems were encountered when the right side avionics bay temperatures reached approximately 37°C. These were probably caused by local hot spots internal to the card cage near a temperature sensitive chip, and were alleviated by venting the autopilot card cage. While this problem is resolved, the "rule of thumb" provides a conservative guide for the minimum operating time prior to overheating.

The observed temperature rise in the vehicle in a flight configuration seems to be slower than that observed in these tests, probably due to the additional heat required to increase the temperature of the avionics. The latter was not present in the AETE environmental tests, and represents a considerable heat sink.

The autopilot card cage contains electronic components whose operating range has a lower limit of 0°C (Table 5). While the results of these tests suggest that at ambient temperatures down to -30°C, self-heating would be sufficient to raise the temperature to or above 0°C, this can be a slow process. The approach currently being taken of preheating the autopilot card cage expedites the launch process in cold environments.

5.2 Environmental Evaluation of the ROBOT-X Structure

Discussion of the structural response of the ROBOT-X airframe due to temperature variations can reasonably be limited to the two temperature extremes due to the increased probability of structural damage at these extremes. During this phase of the environmental tests the low end extreme was approximately -50°C while the high end extreme was approximately +58°C. The following two subsections discuss the structural response as a consequence of testing at these temperatures.

5.2.1 Low Temperature Testing

At -40°C the effects most noticeable are those due to internal stresses in excess of the failure stress. Most noteworthy are the stress cracks which were clearly visible in the Instant Set Polymer (ISP) castings used in the canards, wings and vertical stabilizers.

The most critical cracks are those in the two canards. Of these the most notable is the one generated at the cast in end of the canard shaft (see Figures 12 and 13). Residual stresses due to casting which involves dissimilar materials are to be expected. In the case when the aluminum shaft is placed into the mold for casting with the ISP, the end fixture (the hole at the end of the shaft) provides a semi-enclosed region in which residual stresses are induced due to the effects of casting setting rates. In addition to these residual stresses, a stress concentration factor caused by the geometry of the end fixture must also be considered. The third and most important factor leading to the generation of these stress fractures is the thermal stresses induced by the mismatch of the coefficients of thermal expansion (CTE) of the two materials used. The ISP used has a CTE of about 32 ppm/°C while aluminum has a CTE of about 25 ppm/°C. When combined with the residual stresses and the stress concentration, the stresses induced by the CTE mismatch at -40°C appears to be sufficient to initiate the stress cracks. Considering the embrittlement of plastics at low temperatures, the stress cracks once initiated follow a path of least resistance until they are stopped by a free surface.

The vertical stabilizers do not show stress cracks to the same extent as the canards. This is primarily due to the fact that there is no dissimilar material to produce the stresses due to a CTE mismatch. Examination of Figures 14 and 15 tends to indicate that the stress concentration due to the sharp corners in the magnetometer housing and flight test boom attachment fixture becomes the predominant contributor to crack generation. Since the stabilizers will not be subjected to the same magnitude of flight induced stresses, the cracks in them can be assumed to be inconsequential.

One of the results of this series of environmental tests is that BOC has investigated means to reduce the CTE of ISP. Some success has been achieved through the incorporation of glass fibres into the casting. The result is that the CTE has been reduced to about 11 ppm/°C. Canards using this modification have been manufactured and tested by BOC to -40°C and they show no indication of thermal stress fractures in the unloaded condition. Thermal tests under load were not conducted.

5.2.2 High Temperature Testing

BOC engineers have estimated that +85°C is a conservative high temperature limit at which structural degradation may be expected to begin. In the present tests, the highest temperatures were experienced during runs number 14 and 16.

During run number 16 the ambient temperature was targeted for 55°C. The hottest location (corresponding to thermocouple #7) reached the 85°C limit in about 24 minutes, at which time the heat networks were turned off. During run number 14 (see Figure 11) the ambient temperature was about 42°C when the hottest location reached 85°C and the networks were switched off. This occurred after approximately 90 minutes.

The conclusion to be reached from these runs is that the time required to reach the critical temperature of 85°C is considerably longer than would occur during actual target operations. The actual components that were being modelled by the heat networks, are not turned on long enough (both during preflight and flight) to exceed the rise times indicated by these runs.

During flight tests, when long periods of operation may be necessary in preflight preparation and check-out, critical vehicle internal temparatures will have to be monitored in order to avoid overheating. As well, particular care will have to be taken during long exposures to direct sunlight.

6. SUMMARY AND RECOMMENDATIONS

The environmental tests conducted on the ROBOT-X airframe 10-15 March 1985 in the AETE Walk-In Temperature and Humidity Chamber confirmed canard and vertical stabilizer cold temperature structural problems and provided an extensive data base on vehicle thermal characteristics.

There were two main limitations to the tests:

(a) The tests were conducted with heat sources simulating the heat generated by the avionics, not the actual avionics. While the heat generation is representative, the heat sink properties of the avionics modules have not been taken into account and should be considered in interpreting the data.

(b) Heating caused by direct radiation from the sun was not considered, and is likely to be a factor in hot, sunny weather.

The conclusions arising from the tests are as follows:

(a) Preheat is required in cold temperatures in order to minimize warm-up times.

(b) Structural overheating due to "hot" avionics is not likely to be a problem except in very hot ambient conditions after substantial operating times (30 minutes or more at an ambient of 50°C).

(c) The canard and vertical stabilizer cold temperature structural problems have been confirmed, and have been addressed.

(d) The ADF receiver, with an operating temperature range of -20 to 55°C, could pose a problem under hot ambient conditions for operating times exceeding 40 minutes.

(e) As the actual flights are expected to be of relatively short duration, and there is additional cooling due to slipstream effects, overheating in flight is not expected to be a problem.

(f) In protracted operating conditions in sunny ambient conditions, overheating may be a problem and may require active cooling of the avionics bay or selected components within the avionics.

The recommendations arising from these tests are as follows:

(a) While it is not necessary to repeat WITH Chamber tests of a POC airframe complete wit h functioning avionics, it is recommended that tests be conducted at ambient room temperatures with avionics functioning. This will eliminate uncertainties in the Phase 1 tests produced by the lack of thermal inertia of the full avionics subset.

(b) It is recommended that some of these tests be conducted with radiation sources simulating solar radiation on the vehicle.

(c) It is recommended that these tests be repeated with prototype advanced development models once these are available.

(d) It is recommended that whenever possible, consideration should be given to painting the vehicle fuselage in light reflective colours in order to minimize solar heat absorption.

(e) The canard and vertical stabilizer cold temperature problems could be flight critical. Fixes currently implemented for POC flight testing should be reviewed in advanced development.

TABLE 1 AIRFRAME CONFIGURATION

COMPONENT	SERIAL NUMBER	REMARKS
Nosecone		• Frangible nose structure in place. • Pitot-static probe removed.
Forward Fuselage	0001	• O-ring aft bulkhead seal not in place. • Aft and forward bulkhead connectors not installed (taped over with gun tape). • Canard servo loosely mounted. • Parachute main canopy installed.
Propulsion Module	0001	• Rocket motors not installed.
Recovery Bay Door	0001	• Rested on top of recovery bay opening (not bolted down).
Left Wing	0001 01012002-1 Assy	• Aileron and aileron servo installed. • Dummy primary root bolt was used.
Right Wing	0001 01012002-2 Assy	• Aileron installed (aileron servo not installed). • Dummy primary root bolt was used.
Left Aileron		• Noticeable bumpiness on aileron surface prior to tests.
Right Aileron		

TABLE 1 AIRFRAME CONFIGURATION (cont'd)

COMPONENT	SERIAL NUMBER	REMARKS
Avionics Bay Beam	0001	
Left Vertical Stabilizer	0001	• The flight test boom fitting interface (but not the flight test boom) was installed.
Right Vertical Stabilizer	0002	• The magnetometer fairing (but not the magnetometer) was installed.
Left Canard	0002	
Right Canard	0001	• The WITH chamber ambient temperature thermocouple was taped to the right canard.
Left Aileron Servo	R1205	• M/N DR2148M51
Right Aileron Servo	-----	• Not installed.
Canard Servo	R1206	
ADF Antenna		• Antenna only for King KR87 ADF, no associated cabling or receiver unit.
Radar Altimeter Antenna		• Antenna only for King KRA 10A radar altimeter, no associated cabling or R/T unit.

TABLE 2 RECORDED DATA CHANNELS

SOFTWARE LABEL	SLOT/CARD TYPE	CARD TERMINALS	CHANNEL	TYPE OF TRANSDUCER	FUNCTION	APPROXIMATE LOCATION (FS in cm)	REMARKS
EX SK T (LOW)	0/44422A	A1	1	Type J Thermocouple	Temperature	105	External skin temperature, bottom dead centre opposite #10 thermocouple.
AMB TEMP	0/44422A	A1	2	"	"	85	Ambient WITH chamber temperature; taped to right canard.
AX BAY (UP)	0/44422A	A3	3	"	"	65	Auxiliary avionics bay top compartment air temperature.
ROVER	0/44422A	A4	4	"	"	60	Rover thermocouple attached to monitor external skin temp, top dead centre.
INTF(UP)	0/44422A	A5	5	"	"	170	Interface bay top compartment air temperature.
INTF (LOW)	0/44422A	A6	6	"	"	170	Interface bay bottom compartment air temperature.
FOR BLK (R)	0/44422A	A7	7	"	"	72	Forward bulkhead starboard side air temperature.
FOR BLK (L)	0/44422A	A8	8	"	"	72	Forward bulkhead port side air temperature.
MID AB (UP)	0/44422A	A9	9	"	"	109	Mid avionics bay top skin temperature (bottom of parachute bay).

TABLE 2 RECORDED DATA CHANNELS (cont'd)

SOFTWARE LABEL	SLOT/CARD TYPE	CARD TERMINALS	CHANNEL	TYPE OF TRANSDUCER	FUNCTION	APPROXIMATE LOCATION (FS in cm)	REMARKS
MID AB (LOW)	0/44422A	B0	10	Type J Thermocouple	Temperature	105	Mid avionics bay internal bottom skin temperature.
CRISIS	0/44422A	B1	11	"	"	103	Avionics bay air temperature near CRISIS module.
CR REC	0/44422A	B2	12	"	"	108	Avionics bay air temperature near command receiver module.
AP (R)	0/44422A	B3	13	"	"	125	Avionics bay air temperature near autopilot avionics, starboard side.
AP (L)	0/44422A	B4	14	"	"	130	Avionics bay air temperature near autopilot avionics, port side.
AMPS	0/44422A	B5	15	1 V	Heat Diss. Network Current	N/A	From current probe (Textronix P6042).
VOLTS	0/44422A	B6	16	100 V	Heat Diss. Network Voltage	N/A	From heat source network power supply.

TABLE 3 HEAT SOURCES

NETWORK NO	SIMULATED COMPONENT	LOCATION FS (cm) (approximate)	RESISTANCE			CURRENT		POWER	
			RATED W	ACTUAL W @ 28 VDC	Ω	RATED A	ACTUAL A @ 28 VDC	RATED W @ 28 VDC	ACTUAL W @ 28 VDC
1	AUTOPILOT	Avionics Bay 128	50	31.36	25	1.25	1.12	35	31.36
2	AUTOPILOT	Avionics Bay 127	75	31.36	25	1.25	1.12	35	31.36
3	CANARD SERVO MOTOR	Auxiliary Avionics Bay 65	50	15.68	50	0.5	0.56	14	15.68
4	TRANSPONDER	Auxiliary Avionics Bay 60	50	39.2	20	1.6	1.4	44.8	39.2
5	TELEMETRY TRANSMITTER	Interface Bay 170	50	15.68	50	0.5	0.56	14	15.68
6	PCM ENCODER	Avionics Bay 96	25	10.5	75	0.4	0.373	11.2	10.5
7	AUTOPILOT/PCM ENCODER INTERFACE	Avionics Bay 96	50	15.68	50	0.5	0.56	14	15.68
8	SIGNAL CONDITIONING	Avionics Bay 92	170	100.3	7.78	3.6	3.59	100.8	100.3

NOTE: The CRISIS module and ground command receiver heat generation characteristics were negligible in terms of total wattage and were not modeled. The aileron servos were not modeled as they do not contribute significantly to heating of the auxiliary, main or interface avionics bays.

TABLE 4 RUN SUMMARY

RUN NO	DATE	TIME		AMBIENT CONDITIONS						DATA CARTRIDGE NUMBER	REMARKS
				TEMPERATURE (°C) (THERMOCOUPLE 2)		OUTSIDE RELATIVE HUMIDITY (%)		PRESSURE (in Hg)			
		START	END	START	END	START	END	START	END		
1	11 Mar 85	1416	1623	21.5	22.3	47	48	?	?	1	● Ambient run, door open. ● 100% heat generation @ 28 VDC. ● 28 VDC checked through data acquisition system. ● At 1441 rover moved to spot on exterior of auxiliary avionics bay that is warmest to the touch
2	11 Mar 85	≈1630	0815 (nextday)	22.9	19.8	48	68	?	?	2	● Heat sources turned off. ● Cool-down monitored overnight.
3	12 Mar 85	0818	1039	13.2	- 1.1	68	61	?	29.91	3	● Cold soak monitored. ● Heat sources off. ● Very rapid cooling of ambient to near 0°C. ● Objective was to cool to near 0°C but chamber did not have good temperature stability.
4	12 Mar 85	1044	1300	- 2.2	- 0.4	61	61	29.91	29.74	4	● Heat sources off.
5	12 Mar 85	1306	1538	- 8.1	-21.0	61	41	29.74	29.70	5	● Turned off heat sources and commenced cooling to -20°C.
6	12 Mar 85	1540	1710	-24.3	-25.4	41	55	29.70	29.69	6	● Heat sources off.

TABLE 4 RUN SUMMARY (cont'd)

RUN NO	DATE	TIME		AMBIENT CONDITIONS						DATA CARTRIDGE NUMBER	REMARKS
				TEMPERATURE (°C) (THERMOCOUPLE 2)		OUTSIDE RELATIVE HUMIDITY (%)		PRESSURE (in Hg)			
		START	END	START	END	START	END	START	END		
7	12 Mar 85	1713	0935 (nextday)	-22.5	-41.3	55	69	29.69	29.81	7	• Heat sources off. • Door left closed, chamber turned off. • Chamber turned on next morning circa 0600 for cool down to -30°C.
8	13 Mar 85	0938	1200	-34.8	-32.7	69	44	29.85	29.86	8	• Heat network on.
9	13 Mar 85	1207	1405	-32.8	-40.7	44	36	29.86	29.94	9	• Heat network off. • Chamber temperature targeted for -40°C.
10	13 Mar 85	1409	1525	-41.8	-39.4	36	36	29.94	29.96	10	• Heat network on. • Chamber temperature targeted for -40°C. • Dimpling on both vertical stabilizers observed.

TABLE 4 RUN SUMMARY (cont'd)

RUN NO	DATE	TIME		AMBIENT CONDITIONS						DATA CARTRIDGE NUMBER	REMARKS
				TEMPERATURE (°C) (THERMOCOUPLE 2)		OUTSIDE RELATIVE HUMIDITY (%)		PRESSURE (in Hg)			
		START	END	START	END	START	END	START	END		
11	13 Mar 85	1527	1650	-38.0	-48.5	36	33	29.96	29.97	11	• Parachute taken out. • Heat network off. • Parachute bay door placed on top of bay but not secured. • Collapse on vertical stabilizers confirmed by direct inspection; cracks on canards noted and photographed. • Chamber temperature targeted for -48°C. • Heat network turned on at 1605.
12	13 Mar 85	1650	0833 (nextday)	-50.0	17.3	33	86	29.97	29.94	12	• Overnight run, chamber door left open. • Heat network off.
13	14 Mar 85	0847	1046	19.6	38.4	86	64	29.94	29.87	13	• Heat network off. • Chamber temperature targeted for 35°C. • Parachute refitted into recovery bay.

TABLE 4 RUN SUMMARY (cont'd)

RUN NO	DATE	TIME		AMBIENT CONDITIONS						DATA CARTRIDGE NUMBER	REMARKS
				TEMPERATURE (°C) (THERMOCOUPLE 2)		OUTSIDE RELATIVE HUMIDITY (%)		PRESSURE (in Hg)			
		START	END	START	END	START	END	START	END		
14	14 Mar 85	1049	1251	38.9	42.1	64	41	29.87	29.78	14	• Heat network on. • Chamber temperature targeted for 35°C. • Power turned off when #7 thermocouple (fwd. bulkhead, starboard) reached 85°C.
15	14 Mar 85	1252	1451	42.9	57.7	41	56	29.78	29.74	15	• Heat network off. • Chamber temperature targeted for 55°C.
16	14 Mar 85	1453	1553	57.6	57.3	56	56	29.74	29.74	16	• Heat network on. • Heat network turned off when critical temperatures reached 85°C. • Cool-down after turn off monitored. • Chamber temperature targeted for 55°C.
17	14 Mar 85	1555	0806 (nextday)	57.4	22.7	56	58	29.74	30.02	17	• Heat network off. • Chamber heaters turned off. • Door to chamber opened. • Monitored overnight.

TABLE 5 SUMMARY OF ROBOT-X AVIONICS OPERATING TEMPERATURE RANGES

ITEM	DESCRIPTION	LOCATION	MODEL NO.	MIN (°C)	MAX (°C)	REMARKS
1	Autopilot Electronics	AB	- - - - - - - -	0	85	
2	Magnetometer	Right Wing Tip	Develco 9200 C	0	60	Sensitivity changes significantly below 0°C.
3	Accelerometer Triad	AB	Sundstrand QA800	-40	85	
4	Rate Gyro Triad	AB	Northrop GRG5	-37	71	Northrop gyros will be used on first flight.
5	Pressure Transducers	AAB	Kavlico P655 & P656	-30	100	
6	Radar Altimeter	AB	King KRA10A	-54	71	
7	ADF	AB	King KR87	-20	55	
8	TACAN	AB	King KTU709	-50	70	Not required on POC flights.
9	CRISIS	AB	- - - - - - - -	-40	65	Based on specs for relay.
10	RISER	Upper IAB	- - - - - - - -	-55	80	Based on rotary switch spec.
11	BURP	AB	- - - - - - - -	-50	60	Based on specs for relays.
12	Transponder	AAB	Vega 319X-9	-37	75	Not required on all POC test flights.

TABLE 5 SUMMARY OF ROBOT-X AVIONICS OPERATING TEMPERATURE RANGES (cont'd)

ITEM	DESCRIPTION	LOCATION	MODEL NO.	MIN (°C)	MAX (°C)	REMARKS
13	Command Receiver	AB	Emhiser ECR-33BFW-03	-40	71	Based on mil spec.
14	Batteries	AB	SAFT type VR4D & VR7F	-40	65	Approx. 50% capacity at -20°C; 30% capacity at -30°C.
15	Control Servos	2 in wing roots 1 in AAB	DR2148M44-3 or DR2148M51	-43	71	
16	Telemetry Transmitter	Centre IAB	Emhiser ETT-2DFW202-01	-30	71	Temperature spec for base plate.
17	PCM Encoder	AB	Aydin Vector MMP-600	-10	70	
18	Autopilot/PCM Encoder Interface	AB	- - - - - - - -	-10	70	
19	Telemetry Signal Conditionting	AB	- - - - - - - -	-10	70	

Notes:
AB Avionics Bay
AAB Auxiliary Avionics Bay
IAB Interface Avionics Bay

TABLE 6 TEMPERATURE RISE IN CRITICAL AREAS

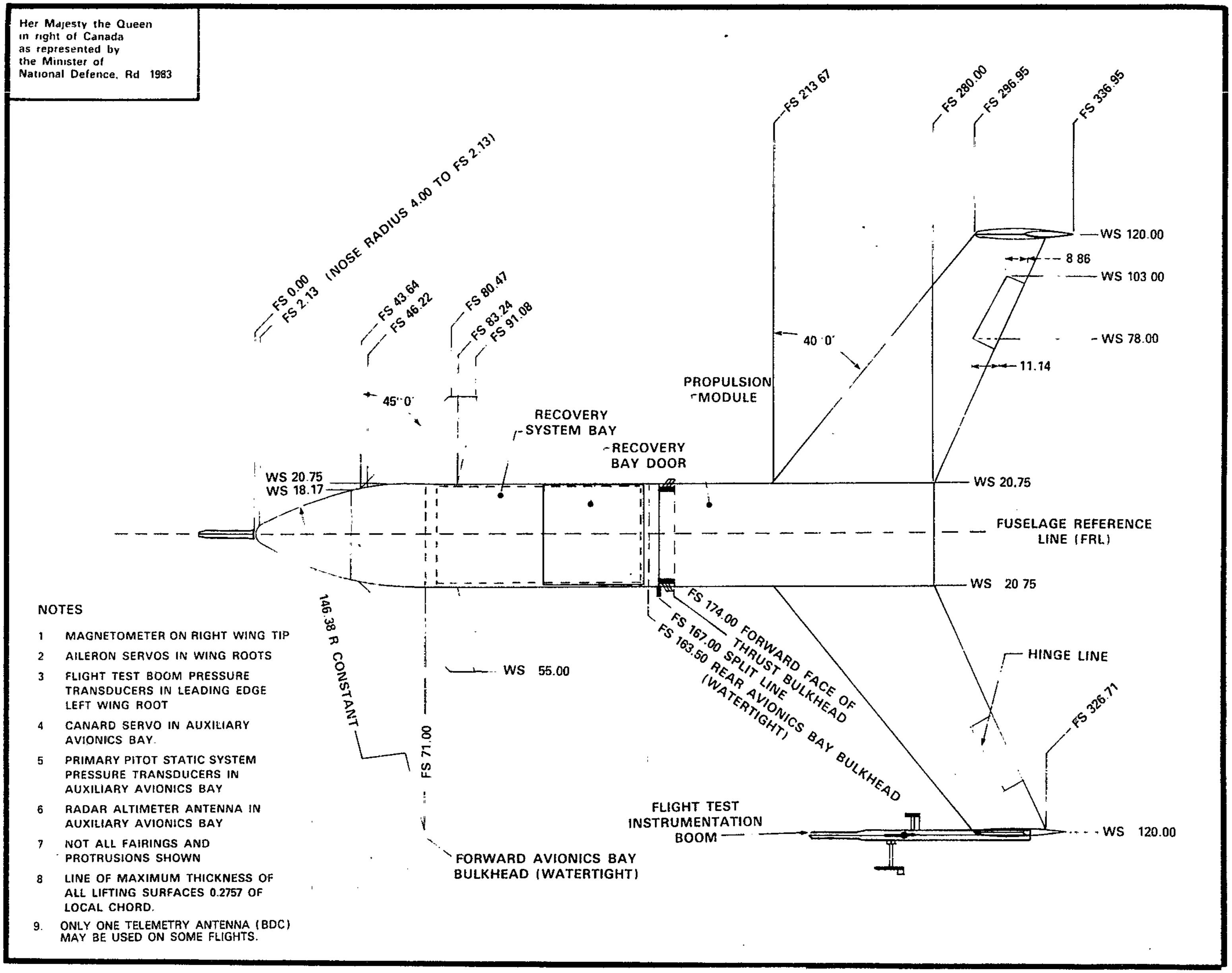
RUN NO	AMBIENT	CRITICAL TEMPERATURES								
		AX BAY (UP)			FOR BLK (R)			MID AB (UP)		
		T_1	T_{10}	T_{20}	T_1	T_{10}	T_{20}	T_1	T_{10}	T_{20}
1	22	22.5	52.0	63.4	21.8	50.7	65.8	21.1	43.8	59.8
4	- 2	- 2.9	25.6	32.6	- 1.5	27.5	41.6	3.1	22.2	37.7
6	-22	-21.1	9.0	15.6	-18.4	11.2	25.3	-10.8	7.3	22.8
8	-30	-32.0	0.9	10.6	-28.7	1.8	18.9	-23.5	- 2.8	15.2
10	-41	-39.1	- 9.2	- 2.4	-36.3	- 6.1	8.1	-28.1	- 9.2	6.5
14	40	37.2	61.8	68.2	34.1	62.9	76.1	29.7	52.0	69.6
16	57	57.3	79.4	N/A	56.5	83.2	N/A	54.3	74.4	N/A

NOTES:
(i) All temperatures given in degrees Celsius.
(ii) N/A = Not available as heat sources off.
(iii) T_j = Temperature on j-th scan.
(iv) 2 minutes/scan; i.e. time in minutes = $2(T_j-1)$.
(v) Heat sources on.

TABLE 7 TEMPERATURE RISE IN AUTOPILOT AREAS

RUN NO	AMBIENT	AP (R)			AP (L)		
		T_1	T_{10}	T_{20}	T_1	T_{10}	T_{20}
1	22	21.9	32.2	41.5	21.9	30.4	37.9
4	- 2	- 2.0	8.7	16.4	- 2.1	6.6	12.8
6	-22	-19.3	- 7.7	- 0.3	-19.6	-10.3	- 4.0
8	-30	-30.0	-16.4	- 6.1	-30.3	-18.9	- 9.9
10	-41	-37.1	-24.9	-17.3	-37.4	-27.9	-21.6
14	40	34.8	44.7	52.6	34.6	42.5	49.1
16	57	56.7	65.2	N/A	56.6	63.1	N/A

NOTES:
(i) All temperatures given in degrees Celsius.
(ii) N/A = Not available as heat sources off.
(iii) T_j = Temperature on j-th scan.
(iv) 2 minutes/scan; i.e. time in minutes = $2(T_j-1)$.
(v) Heat sources on.



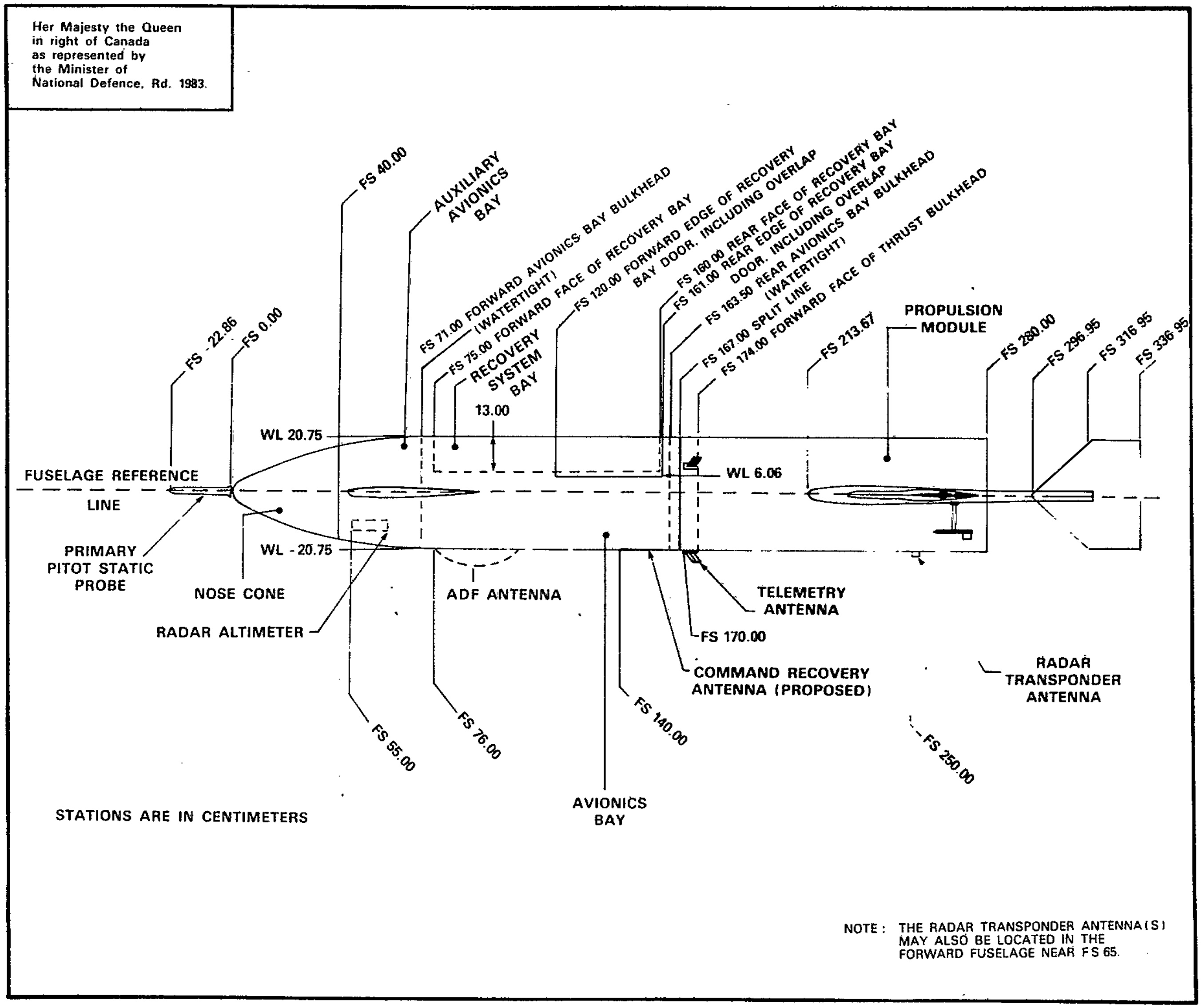
NOTES

1 MAGNETOMETER ON RIGHT WING TIP
2 AILERON SERVOS IN WING ROOTS
3 FLIGHT TEST BOOM PRESSURE TRANSDUCERS IN LEADING EDGE LEFT WING ROOT
4 CANARD SERVO IN AUXILIARY AVIONICS BAY.
5 PRIMARY PITOT STATIC SYSTEM PRESSURE TRANSDUCERS IN AUXILIARY AVIONICS BAY
6 RADAR ALTIMETER ANTENNA IN AUXILIARY AVIONICS BAY
7 NOT ALL FAIRINGS AND PROTRUSIONS SHOWN
8 LINE OF MAXIMUM THICKNESS OF ALL LIFTING SURFACES 0.2757 OF LOCAL CHORD.
9. ONLY ONE TELEMETRY ANTENNA (BDC) MAY BE USED ON SOME FLIGHTS.

Figure 1

ROBOT-X CONFIGURATION

(Top View Looking Down)


Her Majesty the Queen
in right of Canada
as represented by
the Minister of
National Defence, Rd. 1983.

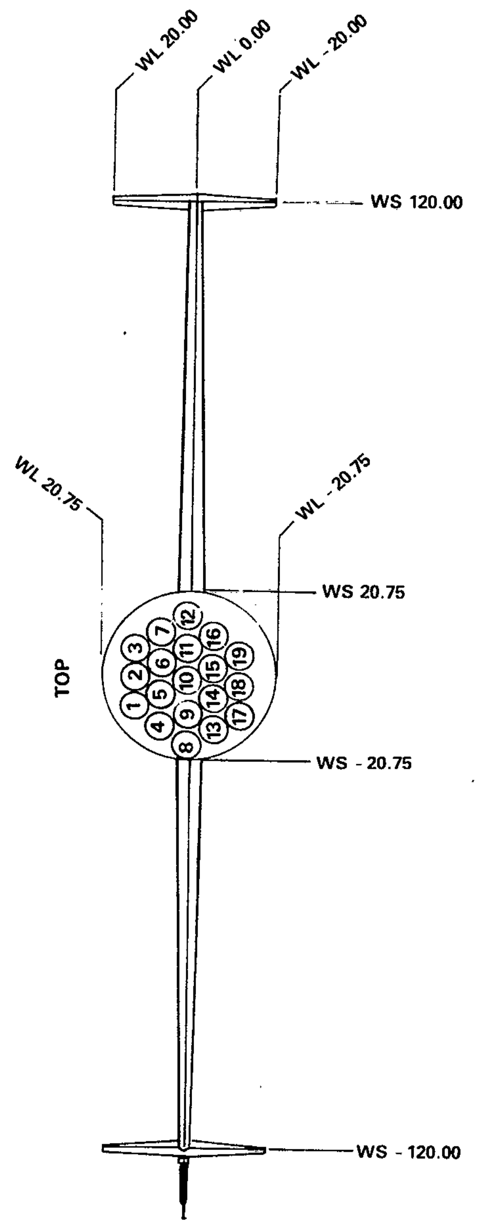
STATIONS ARE IN CENTIMETERS

NOTE : THE RADAR TRANSPONDER ANTENNA(S) MAY ALSO BE LOCATED IN THE FORWARD FUSELAGE NEAR FS 65.

Figure 2

ROBOT-X CONFIGURATION

(Side View)



STATIONS ARE IN
CENTIMETERS

Figure 3

ROBOT-X CONFIGURATION
(Aft View Looking Forward)

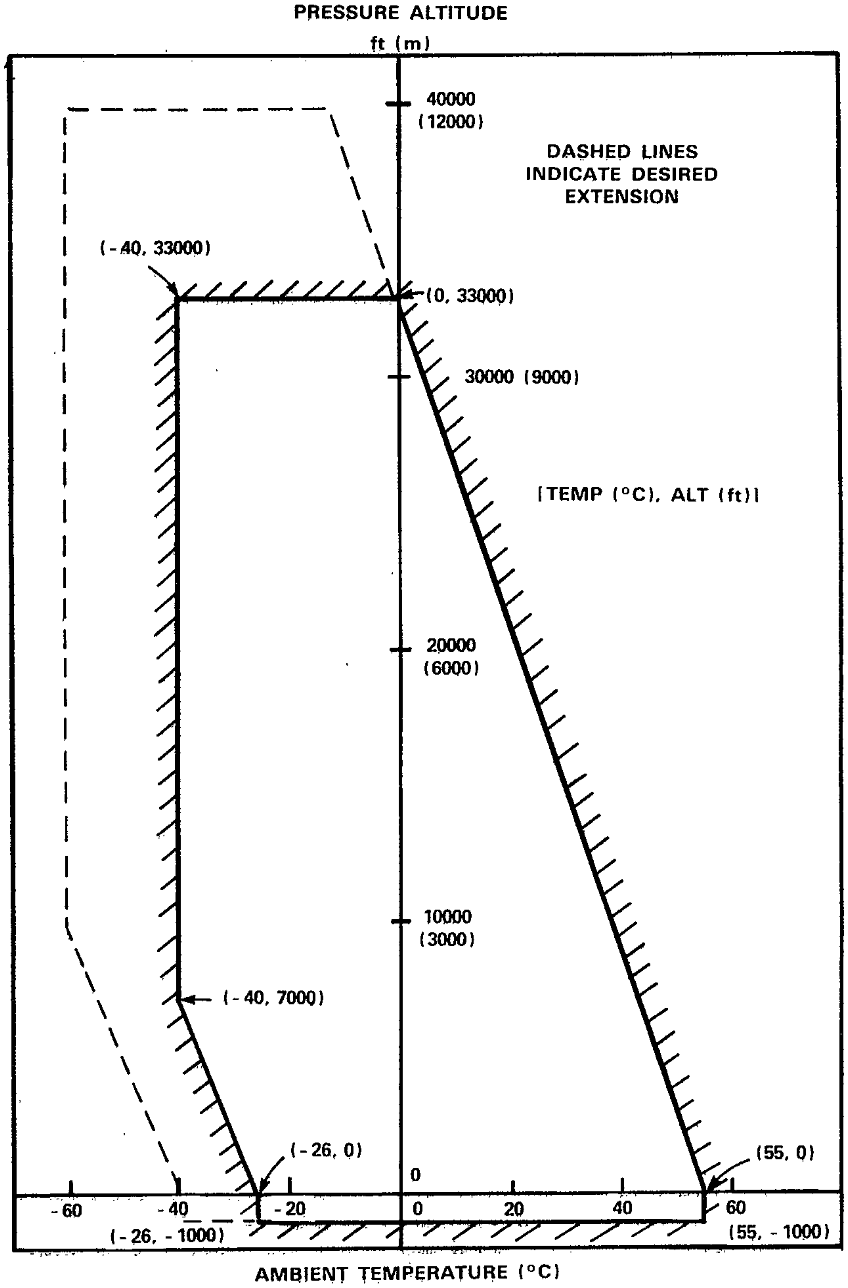
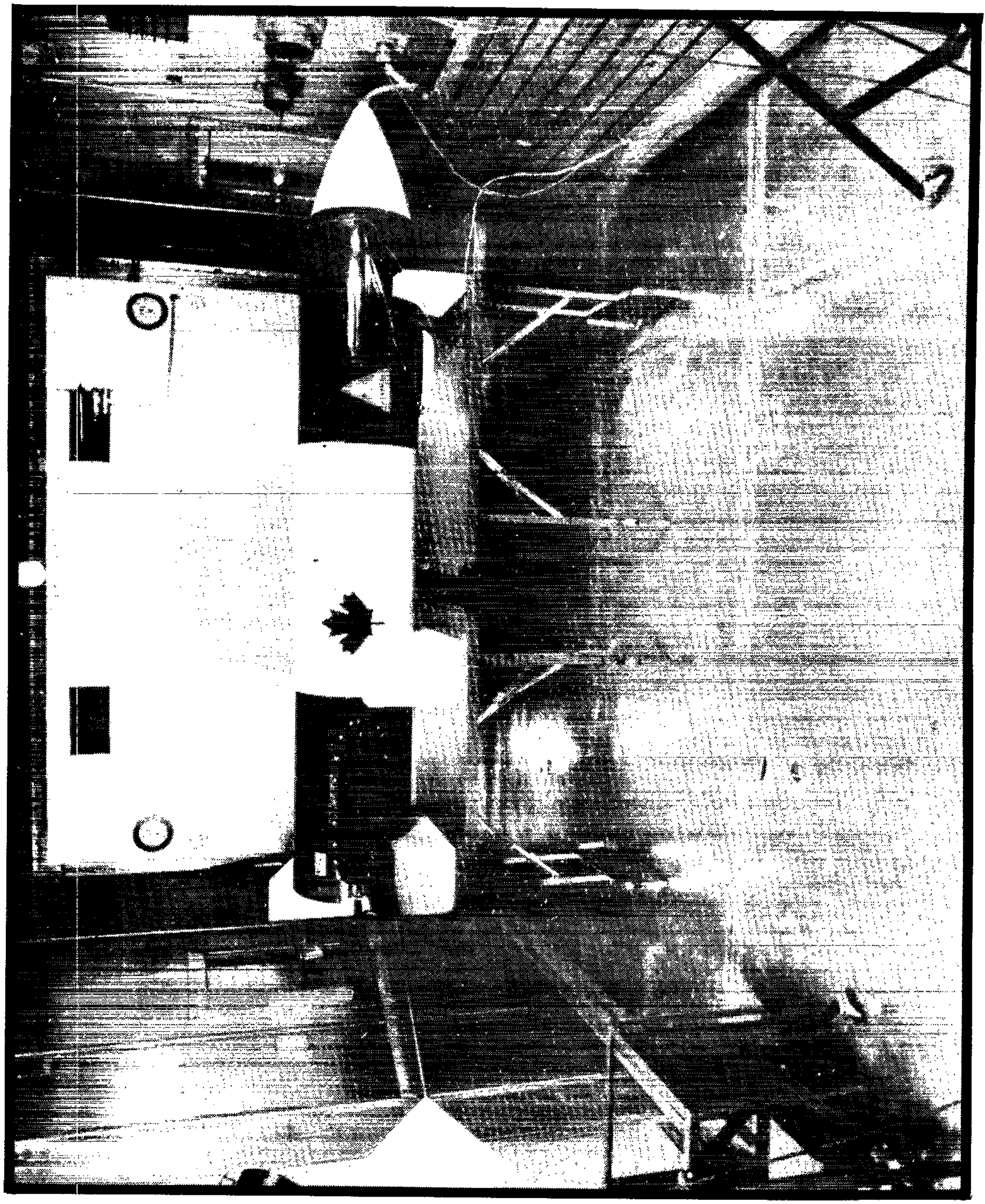


Figure 4

ROBOT-X ENVIRONMENT ENVELOPE

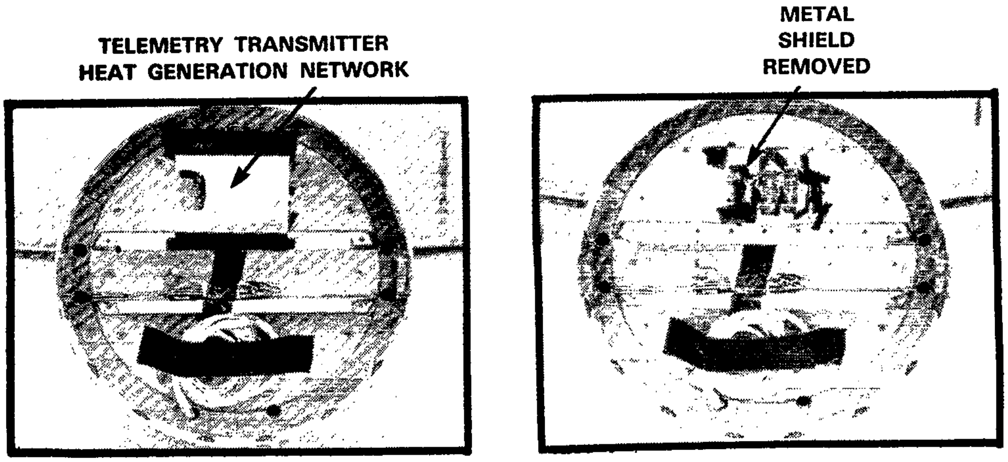


85-99

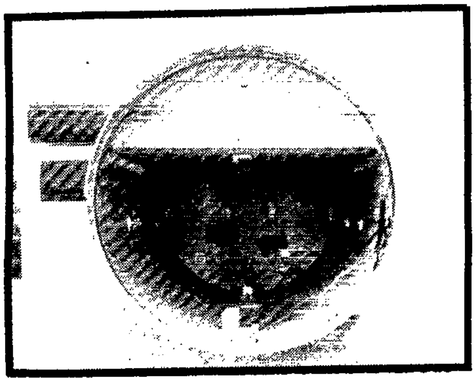
Figure 5

ROBOT-X IN AETE ENVIRONMENTAL TEST CHAMBER

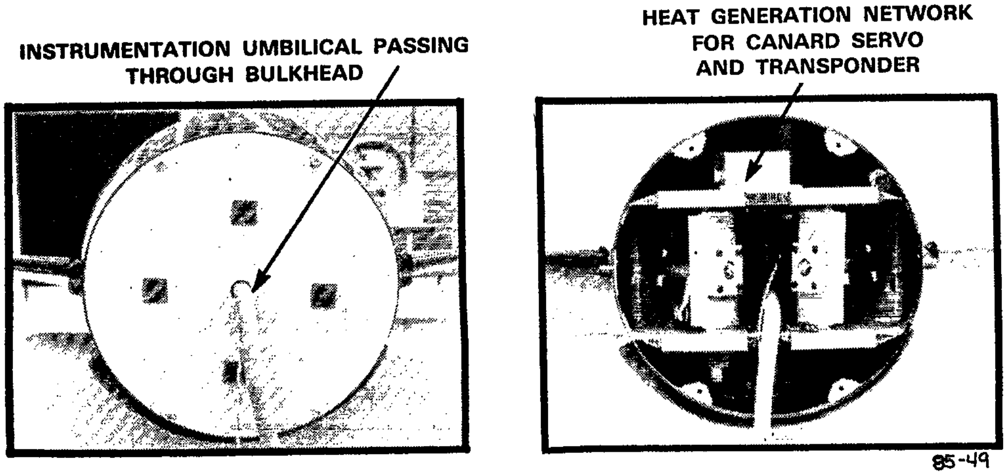
(Courtesy AETE Photo Section)



INTERFACE BAY LOOKING AFT



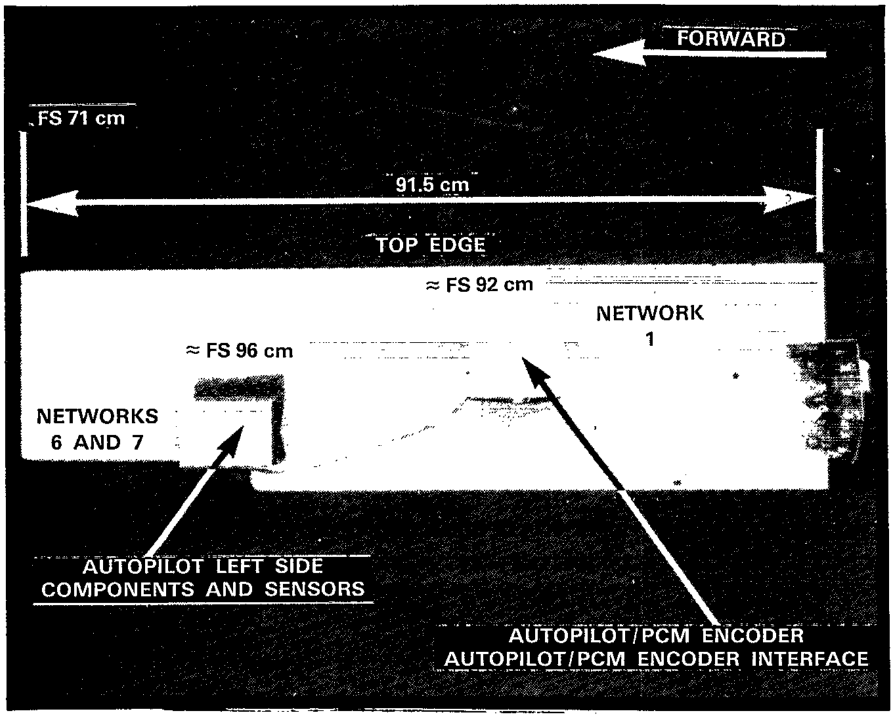
AVIONICS BAY LOOKING FORWARD



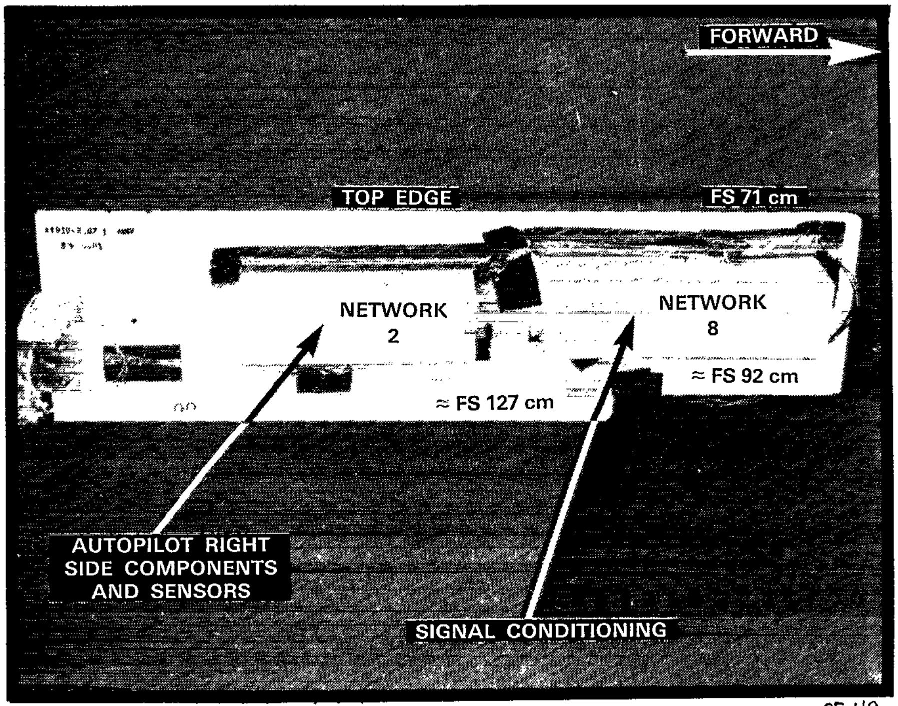
AUXILIARY AVIONICS BAY LOOKING AFT

Figure 6

INSTRUMENTATION CONFIGURATION



LEFT SIDE OF AVIONICS BAY BEAM

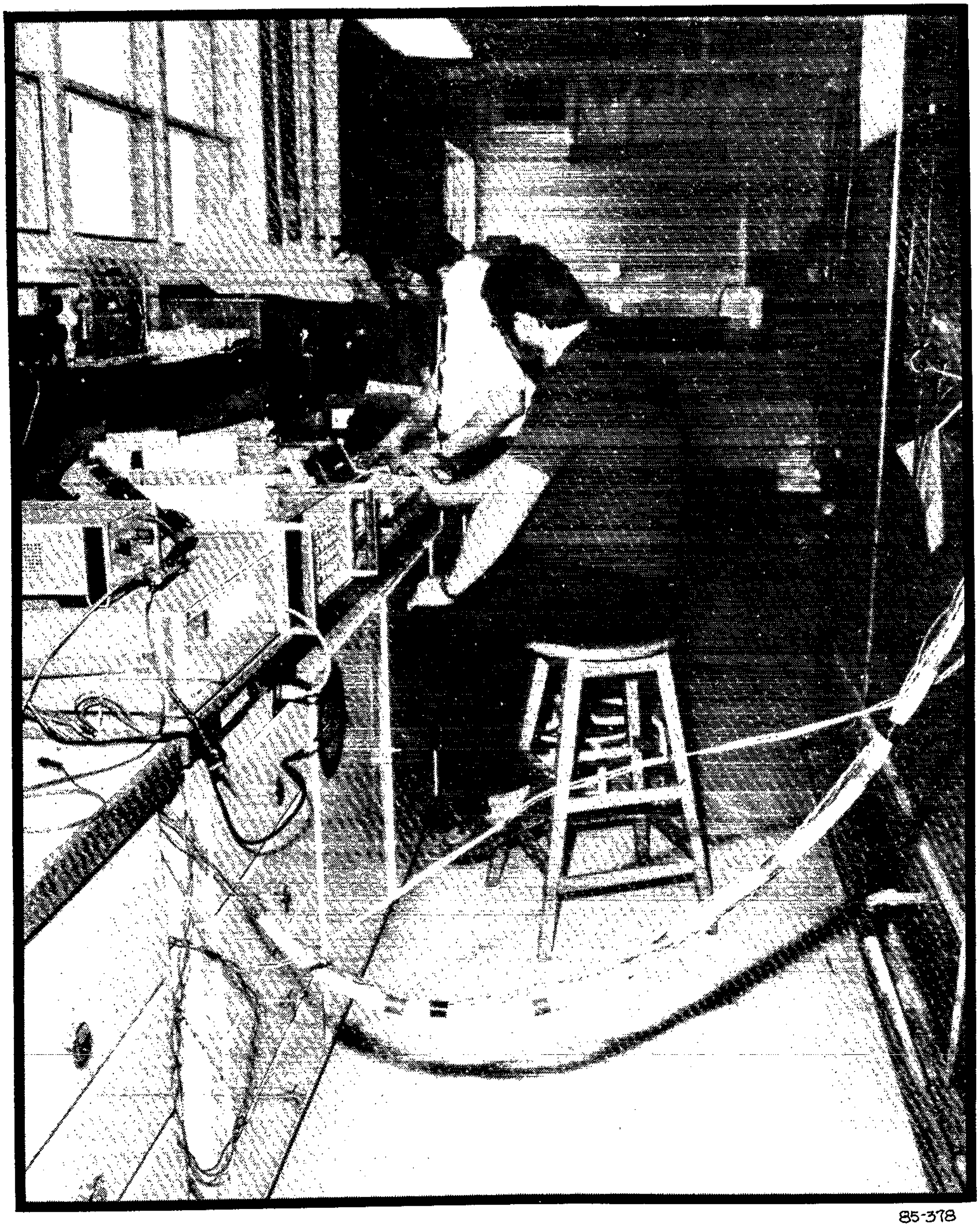


85-49

RIGHT SIDE OF AVIONICS BAY BEAM

Figure 7

AVIONICS BAY HEAT NETWORK CONFIGURATION



85-378

Figure 8

DATA ACQUISITION EQUIPMENT AND INSTRUMENTATION

CHANNEL	DESCRIPTION
1	External Skin Temperature, BDC
2	Ambient Chamber Temperature
3	Auxiliary Avionics Bay Top Compartment
4	External Skin Temperature Rover
5	Interface Avionics Bay Top Compartment Air Temperature
6	Interface Avionics Bay Bottom Compartment Air Temperature
7	Forward Bulkhead Starboard Side Air Temperature
8	Forward Bulkhead Port Side Air Temperature

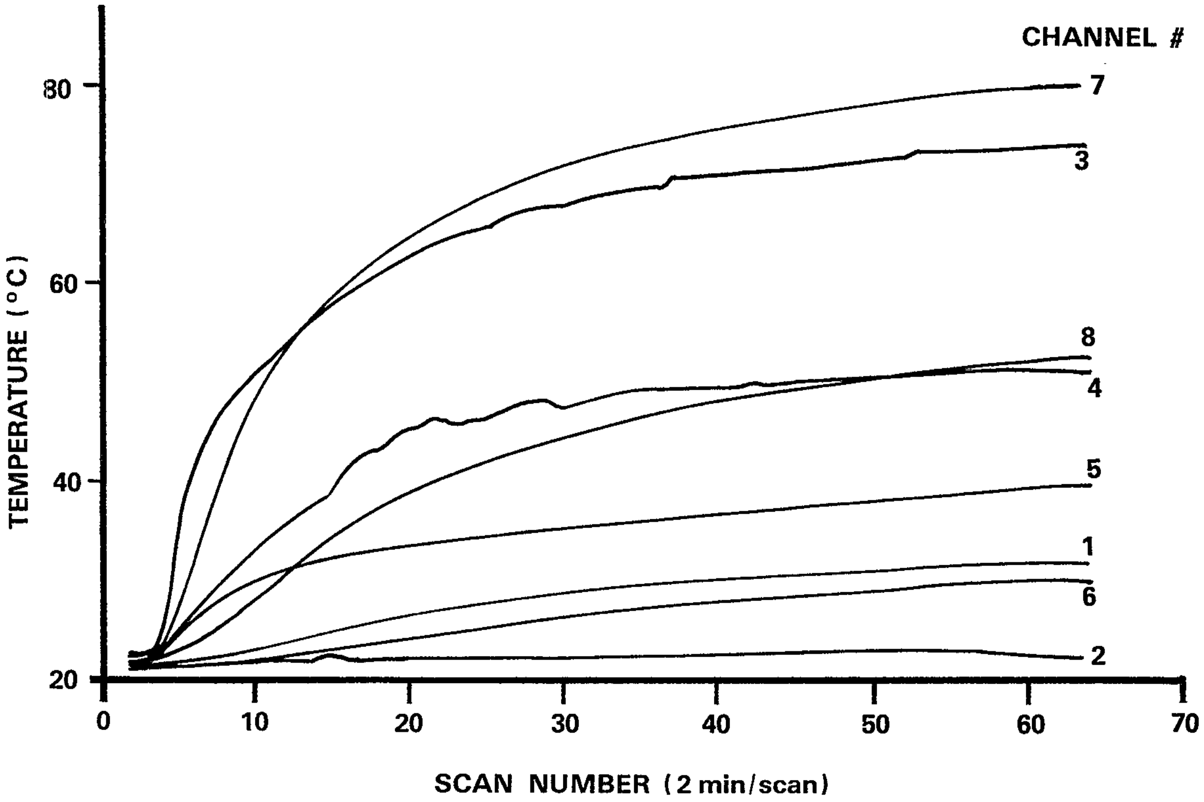


Figure 9a

RUN NUMBER 1

CHANNEL	DESCRIPTION
2	Ambient Chamber Temperature
9	Mid Avionics Bay Skin Temperature (Bottom of Recovery Bay)
10	Mid Avionics Bay Internal Bottom Skin Temperature
11	Avionics Bay Air Temperature Near CRISIS Module
12	Avionics Bay Air Temperature Near Command Recovery Receiver Module
13	Avionics Bay Air Temperature Near Autopilot Avionics, Starboard Side
14	Avionics Bay Air Temperature Near Autopilot Avionics, Port Side

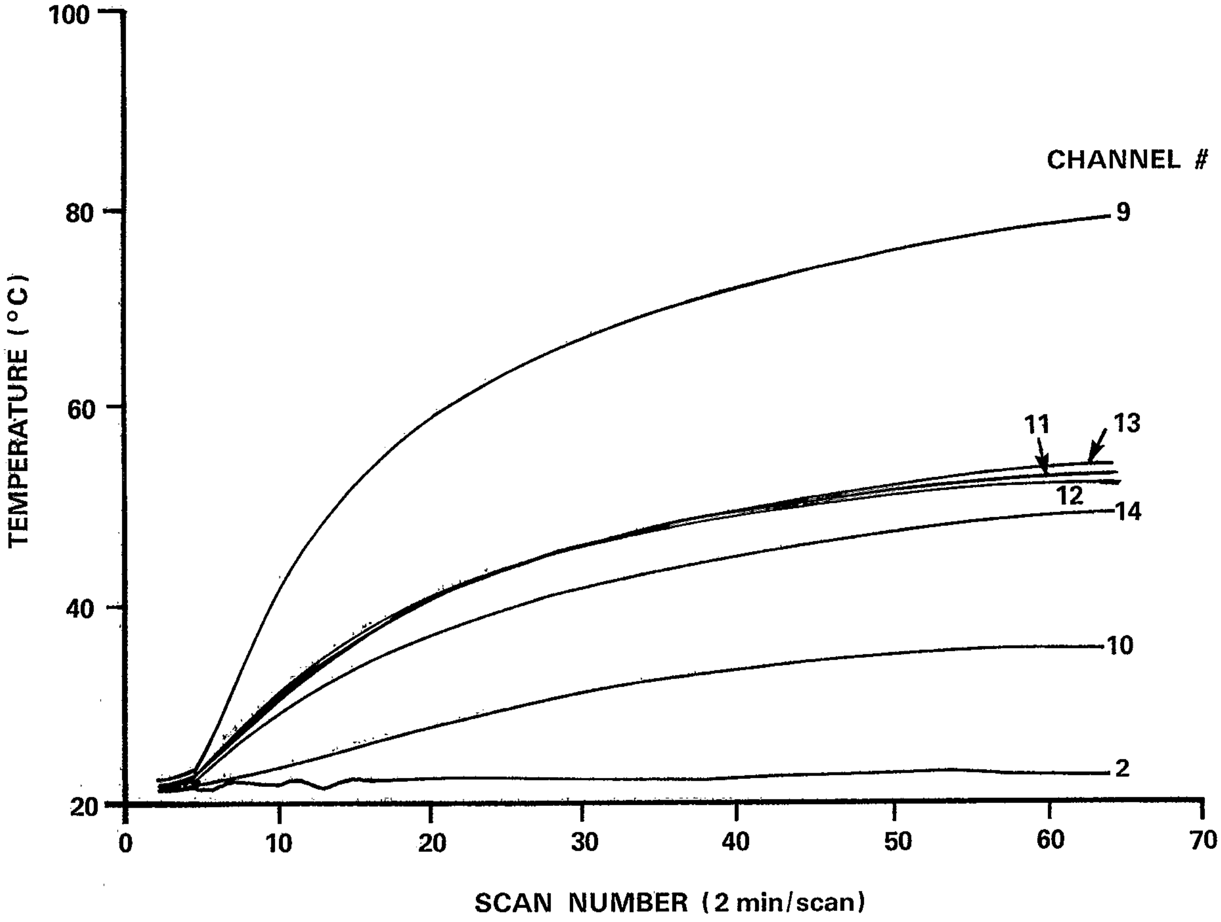


Figure 9b

RUN NUMBER 1

CHANNEL	DESCRIPTION
2	Ambient Chamber Temperature
3	Auxiliary Avionics Bay Top Compartment
7	Forward Bulkhead Starboard Side Air Temperature
9	Mid Avionics Bay Skin Temperature (Bottom of Recovery Bay)

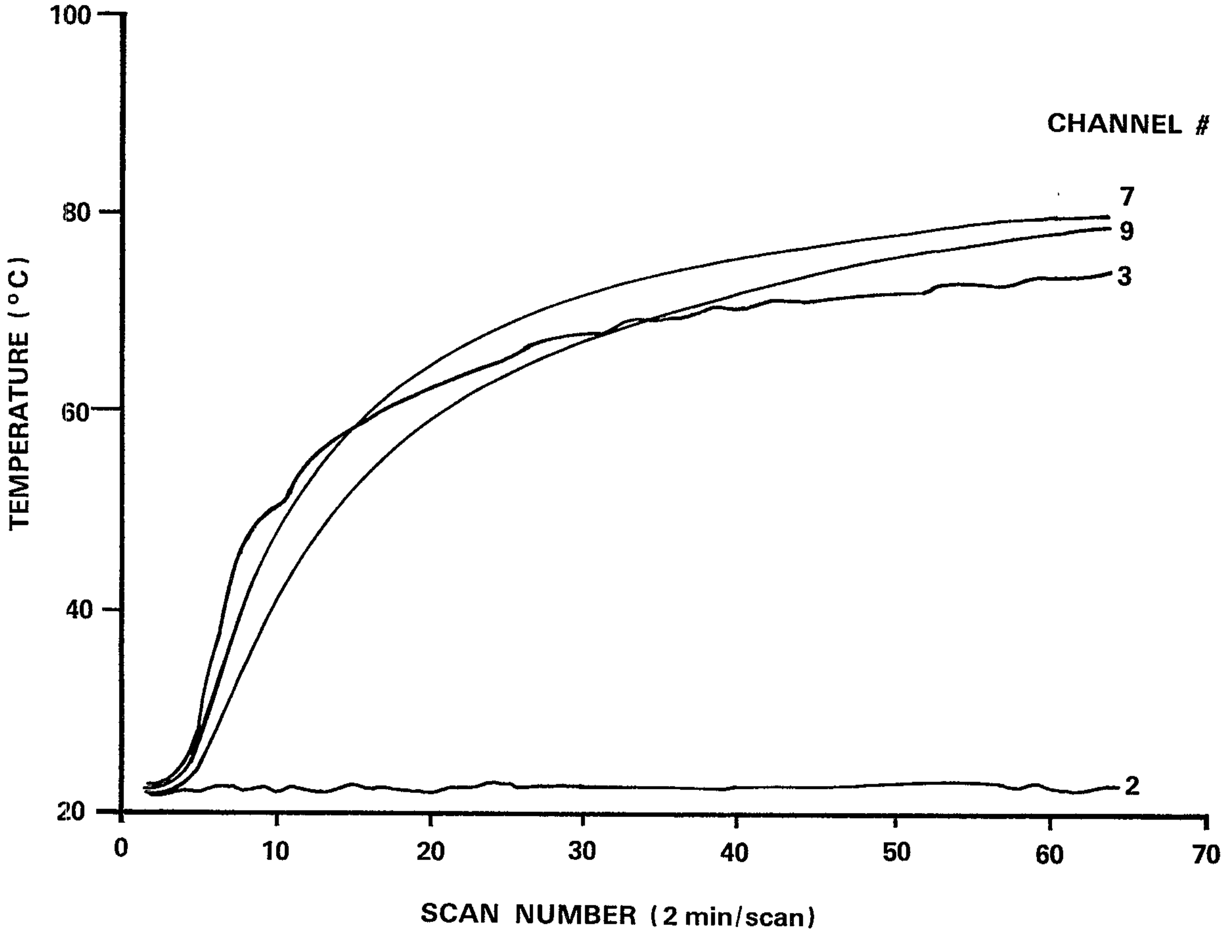


Figure 9c

RUN NUMBER 1

CHANNEL	DESCRIPTION
1	External Skin Temperature, BDC
2	Ambient Chamber Temperature
3	Auxiliary Avionics Bay Top Compartment
4	External Skin Temperature Rover
5	Interface Avionics Bay Top Compartment Air Temperature
6	Interface Avionics Bay Bottom Compartment Air Temperature
7	Forward Bulkhead Starboard Side Air Temperature
8	Forward Bulkhead Port Side Air Temperature

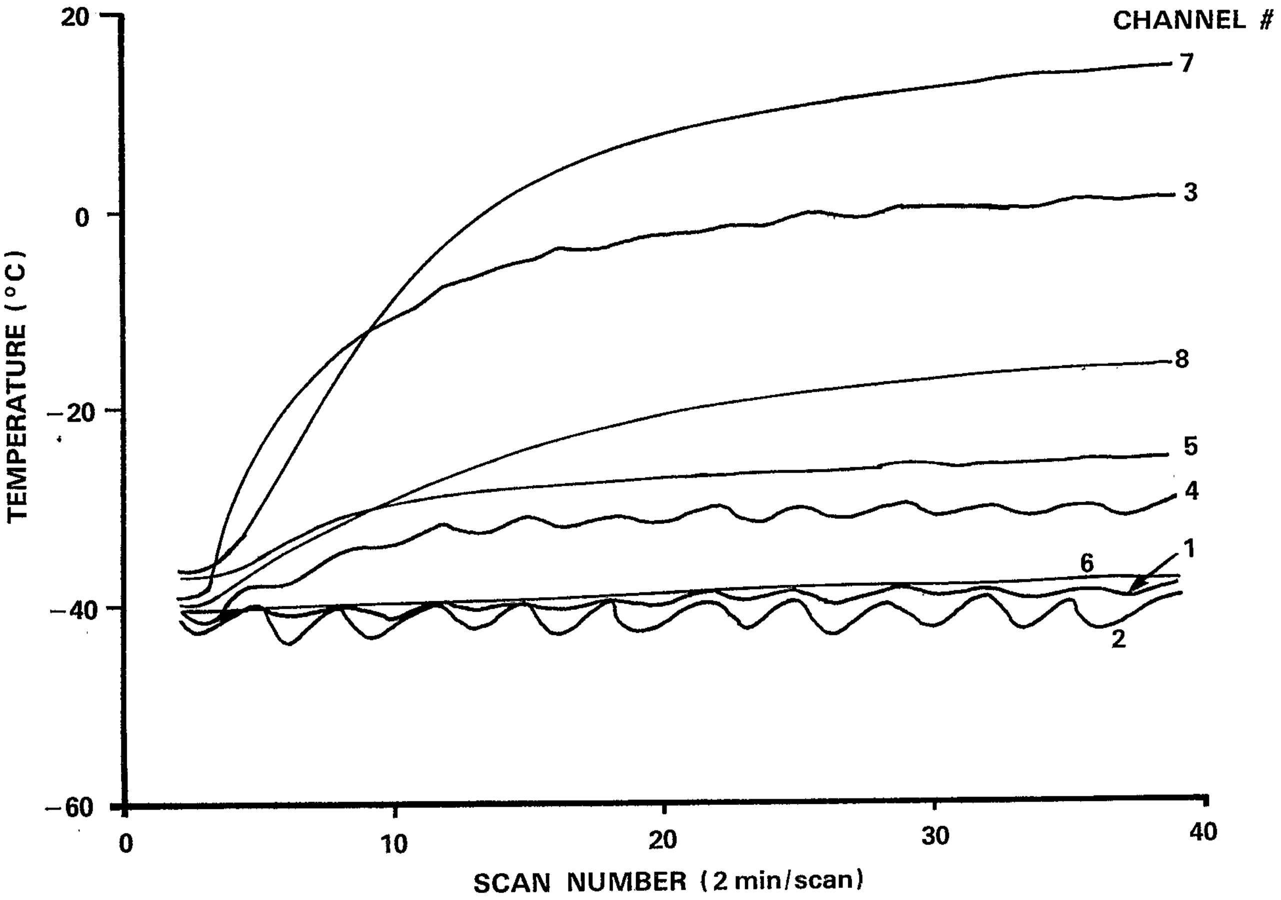


Figure 10a

RUN NUMBER 10

CHANNEL	DESCRIPTION
2	Ambient Chamber Temperature
9	Mid Avionics Bay Skin Temperature (Bottom of Recovery Bay)
10	Mid Avionics Bay Internal Bottom Skin Temperature
11	Avionics Bay Air Temperature Near CRISIS Module
12	Avionics Bay Air Temperature Near Command Recovery Receiver Module
13	Avionics Bay Air Temperature Near Autopilot Avionics, Starboard Side
14	Avionics Bay Air Temperature Near Autopilot Avionics, Port Side

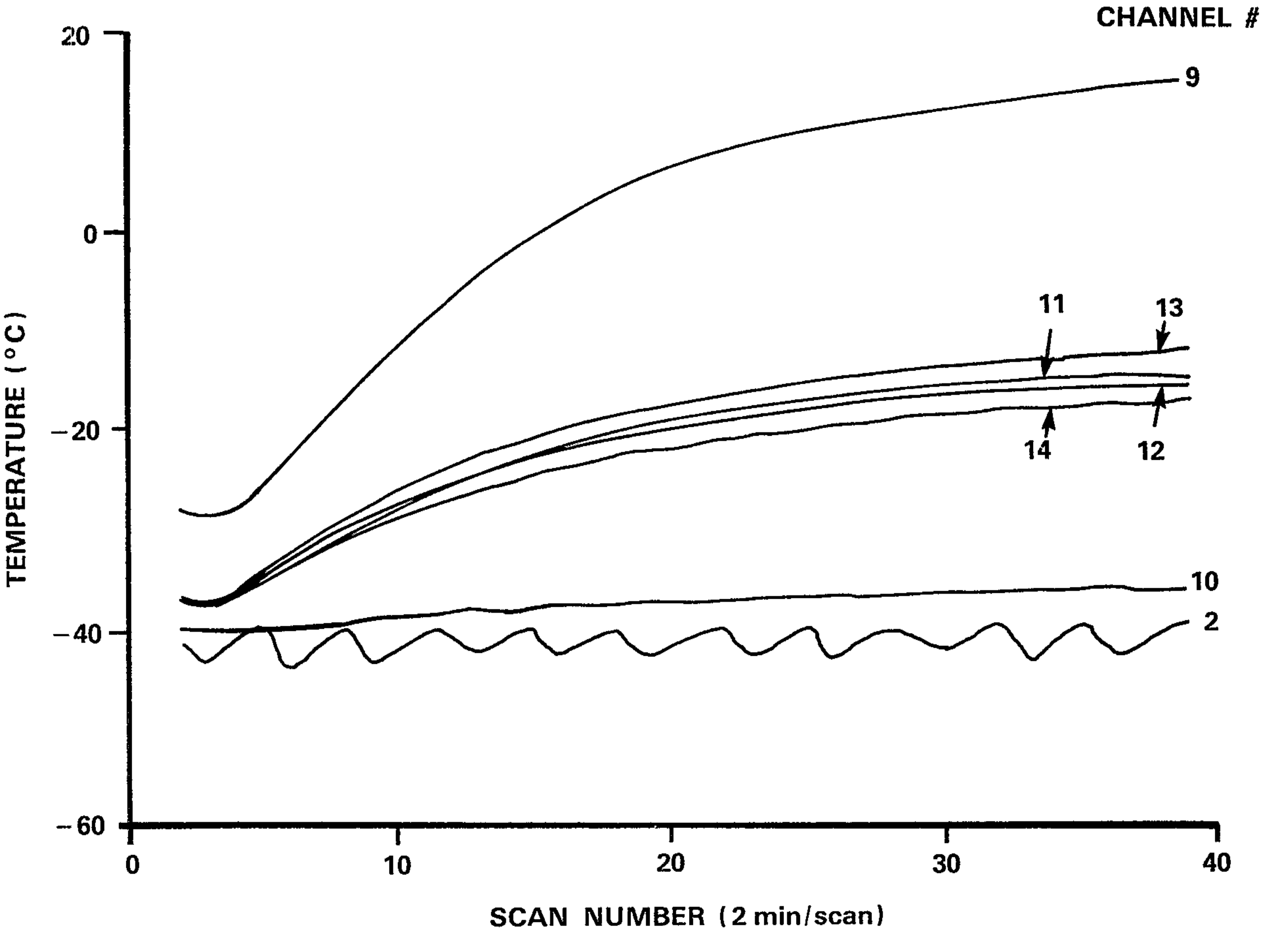


Figure 10b

RUN NUMBER 10

CHANNEL	DESCRIPTION
2	Ambient Chamber Temperature
3	Auxiliary Avionics Bay Top Compartment
7	Forward Bulkhead Starboard Side Air Temperature
9	Mid Avionics Bay Skin Temperature (Bottom of Recovery Bay)

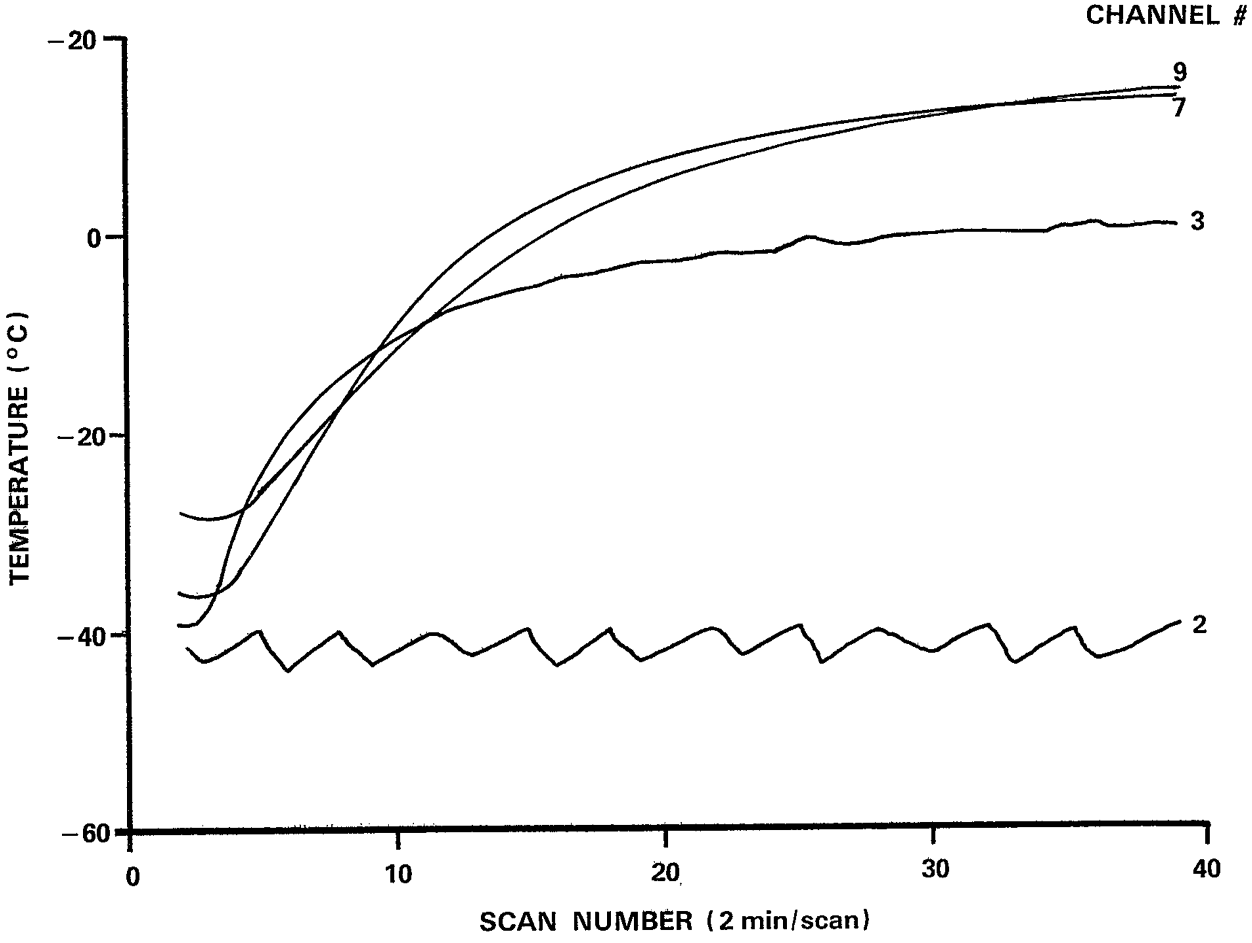


Figure 10c

RUN NUMBER 10

CHANNEL	DESCRIPTION
1	External Skin Temperature, BDC
2	Ambient Chamber Temperature
3	Auxiliary Avionics Bay Top Compartment
4	External Skin Temperature Rover
5	Interface Avionics Bay Top Compartment Air Temperature
6	Interface Avionics Bay Bottom Compartment Air Temperature
7	Forward Bulkhead Starboard Side Air Temperature
8	Forward Bulkhead Port Side Air Temperature

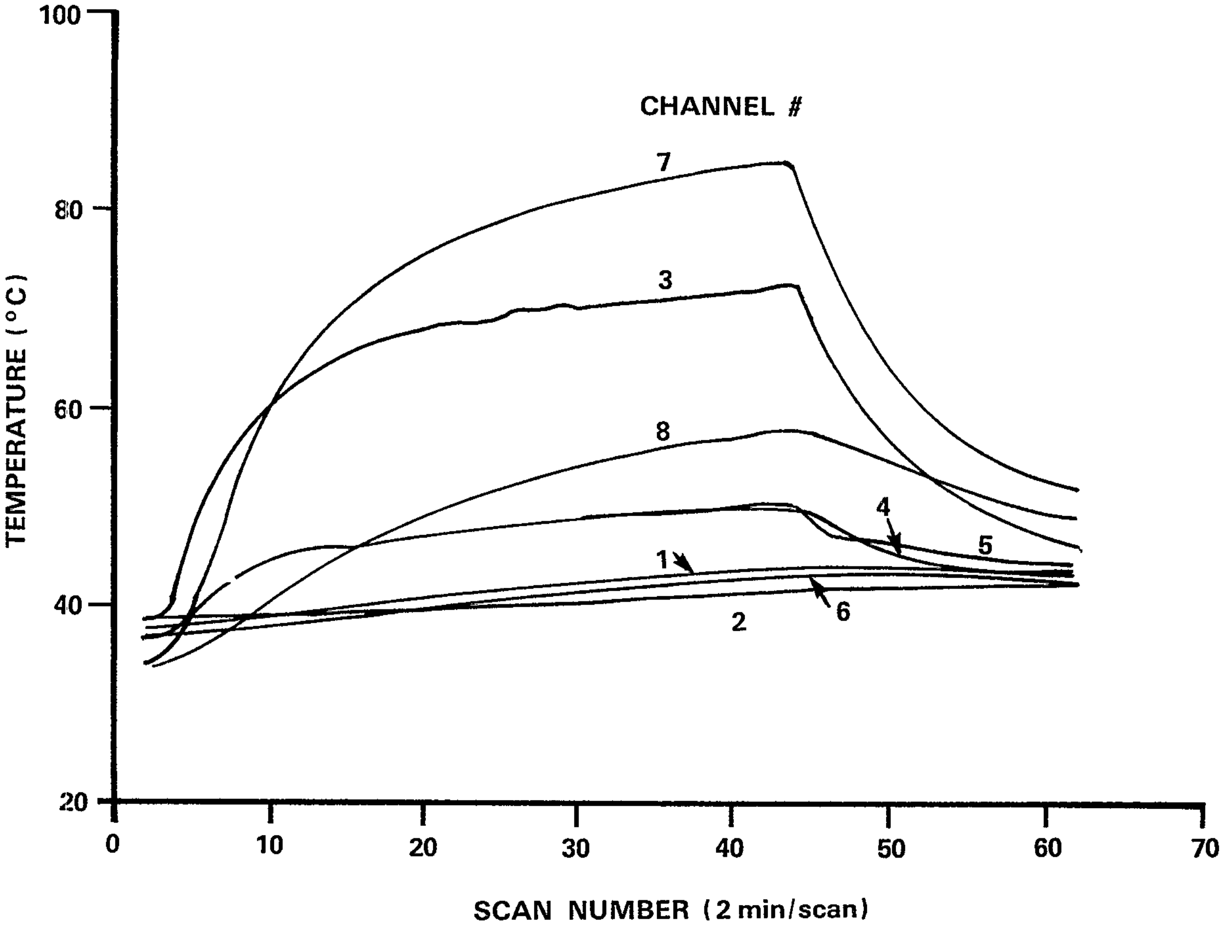


Figure 11a

RUN NUMBER 14

CHANNEL	DESCRIPTION
2	Ambient Chamber Temperature
9	Mid Avionics Bay Skin Temperature (Bottom of Recovery Bay)
10	Mid Avionics Bay Internal Bottom Skin Temperature
11	Avionics Bay Air Temperature Near CRISIS Module
12	Avionics Bay Air Temperature Near Command Recovery Receiver Module
13	Avionics Bay Air Temperature Near Autopilot Avionics, Starboard Side
14	Avionics Bay Air Temperature Near Autopilot Avionics, Port Side

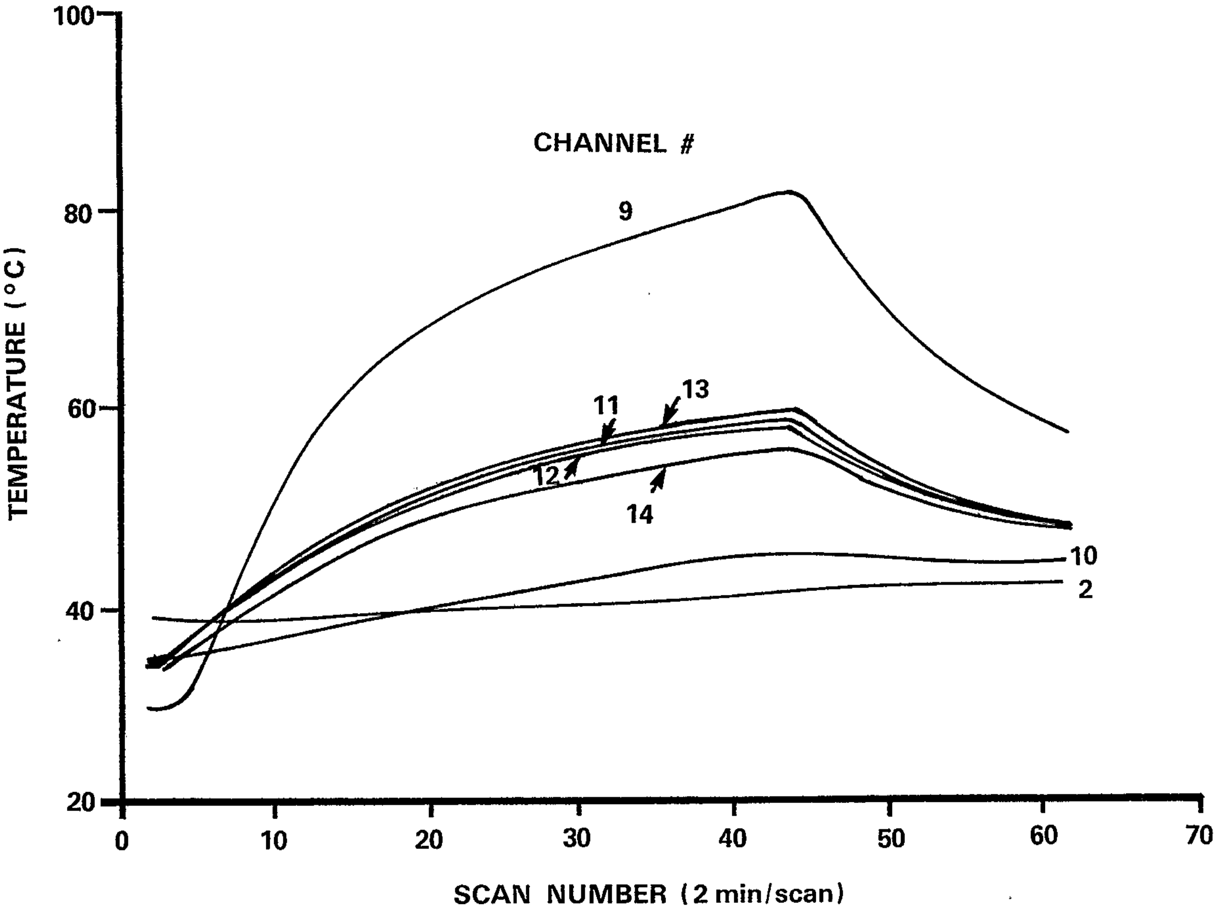


Figure 11b

RUN NUMBER 14

CHANNEL	DESCRIPTION
2	Ambient Chamber Temperature
3	Auxiliary Avionics Bay Top Compartment
7	Forward Bulkhead Starboard Side Air Temperature
9	Mid Avionics Bay Skin Temperature (Bottom of Recovery Bay)

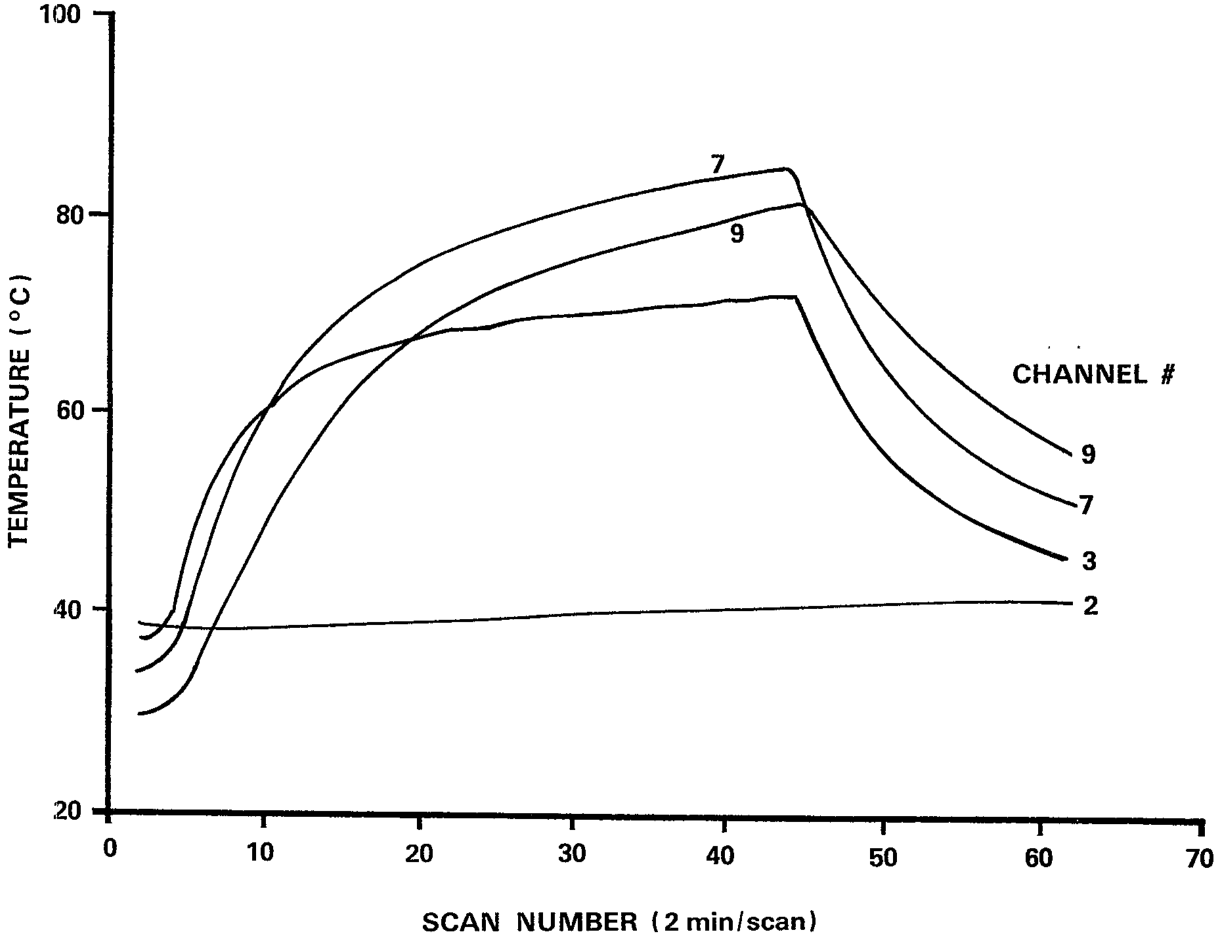


Figure 11c

RUN NUMBER 14

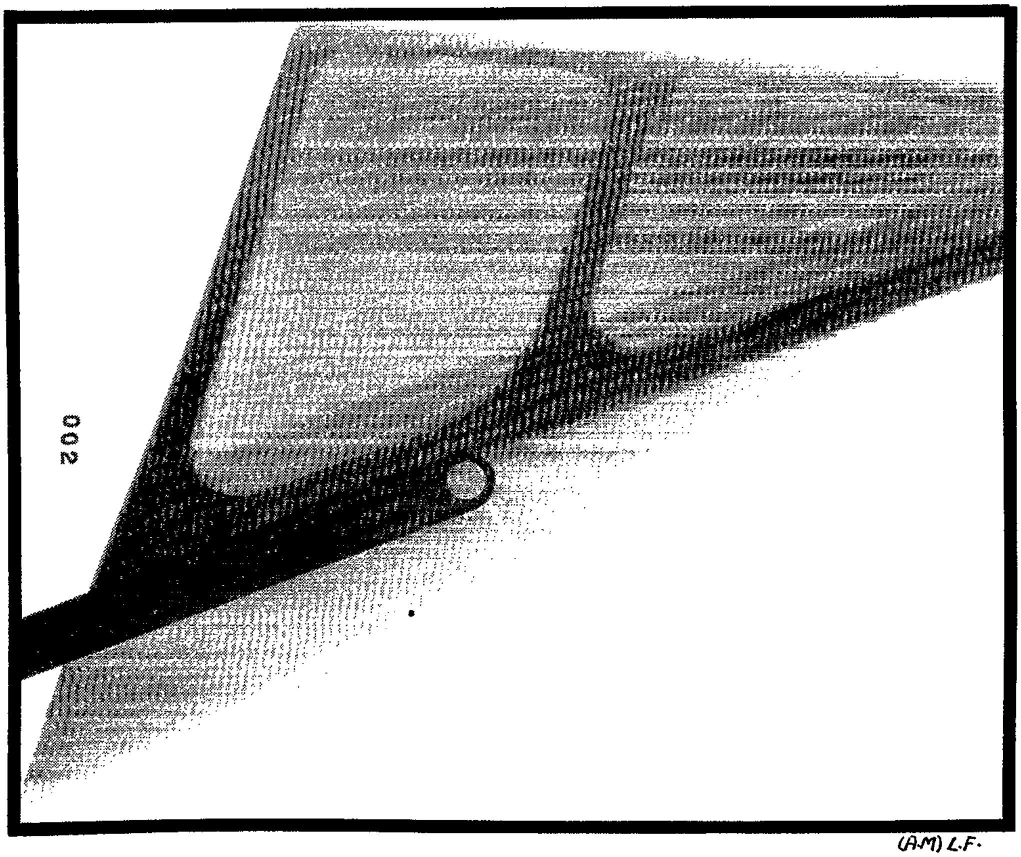


Figure 12

LEFT CANARD X-RAY

(Positive Copy)

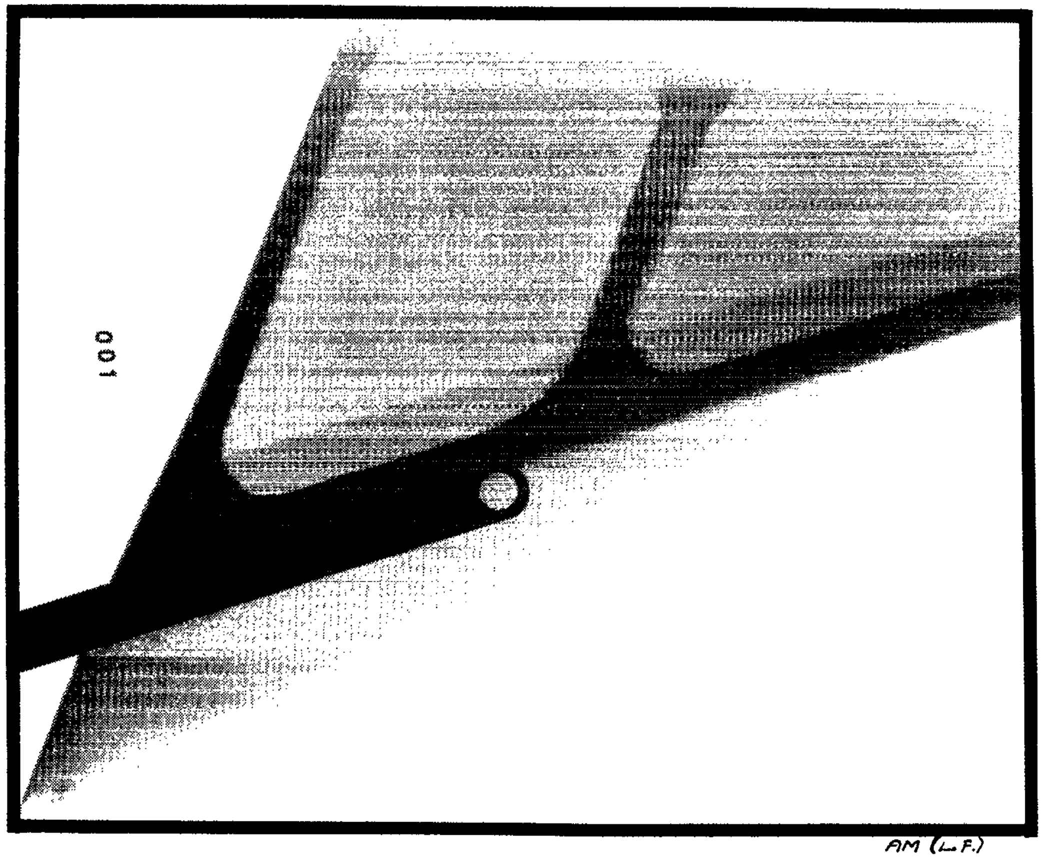


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Figure 13

RIGHT CANARD X-RAY

(Positive Print)

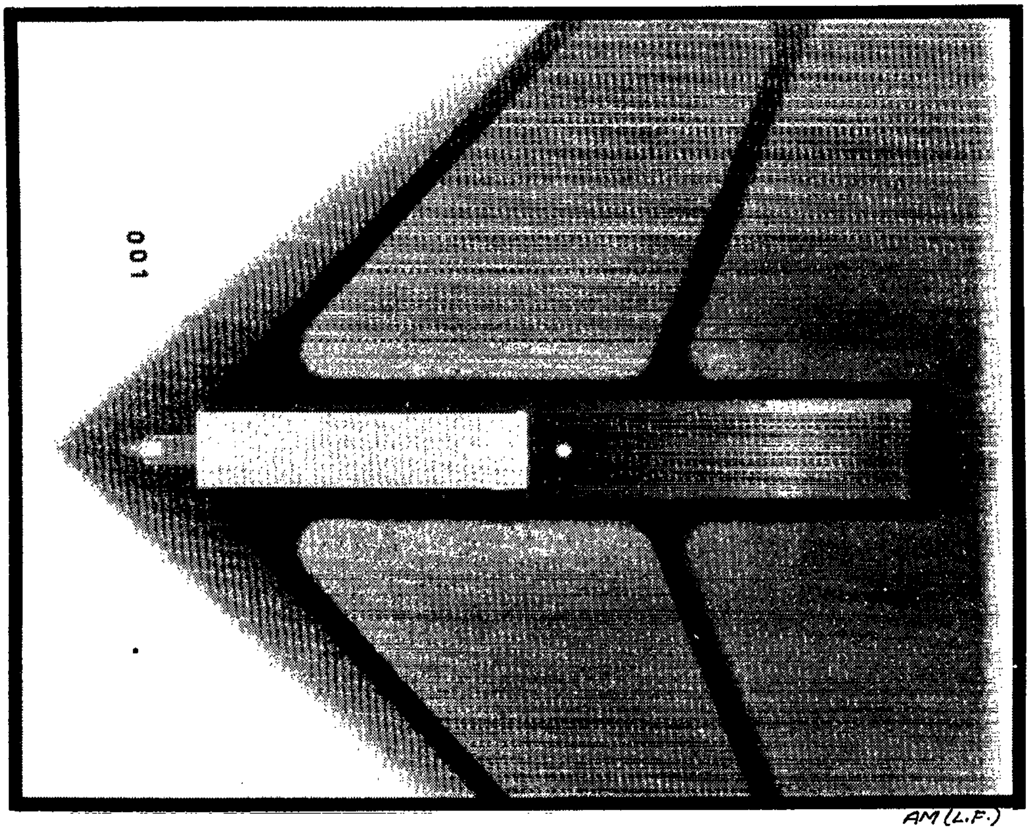

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Figure 14

LEFT VERTICAL STABILIZER X-RAY

(Positive Print)

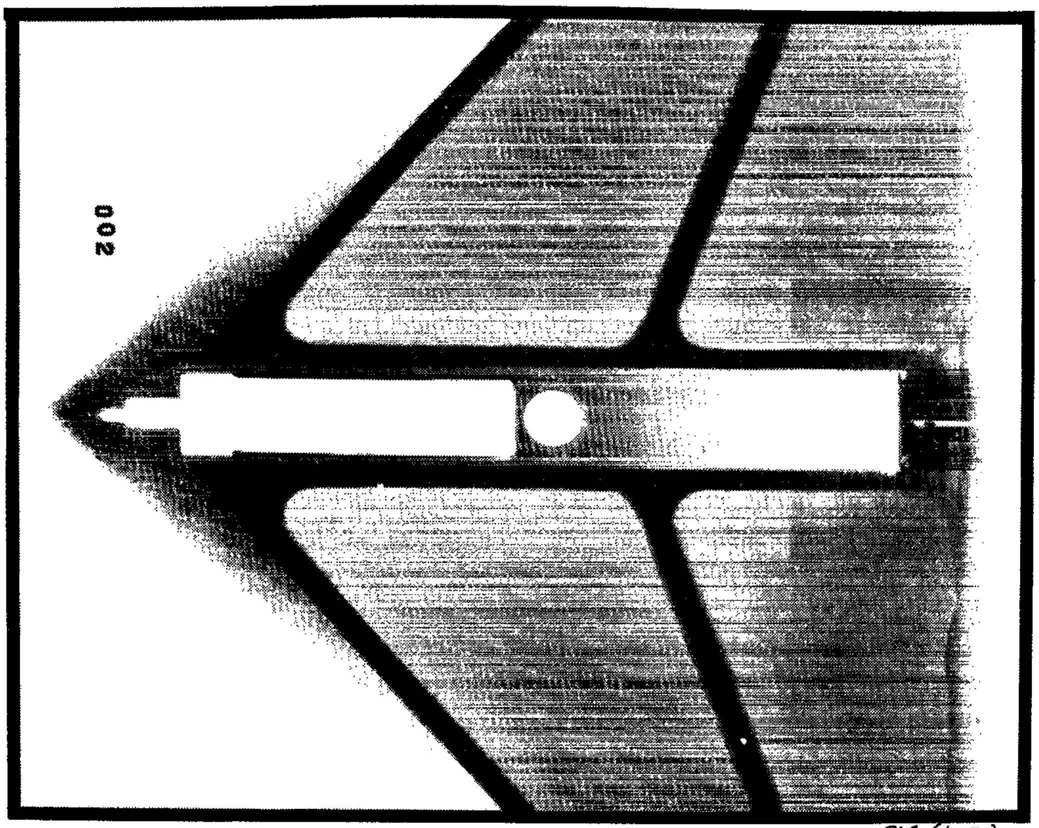

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Figure 15

RIGHT VERTICAL STABILIZER X-RAY

(Positive Print)

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5. AUTHOR(S) (Last name, first name, middle initial) Penzes S.G., Markov A.B., Turner A.E., Boulter B.G.	
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13. ABSTRACT

ABSTRACT

Environmental tests are described in which the ROBOT-X airframe was subjected to a wide range of ambient temperatures, from a minimum of -50°C to a maximum of +58°C. No unexpected problems were encountered. Valuable insight was gained into airframe thermal response under extreme ambient temperature conditions.

This Sheet Security Classification

KEY WORDS

Robot-X

Thermal Testing
Thermal Stresses
Robot-X Airframe
Composite Material

87-01808
#50639

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