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STUDY OF PAYLOAD SENSOR CONTAMINATION

By F. Jack Smith and Stanley Podlaseck

Prepared under Contract No. NAS1-10763 by
MARTIN MARIETTA CORPORATION
DENVER DIVISION
Denver, Colorado

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This report is submitted in compliance with Paragraphs 4.1.5 and 6.2 of the Statement of Work of Contract No. NAS 1-10763.

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By F. Jack Smith and Stanley Podlaseck
Martin Marietta Corporation

SUMMARY

Epoxy/glass test specimens representing Scout fourth and fifth stage motor casings were prepared and studied in a test program designed to determine the relative contamination contributed to payload sensors located near the motor casings.

The relative contamination detected in the test program was dependent on several factors, including: distance of test specimen to sensor, sensor temperature, geometric position of the sensor (relative to test specimen), test specimen temperature, chemical composition of the test specimen, sensor function, and additional materials (such as adhesive-backed aluminum tape) added to the test specimens.

The thermal characteristics and the decomposition and outgassing products were determined. These data were used to better understand the relative contamination data from the remote sensor testing.

Data from the test program indicate that a vacuum cure would be a desirable addition to the epoxy/glass casing cure cycle to reduce possible contamination from the composite. Adhesive-backed aluminum tape was found to be a significant contamination source and should not be used near payload sensors. The Altair III motor casing produced less relative contamination than either the Altair II or Alcyone I motor casings.

INTRODUCTION

This report describes a study that was performed to determine the severity of contamination of payload sensors placed in close proximity to the Scout Launch Vehicle fourth or fifth stage rocket motor cases. The objective of the program was to obtain sufficient data to define the severity of motor case outgassing and to define needed corrective methods that would enable Scout flights to be made without degrading contamination-sensitive payload sensors.

One of the objectives of this program was the quantitative determination of degassing from samples of materials representative of each of the Scout fourth and fifth stage motor cases. Thermogravimetric (TGA) and residual gas (RGA) analysis techniques were employed for these determinations.

Test specimens were subjected to a simulated temperature-time profile in vacuum with various payload sensors and optical elements positioned in close proximity to the specimens. Measurements before and after the exposure determined the extent of performance degradation on the sensors and elements by the motor case offgassing products. These tests were performed in a vacuum chamber with a remote manipulation capability.

Evaluation of techniques for reducing or eliminating condensible degassing products from the Scout fourth and fifth stage motor cases are suggested.

EQUIPMENT AND APPARATUS

Master-Slave Vacuum Chamber

This chamber (fig. 1) can be used for mechanical, electrical, thermal, and optical properties testing, as well as other vacuum tests requiring a sophisticated manipulating capability. The three master-slave manipulators incorporated in each chamber provide the ability to change test fixtures, make electrical or electronic connections, and move material within (and in or out of) the test chamber, while maintaining a high vacuum in the chamber. The chamber will maintain pressures of 10^{-7} torr while handling gas loads in excess of 2×10^{-3} torr-l/sec. Specific features of the system include:

1) Three master-slave type manipulators per chamber;

2) Main chamber 5 ft in diameter by 7 ft long; airlock 2 ft in diameter by 2 ft long;

3) Fully-opening chamber door (5 ft in diameter), and a 24-inch gate valve separating the airlock and the chamber;

4) 10 000-lb universal testing machine mated with each chamber;

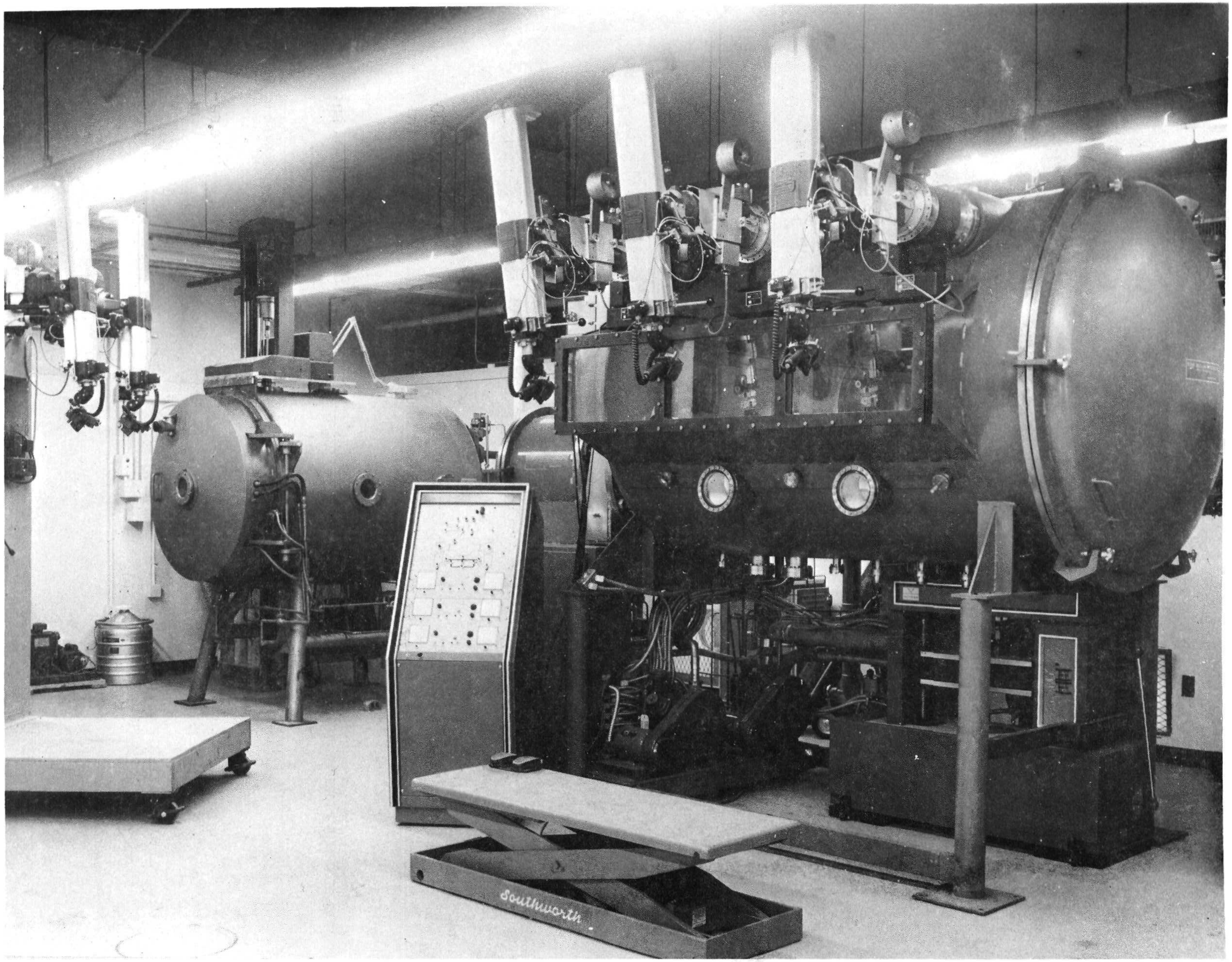

Figure 1.- Exterior View of Vacuum *In-Situ* Test Chamber

5) Ultimate vacuum: 10^{-7} torr;

6) Twenty-two available feedthrough ports, including high voltage (60 kv), high current (500 amp), liquid, instrumentation, RF;

7) Internal lighting in main chamber;

8) Chamber window viewing area: 6 square ft;

9) Two 20-inch diffusion pumps per main chamber; one 6-inch diffusion pump on airlock.

Mettler Recording Vacuum Thermoanalyzer

Brief specifications of this unit (fig. 2) are as follows:

1) Weighing capacity: 16.99 g;

2) Three automatic weighing ranges (0-1000 mg, 0-100 mg, 0-10 mg);

3) Precision in 0 to 10 mg range - ±0.05 mg;

4) Accuracy in expanded diagram of 0 to 10 mg range - ±0.03 mg;

5) Readability in expanded diagram of 0 to 10 mg range - ±0.005 mg;

6) DTA equipment has six measuring ranges (20 μv to 100 mv) with a response sensitivity from 0.2 to 4 mv in the six ranges;

7) Furnace range (25 to 1000°C) with heating and cooling rates selectable in steps of 0.5, 1.5, 2, 4, 6, 8, 10, and 25°C/minute, and temperature regulation accuracy of ±1.5°C;

8) Simultaneous recording of TGA, DTA, DTG, and temperature;

9) DTG equipment has weighing sensitivities ranging from 5 mg/min to 250 mg/min;

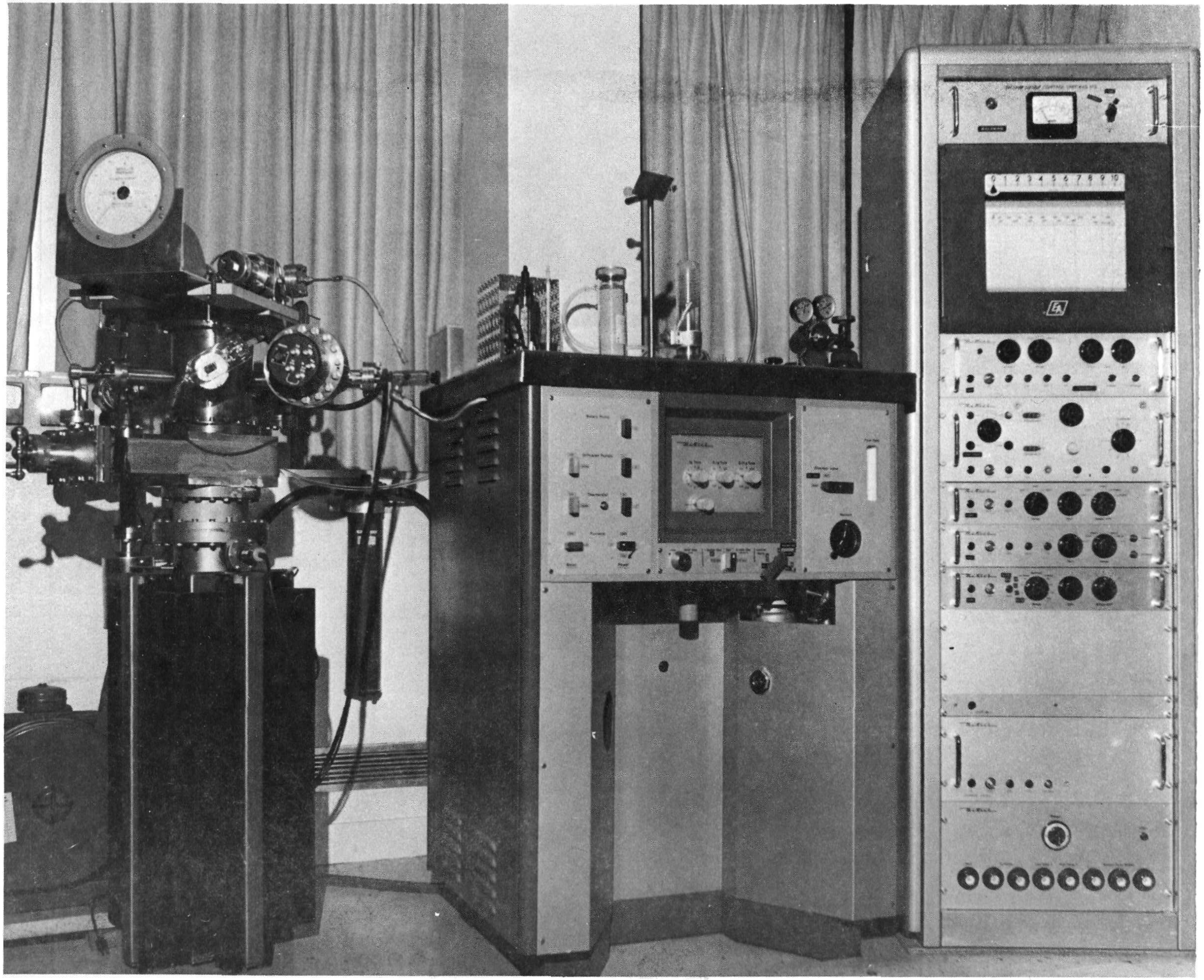

Figure 2.- TGA/RGA Facility

10) Vacuum equipment capable of 5 x 10^{-6} torr;

11) The system is attached to a quadrupole mass spectrometer for offgassing studies under vacuum.

Granville-Phillips Spectroscan 750 Quadrupole Residual Gas Analyzer (Mass Spectrometer)

This unit (fig. 2) is used in conjunction with the Mettler Thermoanalyzer. Specifications are:

1) Mass range: 1 to 750 amu;

2) Sensitivity: 100 amp/torr for N_2;

3) Minimum detectable partial pressure: 10^{-15} torr for N_2 with unit resolution at mass 100 using electrometer. Ratio of total pressure/partial pressure is 10^{-6} (1 ppm);

4) Scan rate: 500 msec to 6 minutes/amu;

5) Bakeout to 400°C;

6) All ionizer parameters are variable;

7) Output - oscilloscope and recorder;

8) Inlet system with automatic pressure controller for calibration.

Beckman IR-12 Infrared Spectrophotometer

This instrument has the following capabilities:

1) Frequency range: 4000-200 cm^{-1} (2.5 to 50μ);

2) Linear wave number (cm^{-1}) presentation;

3) Scanning times: 5 minutes to 18 days;

4) Purging capability;

5) Single-beam and double-beam operating modes;

6) Wilks ATR-9 attachment;

7) Various gas and liquid cells.

Beckman DK-2A Ratio Recording Spectrophotometer

The Beckman DK-2A ratio recording spectrophotometer is a double-beam, single monochromator instrument consisting of a quartz prism for the wavelength range 185 mμ to 3.5 microns. Resolving power is 0.2 mμ over most of the ultraviolet-visible range and 1 mμ in the near infrared. Stray light is less than 0.1% over the range of the instrument. Photometric system maintains accuracy of better than 0.4 mμ in ultraviolet, 1.5 mμ in the visible, and 0.5 mμ in the near infrared. Presentation is nonlinear in wavelength on a flat bed recorder.

Granville-Phillips Series 219 FTM Condensible Film Monitor

This instrument is calibrated to read condensible products deposited on a ¼-inch diameter area directly in $\mu g/mm^2$. The instrument has three ranges: 2000, 20 000, 200 000 $\mu g/mm^2$, with a resolution of 10^{-8} g/mm on the most sensitive range. Drift over a 1 hour period is ±8 $\mu g/mm^2$.

Sensor Materials

1) Number 2, 2x2 cm, 8 to 14 mil thick, solder-dipped solar cells;

2) Silica solar cell covers;

3) One inch diameter x 3.2 mm thick quartz disks;

4) One inch diameter x 4.5 mm thick sodium chloride disks.

TEST SPECIMENS

Test specimens were designed to provide a valid simulation of service hardware. The following requirements represent the principal objectives deemed necessary to achieve a valid simulation:

1) The resin formulation and content of the test specimen must simulate that of the actual motor casing. The resin and catalyst are the major (if not the only) contributors to outgassing contamination from the motor casings, and therefore the prime requirement of any test specimen was that resin formulation and content of the specimens be as similar as possible to that of the motor casings.

2) The number of roving layers in the test specimens was the same as the actual motor casings.

3) The manufacturing and propellant cure cycles used to prepare the actual motor casing were used to prepare the test specimen. The cure cycles used would affect the amount of offgassing by either the motor casings or test specimens.

The test specimens differed from the actual motor cases in the following respects:

1) The roving pattern for the test specimens was altered slightly. The pattern differences were only in the angle of the helical layers and would not cause any difference in the resin contents of the test specimens as compared to the actual motor casings.

2) The dimensions (diameter, length) of the test specimens differed from those of actual motor casings. This was done as a matter of convenience and cost, and did not jeopardize any of the test results.

3) The test specimens did not include the insulation materials found in the actual motor cases. These materials were purposely omitted since their outgassing products would jeopardize program objectives. In the actual case, insulation materials are sealed inside the motor casing and do not contribute to the external outgassing.

4) The test specimens were not stored before use as are the actual motor casings. This imposed a "worst case" condition on the test specimens compared to the actual motor casings. All of the test specimens were analyzed within four months after manufacture, to obtain all the test data included in this study. The actual motor casings are stored over a period of a number of years before they are used. The aged casing skirt from an actual Altair III motor utilized in this study was approximately 4½ years old.

Test Specimen Preparation

Ten by twelve inch test panels were cut from cylindrical test specimens that represent the fourth and fifth stage Scout motor casings. Test specimens and panels were handled and processed in a manner that prevented contamination by any material that would invalidate the test results.

One test panel from the Altair III test specimen was covered with 3M Company Y-9040 aluminum tape (approximately 2 inches wide) applied across its entire surface. This was done to evaluate any additional outgassing from this type tape. This tape is commonly used in the Scout Program to attach items to the motor casings.

Aged Test Specimen for TGA/RGA Analysis

NASA/Langley provided a sample from an actual Altair III motor casing skirt. This sample was prepared for TGA/RGA analysis and handled by the same techniques used for the other test specimens obtained for this program. This specimen was approximately $4\frac{1}{2}$ years old.

TEST PROCEDURES

Test procedures for thermogravimetric analysis (TGA) and residual gas analysis (RGA) in vacuum.

Apparatus and Equipment Check List

1) Testing in vacuum was done in accordance with the detailed operating instructions given by the Mettler Instrument Co., *Mettler Thermoanalyzer Operating Manual*.

2) All measurement and controlling instruments used in these tests were subject to the regular instrument calibration cycle in accordance with standard metrology procedures. In addition, the equipment was calibrated and backgrounds obtained on a sample-to-sample basis.

Test Preparation Check List

1) Check vacuum and gas flow system diagram, gas pressure, before operating valves, stopcocks, or removing sample chamber tube. Check that the balance was arrested.

2) Check proper cooling water flow, thermostat temperature and water level.

3) Ensure proper and consistent sample preparation and packing. Method of specimen preparation was recorded in the laboratory notebook.

Test Conditions

1) Heating rate was 25°C/minute for vacuum TGA tests.

2) TGA curve was obtained for the temperature range of 25° to 500°C.

3) Residual gas analysis spectra for the mass/charge range 10 through 250 was begun when the system pressure was 5×10^{-5} torr or less.

Data

1) Sample and operation test data that were monitored and recorded in the laboratory notebook were:

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Date: Test no.

Trade name:

Sample material (lot/batch no.):

Sample weight: mg
TGA sensitivity: mg/in.
DTG sensitivity: mg/in./min

Preparation of sample:
Filled, pressed, vibrated, sandwiched

Atmosphere:	Vacuum:	Torr:
Gas flow rate	l/hr	
DTA sensitivity:	μV/in.	
DTA reference material:		
Weight:	mg	
Heating rate:	°C/min	
Furnace:	Sample holder:	
Thermocouple: Pt'Pt-Rh10,	Ref. temp:	25°C
Crucible material:	Shape:	Size:
Temperature recording:	2 mv. 10 mv. full scale	
Chart speed:	in./hr	
By:	(Test conductor signature)	

2) TGA data were reduced in graphical form showing the specimen weight vs temperature.

3) RGA data were reduced in graphical form showing the change in relative peak heights of significant M/e peaks (not present in background) vs sample temperature.

4) A continuous recording of the temperature-time history and TGA scans was obtained for each run and stores in an area identified in the laboratory notebook. Test conductor signature and any special observations were also recorded in the laboratory notebook.

5) All notebook entries were dated and recorded in ink.

6) All notebook errors were lined out and initialed and dated.

Tolerances

1) Temperature tolerance during test was $^{+4^\circ}_{-0^\circ}$C.

2) The tolerance to be observed for the time of exposure was ±5%.

SENSOR CONTAMINATION TESTS - VACUUM CHAMBER

Pretest Procedure

1) The test panel and associated test hardware were positioned in the vacuum chamber.

2) The vacuum chamber was evacuated to the 10^{-6} torr range.

3) The contamination sensors were installed through the chamber airlock and placed at a predetermined distance from the test panel after the main chamber was in the 10^{-6} torr range.

4) Initial measurements that were made within the chamber included:

    a) Reference outputs of the reference and exposed solar cells using a standard light source;

    b) System baseline condensible degassing was obtained with the quartz crystal microbalance.

Test Procedure

1) The test panel was subjected to the simulated flight temperature profile and continuous measurements on the microbalance were made during the run.

2) After the temperature profile was completed the following measurements were performed:

    a) Exposed solar cells and reference solar cell outputs were determined using a standard light source;

    b) System background condensible degassing rates were checked after the panel had cooled to 40°C or less.

3) Quartz and sodium chloride sensors were removed from the chamber and transferred, as soon as possible, to the spectrophotometers for reflectance and transmission measurements.

a) Total reflectance and transmission measurements were made with Beckman DK-2A ultraviolet-visible spectrophotometer and Gier Dunkel integrating sphere.

b) Transmission and absorbance measurements were made using a Beckman IR-12 infrared spectrophotometer.

4) A time/event log was maintained with each of the start and finish times and dates of the pretest and test procedure.

TEST RESULTS

Thermogravimetric (TGA) and Residual Gas (RGA) Analysis of Casing Materials

Alcyone I Test Specimen

TGA data show that the major degradation of the specimen starts at 380°C (716°F) with a 0.3% weight loss. This degradation continues until a temperature of 457°C (854°F) is reached, at which time the maximum weight loss of 15.3% occurs. At 240°C (464°F) there is no appreciable weight loss. The weight loss of the Alcyone I test specimen in vacuum as a function of temperature is shown in Table I.

RGA data show that the bulk of the outgassing and decomposition products are given off during the period of greatest sample weight loss and during a temperature range of 372°C to 530°C. The mass weight units of the major decomposition and outgassing products range from 2 to 94; the major mass peaks are given in Table II and are identified as to probable chemical structure. Figure 3 is a plot of the major mass peaks against temperature, and shows sample weight loss as a function of temperature. The RGA data show decomposition products typical of cured epoxy/glass composites and indicate that there are no major decomposition or offgassing products given off during the flight temperature profile (75°F to 415°F) of the Alcyone I engine casing.

TABLE I

ALCYONE I SAMPLE WEIGHT LOSS DURING VACUUM TGA/RGA ANALYSIS

Temperature °C	(°F)	Percent weight loss
25	(77)	0
50	(122)	0
75	(167)	0
100	(212)	0
125	(257)	0.05
150	(302)	0.08
180	(356)	0.12
200	(410)	0.25
240	(464)	0.30
270	(518)	0.45
300	(572)	*
330	(626)	*
360	(680)	*
390	(734)	1.14
420	(788)	12.5
450	(842)	14.8
480	(896)	15.3
510	(950)	15.6
540	(1004)	15.9

*Percent weight loss difficult to measure because of buoyant effect of decomposing sample.

TABLE II

ALCYONE I - RGA ANALYSIS

Major decomposition and offgassing products	
Mass weight, M/e	Probable chemical structure
18	H_2O
28	CO
44	CO_2
50	Substituted ring fragment
66	Substituted ring fragment
94	Substituted ring fragment

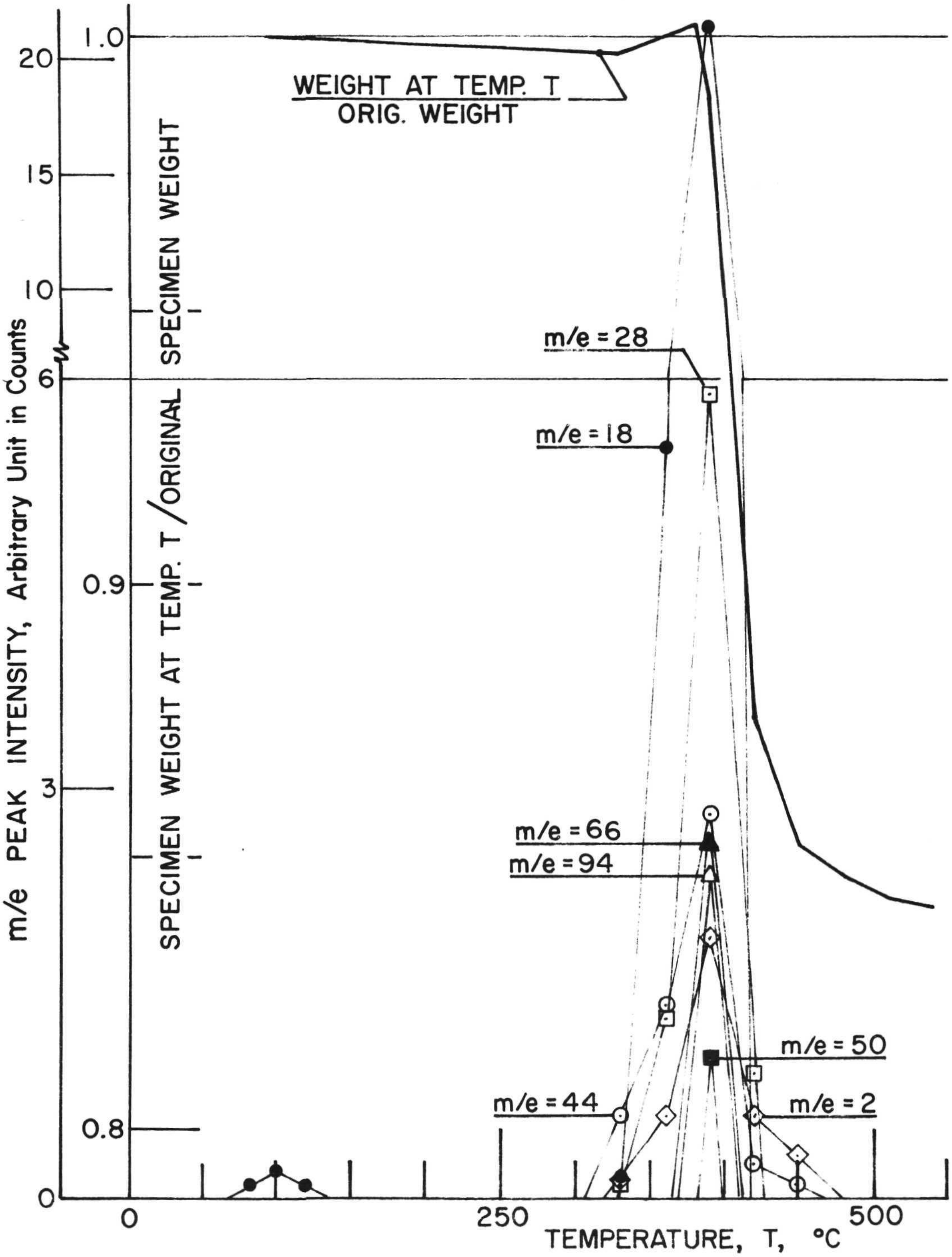


Figure 3.- Alcyone I TGA, RGA Data

Altair II Test Specimen

TGA data show that the major degradation of the specimen begins at 375°C (707°F) with a 1.5% weight loss. The degradation continues until a temperature of 478°C (892°F) is reached, at which time the sample has lost 19% of its weight. At 230°C (446°F) the weight loss is small. The weight loss of the Altair II test specimen in vacuum as a function of temperature is shown in Table III.

TABLE III

ALTAIR II - SAMPLE WEIGHT LOSS DURING VACUUM TGA/RGA ANALYSIS

Temperature °C	(°F)	Percent weight loss
25	(77)	0
50	(122)	0
75	(167)	0
100	(212)	0.02
130	(266)	0.05
160	(320)	0.08
190	(374)	0.11
220	(428)	0.14
250	(482)	0.16
280	(536)	0.19
310	(590)	0.21
340	(644)	0.25
370	(698)	*
400	(752)	6.30
430	(806)	17.0
460	(860)	18.2
490	(914)	18.9
520	(966)	19.2
550	(1022)	19.3

*Percent weight loss difficult to measure because of the buoyant effect of decomposing sample.

RGA data show that the outgassing and decomposition products are given off during the period of greatest sample weight loss and during a temperature range of 380°C to 457°C. The mass/charge units of the major decomposition and outgassing products range from 2 to 94; the major mass peaks are given in Table IV and are identified as to probable chemical structure. Figure 4 is a plot of the major mass peaks against temperature, and shows sample weight loss as a function of temperature. The RGA data show decomposition products typical of cured epoxy/glass composites and indicate that there are no major decomposition or offgassing products given off during the flight temperature profile (75°F to 400°F) of the Altair II engine case.

TABLE IV

ALTAIR II - RGA DATA

Major decomposition and offgassing products	
Mass Weight	Probable chemical structure
18	H_2O
28	CO
44	CO_2
66	Substituted ring fragment
94	Substituted ring fragment

Altair III Test Specimen

TGA data show that the major degradation of the specimen starts at 372°C (702°F) with a 3.3% weight loss. This degradation continues until a temperature of 530°C (986°F) is reached, at which time the maximum weight loss of 15.2% occurs. At 230°C (446°F) there is a 1.2% weight loss. The weight loss of the Altair III test specimen in vacuum as a function of temperature is shown in Table V.

The RGA data show that the decomposition and outgassing products from the Altair III specimens are given off during two temperature levels. The first group of these products is given off over a temperature range of 100°C (212°F) to 350°C (662°F), and peaks out at approximately 275°C (527°F). The second group is given off over a temperature range of 325°C (617°C) to 500°C (932°F), and peaks out at approximately 400°C (752°F). The mass/charge units of the major decomposition and outgassing products

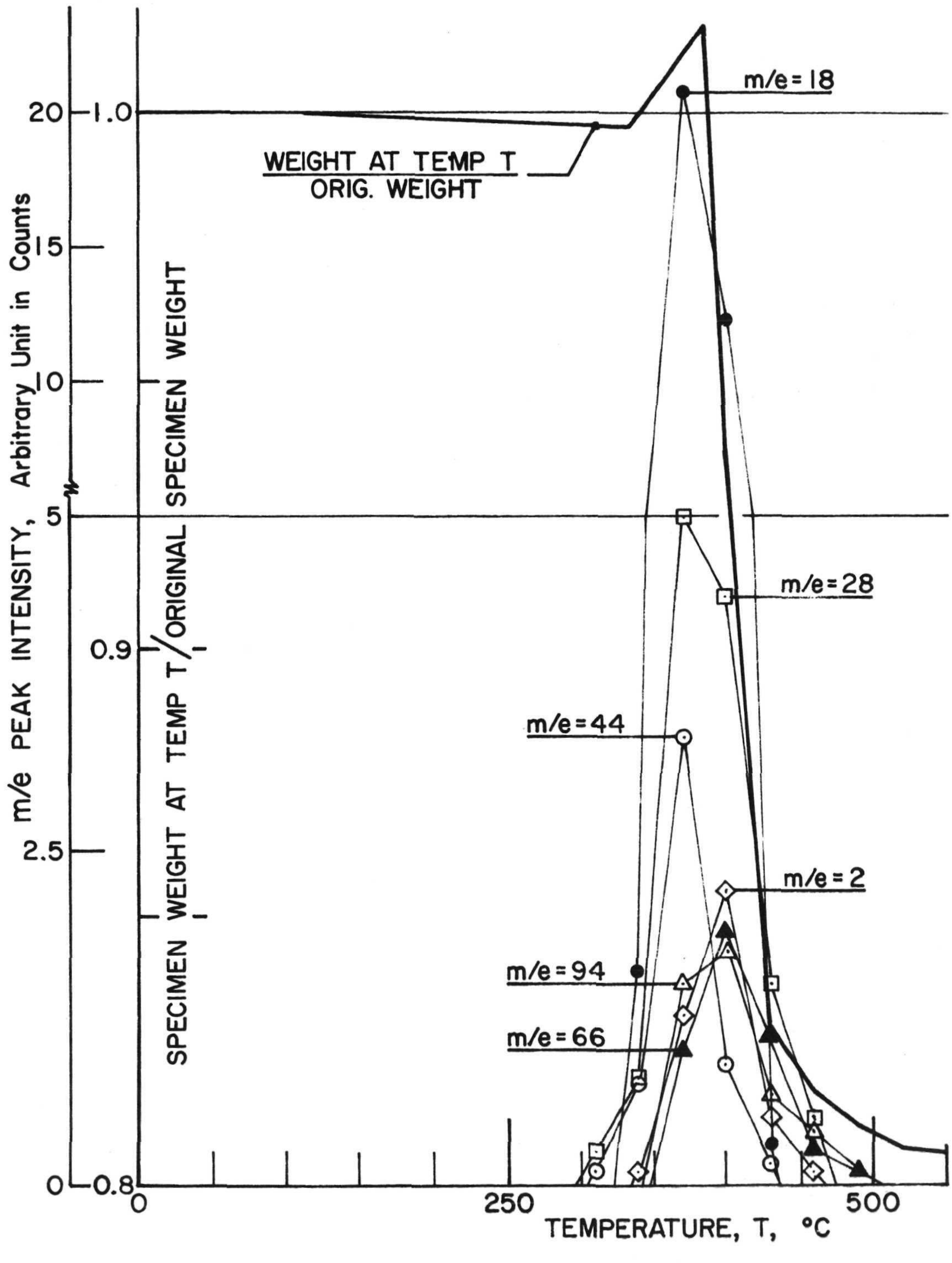


Figure 4.- Altair II TGA, RGA Data

range from 2 to 94; the major peaks are shown in Table VI, and are identified as to probable chemical structure. Figure 5 is a plot of the major mass peaks against temperature, and shows sa sample weight loss as a function of temperature. The data indicate that the first group of products seen are caused by the Nadic methyl anhydride (NMA = methyl substituted 3-6 endomethylene tetrahydrophthalic anhydrides) of the resin formulation. This is further substantiated by a TGA/RGA analysis run on unreacted NMA catalyst that gave a similar group of decomposition and offgassing products. The second group of products given off by the Altair III specimen is what one might expect from a cured epoxy/glass composite. The data indicate that the NMA catalyst used in the Altair III would tend to outgas during the flight temperature profile of 100°F to 475°F of the Altair III engine casing.

TABLE V

ALTAIR III - SAMPLE WEIGHT LOSS DURING VACUUM TGA/DTA ANALYSIS

Temperature °C	(°F)	Percent weight loss
25	(77)	0
50	(122)	0
75	(167)	0.05
100	(212)	0.12
130	(266)	0.16
160	(320)	0.40
190	(374)	0.87
220	(428)	1.12
250	(482)	1.44
280	(536)	1.91
310	(590)	2.23
340	(644)	3.03
370	(698)	3.35
400	(752)	4.44
430	(806)	9.28
460	(860)	13.3
490	(914)	15.2
520	(968)	15.6
550	(1022)	16.0

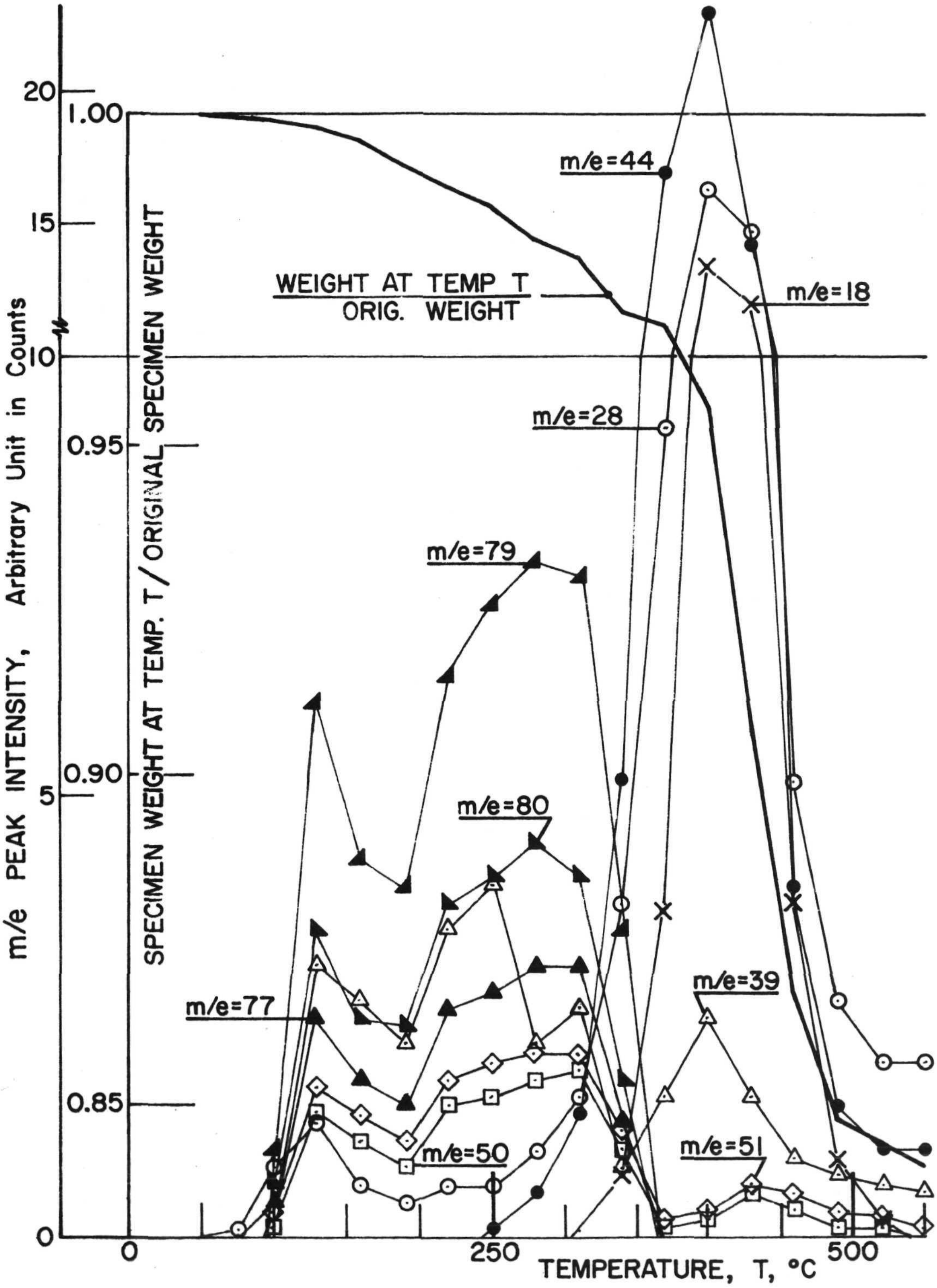


Figure 5.- Altair III TGA, RGA Data

TABLE VI

ALTAIR III - RGA DATA

Major decomposition and offgassing products	
Mass weight, M/e	Probable chemical structure
18	H_2O
28	CO
39	Ring fragment
44	CO_2
50	Ring fragment
51	Ring fragment
77	Ring fragment
79	Ring fragment
80	Ring fragment

Aged Altair III Sample

Figure 6 is a plot of the data obtained from the TGA/RGA analysis in vacuum performed on a piece of an Altair III engine skirt. A comparison of this figure with the TGA/RGA from the Altair III test specimen shown in figure 5 shows that the degradation rate and the types of outgassing and decomposition products are essentially the same. These data would indicate that normal aging, while the motor casing is in storage, does not effectively reduce its contamination potential. Figure 6 is a plot of the major mass peaks against temperature, and shows sample weight loss as a function of temperature. The mass/charge units of the major decomposition and outgassing products range from 2 to 94; the major mass peaks are given in Table VII, and are identified as to probable chemical structures.

TABLE VII

ALTAIR III SAMPLE - RGA DATA

Major decomposition products	
Mass weight, M/e	Probable chemical structure
18	H_2O
28	CO
39	Ring fragment
44	CO_2
50	Ring fragment
51	Ring fragment
77	Ring fragment
79	Ring fragment
80	Ring fragment

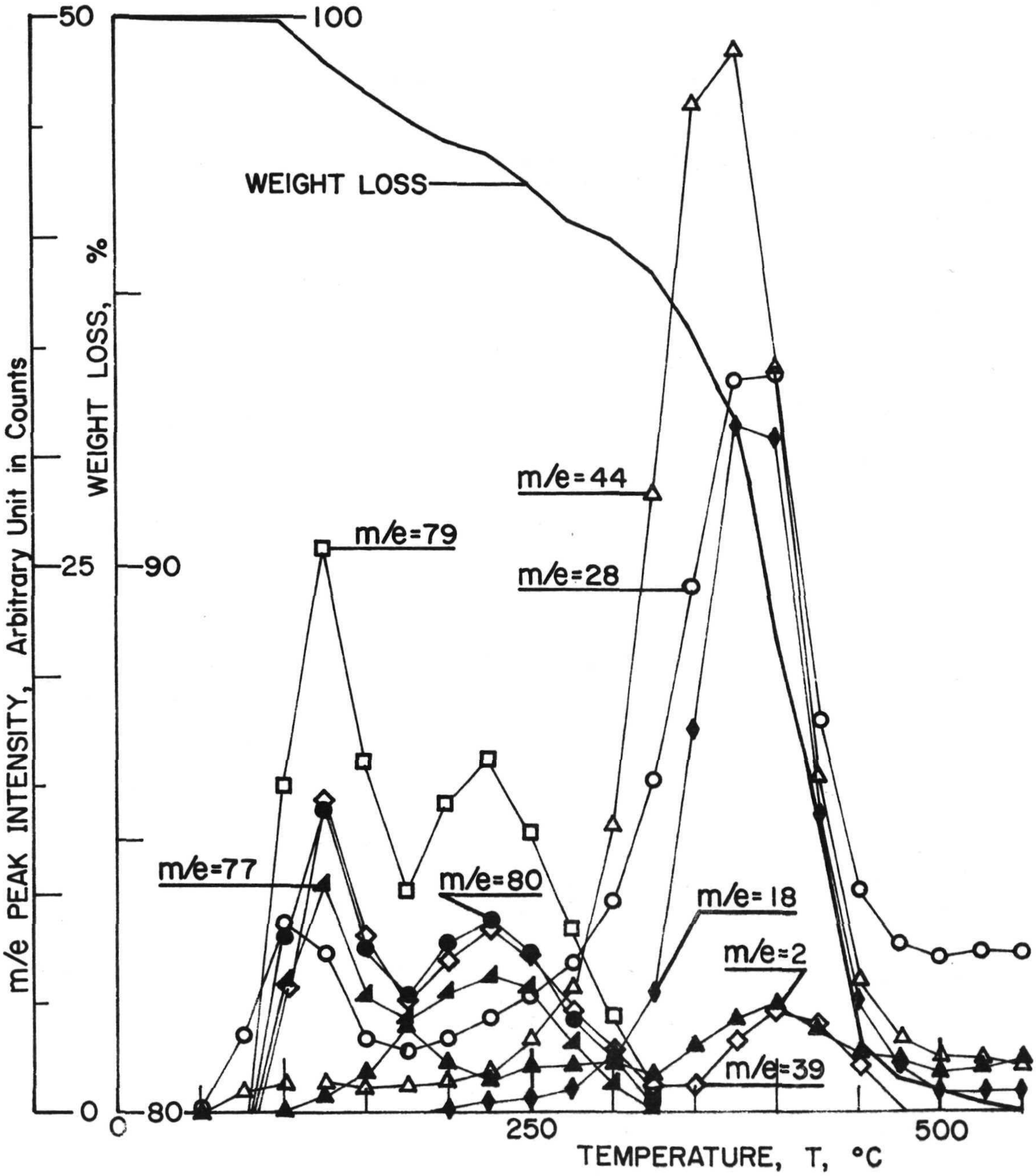


Figure 6.- Aged Altair III Sample TGA, RGA Data

Remote Sensor Testing in Vacuum

Sample array description.- The apparatus, test specimens, and procedures for this portion of the testing effort have been previously described in the text of this report, but the sensor array was not. To better understand the remote sensor results, a brief description of the sample array is given here and a drawing is provided in figure 7. Figures 8 thru 16 show the sample array fixture with various test specimens and setups. The sample array is a fixture with a removable holder made of aluminum which is fixed on a movable vertical track that enables an operator to vary the distance between the array and the test panel. The array is contoured to match the surface of the various test panels and contains the following remote sensors mounted on the holder: a 1-inch diameter sodium chloride disk for infrared determinations; a 1-inch diameter quartz disk for ultraviolet-visible determinations; a position for a recording quartz crystal microbalance for accrued weight (during the temperature profile runs) determinations; a solar cell without a cover plate, which faces the test panel; a solar cell with a fused silica cover plate, which faces the test panel; and solar cell without a cover plate, which faces 180 degrees away from the test panel. The temperature of each solar cell is measured through thermocouples attached to the cells.

Infrared sensor data from Alcyone I test specimen runs.- Alcyone I outgassing and decomposition products were collected on infrared sensors (sodium chloride disks) at distances of 6, 1, and 1/4 inches from the test panels in three separate vacuum temperature profiles. Infrared spectra obtained for the products deposited on the disks are shown in figure 17. The spectra indicate an aromatic hydrocarbon and undetermined polar groups are deposited on the sensors. The transmission and absorbance values determined from the spectra obtained from the sensors are given in Table VIII, which also gives the minimum absorbance point (maximum transmission) of the spectra, and the percent absorbance and loss of transmission caused by each of the major absorbance bands or reference areas of each spectrum.

The infrared data indicate that the outgassing and/or decomposition products given off during the flight temperature profile (75°F to 415°F) of the Alcyone I engine casing would contaminate any infrared sensor within 6 inches, and would interfere at most wavelengths of interest.

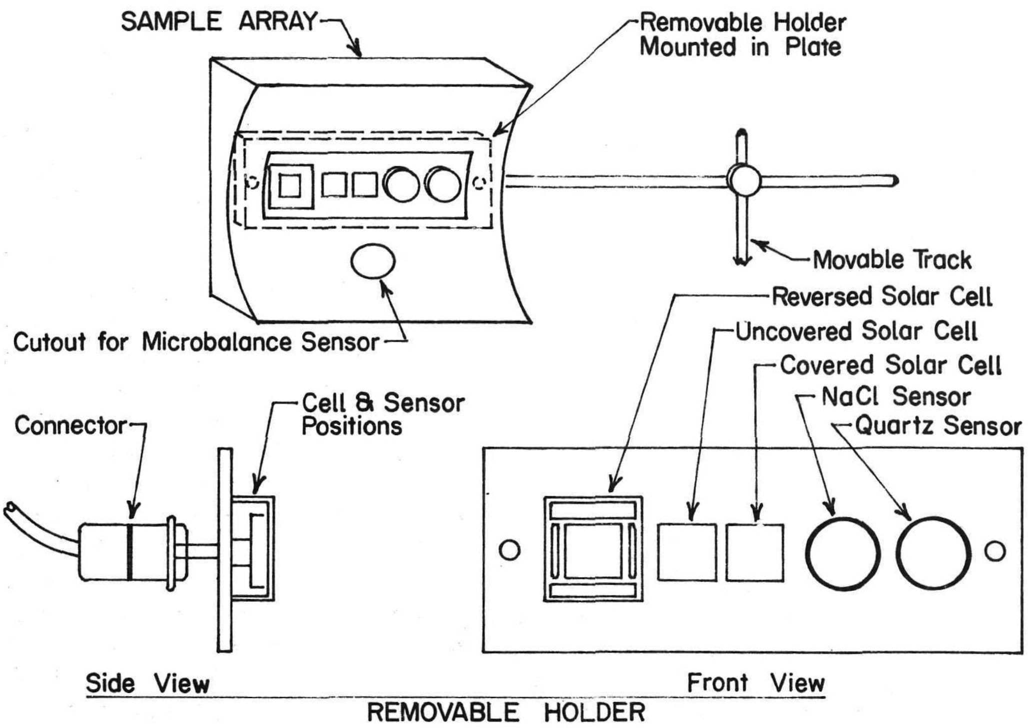


Figure 7.- Sample Array

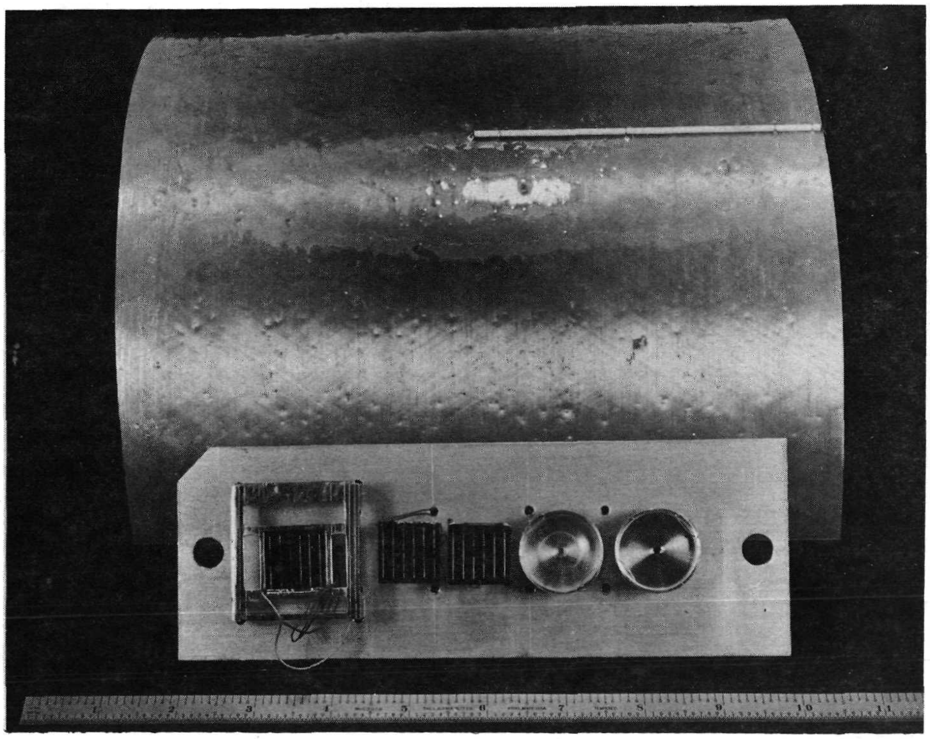


Figure 8.- Altair III Panel and Removable Holder (Sensors Mounted)

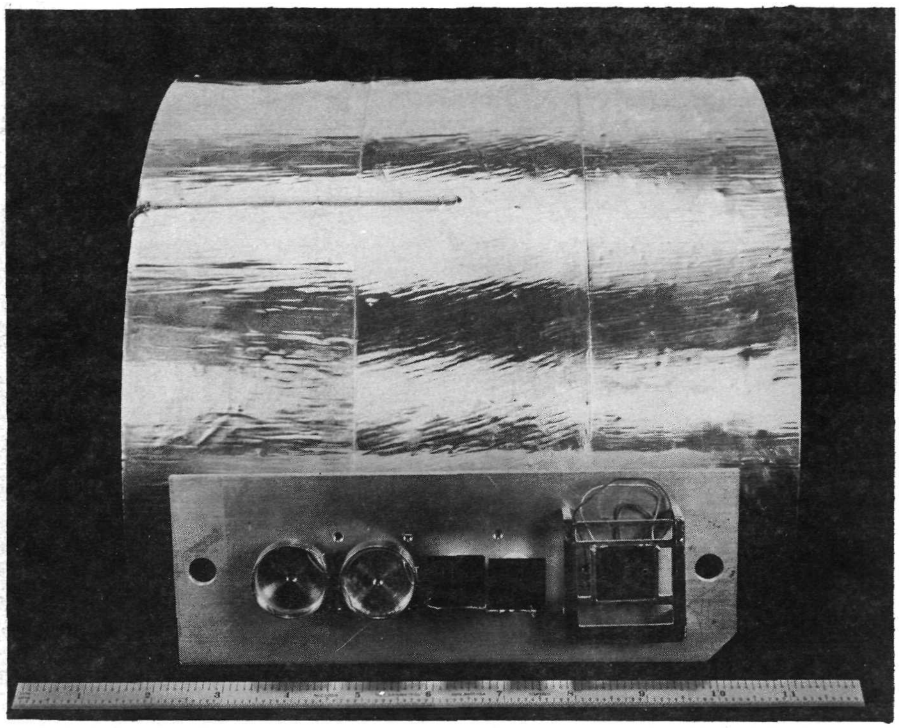


Figure 9.- Taped Altair III Panel and Removable Holder (Sensors Mounted)

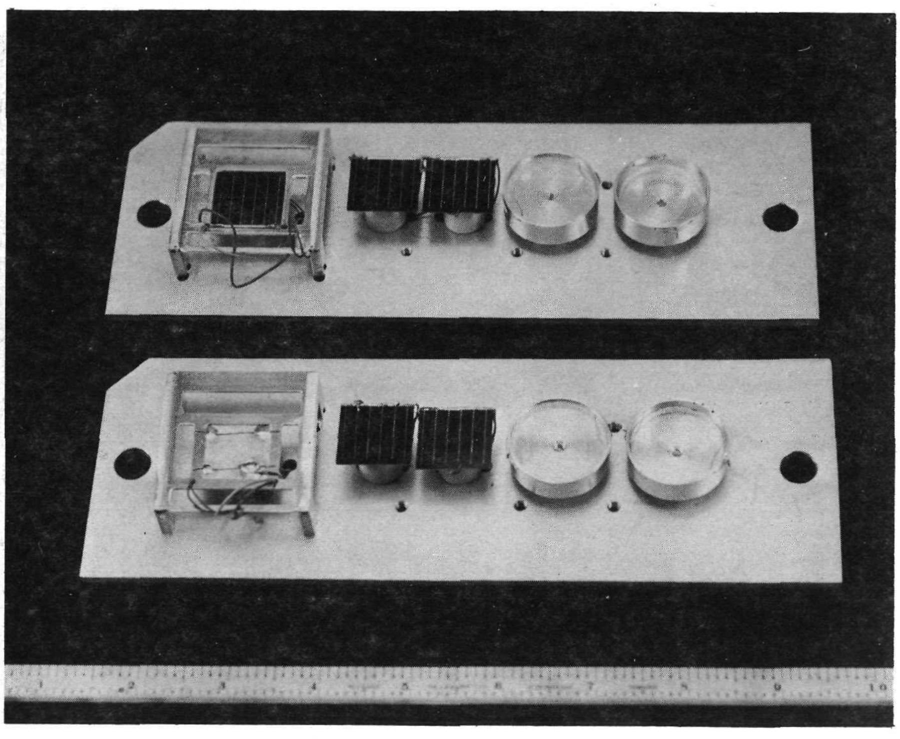


Figure 10.- Removable Holders with and without the Left-Hand Solar Cell Sensor Reversed

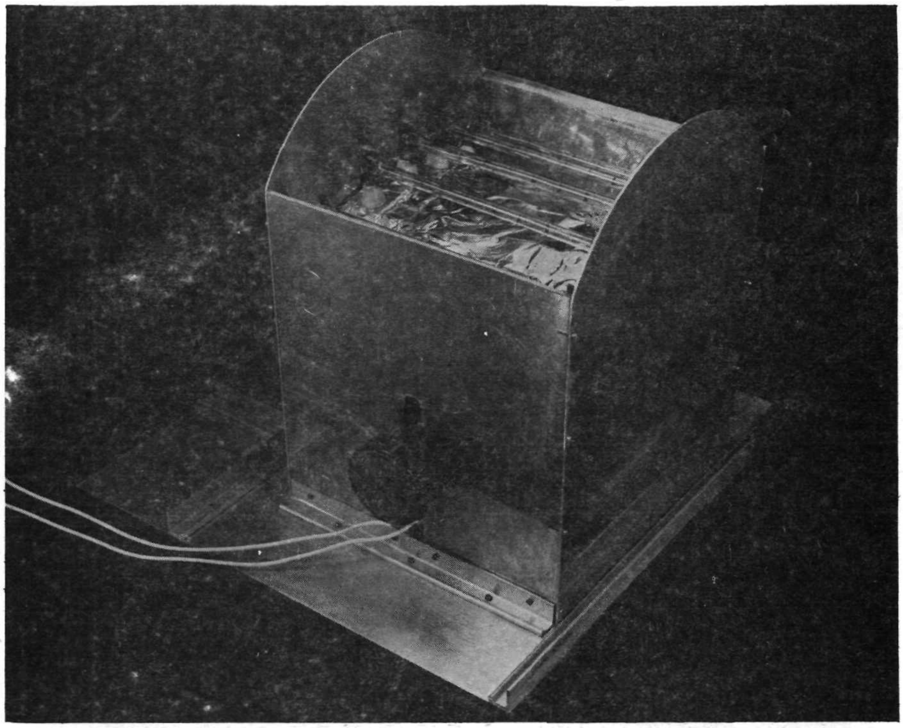


Figure 11.- Test Panel Holder and Heater Fixture Without Panel in Place

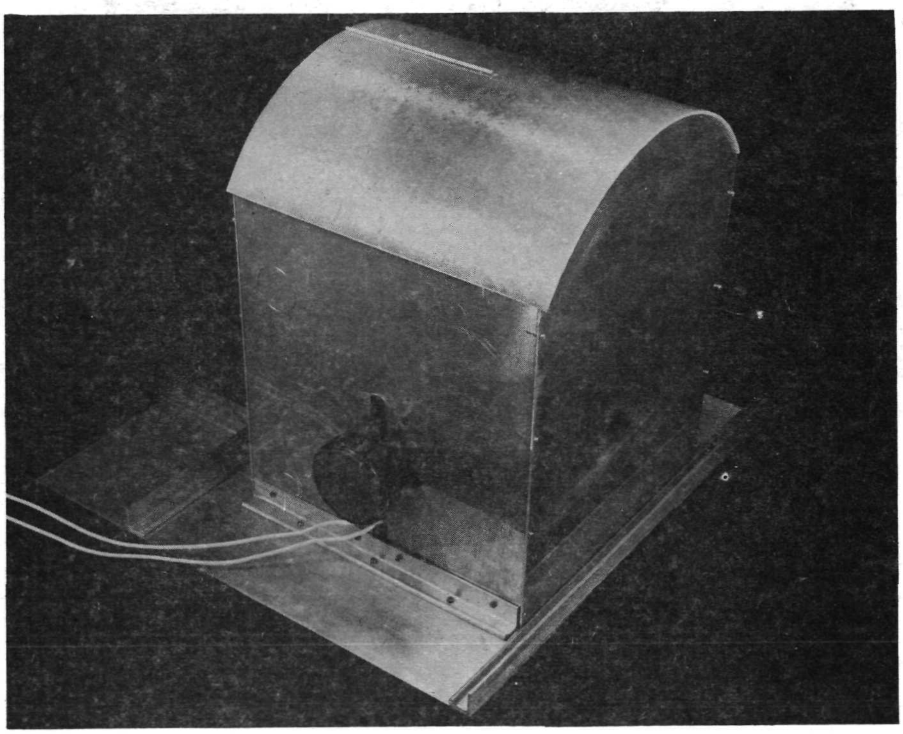


Figure 12.- Test Panel Holder and Heater Fixture With Altair III Panel in Place

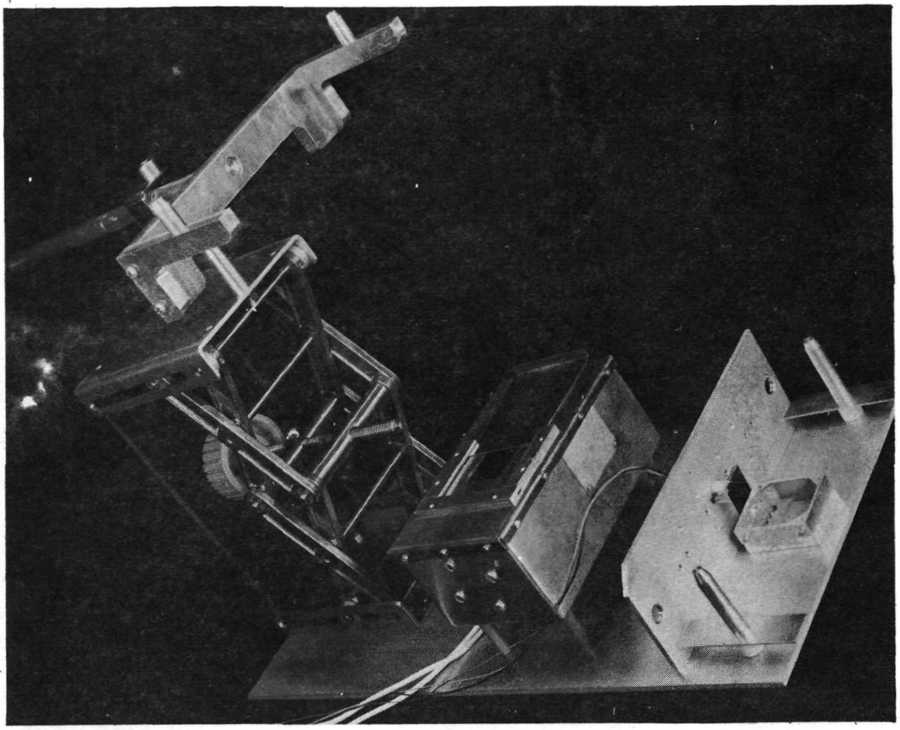


Figure 13.- Solar Cell Measurement Fixture with Energy Source
Open and Reference Solar Cell Shown Uncovered

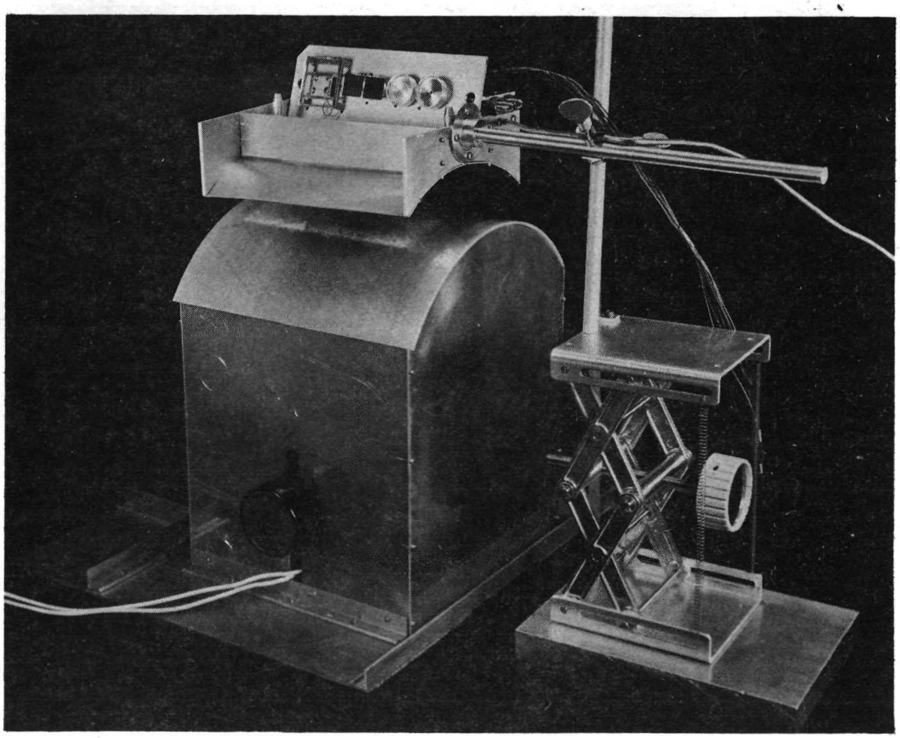


Figure 14.- Remote Sensor Testing Fixtures with Altair III
Panel in Place and Removable Holder Not in Place

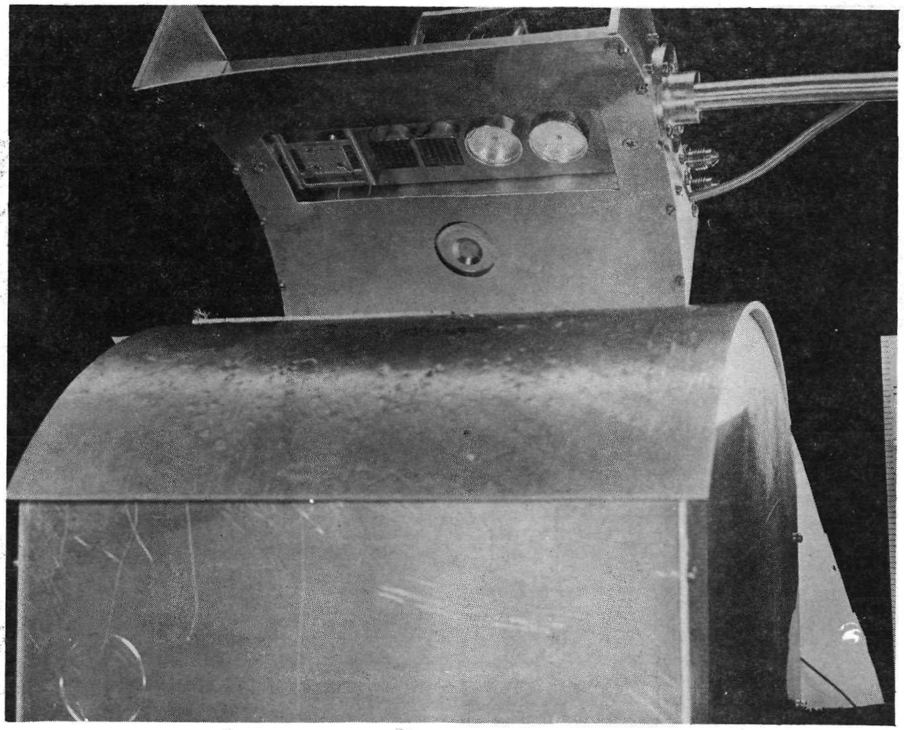


Figure 15.- Sample Array Fixture Shown in Place Over Test Panel Holder and Heater Fixture, with Removable Holder, Sensors, and Altair III Test Panel in Place

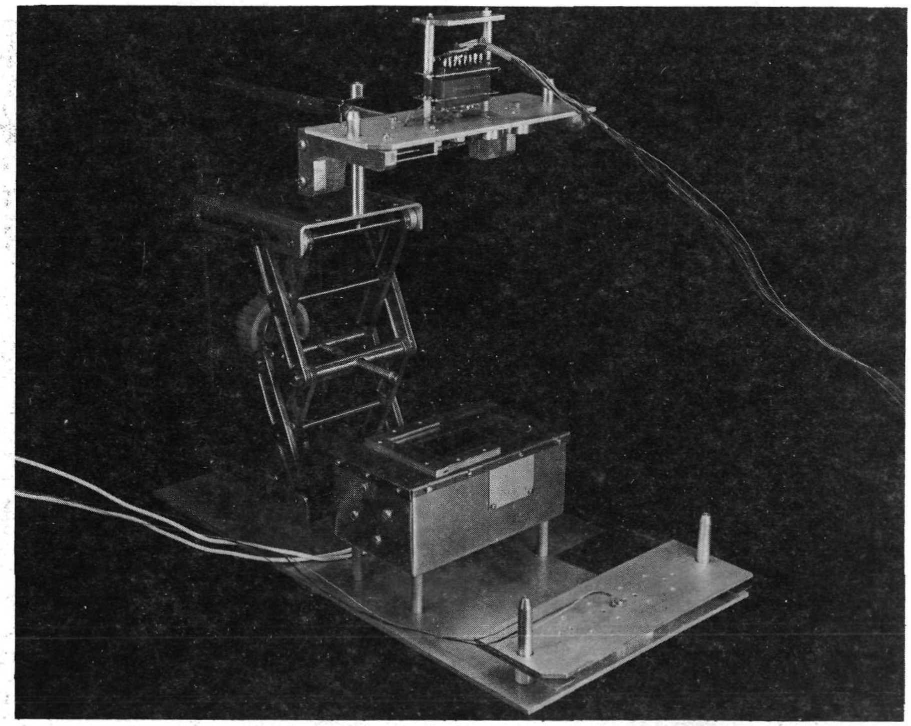
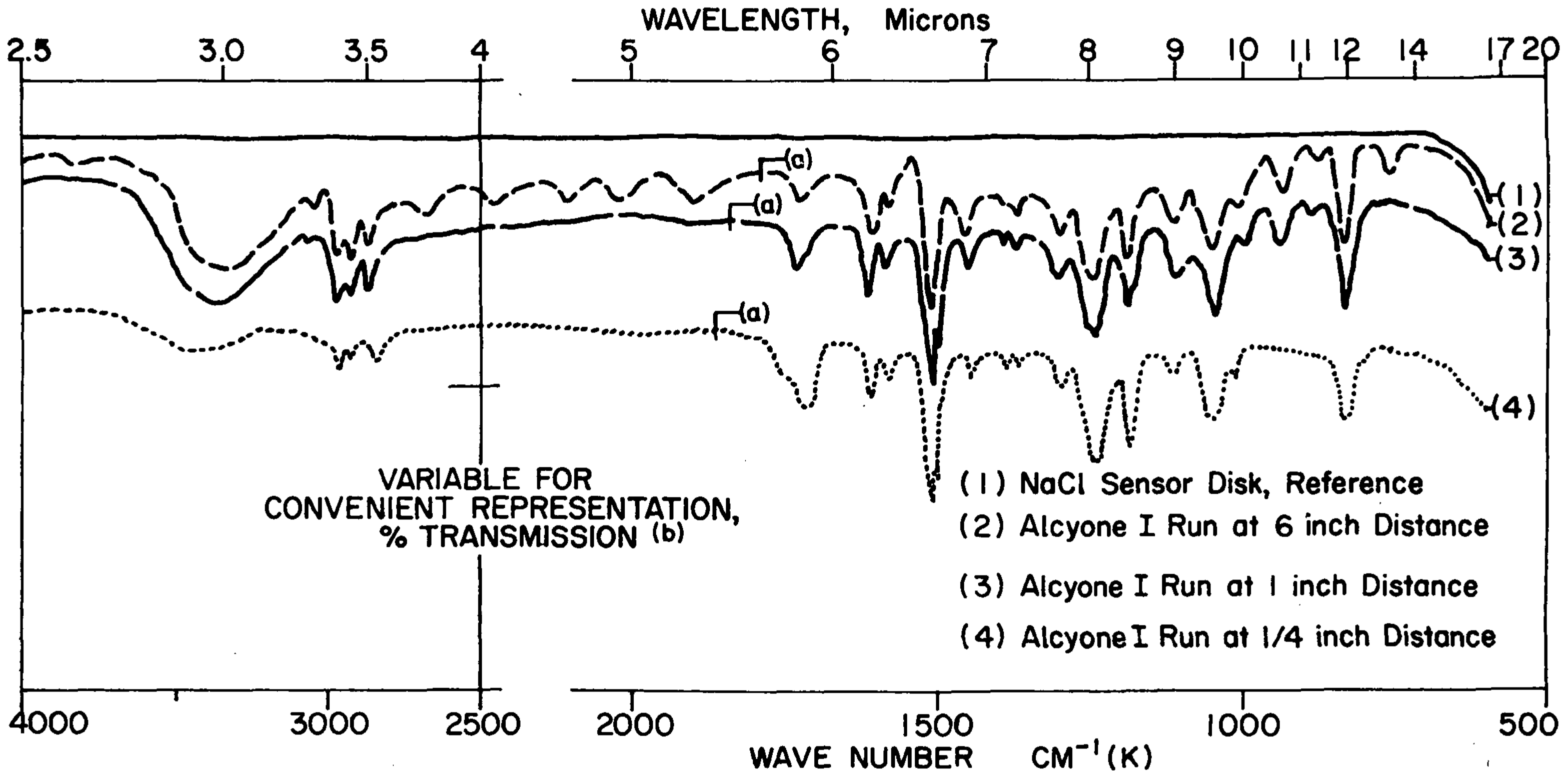


Figure 16.- Solar Cell Measurement Fixture with Removable Holder in Place, Energy Source Open, and Reference Solar Cell Shown Covered



(a) I_0, reference point of spectrum which is near the 100% line.

(b) Spectra separated in this figure for convenience of representation.

Figure 17.- Alcyone I Infrared Sensor Data

TABLE VIII

ALCYONE I - INFRARED SENSOR DATA

Wave number, K	Loss of transmission, ΔT%	Absorbance	Probable functional group
6-inch distance			
1250	39	0.240	Unassigned
[a]1510	45	0.292	C=C (ring)
1610	23	0.125	C=C (ring)
[b]1800	0	0.0	--
2400	8	0.040	C=0
2940	25	0.138	C-H (aromatic)
3400	33	0.197	0-H or N-H
1-inch distance			
1250	33	0.197	Unassigned
[a]1510	38	0.198	C=C (ring)
1610	18	0.114	C=C (ring)
[b]1900	0	0.0	--
2400	0	0.0	--
2940	18	0.114	C-H (aromatic)
3400	22	0.127	0-H or N-H
1/4-inch distance			
1250	25	0.143	Unassigned
[a]1510	27	0.157	C=C (ring)
1610	9	0.046	C=C (ring)
1740	15	0.080	Unassigned
[b]1900	0	0.0	--
2400	0	0.0	--
2940	9	0.046	C-H (aromatic)
3400	9	0.046	0-H or N-H

[a]Strongest absorbance band in spectrum.

[b]Reference point $\left(I_o\right)$, I_o = minimum point of absorbance in the spectrum.

Alcyone I ultraviolet-visible sensor data.- Outgassing and decomposition products were collected on quartz disks at distances of 6, 1, and 1/4 inches from the Alcyone I test panels in three separate vacuum temperature profiles. Ultraviolet-visible spectra obtained of the products deposited on the sensors are shown in figure 18. The spectra indicated that slightly more contamination is deposited on a sensor at a distance of 1 inch from the test panel, than at distances of either 6 or 1/4 inches. The transmission and absorbance values determined from the spectra obtained from the sensors are given in Table IX. The reflectance data from the sensors is given in Table X.

The data indicate that the products deposited on the ultraviolet-visible sensors by the Alcyone I motor casing would not critically affect their performance.

TABLE IX

ALCYONE I ULTRAVIOLET-VISIBLE SENSOR DATA

Wavelength, mμ	Loss of transmission, Δ%T	Absorbance
6-inch distance		
340	0	0.0
400	0	0.0
450	0	0.0
500	0	0.0
700	0.5	0.002
900	2	0.010
1500	2	0.0
[a]1900	0	0.0
2320	2	0.010
[b]2540	3	0.015
1-inch distance		
340	0	0.0
400	0	0.0
450	0	0.0
500	0	0.0
700	0	0.0
900	2	0.010
1280	0.5	0.002
[a]2000	0	0.0
2320	2	0.010
[b]2540	3	0.015

TABLE IX.- Concluded

ALCYONE I ULTRAVIOLET-VISIBLE SENSOR DATA

Wavelength, mμ	Loss of transmission, Δ%T	Absorbance
1/4-inch distance		
340	0	0.0
400	0	0.0
450	0	0.0
500	0	0.0
700	0	0.0
[b]900	2	0.010
1280	0.5	0.002
[a]2000	0	0.0
2320	2	0.010
2540	2	0.010

[a]Reference point (I_o), I_o = minimum point of absorbance in the spectrum.

[b]Strongest absorbance band in spectrum.

TABLE X

ALCYONE I ULTRAVIOLET-VISIBLE REFLECTANCE RATE

Distance from panel, in.	Max. reflectance, %	Min reflectance, %
6	11.5 at 340 mμ	9 at 2660 mμ
1	11.5 at 230 mμ	8.5 at 2660 mμ
1/4	10 at 550 mμ	8 at 2680 mμ

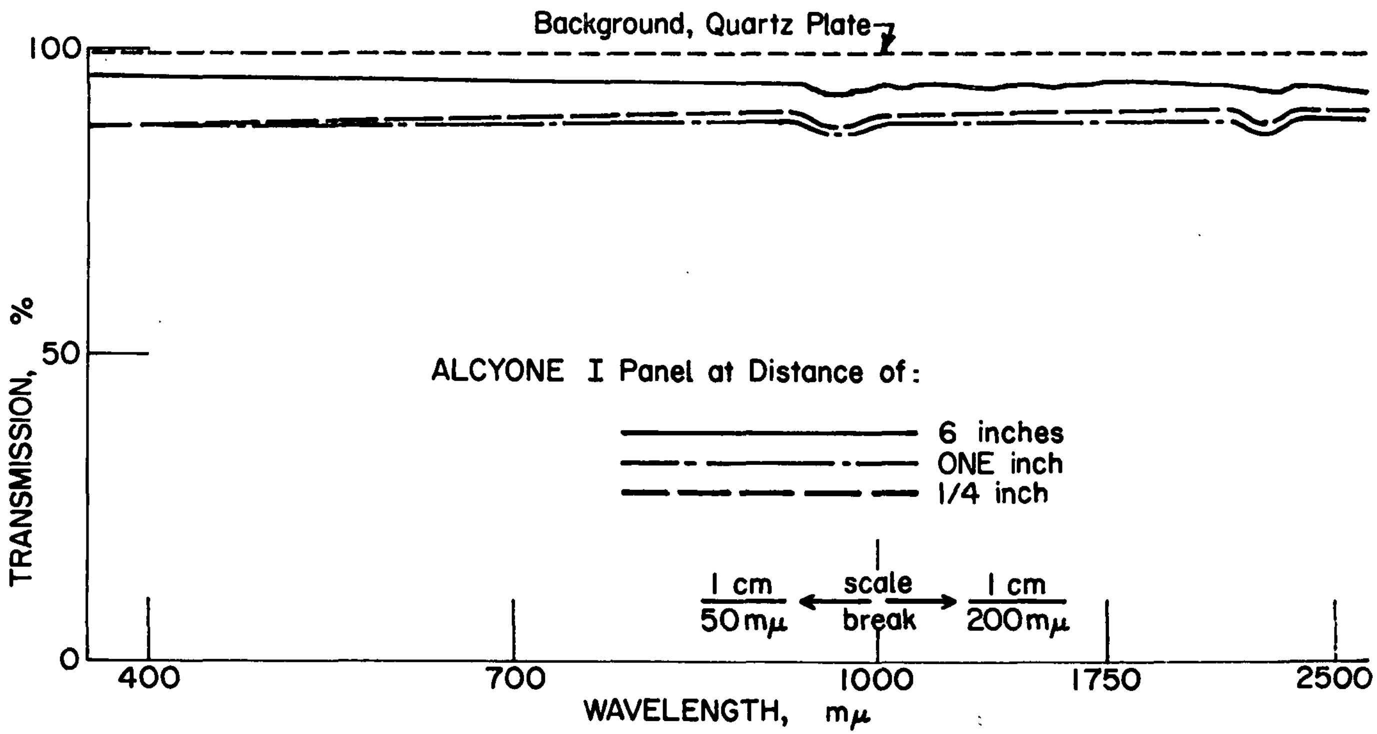


Figure 18.- Alcyone I Ultraviolet-Visible Sensor Data

Solar cell data from Alcyone I test specimen runs.- Three solar cells were subjected to the outgassing and decomposition products given off by each of the Alcyone I test specimens at given distances during temperature profiles in vacuum. The effect of these products on the efficiency of the solar cells is given in Table XI which shows the change in efficiency as related to the distance of the solar cell from the test specimen. Figure 7 shows the sample array and the location of the solar cell sensors.

The data shown in Table XI indicate that a solar cell located at the middle distance of 1 inch receives more damaging contamination than cells removed to a distance of 6 inches or very close to the test panel on one-quarter inch. The data also show that at a distance of 1 inch or more, a cell facing away from the test panel receives less contamination than a cell facing the panel. The Alcyone I test panels also deposited more contamination on the cells with silica covers than the uncovered cells.

TABLE XI

ALCYONE I - PERCENT CHANGE IN SOLAR CELL EFFICIENCY AND MAXIMUM TEMPERATURE DURING TEST (°F)

Distance, in.	Reversed cell- no cover		Cell with no cover		Cell with cover	
6	0.0	220°	-0.6	233°	-0.3	175°
1	-4.6	275°	-5.8	280°	-6.8	330°
1/4	-0.3	360°	-0.2	345°	-0.3	340°

Alcyone I crystal microbalance data.- The crystal microbalance collected offgassing and decomposition at distances of 1 and 1/4 inches during the temperature profiles in vacuum performed on three Alcyone I test panels. The test results show that at a distance of 1/4 inch, less contamination was collected on the crystal than at the 1-inch test distance. The data from the test results are represented in figure 19, where the information obtained from the microbalance is plotted against time (in minutes), as is the temperature profile for the test program. The microbalance malfunctioned at the 6-inch distance, therefore, no data are available at this interval for these measurements. The amount of contamination collected and measured on the microbalance is in the range of 5×10^{-5} to 2×10^{-4} grams.

The microbalance data indicate that the Alcyone I motor casing would be expected to expel decomposition and/or outgassing products during the normal flight temperature profile for the Alcyone I engine.

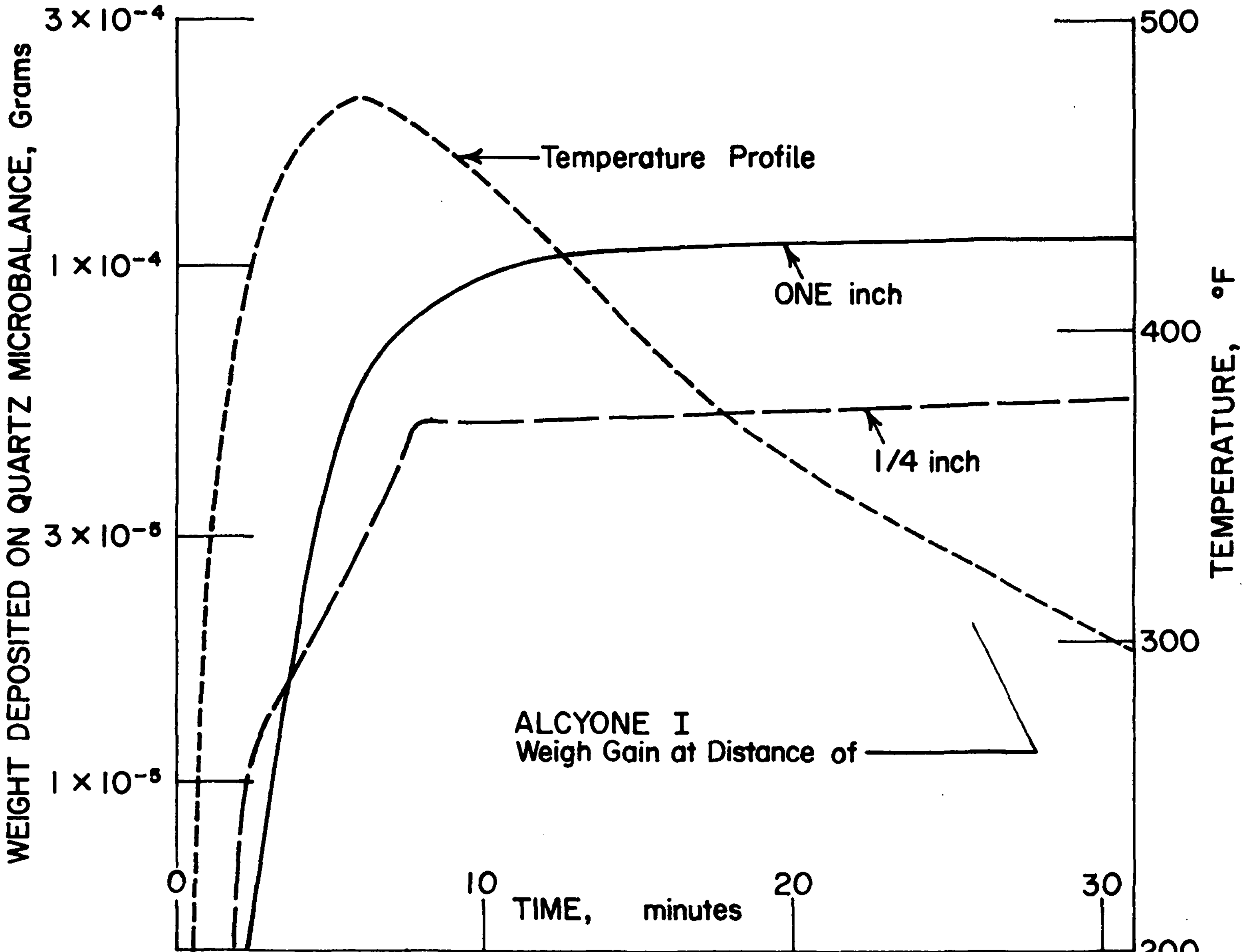


Figure 19.- Alcyone I Quartz Microbalance Data

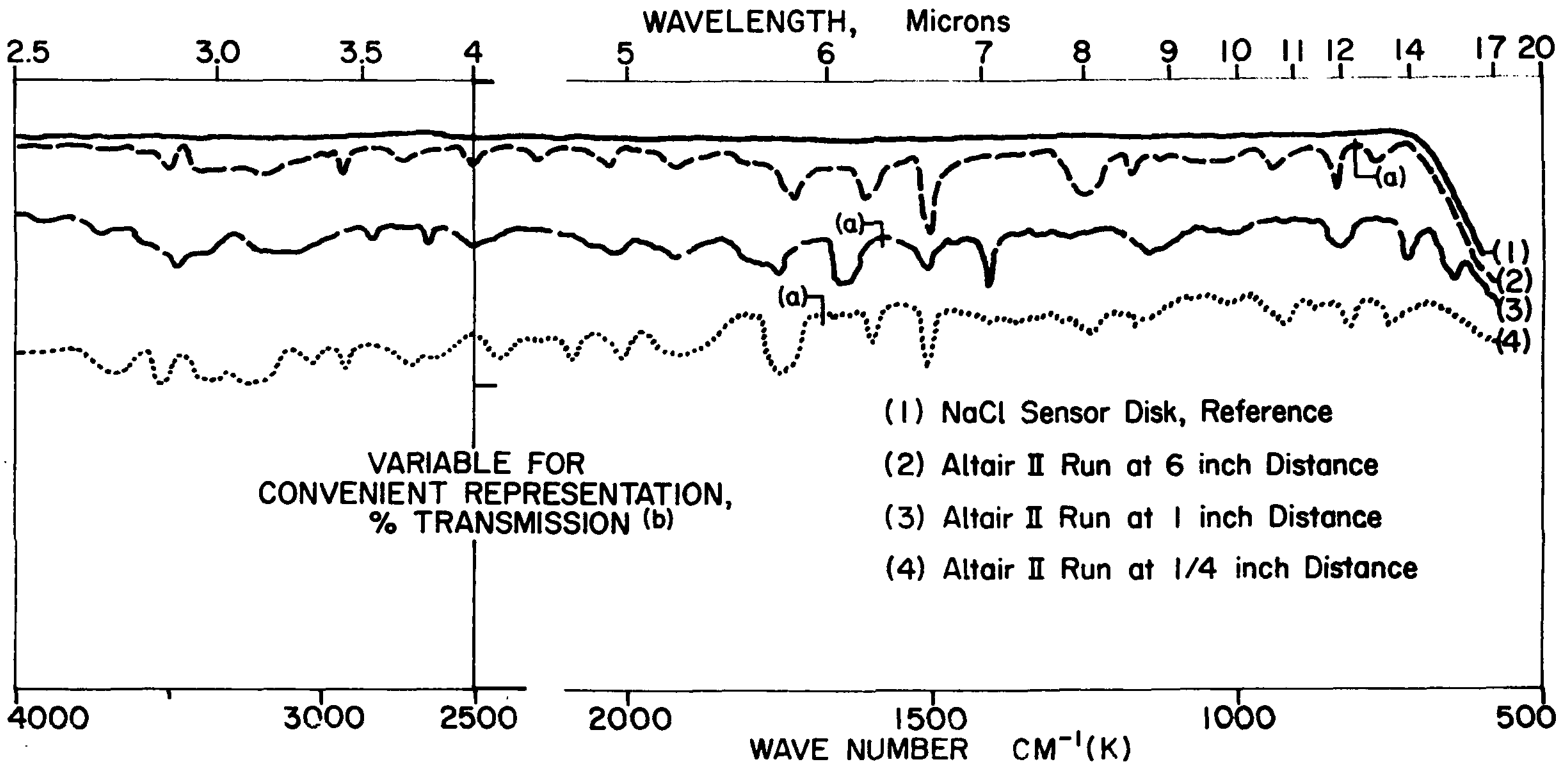
Infrared sensor data from Altair II test specimen runs.- Altair II outgassing and decomposition products were collected on infrared sensor objectives (sodium chloride disks) at distances of 6, 1, and 1/4 inches from the test panels in three separate vacuum temperature profiles. Infrared spectra obtained for the products deposited on the sensors are shown in Figure 20. The spectra indicate that an aromatic hydrocarbon and undetermined polar groups are deposited on the sensors. The transmission and absorbance values determined from the spectra obtained from the sensors are given in Table XII, which gives the minimum absorbance point (maximum transmission of the spectra), the percent absorbance and loss of transmission caused by each of the major absorbance bands or reference areas of each spectrum.

The infrared data indicate that the outgassing and/or decomposition products given off during the flight temperature of the Altair II engine casing would tend to contaminate infrared sensors within 6 inches of the casing. Also shown is that sensors at a distance of 1 inch will receive more contamination than sensors at either 6 or 1/4 inches from the motor casing.

Altair II ultraviolet-visible sensor data.- Outgassing and decomposition products were collected on quartz disks at distances of 6, 1, and 1/4 inches from the Altair II test panels in three separate vacuum temperature profiles (Table XIII). Ultraviolet-visible spectra of the products deposited on the sensors are shown in Figure 21. The spectra show that the sensor stationed at 6 inches away from the panel receives more contamination than sensors at 1 or 1/4 inch away. A summary of the reflectance data is given in Table XIV.

Altair II solar cell data.- Three solar cells were subjected to the outgassing and decomposition products given off by each of the Altair II test specimens during heating. The effect of these products on the output of the solar cells is given in Table XV. Figure 7 shows the sample array and the location of the solar cell sensors.

The data in Table IX show that a solar cell located at the middle distance of 1 inch receives more damaging contamination than cells removed to a distance of 6 inches or very close to the test panel at 1/4 inch. It appears that a cover plate used on the solar cell does not increase its likelihood of contamination. The data indicate that an array of solar cells placed from 6 to 1 inches of the Altair II motor casing would be likely candidates for contamination.



(a) I_0, reference point of spectrum which is near the 100% line.

(b) Spectra separated in this figure for convenience in representation.

Figure 20.- Altair II Infrared Sensor Data

TABLE XII

ALTAIR II - INFRARED SENSOR DATA

Wave number, K	Loss of transmission, ΔT%	Absorbance	Probable functional group
6-inch distance			
[a]870	0	0.0	--
[b]1510	11	0.057	C=C (ring)
1610	5	0.027	C=C (ring)
1730	6	0.030	Unassigned
2400	2	0.011	CO_2
2940	3.5	0.222	C-H (aromatic)
3400	3.5	0.022	O-H or N-H
1-inch distance			
1250	19	0.108	Unassigned
[b]1510	21	0.122	C=C (ring)
1610	9	0.048	C=C (ring)
1740	8	0.032	Unassigned
[a]1900	0	0.0	--
2940	8	0.032	C-H (aromatic)
3400	11	0.059	O-H or N-H
1/4-inch distance			
[b]1430	7	0.035	Unassigned
1630	6	0.030	O-H
[a]1700	0	0.0	--
2400	4	0.020	CO_2
2940	4	0.020	C-H (aromatic)
3400	4	0.020	O-H or N-H

[a]Reference point $\left(I_o\right)$, I_o = minimum absorbance of spectrum.

[b]Strongest absorbance band in spectrum.

TABLE XIII

ALTAIR II ULTRAVIOLET-VISIBLE SENSOR DATA

Wavelength, mμ	Loss of transmission, Δ%T	Absorbance
6-inch distance		
[a]340	42	0.306
400	38	0.266
450	35	0.238
500	33	0.220
700	28	0.179
900	23	0.141
1500	6	0.033
2220	2	0.011
[b]2400	0	0.0
2540	1	0.05
1-inch distance		
[a]340	39	0.250
400	26	0.150
450	16	0.081
500	10	0.052
700	1	0.005
900	2	0.010
[b]1000	0	0.0
1800	2	0.010
2220	5	0.025
2540	5	0.025
1/4-inch distance		
[a]340	21	0.115
400	14	0.083
450	11	0.066
500	8	0.040
[b]800	0	0.0
900	4	0.020
1500	2	0.010
2220	3	0.015
2400	1	0.005
2540	3	0.015

[a]Strongest absorbance band.

[b]Reference point (I_o), I_o = minimum absorbance of spectrum.

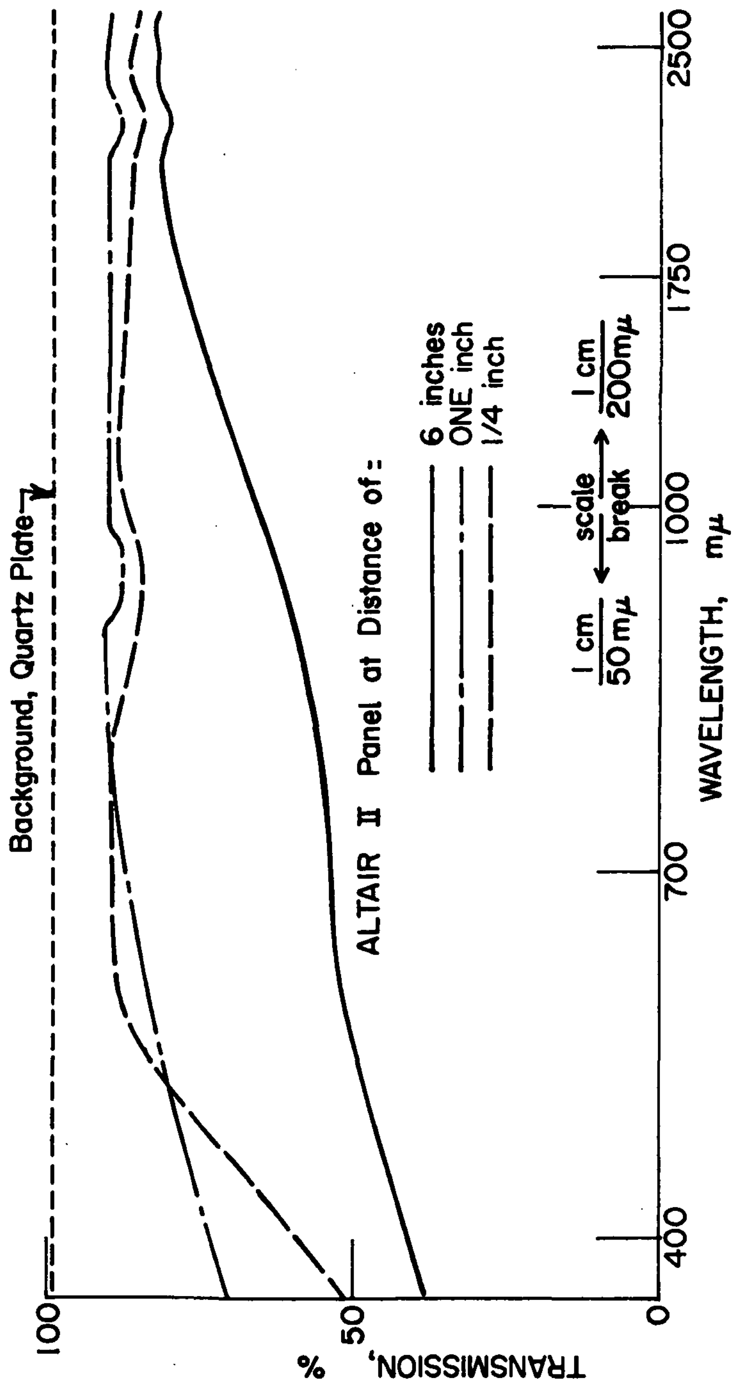


Figure 21.- Altair II Ultraviolet-Visible Sensor Data

TABLE XIV

ALTAIR II ULTRAVIOLET-VISIBLE REFLECTANCE DATA

Distance from panel, in.	Max. reflectance, %	Min reflectance, %
6	10.5 at 550 mμ	9 at 2500 mμ
1	12 at 1300 mμ	7 at 360 mμ
1/4	12.5 at 2100 mμ	7.5 at 380 mμ

TABLE XV

ALTAIR II PERCENT CHANGE IN SOLAR CELL EFFICIENCY AND MAXIMUM TEMPERATURE DURING TEST (°F)

Distance, in.	Reversed cell, no cover		Cell with no cover		Cell with cover	
6	*	*	-5.0	195°	0.0	195°
1	-9.0	330°	-8.1	345°	-7.7	235°
1/4	-0.4	*	-0.6	270°	-0.6	375°

*Solar cell or thermocouple malfunction - no data available.

<u>Altair II crystal microbalance data</u>.- The crystal microbalance collected offgassing and decomposition products at distances of 6, 1, and 1/4 inches during temperature profile runs on three Altair II test panels. The test results show that at a distance of 6 inches, less contamination was collected on the microbalance than at the 1/4- and 1-inch distances. The 1-inch distance contributed the most contamination to the microbalance. Figure 22 shows the relationship of weight of contamination collected on the microbalance and the temperature profile of the sample as a function of time. The amounts of contamination collected and measured on the microbalance ranges from 5×10^{-5} to 2×10^{-4} grams.

The microbalance data indicate that the Altair II motor casing would be expected to expel decomposition and/or outgassing products during the normal flight temperature profile for the Altair II engine.

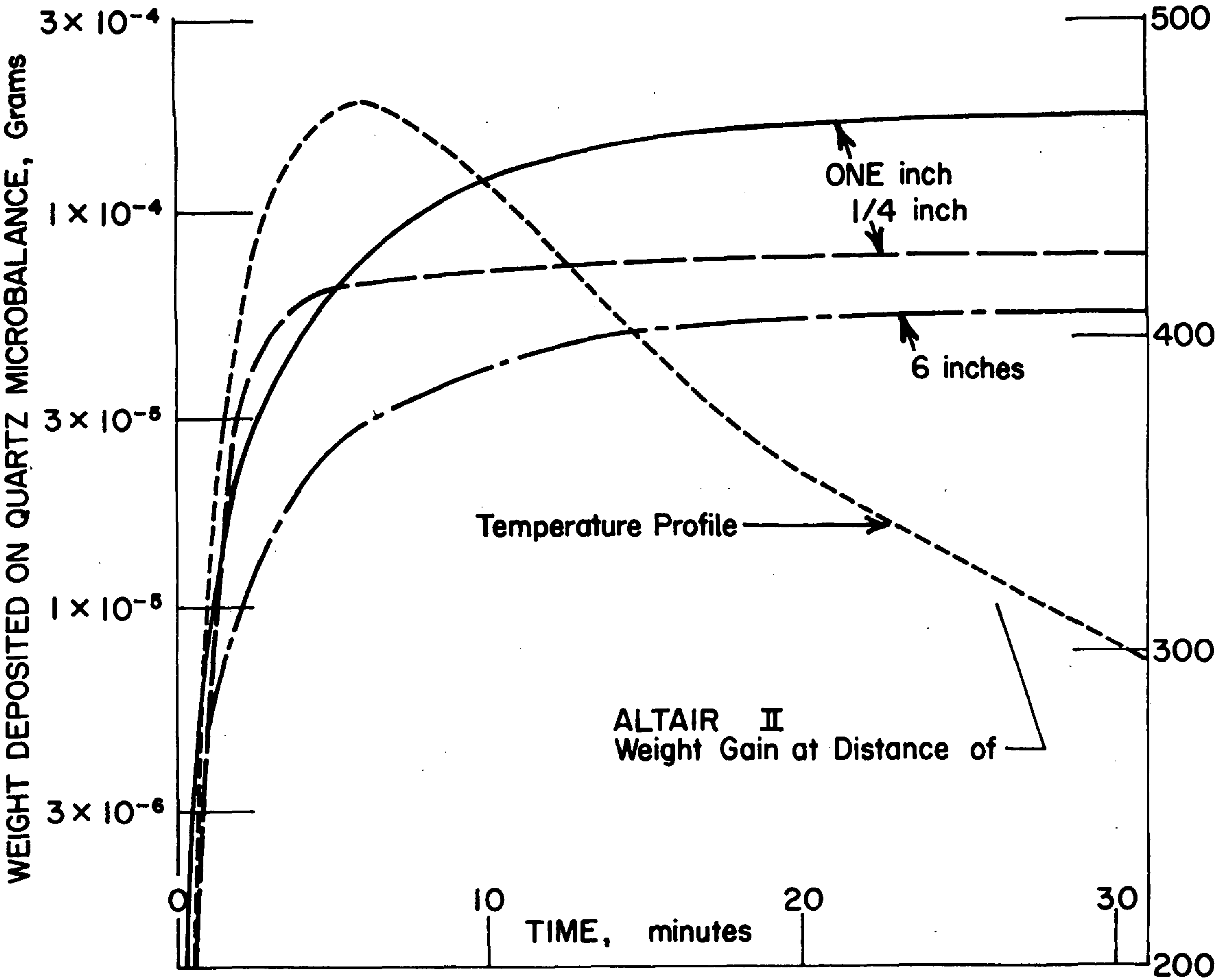


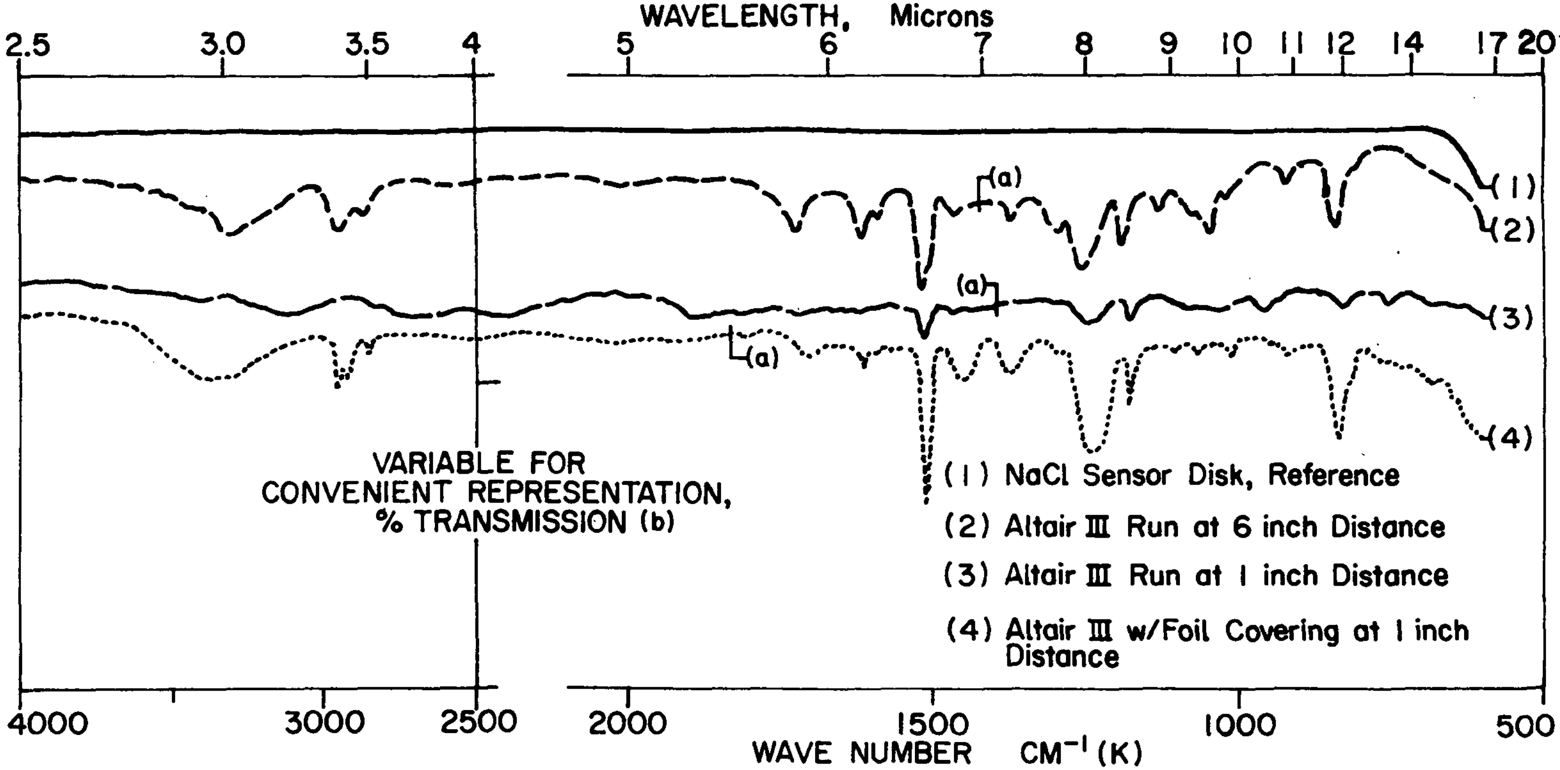
Figure 22.- Altair II Quartz Microbalance Data

Infrared sensor data from Altair III test specimen.- Altair III outgassing and decomposition products were collected on sodium chloride disks at distances of 6, 1, and 1 (taped panel) inches from the test panels in three separate vacuum temperature profiles. Infrared spectra obtained for the products deposited on the disks are shown in figure 23. The spectra of the products from the bare panels indicate that an aromatic hydrocarbon is present as well as quantities of undetermined polar groups. The spectra of the products from the tape covered panel indicate that the major constituent is an aromatic compound. The transmission and absorbance values are given in table XVI, which gives the minimum absorbance point (maximum transmission) of the spectra, the percent absorbance, and the loss of transmission caused by each of the absorbance bands or reference areas of each spectrum.

The infrared data indicate that the outgassing and/or decomposition products given off during the flight temperature profile (75°F to 475°F) of the Altair III engine casing would contaminate slightly any infrared sensor within 6 inches of it. The data from the tape covered panels show that at 1 inch, a motor casing with aluminum tape would contribute much more infrared sensitive contamination than an untaped panel.

Altair III ultraviolet-visible sensor data.- Three quartz sensors were subjected to the outgassing decomposition given off by each of the Altair III test specimens (including one covered with aluminum tape). The ultraviolet-visible spectra obtained are shown in figure 24. The spectra show that there is considerably more interfering contamination given off by the tape covered panel than by the bare ones. A small amount of damaging contamination is indicated from the bare panel runs. The transmission and absorbance values determined from the spectra obtained from the sensors are given in table XVII. A summary of the reflectance data is given in table XVIII.

The data indicate that the contamination from a bare Altair III motor casing would not seriously degrade ultraviolet-visible sensors, but the aluminum tape used on the motor casing would be a contamination source.



(a) I_0, reference point of spectrum which is near the 100% line.

(b) Spectra separated in this figure for convenience in representation.

Figure 23.- Altair III Infrared Sensor Data

TABLE XVI

ALTAIR III INFRARED SENSOR DATA

Wave number, K	Loss of transmission, ΔT%	Absorbance	Probable functional group
6-inch distance			
[a]1400	0	0.0	Unassigned
1510	2	0.009	C=C (ring)
1610	1	0.005	C=C (ring)
2400	5	0.024	C=0
2940	3	0.014	C-H
[b]3000	8	0.034	0-H or N-H
3400	7	0.024	0-H or N-H
1-inch distance			
1250	5	0.025	Unassigned
[a]1400	0	0.0	--
[b]1510	8	0.040	C=C (ring)
1610	3	0.040	C=C (ring)
2400	4	0.020	CO_2
2940	3	0.017	C-H (aromatic)
3400	6	0.030	0-H or N-H
1-inch distance test with aluminum tape			
1250	20	0.101	Unassigned
[b]1510	30	0.168	C=C (ring)
1610	13	0.069	C=C (ring)
1700	8	0.041	0-H (polar group)
[a]1800	0	0.0	--
2400	3	0.015	CO_2
2940	18	0.098	C-H (aromatic)
3400	15	0.080	0-H or N-H

[a]Reference point (I_o), I_o = minimum point of absorbance of the spectrum.

[b]Strongest absorbance band in spectrum.

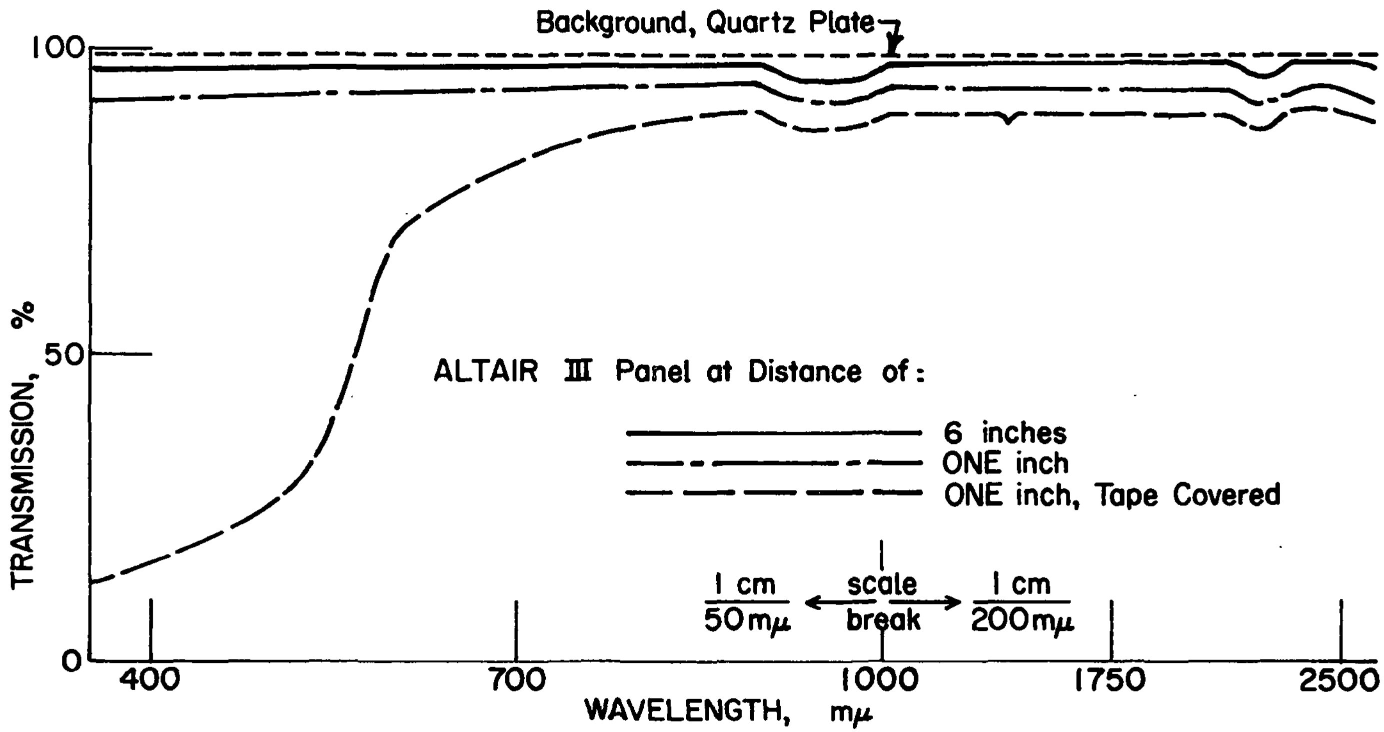


Figure 24.- Altair III Ultraviolet-Visible Sensor Data

TABLE XVII

ALTAIR III ULTRAVIOLET-VISIBLE DATA

Wavelength, mμ	Loss of transmission, ΔT%	Absorbance
1-inch (taped)		
[b]340	70	0.689
400	52	0.388
450	45	0.311
500	28	0.166
700	5	0.025
900	5	0.025
1500	1	0.005
[a]2000	0	0.0
2380	2	0.010
2500	1	0.005
1-inch (untaped)		
[b]340	6	0.029
400	6	0.029
450	6	0.029
500	6	0.029
700	2	0.010
900	3	0.014
1500	0	0.0
[a]2000	0	0.0
2380	2	0.010
2500	0	0.0
6-inch (untaped)		
[b]340	5	0.025
400	5	0.025
450	5	0.025
500	5	0.025
700	4	0.019
900	5	0.025
1500	0	0.0
[a]2000	0	0.0
2380	2	0.010
2500	0	0.0

[a]Reference point $\left(I_o\right)$, I_o = minimum point of absorbance of the spectrum.

[b]Strongest absorbance band in spectrum.

TABLE XVIII

ALTAIR III - ULTRAVIOLET-VISIBLE REFLECTANCE DATA

Distance from panel, in.	Max. reflectance, %	Min reflectance, %
6	10 at 340 mμ	7 at 2650 mμ
1	9.5 at 340 mμ	7 at 2650 mμ
1*	11.5 at 700 mμ	6 at 340 mμ

*Test specimen run with a covering of 3M Y-9040 tape at a distance of one inch.

Solar cell data from Altair III test specimen runs.- Three solar cells were subjected to outgassing decomposition given off by each of the Altair III test specimens (including one covered with aluminum tape). The effect of these products on the output of the solar cells is given in Table XIX. Figure 7 shows the sample array and the location of the solar cell sensors.

The data show solar cells located at a distance of 6 inches from the bare Altair III panel collect more contamination than the cells located 1 inch away. This is caused by the volatile nature of the NMA catalyst that is liberated from the panel. The data indicate that a cooler solar cell (note the values from the reversed cell) will collect more contamination from the bare Altair III panel. The data also show that the aluminum tape used to cover an Altair III panel causes more contamination to the solar cells (except the reversed cell) than a bare Altair III specimen at the same distance. These data indicate a less volatile contamination is given off by the foil covered panel, and that this material condenses on the first available surface (which, in the case of the reversed cell, is the solder side).

TABLE XIX

ALTAIR III - PERCENT CHANGE IN SOLAR CELL EFFICIENCY AND MAXIMUM TEMPERATURE DURING TEST (°F)

Distance, in.	Reversed cell, no cover		Cell with no cover		Cell with cover	
6	-3.8	170°	-2.8	200°	-3.0	155°
1	-2.8	300°	-1.4	345°	-2.5	240°
1*	-1.2	125°	-4.1	130°	-4.4	100°

*Test specimen run with a covering of 3M Y-9040 tape at a distance of one inch.

<u>Altair III crystal microbalance data</u>.- The crystal microbalance collected offgassing and decomposition products at distances of 6, and 1 inches from bare Altair III panels and a distance of 1 inch from an Altair III panel covered with aluminum tape. The data show that less contamination is contributed to the microbalance from a panel at 6 inches than at 1 inch, and that the bare panel contributes more contamination than the tape covered panel tested at the same distance. Figure 25 shows the relationship of weight of the contamination collected on the microbalance and the temperature profile of the sample as a function of time. The amounts of contamination collected and measured on the microbalance range from 5×10^{-5} to 2×10^{-4} grams.

The microbalance data indicate that the Altair III motor casing would be expected to expel decomposition and/or outgassing products during the normal flight temperature profile for the Altair III engine.

<u>Altair III vacuum isothermal data</u>.- An Altair III test specimen was subjected to an isothermal vacuum bakeout at 280°F. The specimen weight was monitored continuously during this period. The weight loss as a function of time is given in figure 26. The data indicate that the Altair III weight loss stabilizes at 18 hours at 0.092%.

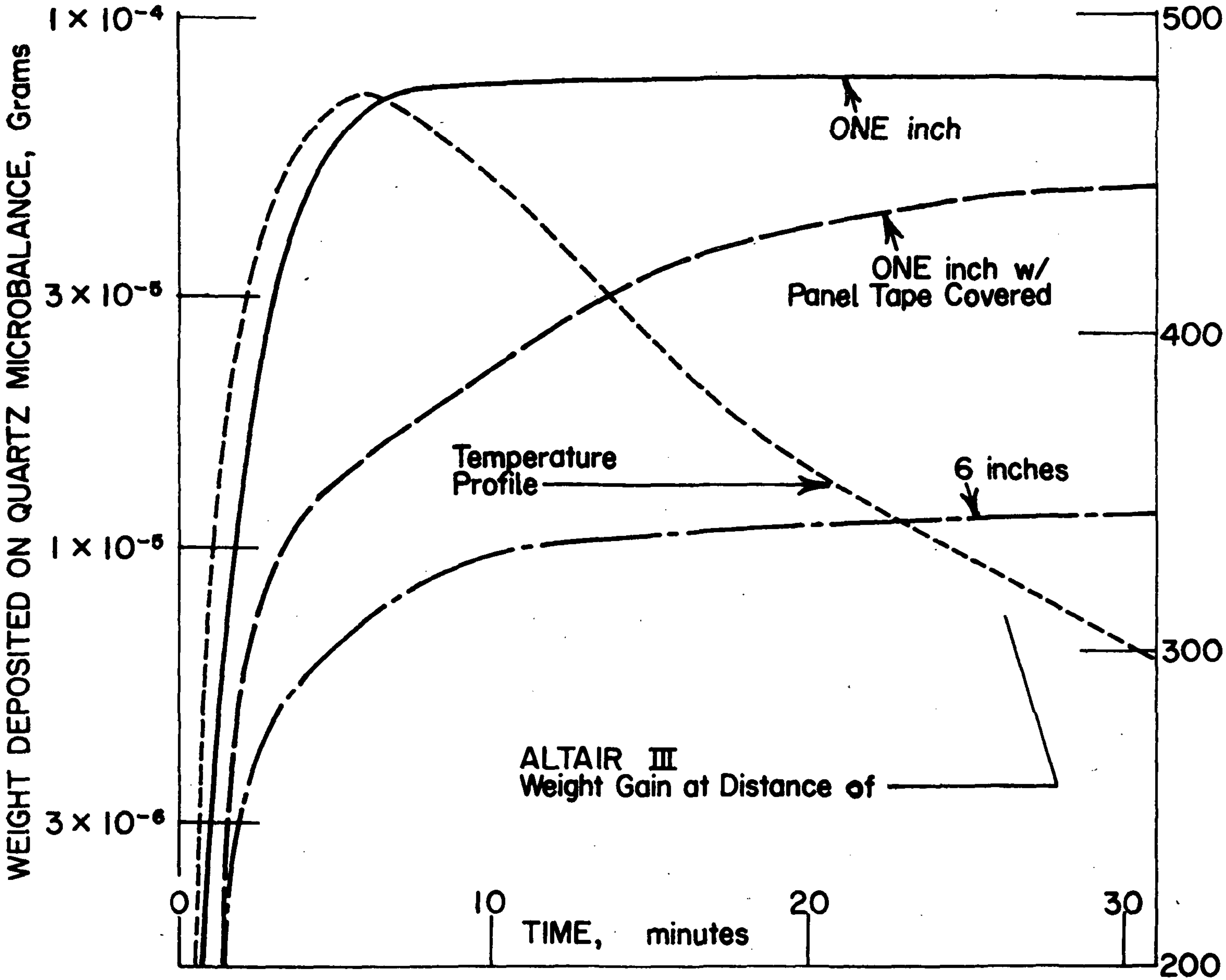


Figure 25.- Altair III Quartz Microbalance Data

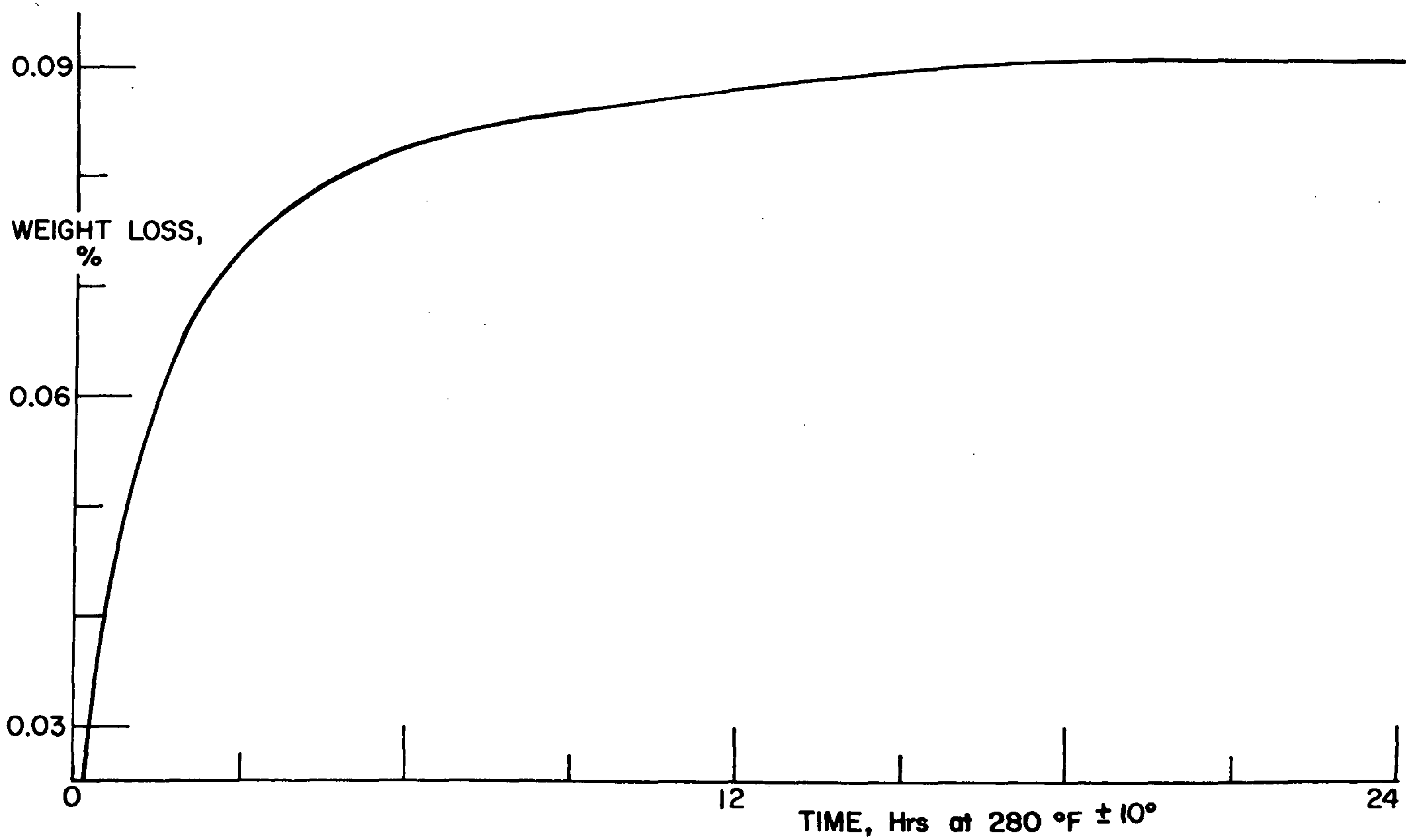


Figure 26.- Altair III Vacuum Isothermal Weight Loss Data

EVALUATIONS

Test Specimen Integrity

The manufacture of test specimens was closely monitored by the Martin Marietta technical director for this contract. This was done to insure against inadvertant contamination of the test specimens would be comparable to the actual motor casing. However, the only actual comparison of the test specimens to an existing motor casing part is provided by the TGA/RGA results obtained from the Altair III test specimen and an actual piece of an Altair III motor skirt supplied to Martin Marietta by United Technology Corporation, under contract to NASA/Langley. As may be seen in the section on test results, the TGA/RGA data from the test specimen and the sample from the Altair III are comparable.

All of the results of this study indicate that the epoxy/glass test specimens used in this study are in fact good representations of the actual motor casing in question.

Test Results from TGA/RGA Analysis in Vacuum

The TGA/RGA data obtained in this study indicate that amine-cured epoxy/glass resin formulations of the type used in the manufacture of the Altair II and Alcyone I engine casings are more stable than the anhydride cured epoxy/glass formulation of the Altair III engine casing. These data indicate that the Altair II and Alcyone I casings would not seriously outgas, and that the Altair III casing would outgas, during the flight service temperatures. The RGA data show the principal outgassing and decomposition products from the Altair II and Alcyone I casing would be water vapor and pyrolosis compounds and those from the Altair III would be similar, but also including compounds indicative of the NMA catalyst of the resin formulation which outgas at lower temperatures. The TGA/RGA data obtained from the Altair III test specimen and the sample from an Altair III engine skirt were very similar in regard to outgassing and decomposition products quantified and identified by residual gas analysis.

Test Results from Sensor Contamination Measurements

Solar cell sensor data.- The solar cell sensors exposed to the Alcyone I test specimens show that a maximum loss of efficiency of 6.8% on a forward facing cell and 4.6% on a reversed cell occurred at a distance of 1 inch. Very little contamination was experienced at distances of ¼ and 6 inches, where a maximum loss of efficiency of 0.6% on a forward facing cell was seen.

The solar cell sensors exposed to the Altair II test specimens show that a maximum loss of efficiency of 9.0% on a reversed cell and 8.1% on a forward facing cell occurred at a distance of 1 inch. Very little contamination was experienced at distances of ¼ and 6 inches, where a maximum loss of 0.6% on two forward facing cells was observed.

The solar cell sensors exposed to the bare Altair III test specimens show that a maximum loss of efficiency of 3.8% on a reversed cell and 3.0% on a forward facing cell occurred at a distance of 6 inches. However, the loss of efficiency at 1 inch was comparable with a value of 2.8% on the reversed cell and 2.5% on a forward facing cell.

The solar cell sensors exposed to a tape covered Altair III t test specimen at a 1-inch distance show a loss of efficiency of 1.2% on the reversed cell and 4.4% on a forward cell.

In relative severity, the Altair II specimen at a distance of 1 inch is the source of more damaging contamination to the solar cell sensors than other specimens at the same distance. The others, in order of decreasing contamination at the 1-inch distance are: Alcyone I, Altair III with tape, and the bare Altair III. The Altair III is shown to be a greater contamination source than the Alcyone I or the Altair II at distances of either 6 or ¼ inches.

Infrared sensor data.- Infrared data show the Alcyone I test panels give off contamination that would be damaging to an infrared sensor. The contamination found at a distance of 6 inches was stronger than the closer distances of 1 and ¼ inches.

Infrared data obtained from the sensors exposed to the Altair II test specimens show a minimal amount of contamination was deposited at distances of 1 and lesser amounts at 6 or ¼ inch. In all cases, the contamination on these sensors was less than the amounts found on any of the Alcyone I sensors.

Infrared data obtained from the sensors exposed to the bare Altair III test specimens show a minimal amount of contamination was deposited at distances of 1 and 6 inches. However, this contamination was less than the amounts found on any of the Alcyone I or Altair II sensors.

Infrared data obtained from the sensor exposed to the taped Altair III at a distance of 1 inch from the test specimen showed a contamination level similar to the amount found on the Alcyone I sensor at a 1-inch distance.

The above data show that the Altair III panel is the least contaminating to infrared sensors and the Alcyone I and taped Altair III panels are the most damaging.

Ultraviolet-visible sensors.- The ultraviolet-visible data show that the contamination from the Altair II is the most damaging at a distance of 6 inches with lesser amount at 1 and ¼ inch in descending order of contamination. The absorbance values gained by this study show the Altair II motor would deposite damaging material on an ultraviolet-visible sensor within 6 inches.

The ultraviolet-visible data obtained from bare Altair III and Alcyone I specimens indicate a very limited amount of contamination is present at all the distances tested.

The ultraviolet-visible data obtained from the taped Altair III specimen show that it gives off a considerable amount of contamination threat to ultraviolet-visible sensors near them; however, the Altair II motor casing and aluminum tape used on any motor offer a contamination threat to such sensors.

Quartz microbalance data.- The data from the quartz microbalance show the highest contamination levels of 1.1×10^{-4} and 1.7×10^{-4} grams are deposited on microbalance. They also show that an aluminum untaped surface will deposit more contamination than a taped one at the same distance.

The data from the quartz microbalance show highest contamination levels of 1.1×10^{-4} grams from the Alcyone specimen and 1.7×10^{-4} grams from the Altair II specimen at distances of 1 inch. The Altair II specimens deposited 1.7×10^{-4} grams of contamination at 1 inch, 7.8×10^{-5} grams at ¼ inch, and 5.6×10^{-5} grams at 6 inches. The bare Altair III specimen deposits 1.1×10^{-5} grams of contamination at 6 inches and 7.6×10^{-5} grams at 1 inch. The taped Altair III specimen deposited 4.8×10^{-5} grams of contamination on the microbalance at a distance of 1 inch. The Alcyone I specimen deposited 1.1×10^{-4} grams of contamination at 1 inch and 5.6×10^{-5} grams at ¼ inch.

These data show the Altair II to be the most contaminating motor casing type as to the total weight of contamination given off.

Vacuum isothermal weight loss data.- The thermal-vacuum weight loss data obtained for the Altair III specimen shows that the specimen weight loss ceases after approximately 18 hours in vacuum while being baked at 280°F.

Overall Evaluation

1) The Altair III motor casing will produce less damaging contamination than the Altair II or Alcyone I casings. This is due to the more volatile nature of the contamination from the Altair III casing. The Altair II motor casing will produce more damaging contamination than the Altair III or the Alcyone I casings. See Table XX for overall contamination correlations;

2) Aluminum tape that incorporates an adhesive will cause more relative contamination than any of the three types of motor cases studied;

3) Payload sensors placed at a middle distance of 1 inch will collect more contamination generally than a sensor placed at either 6 or ¼ inches.

TABLE XX

RELATIVE CONTAMINATION PER TYPE TEST SPECIMEN

Analytical methods	Order of decreasing contamination†			
	1	2	3	4
Infrared	Alcyone I	Altair III*	Altair II	Altair III
Ultraviolet-visible	Altair III*	Altair II	Alcyone I	Altair III
Solar cell	Altair II	Alcyone I	Altair III*	Altair III
Reversed solar cell	Altair II	Alcyone I	Altair III	Altair III*
Microbalance	Altair II	Alcyone I	Altair III	Altair III*
Weighted Avg	Altair II	Alcyone I	Altair III*	Altair III
TGA/RGA	Altair III	Altair II	Alcyone I	

*Altair III test panel covered with aluminum tape - outside surface only
†Contamination as measured at a 1 inch distance.

RECOMMENDATIONS

It is recommended that:

1) Future Altair III motor casings receive a vacuum cure at the end of their cure cycle at the maximum temperature seen during the regular cure cycle (280° ± 10°F);

2) Any epoxy/glass composite that will be in the proximity of a contamination sensitive payload receive a vacuum cure at the highest temperature in its cure cycle;

3) The use of aluminum adhesive backed tape be avoided in the vicinity of any payload sensor;

4) The use of any materials that offer a possible outgassing contamination source such as inks, adhesives, paints, etc, should be avoided until their outgassing characteristics are determined by techniques similar to those described in this report;

5) The cure cycle for the Altair III engine casing should be further investigated and determinations made, to ensure a more acceptable cure cycle. The proposed techniques would involve the preparation of test specimens by several cure cycles and the determination of the relative contamination from such panels on payload sensors by *in situ* vacuum testing at flight temperature profile. This recommendation also applies for any Scout engine casing that would have a contaminant sensitive payload in close proximity to the casing during launch.

6) In a future Scout launch, a temperature probe be placed on the Altair III engine casing to determine the actual flight temperature profile for the casing exterior;

7) In a future Scout launch, a payload sensor similar to the one used in the report be placed at a 1-inch distance from one of the casings studied. Data from this sensor (solar cells) would be used to validate the conclusions drawn in this report.

8) The contamination distance profile of the Altair III engine casing be studied further;

9) The effect of the sensor location geometry on relative contamination from the Altair III engine casing be studied;

10) A comparison of contamination results using specimens prepared with and without fiberglass rovings be made.