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		STATEMENT OF PROBLEM			
		The purpose of this test was to verify the structural integrity of the aluminum-steel R/C concept through the application of various temperature and load conditions to the R/C-10 structure.			
		ABSTRACT:			
		The R/C-10 structure has been subjected to a two phase static structural test.			
		a. Phase I: Aerodynamic pressure distribution in combination with 100 per cent limit loads.			
		b. Phase II: Aerodynamic temperature application in combination with end boost condition loads.			
		The structural integrity of the aluminum-steel R/C concept has been proven. Areas of design modification, for future aluminum-steel radiator condensers, have been disclosed by this test program. Recorded data has permitted analysis verification.			

STATIC STRUCTURAL TEST OF THE ALUMINUM-STEEL

RADIATOR CONDENSER (R/C-10)

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- III. Static Structural Test
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STATIC STRUCTURAL TEST OF THE ALUMINUM STEEL

RADIATOR CONDENSER (R/C-10)

I. Introduction

The third test of the R/C-10 test program was the static structural test. This test was undertaken primarily to verify the structural integrity of the R/C-10. The test was designed to obtain stress information during application of loads and temperatures which approximated the flight environment. The test was divided into two phases: (1) maximum aerodynamic pressure loading in combination with 100 per cent limit loads, and (2) end boost loading conditions and aerodynamic temperatures (Reference 1). This report presents a description of the test setups and procedures employed to attain the R/C-10 static structural test.

II. Test Specimen Description

The R/C-10 is the first full size radiator condenser, of the SNAP program, to be fabricated of aluminum and steel (Figure 1 and 2). It is a semi monocoque structure which utilizes 24 tapered tubes and armor, in conjunction with aluminum frames, as the primary load carrying structure. The tubes and armor are fabricated from L-605 and are attached to the 1100 series aluminum skin by a unique titanium-aluminum braze process (Figure 3).

The general configuration of the R/C-10 is a truncated cone and cylinder. The base cylinder is 60 inches in diameter. The cone extends from this cylinder upwards to a diameter of 26 inches for a total length of 131.25 inches (Reference 2).

III. Static Structural Test

After extensive investigations of possible vendors, IDWA No. N-298 was issued to the Structures Laboratory, Los Angeles Division, NAA (LAD) for the performance of the R/C-10 static structural test per specification (Reference 1).

Initially in the R/C-10 test program, the R/C structure was exposed to both low level vibration and thermal performance test conditions.

Prior to the delivery of the R/C structure to LAD, three basic inspections were performed; 1) helium leak check, 2) contour inspection, and 3) ultrasonic braze joint inspection (Figure 4). It was determined during this inspection period that the 6061-T6 aluminum frames were of lower material properties than was anticipated. Because of the lower material properties and the resultant reduced margin of safety, it was decided to take a more cautious approach to the structural testing than was originally described in the test specification. The cautious approach was implemented on both Phase I and Phase II tests by the addition of runs at lesser values prior to the runs at maximum conditions (Reference 3).

During the test setup period at LAD, it was decided to add stiffeners to the aluminum frames of the R/C structure. This frame joint modification consisted of aluminum plates which were installed across the joints of the flange portion of the frames. The stiffeners and their locations are described in Reference 4.

A. Phase I Testing

1. General Description

Phase I testing simulated the loads which exist during the maximum aerodynamic pressure launch conditions. The loads which were applied at room temperature were; axial, bending moment, shear and outside surface pressure distribution. All loads for Phase I testing, excluding aerodynamic pressure distribution, were applied through a load head, which attached and transmitted the loads to the R/C top ring above Station 137.5. The aerodynamic pressure distribution was applied to the R/C outside surface. A plywood enclosure was utilized which contained polyethylene pressure bags and was contoured to enclose the conical portion of the R/C structure. The aerodynamic load was applied by inflating these bags to obtain the pressure distribution depicted in Table 1. This structure is illustrated in Figure 6. The values of the axial, shear and bending moment loads are depicted in Table I. The direction of loads is illustrated in Figure 5.

In conjunction with the aforementioned test conditions, the mercury system of the R/C was evacuated to less

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than one psia prior to each test to check the integrity of the Hg circuit.

2. Test Facility and Setup

The R/C-10 structure was mounted in the vertical position in the High Bay test area at LAD as shown in Figure 6. A load head was designed and fabricated by LAD which met the requirements of Phase I testing. Hydraulic load cylinders were employed to apply the shear, moment, and axial loads. Load cells were installed in all loading linkages to verify the loads. The axial, shear and moment loads were controlled by an Edison hydraulic load maintainer.

3. Instrumentation

Instrumentation for Phase I testing consisted of two load cells, to monitor applied loads, and 69 strain gages. This total number of gages includes the test specification requirements and additional gages requested by References 5 and 6.

The strain gages may be segregated into three groups:

- a. 57 axial, single leg, strain gages.
- b. 6-60° bi-axial strain gages.
- c. 2-three directional strain gage "rosettes."

The strain gages were located on the tubes, frames and skin of the R/C structure. The reactions of all strain gages were recorded on a 96 channel strain gage plotter and by an IBM summary card punch machine.

In addition to the above mentioned instrumentation, dial gages were installed to measure any deflection of the R/C load head and base load ring.

4. Test Procedure

The following sequence of testing was followed during Phase I static structural test:

Run No. 1	Axial load only. Increments of 20% from 0 to 100% of limit load.
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Run No. 2 Shear load only. Increments of 20% from 0 to 100% of limit loads.

Run No. 3 Axial, shear and bending moment loads. Increments of 20% from 0 to 100% of limit loads.

Run No. 4 Aerodynamic pressure only. Values of 20, 40, 60, 80, 90, and 100% of limit loads.

Run No. 5 100% aerodynamic load plus axial, shear and bending moment loads in the following values: 20, 40, 50, 60, 70, 80, 90, 95, and 100% of limit loads.

5. Summary of Test Results

The R/C-10 successfully withstood the test conditions of Phase I of the static structural test.

The following table presents samples of stress (both recorded and calculated) from the 100% limit load test. This test had simultaneous application of axial, shear and bending moment loads.

Location	Station	Actual Stress (psi)	Calculated Stress (psi)
Aluminum Frame	94	-520	-480
L-605 Tube	46	-6843	-7290
L-605 Tube	42	-6194	-7505

The above stress locations are in the plane of maximum compression.

There was no apparent change in the pressure of the evacuated mercury circuit during Phase I testing of the R/C-10. This indicated that no leaks resulted from the test.

Upon completion of the Phase I tests, two AI inspectors performed a contour inspection of the R/C-10 structure to determine any deformation that may have resulted

from the tests. A visual inspection revealed no indication of any change in the aluminum to steel braze joints. No significant deformation was detected in the frame or centerline alignment. There was a change in the buckles in the aluminum skin. These buckles appeared originally as a result of the thermal performance test. The changes were slight and represented an overall shifting of the buckles within the panels formed by the tubes and frames.

B. Phase II Testing

1. General Description

Phase II testing simulated the skin temperature and load conditions which exist during end boost conditions. The aerodynamically induced skin temperature curves are depicted in Figures 7 and 8. The maximum loads of Phase II are described in Table II. Figure 5 illustrates the direction of loads.

2. Test Facility and Setup

The R/C-10 structure was installed on the test base used for Phase I testing. The shear, axial and bending moment loads were applied through a load head supplied by AI. This load head transmitted the loads through the eight shield mounting brackets to the R/C structure. The applied loads are depicted in Table II. The temperature environment was applied with the utilization of quartz lamps which were distributed about the R/C outside surface, Figure 9. The lamps were set up in six circumferential zones. Each zone had independent control and was regulated by an automatic temperature programmer.

3. Instrumentation

There were 26 elevated temperature axial strain gages and two elevated temperature, 3 directional Rosette strain gages located on the tubes, frames and skin of the R/C structure. A thermocouple was located adjacent to each elevated temperature strain gage and at each elevated temperature Rosette strain gage. There were additional thermocouples located individually at various locations on the frames of the R/C structure.

The foregoing instrumentation description includes the additional strain gages requested by References 5 and 6.

4. Test Procedure

The loads were applied simultaneously and increased linearly, from zero to maximum, over a period of 145 seconds. The loads were applied simultaneously with the programmed skin temperatures of Figures 7 and 8. The maximum load condition occurred simultaneously with the maximum temperatures. When the maximum temperatures and loads were reached, at 145 seconds, the loads were reduced to zero and the R/C was allowed to return to room temperature. The procedure described above meets the requirements of Phase II testing. However, as a cautious approach was taken to achieve this test, a series of runs consisting of eight steps were performed. The eight steps, at progressively increasing values, was to have culminated in the required test of Phase II. Reference 3 defines the eight steps.

5. Summary of Test Results

The R/C-10 has experienced 75% temperature and 100% limit loads with no adverse effects. However, during the subsequent run (100% temperature and no load) a frame deformation took place (Figure 10). A visual inspection of the interior of the R/C revealed that the top aluminum frame was buckled in two places 180 degrees apart. These buckles occurred where the inner flange of the frame was cut away to provide for the vapor riser (Reference 7). The buckle on one side was slight but the one 180 degrees away was displaced downward between the tube tabs approximately $\frac{3}{8}$ of an inch. The mode of frame damage has been analyzed and reported in Reference 8. This evaluation indicates that the damage was associated with the reduced material properties of the frame. Further structural testing of the R/C-10 was discontinued because of the frame crippling (Reference 9). Data collected has permitted analysis verification (Reference 12).

There was no apparent change in the pressure of the evacuated mercury circuit during Phase II testing. This indicated that no leaks resulted from the tests.

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The contour inspection of the R/C structure was repeated at the conclusion of Phase II testing. The inspection revealed that in addition to the frame buckling at Station 114.25, all the frames located between Station 57.5 and 114.25 were slightly deformed, downward, between the tubes. Except for the frame deformation, there were no significant changes in the R/C configuration. The buckles in the aluminum skin underwent further changes of position during Phase II testing but their magnitude remained essentially the same.

Upon the R/C's return to AI, a comprehensive ultrasonic "A" scan inspection was made of all aluminum to steel braze joints. The results of this inspection indicated that the braze joints were only slightly affected by the static structural test. A comparison of the "A" scan made before the structural test and the one made after show almost identical void areas. These void areas are small and have not changed between inspections.

The table below present samples of stress (both recorded and calculated) from the end boost inertia loads and aerodynamic heating loads.

End Boost Inertia Load Stresses

Location	Station	Actual Stress (psi)	Calculated Stress (psi)
L-605 Tube	63	-2170	-2120
L-605 Tube	120	-1460	-1400

Aerodynamic Heating Stresses

Location	Station	Actual Stress (psi)	Calculated Stress (psi)
L-605 Tube	120	24,789	28,500
L-605 Tube	120	36,897	39,734

IV. Conclusions

The load carrying capacity of the R/C-10 proved to be greater than anticipated even though the structure suffered frame damage. Because of the reduced margins of safety of the frames, it was suspected that the structure would not be capable of completing the maximum load conditions of Phase I. As noted, a cautious step-wise approach was taken for this test. Nevertheless, the R/C successfully passed the steps leading up to and including the 100% limit load condition. Likewise, a similar approach was taken for Phase II tests. The R/C successfully passed all steps leading up to and including the 75 per cent temperature and 100% load condition before a crippling reaction occurred. Future designs of the aluminum steel concept have incorporated frame design modifications (including the use of titanium frames) which will preclude this mode of damage.

A report has been prepared by the Structural Testing Group, Department 64, Los Angeles Division, NAA which contains the computer processed data of Phase I and II as well as descriptions of the test setups and test procedures used (Reference 10).

The structural integrity of the aluminum-steel R/C concept has been demonstrated by the performance of the R/C-10 during the test program described in this document. Areas of design modifications of future aluminum steel R/C's have been disclosed as a result of the R/C-10's reactions to certain test conditions. Analysis verification has been permitted through data collected and the effects of the test environments upon the aluminum to steel braze joints have been proven negligible.

V. Current R/C-10 Status

Additional testing is being considered in the form of thermal endurance or structural margin tests. Also, the availability and utility of the R/C-10 for PSM-1 test integration (i.e. backup to the R/C-6) has been evaluated and the R/C-10 is indeed capable of performing in this regard.

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A summary of the entire R/C-10 test program, including vibration and thermal performance as well as static structural testing may be found in Reference 11.

A continuing program of test evaluation and improvement of the aluminum to steel braze joint is also being performed and will be the subject of a separate report.

REFERENCES

1. Specification

"Static Structural Test of the Aluminum-Steel Radiator Condenser (R/C-10)" No. NAO412-004.

2. Specification Control Drawing

"Radiator Condenser R/C-10 Aluminum with Armor," No. 2C-54001.

3. IL

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4. IL

L. Stone to K. Heald, "R/C-10 Frame Joint Modification," October 11, 1963.

5. IL

L. Stone to C. Grace, "Addition Instrumentation and Test Limits for R/C-10 Static Structural Test," November 11, 1963.

6. IL

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7. IL

W. Castle to T. Daugherty/D. Ellis, "R/C-10 Phase II, Structural Test," February 28, 1964.

8. TDR

"R/C-10 Frame Crippling Evaluation," No. NAA-SR-9838.

9. IL

L. Stone to D. Ellis, "Preliminary Results of R/C-10 Structural Testing," April 1, 1964.

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10. Report

"Structural Test of the R/C-10 Radiator Condenser,"
No. NA-64-476.

11. TDR

"Status Report of Aluminum/Steel Radiator Condenser
Test Program, R/C-10," No. NAA-SR-9866.

12. TDR

"R/C-10, Phase II, Structural Test Correlation,"
No. NAA-SR-9923.

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FIGURE 1

ALUMINUM-STEEL RADIATOR CONDENSER (R/C-10)

ALUMINUM - STEEL RADIATOR - CONDENSER (RC-10)

TYPICAL CROSS-SECTION AT STA. 134.300

TYPICAL CROSS-SECTION AT STA. 8.500

- 24 LINEARLY TAPERED TUBES
- SKIN $\dagger$ IS CONSTANT -.063 1100-O AL.
- 134 FT² AREA
- TUBES & ARMOR L-605
- AL. FRAMES 6061-T6

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FIGURE 2

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Cross Section of Typical R/C-10

Braze Joint (No Scale)

FIGURE 3

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FIGURE 4

R/C-10 ULTRASONIC INSPECTION

DIRECTION OF INPUT LOADS - PHASES I & II OF THE STATIC STRUCTURAL TEST

Figure 5

FIGURE 6

R/C-10 PHASE I, STATIC STRUCTURAL TEST SETUP

PHASE II. MAXIMUM TEMPERATURE PROFILE
OF THE ALUMINUM SKIN BETWEEN THE TAPERED TUBES

Figure 7 -

R/C-10 Static Structural
Test, Phase II, Temperature vs
Time - Curves at Selected
Stations

Figure 8

upc

FIGURE 9
HEAT LAMP SETUP FOR PHASE II OF THE R/C-10 STATIC
STRUCTURAL TEST

FRAME DEFORMATION (STATION 114) AFTER 100% AERODYNAMIC HEATING TEST

1. THE FRAME BUCKLE, DEPICTED ABOVE, OCCURRED AT TWO PLACES ON THE FRAME AT STATION 114, 180° APART. THE INNER FRAME FLANGE IS CUT AWAY AT THESE TWO LOCATIONS TO PROVIDE FOR THE VAPOR RISERS.
2. ONE BUCKLE IS SLIGHT, THE OTHER ONE IS DISPLACED APPROX 0.5 INCHES, AS SHOWN BY THE DASHED LINE ABOVE.

Figure 10

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TABLE I
100 Per cent Limit Loads
(Phase I Test Only)

Axial Loading =	6,575 lbs.
Bending Moment =	20,000 in-lbs
Shear Loading =	2,600 lbs.

The above values are applied loads at Station 137.75 and include the weight of the load head.

Pressure Distribution

The pressure is constant longitudinally over each area.

(Between Sta. 44 & Sta. 137.75)
Values of Table I are from TDR 8588

TABLE II
End Boost Loading
(Phase II Test Only)

Axial Loading =	4,970 lbs
Bending Moment =	16,480 in-lbs
Shear Loading =	654 lbs

The above values are applied loads at Station 137.75 and include the weight of the load head.