RF TRANSPARENT, ENERGY ABSORBING

STRUCTURAL ELEMENTS

MONTHLY PROGRESS REPORT NO. 9

February 1 - March 31, 1964

Contract No. 950564

(Subcontract Under NASA Contract NAS 7-100)

by

General Electric Company
Missile and Space Division
Spacecraft Department
P. O. Box 8555
Philadelphia 1, Pennsylvania

for

California Institute of Technology
(Jet Propulsion Laboratory)
4800 Oak Grove Drive
Pasadena, California

PROGRAM PLAN

FOR

RF TRANSPARENT, ENERGY

ABSORBING, STRUCTURAL ELEMENTS

PHASE II

Contract No. 950564
(Subcontract Under NASA Contract NAS 7-100)

by

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Missile and Space Division
Spacecraft Department
P. O. Box 8555
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for

California Institute of Technology
(Jet Propulsion Laboratory)
4800 Oak Grove Drive
Pasadena, California

ESTIMATED COST	$57,695.00
FIXED FEE	3,869.00
TOTAL AMOUNT	$61,564.00

Contract Effective Date: March 17, 1964
(Phase II Go-ahead)

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1. Foreword

Contained herein is a detailed program plan which will be followed in performing the additional work on JPL contract No. 950564, as per the Supplemental Agreement executed on March 17, 1964, with the Spacecraft Department of the General Electric Company, King of Prussia, Pennsylvania.

Minor changes from the described schedule, analyses, specimens, and test will be made if this is found to become desirable during the course of the program. However, no significant deviations from the program will be undertaken without customer approval.

2. Objectives

The objectives of this Phase II of the program are:

(1) to acquire additional information and design data on the energy absorption values of glass fiber reinforced plastic honeycomb including the effect of angular impact.

(2) to determine the optimum density for given cell sizes.

(3) to demonstrate the feasibility of manufacturing singly and doubly curved specimens of this glass fiber reinforced plastic honeycomb material.

(4) Using the data obtained from tests in this program, to establish design parameters and prepare curves which will permit an easy method of designing a landing system for a vehicle of any shape or size.

3. Statement of Work

3.1 Design and Fabrication of Specimens

3.1.1 Curved Specimens

Two each, of four specimen shapes will be fabricated from ¼" cell, 10 lb/cu ft. phenolic resin honecomb. These specimens are as follows:

(1) Specimen to be four inches thick, two foot square, formed to a cylindrical shape having a minimum radius as dictated by the vendor's present capability.

(2) Same as item 1, except specimens to be curved to a spherical radius instead of a cylindrical radius.

(3) Same as item 1, except material to be twelve inches thick.

(4) Same as item 2, except material to be twelve inches thick.

The method used by the honeycomb vendor is proprietary, but is basically a time-temperature creep forming over a male die. While the vendor has previously fabricated doubly curved surfaces, a limit of curvature for a given thickness has not yet been established, and forming of curved surfaces from sections 12 inches thick has not been previously attempted.

This forming will therefore be a best-effort attempt. Various tricks of the trade will be tried to obtain a minimum radius in all cases. If the 12" specimen is found to be too thick for curving, the thickness will be reduced, and a maximum radius for this reduced thickness will be established.

3.1.2 Optimum Density Specimens

The following specimens will be fabricated for use in testing to determine the effect of core densities on specific energy absorption for a given cell size.

Specimen Type	Cell Size inches	Density lb/cu-ft	Resin
10P	3/16	12	Phenolic
11P	3/16	14	Phenolic
12P	1/4	10	Phenolic
13P	1/4	12	Phenolic
10R	3/8	12	Polyester
11R	3/8	16	Polyester

(1) Specimen Types 10P, 11P, 12P, and 13P are standard honeycomb fabrications except for densities and tolerance on densities which will be ± 3% instead of the usual ± 10%. Number 112 cloth will be used and reinforced with high temperature phenolic resin, Plaskon V-204.

(2) Specimen Types 10R and 11R will be fabricated from existing specimens at G.E. by dipping in polyester resin, Plaskon 911, and curing a sufficient number of times to obtain the desired density.

(3) All specimens will be fabricated by the expansion method.

As discussed in the Phase I Final Report, the densities in which plastic honeycombs are commercially fabricated are not optimum for energy absorption purposes. Increasing the density of existing specimens showed that the specific energy increased with this increase in density. Results of these data were summarized in Figure 9-2 in the Phase I Final Report.

During the current phase of the program, the specimens in the Table above will be fabricated and tested to determine at what density, for a given cell size, the maximum specific energy is obtained. Two additional items which must be considered in this investigation are manufacturing limitations and the uniformity of the crushing load during testing. At some density the specific energy will probably start to decrease in value and/or the crushing load will become non-uniform to a point where it is prohibitive. If the chosen densities are not sufficiently close to the optimum densities for the various cell sizes these specimens will be reworked to increase the densities and be retested.

The 3/16" and 1/4" cell size specimens will be fabricated to a size of 2" x 2" x 4". Based on previous experience, this size is sufficiently large to prevent edge effects on good specimens and small enough to prevent overloading of the static testing machine.

3.1.3 Angular Impact Specimens

One design configuration will be used for all angular impact testing. This configuration will be chosen based on results of the test data obtained from the optimum density specimens described in Section 3.1.3. The design which yields the maximum specific energy value will be used.

Each specimen will be bonded to a metal end plate which will permit attachment of the specimen to the lower platen of the testing machine. The size of the test specimens will be determined prior to ordering the material. Preliminary testing will be performed on some existing honeycomb specimens to determine if the configuration, as shown in Figure 3-1, is satisfactory and will perform as expected. Included in this preliminary investigation will be the effect of specimen height to width ratio.

Because honeycomb is made up of corrugated strips which are bonded together, the specimens are not symmetrical about a center through the core axis, and therefore may have different energy absorbing properties as the axis of angular force is rotated about the cell centerline. To evaluate this effect, each specimen tested for angular impact resistance will be tested at three angles of rotation about the cell axis, namely ϕ , 0, 45, and 90 degrees, for each force angle, except 0 degrees. Four angles of crushing force θ, 0, 10, 20, and 30 degrees, will be evaluated.

Until tests are run to determine the effect of angular impact on the specific energy of the specimen, the energy value available in a specimen cannot be accurately predicted. Therefore, no attempt will be made to size the dynamic tests specimens so that the entire specimen is crushed at an impact velocity of 50 fps. As shown on previous tests (Phase I), the energy values obtained in a specimen are repeatable when the same specimen is crushed in more than one loading.

The tests planned for angular impact will be performed so that friction of the landing surface is assumed to be zero. This assumption established allowable or dictated test procedures which must be used to obtain data which are divorced from friction effects. Considering the three cases of angular impact that can occur (see Figure 3-2), it can be shown that all desired data can be obtained from using the results of two types of tests for any combination of angles.

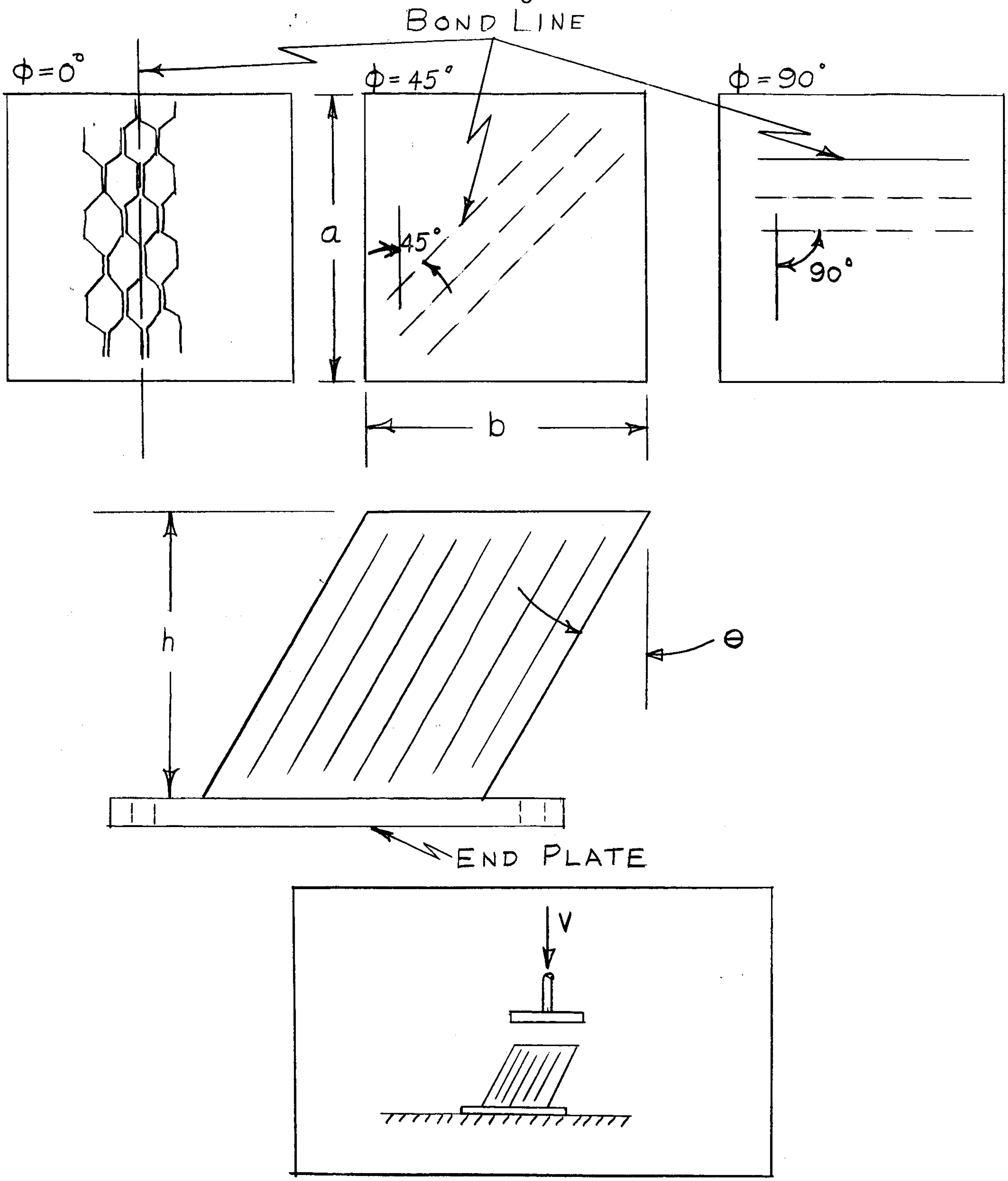


FIGURE 3-1

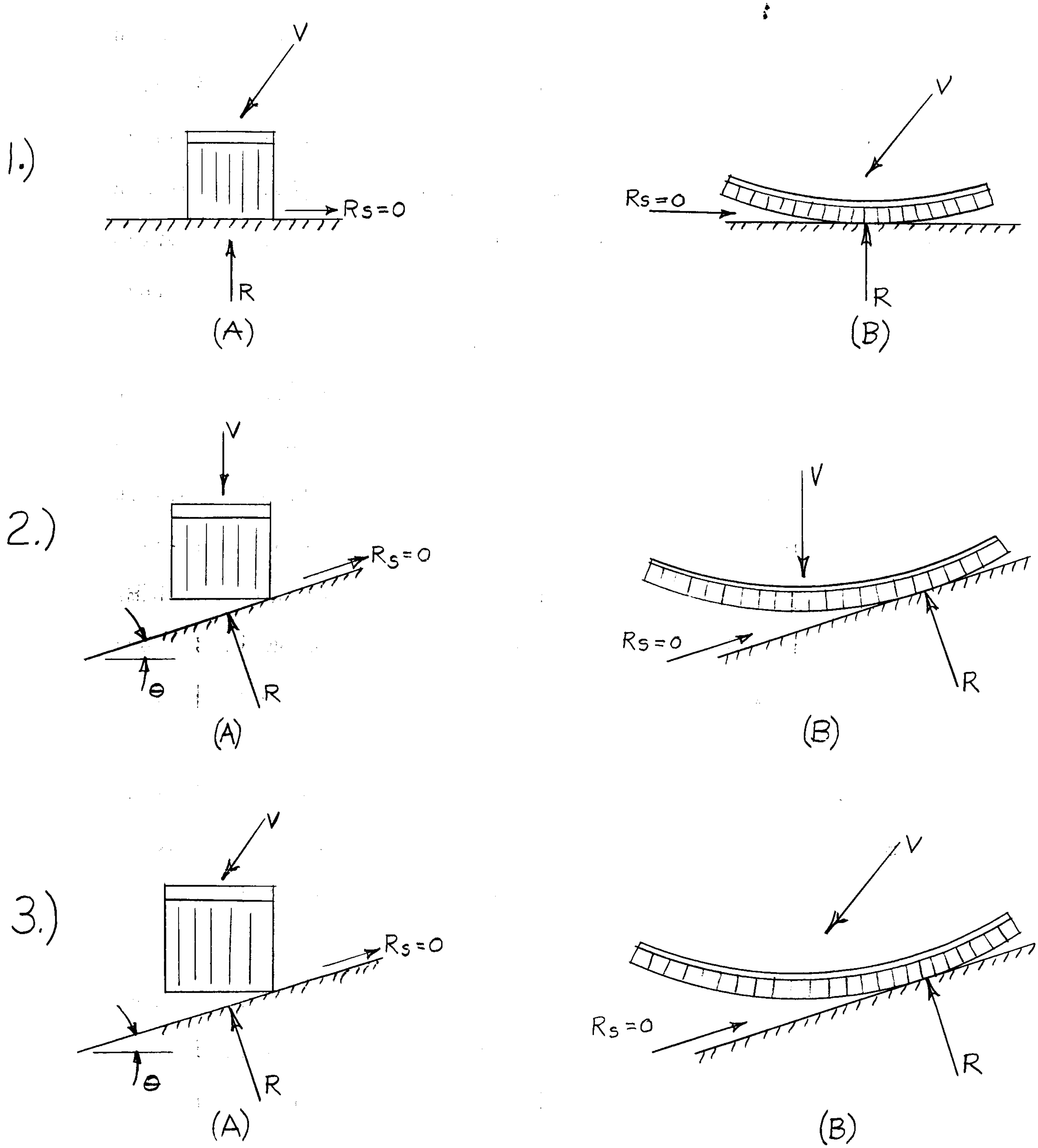


FIGURE 3-2

The two test types are (1) a crushing test with the direction of force being parallel to the axis of the honeycomb and (2) a crushing test with the direction of force being at some angle Theta to the axis of the honeycomb. This can be explained as discussed below.

In Case 1A (Figure 3-2) the only force being exerted on the specimen is a crushing force along the axis of the core. The horizontal component of the force vector V would remain constant and cause the specimen to continue at its original horizontal velocity, even after crushing.

In Case 2A (Figure 3-2) assuming the direction of motion of the vehicle remained the same during crushing, this motion could be simulated by fixing the vehicle end of the specimen and exerting a force along R, at an angle Theta with the core axis.

By the same reasoning, the remaining four cases of Fig. 3-2 can be calculated from the data obtained in these two tests. Therefore, specimens tested in this program will be subjected to first a crushing force parallel to the core axis and secondly a force as shown on Figure 3-1.

3.1.4 End Plate Design

In the testing of angular impact specimens, an end plate will be bonded to one end of the specimens only. This end plate will then be rigidly attached to the base of the testing machine, in both dynamic and static test set-ups. By using this end plate, the specimen will be forced to remain in its original position, as would be the case if the specimen were attached to a vehicle. This assumes that the vehicle would continue to move in the same direction after crushing had started and remain in that position until the vehicle was stopped. Thus, tumbling of the vehicle is ruled out.

Because it is necessary to prefail the specimen ends to prevent a high force impulse on contact, there should be no advantage to bonding an end plate to the end to be crushed for this phase of the testing. This end plate would only serve as a base on which to crush and would no longer be connected to the specimen once crushing had begun. Such an end plate could be advantageous where a landing was being made on a rough surface with the impact velocity vector perpendicular to the surface. In the case of sliding angular impact on a flat surface, the plate would probably slide off the honeycomb material and not serve any useful function.

If the vehicle were spherical or cylindrical in shape and the cover was continuous and therefore prevented from coming loose, a gain in efficiency would probably occur provided the surface was relatively rough and therefore tended to rip the honeycomb material before it absorbed energy by crushing. Testing of the material on various types of surfaces would be required to establish these parameters.

Therefore, because of the reasons discussed above, end plates will not be used on the end of the specimen which is to be crushed.

3.2 Static Testing

3.2.1 Optimum Density Specimens

A minimum of three specimens each will be tested on an Instron 10,000 pound testing machine at a crushing speed of 0.5 inch per minute. The specimens will be placed between the two standard platens of the machine. Data from all test will be recorded on a high-speed Leeds and Northrup graphic recorder. No venting or special fixtures will be required because of the low cross-head speed.

To prevent buckling and failure of the specimen before crushing takes place, each specimen will be prefailed at one end before testing by placing sawcuts, approximately 1/8 in. deep, through the webs of the cells.

Each specimen will be weighed before testing and this value used in calculating the specific energy. This is required because, in higher density specimens the density per inch of stroke length varies due to uneven resin build-up.

This method of static testing is identical to the one used during Phase I of this contract.

Specimen Type	Cell Size Inches	Density lb/cu-ft	Resin
10P	3/16	12	Phenolic
11P	3/16	14	Phenolic
12P	1/4	10	Phenolic
13P	1/4	12	Phenolic
10R	3/8	12	Polyester
11R	3/8	16	Polyester

Specimens to be tested will have the following configurations:

Specimen Type No.	Angle Theta	Angle Phi
AS-0-0	0	0
AS-10-0	10	0
AS-10-45	10	45
AS-10-90	10	90
AS-20-0	20	0
AS-20-45	20	45
AS-20-90	20	90
AS-30-0	30	0
AS-30-45	30	45
AS-30-90	30	90

Here A denotes a particular optimum design configuration, and S denotes static test specimens.

3.3 Dynamic Testing

3.3.1 Optimum Density Specimens

As shown in tests performed during Phase I and described in the Final Report, there is no apparent difference in energy absorption values in the range of zero to fifty feet per second impact velocity. Therefore, static tests only will be performed on the optimum resin density specimens.

The velocity of the optimization design based on static specimens will be demonstrated by the dynamic specimens made for zero degree Theta and Phi angles, described in the following section. Thus, a direct check can be obtained by comparing the results of specimens AS-0-0 and AD-0-0.

3.3.2 Angular Impact Specimens

The same configuration as used in the static testing and shown in Figure 3-1 will be used for the dynamic tests. A minimum of three specimens will be tested for each condition. Of these three, a minimum of one will be tested at full impact head velocity of approximately 46 ft/sec., assuming that preliminary tests show the specimen capable of absorbing the total energy required without damaging the test equipment. A perforated plate will be used, as in Phase I testing, to eliminate the effects of air trapped inside the specimens during crushing. Acceleration versus time curves will be obtained for each test.

Specimens to be tested will have the following configurations:

Speciman No.	Angle Theta	Angle Phi
AD-0-0	0	0
AD-10-0	10	0
AD-10-45	20	45
AD-10-90	30	90
AD-20-0	10	0
AD-20-45	20	45
AD-20-90	30	90
AD-30-0	10	0
AD-30-45	20	45
AD-30-90	30	90

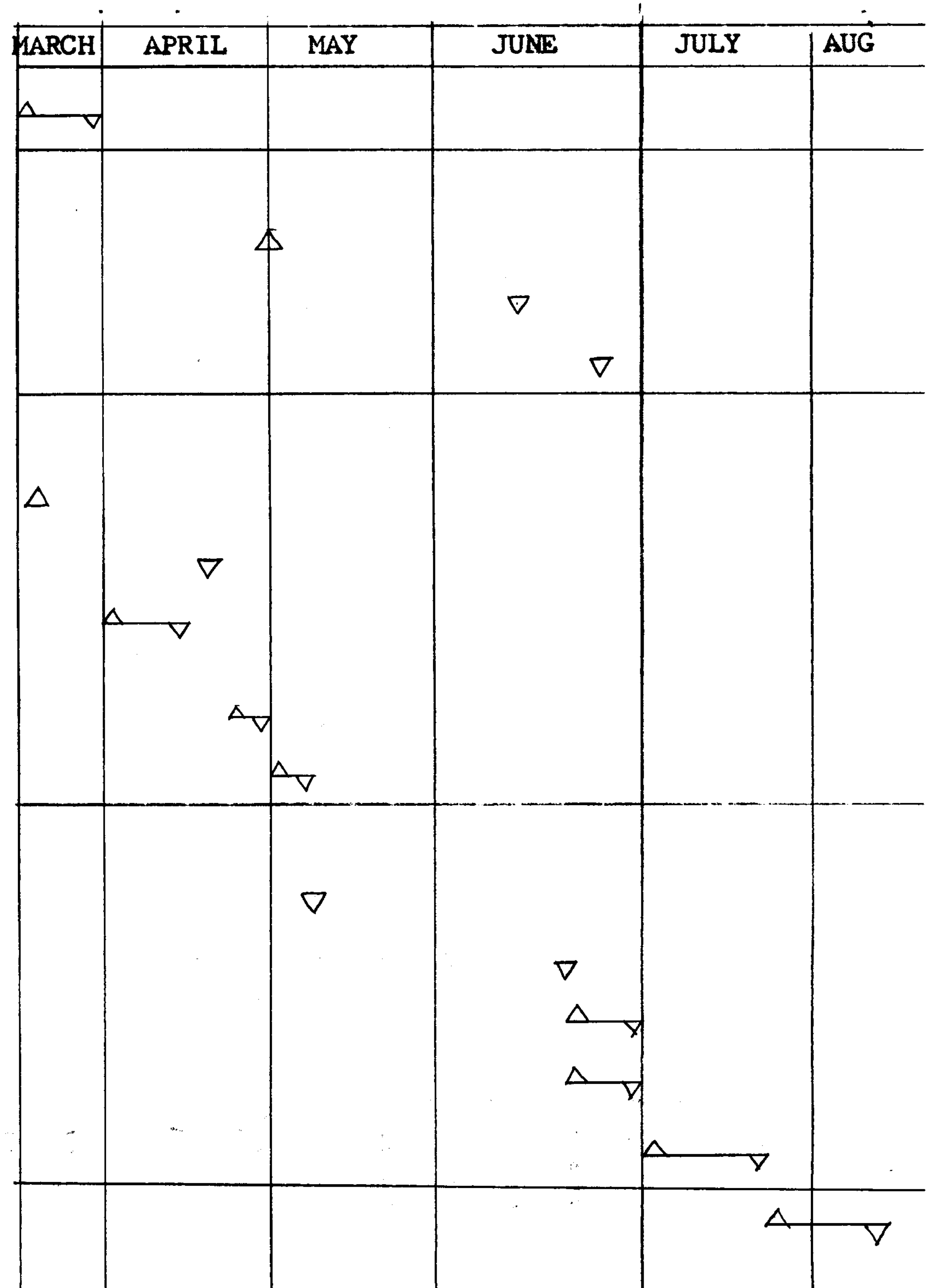
Here D denotes dynamic test specimens.

3.4 Analysis

During Phase I of this contract attempts to analytically predict energy absorption values for various glass reinforced plastic honeycomb designs were unsuccessful. However, design curves were established using the results of static and dynamic tests, which serve the same function as an analytical solution. In this phase of the program, the design curves will be revised to include the new data which will take into account the effect of angular impact landings on smooth surfaces which are essentially frictionless. This data will be applicable to both flat and curved vehicle designs. The specific energy curves for various specimen designs (Phase I Final Report, Figure 9-2) will be revised and extended to include values for optimum designs having various cell sizes and densities. Specific energy absorption and crushing stress values will be calculated for all specimens tested.

TASK

1. PREPARE PROGRAM PLAN
2. CURVED SPECIMENS
   - a. order
   - b. receive
   - c. ship to customer
3. OPTIMUM RESIN CONTENT SPECIMENS
   - a. order new phenolic resin specimens
   - b. receive new phenolic resin specimens
   - c. redip existing polyester resin specimens
   - d. static test
   - e. analysis of test results
4. ANGULAR IMPACT SPECIMENS
   - a. determine design and order
   - b. receive
   - c. static test
   - d. dynamic test
   - e. analysis of test results
5. PREPARE FINAL REPORT



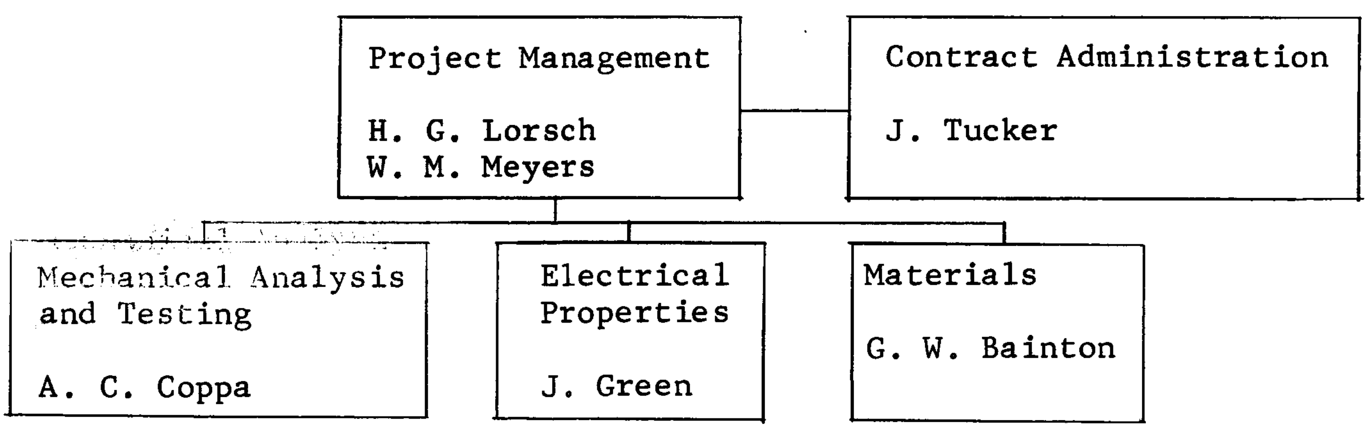
	MARCH	APRIL	MAY	JUNE	JULY	AUG.
MAJOR MILESTONES						
Ship Curved Specimens to JPL				⇩		
Order Angular Impact Specimens			⇩			
Final Report						⇩
MONTHLY PROGRESS REPORTS		▽	▽	▽	▽	

Organization

The contract will be performed under the direction of Dr. H. G. Lorsch, Manager, Structures Design who will act as project manager. All technical information will be transmitted through him.

Mr. J. Tucker will act as contract administrator. All contractual and financial information will be transmitted through him.

Mr. W. M. Meyers will act as project engineer, directing and coordinating the various technical areas as shown on the chart below.



1. SUMMARY

The Final Report for Phase I was completed and submitted to JPL. A contract extension covering Phase II was signed on March 17, 1964. Materials required for the initial tests of Phase II have been ordered.

Attached to this Monthly Report is the Program Plan for the increased scope of effort required in Phase II.

2. TEST SPECIMEN FABRICATION

Specimens required for performing the optimum density tests have been ordered from Honeycomb Products, Inc. These specimens are fully described in Section 3 of the Program Plan.

Quotations for fabrication of the curved specimens have been received and are being evaluated.

3. WORK PLANNED FOR APRIL 1964

Work, as outlined in the Phase II Program Plan, will be carried out.

Prepared by: Wm M Meyers
Wm. M. Meyers
Structural Design Engineer

Approved by: H G Lorsch
H. G. Lorsch,
Manager
Structures Design