SPACE FABRICATION:
GRAPHITE COMPOSITE TRUSS WELDING AND CAP FORMING SUBSYSTEMS

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LSST SPACE FABRICATION

Although funding limitations have precluded extensive support, LSST has provided some resources for beam builder subsystem technology studies. The contract with General Dynamics-Convair is for nine months beginning September 25.

LSST SPACE FABRICATION

- SPACE FABRICATION OF STRUCTURE BY A BEAM BUILDER IS NOT A MAJOR LSST ACTIVITY

- FORMING AND WELDING OF COMPOSITES HAS BEEN SUPPORTED WITH $125,000

- GENERAL DYNAMICS-CONVAIR IS UNDER CONTRACT TO DO FORMIN AN WELDING WITH EXISTING BENCH TEST EQUIPMENT AND TO BUILD A PROTOTYPE TRUSS

Figure 1

PROGRAM DESCRIPTION

The Graphite Composite Truss Welding and Cap Forming Subsystems contract was begun in late September 1979. This program description provides basic contractual data, identifies all milestones and shows the time spans planned for accomplishing each subtask within the three major task groups. The program is being conducted in accordance with the following groundrules:

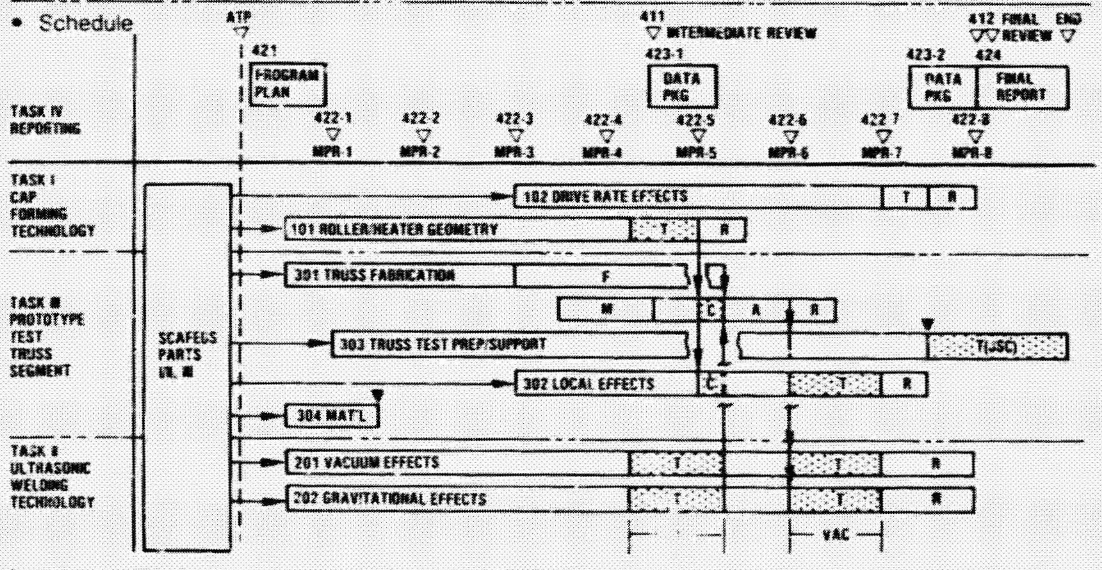
Cap forming
- On existing bench model machine

Welding
- On existing commercial welder
- General Dynamics Convair-developed horn/tips/schedules

Truss
- Geometry, element/joint details, material per SCAFEDS, Part III (NAS9-15310)
- Length: 4.90m (3 bays + std end cutoff)
- Die-formed cross-members
- Instrumentation & load intro fittings provided
- Tests conducted at JSC

Material
- Consolidated strip for testing at LaRC: woven single-ply graphite/glass; polysulfone resin

- Contract data
  - NAS 9-15973 — Value: $120,102
  - Agency: NASA/JSC — Contractor: General Dynamics Convair Division

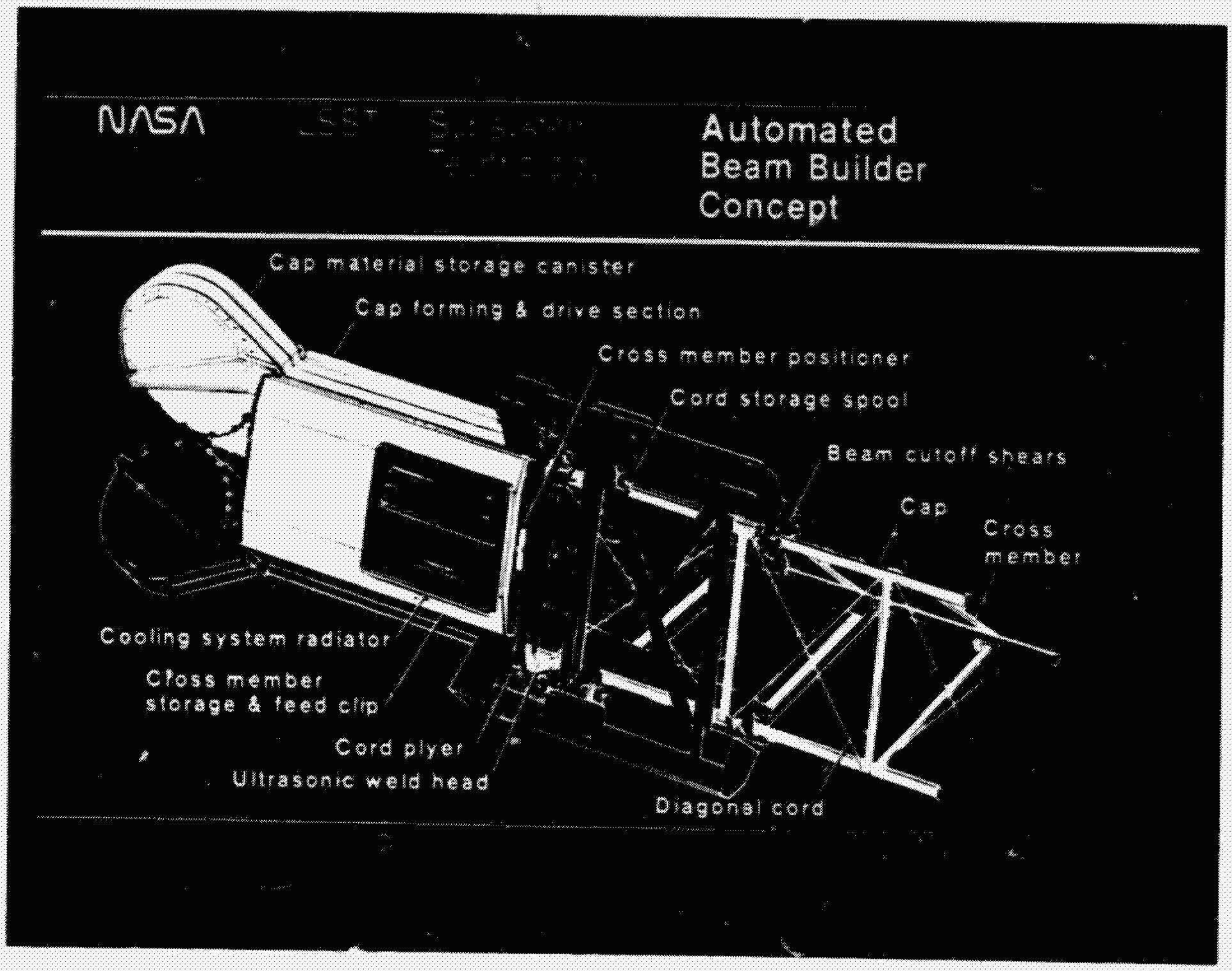


Legend A = Truss assembly F = Fixture fab assembly R = Report ▼ = Deliver to NASA
C = Cap forming M = Material preparation T = Test

Figure 2

AUTOMATED BEAM BUILDER CONCEPT

The beam builder concept developed during the SCAFEDS forms a triangular truss 1.3 meters on a side. Flat strips of preconsolidated graphite fiber fabric in a polysulfone matrix are coiled in a storage canister. Heaters raise the material to forming temperature then the structural cap section is formed by a series of rollers. After cooling cross members and diagonal tension cords are ultrasonically welded in place to complete the truss.



NASA

Automated
Beam Builder
Concept

Figure 3

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PROTOTYPE COMPOSITE TRUSS TEST

Because no performance data existed on the lightweight graphite composite truss configuration planned for automated space fabrication, a test was performed using a display article fabricated under the Space Construction Automated Fabrication Experiment Definition Study (SCAFEDS). Although the graphite fiber and polysulfone matrix were representative, the cap forming technique was not. Schedule incompatibility dictated hand lay up/vacuum cure on aluminum tooling in lieu of continuous roll-forming as originally planned. This resulted in undetected cracks on the free edges which in turn led to premature failure during compressive tests. A repeat test is planned with the truss built under this contract.

PROTOTYPE COMPOSITE TRUSS TEST

TEST OBJECTIVE: TO OBTAIN EARLY DATA ON TORSIONAL STIFFNESS, DAMPING AND SHORT COLUMN STRENGTH.

TEST ARTICLE: SCAFEDS DISPLAY, 3 BAY, 1.3 M X 4.9 M, 6.4 KG, GRAPHITE FIBER-POLYSULFONE COMPOSITE

TEST RESULTS: CRACKS IN EDGE OF OPEN CAPS AT 500 KG (1216 LB) LOAD, TEST STOPPED SHORT OF 1230 KG PREDICTED

TEST ANALYSIS:

- PREMATURE COMPRESSIVE FAILURE DUE TO UNDETECTED FIBER DAMAGE DURING FABRICATION LAYUP
- TORSIONAL STIFFNESS LOWER THAN PREDICTED
- DAMPING IN 2% RANGE

CONCLUSIONS:

- HIGH RISK IN TESTING ARTICLE NOT BUILT FOR THAT PURPOSE
- REPEAT TEST WITH NEW TRUSS

Figure 4

TRUSS TEST SETUP

The white SCAFEDS truss test article is shown against the structural test "backstop" at JSC. Compressive load is applied to end loading fixtures by a hydraulic cylinder from the Apollo-Soyuz docking test rig. Bending and torsional loads were applied to the upper fixture.

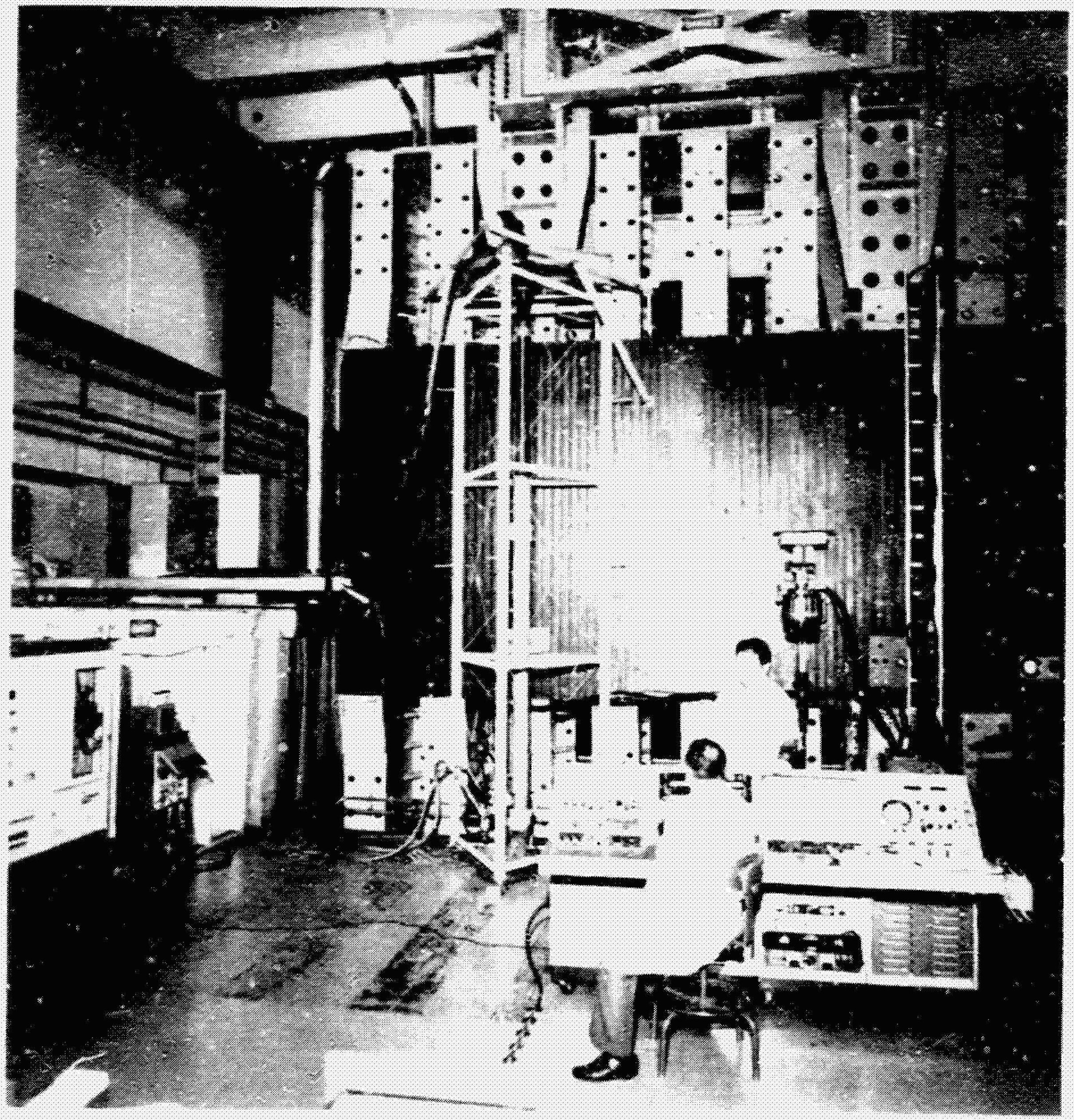

Figure 5

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PROTOTYPE TRUSS CAP EDGE CRACK

This is a photograph of one of twenty edge cracks observed during the compression test. The cracks were less than one centimeter long and occurred in all three caps. They were randomly spaced, but none closer than 20 cm to each other. Some cracks had been detected and patched during fabrication while others went undetected until exposure under test loads. Non-linear analyses as well as the results of several tests show that the edge cracking failure mode does not reflect the behavior of representative specimens.

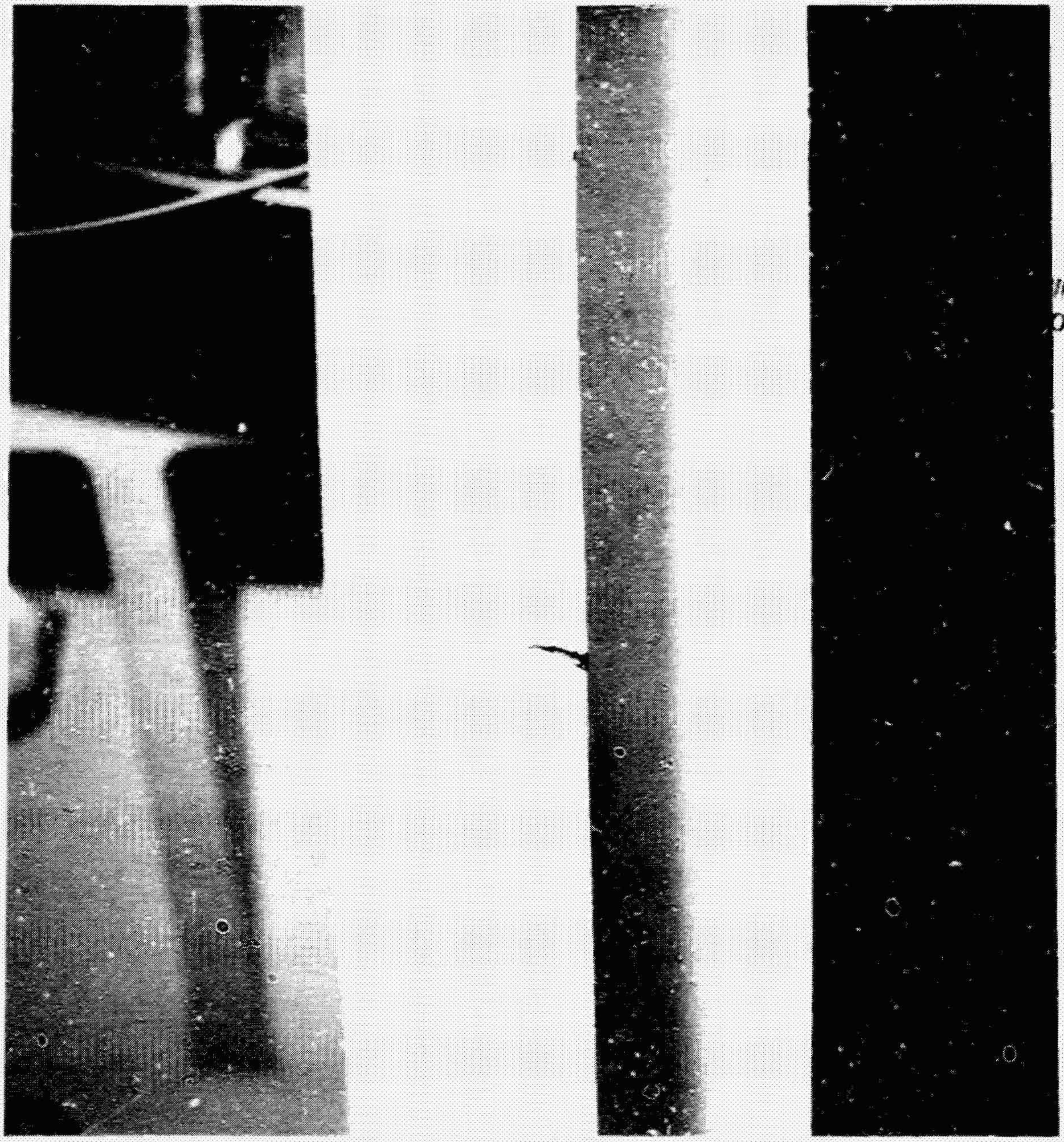


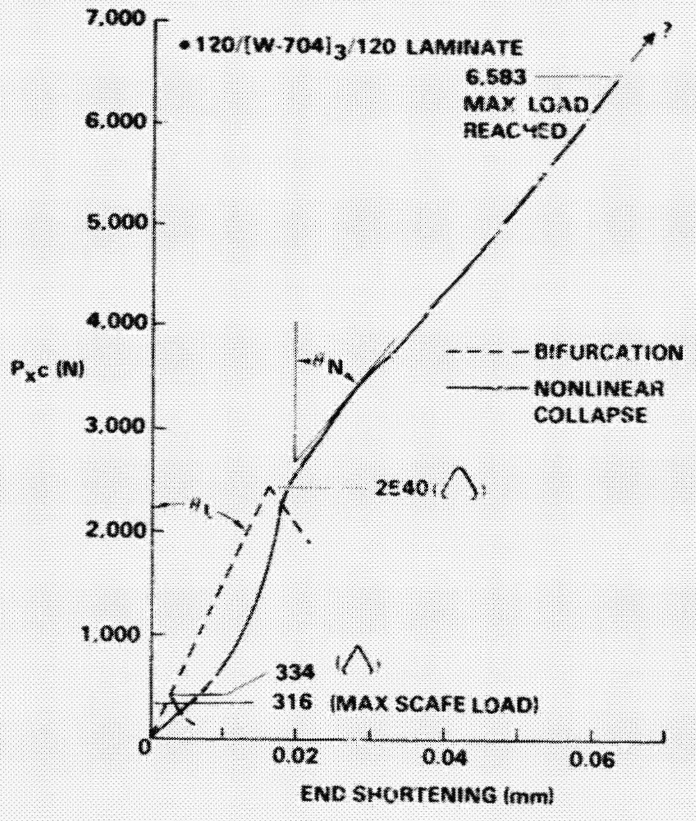
Figure 6

OPEN CAP STABILITY ANALYSIS

The compressive stability of open triangular caps was assessed for both round- and sharp-cornered sections of equal perimeter using the STAGS C computer code (ref 1). Linear bifurcation analyses showed that local buckling of the side flats occurred first in both sections and the dashed lines show a load-carrying advantage of about 7.6 times for the round-cornered section.

A non-linear collapse (crippling) analysis was also conducted to determine the ultimate strength of the round-cornered section. The solid curve shows load vs. deflection for this analysis, which was continued to a load of 6583N without indication of failure. Flexural (Euler) and torsional buckling allowables were also predicted by linear analyses, with torsional failure occurring first at a load of 13646N. Thus, the correct compression allowable lies between the crippling cutoff and torsional instability loads, resulting in a very large margin over the anticipated maximum SCAFE cap load of 316N.

• LOCAL BUCKLING



• COLUMN/TORSIONAL BUCKLING

- CURRENT ANALYSIS
  - BIFURCATION ONLY
  - ARTIFICALLY SUPPRESS LOCAL BUCKLING
  - REDUCE AXIAL STIFFNESS BY 50% TO REFLECT $\theta_N = 2\theta_L$

⇩

MODE	P_{CR}, N
TORSION	13,646
COLUMN	21,230

⇩

$6{,}583 < P_{FAILURE} < 13{,}646$

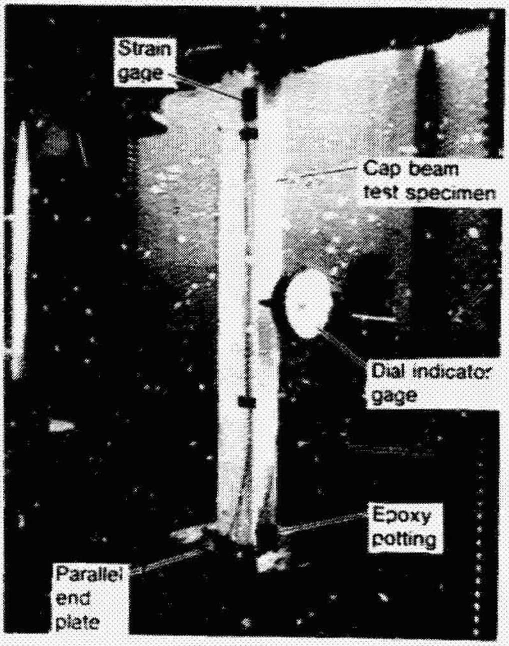
- FUTURE EFFORT
  - CONTINUE NONLINEAR ANALYSIS
  - TEST FULL SPAN CAP

Figure 7

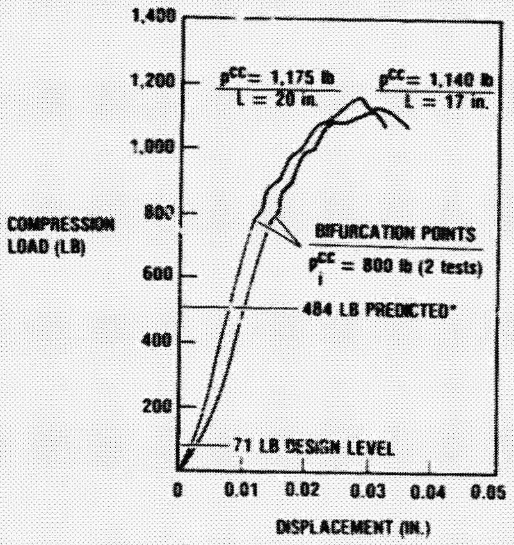
CAP SECTION TESTS

Cap strength and failure mode characteristics have been determined through several tests employing a setup similar to the one shown here. Low slenderness ratios are chosen to assure crippling failure, and strain gages are used during setup to assure uniformity of load introduction to the cross-section. Both the original laminated and later single ply materials have been tested. Results of laminated specimen tests and their close correlation with bifurcation analyses are given in ref. 1. Results for roll-formed single-ply specimens are shown and appear to indicate substantial benefit in initial buckling load due to the woven fiber construction.

- Test set-up



- Test results
  - Roll-formed specimens
  - t = 0.032 in.



*For quasi-laminate

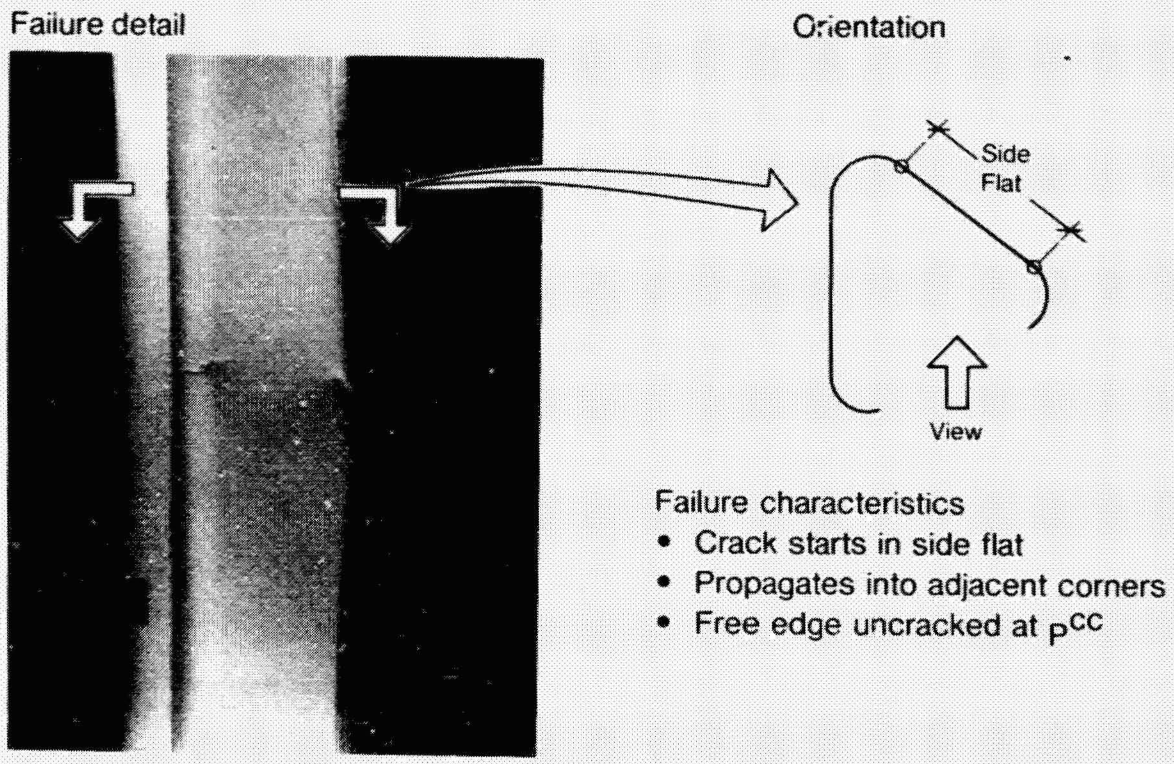
P^{cc}: CRIPPLING LOAD

P_i^{cc}: INCIPIENT BUCKLING LOAD

Figure 8

CAP SECTION CRIPPLING FAILURE MODE

The cap failure mode seen in all tests to date is shown in the photo, with the direction of view as indicated. Typically, cracks initiate at the edges of a buckled side flat, and propagate into the adjacent corners as the load is increased to ultimate. At failure the free edges remain uncracked.



Failure characteristics

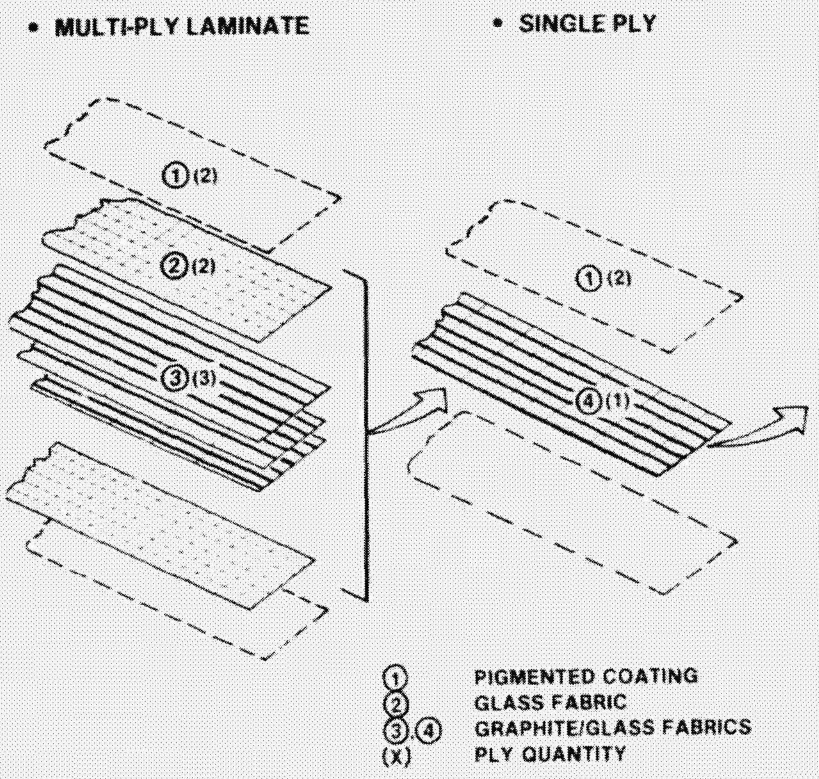
- Crack starts in side flat
- Propagates into adjacent corners
- Free edge uncracked at P^{cc}

Figure 9

SINGLE-PLY STRIP MATERIAL

During initial SCAFED study effort a material design evolved which combined the benefits of two fibers (glass and graphite), thermoplastic resin, and a white pigmented coating into a strip material suitable for the SCAFE fabrication process and service environment. Properties of this "sandwiched-graphite" multi-ply laminate, using then-available materials, were first predicted using conventional analytical techniques, and later verified by coupon tests. At the start of laminate evolution, however, the processing and forming benefits to be achieved by combining the desirable features of the constituent materials into a single-ply woven strip were already recognized. As weavable high-modulus graphite yarn became available, private development of single ply strips began, adopting the SCAFE cap laminate as a baseline for fiber percent/orientation and thickness.

However, a further valuable asset of single-ply material is the flexibility in gage selection since the ply thickness and stacking symmetry constraints of the laminate approach are eliminated. Consequently a new material, designed for increased stiffness plus improvement in various "second-order" characteristics is now in development. Comparison with the original laminate shows a 20% gage reduction, significant weight decrease, a small but acceptable reduction of beam fundamental frequency and essentially unchanged local stability of the cap side flats. As an added benefit, it also permits cap/crossmember material commonality.



- **CHARACTERISTICS**

- **Composite vs. metallics**
  - Improved properties
    - Low density
    - High strength
    - High stiffness
    - Superior thermal stability
    - High buckling load
    - Except: Low failing strain
  - Less energy to produce
  - Expensive, becoming cheaper

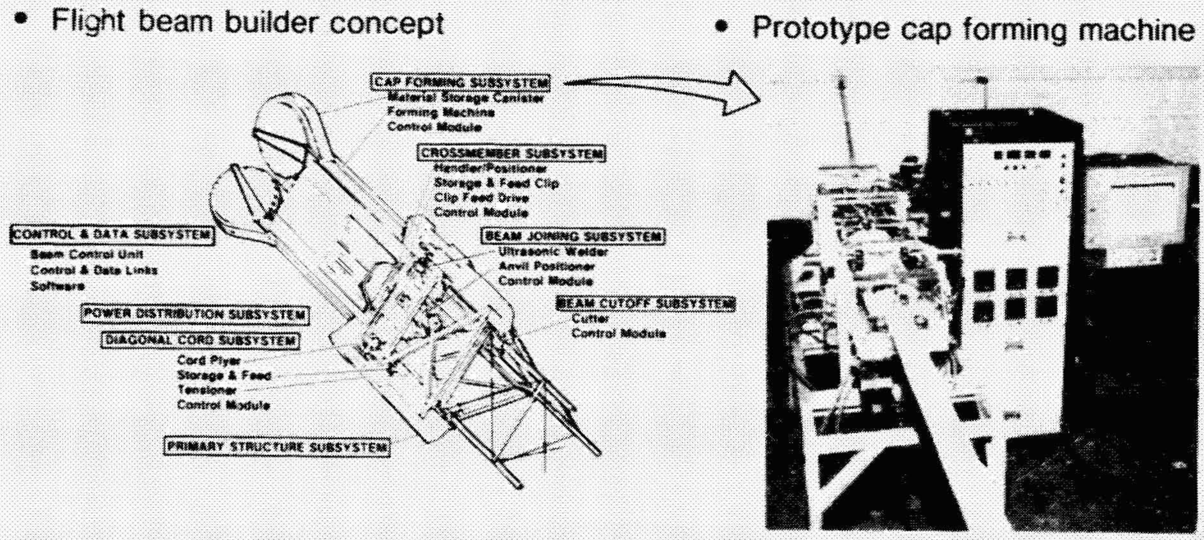
- **Single ply vs. multi-ply**
  - Improved raw material processing
    - Simplicity, cost
    - Uniformity
  - Key properties retained
    - High E
    - Low CTE
    - Low transverse k
  - Improved forming
    - Less energy
    - No delamination
  - No thickness constraint

Figure 10

CAP FORMING

The beam builder system is comprised of eight subsystems, each of which consists of one or more subsystem modules. This concept permits each subsystem module to be developed separately before integrating the complete subsystem into the beam builder.

The cap forming subsystem, for example, consists of three cap forming machines. General Dynamics Convair Division has built and demonstrated the prototype cap forming machine shown. It is being used to develop the materials, processes and techniques to be incorporated in the flight beam builder cap forming machines. It will also be used to meet the objectives of this program by producing cap members for the test truss and cap test specimens for determining local effects of column loaded cap members. Cap forming technology will be further advanced by the improvements to be made in forming roller and heater geometry, and through an evaluation of drive rate effects.



- Flight beam builder concept
- Prototype cap forming machine

Figure 11

WELD PROCESS DEVELOPMENT AND APPLICATION

Early development of ultrasonic welding technology for joining graphite polysulfone composites started with the evaluation of weld tips and welding schedules using small samples of both bare and coated material. This led to a joint design for the triangular truss beam, which not only connects the beam caps and crossmembers together but captures the diagonal cord within the welded zone as well.

This joint design was demonstrated with the fabrication and assembly of the first prototype truss demonstration article produced during the initial phase of the SCAFEDS program. Improvements in this joint design have occurred through subsequent development activity and will be employed in the truss test article to be produced under this contract.

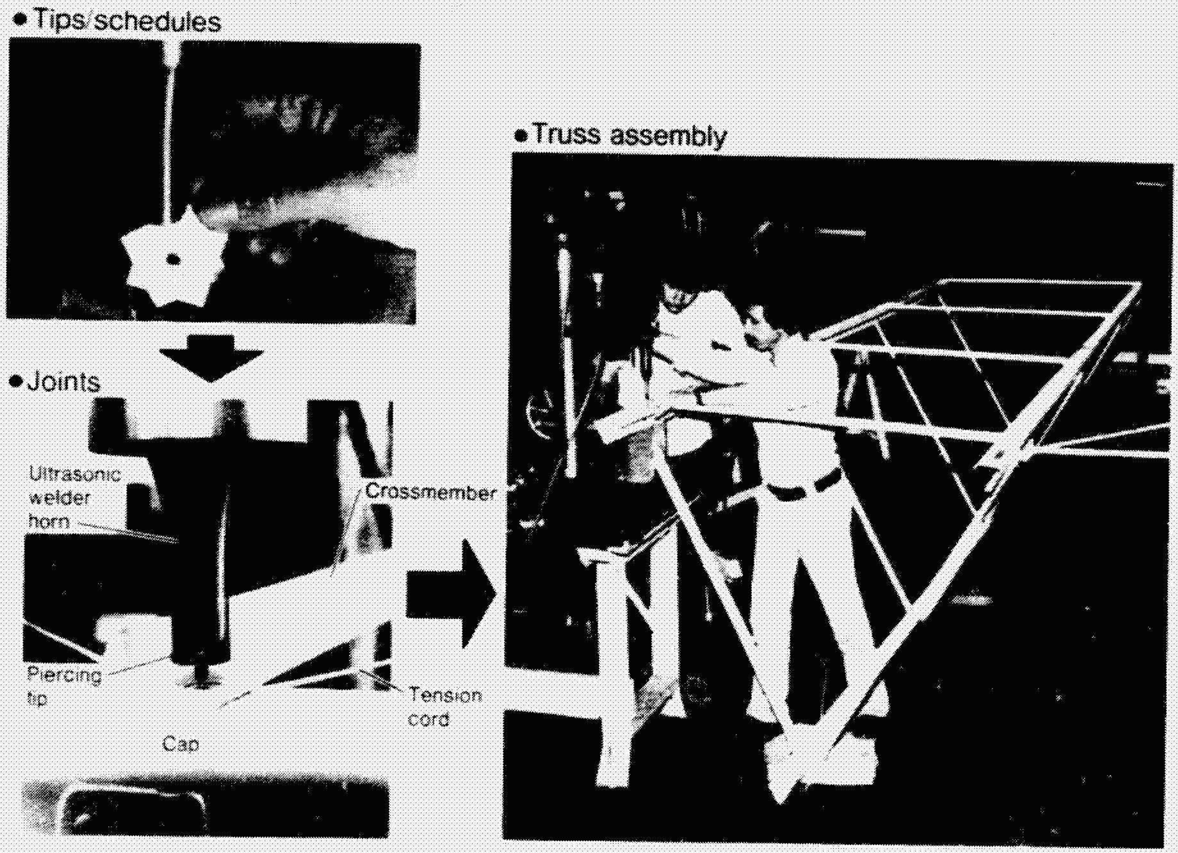
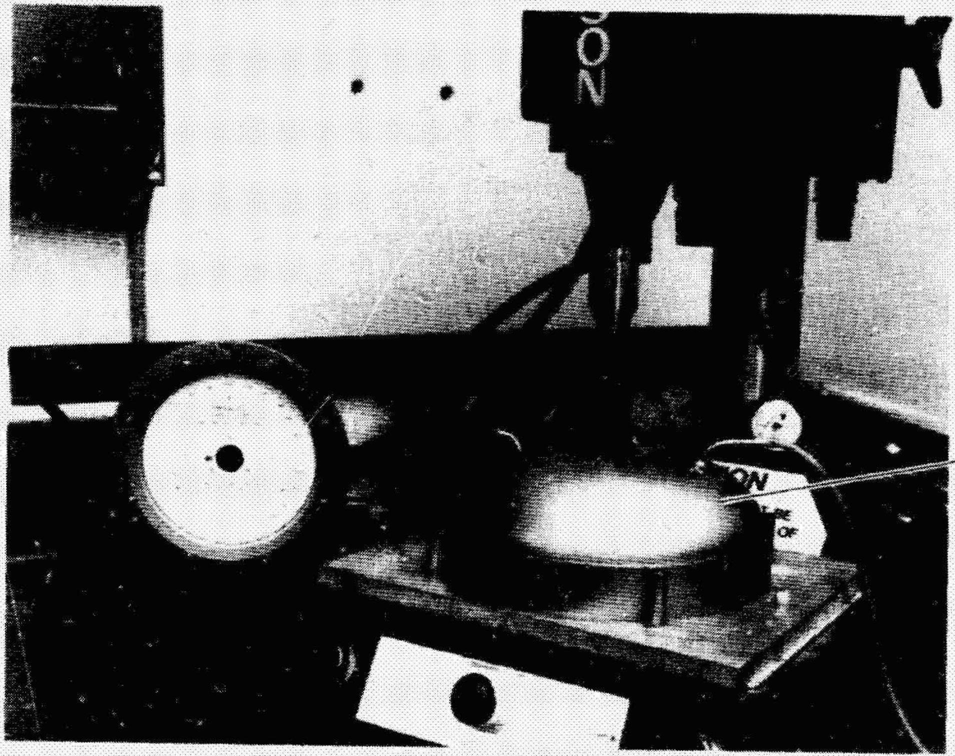


Figure 12

WELDING IN PARTIAL VACUUM

The existing data base for the ultrasonic welding of graphite/polysulfone composite material includes the performance of welds in partial vacuum using a vacuum chamber which encloses only the weld horn and weld specimen as shown. Results indicate no reduction of weld strength down to the vacuum levels achieved with this approach.

By placing the entire welder inside a vacuum chamber, the overall effects of in-vacuum welding on both the weld specimens and machine performance will be more thoroughly assessed, at vacuum levels approaching those to be experienced by the flight beam builder.



- 5mm Hg
- Single-ply, T_iO_2-coated specimens

Figure 13

REFERENCES

1. Spier, E.E.: Stability Analysis and Testing of Thin-Walled Open-Sectioned Graphite/Thermoplastic Structures; in the Proceedings of the 10th National SAMPE Technical Conference, Oct. 1978.