SUBMILLIMETER ARRAY PROJECT
TECHNICAL MEMO 151

TITLE: TESTING OF NYTEX TUBES FROM ANTENNA 3 AND SPARE TUBE INVENTORY

FOREWORD: Joshua B. Kivela (SGH) conducted the tests, summarized the test procedure, and documented the results in the form of Tables 1 and 2 and Photos 1-3. George Nystrom (SAO) has provided an engineering assessment and recommendations for future testing to ensure BUS safety and performance.

SGH REPORT: Joshua B. Kivela
Test Engineer
Simpson Gumpertz and Heger Inc. (SGH)
41 Seyon Street
Building 1, Suite 500
Waltham, MA. O2453
Phone: 781-907-9000
Fax: 781-907-9009

Analysis And Comments: George Nystrom
Project Engineer
SMA Project
Phone: 617-495-7190
Fax: 617-495-7040

REPORT ON SMA TESTING, JOSHUA B. KIVELA

SUBJECT: Strength of Carbon Fiber Tube Assemblies
(Test Date: 10 – 11 June 2003)

SAMPLES: The tubes were identified as “Crack tubes from Antenna 3” and “Crack tubes from Spares.” A total of thirty-six (36) carbon fiber tube assemblies were shipped to SGH from the SMA site on the summit of Mauna Kea, HI. The assemblies were constructed of various length and diameter carbon fiber tubes with stainless steel end fittings inserted and bonded to the tubes.

PROCEDURES

We followed the procedures outlined in “SMA-ASIAA Crack Bus Tube Test Procedure” written by George Nystrom dated 17 April 2003. The following summarizes our procedure:

- We configured our MTS Testing Machine with a 10,000 lbf. Load cell and fixtures (Photo 1).
- We screwed forged steel threaded eyebolts into both stainless steel ends of the carbon fiber tube assembly.

- We mounted both ends of the carbon tube assembly in the fixtures and applied a 20 lbf seating load (Photos 2-3).

- We aligned the specimens in the fixtures and moved the crosshead up at a rate of 1.5 mm/min.

- When the “Hold Load 1” in Tables 1-2 was reached we held the load for 5 minutes and recorded the distance the crosshead moved.

- After we confirmed that the creep rate was less than 5 microns/minute, we moved the crosshead up at a rate of 1.5 mm/minute until we reached the “Hold Load 2” value listed in Tables 1-2. We held the load at this value for 5 minutes.

- After we confirmed that the creep rate was less than 5 microns/minute we unloaded and removed the test article.

- We recorded the applied load and resulting amount of creep for both sustained load segments.

TEST PHILOSOPHY AND RESULTS

The test philosophy was to repeat the testing done at the manufacturer to establish that the tubes strength (in tension) has not degraded. Load 1 is the maximum predicted tube load. SMA Technical memo 119 defines the computation of load1. The computation used a wind velocity of 56M/sec, gravity, assembly loads and a temperature loading of ±25 degrees C. Load 2 is the tubes “proof load” which is 1.5 times load 1, thereby yielding a 1.5 factor of safety on the maximum expected load. Table 1, in Technical memo 119, was used here to specify the test loads

The test results for cracked tubes from Antenna 3 and spare tubes are listed in Tables 1 and 2, respectively. All thirty-six-carbon fiber tube assemblies tested had a creep rate of less than 5 microns/minute at the designated loads and all passed without rupture.

Table 1 - Cracked Tubes From Antenna 3								
			Creep				Hold Load (lbf.)	
			At Load 1		At Load 2			
SAO Designation	Tube Number	Tube Type	Total (㎛)	Rate (㎛/min.)	Total (㎛)	Rate (㎛/min.)	1	2
1	12-4-X	4	4.0	0.8	3.5	0.7	258	390
2	12-4-X	4	0.0	0.0	4.0	0.8	258	390
3	12-4-X	4	1.5	0.3	3.5	0.7	258	390
4	12-8-X	8	5.5	1.1	9.5	1.9	519	780
5	12-5-X	5	2.0	0.4	2.5	0.5	331	500
6	12-5-X	5	0.5	0.1	3.5	0.7	331	500
7	12-7-X	7	1.0	0.2	2.0	0.4	238	360

Notes:

1. Creep is the total crosshead displacement during the hold load period. Creep rate is the total crosshead displacement during the hold load period divided by the hold time (5 minutes).

Tube Number	Tube Type	Total (m)	Rate (m/min.)	Total (m)	Rate (m/min.)	1	2	Notes
10-01-09	1	10.0	2.0	11.0	2.2	719	1060	
1-1-SGH	1	3.5	0.7	5.0	1.0	719	1079	2
10-2-13	2	3.0	0.6	6.5	1.3	681	1000	
10-2-14	2	2.5	0.5	4.5	0.9	681	1000	
9-2-16	2	5.0	1.0	7.0	1.4	681	1000	
9-2-18	2	2.0	0.4	6.0	1.2	681	1000	
8-3-13	3	6.5	1.3	5.5	1.1	647	950	
10-03-17	3	4.0	0.8	7.0	1.4	647	950	
14-03-26	3	2.0	0.4	7.0	1.4	647	950	
14-3-01	3	5.0	1.0	5.6	1.1	647	950	
4-4-SGH	4	1.0	0.2	2.5	0.5	258	387	2
9-5-11	5	3.0	0.6	2.5	0.5	331	500	
9-05-12	5	4.0	0.8	5.0	1.0	331	500	
9-5-22	5	9.5	1.9	11.5	2.3	331	500	
8-05-24	5	1.5	0.3	3.0	0.6	331	500	
12-05-25	5	8.5	1.7	2.5	0.5	331	500	
05-5-SGH	5	1.5	0.3	3.5	0.7	331	497	2
10-7-41	7	1.5	0.3	1.0	0.2	238	360	
7-9-SGH	7	0.5	0.1	1.5	0.3	238	357	2
11-11-SGH	11	2.5	0.5	4.5	0.9	588	882	2
8-12-?	12	4.0	0.8	9.0	1.8	850	1270	
14-12-SGH	14	4.0	0.8	7.0	1.4	800	1200	
14-14-SGH	14	4.5	0.9	6.0	1.2	800	1200	2
10-15-17	15	3.0	0.6	5.0	1.0	654	970	
10-16-33	16	2.0	0.4	2.5	0.5	557	840	
10-16-14	16	2.5	0.5	4.0	0.8	557	840	
16-16-SGH	16	3.5	0.7	5.0	1.0	557	836	2
13-17-46	17	1.5	0.3	2.0	0.4	415	620	
19-18-04	19	9.0	1.8	17.0	3.4	1384	2076	2

Notes:

1. Creep is the total crosshead displacement during the hold load period. Creep rate is the total crosshead displacement during the hold load period divided by the hold time (5 minutes).

2. Tube number modified by George Nystrom.

O:\DATEFILE\2003\KIvela\JBK30-F.ptl.DOC

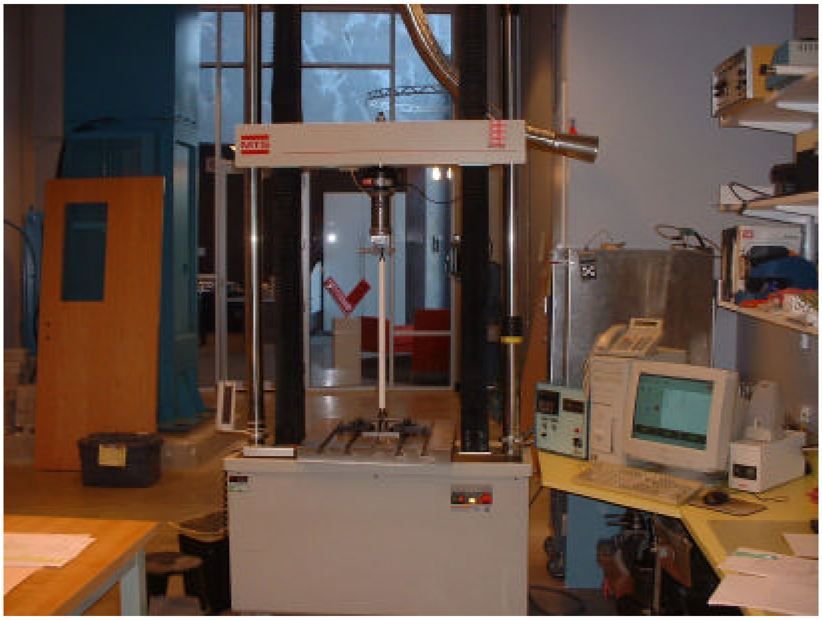

Photo 1

MTS 30/G testing machine and data acquisition system with carbon-fiber tube assembly mounted in machine.

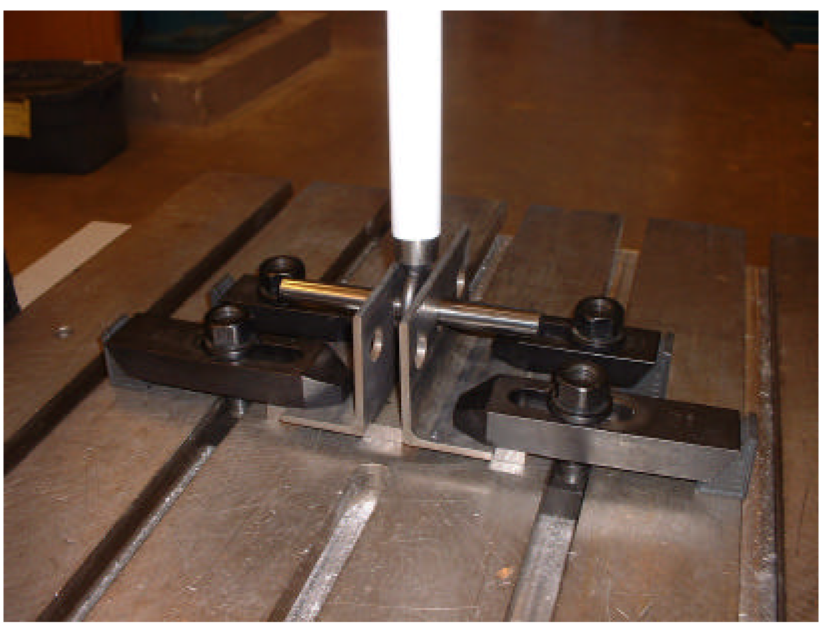

Photo 2

Bottom of carbon-fiber tube assembly mounted in fixture.

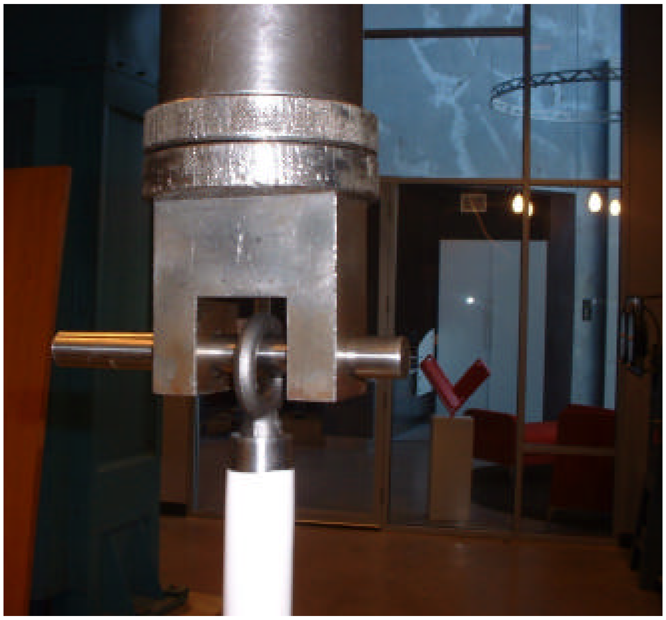

Photo 3

Top of carbon-fiber tube assembly mounted in fixture.

ANALYSIS AND COMMENTS, GEORGE NYSTROM

The test results show that no discernible strength degradation has occurred since the tubes acceptance testing at the manufacturing site. Also, that tube cracking appears to have no effect on tube strength. The SMA engineering staff had predicted tube cracks would not affect tube strength. This is as long as the crack doesn't propagate across the bonded joint between the tube and end fitting.

In discussing the preliminary results in the SAO/ASIAA weekly telecon (6/11/03) some concern was raised as to the amount of creep. George Nystrom stated that it was most likely strain due to loading. A simple way to evaluate this is to compute the tubes strain based on the test data.

Compute the tubes strain: (Tube 1 in table 1)

1. Compute the fiber stress, S

$S = P/A$ Where: P is the applied load in pounds (258)
A is the tubes cross sectional area in in^2

Dimensions of a type 4 tube are: ID is 23.3 mm (0.917 in), OD is 27.4 mm (1.078 in) and the length is 604 mm (23.78 in)

Therefore

$S = 258/ (p/4)*(1.078^2 – 0.917^2) = 1022$ psi

2. Compute the unit strain (δ) based on an estimated modulus of 10.6×10^6 psi. Note: CRFP tubes, in general, have a modulus close to that of aluminum. However, the modulus varies with the lay-up and individual materials used in its construction. Therefore a close approximation of the unit strain can be computed by,

$$\delta = S / E = 1022 / 10.6 \times 10^6 = 9.64 \times 10^{-5} \text{ or } 2.44 \text{ microns per in of length}$$

Therefore the tube’s total strain is,

$$\Delta = L * \delta$$

$$\Delta = 23.3 \times 9.64 \times 10^{-5} = .00225 \text{ inches (57.1 microns)}$$

Now for this tube, the creep in table 1 was 4 microns for a five-minute hold time or 1/14 (7.0 %) of the estimated total strain. Therefore, it is reasonable to assume, that the tube and bond line are still equilibrating due to the applied load. Also, the creep measurement is susceptible to machine readout accuracy, temperature fluctuations and possible setup (fixturing) motions. Therefore, it is my opinion that the creep measured for all tubes is insignificant when compared to the total strain. The measured creep is a small fraction of the total strain for all tubes as can be verified by review of tables A & B in SAO Test procedure 41700490002.

CONCLUSIONS:

All tubes pass this testing without failure. The testing was at the tubes’ acceptance level at the manufacturing plant and therefore indicates that the tubes are still acceptable for use in an antenna. Also, the tube cracks appear not to affect the tubes strength.

RECOMMENDATIONS:

It is recommended that this set of tubes become the test article for monitoring the long-term tube strength by testing the tubes at regular intervals. Furthermore, that the tubes be broken up into sets to evaluate engineering concerns. Those being:

- Aging
- Sustained loading (with cyclic load variation, if possible)
- Environmental conditions, both for the Summit and tube storage.

Aging:

Bonded joints having dis-similar materials display a history of deteriation over time. Especially for CFRP to metal bonded joints, where a high co-efficient of thermal expansion (CTE) difference exists.

Sustained Loading:

Sustained Loading is how the tubes operate within the BUS. The loading comes from temperature difference, gravity, assembly and wind. Temperature and wind introduce a cyclic component to a tubes applied load. Introducing a cyclic load component into the test program will be difficult and I believe not warranted.

Environmental conditions:

A set of test tubes should be exposed to the outside summit environment. This is to simulate the environmental exposure of tubes in an antenna. Secondly, a set should be stored along side the spare tube inventory. This is to ensure that the storage environment is not introducing a failure mode.

SUMMARY:

Testing has not exposed any degradation of BUS tube strength. This provides assurance that the BUS is structurally sound at the present time and should meet its design goals. However, a long-term test plan is needed to measure tube strength over its design life. Listed above is a set of suggested test parameters to evaluate and monitor tube strength. A test plan to carry out these long-term tests is needed. Development of this test plan is beyond the scope of this report and is emphasized here to highlight its need. A test interval of eighteen (18) months is recommended for this testing with testing performed at SGH's Waltham, MA. Facility.