A NASTRAN INVESTIGATION OF SIMULATED PROJECTILE DAMAGE EFFECTS ON A UH-1B TAIL BOOM MODEL

Arnold T. Futterer
U. S. Army Armament Research and Development Command
Ballistic Research Labratory

SUMMARY

A NASTRAN model of a UH-1B tail boom that had been designed for a another project was used to investigate the effect on structural integrity of simulated projectile damage. Elements representing skin, and sections of stringers, longerons and bulkheads were systematically deleted to represent projectile damage. The structure was loaded in a manner to represent the flight loads that would be imposed on the tail boom at a 130 knot cruise. The deflection of four points on the rear of the tail boom relative to the position of these points for the unloaded, undamaged condition of the tail boom was used as a measure of the loss of structural rigidity. The same procedure was then used with the material properties of the aluminum alloys replaced with the material properties of T300/5208 high strength graphite/epoxy fibrous composite material, $(0,\pm45,90)_s$ for the skin and $(0,\pm45)_s$ for the longerons, stringers, and bulk heads.

INTRODUCTTON

This investigation had a two-fold objective:

1. To determine the effect on the structural integrity of the UH-1B tail boom caused by threat projectile damage.

2. To estimate the effect of composite materials on the stiffness of the tail boom.

The model of the UH-1B tail boom used in the analysis was originally prepared under contract by Kamen AviDyne[1] (KAD) for the Ballistic Research Laboratory. The model consisted of beams representing sections of the stringers, bulk heads, and longerons and thin plates representing the skin. The KAD report describes the model in good detail. Figures 1, 2, and 3 taken from the KAD report illustrate the NASTRAN[2] model developed by KAD and give the numbering schemes for the grid points, beam elements and plate elements, respectively. The skin is made of 2024 T3 aluminum alloy with a modulus of elasticity of 7.31×10^4 MPa (10.6×10^6 psi) and a mass density equal to 271.15 kg sec^2/m^4 (0.00025 lb sec^2/in^4). The stringers,bulk heads and longerons are made of 7075 T6 aluminum alloy with a modulus of elasticity of 7.10×10^4 MPa (10.3×10^6 psi) and a mass density of 271.15 kg sec^2/m^4 (.00025 lb sec^2/in^4). For further detail on the assumptions that went into preparing the

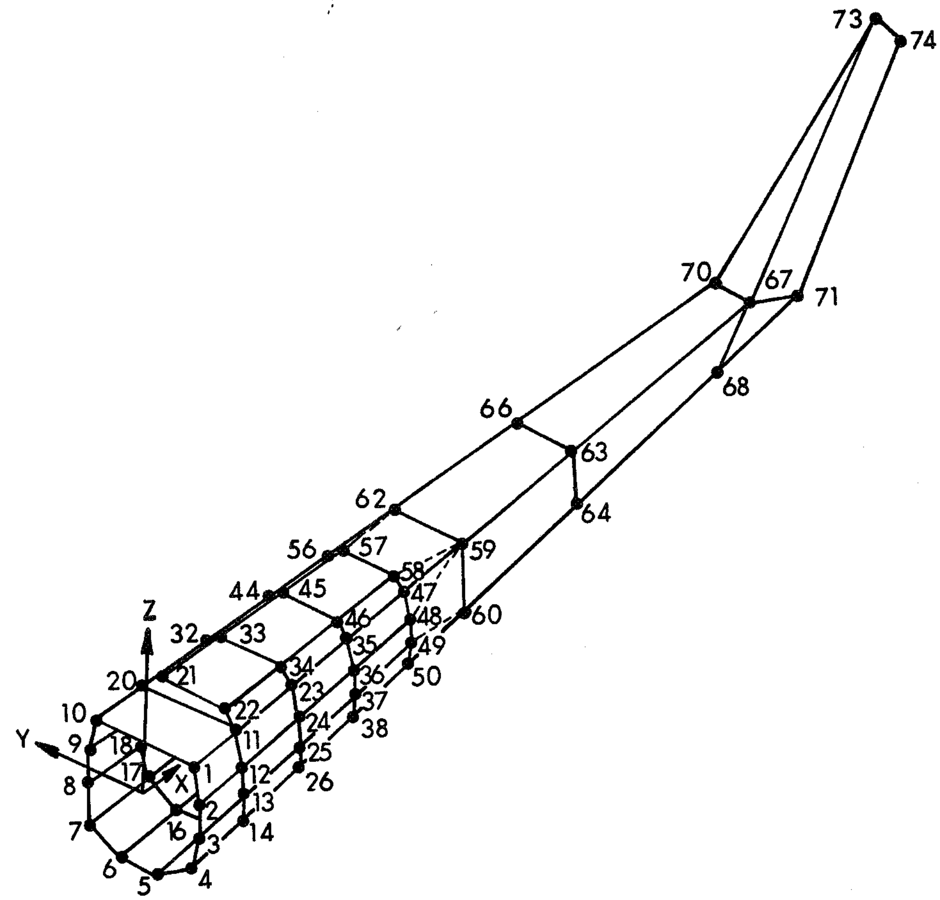

FIGURE 1. UH-1B TAIL BOOM MODEL GRID POINTS AND NUMBERING SEQUENCE

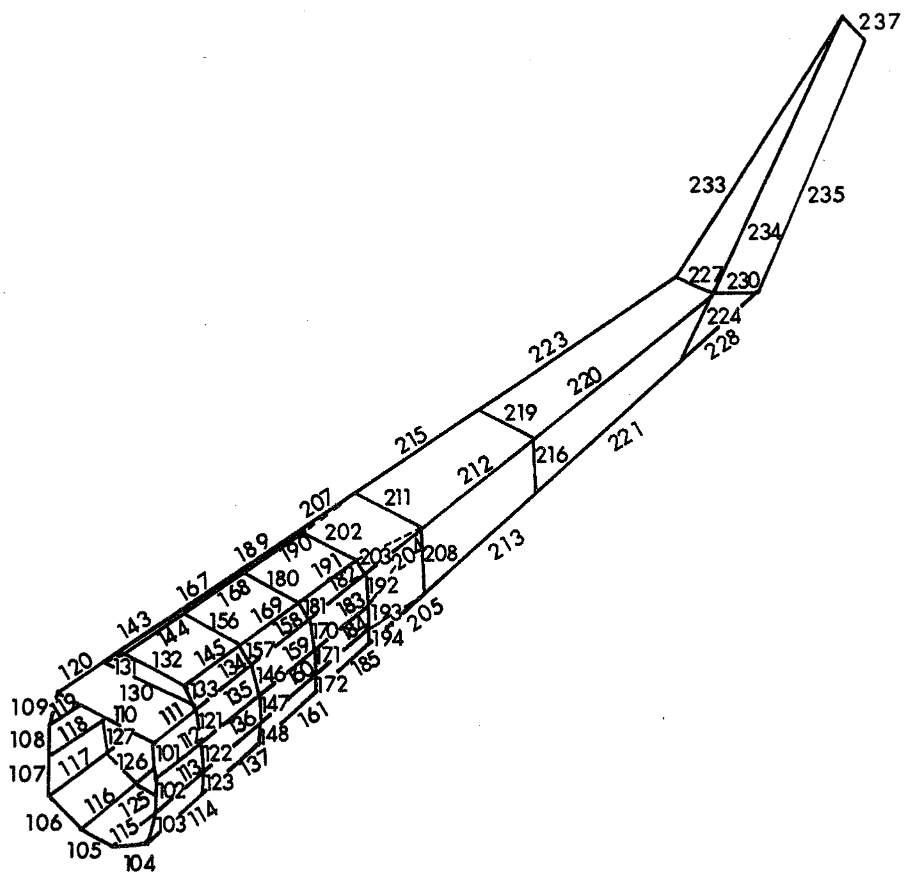

FIGURE 2. UH-1B TAIL BOOM MODEL BEAM ELEMENT IDENTIFICATION

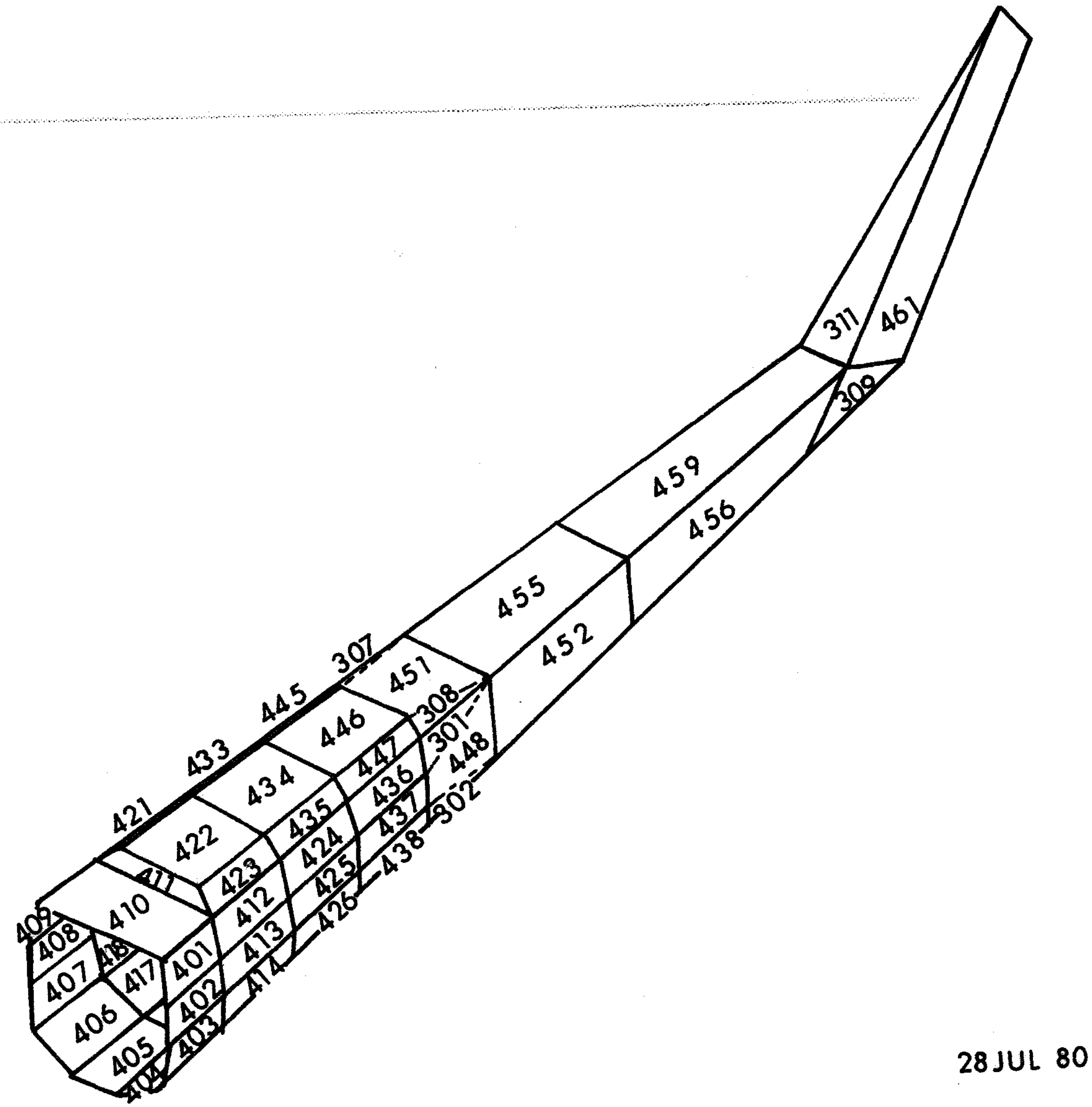

FIGURE 3. UH-1B TAIL BOOM MODEL PLATE ELEMENT IDENTIFICATION

model it is recommended that a copy of the report be obtained from Defense Technical Information Center.

PROCEDURE

The investigation was accomplished by using the NASTRAN code, a complex finite element method computer program. In all 35 NASTRAN calculations were made, 17 using the aluminum alloy construction and 18 using the same structure but using the material properties of T300/5208 high strength, graphite-epoxy fibrous composite. This paper describes the results from 18 calculations (9 aluminum alloy construction and 9 composite construction) The relative displacements, compared to the non-damaged, non-loaded structure, of the four points at the base of the tail fin with the front of the tail boom anchored securely were used as a measure of the deterioration of the structural integrity of the tail boom due to projectile damage. The flight loads that would be imposed on a helicopter cruising at 130 knots were simulated by loading the structure to simulate the loads and torques that the rotor thrust and elevator loading would cause at cruise velocity. The assumption was made that a large hole or tear in a skin panel or a break in a longeron, stringer or bulkhead section would destroy the structural integrity of the element representing that skin panel or section. In the model that damaged element was then deleted. The investigation was conducted by systematically deleting plate and beam elements to simulate greater damage. Table I gives the nomenclature of the damage configurations that were investigated. Damage to

TABLE I. NOMENCLATURE FOR DAMAGE CONFIGURATIONS

Nomenclature	Elements deleted
0	No elements deleted
1	419
2	419, 141, 418
3	431, 153, 419
4	431, 153, 419, 141, 418
5	419, 154, 431, 165, 430, 153, 418, 141
6	419, 154, 431, 165, 430, 153, 418, 141, 164, 140
7	458
8	458, 222

the left and to the right side of the tail boom were studied because the right side has thicker skin than the left. Furthermore, the longitudinal strains were generally compressive on the right side and tensile on the left side. This paper discusses the results of calculations for damage to the right side of the helicopter. The numbers of the elements deleted refer to Figures 2 and 3. As may be noted, the 100 and 200 series numbers refer to the beam elements and the 400 series to the rectangular plate elements.

Tables II, and III are similar in construction. They give the displacements of the points at the rear of the tail boom of the loaded, undamaged tail boom and the loaded tail boom with simulated damage relative to the undamaged, unloaded state of the tail boom. Nomenclature refers to Table I where the damage configurations are set forth. Material lost refers to the mass of the deleted elements. "Direction",X, Y, and Z, gives the displacement of the grid points in the three coordinate directions given on Figure 1 and "R", which is the square root of the sum of the squares of the three coordinate displacements, gives the total displacement of the grid points specified. The displacements are given in inches and millimeters. The displacement values are given in exponential format, i.e., 2.05-2 means 2.05×10^{-2}. Table II contains the results of the calculations with the tail boom constructed of aluminum alloy and the damage is to the forward right side of the helicopter. Figure 4 is a graph of deflection of points on the rear of the tail boom versus mass of aluminum alloy removed from the forward right side of the tail boom. As may be noted, the deflection is quite linear with mass removed until about 1 kg and then further removal causes the displacements to become non-linear suggesting a more rapid approach to failure with further loss of material.

After calculating the displacements for the various damage configurations with the tail boom constructed of aluminum alloys, the calculations were repeated using the material properties of T300/5208 which is a high strength, graphite-epoxy fibrous composite. The skin plates were assumed to be constructed of $[0,\pm45,90]_s$ layered composite and the beam elements of $[0,\pm45]_s$ layered composite. T300/5208 was recommended[3] as being high strength and considerably less expensive than the ultra-high modulus graphite-epoxy. Since the composites have less strength in compression than in tension, the material moduli of elasticity for both compression and tension were used in the calculations. For damage on the left side the tensile moduli, 5.59×10^4 MPa (8.11×10^6 psi) for the plate elements and 6.50×10^4 MPa (9.42×10^6 psi) for the beam elements, were used. For damage on the right side the compressive moduli, 5.38×10^4 MPa (7.81×10^6 psi) for the plate elements and 6.43×10^4 MPa (9.32×10^6 psi) for beam elements, were used. A mass density of 162.69 kg sec^2/m^4 (.00015 lb $sec^2/in.^4$) was used for the beam and plate elements. This paper reports on the more extreme of the two cases, the right side damage and using the lower compressive moduli in the calculations. The total displacements for the various damage configurations for damage done to the forward right side of a tail boom constructed of T300/5208 composite are

TABLE II. DAMAGE TO THE RIGHT SIDE OF HELICOPTER TAIL BOOM CONSTRUCTED OF ALUMINUM ALLOY.

Nomenclature	Material Lost lb/kg	Direction	Grid Point Displacements 67 in.	67 mm	70 in.	70 mm	71 in.	71 mm	72 in.	72 mm
0	.0	X	2.18-2	5.54-1	2.45-3	6.22-2	7.52-3	1.91-1	-1.23-2	-3.12-1
	.0	Y	3.30-1	8.38+0	3.30-1	8.38+0	3.23-1	8.20+0	3.23-1	8.20+0
		Z	-2.22-1	-5.64+0	-2.47-1	-6.27+0	-2.46-1	-6.25+0	-2.70-1	-6.86+0
		R	3.98-1	1.01+1	4.12-1	1.05+1	4.06-1	1.03+1	4.21-1	1.07+1
1	.71	X	2.17-2	5.51-1	2.02-3	5.13-2	7.35-3	1.87-1	-1.27-2	-3.23-1
	.32	Y	3.36-1	8.53+0	3.36-1	8.53+0	3.29-1	8.36+0	3.29-1	8.36+0
		Z	-2.24-1	-5.69+0	-2.50-1	-6.35+0	-2.50-1	-6.35+0	-2.74-1	-6.96+0
		R	4.04-1	1.03+1	4.19-1	1.06+1	4.13-1	1.05+1	4.28-1	1.08+1
2	1.46	X	2.14-2	5.44-1	2.21-3	5.61-2	6.49-3	1.65-1	-1.49-2	-3.78-1
	.66	Y	3.60-1	9.14+0	3.60-1	9.14+0	3.53-1	8.97+0	3.53-1	8.97+0
		Z	-2.36-1	-5.99+0	-2.64-1	-6.71+0	-2.62-1	-6.65+0	-2.88-1	-7.32+0
		R	4.30-1	1.09+1	4.46-1	1.13+1	4.40-1	1.12+1	4.56-1	1.16+1
3	1.46	X	2.17-2	5.51-1	1.55-3	3.89-2	7.29-3	1.85-1	-1.31-2	-3.33-1
	.66	Y	3.43-1	8.71+0	3.43-1	8.71+0	3.34-1	8.48+0	3.34-1	8.48+0
		Z	-2.28-1	-5.79+0	-2.55-1	-6.48+0	-2.53-1	-6.43+0	-2.79-1	-7.09+0
		R	4.12-1	1.05+1	4.27-1	1.08+1	4.19-1	1.06+1	4.35-1	1.10+1
4	2.33	X	2.13-2	5.41-1	-1.99-3	-5.05-2	6.63-3	1.68-1	-1.50-2	-3.81-1
	1.06	Y	3.64-1	9.25+0	3.64-1	9.25+0	3.54-1	8.99+0	3.54-1	8.99+0
		Z	-2.40-1	-6.40+0	-2.70-1	-6.86+0	-2.66-1	-6.76+0	-2.94-1	-7.47+0
		R	4.36-1	1.11+1	4.53-1	1.15+1	4.43-1	1.13+1	4.60-1	1.17+1
5	3.00	X	2.12-2	5.38-1	-1.24-3	-3.15-2	6.04-3	1.53-1	-1.64-2	-4.11-1
	1.36	Y	3.78-1	9.60+0	3.78-1	9.60+0	3.69-1	9.37+0	3.69-1	9.37+0
		Z	-2.51-1	-6.38+0	-2.82-1	-7.16+0	-2.77-1	-7.04+0	-3.06-1	-7.77+0
		R	4.54-1	1.15+1	4.72-1	1.20+1	4.61-1	1.17+1	4.79-1	1.22+1

TABLE II CONT. DAMAGE TO THE RIGHT SIDE OF HELICOPTER TAIL BOOM CONSTRUCTED OF ALUMINUM ALLOY.

Nomenclature	Material Lost lb/kg	Direction	Grid Point Displacements 67 in.	67 mm	70 in.	70 mm	71 in.	71 mm	72 in.	72 mm
6	3.90	X	2.12-2	5.38-1	-3.25-3	-8.25-2	4.45-3	1.13-1	-1.96-2	-4.98-1
	1.77	Y	4.08-1	1.04+1	4.08-1	1.04+1	4.02-1	1.02+1	4.02-1	1.02+1
		Z	-2.73-1	-6.93+0	-3.04-1	-7.72+0	-3.01-1	-7.65+0	-3.31-1	-8.41+0
		R	4.91-1	1.25+1	5.09-1	1.29+1	5.02-1	1.28+1	5.21-1	1.32+1
7	3.18	X	2.62-2	6.65-1	-6.38-4	-1.62-2	8.04-3	2.04-1	-1.07-2	2.72-1
	1.44	Y	3.51-1	8.92+0	3.51-1	8.92+0	3.03-1	7.70+0	3.03-1	7.70+0
		Z	-2.47-1	-6.27+0	-3.33-1	-8.46+0	-2.74-1	-6.96+0	-3.48-1	-8.84+0
		R	4.30-1	1.09+1	4.84-1	1.23+1	4.09-1	1.04+1	4.62-1	1.17+1
8	4.25	X	2.24-2	5.69-1	4.42-4	1.12-2	7.77-3	1.97-1	-1.10-2	-2.79-1
	1.93	Y	3.53-1	8.97+0	3.53-1	8.97+0	3.03-1	7.70+0	3.03-1	7.70+0
		Z	-2.48-1	-6.30+0	-3.37-1	-8.56+0	-2.76-1	-7.01+0	-3.52-1	-8.94+0
		R	4.32-1	1.10+1	4.88-1	1.24+1	4.10-1	1.04+1	4.65-1	1.18+1

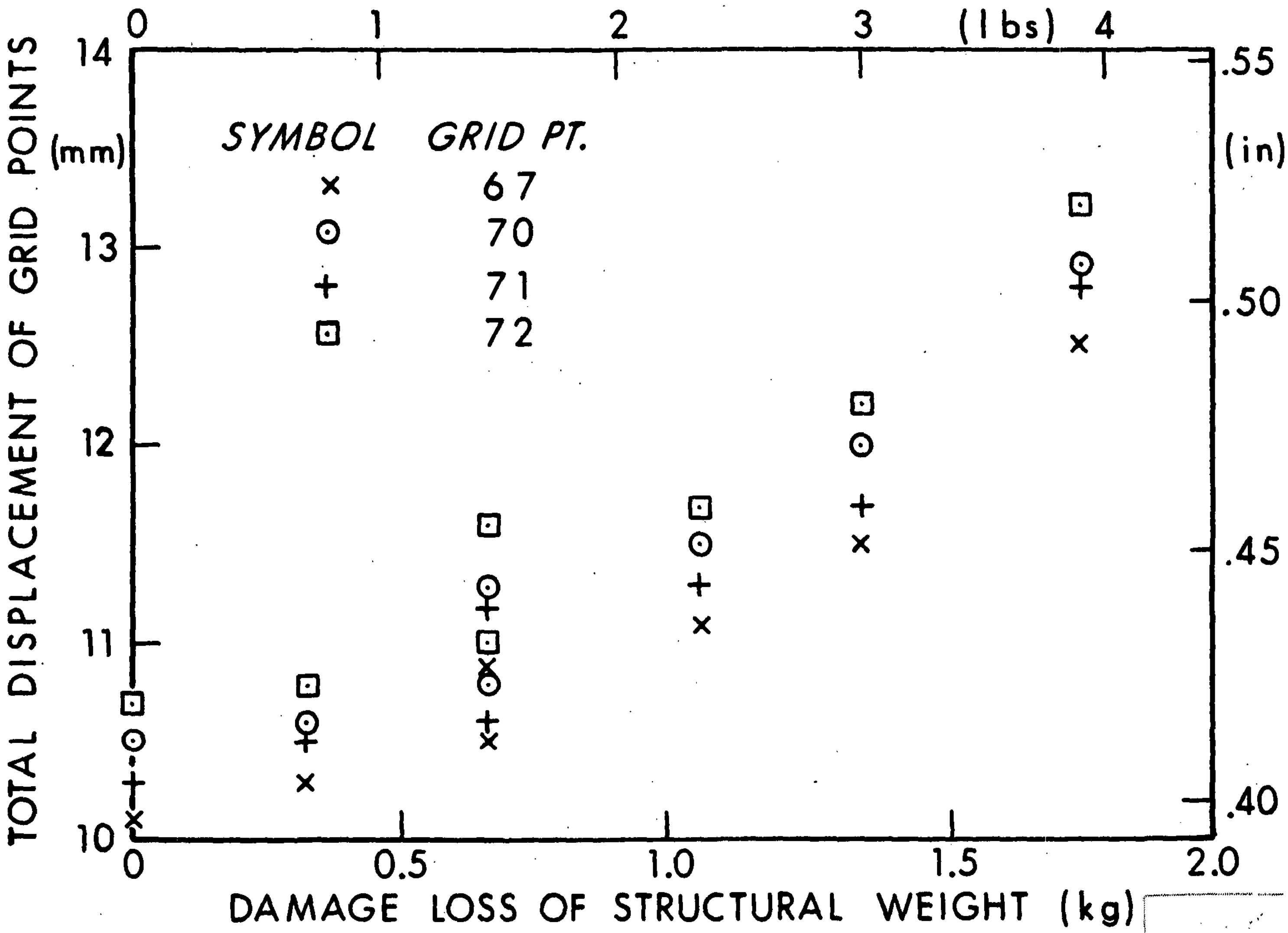

FIGURE 4. GRID POINT DISPLACEMENT VS. DAMAGE LOSS OF STRUCTURAL WEIGHT--ALUMINUM ALLOY CONSTRUCTION

compiled in Table III. Figure 5 is a graph of the relative displacement of points on the rear of the tail boom versus composite material lost through simulated projectile damage to the forward right side. As is to be expected, the non-linear behavior of the curve shows up at lower mass loss due to the lower strength of the material for a given cross-section.

A further consideration is that the tail boom constructed of aluminum alloy had a structural weight of 57.7 kg (127.1 lb) and in the model additional non-structural weight amounting to 24.0 kg (52.9 lb) was distributed along the length of the tail boom. Replacement by the lighter weight composite would result in a weight saving of from 23.1 kg (50.9 lb) up to 32.7 kg (72.0 lb) depending to what extent the aluminum alloy could be replaced by the composite material. This reduction in weight could make the helicopter more maneuverable or able to carry a larger payload. A further consideration is whether use of the more expensive ultra-modulus composite with a modulus almost twice that of T300/5208 and about 50% greater than the aluminum alloy might be warranted. The density of the ultra-modulus graphite/epoxy is only about two percent greater than that of T300/5208.

CONCLUDING REMARKS

The study completed here leaves many questions while providing some answers. Subjects of further study should be to what extent: the loss of structural rigidity of the tail boom can be tolerated; does a composite react to projectile damage better or worse than the aluminum alloy. Can the price differential of the ultra-high modulus composite be tolerated in the construction of the tail boom taking into consideration its much better material qualities?

REFERENCES

1. The NASTRAN User's Manual (Level 17.0),NASA SP-222(04),Dec. 31, 1977, National Aeronautics and Space Agency,Wash., DC

2. Yeghiayan, Raffi P.: Modeling of the UH-1B Tail Boom for Analysis by the NASTRAN Computer Program, ARBRL-CR-00358, Feb. 1978, Kamen AviDyne, Burlington, MA, AD# A052303

3. Duhl, Michael, Air Force Material Laboratory, Wright Patterson Air Force Base, Dayton, OH

TABLE III. DAMAGE TO THE RIGHT SIDE OF HELICOPTER TAIL BOOM CONSTRUCTED OF T300/5208 COMPOSITE.

Nomenclature	Material Lost lb/kg	Direction	Grid Point Displacements 67 in.	67 mm	70 in.	70 mm	71 in.	71 mm	72 in.	72 mm
0	.0	X	2.78-2	7.06-1	2.83-3	7.06-2	9.36-3	2.45-1	-1.56-2	-3.96-1
	.0	Y	4.22-1	1.07+1	4.22-1	1.07+1	4.12-1	1.05+1	4.12-1	1.05+1
		Z	-2.79-1	-7.09+0	-3.17-1	-8.05+0	-3.11-1	-7.90+0	-3.46-1	-8.79+0
		R	5.06-1	1.29+1	5.28-1	1.34+1	5.16-1	1.31+1	5.38-1	1.37+1
1	.43	X	2.77-2	7.04-1	2.28-3	5.79-2	9.17-3	2.33-1	-1.61-2	-4.09-1
	.19	Y	4.29-1	1.09+1	4.29-1	1.09+1	4.19-1	1.06+1	4.19-1	1.06+1
		Z	-2.82-1	-7.16+0	-3.21-1	-8.15+0	-3.15-1	-8.00+0	-3.50-1	-8.89+0
		R	5.13-1	1.30+1	5.35-1	1.36+1	5.24-1	1.33+1	5.46-1	1.39+1
2	.88	X	2.73-2	6.93-1	8.68-5	2.20-3	8.14-3	2.07-1	-1.87-2	-4.75-1
	.40	Y	4.59-1	1.17+1	4.59-1	1.17+1	4.49-1	1.14+1	4.49-1	1.14+1
		Z	-2.97-1	-7.54+0	-3.37-1	-8.56+0	-3.30-1	-8.38+0	-3.68-1	-9.35+0
		R	5.47-1	1.39+1	5.69-1	1.45+1	5.57-1	1.41+1	5.81-1	1.48+1
3	.88	X	2.76-2	7.01-1	1.72-3	4.37-2	9.12-3	2.32-1	-1.66-2	-4.22-1
	.40	Y	4.37-1	1.11+1	4.37-1	1.11+1	4.25-1	1.08+1	4.25-1	1.08+1
		Z	-2.87-1	-7.29+0	-3.28-1	-8.33+0	-3.19-1	-8.10+0	-3.57-1	-9.07+0
		R	5.23-1	1.33+1	5.46-1	1.39+1	5.31-1	1.35+1	5.55-1	1.41+1
4	1.40	X	2.72-2	6.91-1	-3.99-4	-1.01-2	8.37-3	2.13-1	-1.88-2	-4.78-1
	.63	Y	4.63-1	1.18+1	4.63-1	1.18+1	4.50-1	1.14+1	4.50-1	1.14+1
		Z	-3.02-1	-7.67+0	-3.46-1	-8.79+0	-3.34-1	-8.48+0	-3.75-1	-9.53+0
		R	5.53-1	1.40+1	5.78-1	1.47+1	5.60-1	1.42+1	5.86-1	1.49+1
5	1.80	X	2.71-2	6.88-1	-1.67-3	-4.24-2	7.68-3	1.98-1	-2.05-2	-5.21-1
	.82	Y	4.80-1	1.22+1	4.80-1	1.22+1	4.67-1	1.19+1	4.67-1	1.19+1
		Z	-3.14-1	-7.98+0	-3.60-1	-9.14+0	-3.48-1	-8.84+0	-3.97-1	-1.01+1
		R	5.74-1	1.46+1	6.00-1	1.52+1	5.82-1	1.48+1	6.13-1	1.56+1

Table III CONT. DAMAGE TO THE RIGHT SIDE OF HELICOPTER TAIL BOOM CONSTRUCTED OF T300/5208 COMPOSITE.

Nomen-clature	Material Lost lb/kg	Direc-tion	Grid Point Displacements 67 in.	67 mm	70 in.	70 mm	71 in.	71 mm	72 in.	72 mm
6	2.34	X	2.70-2	6.86-1	-4.58-3	-1.16-1	5.39-3	1.51-1	-2.52-2	-6.40-1
	1.06	Y	5.24-1	1.33+1	5.24-1	1.33+1	5.15-1	1.31+1	5.15-1	1.31+1
		Z	-3.46-1	-8.79+0	-3.93-1	-9.98+0	-3.83-1	-9.73+0	-4.26-1	-1.08+1
		R	6.28-1	1.60+1	6.55-1	1.61+1	6.42-1	1.63+1	6.68-1	1.70+1
7	1.91	X	2.87-2	7.29-1	-3.00-5	-7.62-4	1.00-2	2.54-1	-1.39-2	-3.53-1
	.87	Y	4.46-1	1.13+1	4.46-1	1.13+1	3.89-1	9.88+0	3.89-1	9.88+0
		Z	-3.07-1	-7.80+0	-4.13-1	-1.05+1	-3.42-1	-8.69+0	-4.32-1	-1.10+1
		R	5.41-1	1.37+1	6.08-1	1.54+1	5.18-1	1.32+1	5.81-1	1.48+1
8	2.55	X	2.85-2	7.24-1	-5.14-4	-1.32-2	9.64-3	2.45-1	-1.44-2	-3.66-1
	1.16	Y	4.48-1	1.14+1	4.48-1	1.14+1	3.90-1	9.91+0	3.90-1	9.91+0
		Z	-3.10-1	-7.87+0	-4.17-1	-1.06+1	-3.45-1	-8.76+0	-4.37-1	-1.11+1
		R	5.45-1	1.38+1	6.12-1	1.55+1	5.21-1	1.32+1	5.85-1	1.49+1

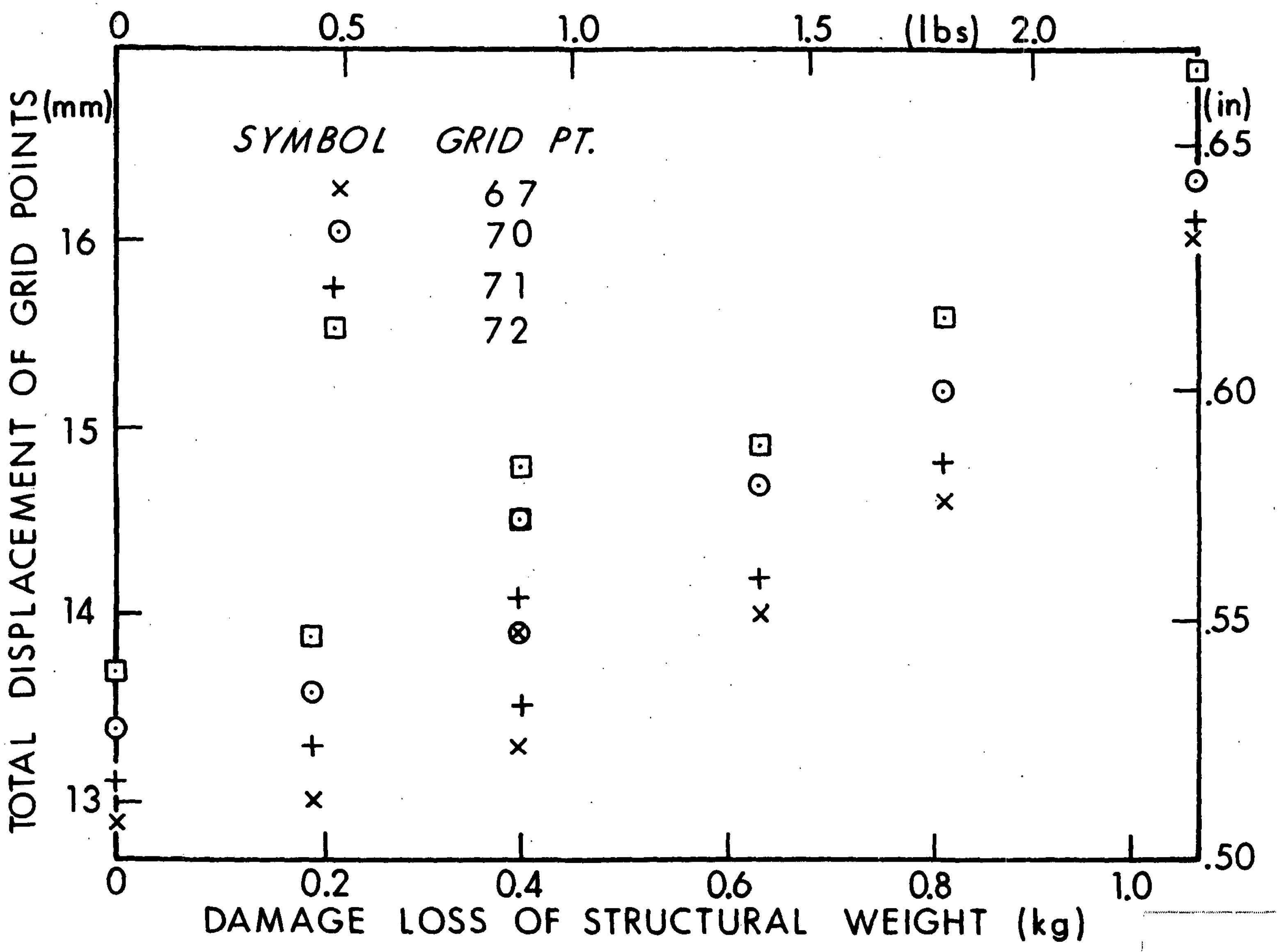

FIGURE 5. GRID POINT DISPLACEMENT VS. DAMAGE LOSS OF STRUCTURAL WEIGHT--T300/5208 COMPOSITE CONSTRUCTION