FINITE ELEMENT ANALYSIS APPLIED TO AVIONICS MOUNT

1989 WORLD USERS CONFERENCE

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I. INTRODUCTION

A MAJOR CONCERN IN THE COMMERCIAL AVIONICS INDUSTRY IS HOW EQUIPMENT THAT IS PLACED THROUGHOUT AN AIRCRAFT, REACTS DURING INFLIGHT CONDITIONS. THIS EQUIPMENT INCLUDES PANEL MOUNTED INSTRUMENTATION, REMOTE RACK MOUNTED BLACK BOXES, AND ANTENNAS THAT ARE MOUNTED ON THE OUTSIDE OF AN AIRCRAFT. ALL OF THE EQUIPMENT IS SUSCEPTIBLE TO A VARIETY OF CONDITIONS: TEMPERATURE, HUMIDITY, SALT, VIBRATION, RAIN, SHOCK, AND ALTITUDE ARE JUST A FEW OF THE ENVIRONMENTAL CONCERNS TO AN AVIONICS ENGINEER IN DESIGNING A PRODUCT.

OTHER DESIGN CONSTRAINTS ARE ALSO PRESENT DEPENDING ON THE MARKET THE AVIONICS IS TARGETED FOR. FOR EXAMPLE, IN THE GENERAL AVIATION MARKET (BUSINESS OR PRIVATELY OWNED AIRCRAFT) SIZE AND WEIGHT OF THE AVIONICS ARE OF PRIMARY CONCERN. OFTEN TIMES, THE AVIONICS MUST BE ARRANGED AND CUSTOM FIT INTO THE NOSE OF AN AIRCRAFT (FIGURES 1 & 2). THESE CONSTRAINTS REQUIRE SPECIAL MOUNTS TO BE DESIGNED TO SUPPORT THE AVIONICS, AND A THOROUGH REVIEW OF STRUCTURAL INTEGRITY MUST BE PERFORMED.

THE GENERAL METHOD OF DESIGN TYPICALLY BEGINS WITH A GOOD "GUESSTIMATE" OF WHAT WILL WORK, USUALLY BASED PARTLY ON PAST DESIGNS, AND SUBSTANTIATED WITH PHYSICAL MODELS BUILT AND TESTED IN ACCORDANCE WITH A DOCUMENT SPECIFIED BY THE FEDERAL AVIATION ADMINISTRATION FOR EN-

VIRONMENTAL REQUIREMENTS (NOTE: DO-160B IS AN RTCA DOCUMENT OFTEN REFERENCED IN FAA REQUIREMENTS). THIS DOCUMENT TRIES TO ENSURE THAT USERS OF AVIONICS BUY EQUIPMENT THAT WILL MEET PREDETERMINED CRITERIA FOR SAFE FLYING. THIS DESIGN PROCESS OFTEN BECOMES VERY TIME CONSUMING AND COSTLY, WITH MULTIPLE ITERATIONS OF PHYSICAL MODEL BUILDING AND TESTING REQUIRED TO MEET THE FAA DOCUMENT REQUIREMENTS. THE LENGTH OF THE PROCESS ADVERSELY AFFECTS PROFIT FOR THE PRODUCER BY INCREASING DESIGN AND MANUFACTURING COSTS, AND JEOPARDIZES ON TIME DELIVERY SCHEDULE OF PRODUCTS.

II. PROBLEM IDENTIFICATION

A "BLACK BOX" (FIGURE 3) IS A COMPUTER, OR AN ELECTRONICS PACKAGE NECESSARY TO RECEIVE, PROCESS, AND RETURN INFORMATION TO THE COCKPIT. THE SPECIFIC PROBLEM ADDRESSED IN THIS PAPER INVOLVES THE DESIGN OF A RACK USED TO MOUNT A BLACK BOX. THE MOUNT UNDER CONCERN INVOLVES A "PIGGYBACK" TYPE OF ARRANGEMENT IN WHICH A SINGLE MOUNT WILL HOUSE TWO BLACK BOXES, ONE ON TOP OF THE OTHER (FIGURE 4). PHYSICAL MODELS OF THESE MOUNTS WERE BUILT AND SUBJECTED TO VIBRATION TESTING IN ACCORDANCE WITH THE DO-160B DOCUMENT, WHICH REQUIRES SINUSOIDAL INPUT TO EACH AXIS OF THE MOUNT. THE MOUNTS PASSED THE SINE TESTS WITHOUT FAILURE. SINCE THE SINE TESTS ARE CONSIDERED MINIMUM REQUIREMENTS, THE UNITS WERE SUBJECTED TO RANDOM VIBRATION WHICH EXCEEDED THE DO-160B CRITERIA. THIS RANDOM TESTING ALSO SIMULATES ACCELERATED LIFE TESTING FOR FATIGUE. WHEN THIS TEST WAS APPLIED TO THE LATERAL AXIS, YIELDING OF THE FRONT BRACKET, OCCURRED IN THE AREA AROUND THE BEND RELIEF NECESSARY FOR SUPPORTING THE LOWER BOX IN THE MOUNT (FIGURE 5).

SINCE THE MOUNTS DID INDEED PASS THE CONDITIONS NECESSARY TO MEET THE DO-160B REQUIREMENTS, THE BRACKET DESIGN COULD HAVE BEEN RELEASED FOR PRODUCTION WITHOUT CHANGE. THE TASK OF MODIFYING THE DESIGN, BUILDING PROTOTYPES, AND RETESTING IN VIBRATION WOULD BE A TIME CONSUMING AND COSTLY PROCESS IN THIS CASE. REALIZING THAT

SOME GAIN WAS POSSIBLE, HOWEVER, AND HAVING IDENTIFIED SEVERAL POTENTIAL IMPROVEMENTS, IT WAS DESIRABLE TO IMPROVE THE STRUCTURE WITHOUT THIS LENGTHY PROCESS , WHILE MAINTAINING INTEGRITY AND CONFIDENCE IN THE RESULTS. THEREFORE, FINITE ELEMENT ANALYSIS (MSC-pal2) WAS USED TO ANALYZE THE BRACKET IN AN EFFICIENT AND ECONOMICAL FASHION.

III. MODEL BUILDING

THE MOUNT WAS SIMPLIFIED TO MODEL ONLY THE CRITICALLY STRESSED FRONT BRACKET. A COMBINATION OF QUADRILATERAL AND TRIANGULAR PLATES WERE USED TO MODEL THE STRUCTURE (FIGURES 6 THROUGH 9). IN CONJUNCTION WITH THE RESPONSE CURVES OBTAINED DURING VIBRATION TESTING, BOUNDARY CONDITIONS, STIFFENERS AND MASSES WERE APPLIED WHERE APPROPRIATE IN ORDER TO MATCH THE NATURAL FRQUENCY OF ACTUAL TESTS TO THE MODEL. IN ADDITION, A FREQUENCY SWEEP AROUND THE FIRST MODE, SHOWED THAT THE HIGHEST STRESS EXISTED IN THE ELEMENT WHICH EXACTLY CORRESPONDED TO THE AREA OF FAILURE DURING ACTUAL TESTING. FURTHER REVIEW OF THE DISPLACEMENT AMPLITUDES SHOWED G-FACTORS AROUND RESONANCE TO CORRESPOND WITHIN 20% OF ACCELEROMETER READINGS DURING TESTING. SOME DIFFERENCE COULD BE EXPECTED UPON REVIEW OF THE TEST SETUP (FIGURE 10), SINCE THE ACCELEROMETER WAS ACTUALLY PLACED ON THE UNIT RATHER THAN THE MOUNT. THIS CREATED AN ACCEPTABLE MODEL FOR EVALUATING POTENTIAL IMPROVEMENTS USING MSC/pal2.

IV. TESTING IMPROVEMENTS

THE POTENTIAL IMPROVEMENTS AND THE RESULTS FROM MSC/pal2 ARE AS FOLLOWS:

MOD 1

THE FIRST ATTEMPT AT IMPROVING THE STRUCTURE INVOLVED ADDING "FEET", LIKE SUPPORTS, TO THE SIDES OF THE BRACKET (FIGURE 11). THIS TYPE OF SUPPORT IS COMMON TO SIMILAR TYPES OF MOUNTS. MSC/pal2 SHOWED AN INCREASE IN THE FIRST MODE BY SEVEN HERTZ, AND A REDUCTION OF MISES STRESS IN THE AREA OF FAILURE BY 24%.

MOD 2

THIS MOD, AGAIN TAKEN FROM THE DATUM VERSION, INCORPORATED WELDED ANGLE SUPPORTS EXTENDING FROM THE SIDES OF THE BRACKET TO THE LOWER BOX SUPPORT (FIGURE 12). THIS RAISED THE NATURAL FREQUENCY BY APPROXIMATELY SEVEN HERTZ AND LOWERED THE MISES STRESS ON THE CRITICAL ELEMENT BY 28%.

MOD 3

MOD 3 INCREASED STIFFNESS TO THE DATUM VERSION BY CONVERTING FROM L-SHAPED TO U-SHAPED SIDES (FIGURE 13). THE FIRST MODE WAS INCREASED BY FOUR HERTZ, WITH REDUCED MISES STRESS ON THE CRITICAL ELEMENT OF 22%.

MOD 4

THIS IMPROVEMENT COMBINED THE MODS OF WELDED ANGLE SUPPORTS (MOD 2) WITH THE U-SHAPED SIDES (MOD 3) (FIGURE 14). THE RESULTANT WAS AN EIGHT HERTZ INCREASE IN NATURAL FREQUENCY AND 33% REDUCTION OF MISES STRESS OVER THE DATUM VERSION OF THE STRUCTURE.

MOD 5

THE HIGHEST STRESSED ELEMENT EXISTED IN THE BEND RELIEF NECESSARY FOR THE LOWER BOX SUPPORT. THEREFORE, MOD 5 WAS A REVIEW OF THE MAXIMUM RADIUS THAT THE DESIGN COULD ALLOW IN THAT AREA. THIS RESULTED IN A CHANGE FROM .050 TO .070 RADII FOR ANALYSIS (FIGURE 15). THE DYNAMIC ANALYSIS SHOWED LITTLE EFFECT ON NATURAL FREQUENCY BUT DID SHOW A 9% DECREASE IN MISES STRESS ON THE CRITICAL ELEMENT.

MOD 6

THE FINAL ATTEMPT AT IMPROVING THE DESIGN INVOLVED COMBINING THE MODS OF WELDED ANGLE SUPPORTS (MOD 2), U-SHAPED SIDES (MOD 3), AND AN .070 RADII (MOD 5) (FIGURE 16). THE FIRST MODE WAS INCREASED BY EIGHT HERTZ FROM THE DATUM VERSION AND THE STRESS LEVEL DECREASED BY A TOTAL OF 39%.

V. CONCLUSION

THE ANALYSES PROVED TO BE A VIABLE ALTERNATIVE FOR DETERMINING THE EFFECT OF POTENTIAL DESIGN CHANGES, WITHOUT AFFECTING PRODUCT DESIGN SCHEDULE. IT ELIMINATED THE NEED FOR PHYSICAL TESTING, WHILE MAINTAINING A DEGREE OF CONFIDENCE IN THE RESULTS. THE BASELINE MODEL USED FOR MODEL VERIFICATION IS A VERY IMPORTANT AND NECESSARY STEP OF THIS PROCESS IN ORDER TO ATTAIN CONFIDENCE IN THE RESULTS. FINITE ELEMENT ANALYSIS IS PARTICULARILY SUITED FOR THE DEVELOPMENTAL STAGES OF PRODUCT DESIGN AND THE EARLY STAGES OF PRODUCTION, WHEN CHANGES AND OUTCOMES MUST BE DETERMINED QUICKLY AND COST EFFECTIVELY.

FIGURE 1

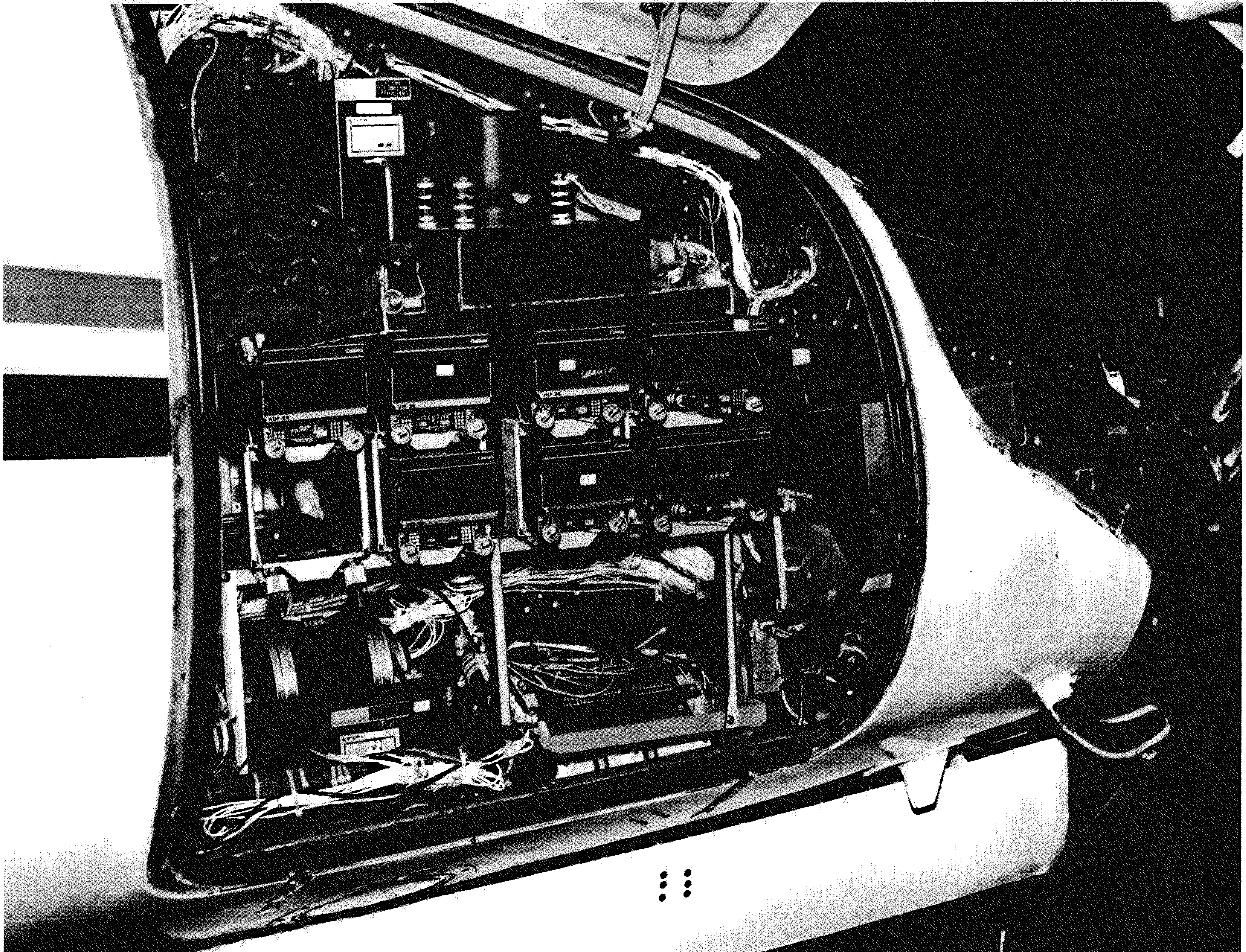


FIGURE 2

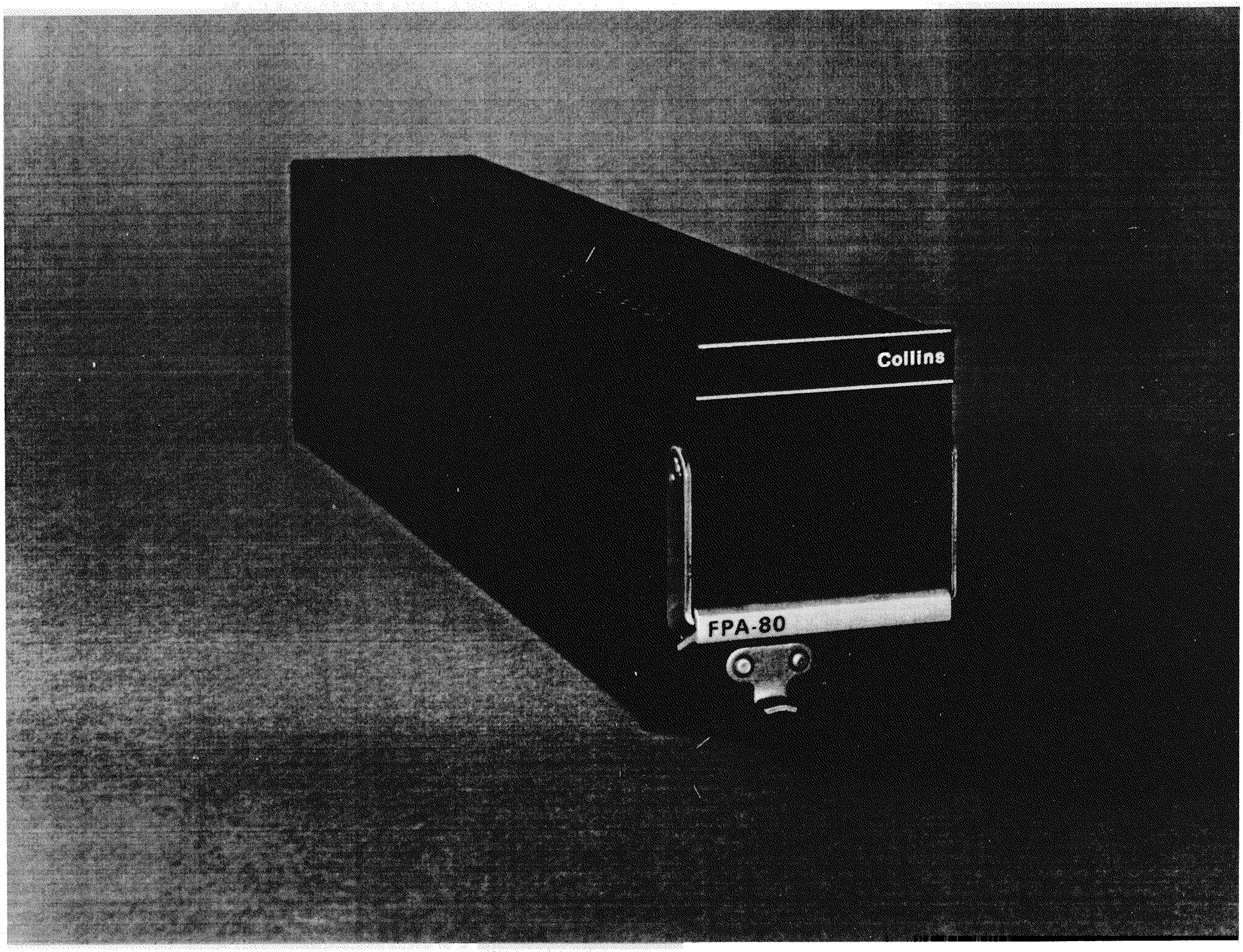
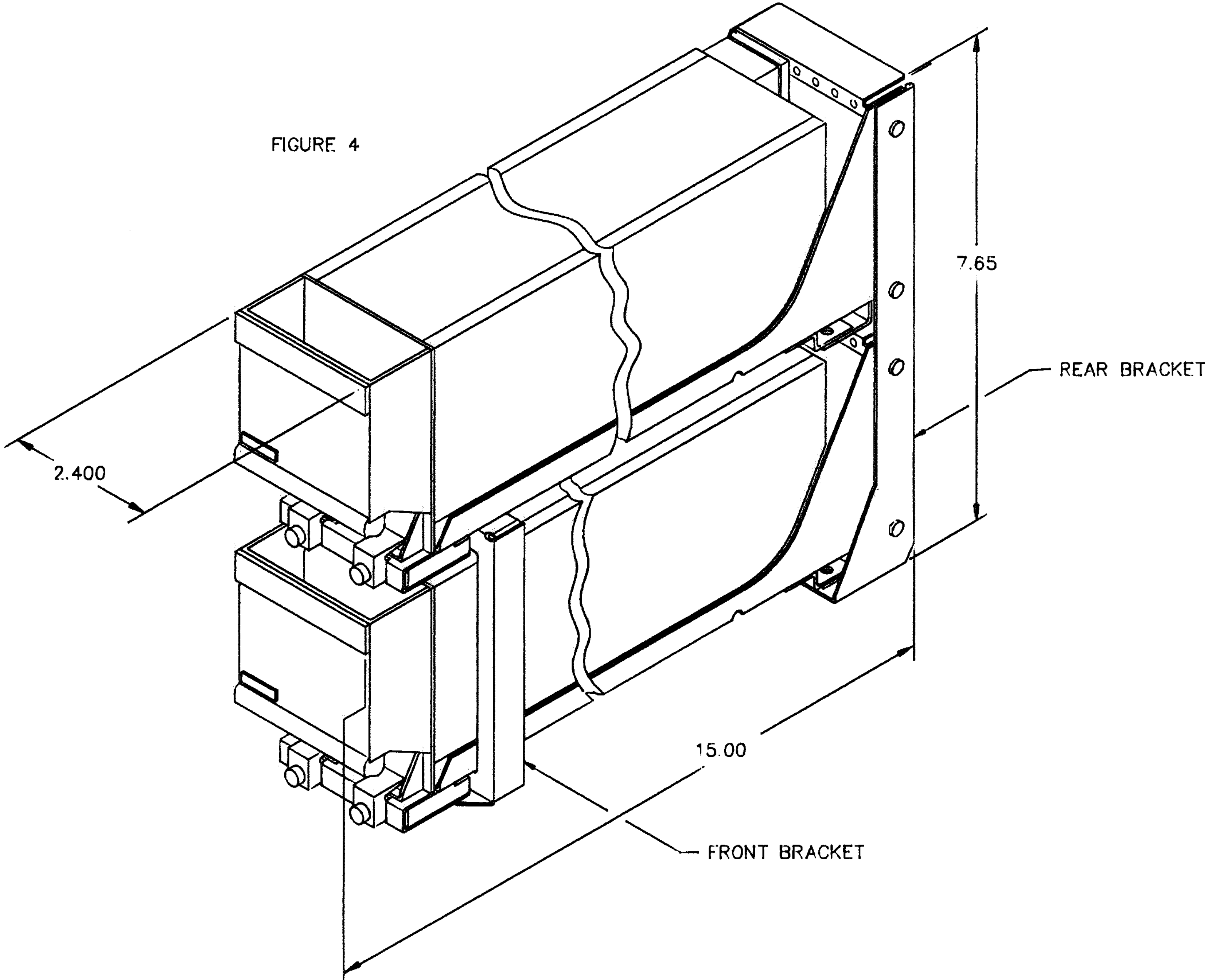


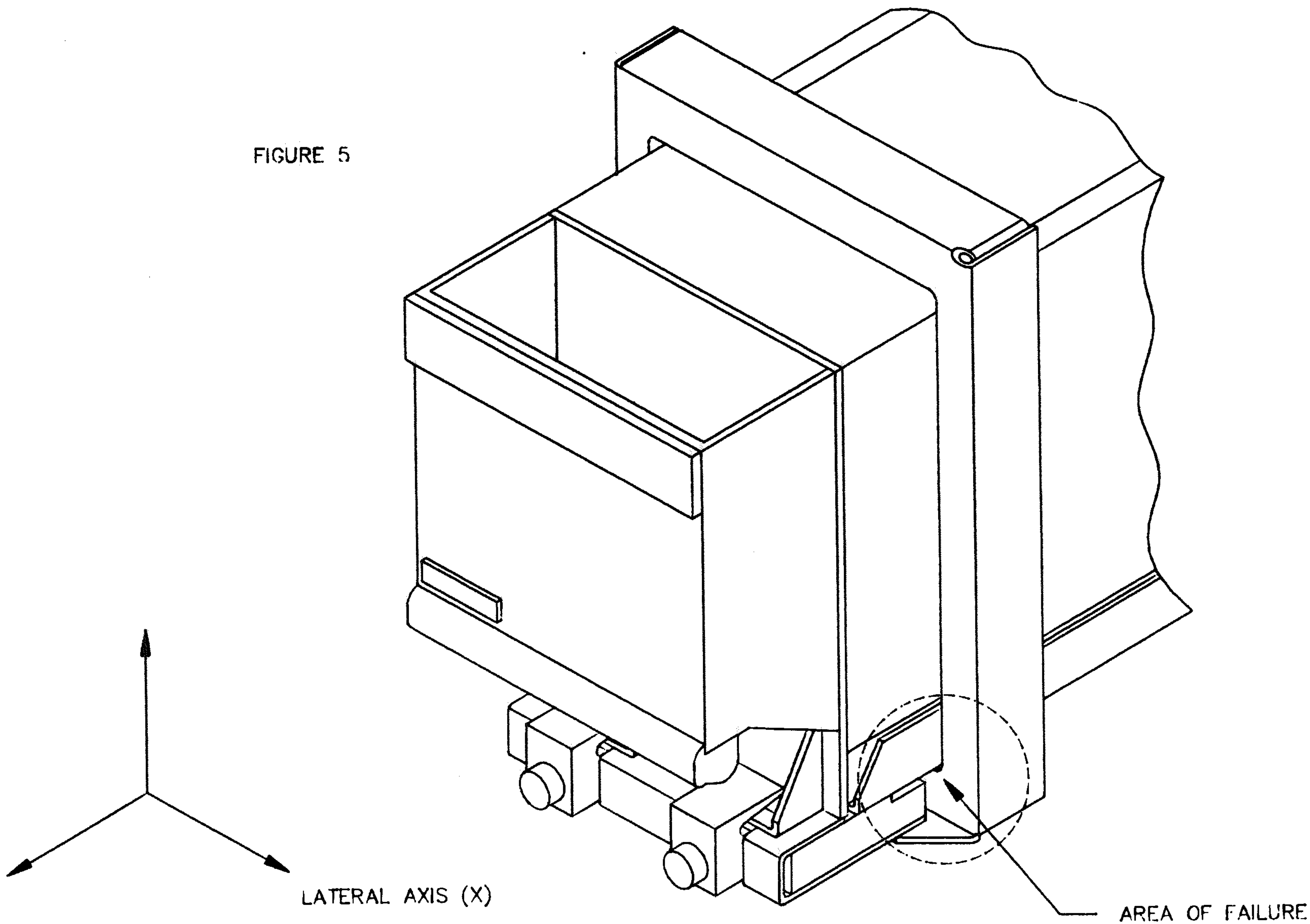
FIGURE 3

FIGURE 4



PIGBAKMT.DWG
DISC #1001

FIGURE 5



BRCKFAIL.DWG

FIGURE 6

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TITLE-FRONT BRACKET
C THIS MODELS THE BRACKET AS THE ORIGINAL DESIGN, TO BE USED AS A DATUM FOR
C PREDICTING STRUCTURAL BEHAVIOR OF POTENTIAL DESIGN IMPROVEMENTS.
C
NODAL POINT LOCATIONS 1
1 0 0 0 THRU 11 3.135 0 0
12 0 .3057 0 THRU 22 3.135 .3057 0
23 0 3.9743 0 THRU 33 3.135 3.9743 0
34 0 4.28 0 THRU 44 3.135 4.28 0
45 0 .6114 0 THRU 55 0 3.6686 0
56 .3135 .6114 0 THRU 66 .3135 3.6686 0
67 2.8215 .6114 0 THRU 77 2.8215 3.6686 0
78 3.135 .6114 0 THRU 88 3.135 3.6686 0
89 .3135 0 .550 THRU 97 2.8215 0 .550
98 3.135 0 -.560 THRU 112 3.135 4.28 -.560
113 0 0 -.560 THRU 127 0 4.28 -.560
128 .627 .4 0 THRU 134 2.508 .4 0
136 .627 .4 -.560 THRU 142 2.508 .4 -.560
145 .3135 4.280 -.560 THRU 153 2.8215 4.28 -.560
135 .4075 .4 0
143 2.7275 .4 0
155 .4075 .4 -.560
156 2.7275 .4 -.560
157 .3135 .4 0
158 .3175 .3279 0
159 .3355 .3099 0
160 .3605 .3057 0
161 .3855 .3099 0
162 .4035 .3279 0
163 2.8215 .4 0
164 2.8175 .3279 0
165 2.7995 .3099 0
166 2.7745 .3057 0
167 2.7495 .3099 0
168 2.7315 .3279 0
169 .4075 .3057 0
170 2.7275 .3057 0
171 .3135 4.280 -1
172 2.8215 4.280 -1
173 .3135 .35 0
174 .4075 .35 0
175 2.7275 .35 0
176 2.8215 .35 0

MATERIAL PROPERTIES 29E6 0 7.33E-4 .287 175000
QUADRILATERAL PLATE TYPE 1 1 .050
DO CONNECT 3 14 15 4 THRU 8 19 20 9
DO CONNECT 23 34 35 24 THRU 32 43 44 33
DO CONNECT 115 116 46 45 THRU 122 123 53 52
DO CONNECT 78 79 101 100 THRU 85 86 108 107
DO CONNECT 45 46 57 56 THRU 54 55 66 65
DO CONNECT 67 68 79 78 THRU 76 77 88 87
DO CONNECT 35 36 146 145 THRU 42 43 153 152
```

FIGURE 7

```
CONNECT 113 1 12 114
CONNECT 114 12 45 115
CONNECT 11 98 99 22
CONNECT 78 22 99 100
CONNECT 55 23 24 66
CONNECT 77 32 33 88
CONNECT 1 12 13 2
CONNECT 10 11 22 21
CONNECT 2 169 14 3
CONNECT 20 170 10 9
DO CONNECT 89 90 3 2 THRU 96 97 10 9
DO CONNECT 128 136 137 129 THRU 133 141 142 134
DO CONNECT 128 14 15 129 THRU 133 19 20 134
CONNECT 135 155 136 128
CONNECT 142 134 143 156
CONNECT 127 145 35 34
CONNECT 153 112 44 43
TRIANGULAR PLATE TYPE 1 1 .050
CONNECT 1 2 89
CONNECT 11 97 10
CONNECT 173 158 13
CONNECT 158 159 13
CONNECT 159 160 13
CONNECT 160 161 169
CONNECT 161 162 169
CONNECT 162 174 169
CONNECT 175 168 170
CONNECT 168 167 170
CONNECT 167 166 170
CONNECT 166 165 21
CONNECT 165 164 21
CONNECT 164 176 21
CONNECT 135 128 14
CONNECT 134 143 20
CONNECT 45 56 157
CONNECT 45 157 12
CONNECT 67 78 163
CONNECT 163 78 22
CONNECT 13 12 173
CONNECT 12 173 157
CONNECT 169 174 14
CONNECT 135 174 14
CONNECT 170 175 20
CONNECT 20 175 143
CONNECT 163 176 22
CONNECT 176 21 22
CONNECT 2 13 160
CONNECT 2 160 169
CONNECT 10 170 166
CONNECT 166 21 10
QUADRILATERAL PLATE TYPE 1 1 .100
CONNECT 126 127 34 23
CONNECT 125 126 23 55
CONNECT 124 125 55 54
CONNECT 123 124 54 53
```

FIGURE 8

```
CONNECT 33 44 112 111
CONNECT 88 33 111 110
CONNECT 87 88 110 109
CONNECT 86 87 109 108
STIFFNESS ELEMENT 5000 0 0 0 0 0
CONNECT 145 TO 171
CONNECT 153 TO 172
MASS 131 .005661
MASS 36 .005661
MASS 38 .005661
MASS 42 .005661
ZERO 1
TZ 2 10 89 97
TY 2 10 89 97
RA 2 10 89 97
ALL 171 172

ACTIVATE 11
TA 136 THRU 142 STEP 2
TA 146 THRU 152 STEP 2
TA 128 THRU 134 STEP 2
TA 36 THRU 42 STEP 2
TA 157 THRU 162
TA 169 THRU 170

ACTIVATE 1
TA 13 15 20 22 24 32 33 58 70 72 82 46 48
TX 2 10 89 97

END DEFINITION
```

2½" Troy MECHANICAL MOTION (MM) FIGURE 10

VERTICAL

EQ RANGE		START	STOP	TOTAL	INIT	DATE
500-5 HZ		1458	1558	1 Hr	[illegible]	5-19-88
IN	OUT					

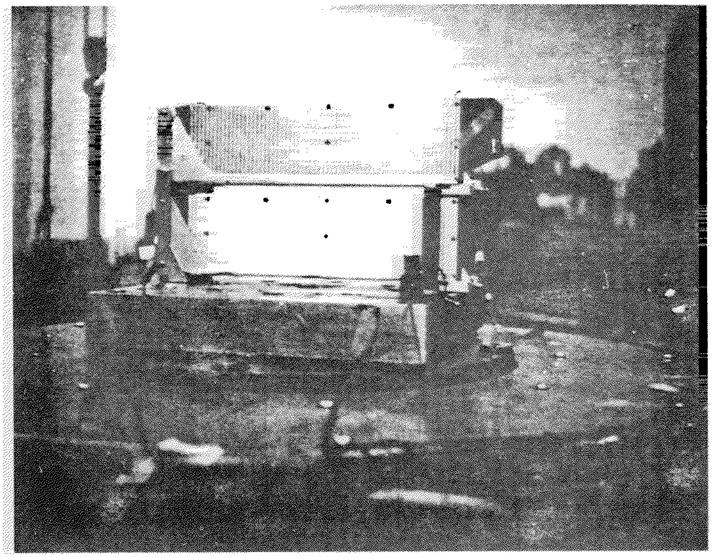
HORIZONTAL

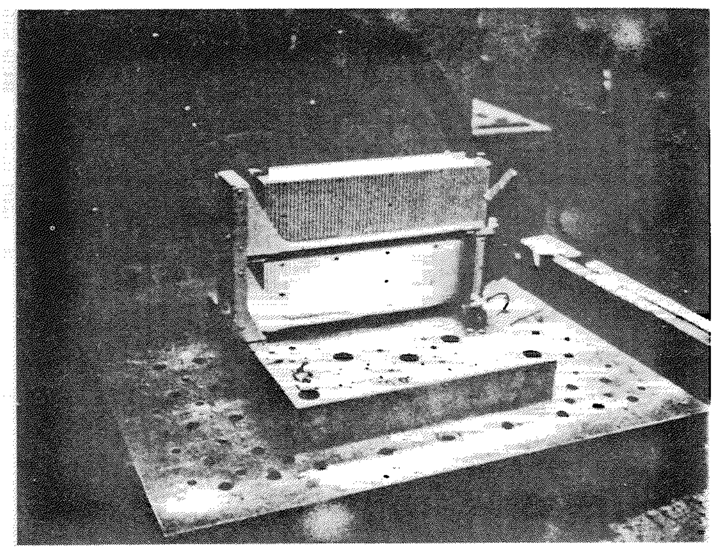
EQ RANGE		START	STOP	TOTAL	INIT	DATE
2000-5 HZ		1256	1356	1 hr	[illegible]	5-19-88
2000-5 HZ		1622	1722	1 hr	[illegible]	5-19-88
3.89 grms		0736	0836	1 hr	[illegible]	5-20-88
IN	OUT					

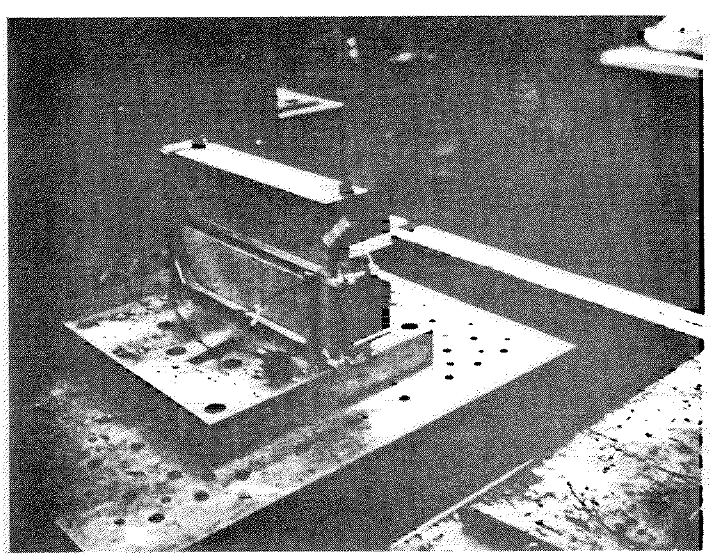
LONGITUDE

EQ RANGE		START	STOP	TOTAL	INIT	DATE
2000-5 HZ		1100	1200	1 hr	[illegible]	5-19-88
2000-5 HZ		1730	1830	1 hr	[illegible]	5-19-88
3.89 grms		1842	1942	1 hr	[illegible]	5-19-88
IN	OUT					

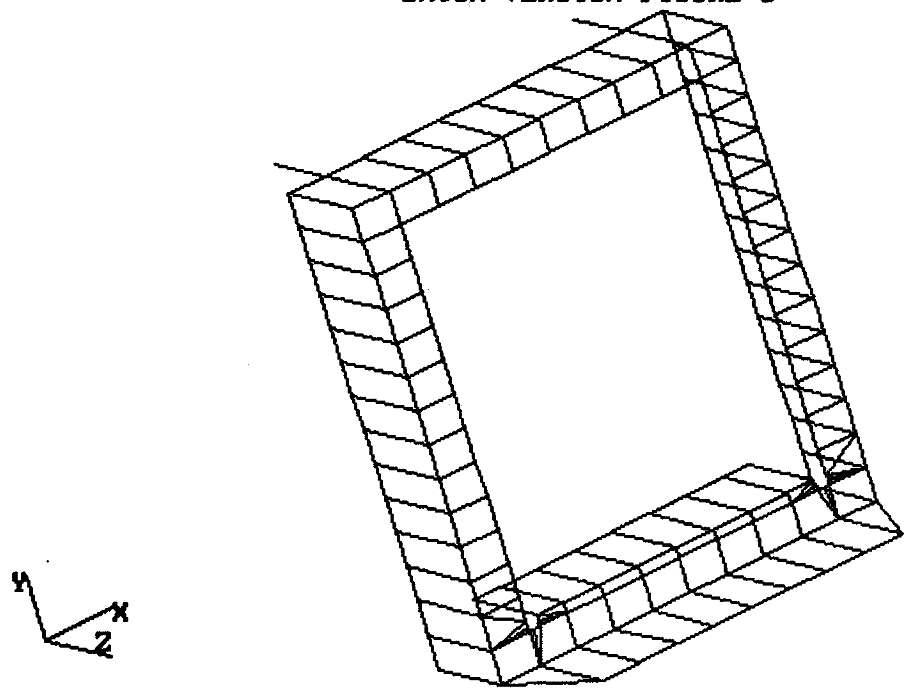
SHOCK/CENTRIFUGE



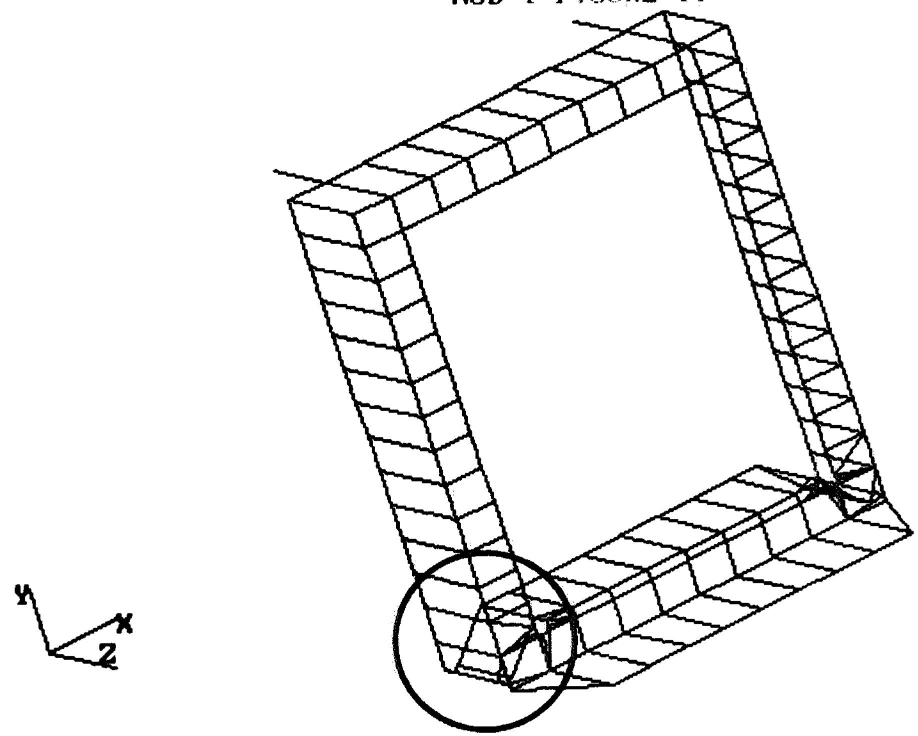




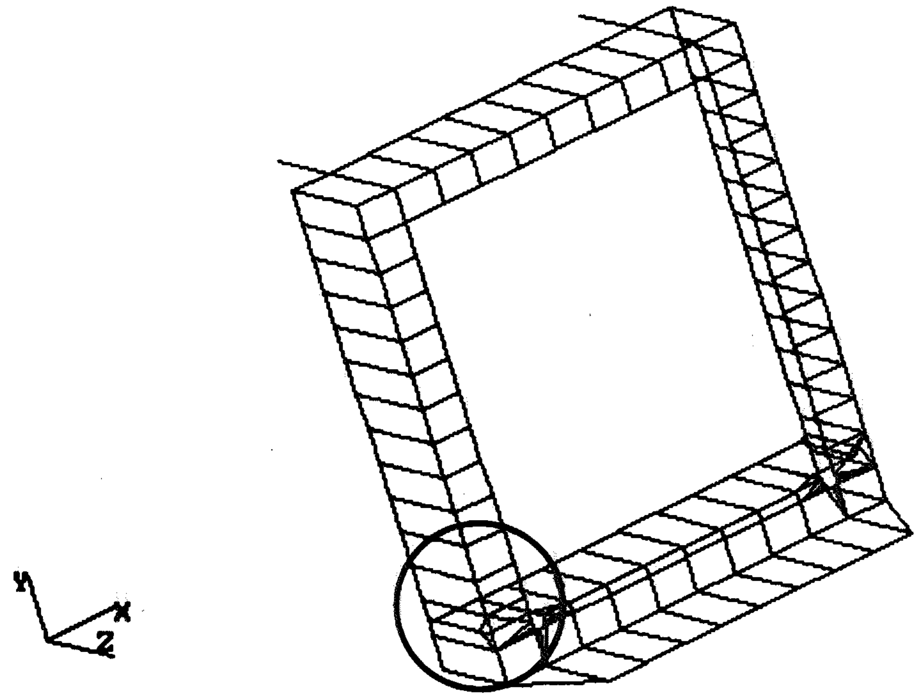
DATUM VERSION-FIGURE 9



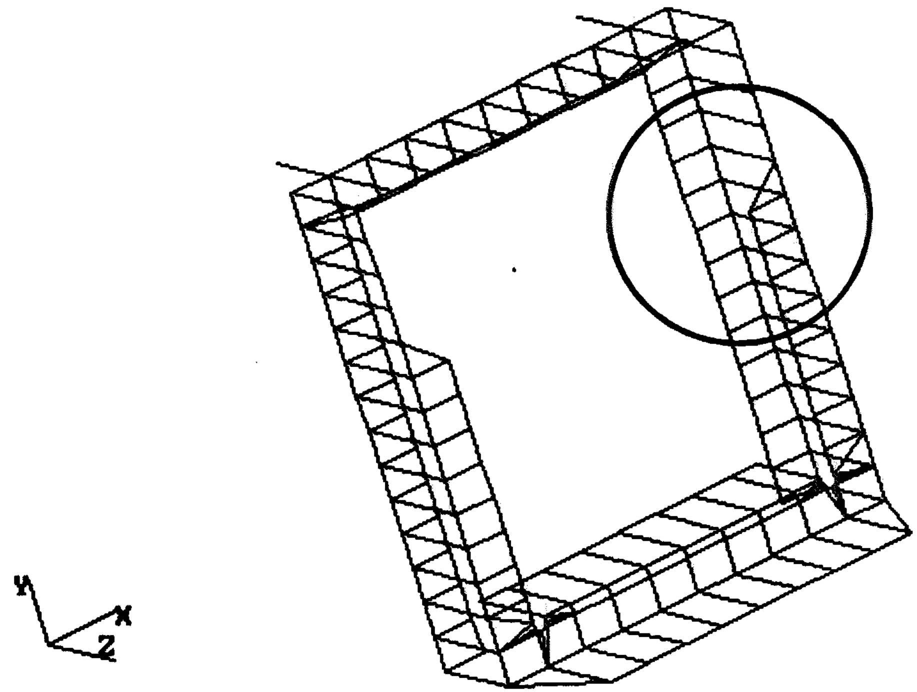
MOD 1-FIGURE 11



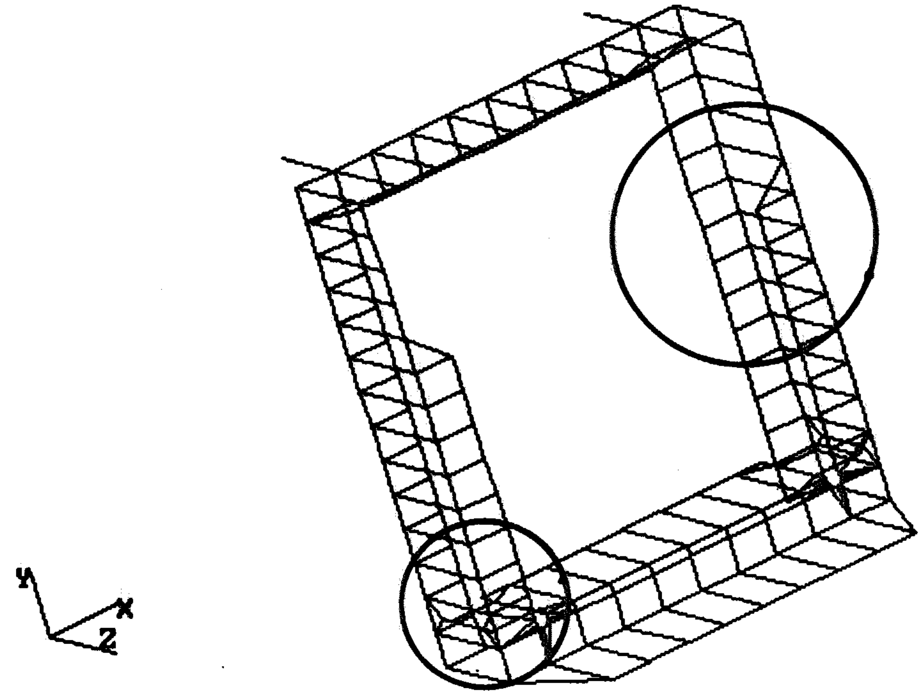
MOD 2-FIGURE 12



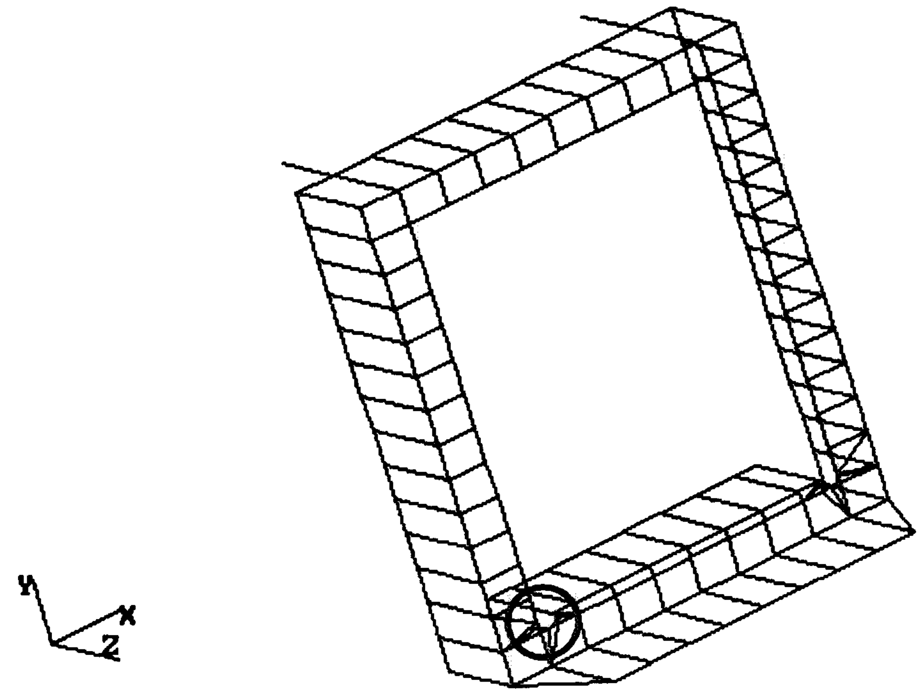
MOD 3-FIGURE 13



MOD 4-FIGURE 14



MOD 5-FIGURE 15



MOD 6-FIGURE 16