MODIFICATION
of
INTEGRATED PARTIAL PAYLOAD LIFTING ASSEMBLY

FINAL REPORT

(NASA-CR-182573) MODIFICATION OF INTEGRATED PARTIAL PAYLOAD LIFTING ASSEMBLY Final Report (University of Central Florida)
30 p CSCL 22B Unclas
N88-18667 G3/15 0128718

Submitted to:
DR. ANDERSON
EML 4505
FALL 1986

Submitted by:
MELODIE GROAH
MICHAEL HADDUCK
WARREN WOODWORTH
The Integrated Partial Payload Lifting Assembly (IPPLA) is currently used to transport and load experimental payloads into the cargo bay of the Space Shuttle. It is unable to carry the astronaut/passenger tunnel without a structural modification. The purpose of this student design is to create a removable modification that will allow the IPPLA to lift and carry the passenger tunnel. Modifications evaluated were full-length insert beams which would extend throughout the existing strongback arms. These beam proposals were eliminated because of high cost and weight. Other proposals evaluated were attachments of cantilever beams to the existing strongback arms. The cantilever proposals reduced cost and weight considerably compared to the full-length modifications. A third method evaluated was to simply make modifications to one side of the IPPLA therefore reducing the materials of the cantilever proposals by 40 percent. The design of the modification selected was completed with two channel beams jointly welded to a centered steel plate. All welds between the channels and the steel plate are made at the channels' opened ends. The extension arm modification is inserted into the existing strongback channel beams and
bolted into place. Two extension arms are added to one side of the IPPLA to provide the extra length needed to accommodate the passenger tunnel. The center counterbalance will then be offset about 20 inches to center gravity and therefore maintain horizontal status. This horizontal status is a necessity for proper loading of the astronaut tunnel. The extension arm modification was selected because of minimum cost, low weight, and minimal installation time.
# TABLE OF CONTENTS

- Executive Summary ................................................................. xxx

- Table of Contents ................................................................. 1

- List of Figures & Tables ............................................................ 2

- Technical Report ........................................................................... 3
  - Introduction .................................................................................. 3
  - Determining Means ....................................................................... 4
  - Solution Optimization ................................................................. 7

- References & Acknowledgements .................................................. 11

- Figures (1-9) .................................................................................. 12

- Tables (1 & 2) ................................................................................ 13

- Appendix A (Computer Program) .................................................... 14

- Appendix B (Computer Results) ...................................................... 15
List of Figures & Tables

FIGURES:

Fig.1: Full Length Solid or Channel Proposal..................12A
Fig.2: Worm Gear Mechanism......................................12A
Fig.3: I-beam Attachment............................................12A
Fig.4: Cantilever Insertion w/ Cables..........................12B
Fig.5: Hinged Cantilever w/ Cables...............................12B
Fig.6: Sleeve/Insertion Cantilever (3-D).........................12C
Fig.7: Hinged/Cable Cantilever (3-D)............................12D
Fig.8: Channel Insert (3-D).........................................12E
Fig.9: Bolt Configuration and Dimensions......................12F

TABLES:

Table 1: Solution Flowchart........................................13A
Table 2: Proposal Advantage/Disadvantage Chart...............13B
INTRODUCTION

The National Aeronautics and Space Administration (NASA) has supplied a request to increase lifting capability of the Integrated Partial Payload Lifting Assembly (IPPLA). The device, at this time, successfully serves as a lifting medium by which actual payloads are loaded into the cargo bay of the U.S. Space Shuttle. The basic need of this entire project is to make IPPLA completely universal. Currently, the function of IPPLA, also referred to as the "white whale", is limited because it is incapable of lifting the astronaut tunnel that leads from the crew cabin to the cargo bay. The device that NASA presently uses to load the astronaut tunnel is referred to as a strongback. In order to use the strongback, NASA must use three engineers, twelve technicians, and two crane crews. NASA wishes to use the white whale which would only require one engineer, four technicians, and one crane crew. The white whale would also do the job in a fraction of the time that the strongback could. The strongback requires two working days or sixteen hours to do the job whereas the white whale could complete the job in two hours.(Ref. 1)

The white whale will have to be modified with
removable parts in order to accommodate the passenger tunnel and still continue to do the job it was designed to do, which is to load pallets and Mission Peculiar Experiment Support Structures (MPESS) containing space-bound experiments. In short, modification to the design problem will save NASA fourteen working hours, reduce manpower by twelve and at an average pay of about $30/hr will save $5040/loading of the passenger tunnel. (Ref.1)

DETERMINING MEANS

The following ideas all serve as probable solutions to the modification of IPPLA. All modifications are being directed toward the lowermost portion of the white whale known as the strongback channel beam. Modification ideas cover a range that varies from the insertion of solid symmetric beams to the coupling of an asymmetric square beam sleeve.

The IPPLA solutions have been categorized into two main groups: full-length and cantilever beams. The full-length beams extend throughout the entire length of the strongback channel whereas the cantilever beams only extend through a portion of the channel. (Table 1)

The four proposed solutions in the full-length beam
category show the greatest strength of all other designs, but the drawbacks are the cost, weight and size. One proposed solution is a solid beam which exhibits the highest strength but also has the highest cost and weight. (Fig. 1) The disadvantage of weight and size would affect installation, portability and labor cost. An improvement on the design above leads us to the proposal of full-length channel beams which could decrease weight by 78.5% and therefore dramatically decrease cost at $0.75/lb of steel. (Ref. 1) The I-beam and worm gear are simple modifications to the previous two designs. The worm gear mechanism (Fig. 2) is used in a hand cranking fashion to stabilize the inserted beam which would improve installation and stability. (Ref. 2) As an alternative, an I-beam design (Fig. 3) was proposed that would distribute the tunnel load over the top of the modified extensions, therefore relieving a portion of the load on the securing bolts. Even though the modifications in this group could successfully solve our problem, further study has shown that other proposals will yield even better results.

The second of the two solution groups is that of cantilever beams. Two divisions within this group have been termed symmetric and asymmetric. All symmetric designs will not offset IPPLA’s center of gravity. The asymmetric modifications will require use of the existing
counterweights to balance the lifting assembly.

The symmetric subgroup contains five proposals. First, hinged extensions with the addition of supporting cables (Fig. 5) was considered because of its portability and weight. Second, a simple insertion of cantilever beams with the use of cables (Fig. 4) may increase strength over the hinged mechanism but it would also increase weight. By eliminating the support cable, cost would decrease slightly with minimal strength lost. The third and fourth modifications could be accomplished by insertion of channel or solid cantilever beams. The channel insertion proves to be dominant due to relatively low weight and cost. A fifth but similar solution is that of a square beam sleeve which would slide over the existing arms of the strongback channel beam. Advantages of the square sleeve include a close fit over the strongback channel beams and an increased moment of inertia resulting in lower stress. (Ref. 3) Once again, the modifications of the symmetric cantilever subgroup are a great improvement over the full-length beams, yet one final group offers even greater appeal.

The final group of proposals consists of the asymmetric designs. The asymmetric designs are exactly the same as the symmetric, with the exception of length dimensions. The asymmetric designs require presetting of
the center counterweight on the main frame because modifications will be made to one side of the IPPLA only.

The advantages and disadvantages of each proposal are weighed in Table 2. The full-length beam proposals have been eliminated due to excessive cost and weight. The symmetric cantilever beams will remain as adequate solutions to the problem, yet advantages of the asymmetric solutions appear to be optimal.

SOLUTION OPTIMIZATION

The two most probable solutions to the modification of IPPLA are the sleeve/insert cantilever (Fig. 6) and the hinged/cable cantilever (Fig. 7). Both designs have been selected because of reduced cost, weight, and installation time over all previously mentioned designs. Above all, the advantage of asymmetric design prevails because strength can be maintained while the amount of building material has been reduced by 40%.

Further insight into the hinged proposal shows complications within the hinged mechanism itself. The hinge would have to be tooled from a single billet of structural steel or it would have to be made of materials exhibiting the properties of titanium. The process of wroughting out the hinge from a steel billet is an
expensive process. (Ref. 1) Titanium exhibits high strength-to-weight ratio and excellent corrosion resistance but high cost of manufacturing products and extracting from their ores rules out this possibility. (Ref. 4) Due to the hinge's disadvantages, the sleeve/insert beam is preferable. (Fig. 8).

By inspection of Figs. 8 & 9, it can be seen that the chosen design meets the requirement of being removable. A total of six bolts, which provides easy installation with minimal labor, will secure the entire modification to IPPLA. The distance between the supporting rods has to be exactly 121.93 inches to accommodate the passenger tunnel. All geometric dimensions have been accounted for and can be seen in both reference figures 10 & 11. The center of gravity of the entire assembly when loaded is maintained by adjusting the center counterbalance 21 inches to offset the modification. A safety factor of five has been used to ensure safe loading conditions. The complete design has been produced by using a multiple of five times the working weight of the astronaut tunnel or 12,500 pounds. All measures have been taken to meet the above conditions, thus the result shows promise for an optimal solution.

The optimal solution to the design consists of two, forty inch channel beams with a 12 x 24 x 1 inch structural steel plate welded to the open end of the beams. The welds
should conform to Kennedy Space Center-Spec-Z-0004, class B. (Ref. 5) The steel plate serves as a mount for the main rod assembly. Only sixteen inches of the total modification will be inserted into the existing strongback channel beams. The American Standard Channel beam for this optimal design is a C7 x 9.8, which will require only five hundredths of an inch machining to fit into the existing strongback channel. (Ref. 3) After installation, the surface of the strongback plate and the surface of the modification plate will be in full contact allowing minimal deformation. ASTM-A307 1 5/8 inch diameter bolts will be used to secure the implemented design. (Ref. 6)

The arrangement and the diameter of the bolts were determined with the use of a detailed computer program written in BASIC. (APPENDIX A) The computer program was written to calculate the total shearing and bearing stress on each bolt. The program also calculates the bending and shear stresses within the dual channel beams. Variables within the program include the length of the channel beams, the number and diameter of bolts, the type of channel beams and the bolt configuration. The main computer steps taken to solve for the variables are as follows: (1) input channel type and length, bolt quantity and diameter, and bolt configuration, (2) calculate bolt pattern centroid, (3) calculate total moment about bolt centroid, (4)
calculate both direct and moment loads, (5) calculate force components and use superposition to find the resultant force on each bolt. After successive program runs, the optimal bolt configuration was found. (Fig. 9 & APPENDIX B) The only restriction within the program was that of maintaining constant bolt diameters. The restriction allows bolts to be interchangeable upon installation and does not affect the optimal design.

Minimum weight, maximum strength, and low cost are three of the contributing factors that make this design optimal. Another factor is the existence of redundancy in this design. For example, the inserted channel beams have been designed such that they will have little room for play, even before they are secured with bolts. If all three bolts fail under a load, IPPLA could still carry the load safely. Another form of redundancy is the fact that the channels are bolted within the existing strongback beam that easily supports loads of eight thousand pounds or more. The total weight of the astronaut tunnel is only one ton. The previous considerations provide some of the added features that make the selected modification of the white whale the most attractive of the feasible solutions.
References

1 Baker, Craig; Mechanical Engineer, Cargo Management, Kennedy Space Center


5 Integrated Partial Payload Lifting Assembly Drawings Documents numbers: 79K25261 sheets 1-10 79K08502 sheets 11-12 John Kennedy Space Center, NASA, Mar.1, 1983.


ACKNOWLEDGEMENTS

A grateful appreciation to Craig Baker at NASA for his encouraging support and insight.

Also, a special thanks to Dr. Loren Anderson at the University of Central Florida for his continuous support.
TOP VIEW

BOLTED PLATE

WELDED PLATE

ABOVE DRAWINGS ARE OF SOLID OR CHANNEL
BEAM PROPOSALS (SIMILAR DESIGN)

FIG. 1

SIDE VIEW

THREADS T-PLATE

CHANNEL INSERTS W/ WORM GEAR
ASSEMBLY

SOLID OR CHANNEL BEAM INSERTS

I-BEAM

FIG. 2

FIG. 3

FULL-LENGTH PROPOSALS
INSERTED CHANNEL BEAM (OR SOLID BEAM) WITH CABLE FOR ADDED SUPPORT & STABILITY

HINGE & CABLE DESIGN

ADJUSTABLE CABLE ASSEMBLY

CABLE - CANTILEVER PROPOSALS
HINGED CANTILEVER

MODIFICATION

FIGURE 7
STRONGBACK BEAM AND MODIFICATION

SIDE VIEW
1 CM = 4 IN

TOP VIEW
1 CM = 2 IN

FIGURE 9
<table>
<thead>
<tr>
<th>Problem Solutions</th>
<th>Safety</th>
<th>Cost</th>
<th>Strength</th>
<th>Weight</th>
<th>Reliability</th>
<th>Size</th>
<th>Trouble</th>
<th>Reward</th>
<th>Total</th>
<th>Total Possible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid bars going all the way through (2)</td>
<td>50</td>
<td>9</td>
<td>40</td>
<td>3.5</td>
<td>30</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>144.5</td>
<td>260</td>
</tr>
<tr>
<td>Solid bars going all the way through with worm gear (2)</td>
<td>45</td>
<td>18</td>
<td>32</td>
<td>10.5</td>
<td>27</td>
<td>5</td>
<td>10</td>
<td>6</td>
<td>153.5</td>
<td>260</td>
</tr>
<tr>
<td>Solid bars going all the way through with I-beam assembly (2)</td>
<td>45</td>
<td>22.5</td>
<td>32</td>
<td>10.5</td>
<td>27</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>156</td>
<td>260</td>
</tr>
<tr>
<td>Channel beams going all the way through (2)</td>
<td>45</td>
<td>22.5</td>
<td>32</td>
<td>10.5</td>
<td>27</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>156</td>
<td>260</td>
</tr>
<tr>
<td>Hinge assembly with cable attachments (4)</td>
<td>45</td>
<td>31.5</td>
<td>32</td>
<td>24.5</td>
<td>27</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>208</td>
<td>260</td>
</tr>
<tr>
<td>Cantilever with cable attachments (4)</td>
<td>50</td>
<td>27</td>
<td>36</td>
<td>21</td>
<td>30</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>200</td>
<td>260</td>
</tr>
<tr>
<td>Solid beam inserts (4)</td>
<td>50</td>
<td>13.5</td>
<td>36</td>
<td>7</td>
<td>30</td>
<td>15</td>
<td>6</td>
<td>4.5</td>
<td>162</td>
<td>260</td>
</tr>
<tr>
<td>Channel beam inserts (4)</td>
<td>45</td>
<td>36</td>
<td>28</td>
<td>21</td>
<td>27</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>193</td>
<td>260</td>
</tr>
<tr>
<td>Square beam sleeves (4)</td>
<td>45</td>
<td>31.5</td>
<td>32</td>
<td>21</td>
<td>27</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>192.5</td>
<td>260</td>
</tr>
<tr>
<td>Hinge and cable assembly using counterbalance (2)</td>
<td>45</td>
<td>36</td>
<td>32</td>
<td>35</td>
<td>27</td>
<td>20</td>
<td>25</td>
<td>15</td>
<td>235</td>
<td>260</td>
</tr>
<tr>
<td>Channel beam inserts using counterbalance (2)</td>
<td>45</td>
<td>45</td>
<td>28</td>
<td>24.5</td>
<td>27</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>217.5</td>
<td>260</td>
</tr>
<tr>
<td>Square beam sleeves using counterbalance (2)</td>
<td>45</td>
<td>40.5</td>
<td>32</td>
<td>24.5</td>
<td>27</td>
<td>20</td>
<td>16</td>
<td>12</td>
<td>217</td>
<td>260</td>
</tr>
</tbody>
</table>

Rating Scale:

5 - Excellent
4 - Very Good
3 - Fair
2 - Below Average
1 - Poor

Each number in the table was computed by multiplying the weight ( ) holder by the number in the rating scale.
192 B(U)=SQR(BY(U)^2+BX(U)^2)
194 NEXT U
198 E=CENT+12.767
200 PD=CENT+12
203 CD=CENT+24-L/2
205 M=3125*E+PWT*PD+CWT*CD
206 PRINT
207 PRINT "THE APPLIED MOMENT (LB-I) ==";M
208 PRINT
210 PRINT "CENTROID POSITION X (IN) ==";CENT
212 PRINT "CENTROID POSITION Y (IN) ==";CENY
214 PRINT
215 SB=0
220 FOR K=1 TO N
225 SB=SB+(B(K))^2
235 NEXT K
240 FD=M/(N*A)
243 PRINT
245 FOR R=1 TO N
250 FX(R)=M*BY(R)/(SB*A)
255 FY(R)=M*BX(R)/(SB*A)
263 NEXT K
265 FOR V=1 TO N
270 IF (X(V)-CENT)>0 THEN TR(V)=FY(V)+FD
275 IF (X(V)-CENT)<0 THEN TR(V)=FY(V)+FD
277 IF (X(V)-CENT)=0 THEN TR(V)=FD
280 NEXT V
285 REM & & CALCULATING TOTAL FORCE ON EACH BOLT & ANGLE OF ATTACK & &
290 FOR Q=1 TO N
295 SF(Q)=SQR(TR(Q)^2+FX(Q)^2)
300 O(Q)=1.571-ATN(FX(Q)/TR(Q))
303 PRINT"TOTAL FORCE ON BOLT("Q") (LB)= "SF(Q):PRINT" AT AN ANGLE OF ";O(Q)*180/3.1416"DEG"
305 NEXT Q
308 PRINT
310 REM @@ CALCULATING BEARING STRESS ON EACH BOLT @@
315 FOR P=1 TO N
320 BS(P)=SF(P)/(2*T*D)
323 PRINT "BEARING STRESS ON BOLT("P") (PSI) ==";BS(P)
325 NEXT P
328 PRINT
330 REM **CALCULATING SHEAR STRESS & BENDING STRESS IN CHANNELS**
335 SS=M*H*(2*IM)
340 SIG=M*H/(2*IM)
345 PRINT "SHEAR STRESS ON BEAMS=";SS
350 PRINT "BENDING STRESS ON BEAMS=";SIG
355 PRINT
360 INPUT "DO YOU WISH TO REPEAT (Y/N)?";F$
365 IF F$="Y" THEN 50
370 END
TYPE OF CHANNEL?? 9.8
LENGTH OF CHANNEL (IN) ?? 40
NUMBER OF BOLTS?? 3
DIAMETER OF BOLTS (IN) ?? 1.625
PLACEMENT OF BOLT FROM ORIGIN? X=? 3
Y=? 2.33
PLACEMENT OF BOLT FROM ORIGIN? X=? 3
Y=? 4.66
PLACEMENT OF BOLT FROM ORIGIN? X=? 10.5
Y=? 2.33

TYPE OF CHANNEL==C7- 9.8
LENGTH OF CHANNELS (IN). == 40
NUMBER OF BOLTS USED== 3
DIAMETER OF BOLTS (IN) == 1.625

=PLACEMENT OF BOLTS FROM ORIGIN==
BOLT( 1 ) X= 3 Y= 2.33
BOLT( 2 ) X= 3 Y= 4.66
BOLT( 3 ) X= 10.5 Y= 2.33

THE APPLIED MOMENT (LB-I) == 59067.09

CENTROID POSITION X (IN) == 5.5
CENTROID POSITION Y (IN) == 3.106667

TOTAL FORCE ON BOLT( 1 ) (LB)==
11237.97
AT AN ANGLE OF 1.523113 RAD OR
87.26776 DEG
TOTAL FORCE ON BOLT( 2 ) (LB)==
11276.53
AT AN ANGLE OF 1.666555 RAD OR
95.48634 DEG
TOTAL FORCE ON BOLT( 3 ) (LB)==
6054.295
AT AN ANGLE OF 1.482029 RAD OR
84.91382 DEG

BEARING STRESS ON BOLT( 1 ) (PSI) ==
16465.89
BEARING STRESS ON BOLT( 2 ) (PSI) ==
16522.39
BEARING STRESS ON BOLT( 3 ) (PSI) ==
8870.762

SHEAR STRESS ON BEAMS== 19411.72
BENDING STRESS ON BEAMS== 4852.93

DO YOU WISH TO REPEAT (Y/N)?? Y