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RACK DISTRIBUTION EFFECTS ON MPLM CENTER OF MASS

Prepared By: John T. Tester

Academic Rank: Associate Professor

Institution and Department: Northern Arizona University
                                             Department Mechanical Engineering

NASA/MSFC Directorate: Flight Projects

MSFC Colleague: Jon Holladay

Introduction

This research was in support of exploring the need for more flexible "center of gravity" (CG) specifications than those currently established by NASA for the Multi-Purpose Logistics Module (MPLM). The MPLM is the cargo carrier for International Space Station (ISS) missions. The MPLM provides locations for 16 standard racks, as shown in Figure 1; not all positions need to be filled in any given flight. The MPLM coordinate system (X_M, Y_M, Z_M) is illustrated as well. For this project, the primary missions of interest were those which supply the ISS and remove excess materials on the return flights. These flights use a predominate number of "Resupply Stowage Racks" (RSR) and "Resupply Stowage Platforms" (RSP). In these two types of racks, various smaller items are stowed. Hence, these racks will exhibit a considerable range of mass values as well as a range as to where their individual CG are located.
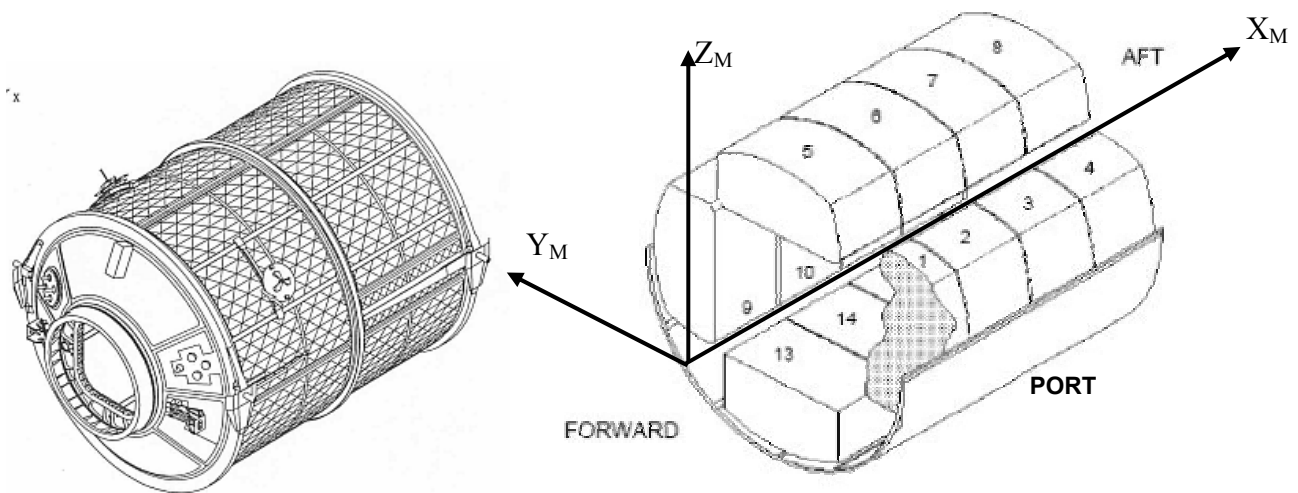

Figure 1: MPLM (left) and schematic of racks arrangement (right).

There are two aspects to this packing problem: Designing the MPLM rack organization such that the CG_M will exist within a specified allowable space (Figure 2) and ensuring that *calculated* CG_M and mass will be sufficiently accurate to match the *measured* corresponding values once the MPLM is packed. For this report, the first scenario is termed "packing design;" the second comparison process is termed "packing validation." For the purposes of this summer study, any RSR or RSP can go into any of the 16 MPLM positions for the ISS support missions.

A Manifest Flexibility Task (MFT) study, conducted by the Johnson Space Center (JSC), evaluated a limited number of alternative MPLM payload scenarios for their resulting loads on the individual rack fittings.[3] This study was used as a baseline for establishing numerous CG_M alternatives based upon variations in individual rack CG. In past flights, the RSR and RSP exhibited a wide range of masses and a relatively wide range of CG. The MFT used a series of analysis categories: Liftoff, Heavy Landing and Light Landing. The Liftoff and Light Landing categories were conducted with the rack masses at (essentially) the same masses as those recorded in previous STS/MPLM flights. The Heavy Landing category used heavier masses for the racks, about $80 - 100$ lbm heavier than that used in the true flight record. Within each of

these mass categories, the racks had further alternative settings per computer simulation. These options were established as low and high values of the rack CG within ranges based upon past flight histories; for brevity, a summary of these cases is given in Table 1, and Figure 3 illustrates these CG locations. As historical data was only available for the landing scenarios, the Light Landing and Heavy Landing situations were the only scenarios explored this summer.
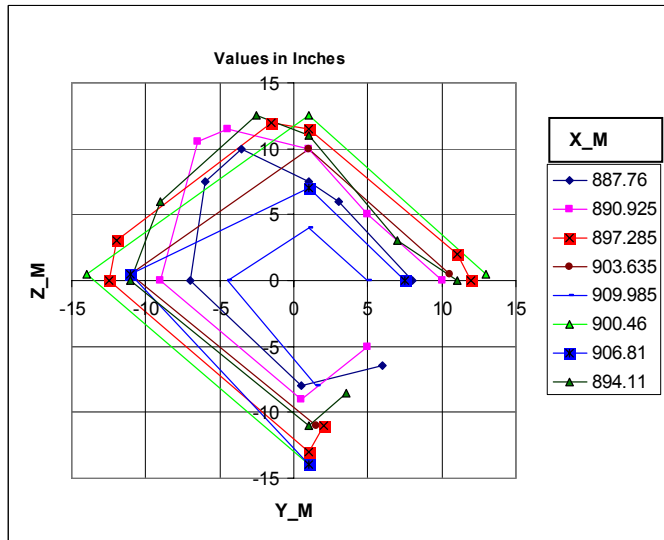

Figure 2: Allowable envelope of CG_M. [1]

Table 1. Rack CG alternatives for each MFT loads analysis.

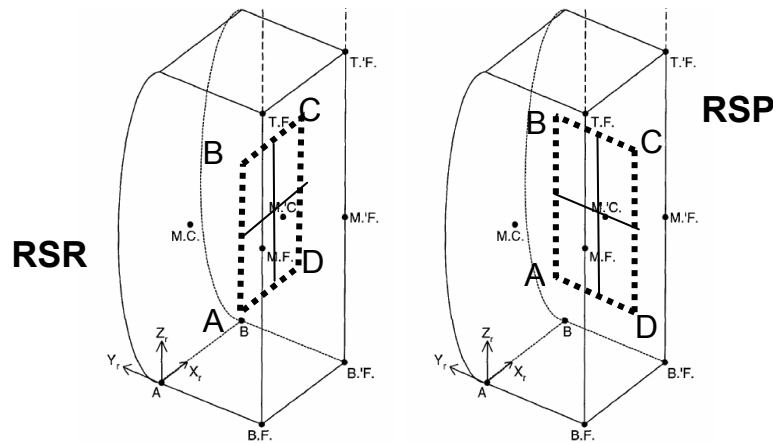| CASE →		A	B	C	D	Nominal (Nom)
X_{rack}		NOM (RSP)	NOM (RSP)	NOM (RSP)	NOM (RSP)	NOM
		LOW (RSR)	LOW (RSR)	HI (RSR)	HI (RSR)	
Y_{rack}		LOW (RSP)	LOW (RSP)	HI (RSP)	HI (RSP)	NOM
		NOM (RSR)	NOM (RSR)	LOW (RSR)	LOW (RSR)	
Z_{rack}		LOW	HI	HI	LOW	NOM

Figure 3: Alternative sub-cases for RSR and RSP local CG.

Problem Definition

The CM of any object is given at right, , where N is the number of racks used in the manifest, x_i is the x-axis position of rack i in the MPLM frame, m_i is the mass of rack i, and $i = 1,2,...N$.

$$CG_{M\_X} = \sum_{i=1}^{N} x_i m_i \bigg/ \sum_{i=1}^{N} m_i$$

Equivalent equations are apparent for Y and Z of the CG_M. For the problem at hand, MSFC desired to have many different, discrete alternatives for the CG of the racks examined for trends in overall CG location. Thus, a program was developed in MatLab in order to enumerate combinations of rack locations for a given manifest, based upon Table 1. It is noted that with n rack positions, n racks to install, with k of type RSP (with only RSR being the other type allowed), the number of alternate examinations would be given in the equation below. The number of alternatives for return flight 6A, for example, had $n = 16$, $m = 8$, and $k = 4$. Such a

situation produced a total of 2.544×10^{17} different CG_M results. Even if each calculation took only 0.001 second, it would require 70×10^9 hours of computer time.

$$alternatives = \left(3^{3k} \right) \left(\frac{n!}{k!(n-k)!} \right) \left(\frac{k!}{m!(k-m)!} \right)$$

Thus, only variations in the end racks were considered for this summer, as the end racks contained racks with the largest x_M values, resulting in the greatest moment arm shifts in the CG_M from the CG equation.

Results

Many different computation runs were examined, more that can be illustrated in this summary report. Figure 4 shows the packing difference of the MFT cases. 23 out of 30 results exceeded the 1" specification. One conclusion in this limited study is that varying the racks tolerances significantly in the Verification Loads Analysis (VLA) process will result in a higher potential for larger packing differences. This trend is confirmed in the enumerated studies as well.
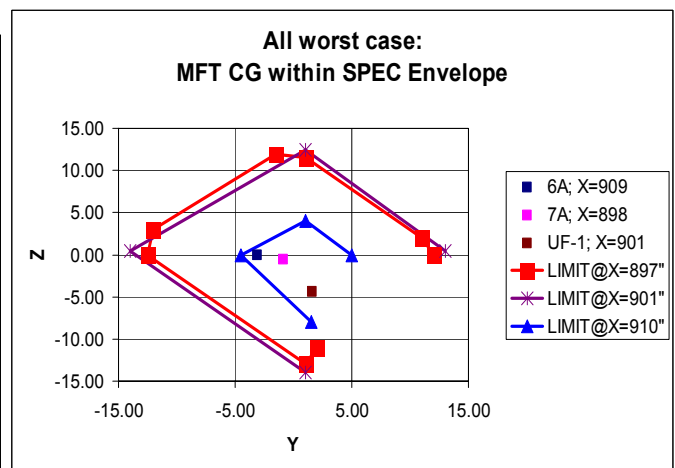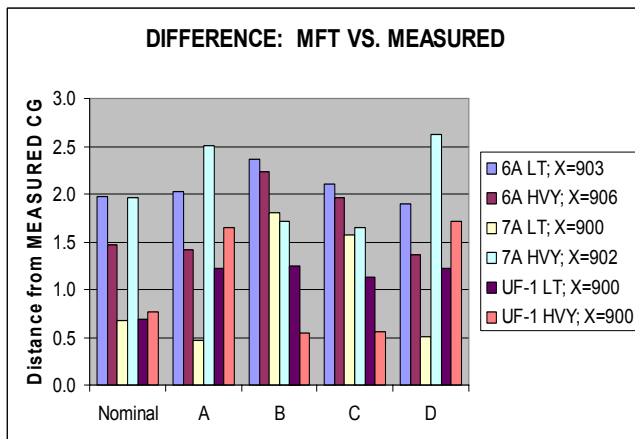

Figure 4: MFT Packing differences.

Figure 5. Worst case CG_M in envelope.

Figure 5 shows the 6A, 7A, and UF-1 return flight worst-case scenarios for off-axis CG_M in the enumerated case studies. In the lightest-loaded flight (6A), the CG_M is trending towards its envelope limit. This chart, along with other data, suggests that lightly-loaded MPLM missions have much more variable potential to be loaded "off-balance." However, even for the worst case of this specific manifest, the CG_M is still within the dimensional envelope. Additional data show also that heavier missions tend to have less packing differences than lighter missions.

Future Applications for the MSFC

In the case studies examined, the center of gravity was calculated in lieu of the maximum loads exerted on the MPLM fittings. This focus was based upon the assumption that the CG_M position is correlated to such maximum loads. Work from the MFT should have data, not reported, which should allow correlation analyses to be conducted as a preliminary confirmation. If the CG_M – maximum loads correlation is proved valid, then using the CG_M as a screening tool for extreme loading cases would be a valuable in STS mission planning and future vehicle design studies.

As part of investigating the VLA process, the author discovered that many different dynamic and structural computer models were required for validating each mission payload.[2] This multi-layered and time-consuming is likely due to limitations of computing power over two decades ago, when the STS was initially developed and deployed. This project, combined with new

computing technology, may encourage streamlining of the VLA process by constructing a single VLA model. Additionally, modern search techniques can be used with the integrated model to examine the safety of multiple missions simultaneously.

Resources

This research utilized routine office personal computer resources available in the Pressurized Carriers Group. Additionally, MatLab was used to conduct the comparisons and enumerations. MatLab was also used to construct plotted data. Microsoft Excel was also used to prepare tables for MatLab input, as well as providing some plotted results. If the correlation analysis were performed in the future, the MatLab Statistics Toolbox module should be purchased for use. Consideration should also be given to access the Engineering Directorate computational resources in the dynamics and structural areas for future research.

Conclusions

The analysis of the MPLM CG is a potentially complex problem to address. By restricting early studies to a few manifest alternatives, the problem becomes manageable, but the results are only valid for those studied manifests. The rationale for restricting such studies is understandable, in light of the literally trillions of alternative scenarios to examine if all possible manifests were considered. However, the MFT report and the results of the CG enumerations conducted by this researcher are only truly valid for the specific manifests under examination. For a more thorough understanding of physical manifest variations (as opposed to the rack variations) to be accomplished, a probabilistic-based analysis is recommended, whereby the discrete factors amongst the racks are assigned estimated values. This approach allows for an estimated CG_M mean to be determined, with an associated deviation and even confidence level. This data can subsequently be input into a probabilistic dynamics and structures model, enabling far fewer computational runs, yet giving statistically valid results.

In order to study the manifest design problem, advanced computer tools should be surveyed in order to determine the best approach for handling the large number of manifest variations. The use of recent computational design tools, such as genetic algorithms, simulated annealing, or neural networks, may aid in future manifest packing designs.

Acknowledgements

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References

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[2] Structural Integration Analysis Responsibility Definition for Space Shuttle Vehicle and Cargo Element Developers, 1/19/01, NSTS 37329 Rev B..

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