NASA KSC/Intern – 07/23/2015

Systems Engineering Intern – MAST Propellant and Delivery System Design Methods

Student Name: Uzair Nadeem
Academic Level: Junior (Rising Senior)
Academic Major: Mechanical Engineering
Academic Institution: Prairie View A&M University

Mentor Name: Carey M. McCleskey
Job Title: Aerospace Technologist—Technical Manager
Org Code/Branch or Division: NASA Kennedy Space Center/NE-EM
Directorate: Engineering

MAST Propellant and Delivery System Design Methods

Uzair Nadeem[1]
Prairie View A&M University, Prairie View, TX, 77443

Carey M. McCleskey[2]
NASA Kennedy Space Center, FL 32899, U.S.A.

Abstract

A Mars Aerospace Taxi (MAST) concept and propellant storage and delivery case study is undergoing investigation by NASA's Element Design and Architectural Impact (EDAI) design and analysis forum. The MAST lander concept envisions landing with its ascent propellant storage tanks empty and supplying these reusable Mars landers with propellant that is generated and transferred while on the Mars surface. The report provides an overview of the data derived from modeling between different methods of propellant line routing (or "lining") and differentiate the resulting design and operations complexity of fluid and gaseous paths based on a given set of fluid sources and destinations. The EDAI team desires a rough-order-magnitude algorithm for estimating the lining characteristics (i.e., the plumbing mass and complexity) associated different numbers of vehicle propellant sources and destinations. This paper explored the feasibility of preparing a mathematically sound algorithm for this purpose, and offers a method for the EDAI team to implement.

Nomenclature

MAST = *Mars Aerospace Taxi*
KSC = *Kennedy Space Center*
LaRC = *Langley Research Center*
HE = *Helium*
LO2 = *Liquid Oxygen*
LCH4 = *Liquid Methane*
GO2 = *Gaseous Oxygen, Oxygen Gas*
GCH4 = *Gaseous Methane, Methane Gas*
EDAI = *Element Design Architectural Impact*
AML = *Adaptive Modeling Language*

---

[1] Systems Engineering Intern, Engineering Directorate, NE-EM
[2] Aerospace Technologist, Engineering Directorate, NE-EM

I. Background and Introduction to Fluid Path Simplifications

A. Importance of the propellant packaging, routing, and servicing in conceptual space system design

Innovative methods and techniques in regards to propellant packaging, routing, and servicing, are needed to avoid the creation of interstitial spaces requiring added hazardous gas detection and safety purge sub-systems. Additionally, storage tank arrangements that inherently control the accumulation of interconnecting fluid distribution and control hardware and software is also desired by operators of these space flight systems" [1]. The prime objective is to optimize the mass relationship between the propellant packaging, routing, and other subsystems in attempt of reducing fluid path complexity.

B. Introduction to EDAI team and AML environment

In a collaboration between Langley Research Center (LaRC) and Kennedy Space Center (KSC), Element Design Architectural Impact (EDAI) is the collaborative design and analysis form that is done as a joint agreement between the two centers to assess the work that is being done with the modeling and simulation which in this case is the MAST concept. The environment far as design and analysis is concerned is achieved using AML (*Adaptive Modeling Language*[3]) which is a geometric generating environment that emphasizes the use of engineering tools and knowledge in creating the models, beyond basic parameter changes. This can for example can influence the geometric mesh structures of ascent engines in the MAST vehicle by setting functions regarding fuel mixture ratios and overall vehicle mass input.

C. Introduction to Mars Aerospace Taxi (MAST) element design

The MAST vehicle models that have been observed so far (Figure 1), the objective is to successfully arrive on Mars with both flight systems (regarding launches, and orbiting around the stratosphere to move cargo & passengers), and ground systems (regarding in-situ fueling, landing, servicing, etc.) to be operational with the least obstructive and optimal mass of fluid and gas fluid line routing (or *lining*) of the overall structure.

The first conceptual design for the MAST vehicle model, or MAST I, consisted of a parallel-discrete tank arrangement as shown. The MAST lining will alter to a certain extent based on any changes in the quantity, position, and geometry of the tanks which consist of methane, oxygen (both gaseous and liquid) and helium gas that dictate the outcome the MAST lining.

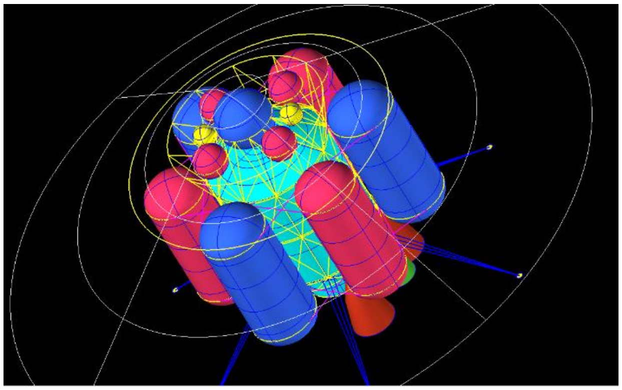

Figure 1—MAST I configuration needing to be lined

---

[3] ® TechnoSoft, Inc. 2015

II. Results of Lining Analysis in AML

First, the discrete tank configuration was lined. In these lining exercises each fluid path represents a plumbing line, but also in concept may represent other components. The task given was to represent a fluid path, and not a detailed plumbing layout.

Following this MAST I exercise, alternate tank arrangements for a torus (circular cross section) and a toroidal (domed, wrap-around)

A. Lining Analysis of the MAST I configuration.

The tank geometries consisted of cylindrical tanks of both Fuel (CH4–highlighted red) and Oxidizer (O2-highlighted blue), and the same commodities for spherical tanks located on the top of the vehicle with the addition of two pressurizing tanks for the descent fluid paths, which is Helium (HE-highlighted yellow). The fluid paths were broken down into seven different categories of commodity and its system association. This includes service panels – used both for CH4, HE, and O2, and propellant tanks with its respective commodity. Ascent gaseous oxygen (GO2) and Ascent gaseous methane (GCH4) are extracted from the engine heat of the engine thrusters and fed into ascent storage tanks (*autogenous pressurization*). The seven paths types are:

1. Descent LO2 Path
2. Descent Liquid CH4 Path
3. Descent Helium Path
4. Ascent LO2 Path
5. Ascent Liquid CH4 Path
6. Ascent GO2 Path
7. Ascent Gaseous CH4 Path

The result of the MAST I lining is shown in Figure 2.

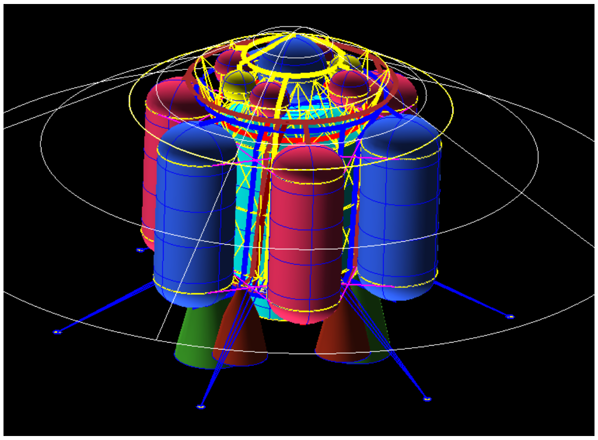

Figure 2—MAST I with lining shown

B. Three Alternative MAST propellant storage concepts

Three other configurations were explored for MAST II in an attempt in finding lesser complexity and other design possibilities. The following sections discuss these other configurations.

1. Descent torus propellant storage alternative

The first alternative tank arrangement combined the multiple spherical tanks into a smaller tank set with torus design. This change in concept is shown in Figure 3.

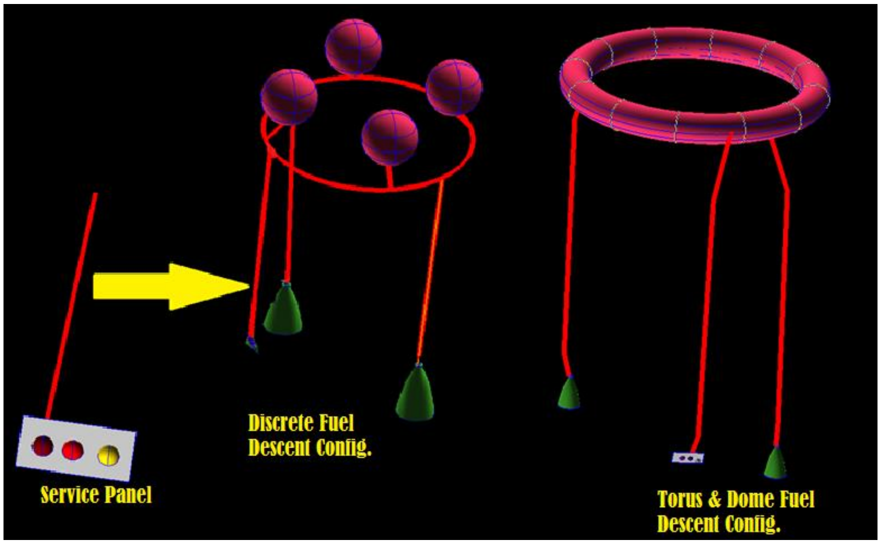

Figure 3--Example of fluid path configuration for fuel – between discrete and Torus/Dome

2. Ascent torus propellant storage alternative

The second alternative tank arrangement combined the multiple cylindrical tanks into a smaller tank set with only two torus tanks. The ascent torus configuration is a complete substitution of both spherical and cylindrical discrete tanks for ascent and descent propulsion arrangements. A circular cross-sectional torus, a self-intersecting tube structure, is used within the vehicle to substitute the previous quantity of tanks used in MAST I. The lining changes made for this simpler arrangement is shown in Figure 4.

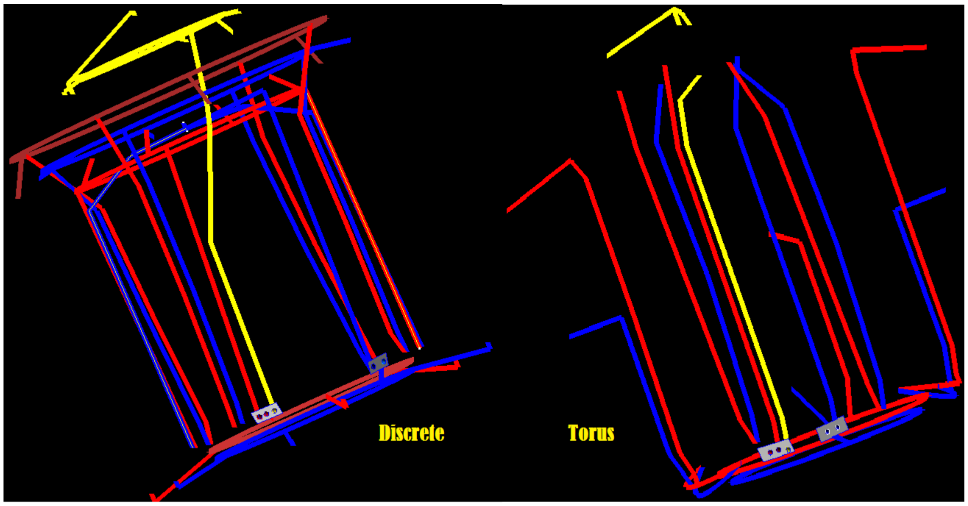

Figure 4—Relining of the torus configuration

Figure 5 shows the comparison between the discrete and torus fluid routing as an overview of the difference in the mass of lining between the two vehicle models.

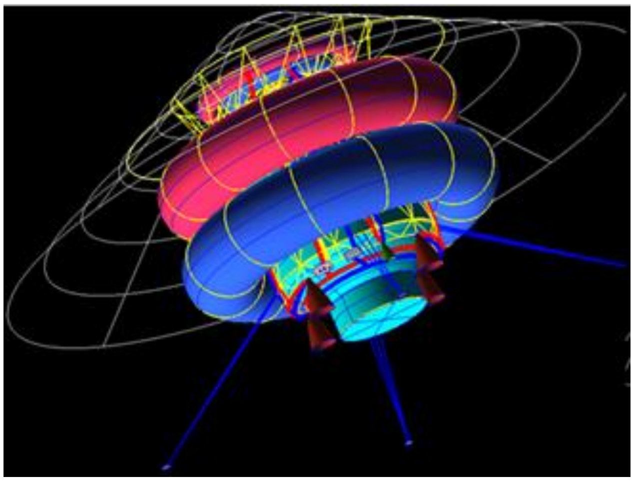

Figure 5—Completed MAST II/Torus with lining complete

3. *Ascent toroid dome/wraparound propellant storage alternative*

The ascent torus wraparound, or “dome” configuration is similar to the circular cross-sectional torus, except only the largest tanks which are designated for the ascent propulsion routing is the only difference. The wraparound is a modification of the conventional torus where the cross-sectional geometry is rectangular rather than circular, creating a self-intersecting circumferential rectangular structure (Figure 6).

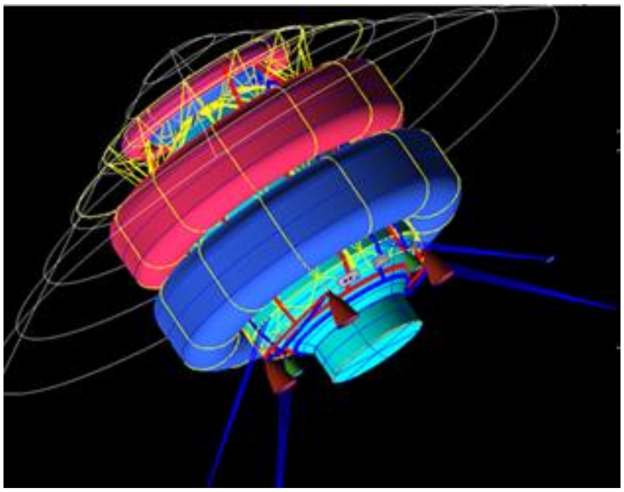

Figure 6-- Completed MAST II/ toroid dome/wraparound with lining complete

III. Algorithm Development

A. Summary comparison of MAST configurations

A quantitative comparison was conducted between the MAST I and MAST II and their respective arrangements. The quantity of the routing needed between the versions were tallied and compared. The results are yielded as shown in Table 1.

The focus was not to analyze fluid mechanic or thermal principals derived from the arrangements, but to derive a conceptual lining based on the sources and destinations given and create an algorithm using AML with in an Excel. Based on observation, the toroid structures yield a lower mass lining, or number of lines needed due to a larger surface area coverage around the central unit of the MAST unit, or the habitat. What was learned was that the MAST I accumulated 53 separate fluid paths, while the MAST II alternatives both required only 37.

Table 1—Quantitative comparison table of MAST I and alternative MAST II linings

Discrete(Cylindrical, Spherical) Tank Configuration	
Propellant Commodities(including helium)	3
Tanks	13
Engines	6
Total Fluid paths w/2 service panels	53
Toroidal Tanks(Torus, Dome)	
Propellant Commodities(including helium)	3
Tanks	5
Engines	6
Total Fluid paths w/2 service panels	37

B. Algorithm development

Still needed by the EDAI team was a general algorithm that can estimate a rough order magnitude quantity of fluid paths for a given propulsion system arrangement; not only for MAST, but for other space system concepts. The results revealed a potential mathematical figure-of-merit (FOM) that is a function of total supplied commodities, number of tanks, and number engines. These results are shown in Table 2.

Table 2—Comparison of theoretical fluid path quantities for different configurations

	Supplied Commodities	Tanks	Engines	Predicting FOM	Paths Modeled
Configuration	C	T	E	C*(T+E)	P
Discrete	3	13	6	57	53
Torus	3	5	6	33	37
Simple Pressure Fed (G-HE)	3	3	1	12	7
Simple Autogenous Press.	2	2	1	6	6

The fluid path FOM was then plotted against a manually estimated set of fluid path routings and is shown in Figure 7. The data points were depicted in a point graph which were derived from the table shown above. This was used as a basic estimation of path quantity estimation to acquire an understanding of the routing differences for each configuration.

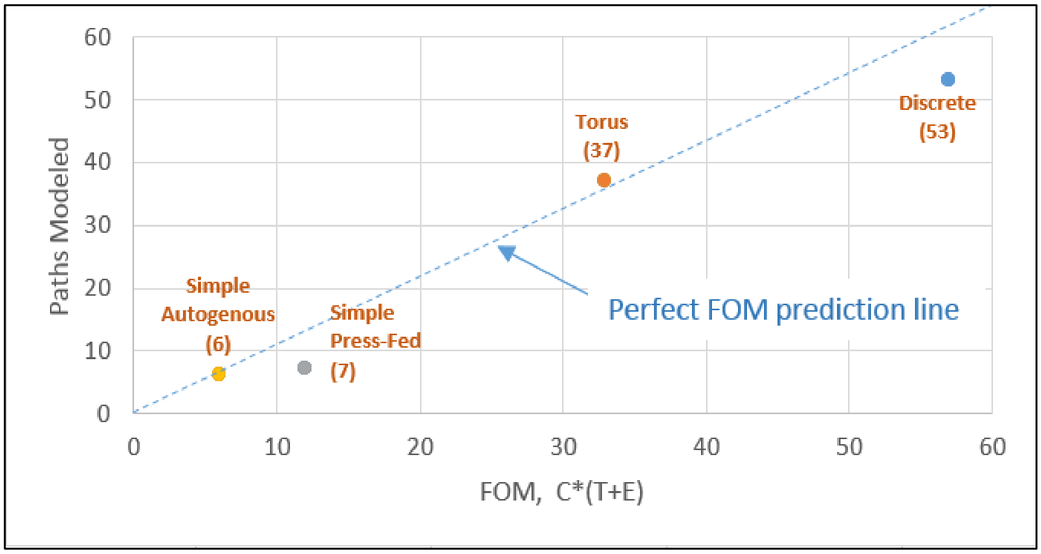

Figure 7—Path quantity estimation as shown in graph

IV. Conclusions and Recommendations

A rough estimation is formulated in the use of excel to predict a sense of quantity of the routing needed for the fluid and gas path in respect to the configuration it is associated with. A calculation might suffice for less extreme cases with a simple equation, but to best determine the factors and variables needed to come up with a more precise formula, more variations and configurations of the propellant tank arrangements must be taken into account to find more data points to find a common pattern or correlation.

Also, a generic algorithm possibly cannot be determined with significantly different configurations between parallel-discrete to toroidal tanks and therefore a recommendation can call for having algorithmic determinations between a category of tank configurations due to drastic changes in geometry in surface area and mass. This can be a necessity especially if using a variety of configurations, especially if the plots begin to disassociate from a predictable pattern.

References

[1] *John G. Martin, Carey M. McCleskey,"Alternative Propellant Storage and Delivery Design Methods and Techniques in Space Flight Systems"*

**All images and software references are used with permission from LaRC*