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An Improved Mobile Trolley for Satellite Test Facility

[Elena Woo Lai Leng]

***Abstract*— A mobile trolley is a form of mechanical ground support equipment that allows engineers to perform integration work at various parts of the satellite body in a safe manner, thus preventing mishandling of the satellite. Existing mobile trolleys available in the market have several limitations, whereby its height is not adjustable and typical mobile trolley doesn't have any mechanism to transport a satellite into the thermal vacuum chamber to undergo environmental test. Therefore, this project was proposed to design and develop a Motorised Adjustable Vertical Platform (MAVeP), an improvement to existing mobile trolleys, which has the ability to move around, to increase or decrease its height and finally, to be able to transport the satellite into the thermal vacuum chamber. The MAVeP is expected to provide assistance in the assembly, integration and testing operation without jeopardizing the safety of the spacecraft.*)**

Keywords— satellite trolley, satellite testing, mobile platform, mechanical ground support equipment

I. Introduction

All satellites required vigorous testing before it can be launched into space due to the huge environmental impact, both while on earth and in space [1] where the vibro-acoustic effect during launch and electromagnetic and thermal effect in space environment may damage the satellite even before it begins its lifetime [1, 2]. In order to shield itself from these impacts, the satellite has to undergo various kinds of tests, such as, vibration test, acoustic test, electromagnetic test and thermal vacuum test. These tests are important to ensure the satellite achieves all the design, performance and quality requirements before it faces the worst conditions in orbit [3].

These tests are typically performed in an Assembly, Integration and Test (AIT) facility, which is a cleanroom of Class 100,000 according to ISO 14644. A test campaign for a satellite occurs before launch and could take between two (2) weeks minimum, and up to months, depending on the complexity of the project. During the test campaign, various kinds of ground support equipment are used, both mechanical and electrical. One of the distinctly noticeable mechanical ground support equipment is the mobile trolley. The satellite placed in the AIT facility is being transported around the facility via overhead crane or mobile trolley [4], with the latter being favoured mode of transport as it allows engineers to perform integration works on various parts of the satellite as well as setting up the satellite for test.

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However, existing mobile trolleys or satellite trolleys are limited in terms of mobility and height, whereby existing trolleys are only able to perform rotation and translation from vertical to horizontal position or vice-versa. A satellite trolley that is able to move up or down is normally found embedded in the floor and does not have the mobility function. Therefore, this project is to improve existing design of a mobile trolley and develop an enhanced trolley that will be mobile and its height adjustable. Since this trolley will be used to transport the satellite into the thermal vacuum chamber, an additional functionality is required of the trolley, which is the telescopic function. This telescopic function is used to push the satellite from the trolley into the thermal vacuum chamber. This improved mobile trolley is given the name Motorized Adjustable Vertical Platform (MAVeP).

This project is funded by Ministry of Science, Technology and Innovation (MOSTI) (Grant No: PKA0514E006), and it is a joint collaboration between the National Space Agency of Malaysia (ANGKASA), Universiti Putra Malaysia (UPM), International Islamic University of Malaysia (IIUM) and SIRIM Machinery Technology Centre. The development of MAVeP will help researchers and engineers to gain knowledge on design of structure, control, automation and integration process as well as material selection and thus, increasing skills in designing mechanical ground support equipment (MGSE) for a satellite project.

This paper is organized as follows: Section II will present the structural and control design requirements for MAVeP, Section III will provide the analysis results; and Section IV will provide the conclusion, future work, acknowledgement and references.

II. MAVeP Structural and Control Design Requirements

The design of MAVeP platform is based on the structural requirements set earlier, and the task to design the platform is undertaken by UPM, led by Dr. Mohamad Ridzwan Ishak. The design of the platform structure has to take into consideration the cleanroom environment, amount of space surrounding the thermal vacuum chamber, operational requirements and maximum load that can be supported by TVC. The design requirements for platform structure is summarized in Table I below

As for the control system of MAVeP, it is the system that controls the movement of the platform. IIUM, under the guidance and leadership of Associate Professor Dr. Salmiah Ahmad, had been tasked to design the control mechanism for MAVeP which includes moving the MAVeP forward and backward, up and down as well as telescopic movement.

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The requirements for control system is summarized in Table II below:

TABLE I. PLATFORM STRUCTURE

No.	Parameter	Specification	Remarks
1.	Platform Length	Platform Deck: 4,000mm (minimum)	Deck Size: Baseplate Size 2m with Operator Area 1m (Front and Back)
2.	Width	Platform Deck: 3,500mm (maximum)	
3.	Adjustable Height	2,500mm (maximum)	Programmable / Adjustable Height
4.	Loading Capacity	1200kg (maximum)	Inclusive of baseplate, jig, DUT and Operator (SF: 1.25)
5.	Mass		Flooring requirement: Can withstand max load of 10 ton (TBC)
6.	Material		Need to consider supported weight, electrostatic discharge and compatible with cleanroom environment
7.	Wheel Type	Polyamide wheels or non-marking tyres or any other type of wheels suitable for cleanroom operation	
8.	Structural rigidity, stability and balance		All design specification to be supported FEA Analysis, CAD Model, Detail / Manufacturing Drawing, Bill of Material
9.	Finishing		

TABLE II. CONTROL MECHANISM

No.	Parameter	Specification
1.	Movement Mechanism	Telescopic Up/Down Forward/Backward
2.	Transition Speed	**Telescopic:** Single Speed: 0.25m/min **Up/Down:** Slow Speed: 0.25m/min Fast Speed: 0.5m/min **Forward/Backward:** Slow Speed: 0.25m/min Fast Speed: 5.0m/min
3.	Acceptable Vibration Range	There should be NO SHOCK introduced to the DUT. Subsequently, there should be no jerking if the stop button is pressed.
4.	Controller	To be proposed
5.	Guidance	• Intelligence guidance for parking • Intelligence guidance for alignment of extended beam • Allow manual override
6.	Emergency Button	• Single emergency button • Emergency button provided at 2 location
7.	Control Panel	To be proposed
8.	Operating Power	Battery operated

The design requirements were discussed and reviewed several times in different review meetings before all parties agreed to it. The design concept for MAVeP was developed from available systems such as the crane, forklift, single scissor lift, double scissor lift and hydraulic power lift before finally coming up with the design concept as shown in Fig. 1 below.

Figure 1. MAVeP design concept

Another notable design improvement of MAVeP compared to other mobile trolley was the introduction of mecanum wheels that allow for in-place rotation with minimal ground friction and low torque. These wheels are the answer to the problem of limited space for MAVeP movement in the facility, however the cost is much higher as compared to normal polyamide wheels. The concept of mechanical locking, taken from the existing multi-purpose trolley, was also added into the design of MAVeP.

As for the control system, IIUM has come up with an overall control system process that will be able to control the platform's functionalities. Fig. 2, 3 and 4 show the overall control system process, baseplate loading and baseplate unloading proces.

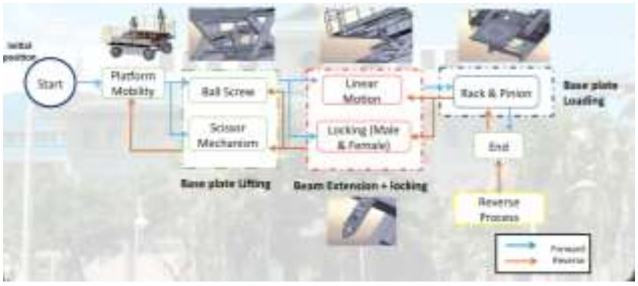

Figure 2. Overall control system process

Figure 3. Baseplate loading process

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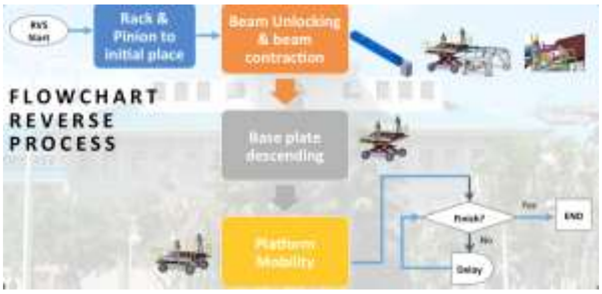

Figure 4. Baseplate unloading process

III. Analysis of Results

A. *Structure Platform*

The MAVeP structure platform is divided into three (3) modules: (i) the Base Module; (ii) the Scissor Arm Module; and (iii) the Deck Module. The bottom part of MAVeP is called the Base Module, the lifting part of MAVeP is the Scissor Arm Module and Deck Module covers the upper platform where the operator, baseplate and the satellite will be located. The figure of the base module, scissor arm module and deck module is as shown in Fig. 5, 6 and 7 below.

Figure 5. Base Module

Figure 6. Scissor Arm Module

Figure 7. Deck Module

The primary structure of MAVeP has been designed to carry a one (1) tonne load consisting of the satellite, the base plate, adapter, maximum of two (2) operators, all secondary structures, control boxes, gear boxes, batteries, motors, sensors and other accessories. The load used in the analysis are of the type concentrated load, pressure load and surface traction load setup. Standard steel is selected as the material for all primary structure and any contacted surface between two structures are assumed to have zero x-, y- and z-displacements.

Structural analysis was performed on the primary structure of MAVeP to determine the reaction forces, maximum stress, deformations and worst-case safety factor. SIRIM Berhad, led by Ir. Rohaizat Omar, performed the analysis based on the assembly drawing of MAVeP. The total weight of the structure is approximately 3500kg with contingency. Structural verification was performed using a combination of hand calculations and finite element analysis using ABAQUS and CATIA Workbench. The maximum Von-Mises Stress allowed for the primary structure is 125 Mpa, corresponding to the safety factor of 2, and exceeding the required safety factor of 1.25. The stress and displacement result is as shown in Table III below.

TABLE III. MAVEP STRESS ANALYSIS

Component	Maximum Displacement (mm)	Maximum Von-Mises Stress (MPa)	Safety Factor
Base Structure Assembly (highest deck position)	0.253	58.7	2.2
Base Structure Assembly (middle deck position)	0.0505	21.16	6.1
Base Structure Assembly (lowest deck position)	0.1145	37.71	3.5
Base Structure (highest deck position)	0.6	90.55	1.4
Base Structure (middle deck position)	0.1032	40.78	3.19
Base Structure (lowest deck position)	0.0982	35.11	3.7
Scissors (highest position)	1.644	101.76	2.3
Scissors (lowest position)	1.992	137.23	1.7
Extended beam (not connected to female)	0.73	36.33	3.6
Extended beam (connected to female)	0.02	10.19	12.8
Deck	0.326	23.72	5.5
I Beam Base Plate Support	0.002	3.52	39.1
Wheel Sliding Rail (highest deck position)	0.00045	3.603	65
Wheel Sliding Rail (middle deck position)	0.00045	3.595	65
Wheel Sliding Rail (lowest deck position)	0.00046	3.649	64
Ratchet	0.0086	50.91	4.56

Some results of stress analysis conducted using CATIA are as shown in Fig. 8, and 9 below.

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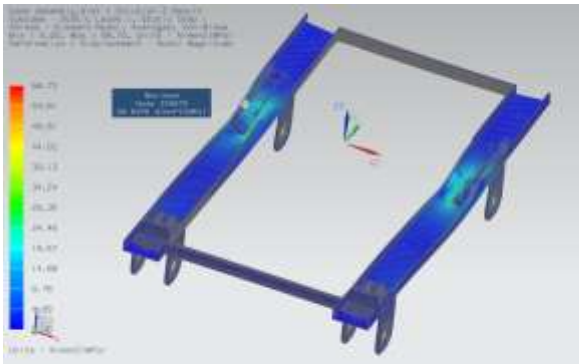

Figure 8. Maximum Von-Mises Stress 58.70 MPa for Base Structure Assembly

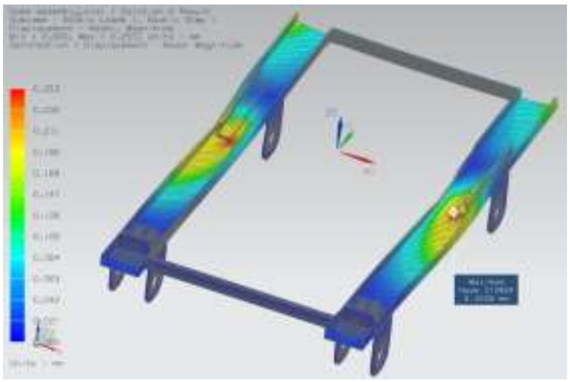

Figure 9. Maximum Displacement of 0.253 mm for Base Structure Assmebly

To determine the stability of MAVeP, the analysis was done on the centre of gravity of MAVeP. The following Fig. 11 gives an example of MAVeP plane view in relation to the centroid origin while Table IV provides the calculations of centre of gravity from centroid origin in three (3) positions.

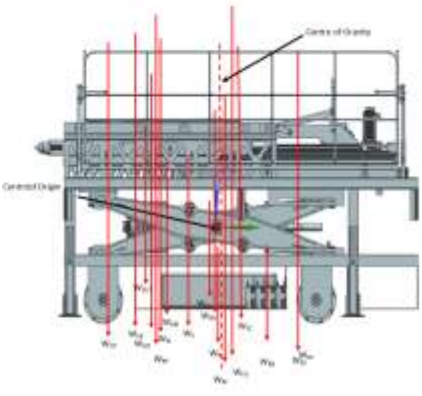

Figure 10. MAVeP at Lowest Position (YZ Plane View)

TABLE IV. CALCULATION OF MAVEP STABILITY

Position	CG_X (mm)	CG_Y (mm)	CG_Z (mm)
Fully Elevated Position	-14.79	223.04	642.69
Fully Elevated and Extended Position	-14.79	78.36	642.69
Partial Elevated Position	-14.79	79.00	507.59
Rest Position	-14.79	38.06	363.87

B. *Control System*

The design and analysis of the control system includes the following processes: (i) mobility control; (ii) parking control; (iii) baseplate loading control; (iv) lifting mechanism; (v) telescopic or beam extension function; and (vi) locking mechanism. The torque is calculated for highest and lowest position using structural analysis method. At the highest position, the torque is 267.86 Nm, where else at the lowest position, the torque calculated was 594.839 Nm. Based on the torque calculations, the suitable motors for MAVeP were selected. During Critical Design Review (CDR) session, it was agreed that the original fast speed requirement of 20.0m/min for mobility is drop, as the battery-operated motor to support this requirement is too expensive. As for motion analysis, Table 5 below shows the expected time of arrival based on the speed requirement for each motion.

TABLE V. MOTION ANALYSIS OF MAVEP

Motion	Speed Requirement (m/min)	Motor Speed (rpm)	Torque (Nm)	Time of Arrival
Forward / Backward	Fast Speed: 5.0m/min	3.901	2647.95 (per motor)	-
	Slow Speed: 0.25m/min	-	-	-
Up / Down	Fast Speed: 0.5m/min	7	764.43	2 minutes 06 second
	Slow Speed: 0.25m/min	3.38	764.43	4 minutes 23 second
Telescopic (Extended Beam)	Slow Speed: 0.25m/min	1.324	0.8345Nm	6 minutes 15 seconds
Locking	-		0.8345	-
Baseplate Loading	Slow Speed: 0.25m/min	1.324	19.683	-

IV. Conclusion

In this paper, the design requirements and design specification has been discussed and presented. Based on the design requirements, the conceptual design of MAVeP was presented. From the conceptual design, a more detailed design was developed, and from this detailed design, the structural, torque and motion analysis results were calculated and presented in this paper. From the analysis results, it is noted that the detailed design of MAVeP has met the requirements set out, and is well within the safety margin.

The next milestone for this project will be manufacturing and assembly process, which is expected to complete by 2nd quarter of this year.

Acknowledgment

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About Author (s):

Elena Woo graduated with a MSc. in Computer Science from University Technology of Malaysia and has been with ANGKASA since 2005. She has been involved in the AITC project from the beginning, and is now overseeing the management and operation of AITC. She is also involved in the project of Designing and Developing a Motorized Adjstable Vertical Platform (MAVeP) from the beginning.