Preliminary Mission Analysis Tool (PMAT) Educational Software for Satellite Mission Design

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ABSTRACT

Satellite mission design and analysis involves complex calculations and repeated tasks in determining the relevant parameters such as orbit determination, field of view and calculations on the effects of perturbations. The experience in performing manual calculations could contribute to practical understanding of space physics and theories; however, the process is time consuming and prone to human errors. Buying a commercial software package that provides similar capability may be an option; nevertheless, such idea is costly and the software may not be tailored to a specific requirement.
This paper presents an effort focused on developing a mission design software aimed to promote better understanding and efficiency in design and analysis techniques for students who specializes in Astronautics Engineering whilst reducing the dependencies towards the commercial off-the-shelf software (COTS). The software is targeted to facilitate analytical aspect of the design process in the form of computer aided interaction (CAI) and computer based learning (CBL).

The outcome of this research is a graphical satellite mission design and analysis software package for educational purposes either for teaching aid or for students' usage. The research does not only provide opportunity for students to contribute their skills in the development process but also acts as a platform for them to better understand the process of satellite mission design.

Keywords: Simulation, satellite mission design

(1) INTRODUCTION

Malaysia is fast becoming a capable satellite manufacturing country with the recent development of RazakSat satellite. The move to manufacture the national satellite is seen to bolster the need for more local scientists in areas related to spacecraft engineering. Any spacecraft development must start from a list of requirements and translated to a set of mission design by responsible engineers. Mission design involves planning for the right flight characteristics in order to satisfy the requirements. Orbital design and analysis are among the prerequisite steps to be taken before moving to higher hierarchy of satellite design phases. Here is where scientists will determine the best orbital location for a satellite to reside whilst reducing transportation cost to the lowest possible.

The time taken for a thorough mission planning and analysis can be reduced from nine months to three months with the use of good computer software. Nowadays, there exist many freeware, shareware and commercial satellite mission design and analysis software in the market. The best software could cost dearly to an organization. Developing equivalent software could be painstaking and time consuming. Nevertheless, the process is seen worthwhile as the development process itself is a learning process. An educator whom assimilates knowledge could better transmit his/her knowledge through software development, while students could benefit from the hands-on experience gained during the process.

Terms Definition

Semimajor Axis - Half the distance between the two points in the orbit that are farthest apart
Apogee/Perigee Radius - Measured from the center of the Earth to the points of maximum and minimum radius in the orbit
Apogee/Perigee Altitude - Measured from the "surface" of the Earth (a theoretical sphere with a radius equal to the equatorial radius of the Earth) to the points of maximum and minimum radius in the orbit
Period - The duration of one orbit, based on assumed two-body motion
Mean Motion - The number of orbits per solar day (86,400 sec/24 hour), based on assumed two-body motion
Eccentricity - The shape of the ellipse comprising the orbit, ranging between a perfect circle (eccentricity = 0) and a parabola (eccentricity = 1)
Inclination - The angle between the orbital plane and the Earth's equatorial plane (commonly used as a reference plane for Earth satellites)

(2) PROBLEM DEFINITION

Experiences gained in early 2001 from the School of Aerospace Engineering, Universiti Sains Malaysia in taught courses ESA111 – Introduction to Aerospace Engineering (Astronautics section), ESA264 – Flight Mechanics and design electives courses indicate that students encounter difficulties in understanding rudimentary theories associated to space mechanics. Lecturers often have to spend more time and energy to prepare visual aided pictorial and models depicting the solar system and satellite orbits to get the message through. Although limited in every aspect (especially in describing derived terms and of course limitation of the material used) this method has transpired certain extend of interest that leads to self-learning of space elements. Nevertheless, students cannot fully benefit from these techniques due to the complexity of the subject as lecturers tend to simplify things up and examples are limited on special cases only.

A more comprehensive and robust technique has to be employed based on one-to-one or step-by-step approach in order to promote self-learning. The physical models and motions described can be depicted in the computer without limitation. Any motions can be simulated in the computer as well as help items for new users.

The primary objective is then to develop a satellite mission design software as a tool to promote better understanding and self-learning of space mechanics and to facilitate analysis aspects of the design process for undergraduate students.

Further enhancement will be conducted (depending on the availability of grants) covering aspects of constellation, perturbation and Earth shape. These aspects will be beneficial for master level students majoring in astronautics engineering and space sciences.

(3) REQUIREMENTS BASELINE

The main purpose of this study is to identify basic requirements in the form of need and then to formulate a total solution for every need. The idea here is to uncover, invent, concoct and/or devise a broad spectrum of ideas and alternatives for missions from which new projects can be selected.

A loosely structured examination of needs must be upheld in a small cluster consisting of interest subject (users), direct benefactors and third-party benefactors.

In this study, four main categories which consist of needs analysis, system operational requirements, system maintenance concept and functional requirements are carried out.

(3.1) Need Analysis

Referring to the problems faced by the group of students, the actual need is to develop a more systematic model to effectively promote better understanding in space mechanics. Students would learn better through graphical representation and best through step-by-step approach. The design of the software should be in such that answers can be immediately seen after the execution of a set of data. Students should also be furnished with a set of default data for comparison with user input data. The final result should be in the form of computer aided interaction (CAI) and computer based learning (CBL).

(3.2) System Operational Requirements

Whilst physical models and pictorial images need papers, scissors and a good artistic hand, the requirements of the proposed solution consist of a computer and a good projector for large audience. On the other hand, the development of the PMAT software requires GUI based design using MATLAB with Simulink and Visual C++ software, and a relatively better computer and brainpower for coding purposes in MATLAB and C languages. The end product consists of only an executable file and some help itineraries. This software will be tested on the latest computer technology using Windows operating system.

(3.3) System Maintenance Concept

This aspect of requirement will be further enhanced as we gain more input from prospective users and benefactors. A more reliable system can only be obtained after corrections and enhancement to the existing software are made in the future based on the following criteria:

- User/Benefactor level of knowledge
- User-program interface
- Ergonomics
- Auto-assistance (help file) *and*
- User-friendliness

(3.4) Functional Requirements

The development of the PMAT software is loosely based on the European Cooperation for Space Standardization on Space Engineering for Software developer documentation, the ECSS-E-40A. A comprehensive top-down diagram will be presented latter in this paper depicting all functions required by the end user. The concept of the software will therefore inherit those highlighted by the ECSS-E-40A standards.

(4) SOFTWARE REQUIREMENTS ANALYSIS

An analysis of the software requirements, or so-called requirements baseline was conducted based on the needs analysis presented earlier. At this stage, functionalities of the software, software architecture and software technical specifications were outlined.

(4.1) Software Functionalities

To cater the needs analysis presented earlier, this software will tackle mainly on the weaknesses of conventional way of teaching orbital mechanics and spacecraft design courses. The first phase of the project will be focusing on the fundamentals of space mission design. Apart from being a teaching tool for lecturers in conducting their space mechanics related courses, the software is targeted to aid students in self-learning of fundamental concepts in orbital mechanics.

As the software will be based on a GUI concept, the theories learned in class can easily be visualized and understood, thus shall increase time efficiency in understanding complex theories, as well as mission design activities. Apart from that, the software shall be user-friendly, that is, it should be simple enough to be used by entry level students. In addition, tool tips and help files will be made available to facilitate software usage.

(4.2) Software Architecture

The software is a module based application, thus more modules can be added for future expansion. Modules planned for preliminary requirements are based on spacecraft mission elements which are:

a) Subject or mission to accomplish
b) Orbital elements
c) Space segment: payload and subsystem
d) Launch Segment
e) Ground Segment
f) Communication Structure
g) Mission Operation

The modules are interdependent between one and another in order to acquire a complete analysis on the preliminary requirements. However, in the first phase of the project, all mission elements listed above are analyzed and programmed as a general overview. Detail analysis of important modules, such as the Orbital Elements, Space Segment and Communication Structure, are done in the second phase of the project.

(4.3) Technical Specification

Due to time limitation, some software constraints were identified and shall be rectified in future phase of the project. Some orbital parameters, such as the type of coordinate system, graphical images or some simulation data were made constant due to these constraints. Greater flexibility is hoped to be achieved in future phases. Since the software runs on modular basis, default values are made available.

Table 1 *Default Values for General Orbital Calculations*

Parameter	Type	Value
Propagator	Constant	Two Body
Coordinate Type	Constant	Classical
Coordinate System	Constant	J2000
Animation Start Time	Variable	
Animation Stop Time	Variable	
Animation Step Size	Variable	
Orbit Epoch	Variable	

(5) DESIGN ENGINEERING PROCESS

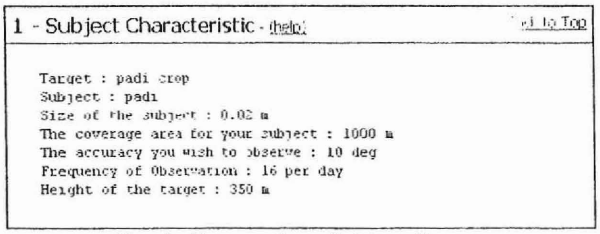
The design process is dependent on the software requirements as discussed above. As such, the software requirements baseline will be used as inputs to the design process. Any new functionalities required will then not be considered, and shall be brought forward only to the next phase of the project. The design process life cycle include designing of software items, coding, testing and integration of software units.

A thorough top-level architectural design is written in the form of seven inter-dependent main modules as mentioned earlier. Users are asked to input a set of variables in the first module which will then output another set of variables to the second module and so on. Though the sequence of operations is invisible to users, the order of each module should be noted in order to obtain a detail analysis. This feature also aims to facilitate users to the step-by-step process of designing a preliminary mission. However, each module can still be executed independently, in which case default values will be used where necessary.

To facilitate usage, the software will be based on Graphical User Interface (GUI) format. Each module will have **animation window**, **parameters input panel** and an **animation control panel**. **Parameters input panel** accepts user input for relevant space mechanics and mathematical calculations. A report on the calculations performed can be viewed by just a click on a button in the **animation control panel**. Any orbital simulation based on the initial input parameters and back-end data processing can be launched from the animation control panel and the graphical simulation will automatically be displayed in the **animation window**.

5.1 Module 1: Subject

The software requires user to specify the subject to be detected or mission to be performed by the satellite. Users need to define the criteria for the subject to be viewed such as the coverage area and spatial resolution.


1 - Subject Characteristic - (help)

Target : padi crop
Subject : padi
Size of the subject : 0.02 m
The coverage area for your subject : 1000 m
The accuracy you wish to observe : 10 deg
Frequency of Observation : 16 per day
Height of the target : 350 m

Fig. 1 Excerpt from Subject Report

(5.2) Module 2: Orbital Design

The second module allows user to define important initial orbital parameters of a satellite orbit. The expected output of the process is a 2-D graphical simulation of the orbit based on the information gathered from user. User has an option to choose one of the following predefined orbits:

a) Critically inclined
b) Critically inclined sun synchronous
c) Geostationary
d) Molniya
e) Repeating ground trace
f) Repeating sun synchronous
g) Sun synchronous

or, a custom defined orbit.

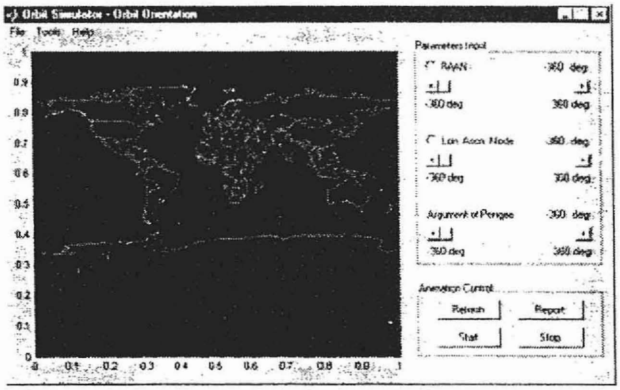


***Fig. 2** Orbit Orientation Module*

Only two input parameters are required to create a custom orbit. As such, the first parameter selected determines the input parameter needed in the second.

***Table 2** Available Pairs of Parameters*

First Parameter	Second Parameter
Semimajor axis	Eccentricity
Apogee Radius	Perigee Radius
Apogee Altitud	Perigee Altitud
Period	Eccentricity
Mean Motion	Eccentricity

Orbit plane changes can be viewed by choosing the kind of transfer orbit required, for example, Hohmann Transfer or Bielliptical Transfer.

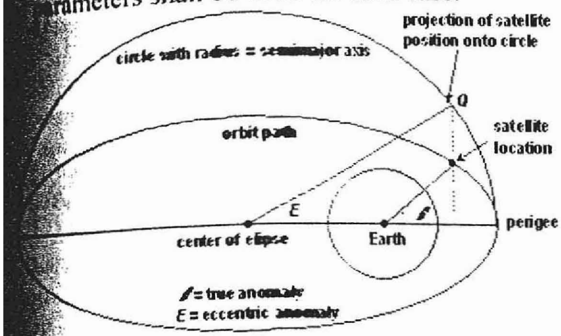
In order to view the orientation of the orbit plane in space, two Keplerian elements, represented by the following parameters, are required:

- Right ascension of the ascending node (RAAN): The angle in the Earth's equatorial plane measured eastward from the vernal equinox to the ascending node of the orbit,

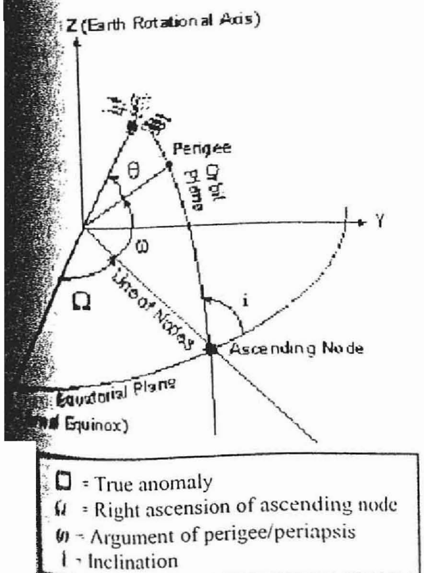
...itude of the ascending node: The Earth-fixed ...ude of the ascending node.
...ment of perigee: The angle, in the plane of ...tellite's orbit, between the ascending node ...the perigee of the orbit, measured in the ...ion of the satellite's motion.

...module will plot the satellite ground trace on ...surface according to the simulation time ... A full report on the result of orbital ...ons can be viewed at the end of the ...on.

...nge of parameters will be used to determine ...ite location above the earth. The following ...rameters shall be used for such case:



...3 *Parameters Determining Satellite Position*



...4 *Parameters Determining Orbit Orientation*

...f parameters determining satellite position:

Mean anomaly, Argument of Time past ascending node, Time past perigee.

(5.3)Module 3: Space Segment

Space segment module lets user to select suitable payload for the spacecraft mission and then to estimate payload's size. The software will calculate the aperture size and aperture ratio of the payload based on the wavelength and resolution required.

5.3 Module 4: Communication Architecture

In this module, the software will perform the link budget analysis for the specified mission, which is the command link budget and telemetry and data link budget.

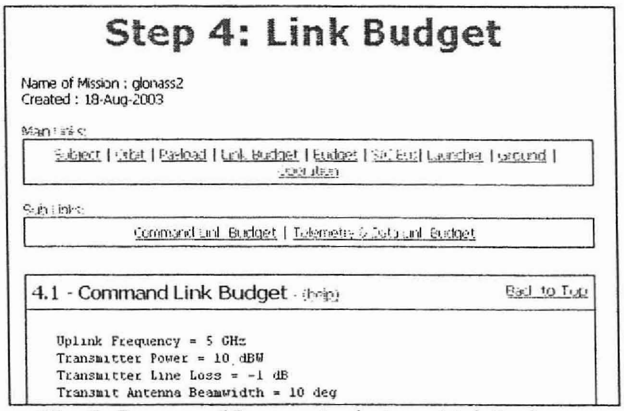


***Fig. 5** Excerpt of Report Analysis on Link Budget*

5.4 Module 5: Mass Budget

Two analyses will be done in this module, which are to calculate the power budget and the mass budget for the whole spacecraft. For this purpose, the payload power estimation calculated in the earlier module will be used. However, basic assumptions need to be made to calculate the approximations.

5.5 Module 6: Spacecraft Bus

In this module, users will be guided through the subsystems analysis: attitude determination and control, communication, command and data handling, power, thermal, structure, guidance and propulsion. In each subsystem analysis, the elements to be used or specified parameters are to be determined and calculated.

5.6 Final Result

All results from each module are stored in HTML documents during the process. Each HTML file contains the results from each module and all these files are stored in a folder created during runtime. As such, users can compare the results obtained from one mission to another for further analysis.

[6] VALIDATION AND VERIFICATION PROCESS

The validation and verification of the software is trivial in confirming that all requirements have been met and all design constraints discussed earlier are respected. In this process, each software module will be checked for validity of output, and consistency. The validation and verification plan shall be developed and carried out before the software can be deemed "qualified".

In conducting the process, the software shall be installed and evaluated in its operational environment, where the evaluation will be carried out by the software developers as well as prospective users. The results obtained from this software will be compared to the results obtained from other satellite software available in the market by using the same sets of data.

6.0 SOFTWARE APPLICATION

Currently, some parts of the modules have been identified for further enhancement to include more functionality and to be more user-friendly. Since the software is design for beginners in satellite mission design, a lot of default parameters will be incorporated where suitable. Enhancements need to be done as to minimize the number of assumptions made in order to get better results.

Among the modules that have been identified for further expansion are Orbital Design and Communication Architecture. All of these advance modules will be developed separately before being reintegrated in the main software. One of the advantages in this method is that these individual advance modules can be used separately in courses such as Orbital Mechanics and Satellite Communication. The software as a whole shall be used in Spacecraft Design courses.

7.0 CONCLUSIONS

The development of this software is carried out with respect to the needs of Astronautic Engineering students in learning the process of earth observation satellite mission design. Each software module developed has the potential to be made stand-alone to provide more functionality and to be used by more advanced users. Apart from being a teaching tool for lecturers in conducting their space mechanics related courses, the software is targeted to aid students in self-learning of the fundamental concepts of orbital mechanics as well as to enhance the programming skills of the students involve during the development process.

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