6 February 2012

English only

Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
Forty-ninth session
Vienna, 6-17 February 2012

International cooperation in the peaceful uses of outer space: activities of Member States*

I. Note by the Secretariat

1. In the report on its forty-eighth session, the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space made a recommendation, endorsed by the Committee on the Peaceful Uses of Outer Space at its fifty-fourth session (A/66/20), that the Secretariat continue to invite Member States to submit annual reports on their space activities (A/AC.105/987, paragraph 27).

2. In a note verbale dated 31 August 2011, the Secretary-General invited Governments to submit to the Secretariat their reports by 31 October 2011.

3. The present document was prepared on the basis of reports received from the following Member States after 31 October 2011: Thailand, Turkey (additional information).

4. The replies contained in the present document are original documents, as submitted, and were not formally edited.

* The present paper is reproduced in the form in which it was received.

II. Replies received from Member States

Thailand

[Original: English]

[17 January 2012]

Thailand Country Report

2011

In year 2011 is considering one of the most successful year for Thailand in space technology and applications, for example: the Thai delegations actively participated in many international forum. In addition, in April, Thailand hosted the 4th Board of Directors Meeting for Sirindhorn International Center for Geo-informatics during 4-5, 2011 in Phuket which consisting of participants from Wuhan University and Ministry of Science and Technology of Thailand. Thailand also hosted ASEAN Committee on Science and Technology-COST to the 6th Informal ASEAN Ministerial Meeting on Science and Technology on 17 December 2010, Krabi, Thailand. The Meeting adopted the report and the outcome shall be called the Krabi Initiative. The Meeting further agreed that Science, Technology and Innovation (STI) for a Competitive, Sustainable and Inclusive ASEAN shall be the theme for the Krabi Initiative. Consistent with the efforts to achieve the goal of establishing the ASEAN Community by 2015, the Meeting agreed the Krabi Initiative which identified eight thematic tracks as key areas to be pursued. Thailand also proposed ASEAN Earth Observation Satellite for ASEAN nations to be one of the Initiative.

Thailand is well aware that natural disasters appear to occur more frequent recently in Southeast Asia. Severities of those events may be due partly to natural causes or cycles but many were also happened by inadequate planning and unpreparedness. Earth observing system, comprising of optical and radar satellites, analytical models, and information communication network, had been proven to be very valuable technology during major flood events in Thailand in 2006, 2010 and lately 2011 in terms of prediction monitoring and assessment of inundated areas and damages as well as relief and rehabilitation. ASEAN as a region still needs satellite and observing system that is jointly owned or operated among member countries. Joint operation of a satellite in the form joint ownership where countries share cost of the entire satellite or in the form of joint mission whereby countries share cost of the basic platform but each country responsible for their own sensors on board are possible points.

Thailand through Geo-informatics and Space Technology Development Agency hopes that ASEAN EOS may not only serve the region but can also be the regional node that supports other developing regions that share similar restriction and constraints in space-based technology.

Besides, a number of workshops and trainings in space technology applications especially remote sensing and GIS were also organized to widen and strengthen the use of this technology in various fields. For the coming year 2012, Thailand schedules to jointly organize the Techno-mart and Inno-mart 2011 during 5-13 January in Bangkok. We cooperate with NASA and JAXA to promote space technology in this event as well.

We also maintain our use of space technology to decrease coastal erosion and land subsidence in Thailand. Many projects are conducted and integrated in many agencies concerned by compiling and using low up to high resolution satellite imageries from satellites – IKONOS, QuickBird, SPOT-5, Landsat 5, Terra/Aster and Terra/Modis, along with NOAA. Appreciation and thanks to these service providers.

Satellite imageries and interpretation maps are in both digital and hard copy forms. Hopefully, all fruitful outcomes will be well organized and pave a way to all necessary measures to handle not only disasters but also for our well being of all human kind. Of course, space technology and the applications will definitely play a vital role on this aspect.

Lastly, Thailand, one of the members of COPUOS community, wish all space technology and applications which contributed to the forum, from all members help the world reduce, or even stop, any adversely affected in the very near future for the happiness of mankind.

Attachment

Space Activities Report

by

Geo-Informatics and Space Technology Development Agency (GISTDA)

THAILAND

INTRODUCTION

Geo-informatics and Space Technology Development Agency or GISTDA, the public organization was established on 3rd of November in 2000 so as to enhance the utilization in remote sensing as well as GIS and be responsible for all space concerning activities of the state. One of those is to operate Thailand Earth Observation Satellite (THEOS), which was put into operation in 2008.

So as to operate THEOS, The Ground Control Segment (GCS) was set up consisting of 4 divisions, SCC (Satellite Control Center), MPC (Mission Planning Center) S-band Station and ***OSpA (Orbit and Space object Analysis division)***, which is responsible for Orbit Determination, Station Keeping, OCM Maintenance Maneuver and Collision Avoidance. Aside from those, OSpA is also conducting researches and developments for pursuit of excellence activities.

And, as we are moving on our research subjects as mentioned, we also realized the importance of passing on the knowledge. For this reason, we have issued publications and technical articles as followed; THEOS Ground Track Maintenance, Collision Avoidance Strategy and Introduction to Satellite Operation which are purposely not only to distribute space concerning knowledge, but also motivate and introduce the passionate one into the space engineering.

CHAPTER

Chapter: 1. Closed Approaches of Space Debris or Space Objects

1.1 Space Debris or Space Objects

Since 2010, Flight Dynamics System (FDS) of THEOS spacecraft on behalf of OSpA under Geo-Informatics and Space Technology Development Agency (GISTDA) has been collaborated the space conjunction surveillance cooperation with Center for Space Standards and Innovation (CSSI) and Joint Space Operations Center (JSpOC) under U.S. Air Force. The daily closest approaching report has been informed by Dr. T.S. Kelso, a senior research astrodynamicist for Analytical Graphic, Inc. (AGI)'s CSSI. All of space objects within 5 km from THEOS spacecraft has been daily reported by cooperative with CSSI and their information is analyzed by OSpA as following in figure 1 (example: July – September 2011).

From figure 1 has exactly shown quantity of space debris within 4 km of THEOS spacecraft radius and notified the closest approaching of 4 space debris ordered the distance of 219, 206, 158 and 30 meters respectively as shown in figure 1.

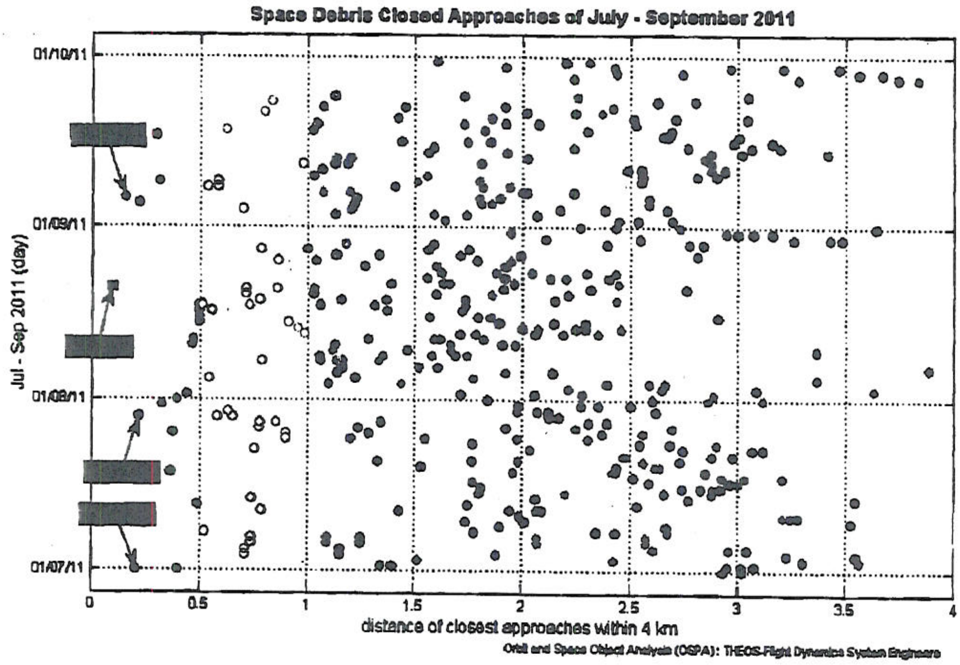

Figure 1. Space Debris Closed Approaches of July – September 2011 which was analyzed by OSpA

From figure 1 has exactly shown quantity of space debris within 4 km of THEOS spacecraft radius and notified the closest approaching of 4 space debris ordered the distance of 219, 206, 158 and 30 meters respectively as shown in figure 1.

Joint Space Operations Center (JSpOC) under U.S. Air Force has also kindly notified the closed approach of a space object which possibly approaches by less than 1 km of overall miss distance and less than 200 meters in each direction of RIC frame. OSpA has collected the statistics of space object closed approaches within 5km into data based system and analyzed the trajectory of them. Satellite tracking software that we have is intelligent space tracking software which is useful for collision avoidance analysis by adding TLE.

1.2 Strategy of Collision Avoidance Manoeuvre

OSpA has studied the research of how to procedure when the risk of collision is coming. Because of collision avoidance manoeuvre suddenly appears whenever received the notification from JSpOC. To carefully prepare the procedure is very necessary. So, the strategy of collision avoidance manoeuvre has been researched since 2010. The diagram of collision avoidance system is shown in figure 2.

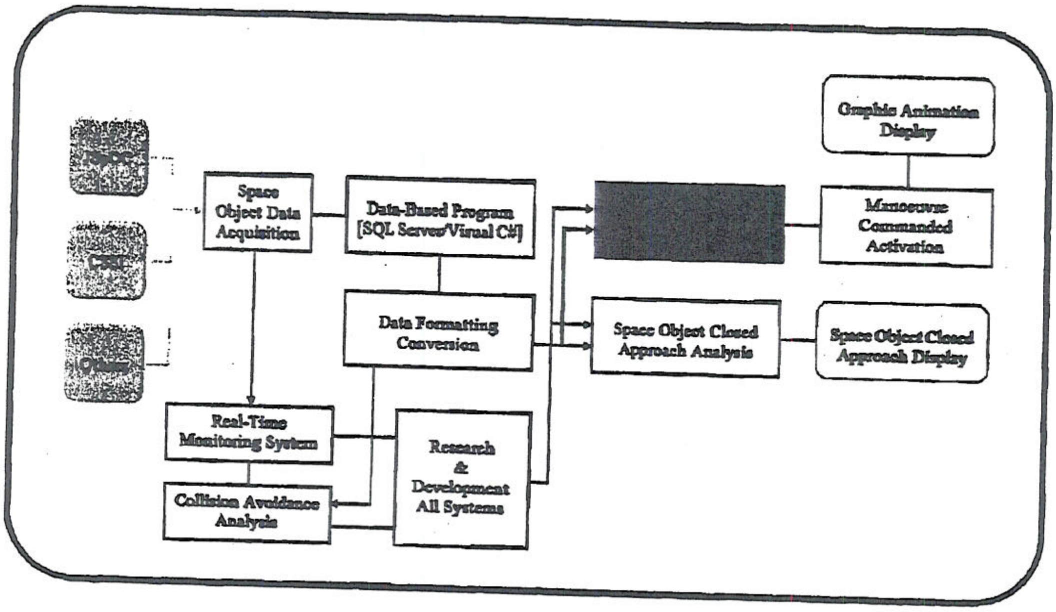

Figure 2. THEOS Collision Avoidance Structure

JSpOC and CSSI are primary data sources of collision awareness notification. All information will be kept into the data-based program by using SQL Server/Visual C#. And then, the interested data will be sent to the collision avoidance strategy and manoeuvre commanded activation respectively. The collision avoidance strategy is the strategy which is consists of 4 procedures and each procedure has a few steps hereafter:

- Deep analysis of collision awareness notification
- Performing the avoidance manoeuvre strategy
- OCM planned testing and sending
- Updated new configuration and status checking

The diagram of collision avoidance strategy is shown in figure 3. This research had been International conference of aeronautics and astronautics engineering with WASET academy. (the dept detail of strategy processing look in http://www.waset.org/journals/waset/v76/v76-22.pdf)

The research conducting plan is demonstrated as follows;

<u>Internal factors</u>

- THOES propellant systems
- Other systems

<u>External factors</u>

- Earth gravitational pull
- Earth magnetic field
- Solar activities

As of now, we are working on collecting propellant data as well as other parameter such as time which data was collected, GPS position, velocity and attitude which may have a contribution during the time of analysis.

To start the phase of data analysis, we have planned to pay our attention on internal factors first since they can be analyzed based on the information we have collected up to now, besides the satellite own instruments are likely to have more effect comparing to those from outside, in our opinion. We are going to make an analysis on the design of THEOS propellant systems including tank, feed lines, Pressure and Temperature measuring sensors, injectors, etc. and also other instruments nearby in order to find their influence on propellant quantity. However, the external factors like gravity, magnetic field and solar activities will be taken into consideration and analysis since then. The summary of this is still hold in process.

SUMMARY

The significant points is to report what we have we research. Actually, we still have a few of activities that we can't describe because of more detail, but the importance researches have been revealed. If we will be obtained something is worth for research adjustment or any advices, we would be appreciate.

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Mr. Ammarin PIMNOO : Flight Dynamics Engineer/Space Analysis Engineer/Author/Researcher
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Attachment.

The Satellite Collision Avoidance Strategy for THEOS Satellite

Ammarin Pimnoo

Abstract—In recent years number of space objects, which are increasing continuously not only fulfil in the space of the earth atmosphere orbitally as space pollution but also have been rising probability of satellite collision between a space debris and an own satellite or a satellite and another satellite whatever are becoming more likely. Either satellite orbit determination or satellite tracking software is facility of orbit determination and accuracy satellite ephemeris prediction. So, it hardly misses a satellite visibility appointment. Nevertheless, the satellite collision avoidance is a critical event after foreseen computation occurring high probability of satellite collision. Inevitably, the collision avoidance activity has to actively manage a necessary strategy to safely avoid the risk of collision. Unfortunately, in the real action of flight dynamics engineering operators, FDS engineers can scarcely be able to know or predict either what the type of space object is coming closely or where the direction is from.

THEOS is the first earth observation satellite of Thailand which is worthy of growing space technology and space education learning for Thais. So, the prevention of damaged spacecraft is necessary. The United Sates Joint Space Operations Center (JSpOC) and the Center for Space Standards & Innovation (CSSI), which are the space surveillance organization, have usually sent receipt of collision awareness, in the detail of Time of Closest Approach (TCA), to other countries. This paper is to develop a satellite collision avoidance strategy for THEOS spacecraft which is to perform procedures of satellite collision avoidance including Orbit Control Manoeuvre (OCM) plan taking into account of propellant fuel depletion. The strategy consists of 4 steps after the collision awareness monitoring. Absolutely, the first step is to deeply analyze the collision awareness notification warned by JSpOC and CSSI. This step is to analyze and determine the probability of satellite collision from the JSpOC or CSSI receipt. The second step is to perform the risk of collision avoidance manoeuvre strategy from conditional method by collaborative with expert engineers from ASTRIUM. After the second step, OCM plan will be sent to simulate the result using Satellite Simulator, meanwhile the THEOS ephemeris will be sent to JSpOC or CSSI for accuracy checking the result of collision avoidance manoeuvre. Then, the OCM plan will be sent to spacecraft on time. Finally, the status will be normally checked for efficiency calibration and will be updated new configuration. Then, FDS engineers will specially check the result of collision avoidance with own receipt by THEOS ephemeris propagated. However, these steps will be finalized by using the strong constrains and have been consistently solved with the propellant fuel depletion for saving the life-time of THEOS.

Keywords—Satellite Collision Avoidance, JSpOC, CSSI, Orbit Control Manoeuvre Plan, THEOS

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I. Introduction

SPACE Surveillance Network (SSN) has been tracking space objects since 1957 when the Soviets opened the space age with the launch of Sputnik I. Since then, the SSN has tracked more than 24,500 space objects orbiting Earth. Of that number, the SSN currently tracks more than 8,000 orbiting objects. The rest have re-entered Earth's turbulent atmosphere and disintegrated, or survived re-entry and impacted the Earth. The space objects now orbiting Earth range from satellites weighting several tons to pieces of spent rocket bodies weighing only 10 pounds. About seven percent of the space objects are operational satellites, the rest are debris. USSPACECOM is primarily interested in the active satellites, but also tracks space debris. The SSN tracks space objects which are 10 centimeters in diameter (baseball size) or larger.The SSN provides the information to the Joint Space Operations Center (JSpOC), which has the mission to detect, track, identify, and catalog all man - made objects in Earth orbit. Air Force Space Command (AFSPC) provides the personnel, training, maintenance, and long - term acquisitions for most of the SSN sites. Surveillance data from the sensors is routed to the JSpOC, located at Vandenberg, Air Force Base, California. The JSpOC is part of United States Strategic Command (USSTRATCOM) and has operational command and control of the SSN. The JSpOC fuses the SSN data with other sources to provide Space Situational Awareness (SSA) for the US military and other customers. This SSA data is used to maintain the satellite catalog, predict atmospheric re - entry of space objects, catalog new launches, detect satellite maneuvers, and safeguard important satellites such as the International Space Station and Shuttle.

II. Theos History of Collision Avoidance

On the 13th December 2010, JSpOC had formally warned the high probability of closed approach between THEOS spacecraft and KNOWN OBJECT via official e-mail. The JSpOC warning notification had clarified in detail of time of closest approach on the 15th December 2010 at 6:07 UTC and overall miss distance consisted of Radial, In-Track and Cross-Track miss distance as well as other detail of specific characteristic of their two satellites.

In the critical time, THEOS flight dynamics engineers had immediately analyzed detail of the notification and possibility of collision avoidance manoeuvre with ASTRIUM expert satellite orbit engineers. Although JSpOC had usually sent the notifications, THEOS engineers had not ignored a once. And this time, THEOS & ASTRIUM engineers had cooperative analyzing the collision avoidance manoeuvre thoroughly in the detail of RIC frame before THEOS collision avoidance manoeuvre decided on the 15th December 2010 at 3:35 UTC.

III. Collision Avoidance Analysis

Detailed the RIC frame [1], the relative ephemeris of the assigned object with respect to the primary object expresses in cartesian coordinates as a function of time. The relative ephemeris is computed with respect to two rotating frames which are the RIC (Radial, In-Track and Cross-Track) frame and the NTC (Normal, Tangential and Cross-Track) frame. The two rotating frames are defined using the primary's ephemeris. Cross-Track refers to the direction perpendicular to the position and inertial velocity, In-Track refers to the direction perpendicular to both the Radial and Cross-Track (positive in the direction of motion), Tangential refers to the direction along the velocity vector and Normal refers to the direction perpendicular to the velocity and Cross-Track directions (positive outward along radial). This frame is useful for displaying the difference between two orbits in the Radial, In-Track and Cross-Track directions. To obtain the transformation between the ECI (Earth Center Interval) and RIC frames is shown hereafter (assume, given the position and velocity in the ECI frame):

$$\bar{r} = X\bar{i} + Y\bar{j} + Z\bar{k}, \qquad (1)$$

$$^{ECI}\dot{\bar{r}} = \dot{X}\bar{i} + \dot{Y}\bar{j} + \dot{Z}\bar{k}, \qquad (2)$$

$$\bar{h} = \bar{r} \times {}^{ECI}\dot{\bar{r}}, \qquad (3)$$

and

$$\bar{R} = \frac{\bar{r}}{|\bar{r}|} = \frac{X}{r}\bar{i} + \frac{Y}{r}\bar{j} + \frac{Z}{r}\bar{k}, \qquad (4)$$

$$\bar{C} = \frac{\bar{h}}{|\bar{h}|} = \frac{\bar{r} \times {}^{ECI}\dot{\bar{r}}}{|\bar{r} \times {}^{ECI}\dot{\bar{r}}|}, \qquad (5)$$

$$\bar{I} = \bar{C} \times \bar{R} \qquad (6)$$

Or in matrix notation

$$\begin{bmatrix} \bar{R} \\ \bar{I} \\ \bar{C} \end{bmatrix} = \begin{Bmatrix} R_x & R_y & R_z \\ I_x & I_y & I_z \\ C_x & C_y & C_z \end{Bmatrix} \begin{bmatrix} \bar{i} \\ \bar{j} \\ \bar{k} \end{bmatrix} \qquad (7)$$

Define

$$\beta_{RIC}^{ECI} = \begin{Bmatrix} R_x & R_y & R_z \\ I_x & I_y & I_z \\ C_x & C_y & C_z \end{Bmatrix} \qquad (8)$$

Hence, the c[...]omputed from coordinate in th[...]ansformation.

$$\begin{bmatrix} R \\ I \\ C \end{bmatrix} = \beta_{RIC}^{ECI} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}, \quad \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [\beta_{RIC}^{ECI}]^{-1} \begin{bmatrix} R \\ I \\ C \end{bmatrix} \qquad (9)$$

In case of two orbits analyzing in the RIC frame, basically designate one orbit as the reference orbit and call the position and velocity in the orbit $\bar{r}*$ and $^{ECI}\dot{\bar{r}}*$ respectively. Then, use equation (4), (5), (6) and (7) to compute the unit vectors $\bar{R}$, $\bar{I}$ and $\bar{C}$ and β_{RIC}^{ECI} following hereafter:

$$\begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} = [\Delta\bar{r}]_{ECI} = [\bar{r}* - \bar{r}]_{ECI} \qquad (10)$$

Then use (9) to compute differences in the Radial, In-Track and Cross-Track directions in position and velocity hereafter.

$$\begin{bmatrix} \Delta R \\ \Delta I \\ \Delta C \end{bmatrix} = \beta_{RIC}^{ECI} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}, \quad \begin{bmatrix} \Delta\dot{R} \\ \Delta\dot{I} \\ \Delta\dot{C} \end{bmatrix} = \beta_{RIC}^{ECI} \begin{bmatrix} \Delta\dot{X} \\ \Delta\dot{Y} \\ \Delta\dot{Z} \end{bmatrix} \qquad (11)$$

In the critical time of JSpOC awareness, the notification that received on the 13th December 2010 showed the primary detail of RIC frame hereafter:

Primary Object: THEOS (SCC# 33396)
Secondary Object: KNOWN OBJECT
Time of Closest Approach: 15 DEC 2010 06:07 UTC

Overall miss distance: 80 meters
Radial (dU) miss distance: 75 meters
In-Track (dV) miss distance: 2 meters
Cross-Track (dW) miss distance: 31 meters

Primary Radial Error (U): 0 meters
Primary In-Track Error (V): 0 meters
Primary Cross-Track Error (W): 0 meters

Secondary Radial Error (U): 64 meters
Secondary In-Track Error (V): 1202 meters
Secondary Cross-Track Error (W): 99 meters

Following by the detail, the distance of In-Track miss distance was so closed approach much and seemed high risk of spacecraft collision. ASTRIUM expert satellite orbit engineers had accurately computed deciding of collision avoidance manoeuvre by using the collision avoidance condition. ASTRIUM recommends an avoidance manoeuvre doing hereafter:

$$Radial\_dist < Radial\_err \qquad (12)$$

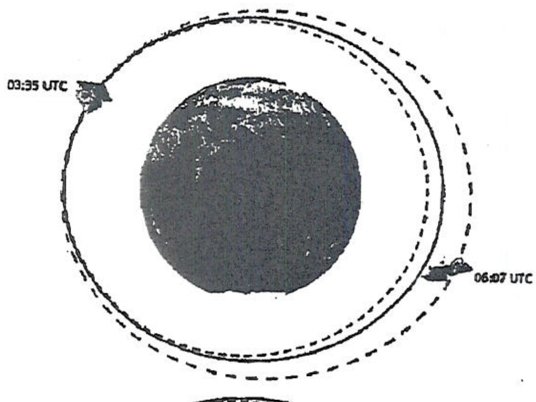
$$\begin{aligned} Radial\_err = {} & 3*Pri\_Radial\_err \\ & + 3*Sec\_Radial\_err \\ & + Radius\_Pri \\ & + Radius\_Sec \end{aligned} \qquad (13)$$

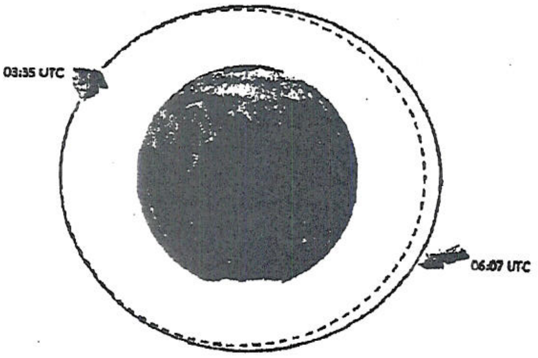
Denotes:

Radial_dist = Radial (dU) miss distance
Pri_Radial_err = Primary Radial Error (U)
Sec_Radial_err = Secondary Radial Error (U)
Radius_Pri = Radius of Primary (m)
Radius_Sec = Radius of Secondary (m)

KNOWN OBJECT which was unknown object and what kind of the spacecraft was, was estimated the radius of its. The condition (12) was used to check deciding of an avoidance manoeuvre by estimating 5m of radius secondary. From (12), can compute herewith $75 < 3*0 + 3*64 + 3 + 5$ (3m of primary radius). Absolutely, $75 < 200$ is in loop of avoidance manoeuvre condition, so the collision avoidance manoeuvre activation started.

The manoeuvre was performed on the 15th December 2010 at 3:35 UTC and would be performed 1/2 orbit prior to the conjunction time. For understanding in the strategy of collision avoidance manoeuvre, illustrate in Figure below.





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$$\Delta SMA = (Radial\_err - Radial\_dist)/2 \qquad (14)$$

Specially, (14) had to take into account manoeuvre 5% over/under performance in a single impulsion half an orbit before the conjunction time.

Simply Gauss Equation, Delta $V_{(t)} = +/-$ delta $a/(2a)*V_{(sat)}$, this is the minimum manoeuvre size. However, it can be changed to ensure more margins.

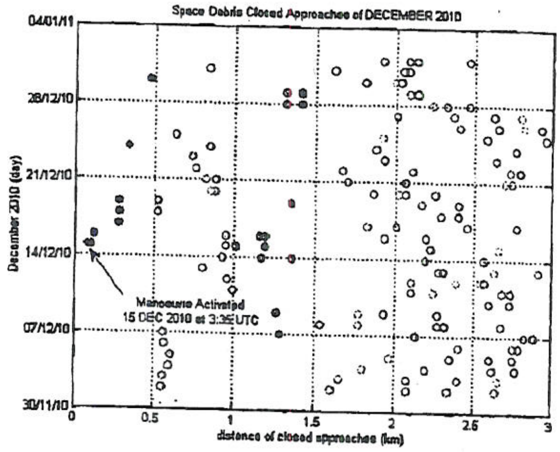

Fig. 2 is quantity of all space objects that closed approach with THEOS spacecraft within 3km [December 2010, Space Object Statistical Report]

IV. THEOS COLLISION AVOIDANCE STRATEGY

Straightforwardly, Geo-Informatics and Space Technology Development Agency (GISTDA) who assigned, created and spent the THEOS spacecraft project has not any RADAR surveillance, satellite surveillance or something like that and THEOS spacecraft is an optical LEO-satellite. Therefore, THEOS-Flight Dynamics System (FDS) engineers have collaborative with JSpOC and Center for Space Standards & Innovation (CSSI) via SOCRATES-LEO software website by Dr. T.S. Kelso, senior research astrodynamicist for analytical graphics, who significantly participates with providing commercial off-the-shelf analysis and visualization solutions to more than 30,000 aerospace, defense, and intelligence professionals via the Satellite Tool Kit (STK) software suite.

The JSpOC and CSSI have kindly sent the collision awareness notification to THEOS-FDS engineers by official email when a space object closed approaches with THEOS. In fact, JSpOC will send the notification when a space object is closed coming and CSSI has daily sent when any space objects closed coming within 5km (by own satellite asking).

THEOS-FDS engineers under the Orbit and Space Object Analysis Sub-Division of GISTDA recently build the Center of THEOS and Space Objects Collision Surveillance & Defensive which is the simplified architecture in figure 3 below.

This paper only describes inside of the Collision Avoidance Strategy Block-diagram. As mentioned in title, a collision risk can be treated at any time. The strategy consists of 4 procedures and each procedure has a few steps hereafter:

- Deep analysis of collision awareness notification
- Performing the avoidance manoeuvre strategy
- OCM planned testing and sending
- Updated new configuration and status checking

As figure 4 of Collision Avoidance Strategy Block-diagram below:

A. Deep analysis of collision awareness notification

First of criterion is to review an awareness notification. If overall miss distance less than 500 m, the notification will be drag into SCAS-THEOS procedures. This step is to thoroughly review the notification which has passed the first criterion. Detail of RIC frame, coordinates of two satellites is useful to check their position and velocity. Two-Line Element may be attached with the notification. TLE or ID number of the approaching satellite is useful to consider their position, velocity, date&time with satellite tracking simulation program (JSatTrak version 4.1.3).

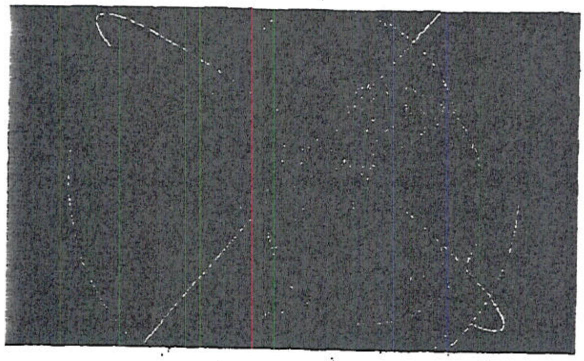

Fig. 5 Sample of Satellite Tracking program

Final of this step is the second of criterion which is limitation of Radial, In-Track and Cross-Track miss distance. Actually, the overall miss distance is from basic geometry mathematical which showed hereafter:

$$Overall\ miss\ distance = \sqrt{R^2 + I^2 + C^2} \quad (14)$$

Practically, some of RIC coordinates might less than 100 m, though the overall miss distance has higher value. So, the criterion 2 is necessary condition.

B. Performing the avoidance manoeuvre strategy

The next step is to determine preliminary Orbit Control Manoeuvre (OCM) plan. Here is to expectedly determine delta semi-major axis (ΔSMA) and what kind of avoidance manoeuvre is (such as ascending or descending etc.). THEOS-FDS engineers are usable QUARTZ++, an official orbit determination program from ASTRIUM, to determine and implement the OCM planning. So as to determine ΔSMA which will be computed by using ASTRIUM criterion (12), the first step of OCM planning module of QUARTZ++, *Initial Guess Module*, which is to determine ΔSMA and plot a simply graphical simulation of ground track evolution after manoeuvre activated, will be neglected. QUARTZ++ will implement delta velocity (ΔV_T, ΔV_N and ΔV_W) and time-tag command. Nevertheless, the quantity of velocity depends on kind of manoeuvre such as *minimize impact on eccentricity* or *target frozen eccentricity*.However, a collision avoidance manoeuvre will be likely either ascending or descending. Due to escape to the left or right, manoeuvre would be done in the orbital plane which could be used more propellant and expensive. The next section is estimated fuel consumption which is the cost function of consideration avoidance manoeuvre.One of manoeuvre strategies mentioned: To go from one orbit to another secant with the first, one impulse is enough. It is done at the intersection point between the two orbits as illustrated in figure 6.

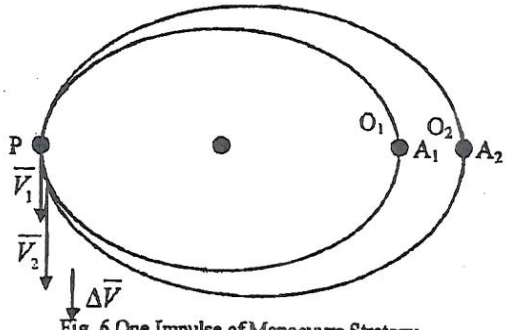

Fig. 6 One Impulse of Manoeuvre Strategy

Another one of manoeuvre strategies mentioned: To go from one orbit to another not secant with the first, it takes at least two impulses as illustrated in figure 7.

The last procedure of this step is to send a predicted ephemeris file to own notification for status checking. After preliminary OCM planning has been finished, the propagated ephemeris would be sent to own notification by reformatted to them for check status. Possibly, the chosen escaping way might be hit by other space object.

C. OCM planned testing and sending

Seriously, this step needs a manoeuvre for avoiding the space obstacle. OCM process [4] has shown hereafter:

- Check the result of SK prediction for both parameters
- OCM planning / generation
- OCM simulation
- Technical meeting with ASTRIUM
- Upload OCM plan to satellite
- Thruster calibration / Update new configuration (satellite position / GPS)
- Propellant accounting / Update new configuration (Tank temperature / pressure)

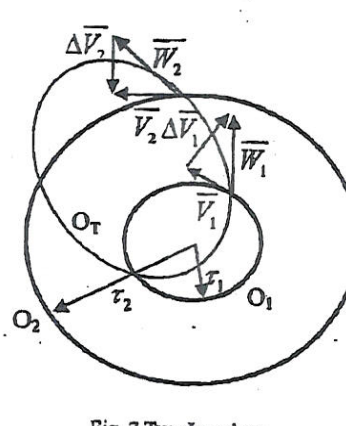

Fig. 7 Two Impulses

ASTRIUM agreement of collision avoidance manoeuvre, the 4th criterion, has been finalized before OCM time-tag commanded sending to the spacecraft.

D. Updated new configuration and status checking

The last step is to update new configuration such as all physical states, remaining fuel or spacecraft weight changed etc. and send data to ASTRIUM for performance monitoring. One thing that is very importance is to send propagated ephemeris file to own notification for check status again. However, it is possible that recently avoiding manoeuvre may be approaching to another space object. So, the 2nd step is seriously analyzed what the status after avoidance manoeuvre done will be.

V. ESTIMATED FEUL COMSUMPTION

THEOS spacecraft was carefully designed for using 5 years of long life time along with hydrazine fuel 77.1 kg in the first injection. It was successfully launched in the 1st October 2008 [5] and used 28 OCMs within 14 days for transfer phase.

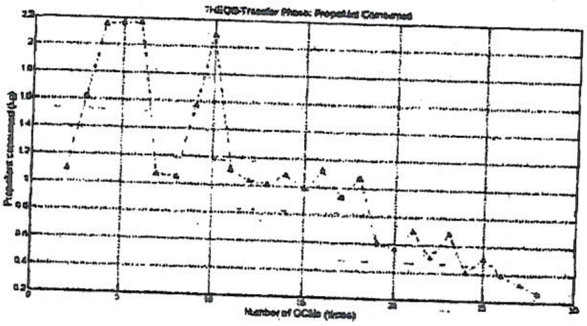

Fig. 8 THEOS Transfer Phase: Propellant Consumed

In case that previous mission plan uploaded to satellite was an orbit maintenance plan, it is interesting to estimate the propellant mass after thrust using the propulsion tank telemetries parameters (temperature and pressure). As pre-requisite, FDS engineering operators would like to ensure that the tank pressure and temperature have been updated and propagated by Satellite Control Centre (SCC) through Satellite Configuration activity and according to the values resulting from the Tank_Check procedure execution. However, propellant mass accounting could be solved by using basic method of propulsion hereafter:

$$PV/T = cte \qquad (15)$$

$$V_{helium}^{current} = cte * T/P \qquad (16)$$

$$V_{propellant}^{current} = V_{Tank} - V_{helium}^{current} \qquad (17)$$

$$M^{current} = V_{propellant}^{current} * 1012.0698 \qquad (18)$$

These equations used to compute remaining propellant mass (kg). So, updating configuration after thrust is necessary especially temperature and pressure.

Following by OCM statistical, delta velocity (V_T, V_N and V_W) is mainly factor of emission propulsion.

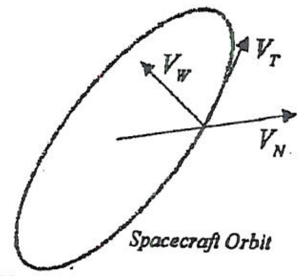

Fig. 9 Vectors of Velocity in Orbital Plane

As ground track correction or inclination correction manoeuvre, delta V_T and V_W is primary respectively. However, collision avoidance manoeuvre depends on the route to be used to evade, that means the delta velocity is not the point but they are an importance part in the consideration for fuel depletion. Following by remaining propellant accounting method (15)-(18), may be inaccurate because of emperature and pressure instability. OCM Statistical is useful or calculation in advance (see Table I). THEOS has 35 manoeuvres maintenance with in-plane, out-of-plane and combine manoeuvres since 1st October 2008 till this present. In Table I, OCM 1-2, OCM 3-4, OCM 5-6, OCM 9-10, OCM 9-30 and OCM 31-34 are working at the same time. In etail, OCM 1-28 use 14 days of transfer phase by ASTRIUM ngineers, OCM 29-30 is the first ground track maintenance manoeuvre [4] and OCM 31-34 is the second maintenance manoeuvre of inclination correction by THEOS-FDS ngineers. The last OCM is the collision avoidance manoeuvre s mentioned above.

TABLE I
THEOS OCM STATISTICAL
DELTA VELOCITY WITH PROPELLANT CONSUMED

No. of OCM	DV_T (m/s)	DV_N (m/s)	DV_W (m/s)	Propellant Consumed (kg)
OCM 1	1.96198	0.00631	0.00883	-
OCM 2	1.96935	0.02616	0.00804	1.0930
OCM 3	3.46885	0.01173	0.01625	-
OCM 4	3.53533	0.01661	0.00476	2.1480
OCM 5	3.44936	0.04324	-0.01340	-
OCM 6	3.53489	-0.00760	0.02318	2.1630
OCM 7	3.37875	-0.00394	-0.47303	1.0690
OCM 8	3.44705	0.11558	-0.47303	1.0500
OCM 9	3.35813	0.06715	0.49662	-
OCM 10	3.40944	0.04114	0.49626	2.0860
OCM 11	3.38853	0.02179	0.01700	1.1080
OCM 12	3.40655	-0.05095	0.02266	1.0330
OCM 13	3.39364	-0.07049	0.00813	1.0150
OCM 14	3.41800	0.05982	0.01679	1.0830
OCM 15	3.37506	0.00324	0.00477	0.9900
OCM 16	3.37481	-0.00115	-0.02317	1.1260
OCM 17	3.37459	0.01615	0.00547	0.9310
OCM 18	3.37539	0.01019	0.00709	1.0710
OCM 19	1.99986	-0.00089	0.00448	0.6080
OCM 20	1.86994	0.00501	0.00078	0.5710
OCM 21	2.20012	-0.01077	0.00432	0.6990
OCM 22	1.89973	0.04115	0.00509	0.5150
OCM 23	2.11558	0.05504	0.00188	0.6870
OCM 24	1.37054	0.03078	0.01701	0.4110
OCM 25	1.47573	0.03033	0.00099	0.5090
OCM 26	1.48164	0.01045	0.00435	0.3890
OCM 27	0.91711	-0.07054	-0.00344	0.3220
OCM 28	0.93543	-0.00678	0.02037	0.2620

OCM 29	0.00838	0.05733	-0.00106	-
OCM 30	-0.04795	-0.00681	-0.01199	0.0286
OCM 31	0.02047	-0.00132	-2.95875	-
OCM 32	0.01959	-0.01083	-2.95800	-
OCM 33	0.02078	-0.00413	-2.96405	-
OCM 34	0.02310	-0.00765	-2.94239	3:7533
OCM 35	-0.03661	-0.02602	-0.01158	0.0200

From Table I, we found the relationship of OCM statistical data between magnitude of all direction of delta velocity and propellant consumed as figure 10.

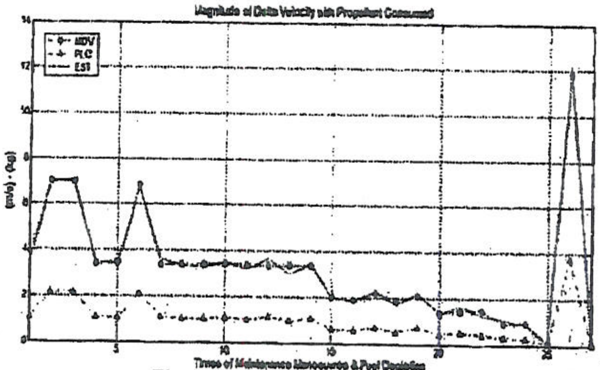

Fig. 10 Magnitude of Delta Velocity with Propellant Consumed and Estimated Cost Function

From fig. 10, is to graphically compare between magnitude of delta velocity (MDV) and propellant consumed (PLC) as OCM statistical data in Table I. Straightforwardly, the relationship between MDV&PLC explicitly shows in the figure. In this case, we have to estimate the ratio of fuel to speed as EST in the figure by using the following formula.

$$EST_j = \frac{\sum_{i=1}^{N} MDV_i}{\sum_{i=1}^{N} PLC_i} * PLC_j \qquad (19)$$

Following by the equation (19), the result of the estimated the ratio of fuel to speed (EST) shows the accuracy of fuel depletion estimation that the magnitude of velocity 3.25386 m/s burnt a kilogram of hydrazine fuel, or 1 m/s per 0.30733 kg as OCM statistical. In this case, we have not negligent the performance of the loss rate. RMS or root mean square method is used to find the error percentages.

$$RMS = \frac{\sum_{i=1}^{N} \sqrt{(PLC - EST)^2}}{N} * 100 \qquad (20)$$

From (20), the error is about 13% that means the error of the loss rate is 3.25386 ± 0.12963 m/s.Estimated fuel consumed is an importance factor of satellite collision avoidance strategy which is used to compute in the step of the performing the avoidance manoeuvre strategy.

VI. Conclusion

The United Sates Joint Space Operations Center (JSpOC) and the Center for Space Standards & Innovation (CSSI), which are the space surveillance organization, have usually sent receipt of collision awareness, in the detail of Time of Closest Approach (TCA), to other countries. This paper is to develop a satellite collision avoidance strategy for THEOS spacecraft, after the first collision avoidance manoeuvre of THEOS with KNOWN OBJECT on 15 DEC 2010, which is to perform procedures of satellite collision avoidance including Orbit Control Manoeuvre (OCM) plan taking into account of propellant fuel depletion. All 4 steps of the strategy as mentioned above are special procedures without daily routine and maintenance manoeuvre. Each step can be brief to improve the performance and to reduce a gap of repetitive working. After the strategy finished, we still do not have the strategy to step two but JSpOC has often sent the risk notifications to us about 2-3 warning.

In the future work, a routine template of THEOS-SCAS will be built and applied to use in each time of warning from JSpOC. And then, we will summarize an annual space objects approaching (as example in figure 11) with THEOS and estimate the fuel consumption for lifespan of THEOS.

Acknowledgements

1. *JSpOC:* for the provided screening and detailed data and the continuous technical support in understanding them and using them as well as possible.

2. *CSSI:* for the daily provided screening all space objects within 5 km far from THEOS spacecraft and the kind continuous technical support in understanding them and sending all ephemeris of those space objects approaching via LEO-SOCRATES: Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space.

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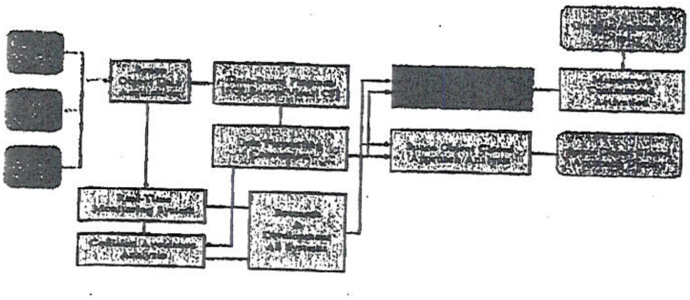

Fig. 3 The Center of THEOS and Space Objects Collision Surveillance & Defensive

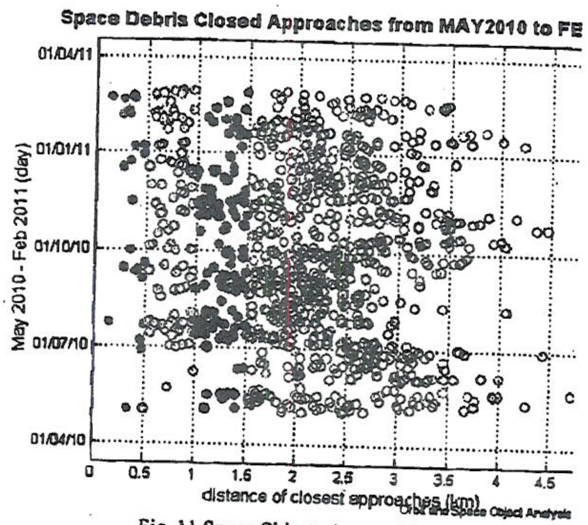

Fig. 11 Space Objects Approaching

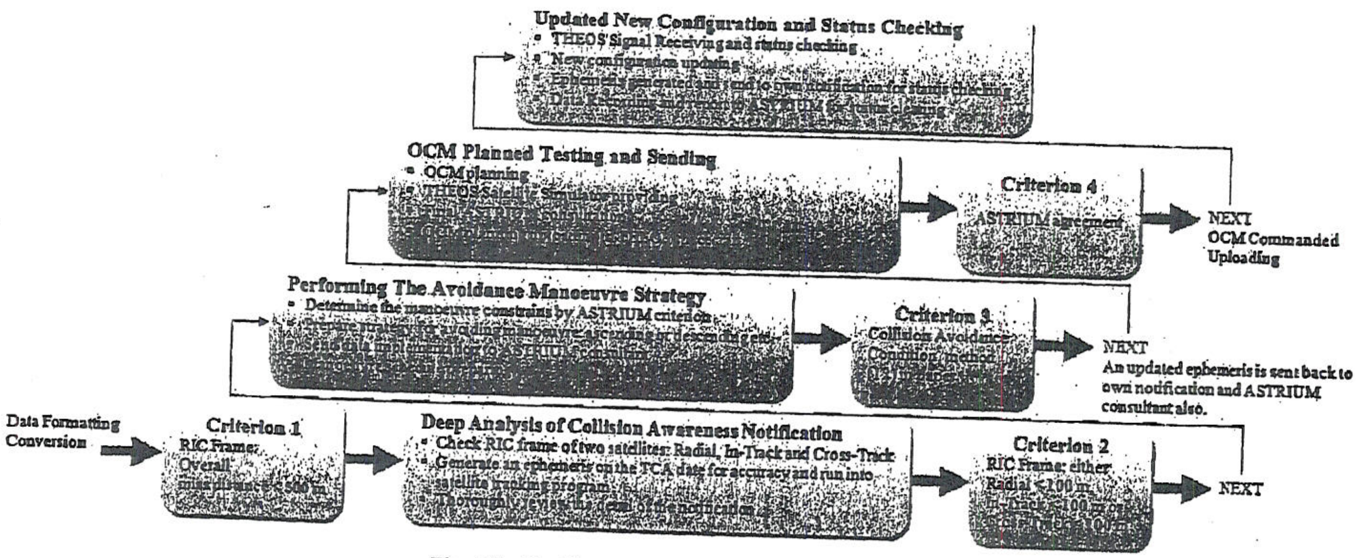

Fig. 4 The Satellite Collision Avoidance Strategy for THEOS satellite (SCAS-THEOS)

Turkey

[Original: English]

[8 December 2011]

Report prepared by the Faculty of Aeronautics and Astronautics of Istanbul Technical University

Activity Report for Committee on the Peaceful Uses of Outer Space

1. In the Space Systems Design and Test Lab, a class 1000 clean room and a thermal-vacuum chamber is used to simulate the space conditions. The tests are performed in accordance with the related projects.
2. In the Satellite Communication Lab, the hardware and software infrastructures related to the moving antenna system used for communicating with satellites, and a part of the tests for antenna pointing and satellite communication are completed in the context of the studies to realize the infrastructure which will maintain the communication with the other and our (ITUpSAT) cubesats. It is planned to act together with the Global Educational Network for Satellite Operations (GENSO). By means of the ground station established in the Department of Astronautical Engineering, ITU, the identification signal of the ITUpSAT launched on September 23rd, 2009 is still received.
3. The project supported by TURKSAT A.S., the development of TURKSAT-3USAT satellite which has a communication payload and will be sent to low orbit is still in progress. The satellite is developed with the contribution from the other departments of ITU (Electric and Electronics and Machine) and is planned to be ready to launch in mid 2012.
4. On October 2011, a project proposal for manufacturing a two-unit cubesat is submitted to TUBITAK. This project, abbreviated as QB50 will contribute to an international project led by Von Karman Institute of Belgium. During the project, numbers of cubesats will be produced by the distinguished education and research institutions in the world, and then the satellites will be launched to space by a single launching rocket in order to study the lower parts of the thermosphere.
5. A course on Cubesats has been created in order to educate and train the interested domestic and foreign organizations. This course has been given to a team from SUDAN.
6. The activities devoted to increase the cooperation on the Astronautical Engineering between Turkish and worldwide organizations are in progress. In this context, on November 2nd, 2011, the UTEP meeting was organized in order to form educational union inter-universities.
7. By invitation, ITU has become an academic member to the International Astronautical Federation (IAF). ITU is the first Turkish university to enroll in the IAF.