THE MINISTRY of EDUCATION and SCIENCE of RUSSIA FEDERATION
SAMARA STATE AEROSPACE UNIVERSITY

System Analysis of Space Missions

Electronic Laboratory Course

SAMARA
2011

The present laboratory practice on discipline «System Analysis of Space
Missions» urged to give practical skills in carrying out of the complex analysis
of almost any typical missions in a circumterraneous space.
Problems in a practical work represent a complex of the interconnected
problems under the analysis of feasibility of space mission, beginning from a
stage of space vehicle launching to a stage of de-orbiting and landing.
Practical work main objective is fastening of theoretical knowledge on discipline
and mastering by pupils of the basic engineering techniques used at the system
analysis of space missions.
The practical work also promotes quantitative estimations of design-ballistic
characteristics for typical operating conditions of space vehicles, and can be
used at final master thesis works.

*Interuniversity Space Research Department, Master Program Educational
Content "Space Information Systems and Nanosatellites. Navigation and
Remote Sensing" for education direction 010900.68 «Applied Mathematics and
Physics»*

THE CONTENT

INTRODUCTION

The present laboratory practice on discipline «System Analysis of Space Missions» urged to give practical skills in carrying out of the complex analysis of almost any typical missions in a circumterraneous space.

Problems in a practical work represent a complex of the interconnected problems under the analysis of feasibility of space mission, beginning from a stage of space vehicle launching to a stage of de-orbiting and landing.

Practical work main objective is fastening of theoretical knowledge on discipline and mastering by pupils of the basic engineering techniques used at the system analysis of space missions.

The practical work also promotes quantitative estimations of design-ballistic characteristics for typical operating conditions of space vehicles, and can be used at final master thesis works.

The laboratory practice supports almost all questions reflected in the lecture courses on given discipline.

The laboratory practice consists of three parts and two appendices.

In the first part the laboratory practice concept is described, the sequence of solved problems, structure of the initial data describing space mission is in details stated. The initial data at practical work performance are design characteristics of the carrier rocket of space appointment, the requirement to the space vehicle, defining its special-purpose designation and technical characteristics (including parameters of a working orbit), the basic design characteristics of the space vehicle and its onboard systems.

In the second part the description, and also the instruction on application of program complex START for the analysis of use of the chosen type of the carrier rocket of space appointment (CRSA) for delivery of the set useful loading (space vehicle) to a launching orbit is resulted. Program complex START is written in language of high level JAVA. This language allows to create the convenient

interface and effectively to organize educational process not only in internal, but also in the remote form.

In Appendix1 settlement techniques and models for the analysis of feasibility of deducing of the set useful loading chosen CRSA are short stated and the sequence of performance of various types of tasks are described.

<u>In the third part</u> the instruction on application of a specialized license package of applied programs STK (Satellite Tool Kit) for the system analysis of space mission is resulted.

This package is used for the analysis of following stages:

- The analysis of the ballistic scheme of flight in a regular mode of functioning of the space vehicle,

- Estimations needed stock of fuel onboard the space vehicle,

- The analysis of the ballistic scheme of flight in emergency operation.

At the analysis of orbital stages following problems are solved:

- A substantiation of a choice of type of a working orbit,

- An estimation of an orbit evolution from action of Earth atmosphere (including calculation of the space vehicle existence time and etc.) and from Earth non-central gravitational field,

- Calculation of space vehicle transfer maneuvers from a initial orbit into a working orbit,

- Calculation of working orbit maintenance maneuvers (maintenance of the set height of flight, movement maintenance in the set range of heights, a correcting of elements of an orbit) on an interval of time of active existence in an orbit,

- Calculation of a line of flight and the auxiliary ballistic information (conditions of mutual visibility of the space vehicle and land point, operability of areas of a terrestrial surface from a board of the space vehicle, conditions of light exposure of the space vehicle),

- Calculation of a brake impulse, a point of its appendix and the characteristic of an extra-atmospheric site of the flight previous descent of the space vehicle in atmosphere,

- A choice of demanded conditions of an input and movement calculation in atmosphere.

In the Appendix 2 the basic theoretical positions are short stated and the sequence of performance of the various typical tasks connected with the analysis of separate stages of space mission is described. The especial attention is given skills of check of possibilities of flight control, planning of sessions of the telemeter information reception, an estimation of visibility conditions and light exposure of various areas of a terrestrial surface.

In laboratory practice the materials prepared earlier by professor I.Timbai and post-graduate student V.Travin were used.

1. The concept of a laboratory practice

1.1. The task and initial data for laboratory practice k performance under the analysis of space mission

1.1.1 Special-purpose designations and key parameters of space mission

Space vehicle special-purpose designation (the companion meteorological, researches of natural resources of the Earth, communication navigating etc.)

_____

Full mass of the space vehicle after separation from the carrier rocket m_0 in kg

_____

Mass of payload $m_{нн}$ in kg _____

The middle square of space vehicle $S_{КД}$ in $м^2$ _____

The middle square of recovery capsule $S_{СА}$ in $м^2$_____

Ballistic coefficient of the space vehicle C_x _____

The maximum of aerodynamic quality for recovery capsule K_{max} _____

Specific impulse for maneuvering engines $P_{уд}$ in km/s _____

The angle of the visibility for onboard equipment $\delta_{КА}$ _____

The operating time of onboard equipment $T_{БА}$ in days_____ _____

1.1.2 Parameters of the realized orbit

<u>Task variant through orbit elements:</u>

Perigee height $H_п^{(0)}$ in km _____

Apogee height $H_a^{(0)}$ in km _____

Orbit inclination $i^{(0)}$ _____

Argument of a perigee $\omega^{(0)}$ _____

Longitude of the ascending node of an orbit $\Omega^{(0)}$ _____

The angle of true anomaly in a orbiting point $\vartheta^{(0)}$ (during the initial moment of time) _____

<u>Task variant through characteristics of the end of an active step of launching</u>:

Co-ordinates of a orbiting point in the initial orbiting time in starting co-ordinates system

x_{ck} in   km

_____

y_{ck} in   km

_____

z_{ck} in   km

_____

Projections of a vector of speed in starting coordinates system

$V_{x_{ck}}$ in   km/s

_____

$V_{y_{ck}}$ in   km/s

_____

$V_{z_{ck}}$ in   km/s

_____

1.1.3 Parameters of a final orbit and additional requirements to movement

Parameters of a final orbit:

Apogee height $H_a^{(p)}$ in km _____

Perigee height $H_\Pi^{(p)}$ in km _____

Orbit inclination $i^{(p)}$ _____

Argument of a perigee $\omega^{(0)}$ _____

1.1.4 Additional requirements for frequency of carrying out of trajectory corrections

For a circular orbit:

Admissible change of a longitude of the ascending knot of an orbit $\Delta\Omega^*$

_____

Admissible falling of height of flight ΔH^* In km _____

For an elliptic orbit:

Admissible change of a longitude of the ascending knot of an orbit $\Delta\Omega^*$ in deg._____

Admissible falling of perigee height ΔH_Π^* in km _____

Admissible change of argument of a perigee $\Delta\omega^*$ _____

1.1.5 Additional restrictions on orbital movement:

Time period of stay in an initial orbit Δt_{OB} in days

_____

The maximum time of transition from a initial orbit into a final orbit $\Delta t_{\text{пер}}^*$ in hours _____

1.1.6 Data for calculation of the auxiliary ballistic information

Geographical width of land point $\varphi_{\text{НП}}$ _____

Geographical longitude of land point $\lambda_{\text{НП}}$ _____

The minimum corner of an eminence of the space vehicle for its visibilities from land point Υ_{min} _____

Corner of declination of the Sun δ_{C} _____

Geographical width of start point for the carrier rocket $\varphi_{\text{СТ}}$ _____

Geographical longitude of start point for the carrier rocket $\lambda_{\text{СТ}}$ _____

1.1.7 Data for calculation of maneuver of rapprochement with an orbiting station

Initial angular distance between the space vehicle in an initial orbit and an space station in a working orbit v _____

Projections of a position vector of the space vehicle concerning an orbiting station after finishing of distant rapprochement (a miss by position)

$$\bar{x}_0 \text{ in m,}$$

$$\bar{y}_0 \text{ in m,}$$

$$\bar{z}_0 \text{ in m.}$$

Projections of a speed vector of the space vehicle concerning an space station after finishing of distant rapprochement (a miss on speed)

$\dot{V}_{x0}$ in km/s,

$\dot{V}_{y0}$ in km/s,

$\dot{V}_{z0}$ in km/s.

1.1.8 Parameters of a prerelease orbit and restriction on controllable characteristics of movement in atmosphere

Inclination $i^{(cn)}$ _____

Flight height $H^{(cn)}$ in km _____

Geographical width of a point of descent φ_τ _____

Geographical longitude of a point of descent λ_τ _____

The maximum admissible value of an thrust-to-weight $n^*_{доп}$ _____

The maximum admissible value of a specific thermal stream in a critical point of the recovery capsule $Q^*_{доп}$ In $\frac{кДж}{с*м^2}$ _____

The maximum admissible temperature in a critical point of the recovery capsule a T^0_{CA} In °C. _____

1.2 Sequence performance of the space mission analysis

1.2.1 Preparation of the initial data

Before the beginning of performance of the space mission analysis it is required to familiarize with the initial data attentively.

If parameters of a working orbit are not completely set, for example, the orbit inclination, it is necessary to choose them independently on the base of a purpose designation of the space vehicle using mentioned below recommendations.

The intermediate orbit of launching can be set by a set of elements or characteristics of the end of an active flight site in starting coordinate systems. On occasion it is required most to be calculated.

If the second form of the task of the initial data it is necessary to settle an invoice by the resulted technique movement entry conditions in absolute geocentric coordinate system is accepted and to find elements of an launching orbit.

1.2.2 Analysis of the ballistic scheme of flight in a regular mode of functioning of the space vehicle

Calculation of movement of the space vehicle on the set interval in a launching orbit

1) the evolution of launching orbit, caused non-central gravity attraction fields ($\Delta\Omega, \Delta\varpi$) on time interval Δt_{OB}

2) the evolution of an orbit caused by influence of atmosphere ($\Delta r, \Delta l, \Delta T, \Delta V_r, \Delta V_n$) on time interval Δt_{OB}.

3) the correction maneuver on maintenance of an launching orbit (for circular and near circular orbits - maintenance of flight height) and full expenses of characteristic speed are defined $\Delta V_{\text{xap}}^{(\text{OB})}$.

4) the flight trace of the space vehicle and the standard ballistic information (a zone of mutual visibility and light exposure of the space vehicle) ;

- on an interval Δt_{OB} with use of program STK, thus coordinates of land point get out of the initial data;

- on an interval of two turns of flight - manually, thus as launching point gets out and geometrical characteristics of the review of a terrestrial surface are in addition calculated.

1.2.3 Analysis of maneuver of transition from a launching orbit into a working orbit (without phasing)

Transition maneuver is determined in a class of two-pulse and three-pulse energetically optimum maneuvers. In a case three-impulse maneuver the

apogee of a transitive elliptic orbit is limited from above from a condition not excess of time of transition of the set size $\Delta t_{\text{пер}}^{\varepsilon}$.

In case the working orbit is elliptic, transition is carried out or in apogee, or in perigee. Thus settlement formulas of definition of impulses are deduced independently with use of integrals of energy and the areas.

Full expenses of characteristic speed and time of flight for each variant of transition are calculated.

1.2.4 Analysis of maneuver of rapprochement with an space station

In the beginning maneuver of distant rapprochement (transition from a deducing orbit into a working orbit with phasing) is considered. The given calculation is carried out only for a transition case between circular orbits.

If two-impulse flight the demanded corner of phasing is defined it is chosen as optimum. At the task of initial angular distance between the maneuvering space vehicle in an launching orbit and an orbiting station in a working orbit the waiting time to an establishment needed phasing corner on also is calculated.

If it is chosen as optimum three-pulse be-elliptical flight the apogee of a transitive elliptic orbit from a condition phasing for the set initial corner of a mismatch between space vehicles is defined needed velocity.

Assuming that as a result of maneuver of distant rapprochement the space vehicle passes in a small vicinity of an orbiting station, finishing maneuver of a stage of rapprochement pays off. It is considered that duration of rapprochement does not exceed a cycle time on an orbit. There is an optimum duration and parameters of maneuver from a condition of a minimalist of size of needed characteristic speed.

1.2.5 Analysis of correcting maneuvers for maintenance of a working orbit

For a case of a circular orbit of deducing maneuver of maintenance of movement of the space vehicle in the set range of heights and longitudes of the ascending node of an orbit in the set range of values pays off.

For a case of an elliptic orbit of deducing correction maneuvers (in the assumption of their incoherence) separately for maintenance of height of a perigee, argument of a perigee, a longitude in the set interval of values according to the requirements formulated in the initial data. Frequency of carrying out of correction by calculation of evolution of an orbit is thus estimated, the quantity of maneuvers of correction and demanded expenses of characteristic velocity on an interval of time of active existence T_{BA}

Results of calculations are represented in the form of tab. 1 for a circular orbit and in the form of tab. 2 for an elliptic orbit.

Table 1

Correction of an element of an orbit	Conditional frequency of correction per 1/days	Expenses of characteristic speed for 1 correction in km/s	Quantity of corrections on an interval T_{BA}	Expenses of characteristic speed for an interval T_{BA} in km/s
Ω				
H				
Full expenses of characteristic speed in km/s				

Table 2

Correction of an element of an orbit	Frequency of correction per 1/days	Expenses of characteristic speed for 1 correction in km/s	Quantity of corrections on an interval T_{BA}	Expenses of characteristic speed for an interval T_{BA} In km/s
Ω				
H				
Full expenses of characteristic speed in km/s				

1.2.6 Analysis of maneuvers at a stage of delivery of payload to the Earth

Maneuvering at a stage of delivery of the information to the Earth includes maneuver of transition of the space vehicle from a working orbit into a initial orbit and maneuver of braking for input realization in dense beds of atmosphere with the set conditions of an input.

The maximum angle of entry on the module $|\theta_{\text{вх}}|$ Approximately it is possible to estimate for the set type of the capsule, substituting instead of n_{max}, Q_{max}, $T^{\circ}_{\text{кр}\,max}$ Their maximum permissible values. Thus speed of an input is necessary equal ~8 km/s.

The initial orbit is considered circular. If height of a initial orbit $H^{(\text{ст})}$ it is set, parameters of transition maneuver. Then maneuver of a descent from a initial orbit pays off.

If the height of a initial orbit is not set, it gets out of a condition of minimization of full expenses of characteristic velocity on maneuver of transition to a initial orbit and on maneuver of a descent from a initial orbit. The optimum height of a launching orbit can be in any image, for example, searching in the chosen range of heights.

1.2.7 Analysis of a de-orbiting stage to the Earth

For chosen of a brake impulse of velocity $\Delta V_{\text{т}}$ and a corner of its orientation and speed and an angle of entry in dense atmosphere, angular range and flight time on an extra-atmospheric site are defined.

Further on the set conditions of an input in atmosphere the decrease trajectory, considering that movement is carried out in a plane of a initial orbit at the maximum aerodynamic quality.

Performance of all restrictions on controllable characteristics of movement is thus checked, and also rough co-ordinates of a point of achievement by the landing of an Earth surface (without a movement site on a parachute). In case restrictions on a descent trajectory are not carried out; it is necessary to offer the measures providing their performance.

1.2.8 Calculation of full expenses of fuel on realization of considered space mission

On the basis of results of calculation of characteristic velocity on all kinds of maneuvering received in the previous sections, tab.2 .

The found full expenses of fuel $m_{\text{т}}$ on realization of the ballistic scheme of flight are compared to a fuel stock $m_{\text{тр}}$ available onboard the space vehicle:

$$m_{\text{тр}} = m_0 - m_{\text{ин}}.$$

If $m_{\text{т}} \leq m_{\text{тр}}$, then the considered ballistic scheme of flight is realizable also a fuel part it would be possible to translate in useful loading or to increase time of active existence of the space vehicle. In this case it is necessary estimate on how many days active existence of the space vehicle can to be prolonged.

Table 3

	Expenses of characteristic velocity V_{XAF} in km/s	Fuel expenses in kg.	Duration of engine works in sec.
1	On maneuver of maintenance of an orbit of deducing		
2	On maneuver of transition from a deducing orbit into a working orbit		
3	On rapprochement maneuver		
4	On maneuver of maintenance of a working orbit		
5	On maneuver of transition from a working orbit into a pretrigger orbit		
6	Pas braking maneuver at a descent from a prestarting orbit		
Full expenses			

If $m_\text{т} > m_\text{тр}$ that the given ballistic scheme is not realizable and it is necessary to offer variants of performance target плачи, for example, to estimate time of active existence of the space vehicle proceeding from available onboard fuel stocks, or to define weight of useful loading for which the accepted ballistic scheme of flight can be realized.

1.3 Analysis of supernumerary variants of realization of space mission
In a practical work the pupil should estimate two possible emergencies.
1. After branch of the space vehicle from the carrier rocket it is not possible to establish communication with it (or correcting impellent installation) has failed and the space vehicle makes no directional passive movement.

In this case it is necessary:

- To count up time of existence of the space vehicle for the minimum, average and maximum indexes of solar activity,

- To define height of a critical orbit,

- To calculate and construct schedules of change of height of flight from time before achievement of critical height.

After achievement of critical height which practically coincides conditional border of dense atmosphere, the space vehicle begins movement on a flat trajectory in atmosphere where there should be its destruction.

For the analysis of process of destruction it is necessary to know overloads and thermal streams at movement. (Space vehicle movement therefore pays off with not separated lowered part) in atmosphere till the falling moment to the Earth. Thus it is necessary that there is a ballistic descent (K=0), and the angle of entry is accepted equal ~-0,1 .

2. At the final stage of flight after a descent of the capsule from an orbit the movement control system has failed. In this case the capsule rotation concerning a longitudinal axis and ballistic descent in atmosphere is carried out.

Trajectory and controllable characteristics of movement (overloads and specific thermal streams) also calculated and movement entry conditions (input conditions in atmosphere dense beds) get out on the basis of recommendations.

As a result of calculation of emergency operation requirements to a design of the space vehicle and its lowered part from the point of view of their self-liquidation should be formulated at a supernumerary situation (compulsory destruction or self-damage).

2. The description and the instruction on application of the START program complex for the analysis of a launching space vehicle into an intermediate orbit

2.1 Block diagram of a START program complex

acvrb.ssau.ru/dinpol/

Calculation of flight of a step in atmosphere dense beds

The task of a final angle of slope of a trajectory	The task of parametres for the decision of a regional problem
The task of design parametres of a step	

Optimum maximum of an angle of attack

The maximum high-speed pressure

Final flight conditions

Calculation of an intermediate step

The task of a final angle of slope of a trajectory	The task of final height of an orbit
The task of parametres for the decision of a regional	
The task of design parametres of a step	The task of entry conditions of flight

Final flight conditions

Schedules of a trajectory, speed and angle of slope of a trajectory from time

Calculation of a finishing step

The task of a final angle of slope of a trajectory	The task of final height of an orbit
The task of parametres for the decision of a regional	
The task of design parametres of a step	The task of entry conditions of flight

Final flight conditions

Choice PH from a database

Viewing of a full trajectory of flight PH

Viewing of a full trajectory flight on the world map (Google maple)

2.2. The description of the interface of the START program complex

The START program complex (personal computer) supposes placing on the Internet for convenience of its use by pupils. As a result of any pupil can have access to modules of calculation of a launching trajectory. Besides the personal computer allows establishing traditionally in a computer class on one computer, connected in a local network with other computers. At home page loading, the window for calculation of an atmospheric step opens, the screen copy is resulted in drawing 1. The left column contains the menu of the user with which help it is possible to choose an interesting kind of calculation, or to use additional functions such, as viewing of a full trajectory of the rocket, a choice flowing ракетоносителя and viewing of a projection of a trajectory of flight of the rocket on card Google Maple. To see a full trajectory of flight, it is necessary to walk consistently on all modules of calculation of missile stages. At calculation of atmospheric steps the final data is automatically transferred to the initial data for calculation of an intermediate step (if the three-stage rocket) or in the initial data of a finishing step (for the two-level rocket).

Trajectory calculation begins with button **"Modeling"** pressing.

Расчет программной траектории ракеты-носителя

Моделирование->

Задание параметров решения краевой задача:

Шаг интегрирования,с:	0.1
Шаг варьирования по углу атаки,град:	1
Допустимая погрешность,град:	0.1
Начальное приближение максимума угла атаки,град:	0.898
Конечный угол наклона траектории,град:	25

Проектные параметры ступени

Стартовая масса,кг:
310000.0

Масса топлива, кг:
181800.0

Площадь миделя,м2:
21.5

Тяга ДУ (в пустоте),Н:
4774020.0

Удельная тяга ДУ(в пустоте), м/с:
3100

Коэффициент высотности сопла:
1.175

Скорость начала аэрод. разворота:
50.0

Скорость окончания аэрод. разворота:
270.0

Left menu:
Расчет ступеней
- Атмосфер. ступени
- Первая ступень
- Первая и вторая
- Вне атмосфер. ступени
- Промежуточная ступень
- Промежуточная ступень с пассивным участком
- Завершающие ступени
- Завершающая ступень

Ракета
- Полная траектория
- Двухступенчатая
- Союз

Аэродинамические параметры

Max:	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
Сха:	0.215	0.215	0.214	0.212	0.218	0.269	0.466	0.524	0.516	0.476	0.461	0.429	0.408

Figure 1 Main window of a program complex

The interface illustrated on an example of the analysis of possibility of deducing of useful loading of the set weight three-stage Rocket "Soyuz" (fig. 2)

РН "Союз-У"	Основные проектные параметры	
	Первой ступени	
Начальная масса, т:		304
Тяга двигателей (в пустоте), кН		4093
Удельный импульс (в пустоте), м/с		3100
Масса топлива, т		157
Коэфф. высотности сопда:		1.218
Площадь миделя, м2		11.282
	Второй ступени	
Начальная масса, т:		131.8
Тяга двигателей (в пустоте), кН		997
Удельный импульс (в пустоте), м/с		3100
Масса топлива, т		93
	Третьей ступени	
Начальная масса, т:		32.3
Тяга двигателей (в пустоте), кН		297
Удельный импульс (в пустоте), м/с		3300
Масса топлива, т		22.9

Figure 2 Input of design parameters of carrier rocket

By pressing the reference **«First step»** there will be a window of calculation of a trajectory of movement of a step in atmosphere dense beds. As input parameters for calculation of the program of management and a flight trajectory it is necessary to set the initial data:

- Parameters of the decision of a regional problem;
- Design parameters of a step;
- A final angle of slope of a trajectory.

The screen copy is shown in Figure 3:

Задание параметров решения краевой задача:

Шаг интегрирования,с:	0.1
Шаг варьирования по углу атаки,град:	1
Допустимая погрешность,град:	0.1
Начальное приближение максимума угла атаки,град:	0.898
Конечный угол наклона траектории,град:	25

Проектные параметры ступени

Стартовая масса,кг:
310000.0

Масса топлива, кг:
181800.0

Площадь миделя,м2:
21.5

Тяга ДУ (в пустоте),Н:
4774020.0

Удельная тяга ДУ(в пустоте), м/с:
3100

Коэффициент высотности сопла:
1.175

Скорость начала аэрод. разворота:
50.0

Скорость окончания аэрод. разворота:
270.0

Аэродинамические параметры

Max:	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
Cxa:	0.215	0.215	0.214	0.212	0.218	0.269	0.466	0.524	0.516	0.476	0.461	0.429	0.408

Max:	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
Cxa:	0.367	0.376	0.354	0.339	0.33	0.321	0.313	0.306	0.299	0.292	0.285	0.279	0.274

Суа,град: 0.173

Figure 3 Task of the initial data for calculation of an atmospheric stage

Results of calculation:

- Parameters of rocket flight at the moment of start,

- Parameters of rocket flight at the moment of the termination of a vertical site,

Parameters of rocket flight the at the moment of achievement of a maximum of an angle of attack,

- Parameters of rocket flight at the moment of the termination of a site of an aerodynamic turn,

- Parameters of rocket flight at the moment of achievement of a maximum of a high-speed pressure,

- Parameters of rocket flight at the moment of the termination of work of a step,

- Schedules of a trajectory of an angle of attack and speed.

The copy of the screen reflecting results of calculation is shown in figure 4.

Данные моделирования

	Время, с	X, м	Y, м	Скорость, м/с	Тета, град	q,	a, град	nx	ny
1	0	0	0	0	90	0	0	1,335	0
2	13,4	0	321	50	90	1 458	-0	1,428	-0
3	21,1	8	838	85	87,54	3 908	-1,593	1,5	-0,05
4	48,2	1 166	5 214	270	65,968	20 456	0	1,86	0
5	66,3	4 673	10 794	470	51,389	26 800	0	2,107	0
6	118,051	45 602	38 129	1 615	25,04	5 237	0	3,811	0

Количество итераций: 11

Тета- угол наклона траектории в стартовой системе координат
q-скоростной напор
a-угол атаки
nx-перегрузка по оси x
nx-перегрузка по оси y

1 - Момент старта
2 - Момент окончания вертикального участка полета
3 - Момент достижения максимума угла атаки
4 - Момент окончания участка аэродинамического разворота
5 - Момент достижения максимума скоростного напора
6 - Момент окончания работы ступени
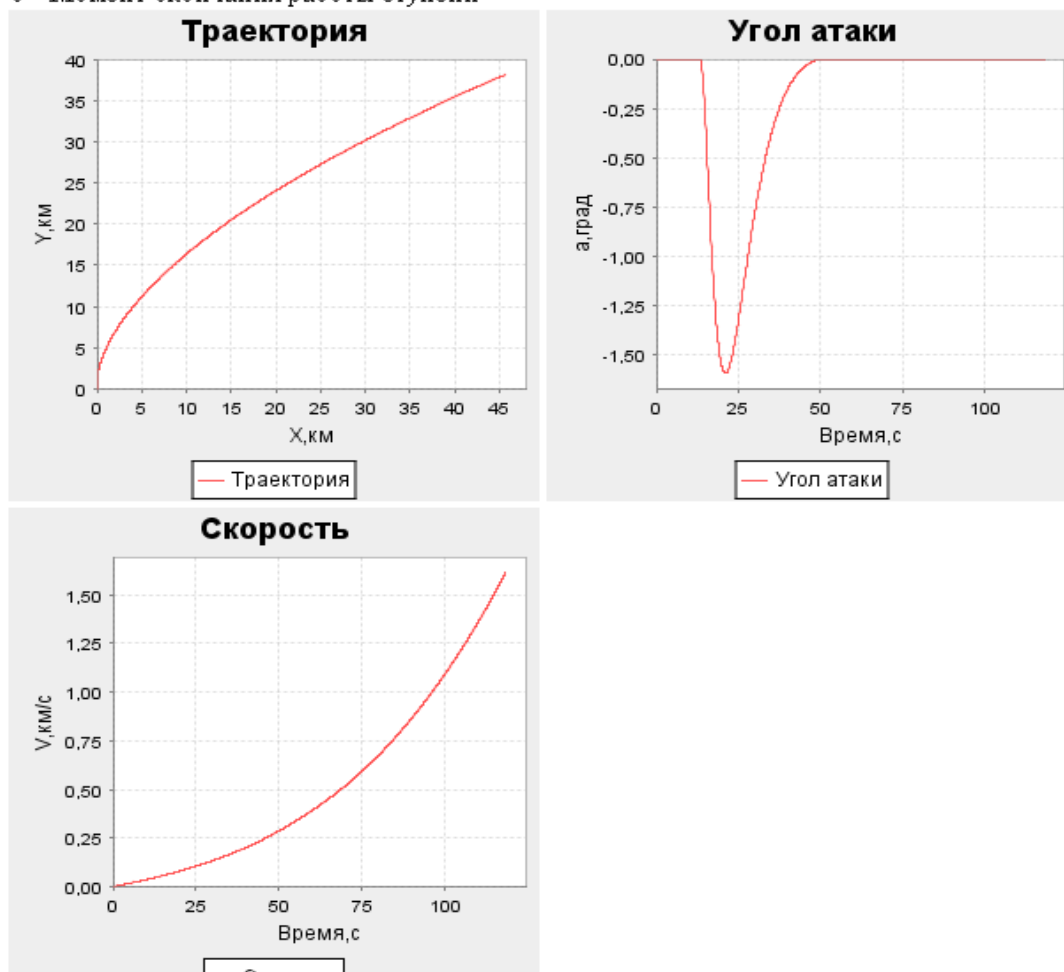
Figure 4 - Results of modeling of movement for an atmospheric stage

As variant of the rocket has three stages we pass to calculation of an intermediate stage, the screen copy is shown in figure 5. For calculation it is necessary to set the following entrance data:

- Parameters of the decision of a regional problem,

- Design parameters of a stage,

- Flight entry conditions.

The end result of modeling of an atmospheric stage will automatically be transferred to entry conditions of flight for an intermediate stage.

Задание параметров решения краевой задача:

Шаг интегрирования,с: 0.1

Шаг варьирования по углу тангажа,град: 1

Допустимая погрешность наклона траектории,град: 0.1

Конечный угол наклона траектории,град: 10

Проектные параметры ступени	**Начальные условия**
Стартовая масса,кг:	Координата x,м:
113000.0	45602
Масса топлива, кг:	Координата y,м:
89900.0	38129
Тяга ДУ (в вакууме),Н:	Начальная скорость по x,м/с:
997000.0	1464
Удельная тяга ДУ(в пустоте), м/с:	Начальная скорость по y,м/с:
3106	684
Время сброса головного обтекателя, с:	
0	
Масса головного обтекателя, кг:	
0.0	

Figure 5 Entrance data for modeling of movement of an intermediate step

Copy of the screen of the received results it is shown in figure 6.

Данные моделирования

Проекция x в конечный момент времени,м:	902 985,156
Проекция y в конечный момент времени,м:	82 501,633
Горизонтальная составляющая скорости,м/с:	5 724,756
Вертикальная составляющая скорости,м/с:	203,394
Модуль полной скорости,м/с:	5 728,368
Высота орбиты в конечный момент,м:	145 369,044
Угол наклона траектории,град:	10,001

Оптимальный параметр управления по углу тангажа fi,град: 26,33
Время работы ступени,с: 280,07
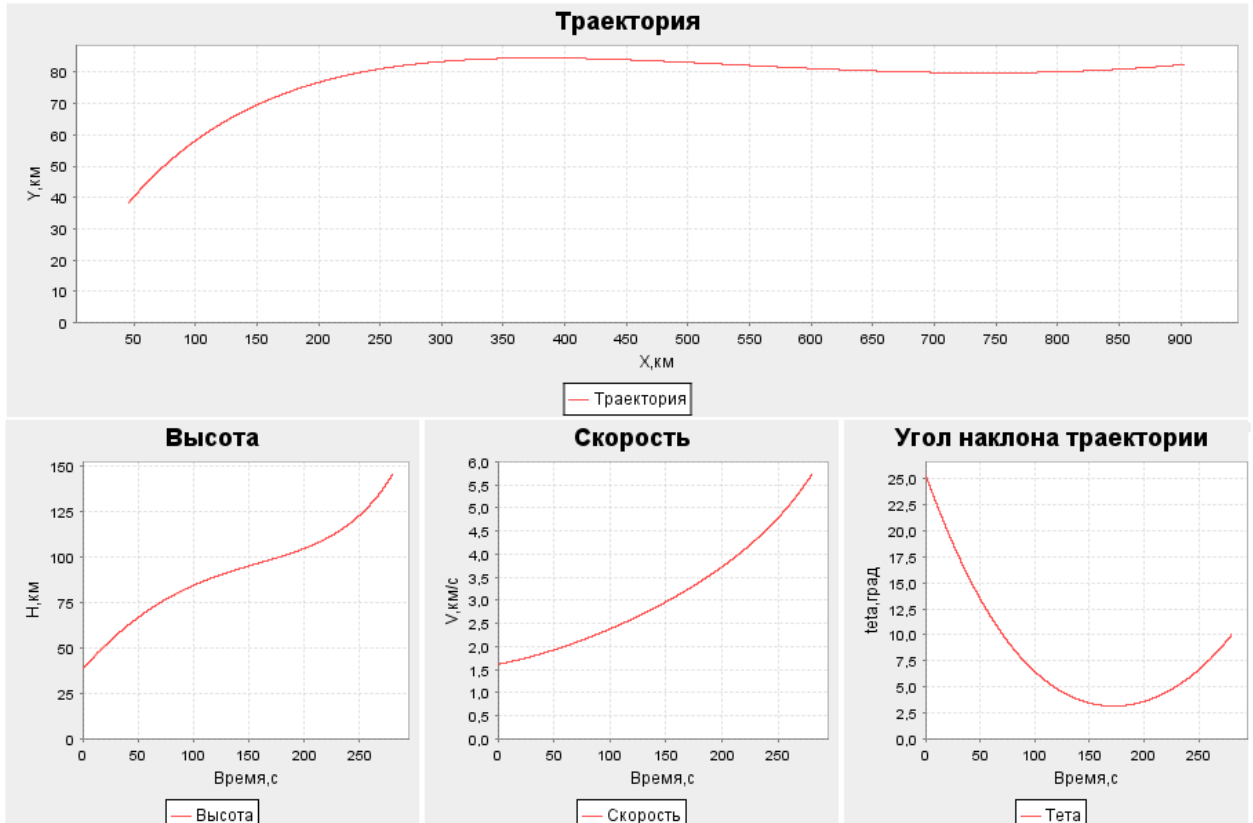
Figure 6 Result of modeling of movement of an intermediate step

In figure 7 the copy of the screen of the task of initial parameters for calculation of the third (finishing) stage is resulted.

Задание параметров решения краевой задача:

Шаг варьирования по углу тангажа,град: `1`

Шаг варьирования по b: `0.1`

Шаг интегрирования,с: `1`

Допустимая погрешность наклона траектории,град: `0.1`

Допустимая погрешность по высоте,м: `10`

Конечный угол наклона траектории,град: `0`

Высота орбиты выведения,м: `200000`

Проектные параметры ступени

Начальные условия

Стартовая масса,кг:
`17100.0`

Координата x,м:
`902985`

Масса топлива, кг:
`8500.0`

Координата y,м:
`82502`

Тяга ДУ (в вакууме),Н:
`297300.0`

Начальная скорость по x,м/с:
`5725`

Удельная тяга ДУ(в пустоте), м/с:
`3303`

Начальная скорость по y,м/с:
`203`

Время сброса головного обтекателя, с:
`0`

Масса головного обтекателя, кг:
`0.0`

Figure 7 Initial data for calculation of a finishing stage

In figure 8 the copy of the screen of results of modeling of flight of a finishing stagep is shown, and in figure 9 the full trajectory of flight is shown.

Данные моделирования

Проекция х в конечный момент времени,м:	1 521 903,838
Проекция у в конечный момент времени,м:	21 337,682
Горизонтальная составляющая скорости,м/с:	7 498,897
Вертикальная составляющая скорости,м/с:	-1 785,356
Модуль полной скорости,м/с:	7 708,499
Высота орбиты в конечный момент,м:	200 009,993
Угол наклона траектории,град:	-0

Оптимальный параметр управления по углу тангажа fi,град: -12,824
Оптимальный параметр управления по углу тангажа b,град:-0,672
Количество итераций:2 044
время работы ступени,с: 94,435
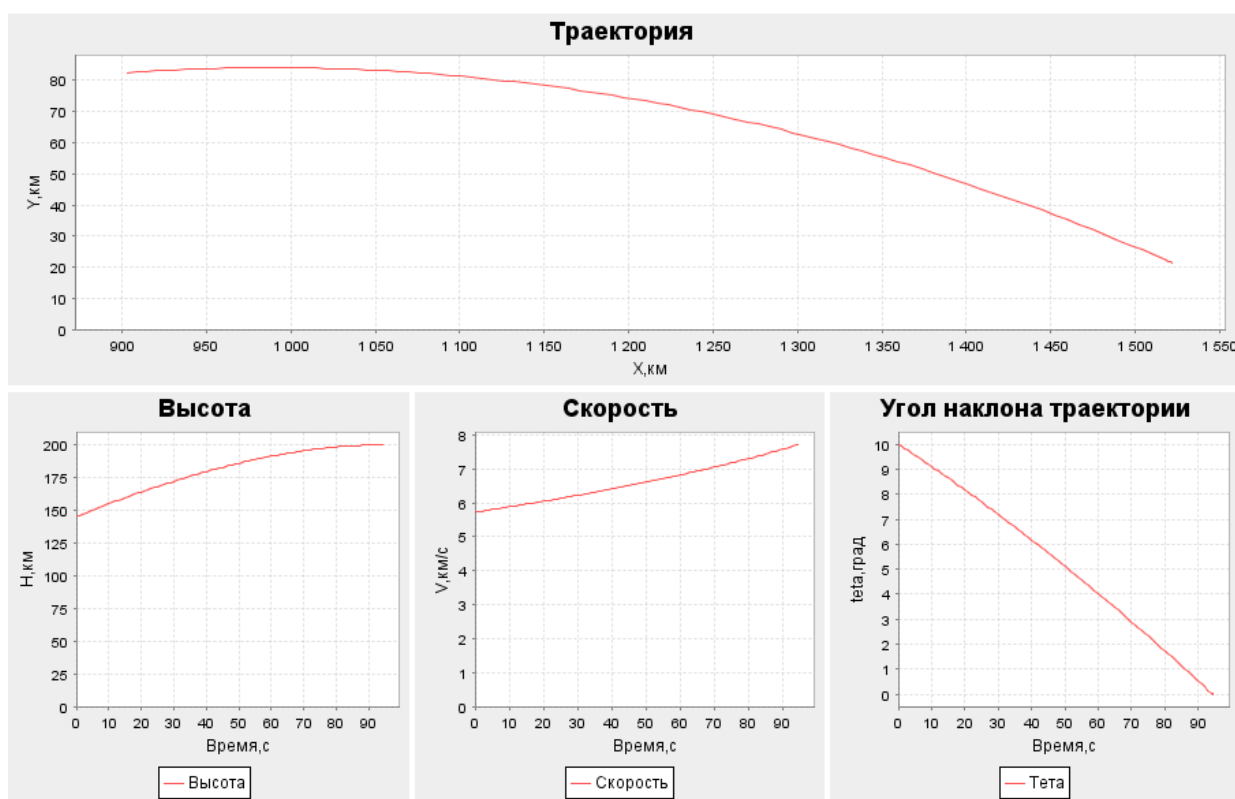
Figure 8 Results of modeling of flight of a finishing stage
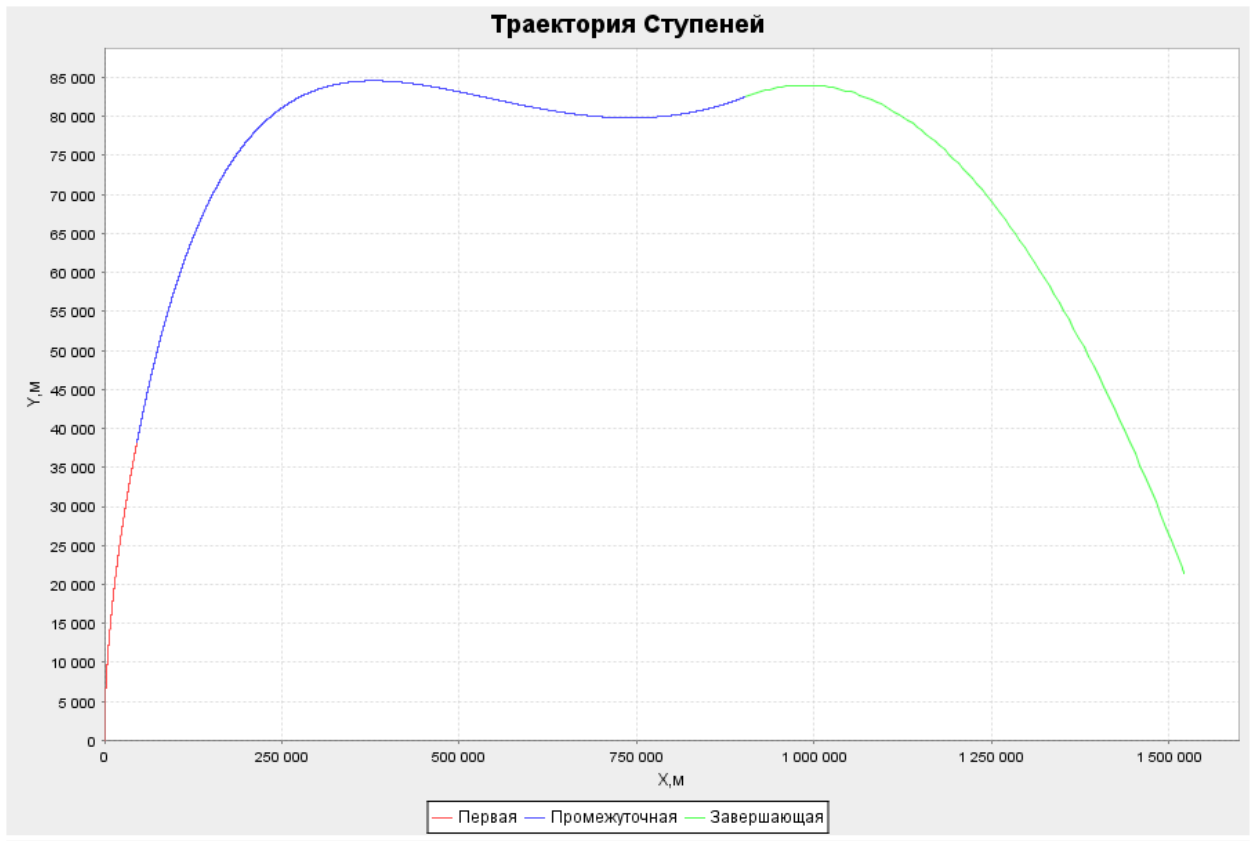
Figure 9 Full trajectory of flight of the carrier rocket "Soyuz"

For reception of the information on used terms, techniques and models it is necessary to address to the Appendix of 1 given practical work.

3 Instruction on application of program complex STK for the space missions analysis

The present instruction allows users to get skills, skills for creation and management of objects in personal computer STK. The pupil will get acquainted with structure of static and dynamic elements of a database of personal computer STK and will learn to keep and take objects from this base. After creation of various objects in personal computer STK the pupil will learn to "recover" the project to receive the information, time-dependent in a window **«Map»**. In addition forms of reception of reports in static and dynamic forms are described.

3.1 Initial skills of work by STK

The folder in which it is established STK, contains a subdirectory **«Tutorial»** in which the information received during independent work of the pupil at mastering of the personal computer remains all.

The first basic step is creation of the educational scenario.

As the scenario is called the object of the highest level in STK it includes a card and comprises all other objects (companions, navigating equipment etc.). This section of the program of training acquaints with process of creation and saturation by the scenario information.

When for the first time it is started STK, in a separate window opens **«Startup Wizard».**
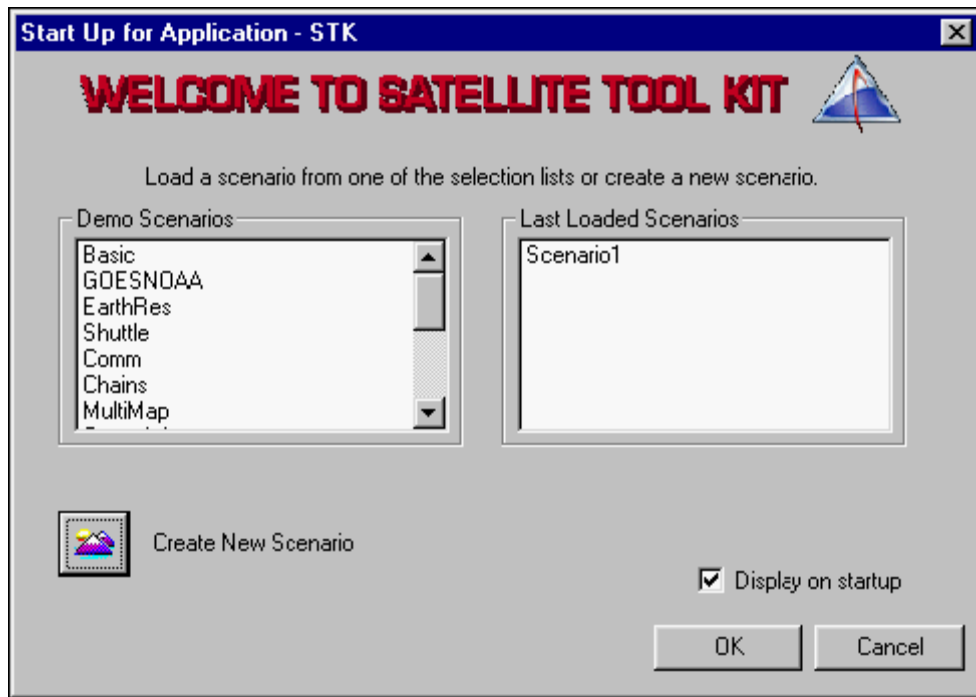
For creation of the new scenario it is required to press the button which is to the left of a field **«Create a New Scenario»** in **«Startup Wizard»** as a result the card window opens. For scenario renaming it is necessary to press an icon to the left of a name, appropriated to the scenario by default, then addressed to Scenario# in the main window. After that it is typed **«Tutorial40»** in the allocated text and button **Enter** is pressed. The main window is updated for display of a new name.
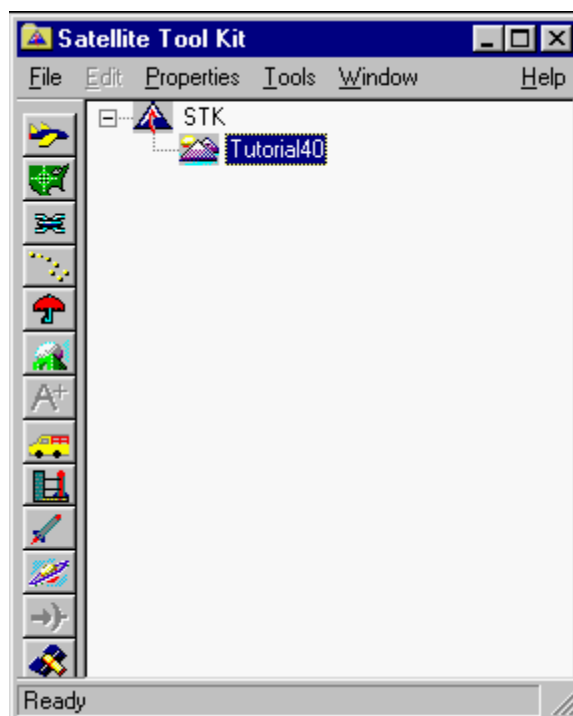
Before carrying out any problems in STK it is necessary to establish parameters **Tutorial40** which will influence all aspects of the scenario, after its creation. For performance of the problems put at the initial stage, it is expedient to use the parameters described further.

There is a possibility to change parameters of the scenario in program work.

First of all it is necessary to install parameters of applications STK as a whole. These parameters of the highest level influence any object in the appendix, irrespective of the open scenario. For installation of parameters of the appendix it is necessary to be convinced that the main window of the program actively. Click on the menu **«Properties»** and choose **«Basic»** in the emerged window. As a result there will be a window of base parameters.

Important often to keep the project for prevention of loss of the information. It is possible to use an option of the **Car** of preservation.
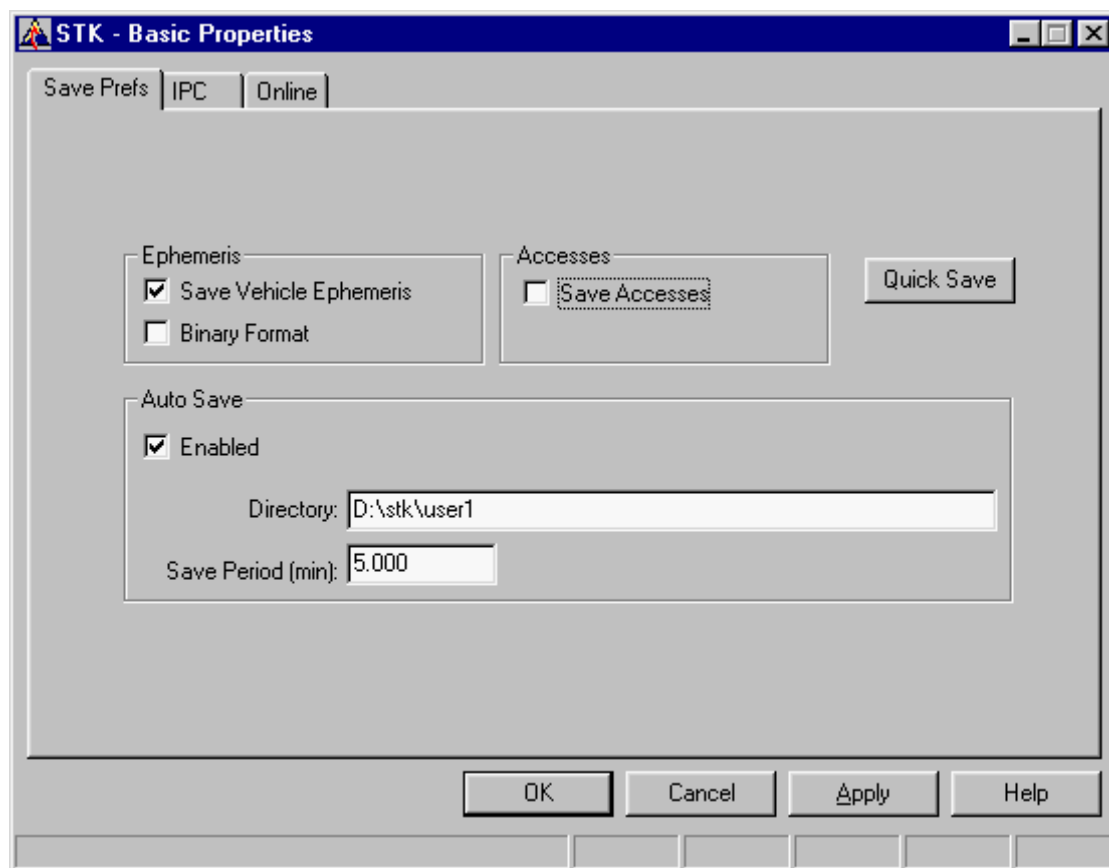
For convenience it is necessary to be convinced that the auto preservation period is equal to 5 minutes, points **«Auto save»** and **«Save Vehicle Ephemeris»** are

included, and points **«Binary Format»** and **«Save Accesses»** are switched off. Press key OK for acceptance of changes and window closing **«Basic Properties».**

It is important to establish parameters not only at appendix level, but also in the scenario. It is necessary to establish the units of measure used throughout all work and as to establish necessary parameters of a drawing for convenience of display and perception of objects and schedules on the screen.

Units of measure get out by allocation by a mouse of scenario **Tutorial40** in the main window and pressing вкладки **Basic** in the appeared window of properties.

For test change time of the beginning of the scenario on 1 Nov 1997 00:00:00.00 and time of its termination on 1 Nov 1997 04:00:00.00. Then press on **"Animation"**.
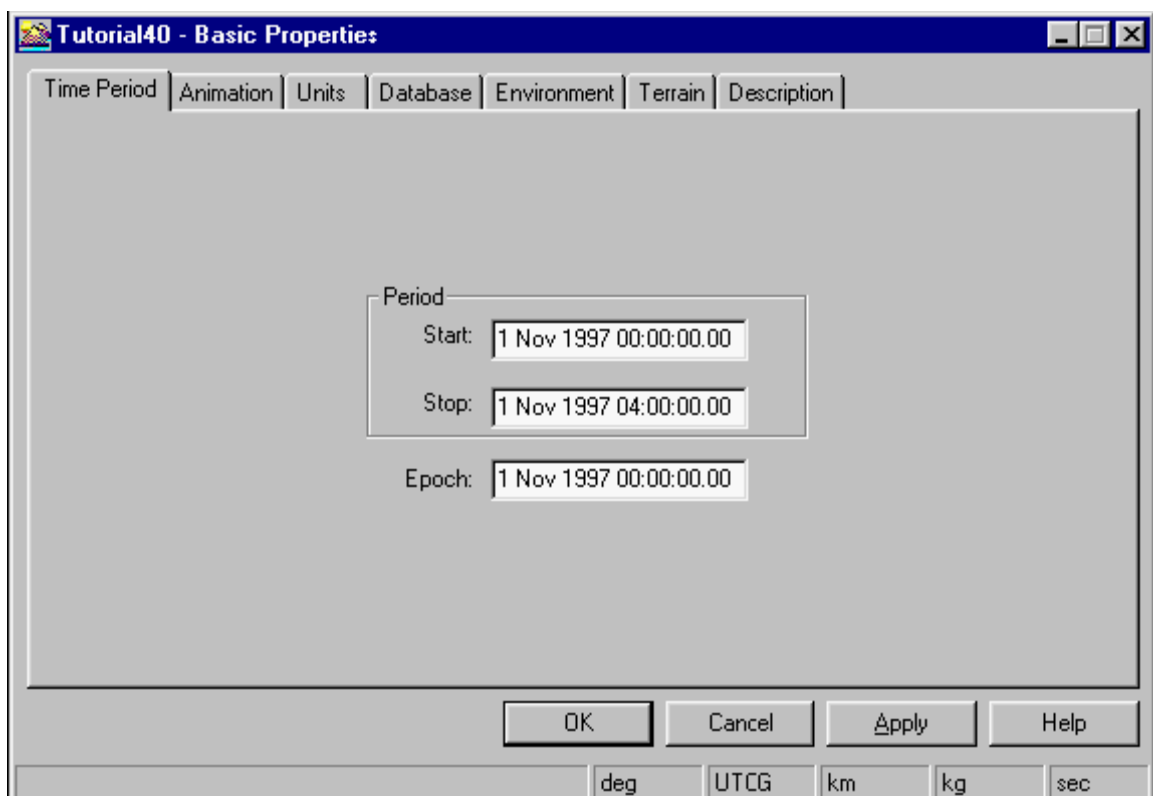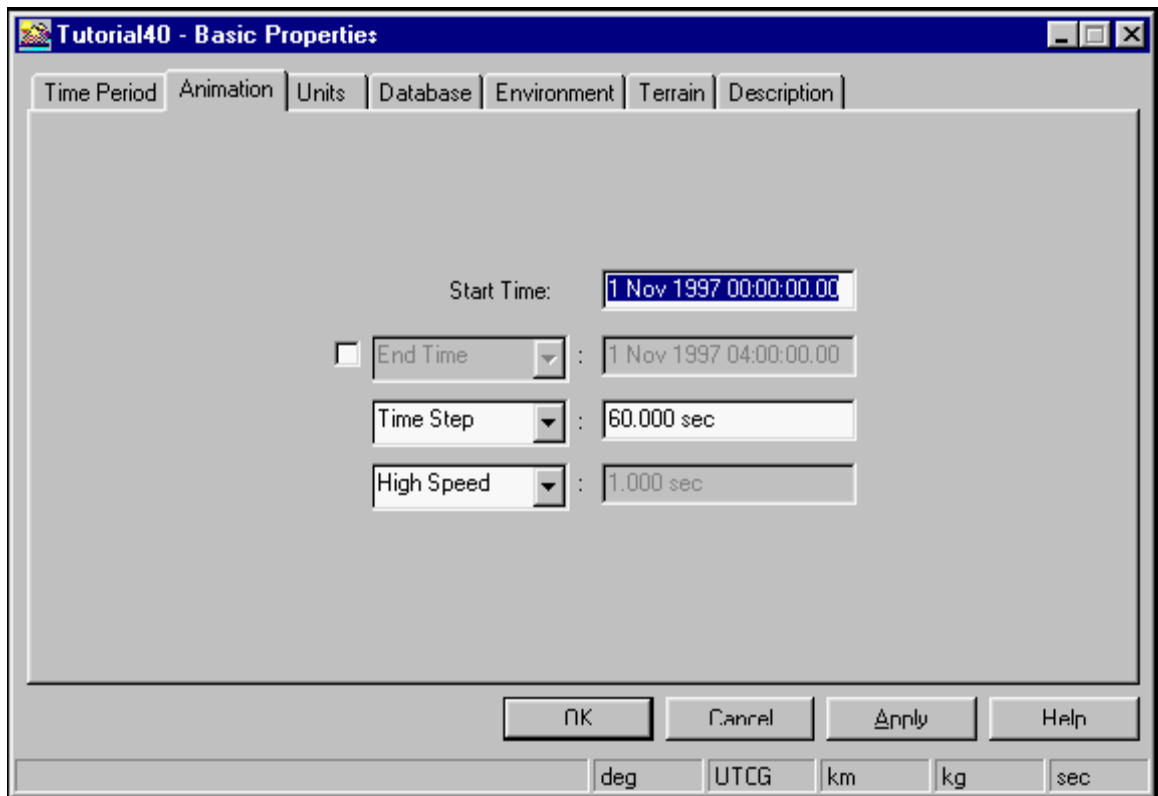
To make sure that the period is set correctly, check up field **Start Time** on Animation 1 Nov 1997 00:00:00.00, then press on **Units.**
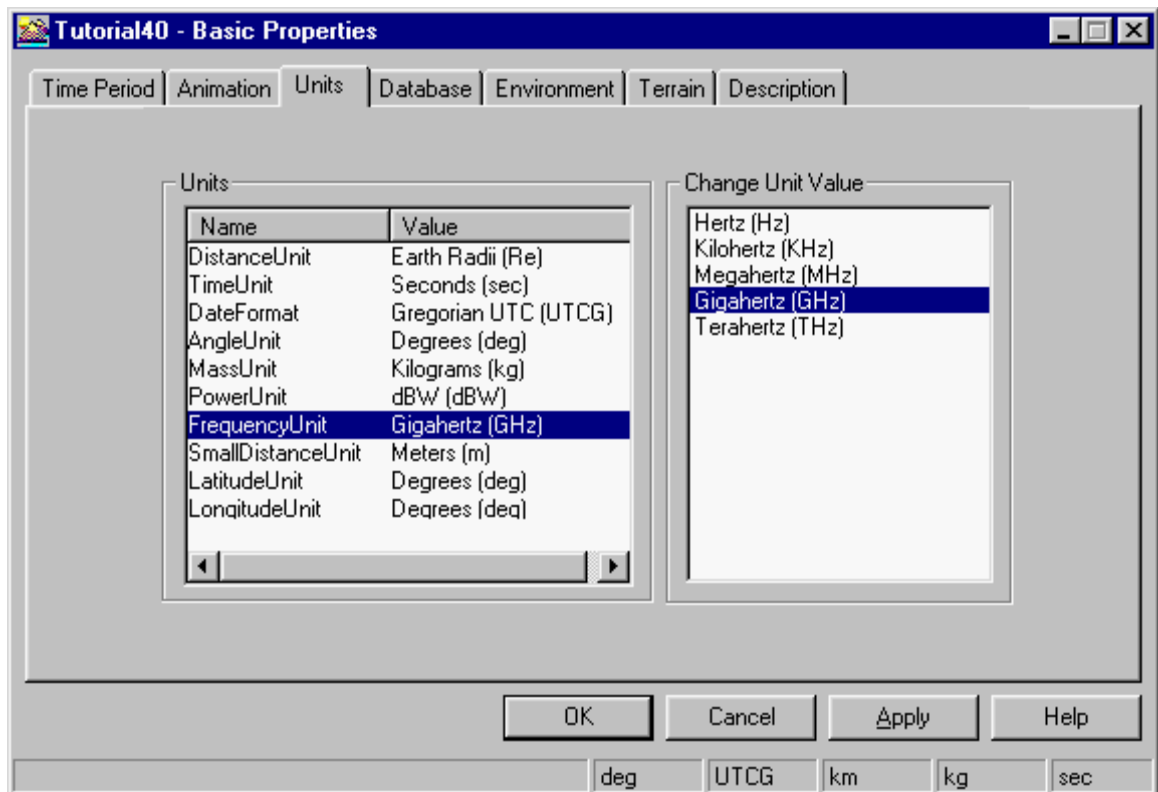
For convenience, establish all units of measurements how it is shown in the table. To change values by default, allocate an element interesting you, then choose correct value in a window **«Change Unit Value».**

To choose an element from the list, allocate with a mouse this element. To remove allocation, once again click it with a mouse.

Field	Setting
Distance Unit (distance)	Nautical Miles (n miles)
Time Unit (time)	Hours (hours)
Date Format (a date format)	UTC Gregorian (the Gregorian calendar)
Angle Unit (corner)	Degrees (degrees)
Mass Unit (weight)	Kilograms (kgs)
Power Unit (force)	dBW
Frequency Unit (frequency)	GHertz (ГигаГерцы)
SmallDistanceUnit ()	Meters (metres)
LatitudeUnit (width)	Degrees (degrees)
LongitudeUnit (longitude)	Degrees (degrees)

After the installation termination it is necessary to press the button **APPRX.**

Drawing parameters operate information display to the screen and the possibilities accessible in window **Map**. To establish parameters of a drawing for own scenario, press the button of the panel of tools of a window of **Mar.**

Properties of a card are responsible for information display: orbits, names of objects, lines KA and other information on the companion.

In the table shown here, the option **«Show Tool Bar»** is included, and the option «Show Elevation Regions» is disconnected.

For convenience, be convinced that options **«Show Tool Bar»**, **«Show Status Bar»** and **«Show Scroll Bars»** are included, and the option **«Show Elevation Regions option»** is disconnected.

After the termination, press on вкладку **Details**.

Further it is necessary to fill the scenario with various objects. It is expedient to begin with a choice and the task of placing of land stations, starting platforms and tracking stations.

Press an icon «Facility icon» in the bottom part of the main window (when the cursor is directed at an icon in the bottom part of a window its value is highlighted). Change the object name, for example, on «Baikonur».

At first it is necessary to allocate with double click of the mouse the old name, and then to enter the new name in the allocated place.

Pressing **Enter** carries out installation of a new name.

As a result the Main window will be updated to display new object.

In a window of the Card it will appear in a place with co-ordinates of 0 degrees of width and 0 degrees of a longitude.

Further it is necessary to choose **«Basic»** from the menu **«Properties»** (or to press the right button of the mouse for menu occurrence in which it is possible to choose properties and tools for object).

Installation of co-ordinates of object is carried out in the first вкладке **Position** windows **Basic Propertie**s.

Coordinates set object position on a card.
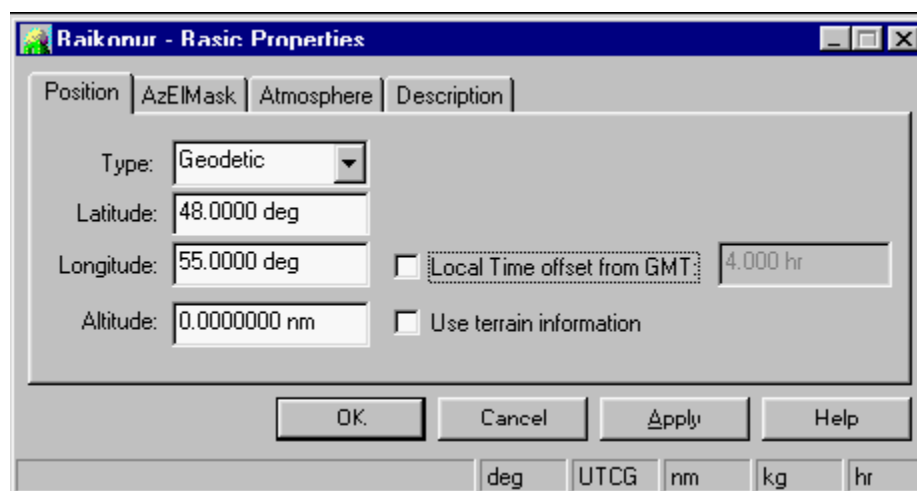
For mastering check establish values on **Position** how it is shown more low, and be convinced that options **Local Time Offset** from GMT and **Use Terrain** Information are switched off.

Field	Setting
Position type	Geodetic
Latitude	48.0
Longitude	55.0
Altitude	0.0

Further it is necessary to press **Description**.

At any moment to receive the information on object it is necessary to use вкладку **Description** where it is possible to describe object independently.
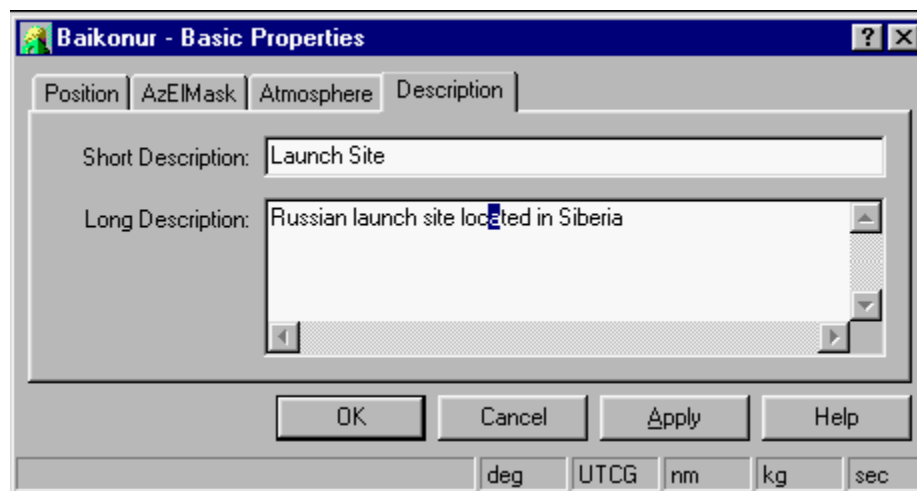
Following stage of development of possibilities of the personal computer is addition of new objects.

For an example it is possible to add four more new objects, specified in the table. For this purpose it is necessary to execute the steps described above for addition of new objects, in details to describe objects unessential.

Name	Latitude	Longitude	Altitude	Short
Perth	-31.0	116.0	0.0	Australian Tracking Station
Wallops	37.8602	-75.5095	-0.0127878	NASA Launch Site/Tracking Station

After definition of parameters of each object it is necessary to press the button APPRX.

For addition of two more objects in the scenario we will use the Database.

For this purpose in the main window it is necessary to allocate the created scenario, and then in menu **Tools** choose **Facility Database**.
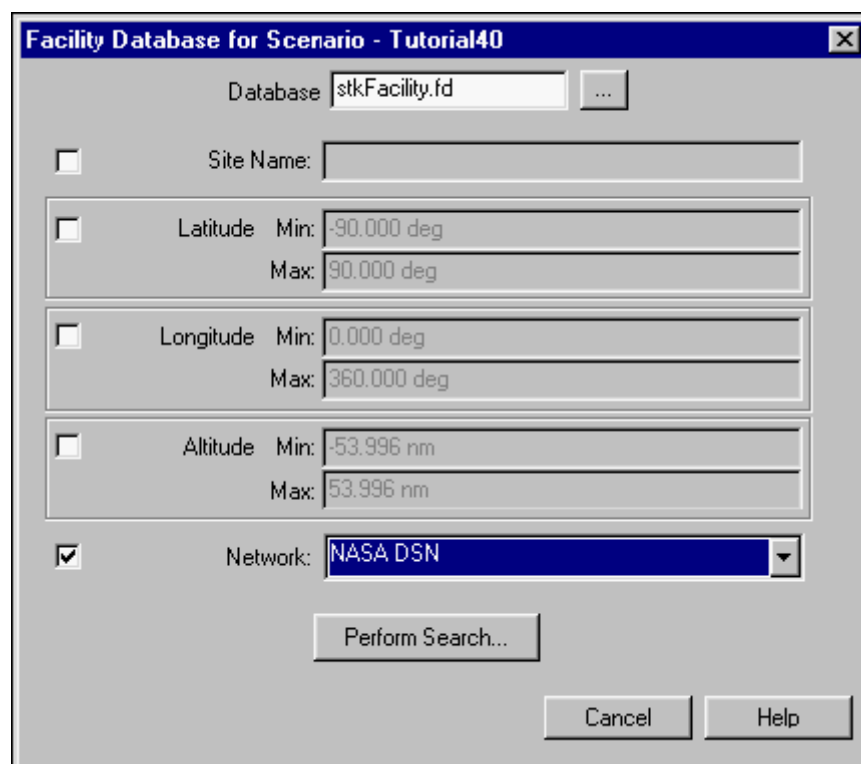
It is necessary to include option Network and to choose, for example, NASA DSN, and further to press button Perform Search …
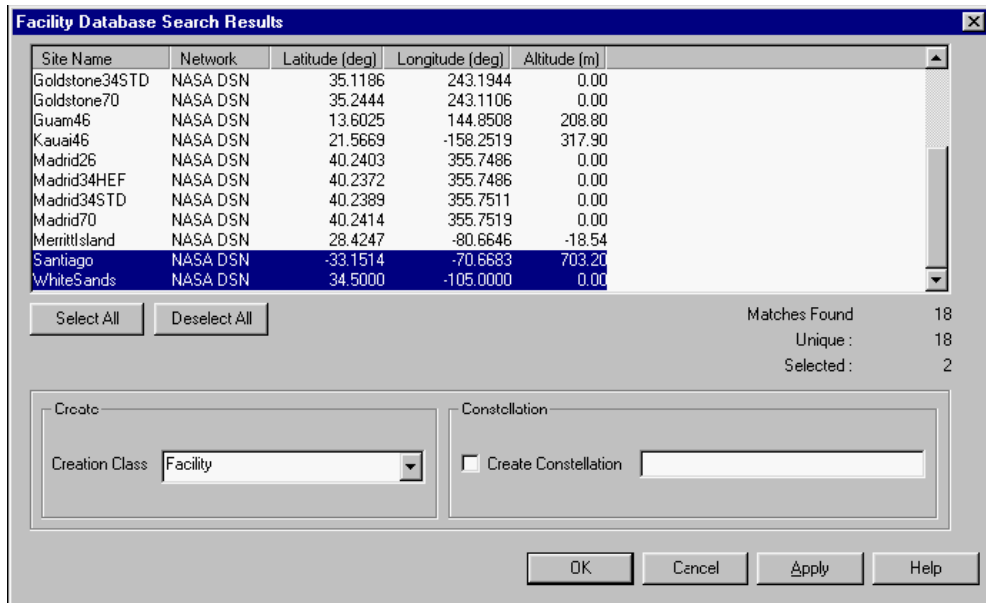
After occurrence in a window of search results, find in the end of list Santiago and WhiteSands, then press APPRX. In window **Facility Database** press **Cancel**.

In the main window allocate Baikonur, and then press and hold button Shift, in passing allocating all remained four objects, then press the right button of the mouse and choose Graphics in the appeared menu.
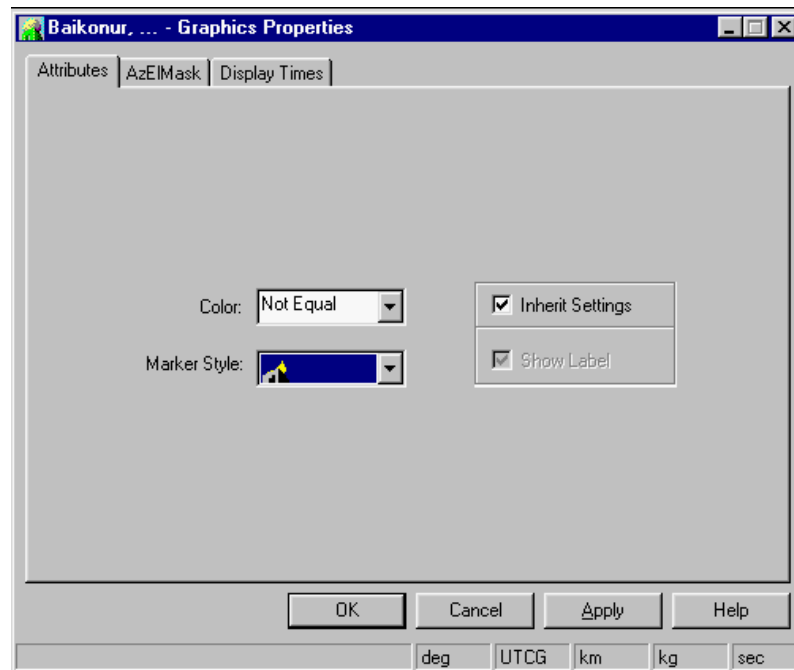
On вкладке **Attributes** change **Marker Style** so that it has displayed an object icon. Press APPRX.
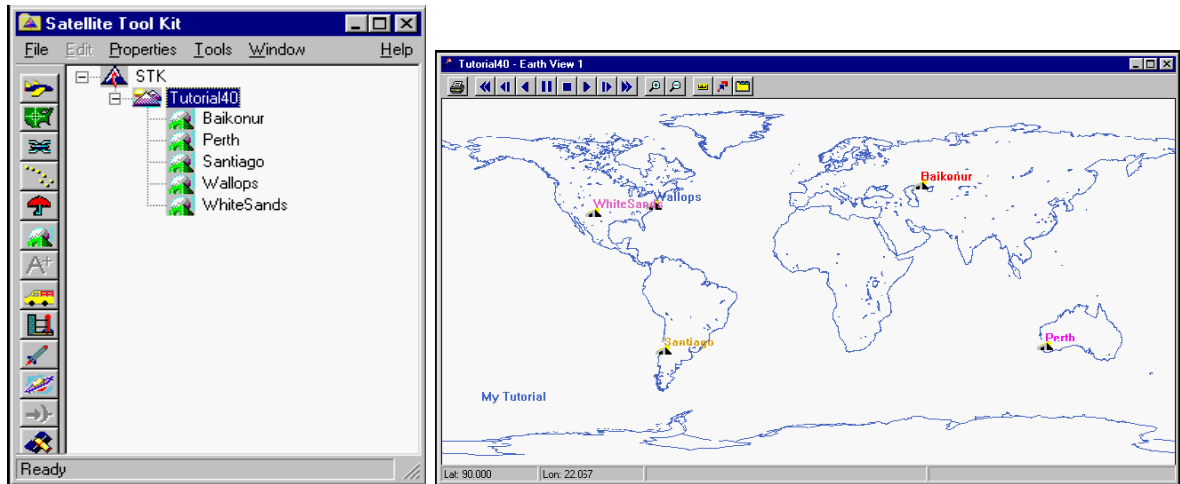
When objects are added in the scenario from a database, for them the description is automatically created. For description viewing, for example, object Santiago it is necessary to open menu **Basic Properties** for this object and to choose option Description.
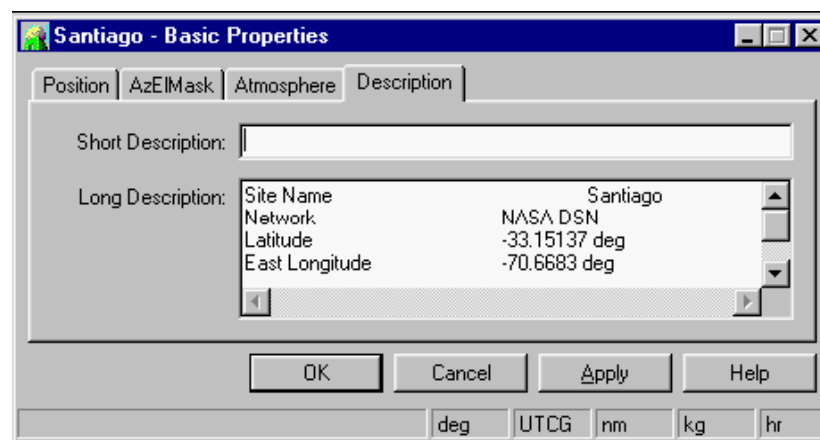
Field **Long Description** contains except the information on a site and other data, concerning the allocated object.

Creation of the purposes of supervision is an important stage of script writing. Let the supervision purpose is the glacier in the North America. It is necessary to press icon Target in the bottom part of the main window, then to designate purpose Iceberg and to press Enter.

Further it is necessary to press on вкладку Basic in menu **Properties** for the purpose of the task of co-ordinates of the purpose and its description.

The first вкладка in window **Basic Properties** is called **Position**.
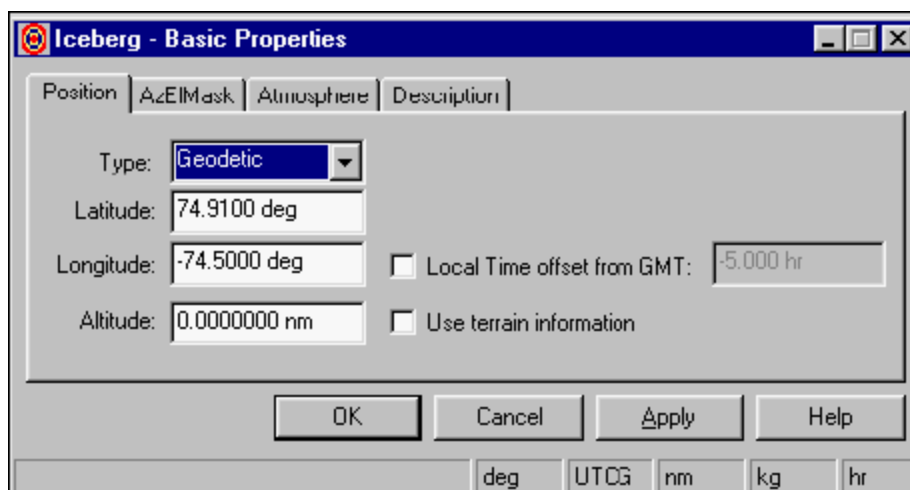
It is necessary to define a longitude, width and height above sea level for the new purpose. On вкладке **Description** the short description is entered. It is necessary to change **Position Type on Geodetic**.

Name	Latitude	Longitude	Altitude	Short
Iceberg	74.91	-74.50	0.0	Only the tip

After the termination to press the button APPRX. That it is better to see object on the **Card**, it is necessary to open its graphic properties and to change **Marker Style** for an object icon.

Creation of the scenario for mobile object is shown for the ship.

In the beginning it is necessary to add the ship in scenario **Tutorial40**. It needs to press an icon of the ship and to change the name of new object on Cruise. Then it is necessary to press Enter to accept a new name.

Further window **Basic Properties** for the below.
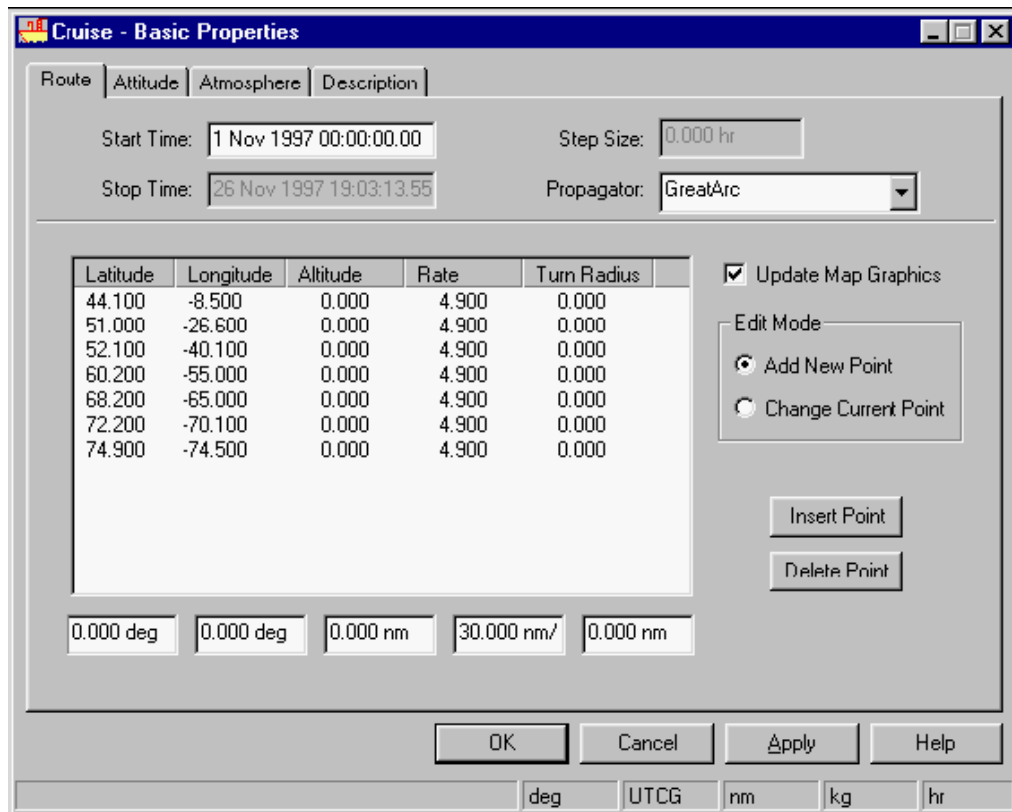
It is necessary to be convinced that start time on вкладке Route is established on 1 Nov 1997 0:00:00 AM and Propagator on Great Arc.

Coordinates of movement of the ship are entered построчно. When input of a line comes to the end button **Insert Point** (the point through which will take place the ship is put) is pressed.

Latitude	Longitude	Altitude	Rate	Turn radius
44.1	-8.5	0.0	4.9	0.0
51.0	-26.6	0.0	4.9	0.0
52.1	-40.1	0.0	4.9	0.0
60.2	-55.0	0.0	4.9	0.0
68.2	-65.0	0.0	4.9	0.0
72.5	-70.1	0.0	4.9	0.0
74.9	-74.5	0.0	4.9	0.0

Further definition of a site of the ship is carried out. It is for this purpose pressed вкладка Attitude in window **Basic Properties** and it is checked that in point Attitude Type it is established ECI velocity alignment with nadir constraint.
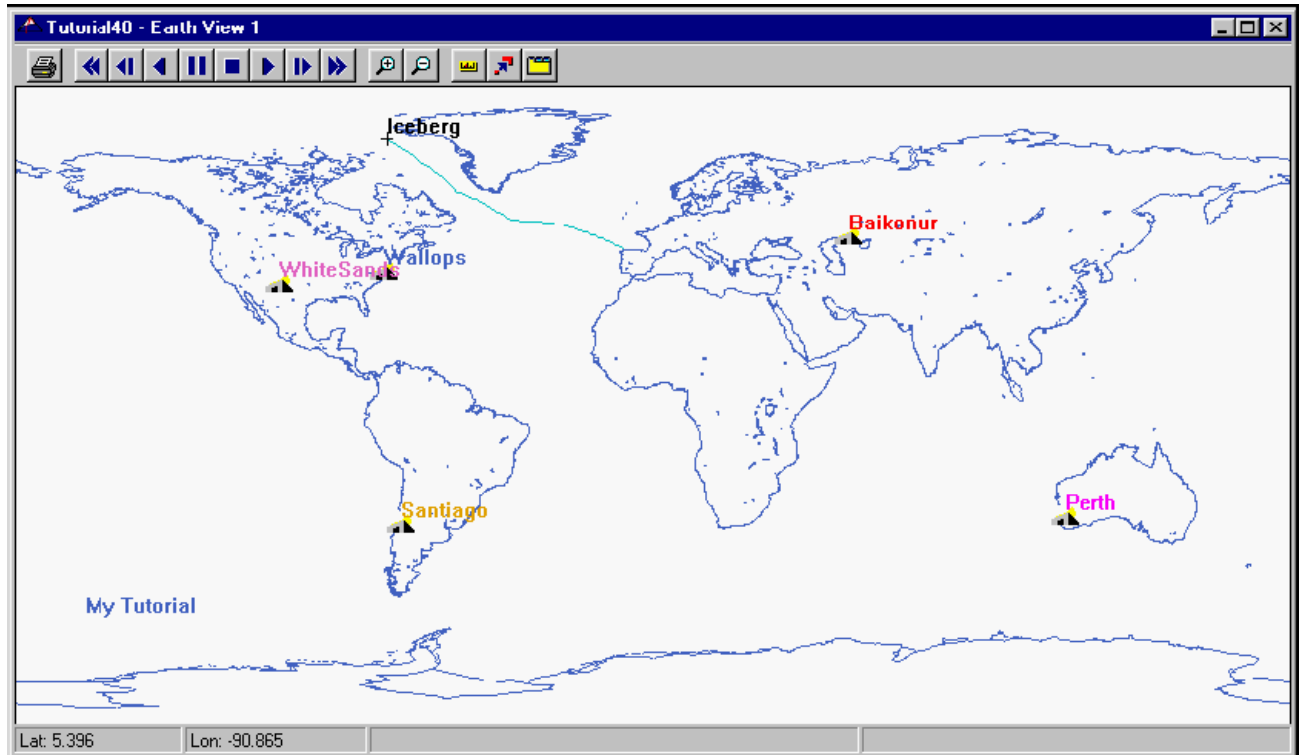
Further at scenario drawing up it is necessary to add companions and space vehicles. For example, are added ERS1, Shuttle, TDRS_East and TDRS_West.

Throughout all exercise time will be displayed in seconds. In window Basic Properties choose вкладку Units, change measurement of time for seconds and press APPRX.

Now companions are added in the scenario. For example, at first in the scenario two transferring geostationary companions (TDRS) are added. In the main window it is necessary to press the companion image. As a result will open Orbit Wizard (the master of a choice of an orbit).

ORBIT WIZARD

☐ Do not display Orbit Wizard at Satellite creation

< Back   Next >   Cancel

| deg | UTCG | nm | kg | sec |
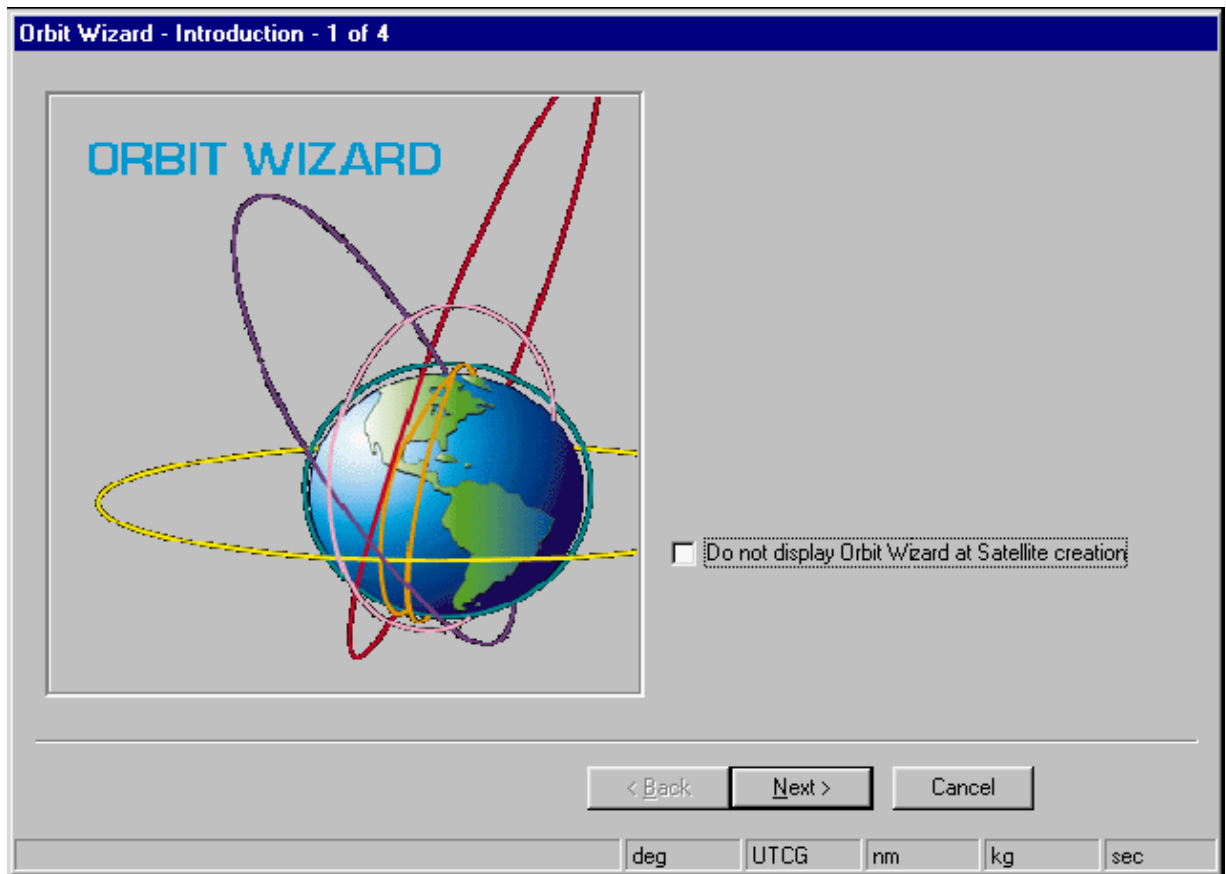
Key Next is pressed. Option Geostationary gets out and is again pressed **Next**.

GEOSTATIONARY ORBIT

A satellite in a geostationary orbit will remain fixed in the sky above the specified longitude.

Subsatellite Longitude: -100.0000 deg

< Back   Next >   Cancel

| deg | UTCG | nm | kg | sec |
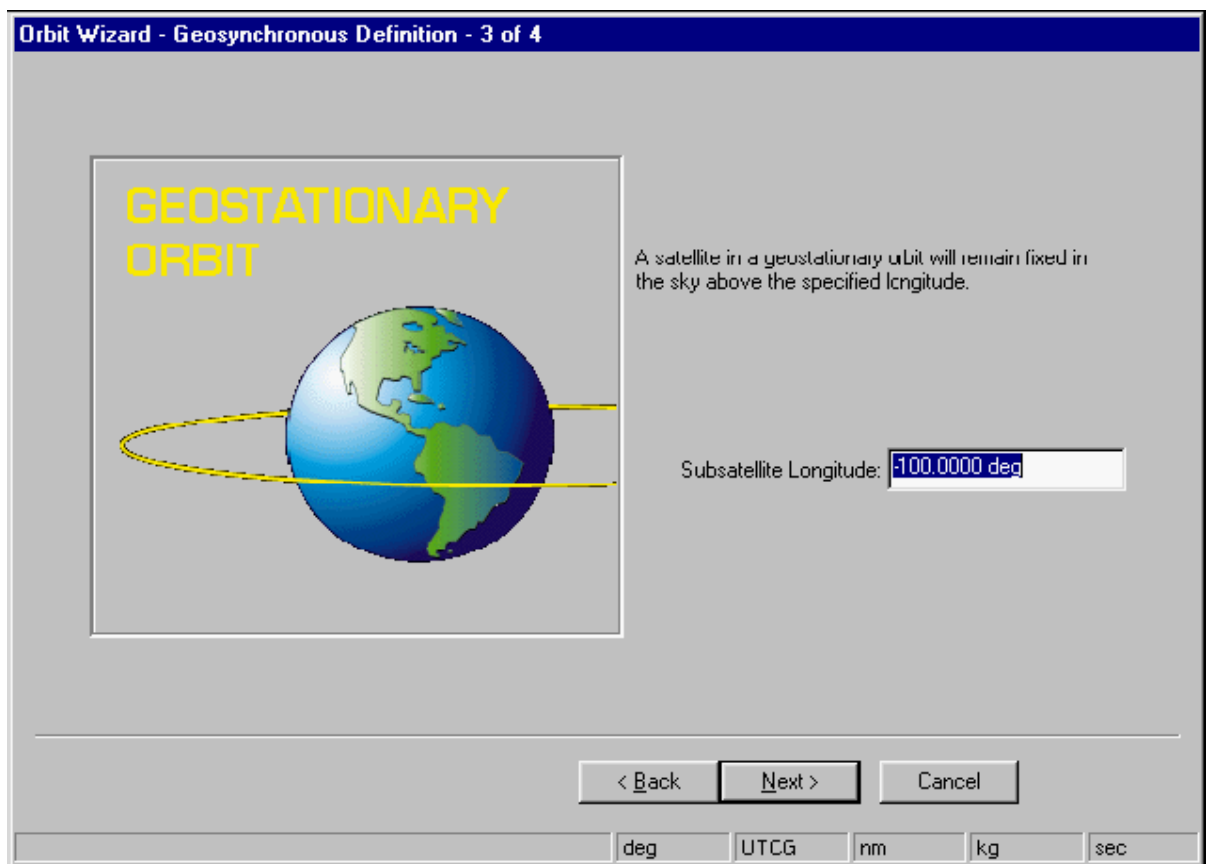
It is necessary to be convinced that in a window of the **Master** of geostationary orbits the longitude (Longitude) matters-100 (a longitude of standing of the companion on equator), then it is necessary to press Next.

Further change time of start of viewing of the scenario and the viewing termination on 1 Nov 1997 00:00:00.00 and 2 Nov 1997 00:00:00.00, accordingly. Further it is necessary to change the companion name on TDRS.

Now it is necessary to enter one more companion TDRS into the scenario. For this purpose it is necessary to make active a scenario window, to choose in menu Files point Insert. After opening вкладки Insert it is necessary to choose the concrete companion from the list of accessible expansions. Further key OK is pressed to add the companion.

Lines of both companions are displayed in the form of lines. That it is better to see companions, it is necessary to click on companions serially and to choose in appeared menu Graphics. The icon of the companion as Marker Style Further gets out.
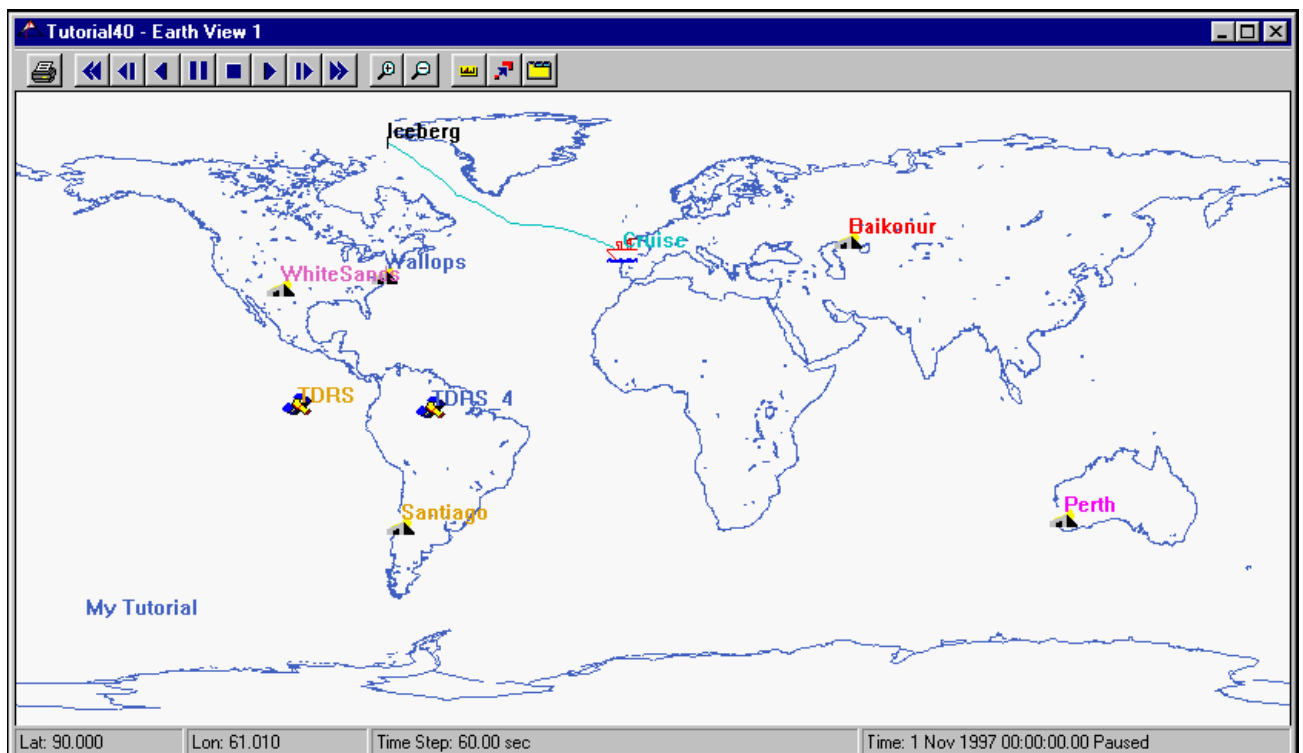
Addition of companions is carried out by pressing an icon with the companion image. When there will be a window of the master of a choice of an orbit is pressed Cancel and the companion name on ERS1 changes.
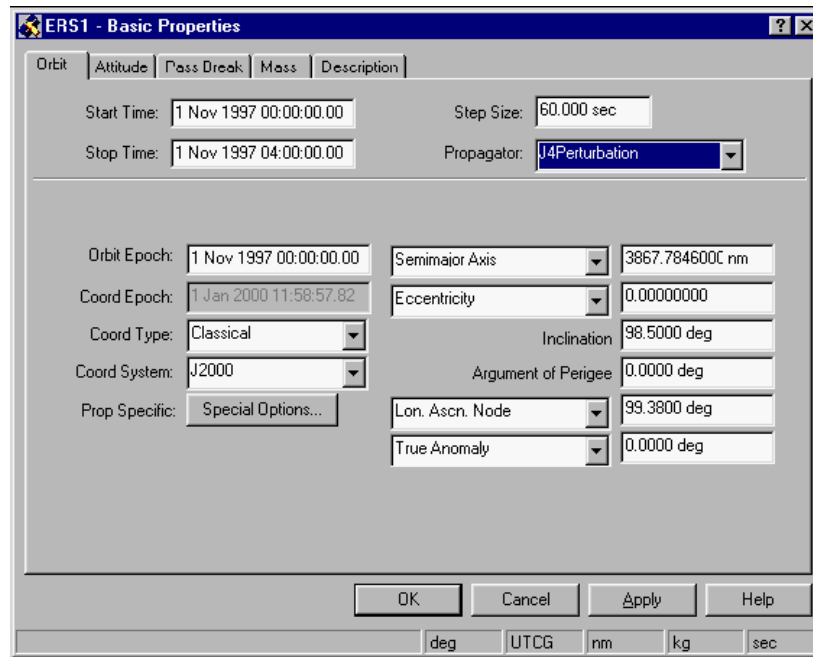
Further parameters of an orbit for ERS1 are entered. Before entering the values resulted in the table, it is necessary to press the button to change value RAAN on Lon Ascn Node (a longitude of the ascending knot).

Orbital Element	Setting
Start Time	1 Nov 1997 00:00:00.00
Stop Time	1 Nov 1997 04:00:00.00
Step Size	60.00
Propagator	J4 Perturbation
Orbit Epoch	1 Nov 1997 00:00:00.00
Coordinate type	Classical
Coordinate System	J2000
Semimajor Axis	3867.7846

Eccentricity	0.0
Inclination	98.50
Argument of Perigee	0.0
Lon Ascn Node	99.38
True Anomaly	0.0

After the input termination it is necessary to press the button APPRX.
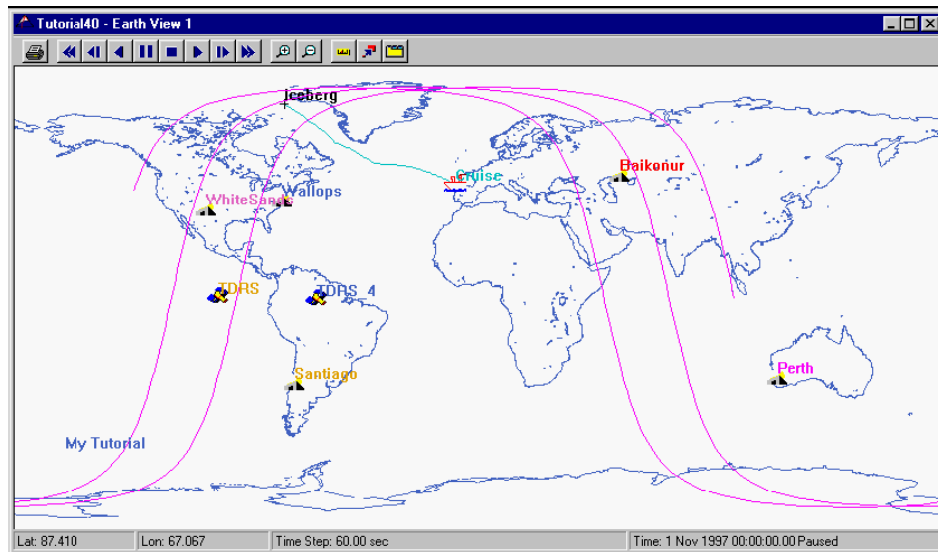
On ongoing educational scenario should be added to the spacecraft. To do this, again click on the icon with the satellite. When the wizard appears select the orbit should click **Cancel** and enter the name of the Shuttle. You must open the basic settings for the **Shuttle** and enter the settings shown in the table, similarly as was done for ERS1.
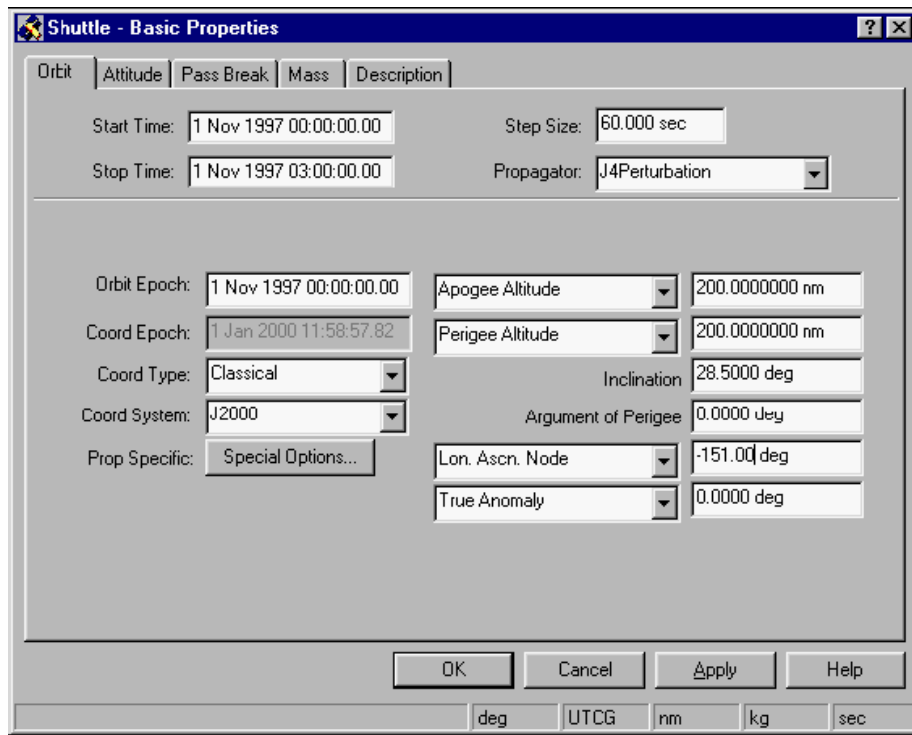
Before entering the values resulted in the table, it is necessary to press the button to change **RAAN** on Lon Ascn Node and **Semimajor Axis** (the main shaft) on **Apogee Altitude (**apogee height).

Orbital Element	Setting
Start Time	1 Nov 1997 00:00:00.00
Stop Time	1 Nov 1997 03:00:00.00
Step Size	60.00
Propagator	J4 Perturbation
Orbit Epoch	1 Nov 1997 00:00:00.00
Coordinate type	Classical
Coordinate System	J2000
Apogee Altitude	200.0 nm
Perigee Altitude	200.0 nm
Inclination	28.5
Argument of Perigee	0.0
Lon Ascn Node	-151.0
True Anomaly	0.0

After finishing, press the **OK** button.

Once you enter the parameters **Shuttle**, you can change the properties of an object, such as the type and color lines to indicate his line on the Earth's surface, to distinguish the road from other moving objects. To do this, select **Shuttle** in the main window, click on it, right-click, select **Graphics** from the menu,
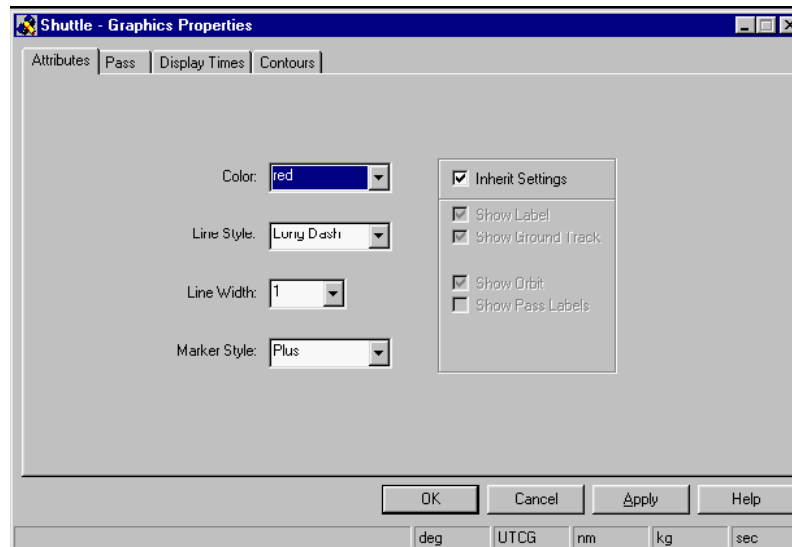
on tab **Attributes** change **Line Style** (line style) on the **Long Dash** (long dashed line), **Marker Style** (marker style) on the **Plus** and click **Apply**.

Then choose the tab **Contours**.
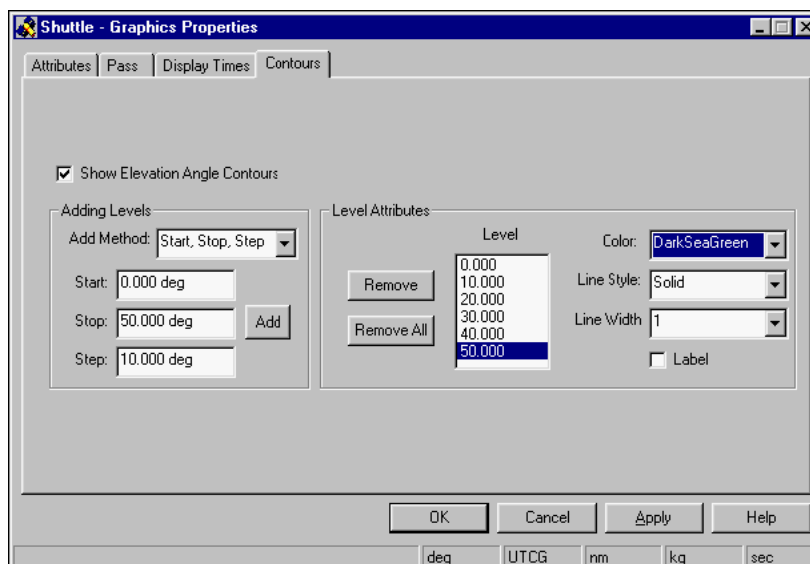
Now, should set a place at which the angle can be observed **Shuttle**. You must make sure that the tab **Contours Add Method** cursor on **Start, Stop, Step. Next**, enter a value of 0, 50 and 10 are, respectively, and click **Add**. In the **Level** select the first level (0.00) and disable the **Label**. Then do the same for the other

levels. **Enable Show Elevation Angle Contours** and click *OK*. Here's an example view of the map
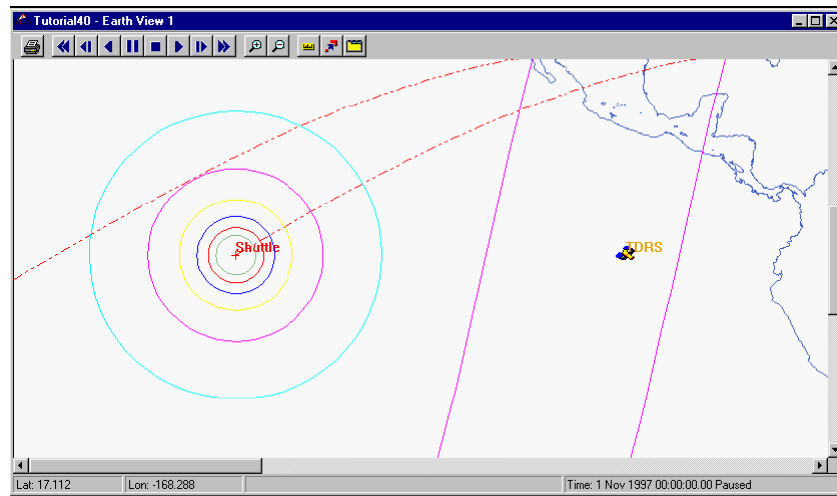
You can watch satellite orbits in 3-D. In the main window should be allocated and choose **Tutorial40** in the **Tools** menu, click **New Window**. When you see the map window, click on the last button in the top row - will appear **Graphics Properties**. Select the tab **Projection**. Put the values shown in the figure below.
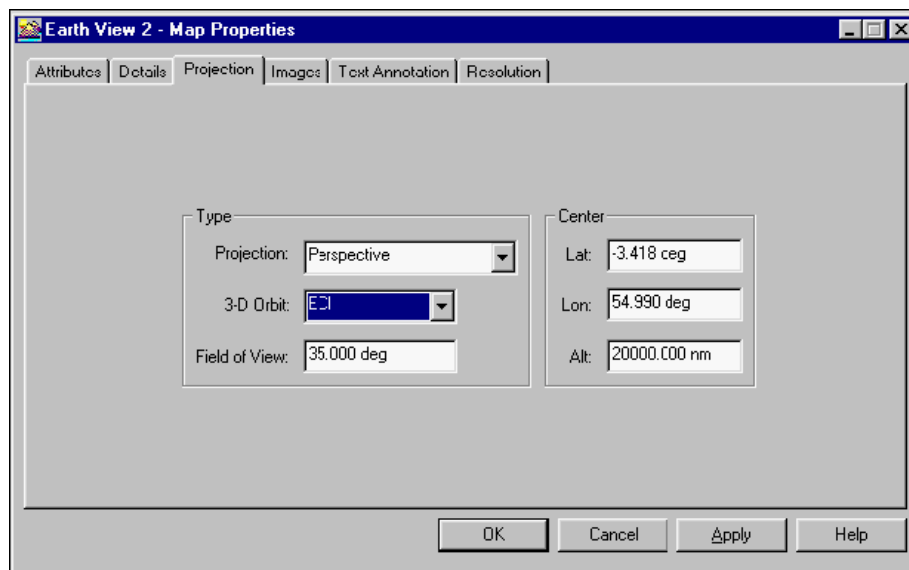
When the scenario is important needed to select the monitoring of the surface (visibility) from satellites. They clearly represent the boundary areas of interest in the Earth's surface.

Consider the situation when the ship ran into an iceberg. Create a scope that defines the boundary of the surviving passengers and search the whole of the remaining equipment. Should click on the icon of Area Target at the bottom of the main window, and then call zone - SearchArea, open the Graphics Properties for

SearchArea. Further **Attributes** tab to change the thickness of the lines (Line Width) at 3, choose **None** for the **Marker Type** and disable option **Inherit Settings** and **Show Label**. Then click OK.

Now you must specify the purpose of observation. You must open a window to set the **Basic Propertie**s of the coverage,
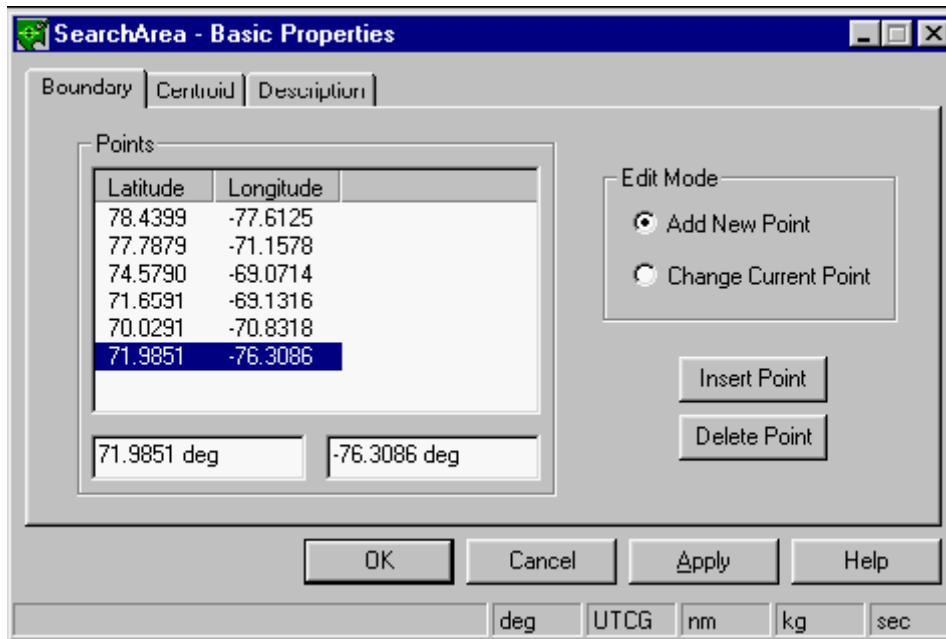
enter the longitude and latitude, as shown in the figure. Once the values have been introduced longitude / latitude, press the Insert Point.

We have to go to the tab **Centriod**.
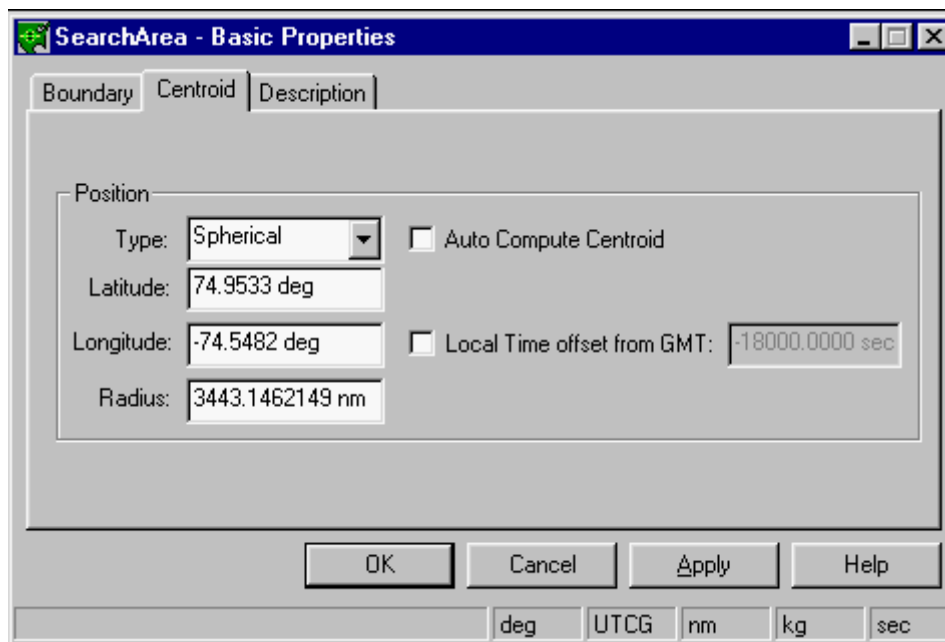
It should disable the **Auto Centroid Compute**, modify **Position Type** to Spherical and the latitude 74.9533 and longitude -74.5482, as well as the radius of 3433.1462149. After graduating from OK Press.

Next, open the window for the Graphics Properties of the iceberg, change the Marker Style to X and click OK.
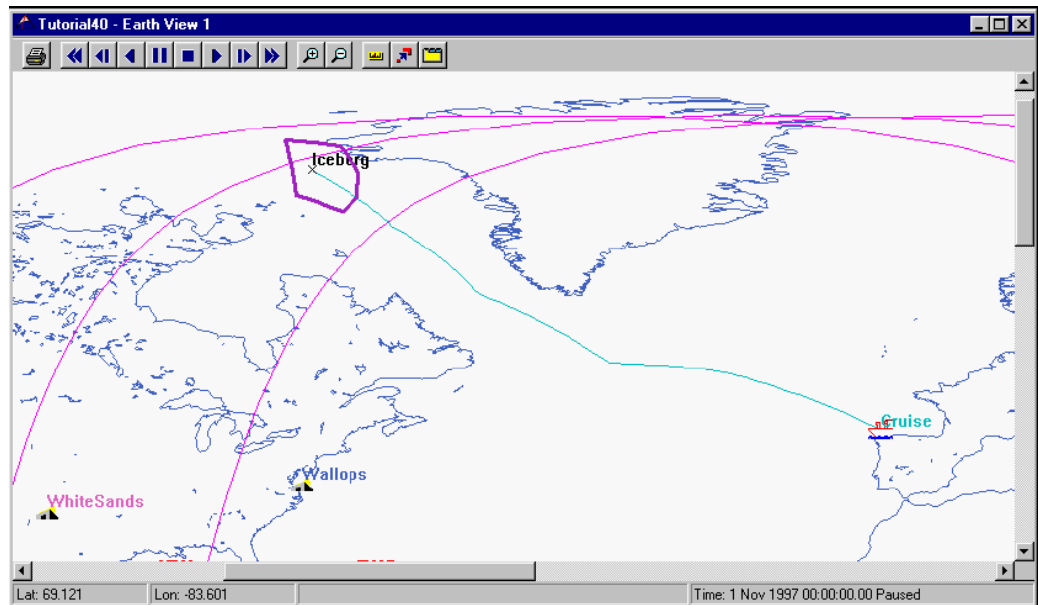
Suppose we want to find out whether satellite ERS1 see the collapse and whether it can assist in finding and rescuing people. In the main window should be made ERS1, click the right mouse button and select Access from the menu. Then choose from a list of **SearchArea** objects, press successively **Compute, Access ...Reports** in the field to see the report of the review of the satellite.

To use the satellite ERS1 for such purposes, it should have on-board scanner and aerial surveillance, to transfer data from the satellite to the Earth.
In the main window should be made ERS1, click on the icon with the image sensor and its name is Horizon. In the class of satellites ERS1 will be a subclass of the

sensor. Now you need to set the properties of the object definitions for the sensor on the tab **Basic Properties**.
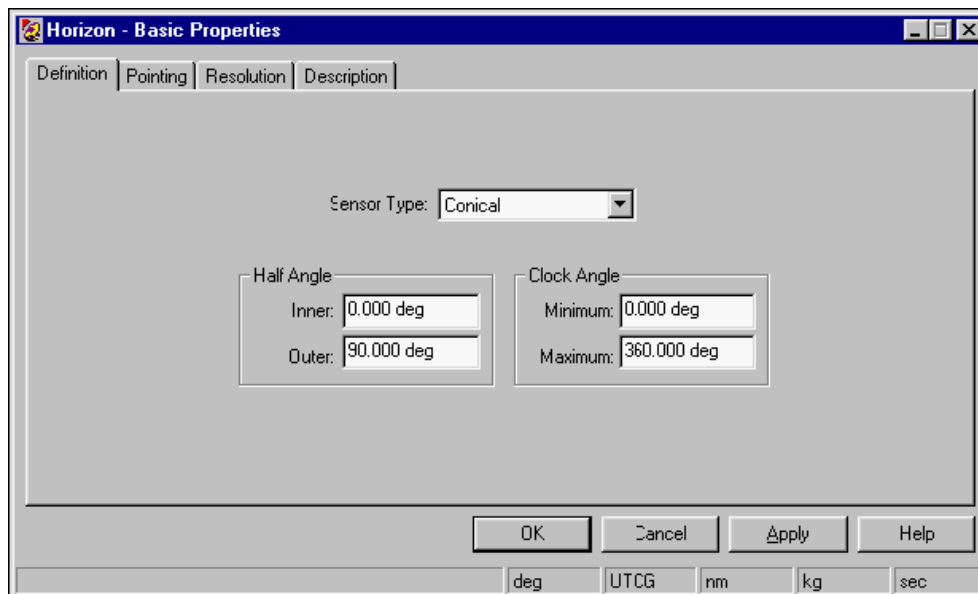
Enter the values as shown in the figure, and then click the **Pointing**.
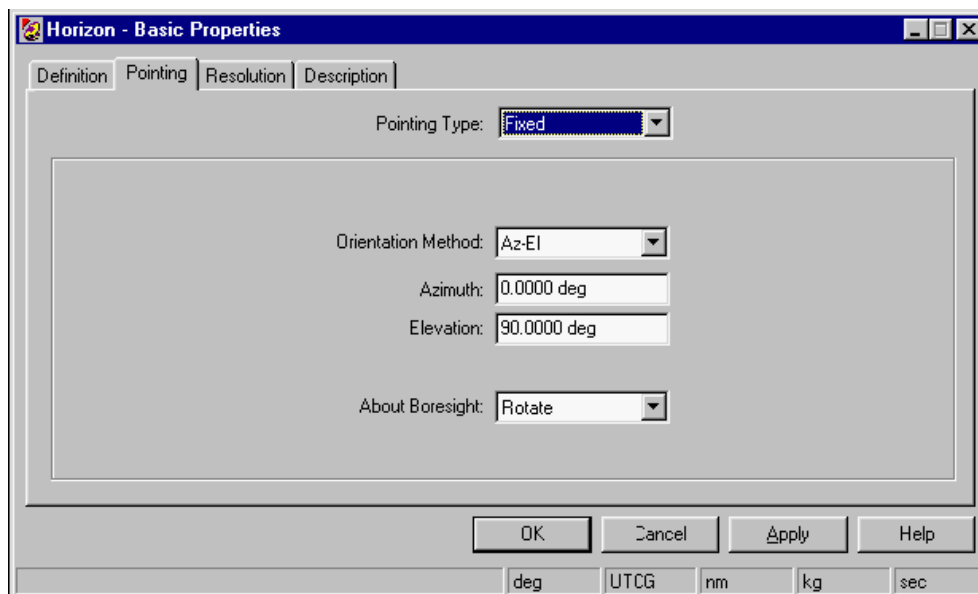
Should be sent to our satellite sensor strictly on Earth. To do this, you should check that the options Pointing Type was pressed Fixed Elevation and values equal to 90 degrees, and after that, click OK.

What follows is to describe the properties of the transmitting antenna mounted on the satellite ERS1, using the steps described above. To set up an antenna, set the **Basic Properties** for her. It should set the values as shown below.
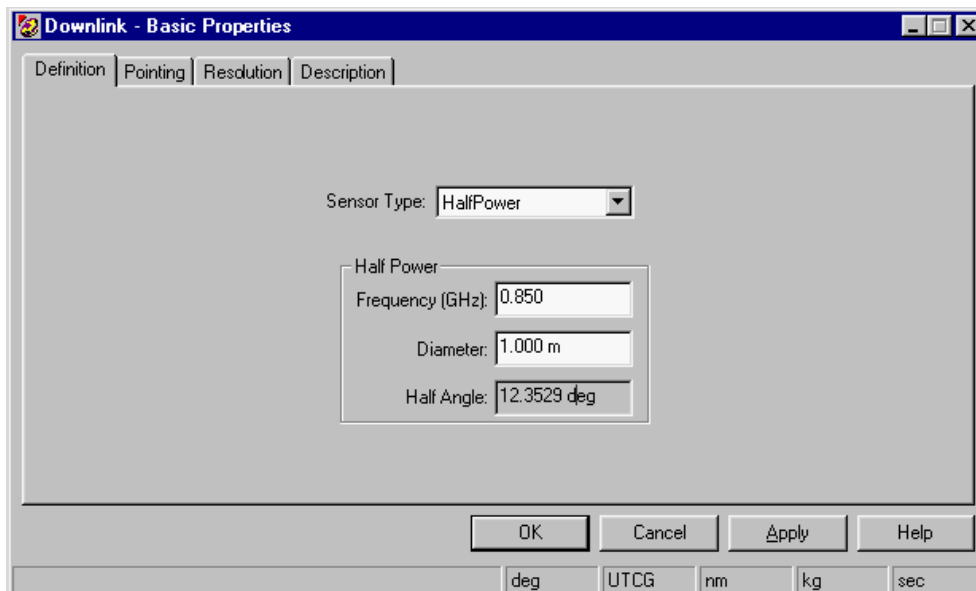
Then go to the tab Pointing.
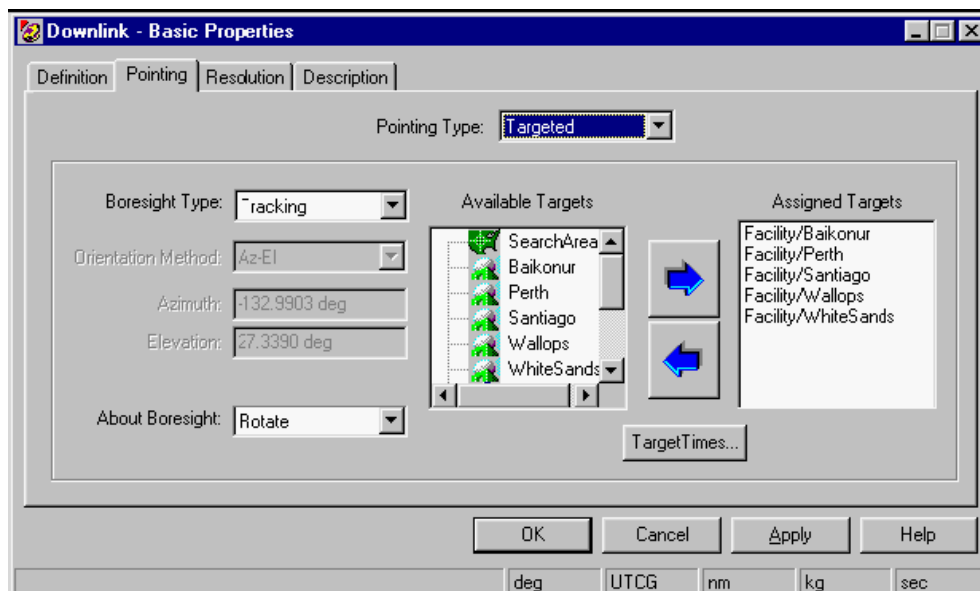
We need to ensure the antenna to the specified ground stations. To do this, change **Pointing Type in Targeted** and **Boresight** (reference direction) Type for **Tracking (Monitoring)**.

Next, select the Baikonur in the list of available objects and click on the arrow to the "right" to add it to the list of existing objects. In the same way, add the remaining objects. Click on OK.

To display the new information is necessary to "revive" the scenario. To do this, click on Play. Below the picture shows the result.
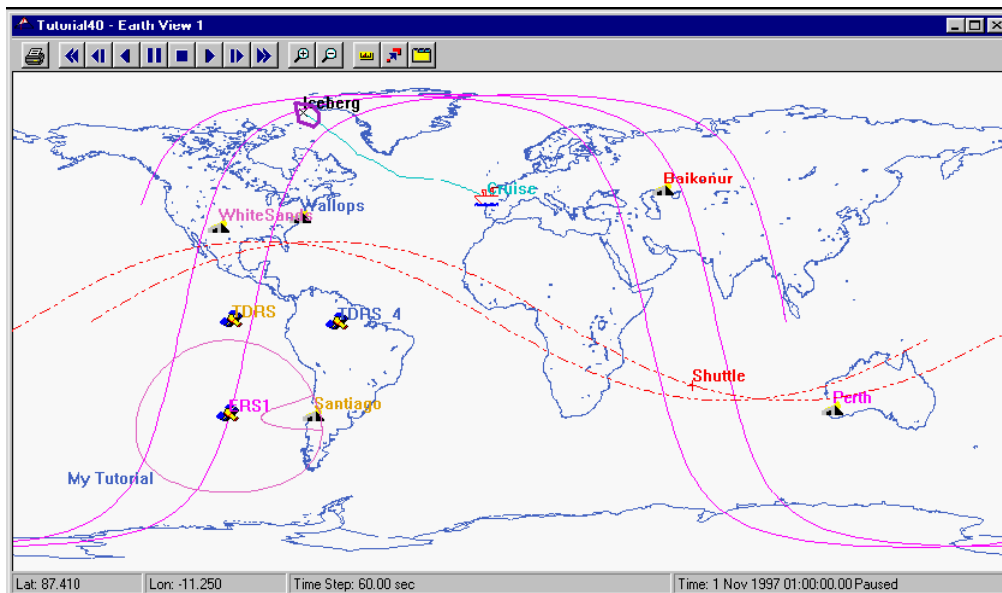
Of their choice modeling and visualization of the script can be interrupted. Sensors purposes and objects can be added. For example, if you want to add an object with the name of Wallops sensor **FiveDegElev** to open its **Basic Properties** to set the parameters. Definition tab in the tab, choose **Conical** and set the Inner Half-angle equal to the value of 0.0 and **Outer Hal**f-angle 85.0, leaving the values for the **Clock Angles** by default. Then select the tab **Pointing**.

On this tab, you should make sure that the options **Pointing Type** set to **Fixed** and **Elevation** value is equal to 90.0. Click OK.

Now, open the **Graphics Properties** window for the sensor and select the tab **Projection**. On this tab, set the **Maximum Altitude** at 424.0 nm and **Step Count** is equal to 1, click OK.
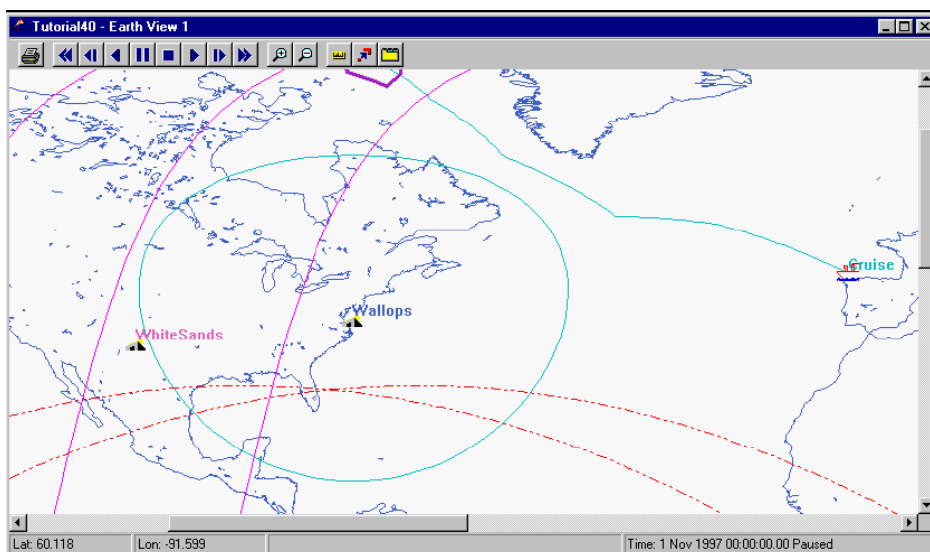
In order for this sensor could be used for another object **WhiteSands**, should highlight **FiveDegElev** sensor in the main window, then select Save from the menu **Files**.

Now add a sensor to an object **WhiteSands**, highlighting the main window **WhiteSands**, and then press the Insert ... menu, **Files**. Should change the **File Type** for **Sensor** and choose **FiveDegElev**.
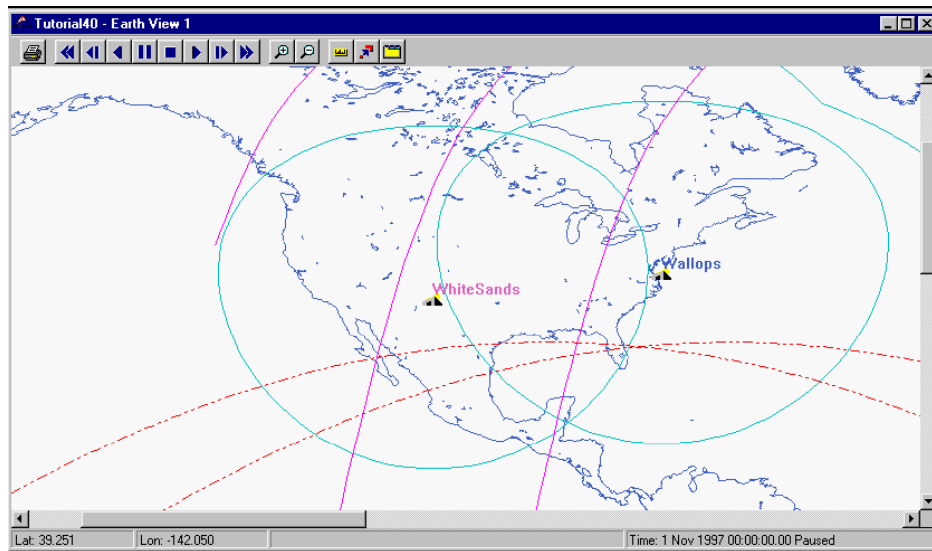
3.2. Analiz orbital missions

In this section, students will acquire skills in analysis of orbital missions (satellite orbits), master control component script for more information and graphical display. In the process of implementation of the student acquires the skills to create the orbit, display tracks the spacecraft imaging scenarios, changing the way the map display and documentation of results.

1. Changing the parameters of the orbit.

If you want to receive information on the height of the perigee and apogee instead of the major axis and eccentricity, it is necessary to click on the icon with an arrow "down" to the right of **Semimajor Axis** and choose **Apogee Altitude** in the list that appears.
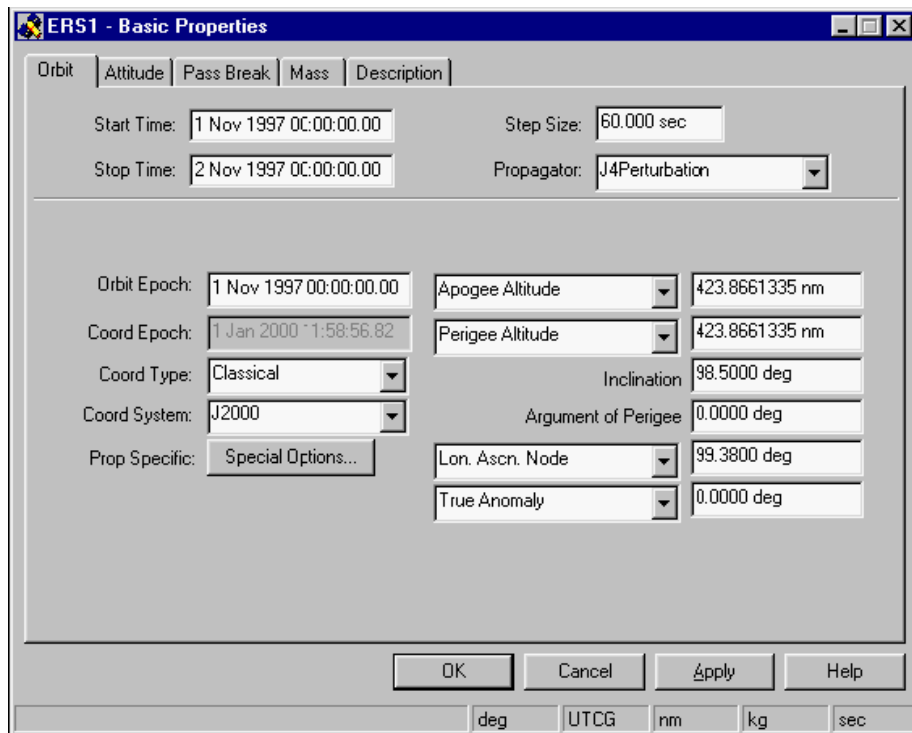
2. Create a report.

Ability to create reports in STK and facilitates data analysis. In STK provides several standard report templates. To create a report in the main window should be made ERS1, right click and select **Report** from the menu.
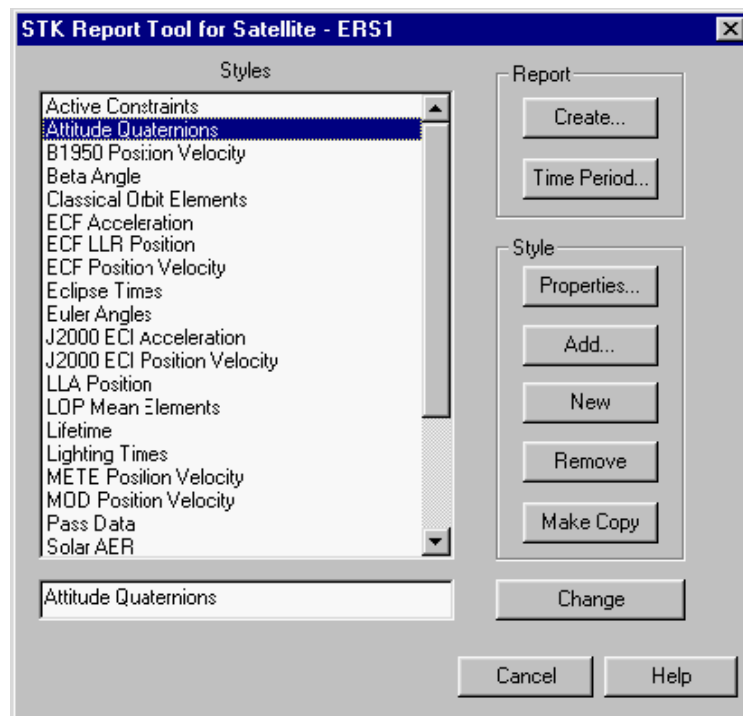
If you need to document information about the orientation of the satellite ERS1, for example, through kvaretniony should be choose **Attitude Quaternions** in the list of templates and click **Create** to get information.

To close this window, select the menu item **Files Close**, to print the report in the menu **Files** should choose **Print**.

3. Getting information in graphical form.

To view the same information in graphical form in the main window should be allocated satellite ERS1 and click **Graph** on the menu **Tools**.
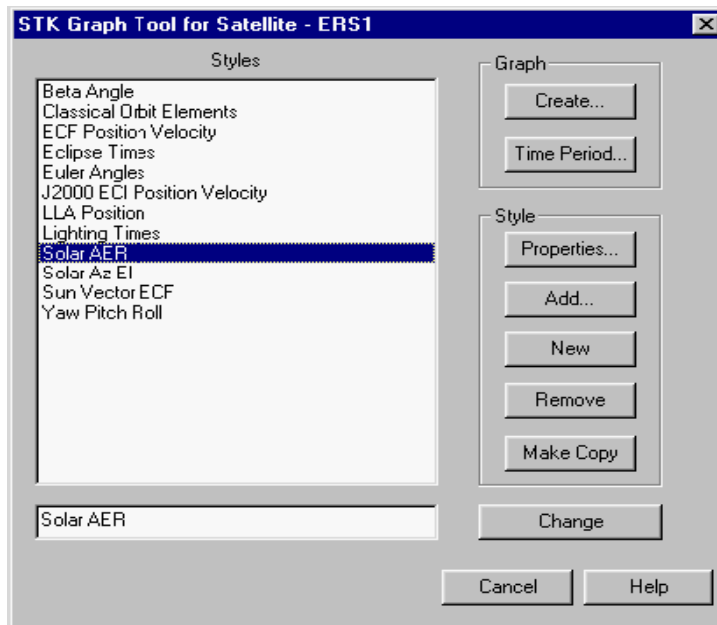
Next in the dialog box to choose **Solar AER** in the style list reports and press **Create**.
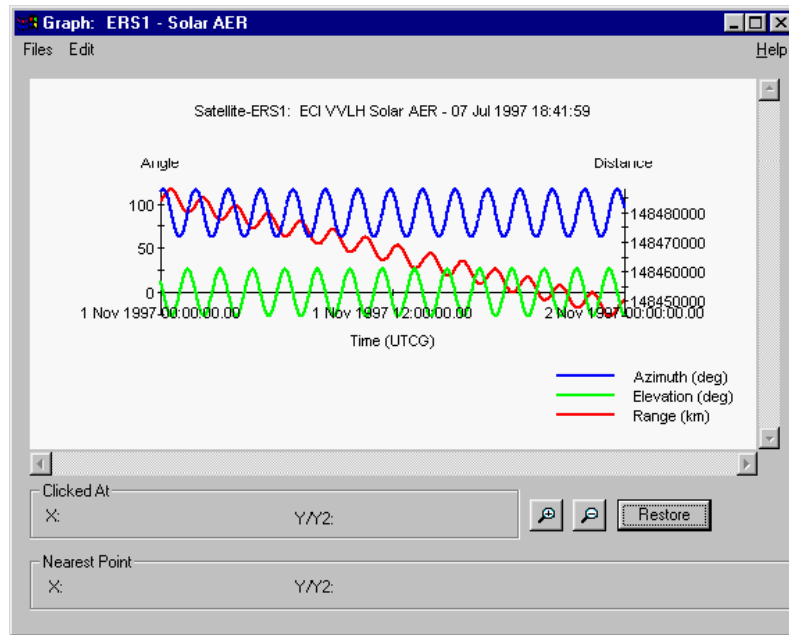
You can click on any point on the graph to obtain numerical information on its coordinates.

4. Dynamic display of information.

You can follow any change in parameters such as azimuth, the longitude of the ascending node and the distance to the object's dynamics. To do this, select ERS1 in the main window and select **Dynamic Display** in menu **Tools**.
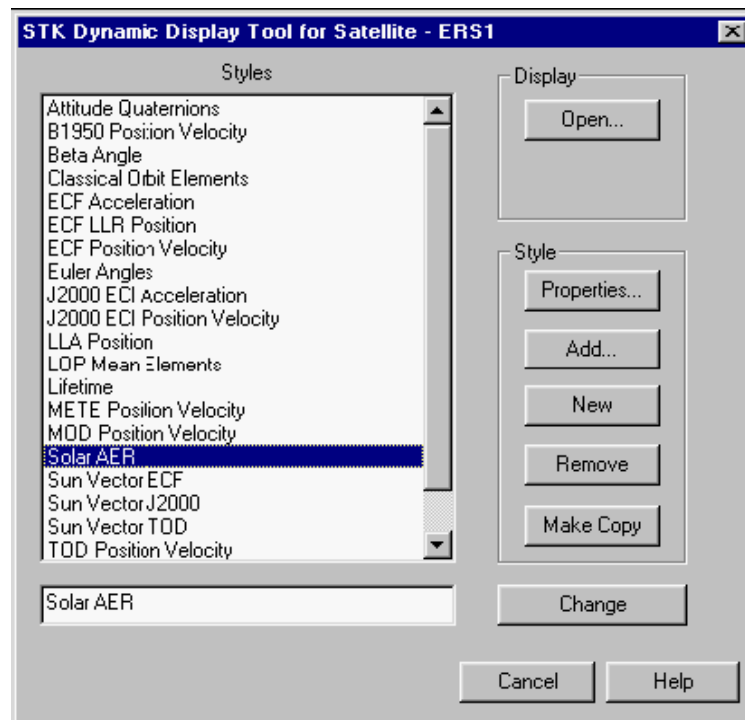
In the window that appears, select **Solar AER** from the list of available templates and click **Open** , then you should run an animation script.
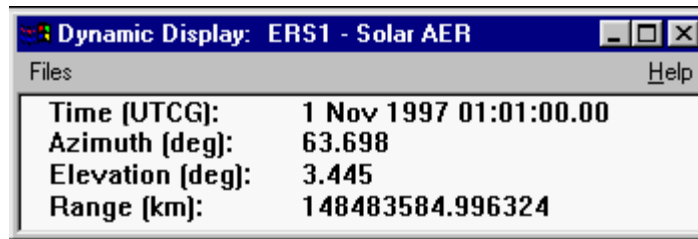
5. Analysis of satellite communication environment with an object or purpose.

To display these processes should be in the main window, select an object and click Santiago Access to the menu **Tools**.
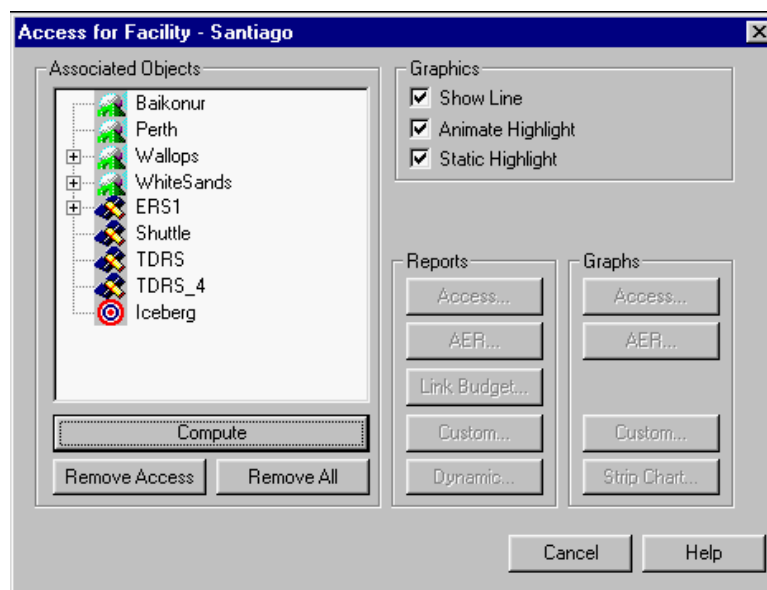
In the **Associated Objects** should be selected ERS1 and make sure that the option **Show Line, Animate Highlight** and **Static Highlight** included. Next, press **Compute**.
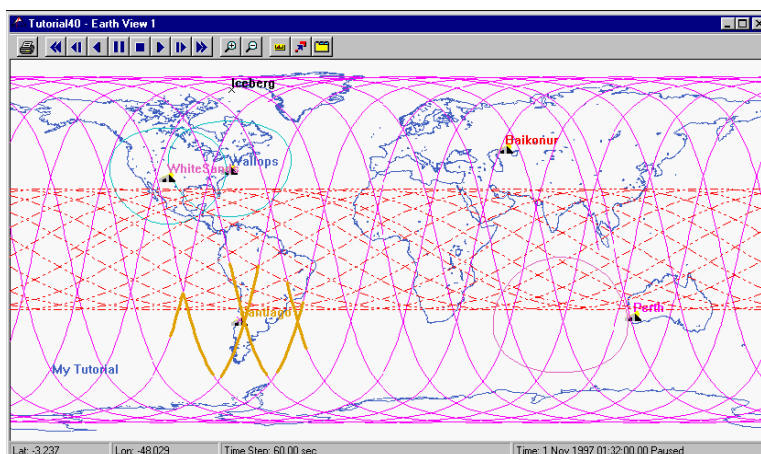
6. Analysis of the conditions of communication between satellites.

An example of analysis and planning capabilities between the two satellites: Shuttle and TDRS_4. To do this, open the Access to Shuttle, select from the list TDRS_4 Associated Objects and press Compute.

7. To analyze the ability to support interplanetary missions is possible to analyze the possibility of communication between the satellite and the planet / interplanetary spacecraft.

To add a planet or interplanetary spacecraft in the script should click on the icon in the world and name the new planet, like Jupiter. To do this, open the **Basic Properties** for the new object.
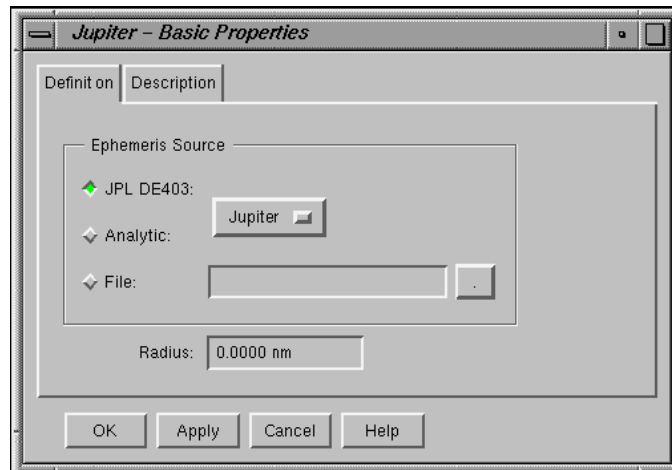
Definition tab, select the JPL DE-403, then select Jupiter on the menu and click OK. Now add in the script, for example, the telescope Hubble. To do this, choose Insert menu in Files, change the File Type and select the Satellite Hubble.
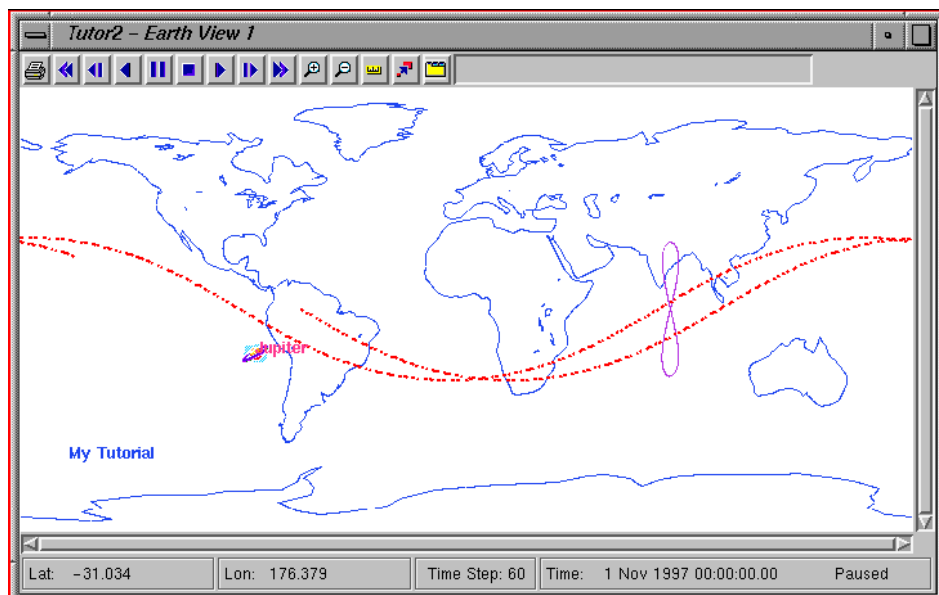
This is followed by openning window **Basic Propertie**s for the sensor and the option to enter **Pointing**.
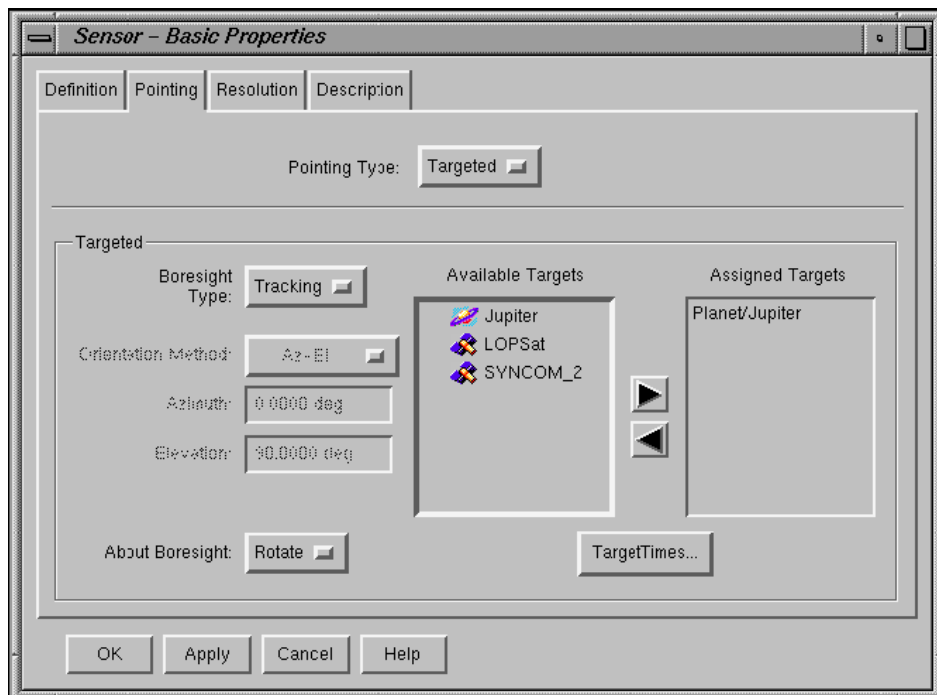
Since the sensor telescope must be sent to Jupiter to be changed **Pointing Type** in **Targeted** and **Boresight Type** for **Trackin**g. Next on the list to choose **Jupiter Available Targets**, click the arrow to the "right" to add it to the **Assigned Targets,** then click OK.

Everything is now ready to establish a link between the telescope and the Hubble Jupiter. It should open the Access to the telescope, Jupiter choose in the list of Associated Objects and click Access. Reports in the field to check the time of communication.

8. Analysis of the survey the Earth's surface.

To display a swath from the satellite as an example of selected Hubble. It should be in the main window, right click and select Swath menu that appears.
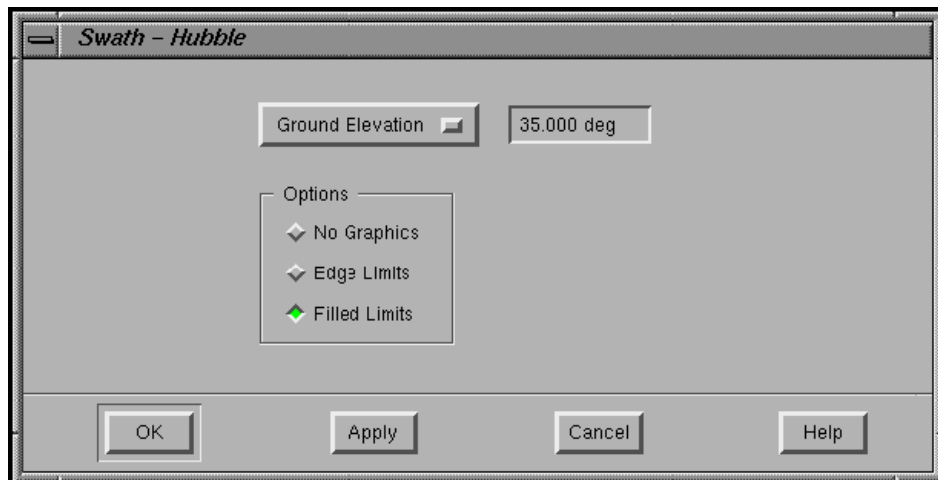

Next, you need to change the **Ground Elevation** at 35.00 ° and enable the option **Filled Limits**, click **Apply**.
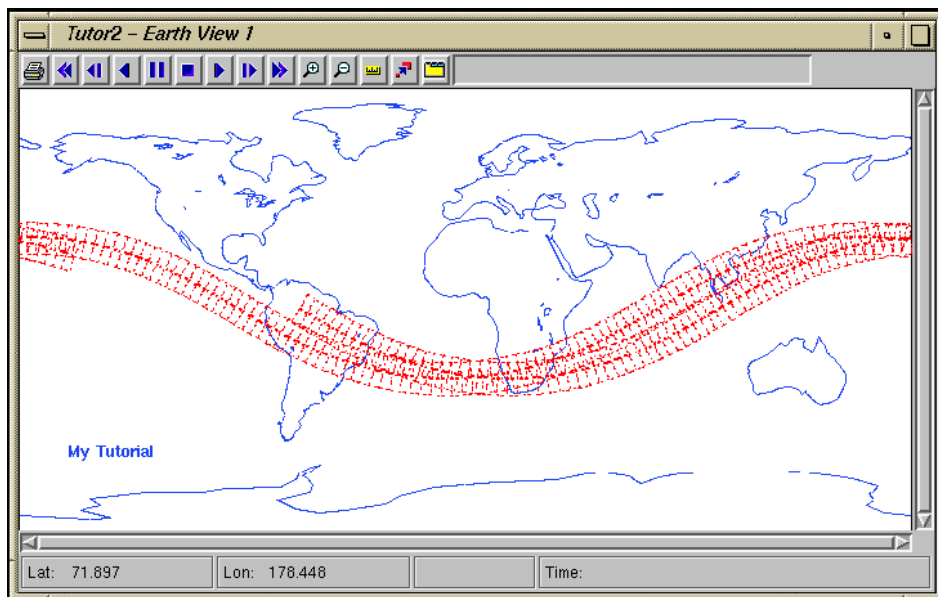

9. Analysis of movement in the long interval of time (Long-term Orbit Predictor)

To analyze changes in the orbit for example, two years, you should perform long-term prognosis. In the main window, select the icon with the image of the satellite. When you see the master orbit selection, press Cancel. Next, specify the name of the new satellite, for example, LOPSat and open the Basic Properties to specify the data to the satellite.
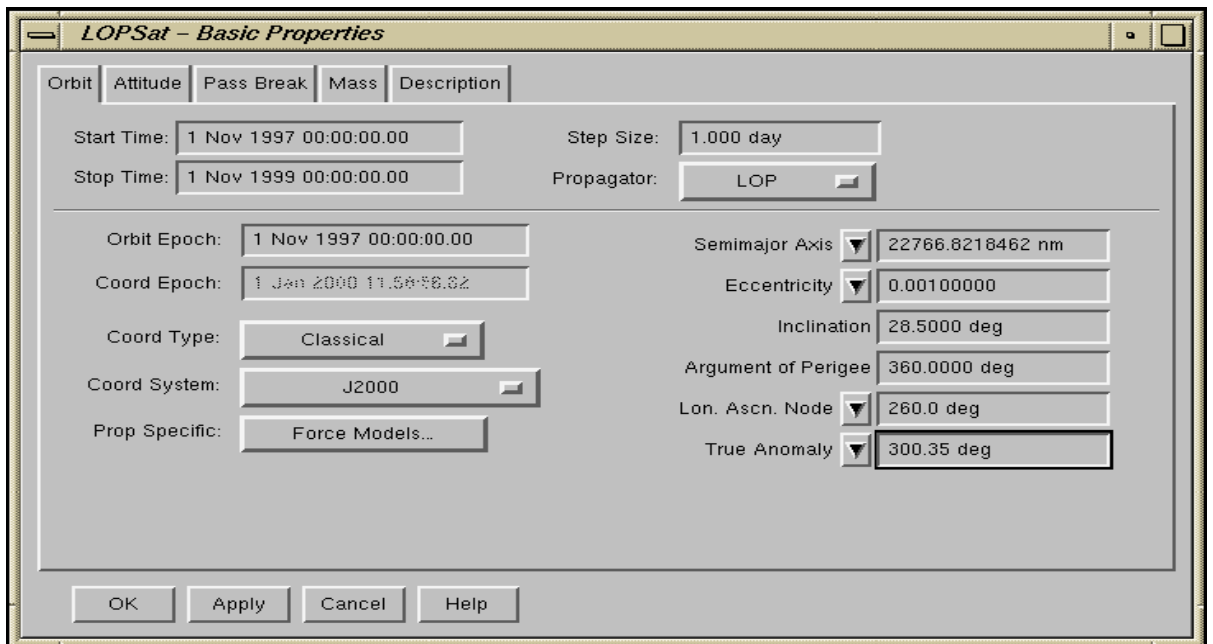
Enter the numbers shown in the picture.

Once values are set, you can click **Force Models** on the same tab.
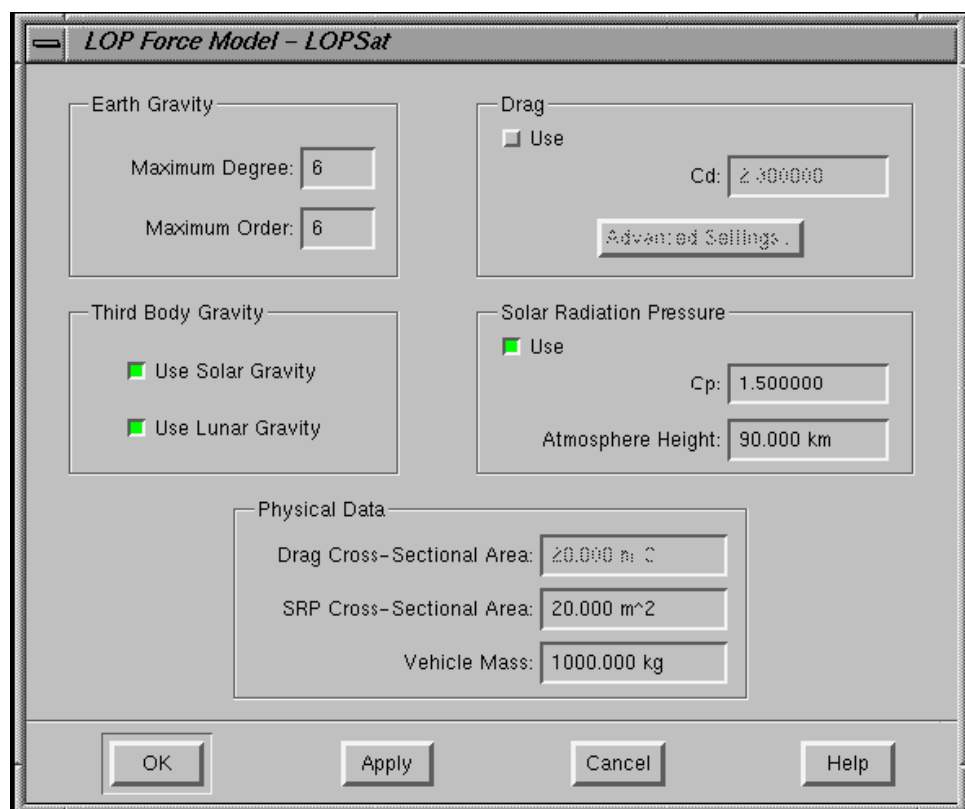
In the window that appears, change the Earth Gravity Maximum Degree and Maximum Order at 6. Make sure the option Use Drag off, and the option Use Solar Radiation Pressure on. Then click the OK button and then click OK on the Advanced tab Orbit.