X-SAR PROGRAM: ORBIT PLANNING AND CONTROL DURING THE DEVELOPMENT PHASE AND MISSION OPERATIONS (SHUTTLE FLIGHTS STS-59 AND STS-68)

Internal Report C95-14

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X-SAR ORBIT PREDICTION ACCURACY ANALYSIS (1ST PART)

X-SAR/MOT Internal Report

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Alberto Foni

Introduction:

The present reports is a collection of documents of the must significant activities and studies performed by the author (as member of the X-SAR Mission Operation Team), during the development, preparation and operation phases of the X-SAR Program. This program, part of the Space Radar Laboratory (SRL) Program, is a joint effort of the Italian Space Agency (ASI) and the German Space Agency (DARA) in cooperation with NASA.
The work documented has been financed by ASI and carried out by CNUCE under the ASI-CNR Agreement.

The report contains:

1) X-SAR Orbit Prediction Accuracy Analysis (1st Part)	September 1991
2) Ephemeris Prediction and DTO Computation for SRL-1 Mission	December 1991
3) Update of orbit decay prediction for SRL mission	April 1992
4) Analysis of the New SRL Baseline Orbit ("Preliminary STS59 Baseline Orbit" JPL IOM 312/92.5-454, D.Casey June 1992)	August 1992
5) Orbital analysis for removing the conflict between two SRL Sites	December 1992
6) Decay Uncertainties and Orbit Adjustments	March 1993
7) How to adjust the Orbit if it goes outside the specified limits	July 1993
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10) Orbit Node/Semimajor axis Control	October 1993
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INTRODUCTION

In order to define the part of the ground system generating the ephemeris for the SRL mission, the causes of error in the orbit prediction process are under investigation by SIR-C and X-SAR teams.

Having in mind that a more accurate trajectory prediction will result in less real-time replanning of the SIR-C/X-SAR timeline, special attention must be paid to the perturbations affecting the Shuttle orbit.

Main points adressed up to now are the air drag effects on the STS orbit (Ref.1), the comparison of different gravity field models (Ref.2), the prediction of the atmospheric density at the epoch foreseen for the mission (Ref.3), the propagation for the duration of a planning cycle of the uncertainty of the MCC State Vector (Ref.4).

Aim of the present note is to complete some of the above mentioned studies with further analyses and to cover those areas that have been addressed but not deeply investigated yet, with the purpose to assess the errors affecting the orbit prediction and ephemeris generation process and to evaluate their impact on the cross range uncertainty.

In particular in this paper some considerations on the air drag modelling are made in addition to Refs. 1 and 3 and the perturbations to the orbit due to the STS maneuvering system are evaluated.

SOURCES OF ERROR

In this chapter a survey of the main causes of error in the orbit propagation process is given. In addition, outcomes of studies already performed for SRL are summarized and a comparison with corresponding results obtained using different techniques and tools (when available), are given.

For the SRL mission the accuracy of the overall ephemeris generation process (i.e. computation of the position and velocity of STS at pre-defined intervals over a certain time span) is affected mainly by:

1. uncertainty of the initial state of STS (MCC State Vector)
2. precision of the orbit propagator
3. modelling of the effects of STS maneuvers/activities on the orbit dynamic.

Uncertainty of the State vector.

The accuracy of the MCC State Vector is by far the more dominating cause of error in the propagation of the STS orbit. In fact the uncertainty in the position and velocity at beginning of the computation, grows considerably as the propagation time increases. In Ref.4 it has been studied at which extent the State Vector uncertainty would result in the "cross range" uncertainty.

The cross range measurement is a very important parameter to be known at moment a Data Take is performed during the real mission. The results of the study performed by SIR-C are summarized in Fig. 1 where it can be seen the behaviour of the cross range uncertainty as function of the propagation time.

Similar analysis performed by X-SAR using the Two Body Error Analysis Program has given the results reported in Tab. 1 which are in good agreement with the corresponding SIR-C results except than at very beginning of the time-span considered.

Since the only error taken into account in both studies is the one associated to the STS initial state, it is clear that to reduce the error in the STS position and velocity after a given time, the only way is to get a more precise estimate of the initial state.

The collection and processing of the tracking data for computing the State Vector at regular intervals are tasks of MCC and therefore neither operations nor procedures can be herein identified to improve the State Vector accuracy.

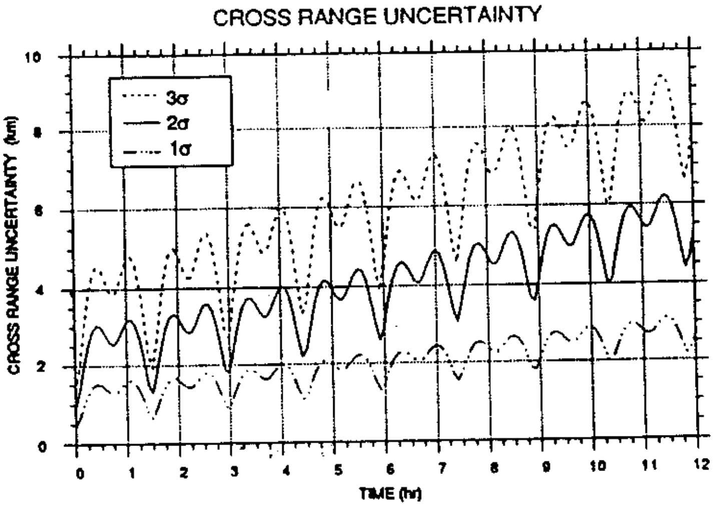

Figure 1 - Cross Range Uncertainties (SIR-C study)

Time (hr)	1σ (km)	2σ (km)	3σ (km)
0.	1.33	2.66	3.99
1.	2.04	4.08	6.13
3.	1.71	3.63	5.07
3.25	2.27	4.54	6.81
3.50	2.27	4.53	6.80
3.75	2.07	4.13	7.42
4.	2.50	5.00	7.50
12.	3.29	6.58	9.87

Table 1 - Cross Range Uncertainties (X-SAR study)

Precision of the Orbit Propagator

Orbit propagation is the process which permits to compute the evolution of the initial orbital parameters over a given time interval. To accomplish this task for Earth orbits it is necessary to integrate the equation of motion taking into account the perturbations which modify the Keplerian motion due to the monopole term of the Earth's gravitational field. The perturbing function defined into the orbit propagator tool will determine the accuracy of the results.

In addition errors due to the software itself will affect the propagation process.

For the above it must be considered that the final accuracy of the orbit propagator depends on:

- Perturbation models
    - Earth's gravity field
    - Air drag
    - Sun-moon gravity
    - Direct Solar radiation pressure
    - Other perturbations (planets gravity, albedo radiation pressure, solid and oceanic tides, micro meteroids, thermal re-emission, etc...)
- Software errors
    - Round-off
    - Calculation errors

Earth's Gravity Field

A study was performed at JPL to identify the gravity field model to be used by SRL software for orbit propagation (Ref.2). The conclusions being that the same model should be used for both the orbit determination and the orbit propagation programs.

A 4x4 gravity field which is commonly used for low Earth orbit computations, would provide sufficient accuracy for SRL mission. Any how it is not a very critical parameter since the adoption of one of the various model available (GEM-9, GEM-10b, FDS, INTEG5 etc.), as well as the use of higher order terms would result in differences in the Shuttle position less than 1 km and in the semi-major axis less than 20 m, after 12 hours of propagation.

Air Drag

The secular **effect** of the acceleration acting on STS due to the atmosphere density, is a main **cause** of perturbation to the Shuttle orbit. Such an acceleration (a_D) is expressed by:

$$a_D = -\frac{1}{2} C_D \rho \frac{A}{m} V^2$$

where:

C_D = Drag Coefficient
ρ = atmosphere density
A = STS cross-section
m = STS mass
V = orbital velocity

All the above values (except ρ) can be precisely assessed well before the beginning of the mission, furthermore they can be considered to be constant during the flight and independent from the launch epoch.

On the other hand, the atmospheric density is influenced by a number of parameters part of which can be roughly estimated prior the flight takes place. The most important ones are the exospheric temperature (Texo) an the geomagnetic index K_P or A_P. Since Texo is directly linked to the Solar activity, the ρ is difficult to predict even if some general trend of the solar activity (as the 11-year cycle) allows raw predictions.

To reduce the uncertainty in the predictions, the measurement of the solar flux at 2800 Mhz (F10.7) and its short-term predictions (performed and disseminated daily), could be used to adjust the atmosphere drag computations by the orbit propagator to the actual atmosphere conditions.

Since the model contained in ASAP is based on the US Standard Atmosphere 1976 which considers a fixed reference Texo of 1000°K, the parameter WT (which is defined "to scale" the results of ASAP for different atmosphere density conditions) should be defined to obtain orbit predictions as close as possible to the actual ones.

The following table shows which value of WT should be used to obtain predictions under different atmosphere density due to corresponding solar flux measurements.

WT (US76)	F10.7 (Harr.-Pr.)
0.8	120
1.0	150
1.2	180
1.4	225

Table 2 - Equivalence between WT and F10.7

Modelling of STS Maneuvers/Activities

Since the **Shuttle** is a very active, maneuverable spacecraft, its activities such as attitude maneuvers, translactional effects from attitude maintenance thrusting and execution errors in orbit maneuvering, can produce significant trajectory errors.

Even though some of these disturbances could be considered in the perturbation terms of the equations of motion coded in the orbit propagation program, at present the orbit propagator selected for SRL (ASAP) doesn't allow to do this.

It is important to note that the effects on the Shuttle orbit due to the above causes are approximately five times bigger than the ones induced by dynamic model uncertainties.

For the purpose to analyze their effects on the STS orbit, the maneuvers/activities can be grouped as follows:

- Planned Maneuvers
    - orbit corrections
    - altitude keeping
    - orbit transfers
- Unmodelled Maneuvers
    - attitude maneuvers
    - attitude keeping
    - IMU maneuvers
    - water dumps
    - crew movements
    - cabin depressurization

Planned Maneuvers

All the maneuvers listed under this group are events defined in the mission timeline and therefore are scheduled for execution at a precise time. Since the time at which the maneuver will be executed is known as well as the required ΔV, the element affecting the accuracy of the predicted post-maneuver status, is mainly the uncertainty in the actual ΔV delivered by the STS RCS. This uncertainty can be assumed much lower than the 5% (normally less than 2%) and therefore, considering the size of the orbit adjustments normally required by SRL mission, its effect on the post-maneuver orbit accuracy is negligeable.

If the uncertainty in the orbit corrections can be neglected, the corrections itself (which could change the semi-major axis up to a few kilometers) must be considered when the orbit is propagated.

Unmodelled Maneuvers

These maneuvers are defined unmodelled because for some of them it is not known how or when the maneuver will be executed (number and duration of the pulses, jet or combination of jets used, sequence of firing, etc.) for the reason that an automatic control is used by STS.

For other events it is impossible to plan the corresponding operations at level of timeline because of the crew active partecipation.

Therefore actvities like water dumps, crew movements, cabin depressurization, EVA, etc. cannot be modelled for orbit propagation purposes. Fortunatly they cause negligeable effects in the STS orbit dynamic.

On the contrary the effects of the Shuttle attitude control on the orbit are considerable and are discussed in the following.

Attitude maneuvers

The maneuvers are executed when STS is requested to change from one attitude to another one.

Normally the process consists in two main pulses from the Shuttle's RCS system. With the first pulse the rotation required to get the desired attitude is started, with the second pulse the rotation is stopped when the new attitude is reached.

The effects on the orbit dynamics of such maneuver depend upon factors like the size of the rotation required, jets used, thrust required for each jet, etc.. Studies conducted at JSC considering energy changes from a single attitude maneuver for the Shuttle missions from STS-1 through STS-31, report that an average increase in the Shuttle altitude of 20 meters (with a standard deviation of 100 meters), has been measured (Fig.2).

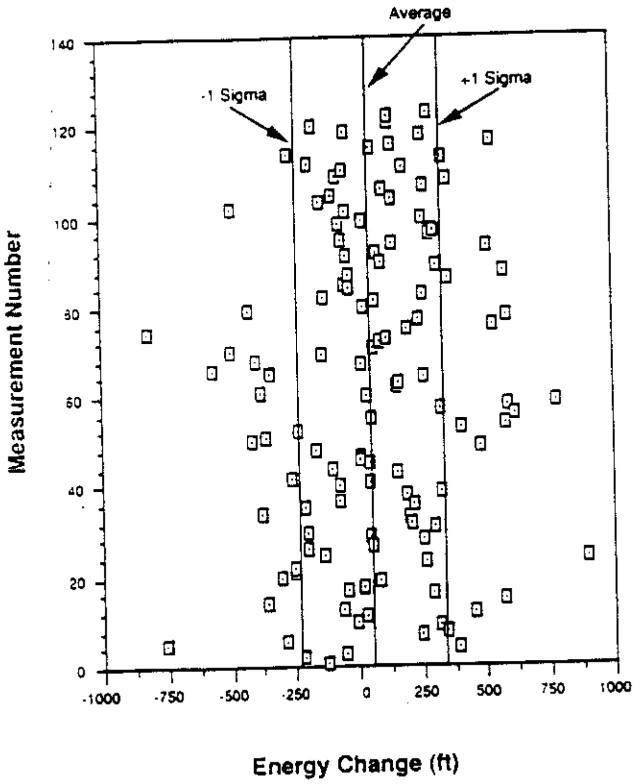

Figure 2 - Energy Changes From a Single Attitude Maneuver

Attitude keeping

For maintaining the nominal attitudes for SRL experimental activities, mainly Bay Down Nose Forward (BDNF) and Bay Down Tail Forward (BDTF), the Shuttle RCS will be active for almost the entire duration of the operational flight.

Throughout the duration of the Shuttle program for these attitudes the orbiter has shown a long-term energy variation. The explaination of the phenomena can be found considering the effects of the firing of the jets used for pitch control (see Fig.3). In this attitude, the aft downfiring jets are principally used to maintain pitch control. The impingement of these jets on the STS body produces a thrust in the STS nose direction. The thrust is responsible for the energy growth experienced during the periods such attitude has been keept by STS and in particular, for the nose to the velocity vector attitude, the variation has been positive.

For the BDTF the thrust is acting in the opposite direction of the velocity vector, thus determining an energy reduction.

Shuttle Ground Navigators have used tracking data to determine the appropriate acceleration to compensate for the energy growth and thereby produce a more accurate State Vector. A vent, a costant force in the STS body coordinate, corresponding to the desired acceleration, has been solved for in addition to the STS State Vector over the tracking data span during the orbit determination process. The vent force (F_T), aligned to the velocity vector and independent from the STS altitude, has been computed at JSC to be about 0.05 lbf.

+ Pitch

- Pitch

Figure 3 - Jets Used For Pitch Control

For evaluating the effect of the vent force on the STS orbit, the following formula can be used:

$$\frac{da}{dt} = \frac{2e\sin\nu}{\left(\mu\frac{(1-e^2)}{a^3}\right)^{1/2}} acc_R + \frac{2a(1-e^2)^{1/2}}{r\left(\frac{\mu}{a^3}\right)^{1/2}} acc_{DT} \qquad [1]$$

where:

a = semi-major axis
ν = true anomaly
e = eccentricity

r = orbit radius
μ = gravitational costant
acc_R = acceleration in the radial direction
acc_{DT} = acceleration in the downtrack direction

since for orbits such as that one for SRL $e \simeq 0$ and $r \simeq a$, making these semplifications in [1] and replacing $\frac{da}{dt}$ with $\frac{\Delta a}{\Delta t}$, the following approximate relation can be considered

$$\frac{\Delta a}{\Delta t} = \frac{2acc_{DT}}{(\frac{\mu}{a^3})^{1/2}}$$

Solving for Δa and considering $acc_{DT} = \frac{F_T}{m}$, then the expression for computing Δa is obtained:

$$\Delta a = \frac{2F_T \Delta t}{m(\frac{\mu}{a^3})^{1/2}} \qquad [2]$$

By using [2], the semi-major axis variation due to F_T as function of time can be computed. In particular, for a period of 12 hours and assuming a Shuttle mass of 99720 kg, we obtain:

$$\Delta a = .163 \text{ km}$$

A slightly higher value of .191 km/12hour is found by using the Goddard Trajectory Determination System which accounts for more precise modelling.

IMU maneuvers

IMU alignment maneuvers consist basically of four main pulses from RCS system plus multiple pulses to search the sky and track the stars selected. Two main pulses are delivered by RCS to start the rotation to acquire the IMU alignment attitude and to stop the Shuttle in this attitude. The last two main pulses are necessary to start the motion from the IMU attitude back to the operational one and then to stop the motion when the final desired orientation is reached.

The execution of the entire sequence takes about 20 minutes. Since in this period of time no radar site imaging will be performed, for the purpose of this study it can be assumed that the perturbations to the orbit occour istantaneously at the time centered on the maneuver execution interval.

The perturbations due to IMU maneuvers computed at JSC, based on the data available of the IMU maneuvers for missions from STS-1 through STS-31, gave an average Δa = 88 m with a standard deviation of 200 m.

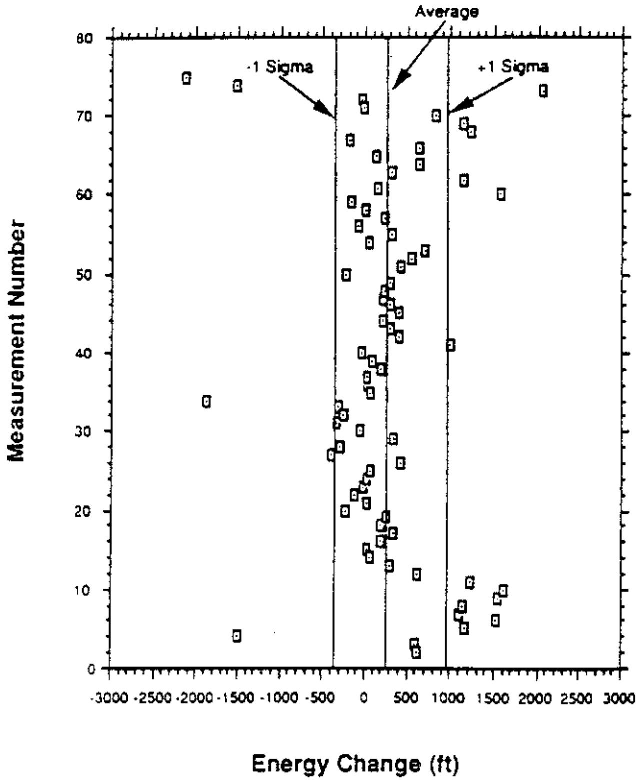

Figure 4 - Energy Changes From IMU Maneuvers

IMPACT OF THE ERRORS ON CROSS RANGE UNCERTAINTY

It is usefull to recall the definition of Cross Range measurement (CR) and associated uncertainty as given in Ref. 4.

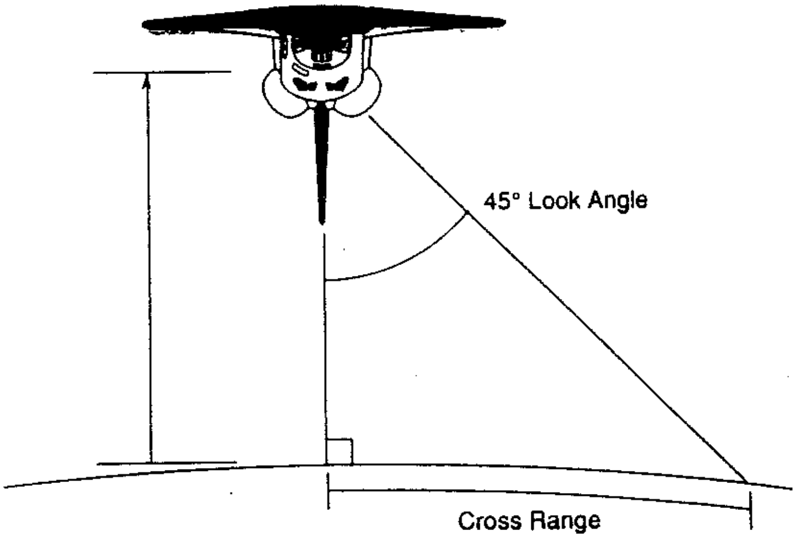

Figure 5 - Cross Range Definition

It is clear that the error in the CR prediction is translated into the antenna tilt angle computation. In particular the Total Cross Range Uncertainty (CR_t) for a 45 deg. look angle, is given by:

$$CR_t = \sigma_{CT} + 1.04\sigma_{RD} + \frac{\sigma_{DT}}{V}\omega R \sin i$$

where:

σ_{CT} = Cross Track Uncertainty
σ_{RD} = Radial Uncertainty
σ_{DT} = Down Track Uncertainty
ω = Earth Rotation Rate
R = Earth Radius
V = orbital velocity
i = orbit inclination

Using the above relation, the CR_i, for each one of the causes of error analyzed in the first chapter, has been computed in order to quantify the contribution to the error affecting the total Cross Range computation during the mission.

The results are given in the following table:

	Δa (m/12h)	Cross Range Uncertainty (m/12h)
State Vector Uncertainty		6200 (2σ)
Earth Gravity Field	20	140
Air Drag 40% error	150	690
Attit. Man.	20	140
Attit. Keep.	191	983
IMU Man.	88	205

Table 3 - Cross Range Errors

CONCLUSIONS

The accuracy of the orbit prediction for X-SAR mission has been investigated and the causes of error affecting the orbit propagation process have been assessed.

For each of the causes of error the impact on the uncertainty of the STS orbit computation has been evaluated and for the most significant ones, the total Cross Range Uncertainty has been computed.

The results show that beside the State Vector Uncertainty (which is by far the dominating source of error), the perturbations to the STS orbit due to the attitude control is the largest cause of error. Air drag computation errors even give a significant contribution to the Cross Range Uncertainty. IMU and attitude maneuver perturbations along with the Earth's gravity modelling, are minor contributors to the final accuracy. Other effects can be neglected.

It should be noted that Air drag and attitude control perturbations give a contribution to the total Cross Range Uncertainty higher than 20%.

Therefore the enhancement of software and procedures at moment planned for the mission should be considered for minimizing the effects of the above mentioned errors aiming to the improvement of the final accuracy of the orbit prediction process.

In particular for improving the air drag computation accuracy by MPS, the concept to use an equivalence table between ASAP WT parameter and the solar flux measurement, should be refined and procedures for calibrating WT during the mission should be defined.

More complicated problem seems to be the implementation in ASAP of the feature to account for continuous thrusting and impulsive maneuvering during orbit propagation. Nevertheless such a capability would improve considerably the final accuracy of the ephemeris computation during the mission and would also allow a more precise reconstruction of ''as flown'' mission profile.

REFERENCES

1. Jayant Sharma 'Predictions of Altitude Decay Rates for a 215 km Circular Orbit SIR-C Mission', JPL Interoffice Memorandum 312/91.6-211, Jan. 1991.

2. Jayant Sharma 'Comparison of SIR-B PATH Tape and ASAP/EGEN State Vector', JPL Interoffice Memorandum 312/90.6-111, May 1990.

3. Jayant Sharma 'Prediction of Atmospheric Density fot the 1993 SIR-C Mission', JPL Interoffice Memorandum 312/90.6-133, June 1990.

4. Jayant Sharma 'State Vector Covariance Analysis for the SIR-C Mission', JPL Interoffice Memorandum 312/91.6-210, January 1991.

X-SAR/MOT Internal Report
13 December 1991
by: Alberto Foni

Ephemeris Prediction and DTO Computation for SRL-1 Mission

This document aims to focus the impact of the orbit prediction accuracy on the pre-mission and mission activities for SRL-1 mission.
Taking into account the current assumptions of the SIR-C Science Investigators for the baseline orbit, recommendations are given with the purpose to guarantee the accomplishment of the pre-mission planning.

Orbit Prediction Accuracy

The "accuracy" of the orbit predicted for SRL mission must be evaluated with respect to the phases of the mission considered. The phases are:

a) mission replanning
b) pre-mission planning

Mission replanning.

During the mission, at regular time intervals orbit determination will be performed by the MCC to define the actual State Vector (Orbit). A detailed plan containing all the Orbiter maneuvers which impact on the trajectory will be available as well as the current status of the atmosphere (for drag computations).
For the above, the accuracy of the ephemeris prediction for the replanning cycle, will depend only on the capability of the orbit propagator to model the actual environment and the maneuvers effect.

Pre-mission planning.

The accuracy and reliability of the ephemeris prediction and subsequent DTOs computation depends by **far on the** possibility to foresee now the Earth's environment how it will be at epoch of the flight **plus** the sequence of events (which impact on the Orbiter trajectory) that will be actually executed during the eight day mission. These conditions will affect the ephemeris prediction accuracy much more than the intrinsic precision of the orbit propagator.

Impact of the Orbit prediction accuracy on the planned DTOs

Mission replanning.

Regularly determined State Vectors will be provided by MCC. The "new State Vector" resets

the dynamical state of the Orbiter and defines the "current true" orbit for any subsequent replanning cycle (short or medium term).
An appropriate evaluation of the impact of the ephemeris prediction uncertainty (excluding the State Vector Uncertainty) in terms of Cross Range Uncertainty, gives a maximum error of 1.5 km after 12 hours (taking into account Eart's gravitational field and atmospheric drag mismodeling, Orbiter attitude maintenance effects and, to a certain extent, also attitude and IMU alignment maneuvers).
Therefore it can be stated that the ephemeris accuracy during the operations, excluding contingencies, will not affect the number and type of the Data Take Opportunities selected during the replanning , but will influence only the precision of the DTO parameters computation.

Pre-mission planning.

The considerations made in the former paragraph are applicable also to the pre-mission phase. The orbit propagation over a period of time 16 times longer, will determine a final Cross Range Error of about 25 km. Such an error can affect the selection of Prime DTOs especially in the second part of the mission. Furthermore to the above it must be added that:

1) the current estimation of the atmosphere density, how it will be at the epoch of the flight, can be affected by an error of about 40% (more than double the error possible during the mission);

2) the perturbing effect of the thrusters used for attitude maintenance is of the same order of magnitude as the drag. Therefore, this effect being directed along the Orbiter x-axis, it can nullify or double the air drag effect (depending on the STS attitude, i.e. BDNF or BDTF);

3) the effect of the STS maneuvers that will be performed during the actual mission cannot be computed, since the precise burn sequences are not known for each maneuver. .

The impact of the above in the pre-mission planning for the 8-day mission, is:

- the error in the air drag computation will determine an uncertainty in the ground track position at the equator of about 72 km.

- the perturbing effect of the attitude maintenance will increase, in the worst case, the above uncertainty by an additional 72 km .

- The effect of each single attitude maneuver could easily change the STS altitude by 120 m and,exceptionally by 290 m (see "X-SAR Orbit Prediction Accuracy analysis (1st Part), A. Foni, X-SAR/MOT Internal report Sept. 1991). Therefore, in the case it is assumed, as in JPL document "SIR-C/X-SAR Science Datatake Selections Version 0, E.Stofan, A. deCharon and D. Casey, that 62 attitude maneuvers are envisaged, a total change of the STS altitude by ~~6.2~~ km 7.4 after 8 days in the worst case must be considered (it is not realistic to consider the "very, very worst case" which would change the altitude by about 18 km).

In order to quantify the impact of the above effects in terms of DTOs changes, a comparison between the conditions assumed in the (JPL) baseline orbit and the case of air drag mismodeling (point 1)) plus RCS perturbations (point 2)), has been performed.
The effect of attitude maneuvers (point 3)) has not been introduced yet, being the object of

further evaluations.
The following table summarizes the total number of DTOs computed for a number of Supersites, assuming the SIR-C Baseline orbit defined in the JPL IM 312/91.6-331.

Case A has been computed assuming an altitude decay (due to the effect of air drag only) of 500 m/day, which corresponds to the JPL baseline.

Case B assumes an altitude decay of 700 m/day (air drag effect 40% larger than the previous case), plus the effect of the RCS perturbations for attitude maintenance. The two effects combined cause the shift of the ground tracks at the equator by 150 km after 8 days.

Site	Case A DTOs No.	Case B DTOs No.
Hawai	4	5
Galapagos	6	6
Sahara 1	6	7
Oberpfaffenhofen	12	11
Amazon 3	8	7
Oetztal	14	15
Bebedouro	14	13
Montespertoli	7	7
Flevopolder	22	21
Amazon 1	6	5
Duke Forest	9	7
Amazon 2	7	5
Raco	12	11
Death Valley	12	12
Northern Andes	5	7
Flevoland	21	20
North Death valley	11	14
Beam Align.	29	29

The table shows the difference in total number of DTOs only, but it must be considered that the parameters associated with each single DTO (i.e. incidence and look angles and time) change too.

Conclusions and Recommendations

The Science Datatake Selections Version 0 was prepared by JPL assuming a "free-decay" orbit having an average altitude of 215 km and a nominal constant 500 m/day decay due to the air drag. No other perturbations due to the STS maneuvering system have been considered.
If an error of 40% in the air drag is introduced, as well as the effect of the attitude maintenance perturbations, the computations performed show that the total number of the opportunities changes for the majority of the Supersites. It is expected that the introduction of the large attitude maneuvers effect (from BDNF to BDTF and vice versa) will increase considerably these

differences. Although this should not be considered necessarily as a negative effect (for some Supersites the number of DTOs increases while for others it decreases), nevertheless it introduces the possibility that the pre-mission timeline will not be executed as planned.
To guarantee that during normal operations (excluding contingencies) the pre-mission timeline is executed as planned, it is recommended to adopt an active control of the orbit (i.e. to plan orbit adjustment maneuvers).

The controlled orbit choice will allow:

- to keep the difference between the actual and planned trajectory, and therefore the DTOs parameters as well, within predefined limits. This will result in less replanning activity;

- to have the execution of orbit maneuvers as a normal procedure and not to restrict this type of operations to the contingency case only;

- to allocate to SIR-C/X-SAR Operations Teams the decision making for orbit control related to experimental activity.

The concern that orbit maneuvers will degrade the orbit determination process or will limit the Data Take process is not a major problem for the following reasons:

- the orbit maneuvers could be executed by four single burns or less;

- the confidence in the STS RCS performances will allow orbit predictions accurate enough until a new post-maneuver State Vector is available;

- the time for orbit maneuver execution is not a critical parameter and it could be defined so as to minimize the impact on the experimental activity.

DLR April1, 1992
by: Alberto Foni

Subject: update of orbit decay prediction for SRL Mission.

Studies aiming to determine the expected Shuttle altitude decay under the effect of the atmospheric drag for SRL mission, have been performed independently by ASI, DLR and JPL. The results of these studies have shown a good agreement among them, even if obtained using different software (i.e. orbit propagators); the expected decay rate was computed to be approximately between 300 and 800 m/day. It was, thus, accepted to adopt 500 m/day altitude decay as the reference value for a launch date around the middle of 1993 and for an STS altitude of 215 km..

It is important to outline that the parameters for the drag model used for the above computations, were provided by JPL as follows:

STS surface area	70 m^2	
STS mass	99790 kg	(JPL I.M. 312/91.6-319 and JPL I.M. 312/91.6-331)
Drag Coefficient	2	

The drag effect is one of the major causes of the orbit perturbations, affecting the strategy for controlling the STS orbit. Since differences in opinion exist between X-SAR and SIR-C on this topic, a further investigation was performed on the drag effects, in order to get a deeper and updated understanding on the matter.

One important part of the investigation was to check the drag model parameters used for the studies.. From some contacts had with NASA/JSC, it was found that70 m^{2}for the STS section area is not an appropriate value, but a larger STS section area should be considered. The value suggested for the SRL mission by Shuttle navigators was 112.2 m^2, which is 60% larger than the one assumed in the previous computations. Furthermore, information taken from 2/4/92 MarshallSpaceflight Center Solar Activity report, gave a best estimate of solar flux and geomagnetic index, to be approximately (for Oct. 1, 1993):

F10.7 = 120 W/(m HZ) Mean solar flux
Kp = 4.0 Geomagnetic Index

Orbit propagations performed using the above information, show an orbit decay much higher than the one assumed previously as reference (500 m/day). In particular, the predictions obtained by using the Goddard Trajectory Determination System give a total altitude decay, for 215 km initial altitude and 8-day mission, of 13.5 km.

Orbit propagation performed at JSC and using the same input, indicates a decay of 17.2 km. The difference in the two predictions is less than 30%, but the point to be stressed is that, according to the new parameters, the expected orbit decay is from 3.4 to 4.3 times higher than the one assumed up-to-now.

In the light of these results, it is extremely important:

1) to have an official assessment of the new parameters,

2) to define an appropriate orbit control strategy,

3) to verify the impact of the higher decay rate on the DTO computation.

The above should be considered high priority tasks to be performed by X-SAR MOT.

Waiting for a confirmation of the new parameters, the science investigators should be informed to evaluate the impact of a decay of about 1.7-2 km/day on the experimental activity.

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ANALYSIS OF THE NEW SRL BASELINE ORBIT ("PRELIMINARY STS-59 BASELINE ORBIT" JPL IOM 312/92.6-454 FROM D. CASEY, JUNE 29, 1992).

CNUCE 20 august, 1992
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1. Introduction

The purpose of the present analysis is to assess the differences, in terms of Data Take Opportunity characteristics, between the old and the new baseline orbits, and to give some inputs for the evaluation of the impact of the new baseline on the mission planning and timeline.
The new baseline orbit differs from the previous one mainly for the initial altitude, which is increased from 217 to 220.5 km to counteract the air drag effect on the orbit. This effect, computed by using new updated values given by JSC (the Shuttle frontal area and the solar flux and geomagnetic indexes predicted for the flight epoch), results in an average daily decay almost three times bigger than the previous one.
From the above the need to increase the initial Shuttle altitude to implement the JPL concept of "letting the orbit decay" during the mission.
For computing the DTOs parameters for both the old and the new baselines, the initial orbits are propagated over a period of 8 days and the opportunities for a selected group of sites, are listed.
The sites considered are the ones used for comparison of the X-SAR and SIR-C DTOG software (IPL fax "SIR-C and X-SAR testing of the Data Take Opportunity Generator", 24 March 1992).

2. DTOs computation

Table 1 contains the site list and the total number of DTOs associated to the sites for the old and the new baseline orbits. Such orbits are reported in Table 2.

N.	ID	SITE	OLD BASELINE	NEW BASELINE
1	ES0	AMAZON B0, BRAZIL	8	8
2	HS1	BEBEDOURO, BRAZIL	13	14
3	HS2	CHICKSASHA, OK	11	12
4	CS1	FLEVOLAND, NETHERLANDS	21	22
5	G16	FOULUM, DENMARK	15	13
6	GS1	GALAPAGOS ISLANDS	7	6
7	CS2	KERANG, AUSTRALIA	7	7
8	HS3	MONTESPERTOLI, ITALY	7	7
9	CS3	OBERPFAFFENHOFEN, GERMANY	12	12
10	ES6	RACO, MICHIGAN	11	13
11	MS1	SAFSAF, EGYPT/SUDAN	10	8
12	NSA	SOUTHERN OCEAN	16	16

Table 1 - Total number of DTOs for the Sites

ORBITAL ELEMENTS		OLD	NEW
SMA	(km)	6595.144	6598.644
ECC		0.00001	0.00001
INC	(deg)	57.0	57.0
NODE	(deg)	75.96	75.96
AP	(deg)	0.0	0.0
MA	(deg)	0.0	0.0
DECAY	(km/day)	-0.5	-1.34
EPOCH		931001.123000	

Table 2 - Baseline Orbits

The detailed list of the opportunities computed for the old and the new baseline orbits, are reported in Table 3 and Table 4.
Due to the stepsize used for orbit propagation, the time associated to each DTO can be affected by a maximum error of 1 second.

DTOs for the Old Baseline Orbit:

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ELAPSED TIME  YYMMDD. HHMMSS.SS  SITE   INC     AZ     RANGE    ONA     LAT     LON    LR AD
D/HH.MM.SEC         GMT                 deg     deg     Km      deg     deg     deg


0/ 8: 9:50.00  931001. 203950.00 ES0  53.20 241.14  355.52  50.74  -4.67 296.83  L  D
0/19:13: 0.0   931002.  74300.00 ES0  62.18 119.36  441.48  58.80  -5.14 301.97  L  A
1/ 7:50:50.00  931002. 202050.00 ES0  61.23 240.36  432.35  57.95  -5.10 296.13  L  D
1/18:53:54.00  931003.  72354.00 ES0  54.81 120.68  364.46  52.23  -4.80 301.23  L  A
2/18:34:40.00  931004.  70440.00 ES0  44.51 119.45  298.17  42.71  -4.37 300.59  L  A
3/18:15:16.00  931005.  64516.00 ES0  30.16 116.75  247.41  29.09  -3.96 299.97  L  A
6/17:16: 0.0   931008.  54600.00 ES0  26.78 300.09  237.14  25.83  -3.01 298.20  R  A
7/16:55:54.00  931009.  52554.00 ES0  39.98 299.87  273.26  38.44  -2.72 297.67  R  A
0/ 6:42: 2.00  931001. 191202.00 HS1  45.33  60.58  306.87  43.41  -8.09 321.39  R  D
0/17:42:44.00  931002.  61244.00 HS1  49.18 120.02  326.53  47.06 -10.09 321.61  L  A
1/ 6:23: 2.00  931002. 185302.00 HS1  29.72  60.31  251.07  28.61  -8.49 320.67  R  D
1/17:23:40.00  931003.  55340.00 HS1  35.87 118.87  265.80  34.55  -9.67 320.92  L  A
2/17: 4:26.00  931004.  53426.00 HS1  17.50 116.29  226.51  16.94  -9.28 320.26  L  A
4/ 5:25: 4.00  931005. 175504.00 HS1  31.47 238.07  255.02  30.34  -9.63 318.72  L  D
4/16:25:28.00  931006.  45528.00 HS1  24.25 303.56  234.66  23.38  -8.56 319.01  R  A
5/ 5: 5:24.00  931006. 173524.00 HS1  44.39 239.44  301.36  42.59  -9.95 318.12  L  D
5/16: 5:42.00  931007.  43542.00 HS1  39.21 297.84  273.02  37.68  -8.32 318.38  R  A
6/ 4:45:34.00  931007. 171534.00 HS1  53.25 239.56  354.97  50.80 -10.27 317.55  L  D
6/15:45:48.00  931008.  41548.00 HS1  49.58 299.72  321.41  47.42  -7.96 317.85  R  A
7/ 4:25:34.00  931008. 165534.00 HS1  59.44 239.03  410.84  56.40 -10.59 317.04  L  D
7/15:25:42.00  931009.  35542.00 HS1  56.81 298.74  373.88  54.06  -7.71 317.31  R  A
1/23:32:28.00  931003. 120228.00 HS2  26.81 311.35  249.10  25.95  35.39 261.08  R  A
2/23:13:12.00  931004. 114312.00 HS2  38.64 312.03  282.05  37.23  35.76 260.58  R  A
3/ 6:59:18.00  931004. 192918.00 HS2  60.61  46.82  435.31  57.43  36.96 264.99  R  D
3/22:53:46.00  931005. 112346.00 HS2  47.37 312.48  321.48  45.43  36.12 260.10  R  A
4/ 6:39:50.00  931005. 190950.00 HS2  56.03  48.95  387.14  53.36  36.55 264.60  R  D
4/22:34:10.00  931006. 110410.00 HS2  53.81 313.05  363.72  51.38  36.47 259.66  R  A
5/ 6:20:10.00  931006. 185010.00 HS2  50.53  48.94  343.50  48.34  36.24 264.13  R  D
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5/22:14:22.00  931007. 104422.00 HS2  58.66 311.41  406.49  55.75  36.71 259.16  R  A
6/ 6: 0:20.00  931007. 183020.00 HS2  43.92  49.49  305.25  42.20  35.93 263.71  R  D
6/21:54:26.00  931008. 102426.00 HS2  62.39 312.89  448.56  59.05  37.06 258.81  R  A
7/ 5:40:20.00  931008. 181020.00 HS2  36.10  51.59  273.32  34.81  35.61 263.33  R  D
0/ 0:28:28.00  931001. 125828.00 CS1  61.95 217.77  460.85  58.27  49.25   2.03  L  D
0/19:33: 0.0   931002.  80300.00 CS1  47.59 338.27  334.49  45.61  54.08   4.00  R  A
0/22:37:38.00  931002. 110738.00 CS1  54.64  20.30  385.46  52.08  54.64   6.99  R  D
1/19:13:56.00  931003.  74356.00 CS1  50.37 339.14  351.41  48.19  54.28   3.92  R  A
1/22:18:32.00  931003. 104832.00 CS1  52.60  20.03  368.13  50.23  54.47   6.85  R  D
2/18:54:42.00  931004.  72442.00 CS1  52.73 339.68  367.63  50.35  54.47   3.83  R  A
2/21:59:16.00  931004. 102916.00 CS1  50.40  19.41  351.42  48.22  54.30   6.69  R  D
3/18:35:18.00  931005.  70518.00 CS1  54.73 340.16  383.00  52.18  54.64   3.76  R  A
3/21:39:52.00  931005. 100952.00 CS1  48.01  22.06  335.31  46.01  54.09   6.74  R  D
4/16:43:52.00  931006.  51352.00 CS1  62.90 142.88  466.93  59.14  49.16   8.69  L  A
4/18:15:44.00  931006.  64544.00 CS1  56.44 340.77  397.41  53.73  54.80   3.71  R  A
4/21:20:16.00  931006.  95016.00 CS1  45.44  21.64  320.04  43.62  53.93   6.59  R  D
5/16:24: 8.00  931007.  45408.00 CS1  60.77 142.77  438.38  57.30  49.40   8.44  L  A
5/17:56: 0.0   931007.  62600.00 CS1  57.91 341.69  410.80  55.06  54.95   3.69  R  A
5/21: 0:30.00  931007.  93030.00 CS1  42.70  21.68  305.74  41.06  53.76   6.48  R  D
6/16: 4:12.00  931008.  43412.00 CS1  58.55 144.54  412.25  55.34  49.57   8.09  L  A
6/17:36: 6.00  931008.  60606.00 CS1  59.19 343.05  423.18  56.20  55.10   3.74  R  A
6/20:40:34.00  931008.  91034.00 CS1  39.79  22.71  292.47  38.33  53.59   6.41  R  D
7/15:44: 8.00  931009.  41408.00 CS1  56.23 143.14  388.49  53.28  49.81   7.96  L  A
7/17:16: 0.0   931009.  54600.00 CS1  60.30 342.74  434.59  57.18  55.21   3.64  R  A
7/20:20:28.00  931009.  85028.00 CS1  36.75  25.49  280.40  35.45  53.40   6.40  R  D
0/19:33:58.00  931002.  80358.00 G16  27.07 161.10  257.83  25.89  55.36  10.16  L  A
0/21: 5:56.00  931002.  93556.00 G16  17.14   8.07  241.62  16.69  56.94   9.74  R  D
0/22:37:50.00  931002. 110750.00 G16  47.02 201.62  331.54  44.75  54.36   8.25  L  D
1/19:14:52.00  931003.  74452.00 G16  23.54 167.27  250.17  22.51  55.48   9.92  L  A
1/20:46:50.00  931003.  91650.00 G16  16.40   2.64  240.19  15.98  56.92   9.63  R  D
1/22:18:44.00  931003. 104844.00 G16  49.78 202.11  347.89  47.31  54.18   8.10  L  D
2/18:55:38.00  931004.  72538.00 G16  20.06 166.29  243.82  19.16  55.62   9.88  L  A
2/20:27:36.00  931004.  85736.00 G16  15.62   8.93  238.74  15.23  56.88   9.74  R  D
2/21:59:28.00  931004. 102928.00 G16  52.27 202.79  364.70  49.60  54.01   7.93  L  D
3/18:36:14.00  931005.  70614.00 G16  16.76 164.83  238.80  16.00  55.75   9.86  L  A
3/21:40: 0.0   931005. 101000.00 G16  54.51 206.21  381.79  51.65  53.89   7.56  L  D
4/21:20:24.00  931006.  95024.00 G16  56.52 206.45  398.93  53.47  53.72   7.40  L  D
5/21: 0:38.00  931007.  93038.00 G16  58.33 206.34  416.00  55.10  53.55   7.28  L  D
6/20:40:42.00  931008.  91042.00 G16  59.96 205.76  432.93  56.55  53.37   7.21  L  D
7/20:20:34.00  931009.  85034.00 G16  61.42 206.78  449.37  57.83  53.24   7.00  L  D
0/ 9:36:56.00  931001. 220656.00 GS1  54.03  59.39  361.82  51.49   1.14 270.92  R  D
1/ 9:17:56.00  931002. 214756.00 GS1  42.56  61.22  293.07  40.83   0.67 270.24  R  D
2/ 8:58:44.00  931003. 212844.00 GS1  26.26  57.11  242.91  25.33   0.35 269.51  R  D
4/ 8:19:54.00  931005. 204954.00 GS1  16.03 236.32  226.90  15.48  -0.46 268.28  L  D
5/ 8: 0:12.00  931006. 203012.00 GS1  33.14 241.94  258.76  31.91  -0.74 267.65  L  D
6/ 7:40:22.00  931007. 201022.00 GS1  45.23 238.94  304.49  43.35  -1.13 267.12  L  D
7/ 7:20:20.00  931008. 195020.00 GS1  53.57 239.69  356.27  51.08  -1.42 266.58  L  D
0/ 4:15:22.00  931001. 164522.00 CS2  29.16 133.64  255.81  28.20 -36.27 144.87  L  A
0/20:10:28.00  931002.  84028.00 CS2  60.23 227.38  432.50  57.09 -37.70 140.87  L  D
3/ 3:17:58.00  931004. 154758.00 CS2  18.31 306.92  233.52  17.57 -35.14 143.28  R  A
4/ 2:58:30.00  931005. 152830.00 CS2  31.46 307.88  257.80  30.18 -34.80 142.78  R  A
5/ 2:38:52.00  931006. 150852.00 CS2  41.59 308.44  291.02  39.80 -34.47 142.30  R  A
6/ 2:19: 4.00  931007. 144904.00 CS2  49.23 309.19  329.15  46.95 -34.14 141.87  R  A
7/ 1:59: 4.00  931008. 142904.00 CS2  54.98 307.43  369.30  52.24 -33.90 141.38  R  A
0/ 0:30:40.00  931001. 130040.00 HS3  17.57  40.14  237.98  17.09  43.84  11.81  R  D
2/23:33:20.00  931004. 120320.00 HS3  21.21 226.34  241.80  20.32  42.84  10.50  L  D
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3/23:13:54.00	931005.	114354.00	HS3	31.46	224.31	262.76	30.14	42.51	10.12	L	D
4/22:54:18.00	931006.	112418.00	HS3	39.76	223.16	289.44	38.02	42.18	9.76	L	D
5/22:34:30.00	931007.	110430.00	HS3	46.30	225.74	319.28	44.16	41.95	9.32	L	D
6/22:14:32.00	931008.	104432.00	HS3	51.49	226.84	350.86	48.98	41.71	8.92	L	D
7/21:54:24.00	931009.	102424.00	HS3	55.64	226.87	382.89	52.76	41.45	8.57	L	D
0/ 0:29:54.00	931001.	125954.00	CS3	55.16	222.17	385.16	52.28	45.83	8.63	L	D
0/18: 1:18.00	931002.	63118.00	CS3	19.05	327.73	240.39	18.53	48.47	10.73	R	A
1/ 0:10:56.00	931002.	124056.00	CS3	59.35	223.58	425.72	56.04	45.54	8.15	L	D
1/17:42:14.00	931003.	61214.00	CS3	27.99	326.55	255.98	27.10	48.76	10.41	R	A
1/23:51:50.00	931003.	122150.00	CS3	62.75	222.96	466.75	59.01	45.20	7.79	L	D
2/17:23: 0.0	931004.	55300.00	CS3	35.36	325.68	275.42	34.12	49.03	10.09	R	A
3/17: 3:36.00	931005.	53336.00	CS3	41.35	325.18	297.10	39.79	49.29	9.79	R	A
4/16:44: 4.00	931006.	51404.00	CS3	46.20	328.85	319.78	44.35	49.60	9.68	R	A
5/16:24:20.00	931007.	45420.00	CS3	50.14	328.83	342.50	48.01	49.84	9.45	R	A
6/16: 4:26.00	931008.	43426.00	CS3	53.38	329.49	364.84	51.00	50.07	9.27	R	A
7/15:44:20.00	931009.	41420.00	CS3	56.07	328.18	386.32	53.44	50.24	8.98	R	A
7/20:21:48.00	931009.	85148.00	CS3	62.01	28.45	454.98	58.68	50.94	13.92	R	D
0/ 0:14:24.00	931001.	124424.00	ES6	22.45	135.64	245.69	21.50	45.56	276.06	L	A
0/ 6:24:40.00	931001.	185440.00	ES6	29.78	39.44	261.70	28.79	47.01	276.30	R	D
1/ 6: 5:40.00	931002.	183540.00	ES6	20.06	36.25	242.16	19.49	46.72	275.87	R	D
3/22:57:38.00	931005.	112738.00	ES6	22.06	323.65	242.50	21.42	46.78	274.56	R	A
4/22:38: 2.00	931006.	110802.00	ES6	30.32	324.49	258.87	29.34	47.07	274.28	R	A
5/ 4:48: 4.00	931006.	171804.00	ES6	22.12	223.44	243.41	21.19	45.56	274.47	L	D
5/22:18:14.00	931007.	104814.00	ES6	37.08	320.73	278.22	35.77	47.27	273.89	R	A
6/ 4:28:14.00	931007.	165814.00	ES6	30.38	224.62	260.05	29.10	45.33	274.11	L	D
6/21:58:18.00	931008.	102818.00	ES6	42.54	323.60	299.04	40.93	47.55	273.70	R	A
7/ 4: 8:14.00	931008.	163814.00	ES6	37.23	224.15	280.03	35.62	45.08	273.80	L	D
7/21:38:10.00	931009.	100810.00	ES6	46.99	323.20	320.43	45.10	47.76	273.43	R	A
0/ 0:37:18.00	931001.	130718.00	MS1	47.32	55.42	320.96	45.34	23.83	32.06	R	D
0/14:55:20.00	931002.	32520.00	MS1	55.64	306.19	378.35	53.01	24.27	27.81	R	A
1/ 0:18:22.00	931002.	124822.00	MS1	34.61	58.72	267.02	33.36	23.36	31.44	R	D
1/14:36:16.00	931003.	30616.00	MS1	62.11	304.92	445.57	58.76	24.61	27.12	R	A
1/23:59:14.00	931003.	122914.00	MS1	17.59	55.15	231.69	17.06	23.03	30.75	R	D
3/23:20:30.00	931005.	115030.00	MS1	20.81	240.37	235.44	20.02	22.32	29.53	L	D
4/23: 0:54.00	931006.	113054.00	MS1	35.42	236.43	268.06	34.00	21.93	29.00	L	D
5/22:41: 6.00	931007.	111106.00	MS1	45.99	238.34	311.13	43.98	21.65	28.43	L	D
6/22:21: 8.00	931008.	105108.00	MS1	53.54	238.78	358.93	50.96	21.36	27.91	L	D
7/22: 1: 0.0	931009.	103100.00	MS1	59.04	238.36	408.08	55.92	21.06	27.44	L	D
0/ 8:28:14.00	931001.	205814.00	NSA	54.70	17.19	386.66	51.80	-55.71	1.44	R	D
0/10: 0: 0.0	931001.	223000.00	NSA	35.54	353.90	281.65	33.95	-56.92	359.72	R	A
1/ 8: 9:14.00	931002.	203914.00	NSA	53.24	16.91	374.03	50.48	-55.83	1.35	R	D
1/ 9:41: 0.0	931002.	221100.00	NSA	36.25	354.89	283.47	34.63	-56.88	359.76	R	A
2/ 7:50: 4.00	931003.	202004.00	NSA	51.84	16.28	362.67	49.20	-55.95	1.24	R	D
2/ 9:21:50.00	931003.	215150.00	NSA	37.08	355.25	285.76	35.41	-56.84	359.77	R	A
3/ 7:30:44.00	931004.	200044.00	NSA	50.49	15.48	352.50	47.97	-56.05	1.13	R	D
3/ 9: 2:30.00	931004.	213230.00	NSA	37.98	355.37	288.46	36.27	-56.80	359.77	R	A
4/ 7:11:14.00	931005.	194114.00	NSA	49.21	14.72	343.43	46.79	-56.14	1.03	R	D
4/ 8:42:58.00	931005.	211258.00	NSA	38.95	350.92	291.50	37.19	-56.76	359.54	R	A
5/ 6:51:34.00	931006.	192134.00	NSA	48.01	14.26	335.39	45.68	-56.23	0.96	R	D
5/ 8:23:18.00	931006.	205318.00	NSA	39.91	351.75	294.70	38.10	-56.71	359.57	R	A
6/ 6:31:42.00	931007.	190142.00	NSA	46.88	10.84	328.21	44.63	-56.29	0.71	R	D
6/ 8: 3:28.00	931007.	203328.00	NSA	40.91	353.33	298.23	39.05	-56.65	359.64	R	A
7/ 6:11:42.00	931008.	184142.00	NSA	45.83	11.87	321.87	43.66	-56.37	0.75	R	D
7/ 7:43:26.00	931008.	201326.00	NSA	41.90	351.66	301.87	39.98	-56.60	359.54	R	A

Table 3 - Opportunities for the Old Baseline

DTOs for the New Baseline Orbit:

ELAPSED TIME D/HH.MM.SEC	YYMMDD. HHMMSS.SS GMT	SITE	INC deg	AZ deg	RANGE Km	ONA deg	LAT deg	LON deg	LR	AD
0/ 8:10:14.00	931001. 204014.00	ES0	53.71	240.15	364.69	51.17	-4.75	296.78	L	D
0/19:13:52.00	931002. 74352.00	ES0	60.40	119.77	425.47	57.19	-5.07	301.80	L	A
1/ 7:52:12.00	931002. 202212.00	ES0	63.10	240.21	461.34	59.54	-5.25	295.89	L	D
1/18:55:38.00	931003. 72538.00	ES0	50.19	121.48	334.26	47.97	-4.64	300.91	L	A
2/18:37: 2.00	931004. 70702.00	ES0	35.34	119.21	264.41	34.02	-4.13	300.16	L	A
5/17:38:36.00	931007. 60836.00	ES0	24.71	301.00	233.18	23.85	-3.04	298.27	R	A
6/17:18:12.00	931008. 54812.00	ES0	37.31	299.34	262.66	35.91	-2.80	297.79	R	A
7/16:57:20.00	931009. 52720.00	ES0	45.50	301.37	293.52	43.67	-2.53	297.44	R	A
0/ 6:42:20.00	931001. 191220.00	HS1	43.89	57.98	304.24	42.03	-8.05	321.29	R	D
0/17:43:32.00	931002. 61332.00	HS1	46.44	121.12	315.06	44.49	-10.04	321.44	L	A
1/ 6:24:20.00	931002. 185420.00	HS1	22.98	57.28	240.26	22.14	-8.58	320.41	R	D
1/17:25:20.00	931003. 55520.00	HS1	28.05	124.02	247.57	27.07	-9.59	320.57	L	A
3/ 5:47: 8.00	931004. 181708.00	HS1	26.97	237.44	245.94	26.04	-9.54	318.89	L	D
3/16:47:44.00	931005. 51744.00	HS1	20.36	296.05	230.20	19.64	-8.72	319.09	R	A
4/ 5:27:54.00	931005. 175754.00	HS1	42.65	237.36	293.90	40.95	-9.95	318.24	L	D
4/16:28:18.00	931006. 45818.00	HS1	37.47	299.78	267.93	36.03	-8.32	318.48	R	A
5/ 5: 8:12.00	931006. 173812.00	HS1	52.43	239.51	348.29	50.06	-10.23	317.62	L	D
5/16: 8:24.00	931007. 43824.00	HS1	48.46	299.16	314.82	46.39	-8.02	317.91	R	A
6/ 4:48: 4.00	931007. 171804.00	HS1	58.68	238.76	400.57	55.74	-10.56	317.13	L	D
6/15:48: 2.00	931008. 41802.00	HS1	55.48	298.91	360.89	52.86	-7.77	317.44	R	A
7/ 4:27:26.00	931008. 165726.00	HS1	62.82	239.59	446.49	59.40	-10.76	316.69	L	D
7/15:27:12.00	931009. 35712.00	HS1	60.04	300.30	401.09	56.99	-7.49	317.09	R	A
0/23:52:38.00	931002. 122238.00	HS2	15.70	309.95	235.24	15.25	35.10	261.46	R	A
1/23:34:20.00	931003. 120420.00	HS2	32.92	307.80	266.67	31.77	35.51	260.76	R	A
2/ 7:20:44.00	931003. 195044.00	HS2	62.13	47.03	458.35	58.72	37.10	265.21	R	D
2/23:15:40.00	931004. 114540.00	HS2	44.69	312.16	310.13	42.91	36.01	260.24	R	A
3/ 7: 1:54.00	931004. 193154.00	HS2	57.15	46.82	400.07	54.35	36.72	264.64	R	D
3/22:56:32.00	931005. 112632.00	HS2	52.63	310.51	356.78	50.28	36.32	259.65	R	A
4/ 6:42:40.00	931005. 191240.00	HS2	51.36	48.98	350.11	49.09	36.29	264.20	R	D
4/22:37: 0.0	931006. 110700.00	HS2	58.08	312.41	401.67	55.23	36.71	259.25	R	A
5/ 6:22:58.00	931006. 185258.00	HS2	44.78	49.42	309.16	43.00	35.96	263.76	R	D
5/22:17: 0.0	931007. 104700.00	HS2	61.94	313.09	442.35	58.66	37.03	258.87	R	A
6/ 6: 2:48.00	931007. 183248.00	HS2	37.68	49.14	277.38	36.32	35.70	263.35	R	D
7/ 5:42:10.00	931008. 181210.00	HS2	30.56	51.31	254.37	29.55	35.44	263.06	R	D
0/ 0:28:30.00	931001. 125830.00	CS1	61.60	217.14	462.89	57.92	49.22	2.08	L	D
0/19:33:54.00	931002. 80354.00	CS1	47.88	339.35	340.46	45.85	54.14	4.03	R	A
0/22:38:38.00	931002. 110838.00	CS1	53.78	19.03	382.77	51.26	54.62	6.86	R	D
1/19:15:42.00	931003. 74542.00	CS1	51.20	340.15	360.65	48.93	54.38	3.93	R	A
1/22:20:24.00	931003. 105024.00	CS1	51.26	21.46	361.40	48.98	54.36	6.89	R	D
2/18:57: 6.00	931004. 72706.00	CS1	53.85	341.37	379.03	51.36	54.60	3.88	R	A
2/22: 1:44.00	931004. 103144.00	CS1	48.58	21.69	341.50	46.52	54.15	6.75	R	D
3/17: 6:10.00	931005. 53610.00	CS1	63.19	142.74	473.84	59.37	49.11	8.75	L	A
3/18:38: 4.00	931005. 70804.00	CS1	55.97	341.44	395.30	53.29	54.78	3.78	R	A
3/21:42:38.00	931005. 101238.00	CS1	45.80	20.62	323.52	43.96	53.97	6.56	R	D
4/16:46:44.00	931006. 51644.00	CS1	60.98	142.11	442.25	57.48	49.39	8.52	L	A
4/18:18:36.00	931006. 64836.00	CS1	57.68	341.71	409.44	54.84	54.94	3.71	R	A
4/21:23: 8.00	931006. 95308.00	CS1	43.00	23.91	307.53	41.34	53.75	6.60	R	D
5/16:26:48.00	931007. 45648.00	CS1	58.87	144.87	415.43	55.63	49.53	8.09	L	A
5/17:58:42.00	931007. 62842.00	CS1	59.06	343.36	421.37	56.09	55.09	3.78	R	A
5/21: 3: 8.00	931007. 93308.00	CS1	40.28	21.69	293.76	38.80	53.62	6.38	R	D

6/16: 6:26.00	931008.	43626.00	CS1	56.93	145.20	393.19	53.91	49.71	7.88	L	A
6/17:38:18.00	931008.	60818.00	CS1	60.18	342.91	431.09	57.10	55.19	3.68	R	A
6/20:42:42.00	931008.	91242.00	CS1	37.76	24.98	282.16	36.42	53.45	6.42	R	D
7/15:45:36.00	931009.	41536.00	CS1	55.25	143.61	375.41	52.42	49.90	7.82	L	A
7/17:17:26.00	931009.	54726.00	CS1	61.06	344.15	438.63	57.90	55.29	3.75	R	A
7/20:21:44.00	931009.	85144.00	CS1	35.59	22.44	272.84	34.37	53.36	6.23	R	D
0/19:34:50.00	931002.	80450.00	G16	26.02	166.42	258.84	24.87	55.37	9.99	L	A
0/21: 6:52.00	931002.	93652.00	G16	16.72	0.72	244.13	16.29	56.94	9.59	R	D
0/22:38:50.00	931002.	110850.00	G16	47.39	203.26	337.75	45.08	54.34	8.12	L	D
1/19:16:38.00	931003.	74638.00	G16	21.68	164.75	249.37	20.71	55.56	9.95	L	A
1/20:48:38.00	931003.	91838.00	G16	15.88	0.83	241.85	15.47	56.90	9.60	R	D
1/22:20:34.00	931003.	105034.00	G16	50.74	203.82	357.63	48.18	54.12	7.92	L	D
2/18:58: 2.00	931004.	72802.00	G16	17.79	159.89	242.28	16.99	55.72	9.97	L	A
2/22: 1:54.00	931004.	103154.00	G16	53.62	203.71	377.38	50.82	53.90	7.78	L	D
3/21:42:48.00	931005.	101248.00	G16	56.05	204.57	396.39	53.04	53.71	7.57	L	D
4/21:23:16.00	931006.	95316.00	G16	58.11	205.03	414.19	54.90	53.54	7.40	L	D
5/21: 3:16.00	931007.	93316.00	G16	59.82	206.28	430.22	56.43	53.40	7.18	L	D
6/20:42:48.00	931008.	91248.00	G16	61.22	206.98	444.15	57.68	53.28	7.01	L	D
7/20:21:50.00	931009.	85150.00	G16	62.35	208.03	455.55	58.69	53.20	6.83	L	D
0/ 9:37:24.00	931001.	220724.00	GS1	52.54	60.38	355.44	50.09	1.05	270.86	R	D
1/ 9:19:20.00	931002.	214920.00	GS1	36.87	58.71	274.18	35.44	0.58	269.95	R	D
4/ 8:22:44.00	931005.	205244.00	GS1	30.92	238.95	253.27	29.79	-0.74	267.76	L	D
5/ 8: 3: 0.0	931006.	203300.00	GS1	44.10	238.72	298.34	42.30	-1.10	267.19	L	D
6/ 7:42:48.00	931007.	201248.00	GS1	52.44	239.01	345.64	50.06	-1.38	266.69	L	D
7/ 7:22: 6.00	931008.	195206.00	GS1	57.81	240.62	388.59	54.96	-1.56	266.24	L	D
0/ 4:15:36.00	931001.	164536.00	CS2	28.12	127.99	257.16	27.18	-36.17	144.93	L	A
0/20:11:24.00	931002.	84124.00	CS2	60.96	226.10	446.60	57.69	-37.84	140.81	L	D
3/ 3:20:30.00	931004.	155030.00	CS2	27.86	306.76	251.37	26.74	-34.91	142.90	R	A
4/ 3: 1:20.00	931005.	153120.00	CS2	40.02	310.66	286.06	38.30	-34.47	142.43	R	A
5/ 2:41:40.00	931006.	151140.00	CS2	48.41	306.21	324.79	46.20	-34.26	141.84	R	A
6/ 2:21:36.00	931007.	145136.00	CS2	54.25	308.43	362.49	51.58	-33.91	141.49	R	A
7/ 2: 1: 2.00	931008.	143102.00	CS2	58.33	308.27	396.24	55.28	-33.67	141.13	R	A
0/ 0:30:42.00	931001.	130042.00	HS3	17.24	43.06	241.21	16.75	43.82	11.84	R	D
2/23:35:48.00	931004.	120548.00	HS3	28.37	226.85	257.01	27.18	42.63	10.20	L	D
3/23:16:42.00	931005.	114642.00	HS3	38.32	223.11	285.08	36.65	42.23	9.83	L	D
4/22:57: 8.00	931006.	112708.00	HS3	45.61	224.39	315.75	43.52	41.95	9.41	L	D
5/22:37: 6.00	931007.	110706.00	HS3	50.92	226.34	345.70	48.46	41.73	8.99	L	D
6/22:16:36.00	931008.	104636.00	HS3	54.79	227.18	372.79	52.01	41.53	8.65	L	D
7/21:55:36.00	931009.	102536.00	HS3	57.57	228.29	395.51	54.55	41.39	8.36	L	D
0/ 0:29:56.00	931001.	125956.00	CS3	54.79	221.46	387.55	51.90	45.80	8.67	L	D
0/18: 2: 6.00	931002.	63206.00	CS3	20.81	319.94	246.17	20.19	48.47	10.54	R	A
1/ 0:12: 2.00	931002.	124202.00	CS3	60.04	221.98	438.53	56.60	45.40	8.14	L	D
1/17:43:56.00	931003.	61356.00	CS3	31.19	325.17	266.54	30.14	48.87	10.24	R	A
2/17:25:20.00	931004.	55520.00	CS3	39.15	323.84	290.92	37.70	49.17	9.84	R	A
3/17: 6:20.00	931005.	53620.00	CS3	45.11	325.30	316.00	43.32	49.48	9.57	R	A
4/16:46:54.00	931006.	51654.00	CS3	49.61	326.50	340.01	47.51	49.76	9.36	R	A
5/16:27: 2.00	931007.	45702.00	CS3	53.02	329.09	361.80	50.67	50.03	9.27	R	A
6/16: 6:40.00	931008.	43640.00	CS3	55.62	328.78	380.58	53.04	50.21	9.07	R	A
6/20:44: 2.00	931008.	91402.00	CS3	62.61	28.29	459.94	59.22	50.99	13.95	R	D
7/15:45:50.00	931009.	41550.00	CS3	57.58	330.32	395.99	54.83	50.40	9.02	R	A
7/20:23: 6.00	931009.	85306.00	CS3	61.56	29.43	443.38	58.33	50.82	13.92	R	D
0/ 0:14:24.00	931001.	124424.00	ES6	22.09	138.91	248.83	21.14	45.53	276.01	L	A
0/ 6:24:58.00	931001.	185458.00	ES6	28.73	37.75	262.91	27.78	47.01	276.24	R	D
1/ 6: 6:58.00	931002.	183658.00	ES6	16.40	34.32	240.01	15.97	46.63	275.73	R	D
2/23:19:32.00	931004.	114932.00	ES6	19.01	322.42	240.05	18.48	46.68	274.65	R	A
3/23: 0:24.00	931005.	113024.00	ES6	28.86	318.51	256.75	27.92	46.95	274.20	R	A

4/ 5:10:34.00	931005.	174034.00	ES6	20.67	217.86	241.89	19.78	45.56	274.60	L	D
4/22:40:52.00	931006.	111052.00	ES6	36.28	322.75	276.10	35.00	47.27	273.98	R	A
5/ 4:50:52.00	931006.	172052.00	ES6	29.53	224.76	257.83	28.29	45.35	274.14	L	D
5/22:20:52.00	931007.	105052.00	ES6	41.87	324.06	295.62	40.30	47.52	273.76	R	A
6/ 4:30:44.00	931007.	170044.00	ES6	36.30	224.34	275.68	34.75	45.12	273.84	L	D
6/22: 0:22.00	931008.	103022.00	ES6	46.02	322.16	313.43	44.20	47.68	273.46	R	A
7/ 4:10: 8.00	931008.	164008.00	ES6	41.35	222.49	292.92	39.53	44.89	273.65	L	D
7/21:39:24.00	931009.	100924.00	ES6	49.03	323.58	328.20	47.02	47.86	273.34	R	A
0/ 0:37:20.00	931001.	130720.00	MS1	46.80	55.72	322.97	44.83	23.82	32.06	R	D
0/14:56: 0.0	931002.	32600.00	MS1	56.55	304.17	391.68	53.78	24.25	27.64	R	A
1/ 0:19:26.00	931002.	124926.00	MS1	30.02	56.52	257.59	28.98	23.29	31.23	R	D
3/23:23:18.00	931005.	115318.00	MS1	33.05	236.78	261.90	31.74	22.00	29.09	L	D
4/23: 3:44.00	931006.	113344.00	MS1	44.94	237.01	305.65	42.99	21.65	28.52	L	D
5/22:43:42.00	931007.	111342.00	MS1	52.71	238.23	351.19	50.22	21.39	27.99	L	D
6/22:23:12.00	931008.	105312.00	MS1	57.88	238.52	393.06	54.92	21.15	27.56	L	D
7/22: 2:12.00	931009.	103212.00	MS1	61.36	239.15	428.32	58.02	20.98	27.21	L	D
0/ 8:28:38.00	931001.	205838.00	NSA	54.17	16.83	387.39	51.28	-55.71	1.40	R	D
0/10: 0:30.00	931001.	223030.00	NSA	35.24	357.94	284.52	33.65	-56.91	359.91	R	A
1/ 8:10:36.00	931002.	204036.00	NSA	52.41	15.76	371.56	49.70	-55.87	1.24	R	D
1/ 9:42:26.00	931002.	221226.00	NSA	36.24	354.61	286.50	34.60	-56.87	359.75	R	A
2/ 7:52:10.00	931003.	202210.00	NSA	50.81	14.55	358.05	48.23	-56.00	1.08	R	D
2/ 9:24: 0.0	931003.	215400.00	NSA	37.38	356.42	289.05	35.69	-56.81	359.83	R	A
3/ 7:33:20.00	931004.	200320.00	NSA	49.37	14.56	346.62	46.92	-56.12	1.03	R	D
3/ 9: 5: 8.00	931004.	213508.00	NSA	38.55	355.38	291.84	36.80	-56.76	359.77	R	A
4/ 7:14: 4.00	931005.	194404.00	NSA	48.11	14.08	336.98	45.77	-56.22	0.95	R	D
4/ 8:45:50.00	931005.	211550.00	NSA	39.70	353.83	294.75	37.90	-56.71	359.68	R	A
5/ 6:54:20.00	931006.	192420.00	NSA	47.04	11.22	328.86	44.78	-56.28	0.73	R	D
5/ 8:26: 6.00	931006.	205606.00	NSA	40.84	354.00	297.72	38.98	-56.65	359.68	R	A
6/ 6:34:10.00	931007.	190410.00	NSA	46.16	11.37	322.15	43.98	-56.35	0.72	R	D
6/ 8: 5:52.00	931007.	203552.00	NSA	41.88	349.45	300.41	39.97	-56.62	359.42	R	A
7/ 6:13:30.00	931008.	184330.00	NSA	45.49	9.46	316.72	43.37	-56.39	0.58	R	D
7/ 7:45:12.00	931008.	201512.00	NSA	42.79	351.36	302.64	40.84	-56.57	359.51	R	A

Table 4 - Opportunities for the New Baseline.

3. DTOs Comparison

Table 5 shows the numerical differences between some significant parameters of corresponding opportunities as computed for the two baseline orbits.

For a correct interpretation of Table 5, it should be noted that:

1. MET corresponds to the one computed for the old baseline DTOs (Table 3).
2. DELTA MET gives the algebric difference between the days, hours, minutes and seconds (as separated values), for corresponding DTOs of Table 3 and 4.
   When MET shows negative values and equal (in module) to MET, it means that the DTO computed for the old baseline was not found in the new baseline (i.e. DTO N. 3, 14, 36, etc). These DTOs are flagged with a *.
3. MET equal 0/0:0:0.0, means that at DELTA MET time a DTO was found only for the new baseline (i.e. DTO N. 7,15,16,25,27, etc.). These DTOs are flagged with a *.

4. D-INC and D-ONA are the algebric differences as computed for incidence and off-nadir angles of corresponding DTOs.

DTO N.	SITE ID		MET dd/hh.mm.sec	DELTA MET dd/ hh. mm. sec	D-INC deg	D-ONA deg
1	ES0		0/ 8: 9:50.00	0/ 0: 1:-36.00	0.51	0.43
2	ES0		0/19:13: 0.0	0/ 0: 0: 52.00	-1.78	-1.61
3	ES0		1/ 7:50:50.00	0/ 0: 2:-38.00	1.87	1.59
4	ES0		1/18:53:54.00	0/ 0: 2:-16.00	-4.62	-4.26
5	ES0		2/18:34:40.00	0/ 0: 3:-38.00	-9.17	-8.69
6	ES0	*	3/18:15:16.00	-3/-18:-15:-16.00	-30.16	-29.09
7	ES0	*	0/ 0: 0: 0.0	5/ 17: 38: 36.00	24.71	23.85
8	ES0		6/17:16: 0.0	0/ 0: 2: 12.00	10.53	10.08
9	ES0		7/16:55:54.00	0/ 0: 2:-34.00	5.52	5.23
10	HS1		0/ 6:42: 2.00	0/ 0: 0: 18.00	-1.44	-1.38
11	HS1		0/17:42:44.00	0/ 0: 1:-12.00	-2.74	-2.57
12	HS1		1/ 6:23: 2.00	0/ 0: 1: 18.00	-6.74	-6.47
13	HS1		1/17:23:40.00	0/ 0: 2:-20.00	-7.82	-7.48
14	HS1	*	2/17: 4:26.00	-2/-17: -4:-26.00	-17.50	-16.94
15	HS1	*	0/ 0: 0: 0.0	3/ 5: 47: 8.00	26.97	26.04
16	HS1	*	0/ 0: 0: 0.0	3/ 16: 47: 44.00	20.36	19.64
17	HS1		4/ 5:25: 4.00	0/ 0: 2: 50.00	11.18	10.61
18	HS1		4/16:25:28.00	0/ 0: 3:-10.00	13.22	12.65
19	HS1		5/ 5: 5:24.00	0/ 0: 3:-12.00	8.04	7.47
20	HS1		5/16: 5:42.00	0/ 0: 3:-18.00	9.25	8.71
21	HS1		6/ 4:45:34.00	0/ 0: 3:-30.00	5.43	4.94
22	HS1		6/15:45:48.00	0/ 0: 3:-46.00	5.90	5.44
23	HS1		7/ 4:25:34.00	0/ 0: 2: -8.00	3.38	3.00
24	HS1		7/15:25:42.00	0/ 0: 2:-30.00	3.23	2.93
25	HS2	*	0/ 0: 0: 0.0	0/ 23: 52: 38.00	15.70	15.25
26	HS2		1/23:32:28.00	0/ 0: 2: -8.00	6.11	5.82
27	HS2	*	0/ 0: 0: 0.0	2/ 7: 20: 44.00	62.13	58.72
28	HS2		2/23:13:12.00	0/ 0: 2: 28.00	6.05	5.68
29	HS2		3/ 6:59:18.00	0/ 1:-58: 36.00	-3.46	-3.08
30	HS2		3/22:53:46.00	0/ 0: 3:-14.00	5.26	4.85
31	HS2		4/ 6:39:50.00	0/ 0: 3:-10.00	-4.67	-4.27
32	HS2		4/22:34:10.00	0/ 0: 3:-10.00	4.27	3.85
33	HS2		5/ 6:20:10.00	0/ 0: 2: 48.00	-5.75	-5.34
34	HS2		5/22:14:22.00	0/ 0: 3:-22.00	3.28	2.91
35	HS2		6/ 6: 0:20.00	0/ 0: 2: 28.00	-6.24	-5.88
36	HS2	*	6/21:54:26.00	-6/-21:-54:-26.00	-62.39	-59.05
37	HS2		7/ 5:40:20.00	0/ 0: 2:-10.00	-5.54	-5.26
38	CS1		0/ 0:28:28.00	0/ 0: 0: 2.00	-0.35	-0.35
39	CS1		0/19:33: 0.0	0/ 0: 0: 54.00	0.29	0.24
40	CS1		0/22:37:38.00	0/ 0: 1: 0.0	-0.86	-0.82
41	CS1		1/19:13:56.00	0/ 0: 2:-14.00	0.83	0.74
42	CS1		1/22:18:32.00	0/ 0: 2: -8.00	-1.34	-1.25
43	CS1		2/18:54:42.00	0/ 0: 3:-36.00	1.12	1.01
44	CS1		2/21:59:16.00	0/ 1:-58: 28.00	-1.82	-1.70
45	CS1	*	0/ 0: 0: 0.0	3/ 17: 6: 10.00	63.19	59.37
46	CS1		3/18:35:18.00	0/ 0: 3:-14.00	1.24	1.11
47	CS1		3/21:39:52.00	0/ 0: 3:-14.00	-2.21	-2.05
48	CS1		4/16:43:52.00	0/ 0: 3: -8.00	-1.92	-1.66
49	CS1		4/18:15:44.00	0/ 0: 3: -8.00	1.24	1.11

DTO N.	SITE ID	MET dd/hh.mm.sec	DELTA MET dd/ hh. mm. sec	D-INC deg	D-ONA deg
50	CS1	4/21:20:16.00	0/ 0: 3: -8.00	-2.44	-2.28
51	CS1	5/16:24: 8.00	0/ 0: 2: 40.00	-1.90	-1.67
52	CS1	5/17:56: 0.0	0/ 0: 2: 42.00	1.15	1.03
53	CS1	5/21: 0:30.00	0/ 0: 3:-22.00	-2.42	-2.26
54	CS1	6/16: 4:12.00	0/ 0: 2: 14.00	-1.62	-1.43
55	CS1	6/17:36: 6.00	0/ 0: 2: 12.00	0.99	0.90
56	CS1	6/20:40:34.00	0/ 0: 2: 8.00	-2.03	-1.91
57	CS1	7/15:44: 8.00	0/ 0: 1: 28.00	-0.98	-0.86
58	CS1	7/17:16: 0.0	0/ 0: 1: 26.00	0.76	0.72
59	CS1	7/20:20:28.00	0/ 0: 1: 16.00	-1.16	-1.08
60	G16	0/19:33:58.00	0/ 0: 1: -8.00	-1.05	-1.02
61	G16	0/21: 5:56.00	0/ 0: 1: -4.00	-0.42	-0.40
62	G16	0/22:37:50.00	0/ 0: 1: 0.0	0.37	0.33
63	G16	1/19:14:52.00	0/ 0: 2:-14.00	-1.86	-1.80
64	G16	1/20:46:50.00	0/ 0: 2:-12.00	-0.52	-0.51
65	G16	1/22:18:44.00	0/ 0: 2:-10.00	0.96	0.87
66	G16	2/18:55:38.00	0/ 0: 3:-36.00	-2.27	-2.17
67	G16 *	2/20:27:36.00	-2/-20:-27:-36.00	-15.62	-15.23
68	G16	2/21:59:28.00	0/ 1:-58: 26.00	1.35	1.22
69	G16 *	3/18:36:14.00	-3/-18:-36:-14.00	-16.76	-16.00
70	G16	3/21:40: 0.0	0/ 0: 2: 48.00	1.54	1.39
71	G16	4/21:20:24.00	0/ 0: 3: -8.00	1.59	1.43
72	G16	5/21: 0:38.00	0/ 0: 3:-22.00	1.49	1.33
73	G16	6/20:40:42.00	0/ 0: 2: 6.00	1.26	1.13
74	G16	7/20:20:34.00	0/ 0: 1: 16.00	0.93	0.86
75	GS1	0/ 9:36:56.00	0/ 0: 1:-32.00	-1.49	-1.40
76	GS1	1/ 9:17:56.00	0/ 0: 2:-36.00	-5.69	-5.39
77	GS1 *	2/ 8:58:44.00	-2/ -8:-58:-44.00	-26.26	-25.33
78	GS1	4/ 8:19:54.00	0/ 0: 3:-10.00	14.89	14.31
79	GS1	5/ 8: 0:12.00	0/ 0: 3:-12.00	10.96	10.39
80	GS1	6/ 7:40:22.00	0/ 0: 2: 26.00	7.21	6.71
81	GS1	7/ 7:20:20.00	0/ 0: 2:-14.00	4.24	3.88
82	CS2	0/ 4:15:22.00	0/ 0: 0: 14.00	-1.04	-1.02
83	CS2	0/20:10:28.00	0/ 0: 1: -4.00	0.73	0.60
84	CS2	3/ 3:17:58.00	0/ 0: 3:-28.00	9.55	9.17
85	CS2	4/ 2:58:30.00	0/ 1:-57:-10.00	8.56	8.12
86	CS2	5/ 2:38:52.00	0/ 0: 3:-12.00	6.82	6.40
87	CS2	6/ 2:19: 4.00	0/ 0: 2: 32.00	5.02	4.63
88	CS2	7/ 1:59: 4.00	0/ 1:-58: -2.00	3.35	3.04
89	HS3	0/ 0:30:40.00	0/ 0: 0: 2.00	-0.33	-0.34
90	HS3	2/23:33:20.00	0/ 0: 2: 28.00	7.16	6.86
91	HS3	3/23:13:54.00	0/ 0: 3:-12.00	6.86	6.51
92	HS3	4/22:54:18.00	0/ 0: 3:-10.00	5.85	5.50
93	HS3	5/22:34:30.00	0/ 0: 3:-24.00	4.62	4.30
94	HS3	6/22:14:32.00	0/ 0: 2: 4.00	3.30	3.03
95	HS3	7/21:54:24.00	0/ 0: 1: 12.00	1.93	1.79
96	CS3	0/ 0:29:54.00	0/ 0: 0: 2.00	-0.37	-0.38
97	CS3	0/18: 1:18.00	0/ 0: 1:-12.00	1.76	1.66
98	CS3	1/ 0:10:56.00	0/ 0: 2:-54.00	0.69	0.56
99	CS3	1/17:42:14.00	0/ 0: 1: 42.00	3.20	3.04
100	CS3 *	1/23:51:50.00	-1/-23:-51:-50.00	-62.75	-59.01
101	CS3	2/17:23: 0.0	0/ 0: 2: 20.00	3.79	3.58

DTO N.	SITE ID	MET dd/hh.mm.sec	DELTA MET dd/ hh. mm. sec	D-INC deg	D-ONA deg
102	CS3	3/17: 3:36.00	0/ 0: 3:-16.00	3.76	3.53
103	CS3	4/16:44: 4.00	0/ 0: 2: 50.00	3.41	3.16
104	CS3	5/16:24:20.00	0/ 0: 3:-18.00	2.88	2.66
105	CS3	6/16: 4:26.00	0/ 0: 2: 14.00	2.24	2.04
106	CS3 *	0/ 0: 0: 0.0	6/ 20: 44: 2.00	62.61	59.22
107	CS3	7/15:44:20.00	0/ 0: 1: 30.00	1.51	1.39
108	CS3	7/20:21:48.00	0/ 0: 2:-42.00	-0.45	-0.35
109	ES6	0/ 0:14:24.00	0/ 0: 0: 0.0	-0.36	-0.36
110	ES6	0/ 6:24:40.00	0/ 0: 0: 18.00	-1.05	-1.01
111	ES6	1/ 6: 5:40.00	0/ 0: 1: 18.00	-3.66	-3.52
112	ES6 *	0/ 0: 0: 0.0	2/ 23: 19: 32.00	19.01	18.48
113	ES6	3/22:57:38.00	0/ 1:-57:-14.00	6.80	6.50
114	ES6 *	0/ 0: 0: 0.0	4/ 5: 10: 34.00	20.67	19.78
115	ES6	4/22:38: 2.00	0/ 0: 2: 50.00	5.96	5.66
116	ES6	5/ 4:48: 4.00	0/ 0: 2: 48.00	7.41	7.10
117	ES6	5/22:18:14.00	0/ 0: 2: 38.00	4.79	4.53
118	ES6	6/ 4:28:14.00	0/ 0: 2: 30.00	5.92	5.65
119	ES6	6/21:58:18.00	0/ 1:-58: 4.00	3.48	3.27
120	ES6	7/ 4: 8:14.00	0/ 0: 2: -6.00	4.12	3.91
121	ES6	7/21:38:10.00	0/ 0: 1: 14.00	2.04	1.92
122	MS1	0/ 0:37:18.00	0/ 0: 0: 2.00	-0.52	-0.51
123	MS1	0/14:55:20.00	0/ 0: 1:-20.00	0.91	0.77
124	MS1	1/ 0:18:22.00	0/ 0: 1: 4.00	-4.59	-4.38
125	MS1 *	1/14:36:16.00	-1/-14:-36:-16.00	-62.11	-58.76
126	MS1 *	1/23:59:14.00	-1/-23:-59:-14.00	-17.59	-17.06
127	MS1	3/23:20:30.00	0/ 0: 3:-12.00	12.24	11.72
128	MS1	4/23: 0:54.00	0/ 0: 3:-10.00	9.52	8.99
129	MS1	5/22:41: 6.00	0/ 0: 2: 36.00	6.72	6.24
130	MS1	6/22:21: 8.00	0/ 0: 2: 4.00	4.34	3.96
131	MS1	7/22: 1: 0.0	0/ 0: 1: 12.00	2.32	2.10
132	NSA	0/ 8:28:14.00	0/ 0: 0: 24.00	-0.53	-0.52
133	NSA	0/10: 0: 0.0	0/ 0: 0: 30.00	-0.30	-0.30
134	NSA	1/ 8: 9:14.00	0/ 0: 1: 22.00	-0.83	-0.78
135	NSA	1/ 9:41: 0.0	0/ 0: 1: 26.00	-0.01	-0.03
136	NSA	2/ 7:50: 4.00	0/ 0: 2: 6.00	-1.03	-0.97
137	NSA	2/ 9:21:50.00	0/ 0: 3:-50.00	0.30	0.28
138	NSA	3/ 7:30:44.00	0/ 0: 3:-24.00	-1.12	-1.05
139	NSA	3/ 9: 2:30.00	0/ 0: 3:-22.00	0.57	0.53
140	NSA	4/ 7:11:14.00	0/ 0: 3:-10.00	-1.10	-1.02
141	NSA	4/ 8:42:58.00	0/ 0: 3: -8.00	0.75	0.71
142	NSA	5/ 6:51:34.00	0/ 0: 3:-14.00	-0.97	-0.90
143	NSA	5/ 8:23:18.00	0/ 0: 3:-12.00	0.93	0.88
144	NSA	6/ 6:31:42.00	0/ 0: 3:-32.00	-0.72	-0.65
145	NSA	6/ 8: 3:28.00	0/ 0: 2: 24.00	0.97	0.92
146	NSA	7/ 6:11:42.00	0/ 0: 2:-12.00	-0.34	-0.29
147	NSA	7/ 7:43:26.00	0/ 0: 2:-14.00	0.89	0.86

Table 5 - DTO parameter differences

The following general considerations can be made after comparing the two baseline orbits:

1. the differences found for the incidence angle of corresponding DTOs are:

- minimun difference	0.29	deg
- maximum difference	14.89	deg
- average difference (approx.)	5.00	deg
- DTO time difference (approx.)	3	min

2. Only three sites (Kerang, Montespertoli and Southern Ocean), experience the same opportunities for both orbits.
   The other nine remaining sites experience at least one DTO (generally two), without a corrispondent one in the other baseline orbit.

ORBITAL ANALYSIS FOR REMOVING THE CONFLICT BETWEEN TWO SRL SITES

CNUCE December, 1992
by: Alberto Foni

1. SCOPE

During the splinter meeting on Calibration, held at JPL as part of the Science Meeting on November 1992, the conflict between Otztal (OT) and Oberpfaffenhofen (OP), was discussed.
With the baseline orbit used for generating the SRL Timeline Version 2.4, the Data Take Opportunities (DTOs) computed for both sites do not allow a satisfactory planning of DTOs. For imaging the two sites during the same pass, different antenna tilt angles are requested and therefore, only one site at time can be imaged.
For the above it was proposed to investigate if different orbits and/or active control of the orbit would eliminate or reduce the above mentioned conflict. This report, describes the work performed and the results obtained.

2. PROBLEM APPROACH

The experimental constraints on the sites, along with the STS operational constraints, do not allow orbits significantly different from the baseline. Orbits with lower inclination would exclude the northern sites from being imaged. Orbits with initial orientation (ascending node) different from the baseline cannot be considered as well, because of the amount of fuel requested by STS during the ascending trajectory. The extra fuel necessary exceeds by far the margin in the Shuttle fuel budget.
Also node changes after injection of STS into the operational orbit, have not been considered because of the high fuel requirements for such operation.
For the above the analysis of an orbital geometry different from the baseline, in order to find the best OT and OP imaging opportunities, was limited to the evaluation of:

1. small variation of the initial Shuttle altitude.
2. suitable positioning of the Shuttle ground track in the early phase of the mission obtained by phasing the STS period with the Earth rotation.

Point 1. affects the daily drift of the ground track. For a constant altitude of 204 km, the ground track repeats itself after 24 hours determining the same site to be imaged in the same conditions (i.e. identical look angle).
Different altitudes will determine a daily drift of the ground track and, consequently, a changing of the imaging conditions at each pass.

Point 2., which cannot be accomplished by changing the orbit node as previously discussed, was covered by defining a specific altitude profile during the initial phase of the mission, which would give an effect similar to a node variation without requiring pratically additional propellant.

3) APPLICABILITY OF THE STUDY

This analysis concentrates only on the two sites OP and OT. The DTOs computed for alternative orbits have been examined in terms of characteristics (number, off-nadir angle, incidence angle, direction of sighting, etc.). No attempt has been made for developing a corresponding timeline.

Therefore this study is limited to identify an acceptable orbit that would give no-conflicting opportunities for the two sites in compliance with the coverage requirements.
For any orbit investigated during the present study, the associated DTOs have been compared against the DTOs computed for the baseline orbit.
In the following table, the DTOs for the baseline orbit are given:

Orb N.	Site Id.	Track A/D	Ldir N/S	MET ddd hh mm sec	Look deg	Inc deg
2	CS3	D	N	000:01:59:53.675	50.86	53.48
2	HS8	D	N	000:02:00:02.621	T 35.07	36.52
14	HS8	A	S	000:19:31:49.137	35.75	37.24
14	CS3	A	S	000:19:32:04.940	17.31 P	17.96
18	CS3	D	N	001:01:41:59.804	55.80	58.97
18	HS8	D	N	001:01:42:08.919	T 44.11	46.12
30	CS3	A	S	001:19:13:55.048	27.80 P	28.89
30	HS8	A	S	001:19:13:39.604	43.24	45.18
34	CS3	D	N	002:01:23:42.976	59.49	63.18
34	HS8	D	N	002:01:23:52.790	T 50.56	53.10
46	CS3	A	S	002:18:55:22.161	35.63 P	37.11
46	HS8	A	S	002:18:55:06.962	48.63	50.99
50	HS8	D	N	003:01:05:12.556	T 55.31	58.35
62	CS3	A	S	003:18:36:25.370	41.68 P	43.52
62	HS8	A	S	003:18:36:10.444	52.74	55.47
66	HS8	D	N	004:00:46:07.809	T 58.67	62.14
78	CS3	A	S	004:18:17:03.381	46.13 P	48.28
78	HS8	A	S	004:18:16:48.566	55.67	58.72
94	CS3	A	S	005:17:57:15.613	49.55(P)	51.97
94	HS8	A	S	005:17:57:00.931	57.94	61.27
110	CS3	A	S	006:17:37.01.089	52.11	54.76
110	HS8	A	S	006:17:36:46.565	59.68	63.25
113	CS3	D	S	006:22:14:25.590	59.33	62.92
126	CS3	A	S	007:17:16:18.737	54.11	56.98
129	CS3	D	S	007:21:53:37.046	58.38	61.81
142	CS3	A	S	008:16:55:06.732	55.50	58.49
145	CS3	D	S	008:21:32:19.925	57.63	60.92

Tab. 1 - DTOs for the Baseline Orbit

It can be seen that:

- OT has a total of 12 DTOs (7 AS and 5 DN)
- OP has a total of 15 DTOs (9 AS, 3 DN and 3 DS)
- OT has no DTOs after the 7th day
- OP offnadir angle is no longer good for calibration after the 5th day
- T and P associated to the look angle, indicate possible "good" opportunities for Otztal and Oberpfaffenhofen respectively.

4. SELECTION OF THE ORBIT

4.1 Selection of the initial altitude and node.

For calibration purposes, OP asks for passes with look angle <48 deg. and the same direction is absolutely requested for all the planned Data Takes. The baseline orbit gives to OP 9 AS passes, but only the first 5 (with the 6th outside, but close to, such limit) provide the requested look angle. This is due to the value of the initial altitude that causes an eccessive drift of the ground track every 24 hours.
To increase the number of passes for both OP and OT, it was investigated the effect of a reduction of the daily drift of the ground track, to maintain the incidence angle for OP within the desired limits.
A semi-parametric investigation was performed in order to identify orbits, close to the baseline, providing better chances for the two conflicting sites. It was found that the orbit with initial altitude of 218.5 km and ascending node 76.7 deg. (+0.5 deg with respect to the baseline), gives 7 useful DTOs to Otztal and 8 to Oberpaffenhofen, all the opportunities are not conflicting among them, because they are not occouring during the same pass. OT has the opportunities during descending passes, while OP during the ascending ones.
The details are given in the following table.

Orb N.	Site Id.	Track A/D	Ldir N/S	MET ddd hh mm sec	Look deg	Inc deg
2	CS3	D	N	000:01:59:48.971	48.72	51.13
2	HS8	D	N	000:01:59:58.087	T 30.89	32.12
14	HS8	A	S	000:19:31:14.072	30.99	32.21
18	CS3	D	N	001:01:41:14.257	53.64	56.52
18	HS8	D	N	001:01:41:23.695	T 39.91	41.63
30	CS3	A	S	001:19:12:38.244	20.83 P	21.61
30	HS8	A	S	001:19:12:22.776	38.63	40.26
34	CS3	D	N	002:01:22:15.232	57.19	60.49
34	HS8	D	N	002:01:22:25.008	T 46.37	48.52
46	CS3	A	S	002:18:53:21.911	28.76 P	29.88
46	HS8	A	S	002:18:53:06.545	44.15	46.13
50	CS3	D	N	003:01:02:51.742	59.94	63.65
50	HS8	D	N	003:01:03:01.651	T 51.19	53.75
62	CS3	A	S	003:18:33:40.010	34.93 P	36.35
62	HS8	A	S	003:18:33:24.766	48.32	50.61
66	HS8	D	N	004:00:43:12.344	T 54.71	57.63
78	CS3	A	S	004:18:13:31.588	39.50 P	41.17
78	HS8	A	S	004:18:13:16.488	48.70	53.95
82	HS8	D	N	005:00:22:56.059	T 57.33	60.56
94	CS3	A	S	005:17:52:55.597	42.98 P	44.76
94	HS8	A	S	005:17:52:40.664	53.70	56.47
98	HS8	D	N	006:00:02:11.698	T 59.22	62.70
110	CS3	A	S	006:17:31.50.449	45.55 P	47.60
110	HS8	A	S	006:17:31:35.526	55.44	58.38
113	CS3	D	S	006:22:14:25.590	59.33	62.92

126	CS3	A	S	007:17:10:15.708	47.30 P	49.47
126	HS8	A	S	007:17:10:01.002	56.72	59.79
142	HS8	A	S	008:16:47:53.744	57.51	60.66
142	CS3	A	S	008:16:48:09.083	48.49 P	50.74

Tab. 2 - DTOs for the Proposed Orbit

It was therefore considered as "new nominal" orbit the following that gives 8 opportunities to OP to be imaged from the same direction, once per day (Ascending track, South looking), with incidence angles between 21 and 48.5 degrees.

The complete definition of the new nominal orbit is:

semimajor axis	6596.644 km (H=218.5 km)
eccentricity	0.00001
inclination	57.0 deg
asc. node	76.711 deg
arg. per.	0.0 deg
mean anomaly	0.0 deg
epoch	1993 10 01 12 30 00

As mentioned before, any ascending node of the initial orbit different from the baseline (in the new nominal orbit the node is 0.5 deg higher than the baseline), is not acceptable because of fuel necessary for such operation.
For the above, to to obtain the desired situation without any fuel penalty, the following mission profile was developed.

1. Injection of the Shuttle in orbit with the following characteristics:

semimajor axis	6586.644 km (H=208.5 km)
asc. node	76.211 (baseline node)

2. phasing of the ground track with the Earth rotation:

   coasting after injection for 14 hours

3. orbit altitude adjustment (in-plane maneuver) to the desired value of 218.5 km

At this point the ground tracks repeat exactly the ones corresponding the new nominal orbit.

5. CONCLUSIONS

The new nominal orbit, found as result of this analysis, is not very different from the baseline orbit used for developing the version 2.4 of the SRL timeline, therefore no major differences are expected if a new version of the timeline would be developed using the new orbit.

The new orbit does not reduce nor eliminate the conflict existing between the examined sites in the strictest sense of the word, but increases considerably the DTOs for both sites (the improvement is of about 50%).
The disavantages, with respect to the baseline orbit, are:

- Initial altitude different from the nominal (but due to the short period of the time required for phasing no major impact on the DTOs is expected)
- Orbit maneuvers necessary necessary after half day from beginning of the mission for rising the Shuttle altitude to the nominal value. Two maneuvers are envisaged at a minimum interval of 45 minutes. These maneuvers don't require additional fuel with respect to the fuel necessary for the nominal orbit. The time requested for each maneuver should be less than 10 minutes (TBC).

```
                                                                               OT   OP
amf 1993:01:15 13:29:25 USER$DISK:[MISSION._PAS_OCT-92._EGENIA21 218.5km +0.5 deg node
  2 D 000:01:59:48.971 CS3 N   48.72 1 46.05  46.25    9.00 229.72    51.13  131.19  35
  2 D 000:01:59:58.087 HS8 N   30.89  45.67  45.87    9.65 229.60 1  32.12  130.82  2
 14 A 000:19:31:14.072 HS8 S   30.99  47.59  47.78    9.71 228.93    32.21   53.16  26
 18 D 001:01:41:14.257 CS3 N   53.64  45.72  45.91    8.50 228.57    56.52  132.22  39
 18 D 001:01:41:23.695 HS8 N   39.91  45.32  45.51    9.17 228.45 2  41.63  131.84  29
 30 A 001:19:12:38.244 CS3 S   20.83  48.52  48.71   10.60 227.86    21.61 1 54.65  24
 30 A 001:19:12:22.776 HS8 S   38.63  47.92  48.12    9.38 227.66    40.26   54.28  29
 34 D 002:01:22:15.232 CS3 N   57.19  45.43  45.62    8.04 227.42    60.49  133.31  43
 34 D 002:01:22:25.008 HS8 N   46.37  45.01  45.20    8.72 227.29 3  48.52  132.93  33
 46 A 002:18:53:21.911 CS3 S   28.76  48.80  49.00   10.30 226.53    29.88 2 55.08  25
 46 A 002:18:53:06.545 HS8 S   44.15  48.21  48.40    9.08 226.32    46.13   54.70  31
 50 D 003:01:02:51.742 CS3 N   59.94  45.14  45.34    7.64 226.18    63.65  133.74  47
 50 D 003:01:03:01.651 HS8 N   51.19  44.72  44.91    8.32 226.06 4  53.75  133.35  36
 62 A 003:18:33:40.010 CS3 S   34.93  49.06  49.25   10.05 225.15    36.35 3 55.60  27
 62 A 003:18:33:24.766 HS8 S   48.32  48.47  48.67    8.83 224.93    50.61   55.21  34
 66 D 004:00:43:12.344 HS8 N   54.71  44.46  44.66    7.96 224.79 5  57.63  133.86  39
 78 A 004:18:13:31.588 CS3 S   39.50  49.27  49.46    9.85 223.68 5  41.17 4 56.20  29
 78 A 004:18:13:16.488 HS8 S   51.40  48.70  48.89    8.62 223.47    53.95   55.81  36
 82 D 005:00:22:56.059 HS8 N   57.33  44.25  44.45    7.64 223.48 6  60.56  134.44  42
 94 A 005:17:52:55.597 CS3 S   42.89  49.45  49.64    9.70 222.14    44.76 5 56.90  30
 94 A 005:17:52:40.664 HS8 S   53.70  48.90  49.09    8.47 221.94    56.47   56.51  38
 98 D 006:00:02:11.698 HS8 N   59.22  44.09  44.29    7.36 222.13 7  62.70  135.10  45
110 A 006:17:31:50.449 CS3 S   45.55  49.60  49.79    9.55 220.57    47.60 6 56.92  31
110 A 006:17:31:35.526 HS8 S   55.44  49.04  49.23    8.32 220.34    58.38   56.52  39
126 A 007:17:10:15.708 CS3 S   47.30  49.72  49.90    9.49 218.88    49.47 7 57.81  32
126 A 007:17:10:01.002 HS8 S   56.72  49.18  49.37    8.26 218.68    59.79   57.42
142 A 008:16:47:53.774 HS8 S   57.51  49.22  49.41    8.16 216.89    60.66   56.85
142 A 008:16:48:09.083 CS3 S   48.49  [illegible]  49.97    9.43 217.11    50.7 8
```

```
                                                                                            OT        OP
     amf 1993:01:14 10:19:17 USER$DISK:[MISSION._PAS_OCT-92._EGENIALB dto for baseline
       2 D 000:01:59:53.675 CS3 N   50.86 1 45.89  46.08    8.77 231.67  D#53.48    131.55
 g-1 { 2 D 000:02:00:02.621 HS8 N   35.07   45.52  45.71    9.41 231.56  1 36.52    131.92
      14 A 000:19:31:49.137 HS8 S 1 35.75   47.80  47.99    9.48 231.07    37.24     53.44
      14 A 000:19:32:04.940 CS3 S   17.31   48.42  48.61   10.71 231.28    17.96 1   54.58
      18 D 001:01:41:59.804 CS3 N   55.80 2 45.50  45.69    8.22 230.59    58.97    132.44
  2    8 D 001:01:42:08.919 HS8 N   44.11   45.11  45.30    8.86 230.47  2 46.12    132.80
         A 001:19:13:55.048 CS3 S   27.80   48.78  48.97   10.32 230.09    28.89 2   54.79
      30 A 001:19:13:39.604 HS8 S 2 43.24   48.18  48.37    9.10 229.88    45.18     54.41
      34 D 002:01:23:42.976 CS3 N   59.49 3 45.14  45.33    7.68 229.46    63.18    133.41
  3 { 34 D 002:01:23:52.790 HS8 N   50.56   44.72  44.91    8.36 229.35  3 53.10    133.02
      46 A 002:18:55:22.161 CS3 S   35.63   49.11  49.30   10.01 228.83    37.11 3   55.85
      46 A 002:18:55:06.962 HS8 S 3 48.63   48.53  48.73    8.78 228.62    50.99     55.47
      50 D 003:01:05:12.556 HS8 N   55.31   44.38  44.57    7.84 228.18  4 58.35    134.04
  4 { 62 A 003:18:36:25.370 CS3 S   41.68   49.43  49.62    9.74 227.55    43.52 4   57.01
      62 A 003:18:36:10.444 HS8 S 4 52.74   48.87  49.06    8.51 227.36    55.47     56.62
      66 D 004:00:46:07.809 HS8 N   58.67   44.10  44.29    7.36 227.01  5 62.14    135.12
  5 { 78 A 004:18:17:03.381 CS3 S   46.13   49.69  49.88    9.49 226.18    48.28 5   57.46
      78 A 004:18:16:48.566 HS8 S 5 55.67   49.15  49.34    8.26 225.98    58.72     57.07
 c 6 {94 A 005:17:57:15.613 CS3 S   49.55   49.93  50.12    9.28 224.78    51.97 6   58.01
      94 A 005:17:57:00.931 HS8 S 6 57.94   49.39  49.58    8.05 224.57    61.27     57.61
     110 A 006:17:37:01.089 CS3 S   52.11   50.14  50.33    9.12 223.30    54.76 7   58.65
  7 {110 A 006:17:36:46.565 HS8 S 7 59.68   49.61  49.80    7.89 223.10    63.25     58.24
     113 D 006:22:14:25.590 CS3 S   59.33   51.00  51.19   14.07 225.17    62.92    119.24
 M 8 {126 A 007:17:16:18.737 CS3 S  54.11   50.32  50.51    9.01 221.77    56.96 8   59.38
     129 D 007:21:53:37.046 CS3 S   58.38   50.85  51.04   13.93 223.72    61.81    119.19
 M 9 {142 A 008:16:55:06.732 CS3 S  55.50   50.44  50.63    8.89 220.13    58.49     59.41
     145 D 008:21:32:19.925 CS3 S   57.63   50.71  50.90   13.89 222.20    60.92    120.05
```

DECAY UNCERTAINTIES AND ORBIT ADJUSTMENTS

JPL March, 1993
by: Alberto Foni

ORBIT PLANNER TASKS

1) To generate Shuttle ephemeris as accurate as possible

2) To check the actual orbit against the planned one

3) To identify and propose (Science approves) orbit corrections

Generation of accurate Shuttle Ephemeris

The perturbations acting on the Shuttle orbit can be only partly modeled in the orbit propagation algorithm.
The major causes of error in the orbit propagation process are:

a) Atmospheric drag
b) RCS perturbations for attitude control
c) Perturbations due to attitude maneuvers, water dumps, etc
d) IMU alignment maneuvers
e) Orbit trim burns.

a) and b) can be modeled, individually or combined, by WT parameter. JSC should provide decay rates for the two nominal attitudes and corresponding values of WT will be identified and used.

c) are quite unpredictable (or not computable). JSC does not use any model for these perturbations. It is possible that after some time, repeated events can be roughly predicted by using the results of similar cases.

For d) and e), JSC computes post-maneuver S.V. and they can be treated in the same way.

Based on the above, orbit propagation for a period of time encompassing maneuvers and/or Shuttle activities, can be performed by sectioning the flight and using different WT and S.V.

Atmospheric Drag

The uncertainty associated to the athmospheric drag effect on the Shuttle orbit must be considered for two different phases of the mission:

- pre-mission planning: the average atmosphere density can be estimated in advance, by using the 11 year solar activity cycle prediction. The uncertainty is approximately 30%.

- mission replanning: daily measured and 3-day prediction of the solar flux value can be affected by an error less than 20% (10% is reasonable).

Orbit Planner actions: receives the daily $F_{10.7}$ values and compares the Solar Flux-WT/decay values with JSC expected decay rate.

RCS effects (venting)

Shuttle jets used for maintaining the operational attidudes (NF, TF), impinge on the Orbiter body, resulting in an acceleration directed toward the +X-axis.
Therefore when Shuttle flies NF, the vent force counteracts the air drag acceleration reducing the altitude decay by approxmately 400 m/day.
An opposite effect occours during TF flight.

$$\Delta a = \frac{2F\Delta t}{m\sqrt{\frac{\mu}{a^3}}}$$

Orbit Planner actions: the +/- 400 m/day altitude variation must be considered as a bias in the altitude decay rate.

Attitude maneuvers, water dumps

These events produce relatively small effects on the Shuttle orbit (< 100m SMA average variation). The impact in the mission planning (DTO parameters) is pratically detectable after one revolution. Primary effect of these activities is in degradating the orbit determination accuracy.

Orbit Planner actions: to consider an additional delta in the expected range of validity of the new State Vector.

IMU Aligment Maneuvers

JSC/MCC **predicts** the effects of such a maneuver in the Shuttle orbit. Therefore a predicted **post-maneuver** State Vector should be available to POCC (TBC). The expected **range of** the perturbation is of the order of 100m in the SMA. In the past missions **variations**, variations up to 600 m have been measured.

Orbit Planner actions: whenever a predicted post-maneuver SV is available, it should be used as initial state for a flight section.

Orbit Trim Burns

Similar situation as the above. A post-maneuver predicted State Vector will be always available.

Orbit Planner actions: Uses the JSC/MCC post-maneuver computed State Vector for generating the ephemeris post maneuver.

Check of the actual orbit against the planned one

For the objectives of the SRL mission, the orbital parameter which has to be monitored and checked, is the semimajor axis (SMA). In fact it determines the viewing conditions of the experimental sites.

Other parameters linked to the orbit SMA are the Shuttle altitude, the longitude and time of the equatorial crossing. These information give an immediate information on the Shuttle trajectory that can be used for planning and scientific evaluation.

The comparison of the most recent ephemeris with the ones used for the current plan, doesn't give any direct information of the impact of the "new orbit" on the science activity. This impact can be more efficiently evaluated by comparing the DTO parameters for corresponding significant cases (Prime Opportunities for Supersites).

Orbit Planner actions: to keep an updated archive of the actual (determined) orbits and to produce plots showing the actual behaviour (against the planned) of selected parameters such as Shuttle altitude, Longitude and Time of the equatorial crossings.

Orbit corrections detection and proposal

Whenever the actual orbit diverges from the planned one causing the parameters of future selected opportunities to assume values not acceptable by Science, the O.P. has the task to evaluate the recovery action for bringing the orbit back to the planned conditions.

The only parameter affecting pratically the Science activity is the Shuttle altitude (the SMA in terms of orbit). The eccentricity has a minor impact and will be controlled by suitably planning the time for orbit corrections (tipically if the altitude has to be increased the maneuver should be planned at the apogee). Inclination and Right Ascension of Ascending Node are not expected to be significantly perturbed by Shuttle activities.

The procedure for orbit correction planning should be the following:

1) Identification of the actual orbit trend that causes the differences in the DTOs

2) Assessment of the delta that if applied would bring the orbit to an altitude that, under the actual experienced trend, will give at the end of the mission an average

" HOW TO ADJUST THE ORBIT IF IT GOES OUTSIDE THE SPECIFIED LIMITS "

DRAFT VERSION

Alberto Foni (X-SAR M.O.T.)
JPL 14 July 1993

1. BACKGROUND

1) The current SIR-C/X-SAR baseline timeline is prepared assuming the following orbit as initial state (baseline orbit) at beginning of the flight and by propagating such orbit taking into account the Earth's gravitational field and the predicted atmospheric drag:

SMA	6598.14400	km
ECC	0.00001	
INC	57.0000000	deg
RAAN	-90.604527	deg
PER	0.0	deg
MA	0.0	deg
EPOCH	1994 03 30 12h 30m 0sec	

2) According to the baseline ephemeris, the Data Take Opportunities (DTO) are computed and selected for compilation of the pre-mission timeline.

3) The actual orbit during the mission will differ from the baseline because of a number of unmodeled/mismodeled perturbations considered in the baseline orbit propagation process.

4) During the mission, a deviation of the orbit from the baseline will be acceptable if the DTO parameters remain within the predefined limits (rule-of-thumb).

5) If the limits are violated and the orbit must be adjusted, a maneuver (trim burn) will be requested to JSC.

6) SIR-C/X-SAR is responsible for for defining how to adjust the orbit, in order to restore the baseline opportunities.

2. ORBIT CONTROL

2.1 Orbital Elements

Assuming **that** at beginning of the mission the orbit is close to the nominal, the differences **between** the actual State Vectors (SV) and the corresponding baseline, are expected to increase as the mission progresses. The orbital parameters mostly affected by the difference will be the in-plane elements and in particular the semi-major axis (SMA).
The out-of-plane elements, Right Ascension of Ascending Node (RAAN) and Inclination (INC), should not significantly differ from the baseline and the impact of the difference on the DTO parameters should be negligeable.
The effects of the perturbations experienced during the actual flight and not modeled

or mismodeled in the pre-mission timeline, do not significantly affect the timeline itself (i.e. they don't violate the pre-defined limits) if they are balanced over the short-term period (i.e. in a few revolutions). For example, if Shuttle operates for the same time in the NF and TF attitudes, the cumulative effect on the orbit of the "vent force", is nullified. The same can also occour if many similar small attitude maneuvers are performed, the effect of one maneuver can be balanced by the effect of another one. Therefore, only if some perturbations cause a long-term effect on the SMA, then the orbit variation impacts on the timeline and the SMA has to be controlled suitably.
Main causes responsible for long-term SMA variations, are:

- actual air drag different from the one used for the baseline ephemeris propagation
- cumulative effect of the perturbations due to the RCS used for attitude control.

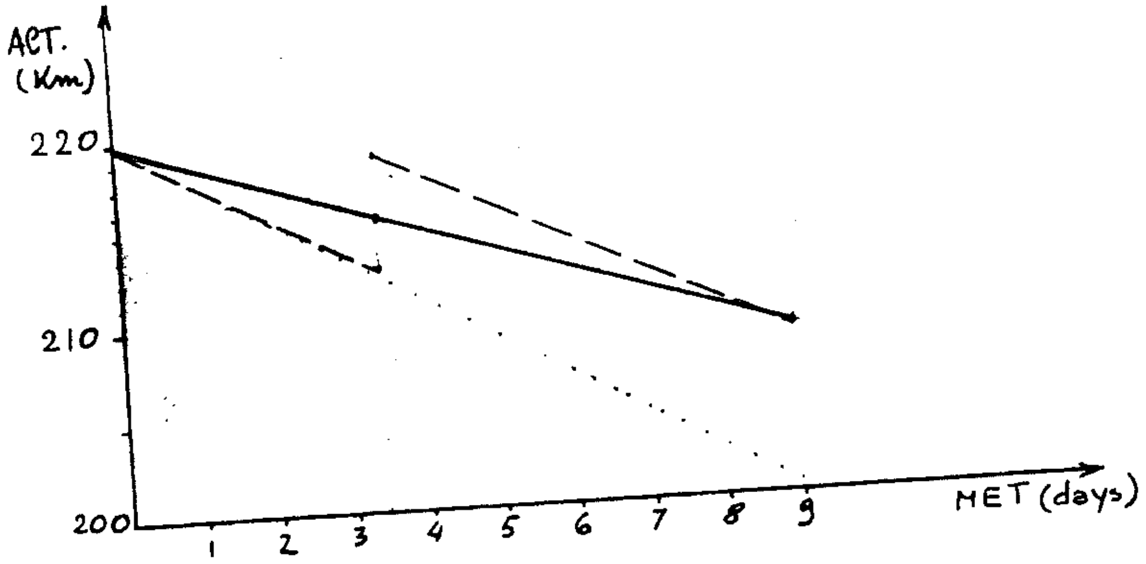
2.2 Maneuver Design

For the purpose of controlling the undesired deviation of the orbit from the baseline one, it can be assumed that an unmodeled acceleration is acting on the Shuttle. The effect of this acceleration can be controlled by performing an orbit maneuver:

a) to remove the undesired variation on the SMA at a certain time,

b) to change the SMA to a value that, under the effect of the a.m. acceleration for the remaining part of the mission, would give a final SMA close to the baseline.

An example of such technique is given in the following figure:



where:

- the solid line represents the baseline altitude decay,

- the dashed line represents the actual altitude decay during the mission with execution of a trim burn after 3.5 days,

- the dotted line represents the actual decay if trim burns are not executed.

In the example it is assumed that the acceleration responsible for the orbit deviation is equivalent to the 50% increase of the baseline drag effect.The trim burn takes place after 3.5 days from the beginning of the mission to prevent the incidence angles to go outside the deadband and to bring them back to the baseline values.
The delta on the SMA for the trim burn is determined to be +5.5 km because of:

a) after 3.5 days, the actual SMA is 2.046 km less than the baseline, corresponding to a major decay of about 0.6 km/day (limit violation would occour after 4.5 days),

b) to compensate for such decay during the remaining part of the mission (5.5 days), the additional delta-SMA would be 3.3 km.

In the following table the incidence angles for two specific sites are reported for both the baseline orbit and for the actual one including the orbit correction.
The specific sites are located at the equator, being this the zone most affected by the ground track displacement due to the SMA deviation.

Tab. 1 - Site GSI (lat.= -0.16 deg, lon = -91.27 deg)

DTO	Baseline Orbit Inc. (deg)	Actual Orbit Inc. (deg.)	Post-man. Orbit Inc. (deg.)
1	50.4	50.4	
2	35.9	36.0	
	********************	Trim Burn	********************
3	29.9	21.5	22.3
4	42.6	32.8	39.9
5	50.5	39.5	50.0
6	55.5	42.8	55.9
7	58.7	43.5	59.4

Tab. 2 - Site GSa (lat. = 0.0 deg., lon. = 0.0 deg.)

DTO	Baseline Orbit Inc. (deg)	Actual Orbit Inc. (deg)	Post-man. Orbit Inc. (deg)
1	37.8	37.8	
2	33.8	30.2	
******************	Trim Burn	********************	
3	46.7	42.4	42.4
4	54.5	49.6	52.5
5	59.4	53.8	58.8

3. TRIM BURN DESIGN

3.1 Delta-v

In order to change the orbit SMA by executing a trim-burn, the appropriate delta-v must be delivered by the Shuttle RCS in the direction of the orbital velocity. If the delta-v increases the orbital velocity, the SMA will be increased accordingly. If the delta-v decreases the orbital velocity, the SMA will be decreased too.
The amount of the delta-v can be computed as function od the desired delta-SMA, by using the following relationship:

$$\text{delta-v} = \frac{\text{delta-SMA}}{2} \sqrt{\frac{\text{Mu}}{\text{SMA}^3}}$$

where:

delta-v are m/sec
delta-SMA are km
Mu = **398600.4** km^3/sec^2

For trim burn execution, in order to exactly align the thrust to the orbit velocity vector, an attitude trim could be required. In any case, since Shuttle will be flying NF or TF almost at all the times, large attitude corrections are not envisaged.

3.2 Maneuver Time

The optimal transfer for circular-to-circular orbits, requires two separate burns occourring 180 deg apart in the orbit. In the case of SIR-C/X-SAR, the tolerance in the orbit eccentricity allows for a single burn transfer, provided that the burn can be performed at the apogee if the SMA has to be increased, or at the perigee on the contrary. For operational reasons, the time for performing the maneuver is constrained by the time slots allocated by JSC in the timeline. The duration of such slots is approximately 30 min which doesn't give many chances that the desired apogee or perigee passage occours in that time. Therefore, if the time slot selected for the maneuver can not be shifted by +/- 30 min, some problems could arise for controlling the orbit eccentricity. In the worst case two burns performed at opposite points of the orbit, would be necessary for the execution of a SMA correction.

4. CONCLUSIONS

a) Only long-term orbit SMA deviations must be controlled for maintaining the actual timeline close to the baseline.

b) Short-term deviations impact only on the DTO parameters accuracy and subsequent radar setting parameter computation.

c) If the orbit SMA deviates from the baseline, the orbit propagations used for long-term planning will indicate when the constraints on the DTOs will be violated. Then:

1 - Slots for trim burns must be identified as potential times for correcting the orbit before the violation occours (at least 24 hours in advance)

2 - suitable time for executing the maneuver must be selected within the possible time slot (search for apogee or perigee according to the desired SMA correction)

3 - the SV corresponding to the time selected must be identified in the planning ephemeris file

4 - post-burn SV must be computed by addind the desired delta to the SMA (mean elements)

5 - the post-maneuver SV must be propagated to the end of the mission using the actual determined decay rate

6 - post-maneuver DTOs must be generated and compared with the corresponding DTOs in the baseline

7 - if the post-maneuver SV gives future DTOs as in the baseline, it must be selected and proposed to JSC/FDO/NAV. If the results of the comparisons are not satisfactory, change the desired delta to SMA and repeat from 5.

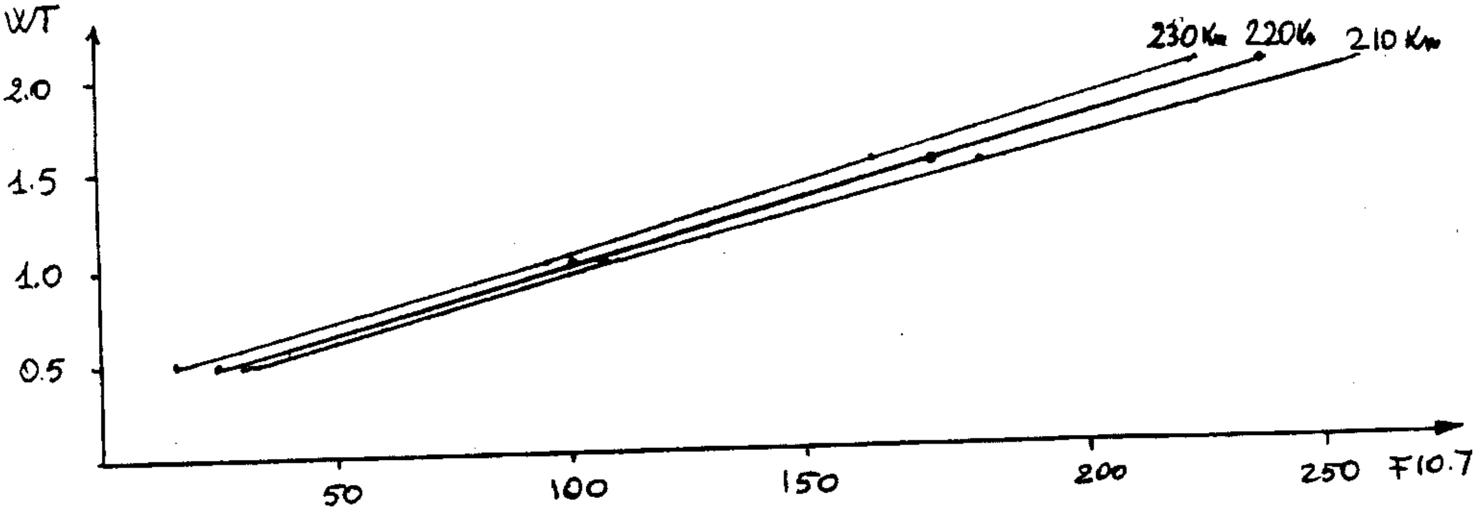
- In order to reduce the impact on the experimental activity, the execution of the maneuver must be discussed in close cooperation with JSC.

CORRESPONDENCE BETWEEN WT PARAMETER AND F10.7 VALUES

DRAFT

Alberto Foni (X-SAR M.O.T.)
JPL July 15 1993

The atmospheric drag effect on the current baseline orbit for SIR-C/X-SAR mission was computed using the EPHEM module of the Goddard Trajectory Determination System and selecting the Harris-Priester model, in order to find the correspondence between F10.7 solar flux and WT parameter values used by SIR-C/X-SAR software.
Three different altitudes were considered and the daily semi-major axis decay was compared.
The results are given in the following figure which can be used for computing the WT parameter corresponding to a specific value of the F10.7 solar flux number.



The above curves have been converted into the following table.

WT	210km F10.7	220km F10.7	230km F10.7
0.5	30	25	16
0.6	45	39	30
0.7	61	53	44
0.8	76	67	57
0.9	91	82	71
1.0	107	96	85
1.1	122	110	99
1.2	137	124	113
1.3	153	139	126
1.4	168	153	140
1.5	183	167	154
1.6	199	181	168
1.7	214	195	182
1.8	229	210	195
1.9	245	224	209
2.0	260	238	223

DRAG EFFECT ON SRL ORBIT

Reference Orbit:

SMA = 6598.144 km (H = 220 km)
ECC = 0.0
INC = 57 deg.
RAAN = -90.6045227 deg.
PER = 0.0 deg.
MA = 0.0 deg.
Epoch = 15 apr 1994 12h 30m 0.0 sec.

STS Mass = 99790 kg.
STS Area = 112.27 m2

Software used : EPHEM Module of Goddard Trajectory Determination System

Atmospheric Model: 1964 Harris-Priester

(Initial Altitude 220 km)

F10.7	D-Alt. km/24h
100	-0.836
125	-0.982
150	-1.163
175	-1.293
200	-1.482

(Initial Altitude 210 km)

F10.7	D-Alt. km/24h
100	-1.104
125	-1.281
150	-1.501
175	-1.653
200	-1.874

(Initial Altitude 230 km)

F10.7	D-Alt. km/24h
100	-0.656
125	-0.765
150	-0.916
175	-1.026
200	-1.188

Software used : ASAP

Atmospheric Model: U.S. Standard Atmosphere 77

(Initial Altitude 220 km)

WT	D-Alt. km/24h
0.5	-0.385
1.0	-0.841
1.5	-1.303
2.0	-1.770

(Initial Altitude 210 km)

WT	D-Alt. km/24h
0.5	-0.544
1.0	-1.150
1.5	-1.768
2.0	-2.396

(Initial Altitude 230 km)

WT	D-Alt. km/24h
0.5	-0.285
1.0	-0.634
1.5	-0.986
2.0	-1.341

FREE FLYER DEORBITING ANALYSIS

(DRAFT)

Alberto Foni A.S.I.-CNUCE/CNR
JPL September 1993

FREE FLYER DEORBITING ASPECTS

Background

It is requested that at the end of its life, the Free Flyer (FF) is removed from the operational orbit and maneuvered back to the Earth controlling the reentry trajectory so that the risks related to the impact with the ground are minimized.
Since the satellite will fragment while reentering the more dense atmosphere, the goal would be to have the debris falling in some non populated regions like the ocean. In the following the results of a preliminary analysis of how this goal can be achieved, are given.
The assumptions the study was based on, are:

a) Operational Orbit: circular, altitude 450 km, inclination 57 deg.
b) maximum time allowed for the reentry sequence should not exceed 60 days (cost reasons)
c) the least risky option (highest accuracy of the impact location) should be identified
d) the aerobraking effect should be used to the maximum extent in order to reduce the total delta-v required for the deorbiting process, saving propellant which can be used for extending the FF lifetime.

1 - Active Deorbiting

To realize a fully controlled reentry from the operational orbit at the end of the nominal mission, it is necessary to put the FF in an elliptical orbit with a perigee low enough to cause the spacecraft to enter the Earth atmosphere with an high attack angle and then to impact the Earth's surface.
A study was performed in order to evaluate the delta-v necessary to perform the above maneuver starting from different altitudes.
The location of the impact and the spreading of the debris were also computed.The results of the sudy are given in fig. 1

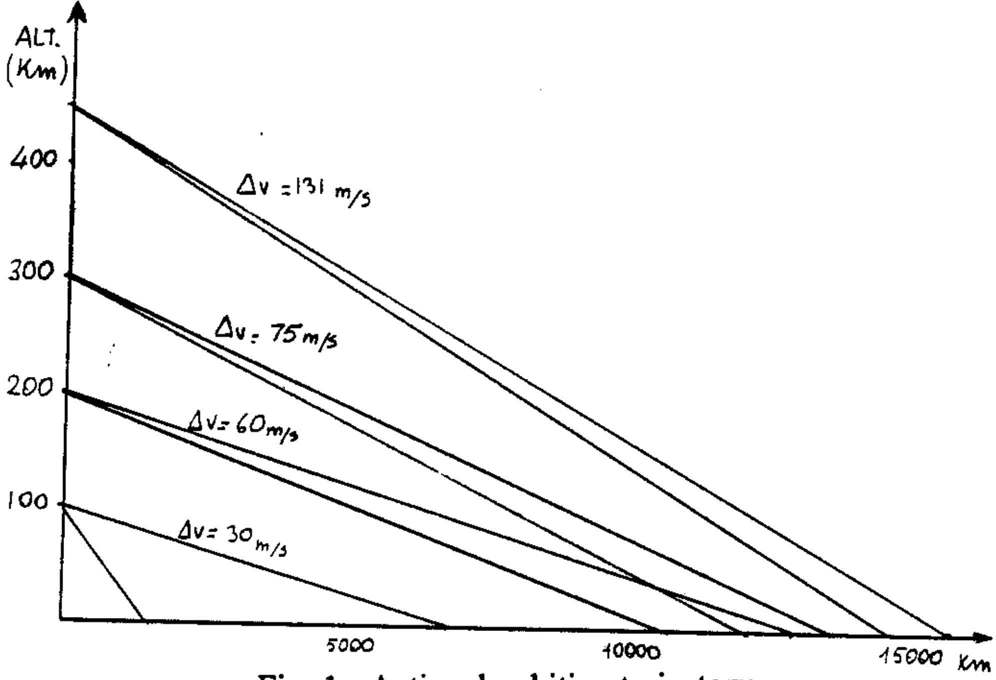


Fig. 1 - Active deorbiting trajectory

2 - Aerobraking Effect

The acceleration due to the air drag can contribute to deorbiting the spacecraft reducing the total delta-v that should be delivered by the FF propulsion system in order to obtain a controlled reentry trajectory.
The air drag effect is function of:

1) S/C cross section
2) Drag coefficient parameter
3) Air density

A parametric analysis was performed in order to compute the FF decay rate from the operational orbit under different configurations. Fig. 2 gives the orbit semimajor axis variation over a period of **5 months** and for 4 different cross sections:

90 m	antenna and solar panels normal to the velocity vector
50 m	antenna only normal to the velocity vector
25 m	average cross section in uncontrolled attitude (tumbling)
5.3 m	minimum cross section

The atmospheric density used corresponds to a solar flux value F10.7=150. For each cross section considered, two Cd parameters have been used (2.0 and 2.7).

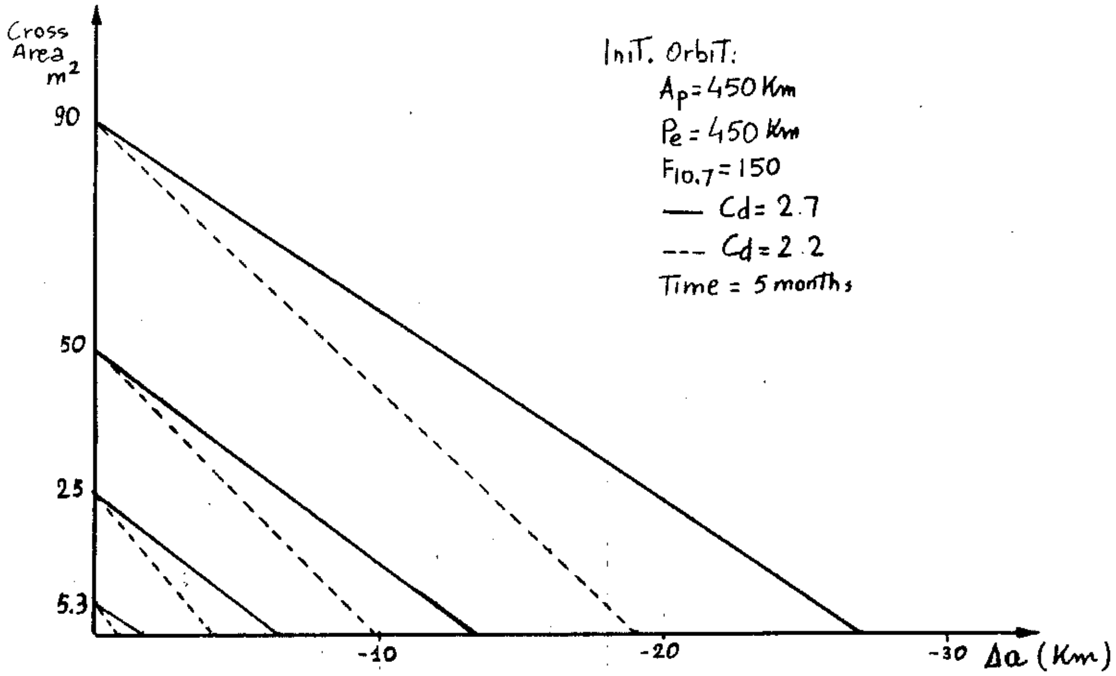


Fig. 2 - Orbit decay for **5-month** period. Initial altitude 450km

From the above it is clear that even in the case of maximun drag (90 m of cross section and drag coefficient Cd=2.7), it would take years before the air drag is able to bring the FF back to the Earth from the operational orbit.

To keep the reentry time within the maximun time of 60 days, it is, therefore, necessary to execute a maneuver for lowering the orbit to an altitude where the atmospheric drag has a significant effect.
This can be obtained by performing a one-burn maneuver to change the operational orbit into an elliptic one with a perigee at 250 km. For this orbit the satellite lifetime under two different air density conditions (F10.7=100 and 150) was computed. The cross section adopted was 25 m which corresponds to the average area of the satellite in un uncontrolled attitude. Fig. 3 shows the time needed for a reentry caused by only the air drag effect.

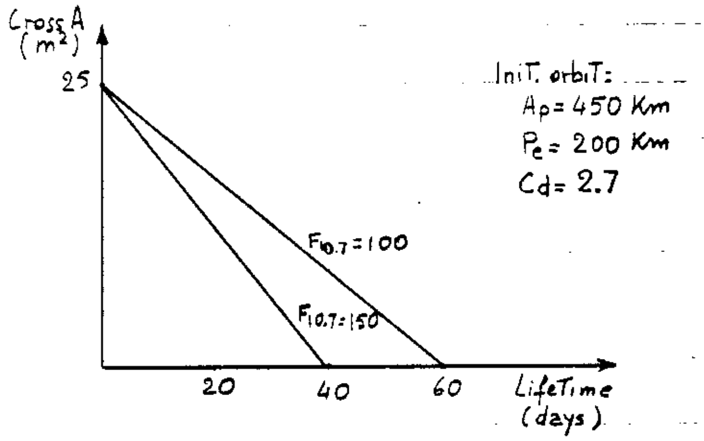


Fig. 3 - FF Lifetime with perigee =200 km (Cd=2.7, initial apogee=450 km)

The same computation was performed also for an initial perigee = 150 km. The results are shown in fig. 4.

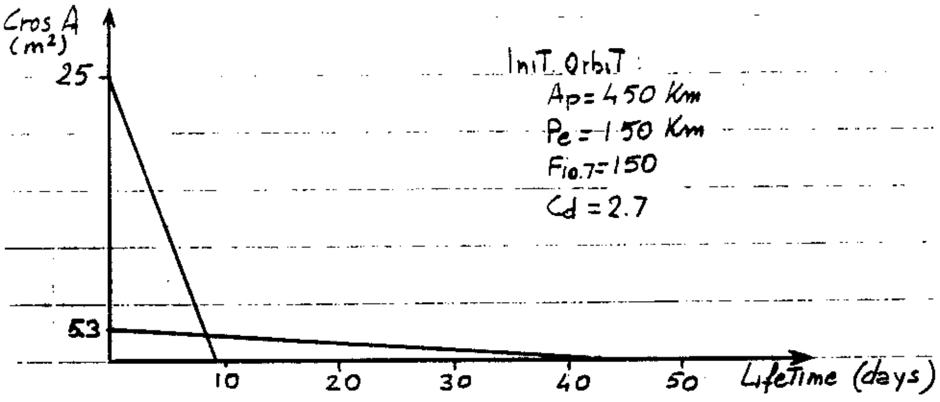


Fig. 4 - FF Lifetime with perigee = 150km (Cd=2.7, init. apogee=450km)

It can be seen that the maneuver performed at 450 km altitude provides the lower dispersion, even though this maneuver requires the highest delta-v. The impact occurs in less than an half orbital period.

3. Combined deorbiting

3. Combined deorbiting

From chapter 2, it is evident that the air drag effect is not enough for causing the FF reentry in a reasonable time. Therefore, it is necessary at the end of the operational life, to change the orbit in order to cause the spacecraft to be decelerated by air drag at each perigee.
To obtain the orbit of fig.3 (init. alt=450 km, perigee=200 km), it is necessary to deliver a delta-v of about 72 m/sec. When after approx. 40 days the reentry is imminent, a final maneuver must be executed to force impact in a predetermined region. This final maneuver requires about 30 m/sec delta-v.

4. Conclusions

The present analysis shows that:

a) The strategy for deorbiting the FF that offers the best chance to control the location of the impact on the Earth surface is the one which requires a maneuver to be performed while the FF is still in its operational orbit. The time for the reentry sequence takes approximately 40 minutes and the selection of the zone of reentry is constrained only in latitude by the orbit inclination (57 deg). The maneuver requires approximately 130 m/sec.

b) The air drag effect is not practical for obtaining a "natural decay" of the FF from the operational orbit because it would requires years.

c) The option to combine the drag effect with an active deorbiting is viable and can provide a certain saving in terms of delta-v (about 30 m/sec). The cost in terms of time for the deorbiting sequence can be considerably less than 60 days. A high accuracy in the selection of the impact zone is possible.

X-SAR MOT Memo N. 93.10.001
Version:
7 October 1993

TO: S. Potts, D. Casey

FROM: Alberto Foni X-SAR MOT AF

SUBJECT: Orbit Node/Semimajor-axis Control

Introduction

SIR-C/X-SAR requires that the actual orbit during the mission remains close to the baseline in order to execute the scientific activity according to the pre-mission timeline. Should the orbit deviate from the baseline causing a supersite opportunity loss, or a variation of the incidence angle for supersites of more than 5 deg, then the orbit has to be controlled by performing an orbit trim maneuver. The design and execution of the eventual maneuver is a task of JSC/MCC, but close cooperation between MCC/FDO and SIR-C/X-SAR POCC is foreseen. JSC/MCC requires that the target for the maneuver is given as longitude of equatorial crossing (node), while SIR-C/X-SAR software at the POCC uses as input for orbit propagation (and subsequent DTO computation) standard orbital state vectors. Therefore it is necessary to find the relationship between nodal crossing and orbit semimajor axis (A) which allows a quick conversion between the two values.

Some Numbers

For elliptical orbits, the period is a function of A (Kepler's Third law). Assuming a reference altitude of 220 km in circular orbit, the period is:

$$P = 5333.888162 \text{ sec}$$

therefore the S/C will cross the equator approximatly 16.2 times every 24 hours. The corresponding separation in longitude between two successive equatorial crossings, should be 22.22 deg. Since the J2 effect causes the precession of the right ascension of the ascending node (Ω) by about 5 deg/day (rotation of the orbital plane), a further 0.3 deg/rev contribution to the longitude of the crossings must be considered. The actual longitude separation between crossings will be, thus 22.52 deg.
The precession of Ω is function of A and orbit inclination, but for small variations around the reference values (few kilometers), it can be assumed to be constant.
If the reference altitude (or semimajor axis) is changed by 1 km, then the corresponding variation of the period (DP) is:

$$DP = 1.21 \text{ sec}$$

and the longitude at the equatorial crossing will also change by 0.004166 deg/rev resulting in a shift of about 0.067 deg/day (or 7.46 km at the equator). Such shift will be eastward for a negative DP (decreased altitude) and westward for increased altitudes.

Conclusions

For the purpose of monitoring the Shuttle trajectory during the SIR-C/X-SAR mission, and considering that the main factor affecting the DTOs is the position of the ground track, the following simple relation can be assumed between the longitude of the equatorial crossings and the orbit altitude:

$$DA = \frac{DS}{0.134\ DT}$$

If an orbit propagation shows that the actual ground track is shifted eastward by DS degrees after DT days with respect to the baseline, then the altitude increment of DA kilometers will be necessary in oder to bring back the longitude of the equatorial crossing to the original value after DT days.
If the shift was found to be westward (negative signature), than the DA is negative too and consequently the altitude must be reduced.

X-SAR MOT Memo N. 93.10.002

7 October 1993

TO: Su Potts

FROM: Alberto Foni AF
INFO: D. Casey

SUBJECT: State Vector Validation Procedure

1. Background

During the mission, any time a TDRS tracking arc is available, an Orbit Determination is performed and a new State Vector (SV) is computed at the MCC and transferred to POCC. At the beginning of the mission as many as two new SVs per orbit are envisaged, but after some time, when the trajectory will be well known and the MOS software and procedures will be "tuned" and checked, the frequency of the SV could be of one per revolution. When a new SV is determined, it is transmitted to POCC electronically for monitoring and planning purposes. The Orbit Planner (OP) must "validate" the new SV before using it for subsequent operations.

2. Definition of Validation

The assessment of the "validity" of a SV is a task which requires a number of infomation used for the orbit determination process such as the number and frequency of the tracking data, the method used, the number of iterations before convergence, solution residuals, etc..
In the case of SIR-C/X-SAR mission, these information are not available at the POCC, so that the assessment of the accuracy of the SV is not possible by the Orbit Planner (OP). Nevertheless, the OP must check that the new State Vector is "valid". It means that no errors like number misplacing/misprinting or data corruption during the transmission occurred.
The validity check of the SV can be accomplished by comparing it with the corresponding predicted one and the new SV will be considered valid if it doesn't differ too much from the expected value. In the following an attempt is made in order to define the range of the acceptable difference for validating the new SV. Parameters that can be used for such comparison are the time and the longitude of the equatorial crossing. If the difference between the new SV and the corresponding predicted one exceedes a certain value, the OP must ask the MCC for confirmation. After the SV has been confirmed or the cause of the difference assessed, it can be used at POCC for replanning activities.
The above mentioned comparison requires an high precision orbit propagation process in order to accurately predict the Shuttle position and velocity.

3. Orbit Predicton Accuracy

The accuracy of the orbit propagation is mainly affected by:

a) uncertainty of the initial State Vector
b) accuracy of the Earth's environment modeling
c) accuracy of the Shuttle RCS effects modeling

a) JSC states that the expected on-orbit accuracy (3sigma) for a SIR-C/X-SAR like mission, are:

Position (feet)		Velocity (fps)	
1800	Radial	11.0	Radial
10000	Downtrack	1.8	Downtrack
2000	Crosstrack	2.9	Crosstrack

Among the above components, only the downtrack impacts significantly on the orbit propagation accuracy. In fact, over a propagation period of a few revolutions, only the downtrack uncertainty grows with the time, while the others remain almost constant

b) the incorrect modeling of the Earth's environment should have a negligeable impact on the orbit propagation accuracy except than for the air drag which, at moment, can be affected by an error up to 50%. Such error is expected to decrease to 20% shortly before the mission

c) the RCS used for attitude and orbit maneuvers, perturbssignificantly the orbit. In some cases JSC is able to predict the perturbations for IMU aligments. The effect on the orbit of the attitude keeping and orbit trim maneuvers can also be estimated by JSC. Whenever these information will be given to POCC, it will be possible to consider the effects (to a certain extent), in the orbit propagation process.

4. State Vector Validation Procedure

For the purpose of validating the SV, it can be defined a "total error" E which affects the orbit propagation accuracy:

$$E = T + Fa + Gd$$

where:

T = downtrack error,
Fa = radial component error
Gd = error in atm. drag

Considering that the downtrack error of the MCC SV is 3.3 km and that such error grows approximately by 12.5 km per orbit (as average over a few number of revolutions), it is translated in a difference of the equatorial crossing time of 1.6 sec. The uncertainty in the air drag can affect the equatorial crossing time by approximately 0.04 sec/rev.
Finally the uncertainty in the radial component translates into an error of 0.54 sec/rev. The total error E is thus 2.18 sec/rev which affects the accuracy of the corresponding predicted longitude of the equatorial crossing, by 0.01 deg.
Since E accounts only for the SV and atmospheric drag uncertainty and doesn't consider the perturbations due to other sources like orbit and attitude maneuvers, IMU alignments, water dumps, etc.. the following procedure should be applicable only to successive SVs without the occurrence of any of the above events in between.

PROCEDURE:

1) When the SV (NSV) is received from MCC and it is propagated with nodal crossings data information

2) the first nodal crossing time and longitude of NSV is compared with the corresponding one of the previous SV

3) if the time difference in seconds is less then 2.18 times the number of revolutions between the epoch of the previous SV and the time of the equatorial crossing selected for validation, then the NSF is declared valid

4) if NSF is not considered valid, OP must contact JSC/MCC for confirmation/correction of NSF

5) if the NSF was incorrect, MCC is asked to send the SV again, then go to 1)

6) if NSF was correct then OP declares it valid and proceeds with the subsequent activity.

5. Conclusions

The above procedure was defined in order to give the OP the capability to perform a rough check that the SV received is not affected by errors, before it is used for internal POCC processing.
Probably the OP will be able to look at the SV also throught the displays available at POCC, and this capability will allow a double check of the SV received electronically.
The numbers computed above, are based on assumptions that might change as the launch date becomes closer and the MOS system implementation progresses, and therefore they might change as well.
Also at the beginning of the mission, it could be necessary to adjust the procedure according to the first results.

remaining part of the mission.

CASE 2 (some time is allowed before response (1-3 hrs))

a) OP determines the orbit (#) when the first 'important' violation occurs.

b) OP checks the altitude/nodes against the reference orbit to assess the differences (if the current node moves eastward it means that the current mean altitude is lower than the reference one).

c) OP looks at the altitude/node history to check if long-term deviations from the baseline are experienced.

d) The effect of the eventual long-term deviation is considered to adjust the value of the desired post trim burn node.

e) OP checks in the ephemeris file if a perigee/apogee occurs during the trim burn opportunity slot : mean anomaly equal to 0 deg for perigee and equal to 180 deg for the apogee (mean elements must be considered because of the low eccentricity).

f) OP determines the SMA variation corresponding to the desired node.

g) If the apogee/perigee occurs in the trim burn opportunity window, OP generates a OP predicted post-burn state vector (adding the appropriate DV to the appropriate SV taken from the ephemeris file).

h) OP generates post trim burn DTOs and consults Replanner/Science.

i) If OK is given by Replannner/Science, OP submits Trim Burn Request to FDO.

l) When predicted post-burn SV arrives from FDO, OP prepares preliminary planning data for Replanner accordinu to the FDO predicted SV.

CHANGING THE NORMAL SHORT-TERM PLANNING.

Whenever a maneuver is planned or announced, three hours before the ignition time, or ASAP if shorter notice is given, OP must prepare STP data either for the case that the maneuver is executed as planned, either in case the maneuver is not performed.
This is necessary in order to have ready planning data for the best setting of the on-board instrument according to the actual STS position.
Science is provided with both data and will decide which ones are to be used in case of partial execution of the maneuver.

Same philosophy applies to the case that unexpected large deviation of the orbit from the reference are detected as consequence of events like IMU maneuver, attitude maneuver, etc.

JPL February, 1994
by: Alberto Foni

CONSIDERATIONS ON CONTINGENCY TRIM BURN PLANNING

Contingency Trim Burns (CTB) will be requested to change the actual semimajor axis to remove the current node deviation from the baseline values. Only in-plane maneuvers will be considered; critical parameters for planning are:

- orbit semimajor axis correction (DV)
- time for the burn execution (eccentricity control)

Note: CTB planning will be required only if sudden, unexpected large STS orbit changes result in loss of 'important' planned events in the next time and the recovery action can not be taken during the next scheduled trim burn assessment activity.

Depending on the time available for reacting to the contingency, two extreme situations can be foreseen for CTB assessment by the Orbit Planner.

CASE 1 (immediate response)

a) OP searches for the orbit # when the first 'important' violation occurs and, in close contact with Replan/Science/OPS(?), requestes to FDO the trim burn maneuver selecting one of the following options:

1) to remove the perturbation that was introduced by the event generating the contingency (i.e: if a collision avoidance maneuver increased the altitude, then OP asks to lower the altitude to the baseline value). The trim burn is requested ASAP in order to minimize the impact on the node shift due to the effect of the higher mean altitude for the time interval between the event initiating the contingency and the trim burn execution.

2) OP sets as target for the trim burn the node as in the baseline (APR0794_1307.NOD) at the rev when the violation occurs.

3) OP set as target the baseline node for a rev some time after the violation occurs.

b) The node tollerance can be assumed 0.03 deg considering that such a value correspondes to a maximum uncertainty in the look angle between 0.3 deg (for 60 deg look angle) and 1 deg (for 15 deg look angle).

c) No eccentricity control is considered. The timing of the maneuver is determined by FDO and eventually adjusted(negotiated) with OP according to the Replanner/Science reccomendations (minimizing the impact on DT or PB).

If the **option** 1 is selected, the post-trim burn ground tracks will be close to the **baseline** ones with the exception of a displacement of the nodes.

In case **the second** option is selected, the baseline node is recovered as targetted, but a subsequent progressive node shift will be experienced. To avoid this effect, a further trim burn is necessary.

The third options avoids a second trim burn (as necessary in option 2) but brings back the mean node to the baseline value, some time in the

IMPACT OF INTERFEROMETRY EXPERIMENT ON SRL POCC PLANNING OPERATIONS

Alberto Foni - X/SAR M.O.T.

Houston, 2 August 1994

Introduction

For SRL-2 mission the last part of the flight will be dedicated to "Interferometry activities" consisting in performing repeated Data takes over designated Sites. It is mandatory requirement that the Data takes are repeated with the same geometric conditions and with the minimum time interval in between, even though a no-zero displacement in the Shuttle position during the repeated Data takes is requested.

1. Definition of Baseline

By using the relationship provided by Richard Goldstein from JPL:

$$B \sin\alpha = \frac{\lambda \operatorname{Tan} \phi \, \rho}{2 \, \Delta \rho}$$

which gives the perpendicular component of the Baseline to the Slant Range (Fig. 1) , it can be computed such a value (**B**) for C, L and X Bands as follows:

L-Band	2440 m
C-Band	575 m
X-Band	311 m

(1)

assuming:

ρ (slant range)	264 km
ϕ (inc. angle)	30 deg
$\Delta\rho$ (sl.range res.)	7.5 m
λ (wavelenght)	3, 5.8, 23.5 cm (X, C, L).

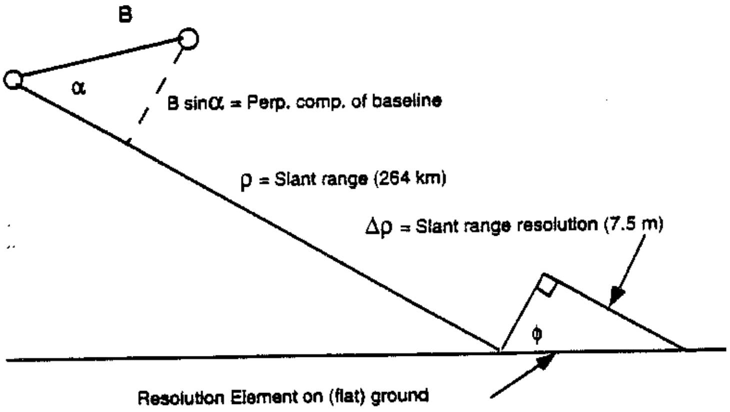


Fig. 1 - Repeated Datatakes Geometry

The requirement on the interferometry repeat orbit is determined by the position error in the direction of the perpendicular to the slant range direction **B** an therefore the goal would be to keep such value well below the numbers given in (1).
David Farless of JPL selected the tolerance on **B** in round number to be:

300 m for C-band
1000 m for L-band

for consinstency X-SAR can then assume:

150 m for X-band.

In order to perform interferometry during the flight, it can be stated that a specific datatake mast be repeated with Bsinα less than or equal to the above values.

2. Position Constraints

In order to maintain **B** within the tolerance, if the second pass occours exactly at the same longitude as the first, an error in the Shuttle altitude is tolerated as follows (Fig. 2):

$\Delta H \leq 300$ m for X-band
$\Delta H \leq 600$ m for C-band (assuming 39 deg. Look angle)
$\Delta H \leq 2000$ m for L-band

Similarly for longitude, assuming the same altitude for both passes, it can be accepted:

$\Delta\Lambda \leq 0.00150$ deg (173 m) for X-band
$\Delta\Lambda \leq 0.00301$ deg (346 m) for C-band
$\Delta\Lambda \leq 0.01005$ deg (1155 m) for L-band

Combined errors both in altitude and longitude reduce the above tolerances.

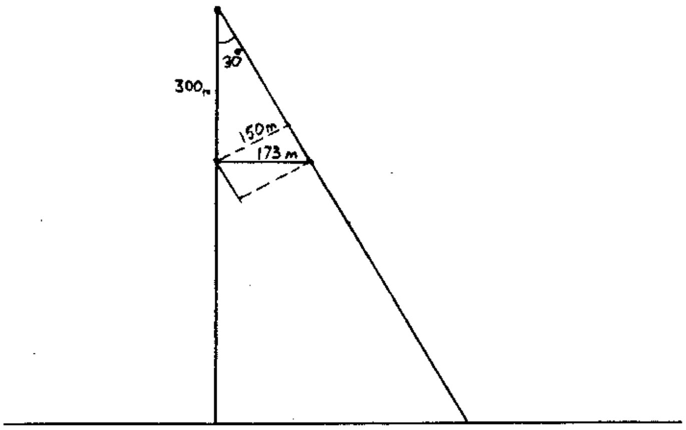


Fig. 2 - Position Tolerance

3. Orbit Control

3.1 Nodal Period and Ground Track Shift

Considering the constraints on Bsinα it is clear that the most critical orbit parameter to be controlled is the orbit semimajor-axis because of its direct influence on the Nodal Period Pn and ,consequentely, on the ground track location.
Pn is a function of the two orbital elements a and i, and is given by:

$$Pn = 2\pi\sqrt{\frac{a^3}{\mu}}\left[1 - \frac{3}{2} J2 \left(\frac{R_e}{a}\right)^2 (4\cos(i) - 1)\right] \text{, sec.} \qquad (2)$$

For SRL, the nodal period variation with respect to the altitude, given by ∂P/∂h, is 1.213 sec/km. In Tab. 1 the nodal period corresponding to altitudes between 204 and 206 km is tabulated.

```
ALT =       204          NP =     5312.983     SMA =      6582.144
ALT =       204.1001     NP =     5313.104     SMA =      6582.244
ALT =       204.2002     NP =     5313.226     SMA =      6582.344
ALT =       204.3003     NP =     5313.347     SMA =      6582.444
ALT =       204.4004     NP =     5313.468     SMA =      6582.544
ALT =       204.5005     NP =     5313.589     SMA =      6582.645
ALT =       204.6006     NP =     5313.71      SMA =      6582.745
ALT =       204.7007     NP =     5313.832     SMA =      6582.845
ALT =       204.8008     NP =     5313.953     SMA =      6582.945
ALT =       204.9009     NP =     5314.075     SMA =      6583.045
ALT =       205.001      NP =     5314.196     SMA =      6583.145
ALT =       205.1011     NP =     5314.317     SMA =      6583.245
ALT =       205.2012     NP =     5314.438     SMA =      6583.345
ALT =       205.3013     NP =     5314.56      SMA =      6583.445
ALT =       205.4014     NP =     5314.681     SMA =      6583.545
ALT =       205.5015     NP =     5314.802     SMA =      6583.646
ALT =       205.6016     NP =     5314.923     SMA =      6583.746
ALT =       205.7017     NP =     5315.044     SMA =      6583.846
ALT =       205.8018     NP =     5315.166     SMA =      6583.946
ALT =       205.9019     NP =     5315.287     SMA =      6584.046
ALT =       206.002      NP =     5315.408     SMA =      6584.146
```

TAB. 1

3.2 Repeat Altitude

In order to determine the altitude profile which would allow Shuttle to repeat a DataTake in geometric conditions suitable for interferometry, it is necessary to take into account the perturbations that will affect the orbit. The most significant ones are:

- Earth's gravitational field
- Atmospheric drag
- Orbiter RCS effects

For the SRL orbit the Earth's gravitational field produces a westward shift of the orbit node by about 5 deg/day. By considering this effect and assuming no accelerations acting on the Orbiter due to the atmospheric drag or to the Shuttle RCS, it can be computed the repeat orbit semimajor-axis to be 6582.744 km. The corresponding mean altitude is 204.6 km.
If the Orbiter would be able to control its altitude extremely accurately at that value for 48 hours, the flight conditions of the first 24 hours would be exactly repeated during the second 24 hours.

It should be noted that:

a) if the repeat altitude is kept for 24 hours, at that time Shuttle will be exactly at the **same longitude and altitude** it was 24 hours before,

b) if the intial altitude is not the repeat one and also if it changes during 24 hours, but if the **mean altitude** during that time is exactly the repeat one, then after 24 hours Shuttle is at the **same longitude** it was at the beginning, but at a **different altitude**.

If the flight conditions as during the first 24 hours are requested also during the second 24 hours, then:

for case a), it is necessary that Shuttle flyies exactly at the **repeat altitude at all the time**,

for case b), after the first 24 hours Shuttle must **maneuver to change the current altitude** at the one it initiated the flight an then **keeps exactly the same altitude profile** flown during the first 24 hours.

4. Orbit Maneuver Design for SRL-Interferometry

In the previous chapter the two cases a) and b) have been addressed. The first one corresponds to the ideal situation where no accelerations are acting on the Shuttle during its flight.
Case b) is better representing the actual flight conditions during the mission, when the combined action of various perturbations will produce a certain orbit decay. It is thus extremely important to predict the altitude decay rate, in order to place Shuttle at the initial altitude that will bring it, after 24 hours, to have flown as average the repeat altitude.

In terms of flight planning this means that before the interferometry part of the mission starts, a very accurate prediction of the orbit decay must be performed. The accuracy of the prediction is the key for the interferometry success because depending on the estimated decay, the initial altitude for the interferometry portion of the mission is computed.

Therefore, the standard mission profile can be designed as:

1) Just right before the interferometry starts, a maneuver is planned to lower the current altitude to the estimated initial altitude at the beginning of the interferometry phase.

Because of the requirement on the eccentricity, the maneuver must be divided in two burns 45 minutes apart. The total Delta-v estimated is 17 fps and, because of that, the Orbiter OMS will be used. In the SRL-2 mission timeline the event is identified as:

116.1	7/03:00	First Orbit Lowering Burn
116.2	7/03:45	Second " " "

2) To account for the maneuver dispersions and for the uncertainty on the actual orbit decay, a maneuver opportunity is planned in the middle of the first 24 hours. Such a maneuver will be performed only if the actual orbit monitoring shows a significant deviation from the predicted one (repeat orbit). This maneuver, to be performed also in two successive burns, is identified by:

124.1	7/13:50	Trim burn
124.2	7/15:05	Trim burn

Purpose of the maneuver is to force the average altitude during the first 24 hours to coincide with the repeat altitude.

3) After the first 24 hours, a maneuver is planned to rise the Shuttle altitude to same altitude it started interferometry. Still two burns are necessary and the total Delta-V required is approximately 9 fps. This maneuver occurs shortly before the N.America Interferometry Datatake. In the timeline the event is:

133.1	8/03:45	Trimburn
133.2	8/04:30	Trim burn

4) As during the first 24 hours, also during the second day of interferometry a trim opportunity is planned to correct eventually the orbit to the one flown during the first day. In the timeline the event is:

140.1	8/13:15	Trim burn
140.2	8/13:50	Trim burn

5) For an additional opportunity for repeated datatakes over North America a final Orbit rising maneuver is scheduled before Orbit 150. The event is:

149.1	9/03:30	Trim burn
149.2	0/04:15	Trim burn

In order to minimize the perturbations to the orbit during interferometry the attitude maneuver will be reduced to a minimum, as well as other operational activities (water dumping, radiators stowing or deploying, etc.).

X-SAR MISSION OPERATION TEAM

X-SAR MISSION 2 (30 Sept.-11Oct. 1994)

C-X ORBIT FINAL REPORT
14 October 1994

(M.O.T. Person: Alberto FONI)

1.1 C-X ORBIT position descritption

Tasks of C-X Orbit were mainly the monitoring of the Shuttle trajectory in order to identify the possible deviation of the actual orbit from the predicted one and to plan and execute trim burns in cooperation with the JSC/MCC. On regular basis, C-X Orbit (OP) had to generate all the data needed at the POCC for short and longterm replanning. The position was a joint position between SIR-C and X-SAR and the system used was the SIR-C MOS system.

Because of experience gained during the first flight and having in mind the activities to be performed by the Orbit Planner for supporting the very demanding phase of the interferometry experiment, two Orbit Planner positions have been operated at the same time during STS-68 Mission.

The two OPs, the 'Primary' having the task to talk over the voice loops and supporting the SV reception and short-term planning data preparation, and the 'Secondary' supporting long-term data planning preparation and maneuver planning and orbit monitoring, have covered 12-hour shifts. Each OP was allocated for 6 hours to the Primary position and to the Secondary for the remaining 6 hours of his/her shift.

1.2 Operational I/F Description

External (to POCC) interfaces:

Interfaces for OP have been the Flight Dynamics Officer (FDO) of JSC/MCC for any Orbit matter and Houston-Track of JSC/MCC for State Vector transfer. In particular FDO and OP interfaced on the MPSR DYN B Voice loop for trim burn window definition, maneuver planning, execution and assessment. FDO also coordinated the State Vector transfer from MCC to POCC. For SV import and verification OP has interfaced TRACK on the MPSR DYN B, while the SV was received electronically.

Internal (to POCC) Interfaces:

Main interfaces for OP have been C/X-OPS, C/X-Science, C and X Replan, C and X Timeliner.

OP to C/X-OPS: notification of main events such as change of maneuver time or if a maneuver was deleted or inserted.

C/X-SCIENCE and C and X REPLANNER were interfaced for any event having impact on the timeline and for finding suitable time spots for maneuver execution.

C-TIMELINE was interfaced at every short term plan occurence for coordinating the Database updating and the short-term plan data transfer.

2. Operational Events

2.1 Pre-mission Design

The datailed description and information on the Orbit Trim Burns design and planning can be found in the Project documentation. In the following a summary of the maneuvers planned for SRL-2 is given:

MET	Man. ID	Description
00/04:05:00.000	Trim 04	To adjust the post OMS-2 (injection) orbit to the baseline value
01/00:59:00.000	01 Trim	To adjust the orbit if deviates from the baseline
02/00:37:00.000	02 Trim	" "
03/00:25:00.000	03 Trim	" "
04/01:28:00.000	04 Trim	" "
05/01:15:00.000	05 Trim	" "
06/02:25:00.000	06 Trim	" "
07/03:02:27.000	07 OA1	To lower the orbit to the repeat altitube (1st step)
07/03:34:21.000	07 OA2	" " (2nd step)
07/14:15:00.000	07 Trim1	To adjust the orbit before Africa pass
07/14:35:00.000	07 Trim2	" "
08/03:21:00.000	08 NA1	To adjust the orbit before North America pass
08/04:03:00.000	08 NA2	" "
08/13:25:00.000	08 AF1	To adjust the orbit before Africa pass
08/14:28:00.000	08 AF2	" "
09/02:48:00.000	09 NA3	To adjust the orbit before North America pass
09/03:24:00.000	09 NA4	" "
09/13:41:00.000	09 AF3	" " Africa pass

2.2 Main Mission Events

After the launch abort experienced on the 18 of August the Shuttle Endeavor lift-off occurred nominally on September 30, 1994 at 6hr 16 min CDT. The actual GMT launch time was 273:11:15:59.975.

The ascent and orbit injection were nearly nominal; the altitude reached by Shuttle after OMS-2 burn was only 800 m higher than the nominal and because of that the projection did show that no significant changes to the timeline were required for three days. It was then decided not to perform the orbit adjustment planned at 0/04:05 (Trim 04). Furthermore it was decided to try to perform interferometric datatakes between Flight-1 and Flight-2 during the first 6 days of the mission.

In order to get the required geometry an extensive analysis was performed together with the MCC Flight Dynamics Officer (FDO) to design the trim burns necessary to refine the actual orbit. The Mammoth Mnt. site was selected as target for that activity because of the favourable orbital baseline (distance).
For trimming the current orbit for rendezvous with the flight-1 orbit, three maneuvers have been designed. The first one aiming to change by approximately 0.00152 deg the current orbit plane orientation (F1/F2 Plane change) and two successive burns in order to phase the ground track to match the one obtained during STS-59 flight (Rendezvous-1 and Rendezvous-2). The maneuvers occurred at MET 03/13:12:36.501, 03/23:53:05.583 and 04/01:16:05.726 respectively. The total delta-v delivered for the above maneuvers was approximately 13 fps.
The subsequent Orbit Determination Solutions (SV), confirmed the achievement of the objective since the baseline between SRL-1 and SRL-2 was computed to be less than 70 meters at Mammoth site closest approach. Such result was confirmed also by the GPS measurements.

The extreme accuracy obtained in the current orbit has also made possible to identify further opportunities for interferometric Data Takes in the remaining part of the flight.

After the maneuvers mentioned above, no further trim burns were necessary until the ones planned on day 7 for lowering the Shuttle altitude to the repeat one for the execution of the main interferometric experiments foreseen during the last three days of the flight in the premission timeline.

The maneuvers planned in the premission baseline for this phase have been performed with slight changes in the execution times. The assessment of the delta-v involved in each maneuver and the accuracy in the maneuver execution can be obtained by comparing the corresponding state vector listed under section 2.3 Mission Specific Events.

The two Lowering Orbit burns (07 OA1 and 07 OA2) occurred at MET 07/03:27:23.659 and 07/03:59:18.567.

The next orbit correction aimed to raise the orbit altitude to allow the exact repetition of the track as flown during day 07 after the lowering burns. Two trim burns (08NA1 and 08 NA2) have been executed just before the North America interferomeric pass at MET 08/03:36:26.990 and 08/04:15:17.840

Instead of the pair of burns planned before the Africa interferometric pass only one was necessary (08 AF1) and it was executed at MET 08:14:00:07.795. Trim 08 AF2 was not necessary.

The pair of burns required to raise the orbit altitude for the repeat orbit on day 9 (09 NA3 and 09 NA4) was executed at MET 09/03:13:28.364 and 09/03:49:32.625.

As happened on day 8 also on day 9 only one trim burn (09 AF4) was necessary to fine tuning the orbit before the Africa pass and it was performed at MET 09/13:38:00.966

After NASA approved to extend the mission by one day, it was decided to perform one more day of interferometry passes and therefore it was necessary to execute a further orbit correction to repeat the track on day 11.The last orbit correction (10 NA5 and 10 NA6) was finally performed to allow the track repetition also during the extension day and it occurred as usual in two legs at MET 10/02:51:12.467 and 10/03:27:33.303. After that time the orbit was no longer controlled until the payload deactivation occurred at MET 11/18:45:0.

The deorbit burn, which concluded the orbital operations, occurred at MET 12/03:35.

2.3 Mission Specific Events

The State Vectors related to all orbit maneuvers executed during the flight are listed. For each maneuver the predicted SV represents the target identified for the maneuver, while the confirmed-executed is the actual orbit after the burn.

The State Vectors are identified by SV# as they are stored in the MPOS PAS Database

MANEUVER	TARGET SV	POST-BURN SV
F1/F2 Plane change	120	135
Rendezvous-1	146	151
Rendezvous-2	147	152
07 OA1	253	275
07 OA2	254	276
08 NA1	320	324
08 NA2	321	325
08 AF1	348	350
09 NA3	383	390
09 NA4	384	391
09 AF4	394	410
10 NA5	427	432
10 NA6	428	433

2.4 Overall Mission Statistics

The orbital maneuvers executed for SRL flight operations have been 13, excluding attitude maneuvers, IMU maneuvers and those necessary to reach the operational orbit and the deorbiting of Shuttle.

About 350 State Vectors (Shuttle orbit determination) have been received by OP trough the whole mission. Almost all of them have been used to predict the Shuttle ephemeris and to compute the Data Take Opportunities (DTO) parameters for replanning the baseline events.

Shortterm planning ephemeris, DTO table and Data Base updating have been performed by the OP every hour from the launch time+6hours, to the end of mission (payload deactivation).

Longterm ephemeris, DTO table and Data Base updating have been performed by OP every 12 hours for the same duration.

Ephemeris data and state vectors have been distributed to the users external to POOC (Scientists, JPL, etc.) on regular basis.

3. System Performance

3.1 MOS

The system (MOS) performed in a satisfactory way, except that some times DTO comparison report required to much time to execute, do to multiple access to the data base by several users or when DB check-point was in progress.

A database server crash was experienced on day 3 and some other failures and problems with the MOS system occurred as well.

Some bugs were detected in the software for DTO computation.

3.2 Procedure

For this flight the problems experienced during the first mission with the planning data delivery were not encountered because of the added Orbit Planner Secondary position.

All the operational procedure were appropriate to the mission requirements.