Improvements of the Gravity Field from Satellite Techniques As Proposed to the European Space Agency

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Abstract. The paper gives a summary of the European Earth Sciences Space Programme and the requirements for earth gravity field mapping resulting from this programme. Three satellite experiments for gravity field improvement proposed to the European Space Agency in the last years are shortly characterized. One of these experiments, the low-low-SST-SLALOM experiment, based on laser interferometry for a "two target-one Spacelab telescope" configuration, is discussed in more detail. Reasons for the low-low concept selection are given and some mission aspects and a possible system concept for a compact ranging, acquisition and tracking system are presented.

Introduction

Improvements of our knowledge of the earth's gravity field include improvements in the determination of the size of spatial features of the spherical harmonic description of the field as well as the increase in spatial resolution. So far we are on a continuous way of gravity field improvements by space methods since results for the first four zonal harmonics were presented by O'Keefe et al. [1959].

Up to about 1976 besides a slow increase in resolution especially the accuracy of the resolved harmonic components was improved by satellite orbit perturbation analysis combined with surface gravity data analysis. But we were still in the large scale regime which is classified by wavelengths λ larger than about 1200 km and which represents signatures of anomaly sources in the deeper and upper parts of the earth's mantle.

Beside using these large scale global gravity models in satellite geodesy for example for satellite orbit determination and global geoid representation Kaula [1972], Marsh and Marsh [1976] and Lambeck [1976] started to correlate patterns of the global free air anomaly field with geological provinces, convection and density inhomogeneites, respectively.

Our picture of at least one equipotential surface of the earth's gravity potential - the geoid - cleared up drastically in ocean areas in the last two years when a number of results from the GEOS 3 altimeter analysis were published [e.g. Anderle 1978, Marsh et al. 1978, Rapp 1977].

A quick glance on the preliminary DOD GEOS 3 geoid [National Research Council, 1978] already demonstrates the high resolution achieved in ocean areas and the strong visible correlation of the geoid with geological structures like oceanic trenches and island arcs. This example shows that satellite geodesy has already obtained geoid features in the medium wavelength (200< λ < 1200 km) and short wavelength (λ < 200 km) region in some parts of the globe and starts to bridge to small scale geodesy, geophysics and geology.

In order to obtain precise medium and short wavelength gravity information over the entire globe - which is essential for our understanding of physical characteristics of material in the asthenosphere, lithosphere and surface topography and of dynamical and thermodynamical processes in the earth's interior - continuous theoretical, technological and financial efforts have to be undertaken in the 80's.

The European Earth Sciences community after having contributed in the past to gravity field mapping - through the developement of methods, ground tracking and satellite instrumentation, surface and tracking data collection and analysis of data - has demonstrated its willingness of contributing to this aim through the Earth Sciences Programme proposed to the European Space Agency during the European Workshop on Space Oceanography, Navigation and Geodynamics (SONG) at Schloss Elmau in early 1978 [ESA, 1978 a].

Objectives for gravity field mapping in the European Earth Sciences Programme

During this workshop two parallel Earth Sciences Space Programmes for the next 10-15 years were identified along with three supporting ground based programmes which could meet the European possibilities and requirements. The two space programmes are (Figure 1):

- the SOLID EARTH PROGRAMME which is intended to prepare a possible operational system for earthquakes prediction. It implies the developement of a very precise (1-5 cm) position determination system supported by an Earth Rotation and Polar Motion monitoring service and the deployment of a reasonable number of automatic geo-

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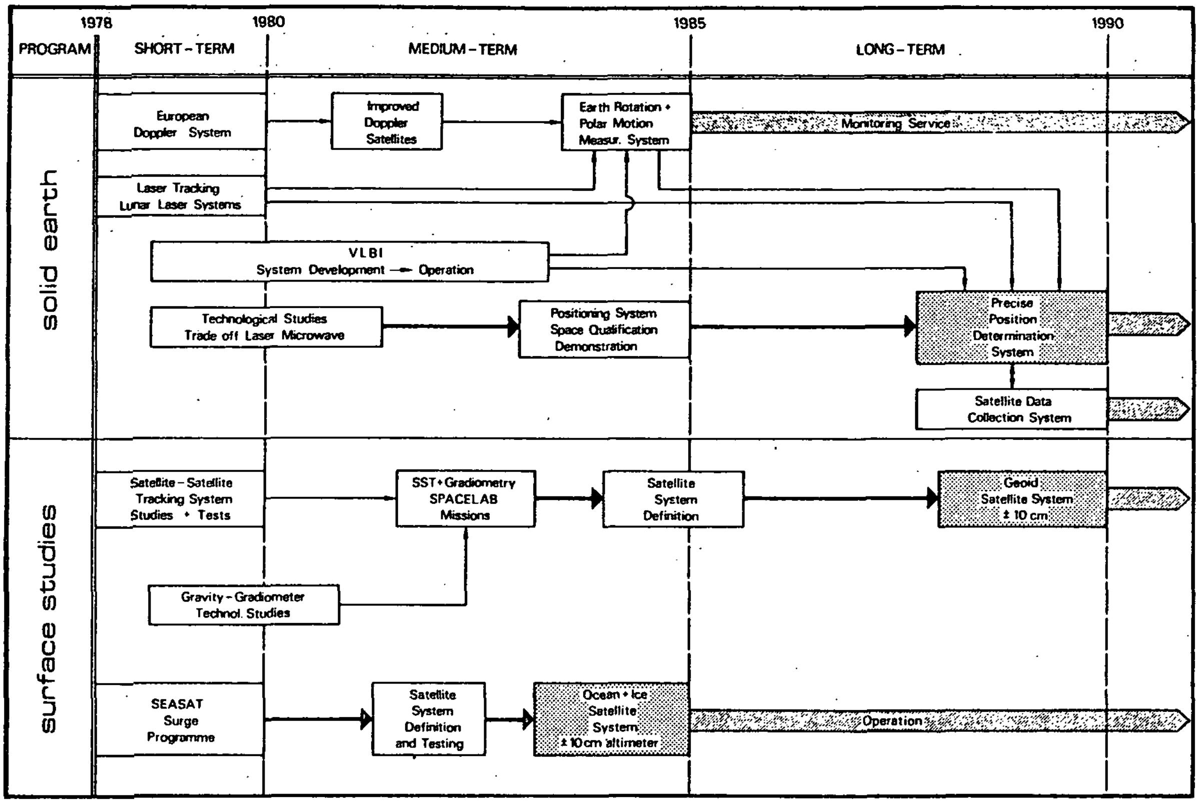

SONG - Workshop Space Programme Proposal

Fig. 1. Modified version of the Steering Comittee's scheme of the SONG-Workshop Space Programme Proposal [Kovalevsky et al., 1978].

physical stations on ground;

- the SURFACE STUDIES PROGRAMME which is aimed at a global study of the oceans and the ice coverage of the earth for better understanding of the physics of the hydrosphere and its relation with the atmosphere. It implies the launch of a "Geoid Satellite" for highly precise geoid mapping subsequent to possible missions of prototype instrumentation launched by the two forthcoming European Space Transportation Systems SPACELAB and ARIANE.

The reasons for fine structure gravity field mapping in the context of these two programmes are:

Solid earth programme

- Determination of accurate satellite orbits resulting in improved station position, polar motion and earth rotation results and vice versa.
- Investigation and modelling of mechanisms and processes which form and/or move lithospheric plates for developing earthquake prediction models on a regional or global scale.

Surface programme

- Precise geoid determination with spatial resolution down to 200 km as global or regional static reference surface for investigation of general ocean circulation, current systems and tides.
- Recovery of detailed regional structures of the gravity field on continents and continental margins for resource exploitation and lithospheric structure description.

Space Experiments proposed to ESA

Already before the formulation of the Earth Sciences Space Programme three space experiments were proposed to the European Space Agency which - with appropriate mission and system characteristics - could meet most of the gravity requirements in the Solid Earth and Surface studies programmes.

These experiments are:

- The DUMB BELL gravity gradient sensor put forward by G. Colombo to the Agency [c.f. European Space Agency 1976, Colombo et al. 1976].
  The Dumb Bell system is a space borne gradiometer consisting of two spacecrafts which are connected by a long (10-20 km) wire and was proposed to be launched in a low perigee

(q ≈ 300 km) near polar orbit by a conventional launch vehicle. Because of the extremly long arm the system would be much more sensitive to local gravity features than usual space borne gradiometer systems [e.g. Forward, 1973] if system noise could be kept small.

- The TWIN PROBE experiment submitted to ESA by Bertotti and Querzola [1977]. In its proposed form the experiment constitutes a low orbit satellite-to-satellite tracking experiment between Spacelab and a specific arrangement of target satellites, in order to get rid of nongravitational forces. The method consists of two equal pairs of target satellites, each pair composed of two dense and equally shaped satellites but different in mass. With the masses M', M" and the positions X'_i, $\bar{X}''_i$ of the ith-pair it is possible to derive on the basis of the principle of equivalence the position of an ideal point [Bertotti and Colombo, 1972] $\bar{X}_i = (M'\bar{X}'_i - M''\bar{X}''_i)/(M' - M'')$ which does not feel surface forces in case the surface forces at positions $\bar{X}'_i$, $\bar{X}''_i$ can be assumed to be equal. Applying this method to both pairs of twin probes one obtains in principle the pure gravitational orbits $\bar{X}_1(t)$, $\bar{X}_2(t)$ of the two ideal points where the orbits or the relative motion between the two ideal points have to be reconstrunced from measurements between Spacelab and the four target satellites.
- The SLALOM (Satellite Laser Low Orbit Mission) experiment proposed by Reigber [1978] and Balmino [1978] for regional medium wavelength gravity mapping in the context of a preliminary call for experiment proposals for the early phase of Spacelab utilisation in Europe. This low orbit SST-experiment is a follow-on project of the former DIABOLO-Experiment [Balmino et al., 1976] and Laser-SST-Experiment [Reigber et al., 1976] put forward in connection with the call for proposals for First Spacelab Payload Experiments.

The DUMB BELL experiment - because of Prof. Colombo's association with the Smithsonian Astrophysical Observatory - cannot be considered as an original European experiment.

Since the TWIN PROBE experiment has many overlaps with the SLALOM experiment and because for the latter a mission and system definition study is just under way, [ESA, 1978 b]* some mission and system aspects of only the SLALOM system will be discussed in more detail in the sequel.

The SLALOM experiment

The SLALOM-experiment is considered to be a "low-low" satellite-to-satellite tracking (ll-SST) experiment. In the usual terminology this characterizes the situation where from a low ($h < 1000$ km) orbiting observing system a spacecraft in a slightly different low orbit and equipped with transponders, corner cubes etc. is tracked. The configuration envisaged for SLALOM is shown in Figure 4. In contrast to the ll-mode we have the "high-low" (hl) mode where the tracking spacecraft is in a high (usually geostationary) orbit. The usual type of intersatellite tracking data is range rates.

Both modes have already been proved practically with good results for long wavelength gravity signal detection in the context of the "high-low" ATS6/GEOS3 and ATS6/APOLLO-SOYUZ SST experiments [Hajela 1977, Marsh et al., 1977, Vonbun et al., 1977] and with almost no result for the gravity signal detection part of the "low-low" APOLLO/SOYUZ Doppler tracking experiment [Weiffenbach et al., 1976].

Before discussing some of the SLALOM mission and system aspects it seems reasonable to explain the reasons for proposing the "low-low" concept solution (c.f. also Rummel et al., 1978). As shown in the last chapter the gravity requirements in the European Earth Sciences programme are mostly related to the medium wavelength domain of the field structure. This information could in principle be obtained from ll-SST as well as from hl-SST, if the same quantity is observed, the measurement accuracy is the same in both cases, the low orbit has the same mean altitude in both configurations and the intersatellite distance in the "low-low" case is not much smaller than the characteristic wavelength of the medium scale region.

This is because the measurement itself has the same sensitivity to medium and short wavelength features of the field in the "high-low" case as in the "low-low" case. The only difference between these two modes is that in the ll-mode the long and medium - wavelength contribution of the spectrum to the observed signal becomes smaller and smaller with decreasing intersatellite di-

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TABLE 1. R.M.S. Velocity difference in mm/sec between degrees l_1 and l_2 at altitude h = 250 km for different intersatellite distances

Inter-satellite Distance	l=2-18	19-36	37-72	73-180	181-2000
	long		medium		short
35 500 km	31.548	1.567	0.379	0.041	$0.190.10^{-3}$
300 km	5.636	1.028	0.325	0.040	$0.190.10^{-3}$
200 km	3.945	0.806	0.277	0.038	$0.189.10^{-3}$
100 km	2.076	0.481	0.185	0.029	$0.179.10^{-3}$
50 km	1.066	0.264	0.109	0.019	$0.145.10^{-3}$
10 km	0.218	0.057	0.025	0.005	$0.480.10^{-4}$
1 km	0.022	0.006	0.003	$0.5.10^{-3}$	$0.546.10^{-5}$

stance so that the low frequency contribution is more and more damped. These conclusions can be drawn from Table 1 and Figures 2 and 3.

The velocity difference variances in these graphs were derived from the expression [ESA, 1978 c]

$$\sigma^2(|\dot{\bar{X}}_{12}|)_l = \frac{1}{|\dot{\bar{X}}_m^2|}\left(1-\left(\frac{r_P}{r_Q}\right)^{l+1}\right)^2 \sigma^2(T)_l \quad (1)$$

where

$\dot{\bar{X}}_m = \left(\frac{GM}{r_P}\right)^{1/2}$ ... mean velocity of satellite

$\sigma^2(T)_l = \left(\frac{R^2}{r_P^2}\right)^{l+1} \frac{R^2}{(l-1)^2} c_l$ ... degree variances of disturbing potential [c.f. Rummel 1975]

$c_l = \frac{425.28\ (l-1)}{(l-2)(l+24)}\ \mathrm{mgal}^2$ ... gravity anomaly degree variance model [Tscherning and Rapp 1975]

and the random measurement noise in the velocity differences is modelled by, [ESA, 1978 c],

$$\varepsilon^2(\dot{\rho}_{12}) = m_o^2\, e^{-c\psi} , \quad (2)$$

with

m_o ... noise level
c ... inverse relative correlation length
ψ ... spherical distance.

From this error model, which approximates white noise, the degree-order variance is obtained as

$$\varepsilon^2(\dot{\rho}_{12})_{lm} = \frac{1}{2}\, m_o^2\, \frac{P^2}{t_c^2} , \quad (3)$$

with P the orbital period and t_c the correlation length in time units.

Defining the maximal resolution which can be achieved for a definite m_o by a signal to noise ratio of 1 : 1 one can derive the additional conclusions:

- for a full medium wavelength description of gravity the altitude of the lower orbit has to be less than 300 km
- a measurement noise level of not larger than ± 10 μm/sec is a definite requirement
- there is no gain by closer intersatellite distances if the measurement accuracy is not increased simultaneously.

Because of the high resolution of ± 10 μm/sec for the range rate which is not achievable with doppler measurements at microwaves we think laser velocity measurements by interferometrical methods are the only way out. This leads - because of laser energy requirements, pointing requirements etc. - to the feasibility of only a "low-low" experiment with an intersatellite distance of not larger than about 350 km.

The Shuttle/Spacelab system with its common user facilities, subsatellite ejection and crew intervention possibilities is thought to be well suited as a platform for such a sophisticated and probably heavy instrumentation.

Mission aspects

The main objective of the SLALOM ex-

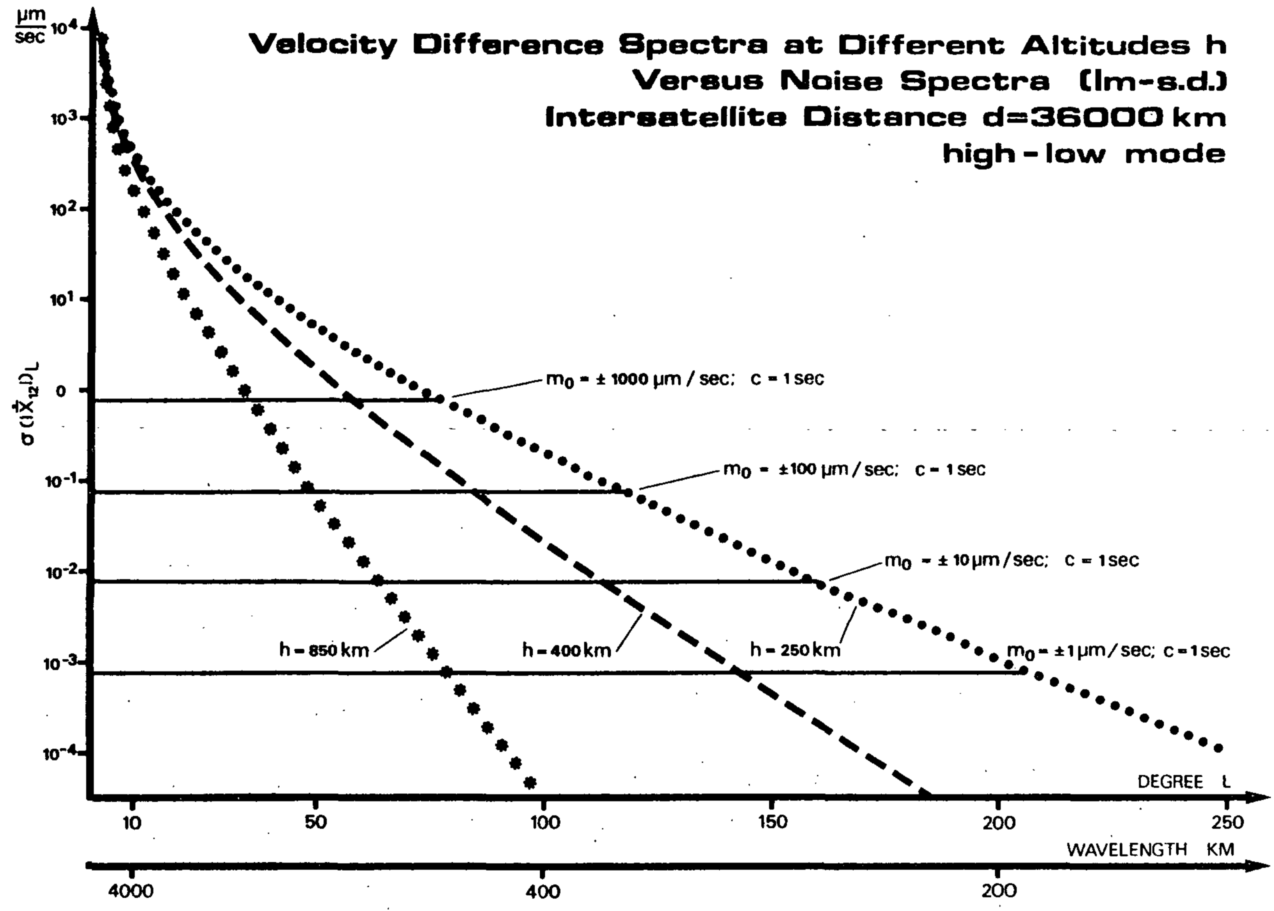

Fig. 2.

periment is to perform with a laser ranging instrumentation during a 7 - 10 days Shuttle/Spacelab mission period over a specific geographical area (e.g. The East Mediterranean region) a cycle of range and range rate measurements. These measurement profiles will in a post flight analysis be used for gravity parameter recovery over this limited area or part of it. Since the resolution of gravity information will strongly depend on the cross-track spacing of the observed profiles above the area of interest the drift of the orbit has to be selected in such a way that an optimal number of ground tracks in the measurement area is obtained without retracing tracks within the mission period. This means to ask for a near resonant Shuttle orbit with a drift period nearly as long as the mission duration. A drift period of 10 days can be reached for a mean semimajor axis $\bar{a}$ = 6603 km, mean inclination $\bar{i}$ = 50 deg. and mean eccentricity $\bar{e}$ = 0.002. The orbit drift rate would be -2.25 deg./rev. This is the optimum drift rate that can be obtained for a Shuttle mission duration of 10 days.

As explained in the next chapter the frequency translated Michelson interferometer principle will be applied for range rate measurements using a highly stabilized continuous wave (CW) gas laser. Spacelab will serve as platform for the laser telescope and subsystems and a subsatellite - equipped with corner cubes and released from Spacelab - as passive target.

The quantity observed in this flight configuration is the rate of change of the distance between the ranging instrumentation zero point and the target reflection point. This raw measurement reflects not only the instantaneous motions of the objects due to differential gravitational and nongravitational forces accelerations but also the movements of the whole Shuttle/Spacelab system due to internal disturbances, the motions of both Spacecrafts around their center of mass (C.M.) and the relative motion of the ranging instrumentation zero point with respect to the C.M. of Shuttle/Spacelab system. All but the gravity field induced effects have to be eliminated or modelled before the data can be used for gravity parameter determination.

This is a very difficult task even

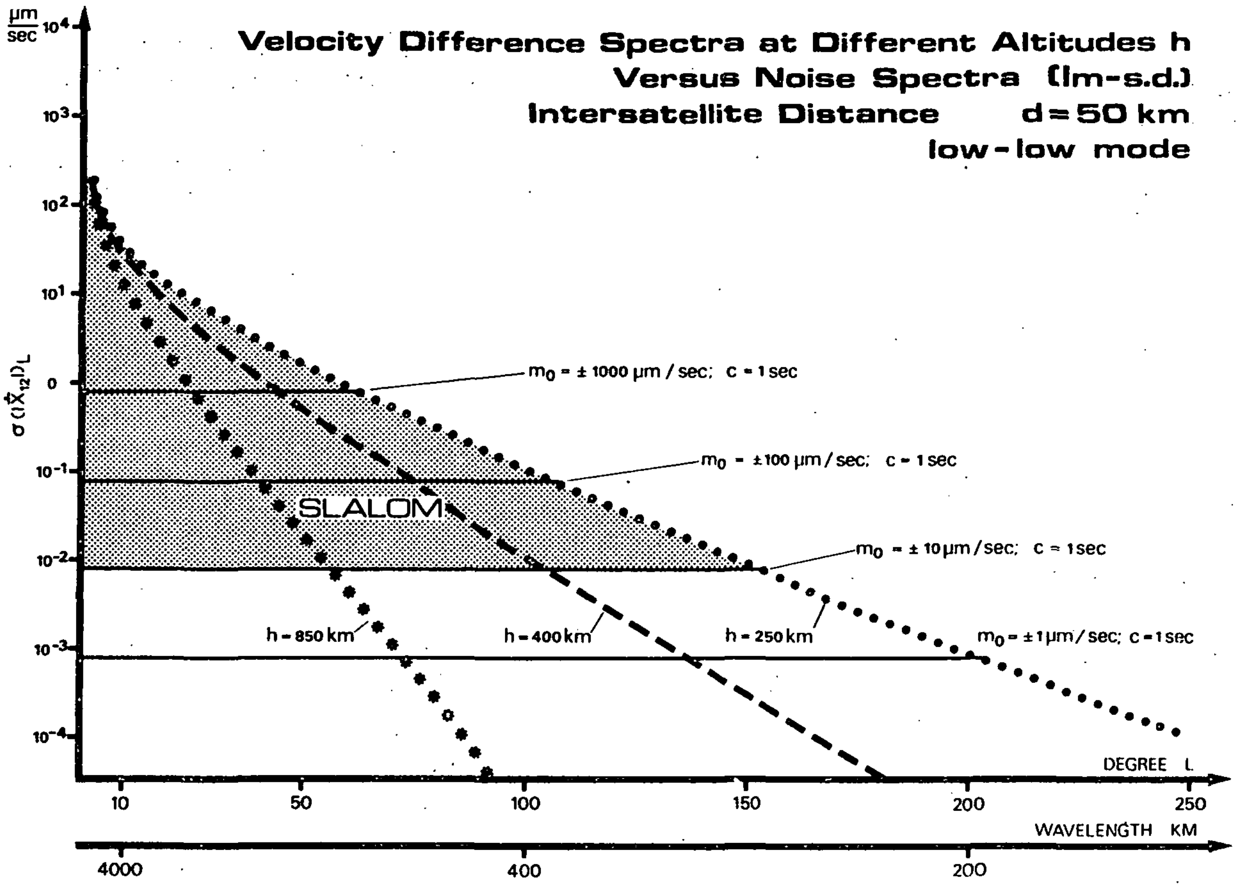

Fig. 3.

when introducing sophisticated hardware for attitude control, C.M. determination and elimination of surface forces effects.

Out of four experiment configurations which were identified in the SLALOM System/Mission definition study [ESA, 1978 b] a concept based on two passive target satellites of the same cross section-to-mass ratio and one laser telescope on the Spacelab pallet was found to be the most appropriate solution for removing all problems mainly caused by critical orbiter operations, crew motions and C.M. shifts. Additionally, because of the same area-to-mass ratio differential surface forces effects will be minimized. This configuration together with the basic equations is illustrated in Fig. 4.

In this configuration the quantities simultaneously observed by one instrument on board of the Shuttle are range and range rates to the two targets and the angular distance ψ between T_1 and T_2. The finally analyzed observation is the range rate $\dot{\rho}_{12}$ between T_1, T_2

$$\dot{\rho}_{12} = \frac{1}{\rho_{12}}(\rho_1\dot{\rho}_1 + \rho_2\dot{\rho}_2 - \cos\psi(\dot{\rho}_1\rho_2 + \dot{\rho}_2\rho_1) + \rho_1\rho_2 \sin\psi\,\dot{\psi}) \quad (4)$$

with

$$\cos\psi \approx \bar{e}_1 \cdot \bar{e}_2; \quad \sin\psi\,\dot{\psi} = \bar{e}_1 \cdot \dot{\bar{e}}_2 + \dot{\bar{e}}_1 \cdot \bar{e}_2 .$$

From the variance expression of this quantity one obtains as configuration constraints and measurement accuracy requirements if the range rate accuracy of ± 10 μm/sec should be propagated into $\dot{\rho}_{12}$

- one target as close to the Shuttle as possible during the experiment phase ($\rho_2 < 20$ km)
- intersatellite angular distance ψ small; if possible even smaller than the $2^o \times 2^o$ field of view (FOV) of the telescope ($\psi < 2^o$)
- high accuracy for the ranges ($\sigma(\rho) \approx \pm 0.1$ m), precise angular distance ($\sigma(\psi) \approx \pm 10''$) and very precise rate of change of angular distance ($\sigma(\dot{\psi}) \approx \pm 0\overset{''}{.}01$).

The two configuration conditions can be satisfied by deploying from the Shuttle the two target satellites with a definite velocity change $\Delta\bar{v}$, exactly controlled in amount and direction or by a controlled Shuttle deceleration.

With an area-to-mass (A/M) ratio of the target satellites larger than the Shuttle A/M (2.045E-3 in X(POP) ± Z nadir drift mode) by 1-30% and ejection in along-track direction with a Δv between 1-40 cm/sec target orbits could be reached which would be trackable from the Shuttle within a 350 km distance during the whole mission. The usual form of the relative distance in the (ρ,t)-plane is a parabola. An example that would fit to the SLALOM mission requirements is shown in Figure 5.

For this example within the experiment period of about 6 days no safety problems would occur and all before mentioned requirements are fulfilled with $\rho_1 < 350$ km, $\rho_2 < 20$ km, $\psi < 1^o$.

With the mentioned accuracies for the range ρ and the angular quantities ψ and $\dot{\psi}$, the maximum standard deviation of the range rate, $\sigma_{max}(\dot{\rho}_{12})$, would be $\pm$ 13 μm/sec.

Assuming that the measurements are not influenced by optical disturbances the final range rate $\dot{\rho}_{12}$ is solely affected by the difference in the instantaneous state of the two target satellites and the motion due to differential gravitational and surface forces accelerations. All variations induced by non earth gravity influences in the raw data $\dot{\rho}_{12}$ have to be eliminated.

This is apart from the differential air drag effect easily be done because the effects are either small or can be modelled precisely. At SLALOM altitude the differential drag effect will probably not be zero but will be small because of the same cross section-to-mass ratio of both target satellites.

Such small drag effects are caused by small scale density changes in the upper atmosphere and have to be expected especially during periods of increasing geomagnetic activity. It is difficult to give some realistic figures of mass density changes for horizontal distances of 50 to 250 km at an altitude of 225 km.

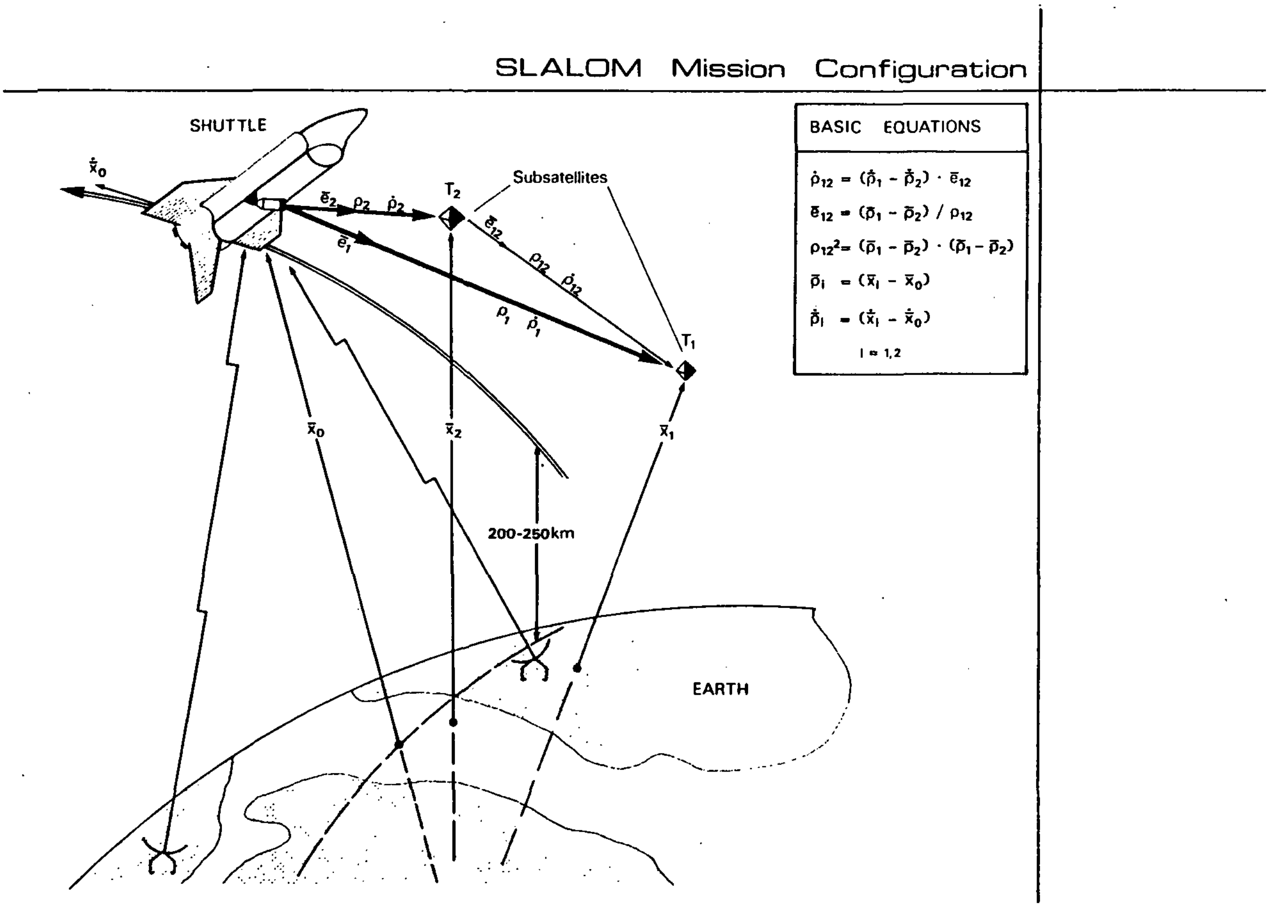

Fig. 4. SLALOM baseline experiment configuration

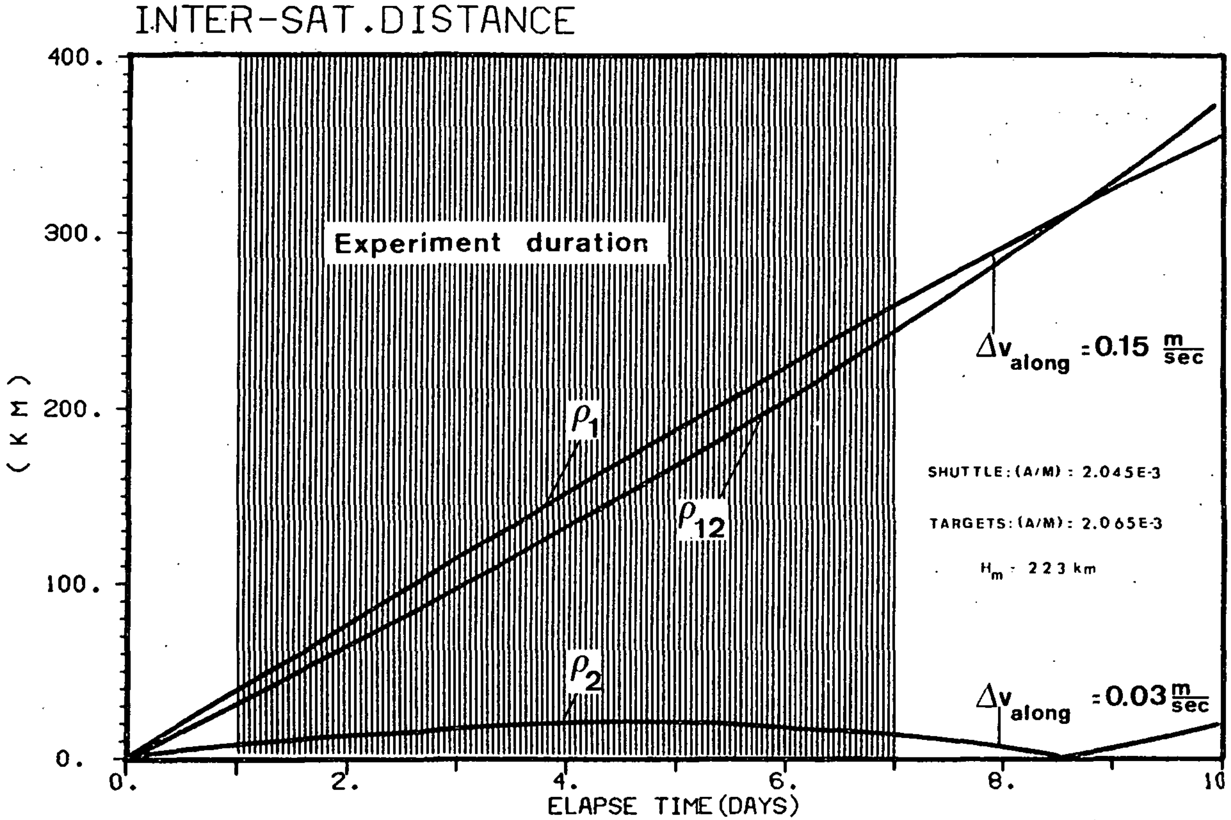

Fig. 5. Intersatellite distances (c.f. Figure 4) obtained from orbit integration using CIRA 65 standard atmosphere.

The only information we have is from in situ measurements of the neutral atmospheric composition obtained by gas analyzers aboard of satellites [Trinks and von Zahn, 1975]. These data indicate the presence of small scale density variations with peak-to-peak amplitudes of 5% up to 30% under disturbed conditions and with amplitudes of 1% - 10% during quiet-time conditions [Prölss and von Zahn, 1975, Prölss and Fricke,1975]. The wavelengths of these fluctuations range from 100 to some hundred kilometers but can probably even be shorter.

Taking as a reasonable number for the relative difference of the atmospheric density at the two positions X_1, X_2 with horizontal distance of 200 km a value of $\Delta R/R = 0.1$ will result at $h = 225$ km in a differential drag acceleration ΔF_D of

$$\Delta F_D = F_D \cdot \Delta R/R \approx 1.10^{-6} \text{ m/sec}^2 \doteq 0.1 \text{ mgal.}$$

As it is seen from Figure 6 - which shows gravity induced acceleration difference spectra (derived by differentiating eq. (1)) and acceleration noise spectra at $h = 250$ km - this unmodelled drag acceleration would be small enough to allow the recovery of medium wavelength structures of the gravity field.

On the other hand unmodelled residual accelerations of this order in satellite hight would result in 1-2 mgal errors of recovered gravity information on the earth surface because of the strong amplification of the medium frequency components of the noise spectrum in the downward continuation process by a factor of about 20 [c.f. Rummel,1975].

Taking the "two target - one telescope" concept as baseline experiment configuration the mission operations will start with alignment of the optical system, switching on laser to standby mode, possible orbiter manoeuvres for subsatellite launch and then the sequential deployment of the two target satellites along track with a positive impulse and a well defined spin. At very near distances initial acquisition could be performed by the orbiter KU-band radar system. As soon as an initial orbit is computed, acquisition and tracking can be shifted to the laser instrumentation. When the angular distance between the two target satellites is small enough so that the satellites remain within the field of view of the telescope (approximately after one day) tracking of both targets will be performed simultaneously.

Before passing the selected area of

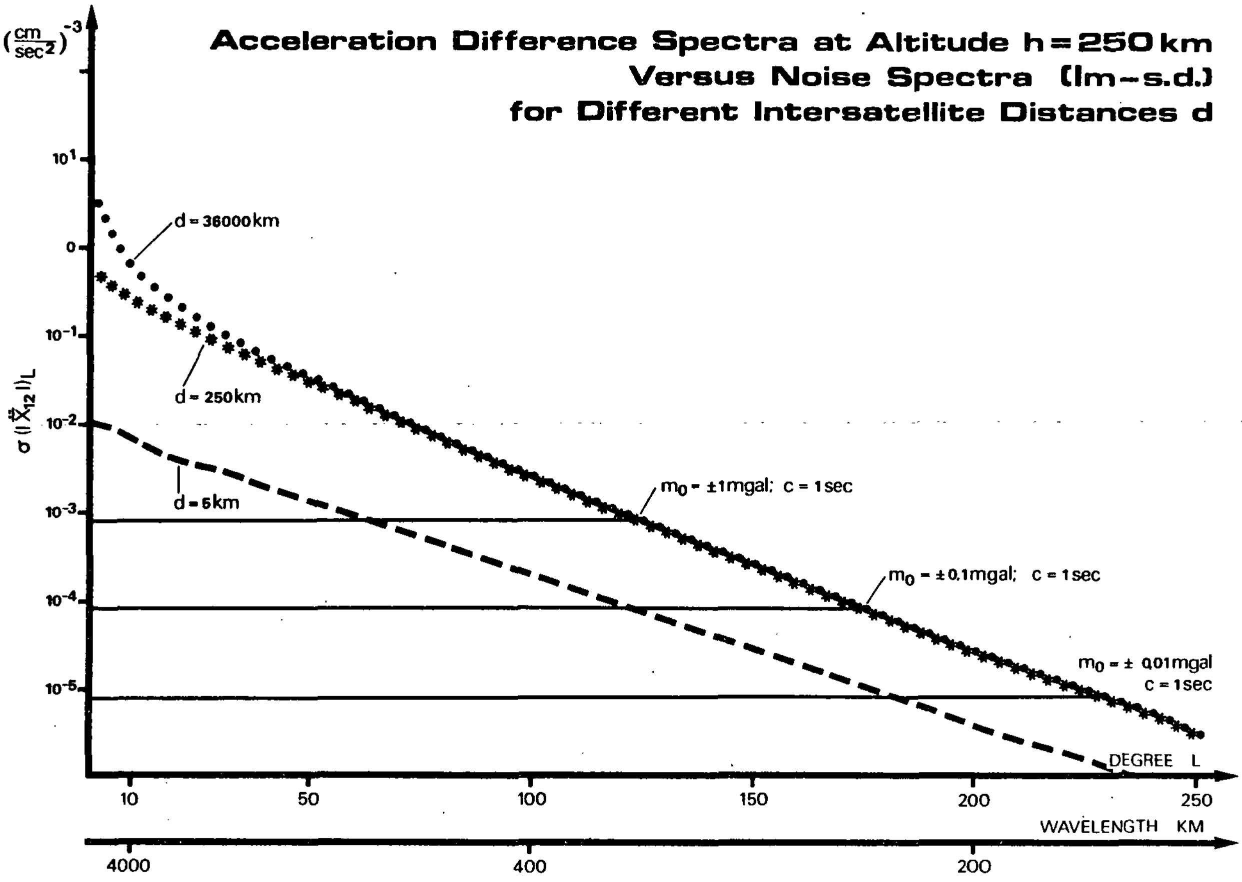

Fig. 6.

investigation the laser telescope will be reorientated to the predicted target position by means of a pointing platform. Reacquisition will be performed with the aid of the laser instrumentation and the instrument will then be switched to tracking mode. Then range, range rate and angular position measurements are obtained with a high repitition rate over a period of about 5 - 6 minutes for both target satellites. These data will be stored for later precise double or triple differential orbit correction and gravity signal recovery.

System Concept

The SLALOM system consists of two targets - a long range and short range satellite - and a laser ranging instrumentation mounted on a support structure which will be directly attached on the orbiter bay fittings.

The main functions of the ranging system are range measurements, range rate measurements and acquisition and tracking. All these functions have to be performed simultaneously for two target satellites with high accuracy.

In a laser ranging instrumentation study performed by MBB and conducted by ESTEC possible solutions for the different functions were identified [c.f. ESTEC, 1978].

In case of ranging an instrumentation based on pulse transit time or phase shift methods is considered to give comparable results. For pulse transit time measurements a Nd:YAG laser or laser diodes are considered as effective transmitter candidates whereas for phase shift methods continuous wave solid state and gas laser like laser diodes, HeNe- ($\lambda=3.37$ µm) Argon- ($\lambda=0.51$ µm) and CO_2- ($\lambda=10.6$ µm) gas lasers could be used as emitters.

Out of the three methods which are mainly used for velocity measurements with lasers - range increment measurement method, doppler shift measurement of microwave modulated on a CW laser, phase shift (or doppler shift) measurement by interferometrical methods - only the interferometrical methods are capable of reaching the required range rate accuracy of ± 10 µm/sec for SLALOM. Possible lasers for emission are CO_2-, HeNe-, and Argon gas lasers. With the classical Michelson Doppler interferometer [Watrasiewicz and Rudd, 1976] no possibility exists for distinguishing between positive and negative range rates as they appear in the SLALOM experiment. This difficulty can be avoided by changing to a frequency translated Michelson interferometer which has the capability of bidirectional counting. This is achieved by frequency modulating the local oscillator with a single constant frequency. The problem of low signal-to-noise ratio in case of large frequency - receiving - bandwidth (which is necessary in case of SLALOM because of large range rate changes) can be overcome by frequency off-setting the local oscillator. A basic requirement for a high doppler shift frequency resolution is a high short time laser stability. For a 10 µm/sec resolution the stability of the laser in the detector's integration time has to be better than 10^{-11} for a CO_2 laser at $\lambda = 10.6$ µm and about 20 times better for a HeNe laser with $\lambda = 0.6$ µm.

The SLALOM ranging instrumentation functions for target acquisition and tracking are: Illumination of the satellites for optical acquisition, directional sensing of the targets and beam deflection for scanning over the field of view of the telescope (acquisition) and over a partial area of it around the most probable position of the target (tracking method).

For sake of simplicity the laser illumination should be performed with one of the already existing lasers for range or range rate measurements. This solution would guarantee coaxial alignment with the instrument's pointing direction. For optical sensing of the targets the Instrumentation Study [ESTEC, 1978] proposes the use of image dissector tubes - as used for example in the IPS star tracker - which are synchronized with the motion of beam deflectors based on rotating mirrors or piezoelectric drives for fine pointing.

In Figure 7 a schematic diagram for a possible SLALOM instrumentation with a two target ranging and tracking capability is shown. A Ritchey Chretien type telescope with an aperture of 0.2m is used for transmission and likewise for reception. Within this telescope all optical subunits will be integrated leading to minimized optical distortions because of identical pointing axes and same thermal conditions.

Finally something remains to be said

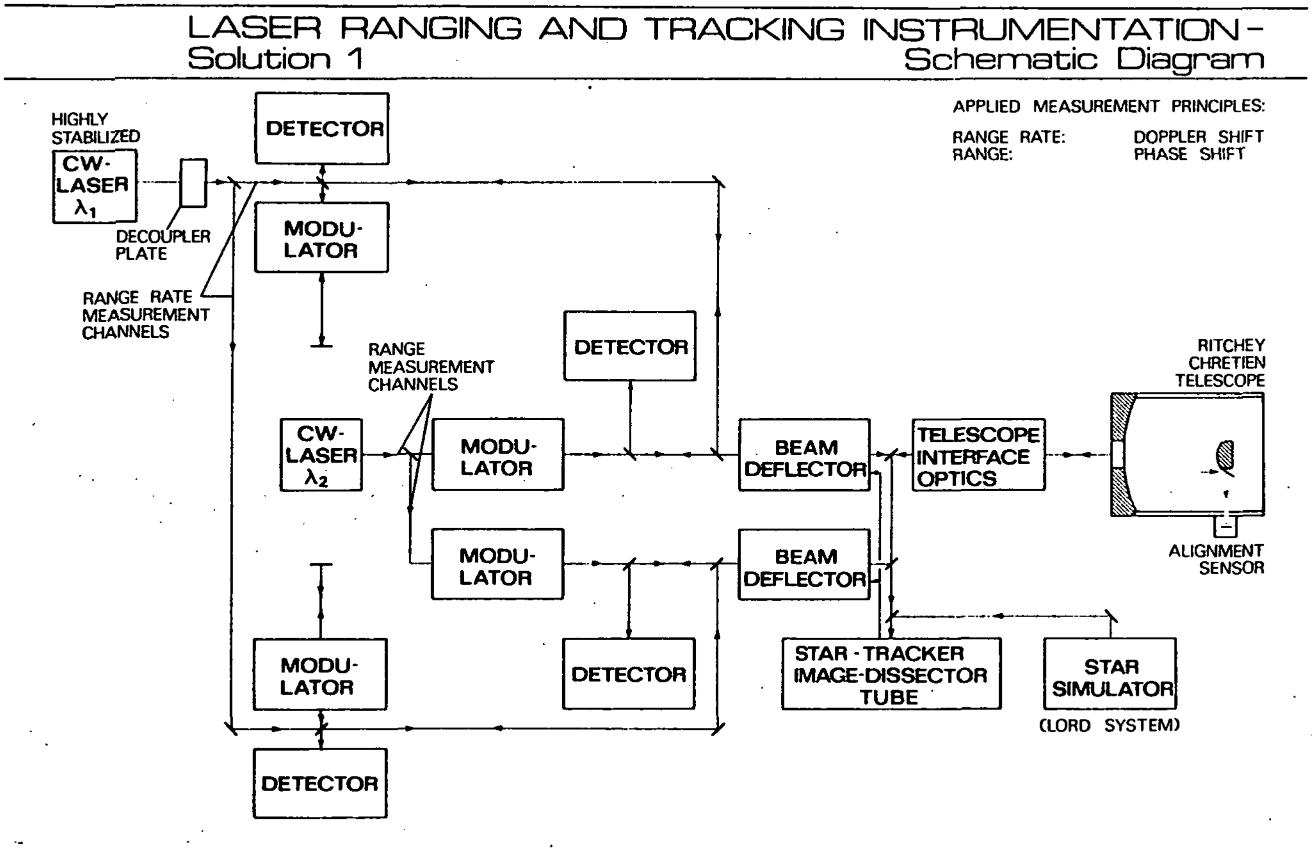

Fig. 7. Possible laser ranging and tracking instrumentation for SLALOM experiment (Schematic diagram from ESTEC, 1978: Laser Ranging Instrumentation-Interim Report).

about the subsatellites lay-out. For this one has to consider that

- the area to mass ratio for both subsatellites has to be equal and within some percent similar to the Shuttle cross section-to-mass ratio for the experiment flight attitude (e.g. 2.045×10^{-3} m^2/kg for (-Z/LV; Y/VV)-mode)
- the reflecting cross section has to be large because of the maximum range of 300 km
- doppler shift due to rotation should be minimal.

These conditions are best met for a subsatellite covered with corner cubes and which is of octahedron type. With a wall assembly made of glas ceramics plus for instance lead inlay and a 50 cm length of each octahedron axis the satellite mass would be about 53 kg. This would result in the required A/M ratio of 2.045×10^{-3}.

Conclusion

Although the early Shuttle/Spacelab missions are to a certain extent not ideal with respect to earth surface coverage and although still a number of problem areas exist for the SLALOM experiment - e.g. laser stability requirements, angular distance rate accuracy, high simultaneous pointing requirements, blackouts and doppler shifts due to target rotation, slow convergence in the double differential orbit improvement process and strong amplification of unmodelled contributions of the range rate signal in the gravity recovery process - we believe that the SLALOM experiment will provide a compact gravity sensing system for medium and fine structure resolution in the near future. It may also have its implications on the developement of spaceborne laser systems for other geodetic applications.

The handicap of the short Spacelab mission duration is on the other hand balanced out by a number of advantageous features of the Shuttle/Spacelab system for a SLALOM like experiment and the possibility of repeating the experiment in other missions. For the future it is even possible to think in terms of longer Spacelab missions or a retrievable detached laser platform.

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