San Marco Project and Space Research at the University of Rome*

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Generalities

The San Marco Project (SMP) has been created the 30th of May, 1962 by the signature of a "Memorandum of Understanding" between the University of Rome "La Sapienza" and the American "National Aeronautics and Space Administration" (NASA) in order to cooperate in a space research project. This memorandum has been then approved by means of an agreement between the Governments of Italy and USA the 7th of September, 1962.

The Government of Italy funds the Project. The originator and Director of the Project, Prof. Luigi Broglio, promoted and initiated space researches in Italy through the University of Rome proposals and initiatives. These activities took place both in Rome (where the research and study centers, laboratories and test facilities for satellites design are located) and abroad, particularly in Kenya (fig.1) where the San Marco Equatorial Range (SMER) is situated, for space launches and satellite telemetry supports.

Since the beginning, the SMP has developed and maintained active, fruitful and mutually advantageous cooperation with NASA and, in due time, with the European Space Agency (ESA). Presently many Italian and foreign organizations are collaborating with the SMP, namely: Italian Air Force (AMI), National Council of Research (CNR), Italian Space Agency (ASI), National Aeronautics and Space Administration (NASA), American and European Universities (i.e. Dallas, Michigan, New Hampshire, Max Planck Institute, etc.), European Space Agency (ESA) and national and international industries. The main purpose of the SMP is the space research through international collaborations.

San Marco Project facilities

The activities of the SMP concerning the satellite designing, building and testing are performed in Rome where a space environment simulator (first built in Europe), mechanical and electronics laboratories, computer centers and administrative offices, are available.

In Kenya the SMP has established since 1964 the SMER for launch operations and satellites support. The location of the range is close to the Equator, in the Indian Ocean (Ngwana Bay) at 40°12'45" degrees East and 2°56'18" degrees South, close to town of Malindi.

The SMER consists mainly of three "off-shore" type platforms, namely: the "San Marco" (for vehicle assembling, testing and launching), the "Santa Rita" (for communication, vehicle telemetry, command-control and meteo station) and the "Santa Rita II" (for radars) connected with each other by means of submarine cables. Other two small platforms contain the electrical power generation plant. All the platforms are standing on their own steel "legs" above the ocean (from 10 to 14 meter deep, depending on tides). The distance between Santa Rita and San Marco platforms (about 1 Km) is enough to provide the proper safety conditions during rocket ignition and lift-off. The San Marco platform is evacuated during the last phases of the count-down. Each platform is self supporting and fully equipped with personnel accommodations and services.

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The main support to the SMER is located on land (about 45 minutes boat-ride from the platforms, 60 minutes car-ride from Malindi airport) in the so-called "base camp". At the base camp are located the SLX-band and VHF-band telemetry stations, electric power generation plant, water distillers, administration offices, metal and wood machine shops, boat and car engines repairing shops, maintenance activities, motor-generators overhauling and housing facilities. A medical doctor and medics assure health care and hygienic living conditions at the base camp and on board the platforms; furnished dispensary and sick bays are available. Through a switchboard placed on Santa Rita, local and worldwide communications (voice/data) are possible. Personnel and supplies transportation among platforms and base camp is provided by means of motor boats and, for urgent and light transportation, by fast rubber-boats. Some relevant features, unique to this range, are:

(-) equatorial, where the earth spinning gives the maximum contribution to the due-East launches while the equatorial position allows to achieve any orbit inclination (from equatorial to polar).
(-) mobility, very useful because puts the range in an autonomous position with respect to the local situation and conditions; furthermore the platforms steel structure life has been re-certified up to 2014.
(-) environment, always temperate climate due to the sea influence; this allows to launch almost all year around.
(-) flight safety, due to the geographic position the ground path of the initial trajectory, being on the Indian Ocean, does not cover any populated area.
(-) accessibility, the ships can unload directly on board the platforms avoiding road transportation;
(-) skill, includes assembly and launch crew, studying, designing, testing and checking-out specialists, well experienced in medium size low-orbit spacecraft which result in costs reducing;

SMER with its powerful telemetry stations, together with a satellite equipped with a modest recording capability, constitute an autonomous space system for low equatorial orbit missions (circular, 550 Km). This kind of orbit is very interesting for the astronomic research because it is not affected by the Van Allen lower belt disturbances.

San Marco history

The first San Marco spacecraft (San Marco 1) was launched from Wallops Island (15 december 1964) by an italian crew while the first launch operation from SMER occurred the 26th of april, 1967 (San Marco 2). Since 1964, a number of sounding sub-orbital launches have been performed, often in co-operation with other scientific organizations and for world-wide interest type of missions (such as solar eclipse). Up to now, nine satellites have been put into equatorial orbits, some of them as international co-operation, particularly with USA, UK and Germany.

Four NASA satellites (for x-and-γ rays astronomy) have been launched from SMER. One of these satellites (Uhuru) led to the discovery of the black holes in the Cygnus-x1 constellation. Also, the Great Britain UK5 satellite for x-rays astronomy, was launched from SMER. One of the reasons why USA and UK selected SMER for these launches is because of its particularly favorable position with regard to the lower Van Allen Belt. These spacecraft were all put successfully into orbit and the data collected have been of great importance to the scientific world, in the field of x-rays astronomy.

SMP has designed, fabricated and launched 5 scientific satellites. All launches have been entrusted to and performed by the Italian launching team consisting of highly skilled engineers and technicians. There have been no failures during these 30 years of the SMP activities. All the San Marco satellite series were designed and fabricated in Rome by the SMP personnel.

San Marco Programs

The SMER is equipped for and fully capable of the operational support of spacecraft tracking, command-control, data acquisition and evaluation. In particular, the tracking of the "transfer-orbit" of the geostationary satellites launched from Kourou, is one of the most useful and important support to ESA. Because of the about 90 degrees difference in longitude between Kourou and Malindi, the SMP ground station is the first one to acquire the above mentioned satellites in their transfer orbit and, moreover, to have them at their apogee for long time over SMER.

The SMER location allows to the easy achievement of geostationary and multistationary orbits. A system of four multistationary spacecraft holds significant importance since it allows to economically obtain every day, six-hour stationary survey of all the areas on the Earth, providing a continuous coverage of the entire Earth, with exception of the polar regions.

The SMP proposed some satellites [ref.2] which, through remote sensing, perform land survey. This would help the third world countries for economic planning and for a better knowledge of their own natural resources (agricultural, mineral, census, etc.). The final purpose of this satellite set is aimed at achieving better and more reliable weather prediction models by atmosphere sensing techniques. Data would concern the carbon dioxide, humidity and ozone distributions along the critical and important equatorial area. They would also cover the fields of communications, climatology and earth observation. In order to cover the above items of general interest, small and medium mass satellites would be the best choice due to the (a) economic convenience, (b) shorter design and accomplishment times (call up times), (c) programs based on many small satellites are more suitable as a training means and (d) vulnerability is also decreased owing to the satellite redundance. For the above said reasons it is obvious that in the near future the need of small and medium mass satellites will increase. SMER is optimized (then economic) and finalized for these kinds of satellites.

The vehicle used up to now has been the standard Scout missile (fig.2), which achieves a reference orbit (equatorial, circular at 550 Km) with a payload of about 210 Kg. The THOR-DELTA rocket, in its basic version, has a launch capability of 1400 Kg. Presently no space vehicles are available in Europe and USA for covering the intermediate weight range (from 400 to 800 Kg) which is considered the optimum for the above mentioned space missions and also for the future telecommunication systems based on many satellites of medium weight.

Should now Italy be willing to develop a new vehicle of this sort it would require a great financial and technological effort that the present economic situation could not afford. For these reasons the SMP has proposed a new program called "San Marco Scout" which consists of enhanced versions (with 4 or 5 stages) of the standard Scout "G-1" configuration.

The SMS-1 (5 stages) consists of a standard Scout with the addition of four Algol III-A rocket motors which will function as its first stage. This configuration is particularly suitable for the performance of very elliptical orbits, e.g. multistationary, transfer orbit for geostationary satellites, etc. The SMS (4 stages) version is similar to the SMS-1 with the exception of the last stage (Altair III). The SMS vehicle has all four stages equipped with guidance and control system, and can be utilized for low altitude orbit. Figg. 3,4,5 sketch both the vehicles SMS and SMS-1 as well as theyre performances.

The SMS vehicle will have a reliability very close to the standard Scout, since it is based on the assembly of existing and well proved parts, with minor additions. The accuracy will be very high since all stages are guided and controlled. This new rocket will be conveniently used by a class of satellites ranging from 400 to 700 Kg and to be placed in LEO. This set of satellites will increase the performances of the applications for remote sensing, scientific research and telecommunications.

San Marco 5 (SM5)

The last SMP satellite (fig.6, ref.1,3,6) launched from SMER on the 25^{th} of march, 1988 was the SM5 (250 Km perigee, 620 Km apogee at injection). This spin stabilized spacecraft (nominally at 6 rpm) was carrying two digital sun sensors, a couple of IR-earth sensors, three magnetometers and a fine 3-slit star mapper sensor [ref.5,10]. Both the orientation and the rate of the spin axis were magnetically controlled (figg. 7, 8 and 9). The spin axis has pointed toward the earth geographic south, to the direction where there is a full compensation on the spin axis drift between orbit inclination and gravity gradient influences. This spacecraft was carrying five scientific instruments to investigate the upper part of the atmosphere (equatorial thermosphere), they were:

Ion Velocity Instrument (IVI, USA), for measuring the three-dimensional bulk velocity of the ambient ions in the spacecraft velocity frame, the ambient plasma concentration and the ion temperature;

Wind And Temperature spectrometer Instrument (WATI, USA), for measuring two components of the wind velocity perpendicular to the spacecraft velocity and the neutral atmosphere kinetic temperature;

Electric Field Instrument (EFI, USA), for measuring the DC electric field and the RMS wave electric field in a three-dimensional spacecraft frame;

Airglow Solar Spectrometer Instrument (ASSI, Germany), for measuring the airglow, the solar and the interplanetary radiation at wavelengths from EUV to the visible spectral regions.

Drag Balance Instrument (DBI, Italy), suited to the measurement of the total instantaneous aerodynamic force on the spacecraft, and hence the atmospheric density and related density variations. DBI is employed for the density mapping with respect the local time, longitude and altitude. The evaluation of the aerodynamic force is determined by measuring the relative displacement between the low mass outer shell (3 Kg) and the massive main structure (234 Kg) of the satellite (fig.10). The relative displacement is converted to a voltage which is proportional to the drag force on the satellite. The sensitivity of the system permits density measurement at altitudes as high as 500 Km.

From DBI data [ref.9] it has been possible also to show the atmosphere density as a function of the sun activity and of the earth magnetism. These informations, together with the other experiments principal results allowed to obtain a picture of important geophysical phenomena occurring in the equatorial atmosphere [ref.11]. Some features of this pictures are summarized as follows:

- (-) The SM5 DBI detected a large number of density wavelike oscillations [fig.11, ref.8] occurring mostly during the night and in definite altitude ranges.
- (-) The frequency of the occurrences matches fairly well that of the ionospheric "bubbles" contemporarily detected by IVI and EFI (fig.12).
- (-) The apparent wavelength distribution of the DBI waves is globally consistent with the predictions of a simple linearized wave theory.
- (-) The ion drag damping mechanism can explain the distribution of the waves with respect to both altitude and local time.
- (-) The strong neutral-ionosphere interaction is evidenced, and the correlation with the plasma bubbles occurrences suggests the need of a comparative analysis of the waves with the ionospheric and electric field measurements contemporarily performed inboard (IVI and EFI experiments).
- (-) The suggestive hypothesis of the waves origin at the terminators shall also be investigated.

Another phenomenon that comes from the DBI data processing is a relative maximum density that occurs around midnight [figg.13, ref.12]. This density behaviour has been explained in terms of air flowing mechanisms driven by the solar heating on the dayside. The interactions among the neutral atmosphere, the magnetic field and the ionospheric plasma complicate the understanding of the phenomenon. The main results of the DBI data analysis for the relative maximum density are the listed below:

(-) The secondary density maximum is present on the profiles with amplitudes which are however strongly dependent on season and altitude. In particular the amplitudes are from small to moderate at low altitude (260 Km) then are becoming negligible toward the altitude of $\approx$ 300 Km, then they increase again with altitude toward rather large values particularly in the second period (fig.14).

(-) Considering the high altitude fittings (h $>$ 340 Km), the peak local time is shifted later during the first period (21 Apr, 15 Aug) and before in the second (1 Aug, 5 Dec).

(-) At lower altitudes (h $<$ 340 Km) the position of the peak is less clearly definable (due also to the lower amplitudes) but seems to indicate an inversion (peak of the first period occurring earlier than that of the second).

The possibility of extracting useful geophysical information from the DBI depends heavily on the availability of a satisfactory dynamic model of the spacecraft. The data processing [ref.9] shall in fact clean out all the disturbances (dynamic, thermal, sun pressure, digitization, instrument noise, data reduction). For these reasons some aspects of the spacecraft dynamics, which are important under the point of view above, are hereafter described.

Spin axis misalignment

The increasing accuracy requirement in the spacecraft attitude determination implies great accuracies in both the knowledge of the spacecraft parameters and in the attitude determination algorithms. For spinning satellites the spin axis orientation is of capital importance because the attitude sensor data processing is based-on and referred-to this direction. Since the nominal mass distribution is seldom representative of the real condition, the evaluation of the spin axis direction has to be recomputed in flight. A particular attention is then given to the star sensor data processing because of its great pulses accuracy. The computation of the attitude from the starmapper data is shown in the flow-chart plotted in fig. 17. Fig. 16 shows the star sensor slits in the body coordinate system.

For the SM5 mission the "3-slits" misalignment determination technique [ref.5] that is, to identify the spin axis direction in the body coordinate system, is also developed from the star mapper data. The mathematical condition that a star describes a cone around the spin axis is written for each star. This function is linearized (under the condition that the misalignment angle is supposed to be not greater than 0.5 degrees) and the solution is obtained by a least square method. Figg. 18, 19 and 20 are showing the differences between the requested and computed spin axis polar angles.

The accuracy of this determination algorithm is increasing with the data time accuracies and decreases with the spin rate increasing. The results from the data processing (still in progress) are showing reasonable accuracy even in presence of disturbances like a certain ammount of spin ripple, spurious pulses and a rather unfavorable star configuration. These disturbances influence only the star triplet identification, while the limited time (1/3 msec) accuracy influences the "3-slits" misalignment determination technique.

Spin period ripple

The star mapper data processing has evidenced a dynamic phenomenon occurred because this satellite was carrying long wire antennae in a plane normal to the spin axis while flying across orbit thermal transition (sun-to-shadow and viceversa). The SM5 can be modelled as a central rigid body (hub) with four "flexible" (with no bending stiffness) radial antennae with tip mass at the ends. For this satellite the orbit thermal transitions cause a variation of the antennae length (they have a copper core). The antennae length change implies a variation of the spin velocity of the overall system and induces Coriolis forces that cause the system to oscillate (spin period ripple).

A study on this phenomenon has been developed [ref.4]. It includes (a) a mathematical model of the dyanmics of the spin rate ripple, (b) a best fitting of the star mapper data for identifying the spin period history (fig.21), (c) the integration of the model with the initial conditions derived from point (b) at particular time instant (fig.22) and (d) the determination of the antenna length history (fig.23) and of the associated thermal gradient.

The overall results are allowing a quantitative assessment of the thermal gradient history, useful for the understanding of the phenomenon and for future predictions. The understanding of the thermo-mechanical phenomenon and the optimum fitting of the experimental spin data is very important for improving both the attitude and the misalignment determinations which are, in turn, very significant for the on-board science. Moreover the spin rate data basis, cleaned from the thermal influence, provides a complementary mean for the evaluation of the aerodynamic force, very useful in the frame of the aeronomic analysis.

Conclusions

The SMP proved in the years to be not only a valid enterprise for the Italian and international cooperative space activity, but also an excellent school in this field. Its University type of affording the problems offers to the operators as well as to the young people of the Aerospace Engeneering School the opportunity to learn "on the field".

Within the scopes of this Project, therefore, there has not been only the implementation of the practical activities related to the specific programs, but also an educational aspect. This finds application in scientific research in many fields, as for instance Dynamics [ref.4,15], Structures, Control [ref.13], Thermal [ref.14,16], Data processing [ref.5], etc. These activities lead also to a wide partecipation to the international scientific life [ref.17].

Used Acronyms

SMP = San Marco Project
SMS = San Marco Scout
SMER = San Marco Equatorial Range
NASA = National Aeronautics and Space Administration
ESA = European Space Agency
ASI = Agenzia Spaziale Italiana
CNR = Centro Nazionale delle Ricerche
UTD = University of Texas, Dallas
GSFC = Goddard Space Flight Center (Greenbelt MD, USA)
LEO = Low Earth Orbit
GSO = GeoStationary Orbit
DARA = Deutsche Agentur Fur Raumfahrt Angelegenheiten

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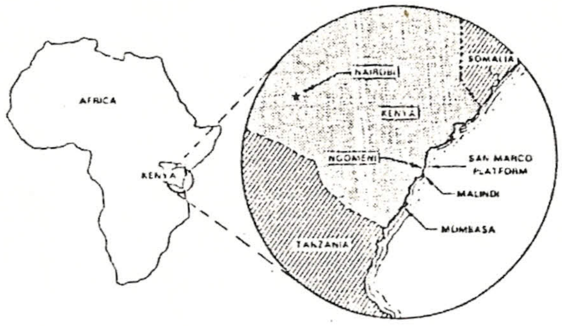


fig.1

San Marco Range Launch Site Map

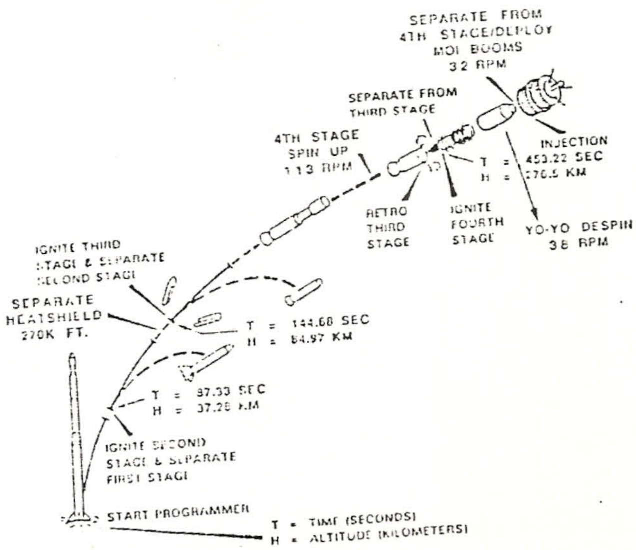


fig.2

Scout Mission Profile

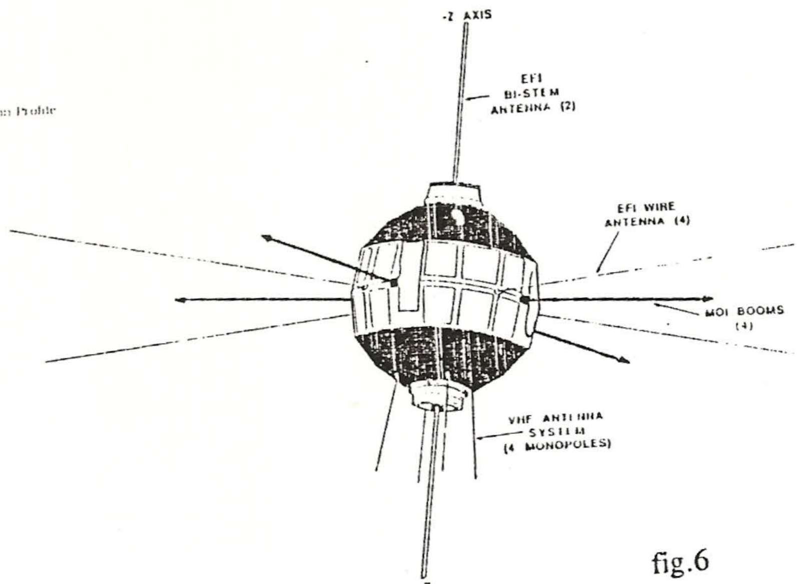
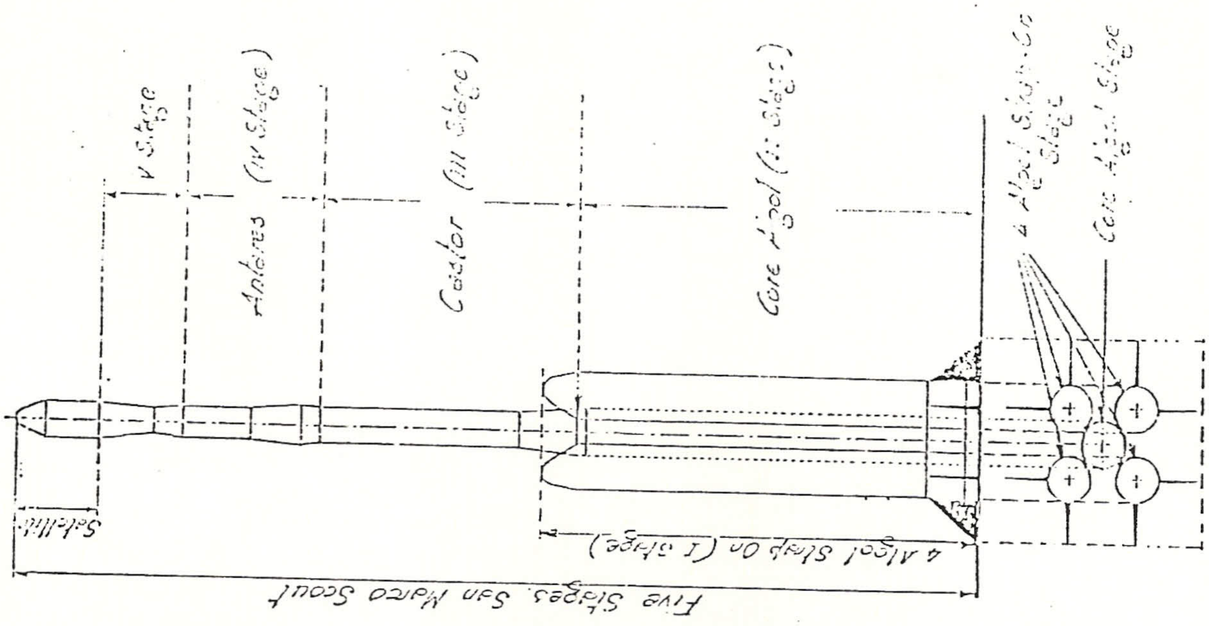


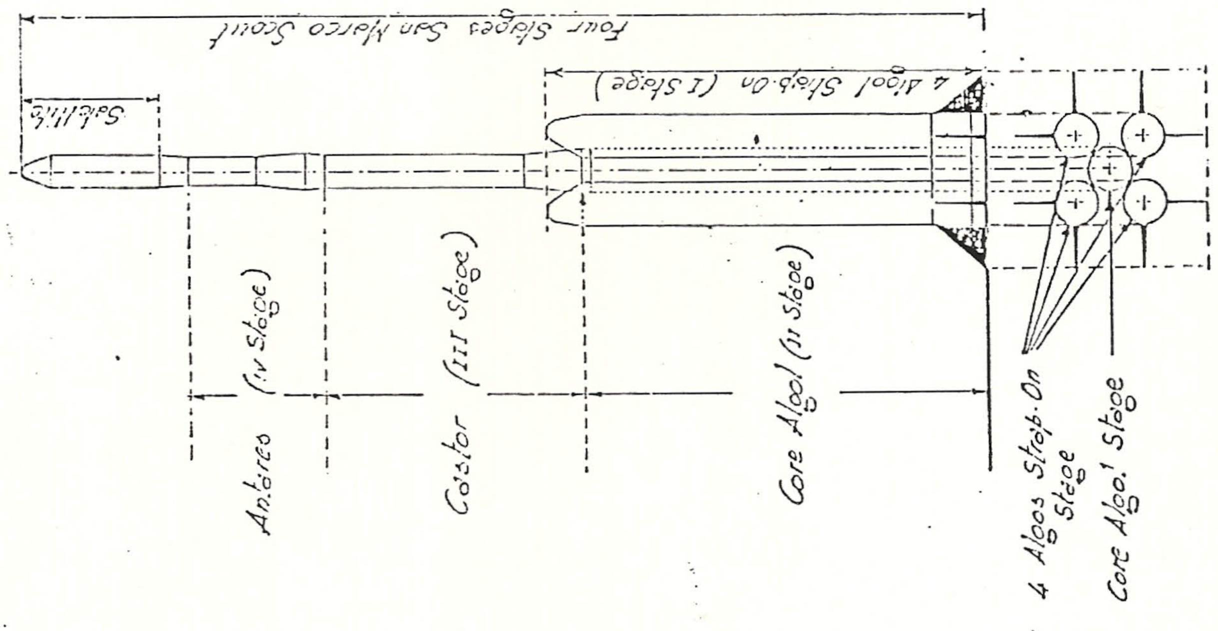
fig.6

San Marco D/L



San Marco Scout (5 stages)

fig.4



San Marco Scout (4 stages)

fig 3

	San Marco Scout vehicle performances			
Perigee (km)	500	800	420	270
Apogee (km)	500	800	27400	35786
Inclination (deg)	2.9	2.9	2.9	2.9
Payload weight (Kg)	600	470	230	220
Vehicle type	SMS	SMS	SMS-1	SMS-1

fig.5

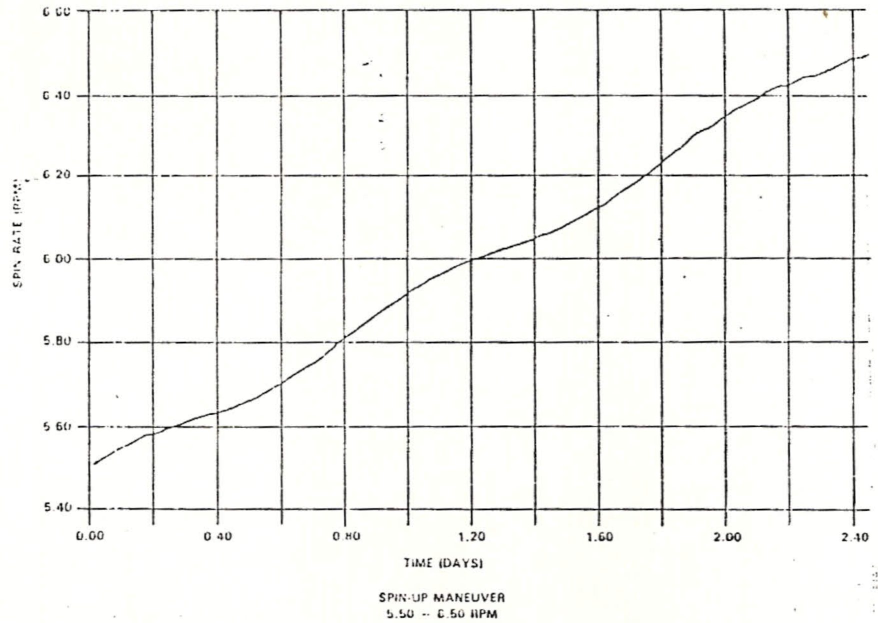


fig.7

Spin Adjustment

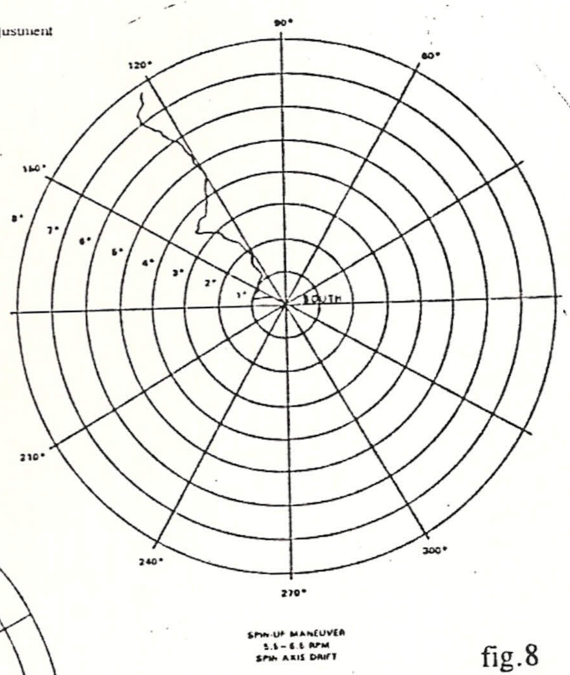


fig.8

Spin-Up Maneuver

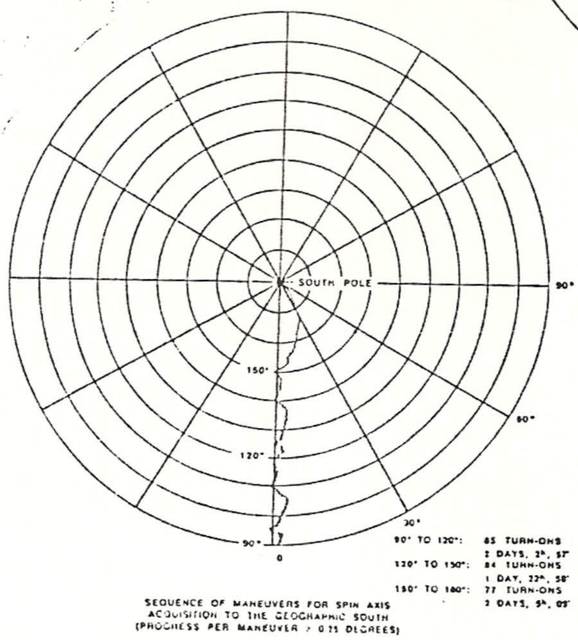
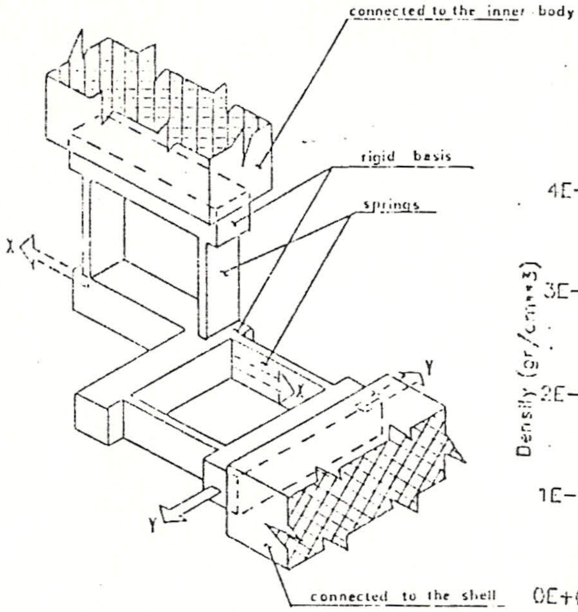


fig.9

Sequence of Maneuvers for Spin Axis Acquisition to the Geographic South



The Neutral Atmospheric Density (Drag Balance) Assembly

fig.10

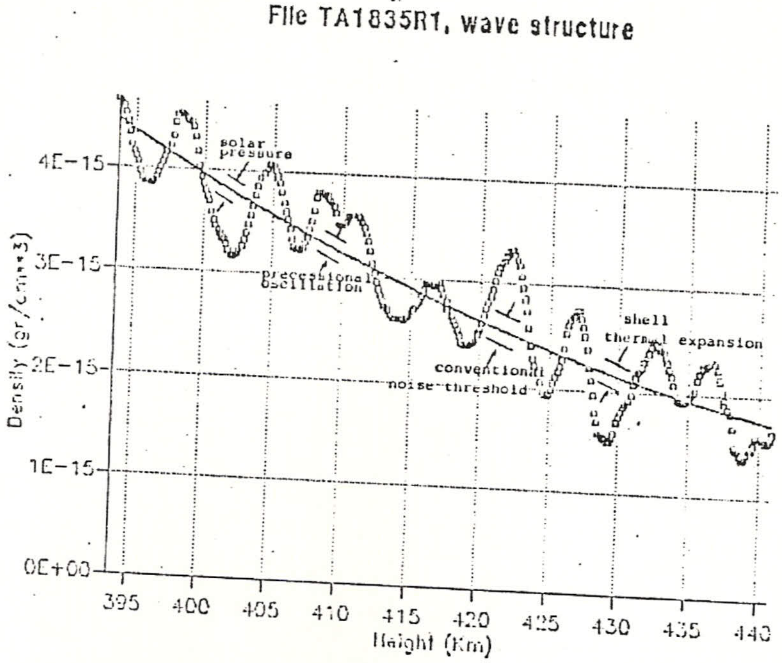


fig.11

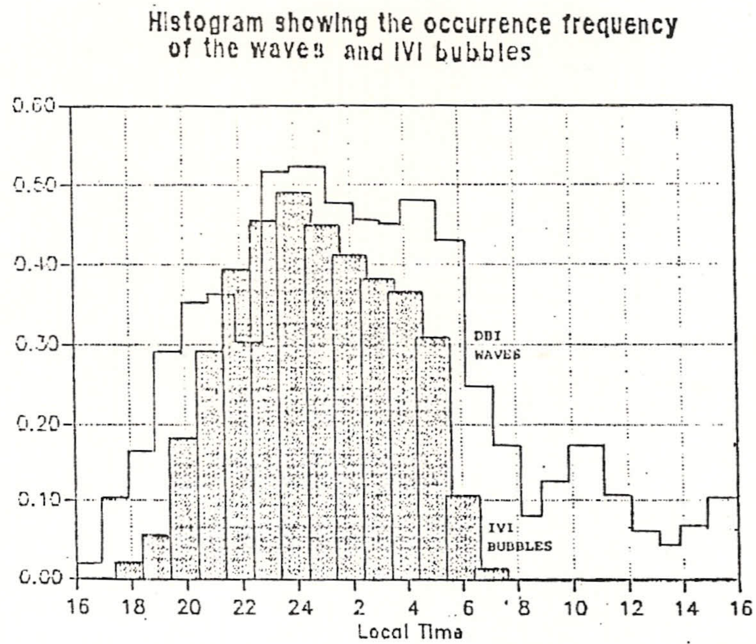


fig.12

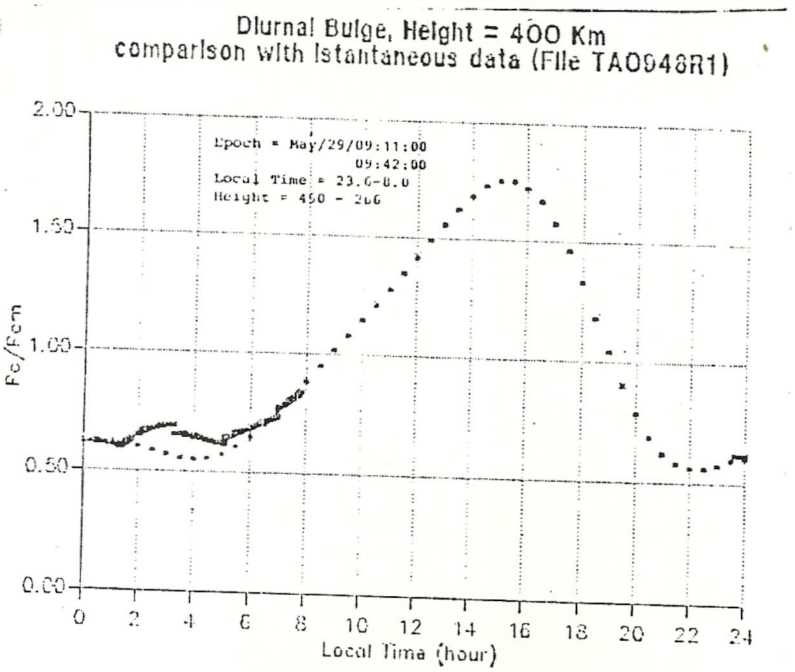


fig.13

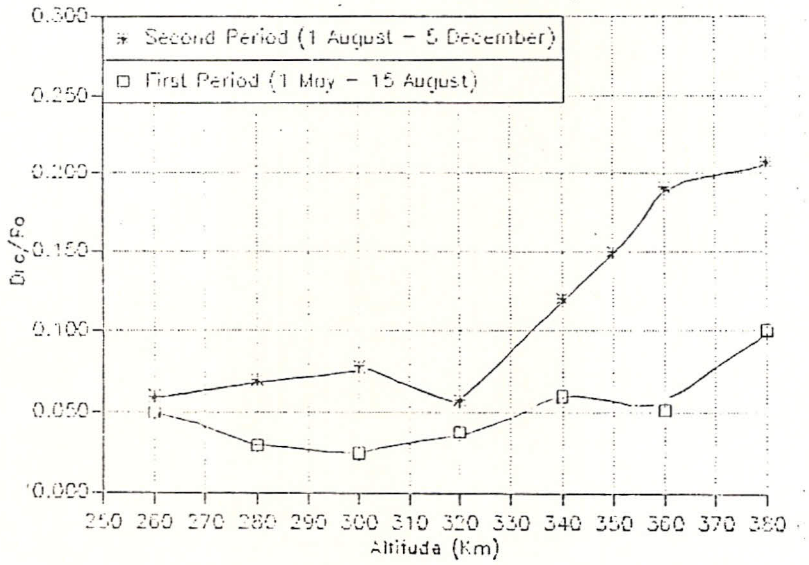


fig.14

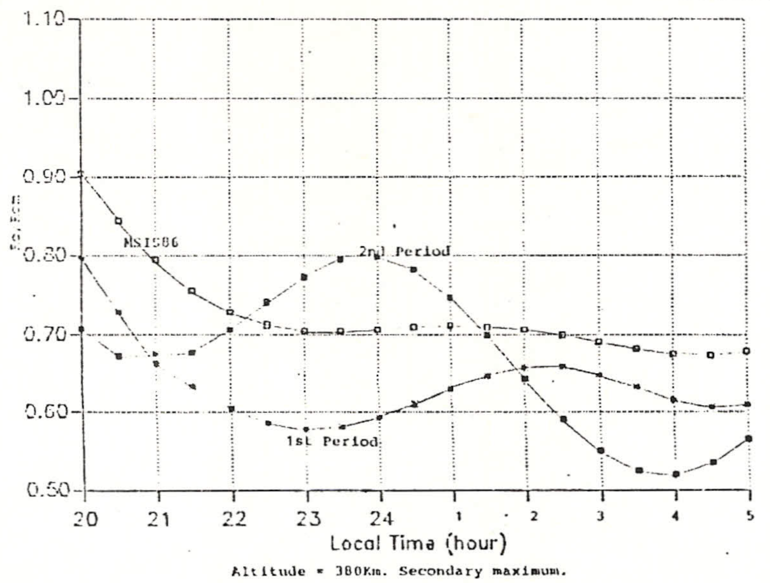


fig.15

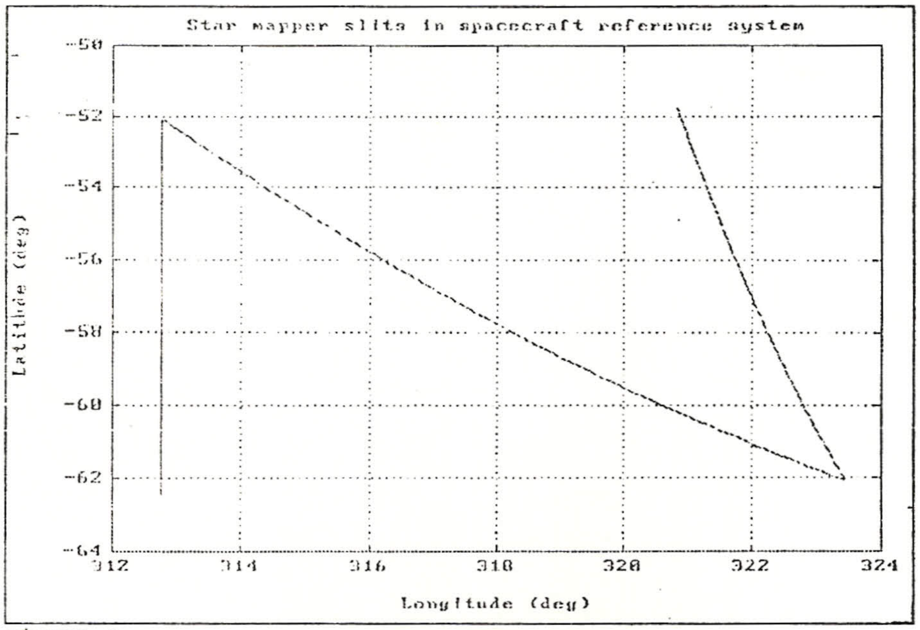
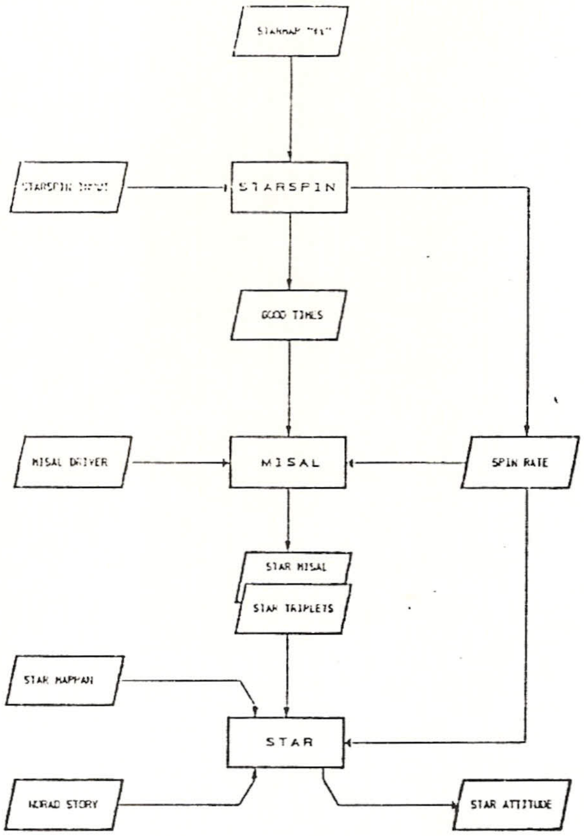


Figura 3

fig.16



FLOW DIAGRAM OF STARMAPPER DATA PROCESSING

fig.17

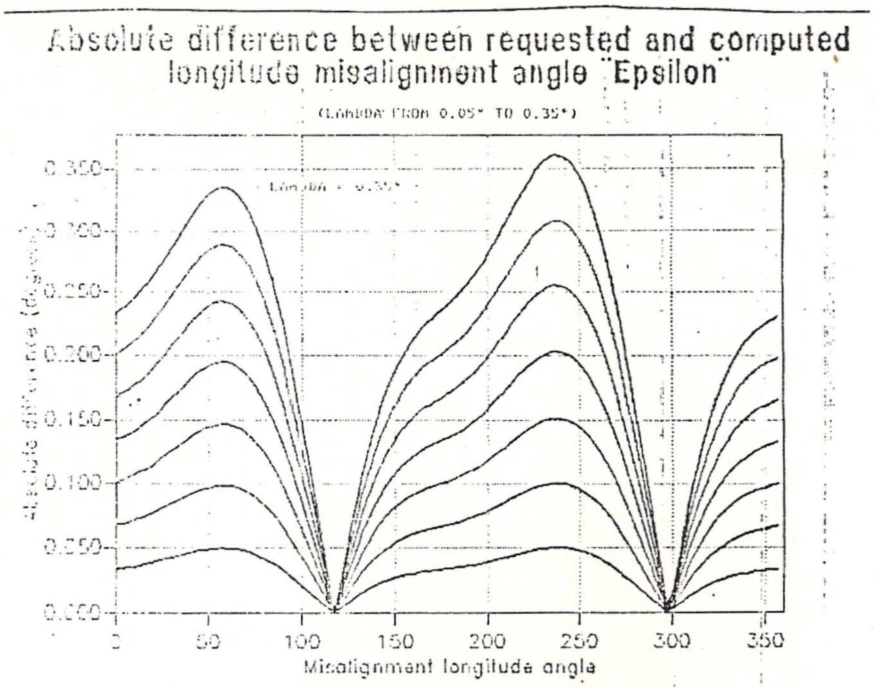


fig.18

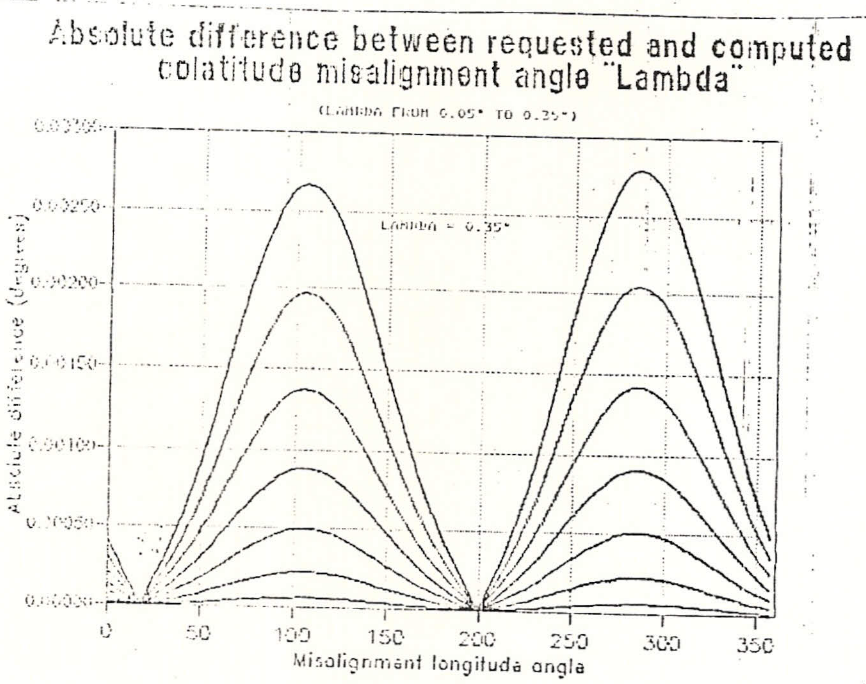


fig.19

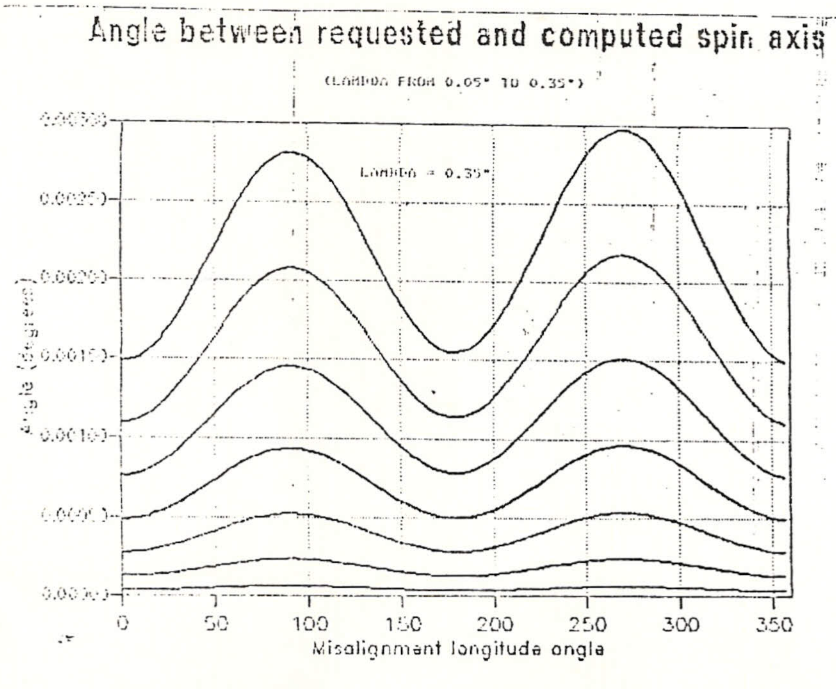


fig.20

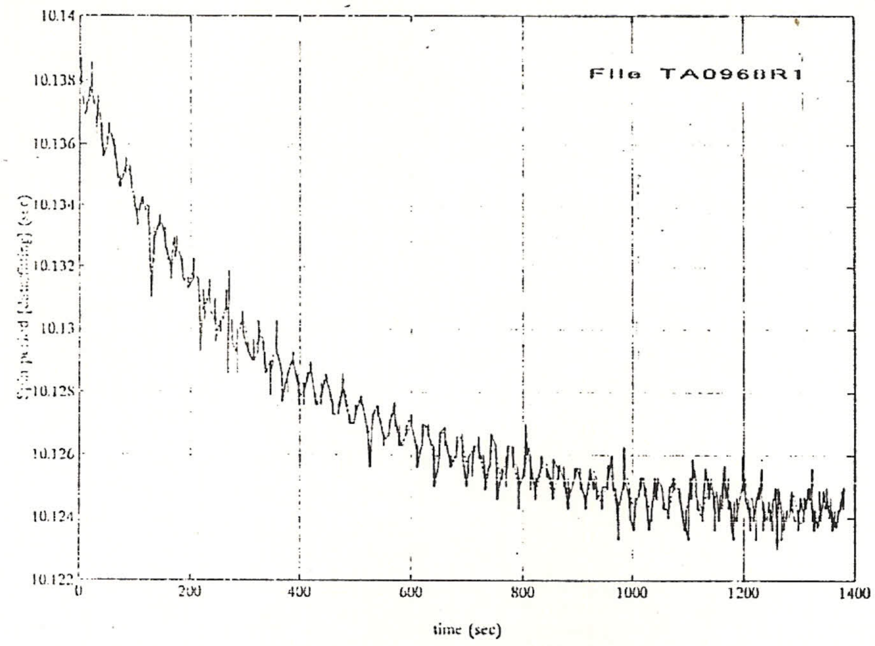


fig.21

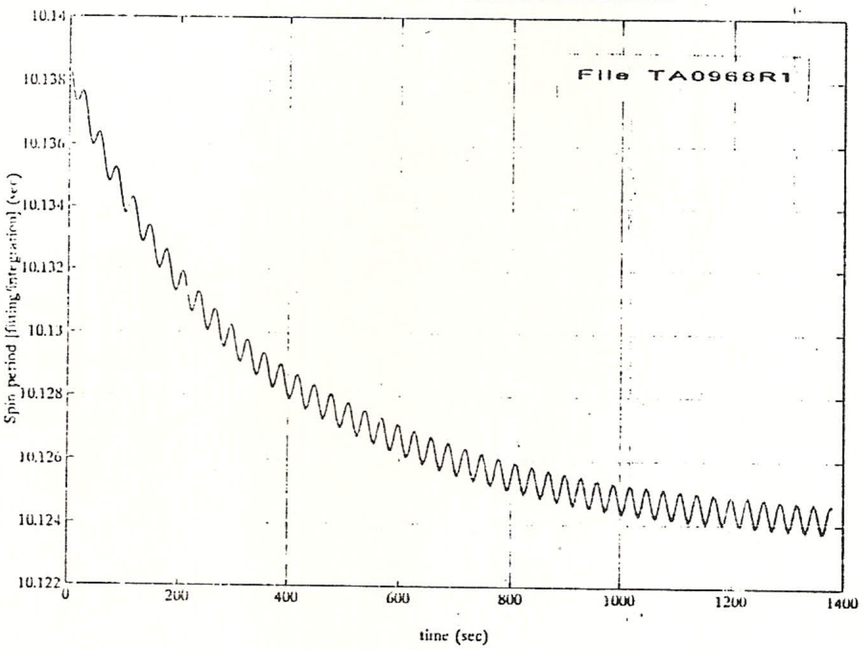


fig.22

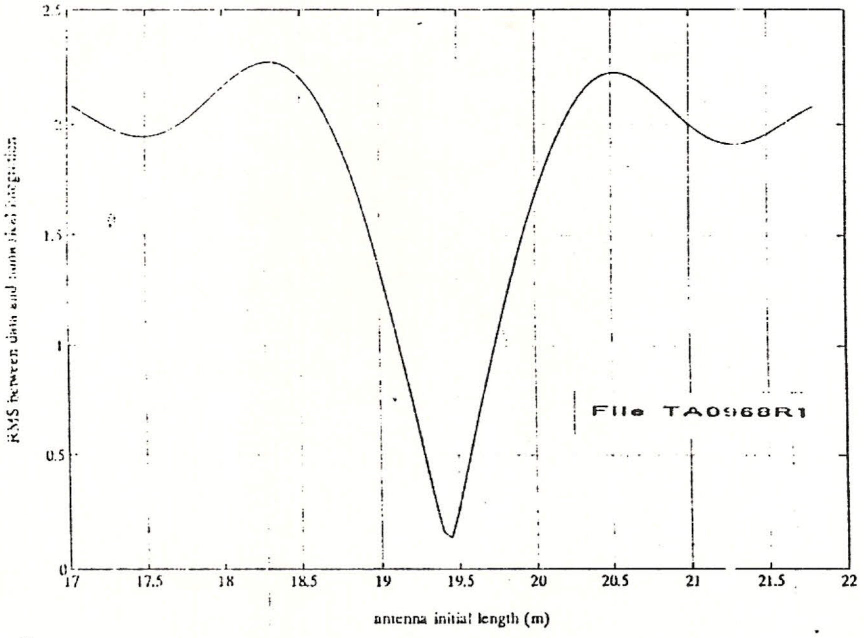


fig.23