# THE SWEDISH VIKING SATELLITE — THE CONCEPT AND IN-ORBIT EXPERIENCES

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## ABSTRACT

The Viking Satellite that was launched on Feb 22 1986, is a unique combination of advanced space research and low development cost. An international team of scientists presently acquires large amounts of magnetospheric data including high-quality UV images of the auroral activity over the northern hemisphere. The eight months of estimated lifetime of the Saab Space-produced satellite have almost passed, and there is good hope for continued operations.

In this paper, the general Viking design is briefly described. The attitude control system design is given a deeper consideration and some flight results are given along with a general judgement upon the pros and cons of the concept. Finally some words are said about the analyses of the Viking dynamics.

Keywords: Viking, Small Satellite, Attitude Control, Magnetorquer, Attitude Determination, Boom, Dynamics.

## 1. INTRODUCTION

Saab Space AB has been the prime contractor for the Swedish Viking satellite project on a contract from the Swedish Space Corporation. Viking was launched from Kourou on Feb 22 1986, as a piggy-back payload on the Spot-1 Ariane launcher. Presently, it is about to complete its first eight months of successful operation, which happens to coincide with the predicted in-orbit lifetime. Plans have been made for a continued operation, since an extended lifetime is possible.

The scientific objective of Viking is to perform systematic and comprehensive measurements of plasma phenomena in a region of the magnetosphere where charged particles are accelerated to high velocities and energies. Such regions, one above the North Pole and one above the South Pole, are roughly located in the 4 000-15 000 km altitude band, where the magnetic field lines lead down to the auroral zones. The northern region is under study now and the southern region will possibly be studied during the extended operations. Although the satellite as such is national, the payload is highly international with participation from Canada, USA, Denmark, West Germany, France and Sweden.

In spite of its advanced scientific mission, Viking has been produced at a total cost of only around 100 MSEK or US$ 15 million, including launch. Factors that have kept the costs down are:

- Maximum use of existing, qualified and flight-proven hardware.
- An efficient model and test philosophy with
  - acceptance tests on unit level for qualified units.
  - a separate payload engineering model.
  - platform protoflight test with structural qualification.
  - all other tests on the complete flight model.
- Strict control of interfaces.
- Efficient cooperation with the customer and with the science groups.
- Cost efficient working methods in a small, compact project organization.
- Optimal use of the space available between Spot and the Ariane adapter, giving a low launch cost.

## 2. GENERAL DESCRIPTION

Viking is depicted in Figure 1. Structurally, it consists of three main parts: An octagonal platform, a payload deck and retention mechanism. The platform is built around a central tube that is designed to withstand all the loads put upon it by the Spot satellite, which rides on top of it during the launch. In the lower end, the tube fits onto the Ariane adapter, and in the upper end, it has the exact dimensions of an Ariane adapter interface. By using that design, Spot could be built with a regular Ariane interface without any Viking-specific requirements. The central tube contains the perigee boost motor that raises Viking's orbit from the circular 822 km orbit to an elliptical one with apogee at 14 000 km. On its sides, the satellite is covered by eight solar panels.

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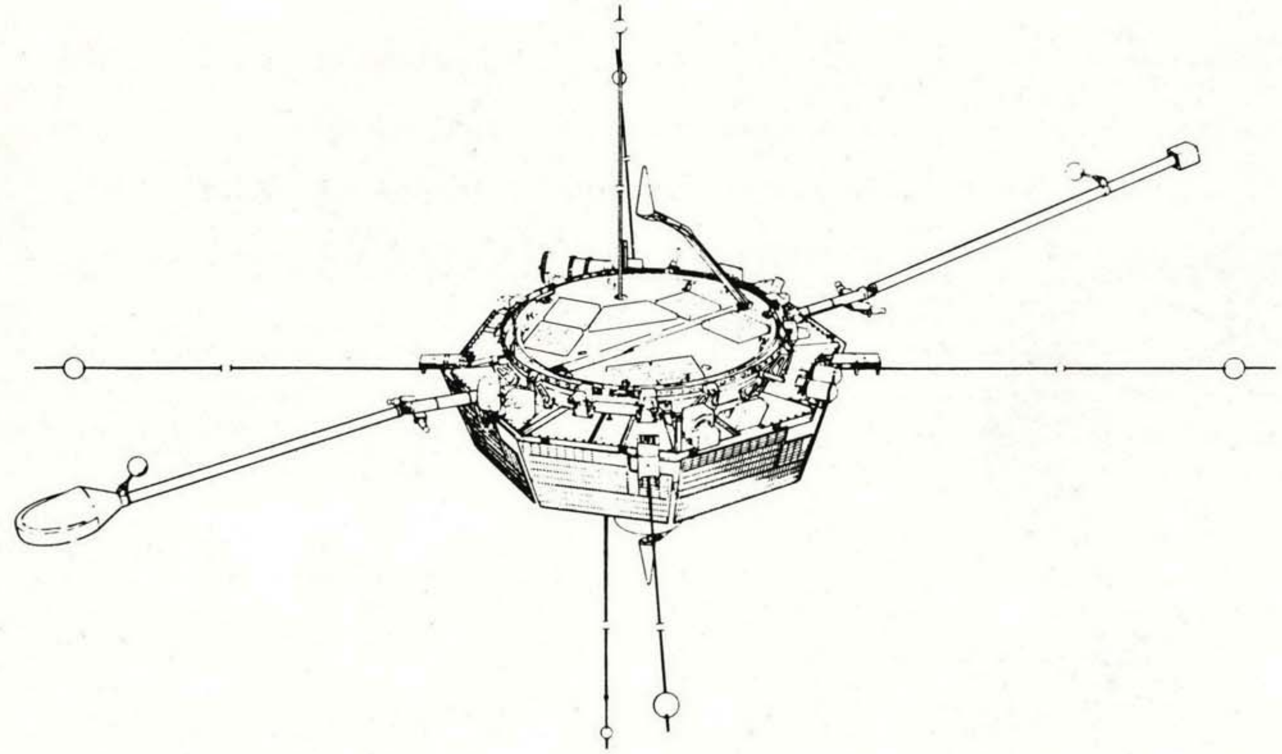

Figure 1. The Viking in-orbit configuration.

The platform contains all the subsystems of the satellite, see Figure 2. On top of the central tube, there are three louvers that are used for thermal control of the battery and the high-power units. The remaining part of the satellite uses passive thermal control. Two deployable antennas also are parts of the platform subsystems.

The payload deck is mounted on top of the platform. There are five groups of experiments, each consisting of a number of units that are attached to both sides of the payload deck. Viking is always oriented in such a way, that the payload deck is not illuminated by the sun (a scientific requirement). Some of the sensors of the payload are located at the end of deployable booms. There are four radial 40 m wire booms, two radial 2 m stiff booms and two axial 4 m stiff booms.

The retention mechanism, finally, releases Spot from Viking at Spot separation. The mechanism is separated from Viking prior to perigee motor firing in order to lower the satellite weight and thereby to gain apogee performance.

The dry mass of the in orbit configuration is 285 kg. The launch mass was 538 kg. The solar panel power available now is around 70 W. The maximum power consumed during data taking periods is appr 80 W. The difference, and the power required during eclipses, is provided by a 12 Ah nickel-cadmium battery.

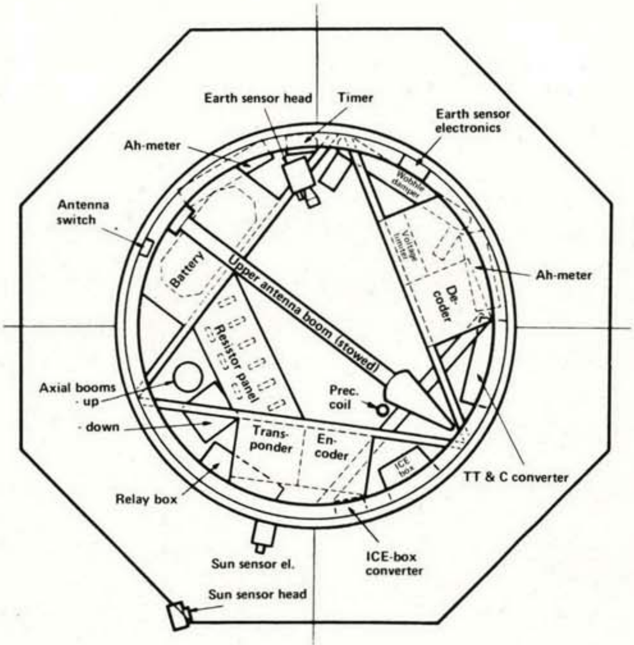

Figure 2. Platform equipment.

## 3. THE ATTITUDE CONTROL CONCEPT

In its operational state, Viking has an inherent attitude stability because of its 3 rpm spin around the axis of maximum moment of inertia. The spin rate was chosen in such a way that a minimum wire boom tension was always present. For the same reason, the spin rate was higher during the boom deployment sequence.

Attitude information is provided by three sensors: a sun sensor, an earth sensor and a magnetometer, the latter one also being part of the payload. The sun sensor has two accuracy ranges, a digital one with a resolution of 2 deg. and an analog one with an accuracy of 0.25 deg. At the best viewing angles, the earth sensor based measurement has a similar accuracy. The earth sensor provides pulses at horizon crossing. The magnetometer based attitude estimation is accurate only within a few degrees, because of the lack of exact knowledge of the magnetic field of the Earth. Thus, the performance of the magnetometer is inferior to that of the sun and earth sensors, but still it is used as a backup source.

The raw attitude sensor data is telemetered to the Esrange ground station, where it is processed. Three sets of attitude estimations are computed using various combinations of sensor data. After that, the most accurate estimation is chosen (the accuracy depends on the sun-earth-satellite geometry) and it is utilized as input to the software that calculates how to achieve a desired attitude maneuvre. The spin rate is unambiguously computed from sun or earth sensor data. Telecommands are then sent to two electromagnetic coils, one for precession control and the other one for spin control.

Precession control is based upon quarter orbit torquing, see Figure 3. In that concept, the precession coil current is reversed four times per orbit. Ideally, this should take place at the points where the local magnetic field line is parallel to the line between the north and south magnetic poles of the Earth. Performing coil current switching at those four points, maximum precession of the spin axis is obtained. In Viking, only four sets of four switchpoints are available, so that the ideal ones can normally not be chosen. However, the resulting performance drop is insignificant.

Spin control is achieved by reversing the current of a spin coil twice per satellite rotation. The coil is mounted perpendicular to the spin axis. The coil current is reversed when the spin plane component of the Earth's magnetic field is parallel to the longitudinal axis of the coil. Current reversal impulses are provided by the magnetometer.

In order to suppress wobble during all phases of the mission, the attitude control subsystem also includes a ring-formed wobble damper.

Figure 4 is an example of performance of the attitude control system. The maneuvre is the initial one, when Viking was put into cartwheel mode, i.e. with the spin axis perpendicular to the orbit plane. No booms were deployed at that time and the spin rate was appr 12 rpm. In the so-called low mode, the slew rate was 2 deg. per orbit and in the high mode it was 6 deg. per orbit (1.4 deg/hour). An interesting detail may be mentioned here: Initially, only sun sensor data was available, since the geometry was such that the Earth was not in the field of view of

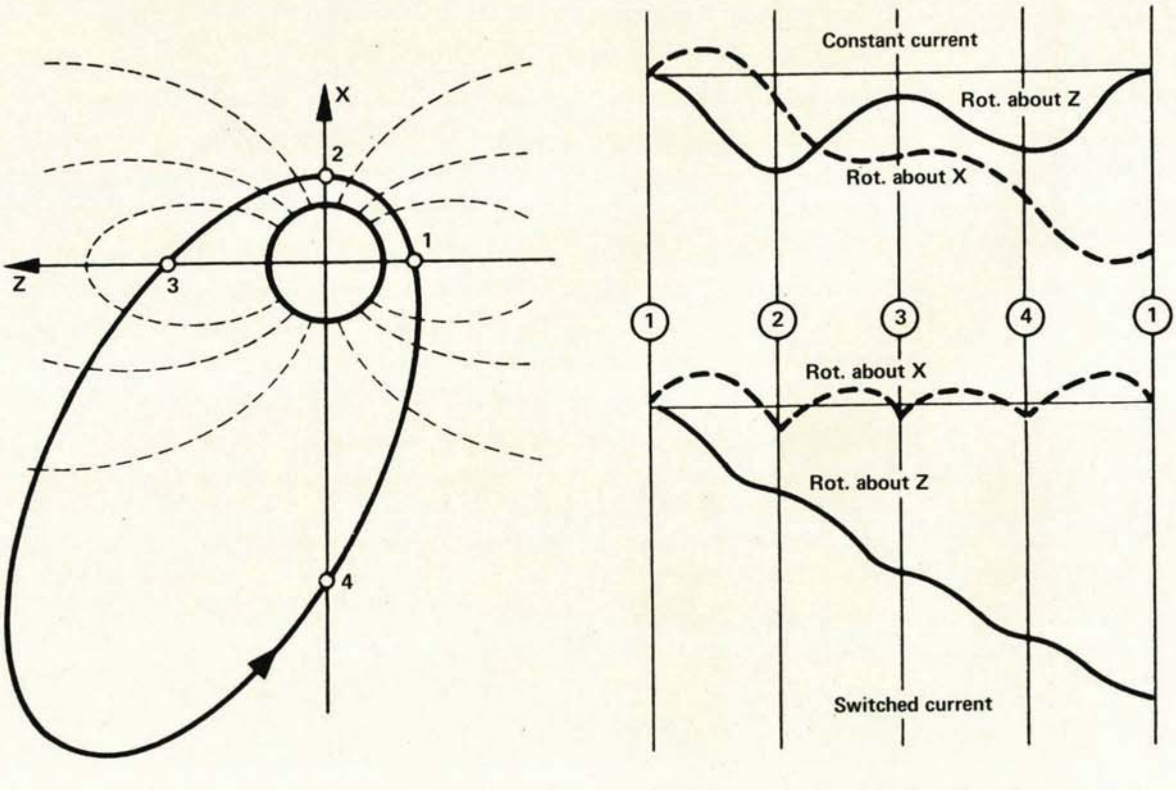

Figure 3. The quarter orbit torquing concept.

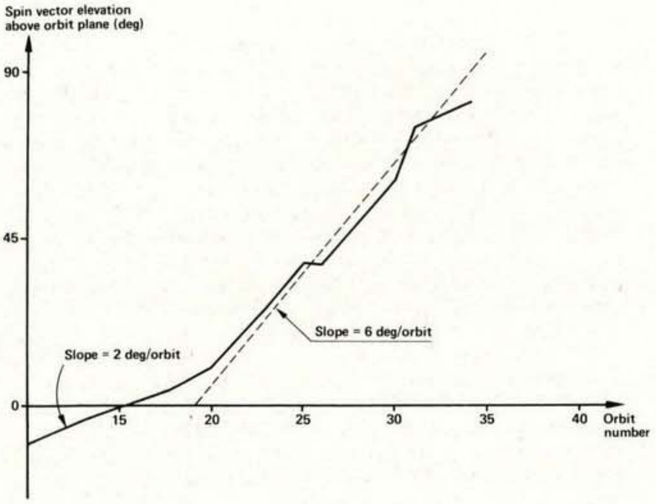

Figure 4. Maneuvering into cart-wheel mode.

the earth sensor (in accordance with mission planning) and because the magnetometer software was faulty (which, of course, was not planned). With only one angle thus determined, the attitude was in fact unknown. However, since there were no indications of large attitude errors, the planned 90 deg turn towards cartwheel mode was started anyway. The maneuvre was cautiously performed at a low rate, while carefully comparing the sun sensor output to the predicted output. The comparison indicated no problems so the maneuvre was continued until earth sensor data started to appear, thus making it possible to perform a full attitude determination. The attitude was as expected. After a few days, the magnetometer software was corrected, and the attitude determination system has been working flawlessly since then.

The Viking attitude determination and control concept is well suited for a class of satellites that require only medium attitude accuracy. Some advantages are:

- * The total avoidance of on-board computing capability lowers the satellite cost.
- * There are no ACS propellant-based limitations on the life-time of the satellite.
- * Any attitude maneuvres are possible.
- * The ground based computations keep the ground station satellite operators more active. Their system knowledge is expanded and so is their ability to detect error indications at an early stage.

Among disadvantages, these could be mentioned:

- * All attitude maneuvres are very time consuming.
- * The magnetic environment for the experiment is disturbed during the maneuvres. (Magnetorquer deperming is performed after each maneuvre to remove residual magnetism.)

In table 1, the major events concerning attitude control and dynamics during the mission so far are listed. Most of these took place in the very beginning of the mission. Viking was operational after six days and the final capability was achieved three weeks after launch.

A large number of small attitude corrections have been performed to keep the sun angle within a thermally suitable interval. The largest single maneuvre was the 180 deg turn performed in August. Such a maneuvre is needed twice a year to keep the sun from shining on the payload side of the satellite. The turn rate of the maneuvre which was performed at the lowest possible spin rate that still keeps the wire booms stretched, was 7.3 deg/day.

The spin maneuvres were performed at rates of appr. 0.2 rpm/hour when the booms were not yet deployed and appr. 0.013 rpm/hour after full deployment. The values coincide well with the predictions.

| DATE | ORBIT NO | EVENT | STATUS OF EVENT |
|---|---|---|---|
| 86-02-22 | 2 | Determine spin rate | 9.8 rpm (nom = 11.4 ± 2.4) |
| 86-02-22 | 2 | Switch on V2 experiment for attitude determination | V2 on confirmed |
| 86-02-22 | 2 | Monitor stiff boom deployment | Released and locked |
| 86-02-23 | 10 | Initiate 90 deg maneuvre | OK, completed during orbit No. 35 |
| 86-02-28 | 35 | Deploy wire booms to 20 m | Successful deployment, spin rate = 3.0 rpm |
| 86-02-28 | 35 | Deploy axial booms | Released and locked, wobble below 0.1 deg |
| VIKING IS NOW IN OPERATIONAL CONFIGURATION | | | |
| 86-02-28 ff | 35 ff | Start spin-up maneuvre | Functional nominal rate |
| 86-02-28 ff | 38 ff | Continue wire boom deployment to 40 m | 40 m state was reached three weeks after launch |
| 86-08-05 | 905 | Start 180 deg maneuvre and spin down | OK, completed within three weeks |

Table 1: Major attitude control and dynamics events.

## 4. DYNAMICS

A comprehensive analysis of Viking dynamics has been performed by Saab during the design phase. In particular, the analysis and the associated simulations have concerned the following areas:

- Dynamics during separation events.
- Body dynamics during and after perigee motor firing.
- Wire boom deployment dynamics including root damper action and wire tension.
- Rigid boom deployment dynamics.
- Dynamics of the central body and the booms during attitude maneuvring including spin rate control.
- Overall stability and disturbance sensibility of initial, intermediate and final boom configurations.

Part of the analysis that covered the first two points included a large number of simulations with random input data that describes the stochastical nature of some variables like the attitude errors and the rates associated with Ariane separation, spin up/down rocket burns, retention mechanism separation, wobble damper action and perigee motor burn.

A typical result of such simulations is shown in Figure 5, where the expected satellite pointing and wobble half an hour before first ground station contact is plotted. From the diagrams, the 2 $\sigma$ stochastical limits were estimated to $1.3^{\circ}$ of wobble and $2.7^{\circ}$ of pointing error. Due to the very limited set of sensors on Viking, the actual flight data for these variables could not be evaluated with accuracy. During the first period of Viking contact, oscillations with a 0.2-0.3 deg. amplitude were observed in the sun sensor read-outs. This at least confirms that the wobble was within predicted limits.

Most aspects of the boom deployments were very thoroughly simulated and analysed. Among the many results achieved, it could be mentioned that the expected wire boom out-of-plane oscillations during attitude maneuvring would be only 0.5 deg peak-to-peak. The largest oscillations would be experienced not during attitude control but during deployment. It was shown that the in-plane oscillations would reach a maximum if the deployment was stopped at a length of around 10 m, see Table 2 below.

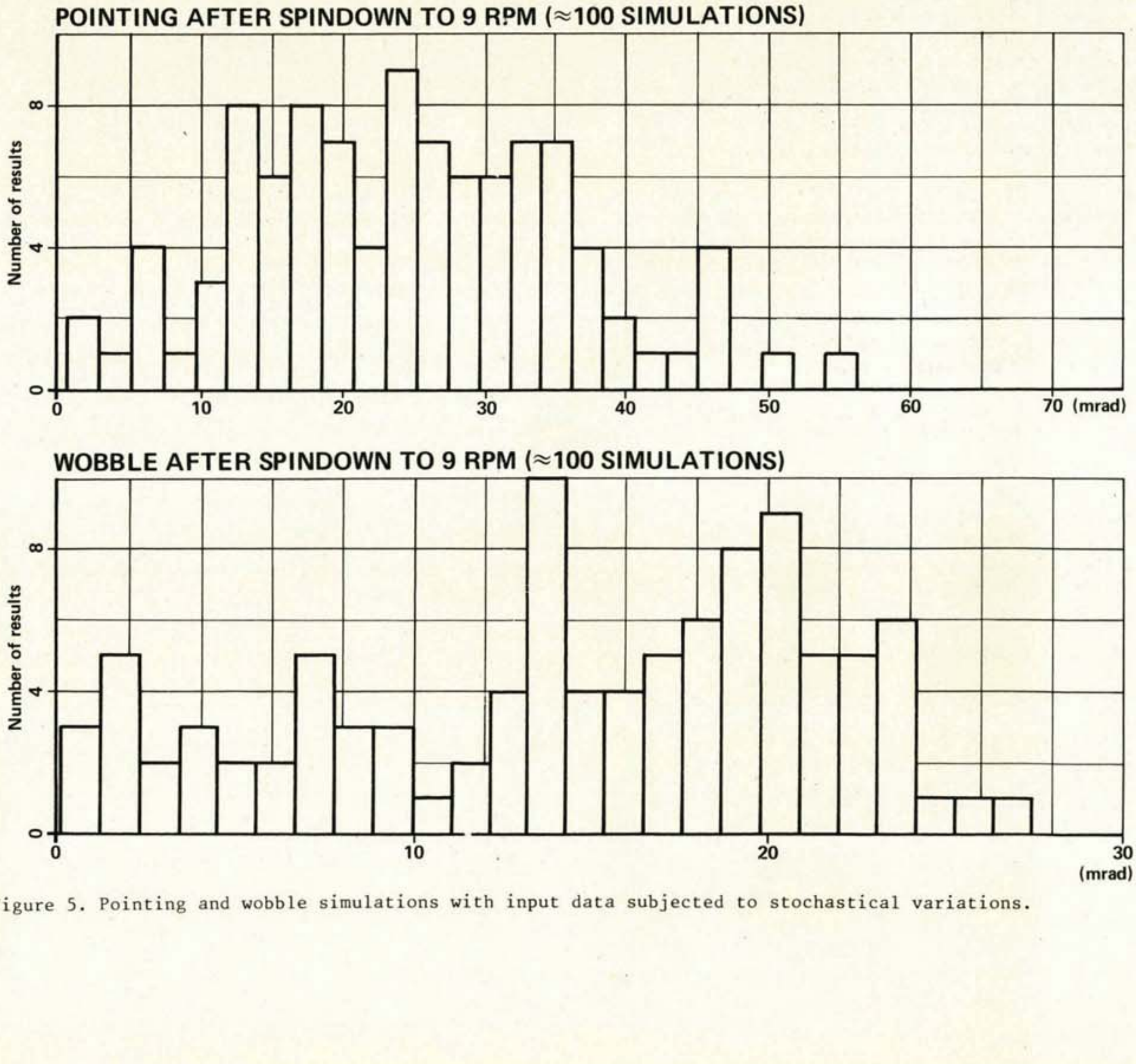

Figure 5. Pointing and wobble simulations with input data subjected to stochastical variations.

| Wire boom length at deployment pause (m) | Oscillation peak amplitude at deployment pause (deg) |
|---|---|
| 7 | 4.9 |
| 11 | 6.9 |
| 15 | 4.6 |
| 19 | 3.4 |
| 23 | 2.3 |
| 20 | 1.7 |
| 33 | 1.1 |
| 40 | 0.9 |

Table 2: In plane oscillations as a function of deployment pause length.

No boom oscillation sensors are available on Viking, so comparisons to actual flight data could not be performed. Damping of wire boom oscillations is handled partly by a friction type root damper and partly by internal bending of the wire boom, which dissipates the energy of the oscillation. The time constant of the root damper has been estimated at around 3 hours.