2

X-723-69-214

PREPRINT

NASA TM X-63685

DYNAMICAL PERFORMANCE TO DATE OF RAE-A (EXPLORER 38)

David L. Blanchard

MAY 1969

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

FACILITY FORM 602

N69-38560
(ACCESSION NUMBER)
(THRU)
54
(PAGES)
1
(CODE)
TMX-63685
(NASA CR OR TMX OR AD NUMBER)
31
(CATEGORY)

X-723-69-214

DYNAMICAL PERFORMANCE TO DATE OF RAE-A (EXPLORER 38)

David L. Blanchard

May 1969

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

ILLUSTRATIONS

TABLES

I. INTRODUCTION

A unique tactical scheme was devised, studied and then successfully used for the deployment and gravity-gradient capture the RAE-A. The attitude stability has been very good during and following deployment. It is the purpose of this report to describe in detail this sequence of deployment maneuvers and to present a comparison of the computer simulations to the observed attitude data during these deployments as well as a summary of data since deployment. The underlying concept used in all the deployments is called "dead beat" and is described in reference (a). Also reported in reference (a) is a rather exhaustive study of the use of this technique to achieve gravity-gradient capture under a wide range of initial conditions.

II. COMPUTER SIMULATIONS

Early in the RAE program it was recognized that a computer simulation was needed to adequately describe the flexible body dynamics of the spacecraft in its orbital environment. Reference (b) had infact demonstrated that the antenna deflections would be in the non-linear range even in the equilibrium state. Consequently, a very complete and sophisticated math model and resulting computer simulation were developed to describe the orbital dynamics of the RAE spacecraft including the large flexible antenna array under the perturbations of orbit eccentricity, thermal bending, solar pressure and gravity-gradient. This math model is derived and the simulation is described in references (c), (d) and (e). This simulation (GRAVFLEX) was then used to design a damper system, to perform a parametric study of the dynamics, and to develop the tactical scheme for deployment and gravity-gradient capture of the spacecraft. Also several simulations of 30 days of real time were run to estimate the long term stability.

Subsequent to the development of the dynamics simulation, an in-orbit simulator (IOS) of the RAE-A was developed to support the deployment phase and to be available for use if desired for the definitive data reduction during the mission phase of the spacecraft. Reference (e) is a detailed description of this IOS. A brief description of its structure and capability is included here. Figure 1 shows the modular construction of the system while Figure 2 shows a simplified data flow diagram.

An Executive Module controls the overall system by either calling the respective modules as they are required for performing their separate functions or as it is directed to do so by input control cards.

The function of the data analyzer as shown on Figure 2, is to interface between the spacecraft data and the other modules which use this data. The spacecraft data is usually input via tape but may be by punched cards. The analyzer converts all of the input data into a format and units which are usable by the other modules. In performing this function it reduces the T.V. boom tip data from line and dot positions into the in-plane and, out-of-plane deflections (in feet) which may be immediately used to give an understanding of these deflections without further processing. This conversion takes into account the gain and optical abberation corrections necessary to give accuracy commensurate with the half degree resolution of the T.V. system. There are several other functions which may be performed by the data analyzer such as filtering and smoothing of data, determination of rates, etc. These functions are explained in detail in the users manual which is reference (e).

The dynamics simulator module is basically the one which was developed very early in the program in order to study the dynamics and the deployment schemes as presented in reference (a) (i.e.: the GRAVFLEX program). The math model and simulation are described in some detail in references (c), (d), and (e). Only those modifications necessary to use it for flight support and to incorporate it into the IOS were made.

The corrector module is designed to be used in finding the optimum values of preselected parameters which minimize a function of the difference between the computed and the observed performance of the spacecraft. These parameters may include a variety of things such as antenna bending stiffness, their thermal gradient, etc. It was anticipated that this module would assist in defining an accurate mechanical model as well as in giving definitive attitude and tip positions. Some additional effort is needed to fully implement this aspect of the system for use in definitive data reduction.

The frequency analyzer module is designed to reduce a discrete block of time variable data to its component frequencies. It can be used to determine the frequency components of the antenna motions as well as the central body motions.

To use all of the information furnished by this IOS it is necessary to present it in some readily usable format. The display module can print out graphs on the printer or make a tape for use on the SC4020 or SC4060 plotters. The usual printout is available at two different levels. One level presents only a survey of the essential parameters while the other level is quite extensive and for use in detailed analysis. Also, real and simulated data may be presented from the Data Analyzer and Simulator respectively for a direct comparison of predicted versus observed data on an appropriate plot. Figure 2 shows how the information flows from one module to another until it is output in a usable format.

This IOS can be used in several modes. Perhaps the four most useful ones are: (a) to act as a stand alone simulation of the spacecraft dynamics (b) to analyze the frequency content of antenna motions or central body motions (c) to evaluate the antenna tip positions from T.V. data and (d) to perform corrections on the significant parameters such as EI and ΔT by use of the predictor corrector scheme.

It was necessary to include the usual attitude sensors as well as some sensors which are particular to this satellite in order to provide the information necessary to accurately determine the spacecraft and antenna motions and to effectively use the IOS. The usual magnetometers and solar aspect sensors are used to provide the central body attitude. The specialized sensors include a T.V. system which is used to give boom tip information, an angle indicator to give the angular relationship between the damper and central body, and boom length indicators to provide the length of all booms except the dipoles. This information is needed both for the dynamics and for the experiment.

III. DEPLOYMENT AND CAPTURE

Preliminary Maneuvers

Table I lists a chronology of events from launch on 4 July 1968 to the completion of the final deployment on 8 October 1968 at 19:42. After launch on 4 July the spacecraft was placed in a very circular orbit with an eccentricity of about .0015. A yo-yo was used to despin from the excessive spin rate of about 90 rpm to about 3 rpm. A magnetic torquing system was then used for two days and reduced this to about .4 rpm, at which time the enhanced hysteresis damper was activated. After several days in this mode it became apparent that the closed loop magnetic control system was inadequate to provide the necessarily low spacecraft tumble rates. This may have been due to solar pressure torque on the solar celled paddles and/or a resonance type interaction between the magnetic field and the dynamics. Consequently a "fly by wire" mode was instituted which was reasonably successful, however, impossible to predict. This lack of predictability necessitated the institution of real time attitude determination. Roger Werking of T & D.S. and his support contractor were able to provide this information with a quickly devised system called MINI-TRIAD. With this real time attitude it was possible to ascertain the proper time for initiation of deployment.

The damper boom mechanism package was pushed out prior to any boom deployment since analysis indicated that the acceleration of deploying this package could generate oscillations of the primary booms if it were deployed while the booms were in the extended configurations and these oscillations are not readily damped. See reference (f). The damper package was deployed on 16 July 1968 at 18:55. The spacecraft and damper package relative motion during and subsequent to deployment indicated that this motion was critically damped as had been calculated and predicted. Subsequent to this the magnetic control system was used to maintain the low tumble rates and provide the desired initial angular conditions for deployment.

Deployment to 450 Feet

Reference (a) recommended a dead beat deployment of the primary booms (the X antennas) to this length of 450 feet and then a study of the dynamics to verify the computer simulation. It was concluded in reference (a) that capture would be successful if the initial conditions were less than 20° in roll, 20° in pitch, and 40° in yaw with rates less than twice orbital. Once these limits were established it was rather straight forward to establish the most probable geographic sub orbit location where the magnetorquer would provide these conditions. Figure 3 presents this favorable location based on the magnetic field declination at the surface of the earth and the anticipated performance of the magnetorquer system. The anticipated performance was that the spacecraft z axis would point within 5° of the local magnetic field near the magnetic poles. This gave the general area for 1st deployment with station coverage by Rossman. The second deployment in a single dead beat is determined primarily by the condition that the pitch angle (β) goes to zero and for RAE-A this occurs about one half orbit after first deployment. (See "dead beat" description in Reference (a)). For an antenna half angle of 30° in this orbit, it was predicted in reference (a) that this coast time (time between deployments) should be about 135 minutes. However, this coast time is very sensitive to the antenna half angle and somewhat less sensitive to initial conditions. Measurement of these boom angles at the time of final assembly indicated an average half angle of 27.8°. When the measured half angles were used in the simulation, the coast time was from 100 to 110 minutes depending upon initial conditions. This fixed the general location of 2nd deployment over Australia with Ororal station coverage.

Preparation was made for deployment on a favorable orbit which entered the area of Figure 3 at about 17:00 GMT on 22 July 1968. The real time support of T. & D.S. was set up to provide information on the spacecraft attitude on a continuous basis from about 16:30 GMT through damper deployment. At 17:02 the recommendation was given to deployment. Deployment was implemented at 17:02:36 from the conditions indicated in Table II.

The first deployment stopped the booms at an average length of about 364 feet. See Table II for a complete listing of initial conditions, deployment rates and lengths. Immediately following this several parametric computer simulators were made to predict the length of the coast time. Table III gives a list of the various predictions and the times of actual occurrence of the events for each of the several deployments. The first predictions were based on nominal spacecraft parameters which were measured before launch and they predicted times for 2nd deployment of 18:51, 18:47 and 18:47 GMT. It should be noted that due to the finite time of boom extension, which is about three minutes for this deployment, it was planned that initiation of 2nd deployment should anticipate the pitch going to zero ($\beta \rightarrow 0$) by about 2 minutes. This time is already subtracted from the above predictions. As mentioned above, several parametric deployment cases were run during this coast period in anticipation that the in flight antenna half angle might not be that measured on the ground due to lack of straightness, poly angle, etc. One of these cases was found to fit the data best as the attitude was being monitored in real time. The agreement with real time attitude data during this deployment and following it for about 2 orbits is shown in Figures 4, 5, and 6. From the agreement during the coast period it was possible to derive a better estimate for the time of 2nd deployment. Two estimates were made at about 18:30 that second deployment should occur at 18:43 and 18:44. See Table III again. Extrapolating the real time data it was possible to anticipate the zero crossing for the pitch angle. From this data and the computer simulations a decision was made to command second deployment at 18:44. The final predictions were therefore either exact or at worst one minute off out of a total of 101 minutes of coast time. The predictions which were made several months before deployment bracketed this time by predicting 100 to 110 minutes. The correspondence between observed and predicted attitude during the 2 1/2 orbits presented on Figures 4, 5, and 6 is quite good, considering this was the first time that it was possible to critically compare the math model and computer simulation to real data and the first time that these long booms had been deployed in the actual space environment.

The initial conditions were so favorable and the timing of the primary deployments so precise that the residual motions were only about ±10°, in roll, ±5° in pitch, and ±5° in yaw. The computer predicts showed that yaw (γ) would only go to a minimum of -5° within the next several orbits. This was unfortunate because the equilibrium position in yaw with the damper extended to 280 feet is about -19° and yaw should be as near as possible to this value when it is deployed. Consequently, the damper deployment would introduce a transient of about 14°. The simulations showed that yaw should be near this minimum value of -5° at 21:45 to 22:00. Real time attitude determination was initiated a few minutes before this time and the predicts again agreed well with observed data. The damper boom was deployed at 21:45 to a length indicated at 270 feet. It was later corrected to 276 ft. As predicted this introduced an undesirable but unavoidable oscillation in yaw of ±15° about the -19° equilibrium position.

The 60 foot dipole was deployed the next day at 15:09 on 23 July 1968. There were no apparent perturbations caused by this deployment.

Television pictures were taken just prior to 1st deployment to verify the spacecraft attitude, and shortly after 1st and 2nd deployment to look at the booms. The pictures taken after deployment showed transverse tip motion at such a rapid rate that it left a blurr on the picture. These motions were three to four feet in amplitude and the type of thing one might expect due to the transient of deployment stops and starts. When the T.V. pictures were taken about one half orbit later this high frequency motion was gone. Subsequent to this, T.V. pictures were taken about once per orbit until 30 July. On 30 July one complete orbit of T.V. pictures was recorded. Reduction of this data has given a tentitive average tip position. This data is discussed later on page 10 of this report.

A concentrated effort was made to fit the computer model to the observed data at this length of 450 feet. Without any adjustment of parameters the libration period results were:

Observed	1st Simulations
α = 124 min.	α = 116 min.
β = 158 min.	β = 159 min.
γ = 330 min.	γ = 345 min.

These agree to about 6% which is very acceptable for a first guess but not good enough for definitive effort. After some adjustment it is now possible to obtain agreement to about 1%. Needless to say, most of the parameters measured on earth under one "g" seem to have been measured quite accurately and the math model seems adequate when one obtains such agreement.

Following this deployment to 450 feet the hystersis damper and the material damping in the antennas continued to slowly damp the libration motions. By the time deployment to 600 feet was initiated on 24 September 1968, the motions were ±2° in roll about a -2° bias caused by the damper, ±3 in pitch about 0° and ±10° in yaw about -19° bias caused by the damper.

IV. DEPLOYMENT FROM 450 TO 600 FEET

It was recommended that the deployment from 450 to 600 feet be a dead beat as described in reference (a). Table IV presents a summary of 19 runs which were made based on the expected initial conditions of 24 September 1968. The residuals mentioned in the table are the maximum peak to peak librations observed following complete deployment.

Several things became apparent from the study. Runs 748 and 768, although not quite the same I.C.'s, indicate that there is very little difference in residual motions whether one performs the maneuver with the damper caged or uncaged. Consequently, due to a problem from an electrical transient caused by uncaging the damper as well as other complicating factors it was recommended that this deployment be performed without caging the damper.

The coast time between 1st deployment and 2nd deployment is a minimum of 78 minutes when the initial pitch angle is -3° or 0.0° and going negative and a maximum of 85 minutes if the initial pitch angle is +3° or 0.0° and going positive. This gave a nice bound on the coast time.

Yaw angle is the determining factor for initiating this deployment and from the Table IV results it is apparent that about -11° is optimum (see run 759) but that anything from -13° to -8° is acceptable. Further, run 765 compared to 752 indicates that a variation of 15 feet or so in stopping lengths doesn't significantly affect the residual oscillations. Another important factor presented earlier in Reference (a) is that the 280 foot damper is adequate for this length of 600 feet of primary booms consequently no damper deployment was necessary.

The observed oscillations of yaw were very regular and made it possible to predict quite precisely by hand calculations for at least two days in advance. Consequently, data from 22 and 23 September were used to predict times for initiation of deployment on 24 September. It was predicted that yaw would be at about -13° going toward zero at 19:00 on 24 September and that this would give the desired initial conditions which were also commensurate with station coverage for both phases of the deployments. As shown on Figure 9, the real time attitude determination agreed with the hand calculated prediction to within 0.5°. This means, that the yaw period was very regular and known to within a fraction of a percent. Satisfactory initial conditions for deployment were achieved shortly after 19:10 on 24 September 1969, when yaw reached -9°. Consequently, deployment was initiated at 19:13. Figures 7, 8, and 9 show the simulation of the deployment compared to the observed data. No simulation runs were made during this deployment because of the previous success of fitting the dynamics. The coast time was 78 minutes which is exactly that predicted for similar pitch (β) initial conditions in runs 757 and 759 of Table IV made several days before this deployment. This as well as the spacecraft motions on Figures 7, 8, and 9 show quite close agreement with predictions in view of the fact that the attitude measurements are some what scant during this deployment and only stated to be accurate to 3 degrees.

The initial conditions with the exact boom lengths for this as well as the other two deployments are given in detail on Table II. It should be noted that the values in Table II are those which were corrected after full deployment since this gave a well defined point on the calibration curves.

V. DEPLOYMENT FROM 600 TO 750 FEET

A deadbeat was first considered for the 600 to 750 feet deployment. It was anticipated from the behavior of the dynamics that roll and pitch would be less than 3° and yaw would be oscillating from about -15° to -5° on 8 October which was the day set for this deployment. Table V shows a series of runs made based on this band of initial conditions. However, for this deployment the situation is considerably more complex than the previous deployments because the initial conditions of the antennas is now very significant as well as very difficult if not impossible to deduce in real time. The most significant contribution of Table V is the demonstration of this fact by a comparison of runs 780 and 808 which have identical central body initial conditions. There is almost a factor of two difference in yaw motions from these two runs where only antenna initial conditions have been changed.

From a consideration of these results it became apparent that some new deployment technique was needed to insure that the libration motions would be small. It had been suggested earlier that it might be desirable to phase the antenna deployment such that it would minimize the antenna oscillations but since their frequency is not commensurate with the pitch libration it is difficult to use this with a pitch deadbeat. After much thought over the problem Mr. Ed Lawler of AVCO proposed a unique combination of previous suggestions as a solution to the problem. The idea is presented in simple essence in Figure 10. The scheme was to deploy a pair of antennas (not all four) to 680 feet at t_1, wait until the antennas have oscillated a half period and are nearest to the spacecraft z axis at t_2 (i.e.: this is almost their equilibrium position for a 750 foot length) and immediately deploy this pair to 750 feet. The deployments take place in a matter of about 2 minutes (called Δ on Figure 10) while the natural period of the antenna oscillations is of the order of 60 minutes. The double deployment causes the whole array to pitch out to some maximum pitch overshoot at t_3. Then the antenna array is allowed to coast while the pitch libration motion returns it to the local vertical just as in the simple deadbeat. However, at a time which is half an antenna oscillation prior to $\beta = 0$ (i.e.: at time t_4) the other pair of antennas is deployed to 680 and then as the pitch angle approaches zero at t_5 they are deployed to the full 750 feet. Thus both the libration motions and antenna motions have been phased so as to end up near their equilibrium position at t_5.

As described above, Figure 10A shows the libration motion and position in orbit while Figure 10B shows the position of a typical long boom relative to its straight position and the z axis at the appropriate times. Figure 11A shows a phase plane plot for the boom motions while Figure 11B shows the phase plane plot for the pitch libration motions.

It is apparent from a comparison of run #1 on Table VI to run #774 of Table V that this double deadbeat significantly improves the residual libration motions since it reduces the yaw oscillations by a factor of 5. The damper was uncaged during all these study cases. It is also apparent that this deployment scheme is almost independent of initial antenna deflections at these long lengths where the deflections may be quite large. (i.e.: up to 250 feet deflections at 750 feet lengths.) In fact this seems to be the significant contribution of this "double deadbeat" deployment scheme. The coast times T_1, T_2, T_3 on Table VI refer respectively to the times between t_1 and t_2; t_2 and t_4; and t_4 and t_5 on Figure 10A.

Figures 12, 13, and 14 show the prediction and observed data from this "double deadbeat" deployment from 600 ft. to 750 ft. boom lengths. This time the agreement is not as good as one would desire. Several factors may be responsible. The antenna initial conditions are unknown and the flexible nature of the spacecraft makes these as well as other initial conditions quite critical. Perhaps the most significant factor is the error bar on the observed data which is about 3°. In the previous charts this uncertainty is a small fraction of the amplitude while on Figure 12 the error bar is larger than the measured amplitude and on Figure 13 it is a significant fraction.

The damper was extended from 280 feet to 315 feet at 19:42 on 8 October 1968. The yaw position was not at an optimum position, however, it was about as good as could be obtained within a reasonable delay after primary boom deployment and also be commensurate with station coverage. Again this introduced some yaw motion with an amplitude of about ±8°. Since the damper system was designed for the inertias of these full out lengths and a 6000 Km circular orbit, it should damp the libration motions more effectively than at the shorter lengths. This seems to be verified since the libration motions were reduced to about steady state values within 48 hours after this last deployment on 8 October 1968.

VI. POST DEPLOYMENT DYNAMICS PERFORMANCE

A discussion of the spacecraft dynamics is best described in terms of its performance during and immediately following deployments, during the period of 100% sunlight orbits, and during the period of time when each orbit experiences some shadow. The performance during the deployment period has been discussed in the previous sections as it pertained to the deployment maneuvers. In this section all the attitude data during and following the deployment period will be reported. The deployment period covered from 22 July 1968 through 8 October 1969. The inclination of 121° and other initial conditions for the orbit were selected so as to obtain about 180 days of full sunlight orbits after which the spacecraft is occulted on each orbit for about 120 days. This period of 100% sunlight existed from about 6 July 1968 through 19 January 1969. Figure 15 shows how the shadow builds from a few seconds each orbit on 19 January 1969 up to a maximum of about 39 minutes in mid March and reaches 100% sunlit orbits again on 19 May 1969.

Considering the deployment period first, Figure 16 shows a hand smoothed plot of the quick look central body libration motion following the first deployment on 22 July 1968. This data is quite continuous up through 1 August. Following that time and until the next deployment only about 4 hours of quick look data were collected each day since the spacecraft dynamics were so well behaved. These libration motions are not quite as regular as they were later at 600 ft. lengths. Only on one occasion, 0900, 28 July 1968, does there appear to be any increase in the amplitudes of the motions. There is some question as to the validity of this data due to the fact that the two vectors being used to determine attitude were almost co-linear at this time. There is a small trend of decreasing amplitude in the motion about all axes. The damper system is designed for the 750 ft. lengths and although effective at these shorter lengths of 450 feet it is not near optimum.

The antenna tip positions were observed with the onboard T.V. cameras. Unfortunately, the lower tips could not be distinguished from the bright earth background. The tip motions seemed to be in an elliptical type pattern about some average position. This average position was about 10 feet out of plane and tending to be away from the sun. The inplane position was about 20 feet away from the rigid position toward the radius vector from the earth thru the c of m of the spacecraft. This is commonly called the gravity gradient sag. The half amplitude of the antenna oscillations about this position was about 10 feet.

Figure 17 shows the attitude behavior from deployment to 600 feet on 24 September 1968 through 28 September 1968. The motion at this length is very smooth and regular. Again, only a slight amount of damping is apparent. The equilibrium position of the antennas was about 20 feet out of plane with about a 55 feet inplane gravity gradient sag. The oscillations about this position were about 30 feet half amplitude.

Figure 18 shows the central body attitude following the deployment to 750 feet on 8 October 1968. This data picks up after that plotted on Figures 12, 13, and 14 and is the observed data plotted at two minute intervals. This is the actual data and not like the two preceeding figures (Figure 16, 17) which are hand smoothed curves. A higher frequency motion appears superimposed on the libration oscillations which was hardly observable at the shorter antenna lengths. The higher frequency seems to be quite consistent at a 20 minute period with an amplitude of about ±1°. These higher frequencies are clearly distinguished from the much longer period libration motions.

The damper system was designed for these full out lengths and a 6000 Km circular orbit. Consequently, the damping should be more effective at the 750 ft. lengths than at the shorter ones. This seems to be verified since the first yaw oscillation of ±7° damped within eight yaw oscillations to ±4°.

As mentioned previously the bright background of the earth made it impossible to observe the positions of the lower boom tips with the 4-gray level T.V. system on the spacecraft. Just following the deployment to 600 feet one of the upper T.V. cameras went out so only one boom tip could be observed at this length of 750 feet. This boom tip appeared to have an average out of plane position of about 25 feet just following deployment to 750 feet. This bias changes as the orbit precesses in time since the booms tend to bend away from the sun. The average in plane position was about 120 feet due to gravity-gradient sag.

The spacecraft dynamics since deployment have been so well behaved that it is uneventful and it is only necessary to summarize it briefly. From 10 October 1968 until first shadow on 19 January 1969, the libration motions have consistently been less than ±3° in roll and pitch and less than ±4° in yaw. During the shadow period (19 January 1969 - 19 May 1969) there has been only a slight build up in the yaw librations to about ±5° while roll and pitch have remained less than ±3°. For completeness, Appendix A has been added to show typical data during this shadow period.

The initial plans were to perform a well defined study on the spacecraft dynamics so as to validate both the math model (i.e., computer simulation) and the material characteristics measured here on earth. The IOS was designed for this purpose. As it turned out the deployment and general performance of the dynamics have been in quite close agreement with the model with very little adjustment. On the other hand it is quite a complicated and difficult problem to obtain the very close correlation which one would desire and it would require a vast amount of data and simulation to perform such a study with validity. This is further complicated by the excellent behavior of the dynamics since the oscillations are so small they are difficult to measure accurately as well as to simulate. Consequently, most of the effort has been confined to matching the deployment dynamics, matching the libration periods, and bounding the amplitude motions of the librations and the antenna oscillations. This sort of effort is a continuing process and it may be reported in more detail later.

From the present fit of simulation to data it appears that the thermal gradient across the booms is about 1.0° to 0.75°F, the EI is about 2000 to 2200 $\#in^2$, and the damping in the antennas is at least 0.00732 of critical. These values bound those measured on earth before launch. A simulation study of the deployments indicates that the antenna half angles agree well with those measured before launch (this included the effect of ploy).

The one parameter which does not seem to agree with preflight measurement is the plane of the damper motion with respect to the plane of the primary antennas. This is probably an effective angle and thermal bending, ploy angle and/or lack of straightness of the 630 ft. damper boom tend to make it appear to have an effective angle of 63.5° instead of the measured 66.5°.

VII. CONCLUSIONS

1. The dynamical motions of RAE-A during deployments to 450 feet, 600 feet and 750 feet were well behaved.

2. The spacecraft motions following the deployment period in both the 100% sunlight orbits and occulted orbits have been well behaved.

3. In the region where boom deflections are small and the dynamics essentially rigid body, the deadbeat deployment scheme is extremely effective in quickly achieving capture with very small initial transient librations.

4. The three dimensional behavior of this deadbeat deployment has been very accurately predicted with the GRAVFLEX computer simulation.

5. The boom parameters as measured on the ground seem to be quite adequate in acquiring a model fit for the deployment and acquisition phase.

6. In the very flexible region where large boom deflections occur, the double deadbeat is extremely effective in quickly acquiring steady state libration motions.

7. The three dimensional behavior of the double deadbeat deployment has been accurately simulated with the GRAVFLEX computer simulation even where the boom deflections may have been quite large.

ACKNOWLEDGMENTS

I would like to express my appreciation for the very competent programming support of Mrs. Marge Johns and Mr. William Burchard especially during some of the rather hectic days of deployment; also, to Dr. Ralph Barclay who capably directed the follow on effort with AVCO to develop the I.O.S.

REFERENCES

(a) Parametric and Initial Condition Study of the RAE Dynamics, X-723-68-209 by David L. Blanchard.

(b) Equilibrium shape of an Array of Long Elastic Structural Members in Circular orbit. NASA TN-D3193 by Thomas W. Flatley.

(c) Interim Report for Investigation of the Dynamics of a V Antenna for the RAE Satellite, Contractor Report #962.

(d) Interim Report for Investigation of the Dynamics of a V Antenna for the RAE Satellite (Final Report for Phases B and C).

(e) Users' Manual for RAE In-Orbit Simulator Computer Program. January 1969, AUSSD-0017-69-CR. Contract NAS5-11050.

(f) RAE Antenna-Damper Package Deployment Interaction. X-723-69-251, by Joseph V. Fedor and Bowden W. Ward.

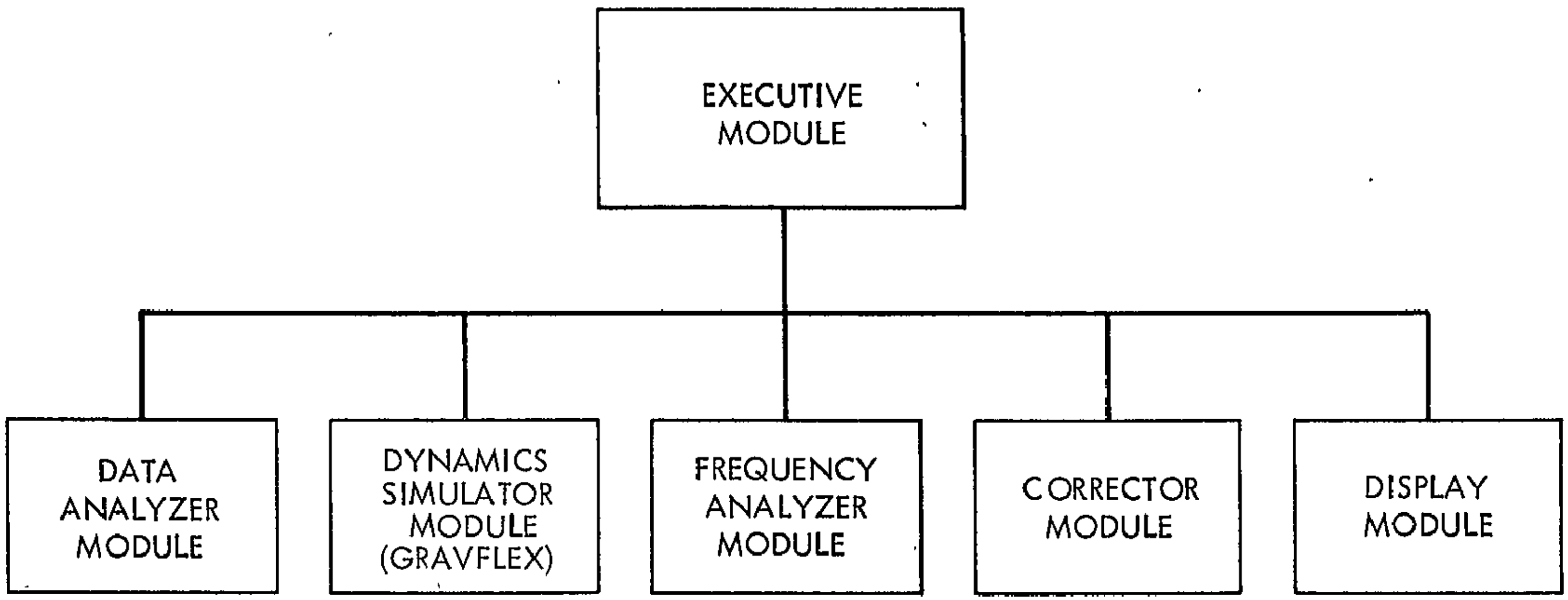


Figure 1. Modular Structure of the In-Orbit Simulator of RAE-A

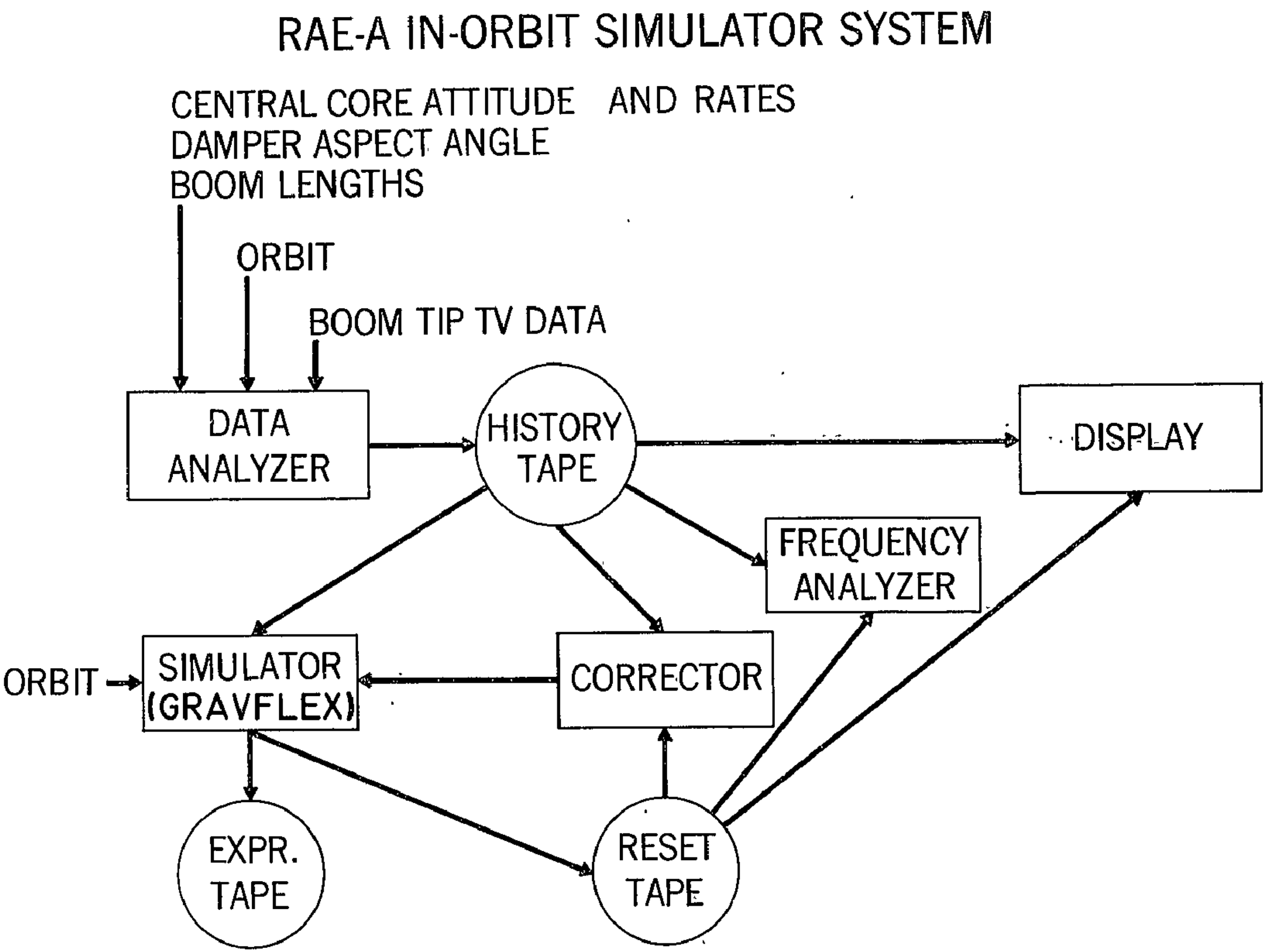


Figure 2. Block-Flow Diagram of the In-Orbit Simulator of RAE-A

FAVORABLE SUB ORBIT LOCATION FOR INITIAL RAE-A DEPLOYMENT

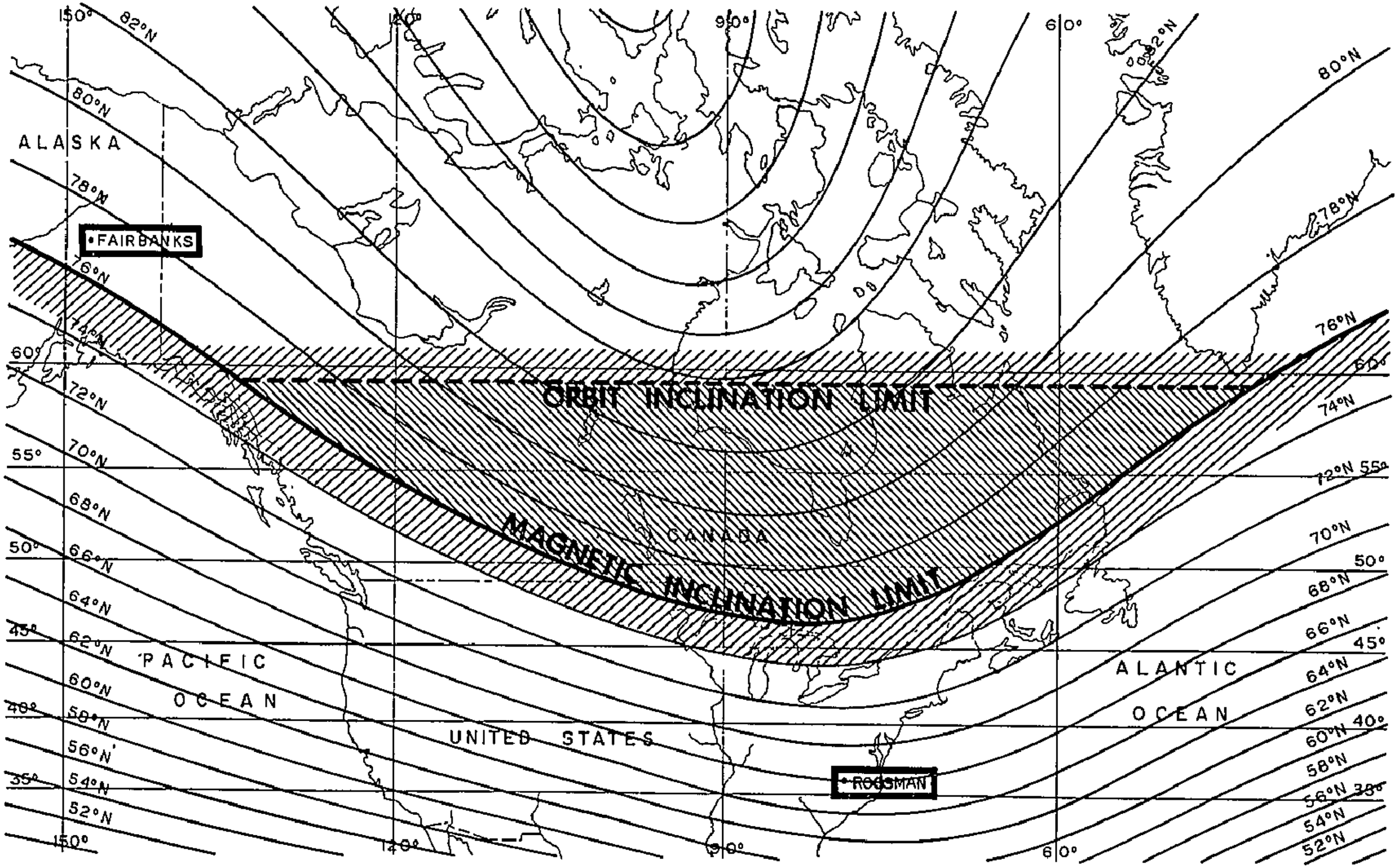


Figure 3. Favorable Sub-Orbit Location for Initial RAE-A Deployment

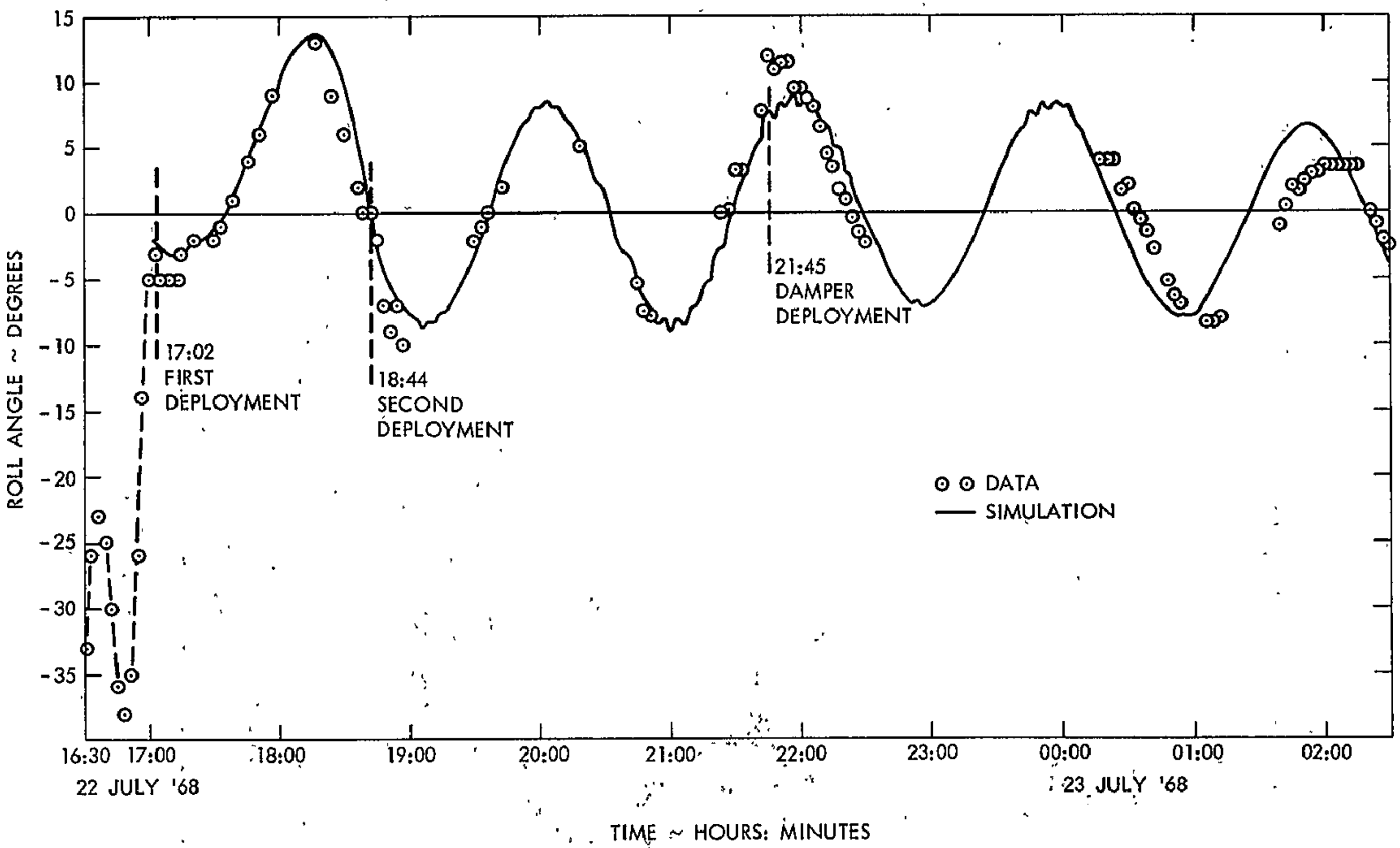


Figure 4. Roll Motion During Deployment to 450 feet (Simulated and Observed)

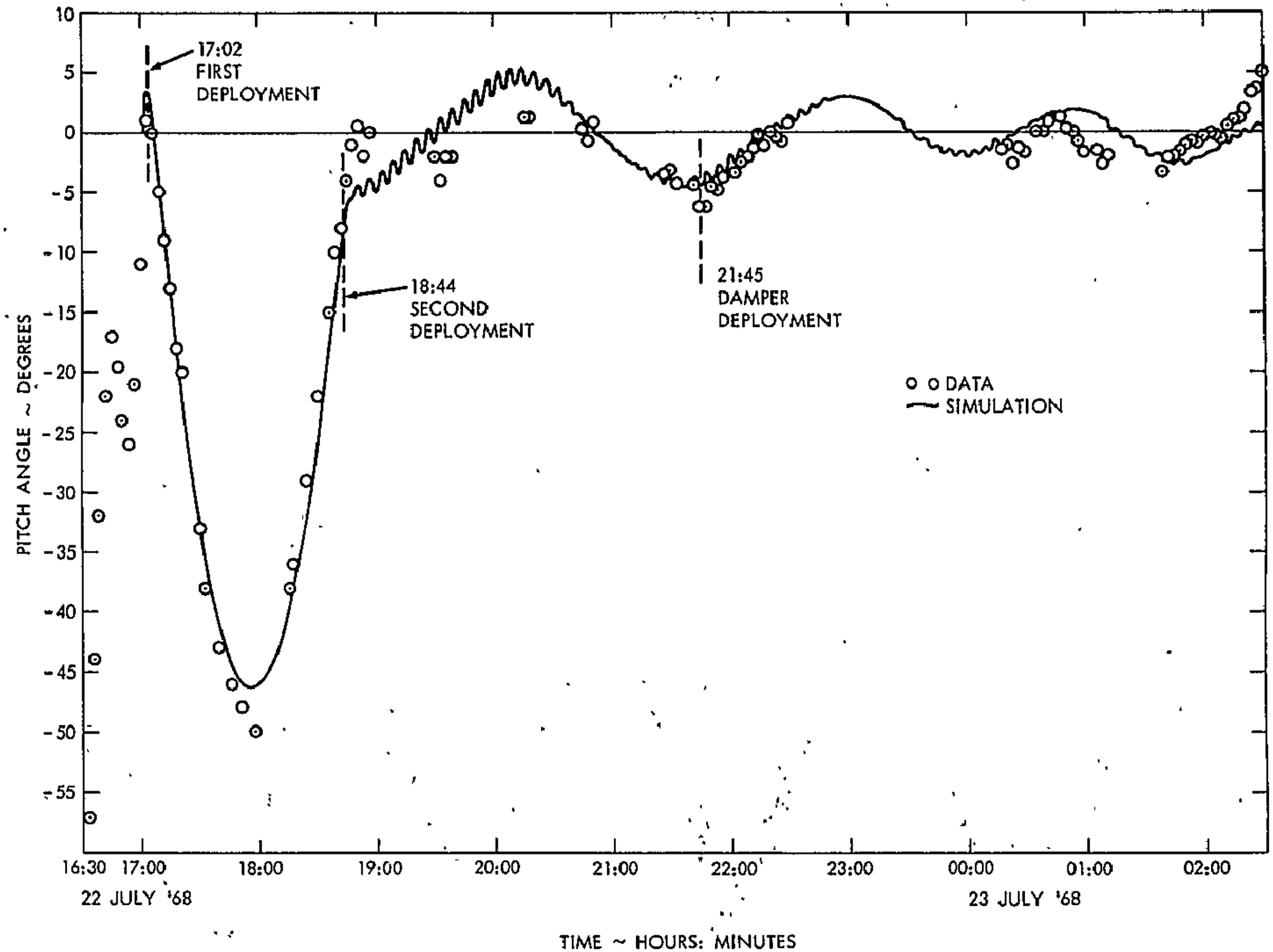


Figure 5. Pitch Motion During Deployment to 450 feet (Simulated and Observed)

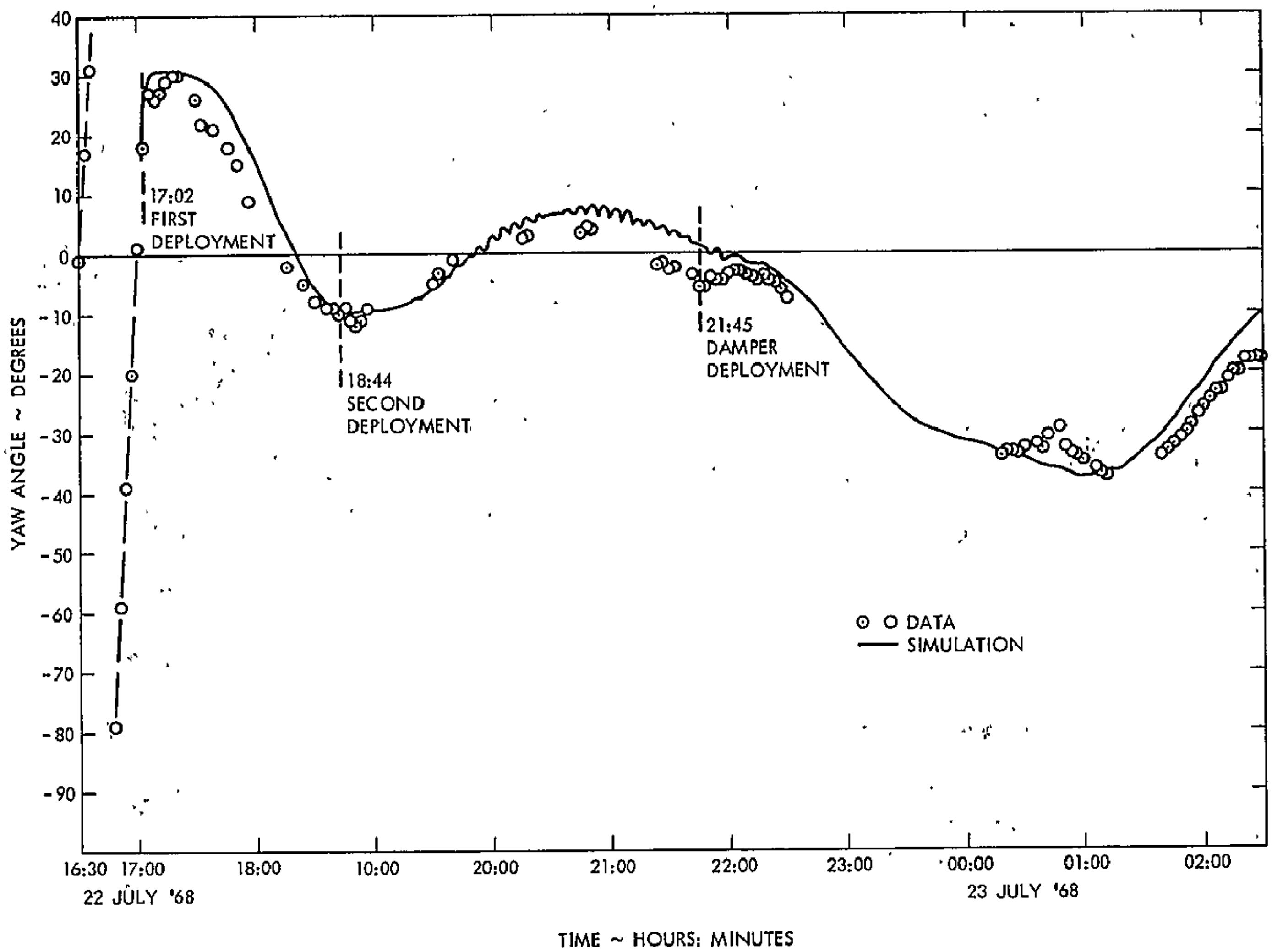


Figure 6. Yaw Motion During Deployment to 450 feet (Simulated and Observed)

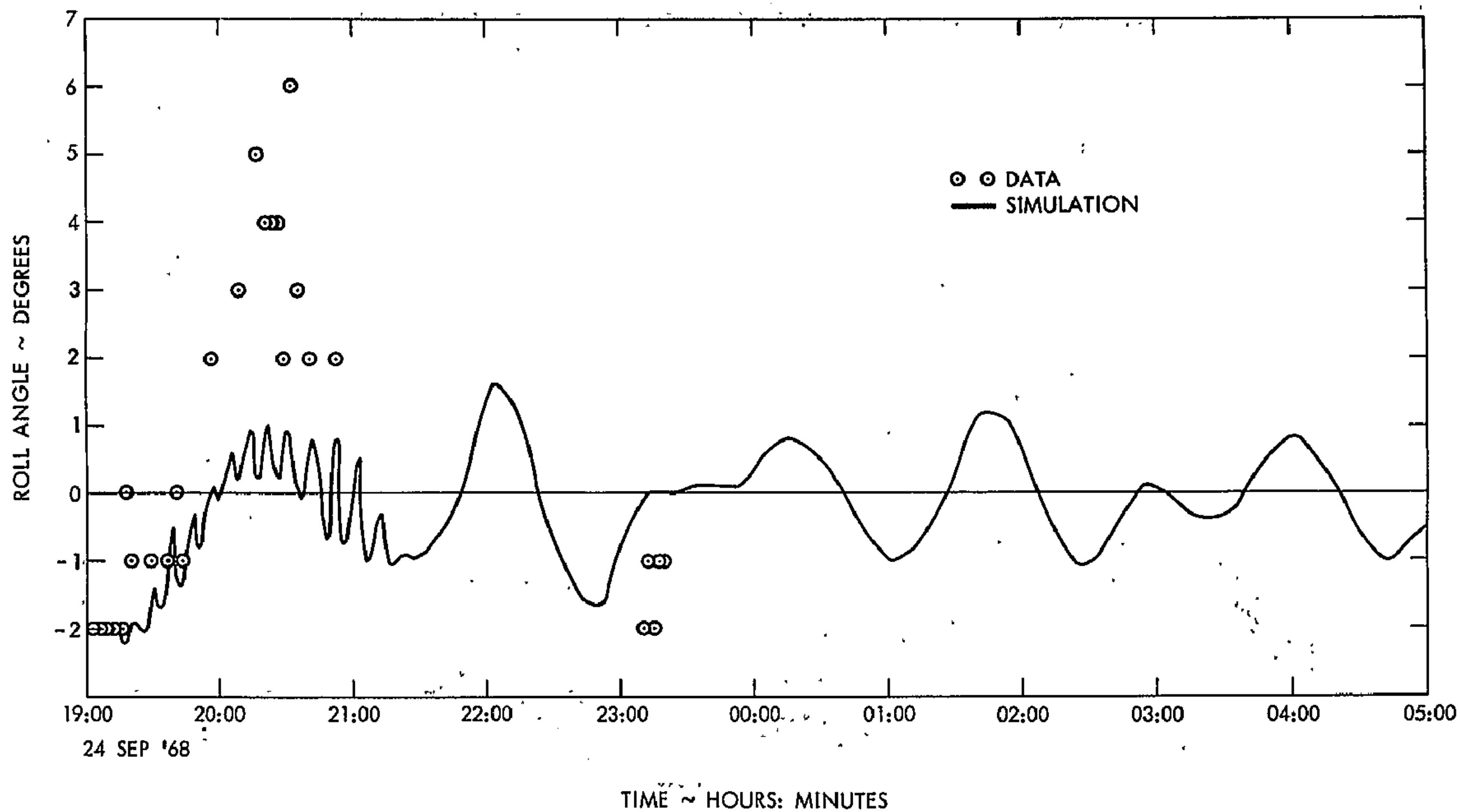


Figure 7. Roll Motion During Deployment 450 to 600 feet (Simulated and Observed)

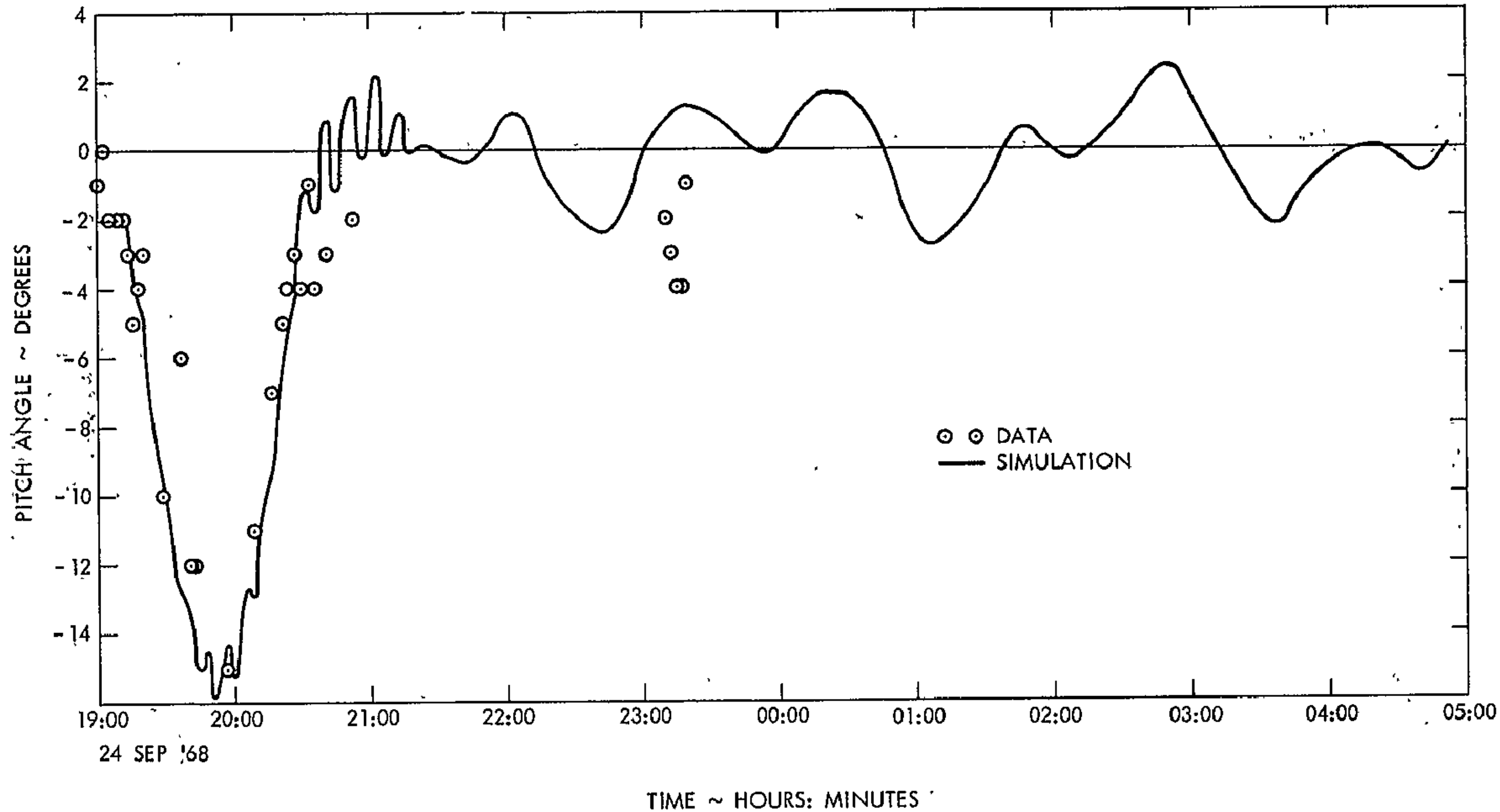


Figure 8. Pitch Motion During Deployment 450 to 600 feet (Simulated and Observed)

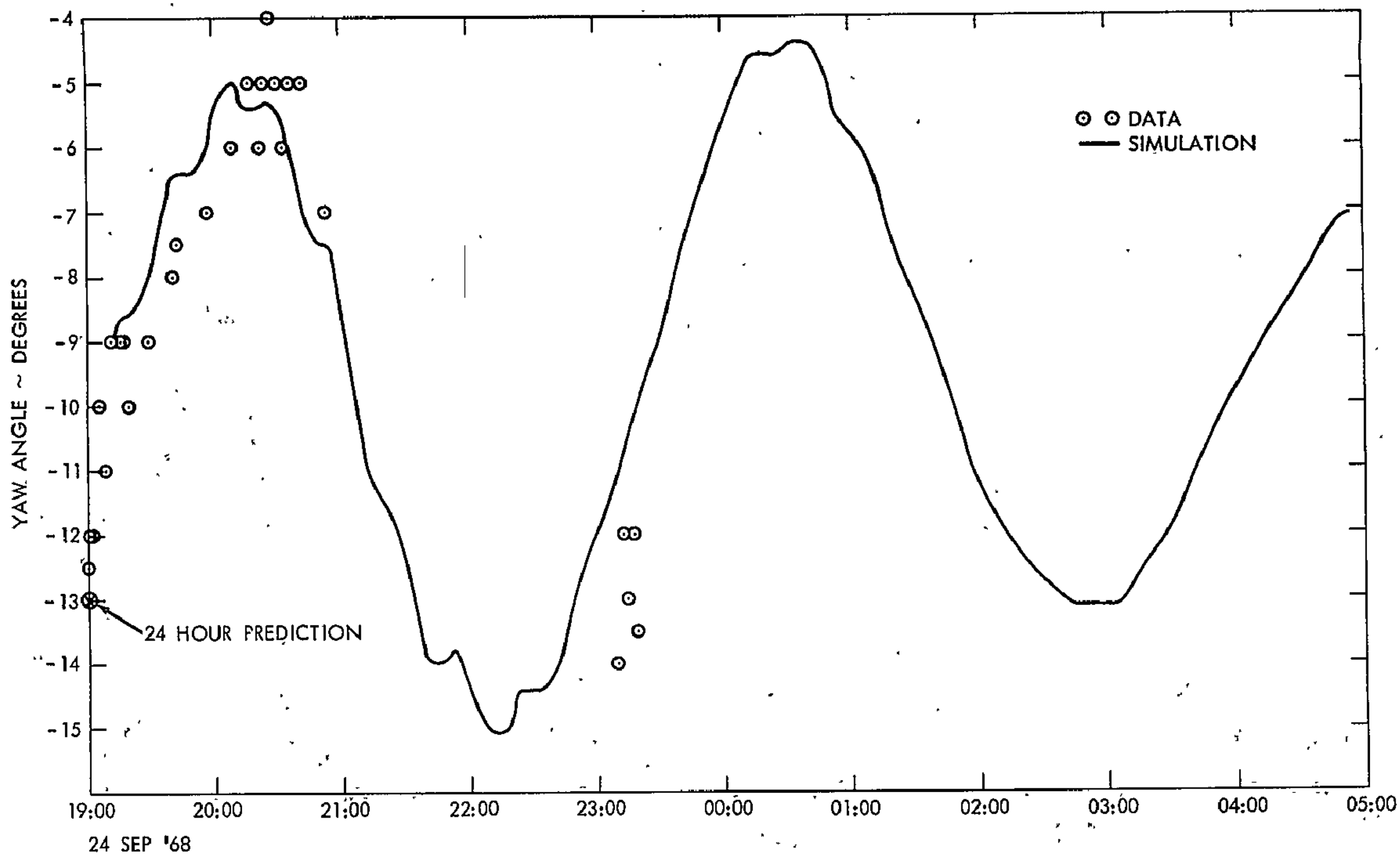
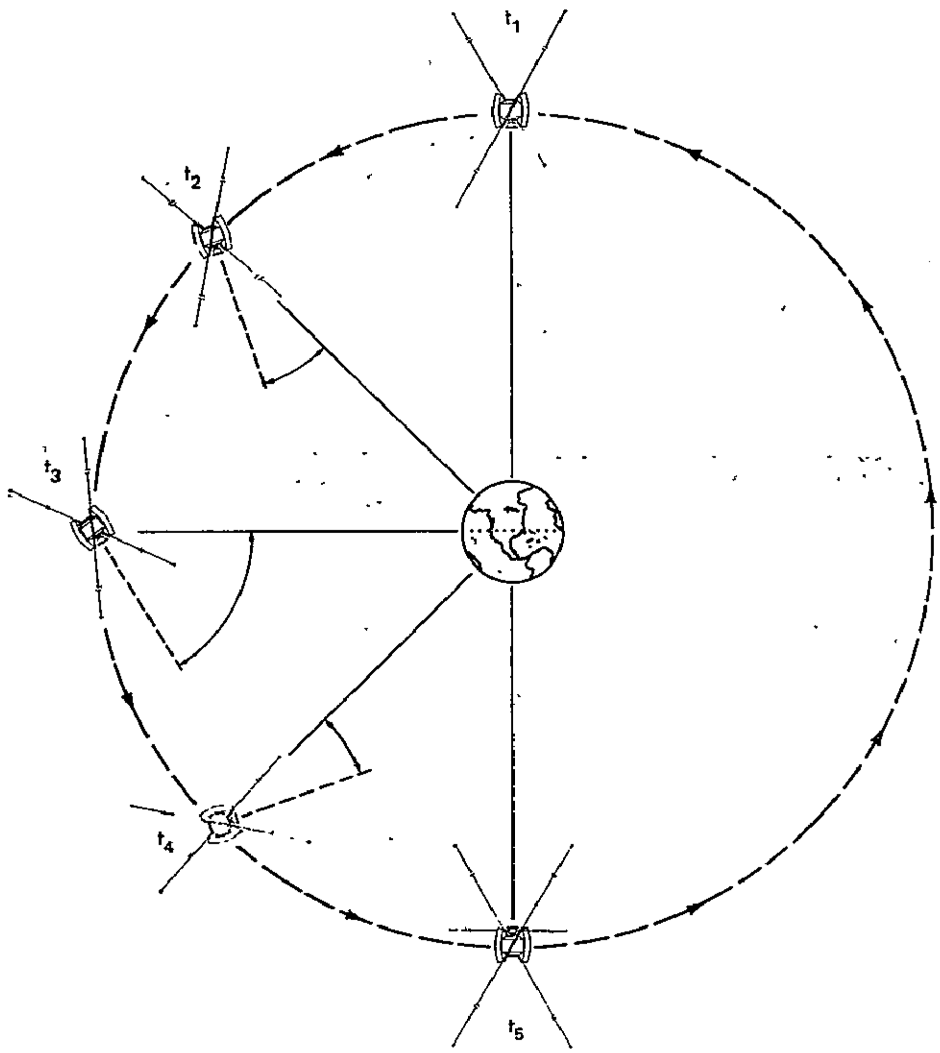
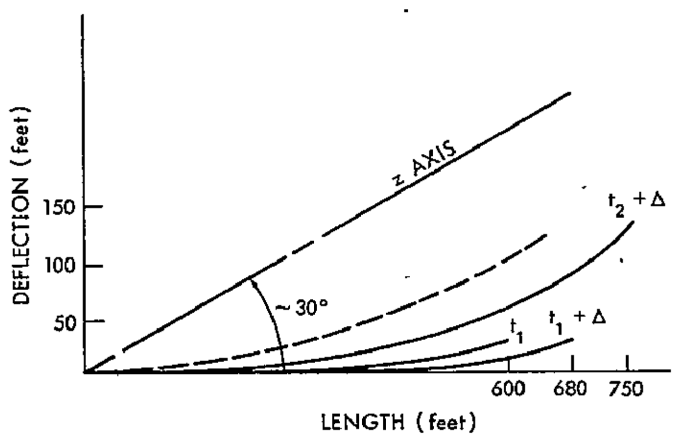


Figure 9. Yaw Motion During Deployment 450 to 600 feet (Simulated and Observed)

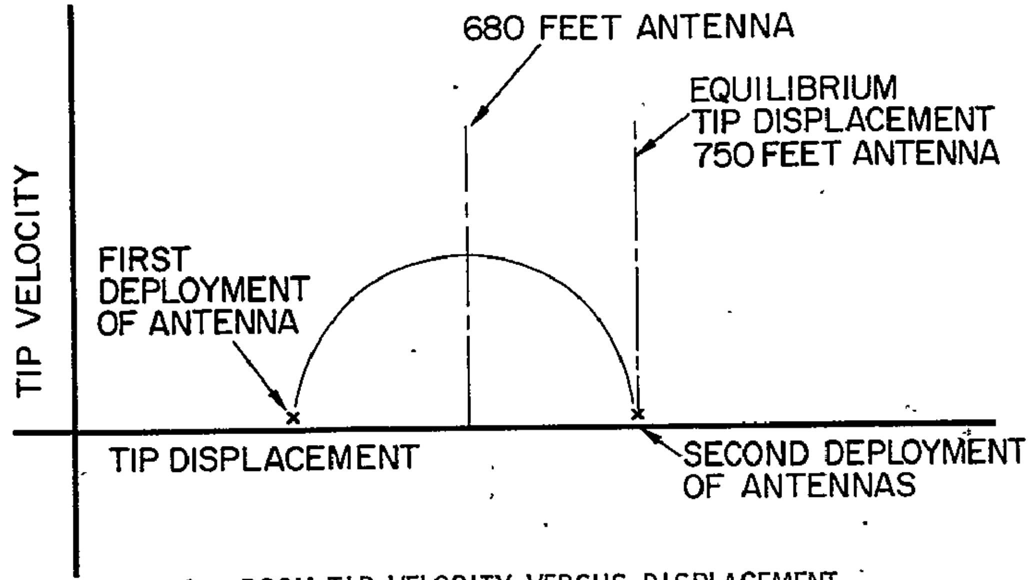


A. PITCH MOTION AND POSITION IN ORBIT

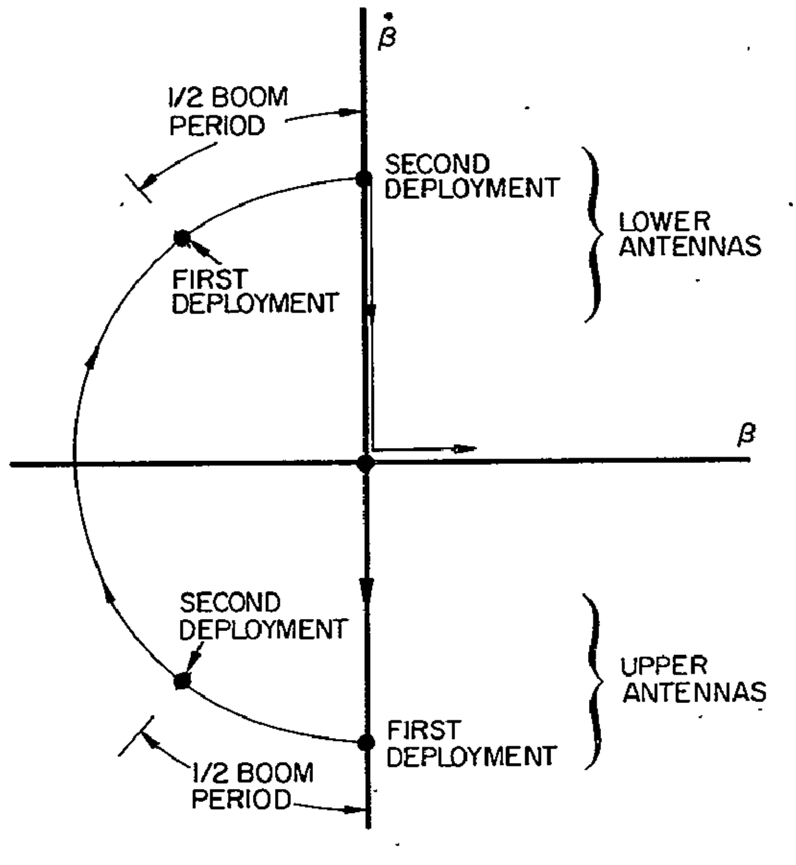


B. BOOM POSITION AT CORRESPONDING TIMES

Figure 10. Double Deadbeat Schematic



A. BOOM TIP VELOCITY VERSUS DISPLACEMENT



β = PITCH ANGLE

B. PITCH RATE VERSUS PITCH ANGLE

Figure 11. Phase Plane Plot of Double Deadbeat

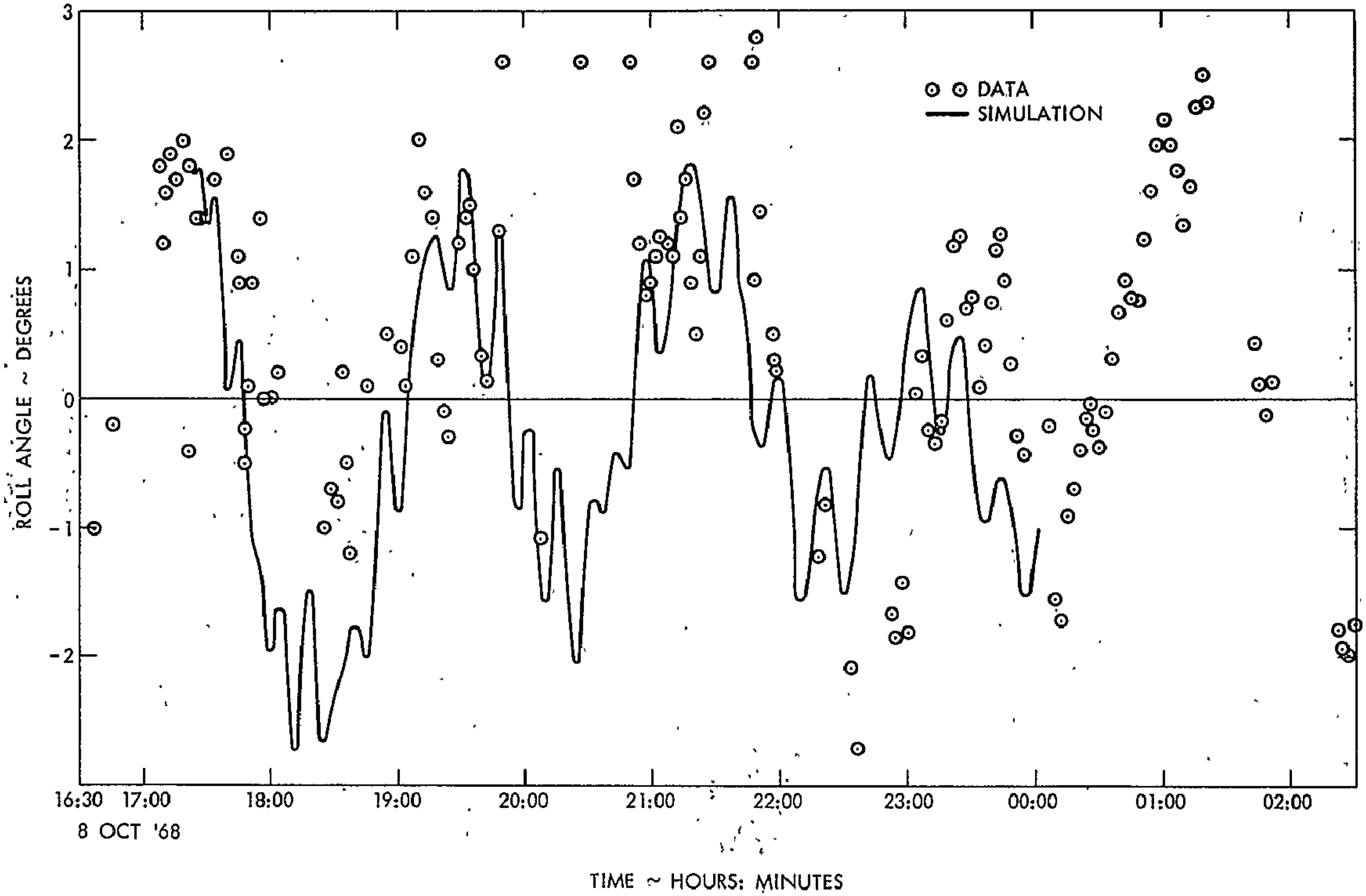


Figure 12. Roll Motion During Deployment 600 to 750 feet (Simulated and Observed)

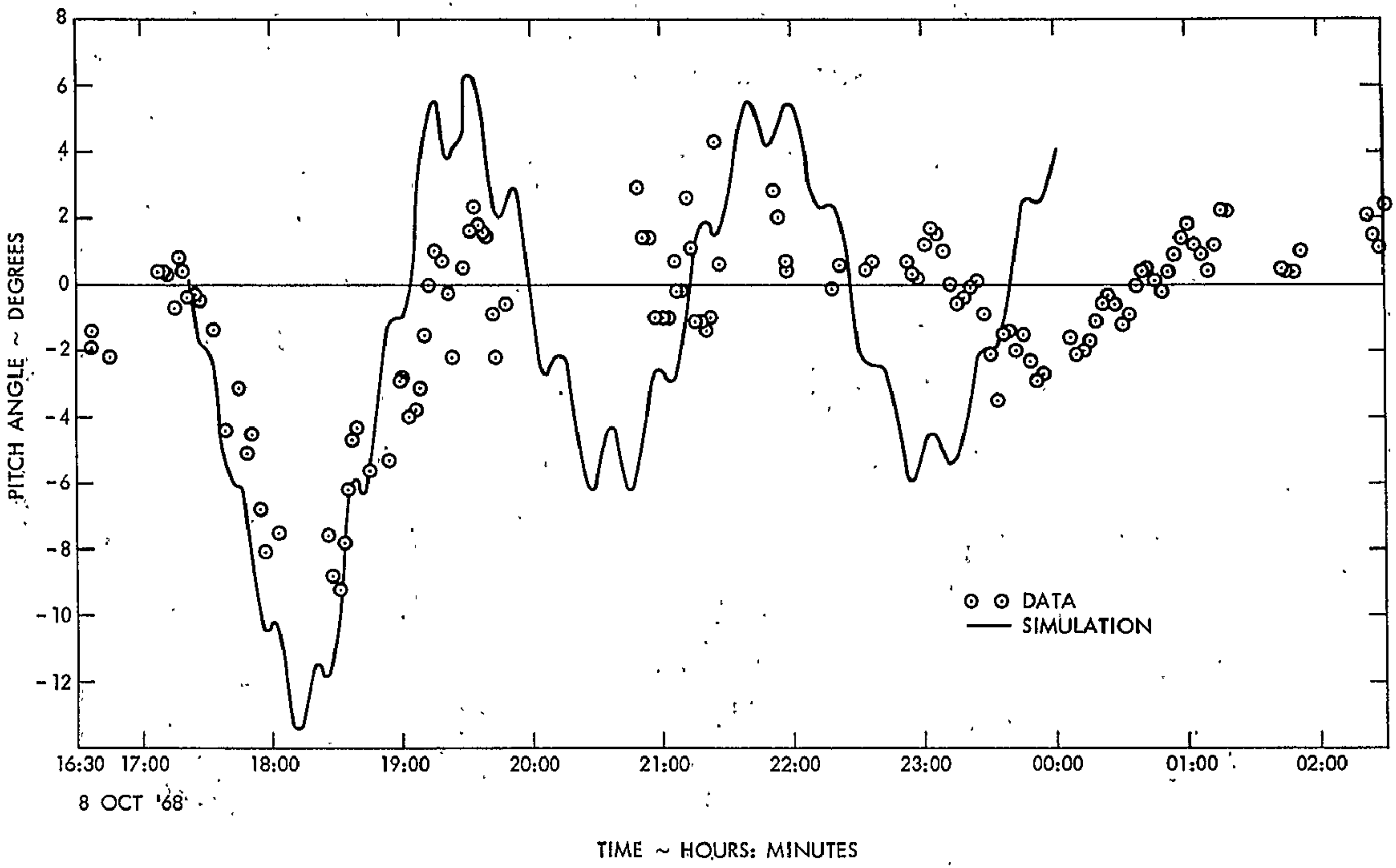


Figure 13. Pitch Motion During Deployment 600 to 750 feet (Simulated and Observed)

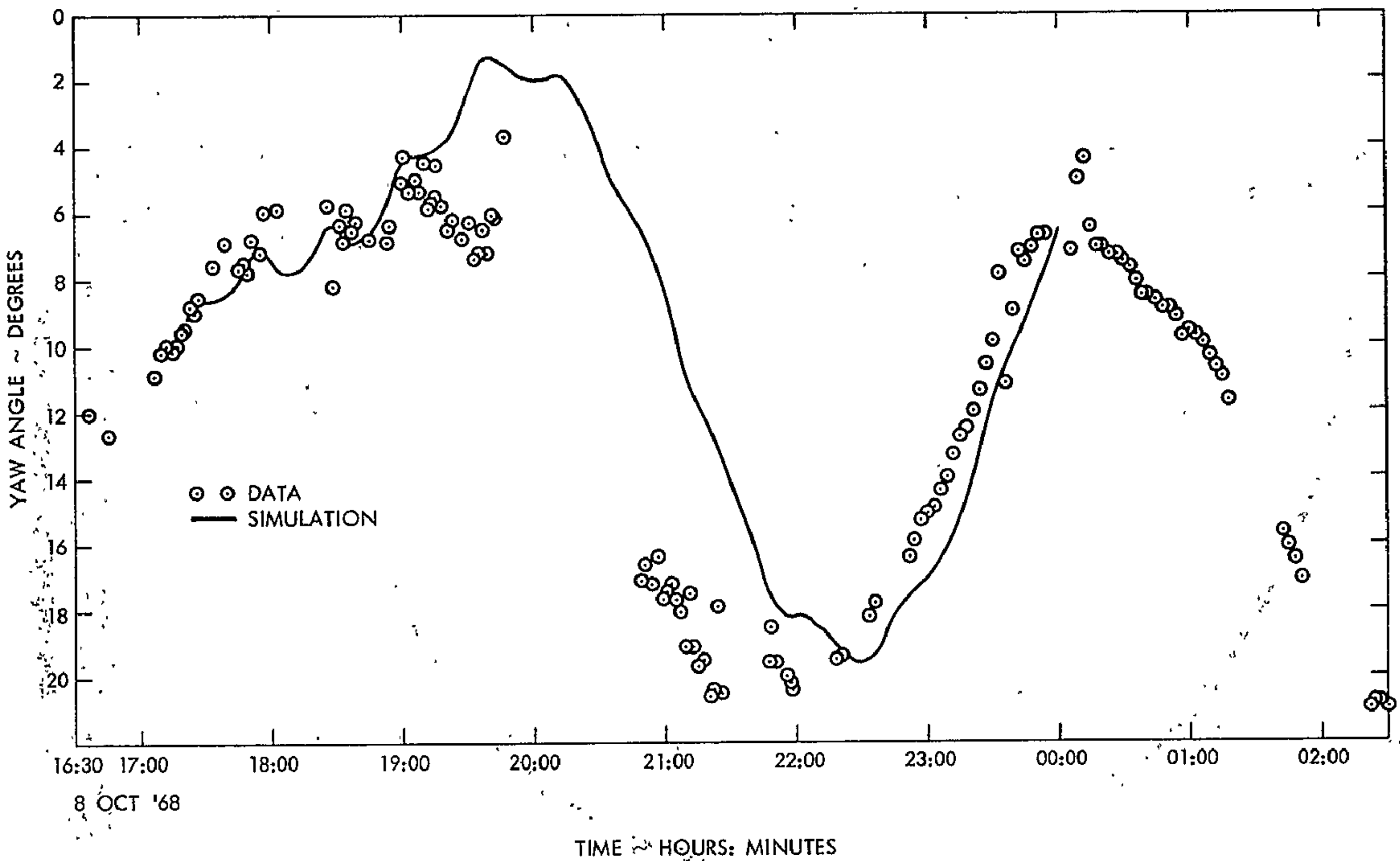


Figure 14. Yaw Motion During Deployment 600 to 750 feet (Simulated and Observed)

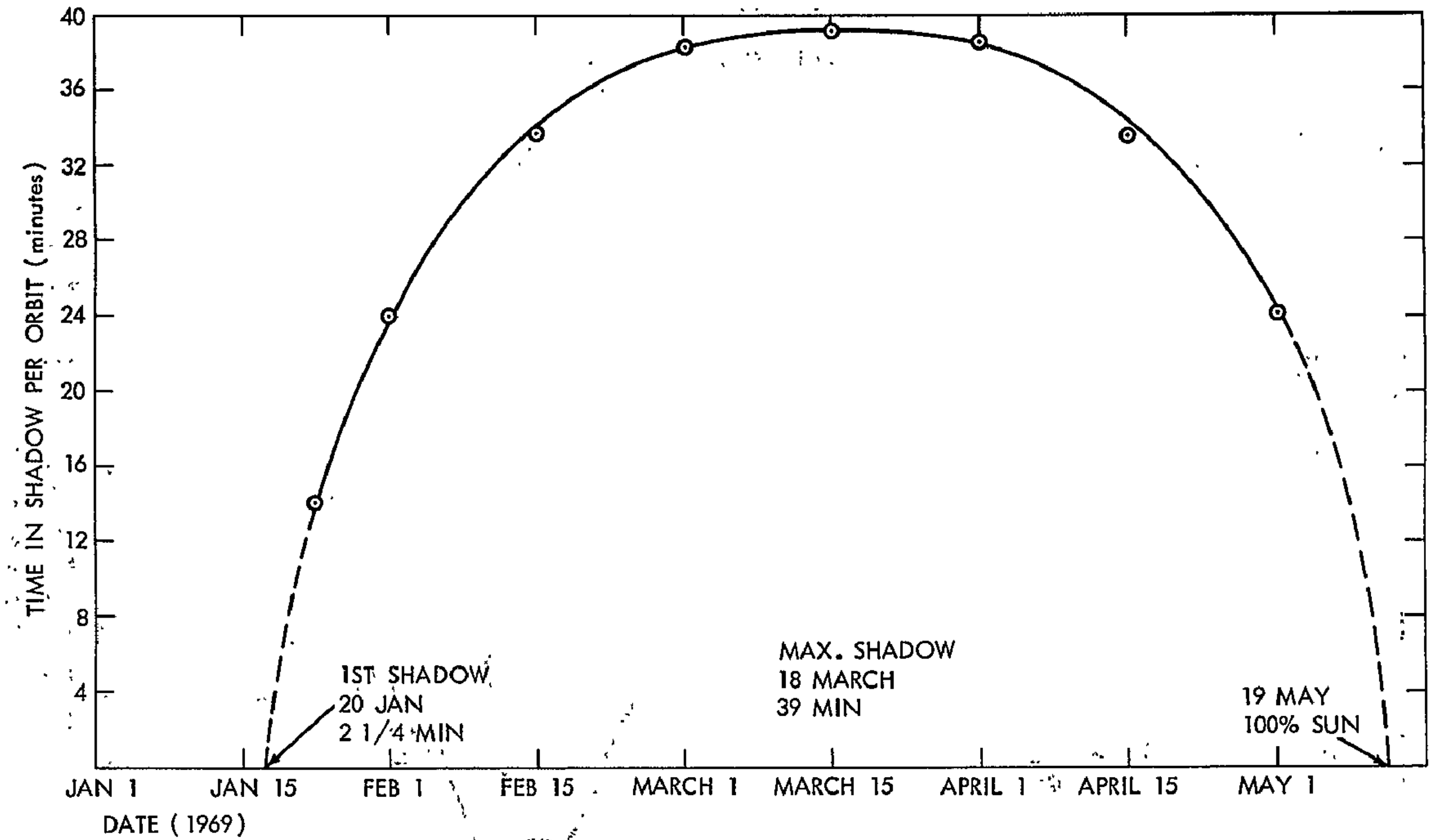


Figure 15. Time in Shadow for each Orbit

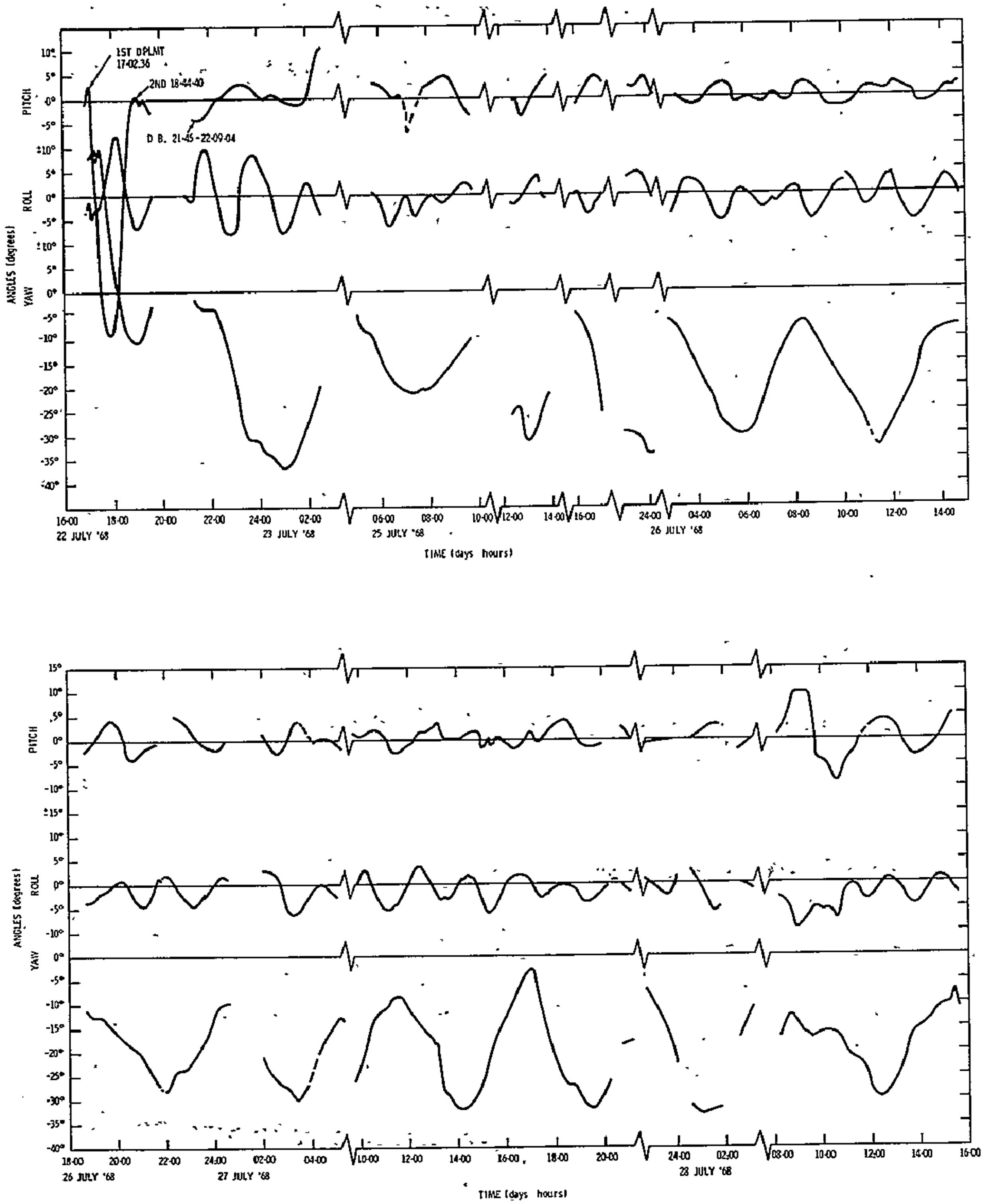
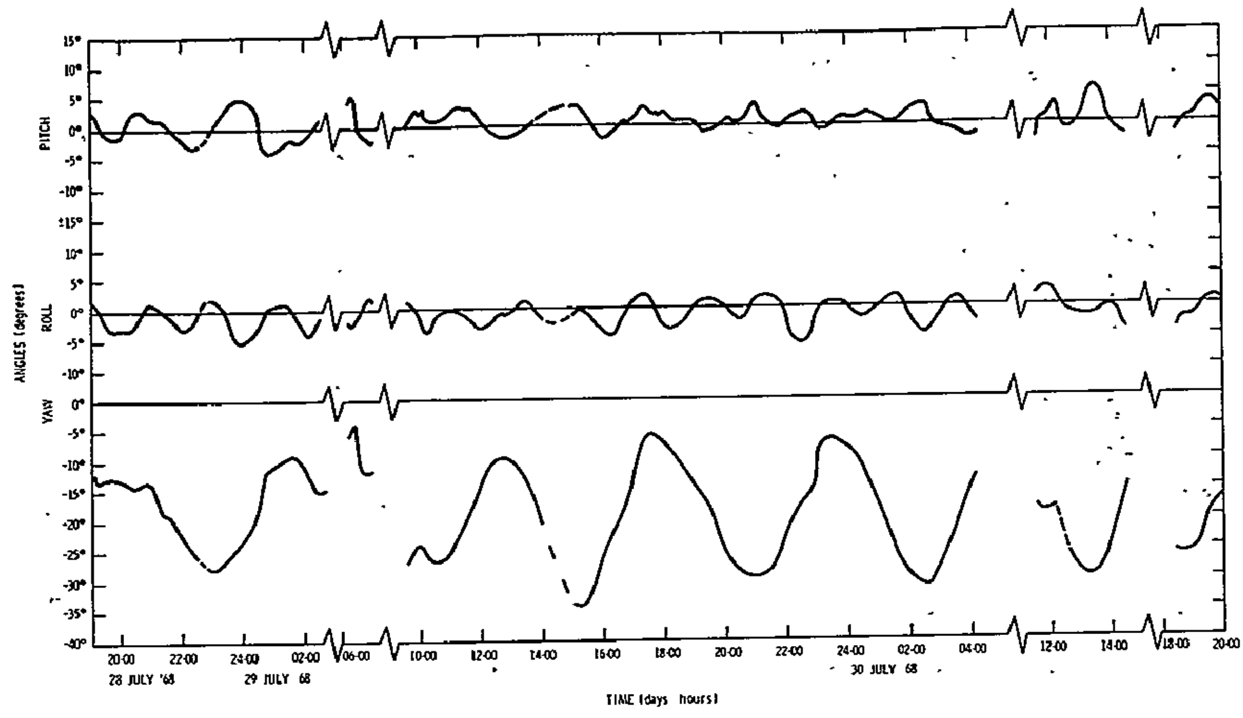


Figure 16. RAE-A Attitude Following Deployment to 450 feet



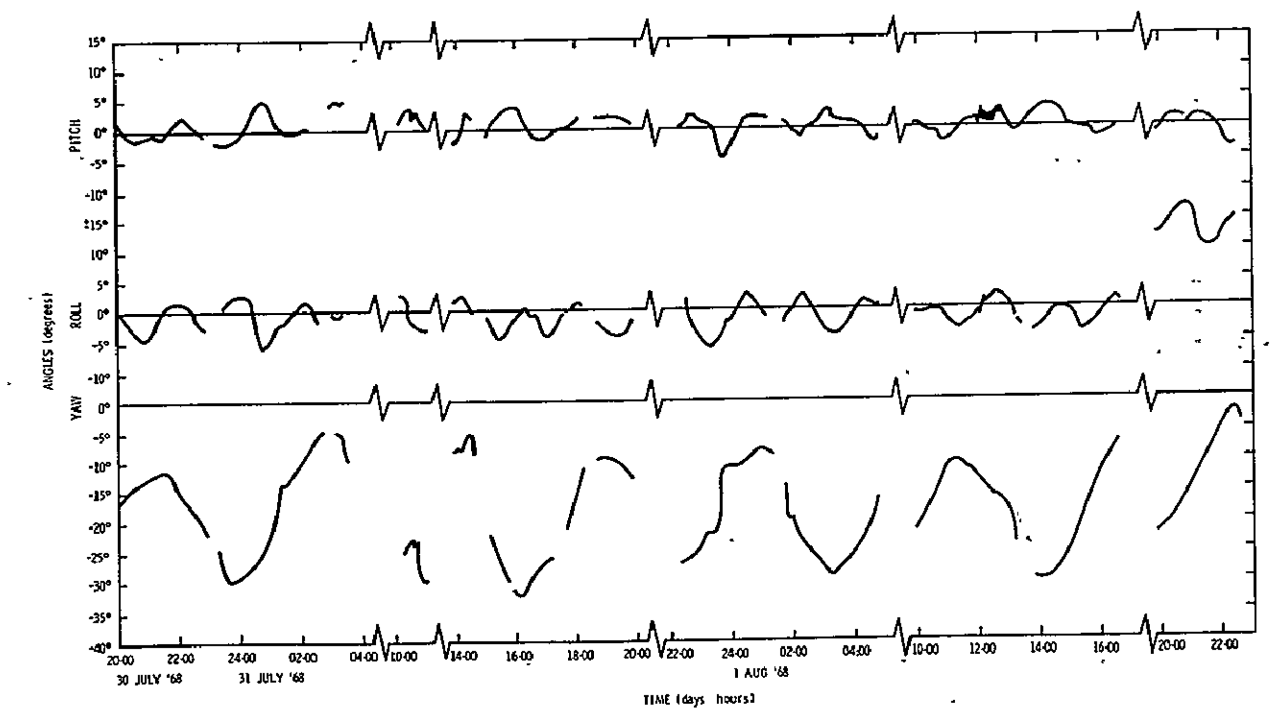


Figure 16. RAE-A Attitude Following Deployment to 450 feet (continued)

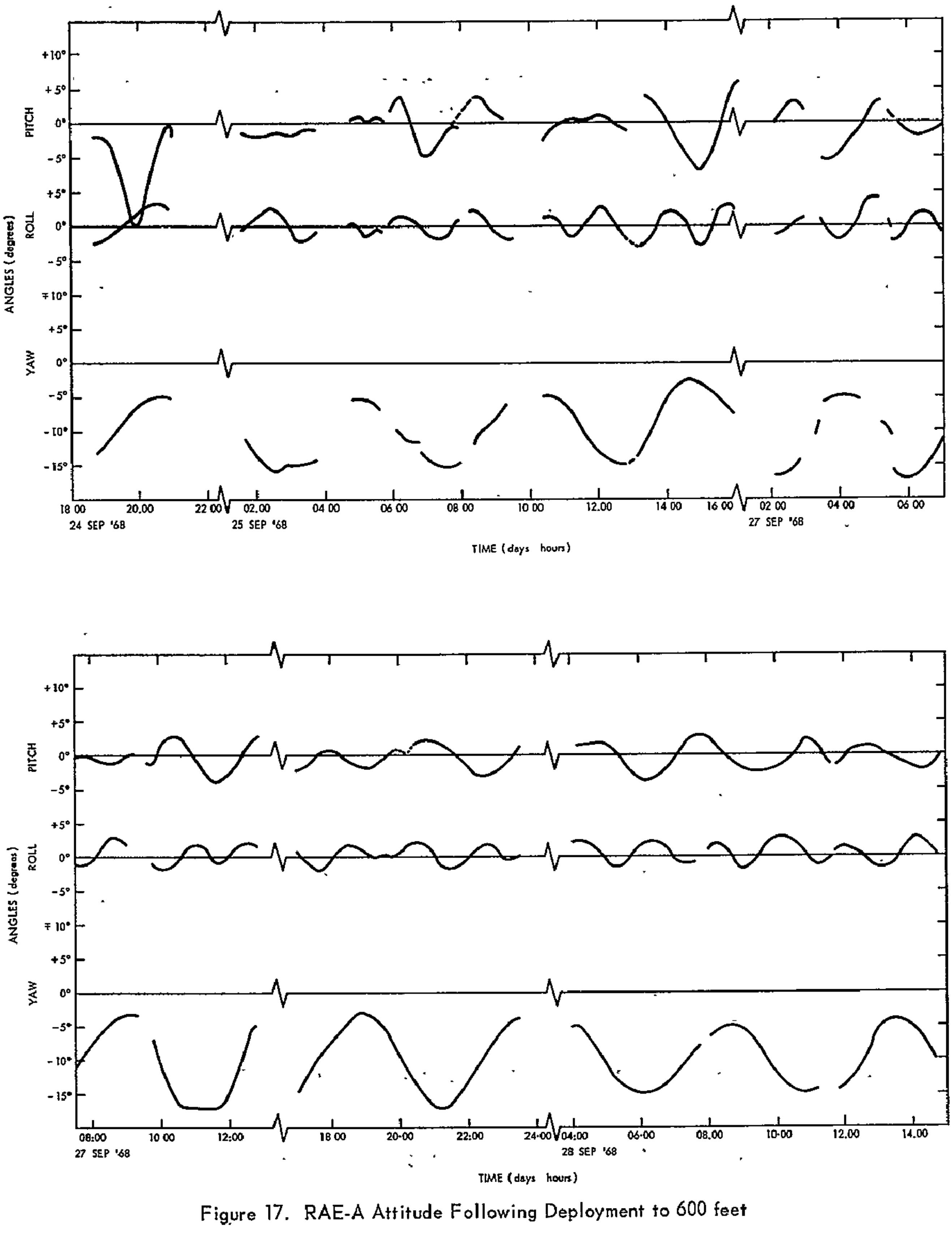
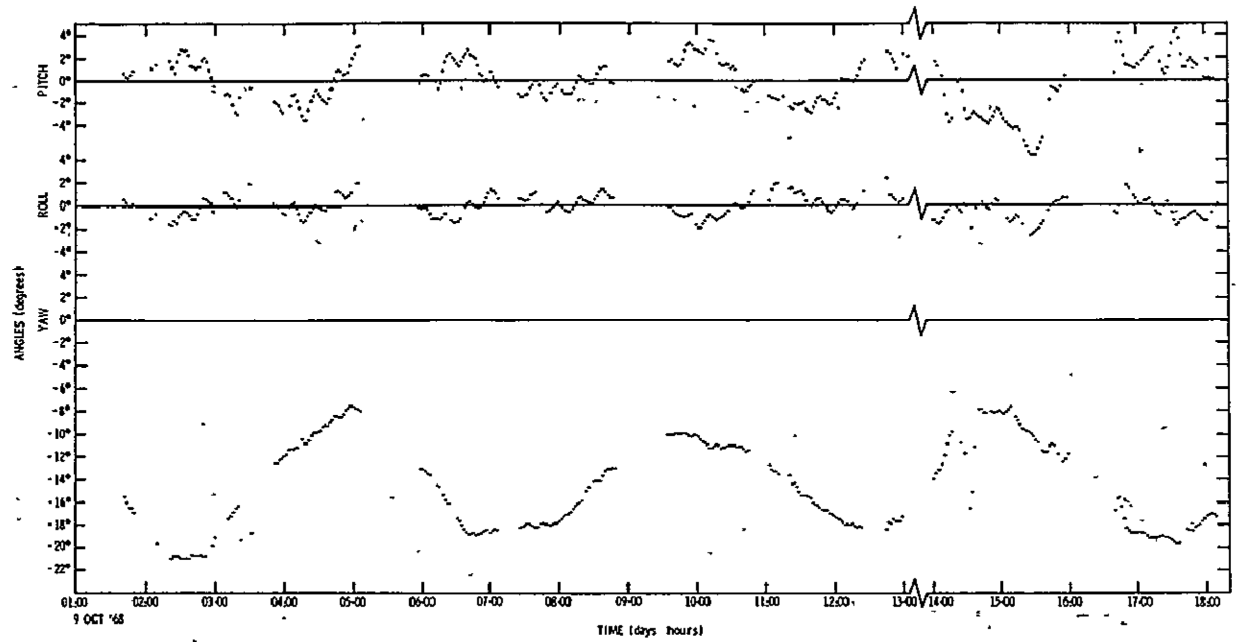


Figure 17. RAE-A Attitude Following Deployment to 600 feet



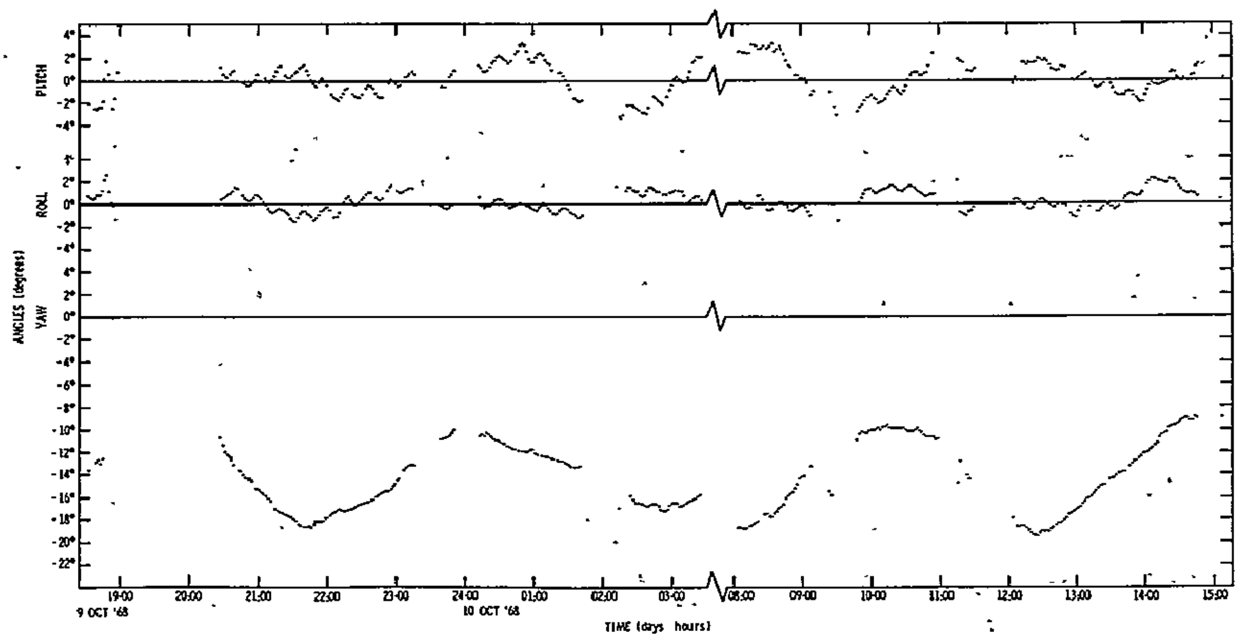
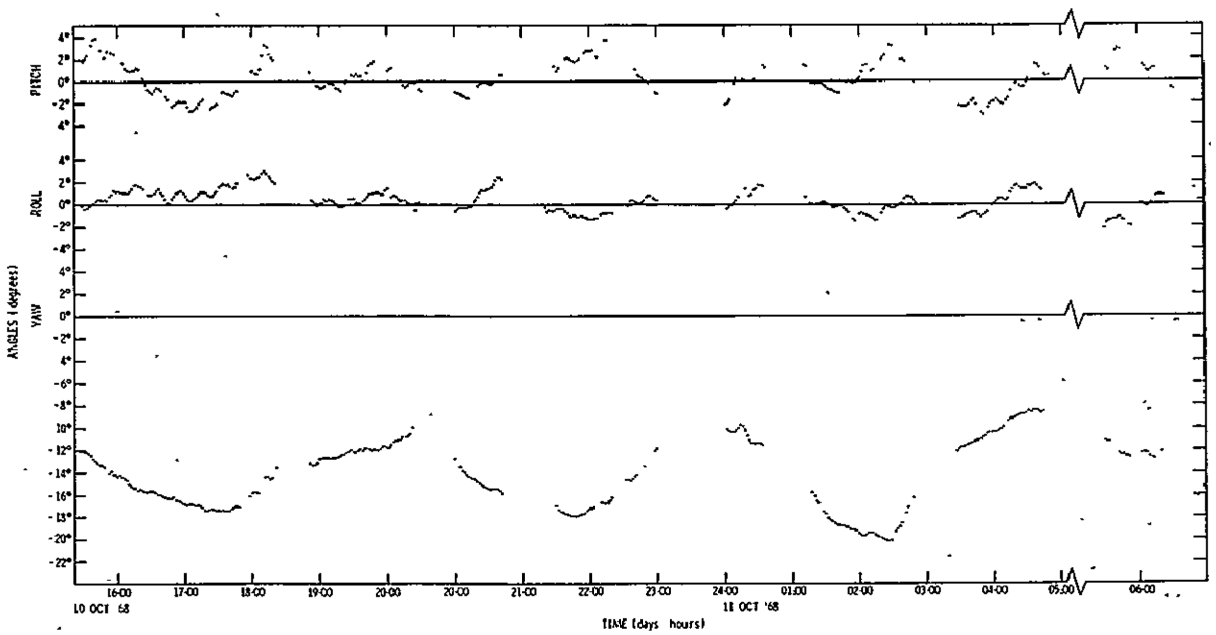


Figure 18. RAE-A Attitude Following Deployment to 750 feet



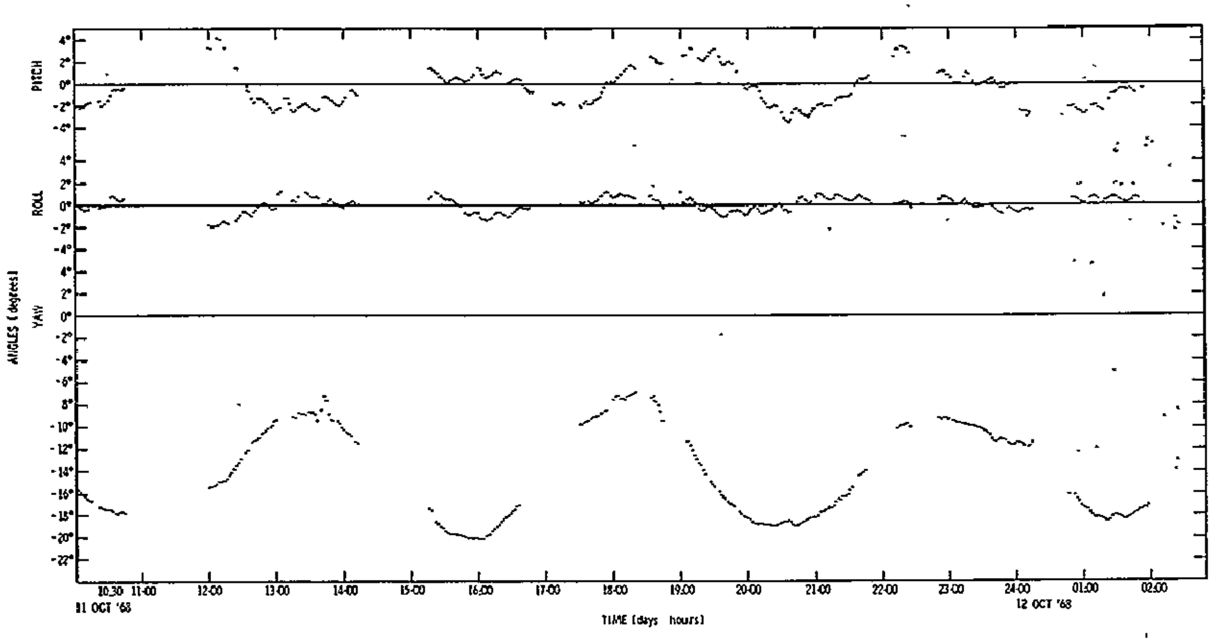


Figure 18. RAE-A Attitude Following Deployment to 750 feet (Continued)

TABLE I

CHRONOLOGY OF DEPLOYMENT EVENTS

Date	Time	Event
4 July 1968	17:26.5	Launch from WTR
7 July 1968	09:37	Orbit Circularization $\epsilon \simeq .002$
8 July 1968	16:30	Yo–Yo despin to ~ 3 RPM
8 July 1968	16:44	Magnetic torquing to despin from 3 RPM to
10 July 1968	18:55	0.4 RPM
10 July 1968	18:55	Torquing system to achieve required low rates; attempts to
16 July 1968	18:55	predict motions; simulations of deployment
16 July 1968	18:55	Deployment of damper mechanism package
22 July 1968	17:02	First boom deployment to 360 ft
22 July 1968	18:44	Second boom deployment to 450 ft
22 July 1968	21:45	Damper boom deployment to 270 ft
23 July 1968	15:09	60 ft dipole deployment Detailed study of dynamics at this length and gathering of scientific data
24 Sept. 1968	19:13	Third boom deployment to 540 ft
24 Sept. 1968	20:31	Fourth boom deployment to 600 ft
24 Sept. 1968	20:31	Study of dynamics to bound the motions
8 Oct. 1968	17:22	Collection of scientific data
8 Oct. 1968	17:22	Fifth deployment – upper booms to 680 ft
8 Oct. 1968	17:52	Sixth deployment – upper booms to 750 ft
8 Oct. 1968	18:37	Seventh deployment – lower booms to 680 ft
8 Oct. 1968	19:15	Eighth deployment – lower booms to 750 ft
8 Oct. 1968	19:42	Damper booms to 315 ft – full mission status

TABLE II

INITIAL CONDITIONS AT TIME OF DEPLOYMENT

(to 450 feet)

Date; Time (Hours/minutes)	Function	Central Body Attitude (Degs, degs/sec)	Orbit Position* & Velocity (Km, Km/sec)	Deployment Rate (ft/sec)	Final Length (feet)
22 July 1968 17:02	1st Deployment 0 to 360 feet	$\alpha = -2.0^\circ$ $\beta = 0^\circ$ $\gamma = 16.0^\circ$ $\mathring{\alpha} = -.4 \times 10^{-2}$ $\mathring{\beta} = .7 \times 10^{-1}$ $\mathring{\gamma} = 0.10625$	x = -6116.467 y = 2181.204 z = 10355.42 $\mathring{x}$ = 3.047979 $\mathring{y}$ = 4.765078 $\mathring{z}$ = 0.7893965	#1 0.4991 #2 0.4779 #3 0.4044 #4 0.4294	363 365 363 364
22 July 1968 18:44	2nd Deployment 360 to 450 feet			#1 0.5833 #2 0.4912 #3 0.4494 #4 0.4598	464 460 450 452
22 July 1968 21:45	Damper Deployment			.187	276

* These are for an orbit with an Epoch of 7/15/68 – 00:00:00
with elements a = 12,225.1, ϵ = .001310, i = 120.844°
Mean anomaly = 130.922°, Arg. perigee = 131.235°, R. A. of Asc. Node = 228.578°

TABLE II (Continued)

INITIAL CONDITIONS AT TIME OF DEPLOYMENT

(to 600 feet)

Date; Time (Hours/minutes)	Function	Central Body Attitude (Degs, degs/sec)	Orbit Position* & Velocity (Km, Km/sec)	Deployment Rate (ft/sec)	Final Length (feet)
24 Sept. 1968 19:13	1st Deployment 450 to 540 feet	$\alpha = -2.0^\circ$ $\beta = -2.0^\circ$ $\gamma = -9.0^\circ$ $\mathring{\alpha} = 0.0$ $\mathring{\beta} = 0.0$ $\mathring{\gamma} = 0.208 \times 10^{-2}$	$x = 5925.066$ $y = 5262.505$ $z = -6312.439$ $\mathring{x} = 1.01518$ $\mathring{y} = -5.14056$ $\mathring{z} = -2.26773$	#1 0.5544 #2 0.4741 #3 0.4507 #4 0.4376	537 542 545 544
24 Sept. 1968 20:31	2nd Deployment 540 to 600 feet			#1 0.5303 #2 0.5070 #3 0.4645 #4 0.4669	606 608 604 605

* These are for an orbit with an Epoch of 9/19/68 – 00:00:00
with elements $a = 12{,}232.07$, $\epsilon = .001388$, $i = 120.842^\circ$
Mean anomaly = 0.9546°, Arg. perigee = 155.625°, R. A. of Asc. Node = 263.16°

TABLE II (Continued)
INITIAL CONDITIONS AT TIME OF DEPLOYMENT
(to 750 feet)

Date; Time (Hours/minutes)	Function	Central Body Attitude (Degs, degs/sec)	Orbit Position* & Velocity (Km, Km/sec)	Deployment Rate (ft/sec)	Final Length (feet)
8 Oct. 1968 17:22	1st Deployment upper pair 600 to 680 feet	$\alpha = 1.8°$ $\beta = 0.1°$ $\gamma = -9.1°$ $\dot{\alpha} = 0.0°$ $\dot{\beta} = -0.2167 \times 10^{-2}$ $\dot{\gamma} = 0.2024 \times 10^{-2}$	x = -1339.825 y = -11676.85 z = 3427.82 $\dot{x} = -2.87198$ $\dot{y} = 1.69302$ $\dot{z} = 4.62790$	#1 0.5521 =2 0.5184	687 683
8 Oct. 1968 17:52	2nd Deployment upper pair 680 to 750 feet			=1 0.5583 =2 0.5538	750 750
8 Oct. 1968 18:37	3rd Deployment lower pair 600 to 680 feet			=3 0.4932 =4 0.4723	685 685
8 Oct. 1968 19:15	4th Deployment lower pair 680 to 750 feet			#3 0.5392 #4 0.5476	732 750
8 Oct. 1968 19:42	Damper 270 to 315 feet				315

* These are for an orbit with an Epoch of 9/19/68 – 00:00:00
with elements a = 12,232.07, ϵ = .001388, i = 120.842°
Mean anomaly = 0.9546°, Arg. perigee = 155.625°, R. A. of Asc. Node = 263.16°

TABLE III

PREDICTED AND ACTUAL DEPLOYMENT TIMES

Function	PREDICTED			Actual
	W	A	DLB	
Deployment on 22 July 1968				
1st Deployment to 360 feet				
1st pre-deployment estimate	17:03	–	17:00 to 17:27	17:02:36
2nd pre-deployment estimate	16:59	–	–	
Deployment 360 to 450 feet				
1st estimate	18:47	18:47	18:51	18:44
2nd estimate	18:43	18:44	18:44	18:44
Damper to 280 feet	22:00	21:42	–	22:45
Deployment on 24 Sept. 1968				
Deployment 450 to 540 feet				
1st estimate	–	19:10 to 19:40	19:10 to 19:40	19:13
Deployment 540 to 600 feet	–	–	20:30	20:31
Deployment on 8 Oct. 1968				
Upper pair				
Deployment 600 to 680 feet				
1st estimate	–	16:30	–	17:22
2nd estimate	–	17:12	–	17:22
Deployment 680 to 750 feet	–	17:52	–	17:52
Lower pair				
Deployment 600 to 680 feet	–	18:37	–	18:37
Deployment 680 to 750 feet	–	19:07 to 19:21	–	19:15
Damper Deployment 280 to 315 feet	–	–	–	19:42

TABLE IV

SIMULATION RESULTS OF

DEADBEAT DEPLOYMENT FROM 450 to 600 FEET

Log Number	Initial Conditions						Residual Peak-to-Peak			Coast Time
	Degrees			Degrees / Sec			Degrees			
	α	β	γ	$\mathring{\alpha}$	$\mathring{\beta}$	$\mathring{\gamma}$	α	β	γ	Minutes
748**	0.0	-2.0	-15.0	0.0	0.0	0.0028	2	3	10	82
751	-3.3	0.9	-10.0	0.0013	-0.003	0.003	12	6	28	86
752	-3.0	0.0	-9.0	0.0	-0.003	0.001	6	5	10	87
753	-3.0	0.0	-9.0	0.0	-0.003	0.002	6	5	14	84
754	-3.0	0.0	-9.0	0.0	-0.003	0.0	13	6	8	85
756	-3.0	0.0	-9.0	0.0	-0.003	-0.001	6	6	8	84
757	0.0	-3.0	-9.0	0.003	0.0	0.001	5	3	8	78
758	-3.0	0.0	-11.0	0.0	-0.003	-0.001	6	6	10	84
759	0.0	-3.0	-11.0	0.003	0.0	0.001	5	4	5	78
760	3.0	0.0	-9.0	0.0	0.003	0.001	8	7	13	84
761	3.0	0.0	-9.0	0.0	-0.003	0.001	8	5	7	84
762	-3.0	0.0	-11.0	0.0	-0.003	0.002	5	5	12	84
764	-3.0	0.0	-6.0	0.0	-0.003	0.001	6	6	12	84
765*	-3.0	0.0	-9.0	0.0	-0.003	0.001	5	4	10	85
766	-3.0	0.0	-11.0	0.0	-0.003	0.002	6	6	13	84
767	-3.0	0.0	-13.0	0.0	-0.003	0.003	5	6	16	84
768	0.0	-3.0	-13.0	-0.003	0.0	0.003	8	5	12	79
-	3.0	3.0	-15.0	0.0	0.0	-0.003			32	84
-	-3.0	3.0	-15.0	0.0	0.0	-0.003			28	85

*This deployment stopped at an intermediate length of 525 ft. instead of 540 ft.

**The damper was caged during this deployment but uncaged for the others.

TABLE V
SIMULATION RESULTS OF
SINGLE DEADBEAT DEPLOYMENT FROM 600 to 750 FEET

Log Numbers	Initial Conditions								Residual Peak-to-Peak Degrees			Coast Time
	Degrees			Degrees/Sec			FEET					
	α	β	γ	$\dot{\alpha}$	$\dot{\beta}$	$\dot{\gamma}$	A_i	B_i	α	β	γ	Minutes
771	-2.0	-2.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	10.0	2.0	27.0	73
772	+3.0	-3.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	16.0	6.0	45.0	72
773	0.0	-3.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	10.0	3.0	34.0	72
774	-3.0	-3.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	7.0	6.0	60.0	73
775	3.0	0.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	17.0	8.0	48.0	75
776	0.0	0.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	12.0	2.0	34.0	75
777	-3.0	0.0	9.0	0.0	0.0	0.175×10^{-2}	-20	±50	15.0	11.0	55.0	74
778	3.0	3.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	15.0	5.0	38.0	76
779	0.0	3.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	10.0	3.0	28.0	76
780	-3.0	3.0	-9.0	0.0	0.0	0.175×10^{-2}	-20	±50	12.0	3.0	50.0	76
781	3.0	-3.0	-4.0	0.0	0.0	0.175×10^{-2}	-20	±50	15.0	8.0	42.0	72
782	0.0	-3.0	-4.0	0.0	0.0	0.175×10^{-2}	-20	±50	15.0	5.0	42.0	72
784	-3.0	-3.0	-4.0	0.0	0.0	0.175×10^{-2}	-20	±50	17.0	5.0	42.0	72
785	3.0	0.0	-4.0	0.0	0.0	0.175×10^{-2}	-20	±50	15.0	8.0	46.0	75
803	-3.0	+3.0	-9.0	0.0	0.0	0.2×10^{-2}	-30	±70	8.0	3.0	32.0	75
804	0.0	3.0	-11.0	0.2×10^{-3}	0.0	0.2×10^{-2}	-30	±70	3.0	2.0	10.0	75
805	-3.0	3.0	-14.0	0.0	0.0	0.0	-30	±70	8.0	3.0	30.0	75
806	-3.0	3.0	-11.0	0.0	0.0	-0.2×10^{-2}	-30	±70	8.0	4.0	35.0	75
808	-3.0	3.0	-9.0	0.0	0.0	0.17×10^{-2}	-30	±70	8.0	3.0	26.0	75
809	3.0	-3.0	-4.0	0.0	0.0	0.17×10^{-2}	-30	±70	10.0	3.0	26.0	71

TABLE VI
SIMULATION RESULTS OF DOUBLE BEAT DEPLOYMENT 600 to 750 FEET

Run Numbers	Initial Conditions								Residual			Coast Time		
	Degrees			Degrees/sec.			Feet		Degrees			Minutes		
	α	β	γ	$\mathring{\alpha}$	$\mathring{\beta}$	$\mathring{\gamma}$	A_i	B_i	α	β	γ	T_1	T_2	T_3
1	-3	-3	-9	0.0	0.0	0.00175	-20	±50	6	6	12	29	26	39
2	-3	-3	-9	0.0	0.0	0.00175	-30	±70	6	6	14	29	26	39
3	-3	3	-9	0.0	0.0	0.00175	-30	±70	6	8	15	29	38	40
4	-3	0	-9	0.0	0.003	0.00175	-30	±70	7	6	17	29	29	51
5	-3	0	-9	0.0	0.003	0.00175	-30	±70	7	6	12	29	34	44
6	-3	+3	-9	0.0	0.0	0.00175	-30	±70	6	10	12	29	34	44
7	-3	-3	-11	0.0	0.0	0.00175	-30	±70	7	3	25	29	34	30
8	-3	-3	-9	0.0	0.0	0.00175	-30	±70	7	3	23	29	34	30
9	-3	-3	-9	0.0	0.0	0.00175	-10	±30	7	5	19	29	34	29
10	-3	-3	-9	0.0	0.0	0.00175	-40	±80	6	5	17	29	34	30
11	-3	+3	-9	0.0	0.0	0.00175	-30	±70	6	11	16	29	34	44

APPENDIX A

The following memo is included so as to present some spacecraft attitude data during the period of time when the spacecraft was entering and leaving the shadow.

As a result of this memo an effort was made to obtain attitude data at times when the small biases would be much less significant, i.e.: at a time when the magnetic field vector and the sun line were significantly different from being colinear. The result was a drastic improvement as is shown on Figure 4-A which is typical of subsequent attitude data.

MEMORANDUM

TO: Mr. John T. Shea DATE: March 11, 1969
RAE Project Manager
Spacecraft Integration & Sounding Rocket Division

FROM: Mr. David L. Blanchard
Mechanical Systems Branch
Spacecraft Integration & Sounding Rocket Division

SUBJECT: THERMAL "TWANG" OF RAE-A

It has previously been reported that the RAE-A is experiencing an oscillation of 25 minute period of 5° to 9° half amplitude about all axis immediately following the shadow. The data does indicate this and since it had been predicted by simulation it was quite believable. However, for the past month I have been questioning whether all of this is a real oscillation. It now appears that there is almost no spacecraft oscillation from a "thermal twang." The following observations have lead indirectly and finally directly to this conclusion:

1. There has not been any build up of the libration motions as a result of this transient oscillation ("thermal twang"). This motion, if it is as large as is indicated, should eventually couple to the libration motions.

2. The damper aspect has remained in the 3.39° position since the last deployment even though it moved during each of the three deployments. The last deployment caused libration motions which were smaller than many of the transient oscillations indicated in recent data. It should be noted that the slot is about 2.3° wide in the 3.39° position.

3. The available T.V. data does not indicate either tip motion or earth motion relative to the spacecraft which is commensurate with this large amplitude 25 minute oscillation.

4. The solar sensors do not indicate this oscillation.

5. The magnetometers are the only sensor of the several direct or indirect sensors mentioned above which indicates that this transient oscillation does occur.

6. There are some transient current conditions associated with solar currents and charge-discharge of the battery which seem to be correlated with these oscillations and are of 25 minute duration. The remainder of the memo will be devoted to explaining the investigation of this last point.

Figure 1 is fairly typical of the attitude data taken during a recent shadow times (on 13 February 1969). Just prior to the shadow at 05:03 the oscillations and librations are all small and well behaved. Just following shadow the indication is that roll goes thru a 28° peak-to-peak oscillation while pitch amplitude is about 11° and yaw is about 26°. There is a space where no data is available from 06:10 to 06:40 and then indications of another large oscillation.

Figure 2 is a plot of the total spacecraft solar current and dump current. Prior to shadow the current is dumping and things are in a steady state just as was the case during the full sunlit orbits. The attitude is also well behaved during this period.

At 05:00 the solar current drops exponentially and then the current falls in a step function from a dump condition to drawing entirely from the battery. We lose solar sensors at this time and have no attitude until the solar cell current rises in a step at 05:35. However, the current from the solar array is not adequate to supply the total spacecraft requirement until about 25 minutes later. During this period of time there is a considerable change in the paths of the current flow thus causing complex changes in the magnetic fields which the magnetometers see. This is obviously reflected in the spacecraft attitude data in Figure 1. At 06:40 there is a significant change in the solar cell current which is also reflected in the spacecraft attitude on Figure 1.

One could argue that there is a similar transient at 04:50. However, during that time the current is being dumped while at 06:50 the battery is taking the current.

No magnetometer calibration is available from spacecraft integration and testing which duplicates these charging conditions. However, from somewhat similar test data there are magnetometers biases of about 100γ. Consequently the data from the magnetometers was re-run with various biases on them to see whether this transient oscillation could be explained away. It was found that the Z magnetometer is rather insensitive to changes as was expected since it is recording the major component of the earth's magnetic field at this time.

Table I shows the combination of steady biases on the X and Y magnetometer which was tried. The combination of +200γ on the X and -200γ on the Y seem to be the best combination. The data just following shadow with this and with no bias are presented on Figure 3. It is apparent that the improvement is significant. For example, the roll amplitude is reduced from 28° to 6° peak-to-peak. If one knew the time history of the magnetometer bias changes, it is possible that even this could be removed.

Table II is included for completeness to show a comparison of the three cases of no bias, ±100γ and ±200γ bias.

One other point is quite pertinent. At the time these small biases are taking place, there is a condition we call "bad geometry." The magnetic field vector and sun vector are very nearly collinear so that a very small sensor error causes large discrepancies in angles. In fact the attitude may become completely indeterminant.

In conclusion, it seems evident from available data that the spacecraft is experiencing only a small "thermal twang," if any at all, as it emerges from shadow.

The thermal balance across the boom and the damping characteristics of the booms seem to be better than had been predicted.

David L. Blanchard

Attachments

cc: Mr. R. C. Baumann
Dr. Robert Stone
Dr. Robert Coates
Dr. Ralph Barclay
Mr. Thomas Flatley
Mr. Roger Tetrick
Mr. Roger Werking
Mr. David Stewart
Mr. Robert Mattingly
Mr. Earl Angulo
Mr. Carl Wagner
Mr. Mac Grant

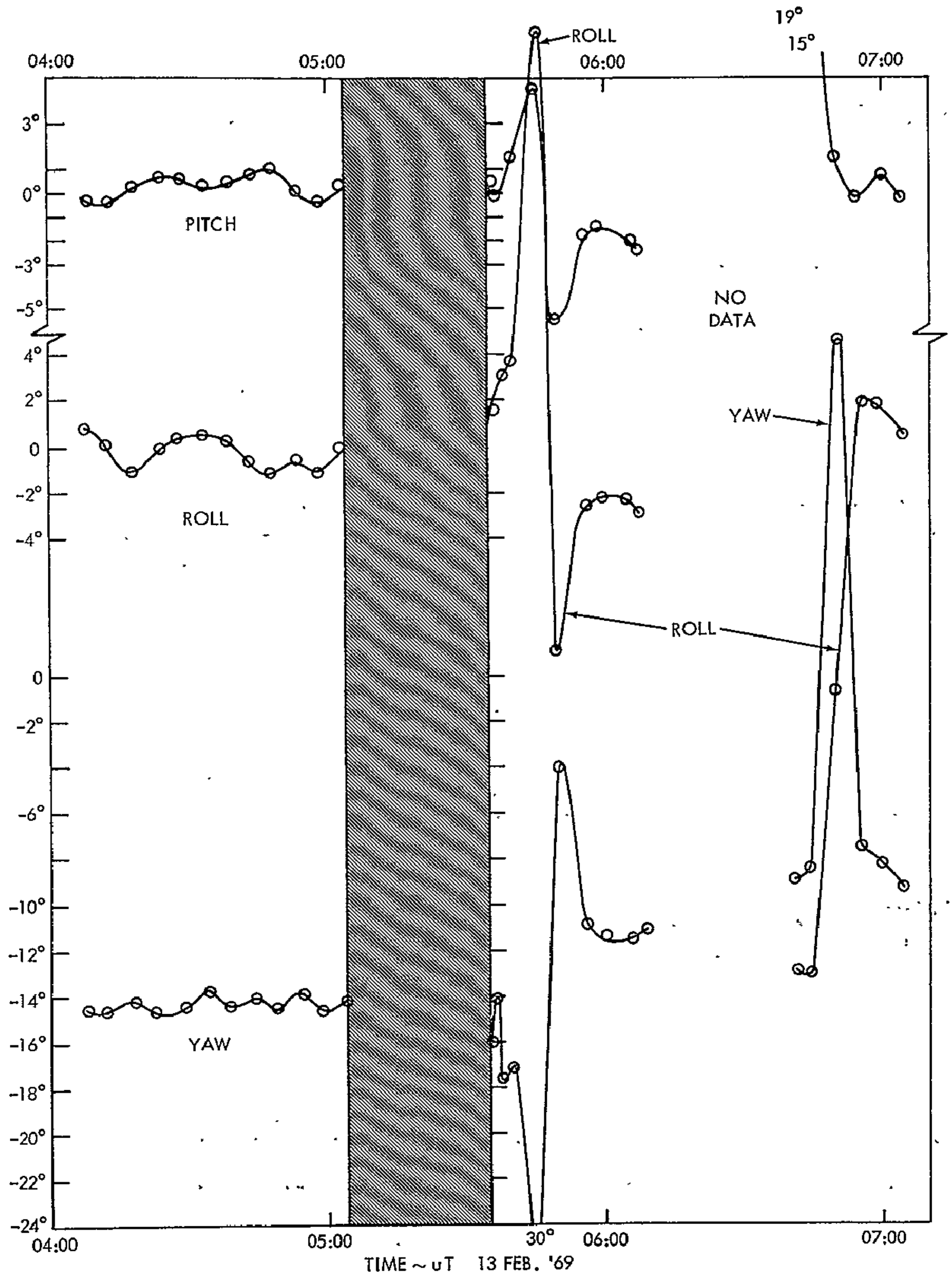


Figure A-1. RAE-A Attitude

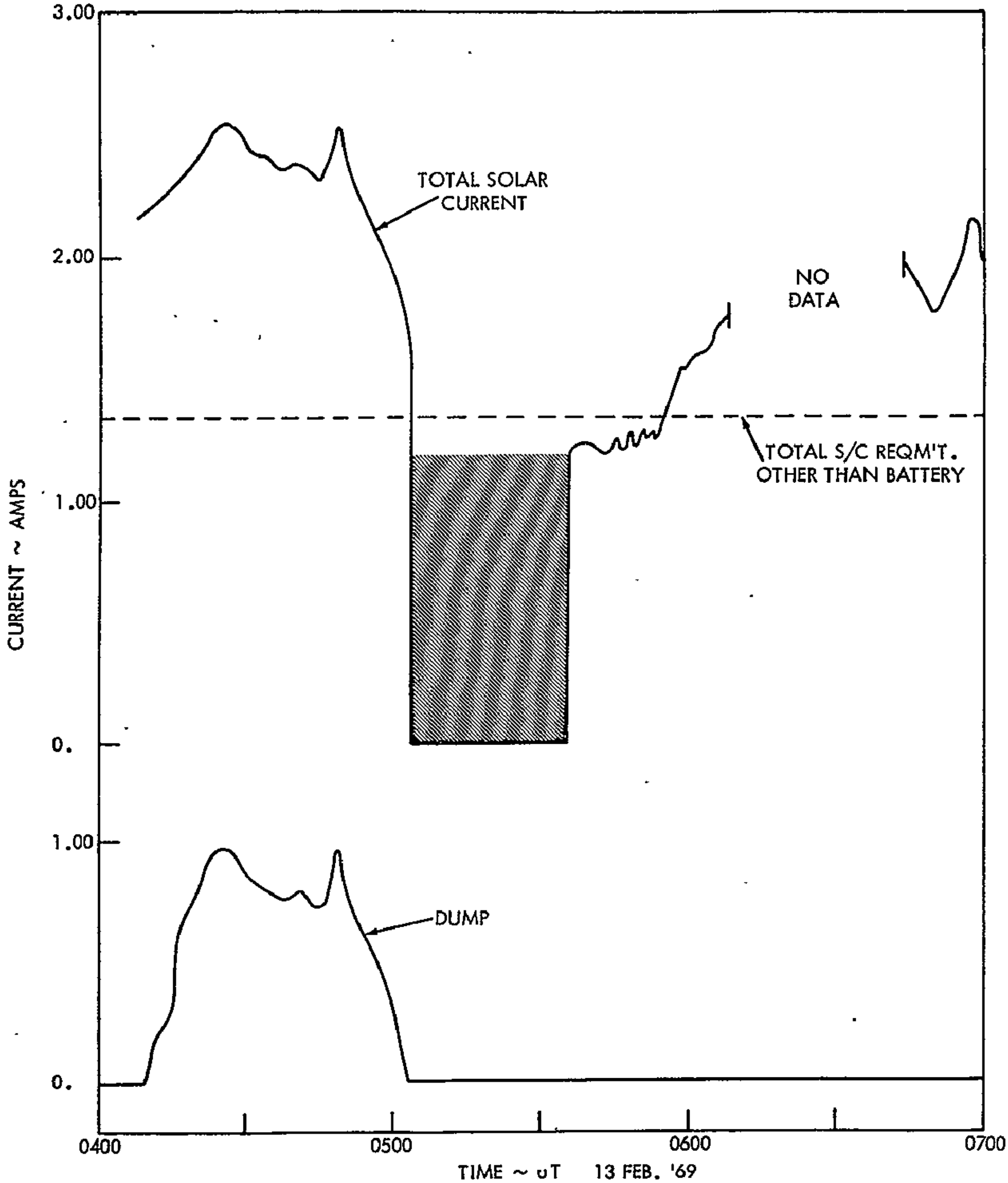


Figure A-2. RAE-A Spacecraft Current

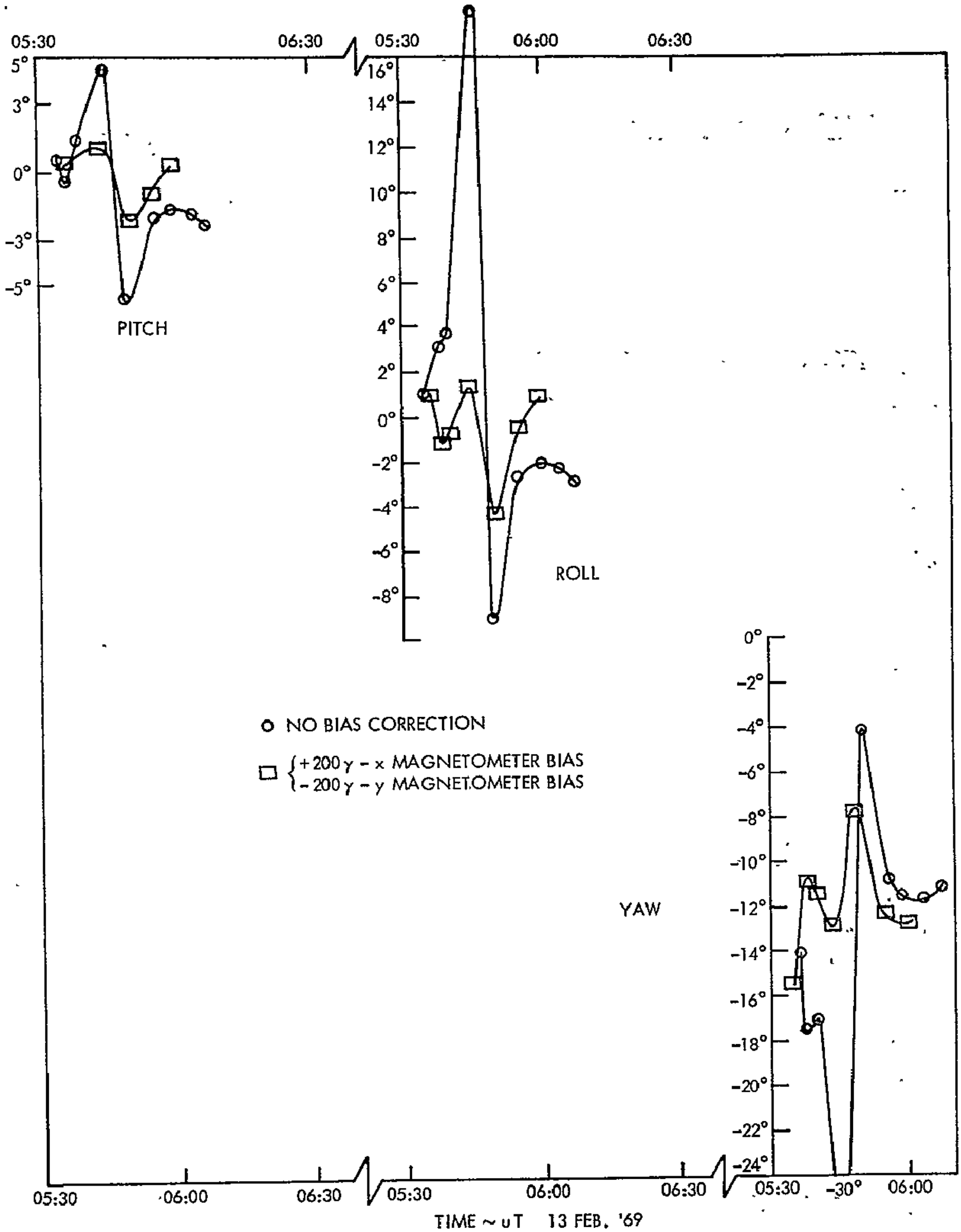


Figure A-3. RAE-A Attitude Following Shadow

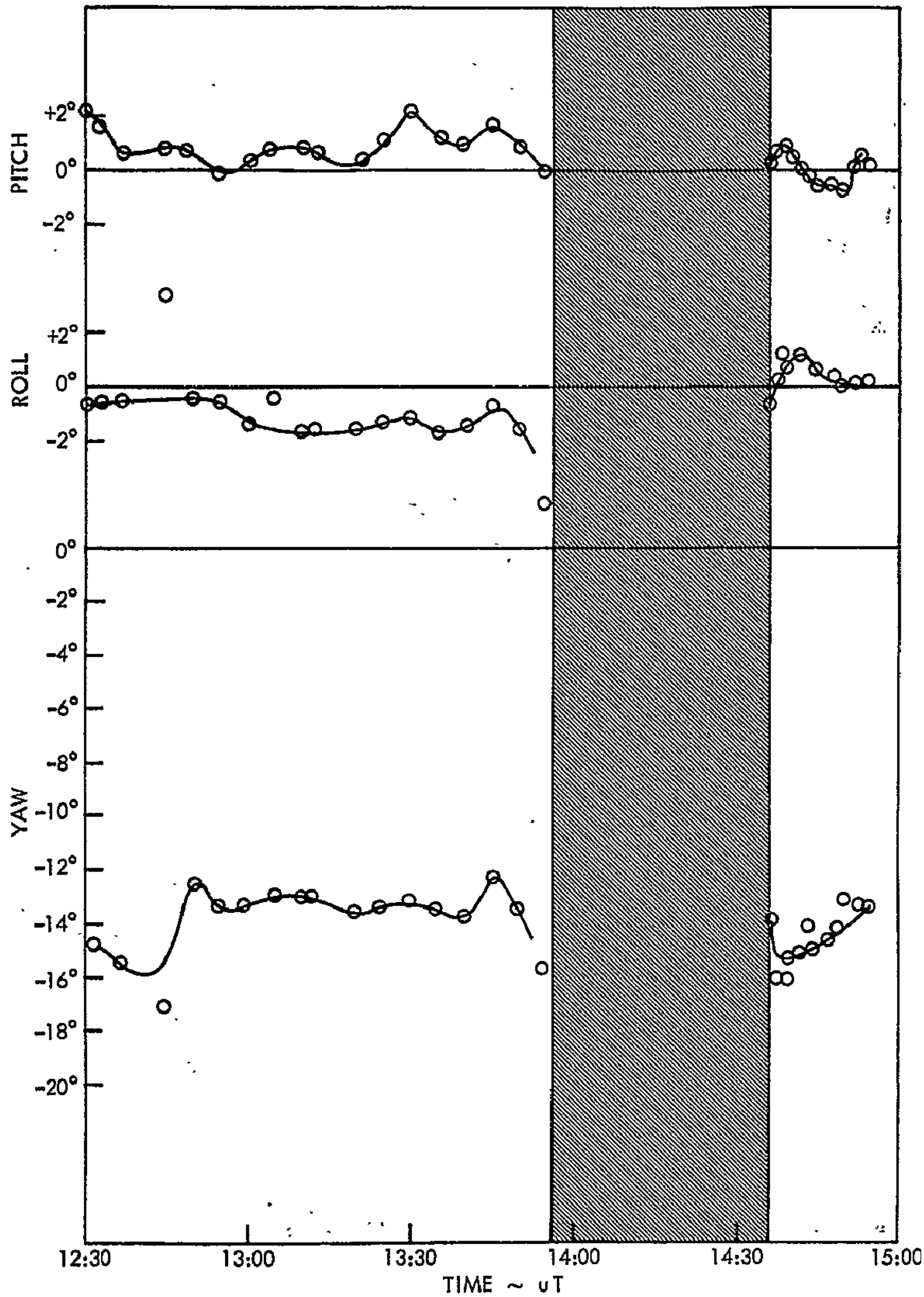


Figure A-4. RAE-A Attitude on 8 April 1969

TABLE I-A

MAGNETOMETER BIAS COMBINATIONS

X Bias (γ)

y Bias (γ)

-200	-100	0	+100	+200
-100				
0				
100				
200				

Best Combo

TABLE II-A

ATTITUDE DATA FOR VARIOUS MAGNETOMETER BIAS

Time	Bias (γ) x	Bias (γ) y	Pitch	Roll	Yaw
05:35:52	0	0	1.6°	2.6°	-19.°
	100	-100	1.0°	1.8°	-17.°
	200	-200	.4°	.8°	-16.°
05:36:53	0	0	1.6°	3.6°	-18.°
	100	-100	1.0°	2.5°	-16.°
	200	-200	.4°	1.4°	-15.°
05:38:56	0	0	1.2°	1.8°	-16.°
	100	-100	.2°	.3°	-13.°
	200	-200	- .8°	- 1.4°	-11.°
05:40:51	0	0	1.7°	3.3°	-16.°
	100	-100	.8°	1.5°	-14.°
	200	-200	- .3°	- .4°	-11.°
05:45:51	0	0	5.3°	14.0°	-25.°
	100	-100	3.9°	9.0°	-20.°
	200	-200	1.2°	1.2°	-13.°
05:50:50	0	0	-9.7°	-15.°	+ 2.8°
	100	-100	-6.2°	-10.°	- 2.6°
	200	-200	-3.0°	- 4.8°	- 7.8°
05:55:50	0	0	-2.6°	- 5.4°	- 8.9°
	100	-100	-1.6°	- 3.0°	-10.5°
	200	-200	- .6°	- .6°	-12.°
06:00:49	0	0	- .95°	- 2.4°	-11.°
	100	-100	- .36°	- .8°	-12.°
	200	-200	.2°	.8°	-12.°