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Nimbus Satellite

Stability Study

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I INTRODUCTION

The Nimbus Satellite is a complex structure from an aerodynamic re-entry point of view which must be understood to evaluate the need of an ejection system for the two SNAP 19 generators for compliance with the safety approach described in the safety study. Therefore, an investigation was undertaken to determine the re-entry behavior of various representative satellite configurations.

Since it is possible to have solar platforms remain folded because of a malfunction of the locking mechanism, one configuration was with the platforms closed, the other was with the platforms unfolded. The latter extends work performed on the satellite behavior in Reference 1. Specifically, the study was made by parameterizing the pitch motion of the satellite with respect to pitch rate, angle of attack, and platform incidence.

The analysis was done using a three degree of freedom program which describes a trajectory along which the dynamic motion is established as a function of time. The study is limited to motion in the pitch plane only. However, this is adequate to evaluate the objective of the study. Results are presented by establishing the exposure time of the generators to aerodynamic heating.

II ANALYTICAL MODELS

The two Nimbus Satellite models used in this analytical study are fitted with the SNAP 19 generator. One configuration represents the normal configuration with the solar platforms extended. This case is described in Reference 1 together with the aerodynamic static stability data. The other model, representing an abort condition, has the platforms locked in the fully folded position, Figure 1. Aerodynamic static stability data, Figures 2 through 4, have been estimated for this latter configuration using the modified Newtonian concept described in Reference 1. The three-degrec-of-freedom computer program, UB-104, was used to determine the dynamic motions in the pitch plane. The results are, therefore, consistent with those given in the safety report, Reference 1.

The following conditions are analyzed herein.

Table 1

Satellite Configuration	Initial Angle of Attack	Initial Platform Incidence	Initial Pitch Rate
Platform Extended	0	-90°	-.001 Rad/Sec.
" "	0	-90°	-.010 Rad/Sec.
" "	0	-90°	-.100 Rad/Sec.
" "	0	-45°	0
" "	0	-70°	0
" "	0	-110°	0
" "	0	-135°	0
" "	-10°	-90	0
" "	+10°	-90	0

Table 1 Continued

Satellite Configuration	Initial Angle of Attack	Initial Platform Incidence	Initial Pitch Rate
Platform Extended	0*	-100	0
" "	0*	-90	0
" "	0*	-80	0
" "	0*	0	0
" "	0*	+10	0
" "	0*	+20	0
" "	0*	+45	0
" "	0*	+90	0
" "	0*	+145	0
" "	0*	+180	0
Platform Folded	0	Folded	.05
" "	0	"	.20
" "	0	"	.30
" "	0	"	.40
" "	0	"	.60
" "	0	"	.80
" "	0	"	1.00
" "	0	"	-.20
" "	0	"	-.40
" "	0	"	-.60
" "	0	"	-.80

The vehicular weight is estimated to be 1100 pounds and the moment of inertia is equal to 140 slug-ft.². All of the trajectories were started at an altitude of 400,000 feet. Orbital decay analyses indicated an average flight path angle of -0.1 degrees and a velocity of 25,686 feet per second could be expected at that altitude.

III ANALYSIS AND DISCUSSION

A. Platforms Extended

Near the completion of the preliminary Nuclear Safety Study on the NIMBUS/SNAP 19 it was discovered that the craft would not tumble if the platforms were set at an initial incidence angle of -90°. This is the case where the flat side of the platform containing the solar cells is facing to the wind. Subsequently, additional trajectories were computed to provide the data so as to analyze this problem area. Table 1 summarizes the trajectories calculated for the NIMBUS/SNAP 19 satellite with unfolded platforms. Those marked by an asterisk are discussed in the Nuclear Safety Report, Reference 1. The balance are treated in this report. Where necessary for amplification, some of the previously reported data have been reintroduced.

First, it is necessary to establish the range of initial negative platform incidences which cause the satellite to re-enter in a non-tumbling mode. New trajectory calculations for platform incidences of -45, -70, -110, and -135 were made. These, together with the original trajectory data have been examined as a group. Since high altitude exposure is paramount for generator burn-up, the point at which tumbling begins is of prime importance. Figure 5 is a

graphic representation of this parameter. It is noteworthy that tumbling occurs in all cases except for the range of platform incidences between -80 and -135 . A detailed study of this range is presented below.

Pitch amplitude as a function of initial platform angle of incidence is presented in Figure 6. The pitch angles at which the generator is exposed to the flow, partially shadowed, or completely shadowed are indicated by the scale above the curves. It will be noted that the curves for platform incidences are labeled as pairs. These pairs are the limits of the excursion in amplitude. For example, in the -110° incidence case the satellite oscillates in pitch in the range 0° and -153° at 400,000 feet and damps to an oscillation of -28° to -114° at 335,000 feet. When the platform is at an initial incidence of -135° the oscillatory pitch range is 0° to -89° at 400,000 feet. By the time 345,000 feet altitude has been reached the divergent pitch amplitude has increased to the point where tumbling begins. Note the very limited exposure of the generator for platform incidences of -90 , -100 and 110 ,

Trends can be detected in the curves with changes in incidence. All of the convergent conditions indicate that the satellite will stabilize at an angle of attack equal to -60° . There is a slight divergence in the curvature of the -110° data above 365,000 feet, then a decided convergent trend is established. This is consistent with the strong convergence at -100° and strong divergence at 135° . Angles of incidence less than -90° degrees are very sensitive to factors causing tumbling as indicated by the comparison of the -80° and -110° degree cases.

A plot of platform incidence versus altitude (time) is shown in figure 7 for the above five initial incidence settings. Both the -90° and -100° curves show very small changes with time. The -110° curve shows a decided trend toward lower angles until 365,000 feet altitude at which point the trend reverses. Note that this is the point where the pitch amplitude in Figure 6 changes from slightly divergent to strongly convergent. All three of these conditions appear to seek an incidence angle in the range of -100 degrees. When the initial incidence setting of -135° is used the platform is acting in the manner of a trimming device which is sufficiently powerful to cause divergent oscillations in pitch. The change in incidence with time is such as to decrease the effectiveness of the platform as a trim device. However, since the dynamic Pressure is increasing with time, i.e. density increases with reduced altitude and velocity remains relatively constant, the driving forces to upset the satellite are not reduced sufficiently to damp the oscillations. The result is tumbling below 345,000 ft. For -80° incidence the curve shows increasing trimming power with time due to the fact that the platform assumes an incidence of -45° . (At zero degrees angle of attack for the satellite a platform incidence of $\pm 45^\circ$ provides a platform angle of attack relative to free stream of $\pm 45^\circ$)

The effect of pitch rate is shown in Figure 8 for an initial platform incidence setting of -90° . Figure 9 presents the incidence change with time. Initial pitch rates of $-.01$ or less show no measurable effect on the dynamic action. For a pitch rate of -0.10 the satellite is tumbling until an altitude of 373,000 feet is reached.

at this point it stops tumbling for a period of time during which the amplitude damps to an excursion range -38 to +172 then diverges again and begins to tumble at 347,000 feet. During the oscillatory regime the generator is fairly well exposed to the free-stream.

The effect of initial small angles of attack, $\pm 10^\circ$, on the re-entry behavior with a platform incidence of -90° is given in Figure 10 and 11. It is quite apparent that initial angle of attack has a secondary affect on the dynamic action within the range selected.

B. Platforms Folded

It is possible to have the solar platforms remain in the folded position due to a malfunction of the locking system. If this occurs the satellite will begin its re-entry from orbit in that configuration. As the satellite falls toward the earth it may either follow a stable path, oscillate to some degree, or tumble. An analysis of these motions using the three-degree-of-freedom program for calculating the trajectories is given below. Aerodynamic static stability data for the platforms folded configuration have been estimated for use with this program using modified Newtonian concepts described in Reference 1. They are shown in Figures 2, 3 and 4.

The two conditions which could cause tumbling or large excursions in trim angle are either initial angles of attack or initial pitch rates. It was decided to analyze only pitch rate since initial angles of attack essentially provides a rate of pitch at time $0+$ which is limited in magnitude.

Figure 12 shows the pitch amplitude as a function of initial pitch rate starting at an altitude of 400,000 feet. The time versus altitude has been superimposed on the plot. The pitch angles at which the generator is exposed are indicated at the top of the graph to facilitate an understanding of the importance of initial pitch rate and amplitude. It should be noted that the generator is shadowed by the sensory ring, stability and control subsystem, and platforms for all negative angles of attack whereas it is exposed when the platforms are unfolded. For clarification, it should be remembered that tumbling occurs in this case when the amplitude equals or exceeds ± 180 degrees. As an example, when the initial pitch rate is equal to +1.0, tumbling occurs above an altitude of 354,000 feet.

It should be noted that tumbling eventually stops for all positive pitch rates shown in Figure 12. Because of the asymmetry in the pitching moment curve caused by the generator and folded platforms, trajectories were calculated using negative pitch rates of -0.2, -0.4, -0.6 and -0.8. It was found that these negative rates caused tumbling in all cases except -0.2 which was found to have an amplitude variation similar to +0.2. In fact, once tumbling was started the dynamic pitch rate increased with time for the other initial negative pitch rates.

IV CONCLUSIONS

The extended study of the NIMBUS/SNAP 19 with solar platforms unfolded shows that:

- a. Initial solar platform incidences of +20 to +150 and -10 to -80° will cause the satellite to begin tumbling in the altitude range of 350,000 to 360,000 feet.
- b. Initial solar platform incidences in the region of 0 and ±180 degrees delays tumbling to an approximate altitude of 310,000 feet.
- c. No tumbling will occur with the platforms set at initial incidences in the range -80 to -120 degrees.
- d. Oscillations in these non-tumbling conditions do not appear to expose the generator to the free stream enough to permit its burn up.
- e. Initial pitch rates on the order of -.10 radians per second are required to cause tumbling when the initial platform incidence is equal to -90°.
- f. Initial angles of attack of ± 10° have little affect on the oscillations when the initial platform incidence is equal to -90°. They remain similar to the 0 degree case.

From the results of the folded platform study it is concluded that:

- g. For the range of initial pitch rates from -0.20 to $+1.00$ radians per second the satellite stops tumbling at altitudes in excess of 350,000 feet.
- h. Initial pitch rates must be in excess of $\pm .20$ radians per second in order to expose the generator.
- i. The damping rate for the non-tumbling conditions is sufficient to reduce the amplitude of the oscillations such that the generator will be only partially exposed at altitudes near 300,000 feet, even for pitch rates of $+ 1.0$ radians per second.

The above conclusions are limited to the situations wherein the satellite remains intact in the altitude range analyzed. Also the results are limited to the three-degree-of-freedom method of analysis.

These conclusions show that there is a good probability, even with the above restrictions, that the generator will re-enter without complete disintegration and burn-up under some conditions. Therefore, it is recommended that the SNAP 19 generator system be separated from the spacecraft to assure burn-up.

V REFERENCES

1. T. Dobry, G. Cahen, R. Emrick, M. Scheider, M. Haar,
"Preliminary Draft Safety Evaluation of The SNAP 19
Thermoelectric Generator On Board The Nimbus B
Satellite", MND-3169-41, January 1965 CRD.

FIGURE 1
FOLDED SOLAR PLATFORM MODEL

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FIGURE 3
NIMBUS SNAP 19
PLATFORMS FOLDED
AXIAL FORCE COEFFICIENT

FIGURE 4

NIMBUS SNAP 19
PLATFORMS FOLDED
PITCHING MOMENT COEFFICIENT

FIGURE 5

FIGURE 6

FIGURE 7

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FIGURE 8

FIGURE 9

PLATFORM INCIDENCE VS. ALTITUDE FOR
NIMBUS SATELLITE
INITIAL ANGLE OF ATTACK 0°

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FIGURE 10

FIGURE 11

PLATFORM INCIDENCE VS. ALTITUDE
FOR NIMBUS SATELLITE
INITIAL PITCH RATE: ZERO

NOTE: α : 0° TO -180° FLAT FACE (SOLAR CELLS) TO WINDWARD

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