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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

INTERNAL NOTE MSC - EG - 68 - 13

A PILOTED SIMULATION STUDY OF TILTOVER ABORTS

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INPUT BRANCH

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PROJECT APOLLO

A PILOTED SIMULATION STUDY OF
TILTOVER ABORTS

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INTRODUCTION

In the latter part of 1966, the GCD conducted a piloted simulation study of the LM tiltover abort capability. Although the results were not published formally, they were presented at the 29 September 1966, GCD coordination meeting held with MIT and GAEC (meeting no. L29A). Since that time, however, changes have been made in the length of the touchdown probe and recent test data on the DPS engine indicate a slower thrust decay than that assumed in 1966. Current APS thrust buildup characteristics are very nearly the same as the 1966 model. Because of the changes in the touchdown probe and DPS tailoff characteristics, it was decided to reevaluate the results obtained in the piloted tiltover abort study. Upon a reevaluation of the study, the results still appear to be valid. Thus, it is considered advantageous to formally publish the results from that study at this time.

SCOPE OF STUDY

The GCD conducted an analytical study (MSC Internal Note 66-EG-31) of LM tiltover aborts previous to this piloted study. The conclusions of that study were:

a. The LM pilot should be able to manually detect any tiltover situation which might result from landings within the gear design envelope.

b. If it is desired to utilize the full tiltover abort capability of the LM, an automatic abort logic is required.

It was considered desirable to investigate the LM tiltover abort problem in a piloted simulation to either prove or disprove these conditions. Thus, LM landings were investigated from touchdown to the point where the LM became either stable or statically unstable (tilt angle 40 degrees).

DESCRIPTION OF SIMULATION

The tiltover abort simulation was implemented in three degrees of freedom (pitch, roll, and yaw). Two pilot stations were implemented as shown in figure 1.

The left-hand pilot station contained an FDAI and an abort stage switch. From this station, the pilot monitored the inertial pitch attitude of the LM to determine a tiltover situation. Previous investigation revealed a pitch angle of -30 degrees to be approximately equal to the neutrally stable tilt angle of 40 degrees (see figure 2). The right-hand pilot station consisted of two abort indicator lights and an abort stage button. The abort indicator lights (right-hand pilot station) were driven by the automatic tiltover abort logic given in the appendix. The derivation for these abort logic is given in MSC Internal Note 66-EG-31. Since the purpose of this simulation was to verify the conclusions of the previous analytical tilt-over abort study, no attitude or translation controls were required. Each pilot simply monitored the instruments which were available to him to determine if a tiltover situation existed.

DISCUSSION OF RESULTS

The results are given in the form of tiltover phase planes shown in figures 3 through 9. Each of these figures shows the ascent-engine-on boundary and the abort-recognition boundary corresponding to an attitude rate limit of 20 degrees per second. Moreover, the landing dynamics time history shown in each figure corresponds to touchdown velocities of seven feet per second in the downrange direction. Figures 3 and 4 give the dynamics for a 2/2 landing where the two forward footpads fell into a seven-foot hole. The X's plotted on the tiltover time history in both figures correspond to the points where the abort stage button was pushed, thus indicating that the pilot believed this landing was resulting in a LM tiltover. Figure 3 corresponds to the data obtained where the abort indicator lights were used; figure 4 corresponds to the data obtained using the 8-ball. Figure 5 is a phase plane plot of a stable landing and thus, neither pilot pushed the abort stage button. Figures 6 and 7 give time history of another landing which resulted in a LM tiltover. The landing represented here was a 1/2/1 landing where the forward footpad slid before falling into a seven-foot hole. One of the side footpads fell into a four-foot hole. Again, the X's indicate the points at which abort stage button was pushed. Figure 6 presents the data for the abort indicator lights and figure 7 presents the data where the 8-ball was used. Figures 8 and 9 present another tiltover which resulted from a 2/2 landing where the two forward pads fell into a six-foot hole. The X's shown in figure 8 are the data corresponding to the indicator lights and those of figure 9 are the data corresponding to the 8-ball. The data shows that for all the tiltover cases presented to the pilots, the abort recognition capability of both the abort indicator lights and the 8-ball was equally good. Only one tiltover (figures 6 and 7) yielded abort recognition data which fell beyond the abort recognition boundary; however, both the abort indicator lights and the 8-ball yielded this same data trend.

CONCLUSIONS

1. Pilot can successfully determine a tiltover situation and initiate abort/abort-stage sequence by monitoring the 30 degree pitch line on FDAI.

2. Pilot monitoring of tiltovers using FDAI is adequate for a significant portion of landings which might occur outside the gear design envelope.

3. The results indicate an automatic tiltover abort system would not appreciably increase the tiltover abort capability of the LM.

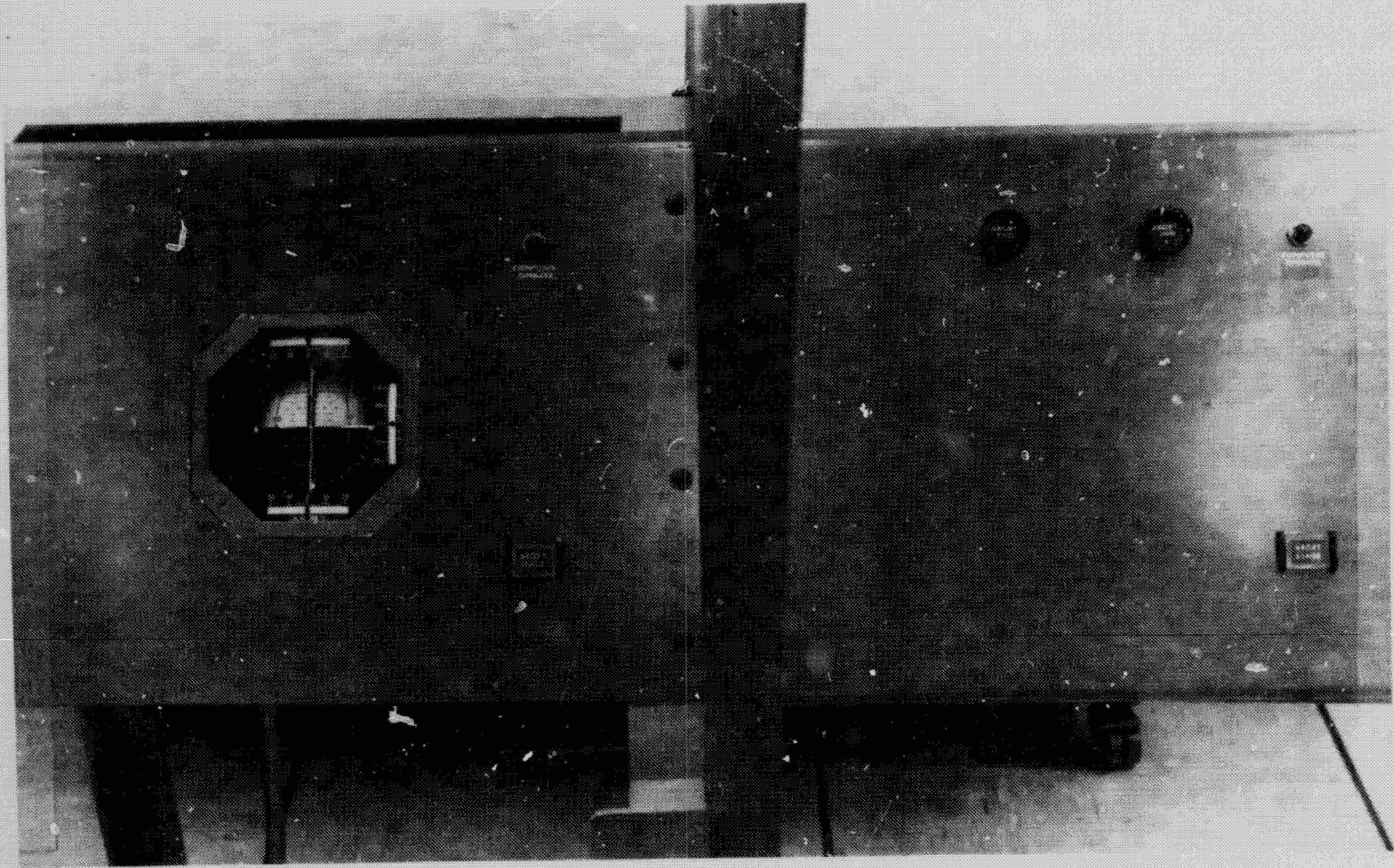

FIGURE 1. - PILOT STATIONS

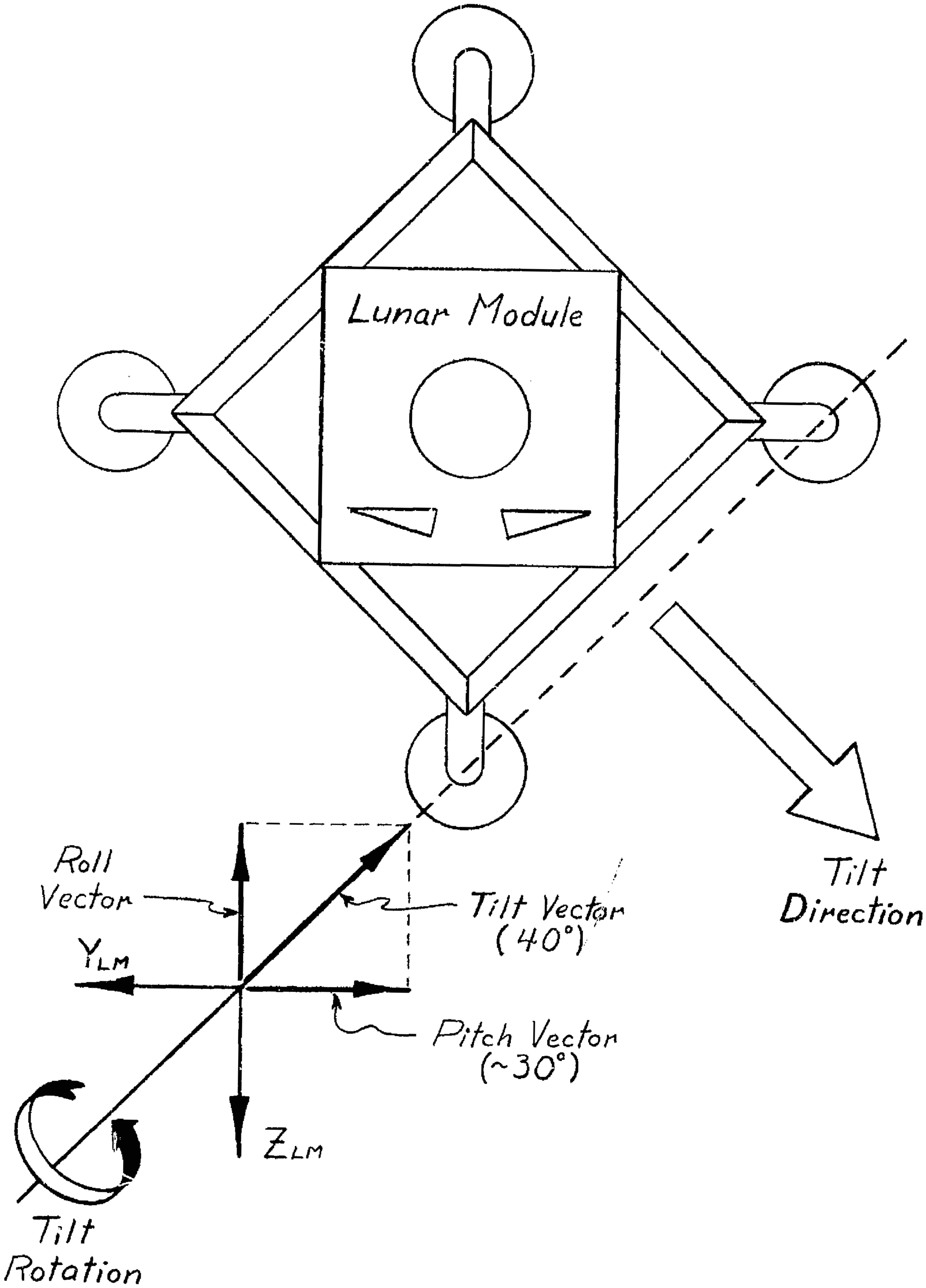

Figure 2 - Tilt Angle Resolution

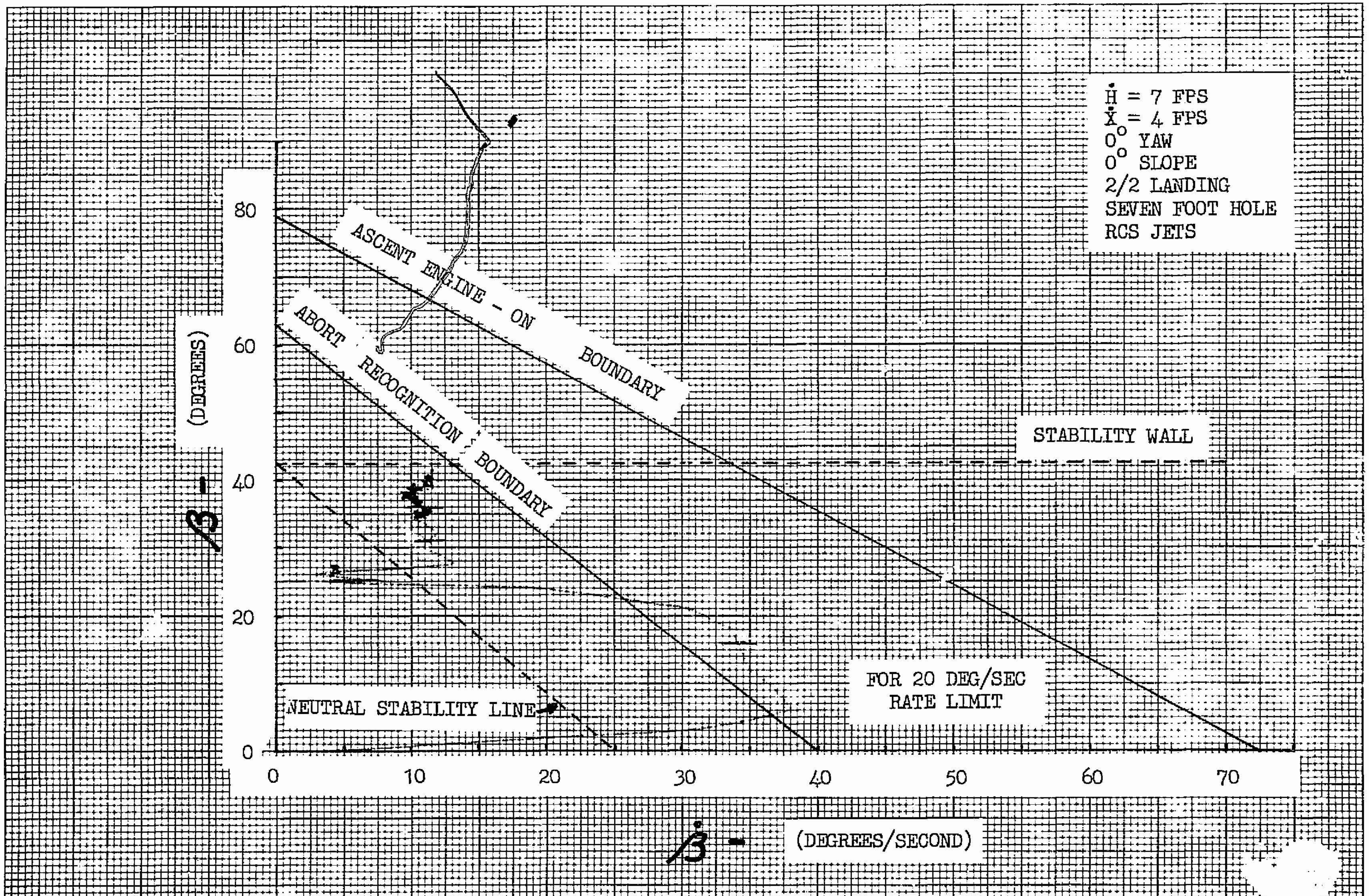

Figure 3 - Tiltover time history for unstable 2/2 landing - Abort indicator light data

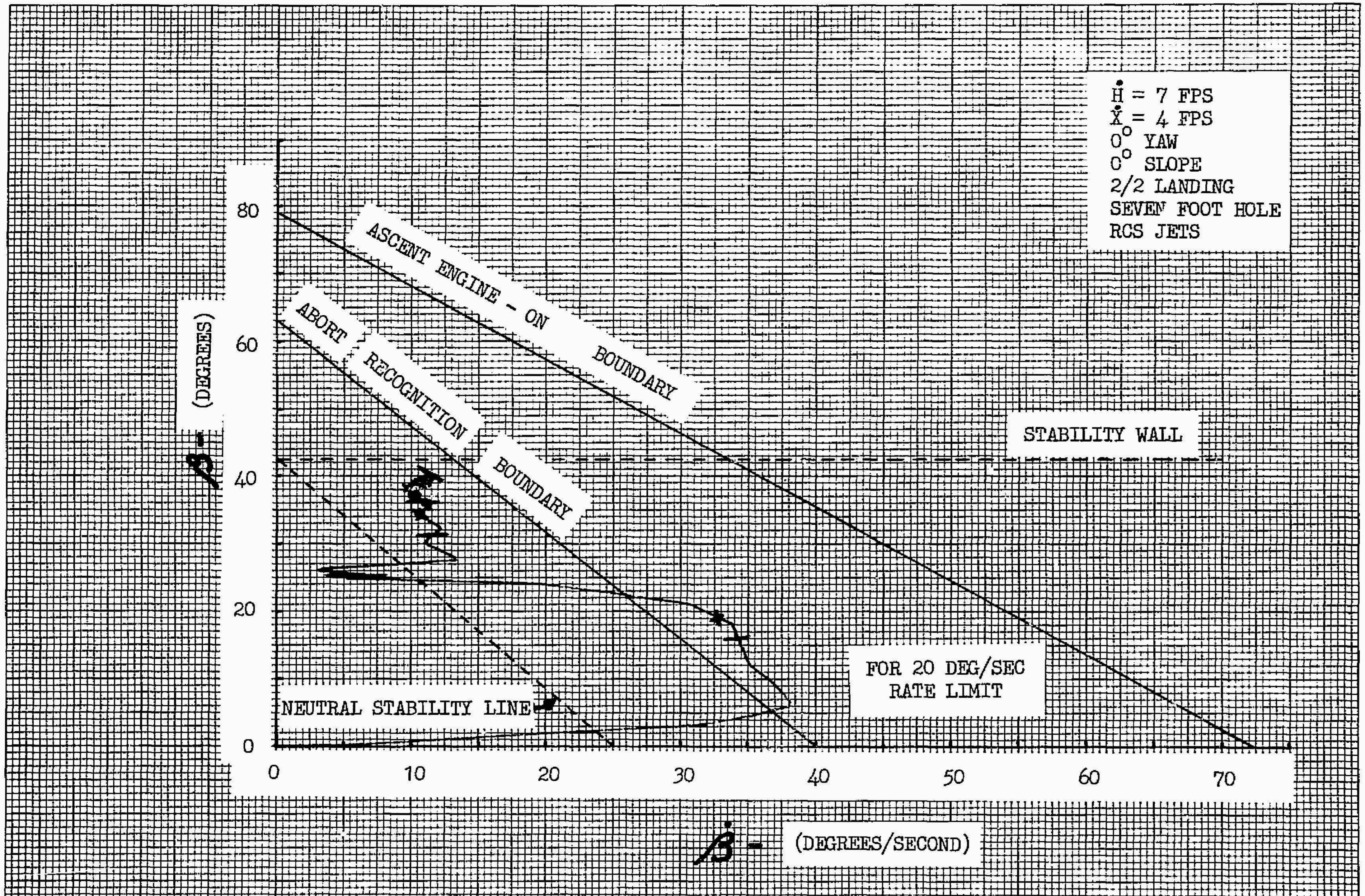

Figure 4 - Tiltover time history for unstable 2/2 landing - FDAI data

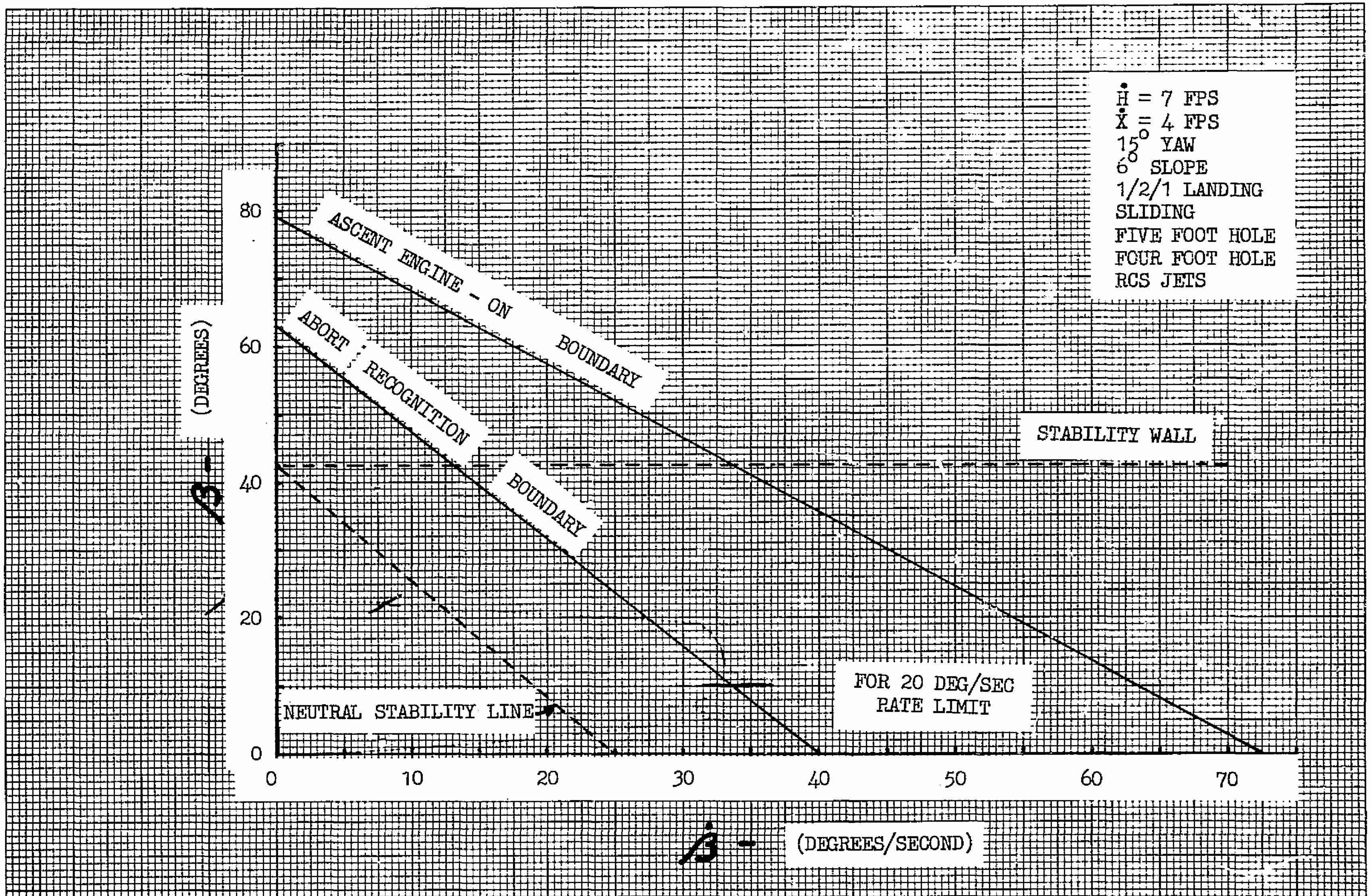

Figure 5 - Tilt time history for stable 1/2/1 landing - Abort indicator light and FDAI data

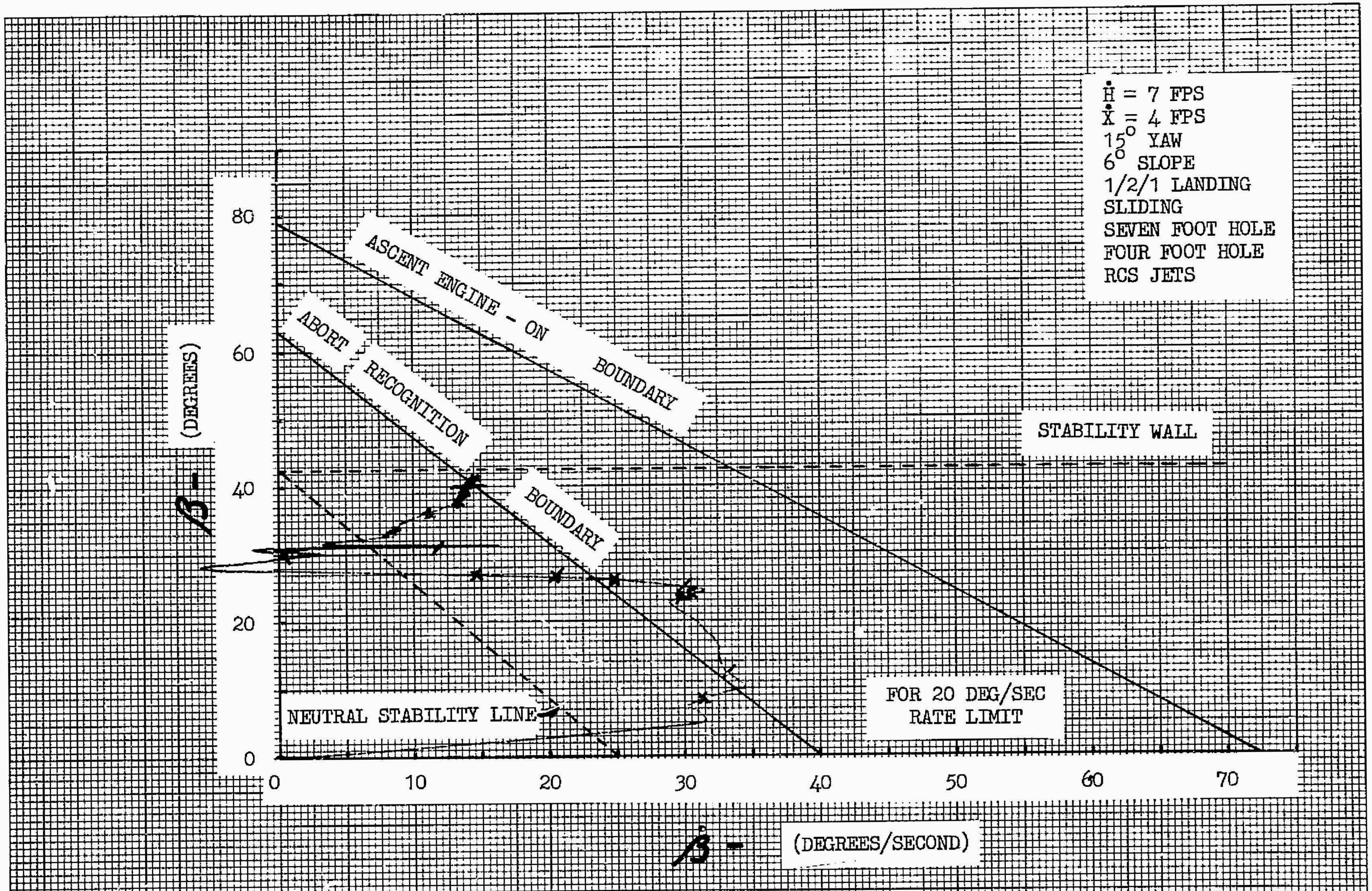

Figure 6 - Tiltover time history for unstable 1/2/1 landing - Abort indicator light data

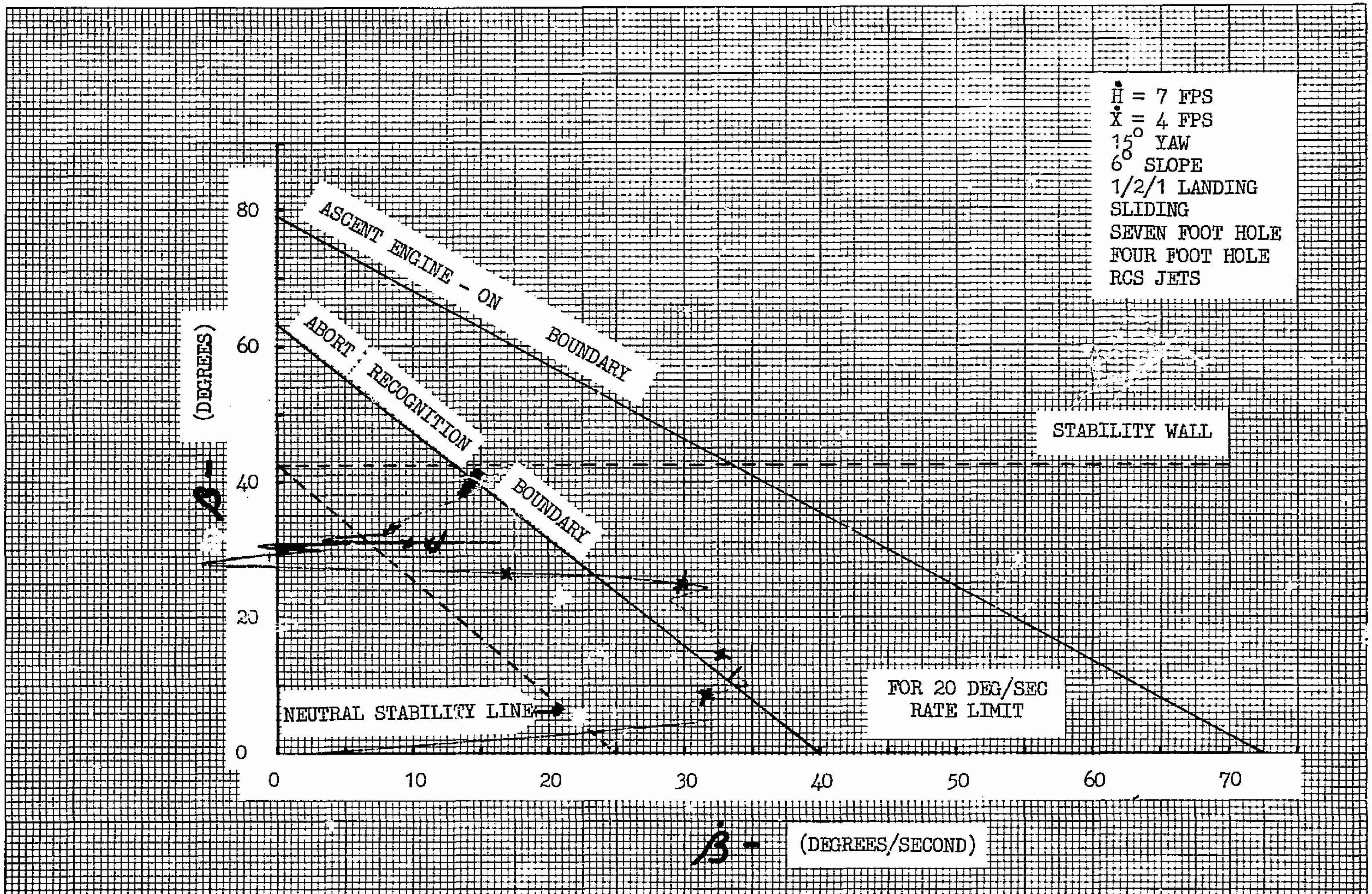

Figure 7 - Tiltover time history for unstable 1/2/1 landing - FDAI data

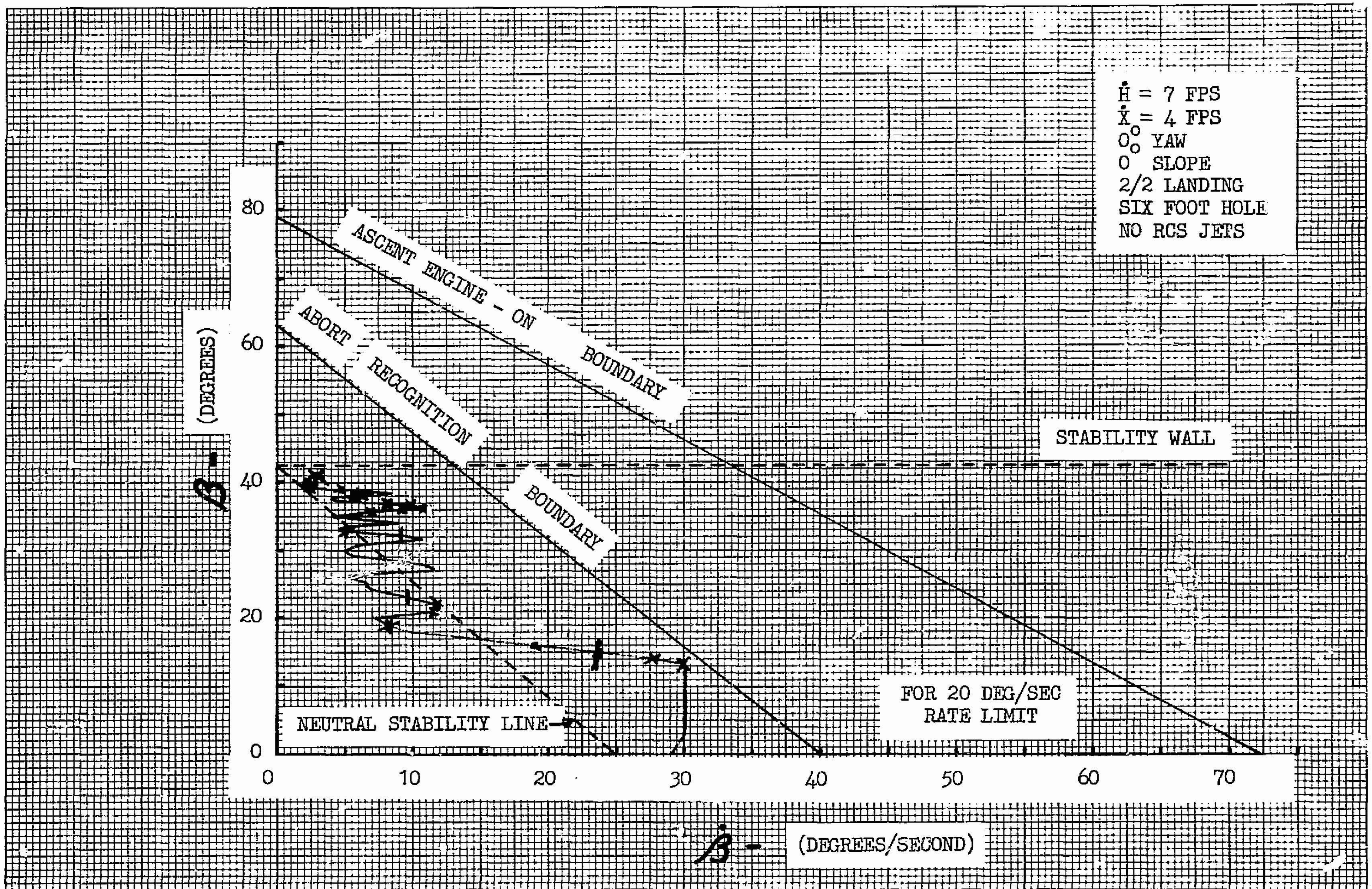

Figure 8 - Tiltover time history for unstable 2/2 landing - Abort indicator light data

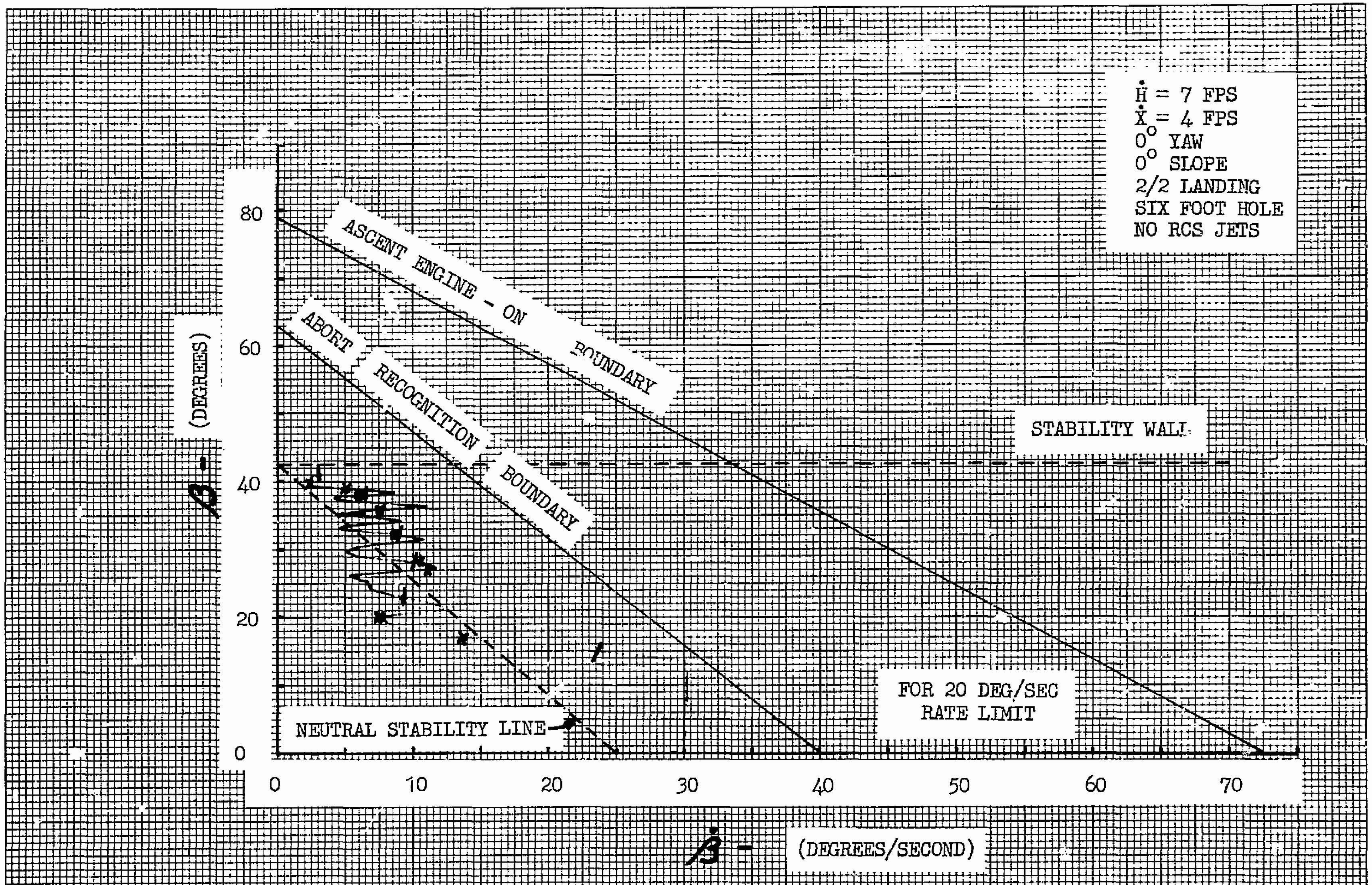

Figure 9 - Tiltover time history for unstable 2/2 landing - FDAI data

Appendix

Automatic Tiltover Abort Logic

$$\dot{\beta}'_{ACT} = -\Delta a_{11} / \Delta t \sqrt{1 - a_{11}^2}$$

$$\beta'_{NEU\ STAB} = -1.7 \left(\dot{\beta}'_{ACT} \right) + 42.5^\circ$$

$$\beta'_{ACT} = \arccos a_{11}$$

$\beta'_{ACT} < \beta'_{NEU\ STAB} \longrightarrow$ SAFE LANDING

$\beta'_{ACT} > \beta'_{NEU\ STAB} \longrightarrow$ ABORT

OR,

$\beta'_{ACT} > 42.5^\circ \longrightarrow$ ABORT

Where: β' = angle between LM X-body axis and local vertical.
a_{11} = direction cosine (computed in AEA) of angle between LM X-body axis and local vertical at proposed landing site.