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BACKUP THRUST VECTOR CONTROL

by

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February 1963

MIT INSTRUMENTATION LABORATORY

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BACKUP THRUST VECTOR CONTROL

ABSTRACT

This report contains a description of a backup method of attitude control for use during Service Module thrusting. An analog computer simulation that was used to demonstrate its feasibility is also described. Results of experiments with the analog computer dealing with the human factor are given.

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Backup Thrust Vector Control

For the case of computer failure, a G & N system backup mode for attitude control during thrusting can be provided. Should the computer fail, DSIF* will transmit guidance information and velocity change instructions for abort or continuance of the mission. The IMU can be aligned to approximately 0.1° without use of the AGC by means of a backup mode in which the Spacecraft tracks a star seen through the Scanning Telescope while the IMU is in Coarse Alignment. X_{SM} is aligned with the desired ΔV. The SCS backup accelerometer then provides engine cutoff while the Y_{SM} and Z_{SM} PIPA's indicate unwanted cross-axis acceleration. The AGC ΔV pulses are used to flash lights (one flash per ΔV increment). In the ternary pulsing mode with four lights we get + and - indication for each axis with flash rate proportional to magnitude of acceleration error. Scale factor is not critical.

The astronaut commands pitch and yaw attitude increments through the pitch and yaw CDU thumb-wheels until the lights stop blinking (see Fig. 1).

To make this mode possible the following components must be added to the G & N system: Refer to APOLLO Project Memo No. 313 for further details:

1. Gyro caging electronics (for backup alignment)
2. Emergency clock circuit for PIPA electronics activiated by AGC failure.
3. Four lights on PSA front panel to display PIPA torque pulses.

A one-dimensional simulation has been made of this mode to test its feasibility. The attitude trimming is done by the operator at the G & N station by moving the CDU thumb-wheel, which effects

* Deep Space Instrumentation Facility

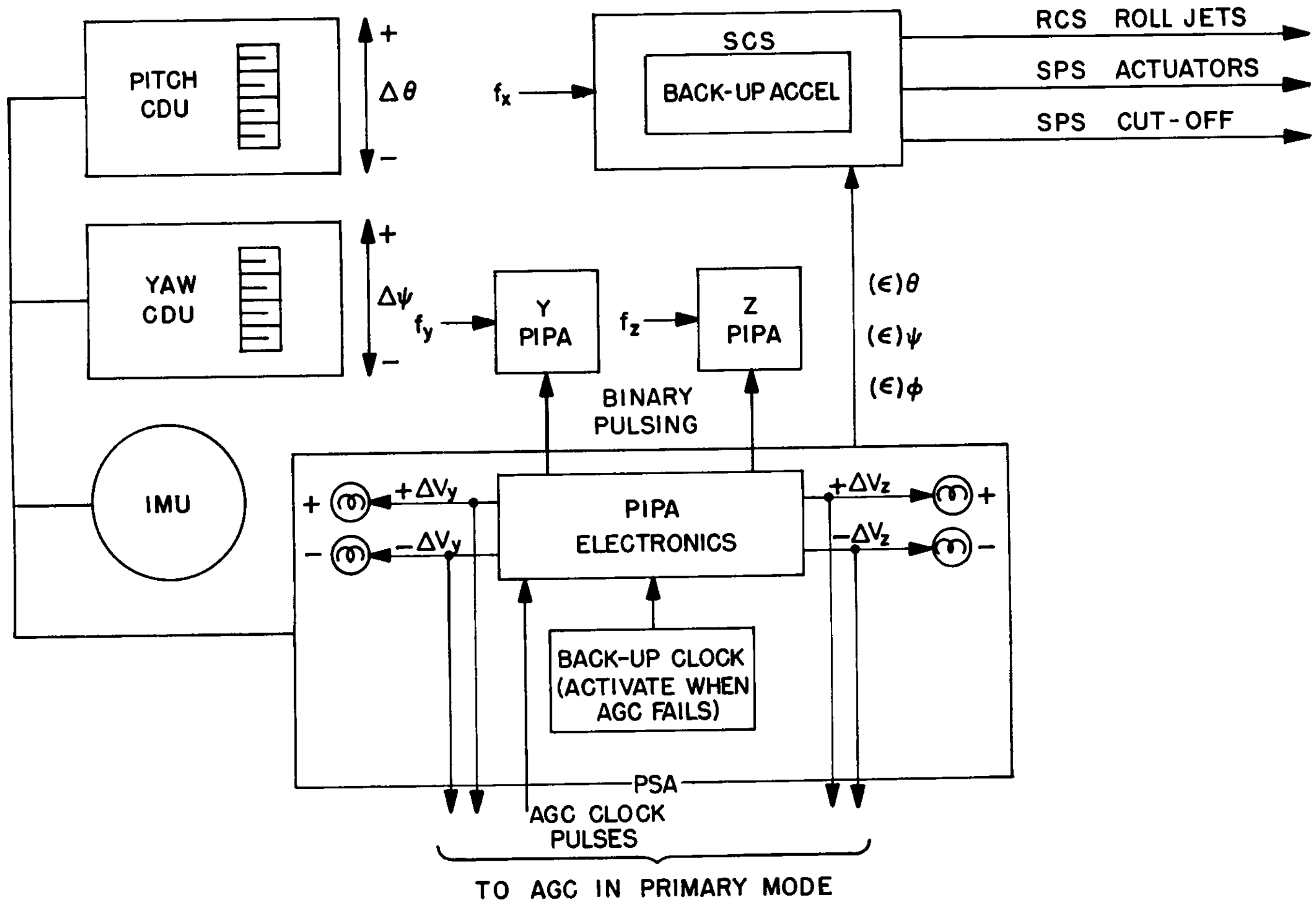

Fig. 1 G & N station controls and displays for TVC backup mode.

a 1^{o} attitude change for a full turn of the wheel.

Two vehicle configurations were employed in the simulation, representative of the two extreme possible conditions. Veh 1 consists of the service module with no fuel and the command module corresponding to pre-entry conditions and the heavier Veh 2 has the service module full, LEM, and the command module corresponding to the situation immediately after translunar injection. For Veh 1 the acceleration is 28 ft/sec^2 and for Veh 2 the acceleration is 7.8 ft/sec^2. (All values used in this simulation are taken from AGANI page 463.) The scale factor in this simulation is 5.22 cm/sec/pulse. It is seen that a 1^{o} misalignment in pitch or yaw would produce, for the light Veh 1

$$\frac{\frac{1^{o}}{57.3} \times 28 \text{ ft/sec}^2}{\frac{5.22 \text{ cm/sec}}{2.54 \times 12}} = 2.75 \text{ blink/sec}$$

and for the heavy Veh 2

$$\frac{\frac{1^{o}}{57.3} \times 7.8 \text{ ft/sec}^2}{\frac{5.22 \text{ cm/sec}}{2.54 \times 12}} = 0.766 \text{ blink/sec}$$

and proportionately for other small misalignments. Note that the initial misalignment arises from the fact that the vehicle CG location is uncertain. Once the initial transient dies out, the thrust vector goes through the CG and has some angle with respect to X_{SM} which is defined as the misalignment. The autopilot has an uncertainty of approximately 1^{o} in correcting for this misalignment, by means of preflight C. G. location prediction.

This simulation was made on the REAC analog computer using the SCS autopilot system described in S & ID Memo, S & CA-62-11 of September 13, 1962. The accelerometer lights were simulated with the REAC comparator amber lights, which are parallel to the relay coils. A potentiometer was employed as the CDU wheel, giving 1^{o} for a full turn. The procedure used in evaluation of this technique was to initiate the problem by providing a step signal of attitude command which is seen on the flashing lights. This step corresponds to initiation of thrust where an attitude error in general exists that should be nulled out. The subjects were provided with indicators by each light to show which direction to turn the CDU wheel to null out the light.

Upon application of the step signal there was a transient period during which both positive and negative lights flashed in sequence before settling down to steady error indication. For the light vehicle this transient lasted about 1 second, corresponding to the SCS fourth order attitude position loop time constant. For the heavy vehicle the transient lasted about 2 seconds, because of thrust engine gimbal motion limits. The engine gimbal limits are $\pm 7.5^{o}$ but since a 3^{o} center of gravity deviation from the axis of symmetry is possible, the gimbal limits were set to $+4.5^{o}$ to -10.5^{o} for all the tests described in this note.

Considerable effort was made to make this transient condition correct in describing the actual conditions, but this portion of the simulation will not be described in detail because it is really not essential to the questions at issue here. Traces of the transient conditions also are observed while turning the CDU wheel. It is sufficient to realize that the operator must wait until the steady-state blinking condition is reached before assessing the attitude error. The results of the experiments made with six subjects are given in the table and shown in the two diagrams, Figs. 3 and 4.

It is observed in the diagrams that because the acceleration with the lighter Veh 1 is 28 ft/sec^{2} and that with the heavy Veh 2 is 7.8 ft/sec^{2}, the velocity error accumulates much faster with the light vehicle and so the error is greater. It is not proportionately greater because the higher light blinking rate with the light vehicle is very much better as an indication for nulling. Thus with the heavy vehicle by the time the attitude error has been reduced to 1/2; the flashes are only once every three seconds, necessitating an appreciable wait after each nudge of the CDU wheel to see what is happening. The accelerometer specific force and its integral, the velocity error, were recorded on a Brush Recorder (see Fig. 2). One technique that was employed in this one dimensional simulation was to count the flashes of one polarity and null them with an equal number of flashes of the opposite polarity. The tests done by this method are identified in the tabulation. This technique was very successful with the slower flashes of the heavy vehicle but not so successful with the light vehicle. However, in the actual two-dimensional case, this technique might well be unworkable, especially for large initial thrust misalignments. The two-dimensional case will be simulated later.

The greater portion of the time required to correct the attitude is taken up with the final fine portion of the correction, particularly with the heavy vehicle. Of course when the test subject says "O. K. it's all nulled out", there is still some error remaining. Velocity error is building up and a light is flashing at a slow rate. In this simulation the rate remaining was about 0.05 ft/sec^2 (heavy vehicle). If, in the actual two dimensional case the operator remains alert, he can null out these flashes with flashes of opposite polarity.

Fig. 2 is a Brush Recorder trace of an initial vehicle trim procedure as done in this simulation. Trace 1 is $\delta - \delta_o$, the Service Module main engine gimbal angle, in the pitch or yaw plane. Trace 2 is total accelerometer specific force in this plane. Trace 3 is the integral of Trace 2, the velocity error The units of Traces 2 and 3 are 1^o/small division. The time scale is 1 sec/line. From A to B is the initial transient upon initiation of thrust with 2^o attitude error for the heaviest vehicle.

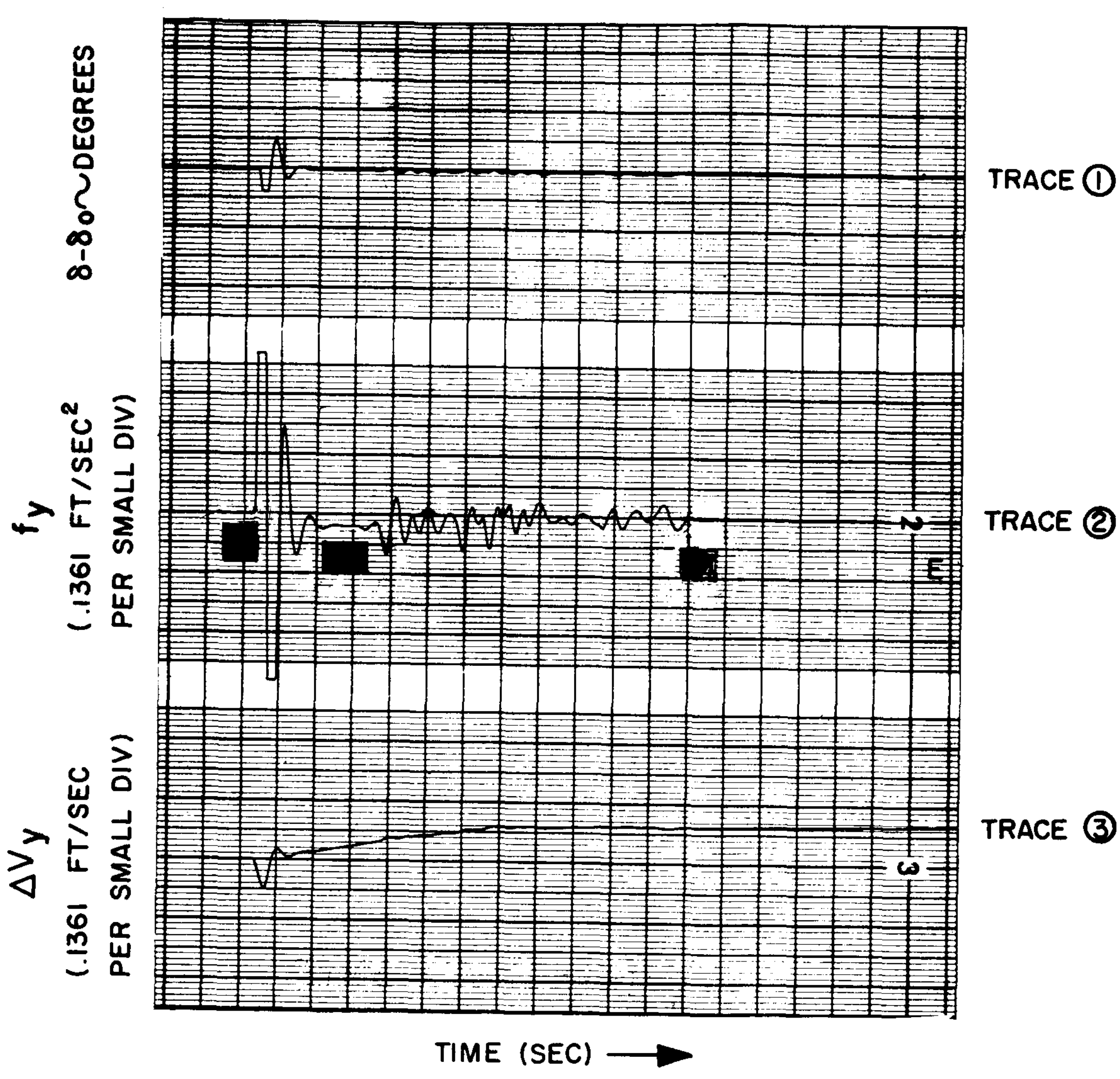

Fig. 2 Brush recorder results of attitude correction.

From B to C is a stable condition with 2^{o} error during which the operator observes the error. From C to D is shown the result of correction with the CDU wheel. The random "step" and "ramp" CDU wheel correction signals cause specific force signals that look rather like noise here. From D to E the effect of the undetected error is seen in trace 3.

TABULATION OF RESULTS

A. In ascending order of velocity error remaining:

1. Veh 1, Lighter Vehicle

a. 1^{o} Step

0 ft/sec	29 sec	Sub. 3*
0.979 ft/sec	23 sec	Sub. 2
2.44 ft/sec	5 sec	Sub. 4
2.45 ft/sec	11.5 sec	Sub. 1
3.42 ft/sec	20 sec	Sub. 1

b. 2^{o} Step

3.42 ft/sec	18 sec	Sub. 2
4.9 ft/sec	13.5 sec	Sub. 1
6.05 ft/sec	12 sec	Sub. 1

c. 3^{o} Step

3.18 ft/sec	17 sec	Sub. 3
3.18 ft/sec	21.5 sec	Sub. 6*
4.89 ft/sec	7 sec	Sub. 5
5.12 ft/sec	10 sec	Sub. 5

*Subject attempted to null out velocity error by counting pulses

TABULATION OF RESULTS (con't.)

6.1 ft/sec	19.5 sec	Sub. 4	
6.36 ft/sec	7 sec	Sub. 1	
6.84 ft/sec	19 sec	Sub. 4	
7.04 ft/sec	13 sec	Sub. 1	
7.32 ft/sec	14 sec	Sub. 6	
7.33 ft/sec	15 sec	Sub. 4	
9.26 ft/sec	15 sec	Sub. 3	
9.79 ft/sec	16 sec	Sub. 2	
13.29 ft/sec	12.5 sec	Sub. 1	
13.69 ft/sec	14 sec	Sub. 1	

d. 3.5° Step

8.71 ft/sec	17 sec	Sub. 1	
9.79 ft/sec	16 sec	Sub. 2	

2. Veh 2, Heavier Vehicle

a. 1° Step

0.681 ft/sec	10 sec	Sub. 4	
1.635 ft/sec	20.5 sec	Sub. 1	(0.545 ft/sec in 15 sec drift undetected)
2.5 ft/sec	12 sec	Sub. 1	

b. 2° Step

2.725 ft/sec	15.5 sec	Sub. 1	(2.725 ft/sec drift in 52 sec undetected)

c. 3° Step

0.681 ft/sec	63 sec	Sub. 4	(counting and nulling vel.)

TABULATION OF RESULTS (con't)

1.36 ft/sec	57 sec	Sub. 3 (over correcting)
2.045 ft/sec	36 sec	Sub. 2
3.065 ft/sec	16 sec	Sub. 4
3.27 ft/sec	11.5 sec	Sub. 1
3.62 ft/sec	14.8 sec	Sub. 1 (drift remaining 0.545 ft/sec in 10 sec)
3.75 ft/sec	18 sec	Sub. 4
4.09 ft/sec	20 sec	Sub. 4
6 ft/sec	38.5 sec	Sub. 1

d. 3.5° Step

5.31 ft/sec	22 sec	Sub. 1
6.81 ft/sec	21.5 sec	Sub. 1

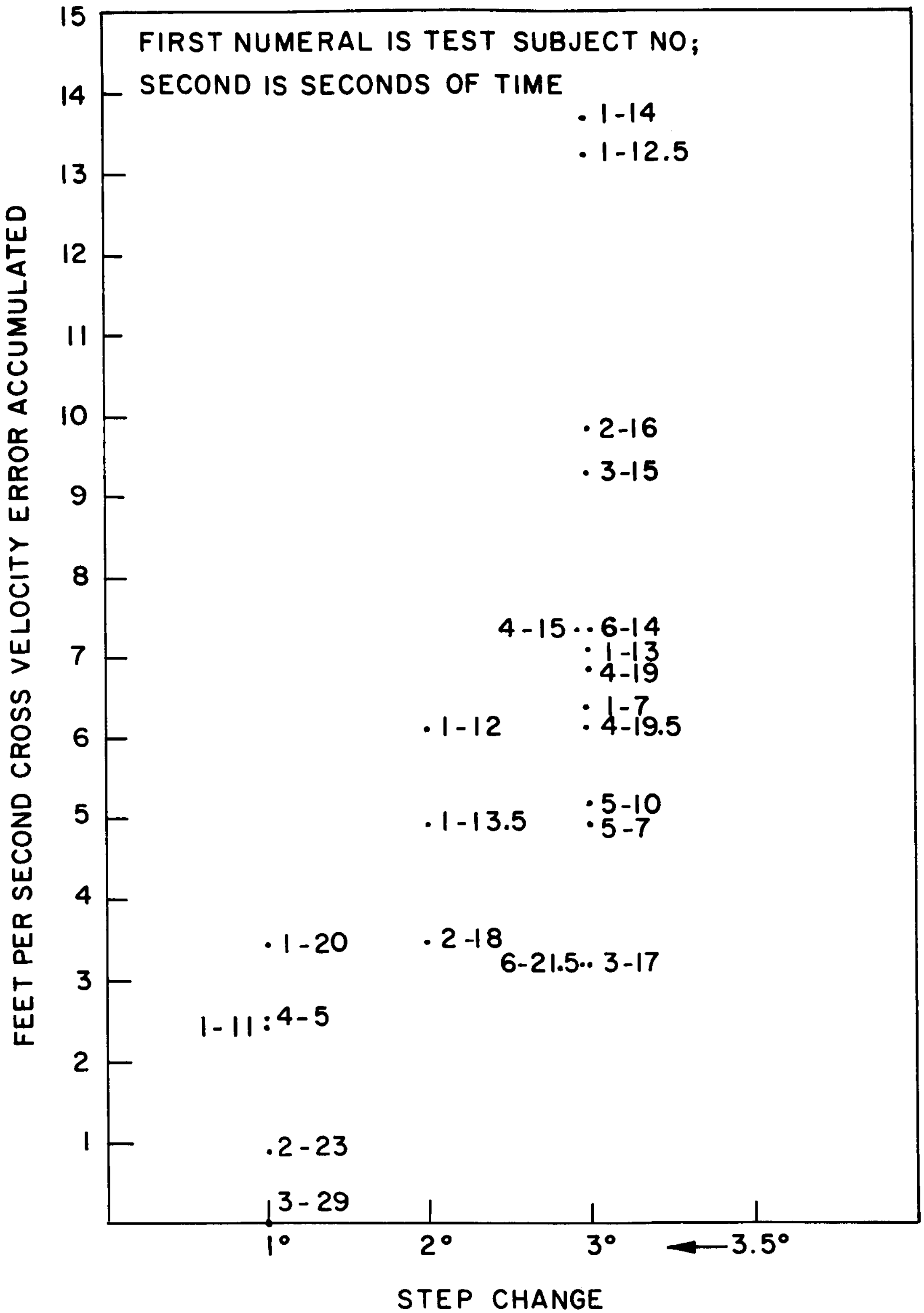

Fig. 3 Manual attitude correction during thrusting - lighter vehicle,

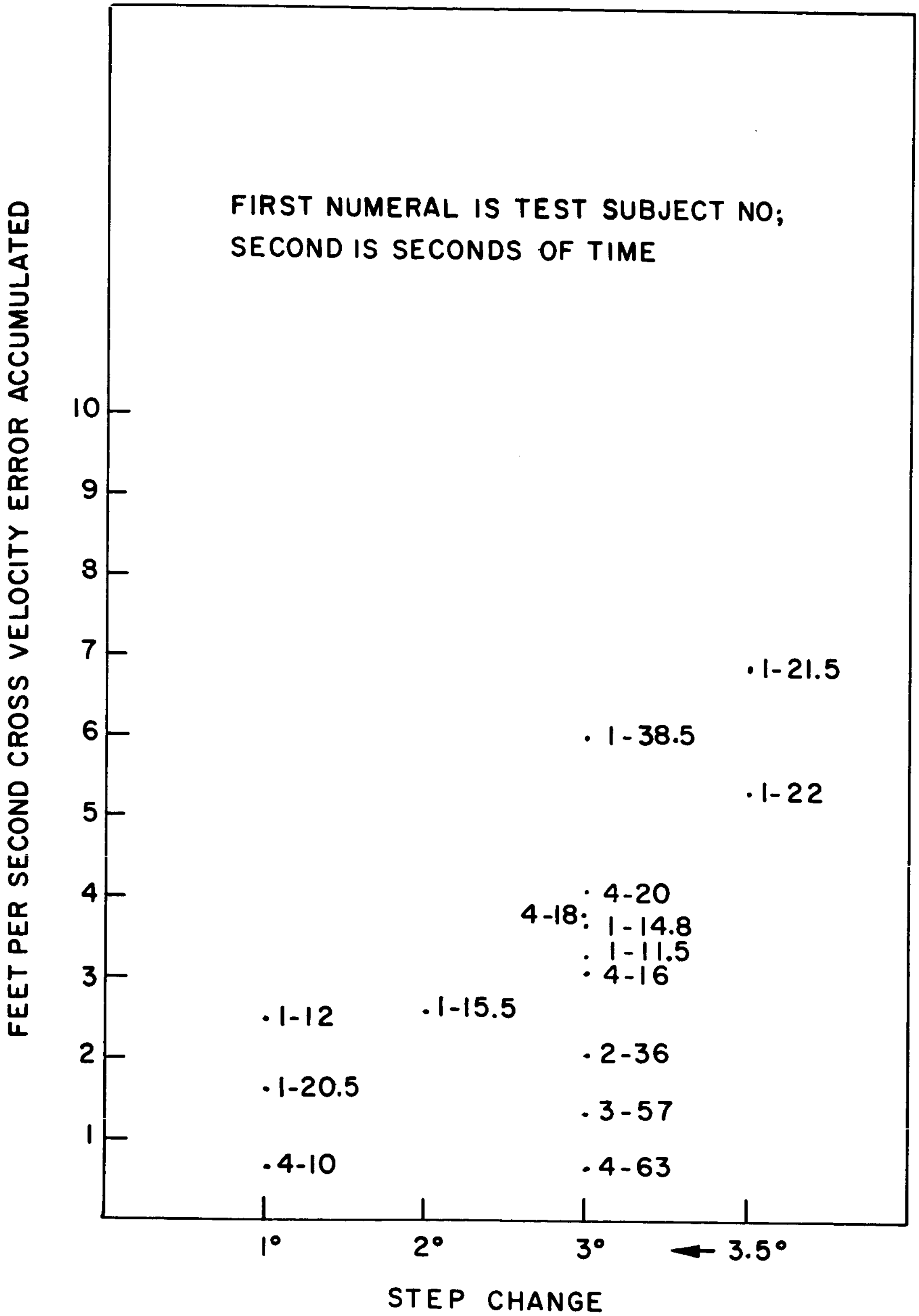

Fig. 4 Manual attitude correction during thrusting - heavier vehicle.

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