SECONDARY TASK FOR FULL FLIGHT SIMULATION INCORPORATING TASKS THAT COMMONLY CAUSE PILOT ERROR: TIME ESTIMATION

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INTRODUCTION

The objective of this joint research program was to provide human factors investigators with an unobtrusive and minimally loading additional task that is sensitive to differences in flying conditions and flight instrumentation associated with the main task of piloting an aircraft simulator. The additional task under investigation was time estimation, an activity occasionally performed by pilots during actual flight. Previous research, supported by NASA-Ames Consortium Agreement NCAR-050-404, indicated that the duration and consistency of time estimates is associated with the cognitive, perceptual, and motor loads imposed by concurrent simple tasks. The present research was aimed at clarifying the relationship between the length and variability of time estimates and concurrent task variables under a more complex situation involving simulated flight.

METHOD

Commercial airline pilots, nine in the first group and six in the second, generated 10-sec time estimates using the method of production. They began each estimate by the activation of a switch, always in response to an automatically presented cue, and they terminated the estimate by another switch activation when they judged that 10 sec had elapsed. Pilots in the first group produced time estimates in the absence of a concurrent task (baseline) and then under four different complexity levels of a compensatory tracking task. After baseline estimation, pilots in the second group produced estimates while flying a transport aircraft simulator under eight different combinations of wind velocity and flight instruments.

Tracking Task

The compensatory tracking task, outlined in Figure 1, combined two levels of dimension (one or two axis) with two levels of difficulty of the quasi-random forcing function ("easy" or "hard", corresponding to low pass filtering at a frequency of 0.5 or 1.5 rad/sec respectively). The first-order control task consisted of attempting to maintain either or both of the horizontal and vertical driven lines at the center of the display, superimposed upon a fixed reference cross. Pilots produced seven 10-sec time estimates in the absence of concurrent activity (baseline) and then again under each of the four tracking conditions. The signal to begin each time estimate was the appearance of the phrase "10 SEC" across the top of the display. That signal appeared 10 sec after initiation of a tracking condition or termination of the preceeding estimate. Actual interestimate intervals typically varied between 10.7 and 13.0 sec depending upon exactly when the individual pilots actually began each estimate. The design of the tracking esperiment is illustrated in Figure 2.

Flight Simulation

The flight simulation involved two levels of each of three controlled variables: (a) wind velocity of either 4 or 32 knots, (b) presence or absence of a flight path predictor, and (c) presence or absence of a graphic wind vector. The eight possible experimental conditions were balanced in presentation across trials, pilots, and days, and all were given once on each of 4 different days. The pilots completed participation in the study over a period of between 4 and 8 days. Daily sessions lasted about 1.5 hr, and individual runs required approximately 6 min to fly. The design of the flight simulation experiment is illustrated in Figure 3.

The flight path predictor and the wind vector, when present, were each graphic elements of a moving map display (Figure 4) used by the pilots for lateral control and navigation of the simulator. The predictor originated from the symbolized aircraft position on the map. It dynamically reflected aircraft flight characteristics, pilot control inputs, and wind effects, providing a 30 sec projection of the route that the simulated aircraft would fly under existing conditions. The wind vector displayed the direction and velocity of the prevailing wind, and aircraft drift due to wind was dynamically represented by the angle between vector arrowhead and shaft. Pilots had the task of maintaining the simulated aircraft at 1,000 ft assigned altitude and of following the route of flight (Figure 5) depicted in the map display as precisely as possible.

Pilots produced six 10-sec time estimates in the absence of concurrent activity (baseline) and then again under each of the eight experimental conditions during each of the four days they participated in the simulation. A 1,020 Hz tone, and the appearance of the phrase "EST 10 SEC" just to the right of the flight instruments, signalled the pilots to begin each estimate. The tone ceased once the estimate was begun, while the phrase "10 SEC" persisted as a reminder that an estimate was in progress. Termination of an estimate caused the reminder phrase to disappear. The signal to begin a time estimate occurred when the simulated aircraft was at or abeam each of the six geographical locations along the assigned route of flight indicated in Figure 5. The cue to begin the first estimate occurred approximately 20 sec after initiation of flight, while the interestimate interval, assuming that each estimate lasted approximately 10 sec, typically ranged between about 35 and 70 sec. The flight instruments remained static in the baseline condition, but pilots produced time estimates as though the simulator were flying the assigned route.

RESULTS

Baseline estimates, produced in the absence of a concurrent task, were consistent within individual pilots, generally quite accurate, and appeared to be normally distributed. With the addition of a concurrent task, individual pilot's estimates became more variable, less accurate, and were distributed with positive skewness.* Since skewness characterized the distributions of estimates produced with concurrent activity, the arithmetic mean misrepresented central tendency by giving undue weight to the few particularly deviant (long) estimates (Figure 6). For example, the mean was 1.0 sec longer than the median of estimates made during concurrent flying. However, the mean and median were approximately the same for baseline estimates, as one would expect from a normal distribution. The median of each pilot's estimates within a session was therefore chosen as the more representative measure of central tendency. It follow that the average (absolute) deviation of scores from the median was appropriate as a measure of dispersion.

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* The following descriptive statistics are mentioned in the discussion of experimental results:

Mean $= \sum X/n$

Median (Md) = point which divides the upper half of scores from the lower half: It is the centermost score for an odd number of scores and the mean of the two centermost scores for an even number.

Average Deviation (AD) $= \sum |X - Md| / n$

Skewness (Gamma 1) $= \dfrac{\sum(X - \bar{X})^3/n}{(\sum(X - \bar{X})^2/(n - 1))^{3/2}}$

Kurtosis (Gamma 2) $= \left(\dfrac{\sum(X - \bar{X})^4/n}{(\sum(X - \bar{X})^2/(n - 1))^2}\right) - 3$

Tracking Task

Pilot performance under the four tracking conditions varied significantly as a function of the number of dimensions and the difficulty of the forcing function. Tracking error increased as the number of axes controlled was increased from one to two and as task difficulty was increased from the easier to the more difficult forcing function.

For the group of pilots who performed the tracking task, a slight increase in positive skewness charterized the distributions of estimates made with, as compared to those made without concurrent tracking. Overall, estimate length increased by 50% and the average deviation increased by 94% with the addition of compensatory tracking (Figure 7).

During concurrent tracking, positive skewness increased, median duration decreased, and average deviation increased as the number of controlled axes was increased from one to two (Figure 8). As the difficulty of the task was increased from the easier to the more difficult forcing function, there was a substantial increase in positive skewness, average deviation, and median estimate length (Figure 9).

Flight Simulation

Piloting performance in control of the simulator was assessed by measures of error in lateral guidance, error in maintaining assigned altitude, aileron control activity, and elevator control activity. Scores on all measures increased significantly as wind velocity was increased from 4 to 32 knots. The flight path predictor was associated with a significant decrease in lateral error and in aileron and elevator control activity, but altitude error was not significantly affected. An interaction with subjects obscured the difference between overall flying precision and control activity and the presence or absence of the graphic wind vector.

Although the central tendency and skewness of baseline estimates produced by the pilots who flew the simulator were virtually identical to those of the group of pilots who performed the tracking task, the average deviation of baseline estimates was greater for the latter group. With the added task of flying the simulator, positive skewness increased substantially and overall estimate length decreased by 10%. While the absolute change in average deviation with the addition of either concurrent task was numerically the same, it represented a 204% increase with respect to baseline for the pilots flying the simulator compared with a 94% increase for the other group.

During simulated flight, positive skewness increased, median estimate length decreased, and average deviation increased as the wind velocity was increased from 4 to 32 knots (Figure 11). Similarly, with the addition of the predictor to the map display, positive skewness again increased, median estimate length decreased, and average deviation increased (Figure 12). The addition of the wind vector to the map display again produced the same, though smaller, changes in all three measures of time production distributions (Figure 13).

DISCUSSION

Theoretically, one may distinguish two ways in which an individual can produce a time estimate: active and retrospective. Active estimation hypothetically involves a conscious attempt to keep track of time on a sustained basis during an estimate. For example, this may be done by counting off seconds. The various techniques used for active estimation each require a moderate amount of attention. Any concurrent activity that also requires attention clearly competes with active estimation. When an additional task momentarily diverts attention from estimation, clock time continues whereas subjective timekeeping may not. Thus, the amount of time that has passed may be underestimated, so that the resulting production is too long.

The time estimation task may be forgotten for relatively long periods of time as a consequence of attention paid to other activities, resulting in very long productions that no longer represent subjective estimates of time and are limited in length only by the maximum duration allowed by the experimental design. If concurrent tasks exert heavy attention demands, active time estimation becomes impossible.

The retrospective mode of estimation hypothetically provides an alternative way to produce specified durations when concurrent task demands preclude active estimation. Using the retrospective mode, the amount of time that has elapsed since the beginning of an interval is estimated at one or more discrete points. The length of each such estimate is determined by one's memory of the events that occurred during the preceeding interval. The usual finding is that intervals filled with many events and complex mental processing seem to last longer than they in fact do, an overestimation of elapsed time resulting in productions that are too short. The decision to terminate the production is thus based on a comparison between one's idea of how much time has passed since the beginning of the estimate and one's conception of the interval of time being estimated.

Retrospective estimation does not require sustained attention to the passage of time throughout the interval. Consequently, retrospective estimates should not lengthen as a function of distraction, as would be expected of active estimates.

The time estimation task may be forgotten for relatively long periods of time during retrospective, as well as active, estimation. The frequency of the resulting overly long productions should be greater as the demands of the concurrent task increase. The frequency of overly long productions should also be greater during retrospective than active estimation, as a direct consequence of the fact that only intermittent attention is paid to timekeeping in the retrospective mode. The effects of concurrent activity on the central tendency of distributions of time productions are reiterated in Figure 14. That figure also indicates the hypothesized changes in variability and shape of estimate distributions, relative to baseline, under the two modes of time estimation.

We inferred that the retrospective mode would dominate time estimates made during simulated flight, because the very nature of the task should militate against pilots paying continuous and active attention to timekeeping. Averaging across all pilots, the addition of display elements and other factors relevant to the control task all were associated with distributions of estimates characterized by a decrease in central tendency and an increase in variability and positive skewness (Figure 15). These are the results that one would espect with retrospective estimation. However, several pilots reported attempts to actively estimate time by counting. Those pilots generated estimates which lengthened with increased concurrent activity, exactly as would be expected with active time estimation.

The visual displays and cognitive processing requirements were less complex and demanding for compensatory tracking than for the flight simulation. We inferred that relatively more of the estimates were produced actively in the former situation. Thus, concurrent tracking should exert a distracting influence on estimation, thereby increasing median estimate length. Indeed, the estimates made during tracking averaged 5.0 sec longer than baseline estimates and were more than 6.0 sec longer than those made during simulated flight. Variability and positive skewness also increased relative to baseline with the addition of a tracking task (Figure 15). However, the frequency of very long productions and the increase in variability was considerably less with compensatory tracking than with simulated flight, indicating relatively less distraction.

Within the tracking task, the median estimate length and variability increased with addition of either a second axis or the more difficult forcing function, as would be expected with actively produced estimates. When both axes as well as the more difficult forcing function were combined, median estimate length decreased whereas variability increased sharply. We infer that the demands of this particular condition made active estimation more difficult, resulting in a larger proportion of shorter, retrospective estimates with accompanying increased variability. Such retrospective estimates would account for the apparent decrease in median estimate length reported for the addition of a second axis when estimates were averaged across forcing function difficulty.

CONCLUDING REMARKS

Hypothetically, for time estimate productions made actively, increasing task attention demands should progressively increase the central tendency of estimates relative to baseline. However, active estimation will be rendered difficult, if not impossible, at higher levels of distraction, so that retrospective estimation remains the only mode available. The change from the active to the retrospective mode should result in a discontinuity in the estimate length function, with associated decrease in the length of time productions. Retrospective estimate duration will then decrease further with still greater increases in the level of concurrent activity. The wrap-around effect with respect to baseline duration, a consequence of mode switching at intermediate levels of concurrent task distraction, should contribute substantially to estimate variability and have a complex effect on the shape of the resulting distribution of estimates.

Figures 16, 17, 18, and 19 summarize four measures of the estimate distributions for all of the experimental conditions. An example of the hypothetical wrap-around phenomenon can be seen in Figure 16, where the addition of a tracking task resulted in a 50% increase in the length of produced durations relative to baseline while the addition of a simulated flight resulted in a 10% decrease in the length of produced durations. As predicted, estimate variability increased as a function of the complexity of concurrent activity. As can be seen in Figure 17, the average deviation increased by 94% with the additional task of tracking and by 204% with the additional task of simulated flight. The expected increase in positive skewness of the estimate distributions occurred for both groups of pilots

(Figure 18) with the addition of a concurrent task. The distributions of estimates made during simulated flight were particularly skewed as a consequence of the few, extremely long durations that were recorded when the concurrent task demanded so much attention that the time estimation task was forgotten for relatively long periods of time. Kurtosis, which is a measure of the peakedness or flatness of a distribution, also differentiated estimates obtained during simulated flight from those obtained with no additional task or during compensatory tracking. Estimates presumably made actively, such as those in the baseline conditions and with concurrent tracking, formed platykurtic or flattened distributions, whereas estimates believed to have been made retrospectively, such as those produced during simulated flight, formed leptokurtic or peaked distributions (Figure 19).

Time estimation is an unobtrusive and minimally loading task. The central tendency, variability, and shape of the distributions of time productions provide indices of concurrent task processing requirements. Thus, time estimates may prove useful to human factors researchers interested in comparing different combinations of displays and controls associated with complex piloting tasks.

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Hart, S. G. & McPherson, D. Airline pilot time estimation during concurrent activity including simulated flight. Preprints of 1976 annual scientific meeting. Washington, D.C.: Aerospace Medical Association, 1976.

Hart, S. G. & McPherson, D. Airline pilot time estimation during concurrent activity including simulated flight. Paper presented at the 47th annual meeting of the Aerospace Medical Association, Bal Harbour, Florida, May 1976.

BLOCK DIAGRAM OF EXPERIMENTAL TRACKING TASKS

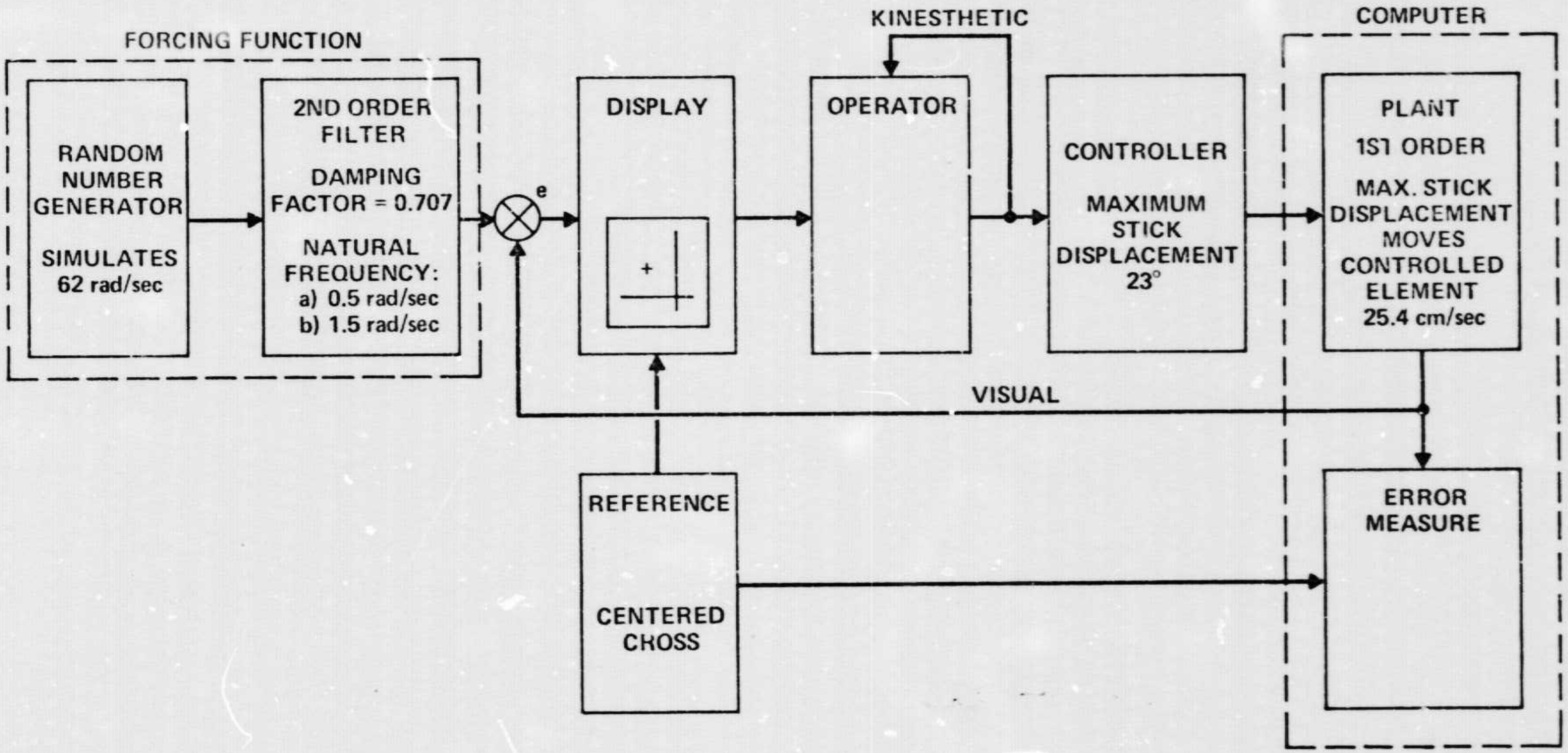

FIGURE 1

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EXPERIMENTAL DESIGN

EXPERIMENT 1:

COMPENSATORY TRACKING CONCURRENT TASK

A. BASELINE

NO CONCURRENT TASK

B. TRACKING

	1 AXIS	2 AXIS
EASY*		
HARD*		

*FORCING FUNCTIONS:

"EASY" = 0.5 RAD/SEC BANDWIDTH
"HARD" = 1.5 RAD/SEC BANDWIDTH

9 PILOTS
7 ESTIMATES/CONDITION
1 REPLICATION

FIGURE 2

EXPERIMENTAL DESIGN

EXPERIMENT 2:

SIMULATED FLIGHT CONCURRENT TASK

A. BASELINE

NO CONCURRENT TASK

B. SIMULATED FLYING

	4 KNOT WIND	
	NO VECTOR	VECTOR
NO PREDICTOR		
PREDICTOR		

	32 KNOT WIND	
	NO VECTOR	VECTOR
NO PREDICTOR		
PREDICTOR		

6 PILOTS
6 ESTIMATES/CONDITION
4 REPLICATIONS

FIGURE 3

MOVING MAP HORIZONTAL SITUATION DISPLAY

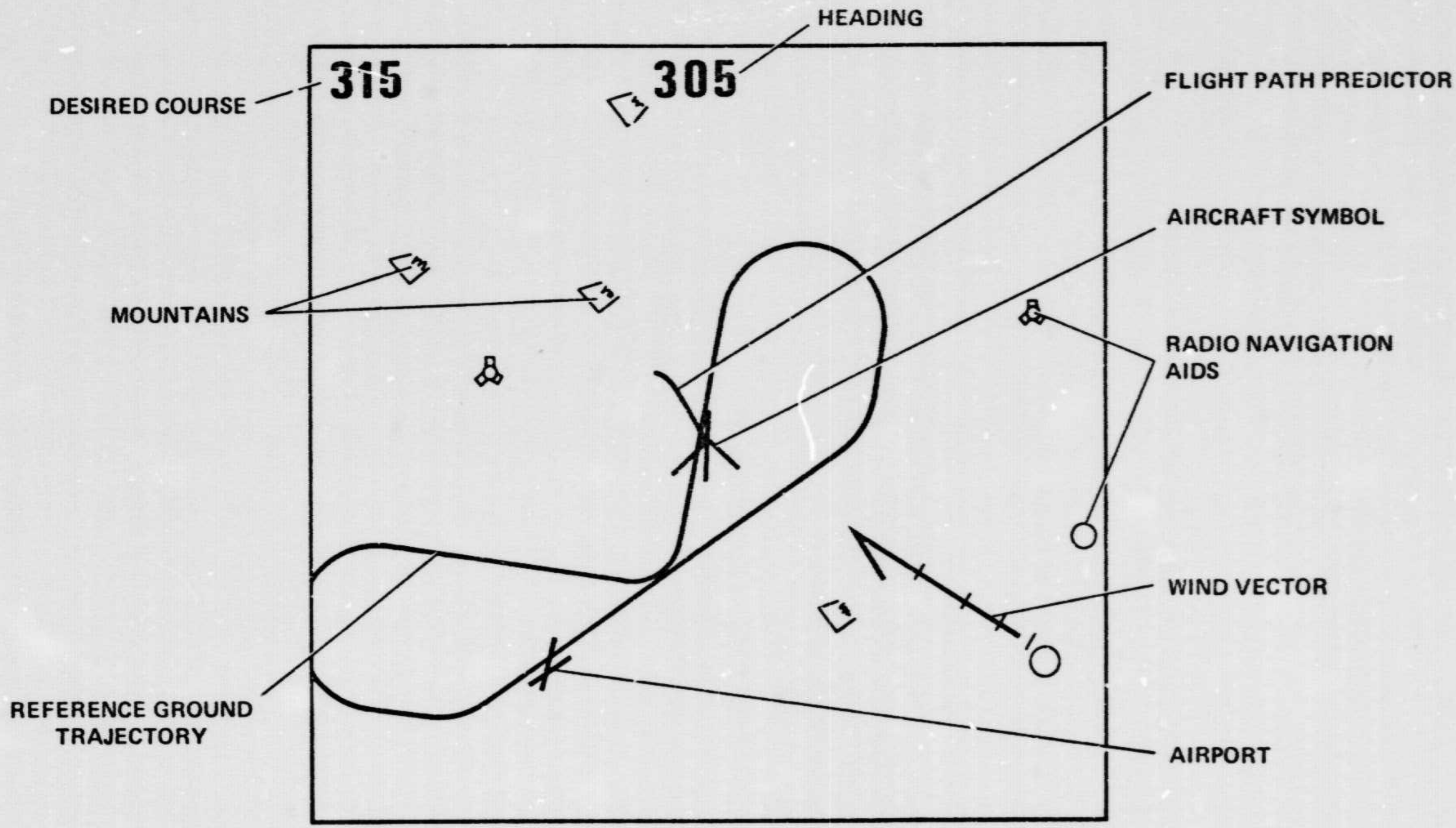


FIGURE 4

ASSIGNED ROUTE OF FLIGHT AND SIX TIME ESTIMATE LOCATIONS (E1 - E6)

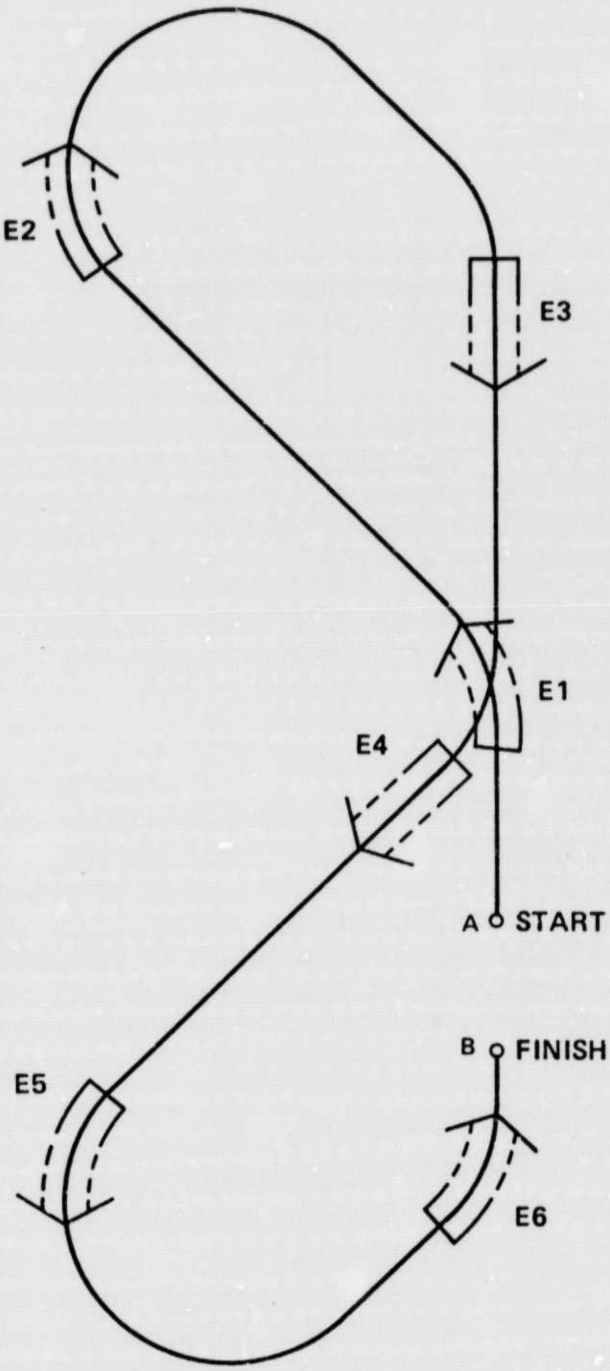


FIGURE 5

STYLIZED DISTRIBUTIONS OF TIME ESTIMATES

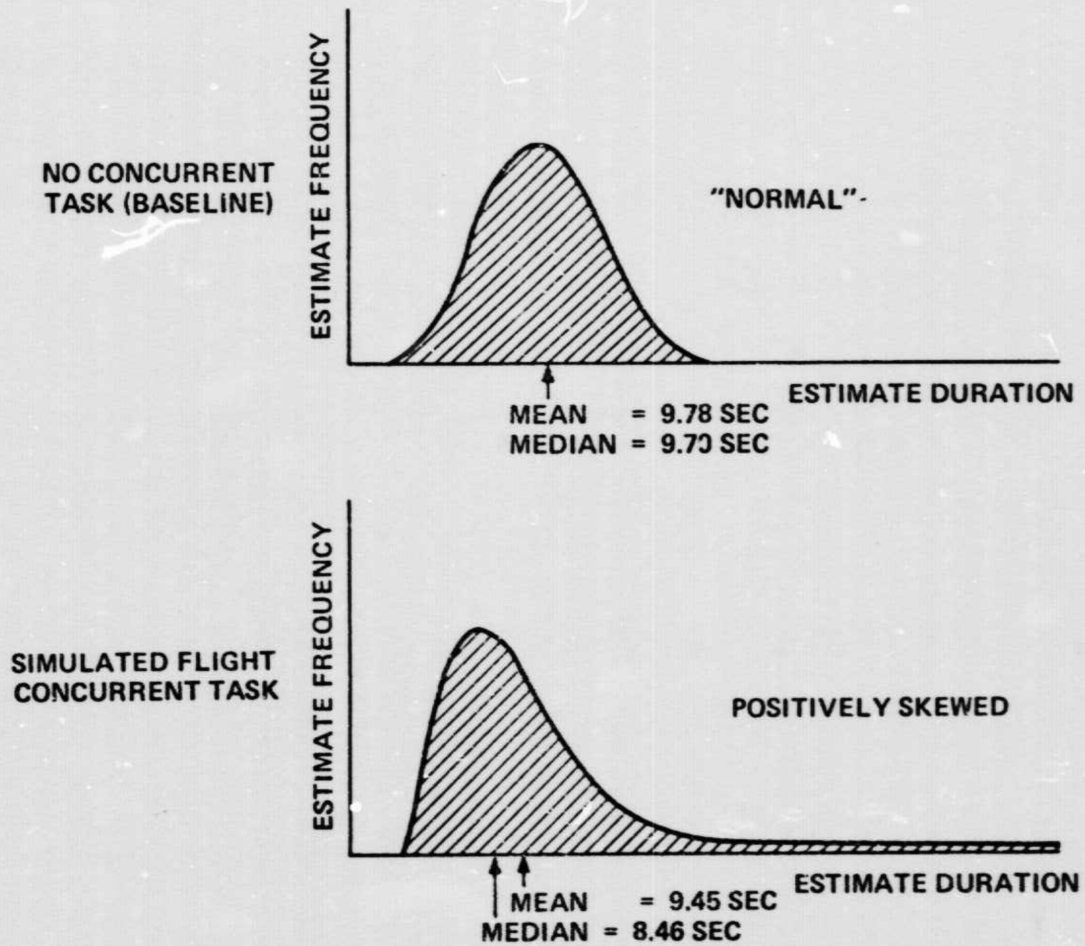


FIGURE 6

BASELINE ESTIMATES COMPARED TO THOSE PRODUCED DURING COMPENSATORY TRACKING

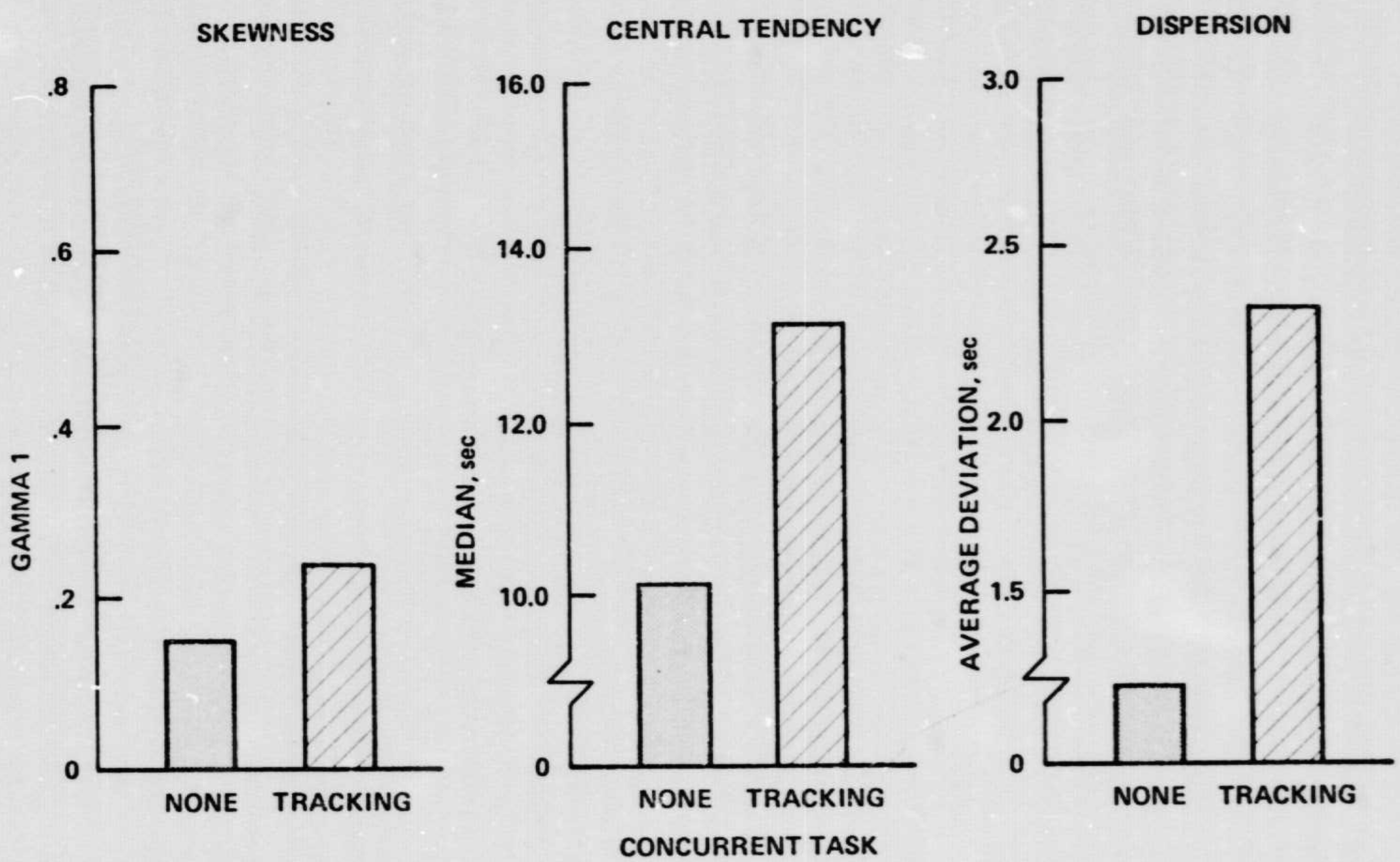


FIGURE 7

INFLUENCE OF NUMBER OF CONTROLLED AXES ON TIME ESTIMATE DISTRIBUTIONS

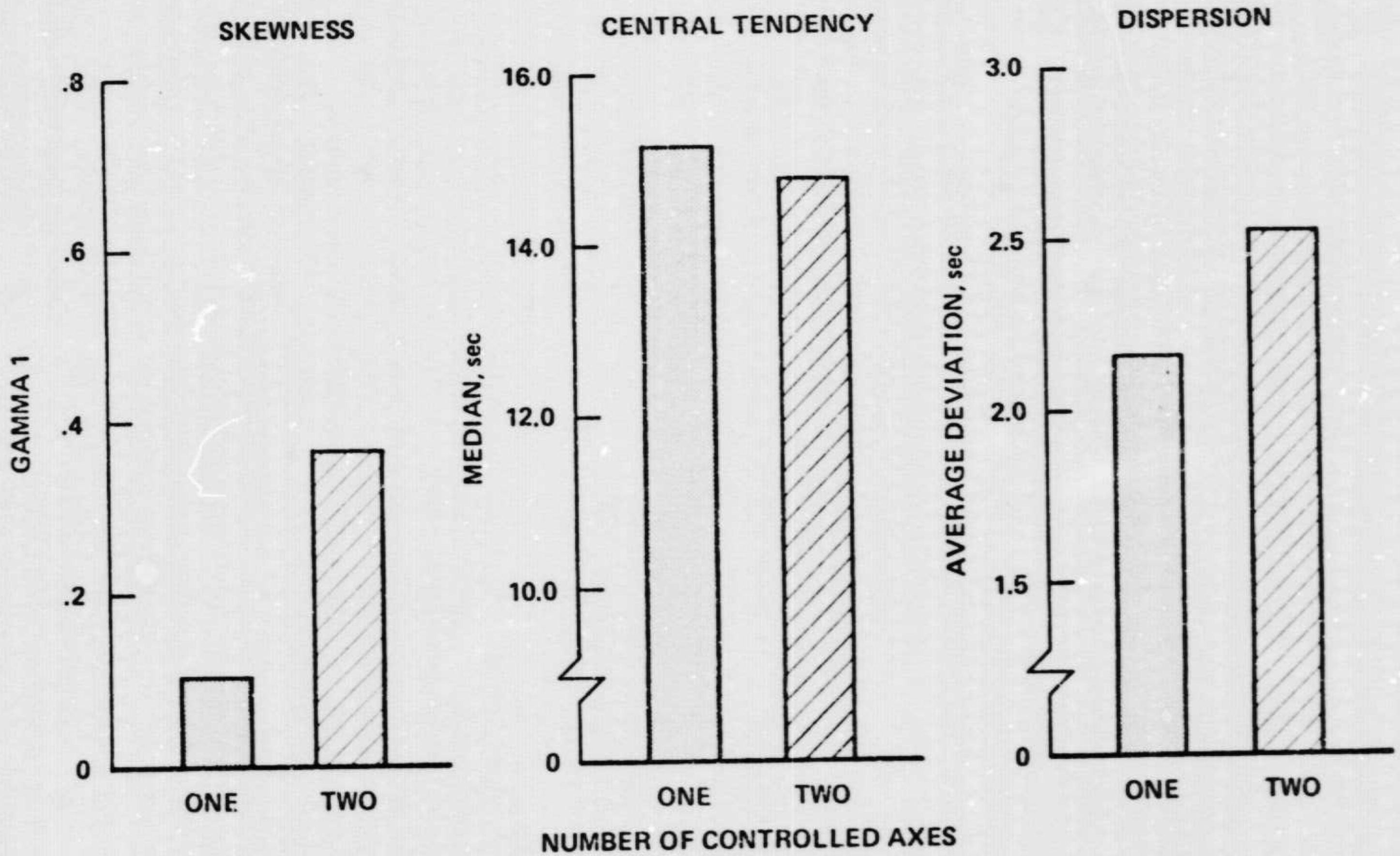


FIGURE 8

INFLUENCE OF FORCING FUNCTION DIFFICULTY (BANDWIDTH) ON TIME ESTIMATE DISTRIBUTIONS

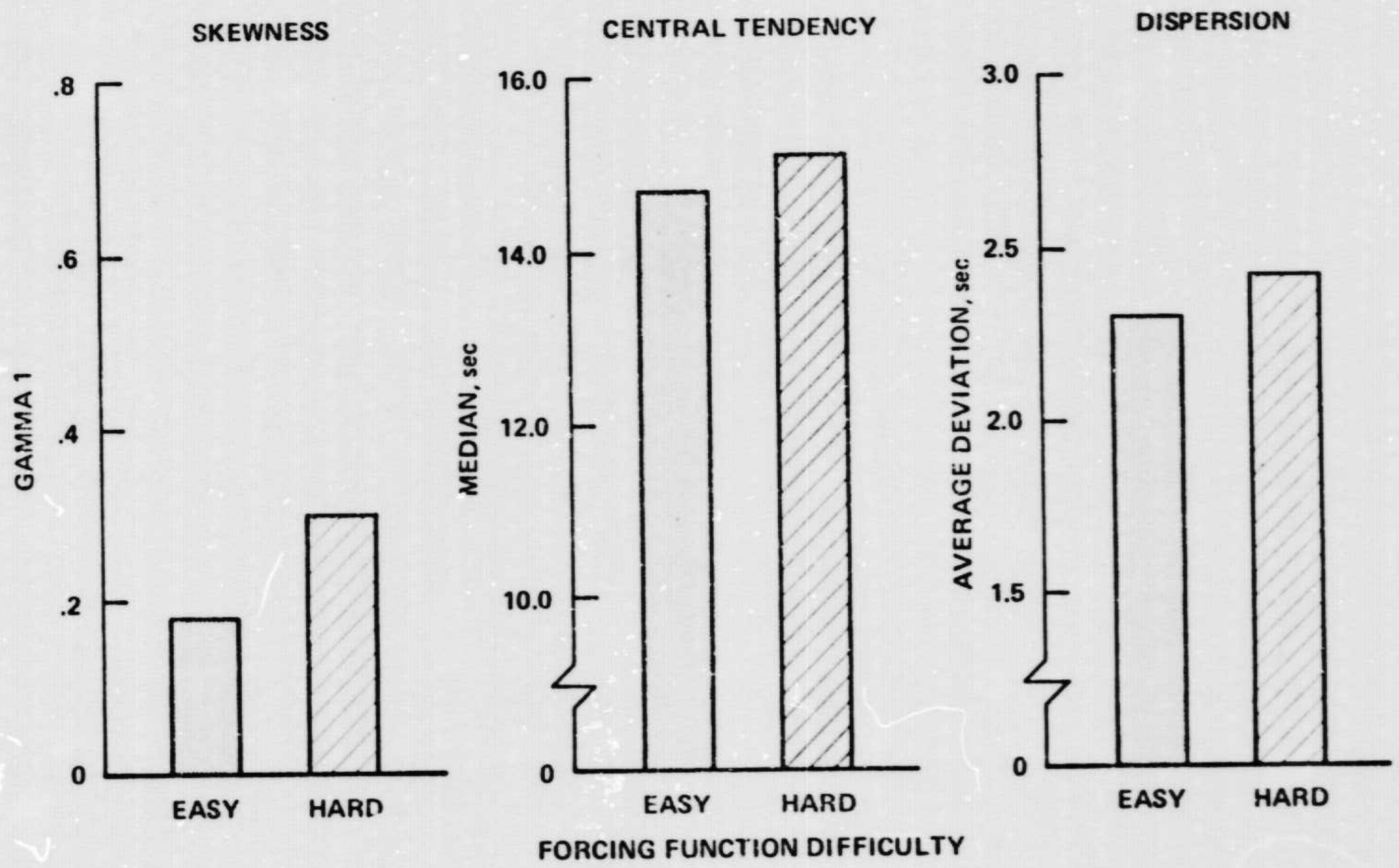


FIGURE 9

BASELINE ESTIMATES COMPARED TO THOSE PRODUCED DURING SIMULATED FLIGHT

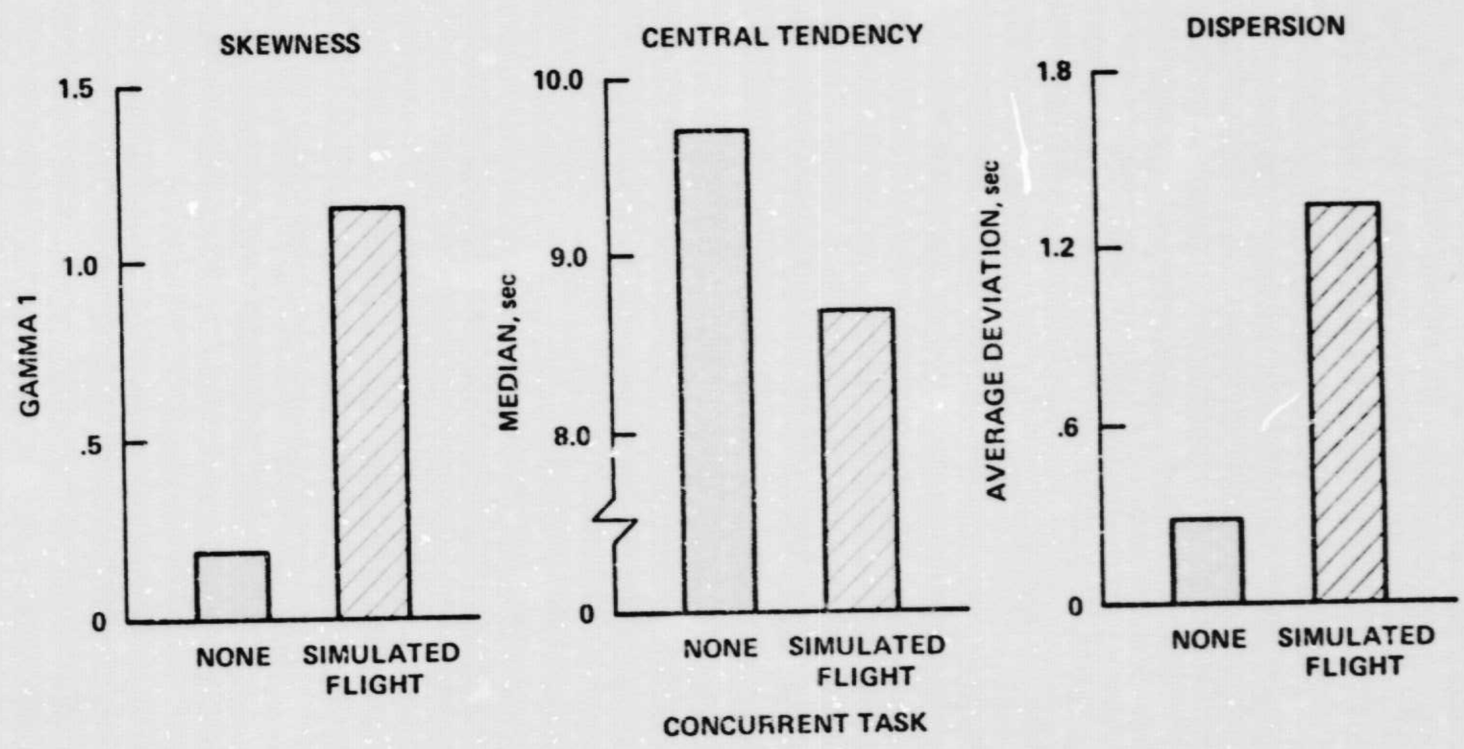


FIGURE 10

INFLUENCE OF WIND VELOCITY ON DISTRIBUTIONS OF TIME ESTIMATES PRODUCED DURING SIMULATED FLIGHT

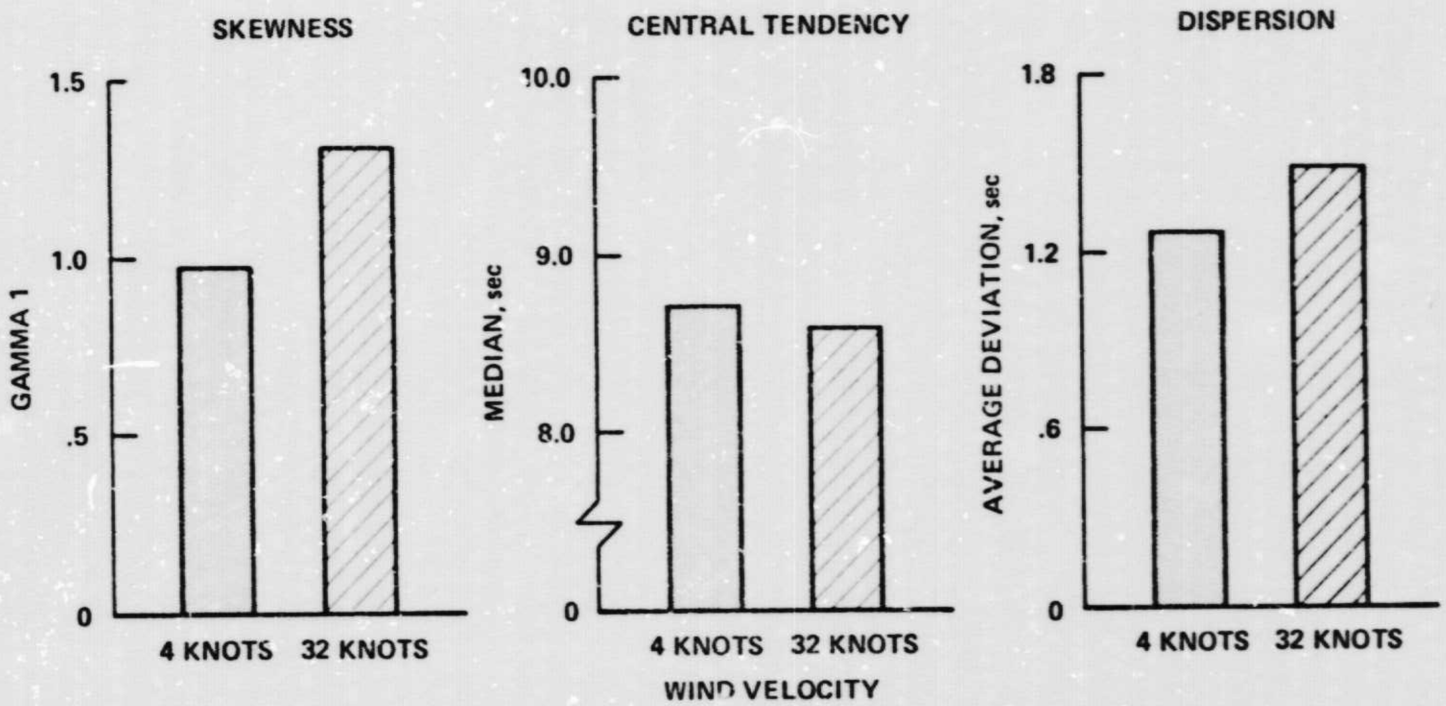


FIGURE 11

INFLUENCE OF THE FLIGHT PATH PREDICTOR ON DISTRIBUTIONS OF TIME ESTIMATES PRODUCED DURING SIMULATED FLIGHT

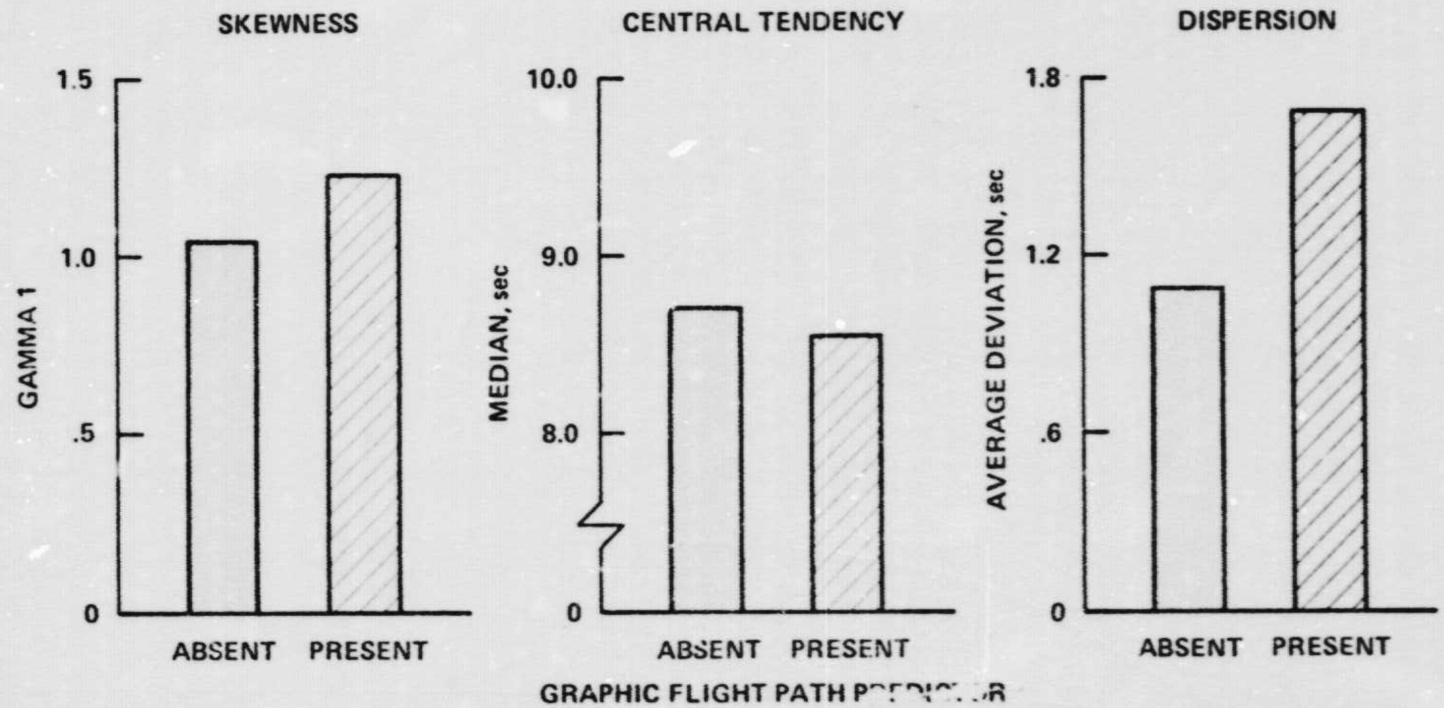


FIGURE 12

INFLUENCE OF THE WIND VECTOR ON DISTRIBUTIONS OF TIME ESTIMATES PRODUCED DURING SIMULATED FLIGHT

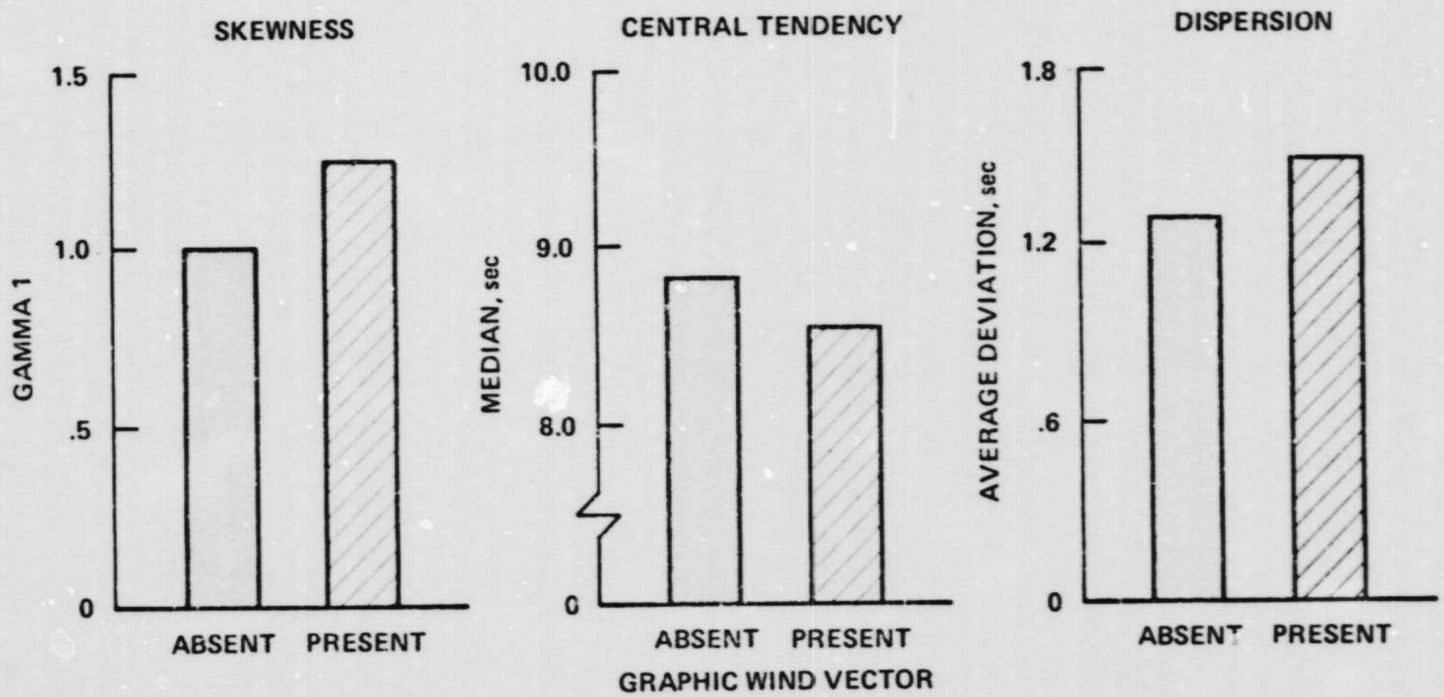


FIGURE 13

THE INFLUENCE OF CONCURRENT ACTIVITY ON DISTRIBUTION OF TIME PRODUCTIONS

		Mode of Estimation	
		ACTIVE	RETROSPECTIVE
DIRECTION OF CHANGE RELATIVE TO BASELINE	CENTRAL TENDENCY	LONGER	SHORTER
	VARIABILITY	INCREASED	INCREASED
	SHAPE OF DISTRIBUTION	POSITIVELY SKEWED	POSITIVELY SKEWED

FIGURE 14

THE INFLUENCE OF COMPENSATORY TRACKING AND SIMULATED FLIGHT ON DISTRIBUTIONS OF CONCURRENT TIME PRODUCTIONS

		EXPERIMENTAL CONDITION	
		COMPENSATORY TRACKING	SIMULATED FLIGHT
DIRECTION OF CHANGE RELATIVE TO BASELINE	CENTRAL TENDENCY	LONGER	SHORTER
	VARIABILITY	INCREASED	INCREASED
	SHAPE OF DISTRIBUTION	1. SLIGHT POSITIVE SKEW 2. PLATYKURTIC	1. MODERATE POSITIVE SKEW 2. LEPTOKURTIC

FIGURE 15

CENTRAL TENDENCY OF PRODUCED DURATIONS

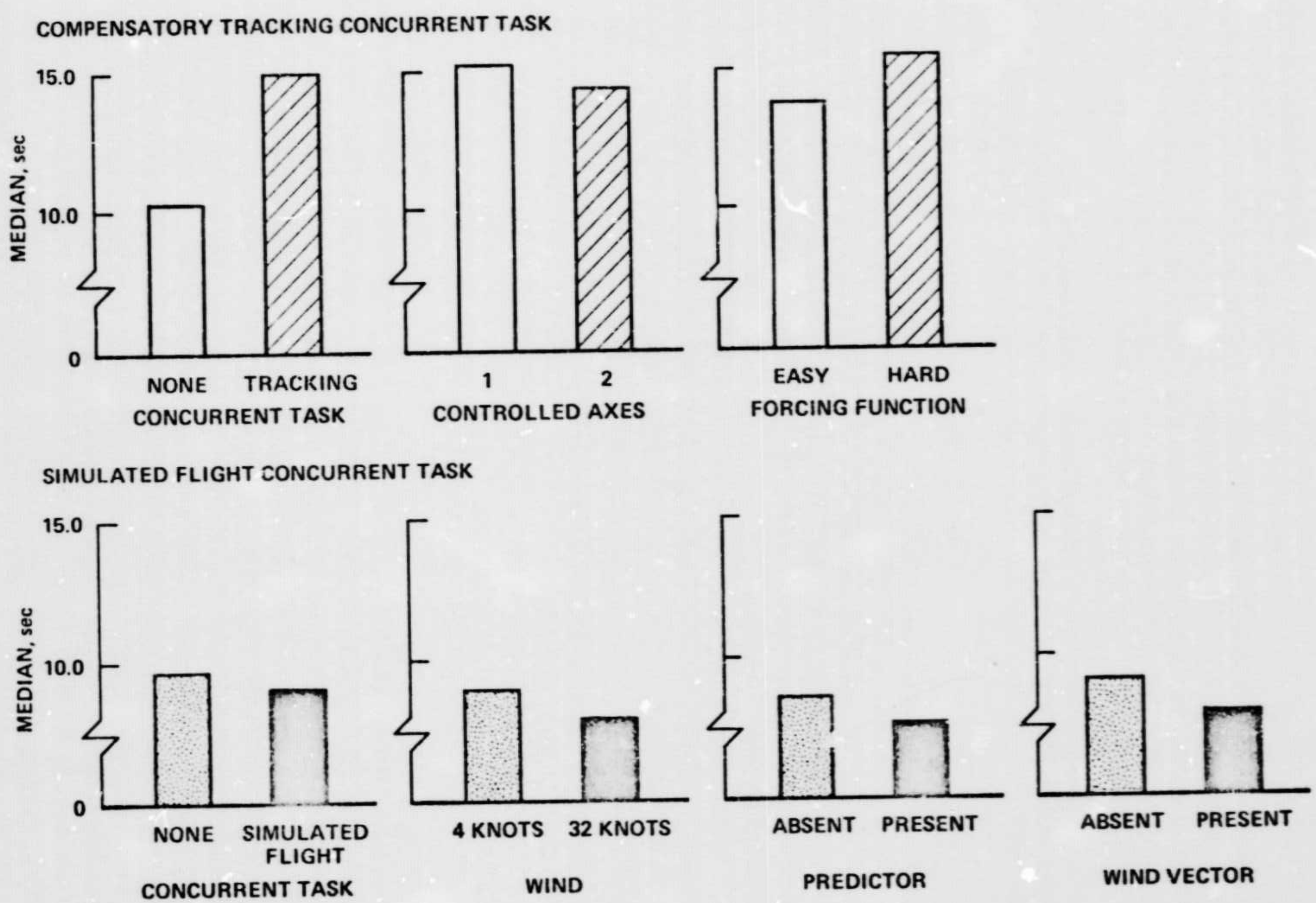


FIGURE 16

VARIABILITY (AVERAGE DEVIATION) OF DISTRIBUTIONS OF PRODUCED DURATIONS

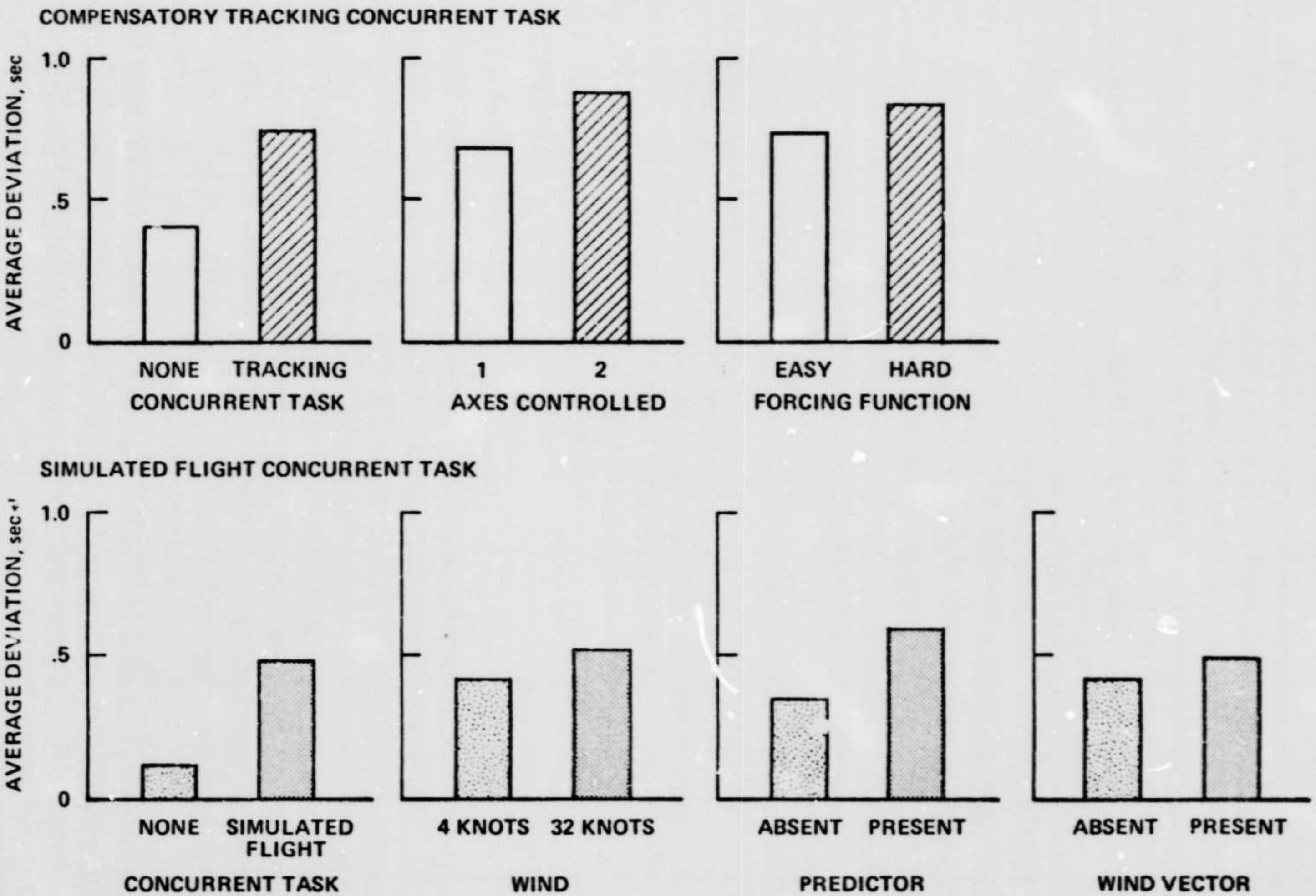


FIGURE 17

SKEWNESS (GAMMA 1) OF DISTRIBUTIONS OF PRODUCED DURATIONS

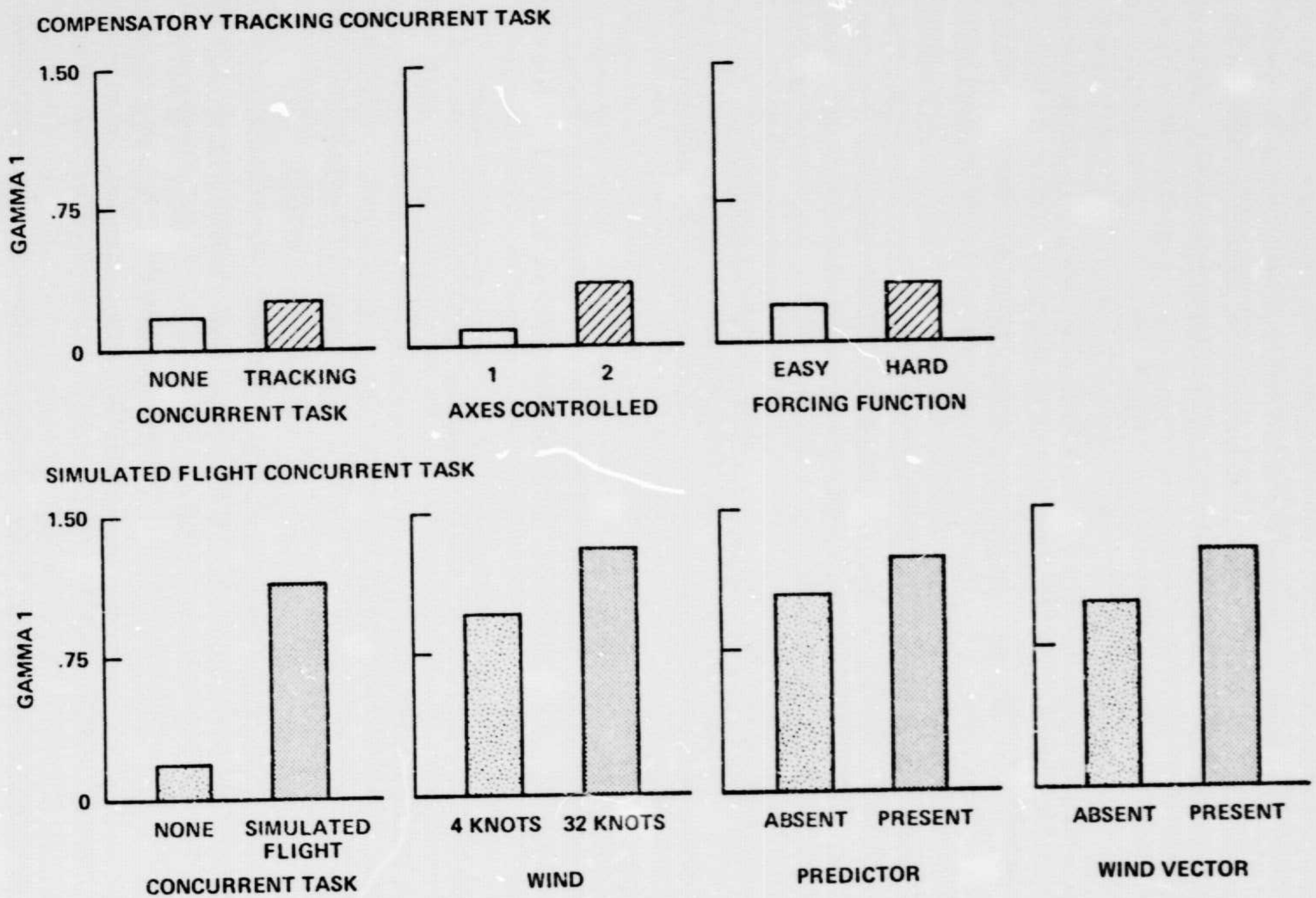
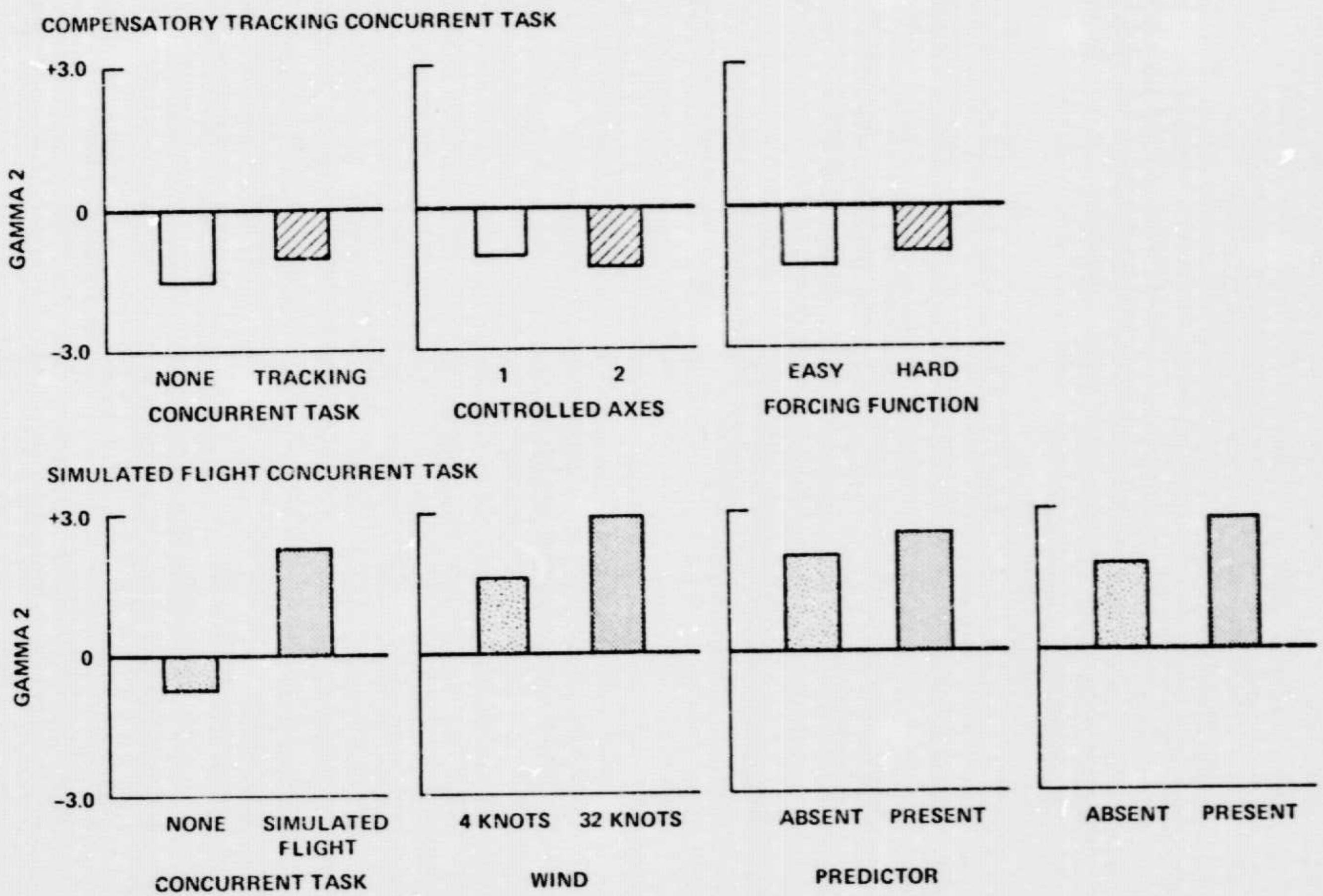


FIGURE 18

KURTOSIS (GAMMA 2) OF DISTRIBUTIONS OF PRODUCED DURATIONS



NOTE: + GAMMA 2 = LEPTOKURTIC (PEAKED)
– GAMMA 2 = PLATYKURTIC (FLAT)

FIGURE 19