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COMPARATIVE MOTION SICKNESS SYMPTOMATOLOGY AND PERFORMANCE DECREMENTS OCCASIONED BY HURRICANE PENETRATIONS IN C-121, C-130, and P-3 NAVY AIRCRAFT

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13. ABSTRACT

The purpose of this research was to compare complex monitoring performance and motion sickness symptomatology during hurricane penetration in three types of aircraft.

Three different Navy aircraft made six flights, each flight penetrating hurricane Inga several times. The controlling aircraft (a C-121) is routinely employed by the Navy for hurricane penetrations. The other two aircraft (C-120 and P-3) followed the C-121 into the storm at short intervals and penetrated the storm at the same altitude, heading, airspeed, etc.

Most subjects experienced slight to moderate malaise during the flights with generally higher sickness rates occurring during the more turbulent flights. The subjects' overall flying experience afforded some protection. Airsickness rates in the C-121 were greater than those in the C-130 and P-3. The results on a complex counting task showed that performance decreased as a function of increased turbulence.

In-flight recordings of linear and angular accelerations were related to sickness rates, and it is suggested that the frequency of the linear oscillations may be a more important variable for producing motion sickness than the magnitude of the acceleration per se. Further, because the relationship between motion sickness and linear accelerations does not appear to be linear, this finding could have important implications for the design of vehicles to be used in similar force environments. These implications are discussed.

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SUMMARY PAGE

THE PROBLEM

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FINDINGS

Three different Navy aircraft made six flights, each flight penetrating hurricane Inga several times. The controlling aircraft (a C-121) is routinely employed by the Navy for hurricane penetrations. The other two aircraft (C-130 and P-3) followed the C-121 into the storm at short intervals and penetrated the storm at the same altitude, heading, airspeed, etc.

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IV

INTRODUCTION

During 1969, an investigation was initiated to determine the comparative incidence of motion sickness and the amount of performance decrement associated with hurricane penetrations by three different types of Navy aircraft (P-3, C-130, and C-121). All aircraft were of standard design and without special structural modification for hurricane penetration. All three aircraft flew the same flight path on each of six flights around and through hurricane Inga. Wind velocities as high as 115 knots were recorded, and most of the flying in the hurricane areas was at approximately 500 feet. The hurricane was approached at cruise altitude. The combat information center officer (CICO) in the C-121 maintained radar control over all three aircraft and ensured that each aircraft entered the same storm area on the same heading, altitude, airspeed, configuration, etc. He also advised the experimenters aboard each aircraft of the appropriate time to initiate and terminate data collection.

It was expected that as turbulence increased, the incidence of motion sickness would increase and performance would decrease.

PROCEDURE

SUBJECTS

The subject population was comprised of regular members of the crews of the respective aircraft (N = 21) and 18 subjects/experimenters (12 air-rated personnel and 6 aeromedical specialists). The six aeromedical specialists had had little exposure in the three types of aircraft and none in hurricane penetrations. The 12 air-rated personnel were experienced crew members from a C-121 "hurricane hunter" squadron but they had had no recent experience in the P-3 and C-130. All hurricane penetration flights were flown within a 7-day period, and, in general, each subject/experimenter had two flights in each aircraft, 4 days apart. Performance-test data were collected from six members of the subject/experimenter group: two were in each aircraft with one subject forward, facing forward, and one subject aft, facing outboard, on each flight.

MOTION SICKNESS

History

The Pensacola Motion Sickness Questionnaire (MSQ) was used to determine the past history of motion sickness and was scored according to a method (2, 6) empirically validated on a student pilot population; however, because the present subject population was comprised mainly of experienced aviation personnel, three items that dealt with aircraft experiences were excluded.

Symptomatology

Response forms (5) that inquired about individual symptoms of motion sickness were completed by all personnel several times on each aircraft as the aircraft flew through the hurricane. These data were collected by the six aeromedical specialists and scored by an experienced rater who had no knowledge of the subject's identity or of the flight conditions under which the data were collected. These data were scored according to the method described by Graybiel (7); however, in this case values were assigned to the rated level of motion sickness. The scoring was as follows: vestibular sickness with emesis, 5; vestibular sickness without emesis, 4; Malaise III, 3; Malaise II, 2; Malaise I, 1; and "no symptoms," 0. Based on these scores, the average symptomatology for each subject for the duration of each flight and the maximum symptomatology for each subject within each flight were obtained. These scores were then combined in order to compare subject groups, aircraft, and flights.

PERFORMANCE

A performance test (4) that required the subjects to monitor low, middle, and high frequency tones (100, 900, 1800 Hz, respectively) was utilized to determine performance decrement. The tones, which appeared randomly, were presented from recorded tapes to the subjects via standard Telephonics headsets (H173). The various forms of the test are described elsewhere (4), and in the present study the most difficult version was employed. The subject's task was to count, separately, each tone and respond by means of a switch closure when each had occurred four times. In this form the test is an information overload task, and perfect scores are rarely obtained by any subject for any length of time. Responses to only two of the three tones were recorded because practical considerations limited the number of recording channels on the in-flight recorder. However, it had been reported (3) that scores obtained by this abbreviated scoring procedure were well correlated (r = .95) with scores obtained from complete scoring.

Performance data were collected in-flight within three time frames: 1) early—when proceeding to the hurricane area (two 10-minute samples); 2) middle—during hurricane and weather band penetration (several samples of various lengths); and 3) late—when returning to base from the hurricane (one 10-minute sample).

RESULTS

MOTION SICKNESS

Table I is a listing of the maximum symptomatology attained by experienced crew members and by aviation personnel with relatively little exposure in the aircraft type in which they flew (subjects/experimenters). While only one member of the experienced crew-member group exhibited motion sickness, six members of the subjects/experimenters group did so. The advantage of experience was also evident in the other sickness categories. This is graphically presented in Figure 1 that summarizes the maximum symptomatology data from Table I for the two groups and also shows the average symptomatology within all six flights for the two groups. The average symptomatology (0.8) and the mean maximum symptomatology (1.9) reported by the experienced group were significantly less (p's $< .01$) than the average (1.63) and the mean maximum symptomatology (3.11) experienced by the subjects/experimenters group.

The correlation between motion-sickness-questionnaire scores and maximum symptomatology in all flights was calculated for the experienced crew-member group (N = 21), for the subjects/experimenters group (N = 18), and for both groups combined (N = 39). These correlations appear as Table II, and, as expected, all are negative, indicating that, in general, the absence of a history of motion sickness is predictive of a relative freedom from symptoms. The sample sizes are small, and only two of the three correlations are statistically significant. The low magnitude of the correlations is explained in large part by the similarity in symptomatology reported by members of the experienced crew-member group and partly by the fact that, while no significant difference in MSQ score was obtained between the groups, mean differences in symptomatology were observed.

The amount of turbulence encountered during each flight was recorded by linear and angular accelerometers mounted in each aircraft. These records were evaluated by experienced personnel, and the amount of turbulence was rated from one (least) to six (greatest). A gradual increase in turbulence was noted from flight 1 to flight 5. Figure 2 compares the turbulence ratings with the mean maximum motion sickness scores attained on each flight by members of the subjects/experimenters group and by the experienced group. A theoretical habituation curve to be discussed later is included in Figure 2.

Table I

Maximum Symptomatology Observed On All Hurricane Flights

Experienced Crew Members		Aviation Personnel with Little Exposure in the Aircraft Type	
Subject	Symptoms	Subject	Symptoms
GR	MS* with Emesis	PR	MS with Emesis
GE	Malaise III	BA	"
PT	"	MO	"
ED	"	UL	MS without Emesis
LE	"	HB	"
HE	"	GR	"
CA	Malaise II	AB	Malaise III
TO	"	MA	"
RE	"	EL	"
LA	"	HN	"
EH	"	KE	"
LI	"	BA	Malaise II
NO	"	BO	"
WO	Malaise I	GR	"
HU	"	RO	"
BO	"	HA	"
NI	"	SM	"
CO	"	KE	"
JA	"		
FL	No Symptoms		
SA	"		

*MS = Motion Sickness

Table II

Correlation Coefficients Between Motion Sickness Questionnaire Score and Maximum Motion Sickness Symptomatology for Experienced Crew Members and Members of the Subjects/Experimenters Group

	r	P	N
Experienced crew members group	-.328	N.S.	21
Subjects/experimenters group	-.529	.05	18
Both groups combined	-.387	.02	39

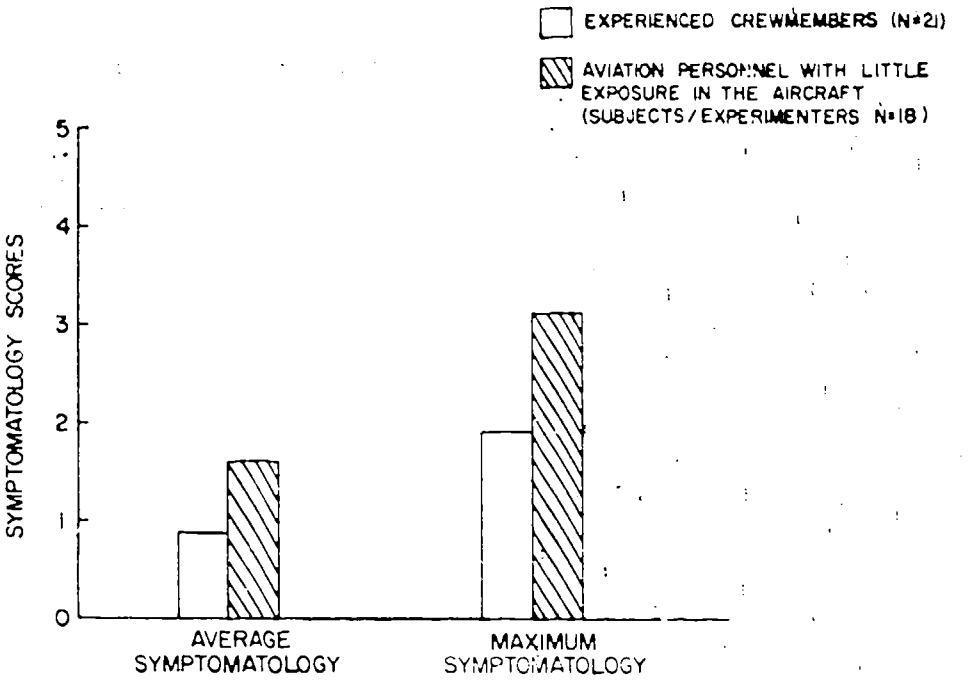

Figure 1

Average and Maximum Motion Sickness Symptomatology Observed During Six Hurricane Penetration Flights

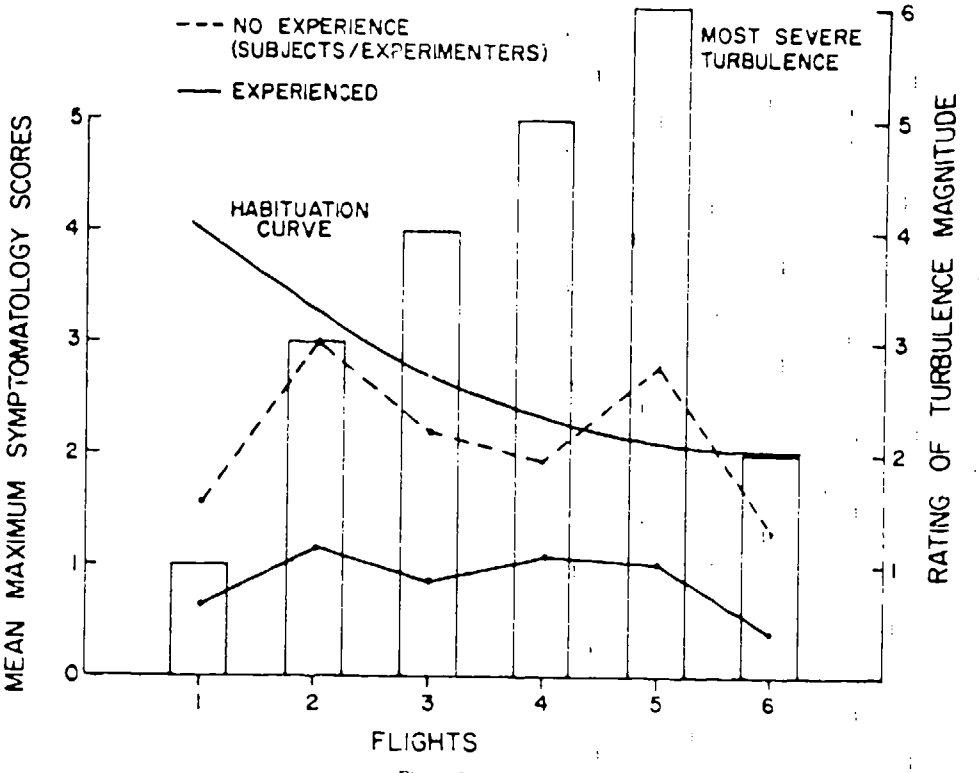

Figure 2

Interaction of Maximum Symptomatology (Averaged Independently Over Subjects/Experimenters and the Experienced Groups for Each Flight) With Turbulence and Posited Habituation Effects

Figure 3 compares the motion sickness symptomatology for the 18 subjects/experimenters who rotated among the three aircraft. The average sickness level attained by these 18 subjects/experimenters in the C-121 was selected as a baseline and contrasted with the sickness level attained in the other aircraft. Subjects experienced relatively less sickness during their flights in the P-3 than in the C-130, and in both the rates were less than in the C-121.

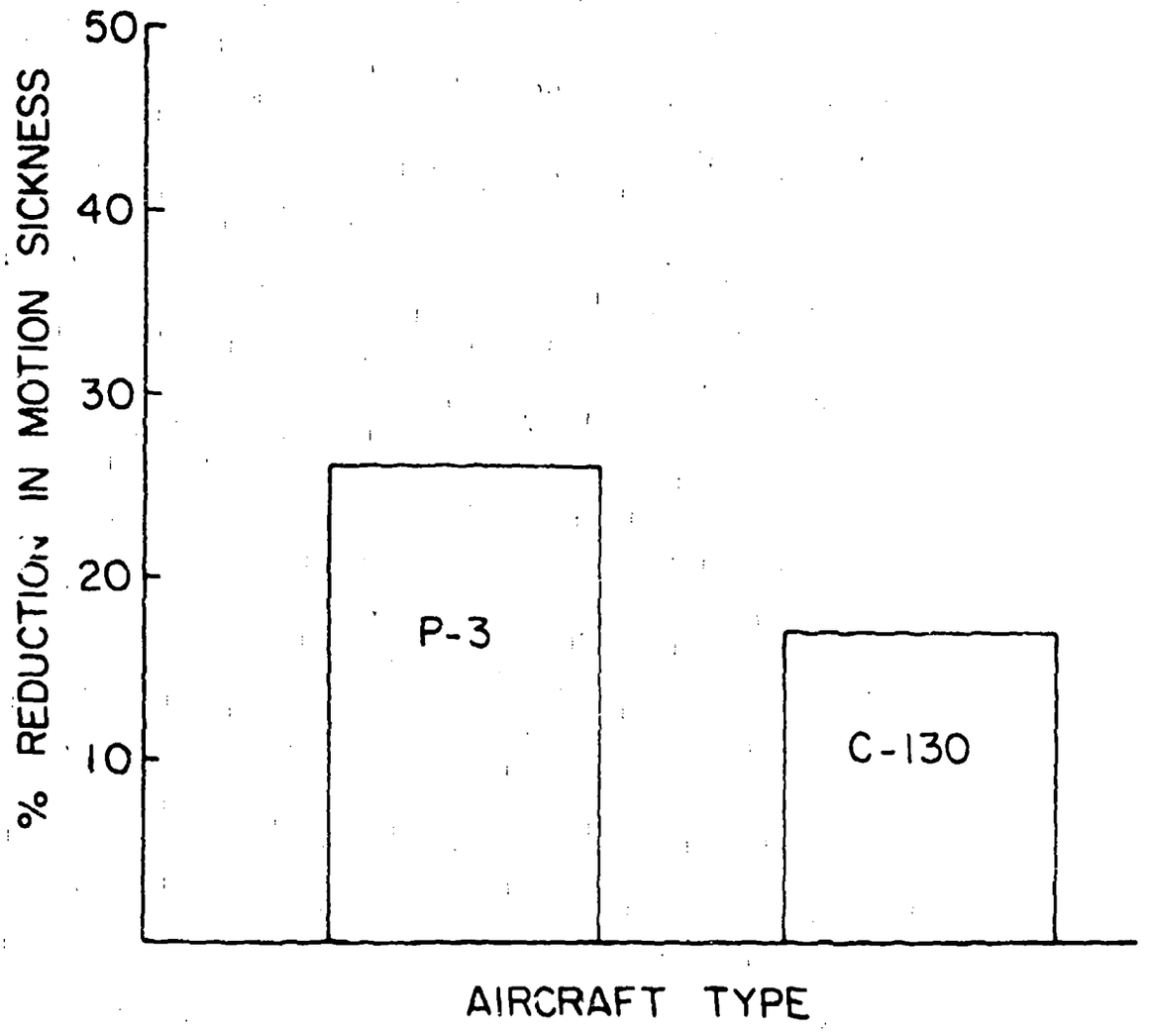

Figure 3

Percentage of Reduction in Motion Sickness Among Subjects/Experimenters in P-3 and C-130 Aircraft Utilizing Incidence of Motion Sickness in the C-121 as Baseline

PERFORMANCE

The subjects' responses on the counting task were scored as percentage of correct responses. Figure 4 shows the amount of performance decrement (relative to the early portion of the flight) as a function of flight number. Flights 2 and 6 were not included due to a malfunction of the recording equipment. A comparison with the turbulence ratings in Figure 2 shows that performance decreased as turbulence increased.

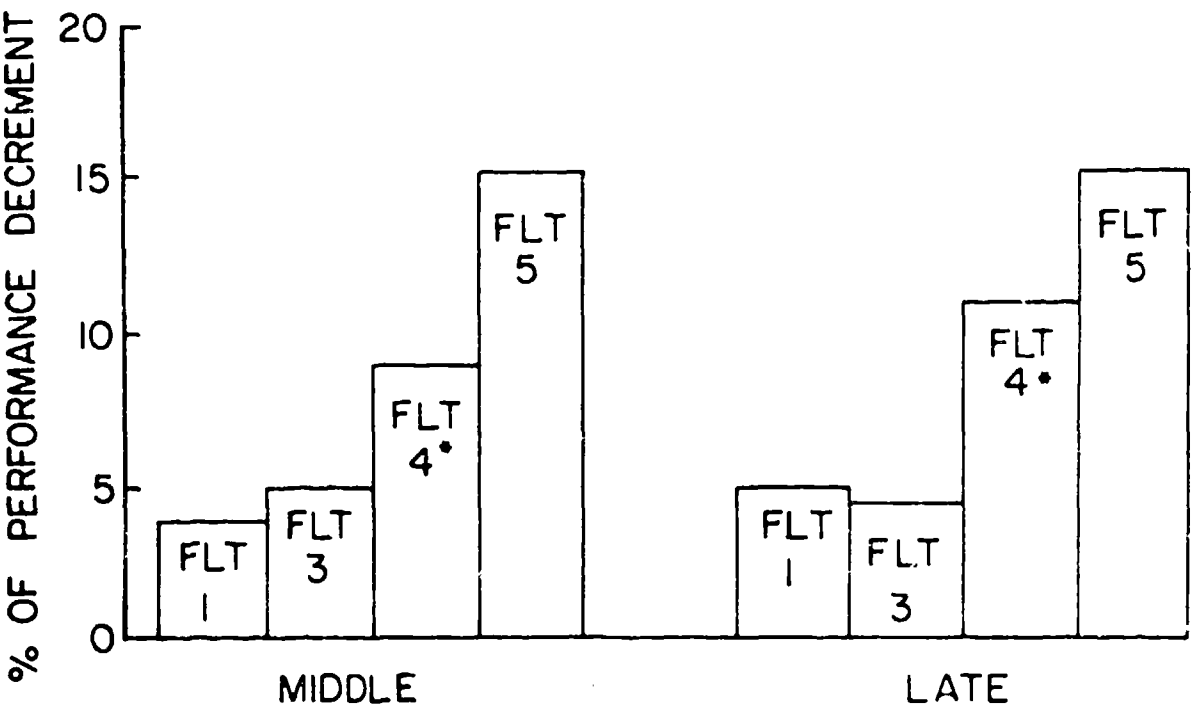

Figure 4

Performance Decrement on Four Flights of Increasing Severity. (Early portion of flight used as a baseline.)

*Due to technical difficulties no performance data were obtained from the C-121 on Flight 4.

Figure 5 compares the decrement in performance in each aircraft during the most turbulent flight (flight 5). Performance during the hurricane penetration (middle portion of flight) appeared least disrupted in the C-121. Also, the subjects in the P-3 showed a recovery toward the latter part of the flight (i.e., when returning to base), while the subjects in the C-130 and C-121 showed additional decrements in performance over time.

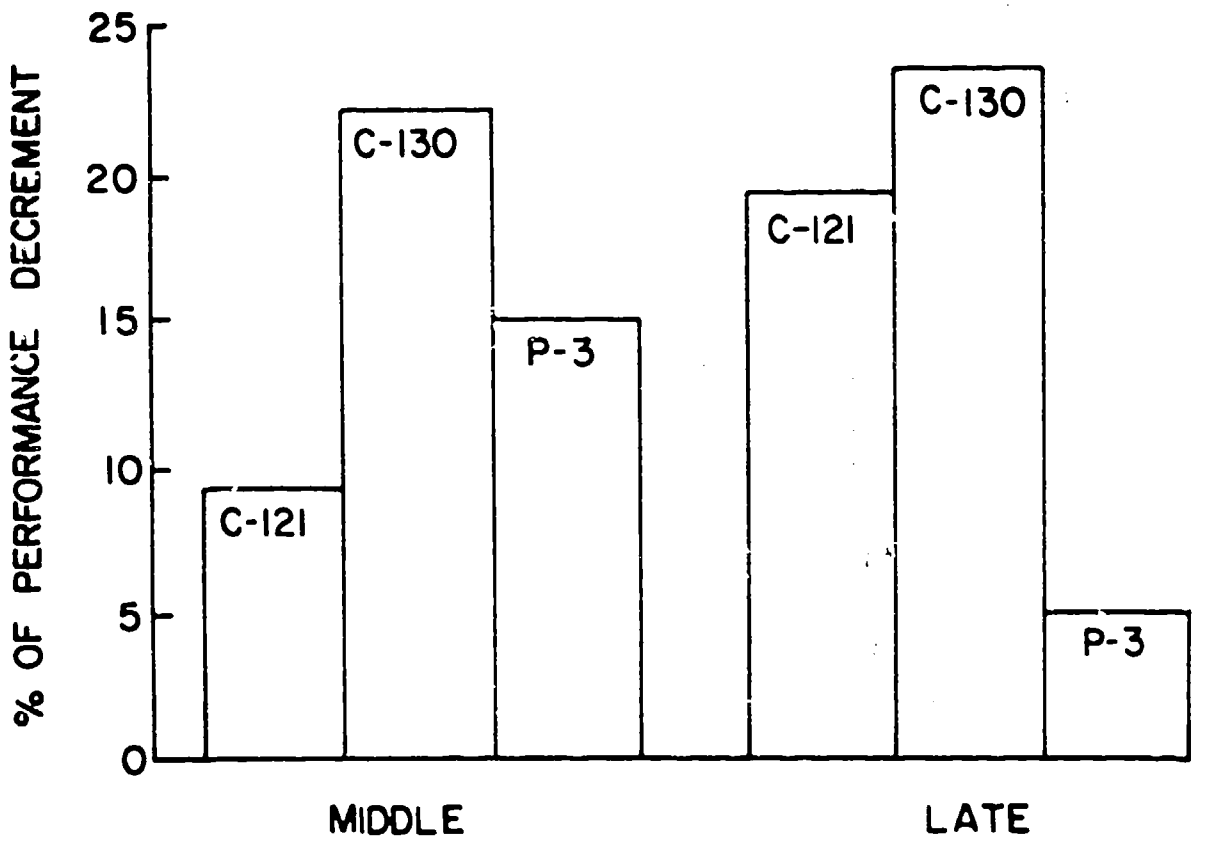

Figure 5

Performance Decrement in Each Aircraft during the Middle and Late Portions of the Most Turbulent Flight (Flight 5)

Similar but smaller effects were obtained on other flights, as may be seen in Figure 6 which combines data for flights 1, 3, and 5. On flights 2, 4, and 6, technical difficulties precluded data collection on one of the three aircraft, so direct comparisons could not be made for them.

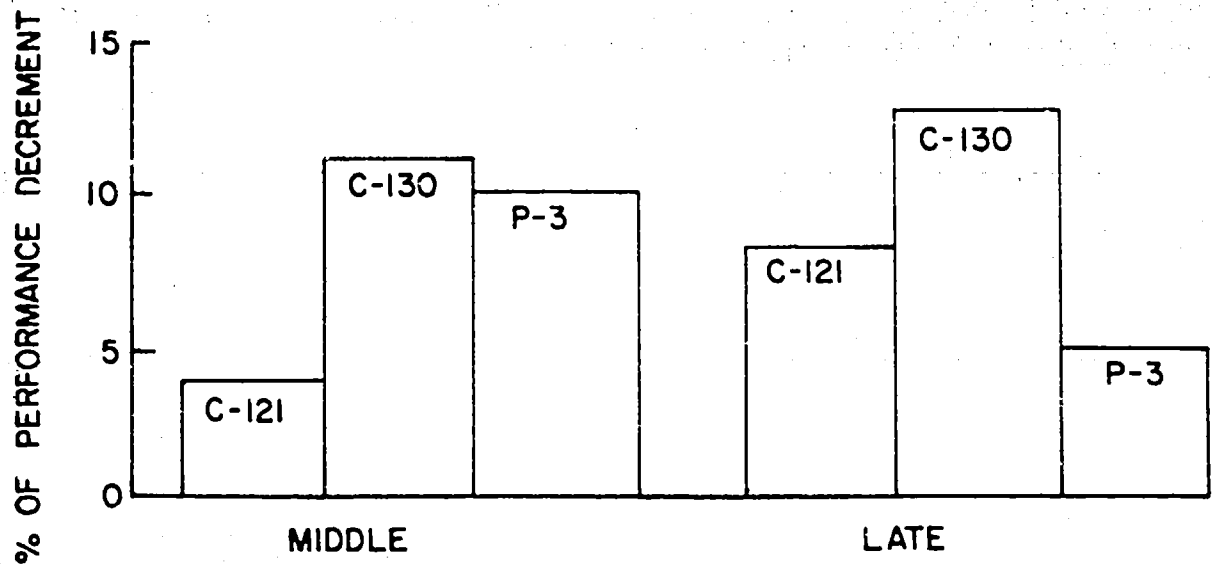

Figure 6

Performance Decrement in Each Aircraft During Middle and Late Portions of Flights 1, 3, and 5

DISCUSSION

The results of this experiment support the experimental hypotheses. Thus, performance decrements tended to be greater during the rougher flights; motion-sickness-history-questionnaire scores generally were predictive of subsequent maximum airsickness symptomatology; recent flying experiences within a type of aircraft, but not necessarily in hurricane flying, afforded some protection from motion sickness. It should be noted that this conclusion holds only for the experienced crew members (i.e., pilot, co-pilot, etc.) who were performing their routine duties. Of the 18 who served as subjects/experimenters and rotated through all three aircraft, 12 were from a C-121 hurricane hunter squadron and were experienced in both the C-121 and in hurricane flying, yet their sickness rates were relatively high in the C-121. The importance of mental occupation in familiar duties in avoiding motion sickness as opposed to "no occupation" or "performing unfamiliar monitoring tasks" (as in this investigation) should be explored further.

While the degree of motion sickness seems to be related partly to the amount of turbulence, and particularly to previous experience in aircraft type mission, the influence of habituation should be considered. A smooth, theoretical habituation curve has been included in Figure 2, and the expected effects of habituation and turbulence, considered together, aid in explaining the results. For example, where habituation effects could be expected to be small (flights 1 and 2) small amounts of turbulence caused relatively high sickness scores; where habituation effects could have been greater (flights 3, 4, and 5) severe turbulence appeared to have caused relatively less sickness. An additional factor should also be considered; i.e., it was expected that the C-121, which has long flexible wings, would provide a less choppy and therefore less motion-sickness-inducing environment

than either the P-3 or the C-130, which have comparatively short rigid wings. While both the subject reports and the force environment recordings attested to the comparative choppiness of the C-130 and P-3 aircraft versus the C-121, a lower, rather than a higher, incidence of motion sickness was noted for both the C-130 and P-3 aircraft. A possible explanation for this inverse result may be found by an examination of the recordings made from accelerometers mounted within the aircraft. Force-environment records were obtained during these flights primarily to determine if the storm conditions encountered would produce forces exceeding the structural limitations of the aircraft; as a result, there are some difficulties in interpreting these data as physiological stimuli. However, the following determinations were made:

1. *Angular Velocity.* The largest angular velocity experienced *during all hurricane penetrations** for all aircraft was 11°/sec in the roll axis, a relatively mild stimulus from the standpoint of direct stimulation to the semicircular canals. For example, even if rapid head movements were crosscoupled with that angular velocity, slow rotation room studies suggest that continuous rotation at 3 rpm (18°/sec) does not result in a high incidence of motion sickness (9).

2. *Linear Forces.* The strongest linear forces recorded during the hurricane flying missions were in the vertical plane. Unfortunately, due to insufficient gradations in the altitude recordings obtained, the extent of linear displacement could not be adequately determined although it was probably greater than 20 feet. However, it was possible to estimate the frequency of the linear oscillations for the three aircraft. The most turbulent period of each flight was selected, and several portions of the in-flight records were analyzed. For each flight, during turbulence the frequency of linear oscillations appeared highest in the P-3 and lowest in the C-121, and frequencies tended to be higher for the rougher flights. The average frequencies over all flights were 59 cycles/min, 50 cycles/min, and 25 cycles/min for the P-3, C-130, and C-121 aircraft, respectively. An examination of the results of a laboratory investigation (Figure 7) by Alexander, Cotzin, Hill, Ricciuti, and Wendt (1) may aid in explaining why the lowest sickness rates were noted in the "bumpiest" aircraft. For the stimulus values employed those investigators found that when linear oscillation was the stimulus, the severity of motion sickness was not monotonic with an increase in frequency of oscillations. Rather, sickness rates were highest for the two mid-range stimuli used and lower for the highest and lowest frequencies. The highest sickness rates found in the present hurricane penetration study occurred in connection with flights in the C-121, where the average linear oscillation frequency (25 cycles/min) was close to the optimum value for inducing motion sickness (22 cycles/min) reported by Alexander et al. (1). Others have also reported that the incidence of motion sickness was not a monotonic function of frequency (11).

This finding should be studied further under conditions where frequencies and displacements could be varied independently and parametrically in order to cross validate the notion that an envelope exists within which maximum sickness occurs; below and above which sickness rates are lessened. The data from both this study and that of Alexander et al. (1) suggest that where linear oscillations are the major stimulus, the most important variable is the frequency of oscillation rather than acceleration, displacement, or variability, although the latter may be relevant also.† If continued support for this finding is obtained, it could have important applications for the design of systems. For example, when environmental conditions interact with a man-bearing vehicle (aircraft, boat, etc.) such that a particular linear oscillation frequency is produced, it may be as efficient (from a motion sickness prophylaxis standpoint) to *increase* the frequency (by increasing airspeed, etc.) as to *decrease* the frequency. This point of view is not generally

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*It should be mentioned that the pilot's objective at this time was to maintain heading, airspeed, altitude, etc., thus flying "straight and level."

†Sight should not be lost of the fact that combinations of angular acceleration are also sufficient for provoking high sickness rates (7,8). However, in the present experiment the low level of angular stimulations encountered suggest that angular accelerations were probably not an important factor in this environment.

considered in present design criterion. The findings of both the present study and that of Alexander et al. (1) suggest that frequencies of linear oscillation less than 0.8 Hz are conducive to motion sickness. However, as reported in MIL-STD-1472A (10), frequencies of linear oscillation greater than 3.0 Hz are generally considered harmful as vibration. Perhaps the range 0.8 - 3.0 Hz may be a useful envelope within which one should design moving vehicles in order to maximize creature comforts.

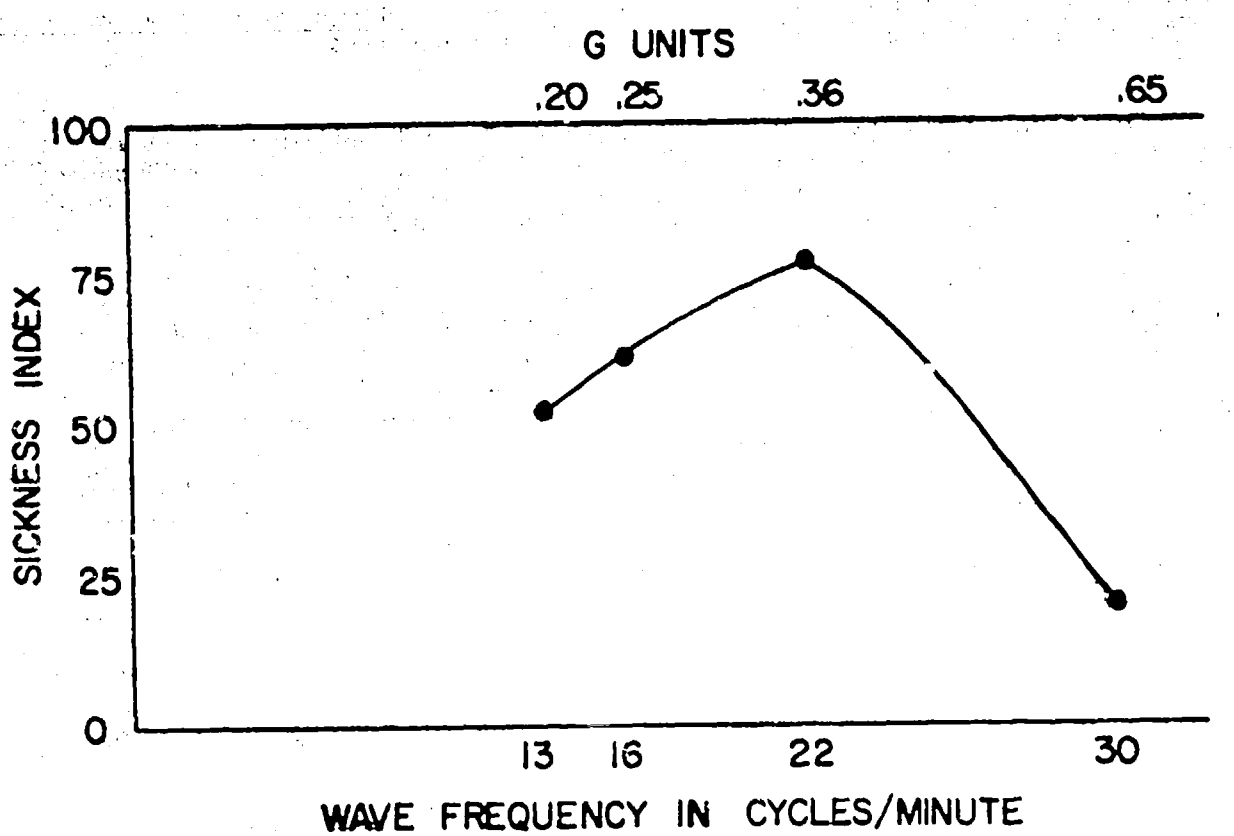

Figure 7

Severity of Sickness Due to Linear Oscillations
(Based on Data of Alexander et al.)