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AVIATOR PERFORMANCE DURING LOCAL AREA, LOW LEVEL AND NAP-OF-THE-EARTH FLIGHT

By

Kent A. Kimball
Thomas L. Frezell
Mark A. Hofmann
Allen C. Snow, Jr.

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This paper presents baseline data concerning aviator performance and aircraft state variables during local area, low level and nap-of-the-earth flights. Further, information is provided concerning differences in aviator control inputs per unit of time across the three profiles. From the data, it is evident that NOE flight places more demands on both crews and aircraft than the other two types of flight.

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SUMMARY

Six experienced rotary wing aviators were required to fly local area, low level and nap-of-the-earth flights in a UH-1H instrumented helicopter. Continuous information from twenty pilot and aircraft monitoring points was recorded for all test flights. Fixed time segments of each type of flight were submitted to analysis. The results obtained from these data demonstrated substantial differences between these flight profiles as evidenced by aircraft state variables and aviator control inputs per unit of time.

ROBERT W. BAILEY
Colonel, MSC
Commanding

PREFACE

The authors would like to express their sincere thanks to all those persons who supported this research. They would specifically like to thank LTC H. Merritt, Commander, Advanced Division, DUFT, and the following aviators of his command who served as subjects for this investigation: CW2 T. Duffer, 1LT J. LaBruyere, CW3 T. Mokrzycki, CPT P. Moore, CW2 W. Penzin, CPT L. Sloan. Also thanks to Roderic L. Kreger for his expert technical support.

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INTRODUCTION

Because of the threat environment in which helicopters will operate, if deployed tactically, there exists the requirement to fly close to the earth. This type of flight has been segmented into three primary profiles. These profiles are defined as:

NOE: Flight as close to the earth's surface as vegetation or obstacles will permit, while generally following the contours of the earth. Air speed and altitude are varied as influenced by the terrain, weather and enemy situation. The pilot preplans a broad corridor of operation based on known terrain features which has a longitudinal axis pointing toward his objective. In flight, the pilot uses a weaving and devious route within his preplanned corridor while remaining oriented along his general axis of movement in order to take maximum advantage of the cover and concealment afforded by terrain, vegetation and manmade features. By gaining maximum cover and concealment from enemy detection, observation and fire power, nap-of-the-earth flight exploits surprise and allows for evasive actions. CONTOUR: Flight of low altitude conforming generally, and in close proximity to the contours of the earth. This type flight takes advantage of available cover and concealment in order to avoid observation or detection of the aircraft and/or its points of departure and landing. It is characterized by a constant air speed and a varying altitude as vegetation and obstacles dictate. LOW LEVEL: Flight conducted at a selected altitude at which detection or observation of an aircraft is avoided or minimized. The route is preselected and conforms generally to a straight line and a constant air speed and indicated altitude. This method is best adapted to flights conducted over extended distances or periods of time.

The most demanding of these profiles is NOE flight because of its unique control and navigation requirements. The aviator who is flying NOE must maintain a high level of alertness to detect and avoid obstacles while maintaining maximum concealment and desired flight path. The aviator acting as navigator has the difficult task of determining aircraft position and giving navigation instructions based on recognition of land marks and terrain feature, in a highly accelerated perceptual world. In many cases he also has the responsibility for monitoring instruments and making necessary radio contacts. Though research has been conducted to demonstrate the capabilities of aviators to perform such flight and the US Army Aviation School conducts NOE training in accordance with appropriate regulations to include Training Circular 1-15, much yet remains to be known about performance in these profiles.

One area in which quantitative data is needed with regard to NOE flight concerns the problems of flight performance and the stress and workload it imposes on the aviator. The purpose of this investigation was to provide data concerning aviator control inputs per unit time and information about certain aircraft state variables based on measures collected during local area, low level, and NOE flight. No attempt was made to investigate navigation. Though one of the most important factors in this type of flight, it was beyond the scope of this investigation and will be addressed in future research. Physiological parameters measured during the course of this investigation which included muscle activity, heart rate and changes in body chemistry will be covered in other reports.

METHOD

Subjects

Subjects utilized for the present investigation were six experienced rotary wing aviators. Each of these pilots had an average of 2249 career flight hours and had flown an average of 1397.5 of these hours in an aircraft similar to the test vehicle. Of the six aviators, four had extensive NOE flight experience, each having flown an average of 153.75 NOE hours. Two pilots had had less experience with this type of flight.

Apparatus

The test vehicle was a JUH-1H helicopter instrumented to measure and record pilot control inputs and aircraft positions, rates and accelerations. This helicopter inflight monitoring system (HIMS) measures aircraft position in all six degrees of freedom while simultaneously recording cyclic, collective and pedal inputs and aircraft status values. These data were recorded in real time on an incremental digital recorder. A more detailed description of HIMS can be found in USAARL Report No. 72-11.

Procedure

For design purposes the six test subjects were divided into two groups of three aviators each. Each group participated in flight over a two-day period, with each day representing a different test condition. One condition called for an NOE and low level (LL) flight profile and the other required a normal local area flight. These conditions were counterbalanced across the two groups. The procedure on the NOE-LL day required the three subject pilots to be briefed at USAARL after which they were flown to High Falls Stagefield where the testing was begun. Each aviator in turn was requested to enter the right side of the cockpit and prepare for flight. He was then given the following verbal instructions:

"We will take off from High Falls and proceed directly to the course area. We will fly along the course at altitude so you can view the route. While in flight, the flight profile will be explained and you may ask any questions you have about the course. After we finish the run you will be given the controls and will fly back along the course maintaining an altitude of 500 feet MSL and an airspeed of 80 knots. When we reach the end of the course, I will take control of the aircraft and position it on your course heading for the first low level segment of the test. You will be requested to maintain a heading of 021^{O}, an altitude of 200 feet MSL, and a speed of 80 knots for this segment of the test. Upon reaching the end of this flight segment, you will begin the NOE segment of the flight. You will be required to follow the river during this segment, maintaining a track as near as possible to its center. Sustain an airspeed of 45 knots and maintain as close as possible an altitude such that the rotor blades are at or slightly above the trees. This will position the aircraft at approximately 40 ft. above the river bed for the greater share of the course. When we reach the end of the course, land the aircraft. At that time, we will require approximately 60 seconds to check our monitoring equipment and then we shall fly the course again. The course will be flown three times in this manner."

It is recognized that the instructions for the NOE portion of the course did not adhere strictly to the definition of NOE flight. However, such instructions were given so the aviators would be forced to put forth maximum effort to maintain concealment while attempting to complete the course expeditiously. It had been previously established that the entire course could not be completed at an airspeed of 45 knots at an altitude of 40 feet AGL because of its width and winding path. However, such constraints would force the aviators to make airspeed and altitude tradeoffs in an attempt to maintain maximum concealment while trying to complete the course as quickly as possible.

The subject was then given a chance to ask any questions about the course or the procedures to be followed. The familiarization runs were then begun. On the first run the safety pilot flew the straight line course at 500 feet MSL and 80 knots. During this run the subject pilot was able to view the river area and ask questions. When the start of the course was reached the subject was given the aircraft and was allowed to fly a run at the same altitude and airspeed to familiarize himself with the aircraft. Upon reaching the end of the run, the subject was required to begin the first low level segment of the familiarization run. This segment was followed by his first run down the river. After these flights were completed, three flights by the subject were recorded. Each flight consisted of a low level segment and an NOE segment. Total flight time for these three runs was approximately 34.5 minutes. On the average the NOE segment of the flight required 7-8 minutes and the low level segment took approximately 2.5 minutes.

The local area flight which took place on another day of testing required each pilot to fly a straight line course at an altitude of 1000 feet MSL and an airspeed of 80 knots, for approximately 30 minutes. Baseline data directly comparable to the NOE-LL phase of the study were collected on this flight.

Data Collection and Analysis

Continuous information from twenty pilot and aircraft monitoring points was recorded for all flights. A list of these parameters is included in Table 1. This table also lists the derived measures which can be obtained from the recorded parameters. All of these measures, however, were not obtained for the present study. Based on judgments made during previous pilot work, it was decided that concentration would be placed on a limited number of parameters. Eight parameters were utilized. Aircraft parameters were pitch, roll, heading, radar altitude and airspeed. Parameters measuring pilot performance included cyclic movements (fore, aft; left, right) collective, and pedal movements.

TABLE 1

Parameters Measured and Derived Measures

Parameters Measured	Derived Measures
Pitch	Pitch Rate
Roll	Roll Rate
Heading	Rate of Turn
Position x	
Position y	Ground Speed
Acceleration x	
Acceleration y	
Acceleration z	
Roll Rate	Roll Acceleration
Pitch Rate	Pitch Acceleration
Yaw Rate	Yaw Acceleration
Radar Altitude	Rate of Climb
Barometric Altitude	Rate of Climb
Airspeed	
Flight Time	
Rotor RPM	
Throttle	
Cyclic Stick (Fore-Aft)	Control Position, Absolute Control Movement Magnitude, Positive Control Movement Magnitude, Negative Control Movement Magnitude, Absolute Average Control Movement Rate, Average Positive Control Movement Rate, Average Negative Control Movement Rate, Control Reversals, Instantaneous Control Reversals, Control Steady State, Control Movement.
Cyclic Stick (Left-Right)	
Collective	
Pedals	

Inasmuch as the LL flight took approximately 2.5 minutes, a similar time block for comparative purposes was extracted from the other flight segments. To ascertain if time effects were present, this was done for the first and final runs for each subject. These samples were matched in accordance with time so that they represented simultaneous periods during the profile for both runs. Inspection of the data showed that these short segments for NOE and local area flights were representative of the total flights for these profiles.

TABLE 2

Parameters Utilized

Parameter	Statistics
Pitch	Maximum Values
	Minimum Values
Roll	Maximum Values
	Minimum Values
Heading	Maximum Values
	Minimum Values
Airspeed	Mean
	Standard Deviation
Radar Altitude	Mean
	Standard Deviation
Cyclic Stick (Fore-Aft)	Mean Time Steady States
Cyclic Stick (Left-Right)	Mean Duration Control Movements
Collective	Magnitude of Control Movements
Pedals	Frequency of Control Movements

Table 2 presents the parameters and the measures derived for each. It can be noted that minimum and maximum status values across these flight segments were obtained for the pitch, roll and heading parameters. These values were computed by checking each sampled value for the complete 150 second segment and determining its relation to previous values sampled. Means and standard deviations were obtained for radar altitude and airspeed. These values were computed by utilizing all sampled data for the flight period and applying the following mathematical formulae:

1. Mean = $\bar{X} = \sum_{i=1}^{n} \frac{X_i}{n}$ where X_i is equal to each sampled status value and n is equal to the total number of samples in the flight segment.

2. Standard Deviation = $\sqrt{\frac{\Sigma X^2}{n} - \overline{X}^2}$ where ΣX^2 is the squared sample values summed over the flight segment and $\overline{X}^2$ is the squared mean of all samples.

Pilot inputs to controls were treated somewhat differently than the previously discussed measures in that six measures of each parameter were derived. In considering these measures it is necessary to define three key terms. First, in obtaining measures on these controls, it was decided that a steady state occurs when a control has not exceeded an empirically defined distance in a specified time. Second, a control reversal occurs any time a control changes direction. Finally, a control movement was defined as any movement starting from a steady state or control reversal and ending with a steady state or control reversal. Using these established criteria, means were computed from all sampled values for magnitude, duration and rate of control movements and mean time for steady states. The totals for number of steady states and control movements were also recorded. Table 3 presents the times and distances which were utilized as criteria delineating movements in these controls.

The distance ranges were established by determining the minimum perceived control movement for the directions of concern which were thought to yield airframe movement independent of time. The times were established by taking one-half the minimum time it took to move the various controls through the distance ranges previously established.

TABLE 3

Baseline Times and Movement Limits for Controls

	CYCLA	CYCLR	COLL	THROTTLE	PEDAL
Time durations in seconds	.25	.15	.45	.50	.50
Movement limits in inches	.37	.32	.35	.50	.35

RESULTS AND DISCUSSION

Preliminary analysis revealed no differences across the three recorded NOE flight segments. Also, data were found to be similar across all LL segments. Because of these findings only data from the first and last segments of each type profile will be presented.

Graphic presentations of mean minimum and maximum values for pitch and roll for all subjects over the flight profiles are presented in Figures 1 & 2. Comparing mean degrees of pitch across flights, it can be noted that the large variations in the range of this measure occurred during the NOE and LL flights as opposed to the local area control flights. Further, increases in the degree of pitch both maximum and minimum, are extremely pronounced for the NOE flight segment. The same trend is in evidence for the roll measure. For the local area and low level flights, a small amount of roll was measured but in the NOE flight segments where numerous turns were necessary, roll in these turns very nearly reached the operational limits of the aircraft.

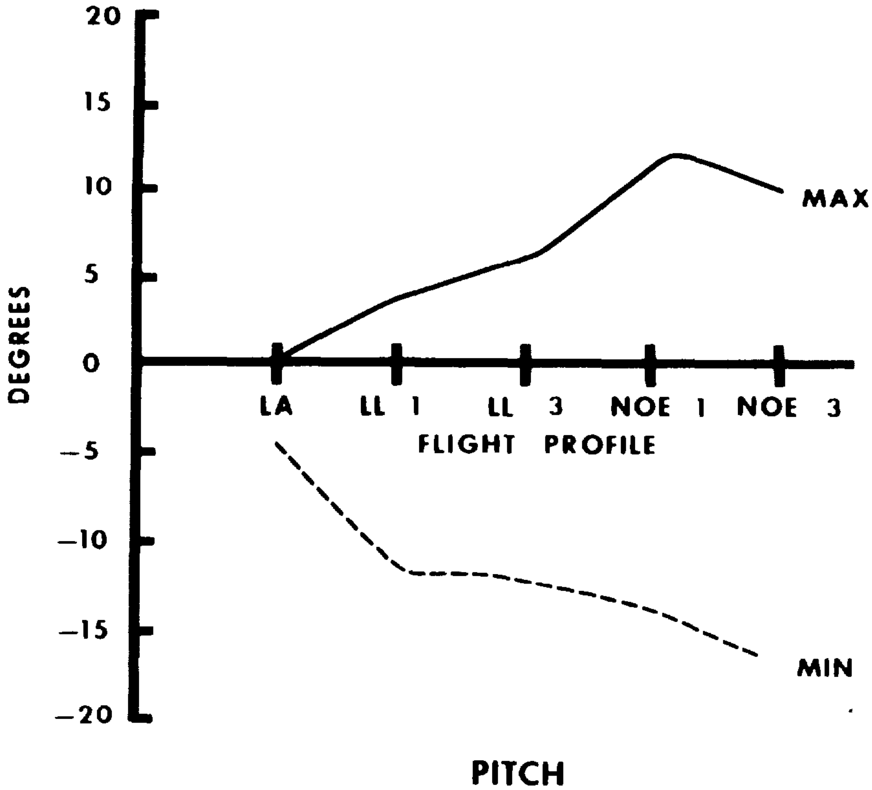


Figure 1

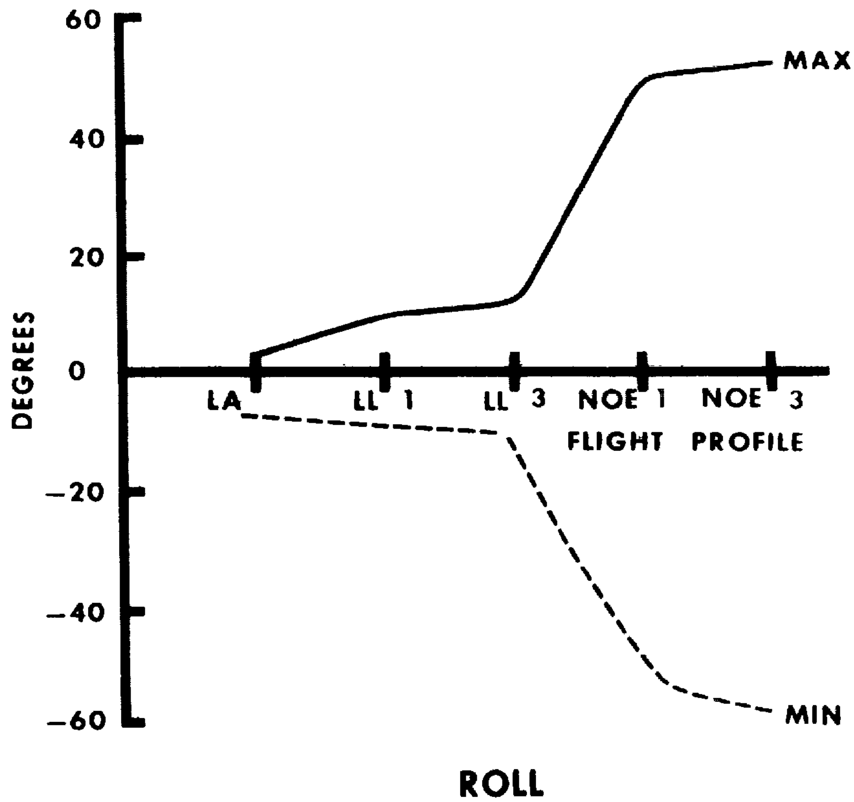


Figure 2

Figure 3 presents the maximum range of the heading values for each flight. It can be seen that large changes in heading occurred with the NOE profile while there were considerably smaller variations with the local area and low level flights. This result is not surprising when consideration is given to the differences in the physical configurations of the courses flown. Both the local area and the low level courses could be considered straight line courses.

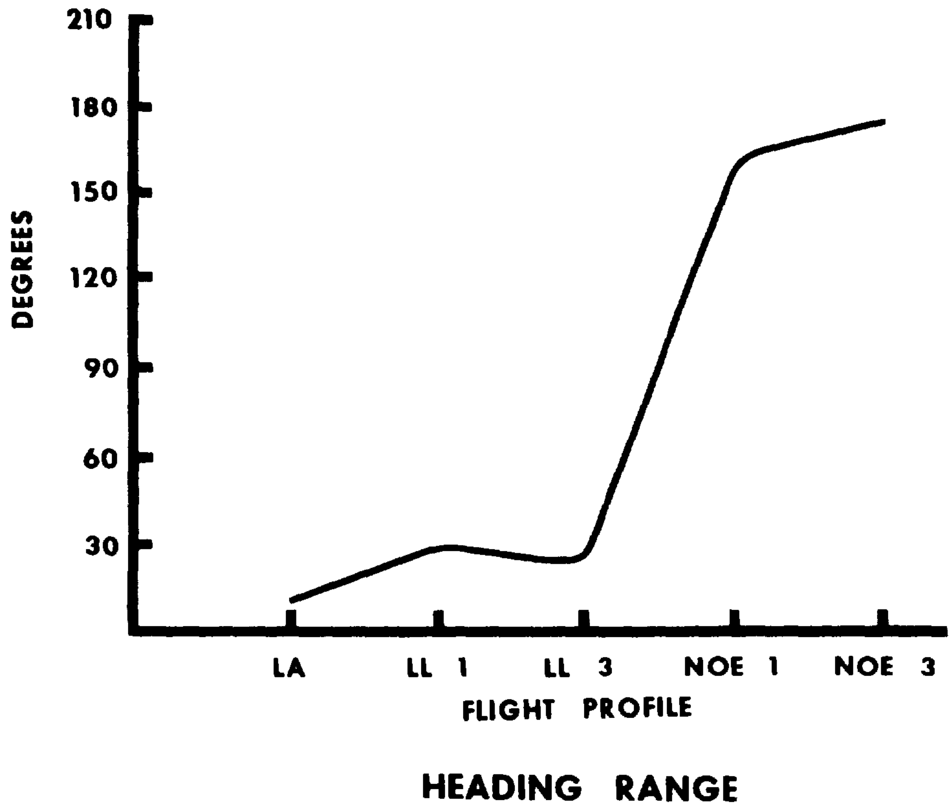


Figure 3

Figures 4 and 5 are graphic representations of the means and standard deviations for radar altitude and airspeed. Referring to Figure 4, it is apparent that altitude was more variable for the local area and low level than for the NOE flight. Considerable variation in this measure again serves to illustrate the different requirements of each mode of flight. With the low level and local area modes, altitude may vary to a greater degree than would be allowed when pursuing a tactical NOE profile where concealment of movement is important.

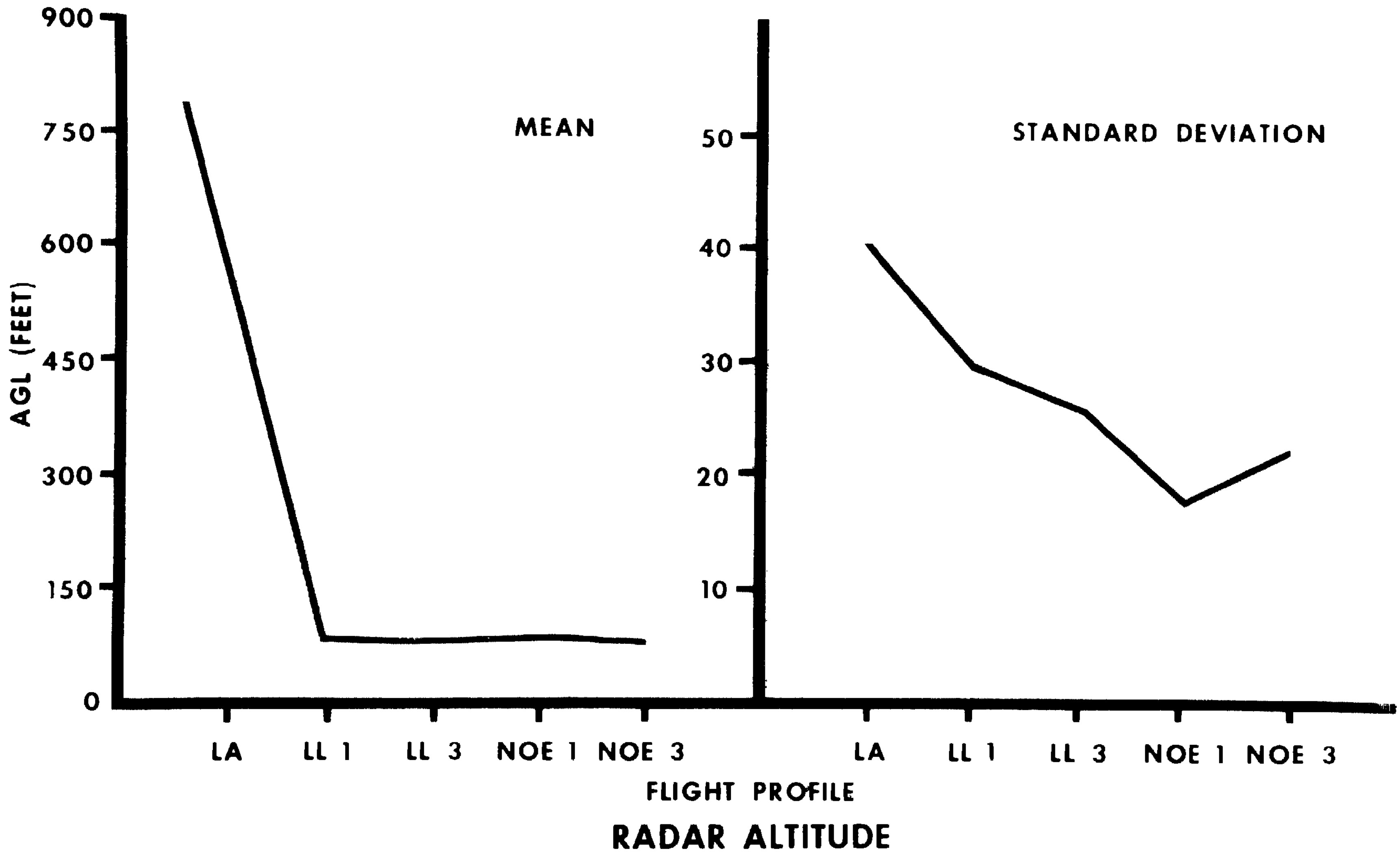
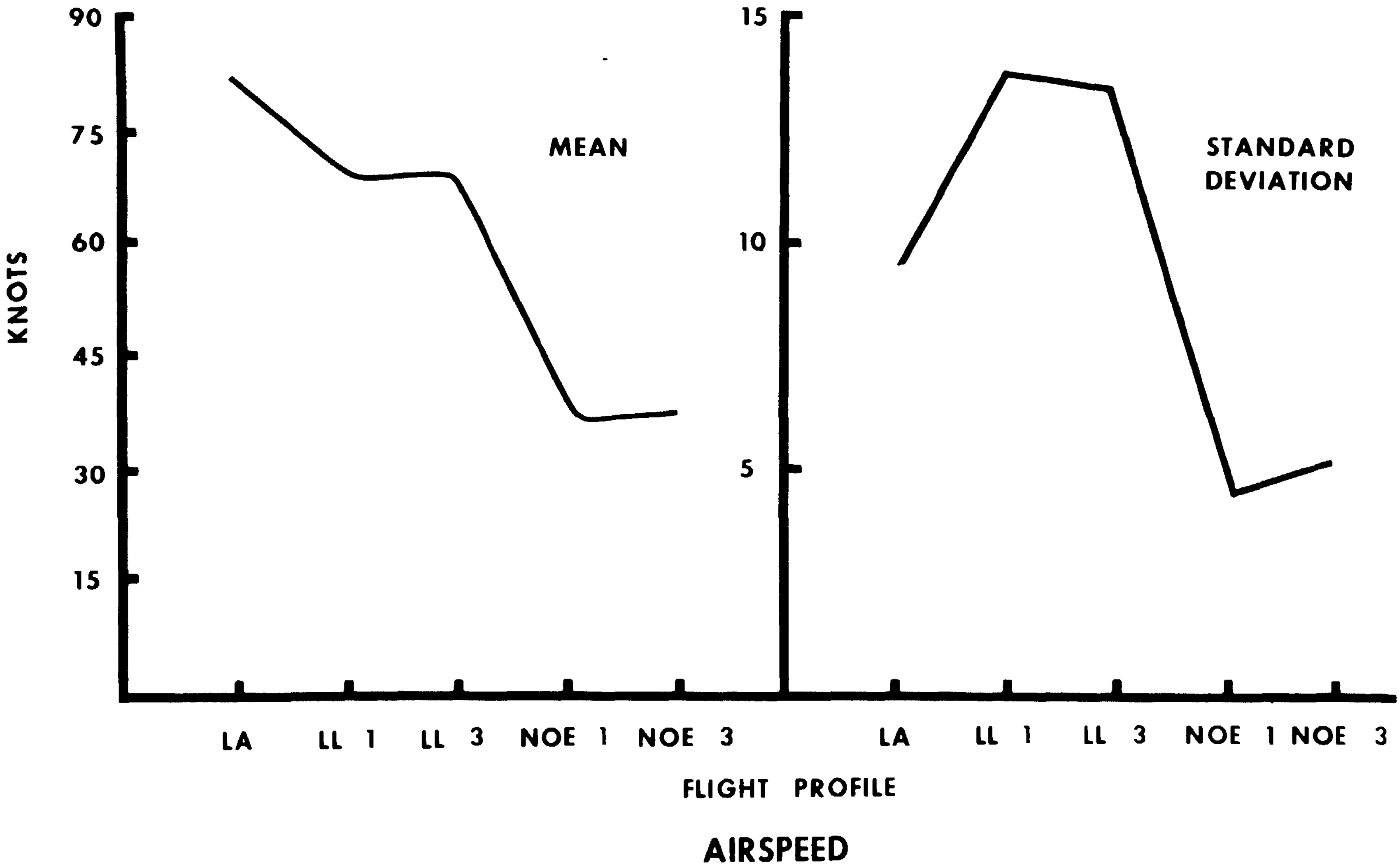

900
750
600
450
300
150
0
AGL (FEET)
MEAN
50
40
30
20
10
STANDARD DEVIATION
LA
LL 1
LL 3
NOE 1
NOE 3
LA
LL 1
LL 3
NOE 1
NOE 3
FLIGHT PROFILE
RADAR ALTITUDE

Figure 4



90
75
60
45
30
15
KNOTS
MEAN
15
10
5
STANDARD DEVIATION
LA
LL 1
LL 3
NOE 1
NOE 3
LA
LL 1
LL 3
NOE 1
NOE 3
FLIGHT PROFILE
AIRSPEED

Figure 5

The different requirements for each type of flight are reflected also in the airspeed measure. In Figure 5 it can be seen that airspeed, although maintained at a higher rate for low level flight was more variable than for the NOE condition. The probable cause of this result could be that in order to negotiate the NOE course it was necessary to maintain the slowest possible speed while still allowing enough forward airspeed for reasonably safe flight.

The results presented thus far would seem to indicate that the NOE requirement then, creates a situation where the aviator attempts to maintain as low and as constant an altitude as possible to avoid detection while at the same time reducing and then maintaining his forward velocity at a point where he can safely avoid obstacles and negotiate the required course.

The large differences reflected in these previously discussed measures would seem to adequately demonstrate that the requirements of pilot and aircraft are both different and more intense for NOE flight than the other two flight modes. If this is indeed the case, pilot performance as measured by control inputs during aircraft flight should also reflect differences.

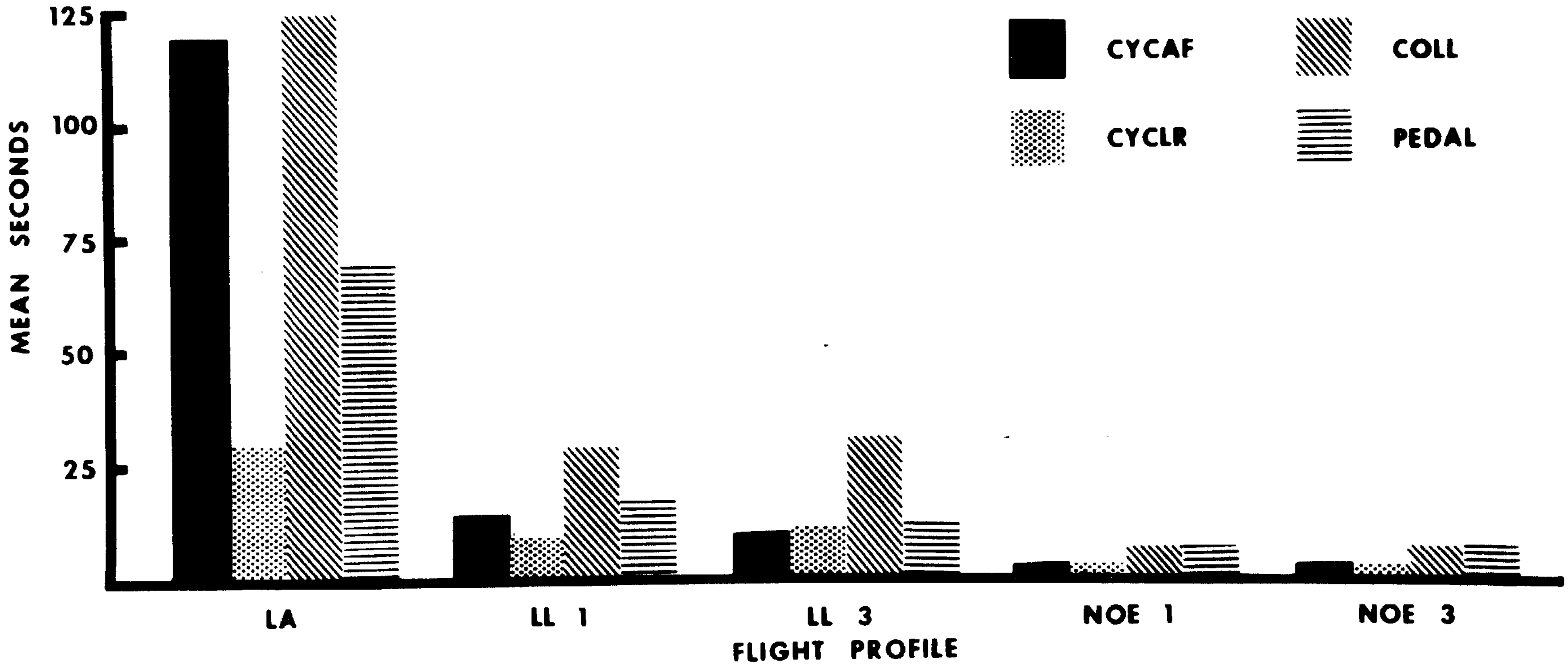
Figure 6 is a histogram depicting the mean durations of time during which the various aircraft controls were held in steady state during flight. On every control parameter considerably more time was spent in steady state during the local area flight condition than the other flight modes. The NOE condition resulted in an almost negligible amount of steady state time during a flight.

When these data are compared with the mean times for control movements presented in Figure 7, it can be seen that an increasing amount of time is spent in movement between local area, low level and NOE flights. Similarly, the magnitude of these movements also follows this same trend.

In Figure 8, mean magnitude of movement in inches is plotted for all flight modes. It is of interest to note that movements for the control required to fly the NOE course are considerably larger than the local area or low level flight modes. Thus, both the amount of time spent in movement and the size of the movements for all four control parameters are much larger for the NOE condition.

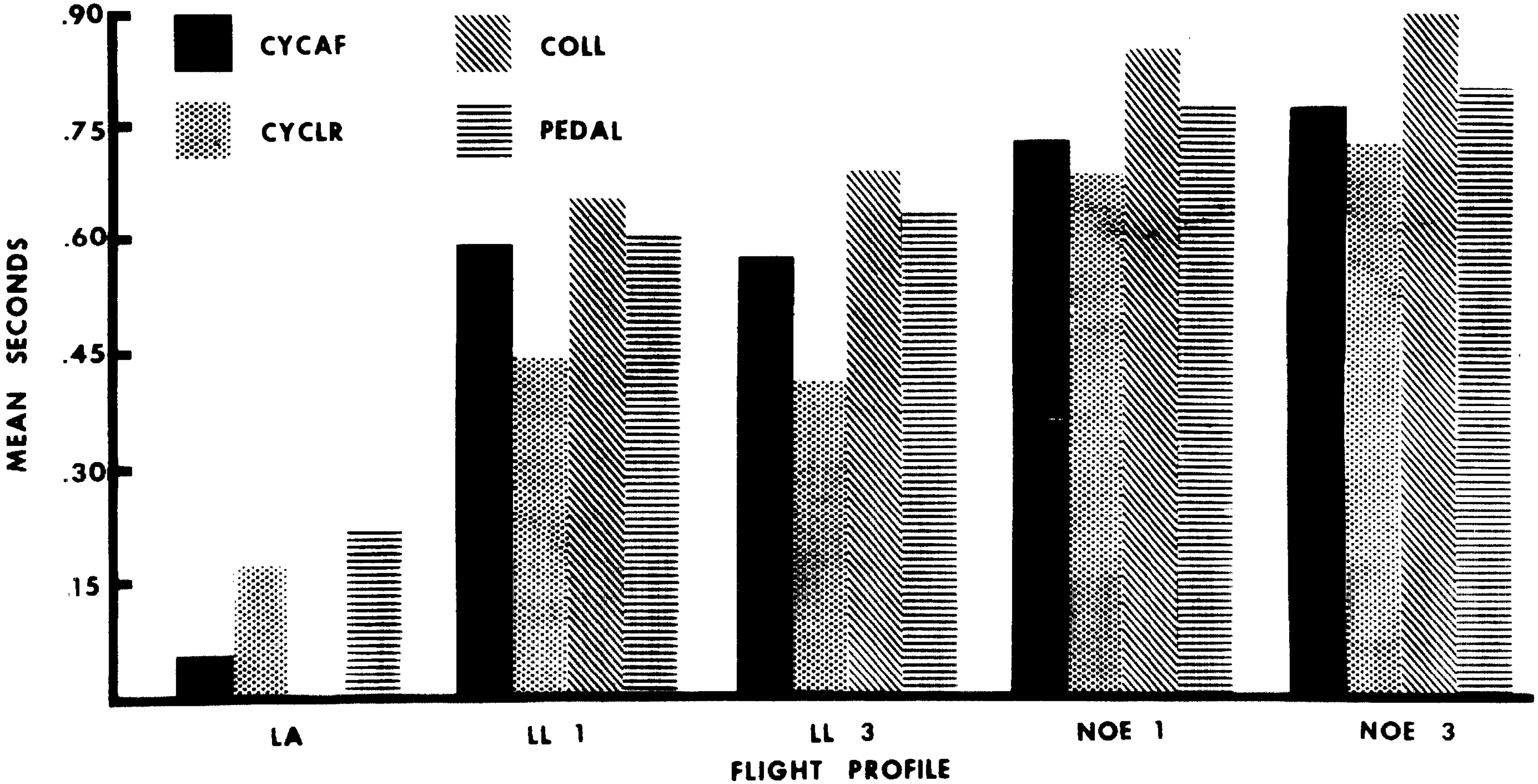
Frequency of movement of controls was also plotted for each flight condition. A histogram of these data is presented in Figure 9. In the case of frequency as with magnitude of movement and time necessary for movement, a larger number of control responses were found for the NOE flights.

Although the feasibility of nap-of-the-earth flight and low level flight is well established, little quantitative data about the actual



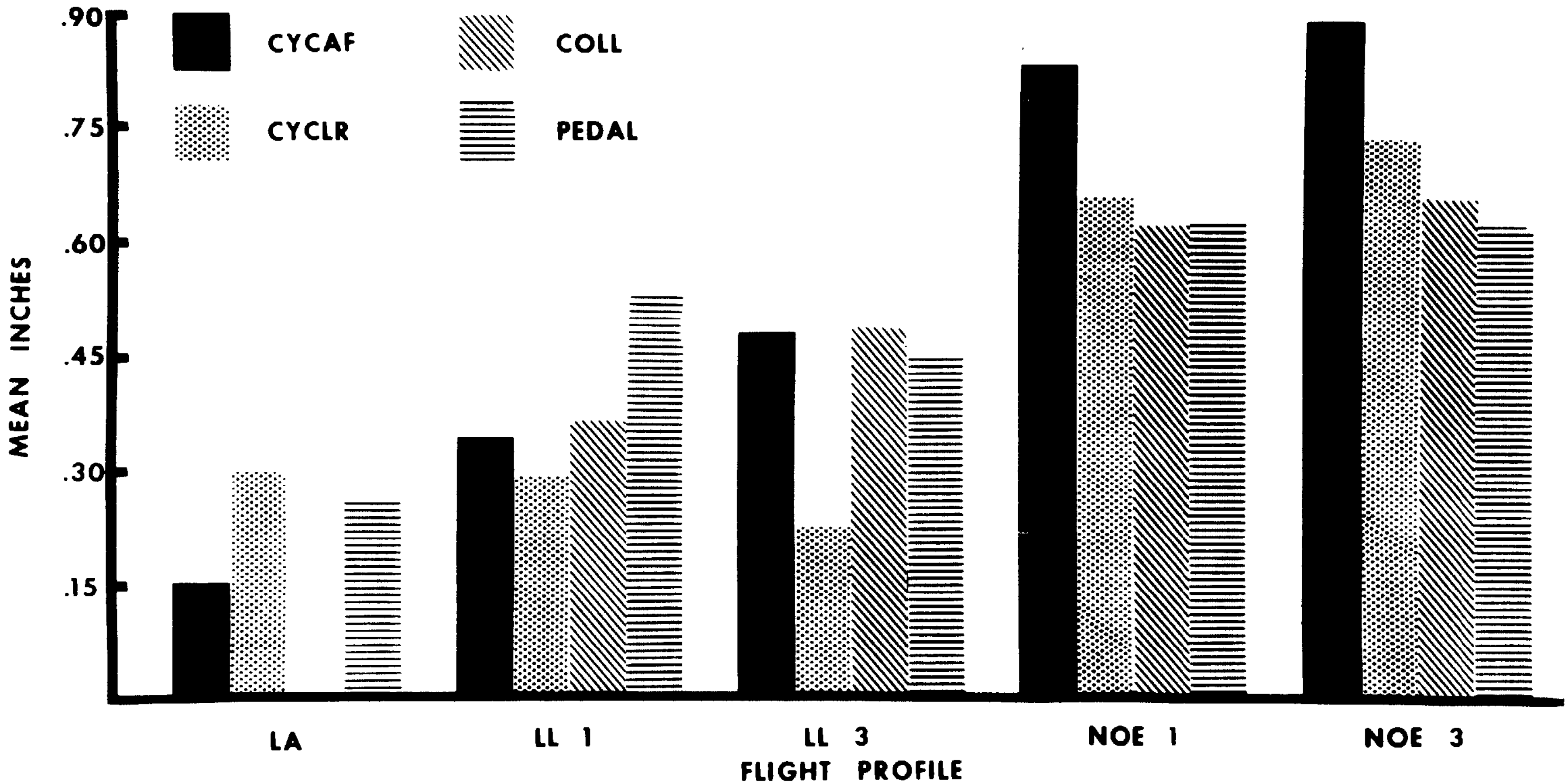
STEADY STATE

Figure 6



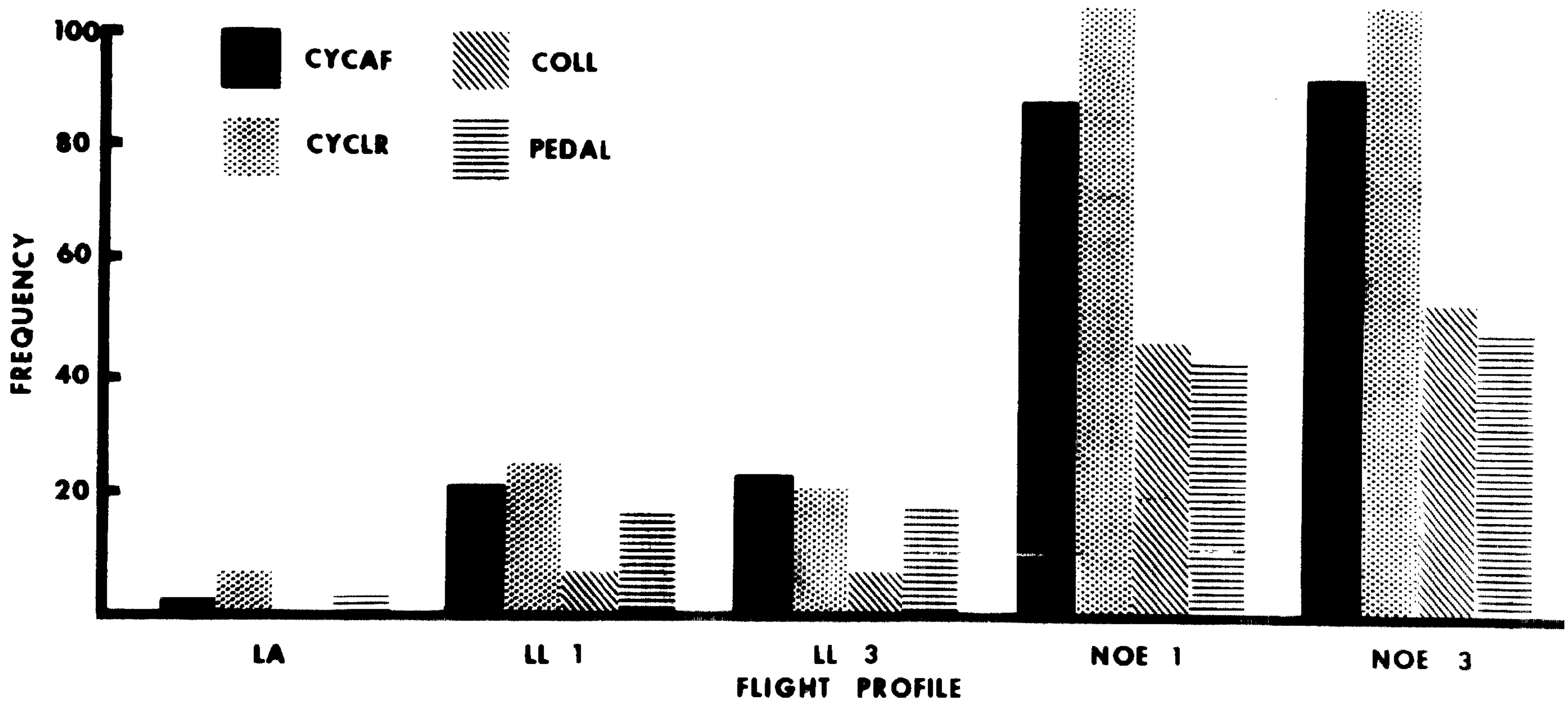
CONTROL MOVEMENT

Figure 7



CONTROL MOVEMENT MAGNITUDE

Figure 8



CONTROL MOVEMENT

Figure 9

performance of the aviator and aircraft in this type flight is currently available. This research was conducted in an effort to gain some baseline data in this regard.

It is apparent from the data reported that NOE flight places more demands on both crew and aircraft than the other flight profiles investigated. The much accelerated and constantly changing flight environment which the aviator is operating in during this type of flight requires rapid perceptual judgments and similar rapid while extremely precise control responses. Further, this mode of flight, unlike normal flight conditions where adequate time can be allotted to various crew tasks, requires continual multi-task coordination. As a consequence, it seems that a degradation in the performance of this type of flight would occur if conducted over extended periods of time. Analysis of the data collected during the present work, however, did not reveal any such performance differences between first and final NOE flights. Control inputs by all aviators remained the same and aircraft parameters were also quite similar. This, perhaps, should not be unexpected for the time spent on flight task was relatively short and there was a brief break between flights. It will be recalled that the NOE flight segment lasted approximately 7 minutes after which the aircraft had to be landed for a brief period of time. Any flight consisting of the low level and NOE segments only required approximately 10 minutes, 30 seconds. It can be hypothesized that this brief period may have provided a sufficient period of rest between flights to nullify observable fatigue effects. Had continuous flight been possible over longer periods of time, performance degradation as a result of fatigue may have been a factor. It also must be remembered that the pilots in this experimental situation were performing only a part of the task required in a tactical NOE mission. In order to assess only the aircraft handling requirement, these pilots were just required to operate the aircraft and had no communication or navigation tasks placed upon them. Further, it was considered necessary that they familiarize themselves by observing the course before they flew it. These conditions are not likely to exist when a normal NOE mission is performed. The addition of these tasks will be a critical factor and will necessarily demand more from the aviator. This work has provided data which has demonstrated the uniqueness of the NOE flight profile and provided some baseline data. Further efforts are being conducted to provide additional information relative to aviator performance in this type of flight.