PROJECT SUMMARY

Final Research Report Submitted to
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Abstract

The purpose of this research was to explore the performance limits for helicopter pilots who inadvertently fly into IMC conditions. The problem of inadvertent VFR flight into IMC has been well documented as a major cause of general aviation accidents. The performance limits of fixed wing pilots under these circumstances have also been investigated with alarming results. However this problem has not yet been studied sufficiently in civilian helicopter pilots. In general helicopter operations are more complex than those of fixed wing aircraft for several reasons including increased control difficulty and the ability to operate in a variety of flight regimes such as slow flight, hover, low level, and high speeds. Each of the different helicopter flight regimes has different operational and control demands. The present study is aimed at quantifying helicopter pilot performance after inadvertent VFR into IMC at different speeds and altitudes of operation. A secondary goal was to develop an objective method to quantify pilot effort and performance. We report here on data collected from instrument rated commercial helicopter pilots in simulated flight from VFR conditions to IMC. Data were collected on aircraft attitude and performance as well as pilot control inputs. An "error" analysis was conducted on the aircraft attitude data which enumerated the number of times and the percentage of time that the aircraft was judged to be in a attitude that would reduce safety as predetermined by helicopter pilot experts. In addition a novel "power" analysis was performed on the pilot input data that provided information regarding the amount of corrections that the pilots were using during flight. This analysis treated pilot inputs as time series and quantified variability in the inputs by calculating power in the Fourier spectrum of the digitized control position data stream. This analysis is unique in that it provides an objective measure of pilot effort. The analysis was also applied to aircraft performance metrics. Both the error and power analyses revealed important information regarding the relationships between visibility, altitude, airspeed, aircraft performance, and pilot effort. In particular, while pilots quickly improved performance such that safe attitudes were maintained, the amount of effort required to maintain proper attitude remained high for longer periods of time. Pilot effort eventually decreases with repeated practice.

Introduction

Background

Helicopter pilot performance during inadvertent VFR flight into IMC.

The problem of inadvertent VFR flight into IMC is well known. From 1990-1997, inadvertent VFR flight into IMC account for approximately 11 % of fatal general aviation accidents. In addition the fatality rate for accidents involving VFR flight into IMC was about 75% while that for accidents attributed to other causes is about 18% (Wiegmann and Goh, 2000, Goh and Wiegmann, 2002). The situation has not improved significantly since that time. It is generally accepted from previous studies that most fixed-wing pilots that are not trained specifically in IFR operations have great difficulty maintaining control over the aircraft when visual cues are lost. The most quoted data set suggests that an alarmingly short 178 seconds is the average time that a VFR rated, fixed-wing pilot has after entering IMC before a catastrophic loss of control occurs. The high frequency with which inadvertent VFR flight into IMC occurs, greatly amplifies the cause for concern over these data. However there is little data on the ability of commercial helicopter pilots to maintain control of the aircraft after inadvertent instrument conditions are encountered.

VFR into IMC accidents are a major concern in commercial helicopter operations and are recognized as a major safety problem. A white paper released by Helicopter Association International (HAI) in Fall of 2005 addressed the issue of continued VFR flight into IMC in emergency medical service (EMS) operations and states *"Fifty-nine (46.8 percent) of these pilot-induced accidents were a result of either controlled flight into terrain, water, or obstacles; striking an object with either the main or tail rotor; or a loss-of-control resulting in impact with terrain due to spatial disorientation. Of these, 40 occurred at night, and of these, 23, or over half, involved intentional or inadvertent continued VFR flight into IMC conditions"*. In addition, the industry's major operators and manufacturers often address the issue of VFR flight into IMC in safety circulars and publications (e.g. Bell Helicopter, 2004). However, a perusal of recent NTSB annual safety reports reveals that weather and continued VFR flight into IMC remains responsible for many aviation fatalities.

Since helicopter operations by nature are largely conducted in VFR environments many helicopter pilots, even those with instrument training, have relatively little instrument flight time in actual IMC. In addition, helicopters are inherently less stable than fixed-wing aircraft and can operate in a wide variety of flight regimes each of which has its own degree of stability and difficulty of control. Such regimes include vertical takeoff and landing, hover, low speed flight in virtually any direction, and high speed forward flight. The performance of pilots during inadvertent VFR flight into IMC must depend on many interacting factors including aircraft altitude, direction, and speed as well as pilot variables such as experience, fatigue, external distractions, and stress. It would be useful in promoting safety to understand the nature of the pilot performance envelope for VFR into IMC situations, in the multidimensional variable space within which helicopters are flown. This portion of the present application proposes to investigate pilot performance for inadvertent VFR into IMC operations for helicopter pilots operating in several different flight regimes experienced during normal flight. It is the hope that this information can be used to guide helicopter instruction and to make recommendations regarding pilot response during inadvertent VFR into IMC.

Goals

The main goal of the present investigation is to contribute to the knowledge of pilot performance limits in order to improve flight safety for civilian helicopter operations. Specifically, we have evaluated how well civilian, instrument-rated helicopter pilots maintain control of their aircraft after inadvertent VFR flight into IMC across a variety of flight altitudes and speeds. A second goal is to develop an objective method to quantify both aircraft control and pilot's control inputs.

Methods

General design-

We have investigated pilot performance after VFR flight in to IMC using an FAA approved helicopter simulator (Flyit) running a Microsoft flight simulation package for the Bell 206 (see Figure 1). The simulators were owned by and located at Silver State Helicopters Flight Academy in Sacramento, California. We developed scenarios for the simulator that introduced a relatively rapid decrease in flight visibility to IMC conditions over a period of about 3 minutes of flying time. However since many VFR into IMC scenarios involve slow and sometimes insidious weather deterioration, it is hoped that future research may be aimed at determining how rate of weather decline affects helicopter pilot performance and decision making. The scenery environments were chosen to mimic common commercial helicopter operations and included departure from an offshore (island) site with a short flight to the "mainland" and a scenario flying along moderately mountainous and forested terrain.

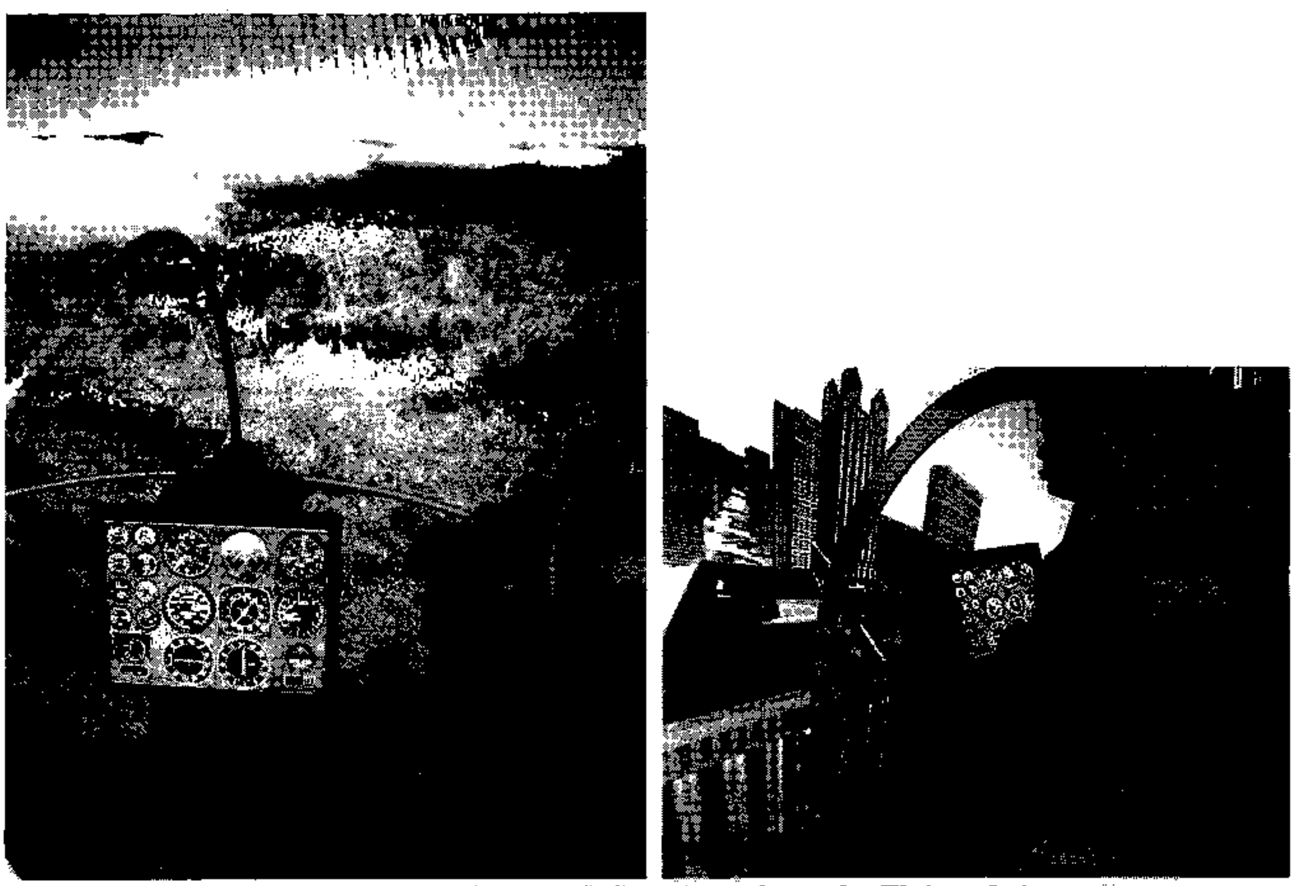

Figure 1. Two views of the Flyit Simulator from the Flyit website.

We have investigated a range of flight conditions including four different altitudes and five different airspeeds (see table 1) as independent variables. Shaded regions in Table 1 indicate those conditions that were tested. Data were collected from the simulator program regarding the flight instruments, aircraft performance, scenario information, and control inputs. These data were collected using a program which we developed to run simultaneously with the simulator and download and record data and flight parameters in real time. We performed two different post-hoc data analyses which are described in detail below. In addition the flight information was recorded and can be played back for later viewing and subjective analyses using a program developed by Joseph Sullivan and his colleagues at the Naval Postgraduate School in Monterey, CA.

	Altitude (ft. AGL)			
Airspeed (knots)	300	500	1000	1500
20				
40				
60				
80				
100				

Table 1. Flight altitudes and airspeeds/maneuvers at IMC encounter. Shaded regions indicate those conditions that were tested in the simulator.

Subjects-

We tested 20 commercial, instrument rated pilots. The pilots were recruited through Silver State Flight School in Sacramento, CA and by an announcement posted by HAI in their news letter and on their website.

All of the pilots were qualified to fly the Bell 206 prior to the testing and had current medical certificates. Because of the great interest in this study by the helicopter operator industry our subject pool was probably biased towards high-time pilots. The range of helicopter experience was from 1,400 to 25,000 hours of pilot-in-command (through self-report). The mean and median times were 7,185 and 4,850 hours respectively.

Procedure-

A helicopter flight instructor from Silver State Helicopters supervised the operation of the simulator and acted as ATC for the pilot and as experimenter to collect the data. Pilots were given between 5 and 10 minutes to familiarize themselves with the flight characteristics of the simulator. Practice was considered sufficient if the pilot could confidently maintain control of the simulator during takeoff, level flight, hover, and landing under normal visual guidance. Each pilot flew six assigned "missions" at given altitudes and airspeeds. The specific altitudes/airspeed conditions and order of the conditions was randomly chosen to control for practice effects. Each scenario was flown for approximately 5 minutes after which flight visibility was gradually reduced over a 3 minute period to low IMC with ceilings of 100 ft or less and near zero visibility. Flight visibilities dropped from > 10 nm, to 3 nm, to 1 nm, to 0.5 nm, and essentially zero visibility when clouds levels were below the flight altitude. The pilot was allowed to take any action required to cope with the changing conditions including declaring an emergency, requesting an IFR clearance, descending, continuing the flight, or making a precautionary landing. The flight was allowed to continue for a total flight time of 15 minutes or until loss of control, precautionary landing, or crash occurred. Flight data was automatically downloaded to a laptop computer for offline analysis. A sample of the raw data obtained over a 30 second period of time for one run is shown in Appendix 1. Complete raw data files are available from Dr. Crognale upon request.

Raw Data Analysis

As mentioned above we performed two types of analyses on the data. The first analysis was a novel procedure which we termed a "power" analysis and is based upon the power in a Fourier transform of the data. The logic was that a decrease in aircraft control would produce more fluctuations or variability in aircraft performance parameters such as pitch, and bank. These greater fluctuations would result in greater power in the Fourier spectrum of the time series that describes the parameters. Thus Fourier power is inversely proportional to stability or aircraft control performance. This analysis has an additional advantage since it also can be applied to control input data. So even if the aircraft stability is being maintained it might be true that the pilot is working harder to achieve flight stability and may have increased control input fluctuations. Therefore the power in the Fourier spectrum of the time series for control inputs may be a convenient and objective metric for quantifying pilot effort or task difficulty. Such an objective measure would be valuable in studies of pilot performance, training efficacy, workload manipulations, and fatigue.

The second analysis (error analysis) looked at pilot performance by comparing the "error" rate that occurred during the VFR and IFR portions of the flight. Errors were operationally defined after consultation with experienced helicopter Safety personnel at the FAA. An error occurred anytime a pilot crashed or exceeded the following parameters for aircraft attitude: pitch-exceeding + or – 5 degrees; bank- exceeding + or – 18 degrees; vertical speed-exceeding + or – 1000 ft/min. The error rate (the amount of time spent exceeding the limits per unit time) provides an index of flight control with high numbers indicating poor control.

The processed data (power and error rate analyses) used in the statistical analyses for all runs are tabled in Appendix 2. These data are in a format compatible with SAS and other statistical analysis packages.

Data Sampling

In order to fairly compare pilot performance during different visibility phases of flight we sampled the simulator and pilot data during the times of reduced visibility and for an approximately equivalent time in non-reduced visibility just prior to the change in visibility. In an example of the procedure, the pilot flies for about five minutes; .the weather starts to deteriorate and falls to solid IMC over a few minutes; the pilot continues flight for an additional five minutes. The data for this flight would be sampled for a maximum of 5 minutes prior to a change in visibility, during the change in visibility, and for a maximum of 5 minutes after IMC conditions are attained. The first data analysis phase began after the pilot reached cruise altitude and was objectively quantified as the time of the first zero or negative vertical speed indication when within 50 ft of cruise altitude or after reaching cruise altitude. Both the error rates and the power analysis were performed on the data for the different visibility phases of flight.

Statistical Analyses

Data from the power analysis was tested using a General Linear Model from SAS. Each of the eight measures (pitch power, pitch error rate, fore/aft cyclic power, bank power, bank error rate, lateral cyclic movement power, pedal movement power, and vertical airspeed error rate) were analyzed independently using subject, time in type, order of test, visibility, altitude, and speed as parameters in the model. There were 20 subject levels 19 time levels, 2 visibility levels, 5 order levels, 4 altitude levels, and 5 speed levels. We also tested for non-monotonic effects of time in type by using the 2nd order interaction (time X time). We also hypothesized that the IMC visibility condition may show effects of the different variables but under VMC conditions the variables would have little effect. Therefore we also ran the statistical analyses for the IMC condition by itself.

The data from the error analysis contained a large number of zeros since there were times that the pilots made no errors. This was particularly true of the VMC data. In order to analyze these data, we employed a Poisson regression wherein we added a small constant (0.01) to all of the values. This constant had no effect on the tests of significance. The model we chose for the error analysis was the generalized linear mixed model as provided by SAS. The reported probabilities, P are from the chi square of the differences of the least-squares mean. The complete outputs from the different statistical analyses run in SAS are attached as Appendix 3-5. These outputs contain all relevant significance tables including interactions and pairwise comparisons, too numerous to include in the body of the report.

Results and Discussion

General Findings

The experiments generated an enormous amount of data which has the potential to be analyzed in the context of numerous hypotheses. We report here only those data pertinent to our proposed tests of the variables of altitude, airspeed, pilot time, and order effects. The data can be made available to others interested in analyzing them in greater detail or for other effects by contacting Dr. Crognale.

The general results revealed that both the error analysis and the power analysis were useful in objectively quantifying pilot performance. The power analysis had the great advantage of being a continuous measure providing information even when the pilot's performance did not fall below a threshold acceptable level. In addition the power analysis could be applied to control inputs, providing an objective measure of control effort. The ability to replay the flight using the software developed by Dr. Sullivan also allowed for subjective analysis of the flight which in many cases was found to be informative.

In general, the pilots' ability to transition from VMC to IMC conditions was not unacceptable. Comparison with previous fixed-wing studies should be done with caution since the study methods and pilot populations differed greatly. None of the helicopter pilots lost control of the aircraft and only one crash occurred. In this case the crash was not actually the fault of the pilot as he was essentially vectored in the direction of a mountain and experienced controlled flight into terrain (CFIT) as a result of the vector. The relatively good performance of the pilots was no doubt in part due to the fact that they were commercial rated and IFR rated. High pilot experience times probably also contributed to the quality of the performance.

Main Effects

Not too surprisingly, one of the most statistically significant findings of the study was a strong subject effect, indicating that the pilots differed greatly in their ability to transition from VMC to IMC. Interestingly, the statistical analysis of the effect of total pilot time however, was not found to be significant for most measures, even when testing for a non-monotonic effect using the second order interaction. The few statistically significant effects of pilot time in fact showed increasing errors with pilot time, not decreasing as one might expect. However, as mentioned above, the study population was skewed towards high time and even the most inexperienced pilot had over 1,400 hours.

Not surprisingly the most significant main effect was for visibility with all pilots' performance declining significantly after transitioning to IMC. Figure 2 shows raw bank and cyclic movement data collected from one subject with 7600 hrs. These raw data are informative on a qualitative level and one can easily see performance changes due to visibility. The data in the left panel are bank vs. time while those in the right panel are for lateral cyclic movements vs. time. This pilot had more difficulty during the transition periods than did most pilots. The data for bank are plotted to reveal the threshold of + and – 18 degrees, the criterion for a bank error used for the error analysis. Although the drop to 1 mile visibility had little effect on the production of bank errors in excess of 18 degrees, the pilot makes several errors after transitioning to zero visibility.

The power analysis also provides an objective method to quantify the cyclic movement data shown in the right panel of Figure 2. As can be seen there are large changes in cyclic control inputs when visibility changes. Changes are readily quantified for each transition using this analysis. These changes are described in greater detail below. In many cases pilots failed to exceed the error criteria yet showed large increases in cyclic movement or bank movements after transition to lower visibility. In these cases only the power analysis revealed the decrease in pilot performance caused by the initial reduction in visibility. In some cases little changes in bank movements were observed yet the cyclic movement data revealed greatly increased workload.

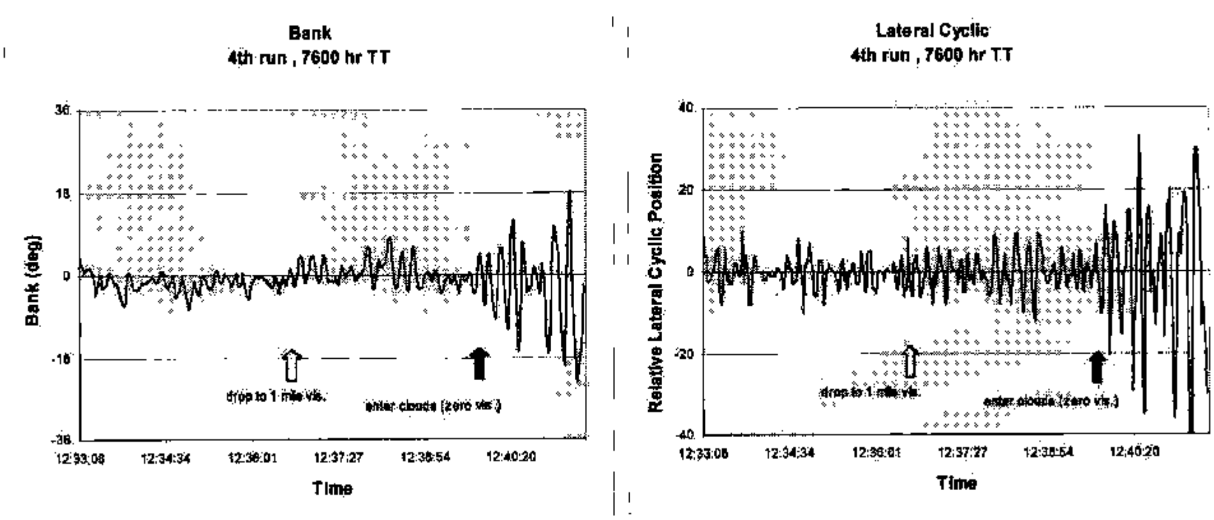

Figure 2. Examples of raw data from bank angle and lateral cyclic inputs. Changes in visibility are indicated with arrows.

To assess the effects of learning or practice during the course of the experiment, we also tested for order effects. For the power analysis, the overall main effect for order was generally not found to be significant since performance under VMC was usually quite good and significant improvement would be difficult to achieve. However, order-by-visibility interactions were found to be significant for some pilots indicating some improvement in learning to transition from VMC to IMC over the course of the experiment. The order effect was not equivalent for all pilots and conditions. These effects will be discussed in more detail below.

Figure 3 shows a sample of the raw data output for bank vs. time (left panels) and for lateral cyclic movements vs. time (right panels) for a pilot whose data were shown in Figure 2. The upper panels show those data from the first test flight and the bottom panels show the data from the last (5^{th}) test flight. The transitions from VMC to visibilities below 1 mile are indicated, as are those transitions to zero visibility upon simulated cloud entry. These raw data are informative on a qualitative level and one can easily see performance changes due to visibility. Comparison of the upper and lower panels reveals that this pilot improved significantly between the first and last runs.

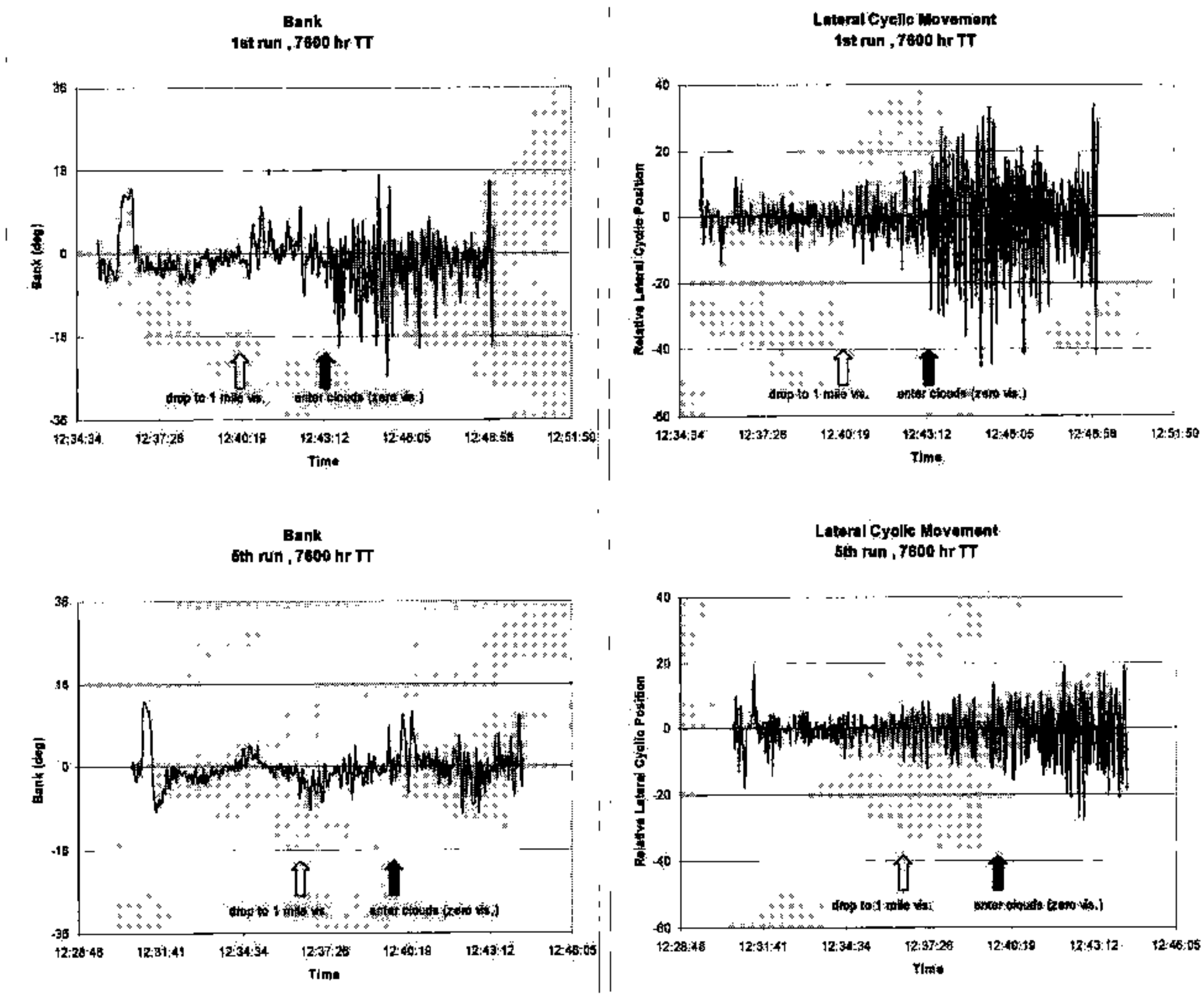

Figure 3. Examples of raw bank (left panels) and lateral cyclic movement data (right panels) from the first run (top) and from the last run (bottom) of the same subject.

One of the more extreme examples of the practice/training effect is shown in Figure 4 which plots the pitch fluctuations for a pilot with 3500 hrs. Rapid and extreme pitch fluctuations can be seen for this pilots first run (left panel) upon reduction of visibility to 1 mile. Further reduction in visibility to zero produce increased pitch fluctuations that continue for a prolonged period of time. Though the fluctuations during the 5^{th} run (right panel) also increase with changes in visibility, the magnitude of these fluctuations is greatly reduced and is not likely to present a hazard to flight.

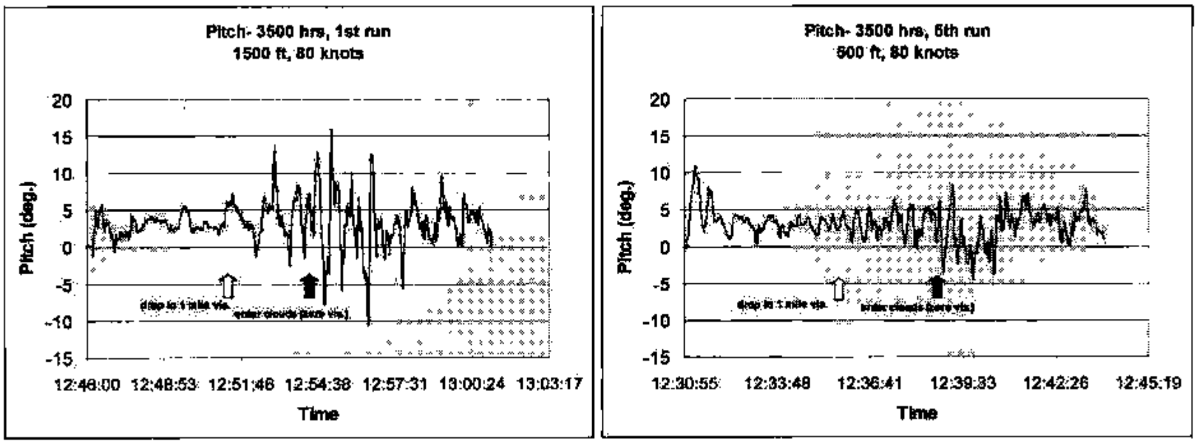

Figure 4. Examples of a learning effect. Pitch fluctuations from the first run (left panel) and the last run (right panel) for a pilot with 3500 hrs.

Power Analysis

Effects of change in visibility-

Figures 5-10 present all of the data for both aircraft attitude measures and for pilot control inputs for both visibility conditions. All of the data are presented rather than just the means in order to better reveal the character of variability in the data. In all of these figures the data are labeled as either IMC or VMC. The left half of each of these figures is all of the flight data collected under VMC while the right half of the figures show those data for IMC conditions. These figures are meant to provide a quick overview of the results in a manner that allows us to see the extent of the visibility effect as well as the range of the scores. Data for all altitudes and airspeeds and tests have been included. The data will be broken down into the specific parameters of airspeed, altitude, and order of testing below.

Figure 5 plots the power (fluctuations) in aircraft pitch in the left panel and for fore/aft cyclic movements in the right panel. Low numbers indicate steady control. In this figure, no change in pitch attitude or cyclic movement would be zero. The relative scaling for the two different measures is arbitrary and based only on the digital outputs of pitch and cyclic position from the simulator. It can readily be seen that both pitch fluctuations and fore/aft cyclic movements were dramatically higher in IMC than in VMC. The visibility effect for pitch was statistically significant ($P<.0001$) as was that for cyclic input ($P<.002$).

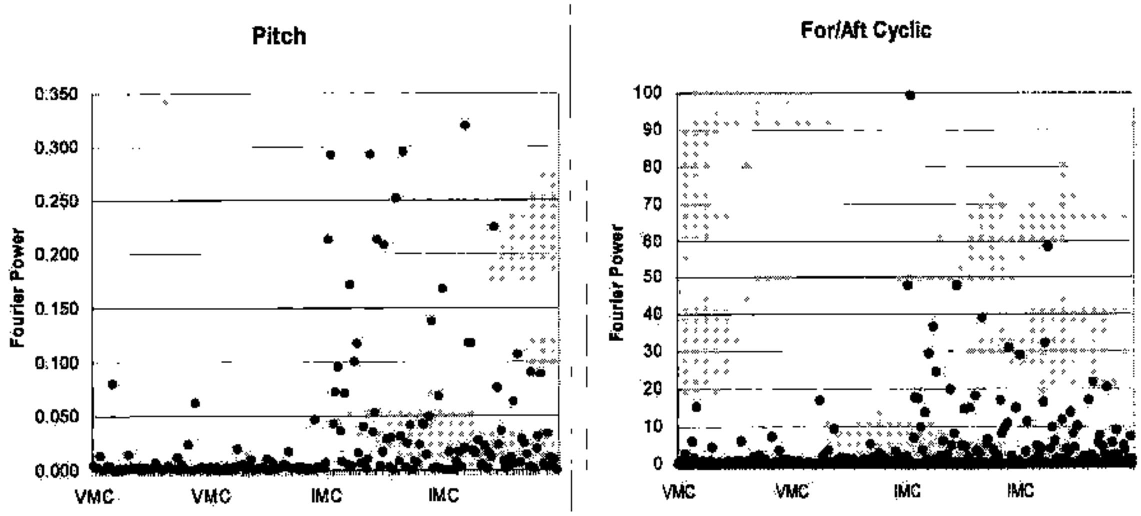

Figure 5. Power analysis results for aircraft pitch (left panel) and for fore/aft cyclic movements (right panel) for VMC and IMC conditions.

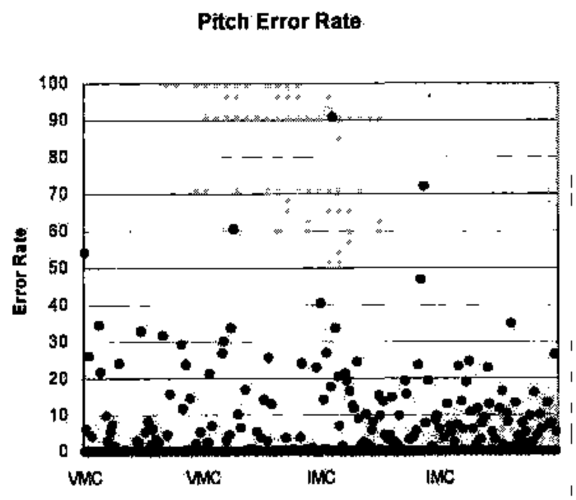

Figure 6. Error rates for pitch vs. visibility condition.

Figure6 shows the error analysis for pitch and plots the percentage of the amount of time during which the pitch exceeded the pre-determined limits vs. the total time in that visibility condition. It should be noted that for some measures, the error data, particularly for the VMC conditions, contained a large number of zeros indicating no errors during that time period. The limits chosen for pitch errors in general produced larger rates than those chosen for bank and for vertical speed. The effect of visibility on Pitch Error Rate shown in Figure 6 is subjectively not as impressive as the effects on pitch and pilot input fluctuations shown in Figure 5. Nonetheless the effect of visibility shown in Figure 5 was found to be highly significant ($P<.001$) with the statistical error analysis.

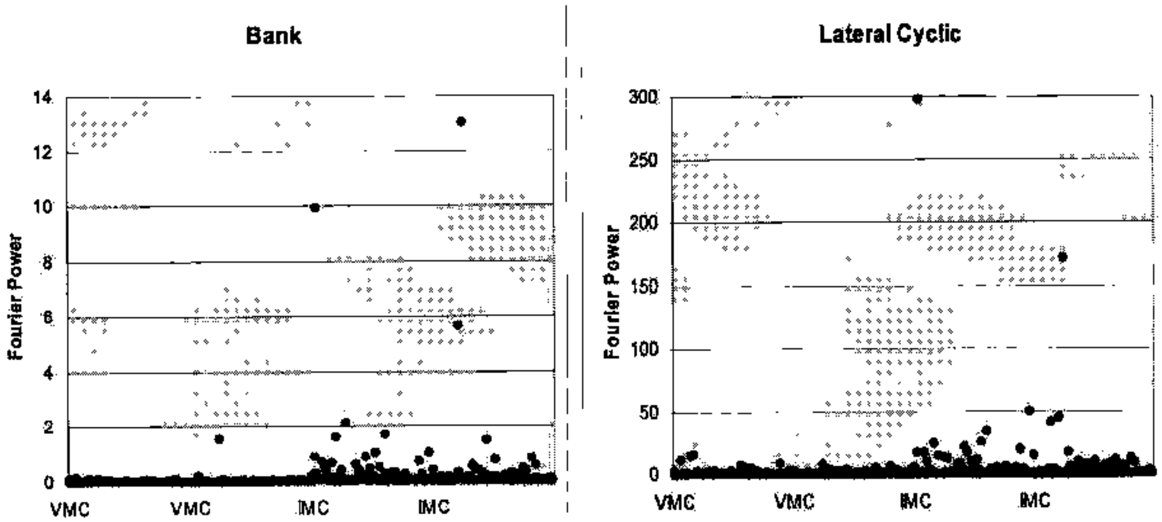

Figure 7. Power analysis for the effects of visibility on bank (left panel) and for lateral cyclic input (right panel).

Figure 7 shows the visibility effect for the measures of bank and for lateral cyclic movement. The visibility effect is clearly seen for both aircraft attitude and for pilot input measures. The magnitude of the effect for most subjects is partially obscured by the presence of very large effects for a few subjects. The difference between VMC and IMC conditions was highly significant for bank ($P<.0016$) and for cyclic inputs ($P<.0023$).

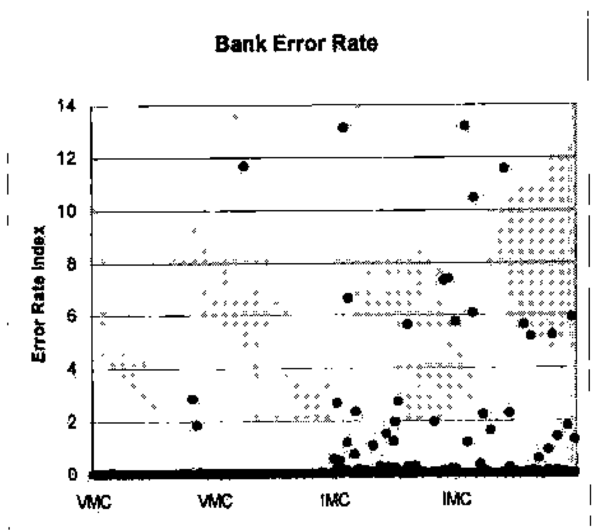

Figure 8. Error rate for bank vs. visibility condition.

Figure 8 shows the error rate analysis for bank. Again the effect of visibility on bank error rate is both subjectively compelling and statistically significant ($P<.0001$). These data indicate that both lateral cyclic movements and bank deviations are particularly sensitive to reductions in visibility.

Changes in the vertical speed error rate with changes in visibility are shown in Figure 9. These data also reveal a significant effect ($P<.0001$) of visibility on aircraft control. Strikingly, vertical airspeeds exceeding 1000ft. /min were much more common under IMC conditions than in good visibility.

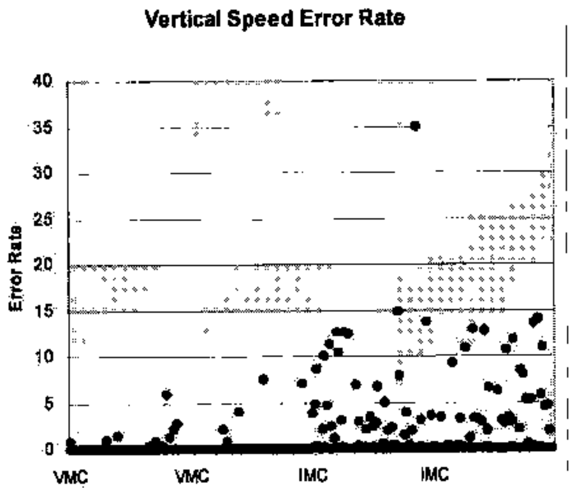

Figure 9. Error rate for vertical speed vs. visibility conditions.

The effects of visibility on the final measure of pilot performance, anti-torque rudder inputs are shown in Figure 10. Despite the small but apparent differences in error rate between the two visibility conditions, the effect was not statistically significant, indicating that rudder input may not be a sensitive indicator of pilot workload. It is possible that with increased sample sizes that the effect would become significant. Nonetheless, this measure appears far less sensitive to changes in visibility than do measures of cyclic input.

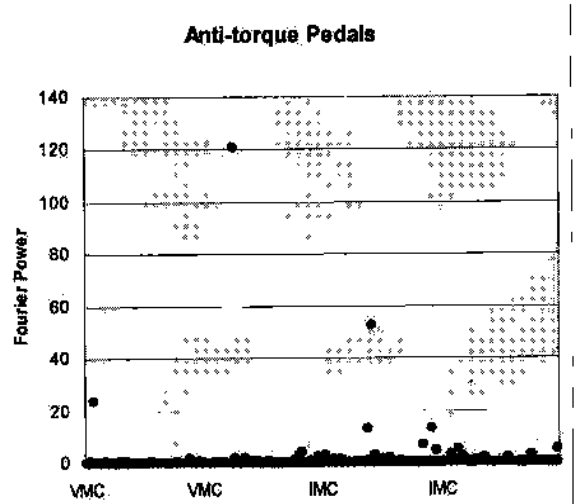

Figure 10. The effects of visibility on pilot inputs to anti-torque pedal input.

Effects of Altitude

We originally hypothesized that aircraft control when changing from VMC to IMC would be most degraded under those conditions that are believed to be more difficult or dangerous, i.e. low airspeeds and low altitudes. However, we did not find an effect of altitude that was consistent with our original ideas. Indeed the main effects of altitude did not appear systematic and were not statistically significant. We originally believed that the transition from IMC to VMC would be more difficult at lower altitudes. This relationship would be measured by the altitude/visibility interaction in the full model. This interaction was also not found to be statistically significant indication that pilots did no worse at lower altitudes than at higher altitudes. The data from this effect is plotted in Figures 11 for Pitch/fore-aft cyclic, Figure 12 for Bank/lateral cyclic, Figure 13 for vertical airspeed and for pedal inputs. These data show clearly the effects of visibility but no obvious effect of altitude. The statistical analysis of error rate for pitch showed that in fact the pilots made significantly more errors at the two highest altitudes. For fore/aft cyclic movements, there was also a trend for decreased control during high altitudes not low altitudes, although the trend did not reach significance. Lateral cyclic input also showed this trend, without statistical significance. Error analysis showed a number of significant differences in altitude performance on a pairwise basis but without any logical pattern consistent with conclusion regarding our hypotheses.

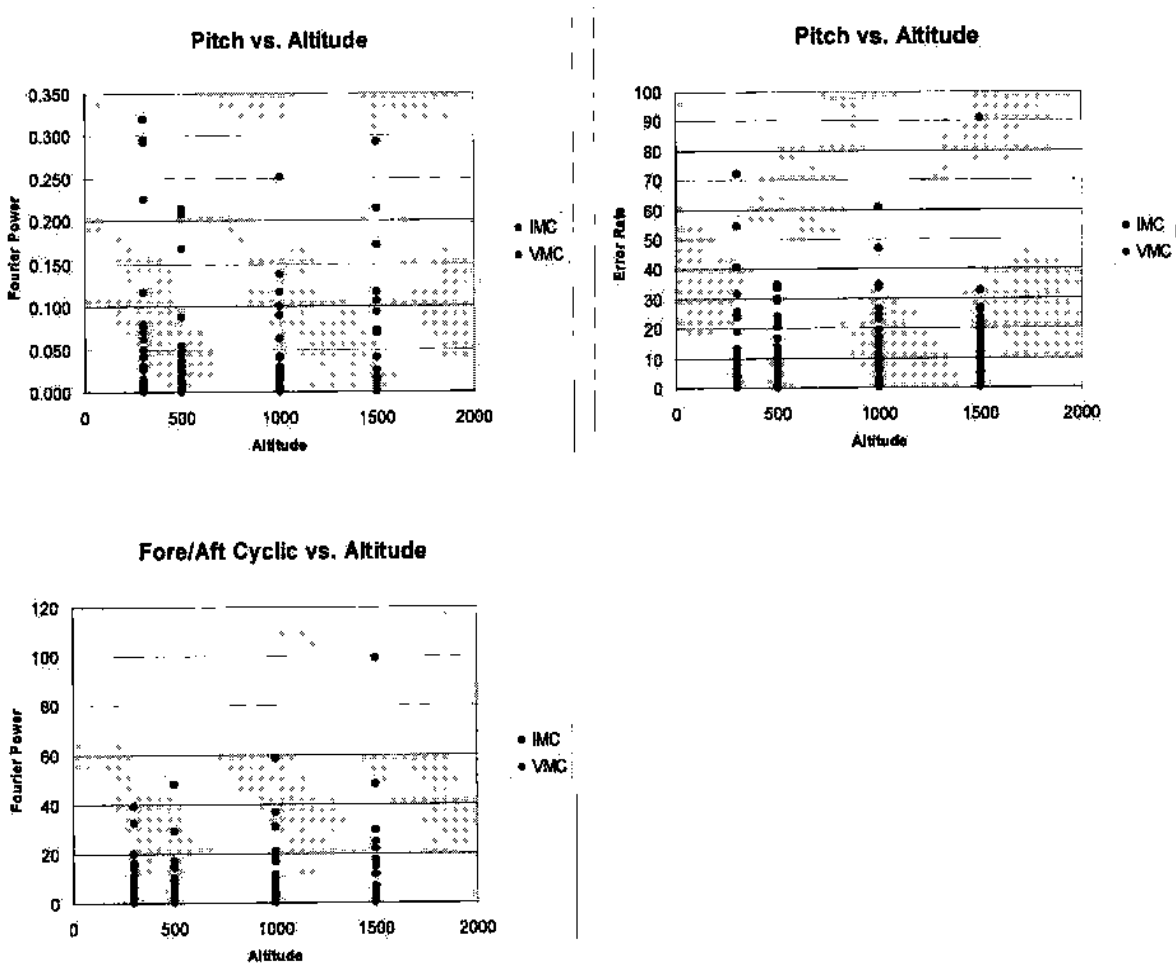

Figure 11. Effects of altitude on pitch fluctuations (top left), pitch error rate (top right), and fore/aft cyclic movements (bottom left) for both IMC and VMC conditions.

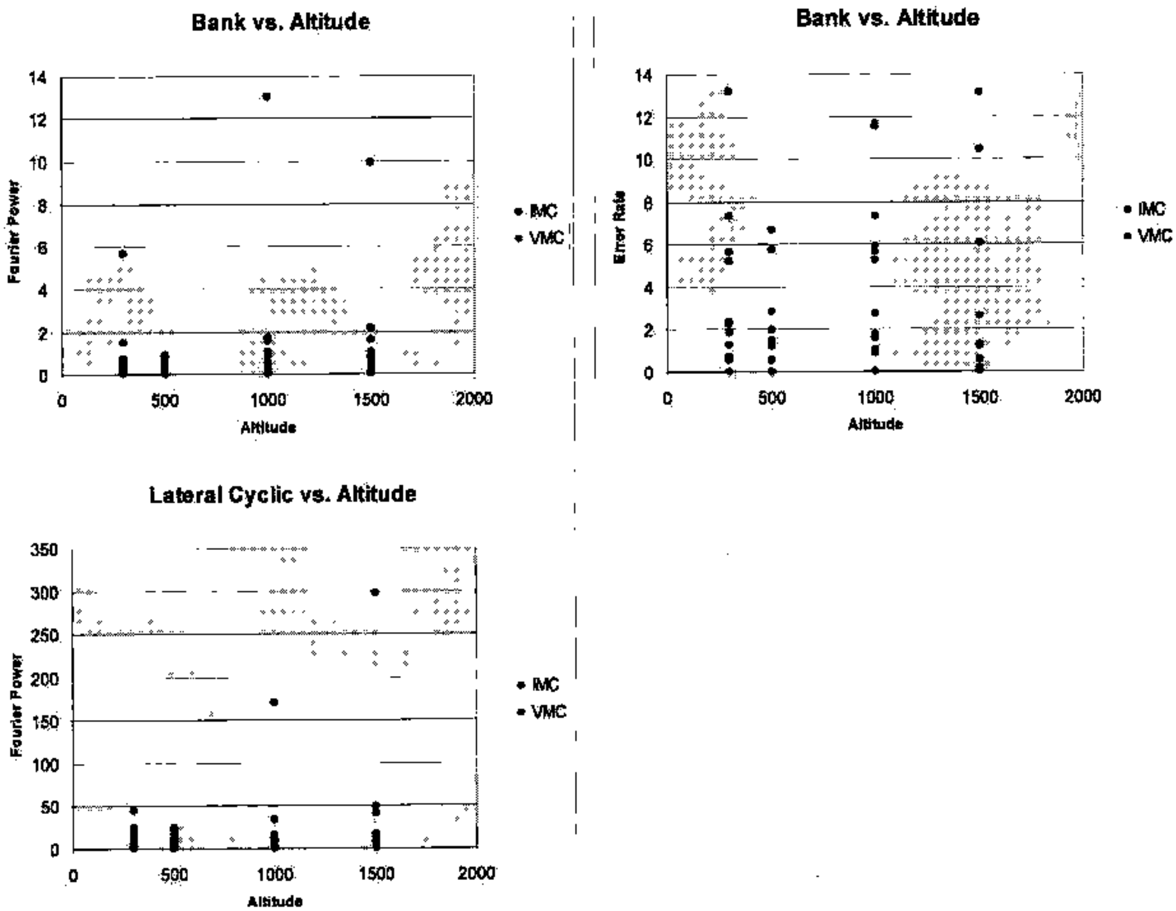

Figure 12. Effects of altitude on bank fluctuations (top left), bank error rate (top right), and lateral cyclic movements (bottom left) for both IMC and VMC conditions.

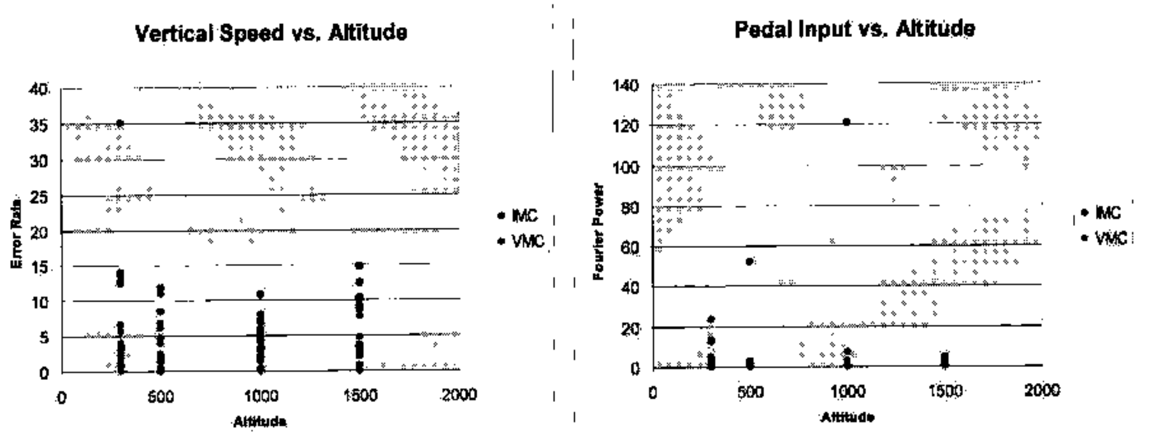

Figure 13. Effects of altitude on vertical speed (left), and pedal inputs (right) for both IMC and VMC conditions.

Effects of Airspeed

As with altitude, in general, we did not find significant effects of airspeed on aircraft control when transitioning from VMC to IMC using the power analysis. However, there was significantly more pedal input at the lowest airspeed (20 knots) under IMC condition. The data for the relationship between pitch/fore-aft cyclic movements, airspeed and visibility are plotted in Figure 14. The error rate analysis of pitch revealed a significant (P<.0001) trend in the opposite direction to that predicted, indicating higher error rates at higher airspeeds. Although the subjective appearance of the fore/aft cyclic data suggests an increase in effort with airspeed, due to large variability, neither this main effect of speed nor the interaction of speed and visibility were statistically significant for this measure.

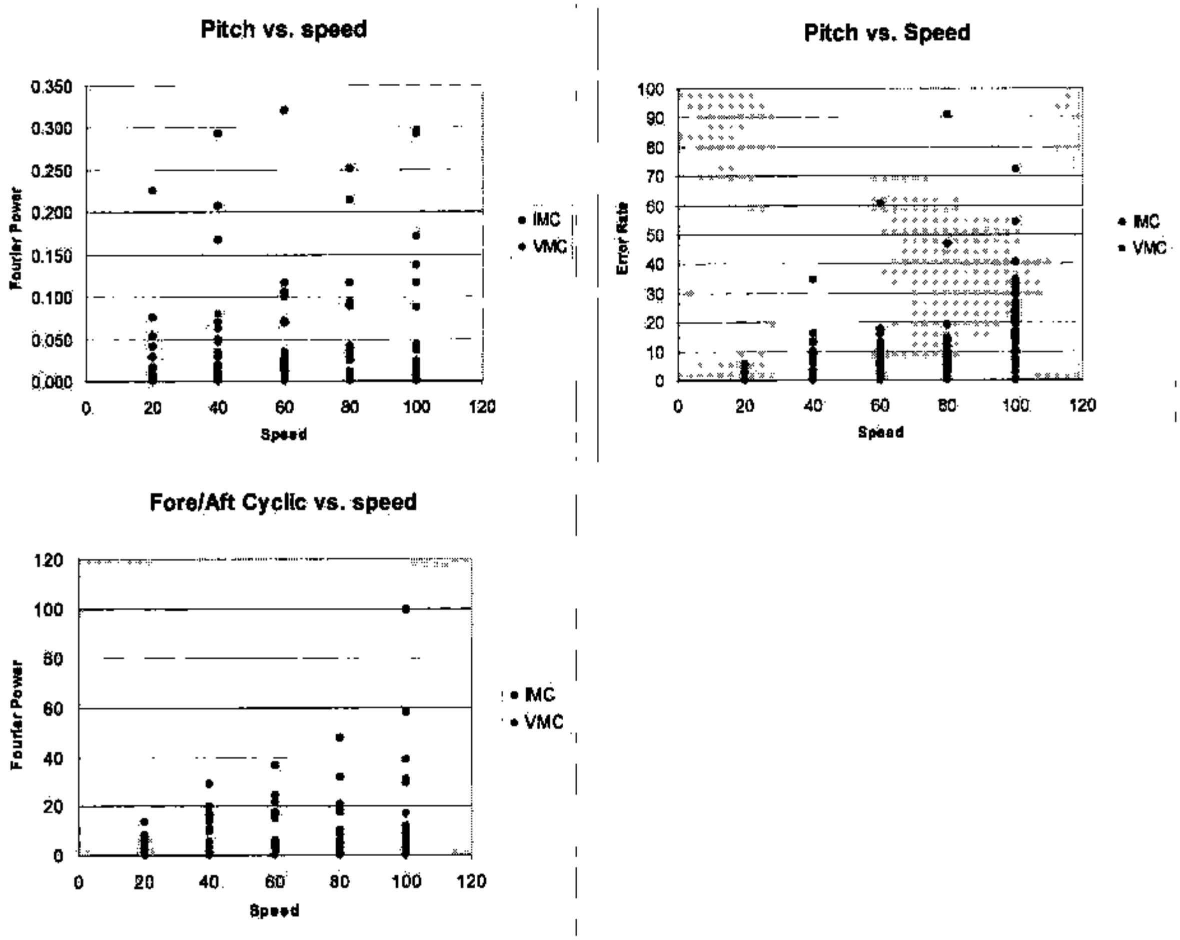

Figure 14. Effects of airspeed on pitch fluctuations (top left), pitch error rate (top right), and fore/aft cyclic movements (bottom left) for both IMC and VMC conditions.

Figure 15 shows the data for the measures of bank fluctuations, bank error rate and for lateral cyclic movements a function of airspeed and visibility. Again these data subjectively suggest an effect of airspeed in the opposite direction of that predicted. However, effects for bank power and lateral cyclic inputs were not found to be statistically significant due to large variability. The error rate analysis showed a significant increase in errors at the higher airspeeds consistent with the pitch data.

Figure 16 shows data for vertical speed errors as well as pedal inputs as a function of airspeed and visibility. The visibility effect is clearly significant for the measure of vertical speed error rate but not for pedal inputs. The error rate for vertical speed showed a significant trend towards increased error rates (P<.001) at higher airspeeds. However, pedal inputs at the lowest airspeeds were significantly greater from those at higher airspeeds under IMC consistent with the original hypothesis.

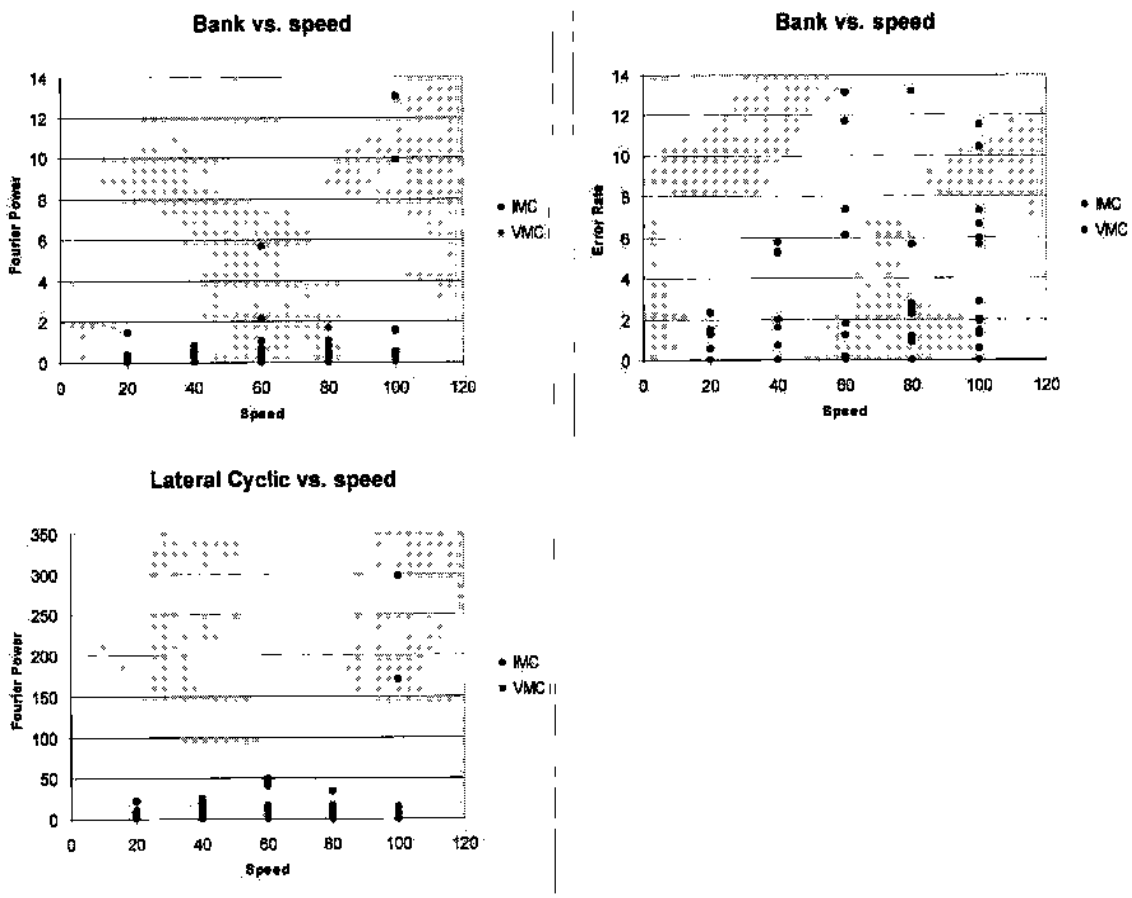

Figure 15. Effects of airspeed on bank fluctuations (top left), bank error rate (top right), and lateral cyclic movements (bottom left) for both IMC and VMC conditions.

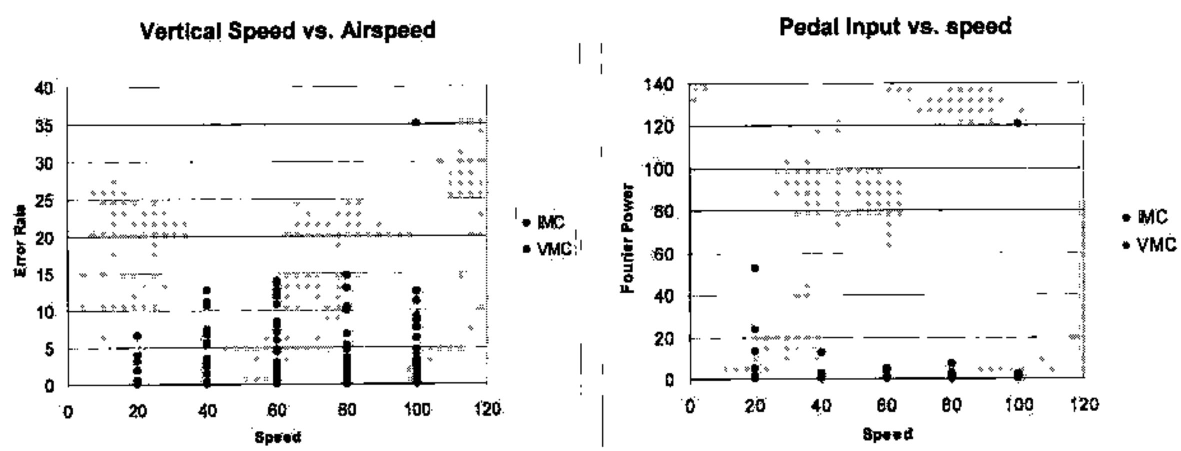

Figure 16. Effects of airspeed on vertical speed (left),and pedal inputs (right) for both IMC and VMC conditions.

Order Effects

The effects of test order on pitch fluctuations, pitch error rates, and fore/aft cyclic inputs are shown in Figure 17. The error rate analysis showed a significant effect of test order ($P<.0001$) with the first test session showing fewer errors than subsequent tests. Neither the main effects for order using the power analysis, nor the interactions with visibility were significant for the group of pilots. Numerous pairwise comparisons between different test sessions were significant for most measures. In agreement with the error analysis, the first test sessions contained significantly more fluctuations in fore/aft cyclic movements than later test sessions. Post hoc pairwise comparisons should however be interpreted with caution so that probability assumptions are not invalidated. Nonetheless, the significance of many of these comparisons suggests that a short training session could significantly improve subsequent performance. Future research should address the question of how long these improvements last and how often pilots should retrain for inadvertent IMC encounters. For some individual subjects, the main order effects were significant. Large inter-subject variability has in this case obscured the point that with some pilots repeat training leads to significant improvement while in others it does not appear to do so. Further analysis of these data are planned to try and determine whetherr or not overall performance was related to the magnitude of individual order effects.

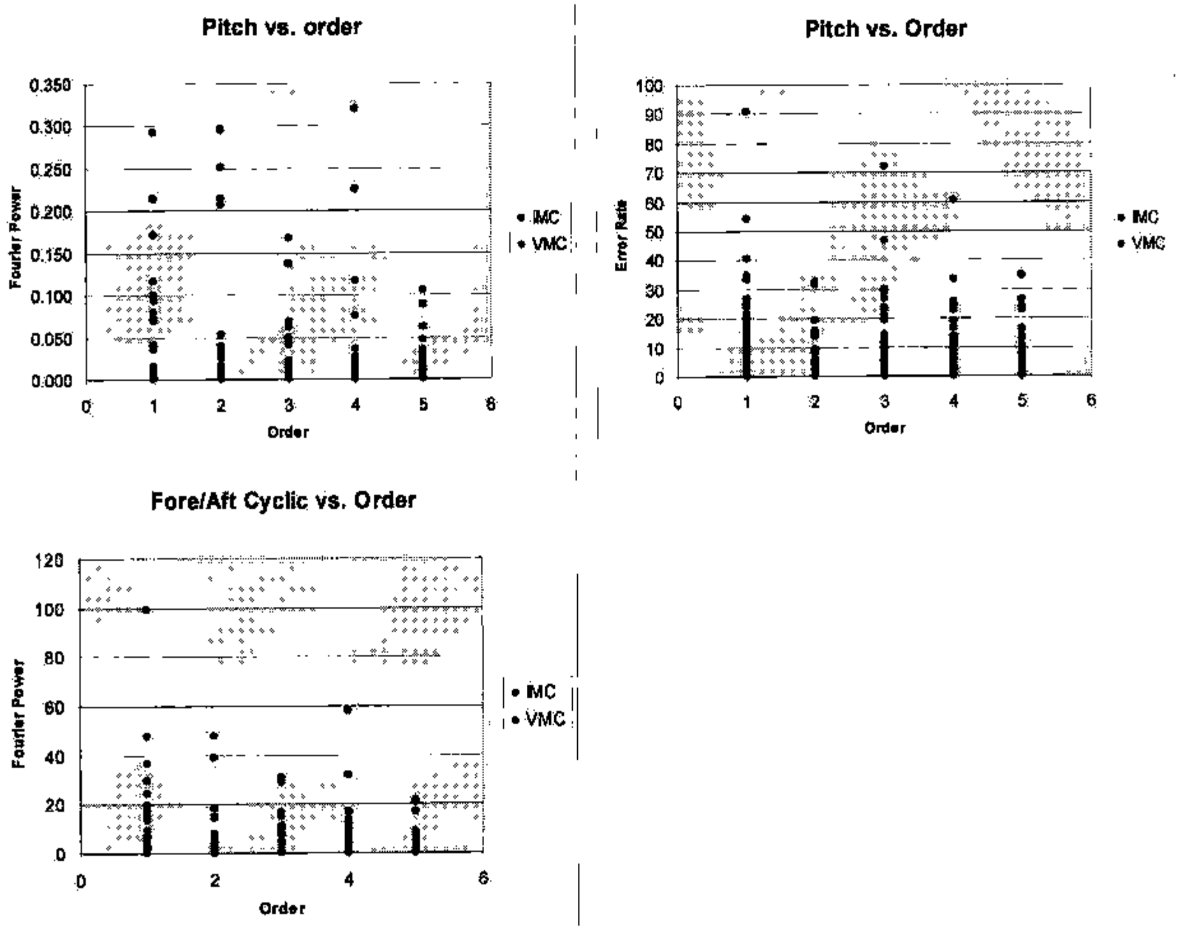

Figure 17. Effects of test order on pitch fluctuations (top left), pitch error rate (top right), and fore/aft cyclic movements (bottom left) for both IMC and VMC conditions.

The effects of test order on bank fluctuations, bank error rates, and lateral cyclic movements are shown in Figure 18. The main effects and interaction of order were not significant for the population, despite strong visibility effects. Pairwise and individual effects however were sometimes significant suggesting that future research need to more closely examine the effects of repeat testing/training on pilot bank and lateral cyclic performance.

Figure 19 shows the effect of test order on the measures of vertical speed error rate and for pedal inputs. The effects on vertical airspeed mimic those shown in Figures 18 with strong visibility effects but little evidence for a systematic effect of test order or interactions between test order and visibility. Note that some of the error rate pairwise comparisons were statistically significant for different order number but the trend was non-monotonic and not-interpretable in terms of the hypotheses. The pedal input measure of the effects of test order also shows no main effects or interactions for these variables.

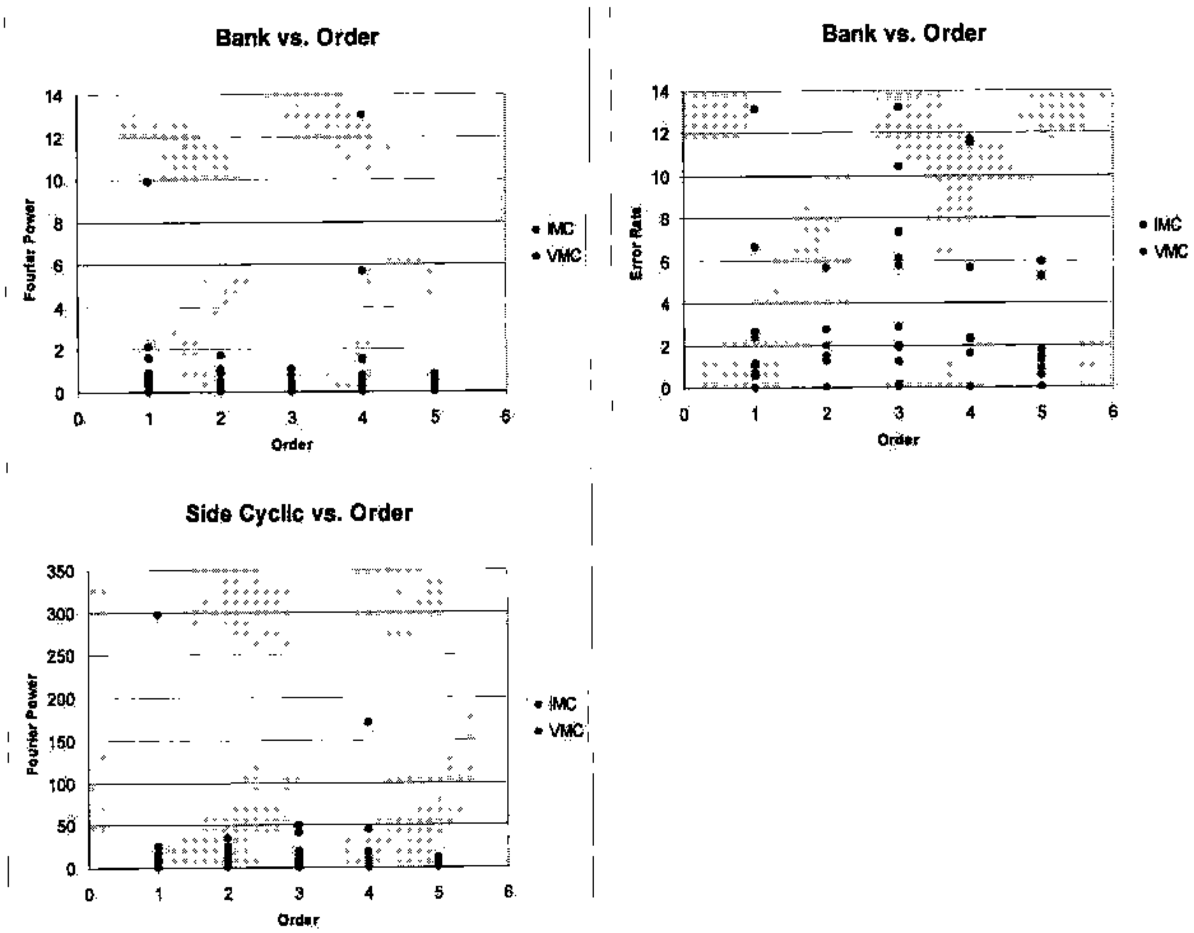

Figure 18. Effects of test order on bank fluctuations (top left), bank error rate (top right), and lateral cyclic movements (bottom left) for both IMC and VMC conditions.

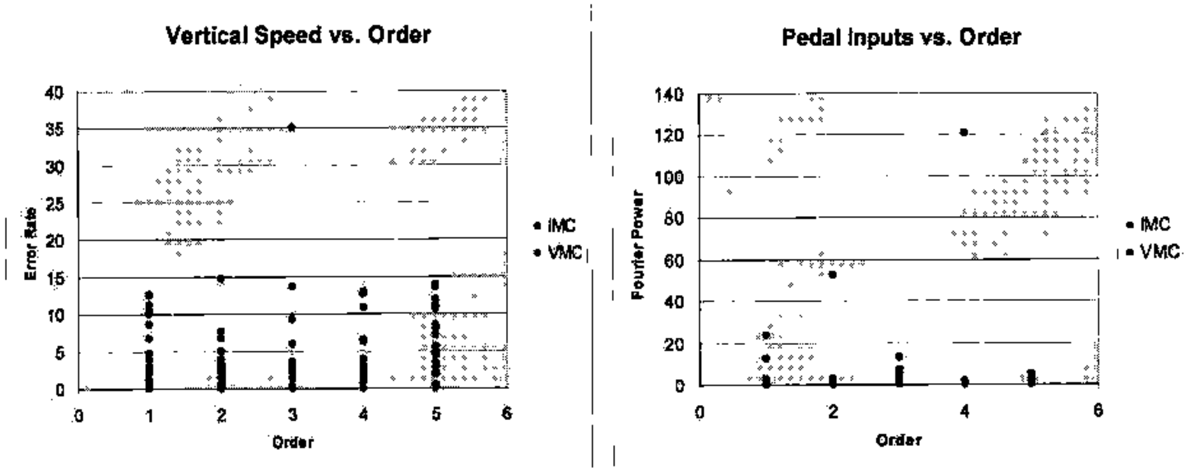

Figure 19. Effects of airspeed on vertical speed (left),and pedal inputs (right) for both IMC and VMC conditions.

Summary

The test subjects in the present study performed relatively well overall. However the data also clearly show a degradation of pilot performance during encounter with inadvertent IMC conditions. Combined with real-world variables such as turbulence and stressors not reproducible in a simulator, these degradations could result in hazardous flight performance with disastrous consequences. Fortunately, many of the pilots improved dramatically with increased testing suggesting that short training periods would greatly improve performance during inadvertent IMC encounters. Future research should address this issue directly and quantify the duration of the improved performance. Interestingly, the data did not provide strong evidence for decreased performance at lower altitudes and lower airspeeds. Further research is needed to address performance during the most demanding phases of flight including hover, takeoff, and landing.

The results presented here suggest that the both the power analysis and error analysis provide important information regarding pilot performance. The power analysis was particularly helpful as an objective and continuous measure of pilot control inputs. It is hoped that methods developed here will be applied to future research in the area of helicopter pilot performance and training. Some important topics for future study are listed below.

Future Work

Whiteout During Hover

We would like to expand these test procedures to include simulated sudden whiteout conditions in hover ascents and descents. Sudden onset of whiteout conditions during low level hover operations has been reported to be a frequent cause of helicopter accidents, particularly during snow and water operations.

VMC/IMC Transition with NVGs

We would also like to expand the study to include night operations particularly those utilizing night-vision systems. The use of NVGs during transition from VMC to IMC presents unique challenges to the pilot. A more thorough understanding of pilot performance in these conditions would greatly contribute to the safety of NVG training and would facilitate the increase in NVG application for helicopter operations.

Fatigue/stressor Effects

The application of the power analysis to control inputs would be a particularly powerful method to quantify the effects of fatigue and other stressors on pilot performance. Often the only data available on these topics results from errors made. These data are either post hoc accident analyses or data collected using some criterion for error as in the present study. Results from this type of analysis can change dramatically depending upon the criterion chosen for the occurrence of an error. However, the methods developed here can supply meaningful data at all levels of performance in a continuous manner such that the time course and magnitude of the effects of fatigue and other stressors can be more accurately assessed.

Training Effects

As mentioned above, we would like to investigate the durability and efficacy of short training sessions in reducing the degradation in performance seen with inadvertent IMC encounters.

References

Bell Helicopter (2004) Spatial disorientation is still a killer. *Human A.D. , Heliprops Publication* 16, 4, 1-6.

HAI (2005) Improving Safety in Helicopter Emergency Medical Service (HEMS) Operations. *Rotor,* Fall, 30-33.

Goh J & Wiegman D (2002) Human facors analysis of accidents involving visual flight rules flight into adverse weather. *Aviat. Spa. Env. Med. 73*, 817-822.

Wiegmann D & Goh J (2000) Visual flight rules (VFR) flight into adverse weather: An empirical Investigation of factors affecting pilot decision making. *FAA Technical Report- ARL-00-15/FAA-00-8.*

Appendix 1,. Sample of raw data output from simulator program.

Tick	Clock	Fore-aft	lat cyc	pedal	Gnd Elev	IAS	IVS	Latitude	Longitude	Altitude	Pitch	Bank	Heading	Vert S	X Lat Acc	Y Vert Acc	Z Long Acc	X Lat Vel	Y Vert Vel	Pitch Vel	Roll Vel	Yaw Vel	Eng1 Torq	Eng1 Roto	Eng1 Thro	Turn Rate	Com	Nav1	Nav2	Surface T	Surface	Vis	Ceiling	Base	Crashed
	24-Hour	%	%	%	ft	knots	ft/sec	degrees	degrees	ft AGL	degrees	degrees	degrees	ft/min	ft/sec^2	ft/sec^2	ft/sec^2	ft/sec	ft/sec	radians/sec	radians/sec	radians/sec	%	%	%	-512 to + 512						miles	ft	ft	
336	12:33:03	-11	3	-9	181	0	179	33.0179	-116.6021	209	3.76	0.09	59.92	190	-0.03	0.46	2.67	0.87	3.34	0.024	-0.008	-0.017	88.15	99.99	82.28	-39	127	111	111	Concrete	Normal	20	5000	2500	No
337	12:33:04	-8	3	-9	181	0	199	33.0179	-116.6021	212	4.67	-0.4	59.11	200	0.26	0.56	2.8	0.98	3.95	0.019	-0.008	-0.018	88.14	99.99	82.28	-121	127	111	111	Concrete	Normal	20	5000	2500	No
338	12:33:05	-9	2	-9	181	0	221	33.0179	-116.602	216	5.78	-0.76	58.29	223	0.5	1.26	3.33	1.3	4.66	0.018	-0.006	-0.019	88.14	99.99	82.28	-153	127	111	111	Concrete	Normal	20	5000	2500	No
339	12:33:06	-10	0	-9	181	0	282	33.0179	-116.602	219	6.69	-1.06	57.4	260	0.66	0.21	3.87	1.77	6.61	0.019	0	-0.016	88.14	99.99	82.28	-169	127	111	111	Concrete	Normal	20	5000	2500	No
340	12:33:07	-8	-1	-9	181	0	343	33.0179	-116.602	224	7.63	-1.15	56.92	351	0.65	0.41	4.27	2.36	8.84	0.016	0.001	-0.016	88.12	99.99	82.28	-156	127	111	111	Concrete	Normal	20	5000	2500	No
341	12:33:07	-12	-2	-8	181	0	438	33.0179	-116.602	230	8.37	-1.13	56.67	442	0.73	-0.19	5.19	2.94	11.26	0.016	0.004	-0.014	88.1	99.98	82.28	-158	127	111	111	Concrete	Normal	20	5000	2500	No
342	12:33:08	-15	0	-5	181	1	535	33.0179	-116.6019	238	9.62	-1.12	56.23	547	0.66	1.23	5.39	3.52	14.37	0.033	0	-0.004	88.07	99.98	82.28	-133	127	111	111	Concrete	Normal	20	5000	2500	No
343	12:33:09	-14	2	-2	181	4	648	33.018	-116.6019	247	11.01	-1.29	55.27	659	-0.11	8.54	6.27	3.8	18.02	0.028	-0.007	0.016	88.04	99.98	82.28	-22	127	111	111	Concrete	Normal	20	5000	2500	No
344	12:33:10	-16	2	-2	181	7	781	33.018	-116.6018	258	12.32	-1.43	56.11	803	-0.25	5.85	7.31	3.68	22.86	0.028	-0.008	0.02	88.04	99.98	82.28	110	127	111	111	Concrete	Normal	20	5000	2500	No
345	12:33:11	-20	2	-2	181	12	935	33.018	-116.6017	272	13.86	-1.49	57.06	948	-0.32	4.73	7.98	3.42	27.39	0.034	-0.007	0.017	87.99	99.97	82.28	170	127	111	111	Concrete	Normal	20	5000	2500	No
346	12:33:12	-12	2	-6	181	16	1011	33.0181	-116.6016	287	15.31	-1.84	57.66	1007	0.43	1.21	8.88	3.38	29.71	0.013	-0.007	-0.004	83.09	99.95	79.13	138	127	111	111	Concrete	Normal	20	5000	2500	No
347	12:33:12	-6	6	-4	181	21	944	33.0181	-116.6014	300	15.63	-2.29	57.13	921	1.16	-0.77	9.24	4.32	29.27	-0.009	-0.023	-0.014	78.05	99.98	74.79	-37	127	111	111	Concrete	Normal	20	5000	2500	No
348	12:33:13	-11	6	0	181	26	808	33.0182	-116.6013	311	14.93	-3.49	56.87	787	0.5	-1.1	9.49	5.16	28.35	-0.02	-0.026	0.009	78.03	99.98	74.79	-79	127	111	111	Concrete	Normal	20	5000	2500	No
349	12:33:14	-16	2	0	181	31	682	33.0183	-116.6011	321	14.24	-4.36	57.57	659	-0.83	-0.26	9.11	4.89	27.89	-0.01	-0.009	0.031	78.03	99.99	74.79	92	127	111	111	Concrete	Normal	20	5000	2500	No
350	12:33:15	-16	-1	0	181	36	575	33.0184	-116.6009	329	13.89	-4.22	59.26	551	-0.94	-0.34	6.63	4.13	27.7	-0.013	0.003	0.033	78	99.99	74.79	255	127	111	111	Concrete	Normal	20	5000	2500	No
351	12:33:16	-14	-8	0	181	41	494	33.0184	-116.6007	338	13.27	-3.39	60.86	462	-0.89	-0.84	6.56	3.4	27.19	-0.021	0.026	0.026	77.99	99.99	74.79	298	127	111	111	Concrete	Normal	20	5000	2500	No
352	12:33:17	-6	-8	0	181	46	439	33.0185	-116.6005	342	12.06	-1.86	62.04	433	-0.56	-1.97	7.51	2.91	26.15	-0.042	0.029	0.014	77.97	99.99	74.79	242	127	111	111	Concrete	Normal	20	5000	2500	No
353	12:33:17	-11	-7	0	181	50	437	33.0186	-116.6003	348	9.96	-0.24	62.62	439	-0.35	-1.74	6.82	2.8	24.14	-0.043	0.018	0.006	77.96	99.99	74.79	182	127	111	111	Concrete	Normal	20	5000	2500	No
354	12:33:18	-10	1	0	181	54	498	33.0187	-116.6	355	8.24	-0.12	62.74	505	0.21	0.51	6.52	2.19	24.04	-0.023	-0.006	-0.005	77.96	99.99	74.79	53	127	111	111	Concrete	Normal	20	5000	2500	No
355	12:33:19	-14	-4	0	181	57	592	33.0188	-116.5998	364	7.01	-0.4	62.41	603	0.99	-0.84	4.61	2.7	23.84	-0.03	0.019	-0.011	77.93	99.99	74.79	-31	127	111	111	Concrete	Normal	20	5000	2500	No
356	12:33:20	-12	-5	-3	181	59	699	33.0189	-116.5995	374	5.42	0.61	61.77	711	1.06	-1.49	3.44	3.66	22.98	-0.036	0.03	-0.018	77.9	99.99	74.79	-85	127	111	111	Concrete	Normal	20	5000	2500	No
357	12:33:21	-27	-4	-4	181	61	819	33.0191	-116.5992	387	4.07	1.85	60.67	830	0.9	1.72	2.63	4.65	23.11	-0.005	0.015	-0.028	77.87	99.99	74.79	-175	127	111	111	Concrete	Normal	20	5000	2500	No
358	12:33:22	-20	-2	-6	181	62	936	33.0192	-116.5989	401	3.67	2.56	59.31	944	1.06	-0.32	1.83	5.44	23.76	-0.02	0.002	-0.032	77.83	99.99	74.79	-239	127	111	111	Concrete	Normal	20	5000	2500	No
359	12:33:23	-22	0	-6	181	63	1030	33.0193	-116.5986	416	2.62	2.86	57.77	1040	0.24	-0.07	1.28	5.94	23.8	-0.017	0	-0.027	77.8	99.99	74.79	-262	127	111	111	Concrete	Normal	20	5000	2500	No
360	12:33:24	-29	0	-6	181	64	1114	33.0195	-116.5983	432	2.38	2.52	56.49	1122	-0.05	1.42	1.11	5.97	24.23	0	0	-0.025	77.31	99.98	74.4	-261	127	111	111	Concrete	Normal	20	5000	2500	No
361	12:33:24	-28	0	-11	181	65	1169	33.0196	-116.598	449	2.49	2.47	55	1164	2.21	-4.12	0.67	6.7	24.13	-0.005	0	-0.049	73.44	99.97	71.26	-288	127	111	111	Concrete	Normal	20	5000	2500	No
362	12:33:25	-28	1	-12	181	65	1126	33.0198	-116.5976	466	2.22	2.36	52.2	1112	3.32	-7.62	-0.69	9.56	21.41	-0.011	-0.009	-0.062	72.36	99.9	70.47	-479	127	111	111	Concrete	Normal	20	5000	2500	No
363	12:33:26	-31	4	-12	181	64	1007	33.0199	-116.5975	480	2.04	1.32	49.53	984	1.29	-8.98	-1.69	11.41	19.01	0.004	-0.017	-0.046	72.28	99.87	70.47	-551	127	111	111	Concrete	Normal	20	5000	2500	No
364	12:33:27	-28	-2	-12	181	64	868	33.0201	-116.5972	492	2.36	0.5	47.64	849	-0.33	-6.91	-1.47	11.64	17.66	0.003	0.007	-0.027	72.26	99.87	70.47	-438	127	111	111	Concrete	Normal	20	5000	2500	No
365	12:33:28	-26	-2	-12	181	63	754	33.0203	-116.597	503	2.51	0.81	46.33	738	-1	-4.38	-0.29	10.94	16.4	0.003	0.007	-0.023	72.26	99.89	70.47	-303	127	111	111	Concrete	Normal	20	5000	2500	No
366	12:33:29	-28	-2	-12	181	63	676	33.0204	-116.5967	513	2.71	1.16	45.21	656	-0.56	5.05	-0.06	10.28	15.86	0.005	0.007	-0.027	72.26	99.88	70.47	-283	127	111	111	Concrete	Normal	20	5000	2500	No
367	12:33:30	-25	-4	-12	181	62	626	33.0206	-116.5965	522	2.9	1.56	43.94	616	-0.19	4.74	-0.07	10.04	15.4	0	0.015	-0.032	72.24	99.9	70.47	-270	127	111	111	Concrete	Normal	20	5000	2500	No
368	12:33:30	-24	-2	-12	181	62	596	33.0206	-116.5962	530	2.93	2.24	42.31	577	-0.16	4.99	-0.82	9.93	14.9	-0.002	0.007	-0.034	72.21	99.9	70.47	-305	127	111	111	Concrete	Normal	20	5000	2500	No
369	12:33:31	-24	3	-12	181	62	562	33.021	-116.596	538	2.95	2.15	40.58	557	0.03	-5.55	-0.81	9.9	14.7	-0.001	-0.014	-0.036	72.19	99.89	70.47	-332	127	111	111	Concrete	Normal	20	5000	2500	No
370	12:33:32	-22	0	-12	181	62	545	33.0211	-116.5958	546	2.93	1.45	38.92	541	0.16	5.04	-0.19	10.08	14.52	-0.005	0.004	-0.035	72.21	99.9	70.47	-348	127	111	111	Concrete	Normal	20	5000	2500	No
371	12:33:33	-25	-3	-12	181	61	541	33.0213	-116.5956	554	2.77	1.75	37.28	538	-0.21	5.37	-0.69	10.15	14.09	-0.001	0.011	-0.032	72.17	99.9	70.47	-339	127	111	111	Concrete	Normal	20	5000	2500	No

Appendix 2. Data used in Statistical Analyses.

Subj	Time	order	Vis	alt	speed	Ppitch	Pbank	ail	rud	elev	Epitch	Ebank	Evspeed
1	25000	1	VMC	300	100	0.00358084	0.09328072	2.66871072	0.00847341	0.55290389	54.1996	0.0000	0.7554
2	9500	1	VMC	1500	80	0.00201086	0.01029362	0.13261119	0.06567109	0.92602554	5.8333	0.0000	0.0000
3	7600	1	VMC	1500	100	0.00206889	0.02889873	0.59967612	0.32402719	0.41880478	25.8878	0.0000	0.0000
4	2600	1	VMC	300	20	0.01291734	0.14130457	10.53420814	23.72795295	2.66764602	3.9212	0.0000	0.0000
5	3720	1	VMC	1500	80	0.00011917	0.01451291	0.96867412	0.10437921	0.15633236	0.0000	0.0000	0.0000
6	3500	1	VMC	1500	80	0.00032008	0.00069065	0.21879274	0.01572790	0.35534983	0.0000	0.0000	0.0000
7	6000	1	VMC	500	100	0.00423723	0.01960700	1.62737443	0.01588929	5.96499915	34.4742	0.0000	0.0000
8	3400	1	VMC	500	100	0.00353934	0.04723888	14.27419456	0.10387047	1.45602151	21.6781	0.0000	0.0000
9	14000	1	VMC	300	40	0.07883895	0.01816619	18.28633491	0.76255343	15.41339456	0.0000	0.0000	0.0000
10	4500	1	VMC	300	80	0.00005738	0.00051595	0.03810476	0.00010815	0.04853470	9.7881	0.0000	0.0000
11	8150	1	VMC	1500	100	0.00031001	0.02990114	2.36315364	0.00152581	0.40063196	2.8752	0.0000	0.0000
12	5200	1	VMC	1500	80	0.00141158	0.00684645	0.86238005	0.02053651	0.88720942	6.1837	0.0000	0.0000
13	18300	1	VMC	1000	60	0.00025794	0.08656931	1.65116004	0.00128576	0.25636215	7.3134	0.0000	0.0000
14	2080	1	VMC	1500	60	0.00032369	0.00124654	0.12217114	0.01420580	0.24270066	1.1290	0.0000	0.0000
15	4000	1	VMC	1500	60	0.00154269	0.04753657	0.68379639	0.46746965	0.84238667	0.0000	0.0000	0.0000
16	6610	1	VMC	300	100	0.01465101	0.06761798	2.18627565	0.45449797	4.56123761	23.8235	0.0000	0.8824
17	1450	1	VMC	1000	80	0.00071262	0.00352648	0.23569196	0.00575595	0.05434838	0.0000	0.0000	0.0000
18	1996	1	VMC	300	60	0.00292371	0.02643294	2.19009251	0.45735274	0.35976099	0.4449	0.0000	0.0000
19	14000	1	VMC	500	40	0.00090888	0.00329860	0.10061644	0.00651376	0.56305066	0.0000	0.0000	0.0000
20	2100	1	VMC	300	40	0.00139125	0.00931019	0.27266038	0.00193408	0.19693542	0.0000	0.0000	0.0000
1	25000	2	VMC	500	60	0.00204554	0.00571096	0.83697050	0.18527014	0.23017387	0.0000	0.0000	1.5074
2	9500	2	VMC	500	20	0.00014209	0.00194136	0.33859827	0.05644879	0.38521646	0.0000	0.0000	0.0000
3	7600	2	VMC	500	80	0.00201055	0.01029362	0.13261119	0.06567109	0.92602554	2.7384	0.0000	0.0000
4	2600	2	VMC	500	40	0.00085508	0.00386487	0.28162230	0.09819160	0.07047216	2.6231	0.0000	0.0000
5	3720	2	VMC	1500	100	0.00136795	0.08037016	2.41986641	0.00351939	0.38968623	32.8125	0.0000	0.0000
6	3500	2	VMC	500	40	0.00137636	0.00092709	0.19197020	0.10394896	0.89908459	0.0000	0.0000	0.0000
7	6000	2	VMC	1000	80	0.00078904	0.01919864	1.64936651	0.03745066	0.63646945	5.3765	0.0000	0.0000
8	3400	2	VMC	500	80	0.00626422	0.00165296	1.27818265	0.03622485	0.96242699	7.9441	0.0000	0.0000
9	14000	2	VMC	500	40	0.09287123	0.00771006	7.17755283	0.84106300	5.85352748	1.5291	0.0000	0.0000
10	4500	2	VMC	300	100	0.00168153	0.00046634	0.03695402	0.00608497	0.46672055	5.8138	0.0000	0.0000
11	8150	2	VMC	1000	80	0.00023269	0.06067371	5.01458901	0.00283330	0.45588979	3.1818	0.0000	0.0000
12	5200	2	VMC	300	80	0.00081600	0.00332730	0.24008769	0.14178323	0.84249451	2.5505	0.0000	0.0000
13	18300	2	VMC	500	60	0.00326527	0.05317407	4.49328036	0.00426171	0.11178141	0.0000	0.0000	0.0000
14	2080	2	VMC	300	100	0.00250160	0.01622599	0.45915630	0.02858205	2.08734851	31.4055	0.0000	0.2411
15	4000	2	VMC	500	20	0.00093909	0.02742568	2.30747895	0.04161742	0.24790924	0.0000	0.0000	0.0000
16	6610	2	VMC	1500	80	0.00176019	0.00406444	0.12741636	0.00585140	0.62123894	4.2500	0.0000	0.7500
17	1450	2	VMC	1500	100	0.01147617	0.01619362	1.13299011	0.05369126	2.44233878	16.7922	0.0000	0.0000
18	1998	2	VMC	500	60	0.00010098	0.00153641	0.03200504	0.00240126	0.02488592	0.0000	0.0000	0.0000
19	14000	2	VMC	1000	40	0.00540996	0.01100476	1.63006746	0.36217869	1.13512878	0.0000	0.0000	0.2720
20	2100	2	VMC	500	20	0.00153920	0.00568871	0.61985202	0.00806643	0.18595787	0.0000	0.0000	0.0000
1	25000	3	VMC	1000	60	0.00104692	0.00481292	0.26299765	0.18589364	0.19815996	0.0000	0.0000	5.9322
2	9500	3	VMC	500	100	0.02268319	0.06811621	0.24099997	0.08198325	7.16565037	29.1677	2.8283	1.2384
3	7600	3	VMC	1000	80	0.00047569	0.01164131	0.35338251	0.00060124	0.48765505	11.4149	0.0000	0.0000
4	2600	3	VMC	300	100	0.00038905	0.01907600	0.10740297	0.01132560	0.33955546	23.5630	1.8814	2.0569
5	3720	3	VMC	300	40	0.06143464	0.08227940	8.92129966	1.69109333	3.54280861	0.4412	0.0000	2.8471
6	3500	3	VMC	1000	100	0.00136156	0.00861675	0.06737007	0.01781035	0.91792710	14.3657	0.0000	0.0000
7	6000	3	VMC	300	20	0.00097565	0.00102976	0.30868098	0.01374026	1.16451615	0.0000	0.0000	0.0000
8	3400	3	VMC	300	60	0.00244609	0.00089301	0.04658886	0.06019083	0.43366005	2.0192	0.0000	0.0000
9	14000	3	VMC	1500	60	0.00088842	0.00303654	2.23345100	0.41834189	1.09485094	0.0000	0.0000	0.0000
10	4500	3	VMC	1500	80	0.00004106	0.00048224	0.00924402	0.00038733	0.02711469	5.1418	0.0000	0.0000
11	8150	3	VMC	500	40	0.00192330	0.01748481	2.97467266	0.04029645	0.95956042	0.0000	0.0000	0.0000
12	5200	3	VMC	500	20	0.00065021	0.01261014	0.51499751	0.10161736	0.07132745	0.0000	0.0000	0.0000
13	18300	3	VMC	500	80	0.00003072	0.00982877	0.37574697	0.00011284	0.13326412	2.2951	0.0000	0.0000
14	2080	3	VMC	1500	100	0.00213707	0.19749811	0.38226322	0.00388605	0.97428340	21.3200	0.0000	0.0000
15	4000	3	VMC	300	80	0.00003543	0.04170452	0.13779817	0.00345157	0.17424584	8.8677	0.0000	0.0000
16	6610	3	VMC	500	80	0.00000892	0.00044845	0.04674612	0.00075554	0.01137499	0.0000	0.0000	0.0000
17	1450	3	VMC	1000	40	0.00055116	0.04437354	0.77370253	0.02167439	0.09578706	0.0000	0.0000	0.0000
18	1996	3	VMC	1500	60	0.00317848	0.00368870	0.01798107	0.02384003	0.25981612	0.0000	0.0000	0.0000
19	14000	3	VMC	1500	100	0.00018164	0.01831136	0.22825428	0.00407250	0.06389758	28.6416	0.0000	0.0090
20	2100	3	VMC	500	100	0.00003127	0.00234506	0.04935346	0.00034095	0.01841934	29.9007	0.0000	0.0000
1	25000	4	VMC	300	60	0.00310950	0.00210539	0.21668535	0.01388014	0.14514708	2.7632	0.0000	0.0000
2	9500	4	VMC	300	80	0.00048945	0.00020417	0.01138751	0.00132144	0.18395892	4.2712	0.0000	0.0090
3	7600	4	VMC	1000	100	0.01955267	1.53516886	7.59377417	120.53781569	15.81498863	33.5838	0.0000	0.0000
4	2600	4	VMC	1000	60	0.00354316	0.05645348	0.49226103	1.51381877	1.95946182	60.4545	11.6667	2.1212
5	3720	4	VMC	1000	40	0.00524474	0.04832421	3.45058387	0.03622003	0.39489776	0.0000	0.0000	0.0000
6	3500	4	VMC	300	60	0.00116859	0.00350597	0.21563729	0.00940101	0.59490786	9.9096	0.0000	0.8434
7	6000	4	VMC	300	80	0.00109790	0.01327703	2.25800940	0.02432597	3.78603713	6.3436	0.0000	0.0000
8	3400	4	VMC	300	20	0.00357724	0.00285924	1.92864274	1.47757903	0.42024372	0.0000	0.0000	0.0000
9	14080	4	VMC	1000	100	0.00917098	0.01156287	1.04904972	0.71316999	9.21214586	16.9507	0.0000	0.0000
10	4500	4	VMC	1000	40	0.00001698	0.00023229	0.09440549	0.00207142	0.02708644	0.0000	0.0000	0.0000
11	8150	4	VMC	1000	100	0.00146691	0.01909020	1.82518054	0.00025890	1.21460508	0.3592	0.0000	3.9306
12	5200	4	VMC	300	40	0.00124772	0.01003914	1.09639846	0.69604521	1.49740061	0.2129	0.0000	0.0000
13	18300	4	VMC	300	20	0.00065538	0.05366864	4.10629311	0.01090853	0.20048332	0.0000	0.0000	0.0000
14	2080	4	VMC	300	20	0.00197189	0.00622072	0.82692593	0.38252517	1.52178865	5.0198	0.0000	0.0000
15	4000	4	VMC	1000	100	0.00052875	0.01944173	0.38504620	0.02874046	0.42228772	0.0000	0.0000	0.0000
16	6610	4	VMC	500	80	0.01020446	0.02498217	0.18832543	0.00315913	1.29288085	3.8750	0.0000	0.0000
17	1450	4	VMC	500	100	0.00055116	0.04437354	0.77370253	0.02167439	0.09578706	13.8971	0.0000	0.0000
18	1996	4	VMC	300	80	0.00569968	0.02186547	1.18764343	0.45959615	1.32577010	2.7083	0.0000	0.0000
19	14000	4	VMC	300	100	0.00016166	0.01831137	0.22837166	0.00407339	0.06504829	25.6299	0.0000	0.0000
20	2100	4	VMC	1500	80	0.00100712	0.00960543	0.46472887	0.00201126	0.53307666	12.8376	0.0000	0.0000
1	25000	5	VMC	1000	40	0.00191851	0.01964229	1.96833275	0.02026678	0.24871313	0.0000	0.0000	7.3944
2	9500	5	VMC	300	40	0.00234300	0.00055528	0.11429838	0.09853028	0.81150694	0.0000	0.0000	0.0000
3	7600	5	VMC	1500	60	0.00509010	0.01507159	0.69271946	0.00452106	1.28402387	0.0000	0.0000	0.0000
4	2600	5	VMC	500	60	0.00415772	0.00357723	0.04368794	0.00468627	0.23768801	0.0000	0.0000	0.0000
5	3720	5	VMC	500	20	0.01651970	0.04236423	5.22063883	0.05955863	5.17008727	0.0000	0.0000	0.0000
6	3500	5	VMC	500	80	0.00086037	0.00637712	0.41117088	0.01568072	1.44743949	3.5000	0.0000	0.0000
7	6000	5	VMC	500	60	0.00085191	0.01050531	0.95538375	0.17086598	0.89970951	0.0000	0.0000	0.0000
8	3400	5	VMC	1000	60	0.00070673	0.00256992	0.27035750	0.03709626	0.22911510	0.0000	0.0000	0.0000
9	14000	5	VMC	1000	80	0.00319004	0.00111861	1.24674192	0.28853985	2.95451091	0.5440	0.0000	0.0000
10	4500	5	VMC	500	20	0.00002180	0.00031308	0.24729838	0.00306900	0.05876864	0.0000	0.0000	0.0000
11	8150	5	VMC	1000	40	0.00239966	0.01724172	8.44122705	2.95058273	1.87336000	0.8000	0.0800	0.0000
12	5200	5	VMC	300	60	0.00018145	0.04556255	1.20171613	3.88820007	0.23469426	3.6741	0.0000	0.0000
13	18300	5	VMC	500	100	0.00153578	0.05478523	2.05064028	0.19703892	0.61150740	23.9063	0.0000	0.0000
14	2080	5	VMC	300	60	0.00142280	0.02024080	1.89778574	0.28632544	0.86497786	0.4487	0.0000	0.0000
15	4000	5	VMC	300	40	0.00042831	0.01065974	1.16299451	0.00242016	0.26680913	0.0000	0.0000	0.0000
16	6610	5	VMC	500	40	0.04608775	0.00402079	0.08324909	0.36282115	3.22284942	0.0000	0.0000	0.0000
17	1450	5	VMC	1000	80	0.00161709	0.05673165	0.93646265	0.01428661	1.01446283	0.6714	0.0000	6.9710
18	1996	5	VMC	1000	60	0.00274859	0.00675598	0.25027965	0.03312796	0.17030094	0.6816	0.0000	0.0000
19	14000	5	VMC	1000	100	0.00160543	0.02149425	0.42437441	2.20678258	1.74952333	22.6907	0.0000	0.0000
20	2100	5	VMC	300	20	0.00131136	0.01418788	3.53072917	0.00121662	1.13813177	0.0000	0.0008	0.0000

1	25000	1 IMC	300	100	0.00682671	0.20508737	4.59442233	0.00003986	2.08459058	40.4798	0.5313	3.8889
2	9500	1 IMC	1500	80	0.21355241	0.87864681	16.63006783	2.69212714	47.88628052	14.1956	2.6498	4.7319
3	7600	1 IMC	1500	100	0.29261108	9.90900246	297.12128569	0.09232734	99.23759039	26.9547	0.5295	8.6326
4	2600	1 IMC	300	20	0.04181484	0.04680326	1.12885439	0.02804927	5.86029782	0.0000	0.0000	0.0000
5	3720	1 IMC	1500	60	0.07171375	0.70662492	16.87910452	0.13250674	17.52359437	17.5000	13.1250	2.1000
6	3500	1 IMC	1500	80	0.09394296	0.52184437	10.00899069	1.28571929	17.20265504	90.8427	1.1798	10.0261
7	6000	1 IMC	500	100	0.03602005	0.42442812	2.81600530	0.00081816	9.52112141	33.5601	6.6456	4.6519
8	3400	1 IMC	500	100	0.00735231	0.15114647	2.39727577	1.06772646	3.42144678	20.4362	0.0000	11.2752
9	14000	1 IMC	300	40	0.06997874	0.66639734	24.20451281	1.27558049	13.61166241	6.7683	0.7317	2.3791
10	4500	1 IMC	300	80	0.00549353	0.01669166	0.11826445	0.00041859	1.31804789	1.1842	2.3684	1.0895
11	8150	1 IMC	1500	100	0.17161788	1.61007345	14.36883789	0.00215663	29.44403103	21.0702	0.0000	12.4666
12	5200	1 IMC	1500	80	0.00338754	0.00683947	0.03534803	0.01441344	0.89530693	19.0268	0.0000	10.3943
13	18300	1 IMC	1000	60	0.09988361	0.42697716	13.06678914	0.02631659	36.35626752	16.2626	0.0000	3.0051
14	2080	1 IMC	1500	60	0.11660466	0.08415109	0.98286031	0.08223254	24.44217886	12.6000	0.0000	12.6000
15	4000	1 IMC	1500	60	0.01500424	2.14043752	12.13074971	0.02676911	1.01236388	11.6667	0.0000	0.0000
16	6610	1 IMC	300	100	0.00600797	0.05703936	0.80768663	0.00629106	2.18534793	24.3250	0.0000	12.4250
17	1450	1 IMC	1000	80	0.03919384	0.02466405	1.02834544	0.02633824	5.84196858	8.6326	1.0570	0.0000
18	1996	1 IMC	300	80	0.00112862	0.01069877	0.12274688	0.00115403	0.48064182	1.5856	0.0000	0.0000
19	14000	1 IMC	500	40	0.01051140	0.59801032	7.42330803	0.06259066	2.49421376	2.3438	0.0000	8.7989
20	2100	1 IMC	300	40	0.29303435	0.39187511	8.51676750	12.69398594	19.83400763	9.8438	0.0000	2.8125
1	25000	2 IMC	500	80	0.03474152	0.18028950	5.17427923	0.00013963	4.66332639	1.5556	0.0000	0.0000
2	9500	2 IMC	500	20	0.05282123	0.18776343	21.41369891	52.57594917	7.97875101	5.5040	1.4831	0.0000
3	7600	2 IMC	500	60	0.21355241	0.87864681	16.63006783	2.69212714	47.68628062	8.1336	0.0000	2.0345
4	2600	2 IMC	500	40	0.00445537	0.07203829	1.10351303	0.01534759	0.20798979	0.1778	0.0000	0.0000
5	3720	2 IMC	1500	100	0.01709502	0.48354936	9.36158154	0.01126666	4.89897578	15.2020	1.2384	3.3566
6	3500	2 IMC	500	40	0.20769227	0.06632696	6.59015687	0.86448627	14.43194194	9.4003	1.9520	2.3058
7	6000	2 IMC	1000	80	0.02859968	1.02056687	11.31612336	0.04337401	4.39372637	13.6839	2.7546	2.7545
8	3400	2 IMC	500	80	0.00305639	0.08004635	1.97289484	0.45449467	1.72580200	4.2972	0.0000	6.7260
9	14000	2 IMC	500	40	0.02893999	0.50005468	25.07156669	1.47051109	14.99474680	3.1818	0.0000	0.0000
10	4500	2 IMC	300	100	0.00060894	0.00090097	0.06862718	0.00019910	0.20507092	4.5305	0.0000	0.5330
11	8150	2 IMC	1000	80	0.25102075	1.72044556	34.24832770	0.00110969	18.15474622	14.8225	5.6376	4.9329
12	5200	2 IMC	300	80	0.00758935	0.06025282	0.71563119	0.00539338	3.58224450	2.3057	0.0000	1.9520
13	18300	2 IMC	500	60	0.03021672	0.11259769	3.78754998	0.00438932	2.89691390	1.7736	0.0000	0.0000
14	2080	2 IMC	300	100	0.29456976	0.07534240	2.12823718	0.09890817	39.00445320	9.5455	0.0000	2.2990
15	4000	2 IMC	500	20	0.00290441	0.30180128	5.26466324	0.05158684	0.37073479	0.3512	0.0000	0.3512
16	6610	2 IMC	1500	80	0.02481913	0.03966103	0.49685438	0.00877059	5.11615957	19.1388	0.0000	14.7492
17	1450	2 IMC	1500	100	0.04045606	0.05308828	1.33837641	0.02006534	6.56660712	15.4515	0.0000	7.7258
18	1996	2 IMC	500	60	0.00025305	0.00287251	0.04622033	0.00571873	0.13710057	3.3586	0.0000	0.0000
19	14000	2 IMC	1000	40	0.00720137	0.23933487	5.99953036	0.02511691	3.74221607	3.1711	0.0000	1.4094
20	2100	2 IMC	500	20	0.00663195	0.08771936	2.86459731	0.04555990	1.39832847	3.8758	0.0000	3.8758
1	25000	3 IMC	1000	60	0.02241419	0.01380084	1.20205624	0.00000633	1.84150299	5.6972	0.0000	0.2491
2	9500	3 IMC	500	100	0.04213469	0.07307698	2.56781288	0.15821430	16.90836536	23.6695	1.9586	1.9586
3	7600	3 IMC	1000	80	0.04107768	0.06459572	5.27922662	6.92306373	8.10024459	46.7768	0.0000	0.0000
4	2600	3 IMC	300	100	0.01391340	0.00546449	0.13984579	0.15380773	9.78431952	71.8750	0.0000	36.0000
5	3720	3 IMC	300	40	0.04879167	0.74151763	19.04944851	0.00759593	10.82130840	7.7058	0.0000	0.0000
6	3500	3 IMC	1000	100	0.13711840	0.26849666	2.40371905	0.01226344	30.77150175	19.1071	7.3214	3.0367
7	6000	3 IMC	300	20	0.00121929	0.01408940	3.09027604	13.12611254	1.95255546	0.0000	0.0000	0.0000
8	3400	3 IMC	300	60	0.00266405	0.01855806	0.26588574	0.16892432	1.15215537	1.0500	7.3520	13.6520
9	14000	3 IMC	1500	60	0.06812171	1.03341837	49.70577193	4.41870148	14.78595236	6.4848	0.1778	0.0000
10	4500	3 IMC	1500	80	0.00164320	0.00866766	0.28722981	0.02609301	0.64155713	9.7551	0.0000	3.5473
11	8150	3 IMC	500	40	0.16760627	0.41378023	14.11564773	0.00926362	28.93072609	5.9409	5.7462	0.0000
12	5200	3 IMC	500	20	0.00001942	0.00003942	0.00288882	0.00265812	0.00524791	0.0000	0.0000	0.0000
13	18300	3 IMC	500	80	0.00033069	0.00207280	0.61038219	0.13798964	3.08080200	3.4125	0.0000	0.0000
14	2080	3 IMC	1500	100	0.01717128	0.13030833	1.32256019	0.09803197	11.32379549	12.6421	0.0000	3.3361
15	4000	3 IMC	300	80	0.00028404	0.01340593	0.21609023	2.90018560	0.40615932	6.7180	13.1888	0.0000
16	6610	3 IMC	500	60	0.00055252	0.00170374	0.39554704	0.79057297	0.32262580	5.0710	1.1932	0.0000
17	1450	3 IMC	1000	40	0.00731416	0.14029642	3.32968742	0.00267483	0.65149652	2.4831	0.0000	0.3647
18	1996	3 IMC	1500	60	0.01668459	0.04225260	46.68349779	4.84544797	4.82632252	7.0787	6.0955	0.0000
19	14000	3 IMC	1500	100	0.00300535	0.10531277	3.14050369	1.53220846	2.00118553	23.2622	10.4573	9.1766
20	2100	3 IMC	500	100	0.02084075	0.00350554	0.86017912	2.23056631	4.03547071	13.7500	0.0000	0.0000
1	25000	4 IMC	300	60	0.31995826	5.66498195	44.47679608	0.00285339	16.26806209	6.1661	0.0000	0.0000
2	9500	4 IMC	300	80	0.11686873	0.03667572	0.36507639	0.04585498	32.01782368	18.9223	2.2261	3.1548
3	7600	4 IMC	1000	100	0.11627965	13.01586822	170.90558630	0.02320610	58.32514577	24.4863	0.0000	0.0000
4	2600	4 IMC	1000	60	0.01849662	0.04694338	0.30735187	0.33808490	3.98682444	10.7828	0.0000	10.7838
5	3720	4 IMC	1000	40	0.01647477	0.17575006	17.06787599	0.01939377	9.76322610	6.0714	1.6062	0.0000
6	3500	4 IMC	300	60	0.02673652	0.14980779	5.40653035	0.00741340	5.86222368	1.6293	0.0000	1.0862
7	6000	4 IMC	300	80	0.00348881	0.57199267	4.49304809	0.08374351	1.33873172	11.6033	0.0000	12.9348
8	3400	4 IMC	300	20	0.00488090	0.39218872	2.65766416	1.02156514	1.17151677	3.2927	0.0000	3.1108
9	14000	4 IMC	1000	100	0.02195121	0.40664389	9.79794781	1.42091567	11.51921680	7.4242	0.0000	3.1818
10	4500	4 IMC	1000	40	0.00188298	0.00724614	0.39369691	0.03325560	1.28032868	9.0456	0.0000	0.0000
11	8150	4 IMC	1000	100	0.01527028	0.30749071	6.58058354	0.00023978	4.11531453	22.7500	11.5500	2.8000
12	5200	4 IMC	300	40	0.01138424	0.05117336	0.86244545	0.00823381	3.30155604	12.9040	0.0000	12.7273
13	18300	4 IMC	300	20	0.22456818	1.49969923	6.99603029	0.07221698	13.74035385	5.1101	2.2913	1.9389
14	2080	4 IMC	300	20	0.07606793	0.04473572	0.97173903	0.18621257	8.14764274	3.3473	0.0000	6.5195
15	4000	4 IMC	1000	100	0.02309317	0.13299070	0.41265710	0.00190893	4.59224582	0.0000	0.0000	0.0000
16	6610	4 IMC	500	80	0.03638391	0.79107234	9.37499511	0.03913874	10.16730389	11.7642	0.0000	0.0000
17	1450	4 IMC	500	100	0.00731416	0.14029642	3.32968742	0.00267483	0.65149652	16.4394	0.0000	6.1869
18	1996	4 IMC	300	80	0.00079022	0.00086125	0.03735620	0.01136563	0.61587648	1.5856	0.0000	0.0000
19	14000	4 IMC	300	100	0.00300536	0.10531281	3.14361465	1.53220853	2.00228315	10.4293	5.6566	3.0051
20	2100	4 IMC	1500	80	0.01094978	0.21064851	6.69542322	0.00318911	1.71753077	8.1313	0.0000	2.6515
1	25000	5 IMC	1000	40	0.06202357	0.22771205	4.91945968	0.00354950	16.91278108	34.6392	0.0000	10.6454
2	9500	5 IMC	300	40	0.00533118	0.07778019	0.78503714	0.25980608	2.26092321	1.0031	5.2099	3.4076
3	7600	5 IMC	1500	60	0.10586708	0.33507575	8.01220494	0.01008540	21.73768379	13.0369	0.0000	2.8188
4	2600	5 IMC	500	60	0.00594908	0.26415260	1.20478556	0.01261323	1.12140742	3.8758	0.0000	11.8047
5	3720	5 IMC	500	20	0.02859261	0.13301506	10.26047050	0.01112507	5.46590191	2.6727	0.5738	0.0000
6	3500	5 IMC	500	80	0.02431308	0.25232812	4.76289796	0.00674251	7.82250800	7.6330	0.0000	2.9489
7	6000	5 IMC	500	60	0.01357840	0.32837812	5.49395756	0.09425738	4.49358962	5.0806	0.0000	8.4688
8	3400	5 IMC	1000	60	0.00268432	0.47679853	5.74551646	0.13206317	2.34178505	1.6293	0.0000	7.9655
9	14000	5 IMC	1000	80	0.08889828	0.36897232	6.06793112	2.93410627	20.66123425	9.6696	0.8819	5.2652
10	4500	5 IMC	500	20	0.00064971	0.00091265	0.19139885	0.02461637	0.31637312	2.4747	0.0000	0.4766
11	8150	5 IMC	1000	40	0.01891400	0.80576462	11.56076267	0.01698567	5.45665214	18.1536	5.2676	5.2676
12	5200	5 IMC	300	60	0.03060351	0.01848153	0.14511882	0.01194530	2.51439255	4.4054	0.0000	13.5664
13	18300	5 IMC	500	100	0.08812693	0.55213587	7.99162245	0.11570935	8.89883488	10.0419	1.4094	0.0006
14	2080	5 IMC	300	60	0.00538108	0.03672816	1.10388001	0.06968028	2.52820359	6.1869	0.0000	13.9657
15	4000	5 IMC	300	40	0.00292504	0.00848354	0.19048078	0.00636345	0.46899325	0.0000	0.0000	5.6972
16	6610	5 IMC	500	40	0.03371012	0.02589944	0.19913430	0.00676314	4.88920227	13.3000	0.0000	11.0250
17	1450	5 IMC	1000	60	0.01163116	0.02575035	1.06799790	0.06822843	3.45058435	7.2475	1.7677	4.4192
18	1996	5 IMC	1000	60	0.00410737	0.01311358	0.24395778	0.05559229	1.12146884	7.6786	0.0000	4.6429
19	14000	5 IMC	1000	100	0.00922564	0.11652236	2.45318384	0.06139518	7.26922401	26.3521	5.9241	1.8386
20	2100	5 IMC	300	20	0.00030445	0.00092910	1.06224918	4.88597877	1.28528058	5.1220	1.2805	0.0000

Nicole Saiauskie/ACT/FAA
AJP-795, Acquisition, Materiel & Grants Team

03/31/2008 02:54 PM

To "Michael A Crognale" <mcrognale@unr.edu>
cc Deanna Super/ACT/FAA@FAA, jbest@unr.edu, mikro@unr.edu, Tom McCloy/AWA/FAA@FAA
bcc
Subject RE: FAA expired grant (05-G-018)

Michael,

No I did not receive any of this information. Maybe it was only sent to Tom.

Anyway - thanks! Can you look into the financial status report form (269)???

Thank you,

Nicole Saiauskie
FAA Grants Program Specialist
Federal Aviation Administration
William J. Hughes Technical Center
Acquisition, Materiel, & Grants Team, AJP-7950
Atlantic City International Airport, NJ 08405
phone (609) 485-4781
fax (609) 485-6766

"Michael A Crognale" <mcrognale@unr.edu>

"Michael A Crognale" <mcrognale@unr.edu>

03/31/2008 02:12 PM

To Nicole Saiauskie/ACT/FAA@FAA, <mikro@unr.edu>, <jbest@unr.edu>
cc Tom McCloy/AWA/FAA@FAA, Deanna Super/ACT/FAA@FAA
Subject RE: FAA expired grant (05-G-018)

Nicole,
I submitted the final report back in February. Perhaps you did not receive the submission. I have attached another copy of the report and a PDF of the signed cover page.

Michael Crognale

From: nicole.saiauskie@faa.gov [mailto:nicole.saiauskie@faa.gov]
Sent: Monday, March 31, 2008 11:55 AM
To: Michael A Crognale; mikro@unr.edu; jbest@unr.edu
Cc: tom.mccloy@faa.gov; deanna.super@faa.gov
Subject: FAA expired grant (05-G-018)
Importance: High

Good Afternoon Michael & Jerald,

The above referenced grant expired back on 12/29/07 and the required 90 days have just past. Could you please let me know the status of the closeout documents and when I should be receiving everything?

Thank you,

Nicole Salauskie
FAA Grants Program Specialist
Federal Aviation Administration
William J. Hughes Technical Center
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