Federal Aviation Administration

Pilot and Controller Response Times from the JULY, 2009 Human in the Loop Data Collection Effort

Flight Systems Laboratory
DOT-FAA-AFS-450-61

October 2010

Flight Systems Laboratory
6500 S. MacArthur Blvd.
Systems Training Building Annex, RM 217
Oklahoma City, Oklahoma 73169
Phone: (405) 954-8191

OK-11-0488

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

DOT-FAA-AFS-450-61

Flight Systems Laboratory
Flight Technologies and Procedures Division
Flight Standards Service

Pilot and Controller Response Times from the JULY, 2009 Human in the Loop Data Collection Project

Reviewed by:

Stephen W. Barnes **Date**
Manager, Flight Systems Laboratory, AFS-450

Released by:

G. Powell for 10/20/10

Leslie H. Smith **Date**
Manager, FlightTechnologies and Procedures Division, AFS-400

October 2010

Technical Report

DOT-FAA-AFS-450-61

Flight Systems Laboratory
Flight Technologies and Procedures Division
Flight Standards Service

Pilot and Controller Response Times from the JULY, 2009 Human in the Loop Data Collection Project

Reviewed by:

10/18/2010

Stephen W. Barnes **Date**
Manager, Flight Systems Laboratory, AFS-450

Released by:

Leslie H. Smith **Date**
Manager, FlightTechnologies and Procedures Division, AFS-400

October 2010

Technical Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT-FAA-AFS-450-61		

4. Title and Subtitle	5. Report Date
Pilot and Controller Response Times from the JULY, 2009 Human in the Loop Data Collection Project	October 2010
6. Author(s)	**7. Performing Organization Code**
Dr. Gerry McCartor, AFS-450; Dr. Sherri Avery, AFS-450; Dr. James Yates, ISI, Jim Savage, ISI, Shahar Ledeky, ATSI	AFS-450
8. Performing Organization Name and Address	**9. Type of Report and Period Covered**
Federal Aviation Administration Flight Systems Laboratory, AFS-450 6500 S MacArthur Blvd., STB Annex, RM 217 Oklahoma City, OK 73169	Technical report

10. Sponsoring Agency Name and Address
Federal Aviation Administration
Flight Systems Laboratory, AFS-450
6500 S Mac Arthur Blvd., STB Annex, RM 217
Oklahoma City, OK 73169

11. Supplementary Notes

12. Abstract

In support of the Accelerating Next Generation Air Transportation System (NextGen) initiative, a Human in the Loop (HiTL) data collection project was accomplished to determine Pilot and Controller Response times for Simultaneous Parallel Independent Approaches to Closely Spaced Runways. At the direction of the Accelerating NextGen Committee, the data collection effort evaluated runway spacing and No Transgression Zone (NTZ) dimensions that were significantly reduced from the current standards using a standard ASR-9 surveillance radar, and a Standard Automation Replacement System (STARS) Air Traffic Control workstation with Final Monitor Aid (FMA) display. The current standards are 4300 feet runway centerline to centerline spacing and an NTZ width of 2000 feet. For this data collection effort, the runway spacing was reduced to 3000 feet and the NTZ width to 1200 feet.

13. Key Words	14. Distribution Statement
Simultaneous Parallel Independent Approaches No Transgression Zone NTZ Normal Operating Zone NOZ Blunder Deviation Localizer Instrument Landing System ILS	Controlled by AFS-450
15. Security Classification of This Report	**16. Security Classification of This Page**
Unclassified	Unclassified

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) is identifying improvements to Closely Spaced Parallel Operations (CSPO) as key future capacity enablers, with the goals of increasing capacity during IMC operations, reducing delays and maintaining safety.

To meet these goals, the FAA is investigating methods to conduct closely spaced parallel independent approaches at runway spacing closer than currently authorized using existing NAS resources.

Parallel runway spacing is one of the main parameters which affect airport capacity and that determine whether independent, dependent or single runway arrival operations can be conducted. Other parameters include radar surveillance capabilities, the air traffic automation system and runway threshold stagger. The risk of collision due to a blunder, where one aircraft unexpectedly turns toward the aircraft on the parallel final approach course, putting the non blundering aircraft at risk, is the prime concern.

A Human-In-The-Loop (HITL) data collection effort (DCE) was conducted in July, 2009, using the FAA's Boeing B737-800 and A330-200 Level D flight simulators linked to two Air Traffic Control radar monitor controller workstations. Pilot and controller response times were evaluated with pilots and controllers performing as they would in actual NAS operations. Monitor controllers used a Standard Terminal Automation Replacement System (STARS) with Final Monitor Aid (FMA) displays, a color digital display with enhanced aspect ratios and visual and aural alerts. The navigation system used was the Instrument Landing System (ILS). The surveillance radar was an ASR-9 with a 4.8 second update rate.

The John F. Kennedy International Airport was chosen as the test airport. Runway 22R was modified to duplicate Runway 22L in all aspects and moved so that the runway centerlines were separated by 3000 feet with no threshold stagger. The No Transgression Zone (NTZ) was reduced to 1200 feet, leaving a Normal Operating Zone (NOZ) of 900 feet between each runway centerline and the respective edge of the NTZ.

The Traffic Collision Avoidance System (TCAS) provides the aircraft crew with both Traffic Advisories (TAs), an indication given to the flight crew that a certain intruder is a potential threat, and with Traffic Resolution Advisories (RAs), an indication given to the flight crew recommending a maneuver to provide separation from a threat.

Due to the close proximities of the aircraft in this DCE, the TCAS RAs were issued just before controller instructions for a breakout maneuver. Crew responses to these RAs corrupted the data for determining pilot and controller response times. It was determined to conduct further HITL DCEs with RAs inhibited to determine pilot response times. Further air traffic controller HITL DCEs are to be conducted with just controllers to determine controller response times.

TABLE OF CONTENTS

1.0. Introduction....7
1.1. Background....8
2.0. Discussion....9
2.1. Objectives....9
3.0. Data Analysis....10
3.1. Data Collection....10
3.2. Statistical Analysis....11
3.3. Fitting Johnson Probability Density Functions....12
4.0. Findings....13
4.1. Controller Response Times (CRT)....13
4.1.1. CRT based upon qualification....13
4.1.2.CRT Based Upon Blunder angle....15
4.1.3. CRT Johnson Curves....16
4.2. Pilot Response Times (PRT)....18
4.2.1. PRT to Roll from ATC Message by Pilot Qualification....18
4.2.2. PRT to Pitch from TCAS RA by Pilot Qualification....19
4.3. Aircraft Dynamics....23
5.0. Airspace Simulation and Analysis Tool (ASAT)....31
6.0. Traffic Collision and Avoidance System (TCAS)....31
7.0. Conclusions and Recommendations....32
7.1. Controller Response Times (CRT)....32
7.1.1. CRT based upon qualification....32
7.1.2. CRT Based Upon Blunder angle....32
7.2. Pilot Response Times (PRT)....33
7.2.1. PRT to Roll from ATC Message by Pilot Qualification....33
7.2.2. PRT to Pitch from TCAS RA by Pilot Qualification....33
7.3. Aircraft Dynamics....33
7.4. Traffic Collision and Avoidance System (TCAS)....34
7.5. Use of the data from this Data Collection Effort....34
REFERENCES....35
APPENDIX: Johnson Probability Density Function Parameters....36

LIST OF ILLUSTRATIONS

Figures

Figure 1: Runway Spacing and NTZ/NOZ Depictions 8
Figure 2: Yellow Alert to Controller Message 20 Degree Blunder....17
Figure 3: Yellow Alert to Controller Message 30 Degree Blunder....18
Figure 4: Controller Message to Aircraft Roll Time 22
Figure 5: TCAS RA to Aircraft Pitch Time....23
Figure 6: Airbus Rate of Climb 26
Figure 7: Airbus Rate of Climb Rate....27
Figure 8: Boeing Rate of Climb....28
Figure 9: Boeing Rate of Climb Rate 29
Figure 10: Airbus/Boeing Maximum Roll Angle....30
Figure 11: Airbus/Boeing Roll Rate 31

Tables

Table 1: Descriptive Statistics of Left and Right Controller Times 14
Table 2: Levene's Test of Left and Right Controller Times 14
Table 3: ANOVA of Left and Right Controller Times from Yellow Alert....15
Table 4: Descriptive Statistics of Yellow Alert to Controller Message by Blunder Angle 15
Table 5: Levene's Test of Variances of Yellow Alert to Controller Message by Blunder Angle....15
Table 6: ANOVA of Yellow Alert to Controller Message by Blunder Angle 16
Table 7: Descriptive Statistics of Roll Time from ATC Message by Pilot Qualification 19
Table 8: Levene's Test of Roll Time from ATC Message by Pilot Qualification 19
Table 9: ANOVA of Roll Time from ATC Message by Pilot Qualification....19
Table 10: Descriptive Statistics of Pitch Time from TCAS RA by Pilot Qualification...20
Table 11: Levene's Test of Pitch Time from TCAS RA by Pilot Qualification 20
Table 12: ANOVA of Pitch Time from TCAS RA by Pilot Qualification 20
Table 13: Descriptive Statistics of Rate of Climb, Rate of Climb Rate, Absolute Roll Angle, Absolute Roll Angle Rate 24
Table 14: Levene's Test of Variances for Aircraft Dynamics....24
Table 15: ANOVA of Aircraft Dynamics 25

1.0. Introduction

The Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) Implementation Plan (NIP) and the National Airspace System (NAS) Enterprise Architecture (EA) identify improvements to Closely Spaced Parallel Operations (CSPO) as a key future capacity enabler, with three high level goals:

- Increasing Capacity: Reduce the impact of lower visibility conditions by closing the gap in capacity between Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC).
- Reducing Delay: Reduce system wide NAS delay.
- Maintaining Safety: Ensure an acceptable level of safety exists in reduced visibility conditions with an increased number of approach operations to near that of VMC.

To meet these goals, the FAA is investigating methods to conduct closely spaced parallel independent approaches at runway spacing closer than currently authorized (4,300 feet for this scenario) using existing NAS resources.

The distance between parallel runways is one of the main parameters which affect airport capacity and that determine whether independent (higher throughput), dependent (lower throughput), or single runway arrival operations can be conducted. Other factors include an airport's radar surveillance capabilities, controller displays, and supported approach types and runway threshold stagger. A principal safety concern is the risk of collision due to a blunder, where one aircraft unexpectedly turns toward the aircraft on the parallel final approach course, putting the non blundering aircraft at risk.

A test of these parameters was conducted in July, 2009, using the FAA's Boeing B737-800 and A330-200 Level D flight simulators linked to the two Air Traffic Control radar monitor controller workstations located at the Flight Operations Simulation Laboratory at the Mike Monroney Aeronautical Center, in Oklahoma City.

The John F. Kennedy International Airport was chosen as the test location. Runway 22R was modified to duplicate Runway 22L in all aspects and moved so that the runway centerlines were separated by 3000 feet with no threshold stagger. The No Transgression Zone (NTZ) was reduced to 1200 feet, leaving a Normal Operating Zone (NOZ) of 900 feet between each runway centerline and the respective edge of the NTZ.

The purpose of this data collection effort was to satisfy Phase 1 of the Safety Risk Management Panel's Project Plan CSPO-001, "Simultaneous Independent Dual Straight-In ILS Approaches with Runway Centerlines at 3,000 Feet Using a 4.8 Second Surveillance Update Rate" (reference 1) and was a Human-In-The-Loop (HITL) test with both pilots and controllers performing as they would in actual NAS operations. Monitor controllers used a Standard Terminal Automation Replacement System (STARS) with

Final Monitor Aid (FMA) displays, a color digital display with enhanced aspect ratios and visual and aural alerts.

The Traffic Collision Avoidance System (TCAS) provides the aircraft crew with both Traffic Advisories (TAs), an indication given to the flight crew that a certain intruder is a potential threat, and with Traffic Resolution Advisories (RAs), an indication given to the flight crew recommending a maneuver to provide separation from a threat.

Due to the close proximities of the aircraft in this DCE, the TCAS RAs were issued just before controller instructions for a breakout maneuver. Crew responses to these RAs corrupted the data for determining pilot and controller response times. It was decided to conduct further HITL DCEs with RAs inhibited with only pilots to determine pilot response times, and to conduct air traffic controller HITL DCEs with only controllers to determine controller response times.

1.1. Background

In support of NextGen initiatives, a Human in the Loop (HITL) data collection effort was accomplished to determine pilot and controller response times for simultaneous parallel independent approaches to closely spaced runways. At the direction of the Accelerating NextGen Committee, the data collection effort evaluated runway spacing and NTZ dimensions that were significantly reduced from the current standards using standard surveillance radar, ASR-9, and STARS with FMA display. Those standards are 4300 feet runway centerline to centerline spacing and an NTZ width of 2000 feet. For this data collection effort, the spacings were reduced to 3000 feet and 1200 feet respectively, as shown in the figure.

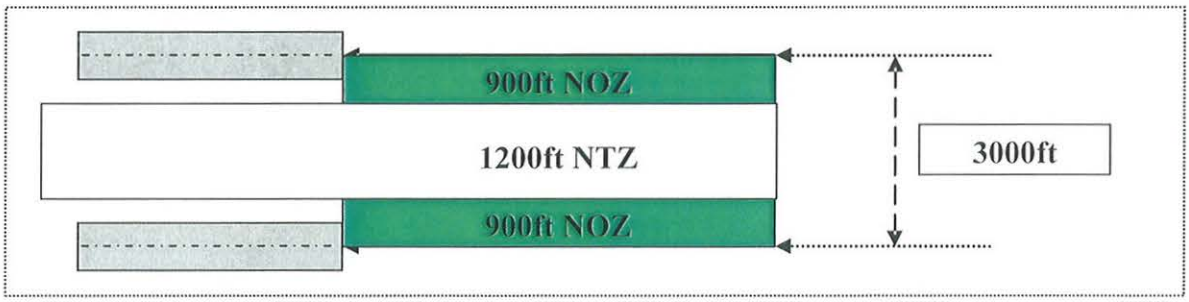


Figure 1: Runway Spacing and NTZ/NOZ Depictions

2.0. Discussion

The airport chosen for this simulation effort was John F. Kennedy International, using runways 22L and 22R. Runway 22R was modified to match 22L. The threshold was moved so there was no threshold stagger. Approach lights were added to runway 22R so that the light arrays of the two runways matched exactly. Runway 22R was moved so that the runways were separated by 3000 feet as shown in figure 1. The HITL was conducted in July, 2009, using the FAA's Boeing B737-800 and A330-200 Level D flight simulators linked to the two Air Traffic Control radar monitor controller workstations located in the Flight Operations Simulation Laboratory.

2.1. Objectives

The objectives of the test were to:

- Perform real-time data collection focused on pilot and controller response times while conducting dual simultaneous independent parallel ILS approaches using a runway spacing of 3000 feet, no threshold stagger, ASR-9 surveillance radar with update rate of 4.8 seconds and STARS with FMA display.
- Determine controller and pilot response times during "at-risk" blunder scenarios to include a mix of responding and non-responding blundering aircraft using 20 and 30 degree angles of blunder. Blunders were simulated using computer generated aircraft (pseudo aircraft) operated by trained specialists. An at-risk blunder is a blunder in which the two aircraft are aligned in such a way that if the monitor controller and/or the endangered pilot did not react in a timely manner, the pseudo-aircraft (computer generated aircraft) and the flight simulator would pass within 500 feet center of gravity (CG) to CG causing a Test Criterion Violation (TCV).
- Collect data on the effects of the Traffic Alert and Collision Avoidance System (TCAS) during blunders and breakouts after a blunder occurs.
- Determine controller and pilot response times during a missed approach breakout caused by an NTZ penetration by the opposite parallel aircraft. No blunders were simulated during the missed approach. Instead, the pseudo aircraft deviated slightly towards the NTZ (10 to 15 degrees) during a simultaneous missed approach or balked landing.
- Collect the specified aircraft operational/aerodynamic data for the A330-200 and B737-800 during approach and missed approach breakouts.

3.0. Data Analysis

3.1. Data Collection

Software was developed for a computer system that operated two simulated radar displays. The radar displays emulated an ASR-9 surveillance radar with an update rate of 4.8 seconds and STARS with FMA display. In addition, the computer system coordinated the approach tracks of the two flight simulators with pseudo aircraft approach tracks. The computer system displayed either two pseudo aircraft tracks or one flight simulator track and one pseudo aircraft track. The test coordinator observed the simulated traffic using a computer monitor and selected appropriate scenarios for the simulation. The test coordinator was also able to manipulate the pseudo-aircraft to align it for an at-risk blunder.

Other personnel simulated tower controller, ground controller and TRACON controllers. Two additional personnel operated computer work stations that controlled the pseudo aircraft. The flight simulators have a built in background noise that is audible to the controller through the pilot's microphone. This background noise was recorded and played at the pseudo pilot work stations during communication with the subject controllers to disguise the "pilots" of the pseudo aircraft.

The computer system provided a common timing system for the flight simulators, the pseudo-aircraft, and the monitor controllers. Therefore, it was possible to record the times when blunders occurred, TCAS alerts occurred, the monitor controllers reacted to issue an evasion command, and the pilot of the flight simulator began the evasion maneuver. The computer system could also record the closest point of approach (CPA) of the simulator and the pseudo aircraft. In addition, the two flight simulators recorded flight dynamics such as roll rates and climb rates. The variables recorded by the system included the following:

1. The blundering aircraft call sign.
2. The evading aircraft call sign.
3. Blunder start time.
4. NTZ warning time (yellow alert).
5. NTZ alert time (red alert).
6. Monitor controller communication start time.
7. Monitor controller communication stop time.
8. Distance to NTZ at yellow alert.
9. Distance to NTZ at red alert.
10. Distance to NTZ at monitor controller communication start.
11. Closest point of approach, 2 D.
12. Closest point of approach, 3 D.
13. TCAS RA time.

14. TCAS TA time.
15. Pilot roll time.
16. Pilot pitch time.
17. Pilot throttle time.
18. Pilot autopilot time.
19. Simulator type
20. Blunder angle.
21. ATC position, Left or Right.
22. TCAS directive, ascend or descend.
23. Rate of climb, fpm.
24. Acceleration into climb, fpm/sec.
25. Maximum roll angle.
26. Roll rate, degrees per second.

Other variables that were derived from the recorded variables included:

1. Monitor controller message duration.
2. Yellow alert to monitor controller message start time.
3. Red alert to monitor controller message start time.
4. Monitor controller message start to pilot roll time.
5. Monitor controller message start to pilot pitch time.
6. Monitor controller message start to pilot throttle time.
7. TCAS TA to pilot pitch time.
8. TCAS RA to pilot pitch time.
9. TCAS TA to pilot throttle time.
10. TCAS RA to pilot throttle time.
11. Monitor controller message start to autopilot uncouple.
12. TCAS RA to autopilot uncouple.

Other variables that were derived from pilot and controller questionnaires:

1. Left monitor controller qualified?
2. Right monitor controller qualified?
3. Pilot qualified?
4. First officer qualified?

3.2. Statistical Analysis

One important purpose of the simulation was to collect data that can be used to develop probability density functions (pdf). The pdf's can be used in a fast-time, Monte Carlo computer simulation to determine the probability of a collision during closely spaced parallel approach operations due to a blunder. The probability of a collision can be

compared to a standard probability or risk, i.e., a target level of safety, to determine the acceptability of the operation. A mathematical algorithm is used to determine a pdf of best fit to the data in question such as controller response time. Confidence in the suitability of the derived pdf increases with increased numbers of observations in the data set. In this simulation data such as controller response times were collected using controllers with varying experience. Some controllers were deemed inexperienced and therefore unqualified while other controllers were experienced and therefore qualified. In other cases, a controller's background led to the conclusion that the controller might be qualified. In some cases there was not enough information to reach any conclusion. Therefore the controller's status was unknown. To build an adequately sized data set, the analyst must determine whether the response times, based on controller qualifications, can be pooled into one data set. A similar situation exists for the pilots of the flight simulators.

Statistical tests have been devised to enable the analyst to decide whether two or more independent samples should be regarded as having come from the same population. Values from different independent samples almost always differ somewhat in means, variance, and other measures that describe properties of the data. The problem is to determine whether the observed sample differences signify differences among populations or whether they are merely the chance variations that are to be expected among random samples from the same population.

One of the most powerful and flexible statistical tests of differences in means of independent sample sets is analysis of variance (ANOVA). ANOVA is a parametric test since it is based on certain assumptions about the data. ANOVA assumes that the data were generated from normal distributions, but having the same variance. These conditions are not often completely met in practical applications and it will be shown that the curves that best fit the data sets are bounded and obviously not from a normal distribution. However, much study has been done by statisticians to ascertain the effects of violations of the assumptions. In most cases, violations of the assumptions, even fairly extreme ones, do not severely affect the outcome of the analysis of variance. ANOVA is easily performed using any statistical package and, in the case of Statistical Package for the Social Studies (SPSS), and Levene's test (reference 2), a test of homogeneity of variance, is conducted concurrently with ANOVA. Levene's test is useful since it provides another measure of whether the data sets are similar enough to be pooled into one set.

3.3. Fitting Johnson Probability Density Functions

The Johnson family of empirical distributions is based on transformations of a standard normal variate. An advantage of such a transformation is that estimates of the percentiles of the fitted distribution can be obtained either from a table of areas under a standard normal distribution or from a computer program which computes areas under a standard normal distribution. Another advantage is that during a Monte Carlo simulation, variates

from the distribution are readily computed from the standard normal distribution. The Johnson distributions are divided into three families as follows:

1. The S_L family is characterized by the transformation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda}\right), \; x > \varepsilon,$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is bounded on the left by ε and is unbounded on the right.

2. The S_B family is characterized by the transformation:

$$z = \gamma + \delta \ln\left(\frac{x-\varepsilon}{\lambda+\varepsilon-x}\right), \; \varepsilon < x < \varepsilon + \lambda.$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is bounded on the left by ε and on the right by ε + λ.

3. The S_U family is characterized by the transformation:

$$z = \gamma + \delta \sinh^{-1}\left(\frac{x-\varepsilon}{\lambda}\right), \; -\infty < x < \infty.$$

where x is the variable to be fitted by the Johnson distribution and z is a standard normal variate. Each curve in this family is unbounded and unimodal.

4.0. Findings

4.1. Controller Response Times (CRT)

The participating controllers were separated into four groups, unqualified, qualified, possibly qualified, and unknown. The controllers were also divided into two primary groups, those who sat at the left radar monitor and those who sat at the right monitor. Intuitively, one would expect that there would be no differences between the left and right monitors. However, it was found that inclusion of the unqualified controllers resulted in significant differences in variance.

4.1.1. CRT based upon qualification.

If the unqualified controllers and their data were excluded, there was no significant difference between left or right controllers. Tables 1, 2, and 3 indicate the results of the ANOVA with the unqualified controller data excluded. In the tables, the lines labeled 1.0 in the left column indicate the left controller monitors. The lines labeled 2.0 indicate the right controller monitors. Table 1 contains the descriptive statistics of all controllers, less the unqualified. Table 2 indicates the results of Levene's test of homogeneity of variances. The table indicates that the probability of a Levene statistic being greater than 0.851 is 0.358. If the probability had been 0.05 or less, then a significant difference in variances would have been indicated and the data could not be pooled. The ANOVA table shown in Table 3 indicates that the probability of an F value greater than 1.923 is 0.168. If the probability had been 0.05 or less then there would be a significant difference in means and the data could not be pooled.

Table 1: Descriptive Statistics of Left and Right Controller Times

Descriptives

Yellow to Comm Start

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.0	80	3.638	4.411	.493	2.656	4.619	-10.9	17.3
2.0	74	4.504	3.195	.371	3.764	5.244	-6.8	12.1
Total	154	4.054	3.887	.313	3.435	4.673	-10.9	17.3

Table 2: Levene's Test of Left and Right Controller Times

Test of Homogeneity of Variances

Yellow to Comm Start

Levene Statistic	df1	df2	Sig.
.851	1	152	.358

Table 3: ANOVA of Left and Right Controller Times from Yellow Alert

ANOVA

Yellow to Comm Start

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	28.866	1	28.866	1.923	.168
Within Groups	2282.256	152	15.015		
Total	2311.123	153			

4.1.2.CRT Based Upon Blunder angle

Two blunder angles were used in the test, 20 degrees and 30 degrees. It is of interest to determine whether blunder angle had any effect on controller response time. ANOVA was computed to test controller response times to 20 and 30 degree blunders. The results of the ANOVA are shown in Tables 4, 5, and 6. Significant differences were observed for both variances and means. Therefore controller response times were separated into two sets, 20 degree blunders and 30 degree blunders. Johnson curves were fitted to each data set. The results are indicated in Figures 2 and 3. The specific parameters computed by the mathematical algorithm can be found in the appendix.

Table 4: Descriptive Statistics of Yellow Alert to Controller Message by Blunder Angle

Descriptives

Yellow to Comm Start

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
20	81	5.351	4.9526	.5503	4.256	6.446	-8.9	22.3
30	81	3.770	3.8733	.4304	2.914	4.627	-10.9	17.3
Total	162	4.560	4.5023	.3537	3.862	5.259	-10.9	22.3

Table 5: Levene's Test of Variances of Yellow Alert to Controller Message by Blunder Angle

Test of Homogeneity of Variances

Yellow to Comm Start

Levene Statistic	df1	df2	Sig.
4.524	1	160	.035

Table 6: ANOVA of Yellow Alert to Controller Message by Blunder Angle

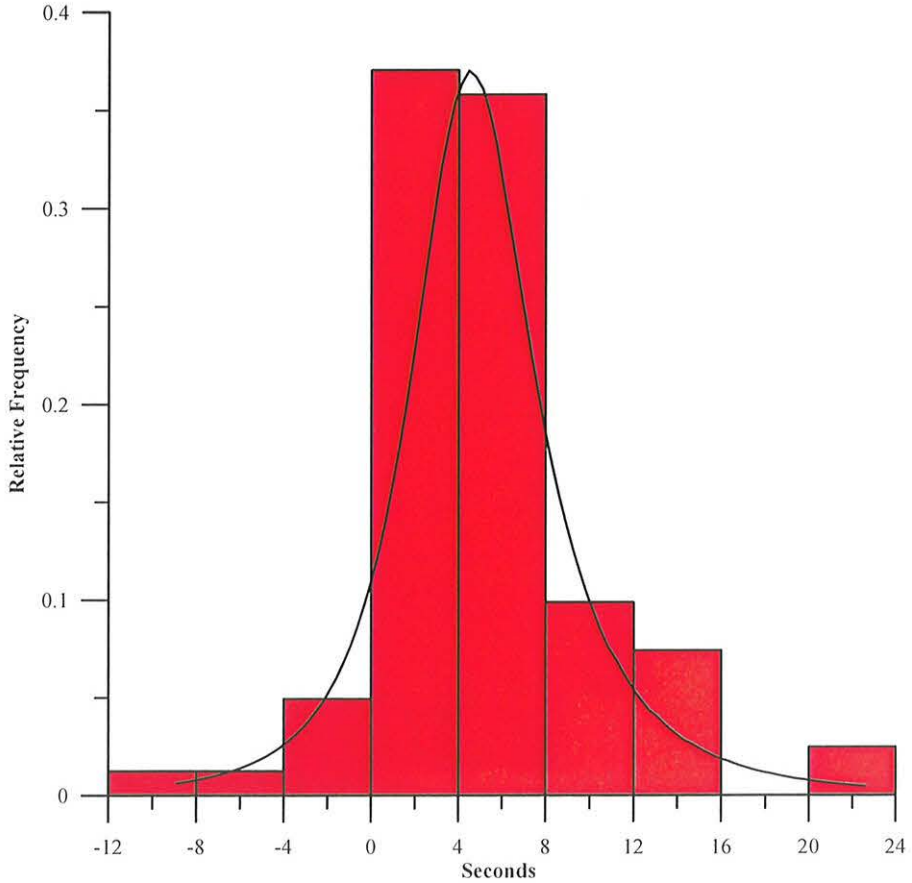
ANOVA

Yellow to Comm Start

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	101.136	1	101.136	5.117	.025
Within Groups	3162.391	160	19.765		
Total	3263.527	161			

4.1.3. CRT Johnson Curves

Based upon results of qualifications and blunder angles, Johnson curves were fitted for CRTs to be used in fast time simulation and further analysis.



Yellow Alert to Controller Message 20 Degree Blunder - Johnson Type S - U
81 Data Points

Figure 2: Yellow Alert to Controller Message 20 Degree Blunder

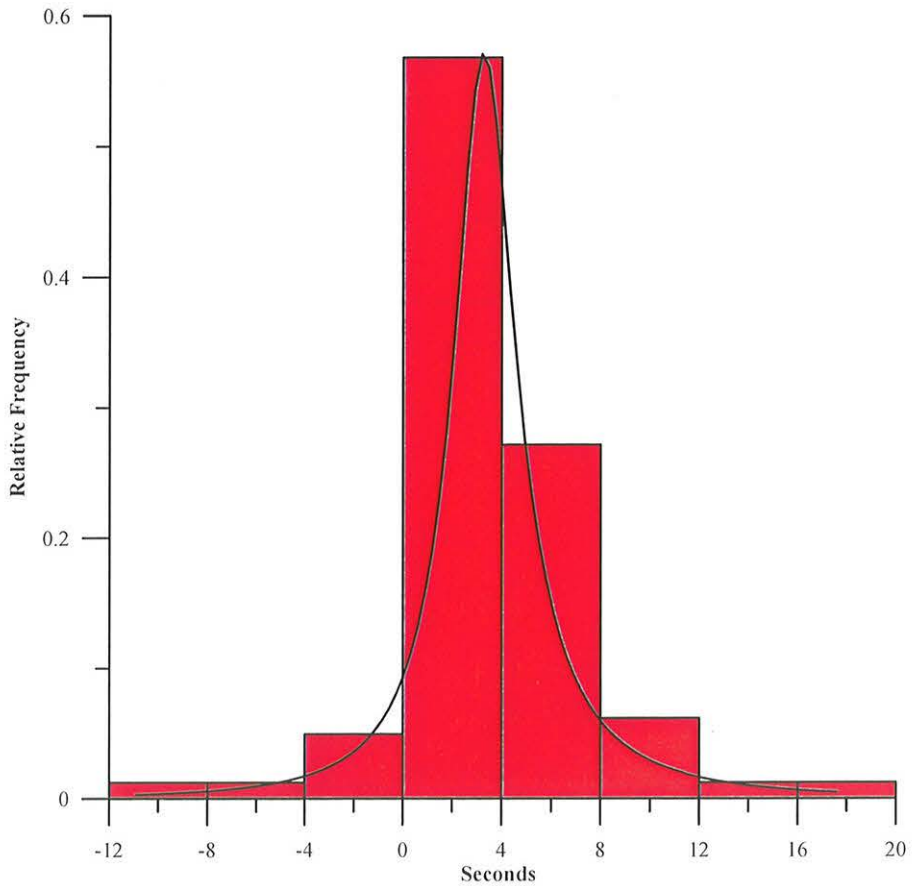


Figure 3: Yellow Alert to Controller Message 30 Degree Blunder

4.2. Pilot Response Times (PRT)

4.2.1. PRT to Roll from ATC Message by Pilot Qualification

Subject pilots were separated into three groups, unqualified, qualified, and unknown. The ATC message indicates a turn or rolling maneuver as well as a climb or descent. ANOVA and Levene's test were computed to determine whether differences in mean or variance of roll time from ATC message could be detected with respect to qualification. The results are shown in Tables 7, 8, and 9. The probabilities in Tables 8 and 9 indicate

that there were no significant differences in means or variances for roll time from ATC message by qualification. The pilot roll times from the ATC message were pooled into

one data set and a Johnson pdf was fitted to the data. A graph of the Johnson pdf overlaid on a histogram of the data is shown in Figure 4.

Table 7: Descriptive Statistics of Roll Time from ATC Message by Pilot Qualification

Descriptives: Pilot Qualified; 1 = YES, 2 = NO, 3 = UNKNOWN

pilot roll frm atc

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	44	7.125	7.1084	1.0716	4.964	9.286	.7	41.1
2	17	7.129	8.2161	1.9927	2.905	11.354	.8	31.1
3	61	5.887	4.9524	.6341	4.619	7.155	.4	25.5
Total	122	6.507	6.2795	.5685	5.381	7.632	.4	41.1

Table 8: Levene's Test of Roll Time from ATC Message by Pilot Qualification

Test of Homogeneity of Variances

pilot roll frm atc

Levene Statistic	df1	df2	Sig.
1.849	2	119	.162

Table 9: ANOVA of Roll Time from ATC Message by Pilot Qualification

ANOVA

pilot roll frm atc

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	46.847	2	23.424	.590	.556
Within Groups	4724.407	119	39.701		
Total	4771.255	121			

4.2.2. PRT to Pitch from TCAS RA by Pilot Qualification

Subject pilots were separated into three groups, unqualified, qualified, and unknown. A TCAS RA indicates to the pilot whether a climb or descent should be performed by the pilot to avoid a conflict with another aircraft. ANOVA and Levene's test were computed to determine whether differences in mean or variance of pitch time from TCAS RA could be detected with respect to qualification. The results are shown in Tables 10, 11, and 12. The probabilities in Tables 11 and 12 indicate that there were no significant differences in means or variances for pitch time from TCAS RA by qualification. The pilot pitch times from the TCAS RA were pooled into one data set and a Johnson pdf was fitted to the data. A graph of the Johnson pdf overlaid on a histogram of the data is shown in Figure 5.

Table 10: Descriptive Statistics of Pitch Time from TCAS RA by Pilot Qualification

Descriptives: Pilot Qualified, 1 = YES, 2 = NO, 3 = UNKNOWN

pitch from RA

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	35	5.623	8.3130	1.4052	2.767	8.478	.1	45.3
2	15	2.727	2.0724	.5351	1.579	3.874	.3	6.8
3	52	4.477	4.1520	.5758	3.321	5.633	.1	20.2
Total	102	4.613	5.7841	.5727	3.477	5.749	.1	45.3

Table 11: Levene's Test of Pitch Time from TCAS RA by Pilot Qualification

Test of Homogeneity of Variances

pitch from RA

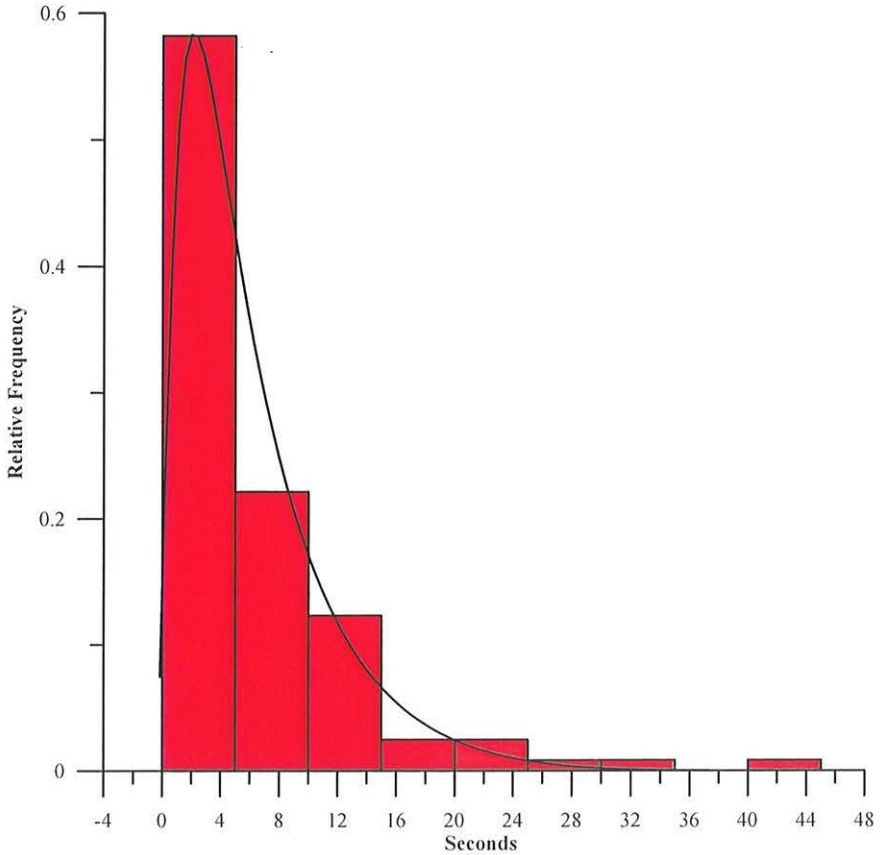
Levene Statistic	df1	df2	Sig.
2.339	2	99	.102

Table 12: ANOVA of Pitch Time from TCAS RA by Pilot Qualification

ANOVA

pitch from RA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	90.030	2	45.015	1.355	.263
Within Groups	3288.963	99	33.222		
Total	3378.993	101			



Controller Message to Aircraft Roll Time
Johnson Type S - B
122 Data Points

Figure 4: Controller Message to Aircraft Roll Time

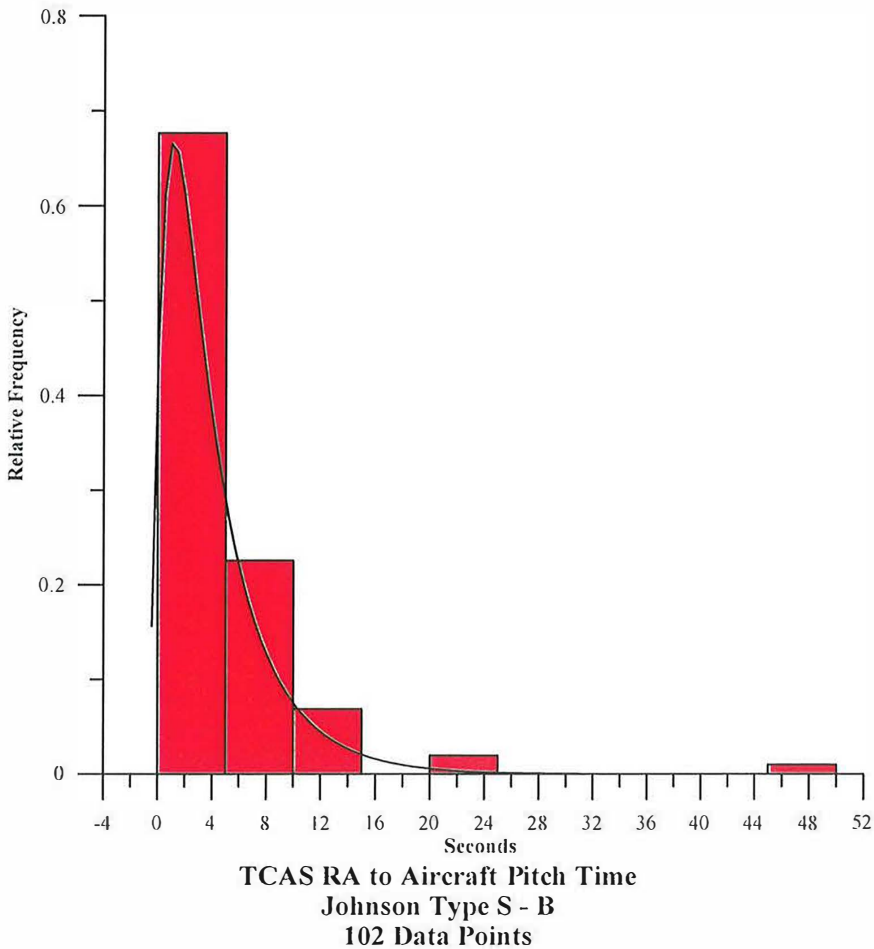


Figure 5: TCAS RA to Aircraft Pitch Time

4.3. Aircraft Dynamics

Two level D flight simulators were used in the test. One simulated an Airbus A330-200 and the other simulated a Boeing B737-800. Since the aircraft are produced by different manufacturers and are in significantly different weight categories, it is appropriate to investigate the flight characteristics of the two aircraft. Levene's test and ANOVA were computed for rate of climb (ft/min), rate of climb rate (ft/min/sec), maximum roll angle (degrees), and roll angle rate (degrees/sec). The maximum roll angles and roll angle rates were recorded as negative numbers for left turns and were converted to positive numbers and combined with the maximum roll angles and roll angle rates for right turns. The results are shown in Tables 13, 14 and 15. Levene's test indicated that there were no significant differences in variances, but ANOVA indicated that there were significant

differences in the means of the rates of climb and the rates of climb rate. Therefore, the data were not pooled and Johnson curves were developed for each aircraft for the variables for rates of climb and the rates of climb rate. Maximum roll angles and roll rates did not have significant differences and the data were combined for the two aircraft. Histograms and Johnson curves are illustrated in Figures 6, 7, 8, 9, 10 and 11.

Table 13: Descriptive Statistics of Rate of Climb, Rate of Climb Rate, Absolute Roll Angle, Absolute Roll Angle Rate

Descriptives: Group 1.0 = Airbus, Group 2.0 = Boeing.

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Rate of Climb (ft/min)	1.0	66	2063.666	1014.499877	124.8763	1814.270668	2313.061064	-1491.37	3715.641
	2.0	75	2527.817	809.87783135	93.51664	2341.480617	2714.152550	-1577.60	4342.490
	Total	141	2310.555	937.31600264	78.93625	2154.493344	2466.615747	-1577.60	4342.490
Rate of Climb Rate (ft/min/sec)	1.0	66	412.4110	231.35064978	28.47730	355.5379136	469.2840900	-305.627	900.00000
	2.0	75	570.0341	219.02866107	25.29125	519.6401450	620.4279814	-210.784	1092.437
	Total	141	496.2531	237.56600809	20.00667	456.6988003	535.8073112	-305.627	1092.437
Abs Roll Angle (deg)	1.0	78	26.41611	4.37875855	.49579677	25.4288485	27.4033635	17.54613	37.91523
	2.0	77	26.61437	4.18442129	.47685906	25.6646201	27.5641144	16.58582	38.36508
	Total	155	26.51460	4.27055582	.34301930	25.8369666	27.1922276	16.58582	38.36508
Abs Roll Angle Rate (deg/sec)	1.0	78	5.0908538	2.12180420	.24024702	4.6124609	5.5692468	1.49515	11.66667
	2.0	76	5.5622170	1.97746182	.22683043	5.1103476	6.0140864	2.37879	12.42857
	Total	154	5.3234746	2.05875675	.16589935	4.9957255	5.6512238	1.49515	12.42857

Table 14: Levene's Test of Variances for Aircraft Dynamics

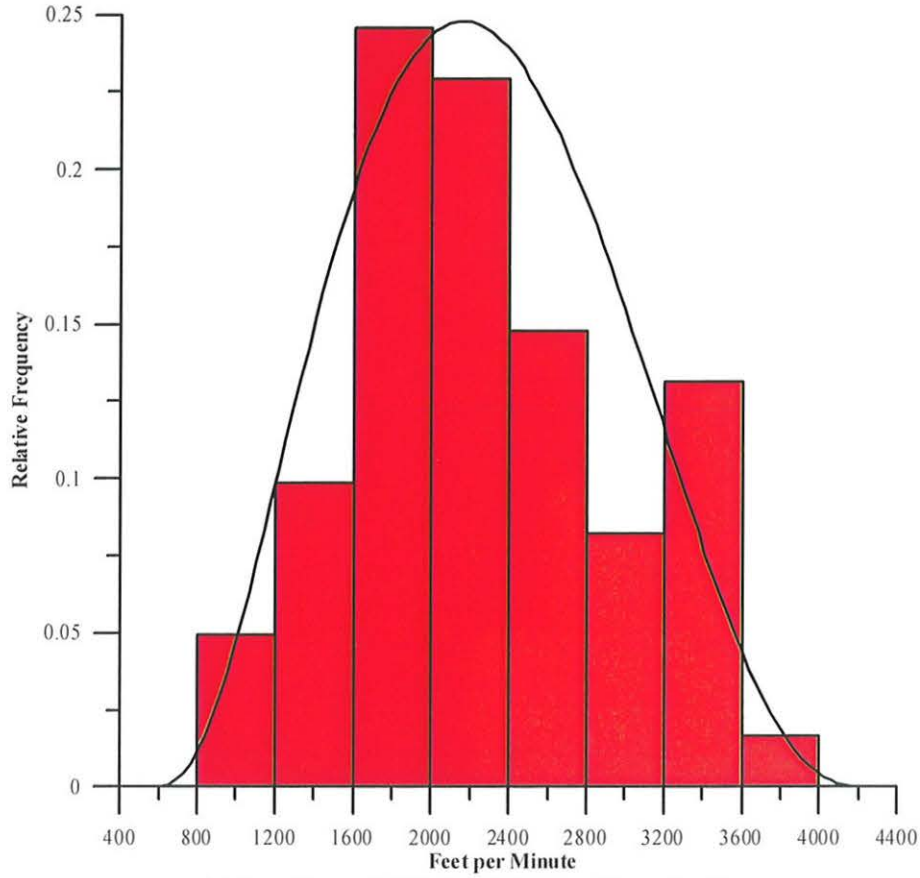
Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Rate of Climb (ft/min)	1.867	1	139	.174
Rate of Climb Rate (ft/min/sec)	.156	1	139	.694
Abs Roll Angle (deg)	.019	1	153	.892
Abs Roll Angle Rate (deg/sec)	.004	1	152	.949

Table 15: ANOVA of Aircraft Dynamics

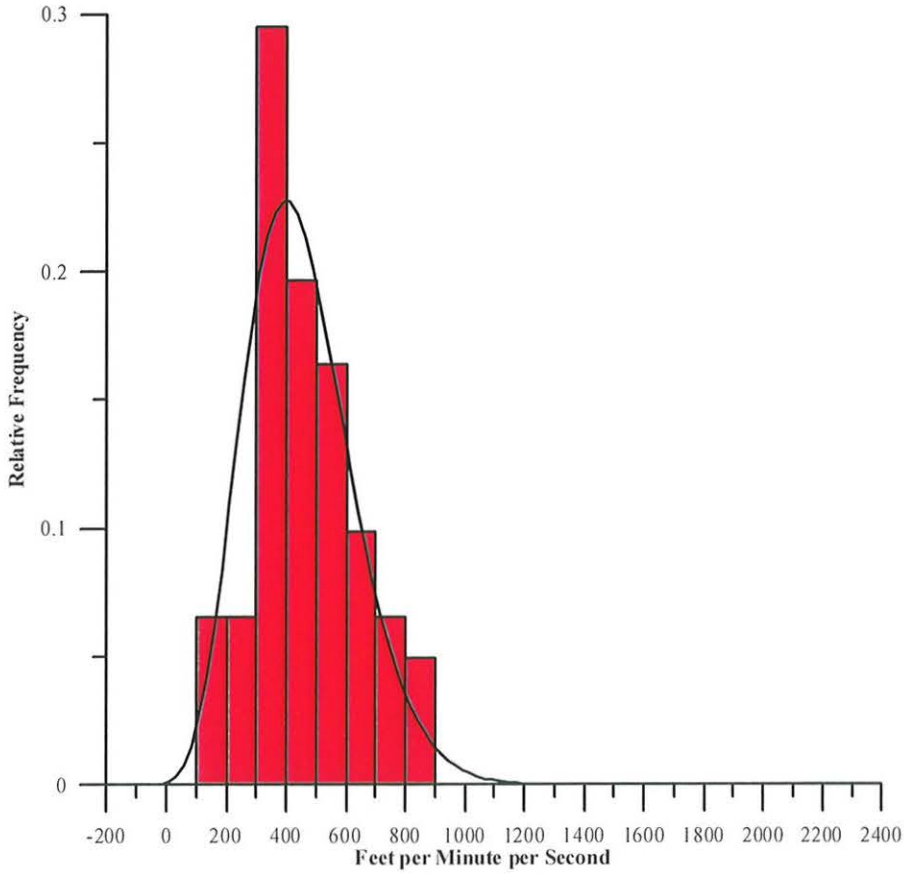
ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Rate of Climb (ft/min)	Between Groups	7563175	1	7563174.822	9.107	.003
	Within Groups	1.2E+008	139	830470.544		
	Total	1.2E+008	140			
Rate of Climb Rate (ft/min/sec)	Between Groups	872219.1	1	872219.120	17.248	.000
	Within Groups	7029046	139	50568.676		
	Total	7901265	140			
Abs Roll Angle (deg)	Between Groups	1.523	1	1.523	.083	.774
	Within Groups	2807.075	153	18.347		
	Total	2808.598	154			
Abs Roll Angle Rate (deg/sec)	Between Groups	8.553	1	8.553	2.031	.156
	Within Groups	639.935	152	4.210		
	Total	648.487	153			



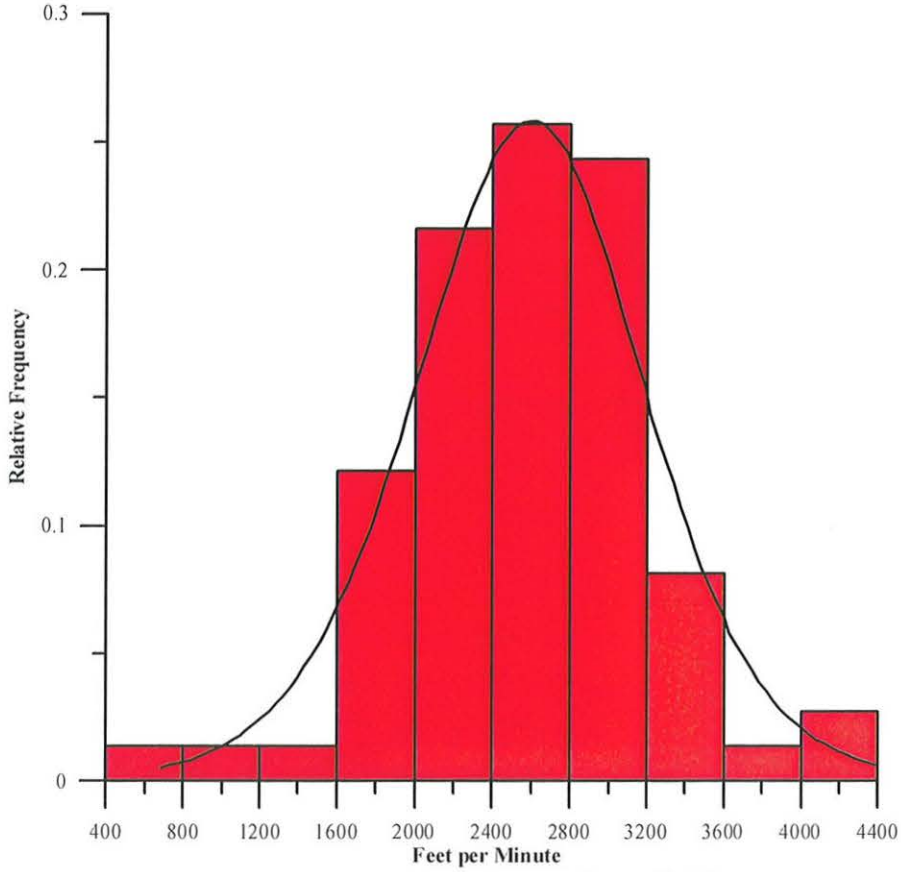
Airbus Rate of Climb - Johnson Type S - B
61 Data Points

Figure 6: Airbus Rate of Climb



Airbus Rate of Climb Derivative - Johnson Type S - B
61 Data Points

Figure 7: Airbus Rate of Climb Rate



Boeing Rate of Climb - Johnson Type S - U
74 Data Points

Figure 8: Boeing Rate of Climb

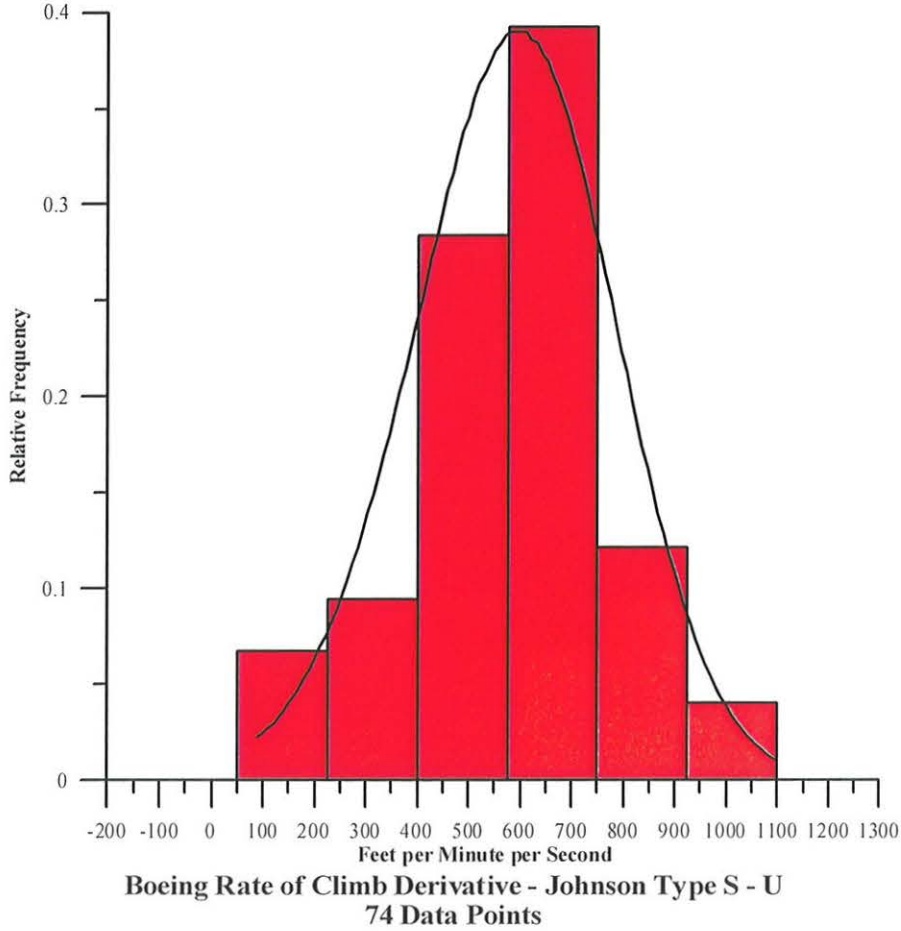
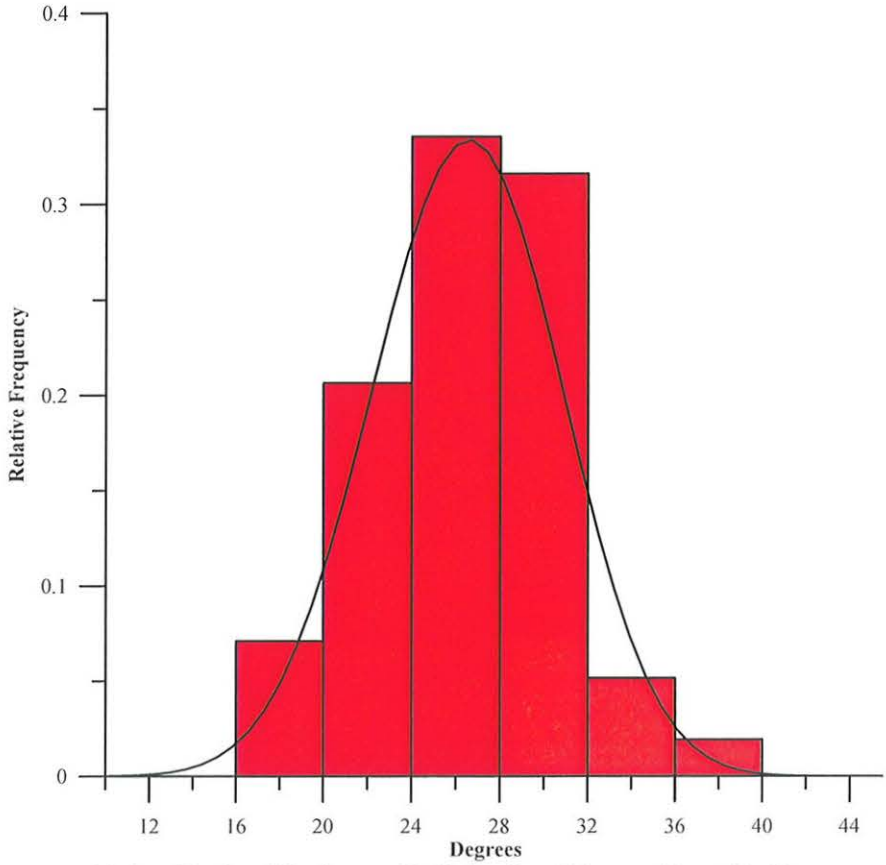


Figure 9: Boeing Rate of Climb Rate



Airbus/Boeing Maximum Roll Angle - Johnson Type S - B
155 Data Points

Figure 10: Airbus/Boeing Maximum Roll Angle

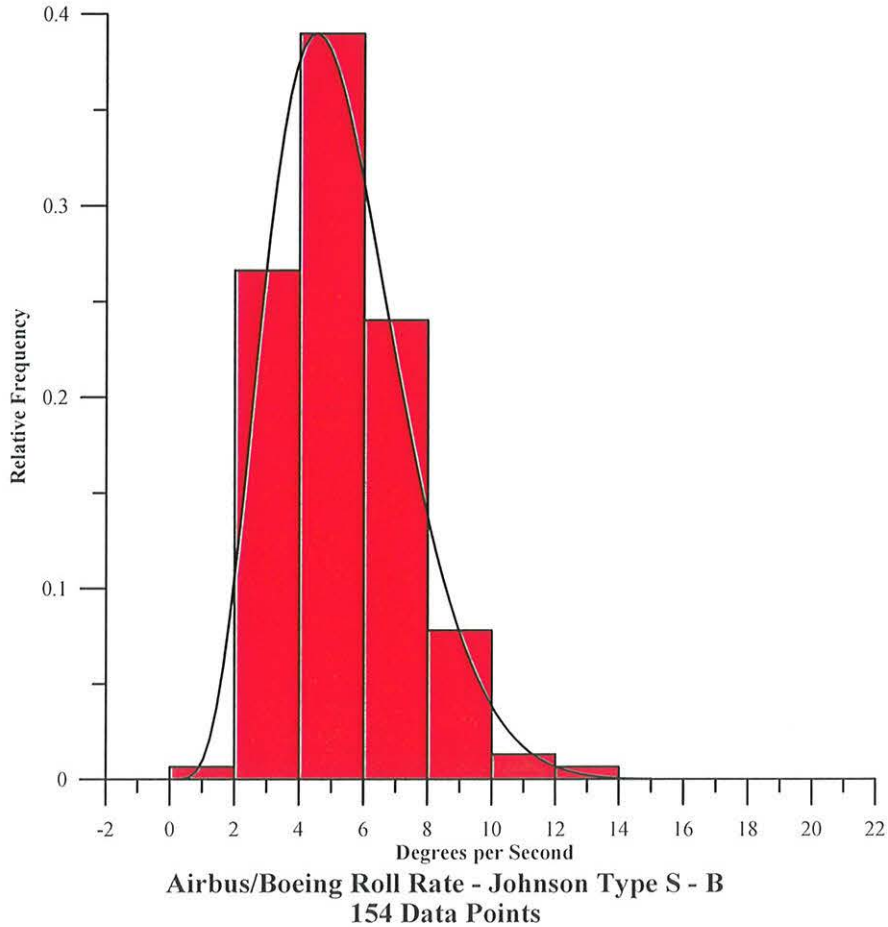


Figure 11: Airbus/Boeing Roll Rate

5.0. Airspace Simulation and Analysis Tool (ASAT)

The probability density functions described above will be incorporated into ASAT to perform fast-time, Monte Carlo simulations. The ASAT model is a new-generation Monte Carlo computer simulation system. It was developed to perform complex multiple aircraft simulations in the study of obstacle clearance and airspace requirements for new standards, the re-evaluation of existing standards, and aircraft to aircraft collision risk assessment during approaches, departures, missed approaches, and operations within the terminal area.

6.0. Traffic Collision and Avoidance System (TCAS)

Due to the close proximities of the aircraft in this DCE, the TCAS RAs were issued just before controller instructions for a breakout maneuver. Crew responses to these RAs

corrupted the data for determining pilot and controller response times. It was determined to conduct further HITL DCEs with RAs inhibited to determine pilot response times. Further air traffic controller HITL DCEs are to be conducted with just controllers to determine controller response times.

The TCAS Traffic Alerts (TA), which were audibly annunciated and were displayed continuously as a target offset and parallel to the crew, were acceptable by the pilots. Some crews actually attempted to use the displayed TA's to maintain their own separation from the target and to determine if the target was deviating from it's course so as to cause a conflict. However, the RAs, which required the crews to take action to alter their flight path, and to communicate with the controller to inform the controller the crew was responding to an RA, caused high crew workload, crew confusion, and missed/interfering communications between crews and controllers. TCAS could be a significant factor for accidents at any CSPO runway separation standard reduction.

7.0. Conclusions and Recommendations

7.1. Controller Response Times (CRT)

The participating controllers were separated into four groups, unqualified, qualified, possibly qualified, and unknown. The controllers were also divided into two primary groups, those who sat at the left radar monitor and those who sat at the right monitor. Intuitively, one would expect that there would be no differences between the left and right monitors. However, it was found that inclusion of the unqualified controllers resulted in significant differences in variance.

7.1.1. CRT based upon qualification.

The unqualified controllers and their data were excluded; there was no significant difference between left or right controllers. The CRT mean was determined to be 4.054 seconds with a standard deviation of 3.887 seconds

7.1.2. CRT Based Upon Blunder angle

Two blunder angles were used in the test, 20 degrees and 30 degrees. Significant differences were observed for both variances and means. Therefore controller response times were separated into two sets, 20 degree blunders and 30 degree blunders. The CRT mean for the 20 degree blunder was determined to be 5.351 seconds with a standard deviation of 4.9526 seconds. The CRT mean for the 30 degree blunder was determined

to be 3.770 seconds with a standard deviation of 3.8733 seconds. The combined CRT mean was 4.560 seconds with a standard deviation of 4.5023 seconds.

7.2. Pilot Response Times (PRT)

Subject pilots were separated into three groups, unqualified, qualified, and unknown. The ATC message indicates a turn or rolling maneuver as well as a climb or descent.

7.2.1. PRT to Roll from ATC Message by Pilot Qualification

There were no significant differences in means or variances for roll time from ATC message by qualification. The pilot roll times from the ATC message were pooled into one data set. The PRT mean for rolling the aircraft was determined to be 6.507 with a standard deviation of 6.2795 seconds.

7.2.2. PRT to Pitch from TCAS RA by Pilot Qualification

A TCAS RA indicates to the pilot whether a climb or descent should be performed by the pilot to avoid a conflict with another aircraft. There were no significant differences in means or variances for pitch time from TCAS RA by qualification. The pilot pitch times from the TCAS RA were pooled into one data set. The PRT mean for pitching the aircraft due to a TCAS RA was determined to be 4.613 with a standard deviation of 5.7841 seconds.

7.3. Aircraft Dynamics

Two level D flight simulators were used in the test. One simulated an Airbus A330-200 and the other simulated a Boeing B737-800. Since the aircraft are produced by different manufacturers and are in significantly different weight categories, it is appropriate to investigate the flight characteristics of the two aircraft. Analysis was conducted on rate of climb (ft/min), rate of climb rate (ft/min/sec), maximum roll angle (degrees), and roll angle rate (degrees/sec). There were significant differences in the means of the rates of climb and the rates of climb rate. Therefore, the data were not pooled. Maximum roll angles and roll rates did not have significant differences and the data were combined for the two aircraft.

The mean rate of climb for the Airbus was 2063.666 ft/min with the standard deviation of 1014.499 ft/min, while the mean for the Boeing was 2527.814 ft/min with a standard deviation of 809.877 ft/min.

The mean rate of climb rate for the Airbus was 412.411 ft/min/sec with the standard deviation of 251.351 ft/min/sec, while the mean for the Boeing was 570.034 ft/min/sec with a standard deviation of 219.029 ft/min/sec.

The mean of the maximum roll angle for the Airbus was 26.416 degrees with the standard deviation of 4.378 degrees, while the mean for the Boeing was 26.614 degrees with a standard deviation of 4.184 degrees.

The mean roll rate for the Airbus was 5.091 deg/sec with the standard deviation of 2.122 deg/sec, while the mean for the Boeing was 5.622 deg/sec with a standard deviation of 1.977 deg/sec.

7.4. Traffic Collision and Avoidance System (TCAS)

Due to the close proximities of the aircraft in this DCE, the TCAS RAs were issued just before controller instructions for a breakout maneuver. Crew responses to these RAs corrupted the data for determining pilot and controller response times. The TCAS Traffic Alerts (TA), which were audibly annunciated and were displayed continuously as a target offset and parallel to the crew, were acceptable by the pilots. Some crews actually attempted to use the displayed TA's to maintain their own separation from the target and to determine if the target was deviating from its course so as to cause a conflict. However, the RAs, which required the crews to take action to alter their flight path, and to communicate with the controller to inform the controller the crew was responding to an RA, caused high crew workload, crew confusion, and missed/interfering communications between crews and controllers. TCAS could be a significant factor for any CSPO runway separation standard reduction.

7.5. Use of the data from this Data Collection Effort.

It is recommended that:

The probability density functions described above be incorporated into the Airspace Simulation and Analysis Tool (ASAT). The ASAT is a new-generation Monte Carlo computer simulation system developed to perform complex multiple aircraft simulations in the study of obstacle clearance and airspace requirements for new standards, the re-evaluation of existing standards, and aircraft to aircraft collision risk assessment during approaches, departures, missed approaches, and operations within the terminal area.

Further HITL DCEs with TCAS RA inhibited to determine pilot response times to controller breakout instructions, and further air traffic controller HITL DCEs to be conducted to determine controller response times.

REFERENCES

[1] Project Plan CSPO-001: *Simultaneous Independent Dual Straight-In ILS Approaches with Runway Centerlines at 3,000 feet using a 4.8 second surveillance update rate.*

[2] Snedecor, George W; Cochran, William G; 1989; *Statistical Methods*, Blackwell Publishing; Ames, Iowa.

APPENDIX: Johnson Probability Density Function Parameters

Table A 1: 20 Degree Yellow Alert To Controller Message

Johnson Type	S - U
Gamma	-0.1802526375E+00
Delta	0.1085824946E+01
Lambda	0.3613785653E+01
Epsilon	0.4217353481E+01
Min	-0.8900000000E+01
Max	0.2230000000E+02
data count	80
ks probability	0.51099

Table A 2: 30 Degree Yellow Alert To Controller Message

Johnson Type	S - U
Gamma	-0.1146314699E+00
Delta	0.7462888311E+00
Lambda	0.1330286422E+01
Epsilon	0.3194929651E+01
Min	-0.1090000000E+02
Max	0.1730000000E+02
data count	74
ks probability	0.40764

Table A 3: Start Of Controller Message To Aircraft Roll

Johnson Type	S - B
Gamma	0.2153147068E+01
Delta	0.1093005789E+01
Lambda	0.4370000000E+02
Epsilon	-0.6000000000E+00
Min	0.4000000000E+00
Max	0.4110000000E+02
data count	122
ks probability	0.28606

Table A 4: TCAS RA To Aircraft Pitch

Johnson Type	S - B
Gamma	0.2867350511E+01
Delta	0.1167684146E+01
Lambda	0.4820000000E+02
Epsilon	-0.9000000000E+00
Min	0.1000000000E+00
Max	0.4530000000E+02
data count	102
ks probability	0.71418

Table A 5: Boeing Rate Of Climb

Johnson Type	S - U
Gamma	0.1067131110E+00
Delta	0.2611758280E+01
Lambda	0.1588962104E+04
Epsilon	0.2653175146E+04
Min	0.6865293600E+03
Max	0.4342489600E+04
data count	74
ks probability	0.67113

Table A 6: Boeing Rate Of Climb Rate

Johnson Type	S - U
Gamma	0.1896637915E+01
Delta	0.6009067804E+01
Lambda	0.1130140399E+04
Epsilon	0.9482999265E+03
Min	0.8893006000E+02
Max	0.1092436970E+04
data count	74
ks probability	0.56233

Table A 7: Airbus rate of climb

Johnson Type	S - B
Gamma	0.2588503685E+00
Delta	0.1296739656E+01
Lambda	0.3862184373E+04
Xi	0.4974634020E+03
Min	0.1105350710E+04
Max	0.3715640800E+04
data count	61
ks probablility	0.45703

Table A 8: Airbus rate of climb rate

Johnson Type	S - B
Gamma	0.3015274459E+01
Delta	0.2653526253E+01
Lambda	0.2577203812E+04
Epsilon	-0.1941004263E+03
Min	0.1323529400E+03
Max	0.9000000000E+03
data count	61
ks probability	0.51567

Table A 9: Maximum Roll Angle

Johnson Type	S - B
Gamma	-0.6205748458E+00
Delta	0.4261810399E+01
Lambda	0.7371147026E+02
Xi	-0.1305228669E+02
Min	0.1658582000E+02
Max	0.3836508000E+02
data count	155
ks probability	0.43472

Table A 10: Roll Angle Rate

Johnson Type	S - B
Gamma	0.2061416909E+01
Delta	0.1962971383E+01
Lambda	0.2108921762E+02
Xi	-0.4094033659E+00
Min	0.1495150000E+01
Max	0.1242857000E+02
data count	154
ks probability	0.69974