7-2024

Study on Pilot Response Time to Reject Takeoff with One Engine Inoperative (OEI)

Lydia Savitri Scrivens
Florida Institute of Technology, lscrivens2018@my.fit.edu

Study on Pilot Response Time to Reject Takeoff with One Engine Inoperative (OEI)

by

Lydia Savitri Scrivens

A thesis submitted to the College of Engineering and Science of
Florida Institute of Technology
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Flight Test Engineering

Melbourne, Florida
July, 2024

We the undersigned committee hereby approve the attached thesis,
"Study on Pilot Response Time to Reject Takeoff with One Engine Inoperative (OEI)."
by
Lydia Savitri Scrivens

Ralph D. Kimberlin, Dr.- Ing.
Professor
Aerospace, Physics, and Space Sciences
Major Advisor

David C. Fleming, Ph.D.
Professor
Aerospace, Physics, and Space Sciences

Brooke E. Wheeler, Ph.D.
Associate Professor
College of Aeronautics

Ratneshwar Jha, Ph.D.
Professor and Department Head
Aerospace, Physics, and Space Sciences

Abstract

Title: Study on Pilot Response Time to Reject Takeoff with One Engine Inoperative (OEI)

Author: Lydia Savitri Scrivens

Advisor: Ralph D. Kimberlin, Dr.- Ing.

The FAA regulation 14 CFR § 25.109 defines accelerate-stop testing for transport-category multiengine aircraft. It specifies that testing must include 2-second distance equivalent at engine failure speed V_{EF} to simulate time taken for pilot to reject takeoff. However, pilot response time is widely debated. The purpose of this study is to determine pilot response time in rejecting a takeoff due to the failure of one engine during the takeoff roll.

Seven multiengine rated pilots participated in this study, which was conducted in a Baron 58 in the X-Plane 12 flight simulator. During the recruiting process, test subject candidates provided their ages and number of logged flight hours, both total and multiengine. The pilots were instructed to perform a normal takeoff but were not advised that they would experience an engine failure at V_Y speed during the takeoff roll. Their response times were determined based on their brake and throttle inputs, and the corresponding horizontal distances traveled by the airplane were recorded as well. It was determined that the number of logged multiengine hours and recent flight experience had significant effects on pilot response time. Although the median response time was less than two seconds, the mean response time that included outliers was a little over three seconds. The results also indicated that the horizontal distance traveled by the airplane was significantly correlated with pilot response time, which may prove to be critical for shorter runways.

Table of Contents

List of Figures

List of Tables

List of Equations

Nomenclature

Acronyms, Abbreviations, and Symbols

$\hat{\beta}_0$	Estimated Intercept
$\hat{\beta}_1$	Estimated Slope.
$\hat{Y}$	Estimated Response
β_0	Intercept
β_1	Slope
°C	Degrees Celsius
AFM	Airplane Flight Manual
ANOVA	Analysis of Variance
ATP	Airline Transport Pilot
CAI	Center of Aeronautics and Innovation
CFI	Certified Flight Instructor
CFR	Code of Federal Regulations
CG	Center of Gravity
Dist	Horizontal Distance Traveled Between V_{EF} Speed And V_1 Speed
dist,___ft	Horizontal Distance Traveled in Feet
FAA	Federal Aviation Administration
FIT	Florida Institute of Technology
ft	Feet

in.	Inches
IRB	Institutional Review Board
KMLB	ICAO Code for Melbourne International Airport
kts	Knots
lbrak,__add	Left Brake Input
lbs.	Pounds
MAD	Mean Absolute Deviation
missn'_time	Mission Time
MultiHrs	Total Multiengine Flight Hours Logged
NASA	National Aeronautics and Space Administration
NPRM	Notice of Proposed Rulemaking
NTSB	National Transportation Safety Board
OEI	One Engine Inoperative
PIC	Pilot in Command
POH	Pilot's Operating Handbook
R^2	R-Squared
rbrak,__add	Right Brake Input
RPM	Revolutions Per Minute
rpm_1,engin	Engine 1 RPM
rpm_2,engin	Engine 2 RPM
RTime	Pilot Response Time
RTO	Rejected Takeoff

SLR	Simple Linear Regression
SSR	Variation Explained by Model
Std. Dev.	Standard Deviation
Syy	Total Variation in Response
TAC	Tactical Air Command
thro1,_part	Engine 1 Throttle Input
thro2,_part	Engine 2 Throttle Input
TotalHrs	Total Flight Hours Logged
TXT	Text File Document
V_1	Airspeed at Which Pilot Takes Corrective Action
V_{EF}	Engine Failure Airspeed
V_{FE}	Maximum Flaps Extended Speed
VFR	Visual Flight Rules
Vind,_kias	Indicated Airspeed
V_{MCA}	Minimal Controllable Speed with OEI, No Flaps
V_{XSE}	Best Angle-of-Climb Airspeed with OEI, No Flaps
V_Y	Best Rate-of-Climb Airspeed
V_{YSE}	Best Rate-of-Climb Airspeed with OEI, No Flaps
Y	Response Variable
x	Predictor Variable
ε	Error in Model

Acknowledgement

I would like to acknowledge Dr. Ralph Kimberlin for the knowledge and guidance he has provided both in his lectures and for my thesis. I would also like to thank Dr. Brooke Wheeler for her advice in my thesis research and her College of Aeronautics IRI funding, as well as Dr. David Fleming for advising me in both my undergraduate and graduate degrees. The mentorship of these individuals has been instrumental in helping me succeed academically.

I would also like to thank the Office of Naval Research for their DON Stem Education and Workforce Grant: Inspiring Students to Pursue U.S. Navy STEM Careers through Experiential Learning N00014-20-1-2669. This grant provided funding for participation incentives in my study.

Additionally, I extend heartfelt thanks to EAA 74 for generously lending their flight simulator equipment for my research and for introducing me to aviation over ten years ago. I would like to thank Dr. Brian Kish for introducing me to flight test engineering and Jennifer Nessmith for her advice and encouragement during my time at Florida Tech. For my research, I would especially like to acknowledge the pilots who participated in my study, Maureen Namukasa and Bhoomin Chauhan for their assistance at the Center of Aeronautics and Innovation, and Dr. Nezamoddin Nezamoddini-Kachouie for his statistical analysis advice.

Lastly, none of this would have been possible without the unwavering support and encouragement from my twin, Hannah Scrivens, and my parents, Lynette Baney-Scrivens and Matthew Scrivens. Their love, sacrifices, and belief in my abilities have given me motivation and strength throughout my academic journey.

Dedication

To the Almighty God, who has provided for me and encouraged me throughout my life. His love, strength, and grace have greatly sustained me in my accomplishments.

Chapter 1
Introduction

Objectives

Accelerate-stop testing is a method of determining the runway distance required for a rejected takeoff (RTO). This is especially used for determining the distance that is traveled by a transport multiengine aircraft when one engine fails.

According to 14 CFR § 25.109, the regulation for accelerate-stop testing, a traveled runway distance equivalent to 2 seconds must be included in an accelerate-stop test to simulate the time it would take for a pilot to recognize an engine failure and take corrective action [1]. In 1998, a Notice of Proposed Rulemaking (NPRM) proposed this change to the FAA to replace the regulation of "two seconds of continued acceleration beyond V_1 speed" [2]. In addition, the proposal recommended that no additional time or distance increments need be applied as long as no more than three pilot actions are needed to reject the takeoff. For every pilot action after that, a 1-second time and distance increment must be added to the 2-seconds distance equivalent [2].

The proposed change of "a traveled runway distance equivalent to 2 seconds" was adopted the same year [3]. Prior to that, the certification of turbine-powered transport category aircraft required that "the time interval used to calculate the AFM accelerate-stop distance must be longer of either the demonstrated time or one second" [2]. For both the previous regulation and the current regulation 14 CFR § 25.109, it is unclear why the distance equivalent of 2 seconds (or one second for the previous regulation) was chosen.

Pilot response time in the event of an emergency is debated. According to an article in the Tactical Air Command's quarterly safety magazine *TAC Attack*, simple reaction time "may occur as rapidly as 0.3 seconds" if the pilot can recognize the problem quickly and is well trained to respond to it [4]. However, in more complex scenarios, that response time "may be 3 – 6 seconds (complex reaction time)". In addition, the pilot may not take action at all if “the perception process is compromised by conflicting data” or if the pilot is unable to understand the new information.

The time available for the pilot to make a decision in the event of an emergency also varies. In 1990, a NTSB special investigation report determined the following for a transport-category turbojet airplane:

“Compounding the difficulty pilots may face in recognizing and reacting to unusual or unique cues is the brief time that elapses between the point at which a transport category turbojet airplane accelerates beyond 100 knots to the point at which it reaches V_1, generally about 4 to 5 seconds. Should an anomaly occur during this time, the crew will have only a second or two to analyze the event and decide if circumstances warrant an RTO.” [5]

Data analysis conducted by Boeing and NASA Langley Research Center suggest that this time period is longer in general for loss-of-control scenarios, where the time available from onset of upset to recovery within limits is 6 – 10 seconds [6].

The purpose of this research is to determine the average pilot response time for rejecting a takeoff due to the failure of one engine in a twin-engine airplane. This may help to determine if the two-second distance equivalent in 14 CFR § 25.109 is enough for simulating the time taken by a pilot to reject the takeoff.

Test Article

The test aircraft chosen for this study was a Beechcraft Baron 58, a twin-engine airplane with a low-wing configuration. Its powerplant consists of two Continental IO-520-C engines, each of which has 285 rated horsepower and a rated maximum speed of 2,700 RPM [7]. Both propellors rotate clockwise.

Although 14 CFR § 25.109 is for transport multiengine airplanes, the choice of aircraft was not important for the purpose of the study, given that the main focus of this study was determining pilot response time. Baron 58 was chosen for ease of use, given that the study was open to multiengine pilots of varying experience levels, including Florida Tech students who were in the process of earning their multiengine ratings.

Given the risks of accelerate-stop testing, a simulator was used instead of an actual aircraft. The simulator chosen for this test was X-Plane 12, which is located at Florida Tech's Center for Aeronautics and Innovation (CAI). This simulator's Beechcraft Baron has an empty weight of 3,983 lbs [8]. and a maximum gross weight of 5500 lbs. The simulator records flight data, which is exported as a txt file.

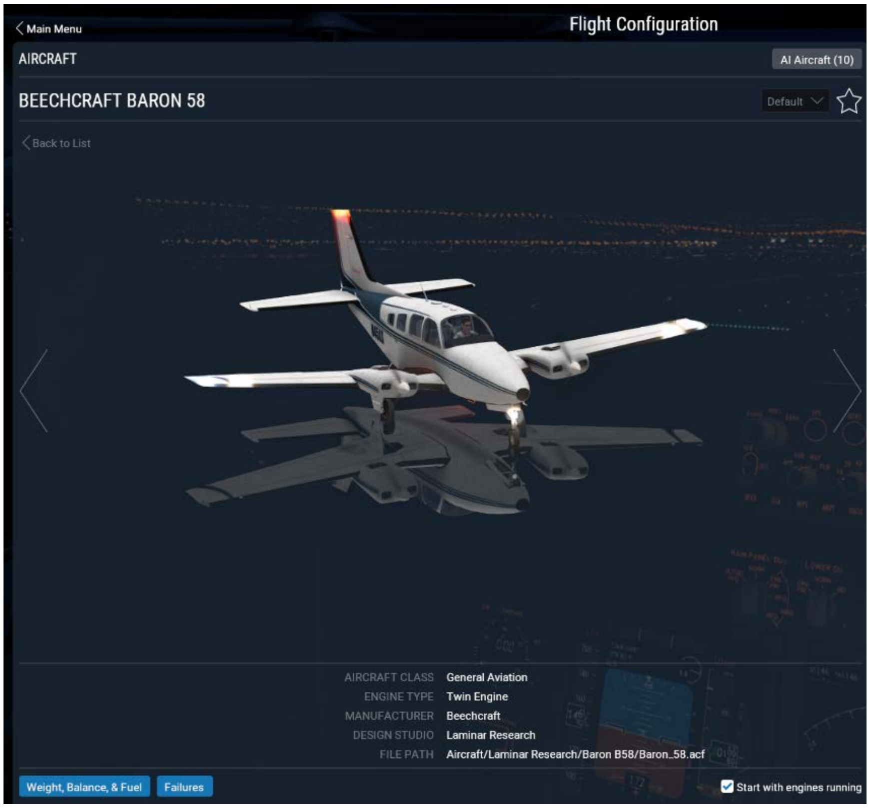


Figure 1: Beechcraft Baron 58 on X-Plane 12 Flight Simulator

For reference, the relevant V-speeds associated with the Baron are listed in knots as follows:

V_Y (Best rate of climb, no flaps) = 105 kts [9]

V_{XSE} (Best Angle of Climb with OEI, no flaps) = 96 kts [7]

V_{YSE} (Best rate of climb with OEI, no flaps) = 100 kts [7]

V_{MCA} (Minimal controllable speed with OEI, no flaps) = 81 kts [7]

V_{FE} (Maximum Flaps Extended Speed) = 122 kts [7]

Test Location and Conditions

All testing was conducted on an X-Plane 12 simulator at Florida Tech's Center for Innovation and Aeronautics (CAI).

Figure 2: Florida Tech Center for Aeronautics and Innovation (CAI)

For each test, the aircraft was set to take off on Runway 09R/27L at Melbourne International Airport (KMLB). Runway surface conditions were dry.

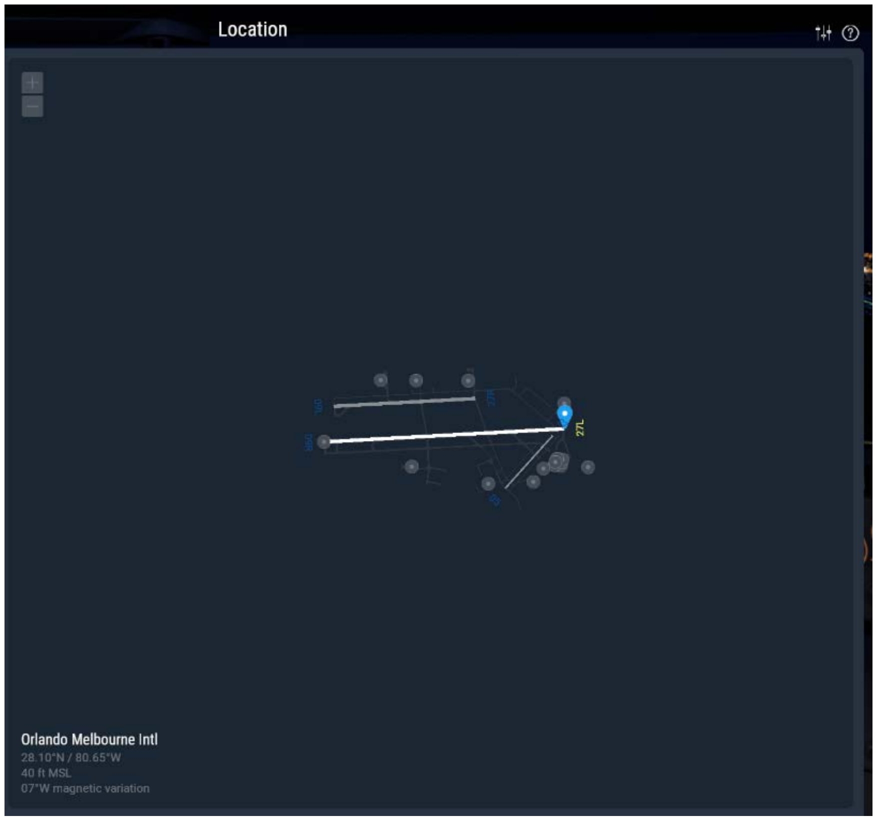


Figure 3: KMLB Airport Diagram on X-Plane 12

Standard weather conditions were used in this test, and there was no precipitation:

- Winds: calm
- Temperature: 15°C
- Barometric Pressure 29.92 in.
- Clear/no clouds below 2500 ft

Weight and Balance

The simulated Baron 58 was loaded at a gross landing weight of 5,400 lbs per the moment limits for maximum takeoff and landing weight in the pilot's operating handbook (POH) [7]. This maximum gross weight was also chosen because X-Plane did not allow for the aircraft to be set at maximum gross weight (5,500 lbs) with full tanks and a forward Center of Gravity (CG) loading. The fuel tanks were full at 300 lbs for each tank, and the remaining weight (817 lbs) was set as payload weight.

A forward CG loading was also used for testing. Ideally, the airplane was to have a maximum forward CG loading, or 83.1 inches forward of center line through the airplane's forward jack points [7]. However, X-Plane's CG setting is a sliding bar that does not list a reference for its "neutral" position. Therefore, an arbitrary CG limit of -5.5 inches from the "neutral" position was chosen, where the negative sign indicates forward CG loading. This was the farthest forward that the simulator settings would allow with full tanks without reducing the maximum gross weight below 5,400 lbs. These weight and balance settings were the same for all tests.

Figure 4: Weight and Balance Settings

Chapter 2
Accelerate-Stop Overview

Accelerate-stop testing is as its name suggests: it is a test in which the Pilot in Command (PIC) accelerates the aircraft to a given speed before applying the brakes and coming to a complete stop on the runway. Additional time is included between the moment the aircraft reaches target speed and the moment the pilot applies brakes to simulate an engine failure during the takeoff roll.

Accelerate-stop testing is also a method used to determine the horizontal distance an aircraft travels during a rejected takeoff. The primary regulation used is 14 CFR § 25.109 (a) [1]:

(a) The accelerate-stop distance on a dry runway is the greater of the following distances:

> *(1) The sum of the distances necessary to—*
>
> > *(i) Accelerate the airplane from a standing start with all engines operating to V_{EF} for takeoff from a dry runway;*
> >
> > *(ii) Allow the airplane to accelerate from V_{EF} to the highest speed reached during the rejected takeoff, assuming the critical engine fails at V_{EF} and the pilot takes the first action to reject the takeoff at the V_1 for takeoff from a dry runway; and*
> >
> > *(iii) Come to a full stop on a dry runway from the speed reached as prescribed in paragraph (a)(1)(ii) of this section; plus*
> >
> > *(iv) A distance equivalent to 2 seconds at the V_1 for takeoff from a dry runway.*
>
> *(2) The sum of the distances necessary to—*

(i) Accelerate the airplane from a standing start with all engines operating to the highest speed reached during the rejected takeoff, assuming the pilot takes the first action to reject the takeoff at the V_1 for takeoff from a dry runway; and

(ii) With all engines still operating, come to a full stop on dry runway from the speed reached as prescribed in paragraph (a)(2)(i) of this section; plus

(iii) A distance equivalent to 2 seconds at the V_1 for takeoff from a dry runway.

As previously described, the distance equivalent of 2 seconds simulates the time needed for the pilot to recognize the problem and take corrective action.

V_{EF} is the speed at which engine failure occurs, and V_1 is the speed at which the pilot takes corrective action [5]. In this test, V_{EF} was set at the V_Y speed for the Baron, or 105 kts. The V_1 speeds for each test were also recorded.

Human Factors Contributing to Pilot Response Time

Various human factors can affect pilot reaction time. The Airplane Flying Handbook covers some key factors:

- Diversion of Attention: May be due to inadequate monitoring, overreliance, or unfamiliarity of automated systems. Pilot may also “attempt to set avionics or navigation equipment while flying the airplane.” [10]

- Task Saturation, or “whenever requirements exceed capabilities” [10]

- Sensory Overload/Deprivation: Although the Airplane Flying Handbook specifically discusses this for upsets during flight, it can be applicable to other situations where a pilot has a limited ability to “adequately correlate warnings, annunciations, instrument directions, and other cues from the airplane”. [10]

The Airplane Flying Handbook also discusses Surprise and Startle Response:

"This human response to unexpected events has traditionally been underestimated or even ignored during flight training. The reality is that untrained pilots often experience a state of surprise or a startle response" [10].

It is then recommended that pilots can reduce this element of startle/surprise through "scenario-based training", and flight instructors can introduce distractions in training "to help provoke startle or surprise" [10]. Again, this is also applicable in a scenario where the pilot needs to reject a takeoff after and engine failure.

Training methods may also have an impact on a pilot's response in the event of an emergency. A journal article by the NTSB cites three factors that affect how pilots make decisions in high-speed rejected takeoffs (RTOs).

"The unique circumstances associated with RTO-related decision-making include the following. There is almost no time available to adequately analyze the event and consider proper alternatives. The cues pilots typically rely on to identify an unusual event are often absent. Finally, pilots generally have little previous experience with unusual events during the high-speed portion of the takeoff roll because of the high reliability of modern aircraft. As a result, they may have difficulty comparing the event with one they have previously experienced" [11].

The article also describes the findings of an investigation made by the NTSB's Safety Board Inspectors, where RTO training for a sample of US airlines was observed. The results of the study revealed that the airlines provided "high quality training and procedures" for RTO events, both in ground school and in training on flight simulators [11]. However, the investigators found that "few airlines presented sufficient information to their flight crews about the stopping capabilities of aircraft approaching V1 to allow pilots to fully evaluate the risks associated with high-speed RTOs" [11]. The same was true for providing pilots "with accurate information on risks associated with high-speed RTOs or of the factors limiting successful RTOs." These findings led the Board to conclude that deficiencies in flight training may contribute to high-speed RTO incidents and accidents [11]. This can certainly be an applicable factor in flight training outside of the airlines.

Finally, age and level of flight experience may have a significant impact on pilot performance and in turn, reaction time. In 1994, a literature review was conducted as part of a research contract for the FAA's Age 60 Rule. Two categories of studies were reviewed: "critical review, analysis, and integration of existing research", and a category of studies "aimed at the development of a 'functional' age profile'" [12].

Several of the articles that were reviewed in this literature review were from a series of studies conducted by Braune and Wickens in 1984 and 1985, where both non-pilots and pilots between the ages of 20 and 60 were given various tasks. In addition to these, studies on the effects of aging and other physiological factors in pilots were conducted or reviewed by Szafran, the National Academy of Sciences' Institute of Medicine, Banich et. al., Gerathewohl, Cerella, Kline et. al., Jensen and Benel, and Stokes et. al. These studies and others are described in the FAA report "Age 60 Study, Part II: Airline Pilot Age and Performance – A Review of the Scientific Literature" [12].

These studies, among others covered in the literature review, found that aging negatively affected various skills, such as perceptual abilities, psychomotor skills, attention to information, memory, and information processing speed. [12]. However, the results of some studies revealed a few contradictions to these conclusions. For psychomotor skills [12] and decision-making [12] especially, subjects who had more practice and experience performed better than those who did not. Newer pilots made worse decisions under "laboratory-induced stress" compared to experienced pilots.

Experience was briefly expanded on in other pilot characteristics covered by the literature review. Based on the results of Golaszewski (1983), where the conclusion that "older pilots with little recent flight experience have a high accident rate" [12] was made, it was presumed that older pilots may have "greater difficulty reacquiring the skills that are lost over the short term when pilots do not maintain currency".

Since pilot age and level of flight experience seem to be significant in determining pilot response during an emergency, the data collected in this rejected takeoff study included the ages of all the pilots who participated in it, as well and the total flight hours and total multiengine flight hours they had logged. The ages of the pilots who participated ranged between 20 and 85 years. Five out of seven participants had over 1000 total flight hours, and all participants except for one maintained currency. Most pilots were either current or former Certified Flight Instructors (CFIs), and at least two were Airline Transport Pilots (ATPs).

Chapter 3
Methodology

Prior to beginning research with human subjects, approval was applied for and granted by the Florida Tech Institutional Review Board (see Appendix 2). Although the risk in this study was minimal, the participants were listed numerically rather than by name to provide anonymity, and they were requested to review and sign consent form in order to participate. A test debrief was included to inform them of the study's purpose.

For this study, pilots from Florida Institute of Technology were recruited to participate. Flyers advertising the study were distributed around the main campus, as well as around the CAI and FIT Aviation buildings (see Appendix 2). A QR code in the flyer provided a link to a survey briefly describing the study, and interested pilots were requested to provide their ages, total flight hours, and total multiengine flight hours. The study was presented to potential candidates as a human factors study with respect to takeoff performance. Both faculty and students with multiengine flight experience were encouraged to participate. When selected, a study session was scheduled for each pilot to participate in the study. Thus, this was a purposive sample of pilots, given that participants were chosen if they had multiengine flight experience.

The participants were instructed to perform one normal takeoff with rotation at V_Y speed (105 kts) and that further information would be given throughout the rest of the test. However, they were not informed that they would experience a simulated engine failure at V_Y speed during the takeoff. The purpose of the test was only revealed to them in the post-test debrief.

A total of seven pilots participated in the study. Although the study was open to pilots of all levels of experience, including student pilots in the process of earning their multiengine ratings, nearly all of the pilots who participated in the study were either current or former (CFIs. At least two of them had an Airline Transport Pilot (ATP) rating as well.

Instrumentation

Data was collected through the use of X-Plane's data acquisition system. This was reserved for use by the flight test engineer (FTE). The participants relied on the instrumentation of the Baron 58's cockpit for testing, and they were advised to pay attention to the airspeed indicator and the tachometers for Engines 1 and 2.

Figure 5: Baron 58 Interior

Test Procedure

The accelerate-stop test procedure is traditionally conducted by a test pilot. Because the purpose of the study was not revealed to the participants until after the test, the procedure was divided among the FTE and the PIC for each study session.

The procedure for the FTE is as follows:

1. Set the data acquisition system to record Mission Time (seconds), Indicated Airspeed (kts), Brake Depression (Left and Right), Engine RPM (1 and 2), and Y Distance (ft).
2. Before each session, set Engine 1 (the left engine) to fail at V_Y in the "Emergencies" tab.

3. Set Runway 27L at KMLB as the aircraft's starting point.
4. Allow the PIC to apply full power, release the brakes, and accelerate the airplane to V_Y.
5. Record Time, Indicated Airspeed, Brake Depression, Engine RPM, and Y Distance
6. Debrief the PIC on the purpose of the study.

The procedure for the PIC is as follows:

1. While holding the brakes, increase engine power to full.
2. Release brakes for the takeoff roll and accelerate to V_Y.

At this point, the engine will fail. The FTE will determine if the PIC takes one of the actions in the following procedure to reject the takeoff:

1. Close both throttles immediately.
2. Apply necessary rudder correction.
3. Apply max braking and stop straight ahead.
4. Turn off master switch and fuel selectors.

The Success Criteria for the test is provided below in Table 1. The first two items to determine success were for the accelerate-stop tests that were conducted. The third item, a verification test based on 14 CFR § 25.109 (a), was omitted during testing due to time constraints.

Table 1: Flight Test Success Criteria

Success Criteria			
	Description	**Success Criteria**	**Test Team**
Accelerate-Stop Test	Determine pilot response time to loss of one engine.	Pilot takes corrective action within 3-6 seconds after engine loss	Lydia Scrivens, Volunteer Pilot
Accelerate-Stop Test	Determine if pilot takes correct corrective actions	Pilot takes the right corrective action after engine loss	Lydia Scrivens, Volunteer Pilot
Verification Test Based on 14 CFR § 25.109 (a)	Determine if airplane comes to complete stop within the sum of distances described by regulation.	Airplane comes to complete stop within the sum of distances described by regulation.	Lydia Scrivens, Volunteer Pilot

Test Hazard Assessment

Simulator testing posed very minimal risk the participants, if any. Because all participants were licensed pilots, they all had flight training or at least flight experience in simulators, and therefore the study posed no greater risk than their regular flight activities. However, a test hazard assessment was created for the test plan to identify potential risks in the event of real-world accelerate-stop testing. Two hazards were identified for this test.

Hazard 1:

The first identified hazard was the risk of the pilot exiting the runway due to the yawing caused by one engine running.

Table 2: Hazard 1 Risk Assessment Table 1

Hazard Number: 1	Risk Assessment					
Test Plan: OEI Ground Roll Testing	Catastrophic	Avoid	High	High	Medium	Low
Flight Test Technique: Accelerate-stop	Hazardous	Avoid	**High**	Medium	Medium	Low
Hazard: Runway excursion	Major	High	High	Medium	Medium	Low
Cause: Insufficient remaining runway distance, delayed pilot response or incorrection action taken	Minor	Medium	Medium	Medium	Low	Low
Effect: Damage to aircraft and airfield, injury to pilot	No Safety Effect	Low	Low	Low	Low	Low
Regulatory Environment: 14 CFR § 25.109	Severity Probability	Frequent	Probable	Occasional	Remote	Improbable

Mitigations and Minimizing Procedures:

1. Pilot must be familiar with aircraft systems and operations, including emergency procedures for an OEI event.
2. Pilot must use the 50/70 rule and/or takeoff distance charts in the Pilot Operating Handbook (POH) to determine if the remaining runway distance is sufficient for a making a complete stop after the engine failure.
3. Pilot must have a pre-takeoff plan that involves the above mitigations.

Emergency Procedures:

1. Apply applicable rudder correction, continue to apply brakes.
2. Reduce power on remaining engine to zero.
3. Wait until airplane comes to complete stop before exiting.

Weather Requirement and/or Flight Conditions: Visual Flight Rules (VFR) conditions, no clouds below 2500 ft pressure altitude, winds no more than 10 kts

Table 3: Hazard 1 Risk Assessment Table 2

Minimum Essential Aircrew:	**YES**	NO	**Parachutes Required:**	YES	**NO**
Post-Mitigation Procedure Risk:	**LOW***	MEDIUM	HIGH	AVOID	

Note: *Indicated as low risk overall because this test will be conducted entirely on a simulator, which removes all risk of injury to the pilot.

Hazard 2:

The second identified hazard was the risk of the aircraft inadvertently becoming airborne during the test.

Table 4: Hazard 2 Risk Assessment Table 1

Hazard Number: 2	**Risk Assessment**					
Test Plan: OEI Ground Roll Testing	**Catastrophic**	Avoid	High	High	Medium	Low
Flight Test Technique: Accelerate-stop	**Hazardous**	Avoid	High	**Medium**	Medium	Low
Hazard: Aircraft inadvertently becoming airborne	**Major**	High	High	Medium	Medium	Low
Cause: Pilot attempt to continue takeoff, wind gust, too much airspeed	**Minor**	Medium	Medium	Medium	Low	Low
Effect: Possible overrun, damage to aircraft and injury to pilot.	**No Safety Effect**	Low	Low	Low	Low	Low
Regulatory Environment: 14 CFR § 25.109	**Severity Probability**	Frequent	Probable	Occasional	Remote	Improbable

Mitigations and Minimizing Procedures:

1. Crew members and pilot must be familiar with aircraft systems and operations, including emergency procedures for an OEI event.

2. Pilot must use the 50/70 rule and/or takeoff distance charts in the pilot operating handbook (POH) to determine if the remaining runway distance is sufficient for a making a complete stop after the engine failure.

3. Pilot must have a pre-takeoff plan that involves the above mitigations.

Emergency Procedures:

1. Apply rudder correction as necessary.

2. Close both throttles.

3. Land on remaining runway length and apply maximum braking.

4. Turn off master switch and fuel selectors.

Weather Requirement and/or Flight Conditions: Visual Flight Rules (VFR) conditions, no clouds below 2500 ft pressure altitude, winds no more than 10 kts

Table 5: Hazard 2 Risk Assessment Table 2

Minimum Essential Aircrew:	**YES**	NO	**Parachutes Required:**		YES	**NO**
Post-Mitigation Procedure Risk:	**LOW***		MEDIUM	HIGH	AVOID	

Note: *Indicated as low risk overall because this test will be conducted entirely on a simulator, which removes all risk of injury to the pilot.

Changes In Test Plan

The first five participants completed the test after a briefing of the simulator's controls, cockpit display, and general takeoff procedure. There were no "familiarization flights" in these tests, partially due to anticipated time constraints. Participants 1 through 4 had no difficulty with the simulator itself, because they had significant experience with flight simulators, so it was further assumed that a "familiarization flight" in the simulator was not needed. However, Participant 5 expressed concern about a lack of a familiarization flight. Although he understood the purpose of not including it, he brought up an important consideration regarding real-world flying. Although one can assume a scenario where a careless pilot may "jump in and go flying", the preflight and startup procedures involved in real-world flying help a pilot "warm up with the airplane" and get reacquainted with its systems. This approach to testing would provide more accuracy rather than simply having the participant conduct the test with only a briefing on the flight controls, target airspeeds, etc. It was then recommended that future participants should have a familiarization flight for this reason. This change was implemented in the tests for Participants 6 and 7.

The familiarization flight involved the pilot taking off from Runway 27L, climbing to 2500 ft at that heading, and making a left turn to a new specified heading. The familiarization flight was ended when the participant felt comfortable with the simulator's controls, and the test proceeded in the same manner as for the previous participants.

Data Reduction

After each test was completed, the data was retrieved in a TXT file, which was then converted into a Microsoft Excel file for data reduction. A table was made for the following parameters:

- Mission time (missn'_time)
- Indicated airspeed (_Vind,_kias)
- Left brake input (lbrak,__add)
- Right brake input (rbrak,__add)
- Horizonal distance traveled in feet (_dist,___ft)
- Engine 1 throttle input (thro1,_part)
- Engine 2 throttle input (thro2,_part)
- Engine 1 RPM (rpm_1,engin)
- Engine 2 RPM (rpm_2,engin)

To find pilot response time, the only data that was used for data reduction were the datapoints from the moment Engine 1 failed to the moment the pilot took corrective action using the throttles and/or the brakes. For both the throttles and brakes, a value of 1 indicated that these controls were "engaged", while a value of 0 signified that they were "disengaged". Therefore, when the pilot applied corrective action, the input values for the throttles were reduced to zero, while the input values for the brakes were increased to 1.

For each set of data, the pilot response time and the distance traveled by the airplane were found by subtracting the first mission time and horizontal distance datapoints in the set from the last datapoints. The data acquisition system's mission time was found to be twice as fast as the actual time during the last test session during the data reduction for

Participant 6's test. This was confirmed when a stopwatch was used to time Participant 7's test. Therefore, mission time was corrected by dividing the recorded mission time values by 2 to find the actual pilot response time in seconds. Once this was done for all the tests, a table of results was made for pilot age, total flight hours, total multiengine flight hours, pilot response time, distance traveled, V_{EF} speed, and V_1 speed.

Statistical Analysis

Once the results were tabulated, the minimum value, maximum value, mean, median, standard deviation, variance, and mean absolute deviation (MAD) were found for each variable. MAD is the average of how much the individual values in a data set differ from the set's mean [13], and it is similar to standard deviation and variance in that it can be used to determine the variability in the data.

Regression was used to determine the correlation between pilot response time, pilot age and number of flight hours (total and multiengine). It was also used to determine the relationship between horizontal distance traveled and pilot response time. For simplicity, simple linear regression (SLR) models were used. Given the extremely small size of the data set of results, as well as the fact that all variables were numerical and continuous, SLR was determined to be better suited for this study than other statistical models. All models and their relevant plots were made using the statistical software RStudio version 4.3.0.

Simple linear regression is used to determine the relationship between a dependent variable Y (also known as the response variable) and independent variable (predictor) that influence it, or x [14]. There can be several predictors in a SLR model, but for this study, models with the response variable "Pilot Response Time" and one predictor ("Participant Age", "Total Flight Hours", or "Total Multiengine Flight Hours") were generated.

The general equation for a true linear regression model with one predictor is as follows:

Equation 1

$$Y = \beta_0 + \beta_1 x + \varepsilon, \text{ [14]}$$

where β_0 is the intercept of the line, β_1 is the slope, and ε is the error in the model that accounts for random variation.

The exact values for β_0 and β_1 are unknown for a data set, so an SLR model is used to determine their estimates. The response Y can also be estimated from the line generated in a SLR model. Therefore, the estimated model for SLR with one predictor is

Equation 2

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x,$$

where $\hat{Y}$ is the estimated response, $\hat{\beta}_0$ is the estimated intercept, and $\hat{\beta}_1$ is the estimated slope.

To determine the goodness of fit between the predictor and the response, the coefficient of determination R^2 is used. R^2 is the percentage of variation explained by the model with respect to the total variation in the response. In other words,

Equation 3

$$R^2 = \frac{SSR}{Syy}. \text{ [14]}$$

The higher the R^2, the closer the relationship is between the response and the predictor, and the better the model explains the variation in Y. [14]

Two sets of SLR models were made for pilot response time vs. total flight hours, pilot response time vs. total multiengine flight hours, and horizontal distance vs. pilot response time. The first was with all participants, and the second was without outliers in pilot response times.

To “fact-check” the results of the generated SLR models, a three-way Analysis of Variance (ANOVA) was used to determine which of the three main predictors (Participant Age, Total Flight Hours, Total Multiengine Flight Hours) was the most significant. ANOVA compares and measures variables to determine their significance to the response [15]. An ANOVA table provides the F-statistics for each variable, which indicates whether or not the variable is significant. A null hypothesis H_0 assumes that the variables are not significant, it is rejected in favor of the alternative hypothesis H_1, which is that the variable(s) are statistically significant. Therefore, a variable with a higher F-statistic indicates that it is more significant.

An ANOVA model with interactions between all three predictors (denoted by asterisks) was used to create the ANOVA table for this study. In RStudio, the function and equation were as follows:

Equation 4

$$aov(RTime \sim Age + TotalHrs + MultiHrs, data = RTODATA)$$

Since Total Flight Hours and Total Multiengine Flight Hours are not entirely independent of each other, a model with interactions would be ideal for these variables. However, interactions resulted in a saturated model, where there are no residuals and therefore no F-statistic values to analyze. Therefore, an additive model was used, where the variables are simply added together.

Chapter 4
Analysis and Results

Results

Table 6 provides the results of the tests conducted. A total of seven tests were conducted.

Table 6: Table of Results

Participant	Age (years)	Total Hrs	Multi Hrs	Response Time (s)	Horiz. Distance (ft)	V_{EF} (kts)	V_1 (kts)
1	30	1300	110	2.113	711.9	89.6	101.8
2	22	1000	26	1.596	552.4	96.1	103.0
3	51	11100	9300	10.597	3424.1	102.8	82.2
4	35	3400	450	1.585	366.5	100.9	99.9
5	41	376	16	10.574	2006.4	99.3	80.3
6	23	460	28	1.585	549.2	100.0	100.9
7	84	9300	2500	2.644	893.8	98.1	95.5

Table 7: Key for Table of Results

Key:
applied correct response
applied correct response, exited runway
applied correct response, crashed on runway
did not apply correct response, crashed

The majority of pilots in this study were between 20 and 50 years old, as shown in Figure 6.

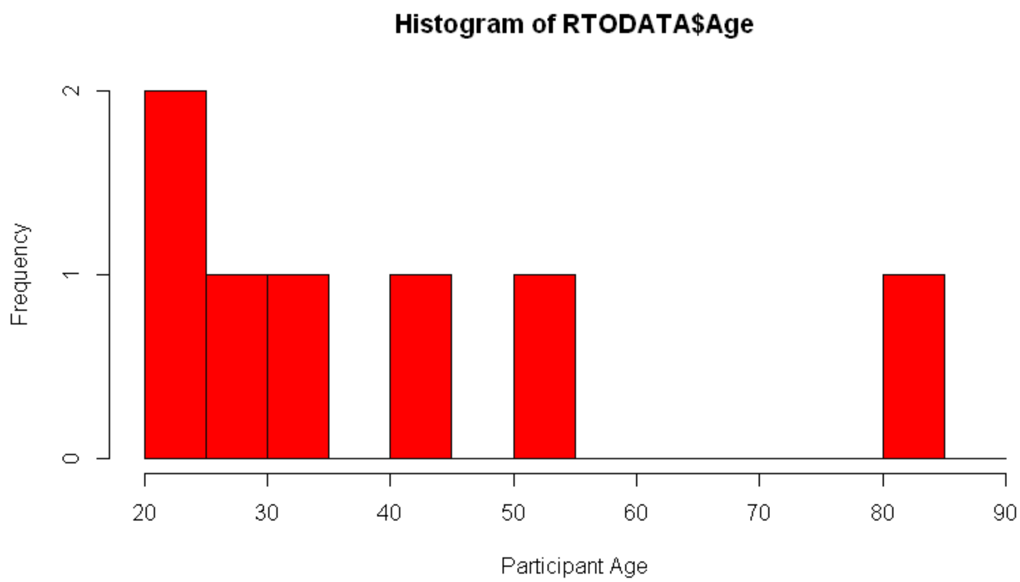


Figure 6: Participant Age Histogram

Figure 7 shows the frequency diagram of pilots by total flight hours. Four participants with less under 2000 total flight hours, which corresponds with the majority of participants between 20 and 40 years of age in Figure 6.

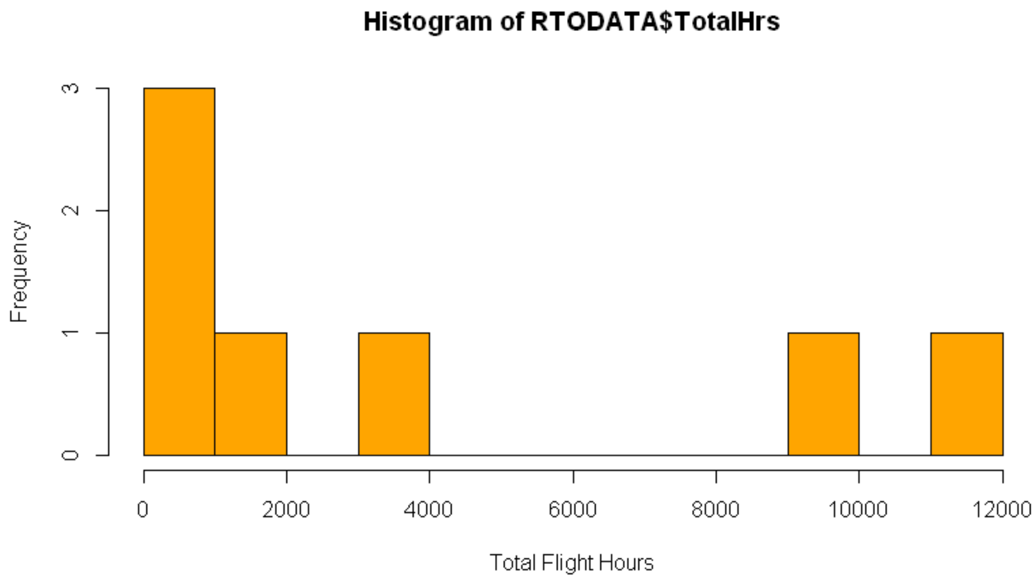


Figure 7: Participant Total Flight Hours Histogram

Figure 8 is a histogram of the participants' total multiengine flight hours. It visually shows that the majority of participants had less than 500 hours in multiengine aircraft.

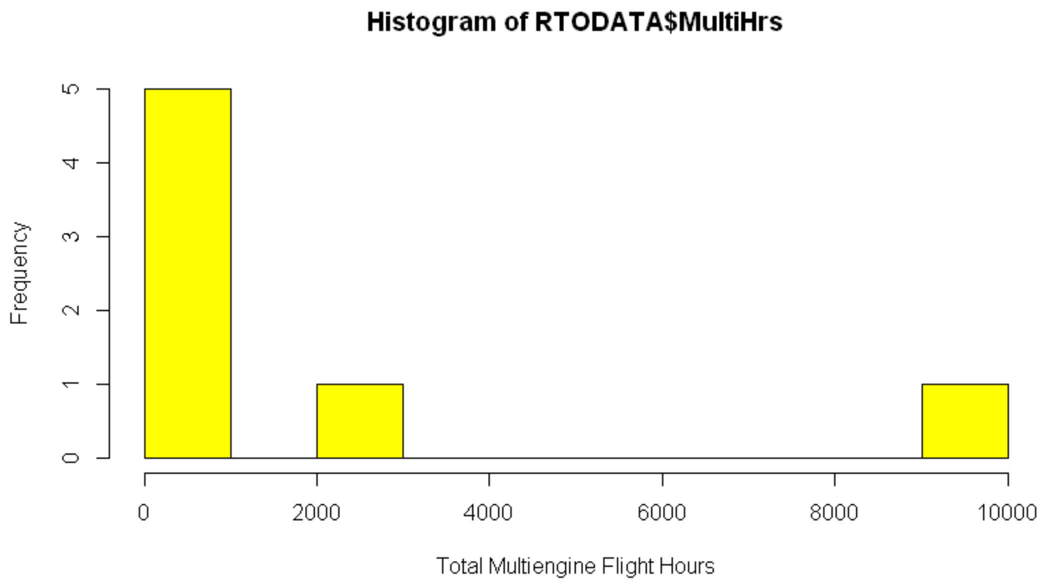


Figure 8: Participant Total Multiengine Flight Hours Histogram

Figure 9 visually represents the participants' response times for all RTO tests.

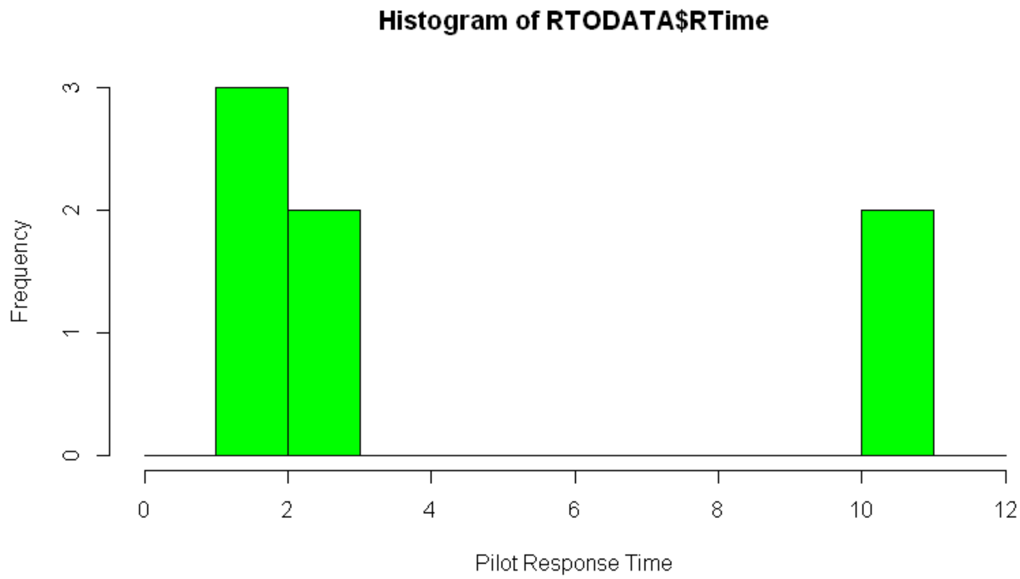


Figure 9: Pilot Response Time Histogram

For the most part, the participants responded quickly to the engine failure and provided the correct response (applying brakes, reducing engine power, etc.). With the exception of the two outliers, who both had response times of roughly 10.5 seconds, pilot response time ranged between 1 and 3 seconds.

Figure 10 is a histogram of the horizontal distance traveled between V_{EF} and V_1 for all tests.

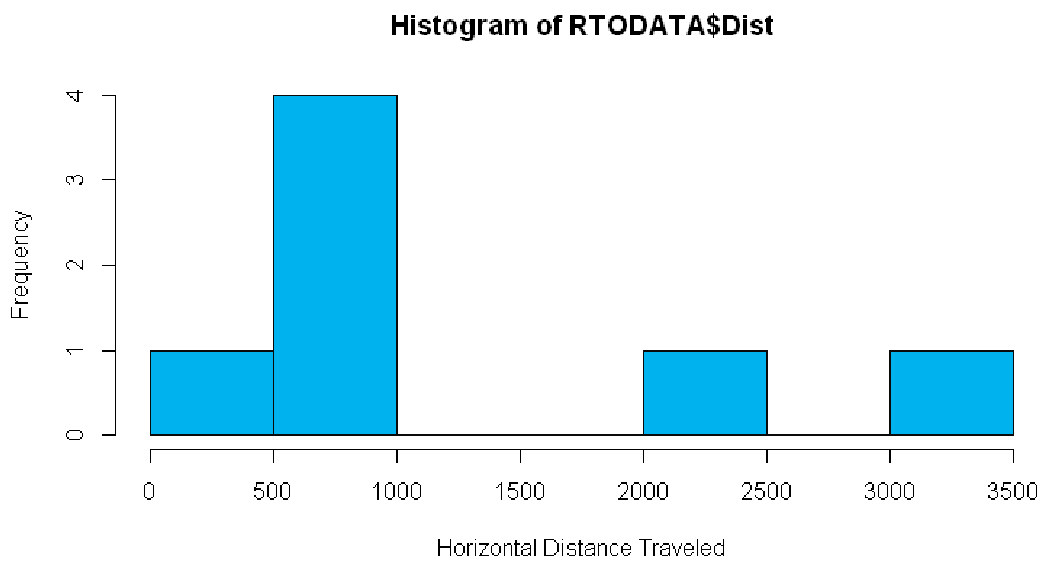


Figure 10: Histogram of Horizontal Distance Traveled

With the exceptions of Participants 3 and 5, the horizontal distances traveled by the airplane in these tests were under 1000 ft, with the shortest distance being just under 300 ft and the longest distance under 1000 ft being 893.8 ft. The longest distance traveled was over 3000 ft, when the participant exited the runway multiple times. These distances are significant, considering that most of the participants' response times were very short.

Figures 11 and 12 are histograms of the V_{EF} and V_1 speeds for all tests. The majority of airspeeds for both were above 95 kts. There was some inconsistency in the V_{EF} speeds, even though Engine 1 was set to fail at a V_{EF} speed of 105 kts in each test. It seems that the set V_{EF} speed was based on the simulated Baron 58's airspeed indicator, which was not entirely reflective of the airspeeds recorded by the data acquisition system. Perhaps this was because of real-world factors that the simulator was imitating, such as ground speed, which often differs from indicated airspeed, and friction between the airplane's wheels and the runway surface.

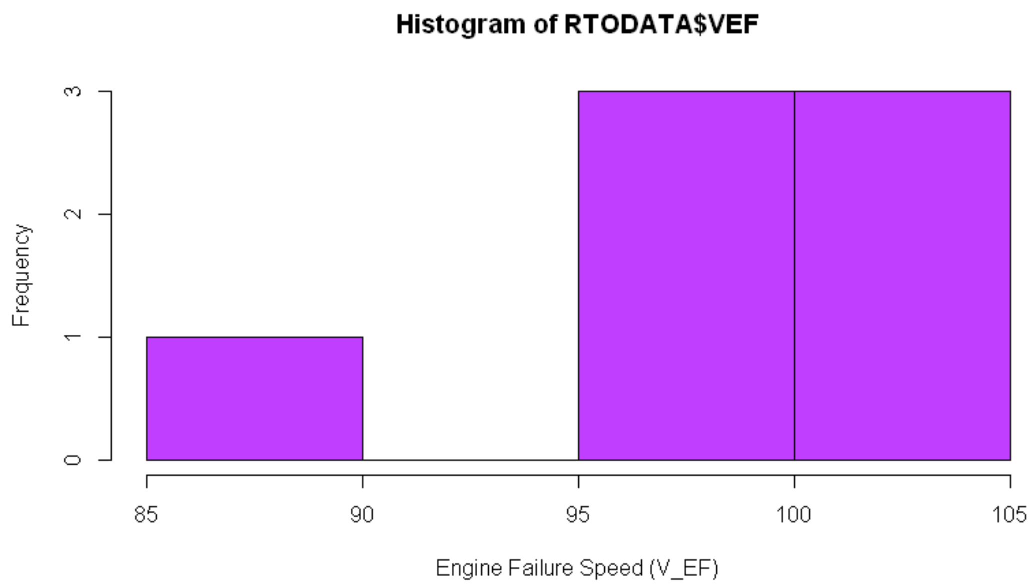


Figure 11: V_{EF} Speed Histogram

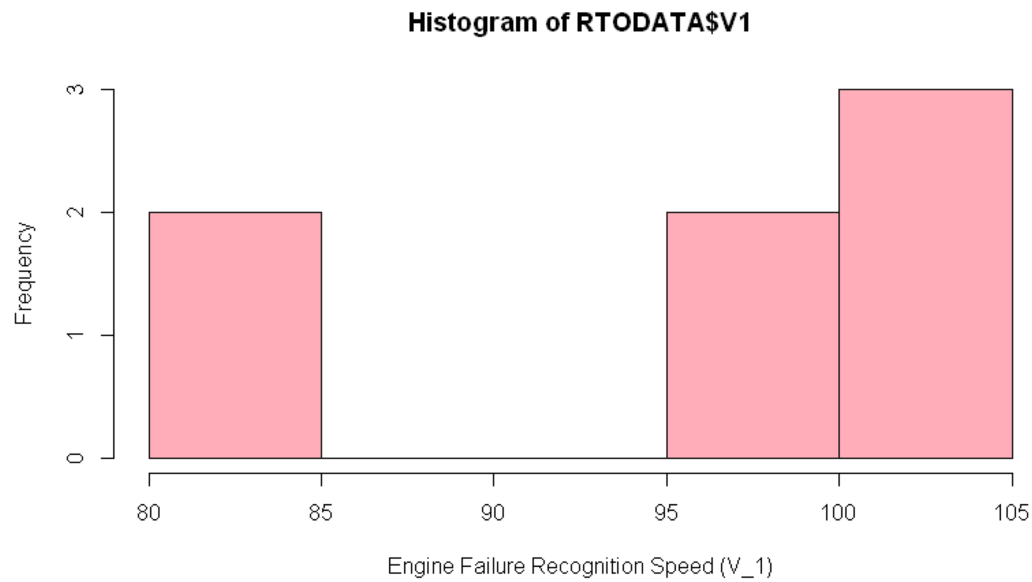


Figure 12: V_1 Speed Histogram

The sensitivity of the simulator affected the participants' abilities to stay on the runway, even for those who applied the correct response to the Engine 1 failure. This was the reason why Participant 4 had crashed after briefly becoming airborne, despite following the correct procedure for a rejected takeoff. The lack of physical flight cues, like airplane movement and distinct engine noise, also contributed to handling difficulties. For example, Participant 3 said that the change in engine noise was not as clear over the simulator's speakers as in a real airplane, which led to him not noticing that Engine 1 had failed until after the test. Based on the feedback from Participants 6 and 7, it seemed that having a "practice run" before the test helped them become familiar with the simulator's differences from an actual aircraft. It may have also helped to improve their test results compared to the previous five tests.

It was also noted that many of the participants who had nearly equal amounts of real-world and simulated flight time, particularly pilots who were current and former flight instructors, performed slightly better than those who had more real-world time than simulator time. This also explains to a degree why some participants had difficulties with the simulator's sensitivity, while others who had more recent simulator experience tended to have less difficulty.

Statistical Analysis

According to Table 8, the median pilot response time was 2.11 seconds, and the mean pilot response time was 4.38 seconds.

Table 8: Statistical Analysis of Results

	Age (years)	Total Hrs	Multi Hrs	Response Time (s)	Horiz. Distance (ft)	V_{EF} (kts)	V_1 (kts)
Min	22	376	16	1.58	366.5	89.57	80.31
Max	84	11100	9300	10.60	3424.1	102.81	103.04
Mean	40.9	3848	1776	4.38	1214.9	98.12	94.81
Median	35	1300	110	2.11	711.9	99.28	99.86
Std. Dev.	21.6	4484	3437	4.25	1115.4	4.32	9.57
Variance	398.7	20108875	11814031	18.09	1244155.0	18.66	91.59
MAD	15.3	3630	2357	3.54	857.3	3.02	7.75

Without the two outliers in pilot response time, which were both over 10 seconds, the median pilot response time was 1.60, and the mean was 1.90 seconds (see Table 9).

Table 9: Statistical Analysis of Results Without Outliers

	Age (years)	Total Hrs	Multi Hrs	Response Time (s)	Horiz. Distance (ft)	V_{EF} (kts)	V_1 (kts)
Min	22	460	26	1.58	366.5	89.57	95.54
Max	84	9300	2500	2.64	893.8	100.92	103.04
Mean	38.8	3092	623	1.90	614.8	96.94	100.24
Median	30	1300	110	1.60	552.4	98.09	100.89
Std. Dev.	25.8	3645	1064	0.47	198.2	4.52	2.88
Variance	666.7	13287320	1131665	0.22	39273.6	20.43	8.28
MAD	18.1	2606	751	0.38	150.5	3.28	2.03

Out of all the variables in both tables, pilot response time had the least variation, possibly because most of the participants had significant recent flight experience in multiengine aircraft. The number of flight hours (both total and multiengine) had the greatest variation.

Figure 13 is a scatter plot of response time with respect to age. The SLR model for it was "RTime ~ Age".

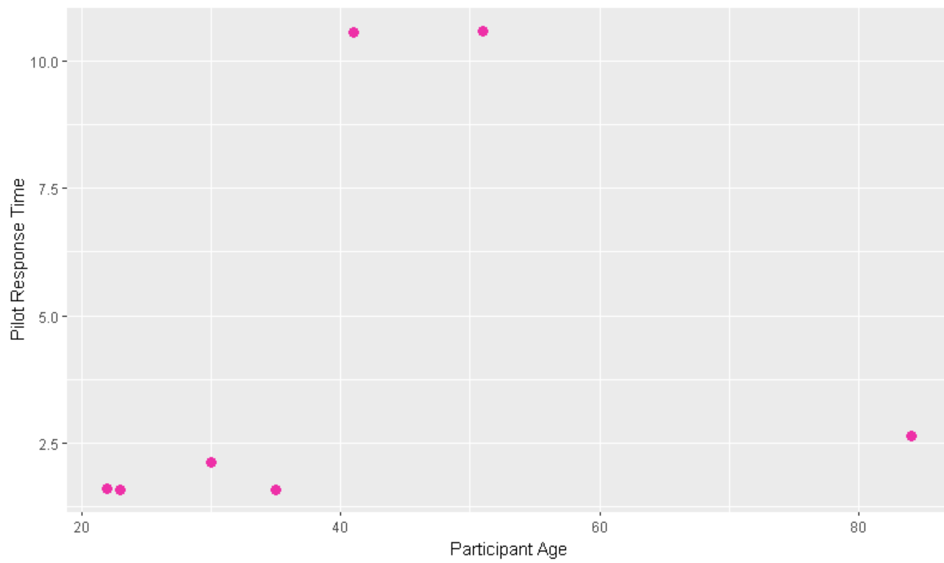


Figure 13: Pilot Response Time vs. Participant Age

The regression of the SLR model $\hat{Y} = 2.446 + 0.0475x$ has an R^2 of 0.058. This indicates a poor model fit to the data, as only five percent of the variation in pilot response time can be explained by pilot age. Because there is so much variation, it cannot be concluded that age is a useful predictor of pilot response time.

Figure 14 is a scatter plot of total flight hours with respect to response time, and it includes the trendline for the SLR model “RTime ~ TotalHrs”.

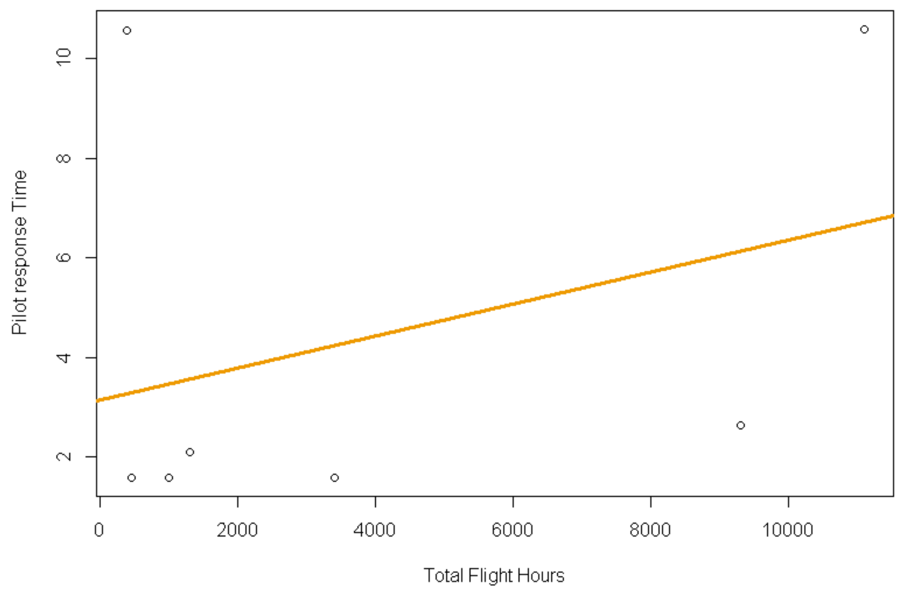


Figure 14: Pilot Response Time vs. Total Flight Hours with SLR Model Trendline

The equation for the linear model “RTime ~ TotalHrs” $\hat{Y} = 3.156 + (3.194 \times 10^4)x$, and the R^2 was 0.113. This indicates a better fit for the data presented in Figure 14 than for “RTime ~ Age”. However, it still indicates that total flight hours is not a very useful predictor of pilot response time.

Although it may seem that response time gets worse with more total flight hours, it may be due to variations in pilot currency and amount of recent flight experience. For example, Participants 2 and 6 had relatively low amounts of total flight time, but performed well because they had significant recent experience in simulators. In contrast, Participant 5, who also had low time, had not flown in a while and therefore did not respond to the engine failure quickly. Participant 3 had the most total flight hours, he had more experience in actual aircraft than in flight simulators, which he claimed played a part in him not recognizing the engine failure due to lack of noticeable changes in engine noise. Meanwhile, Participant 7, who had the next highest number of total flight hours, quickly recognized the situation, and took corrective action. Therefore for this sample of pilots, it seems that the amount of recent flight experience affected how quickly the participants reacted to the engine failure. Additionally, the participants who had recent flight experience in simulators tended to respond faster than those who did not.

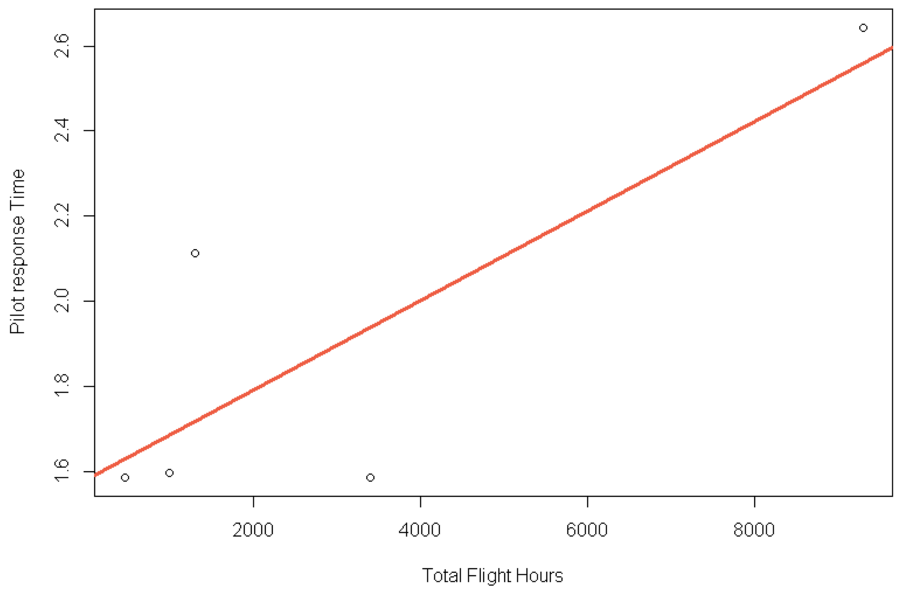


Figure 15: Pilot Response Time vs. Total Flight Hours without Outliers

Without the two outliers in pilot response time, the model "RTime ~ TotalHrs" became $\hat{Y} = 1.579 + (1.054 \times 10^4)x$, where the R^2 was 0.664. This is a significantly better model fit than in Figure 14. Once again, recent flight experience, especially in flight simulators, may have led to the trends in Figure 15.

Figure 16 is a scatter plot of response time with respect to total multiengine hours with the trendline that was generated from the SLR model “RTime ~ MultiHrs”. The model’s equation was $\hat{Y} = 3.086 + (7.316 \times 10^4)x$.

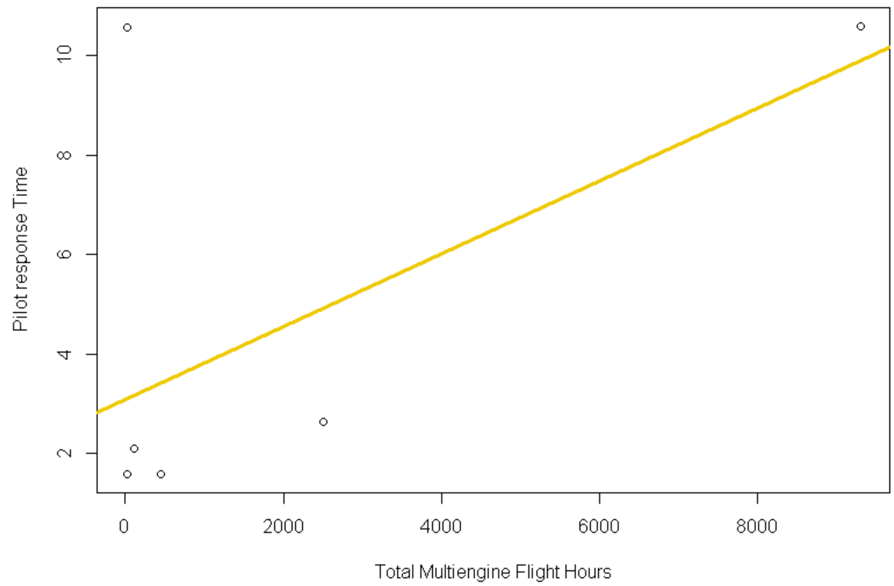


Figure 16: Pilot Response Time vs. Total Multiengine Flight Hours with SLR Model Trendline

With an R^2 of 0.350, this model fits the data better than the models “RTime ~ Age” and “RTime ~ TotalHrs”. Although this trend is similar as in total flight hours plot, where the participants with more current flight experience (especially in flight simulators) had shorter response times compared to those who were less current, the slightly higher R^2 indicates that multiengine flight hours is a more significant predictor of pilot response time than total flight hours or age.

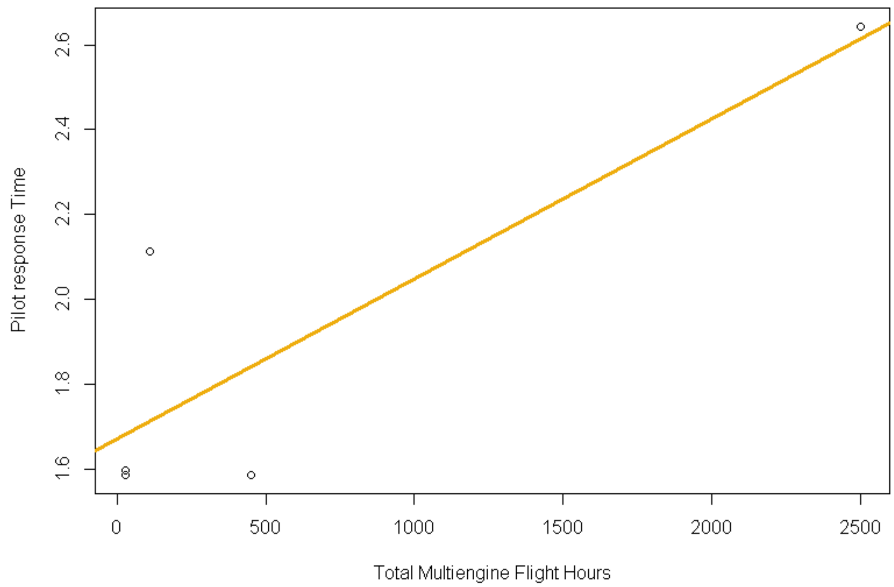


Figure 17: Pilot Response Time vs. Total Multiengine Flight Hours Without Outliers

The same trend is evident in the SLR model without outliers, where the equation is $\hat{Y} = 1.669 + (3.777 \times 10^4)x$ and the R^2 is 0.726. This also seems to confirm that the number of multiengine hours that a pilot has logged is more of a significant predictor of response time than pilot age or the number of total flight hours logged.

Figure 18 plots the horizontal distance traveled by the airplane between V_{EF} and V_1 with respect to pilot response time. It includes the trendline that was generated from the SLR model "Dist ~ RTime", which was $\hat{Y} = 148.0 + 243.3x$. This plot was made determine if there was a linear relationship between response time and distance traveled.

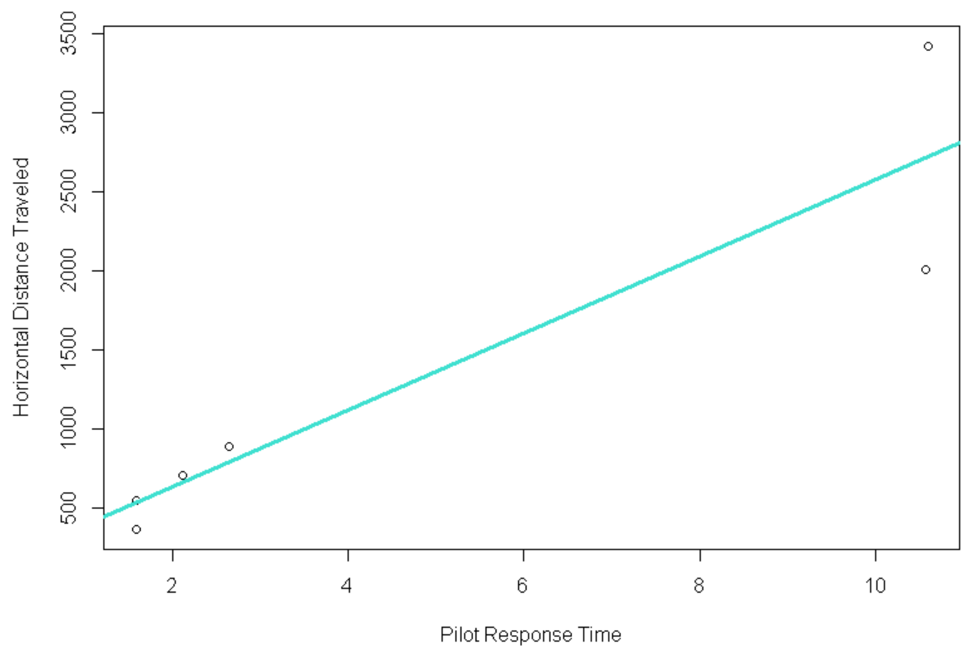


Figure 18: Horizontal Distance Traveled vs. Pilot Response Time with SLR Model Trendline

The R^2 for the trendline in Figure 21 was 0.861. The model's good fit of the data clearly shows that the distance travels between V_{EF} and V_1 increases with pilot response time. It also shows how far the airplane can travel even within less than three seconds. A long runway like Runway 09R/27L can accommodate additions in takeoff roll length that are similar to the horizontal distances traveled in these tests, but for shorter runways, the risk of a runway excursion due to a delayed pilot response is much higher.

The three-way ANOVA model “RTime ~ Age + TotalHrs + MultiHrs” was generated to “fact-check” the SLR models for pilot age, total flight hours, and total multiengine flight hours. Table 9 is the resulting ANOVA table:

Table 10: Three – Way ANOVA Results

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Age	1	6.280	6.280	1.637	0.291
TotalHrs	1	6.160	6.160	1.606	0.295
MultiHrs	1	84.580	84.580	22.033	0.018 *
Residuals	3	11.520	3.840		
Signif. codes: 0 ‘*’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1**					

The main focus of this table is the individual predictors. All of the F-statistic values are very low, due to the significant variance in participant age and both flight hours predictors. The fact that the variables did not exactly show normality (see Appendix 5) may have contributed to this as well. However, the multiengine flight hours variable has the highest F-statistic at 22.033. This confirms that total multiengine hours is most significant in explaining pilot response time for this data set.

Chapter 5
Conclusions

The pilot response times determined in this study had a mean (average) of 4.38 seconds and a median (middle) response time value of 2.11 seconds. Both of these values exceed the 2-second distance requirement in 14 CFR § 25.109. This suggests that 2 seconds is not enough time to simulate pilot response time in an accelerate-stop test, especially given the fact that four out the seven participants had response times that were greater than 2 seconds. Without the two outlier response times (10.597 seconds and 10.574 seconds), the mean response time was 1.90 seconds, and the median was 1.60 seconds. Both of these values are under 2 seconds, but it may not be reasonable to conclude that the 2-second distance requirement is enough time, especially because Participants 1 and 7 responded to the engine failure after just over 2 seconds.

With the two outliers taken into account, the mean pilot response time of 4.835 seconds falls within the estimated complex reaction time estimate of 3-6 seconds that was described in the *TAC Attack* article on information processing. Additionally, the two outlier response times support the findings from the research by Boeing and NASA's Langley Research Center, which ranged from 6 to 10 seconds. Additional studies with a larger sample size of pilots to cover the upper ranges for age and flight hours would better determine if the 2-second distance requirement is enough to simulate pilot response time, but based on this this study, it can be concluded that 2 seconds is not enough time. Even if a pilot has received excellent flight training, as was described in the FAA investigation of flight training provided by airlines, they may not recognize the signs of an engine failure and therefore take much longer than 2 seconds to react, which was the case for Participant 3.

None of the SLR models with all the test results showed a strong fit of the data for pilot response time and age, pilot response time and total flight hours, or pilot response time and total multiengine flight hours. The model for response time with respect to pilot age ($\hat{Y} = 2.446 + 0.0475x$) had a R^2 of 0.058, which indicated that pilot age was not a good predictor of pilot response time for this study. The SLR models for response time with respect to total flight hours ($\hat{Y} = 3.156 + (3.194 \times 10^4)x$) and pilot response time with respect to total multiengine hours ($\hat{Y} = 3.086 + (7.316 \times 10^4)x$), with respective R^2 values of 0.113 and 0.350, are also not very good fits of the data, though the latter explained the highest amount of variance (35%) in the data. Without the two response time outliers, however, the SLR models for response time with respect to total flight hours ($\hat{Y} = 1.579 + (1.054 \times 10^4)x$) and response time with respect to total multiengine hours ($\hat{Y} = 1.669 + (3.777 \times 10^4)x$) fit the data better. The model for response time vs. total flight hours explained 66.4% of the variance in the data, and the model for response time vs. multiengine flight hours explained 72.6% of the variance. Therefore, it can be concluded that the number of multiengine flight hours had the greatest effect on pilot response time in this sample of pilots, and the number of total flight hours was the second most significant factor in explaining response time.

Overall, it is clear that pilot response time varies based on the pilot's flight experience. Recent flight experience is especially key, whether it is in a simulator or in an actual airplane. A pilot with less recent experience or less flight hours may take longer to recognize the signs of an engine failure and take action. Similarly, a pilot who is unfamiliar with an airplane or who misses cues related to an emergency situation may have a longer response time. Therefore, 2 seconds is not enough time to accurately simulate pilot response time in accelerate-stop testing when longer response times by unprepared pilots are taken into account.

Pilot response time in turn has a significant effect on runway distance. The SLR model for horizontal distance traveled by the airplane with respect to response time ($\hat{Y} = 148.0 + 243.3x$) showed this clearly by explaining 86.1% of the variance in the data. Between 1 and 2 seconds, the airplane can cover a horizontal distance of anywhere between 300 and 900 ft at an airspeed equal to or near V_Y speed. Even a few hundred feet are critical for shorter runways when rejecting a takeoff. Therefore, increasing the time-distance equivalent in accelerate-stop testing may be beneficial in determining if a takeoff can be safely rejected in a twin-engine airplane for relatively short runways.

Increasing the time-distance requirement for accelerate-stop testing would also affect the sum of distances needed to reject a takeoff for transport-category aircraft. If the 2-second distance requirement is changed to 3 or 4 seconds, for example, the sum of distances traveled by the aircraft in a test would be increased by at least a few hundred feet. Therefore, it may lead to a situation where a current transport-category aircraft is retested and found to have a new accelerate-stop distance that would restrict it from taking off at airports with runways that are not long enough to accommodate that distance.

Future Research and Suggestions

More accelerate-stop testing like this study would be beneficial in better determining an ideal time length for simulating pilot response time. Several lessons can be learned from this study. The first is that more time to recruit more pilot participants is needed. Ideally, a sample size of 30 to 40 participants would reduce the amount of error in the statistical analysis. A larger sample size would also allow for a wider range of pilots with varying skill levels, including student pilots. Including the pilots' backgrounds (student, CFI, ATP, etc.) as another variable in the data may also provide further insight into pilot response time, especially because the participants who responded the quickest in this study had current or very recent CFI experience.

More time for each study session would also allow for more test runs that could produce better results, although it might come with a trade-off in mortality and/or willingness to participate in a longer study. Designating the first test run as a normal familiarization flight that includes preflight operations would allow the participant to become comfortable with the simulator and therefore be more prepared for the rest of the session. More test runs would provide redundancy in testing and allow for the FTE to add variation in the engine failures, such as failing different engines in different test runs or failing the engine at a lower airspeed.

Finally, using a flight simulator with a better audio system and motion capabilities would be beneficial for testing, because it would provide more realism for participants. This way, the participants will be able to recognize the signs of an engine failure more easily than in a stationary simulator.

References

[1] “14 CFR § 25.109 ‘Accelerate-stop distance.’” National Archives and Records Administration, Jan. 3 2024 [Online]. Available: https://www.ecfr.gov/current/title-14/chapter-I/subchapter-C/part-25/subpart-B/subject-group-ECFR14f0e2fcc647a42/section-25.109

[2] Ford, T., “Rejected takeoff and landing,” *Aircraft Engineering and Aerospace Technology*, vol. 70, Dec. 1998, pp. 1–5.

[3] “63 FR 8298 – Improved Standards for Determining Rejected Takeoff and Landing Performance”, FR 98-3898, 1998, p. 8318

[4] Santilli, S. R., “Information Processing and You,” *TAC Attack*, vol. 2, Jun. 1985, p. 8.

[5] National Transportation Safety Board, “Special Investigation Report: Runway Overruns Following High Speed Rejected Takeoffs,” NTSB/SIR-90/02, National Transportation Safety Board, Washington, DC, February 1990. pp. 18–32.

[6] Oppenheimer, P., “Pilot response in time critical aircraft upset/loss of control inflight (LOC-I) events,” *Aviation Performance Solutions*, Jan. 1 2024 [Online]. Available: https://apstraining.com/resource/pilot-response-time-critical-aircraft-upsetloss-control-inflight-loc-events-2/. p. 5.

[7] “Beechcraft Baron 58 and 58A Pilot’s Operating Handbook and FAA Approved Airplane Flight Manual.” Raytheon Aircraft Company, July, 1994. pp. 2-5–6-10.

[8] X-Plane, X-Plane Beechcraft Baron 58 Pilot’s Operating Manual, Columbia, SC: Laminar Research, 2024.

[9] FSFlyingSchool, “Features of the FSFlyingSchool for FSX Detail Pack for Beechcraft Baron 58,” *FSFlyingSchool*, Feb. 15 2024 [Online]. Available: https://www.fsflyingschool.com/Baron-Detail-Pack-Features.asp.

[10] Federal Aviation Administration, “Chapter 5: Maintaining Aircraft Control: Upset Prevention and Recovery Training,” *Airplane Flying Handbook*, Washington, DC: Federal Aviation Administration, 2021, pp. 5-2–5-3.

[11] Strauch, B., “Factors Affecting Pilot Decision-Making in Rejected Takeoffs,” *SAE Technical Paper Series*, vol. 99, Dec. 1990, pp. 2–7.

[12] Hyland, D. T., Kay, E. J., Deimler, J. D., Gurman, E. B., Hilton Systems, Inc., and Civil Aeromedical Institute, “Age 60 Study, Part II: Airline Pilot Age and Performance – A Literature Review,” DOT/FAA/AM-94/21, Civil Aerospace Medical Institute, Washington, DC, October 1994. pp. 9–17.

[13] Onslow County School District, “Mean Absolute Deviation Notes and Examples,” *Onslow County School District*, July 2, 2024 [Online]. Available: https://www.onslow.k12.nc.us/cms/lib/NC02213593/Centricity/Domain/9562/Mean%20Absolute%20Deviation%20Notes%20and%20Examples.pdf.

[14] Nezamoddin-Kachouie, N., *Linear Regression Analysis-Notes.pdf*, Melbourne, 2024. pp. 3–84.

[15] Tamplin, T., “Analysis of variance (ANOVA): Definition, types, and example,” Finance Strategists, July 2, 2024 [Online]. Available: https://www.financestrategists.com/wealth-management/fundamental-vs-technical-analysis/anova/.

Appendices

Appendix 1: Test Cards

Figures 21 – 26 are the test cards that were prepared for this study. They were used as a guideline for each test session.

1	ADMIN CARD FLIGHT TEST ENGINEERING THESIS| EVENT: __/__/__ - __
	TEST AIRCRAFT:
	CALLSIGN:
	PILOT:
	CO-PILOT:
	PAX #1:
	PAX #2:
	TEST CONDUCTOR:
	GROUND #1:
	GROUND #2:
	GROUND #3:
	T/O TIME:
	LANDING TIME:
	TOT FLT:

Engineering Notes:

Figure 19: Test Card 1

2 | **DANCE CARD**

FLIGHT TEST ENGINEERING THESIS| EVENT: __/__/__ - __

Card #	CARD TITLE	# OF RUNS	ALT
3	MAN-UP / PRE-TEST ZEROES	1	—
4	ENGINE START / CONTROL SWEEPS	1	—
5	TAXI / TAKEOFF	1	—
6	ACCELERATE-STOP WITH OEI	1	—

Engineering Notes:

Figure 20: Test Card 2

3

MAN-UP

FLIGHT TEST ENGINEERING THESIS| EVENT: __/__/__ - __

FW: ______________ [lb] IRIG: ______________Z

1. Pilot: Enter A/C and begin pre-flight checks IAW A/S and FAA Reqs.
2. Everyone: Verify comms and time sync.
    1. A/C with ATC: Radio
    2. TC with Ground Team: Radio
    3. A/C with TC: Radio
    4. A/C with Ground Team: Radio

Engineering Notes:

Figure 21: Test Card 3

4	**ENGINE START / CONTROL SWEEPS** **FLIGHT TEST ENGINEERING THESIS| EVENT: __/__/__ - __**

FW: ______________ [lb] IRIG: ______________Z

1. Pilot: Starts Engine IAW A/C and FAA Reqs.

IRIG: ______________Z

1. Pilot: Performs control surface sweeps IAW A/C and Test Plan Reqs.
    1. Ailerons IRIG: ______________Z
    2. Elevator IRIG: ______________Z
    3. Rudder IRIG: ______________Z

Engineering Notes:

Figure 22: Test Card 4

5	TAXI / TAKEOFF FLIGHT TEST ENGINEERING THESIS| EVENT: __/__/__ - __

IRIG: ______________Z FW: ______________ [lb]

1. Taxi

FW: ______________ [lb] IRIG: ______________Z

1. Takeoff

FW: ______________ [lb]

1. Runway: IRIG: ______________Z
2. Power Up: IRIG: ______________Z
3. Brake Release: IRIG: ______________Z

Engineering Notes:

Figure 23: Test Card 5

6	ACCELERATE-STOP WITH OEI FLIGHT TEST ENGINEERING THESIS| EVENT: __/__/__ - __

IRIG: ______________Z FW:
______________ [lb]

AIRCRAFT CONFIGURATION
Flaps — UP | ALT Air — OFF | Baro — 29.92in | Pitot Heat — OFF

1.	Altitude	0 ft
2.	Throttles	2700 RPM
3.	Brakes	Release
4.	Airspeed Indicator	V1
5.	Engine (Choose One)	Shut Down
6.	RECORD	
7.	Brakes	Apply
8.	Throttles	CLOSED
9.	Rudder	Applied As Necessary
11.	Master Switch	OFF
12.	Fuel Selectors	OFF
13.	RECORD	

Time (s)	
Engine RPM	
Indicated Airspeed (kts)	
Brake Position (0 or 1)	
Throttle Position (0 or 1)	
Distance Traveled (ft)	

Engineering Notes:

Figure 24: Test Card 6

Appendix 2: Recruitment Material for Test Participants

2.1 Florida Tech IRB Notice of Exempt Review Status

Florida Institute of Technology
Institutional Review Board

Notice of Exempt Review Status
Certificate of Clearance for Human Participants Research

Principal Investigator:	Lydia Scrivens
Date:	March 12, 2024
IRB Number:	24-123
Study Title:	Human Factors Study on Takeoff Performance Using X-Plane 12 Simulator

Your research protocol was reviewed and approved by the IRB Chairperson. Per federal regulations, 45 CFR 46.101, your study has been determined to be minimal risk for human subjects and exempt from 45 CFR46 federal regulations. The Exempt determination is valid indefinitely. Substantive changes to the approved exempt research must be requested and approved prior to their initiation. Investigators may request proposed changes by submitting a Revision Request form found on the IRB website.

Acceptance of this study is based on your agreement to abide by the policies and procedures of Florida Institute of Technology's Human Research Protection Program (http://web2.fit.edu/crm/irb/) and does not replace any other approvals that may be required.

All data, which may include signed consent form documents, must be retained in a secure location for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Access to data is limited to authorized individuals listed as key study personnel.

The category for which exempt status has been determined for this protocol is as follows:

2. Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:

   a. The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects; or

   b. Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or

   c. The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and IRB can determine if there are adequate provisions in place to protect the privacy of the subjects and confidentiality of the data.

Figure 25: Certificate of Clearance for Human Participants Research

2.2 Human Factors Study on Takeoff Performance Using X-Plane 12 Simulator: Flyer

Figure 26: Study Flyer

2.3 Human Factors Study on Takeoff Performance Using X-Plane 12 Simulator: Screening Survey

Figures 28 – 30 are screenshots of the screening survey that was distributed through the recruitment flyer and study announcement email.

FLORIDA TECH

My name is Lydia Scrivens, and I am a graduate student in Florida Tech's Flight Test Engineering Master's Program. I am conducting a study on human factors in takeoff performance.

If you are selected, you will be asked to participate in a short flight test at the Florida Tech Center for Aeronautics and Innovation (CAI). You will be flying a Beechcraft Baron 58 on the X-Plane 12 flight simulator. The study session will take approximately 30 to 45 minutes to complete and will include a post-flight debrief.

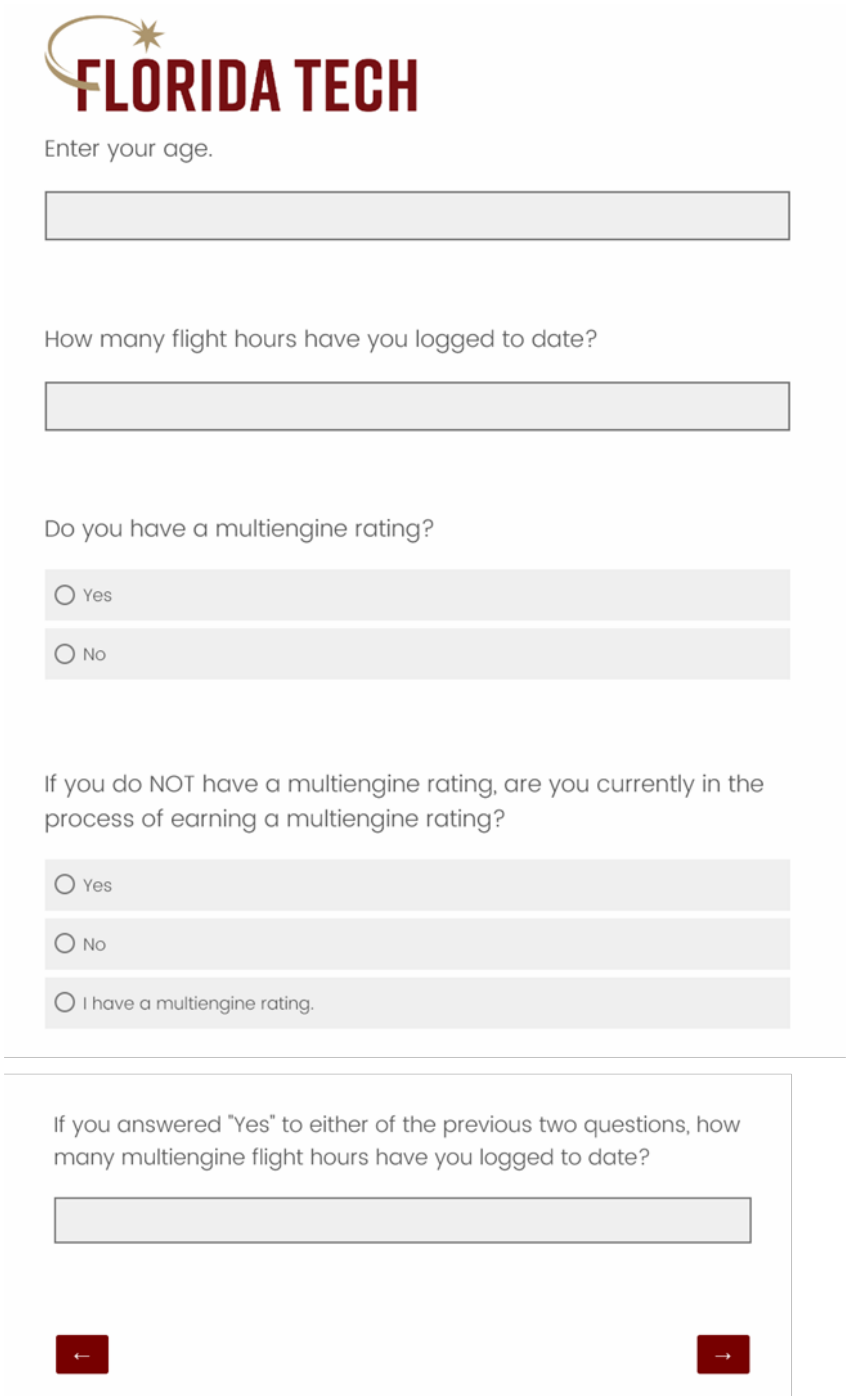
To participate in this survey, you must be at least 18 years of age. Your name and contact information will not be shared.

If you have any questions regarding this survey, contact me via text or email. My contact information is below:

Lydia Scrivens
+1 (407) 799-7558
lscrivens2018@my.fit.edu

→

Figure 27: Screening Survey – Page 1



FLORIDA TECH

Enter your age.

How many flight hours have you logged to date?

Do you have a multiengine rating?

- Yes
- No

If you do NOT have a multiengine rating, are you currently in the process of earning a multiengine rating?

- Yes
- No
- I have a multiengine rating.

If you answered "Yes" to either of the previous two questions, how many multiengine flight hours have you logged to date?

← →

Figure 28: Screening Survey – Page 2

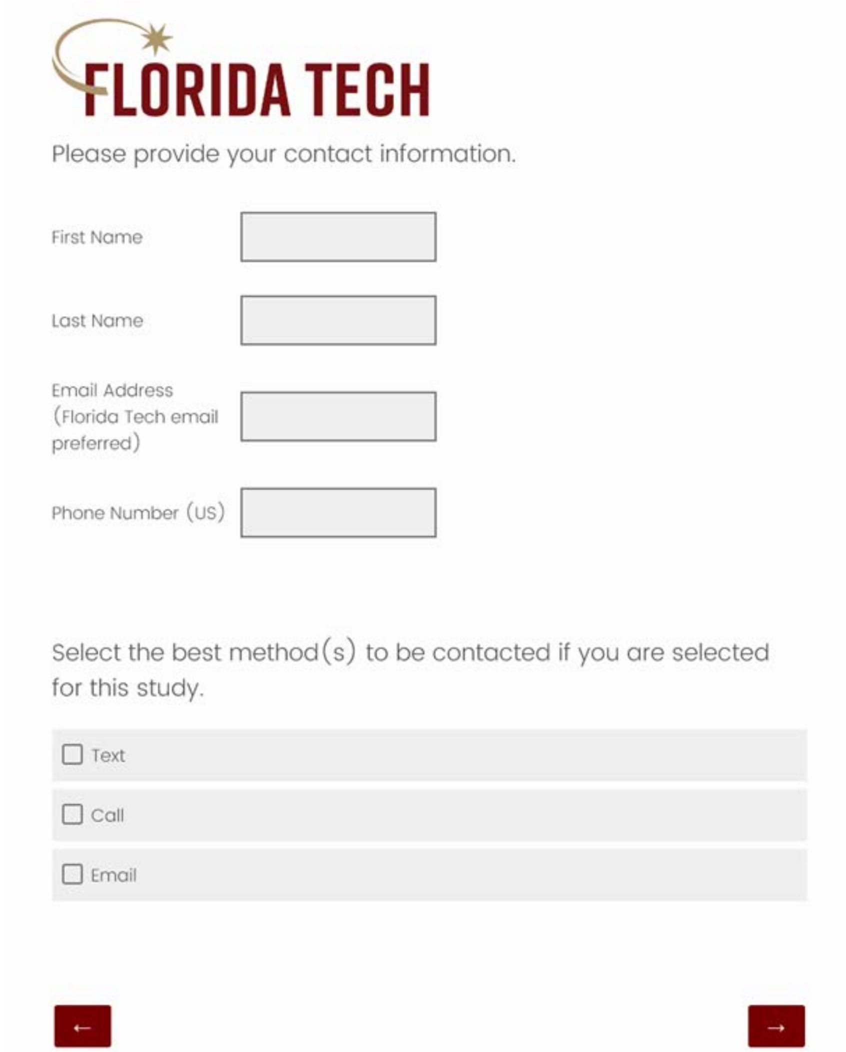


Figure 29: Screening Survey – Page 3

2.4 Human Factors Study on Takeoff Performance Using X-Plane 12 Simulator: Study Announcement Email

Title: Looking for Multiengine Pilots for a Flight Test Engineering Study

Body:

Hello!

My name is Lydia Scrivens, and I am a graduate student in the Flight Test Engineering Master's Program. I am conducting a research study for my thesis on human factors related to takeoff performance for twin-engine aircraft. If you are a multiengine pilot (or are in the process of earning a multiengine rating) and are interested in participating in the study, please follow the provided link to complete a 2- to-3-minute confidential recruiting questionnaire. You can also scan the QR code in the attached flyer to access the questionnaire.

https://fit.co1.qualtrics.com/jfe/form/SV_4MgQEKHzIEy08Ye

If you are selected for the study, further instructions regarding the following information will be provided in a separate email. It is anticipated that this study will pose no greater risk than you would experience through normal daily activities. Your participation is voluntary, and you may withdraw from the study at any time without penalty.

If you have any questions, please contact me via email or text message:

Lydia Scrivens

lscrivens2018@my.fit.edu

+1 (407) 799-7558

Thanks,

Lydia Scrivens

2.5 Human Factors Study on Takeoff Performance Using X-Plane 12 Simulator: Notification Email Following Recruitment

Title: Flight Test Engineering Study: Confirmation

Body:

Hello [Name],

You have been selected to participate in my thesis study on human factors regarding takeoff performance. The study will take place at the Center for Aeronautics and Innovation (CAI) in Room 137. The address is provided below:

1050 W NASA Blvd, Melbourne, FL 32901

An informed consent form is attached to this email. You will be requested to sign it at the beginning of your study session, but feel free to review it in advance.

To schedule a study session, please choose a day and time slot that will work best for you through the following link.

https://doodle.com/meeting/participate/id/dLAOJAge

Note: The above link was updated as more days were offered for scheduling.

It is anticipated that this study will pose no greater risk than you would experience through normal daily activities. Your participation is voluntary, and you may withdraw from the study at any time without penalty. Feel free to inform me of your decision to participate in/withdraw from the study via a reply to this email. If you have any questions, contact me via email or text message.

Lydia Scrivens

lscrivens2018@my.fit.edu

+1 (407) 799-7558

Thanks,

Lydia Scrivens

2.6 Human Factors Study on Takeoff Performance Using X-Plane 12 Simulator: Research Participant Consent Form

RESEARCH PARTICIPANT CONSENT FORM

Lydia Scrivens

College of Engineering

Florida Institute of Technology

Purpose of Research

The purpose of this research is to study human factors during the takeoff phase of flight.

Specific Procedures

You will be flying a Beechcraft Baron 58 (a twin-engine land airplane) on the CAI's X-Plane 11 flight simulator.

Various flight parameters such as control inputs, distance, engine performance, and time, will be collected

via the simulator's data collection system. A short debrief will follow after the test.

Duration of Participation

It is anticipated that your participation in the study will take approximately 30-45 minutes.

Risks

It is anticipated that this study will pose no greater risk than you would experience through normal daily activities.

Benefits

There are no known benefits to your participation other than knowing you have contributed to the

advancement of scientific knowledge.

Compensation

You will receive a gift card upon completion of the study.

Confidentiality

The data collected during this study will be anonymous and confidential. We have no way of learning

your true identity. Your name and logged flight hours will not be linked to your name or any other

personal identifiers.

Voluntary Nature of Participation

Your participation in this research project is voluntary. If you agree to participate, you can withdraw

your participation at any time without penalty. Furthermore, if you withdraw from the study prior to its

completion, your data will be destroyed immediately.

Contact Information:

If you have any questions about this research project, you can contact Lydia Scrivens, principle

investigator, at lscrivens2018@my.fit.edu. If you have concerns about the treatment of

research participants, you can contact the IRB Administrator, Dr. Jignya Patel, FIT_IRB@fit.edu,

321-674-7347.

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I am

prepared to participate in the research project described above. By participating, I verify that I am over 18

years of age and have read/understand/consent to the conditions listed in this document.

Signature: ___________________________ **Date:** ______________________

Appendix 3: CSV Data Files

Table 11: Data File of Results RTODATA.csv

Participant	Age	TotalHrs	MultiHrs	RTime	Dist	VEF	V1
1	30	1300	110	2.113235	711.8926	89.57046	101.85
2	22	1000	26	1.596245	552.4362	96.10983	103.0445
3	51	11100	9300	10.59712	3424.102	102.8078	82.20908
4	35	3400	450	1.584995	366.4878	100.9222	99.86355
5	41	376	16	10.57385	2006.355	99.28319	80.30594
6	23	460	28	1.584995	549.2073	100.0323	100.8906
7	84	9300	2500	2.64371	893.7565	98.08804	95.53807

Table 12: Data File of Results RTODATAWO.csv

Participant	Age	TotalHrs	MultiHrs	RTime	Dist	VEF	V1
1	30	1300	110	2.113235	711.8926	89.57046	101.850
2	22	1000	26	1.596245	552.4362	96.10983	103.0445
4	35	3400	450	1.584995	366.4878	100.9222	99.86355
6	23	460	28	1.584995	549.2073	100.0323	100.8906
7	84	9300	2500	2.64371	893.7565	98.08804	95.53807

Appendix 4: RStudio Script for Statistical Analysis

```
library(ggplot2)

library(mgcv)

library(tidyr)

library(dplyr)


#Test Data#

RTODATA = read.csv("C:/Users/LS/Downloads/Lydia's Grad/Spring
       2024/Thesis/Data/RTODATA.csv")

head(RTODATA)

names(RTODATA)


#Histograms-Demographics#

hist(RTODATA$Age,20,col='red',border="grey4", xlab='Participant Age',
       xlim=c(20,90), breaks=seq(20,90,5))

hist(RTODATA$TotalHrs,20,col='orange',border="grey4", xlab='Total Flight
       Hours', xlim=c(0,12000), breaks=seq(0,12000,1000))

hist(RTODATA$MultiHrs,20,col='yellow',border="grey4", xlab='Total
       Multiengine Flight Hours', xlim=c(0,10000),
       breaks=seq(0,10000,1000))


#Histograms-Tests#

hist(RTODATA$RTime,20,col='green',border="grey4", xlab='Pilot Response
       Time', xlim=c(0,12), breaks=seq(0,12,1))

hist(RTODATA$Dist,20,col='deepskyblue2',border="grey4", xlab='Horizontal
       Distance Traveled', xlim=c(0,3500), breaks=seq(0,3500,500))

hist(RTODATA$VEF,20,col='darkorchid1',border="grey4", xlab="Engine Failure
       Speed (V_EF)", xlim=c(85,105), breaks=seq(85,105,5))
```

```
hist(RTODATA$V1,20,col='lightpink1',border="grey4", xlab="Engine Failure
       Recognition Speed (V_1)", xlim=c(80,105), breaks=seq(80,105,5))


#Q-Q Plots-Demographics#
qqnorm(RTODATA$Age,col='darkred', xlab='Participant Age')
qqnorm(RTODATA$TotalHrs,col='darkorange4', xlab='Total Flight Hours')
qqnorm(RTODATA$MultiHrs,col='gold4', xlab='Total Multiengine Flight
       Hours')


#Q-Q Plots-Tests#
qqnorm(RTODATA$RTime,col='darkgreen', xlab='Pilot Response Time')
qqnorm(RTODATA$Dist,col='blue4', xlab='Horizontal Distance Traveled')
qqnorm(RTODATA$VEF,col='purple4', xlab="Engine Failure Speed (V_EF)")
qqnorm(RTODATA$V1,col='violetred4', xlab="Engine Failure Recognition Speed
       (V_1)")


#Scatter Plots#
qplot(x = Age, y = RTime, data = RTODATA, geom = "point",
       col=I("maroon2"),size=I(3), ylab='Pilot Response Time',
       xlab='Participant Age')
qplot(x = TotalHrs, y = RTime, data = RTODATA, geom = "point",
       col=I("salmon3"),size=I(3), ylab='Pilot Response Time', xlab='Total
       Flight Hours')
qplot(x = MultiHrs, y = RTime, data = RTODATA, geom = "point",
       col=I("darkgoldenrod4"),size=I(3), ylab='Pilot Response Time',
       xlab='Total Multiengine Flight Hours')
qplot(x = RTime, y = Dist, data = RTODATA, geom = "point",
       col=I("turquoise3"),size=I(3), xlab='Pilot Response Time',
       ylab='Horizontal Distance Traveled')
```

```
#SLR#

regmd1a=lm(RTODATA$RTime~RTODATA$Age)

plot(RTODATA$RTime~RTODATA$Age, xlab='Participant Age', ylab='Pilot
response Time')

abline(regmd1a,col='red2',lw=3)

summary(regmd1a)


regmd2a=lm(RTODATA$RTime~RTODATA$TotalHrs)

plot(RTODATA$RTime~RTODATA$TotalHrs, xlab='Total Flight Hours',

     ylab='Pilot response Time')

abline(regmd2a,col='orange2',lw=3)

summary(regmd2a)


regmd3a=lm(RTODATA$RTime~RTODATA$MultiHrs)

plot(RTODATA$RTime~RTODATA$MultiHrs, xlab='Total Multiengine Flight

       Hours', ylab='Pilot response Time')

abline(regmd3a,col='gold2',lw=3)

summary(regmd3a)


regmd4a=lm(RTODATA$Dist~RTODATA$RTime)

       plot(RTODATA$Dist~RTODATA$RTime, xlab='Pilot Response Time',

       ylab='Horizontal Distance Traveled')

abline(regmd4a,col='turquoise',lw=3)

summary(regmd4a)


#ANOVA#

anova_mdl<- aov(RTime~Age+TotalHrs+MultiHrs, data=RTODATA)

summary(anova_mdl)
```

```r
#SLR Without Outliers#
RTODATAWO = read.csv("C:/Users/LS/Downloads/Lydia's Grad/Spring
       2024/Thesis/Data/RTODATAWO.csv")
head(RTODATAWO)
names(RTODATAWO)

regmd2b=lm(RTODATAWO$RTime~RTODATAWO$TotalHrs)
plot(RTODATAWO$RTime~RTODATAWO$TotalHrs, xlab='Total Flight Hours',
     ylab='Pilot response Time')
abline(regmd2b,col='tomato2',lw=3)
summary(regmd2b)

regmd3b=lm(RTODATAWO$RTime~RTODATAWO$MultiHrs)
plot(RTODATAWO$RTime~RTODATAWO$MultiHrs, xlab='Total Multiengine Flight
Hours', ylab='Pilot response Time')
abline(regmd3b,col='darkgoldenrod2',lw=3)
summary(regmd3b)
```

Appendix 5: Normal Q-Q Plots

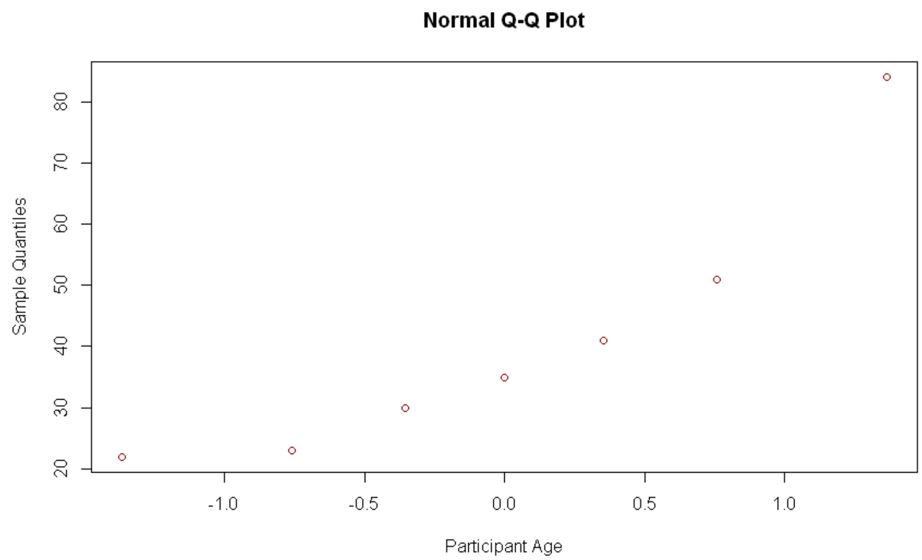


Figure 30: Normal Q-Q Plot for Participant Age

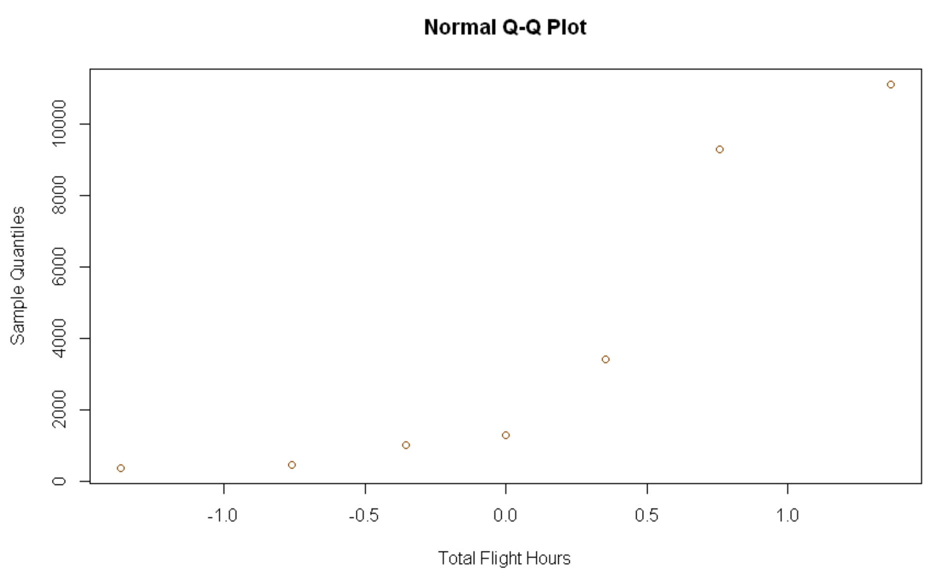


Figure 31: Normal Q-Q Plot for Total Flight Hours

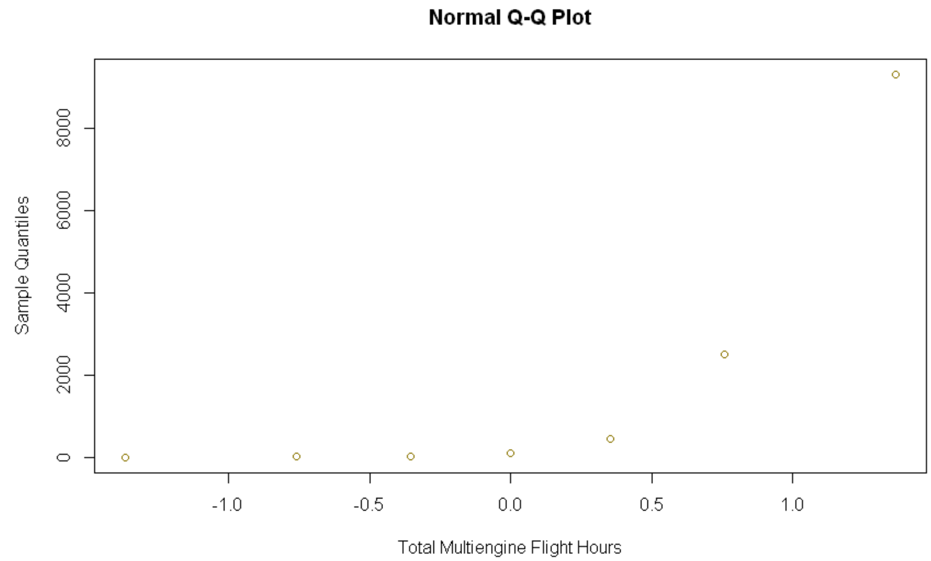


Figure 32: Normal Q-Q Plot for Total Multiengine Flight Hours

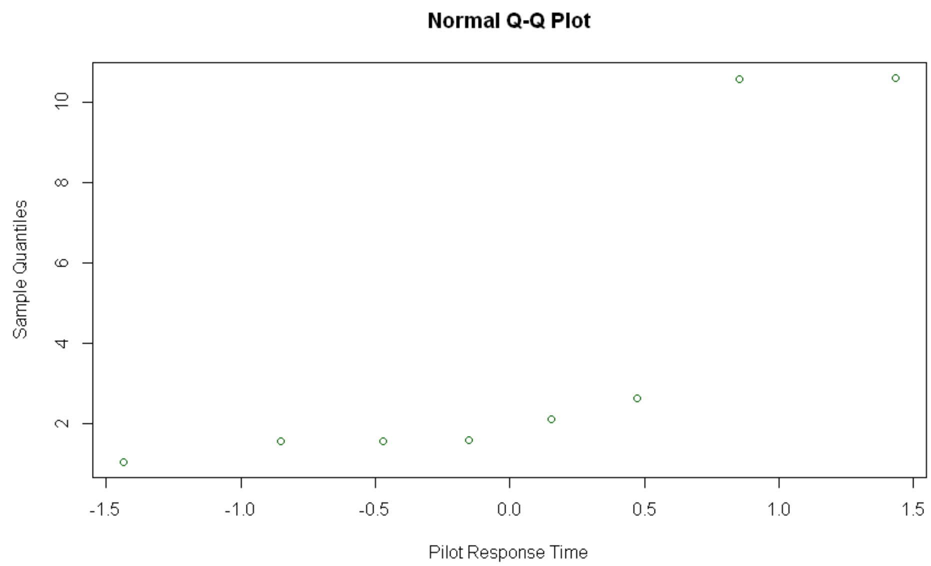


Figure 33: Normal Q-Q Plot for Pilot Response Time

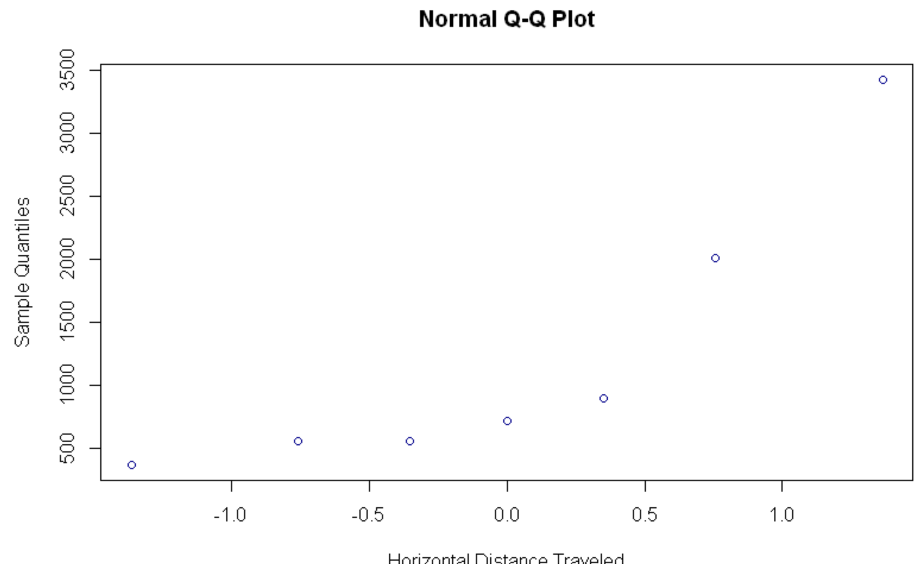


Figure 34: Normal Q-Q Plot for Horizontal Distance Traveled Between V_{EF} and V_1

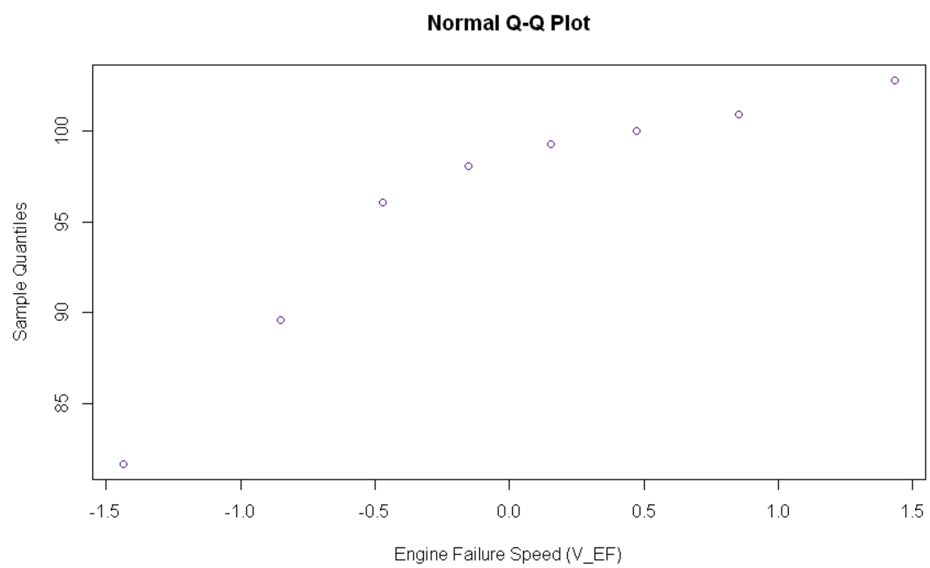


Figure 35: Normal Q-Q Plot for V_{EF} Speed

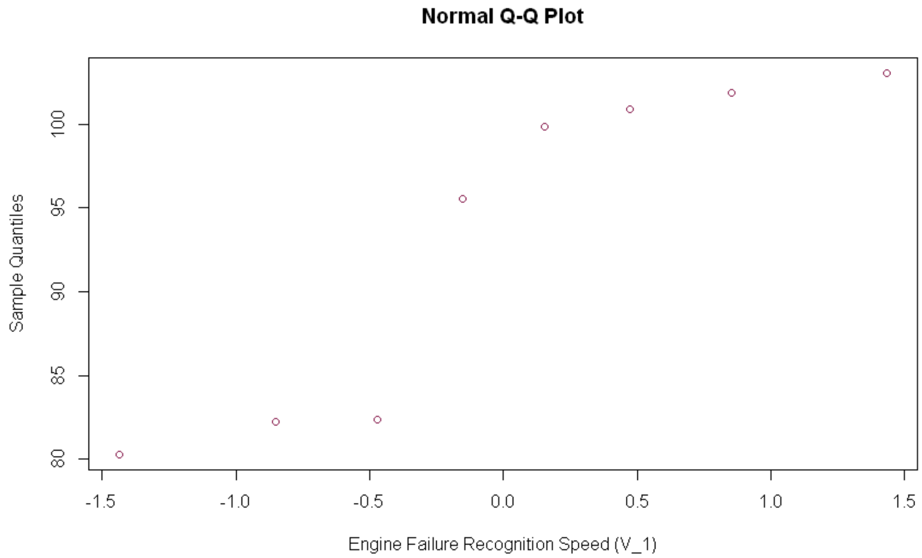


Figure 36: Normal Q-Q Plot for V_1 Speed

Appendix 6: SLR Summaries

6.1 Pilot Response Time vs. Pilot Age "RTime ~ Age"

```
Call:
lm(formula = RTODATA$RTime ~ RTODATA$Age)

Residuals:
     1      2      3      4      5      6      7 
-1.756 -1.894  5.731 -2.522  6.182 -1.953 -3.788 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.44628    3.89290   0.628    0.557
RTODATA$Age  0.04745    0.08560   0.554    0.603

Residual standard error: 4.522 on 5 degrees of freedom
Multiple R-squared:  0.05789,	Adjusted R-squared:  -0.1305 
F-statistic: 0.3072 on 1 and 5 DF,  p-value: 0.6033
```

6.2 Pilot Response Time vs. Total Flight Hours "RTime ~ TotalHrs"

```
Call:
lm(formula = RTODATA$RTime ~ RTODATA$TotalHrs)

Residuals:
     1      2      3      4      5      6      7 
-1.458 -1.879  3.896 -2.657  7.298 -1.718 -3.483 

Coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)      3.1556967  2.2608521   1.396    0.222
RTODATA$TotalHrs 0.0003194  0.0003994   0.800    0.460

Residual standard error: 4.387 on 5 degrees of freedom
Multiple R-squared:  0.1134,	Adjusted R-squared:  -0.06389 
F-statistic: 0.6397 on 1 and 5 DF,  p-value: 0.4601
```

6.3 Pilot Response Time vs. Total Flight Hours "RTime ~ TotalHrs" Without Outliers

```
Call:
lm(formula = RTODATAWO$RTime ~ RTODATAWO$TotalHrs)

Residuals:
       1        2        3        4        5 
 0.39749 -0.08788 -0.35211 -0.04221  0.08470 

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)   
(Intercept)        1.579e+00  1.945e-01   8.118  0.00391 **
RTODATAWO$TotalHrs 1.054e-04  4.328e-05   2.436  0.09287 . 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.3155 on 3 degrees of freedom
Multiple R-squared:  0.6641,	Adjusted R-squared:  0.5522 
F-statistic: 5.932 on 1 and 3 DF,  p-value: 0.09287
```

6.4 Pilot Response Time vs. Total MultiengineFlight Hours "RTime ~ MultiHrs"

```
Call:
lm(formula = RTODATA$RTime ~ RTODATA$MultiHrs)

Residuals:
      1       2       3       4       5       6       7 
-1.0530 -1.5085  0.7074 -1.8300  7.4764 -1.5212 -2.2711 

Coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)      3.0857573  1.6264452   1.897    0.116
RTODATA$MultiHrs 0.0007316  0.0004463   1.639    0.162

Residual standard error: 3.758 on 5 degrees of freedom
Multiple R-squared:  0.3495,	Adjusted R-squared:  0.2195 
F-statistic: 2.687 on 1 and 5 DF,  p-value: 0.1621
```

6.5 Pilot Response Time vs. Total MultiengineFlight Hours "RTime ~ MultiHrs" Without Outliers

```
Call:
lm(formula = RTODATAWO$RTime ~ RTODATAWO$MultiHrs)

Residuals:
       1        2        3        4        5 
 0.40230 -0.08297 -0.25437 -0.09497  0.03001 

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)   
(Intercept)        1.6693901  0.1522301  10.966  0.00162 **
RTODATAWO$MultiHrs 0.0003777  0.0001339   2.822  0.06665 . 
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2848 on 3 degrees of freedom
Multiple R-squared:  0.7263,      Adjusted R-squared:  0.6351 
F-statistic: 7.962 on 1 and 3 DF,  p-value: 0.06665
```

6.6 Horizontal Distance Traveled vs. Pilot Response Time "Dist ~ RTime"

```
Call:
lm(formula = RTODATA$Dist ~ RTODATA$RTime)

Residuals:
      1       2       3       4       5       6       7 
  49.74   16.08  697.63 -167.13 -714.46   15.59  102.53 

Coefficients:
              Estimate Std. Error t value Pr(>|t|)   
(Intercept)     147.95     257.81   0.574  0.59091   
RTODATA$RTime   243.32      43.75   5.562  0.00258 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 455.8 on 5 degrees of freedom
Multiple R-squared:  0.8609,      Adjusted R-squared:  0.8331 
F-statistic: 30.94 on 1 and 5 DF,  p-value: 0.002584
```