Comparison of Commercial Aircraft Fuel Requirements in Regards to FAR, Flight Profile Simulation, and Flight Operational Techniques

by

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ABSTRACT

There are significant fuel consumption consequences for non-optimal flight operations. This study is intended to analyze and highlight areas of interest that affect fuel consumption in typical flight operations. By gathering information from actual flight operators (pilots, dispatch, performance engineers, and air traffic controllers), real performance issues can be addressed and analyzed. A series of interviews were performed with various individuals in the industry and organizations. The wide range of insight directed this study to focus on FAA regulations, airline policy, the ATC system, weather, and flight planning. The goal is to highlight where operational performance differs from design intent in order to better connect optimization with actual flight operations.

After further investigation and consensus from the experienced participants, the FAA regulations do not need any serious attention until newer technologies and capabilities are implemented. The ATC system is severely out of date and is one of the largest limiting factors in current flight operations. Although participants are pessimistic about its timely implementation, the FAA's NextGen program for a future National Airspace System should help improve the efficiency of flight operations. This includes situational awareness, weather monitoring, communication, information management, optimized routing, and cleaner flight profiles like Required Navigation Performance (RNP) and Continuous Descent Approach (CDA).

Working off the interview results, trade-studies were performed using an in-house flight profile simulation of a Boeing 737-300, integrating NASA legacy codes EDET and NPSS with a custom written mission performance and point-performance

"Skymap" calculator. From these trade-studies, it was found that certain flight conditions affect flight operations more than others. With weather, traffic, and unforeseeable risks, flight planning is still limited by its high level of precaution. From this study, it is recommended that air carriers increase focus on defining policies like load scheduling, CG management, reduction in zero fuel weight, inclusion of performance measurement systems, and adapting to the regulations to best optimize the spirit of the requirement.. As well, air carriers should create a larger drive to implement the FAA's NextGen system and move the industry into the future.

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LIST OF SYMBOLS AND ABBREVIATIONS

FAR	Federal Aviation Regulations
ATC	Air Traffic Control
FAA	Federal Aviation Administration
NAS	National Airspace System
RNP	Required Navigation Performance
rNAV	Area Navigation
PBN	Performance-Based Navigation
CDA	Continuous Descent Approach
CDO	Continuous Descent Operations
EDET	Empirical Drag Estimation Technique
NPSS	Numerical Propulsion System Simulation
ETOPS	Extended Twin Operations
CI	Cost Index
JAR	Joint Aviation Requirements
CFR	Code of Federal Regulation
§	Part
min	Minute
hr	Hour
kts	Knots
KIAS	Knots Indicated Airspeed (NM/hr)
KTAS	Knots True Airspeed (NM/hr)
M	Mach Number
NM	Nautical Mile

mi	Mile
ft	Feet
lb	Pound
kg	Kilogram
V	Velocity
TSFC	Thrust Specific Fuel Consumption (lb/lbf-hr)
L	Lift
D	Drag
W	Weight
L/D	Aerodynamic Efficiency
M(L/D)	Aerodynamic Performance Efficiency
FF	Fuel Flow (lb/hr)
SR	Specific Range (NM/lb)
ROC	Rate of Climb (ft/min)
PLA	Power Lever Angle
MLW	Maximum Landing Weight (lb)
MTOW	Maximum Take-Off Weight (lb)
OEW	Operational Empty Weight (lb)
OEI	One Engine Inoperative
FMS	Flight Management System
NASA	National Aeronautics and Space Administration
IFR	Instrument Flight Rules
ADS-B	Automatic dependent surveillance-broadcast
CSS-Wx	Common Support Services-Weather

NVS	NAS Voice System
CATMT	Collaborative Air Traffic Management
SWIM	System Wide Information Management
CFIT	Controlled Flight into Terrain
CG	Center of Gravity
Alt	Altitude (ft)
h	Altitude (ft)
dC_{D0}	Zero-Lift (Parasite) Dimensionless Drag Coefficient Correction
C_L	Dimensionless Lift Coefficient
C_D	Dimensionless Drag Coefficient
S_{ref}	Wing Reference Planform Area (ft^2)
S_{wet}	Wing Wetted Planform Area (ft^2)
AR	Wing Aspect Ratio
t/c	Thickness to Chord Ratio (%)
Λ_{C4}	Wing Quarter Chord Sweep (deg)
λ	Wing Taper Ratio
b	Wing Span (ft)
BPR	Engine Bypass Ratio
C_{D0}	Zero-Lift (Parasite) Drag Coefficient
q	Dynamic Pressure
K_{accel}	Acceleration Factor
x	Distance
t	Time

CHAPTER 1

INTRODUCTION AND BACKGROUND

In the aviation industry, gaps exist between the way aircraft designers intend aircraft to be flown and how operators actually fly the aircraft. Although the connection between operation and design is highly regulated, there are still discrepancies between actual operations and an optimal performance design. These disconnects can occur because of a need for compliance to regulations, a need to meet operational standards, or from situational unpredictability. Either way, aircraft are not always operated in practice in the theoretical manner by which they are designed. Sometimes these differences are advantageous to flight performance and sometimes they are not. This study will highlight areas of discontinuity between optimized flight performance and flight operations to help improve flight performance through the encouragement or discouragement of certain operations.

In the case of flight operations under abnormal conditions, theoretical expectations may not align with actual usage. For example, aircraft takeoff flaps are configured to provide optimal runway and second segment climb performance in compliance with Title 14 of the Code of Federal Regulations (CFR) § 25.111 and 25.121; [1] [2] where the operator must plan for an engine failure. Because virtually all takeoffs occur with all engines operating, the flight after the mandated rotation and initial climb out may experience sub-optimal performance from a noise, emissions or fuel economy perspective. For all references to the CFR, see Appendices A, B, and C for the full text regulation in question of 14 CFR § 25, 91, and 121 respectively. [11] [12] [13] All regulations are current as of March, 2014. This study will focus on domestic operations and will not include any analysis on international flights or regulations that derive from the Joint Aviation Requirements (JAR).

Alternatively, flight operations under normal conditions may conflict with expected usage. For example, during takeoff and initial climb, a commercial flight must maintain an indicated airspeed of 250 KIAS or less for altitudes under 10,000 ft. This is defined by the Code of Federal Regulations Title 14 CFR § 91.117. [3] The optimal flight performance in terms of time-to-climb or minimum fuel-to-climb of an actual design may be closer to a value of 225 KIAS or 275 KIAS, for example. In order to burn the least amount of fuel, the designer may suggest that the operator fly the aircraft around such an optimal value. In the end, the actual performance is defined by the pilot and/or air traffic control. Similarly, the air traffic controllers may instruct the pilot to speed up or slow down for any other reason deemed most appropriate. Now considering these parameters, there is clearly a discrepancy between the designer and flight operator. The resulting issue is that the aircraft is not being flown at its optimal condition. More importantly though, this discrepancy may not be fully documented or analyzed for future flights.

Popular textbooks like Torenbeek's "Synthesis of Subsonic Aircraft Design" [4], Anderson's "Aircraft Performance and Design" [5], Kuchemann's "The Aerodynamic Design of Aircraft" [6], and many others, do not discuss the distinction between theoretically ideal performance and operationally limited performance. For example, the famous Breguet equation:

$$Range = \left(\frac{V}{TSFC}\right)\left(\frac{L}{D}\right)\ln\left(\frac{W_i}{W_f}\right)$$

presumes flight at constant airspeed, constant lift-to-drag (L/D) ratio and constant thrust-specific-fuel-consumption (TSFC). [5] This would imply steady flight with a slowly increasing altitude powered by an engine with no altitude related lapse in thrust or efficiency. This is not reality. Operationally, once at cruise, aircraft must fly at even 1,000 foot altitude intervals. Technically, the TSFC of an engine varies with power lever setting, speed and altitude. Thus, an aircraft sized using Breguet-type assumptions may perform noticeably worse in operational use. Fortunately, aircraft manufacturer's do not solely rely on this design assumption, however from an academic stand-point, the assumption differs from reality.

The consequences for aircraft designed to idealized flight conditions and non-optimal flight planning vary greatly. The main concern is that there may or may not be extra fuel being burned during any particular flight plan. Although it is not allows present on the news, the risk of lack of fuel due to unpredictability in a flight is all but present. In a perfect world, if the dispatch and pilot were omniscient of the future flight, each flight plan would require the aircraft to carry just enough fuel to perform its operations and return to a new fueling location. Because there are always unforeseeable circumstances, a flight plan must account for additional fuel usage. Although there is unpredictability, every measure to reduce the need for additional fuel should be considered.

Unfortunately, fuel performance flight planning relies on the idea that an optimized flight is dependent solely on fuel consumption and that all flights would be flown to optimal fuel burns and not another dependencies. Because commercial flight operations are inherently governed by company profit and service, the ideal flight plan may also be dependent on flight times. Since operational costs include labor and other hourly dependencies, the end optimization relies on the Cost Index (CI). [7] The Cost Index at any particular time defines how fuel burn and flight time should be balanced. This study will focus on optimizing fuel consumption, but it will highlight other discrepancies between design and operation.

For fuel consumption, every additional gallon of fuel consumed represents added operating cost to the airline. Every additional pound of fuel required for flight (whether consumed or held in reserve) represents a pound of potential revenue-generating payload; this adversely increases fuel consumption through its added weight. Luckily, when operating over populated areas, flights can always redirect to alternative airport locations in the case of low fuel levels or if one engine goes out. When operating on longer ranges with less alternates available, FAA regulations require specific fuel reserves per Title 14 CFR § 121.624, 121.646, and 121 Appendix P. [8] [9] [10] These are called extended twin operations (ETOPS). Normal regulations require the flight path to remain in a set proximity from any available alternate airport along the flight; however ETOPS authorization may allow this proximity to be extended to allow a more linear flight direction.

High levels of precaution are important to avoid aircraft crashes for the safety of the passengers. Often, precautions are taken by adding additional fuel by means of contingency fuel. The extent of this contingency fuel needs to be accounted for and implemented with the consideration of actual flight operations. A flight may plan for **X** gallons of fuel as extra reserve fuel with the expectations of certain flight operations but when the actual operations vary from the planned flight, **X** gallons may not be enough to support the safety requirements. Conversely, flight planning may overestimate the fuel requirements when the level of precaution may provide a margin of safety that is unnecessarily generous. Although it is always important to err on the safe side, with modern flight planning and on-board flight analysis, the required fuel reserves may not be as essential as they were in the past.

While it may be hard to identify and prove a change to the CFR is completely necessary and 100% safe, intangible operations can be analyzed for improving fuel consumption. The human factor is a highly unpredictable and sometimes untraceable aspect of flight operations. Although modern operations lean towards more computerized and autonomous operations, pilots and flight operators are still very involved. Pilots and operators may have the best intention to reduce fuel consumption as much as possible, but the end result is not always visible. Under the presumption that fuel consumption is the number one priority, actions outside the flight management system (FMS) that safely improve fuel burn should be encouraged and expanded. Actions that adversely affect fuel burn should be discouraged and highlighted for future flights. Pilot techniques to improve fuel consumption need to be addressed and analyzed to spread the understanding of how real operations are performed. Often insider knowledge or unspoken techniques within a group or organization is coined “tribal knowledge”. The idea behind this study is to gather tribal knowledge information or taboo techniques that are performed in operation that may not be visible to the public or even the airlines standards.

This study will outline various opportunities and areas of concern that affect aircraft performance, in particular, fuel consumption. By analyzing Title 14 of the Code of Federal Regulations and interviewing flight operators, the small discrepancies between operations and performance can be highlighted for further investigation. The goal is to present opportunities in the CFR and flight operations to improve flight performance and reduce fuel consumption. As seen in Figure 1 below, [14] there are various influences on any particular flight. The focus of this study is on personal and organizational influences that can be improved.

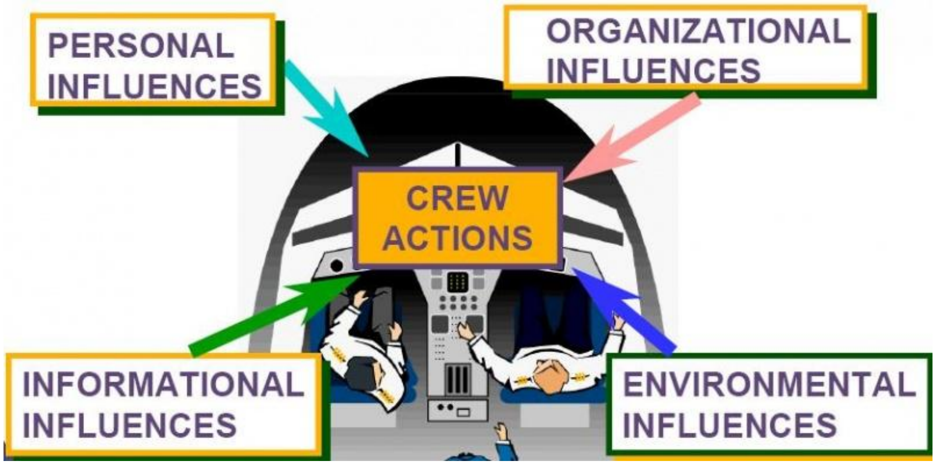


Figure 1. Flight Influences

A numerical flight profile simulation was developed through this study to quantitatively analyze the potential improvements in fuel consumption through CFR changes and flight operations. By gathering anecdotal information from pilots and flight operators, actual fuel consumption data can be analyzed to confirm or deny the benefits of operator techniques to improve fuel burn. Please note that this study is not a statistical analysis of pilot techniques but a qualitative analysis on real-life operations with support from a quantitative simulation. This study is not intended to provide a new methodology for predicating fuel consumption. The simulation uses NASA legacy codes and an iterative scheme to provide a basic analysis of fuel consumption. There are other methods like Base of Aircraft (BADA) processor or Tool for Assessing Separation and Throughput (TASAT) that can be implemented but the in-house simulation development is sufficient enough for this analysis. [15] The fidelity of the simulation will be supported in a later section.

The objective of the simulation is to demonstrate where there is excessive fuel burn and outline the influence of various flight parameters. This report will not show how to improve fuel efficiency but where fuel consumption can be minimized. The focus is less on how performance design can affect operations but how do operations affect performance? By looking at parameters like climb speeds, cruise conditions, and descent/approach situations, specific operational actions can be analyzed. For example, a study was done to compare continuous descent operations (CDO) to its predecessor method, step descents. [16] They found that for wide bodied aircraft, the continuous descent approach was beneficial for fuel consumption. However the opportunity for this method is limited by factors like limited airspace, terrain or obstacles, environmental restrictions like noise, air traffic control procedures, and weather avoidance. Other operational techniques will be addressed later in this paper.

Flight operations are an extremely broad topic and have countless avenues that can be explored. Through this paper, pilot and flight operator interviews will be presented to show where real-life operational influences may be positively or negatively affecting fuel consumption. The CFR will be referenced for opportunity in reducing fuel loading. The simulation development will be outlined to prove its fidelity. Lastly, trade-study results will be shown to highlight which flight parameters have the largest influences on fuel consumption and how they may be addressed. These are all done with the purpose to better connect operations to optimized performance.

CHAPTER 2

PILOT/FLIGHT OPERATOR INTERVIEWS AND COMMON PRACTICE

To truly evaluate flight operations, interviews were conducted with individuals in the industry in order to get a first hand perspective. Individuals ranging from pilots, to dispatch operators, to performance engineers were recruited from multiple airlines and organizations. The diverse group of participants helps outline varying issues and a range of opinions on these issues. For the protection of the individual's identities, no information will be provided and they will be simply referred to as participants. The information gathered during each interview will not be linked to that particular participant but presented in aggregate form with the rest of the participants. As well, any particular information may not pertain to any one individual participant but potentially multiple participants or even the observation by the participant of other individuals in his organization.

Using common practice knowledge, comparisons and contrasts can be made with the expected and actual flight operations. The connection between these interviews and the in-house flight profile simulation will develop the areas of highest concern in flight planning. For flight profiles, the basic areas of interest are presented in Figure 2 below. [17] The margin of safety is a large concern for airlines and pilots, especially at takeoff and landing. The interviews provide a realistic view on these margins of safety and present what should or should not be changed during flight operations. This acts as a springboard for the rest of the study, CFR review, and the flight profile simulation trade-studies.

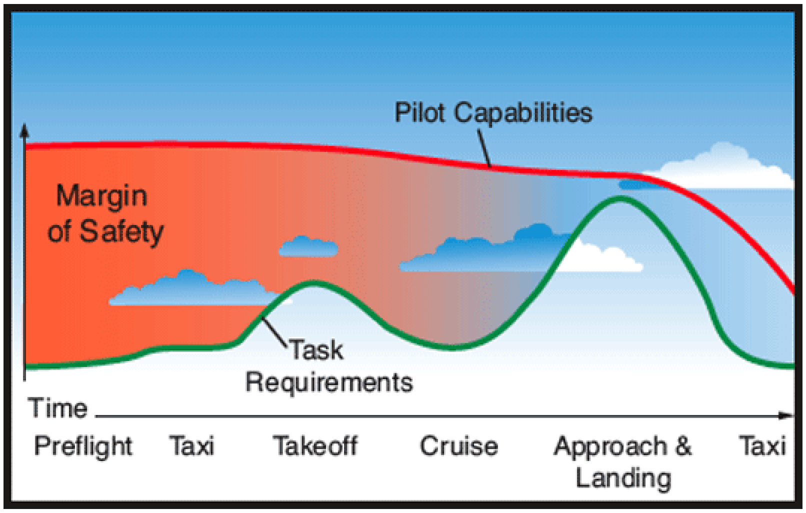


Figure 2. Flight Profile Margin of Safety

2.1 INTERVIEW QUESTIONNAIRE

The main focus of these interviews was to gather tribal knowledge and taboo techniques performed by pilots and flight operators that may affect fuel consumption. The questions are intended to define not only actual flight operations but more importantly, the specific idiosyncrasies of real-life operations that are not considered in design. It is expected that common practice will vary slightly with the actual flight plan but the interviews are intended to find the unique techniques used by the pilots that may define serious performance changes that are not planned or designed for. Although there was a list of questions prepared, the interviews were open ended and did not cover every question available. Often one answer would lead into a new question that was not present on the interview questionnaire.

The following is a list of common questions asked during the interview process. They are worded to accommodate a pilot interview but this was adjusted for each participant depending on their position.

FAA Regulations:

- Do you feel that the FAA margins for extra, reserve fuel are set too low? Too high? Just right?
- Would it be feasible for FAA to accommodate the more modern and higher technologically advanced aircraft? And could newer technologies be encouraged by the FAA?
- Do you think the ETOPS regulations could be adjusted? Why?
- Do you think the "123" rule for determining an alternate could be adjusted? Why? (per 14 CFR § 91.167 and 121.619, IFR standards must contain an alternate airport fuel reserve if weather reports and forecasts show that for one hour before and after the estimated time of arrival, the ceiling will be lower than 2,000 feet above the airport elevation and the visibility will be less than 3 miles.) [18] [19]
- Do you think the 45 minute rule for reserve fuel could be adjusted? Why?

Air Traffic Control (ATC):

- How do you think we can reduce congested airports?
- Is the ATC system out-dated? Why?

Fuel Loads:

- Who determines the fuel load before takeoff? and how often did you add fuel?
- What are your typical fuel loads at landing?
- In general, how often do you deviate from the Flight Management System or flight plan? Why?
- What techniques did you use to improve fuel consumption?

Weather:

- How does the expected weather/storm affect the fuel load? Is there a standard fuel addition or does it account for the new flight path?
- How often were the weather forecasts wrong? And would improved methods highly improve fuel consumption?
- What methods or communications were used to improve head/tail winds?

Takeoff/Climb:

- Do you ever alter climb speed (in terms of indicated airspeed) from the prescribed flight plan to improve fuel consumption or flight time?
- For less than 10,000 ft, do you ever fly less/more than 250 knots? And how often?

Cruise:

- What is a typical speed fluctuation around your planned flight speed/altitude?
- Do you always try to fly the best altitude for fuel burn (per the pilot's handbook)? Or do you or dispatch take into account winds aloft?

Descent/Approach:

- What are some techniques you use to either improve fuel consumption or flight time during descent?
- How often are you put into holding and do you believe there is any way to avoid this extra fuel burning step? Whether it is reduced cruise speed earlier on, better traffic management, etc.
- How often did you utilize Constant Descent Approaches (CDA) or Required Navigation Performance (RNP) approaches?

2.2 INTERVIEW RESULTS AND IMPLICATIONS

Flight operations are an extremely complex task that includes many factors outside the scope of this study. The results from the interviews allowed for only discussing a small percentage in terms of total operational topics. However, the information gathered was still sufficient enough to tackle some of the larger issues at hand that need attention. The responses from the participants were in no means solutions to the problems but were simply educated and experienced personal opinions on the matter.

As shown in the previous section, the diverse topics comprise FAA regulations, the Air Traffic Control system, airline policy, and flight planning. Before the actual responses are presented, there are some important factors to consider. For every flight there are countless unforeseen problems that can arise from weather and changing winds, traffic, blown tires on the runways, runway changes, and requirements from air traffic controllers. Flight operators (pilots, dispatchers, flight performance engineers, and air traffic controllers) work in an imperfect system and must be capable of adapting to any particular event that may occur.

2.3 FEDERAL AVIATION ADMINISTRATION (FAA)

As an over-arching goal of the study, the FAA regulations will be addressed first. One performance engineer joked that if the FAA doesn't understand a problem then the answer is no. Nearly every participant agreed that there were some FAA regulations out of date and need to be adapted to modern times. These included electronic equipment considerations, Required Navigation Procedure (RNP), Continuous Descent Approaches (CDA), Automatic dependent surveillance-broadcast (ADS-B), non-stop restrictions, government regulation of a public market, the "123" rule for determining an alternate, the 45 minute reserve fuel for requirement, and satellite weather considerations. Among these, there were some disagreement but each of these will be addressed below. Issues will be addressed in a similar order outlined by the questions in the previous section. As well, any reference to the CFR or flight profile simulation will be addressed further in the following appropriate chapters.

2.3.1 PERSONAL ELECTRONIC DEVICES IN THE COCKPIT

Firstly, the FAA proposed an amendment to 14 CFR § 121.542 [20] in January 15, 2013 with Docket 2012-0929 that there should be a prohibition on personal use of electronic devices on the flight deck. [21] The purpose was to address concerns that crew members were too distracted from flight management with non-essential tasks. Multiple performance engineers argued that this will hurt flight performance because the pilots lose the capability to remain up-to-date with weather forecasting. The capability to quickly check the weather would allow a pilot to address an issue he may see just ahead of them. However, one pilot suggested that using electronic connectivity for weather forecasting is unrealistic and only opens the door to those "5%" of pilots that ruin it for everyone else by watching movies or listening to music. He then reaffirmed this by suggesting it would probably be faster to check with dispatch or flight service stations for weather updates. On the other hand, as pointed out by another participant who was a pilot and dispatcher, the new regulation would define the restriction by personal-use for non-essential tasks and the pilots would still be able to perform the necessary tasks like weather forecasting without restrictions. The appropriate usage is then defined by the airline and compliance with these approved tasks would be inevitably determined by the pilot.

2.3.2 EXTENDED TWIN OPERATIONS (ETOPS)

Common fuel reserve planning for major airlines include the use of ETOPS in 14 CFR § 121.624, 121.646, and 121 Appendix P [8] [9] [10]and the 45 minute rule for domestic IFR conditions found in 14 CFR § 91.167, and 121.639. [18] [22] An example of how the ETOPS requirements have changed is shown in Figure 3. [23] In the past, twin engine airplanes were required to fly no more than 60 minutes from a usable airport. [24] Over time, this was extended to 120 minutes and now 180 minutes with exceptions as far as 207 and 240 minutes according to Part 121 Appendix P. One individual in dispatch operations has heard of requests even up to 333 minutes. However, he felt that for safety reasons, this is reaching the limits and the requirements are currently sufficient enough. For future studies outside domestic operations, ETOPS may be a very interesting topic to consider for safety implications on overseas flights outside the 180 minute and above limits. On the other hand, the 45 minute requirement can be considered in this study. One pilot suggested that, with research, the 45 minute rule may prove to be unnecessary and could be reduced to 40 minutes or lower. However, two pilots and a dispatch operator felt that the 45 minute requirement was too lenient and did not need to be changed. Further research on this will be shown in the next chapter.

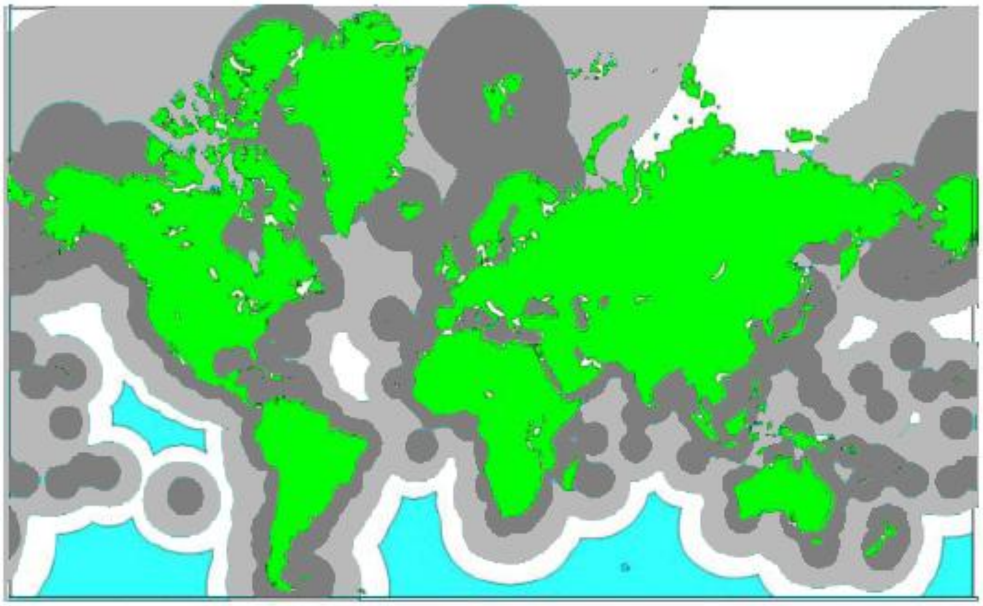


Figure 3. ETOPS Requirements: Dark Grey - 60 Min; Grey - 120 Min; White - 180 Min

2.3.3 THE "123" RULE

Additional fuel reserve requirements include the "123" rule in 14 CFR § 91.167 and 121.619. [18] [19] For IFR conditions, a flight must contain an alternate airport fuel reserve if weather reports and forecasts show that one hour before and after the estimated time of arrival, the ceiling will be lower than 2,000 feet above the airport elevation and the visibility will be less than 3 statute miles. Two pilots and a dispatch operator agreed that with instrumentation, an aircraft can land with worse conditions than outlined. Of these participants, the dispatch operator suggested that the pilot may not even tell a difference between, for example, 2,000 ft and 1,800 ft ceilings. Perhaps like the 45 minute requirement, the regulation is needed but the requirement is too high. Another pilot suggested that these requirements are coupled and if you change one, the other should be left alone. However, a different pilot felt the "123" rule is sufficient and does not need to be changed because weather forecasting is still too unpredictable.

An individual with pilot and dispatch experience expressed that there is an inequality between domestic, flag and supplemental operations' total fuel reserve requirement and that all three operations should follow flag requirements per 14 CFR § 121.645 since this would help standardize the requirements. [25] The fuel requirements become more extensive as operations move from domestic to flag to supplemental. For the case of a supplemental operation, fuel reserve for an alternate airport is required every time per 14 CFR § 121.643 and 121.645 while domestic and flag do not need an alternate every flight. [26] [25] Further research on this will be shown in the next chapter.

2.3.3 OTHER REGULATIONS

In terms of federal regulations, there are additional restrictions in place that affect operators outside the Code of Federal Regulations. For instance, the Wright Amendment from 1979 restricted non-stop flights through Dallas Love Field with only neighboring states. Some alterations were made in 1997 and 2005 however the restrictions on all non-stop flights are intact until October 13, 2014. [27] As well, Ronald Reagan Washington National Airport has a perimeter restriction limiting the non-stop flights to within 1,250 statute miles. [28] There are some exemptions to this rule however these two traffic restrictions are an example of federal regulations limiting the maximum operations of an aircraft. One performance engineer expressed that in his personal opinion, the FAA shouldn't be limiting a public resource and traffic restrictions like the ones mentioned above should be defined by the airlines and not federal regulations. Further discussion on these issues will not be addressed but provides an interesting topic to future studies.

2.4 AIR TRAFFIC CONTROL

Along the lines of federal influence, Air Traffic Control (ATC) was viewed as one of the largest contributors to poor aircraft operations. In general, all the participants had positive views of the controllers themselves but disliked the system and requirements they had to follow. Since nearly every commercial flights operates above 18,000 ft and in Class A airspace, all flights must adhere to and report to ATC per 14 CFR § 91.135. [29] Two pilots, a performance engineer, and a dispatch operator all expressed that their largest concern is the FAA's lack of effort to upgrade the ATC systems in a timely manner. There has been an ongoing attempt by the FAA to develop a Next Generation Air Transportation System (NextGen) however the 2025 completed implementation benchmark is questionable. [30]

This future National Airspace System (NAS) claims to include better departure paths, arrival paths as cartooned in Figure 4, navigation optimization as cartooned in Figure 5, and new systems like ADS-B, Data Comm, CSS-Wx, NVS, CATMT, and SWIM. [30] For departure paths, NextGen would allow for more departure paths horizontally and vertically through smaller separations due to improved satellite navigation. ATC would be able to comply with multiple modern navigation techniques like Area Navigation (rNAV) and Required Navigation Performance (RNP) through a combined system called Performance-Based Navigation (PBN). In terms of new equipment, Automatic Dependent Surveillance-Broadcast (ADS-B) would improve situational awareness through the use of onboard weather and traffic displays. The pilot would be able to see what the air traffic controller sees and monitor their current surroundings even without ATC interaction. As well, the new Data Communication (Data Comm) allows communication through text instead of voice. Pilots are able to read flight plans and communication without having to exchange multiple verbal transmissions. To improve weather influences, NextGen will use Common Support Services-Weather (CSS-Wx) to increase data sharing, faster access to weather information, and more collaboration between weather services. For air traffic operations, the NAS Voice System (NVS) will allow more flexible network communication between TRACON and tower operations to help alleviate communication congestion in certain areas. Additionally, there is the Collaborative Air Traffic Management Technology (CATMT) which is an enhancement to Traffic Flow Management System (TFMS) and lastly, System Wide Information Management (SWIM). SWIM is intended to more efficiently integrate all types of information across multiple sources into one accessible system. It would allow pilots and flight operators to pick and choose what information they would like to monitor or access, like weather, air traffic, etc. [30]

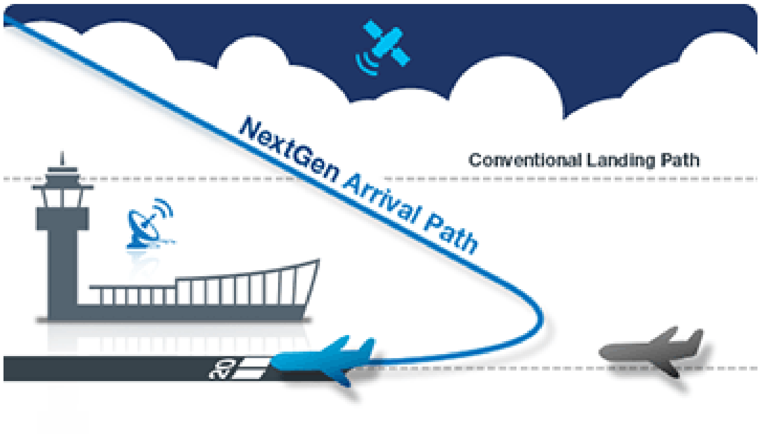


Figure 4. NextGen Optimized Arrival

Figure 5. NextGen Optimized Navigation

Although the NextGen systems seem to be very encouraging and show large potential for improved flight operations, there are still a lot of concerns with the implementation. The two pilots, a performance engineer, and a dispatch operator were pessimistic about the FAA's tangible progress and effort to implement the new systems anytime soon. The FAA claim that the implementation will occur in stages up until 2025. However, this timeline does not seem realistic in the eyes of some of the participants. One participant described this whole process as "analysis paralysis" where the FAA can keep continuously analyzing but this only paralyzes the system from ever being implemented. In Figure 6 below, the FAA provided an info graphic describing the benefits of NextGen and a cartoon concept of flight path optimization. [30] If it is successfully implemented on time, the FAA estimates an aggregate savings of $123 Billion through 2030 using the NextGen system. Whether this is true or not, many participants agreed that ATC systems are holding back the industry and new systems need to be implemented soon. More importantly for this study, the benefits for optimal flight paths would help avoid situations seen in Figure 7, an actual flight profile from Los Angeles to Baltimore. [31] Similar to the info graphic cartoon, ideally, the flight path should avoid non-optimal changes in speed, altitude, and non-directs where possible. The quantitative effects from current conventional methods in comparison to an ideal NextGen method will be shown in a later chapter through the flight profile simulation.

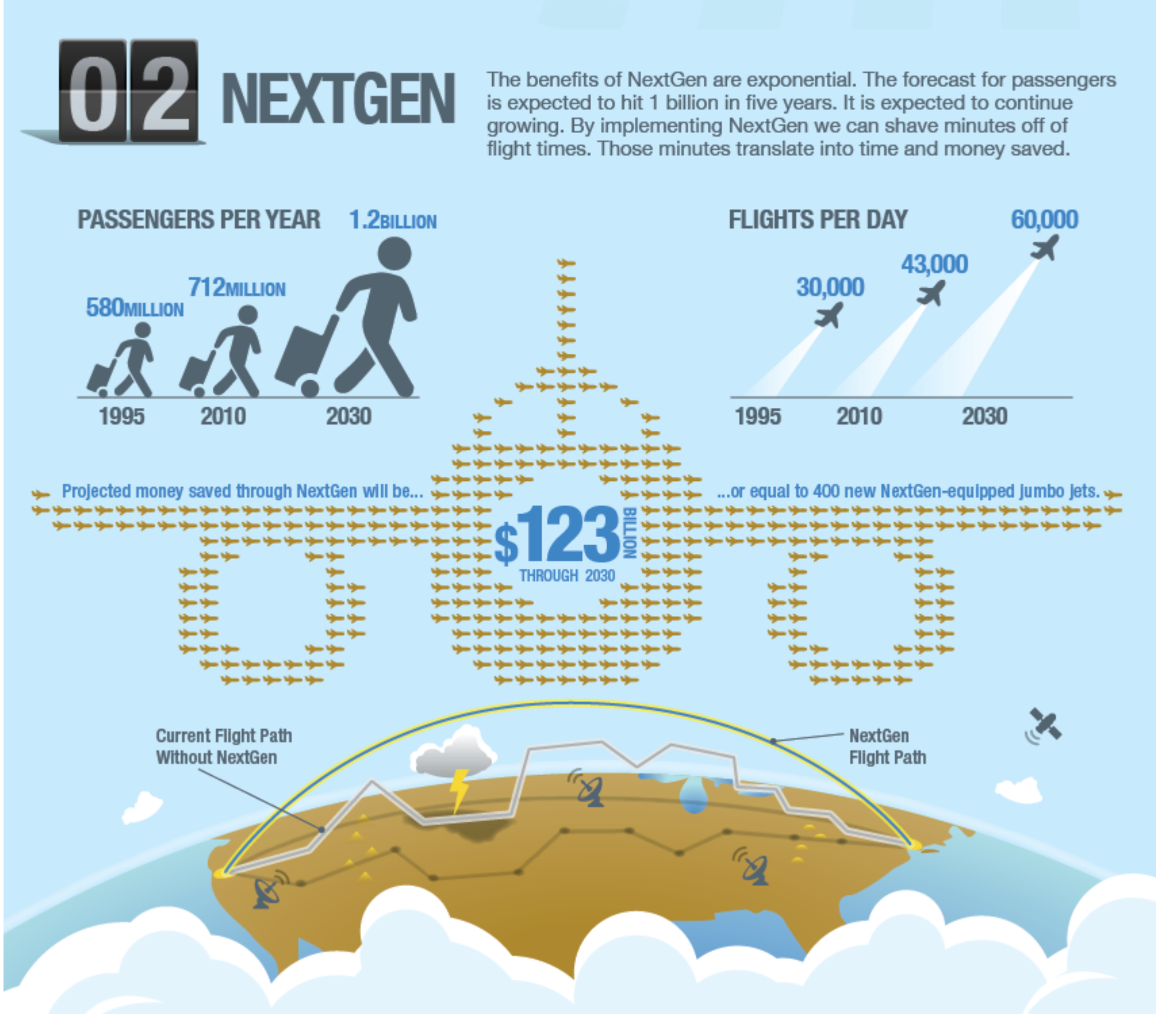


Figure 6. Infographic for the Benefits of NextGen

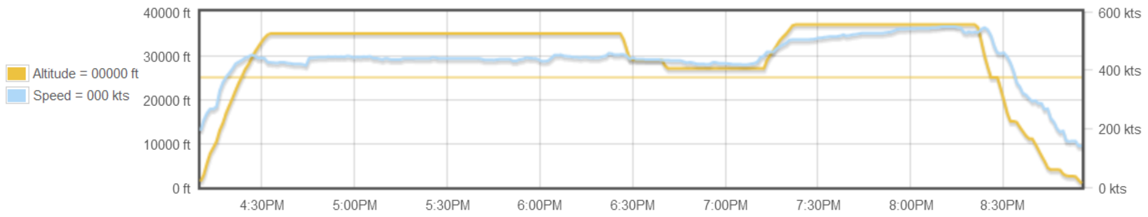


Figure 7. Actual Flight from LAX to BWI

2.5 OPERATOR POLICY

On top of the federal regulations, there are still airline and air carrier policies that affect flight operations and fuel consumption. An individual with pilot and dispatch experience expressed the idea that one shouldn't try to change the federal regulations but instead change the company's policy. He then went on to describe how a lot of air carriers do not think through their own policies and how they are applying the regulations to best benefit themselves.

The structure of a company can highly influence the way actual practice is defined. For instance, the final procedures are often a balance between regulations, customer service, profit, safety, leadership, and inevitably the compliance by the company's employees. The prioritization of these factors is all dependent on the company. Within all of these factors there can be issues with high precision practice, the reach for better technologies, pilot non-compliance, flight time, scheduling, etc. On the other hand, some companies do implement high performance operations and attempt to optimize as much as possible. In general however, there are always small changes that can be made.

For instance, the same participant described the effort to perform better loading schedules and weight and balance practices before takeoff. He described the importance of Center of Gravity (CG) management and how some airlines have even opted to reduce weight by removing unnecessary potable water, using thinner magazines, unload galley carts when not in use, remove pillows and blankets, and resort to electronic tablets instead of large paper manuals. As well he outlined the method of an airline adapting to the regulations by defining their own "normal cruising" to minimize fuel reserve requirements since some regulations define fuel reserves for **X** minutes at normal cruising conditions like 14 CFR § 91.167, 121.617, 121.639, 121.643, and 121.645. [18] [32] [22] [26] [25] These regulations cover the 45 minute reserve fuel and determination of an alternate airport. A company may decide to define this with high fuel reserve consideration for safety or follow the regulation in spirit and decide that true optimal cruise is still sufficient for a fuel reserve and thus reducing the amount of fuel load required and still meet the regulation.

In general, a lot of the operational factors can be outlined through advanced Cost Index (CI) analysis. By prioritizing what is important, operations can be optimized financially through a CI based system. This can consider every possible influence on a flight plan and thus provide the best solution in terms of speed, altitude, location, and other performance parameters. Although many companies, specifically the larger air carriers, have been utilizing a CI system for a long time, not all companies use this or adhere to it and thus open the door for additional issues. For instance, from the interviews, one pilot discussed the practice of some pilots purposefully flying at a different speed than outlined by the CI system. This would be an example of how the practice to utilize the CI system is not entirely accurate to the intended objective. Likewise, an individual in dispatch operations explained that intangibles like customer service may also override these considerations.

For example, the system may suggest one option for optimal fuel consumption however this may result in a more turbulent flight or delayed flight time thus decreasing the service to the passengers. The end decision is not one single answer but a multitude of possible solutions that differ from situation to situation. This is a great example that shows the many influences on flight operations. The preferred option is highly subjective and may be affected by countless factors.

2.6 FUEL MANAGEMENT PLANNING

With the constant increase in fuel prices, airline policies for the most part have become heavily centered on fuel consumption optimization. From Figure 8 below, the jet fuel prices have sky-rocketed since 2000. [33] Unfortunately due to the many unpredictable factors in flight operations, flight planning can only limit fuel loads by so much. An individual with pilot and dispatch experience expressed that for airline policy and practice, Title 14 CFR § 121.647 is a large influence on fuel reserves that can easily be managed by pro-active flight dispatchers. [34] The regulation provides a vague outline of additional fuel reserves that are subjectively determined based on wind, weather, anticipated traffic, possible missed approaches, and other conditions that may delay the aircraft landing. The spirit of the regulation is intended to account for any additional issues that should be considered, however this opens the door to poor flight planning where an individual may add excessive amounts to simply play it safe. With proper airline policies and procedures, these excessive fuel loads are not necessary and a significant amount of fuel loading can be minimized.

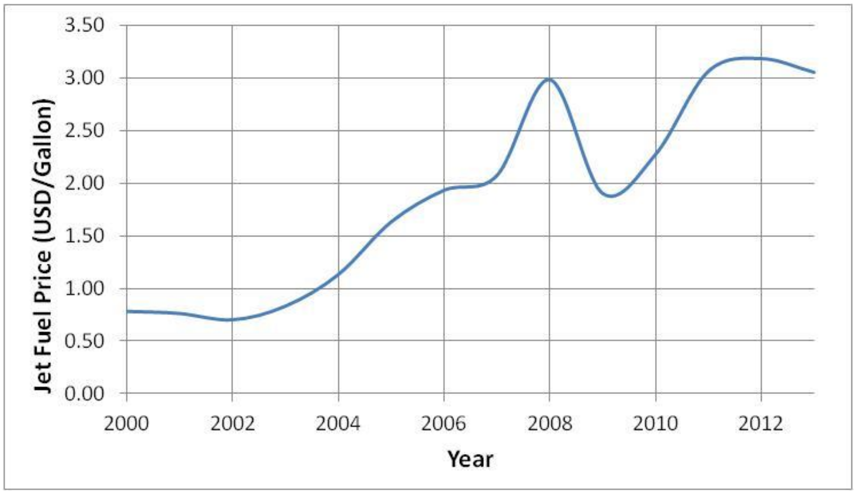


Figure 8. Annual Jet Fuel Prices

2.6.1 PRE-FLIGHT PLANNING

Starting with pre-flight planning, fuel loading is highly dependent on airline policy, human factor, and safety concerns. One individual in dispatch operations described initial flight planning as the process of finding a flight that is safe, meets the regulations, and is efficient. However, he then went on to explain that in the end, the flight operation is defined by the air traffic controllers and pilot practice.

This resorts back to the idea that although a flight plan is made, many influences may still alter the flight and thus should be considered in the original flight plan. Since the flight captain provides the final acceptance, it is not an unusual occurrence for a pilot to add fuel before takeoff. Nearly all the participants outlined this process and described that it is usually due to anticipated weather conditions, additional passenger loading, anticipated holding, runway limitations, or expected delays for a particular airport.

The rate of occurrence was quite different between participants. There were answers ranging from pilots rarely adding fuel before takeoff to pilots adding fuel almost every time. In the case of not adding fuel, the pilots often felt the dispatchers were accurate with their planned fuel loading. As well, if you stay legal, legal should keep you safe. On the other hand, for the cases of adding fuel almost every time, the participant's justifications were that it is always better to be safe than sorry because there are too many unpredictable situations. This may hurt performance and fuel consumption but it is better than a situation where you do not have enough fuel. Although the additional fuel load changes with aircraft and situation, a commercial pilot may typically add about 1,000 to 2,000 lb when requesting additional fuel. The ability to change this practice falls into a very grey area because it is a subjective issue. In the end, the captain of the flight has the final word since the captain is the one on the aircraft and responsibility for the lives of all the passengers onboard. Whether or not this practice will change, the influence of this additional weight is shown in a later chapter with the flight profile simulation.

Once the fuel load is agreed upon, the next important flight stage is takeoff and climb. In terms of takeoff throttle, one pilot illustrated that reduced thrust is a standard practice that pilots are expected to perform. In the case of runways that are longer than the balanced field length, pilots are expected to perform reduced thrust takeoffs or also known as flex takeoffs. Although this actually increases fuel consumption slightly, it is required partly due to contractual responsibilities with engine companies since it will improve the life of the engine. The same pilot then described that an engine company may charge the airlines for performing too many full power takeoffs because it will hurt the life of the engine. Once again, this illustrates how influences outside the airline's control can affect operational performance.

2.6.2 CLIMB SPEED

Climb speed was found to consist of mostly ATC control and 250 KIAS. Since Title 14 CFR § 91.117 [3] defines the maximum climb speed below 10,000 ft as 250 KIAS, multiple pilots expressed that 250 KIAS was the typical climb speed because it was more optimal than flying slower. It was also noted that ATC often defines your climb speed for various reasons including separation criteria and general traffic flow. One pilot and a performance engineer explained that you cannot rely on climb optimization because ATC may alter the flight plan at any time. Once the aircraft exceeds 10,000 ft, one pilot said pilots would then accelerate to cruise speed.

On another note, one pilot described the idea of flying slower during climb when the takeoff direction was opposing the direction of the destination airport. This would be done in order to reduce the distance flown in the wrong direction before being able to turn. Another pilot described that this may only be useful in the case where ATC is delaying the aircraft turn until it reaches a certain altitude. If ATC is delaying the aircraft until a certain distance, then flying faster on climb would actually be more appropriate. As well, another pilot explained that this is unrealistic and the pilot would fly 250 KIAS no matter what. Further analysis on the affects of climb speed and directional speeds will be discussed in a later chapter.

2.6.3 CRUISE SPEED AND ALTITUDE

Cruise is the most important stage in a flight plan because it typically burns the most fuel. In comparison to other flight operations, an aircraft spends the most time at cruise and thus should be highly analyzed for optimization. One of the topics discussed during the interviews was flying direct. Multiple pilots and a dispatch operator explained that as the aircraft reached cruise, pilots typically request a direct routing from ATC. If this was not approved then a request to each center would be requested, one at a time.

In general, the consensus was that pilots prefer direct routings and will request direct on a typical flight. With the availability of area navigation, this is safe and feasible, however may not be the most optimal flight path. With consistent weather and winds, direct would be optimal but that is not realistic. Nearly all participants expressed that dispatch may create a flight plan that flies non-direct because of weather conditions or a jet stream that is causing better or worse winds. A pilot and a dispatch operator each gave an example of a situation where the pilot requested for direct routing when the flight plan was designed to avoid a large headwind that was present on a direct route. It is unclear whether this information was known by the pilots or not but the change in course caused the aircraft to burn an excessive amount of fuel. In one case, the air carrier has improved their policies by requiring dispatch to include warnings on the flight plan to inform the pilots of wind conditions.

Weather and winds aloft are a huge driving factor in flight operations and flight performance. Title 14 CFR § 121.101 [35] requires operators to use the U.S.

National Weather Service with the approval of other sources. [36] The participants expressed a range of confidence in the forecasts provided. The dispatch operator and two pilots felt that the forecasts were typically correct and there were never too many surprises. Two other pilots felt that it was still unpredictable and the forecasts should not be completely trusted. Of course, the farther into a forecast one looks, the more error there will be.

With FAA's proposed NextGen, there are hopes that a more intricate web of up-to-date and accurate weather services will be available to everyone. In the meantime, the interviews suggested that the main source of checking up-to-date and current conditions were through pilot communication with ATC or dispatch.

Through voice communication, ATC or dispatch can ask pilots what winds or flight conditions they are experiencing then relay the information to other aircraft in the area. It should be noted that the interviews did not cover specific methods for forecasting winds aloft so there may be some additional pathways for the information to be updated. However, for the most part, one pilot explained that if a pilot wanted to check the winds at a different altitude, he would ask ATC, who would then ask another aircraft in the area what their winds were. Although the system works, there is a lot of room for automation and the ability to access more information quickly. An individual in dispatch operations explained that on longer flights, dispatch will analyze the winds at specific altitudes to select the most appropriate altitude. He then expressed that in general, dispatch does a good job of selecting the flight plan to best accommodate winds aloft, particularly the presence of strong jet streams. Using the flight profile simulation, specific wind and routing scenarios will be analyzed in a later chapter.

Cruise speed can highly affect fuel consumption but is driven by multiple unrelated factors. Although fuel consumption is typically a top priority, cruise speed affects flight time which is one of the next highest priorities. Flight time requires many considerations like customer service, scheduling, weather, labor costs, and pilot pay. From the interviews, the general consensus was that most pilots obeyed the flight plan and followed the cruise speed per requested, there were some that would alter the speed up or down with the intention to improve fuel consumption, and there were the "5 – 10%" that would disregard the flight speed to benefit their own agenda. Some air carriers have a problem of pilots flying too fast and others a problem of pilots flying too slowly. Multiple participants expressed that this is in part to the pilot's payment method. For instance, some airlines pay the pilots per flight. Since Title 14 CFR § 121.471 [37] restricts pilots to 1,000 hours per calendar year, if a pilot flew fast to reduce his flight time, he would then be able to increase the number of flights per year. One pilot estimated that a non-compliant pilot may boost his speed from the typical Mach 0.74 to as high as 0.78. On the reverse side, if an airline pays by the hour then a pilot could fly slowly to decrease the number of flights per year while still getting the same number of hours. Overall, the consensus was that this does happen but is not a common practice among all pilots. Either way, even "5 – 10%" occurrences can make a large fiscal impact.

Pilots may alter the speed for many other reasons aside from pay related benefits. For instance, a pilot may want to fly faster or slower to avoid expected incoming storms, stay on schedule after a late departure, compensate for head or tail winds, or adhere to requests from ATC. Multiple participants described the importance of on time arrivals for not only passenger service but to ensure that airport scheduling is maintained. Some airlines work in a point to point system where a late aircraft can delay the next flight's departure or delay the ground crew from their next assignment. An individual in dispatch operations expressed that his company was accepting of pilots flying a little faster than planned because it was better to have early arrivals than late ones in terms of scheduling and overall customer service.

It is important to keep in mind that commercial flight operation is a business and although there are standards, the practice is based on how the company runs their business. In the eyes of an administrator, flight operations may be defined slightly different from the eyes of an engineer. In the later chapters, this study will help define that difference by comparing the cost effects on cruise speed.

2.6.4 DESCENT AND APPROACH

Descent and approach is an area of flight operations that needs large regulatory improvement. Although there are optimal approaches available like Constant Descent Approach (CDA) and Required Navigation Performance (RNP) approaches, aircraft are limited by ATC and other aircraft in the sky. Multiple participants expressed that CDA is a common capability and RNP is common with newer systems, however both cannot be used because the ATC system cannot handle these capabilities. In the case of CDA, the performance engineers and pilots explained that pilots hardly ever perform constant descent approaches. The approach will always require at least one step altitude while communication is handed off between ATC (Figure 9). [38] In some cases like Figure 7 above, an approach may consist of many steps that require the pilot to constantly increase and decrease the throttle between each step.

Additionally, in more congested airports, procedures are used like the “Slam Dunk” and “Drive and Dive” approaches. These are scenarios where the aircraft remains at cruise altitude longer then quickly initiates all braking methods and descends rapidly to the airport. In some situations, the landing gear and air brakes are intentionally initiated during the end of cruise and throttle is increased to keep up the speed. These methods fall under “Controlled Flight into Terrain” (CFIT) and “Stabilized Approach Procedures”. Two pilots and a performance engineer suggested that these methods are still being used today even though the FAA released an Air Traffic Bulletin in March, 2001 that highly discouraged the use of these unsafe methods. [39]

Figure 9. Traditional Step-Down Approach vs. Continuous Descent Approach

In the case of Required Navigation Performance (RNP) approaches as seen in Figure 10, [40] an optimized RNP with CDA is the most desirable option since it allows the aircraft to reduce any additional flight distance that is unnecessary. The current ATC system is sophisticated enough for the rNAV approach shown in Figure 10 but will not utilize RNP until NextGen. Additional distance is a large problem with rNAV, however speed is also highly affected. Multiple participants agreed that often times, flight operations are limited by the lowest technology aircraft in the sky. A larger aircraft like the Boeing 737 or Airbus A320 may have to slow down on approach because of traffic in front. This can easily be caused by smaller jets that cannot fly as fast. When aircraft have to start getting in line for approach even up to 300 miles out, ATC may require an aircraft to slow down or speed up outside its optimal cruise in order to compensate for the rNAV approach.

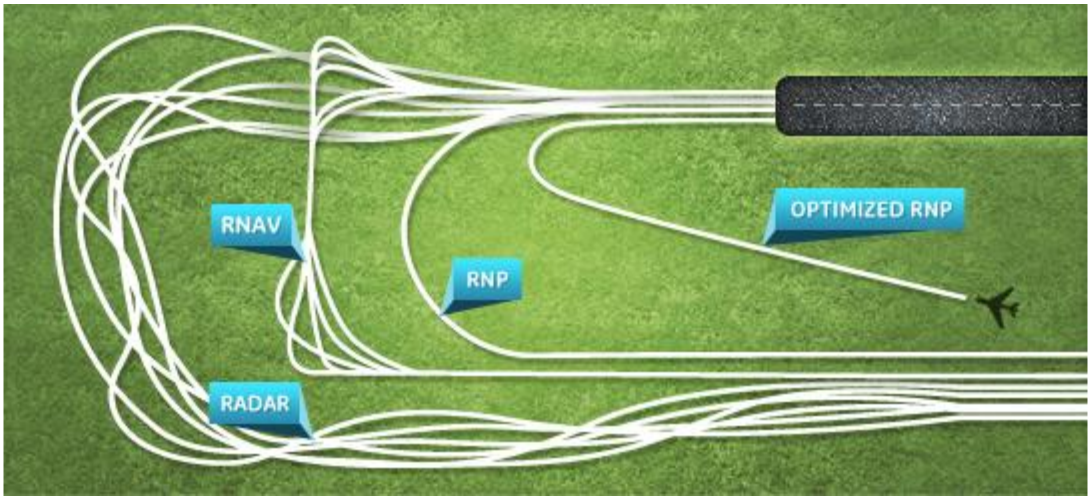


Figure 10. Comparison of Approach Methods

A performance engineer and pilot explained that ideally a free flight system would be perfect. This idea suggests that with enough redundant systems checking the safety of the flight and all other considerations around the aircraft, the pilot may fly however he chooses without restrictions and the systems in place would simply correct for problems like collision, storms, etc. However this is only hypothetical and is in no means a solution in the seeable future. By using systems like CDA and RNP, the industry can take small steps toward this idealized airspace utopia. As discussed earlier, this is all under the assumption that NextGen will be successfully implemented on time. In the meantime, approach is still highly dependent on ATC and the lowest common denominator aircraft in the sky.

2.6.5 TARGET RESIDUAL FUEL AT LANDING

Lastly, upon landing there are final residual fuel loads. These loads will vary between aircraft and air carrier however the interviews showed that there was a fairly consistent fuel load that an aircraft should have on landing. In general, one pilot expressed that it depends more on flight time than weight values for considering how much reserve fuel is required since it will change for each type of aircraft. For instance, the consensus from an individual in dispatch operations and the pilots suggested a typical landing fuel load of about 45 minutes with some extra contingencies. For the larger aircraft like Boeing 737 and Airbus A320, these loads were around 4,000 to 6,000 lb. For the B737, a flight plan was targeted for 5,000 lb. If the aircraft landed with 4,000 lb the weight was marginal and may need some further investigation, while 6,000 lb was considered conservative. One pilot expressed that there may be possibilities to reduce these landing fuel loads by, for example, 1,000 lb however if a flight crashes, or flights are at negatively affected by the change then all those benefits were lost. In the grand scheme of things, it is not worth the risk. As well, two pilots suggested that pilots and flight operators would not be comfortable with anything less.

2.7 SYNOPSIS – ANALYSIS OF INTERVIEWS

As a review of all the main interview topics covered, Table 1 below shows the general consensus for each topic. The descriptions do not provide full detail on the participant's answers but can act as a quick review for the main ideas addressed. Additionally, each topic contains a column for applicable CFR requirements. From the regulations discussed above, the following chapter will go into more detail on how these regulations and airline policies may be altered to improve flight operations in terms of fuel consumptions.

Table 1. General Consensus from Interviews

Category	Topic	General Consensus	CFR Reference
FAA Regulations	Use of Personal Electronic Devices	Good if air carriers define the use correctly. Bad for small percent of pilots that abuse the access.	14 CFR § 121.542
	Extended Twin Operations flight allowances	For domestic flights, the 120 to 180 minute allowances are sufficient. For overseas flight of up to 333 minutes may be breaching the edge of safety.	14 CFR § 121.624, 121.646, and 121 Appendix P
	45 minute reserve fuel	Adequate unless substantial evidence is shown to prove otherwise.	14 CFR § 91.167 and 121.639
	"123" Rule for determining an alternate	Adequate unless substantial evidence is shown to prove otherwise.	14 CFR § 91.167 and 121.619
	Standardization of fuel reserve requirements	Suggested by one participant's opinion to standardize.	14 CFR § 121.639, 121.643, and 121.645
Air Traffic Control	FAA's progress and effort to implement NextGen in a timely manner	FAA's lack of progress have resulted in poor optimism from flight operators. It is unlikely that the FAA will implement NextGen under the timeline they have outlined.	N/A
Airline Policy	Load scheduling with Weight and Balance	Some air carriers are not optimizing CG management and weight considerations from other	N/A
	Adaptation to regulations	Some air carriers do not define regulations properly in order to optimize the wording and spirit of the regulation.	14 CFR § 121.167, 121.617, 121.639, 121.643, and 121.645
	Fuel reserve determination by dispatcher	Fuel loading can be highly affected by lazy flight planning. Careful fuel loading should be encouraged by air carrier.	14 CFR § 121.647
	Scheduling	On time arrivals are highly encouraged to maintain proper scheduling for the other operations following arrival.	
Pre-flight	Pilots adding fuel to flight plan	Rate of occurrence varied greatly. Some pilots hardly add extra fuel and some add fuel almost every time. Usually added about 1,000 to 2,000 lb.	N/A
	Weather forecasts	Mixed opinions including: rarely surprised by the weather and the forecasts are too unpredictable to trust.	14 CFR § 121.101
Takeoff/ Climb	Reduced thrust or flex	Standard practice expected from pilots.	N/A
	Climbing at 250 KIAS	Very typical climb speed unless ATC intervenes.	14 CFR § 91.117
	Slowing down to account for adverse takeoff direction	Mixed opinions including: performed occasionally, unrealistic since 250 KIAS is typical, and speed is more dependent on ATC request.	N/A
Cruise	Direct routing	Common request by pilots. This can have adverse affects when flight plan was created based on winds.	N/A
	Ability to adjust to weather and winds	Radio communication with ATC and dispatch is adequate however potential NextGen systems would be better.	N/A
	Cruise speed based on pay	Small percentage ("5-10") of pilots may increase or decrease their cruise speed to improve their pay.	N/A
	Cruise speed in general	Most pilots typically follow the flight plan with the exceptions of ATC intervention, weather condions, scheduling, etc. Air carrier's are generally laxed about these fluctuations.	N/A
Descent/ Approach	Constant Descent Approach (CDA)	Could be very beneficial but is hardly used because of ATC limit of capability.	N/A
	Required Navigation Procedure (RNP) approach	Could be very beneficial but is hardly used because of ATC limit of capability	N/A
	"Slam Dunk" and "Drive and Dive" approaches	Still present in operations although FAA highly discourages the use of these CFIT approaches.	N/A
Landing	Fuel loads	Larger aircraft flight plans aim for about 5,000 lb of unused fuel loads. This may fluctuation by 1,000 lb for poor flight performance or conservative takeoff weights.	14 CFR § 91.167 and 121.639

CHAPTER 3

CFR AND AIRLINE/AIRCRAFT MANUFACTURING GUIDELINES

Adherence to government established flight regulations is one of the most defining parameters in aircraft design and operation. For the main discussion in this paper, the U.S. Federal Aviation Administration (FAA) regulations will be used as the operational standard. The Federal Aviation Regulations (FARs) are outlined in Title 14 of the Code of Federal Regulations (CFR). Any and all regulations defined by Europe's Joint Aviation Requirements (JAR) will not be considered when the discussion involves United States domestic flights. The inclusion of JAR will occur for overseas missions that must comply with both sets of regulations but may be addressed in future studies. Because this paper focuses on commercial operations, the governing parts on performance of transport aircraft are as follows: 14 CFR § 25, 91, and 121. [11] [12] [13] By outlining the largest driving regulations, further consideration of flight design and planning can be done.

Since the aviation industry is constantly improving and expanding its potential through performance and air transportation management, the CFR must also evolve to match the current state of the industry. For instances runway performance and takeoff/landing speed in the 14 CFR § 25 or 91 do not include any mention of flex thrust or thrust reversers as approved methods to improve performance. Once newer technology becomes fully reliable, the regulations should reflect the opportunity to utilize this technology. 14 CFR § 25 will not be discussed in detail because it only deals with the airworthiness standards of transport category aircraft. Fuel reserve requirements are of the most interest in this study and thus the following will focus primarily on 14 CFR § 91 and 121. For full text of each regulation discussed, see Appendices A, B, and C.

3.1 PART 91. GENERAL OPERATING AND FLIGHT RULES

For commercial air carriers considered in this study, nearly all flights will fall under "domestic operations" and must comply with Instrument Flight Rules (IFR). For air carrier flights that fly internationally or outside the 48 contiguous U.S. and District of Columbia, "flag" and "supplemental" operations would be considered. However, the main focus will be on domestic flights. This will apply to all CFR parts discussed.

The first regulation of interest is Title 14 CFR § 91.117 [3] for aircraft speed. In particular, this limits the aircraft speed to 250 KIAS while less than 10,000 ft. This regulation derives from the concern of mid-air collisions at low altitudes. The idea is that if an aircraft going 300 plus KIAS, it will not have time to recognize and prevent a collision with a smaller aircraft flying slower. [41] As well, ingesting birds at a higher speed is harder to recover from and land. In terms of smaller aircraft, this regulation may be necessary as of now but with the implementation of systems like ADS-B from NextGen, aircraft will be able to monitor their surrounding environments much easier than before. Perhaps when NextGen becomes fully implemented, the 250 KIAS limitation should be re-considered to allow aircraft to climb at their optimal speed.

Within Part 91, fuel requirements for IFR conditions are outlined per 14 CFR § 91.167. [18] This regulation is very important for flight operations because it defines the additional fuel reserve requirements (along with 14 CFR § 121.639 [22]) needed for nearly all commercial flights. The regulation requires enough fuel to complete the flight to the intended airport, then fly to the alternate airport, then fly after that for 45 minutes at normal cruising speed. For aircraft that meet the "123" rule, no alternate airport needs to be filed and thus less fuel reserves are required. For the "123" rule, as mentioned in the previous chapter, an alternate is required if weather reports and forecasts show that one hour before and after the estimated time of arrival, the ceiling will be lower than 2,000 feet above the airport elevation and the visibility will be less than 3 miles.

The second and third segments of this regulation were initially of large interest because of the potential decrease in fuel load per flight. After performing the interviews, it was found that there is not an overwhelming agreement that this regulation could be changed in favor of reduced fuel requirements. In fact, the general consensus said the opposite and the regulation is adequate. In the eyes of two pilots and a dispatch operator, the fuel requirements were considered even too lenient. On September 1, 2003 a Beech B36TC had to perform a forced landing in Uniondale, IN. [42] Upon the landing, two individuals were injured and three passengers were fatally injured. The flight was under IFR conditions and should have planned for 45 minutes reserve fuel. The pilot under-planned the correct amount of fuel due to poor consideration of start, taxi, takeoff, climb, and descent fuel usage. Although the aircraft did not correspond to an air carrier, it still must follow the IFR requirements. In this case, the regulation was actually too lenient to compensate for the pilot's poor planning. A commercial air carrier is under more scrutiny to perform accurate flight planning but one must always consider the human factor. Even in a commercial flight operation, the possibility of incorrect fuel loading could result in a similar situation that the Beech aircraft experienced. One suggestion would be to create an exception to this regulation and allow the more scrutinized air carriers some lee-way in fuel reserves but it is unlikely that pilots and flight operators are comfortable reducing the regulation and further.

For the third segment and consideration of determining an alternate (also addressed in 14 CFR § 121.619 [19]), it is unlikely that a regulation change would be supported by the flight operations industry. Two pilots felt that weather forecasts are too unpredictable and the risk of breaching safety is not worth the reward. Once the FAA implements NextGen weather forecasting and monitoring, this regulation may be considered again, but for now it is not a target for reducing fuel consumption.

3.2 PART 121. OPERATING REQUIREMENTS: DOMESTIC, FLAG, AND SUPPLEMENTAL OPERATIONS

Within this section, there are three main forms of operations. From 14 CFR § 119 section 3, [43] "domestic operations" are essentially any scheduled operations with a turbojet and more than 9 passenger seats that operate within the 48 contiguous U.S. and District of Columbia. "Flag operations" applies to the same type of airplane but with operations that include anywhere outside the 48 contiguous U.S. and District of Columbia. Lastly, "supplemental operations" are any common carriage operations for compensation or hire. This means an airplane with 30 passenger seats and operates under a departure plan negotiated with the customer, along with all-cargo operations, and passenger-carrying public charter operations.

A large influence on commercial flight operations reside in “part 121”. The first of which is the standards for weather forecasting per 14 CFR § 121.101. [35] This regulation essentially outlines that domestic operation inside the 48 contiguous U.S. and District of Columbia require weather reports were prepared by the U.S. National Weather Service. [36] As discussed in the previous section, the weather forecasts are still too unpredictable to allow for some regulation changes. Although it is easy to suggest that other weather report sources may be more accurate, weather is inevitably unpredictable. One pilot commented that weather from your local news station tended to be more pessimistic about the forecast than the U.S. National Weather Service. On the other hand, multiple participants expressed optimism toward accurate winds aloft planning. It may be difficult to forecast accurate weather during landing but wind speeds can be utilized without too many safety concerns. As shown in Figure 11, winds speeds and direction can change drastically across the country but flight planning can still be optimized accordingly. [44] [45] With the impending progress of NextGen, it is possible that this regulation will be slightly altered in the future to incorporate systems like ADS-B, CSS-Wx, and SWIM. [30]

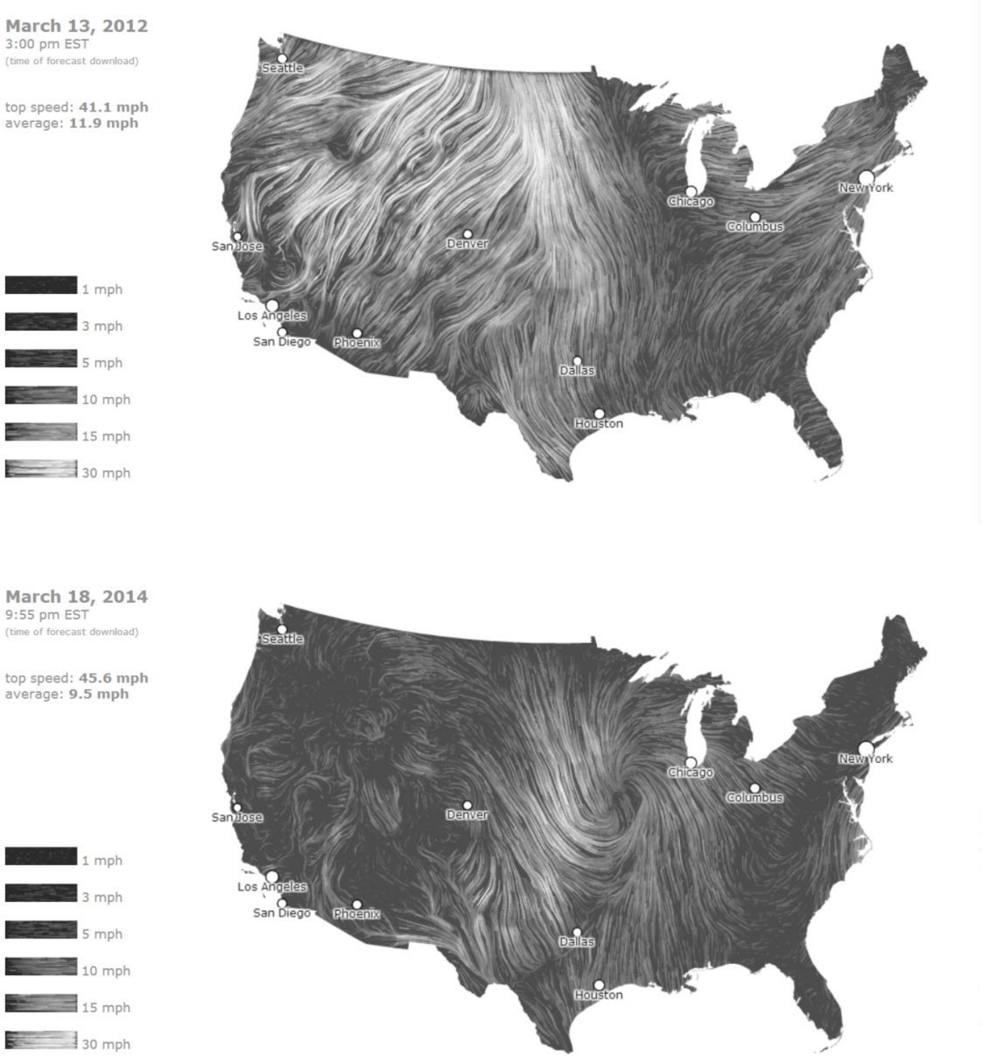


Figure 11. Visual Wind Speeds in the U.S.

ETOPS have been a significant stepping stone in flight operations for improving fuel consumption. 14 CFR § 121.161, 121.624, and 121 Appendix P are incorporated with allowing the ETOPS exceptions. [46] [8] [10] Without ETOPS, CFR § 121.161 would require two-engine aircraft to remain within 60 minutes of an adequate airport. Even though ETOPS is easily utilized, it still remains un-optimized. The current method of navigation relies on rNAV and the use of direct routing requests. Until ATC can comply with the RNP method, flight routing cannot be improved much more. In terms of ETOPS, even the top of the line aircraft do not have full range across the globe. One dispatch operator and pilot expressed that ETOPS has reached its limit of safety. It could be argued that no matter how advanced aircraft become, there should always be some level of security in regards to the aircraft's distance to an adequate airport. As mentioned in the early chapter, this is an interesting topic for a future study but will not be addressed any further in this report.

As an extension to the IFR fuel requirements, 14 CFR § 121.639 [22] is a re-iteration of the three main fuel requirements for domestic operations. Firstly, the fuel required for the mission to the destination airport, and then followed by the alternate airport (when applicable) and lastly, 45 minutes of normal cruising. As discussed in the previous section, there is not a lot of support behind reducing these requirements and in fact, two pilots wish they were higher. One individual with pilot and dispatch experience suggested that domestic, flag, and supplemental operations should all use the same criteria for fuel requirements. 14 CFR § 121.645 [25] outlines for flag operations within the 48 contiguous U.S. and District of Columbia, an aircraft must follow 14 CFR § 121.639 [22] as well as plan for two hours of normal cruise fuel consumption when an alternate airport is not filed. As well, the determination of an alternate under 14 CFR § 121.621 [47] outlines the "123" rule with the addition of ceiling and visibility parameters that may increase the scope of requiring an alternate. Essentially, the fuel requirements for flag operations are higher than domestic operations. If this were to be implemented, the margin of safety would increase but average fuel consumption would increase with the additional fuel loading. Overall, the interviews resulted in minimal concerns with the CFR but suggested that ATC is main federal-related issue with flight operations.

3.3 AIRLINE AND AIRCRAFT MANUFACTURERS SELF-IMPOSED FUEL GUIDELINES

In general, the federal regulations are the strictest form of requirements that a flight operator must comply to. However, there are additional self-imposed requirements defined by the airlines and the aircraft manufacturers. Among these there are guidelines and protocols on improving flight performance. For example, Airbus provides an introductory look at fuel economy in the customer services report "Getting to Grips with Fuel Economy". [7] The report looks at a large range of methods to reduce fuel consumption starting in pre-flight and ending in landing. The airlines and air manufacturer's attempt to improve fuel efficiency and fuel consumption as much as possible however they cannot fully control the end performance due to the unpredictable nature of flight planning. There will always be human and environmental factors involved that should be considered. This paper does not attempt to compete with the resources of these companies to improve fuel efficiency but outline the written and unwritten techniques that can be utilized to improve fuel consumption.

Aircraft manufacturers represent the design side of aircraft performance. From the system level manufacturing, aircraft are slowly improving upon performance. Multiple participants agreed that we are slowly leveling off in terms of technological advances and thus reaching at smaller and smaller improvements.

These improvements can still make a large difference, especially as the number of flight operations is still increasing.

Taking from the service report, “Getting to Grips with Fuel Economy”, Airbus has made many small improvements to the various aspects of aircraft performance. [7] During pre-flight procedures, the report outlines the efforts from Airbus to: 1) improve CG management for fuel burn, 2) reduce the aircraft’s zero fuel weight, and 3) include a performance measurement system to improve flight planning. For takeoff and climb, Airbus encourages the use of flex thrust takeoffs to extend the life of the engine; this saves money in the long run. Because most Airbus models have an optimal climb speed above 250 KIAS, when flying at less than 10,000 ft they cannot climb at their best speed.

Once at cruise, Airbus suggests flying slower and at optimum altitudes. With flight time considerations, a Cost Index system may balance fuel consumption with other operating costs. As well, an optimum altitude can be achieved by step climbs or taking advantage of tailwinds at various altitudes. For descent and approach, the aircraft should remain in a clean configuration and in cruise for as long as possible. This exemplifies how design is attempting to optimize flight planning however realistically; some of these conditions are not common due to weather, ATC, and traffic. In this case, utilization of design improvements is still limited by operational constraints like the ATC system.

The connection between design performance and operations is the same as manufacturers to air carriers or airlines. As discussed throughout this report, the out-dated ATC system is a very influential factor in flight operations. Air carriers can still work around this current speed bump by implementing better internal policies. In terms of the CFR, as mentioned earlier, air carriers can adapt to the regulations and optimize fuel consumption through the phrasing. For instance there are no standards on how you define 14 CFR § 121.639, 121.647 or 91.167 for fuel supply requirements. [22] [34] [18] With poor planning and non-optimal definitions, two identical missions can result in far different fuel requirements. By investing in flight performance measurement systems, flight plans can become more accurate and reduce the overall fuel loading. As well, if an air carrier wants to define normal cruising as a non-optimal condition, the regulation would require an increase in fuel reserve.

Small changes to airline policy and procedures can make a big difference in operations in the long run. Based on the interviews, it is clear that for some companies in the industry, there are corporate culture problems. One individual with pilot and dispatch experience highly stressed that a lot of poor flight operations stem from air carrier policy, and not the regulations. He suggested that air carriers need to re-evaluate themselves before attempting to make external regulatory changes. Some of the larger air carriers may have a better grasp on running a more efficient operation. According to the same participant there are a lot of improvements that can be done internally that a lot of air carriers do not consider. One in particular is the effort to improve CG management and overall load scheduling. By having a more forward oriented CG, the aircraft is more stable but the drag will also increase. Loading the aircraft in a manner that would move the CG aft can help improve fuel consumption. For stability, there is a range of acceptable CG locations and to optimize fuel consumption there should be an effort to shift the CG closer to the aft limit.

CHAPTER 4

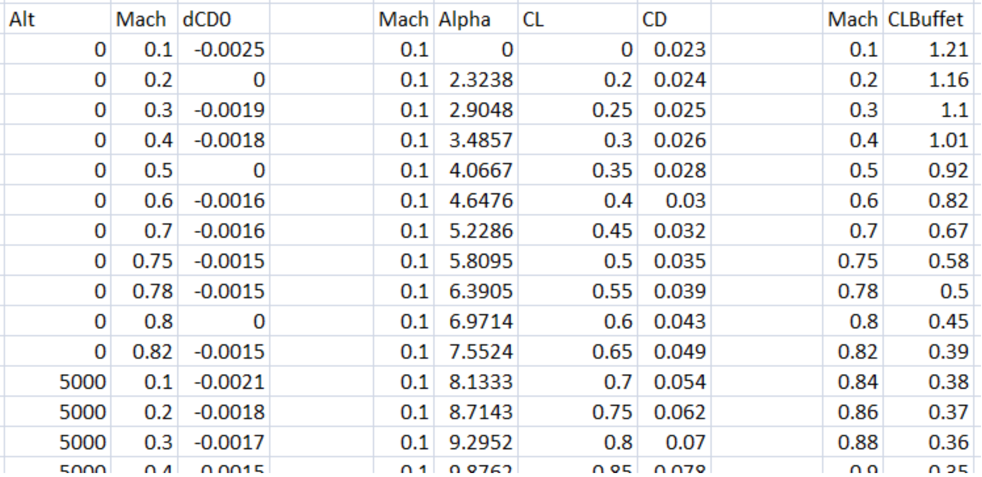
FLIGHT PROFILE DESIGN AND ANALYSIS TOOLS

Based on the topics developed so far, a flight profile simulation can be implemented to analyze the affects of these operational interests. The simulation will be used to perform various trade-studies on any particular flight parameter to see how it may affect fuel consumption or other operational parameters. Aside from regulations and operations, flight design can be routed back to basic approaches and equations. Common textbook design practices derive from methodology founded on basic physical principles. Unfortunately, these methods do not necessarily connect with the reasons behind current government regulations and air carrier policies. Using these basic approaches, the performance impact can be analyzed in terms of fundamental engineering design. The study will take real fluctuations in operational procedures and apply them to a simulation founded in basic methods. Since this study does not require a high fidelity weight model, simplifications will be considered when comparing the flight profile simulation with actual flight data. It is important to consider both basic physics and regulatory compliance when building useful numerical simulations. Often times, simplifications are done to create simplified equations or analytical uniformity across many types of aircraft. This study is intended to show general fuel consumption trends and thus can use the simplifications for this purpose.

The development of this simulation code and integration of legacy codes began through a senior design project with the help of Nicholas Mora and Steve Scoville. [48] Through this study, the basic mission code in the design project has been highly developed to include more flight parameters, higher accuracy, and overall more flexibility to perform the desired flyout models. The two legacy codes integrated into the simulation are an Empirical Drag Estimation Technique (EDET) [49] and the Numerical Propulsion System Simulation (NPSS) [50]. Both tools produce extensive tabular data for the flight simulation. Additionally, empirical weight regression formulas are used to analyze the influences on maximum landing weight and how it can be minimized. [4]

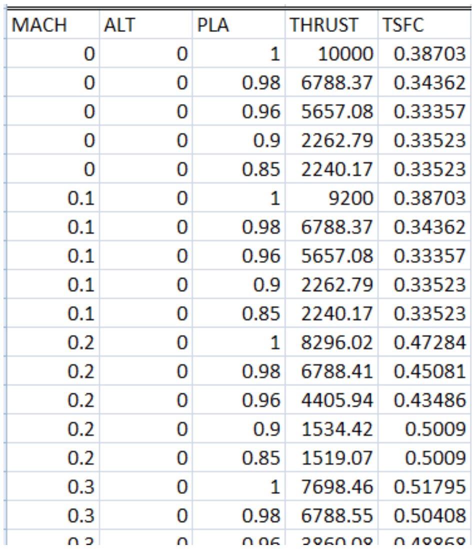
4.1 EDET, NPSS, AND SKYMAPS

The first analysis tool, EDET, uses an input file that defines basic geometry, design flight conditions, and general aircraft characteristics to empirically estimate the base drag for a range of flight conditions. The output data contains coefficient of drag estimates for a range of Mach numbers and equivalent coefficients of lift. As well, it provides altitude drag corrections for a range of Mach numbers. An example of the output data is shown in Figure 12 below. NPSS on the other hand provides a tabular engine data through the form of "5 column" data. The tool provides information and correlation between Mach number, altitude, power lever setting, thrust, and TSFC as seen in Figure 13 below. Once this data is gathered for a particular aircraft, in this case, the Boeing 737-300 model, performance characteristics can be analyzed. A contour plotting method can be used in which different flight variables are calculated and presented as dependent upon Mach numbers and altitudes. These plots are called "Skymaps" and they help present the relevant variables as a function of flight conditions. [51] Skymaps use classical approaches and implementation of the EDET results to show flight envelopes of the aircraft. Finally, using the same classical approaches, EDET, and NPSS results, the flight profile simulation tool can be utilized to model a mission flight profile for any particular aircraft in question. This tool is also known as the mission code and was ultimately independently developed to simulate a flight mission and its resulting flight parameters in terms of fuel consumption, altitude flyouts, Mach number flyouts, and more.



Alt	Mach	dCD0	Mach	Alpha	CL	CD	Mach	CLBuffet
0	0.1	-0.0025	0.1	0	0	0.023	0.1	1.21
0	0.2	0	0.1	2.3238	0.2	0.024	0.2	1.16
0	0.3	-0.0019	0.1	2.9048	0.25	0.025	0.3	1.1
0	0.4	-0.0018	0.1	3.4857	0.3	0.026	0.4	1.01
0	0.5	0	0.1	4.0667	0.35	0.028	0.5	0.92
0	0.6	-0.0016	0.1	4.6476	0.4	0.03	0.6	0.82
0	0.7	-0.0016	0.1	5.2286	0.45	0.032	0.7	0.67
0	0.75	-0.0015	0.1	5.8095	0.5	0.035	0.75	0.58
0	0.78	-0.0015	0.1	6.3905	0.55	0.039	0.78	0.5
0	0.8	0	0.1	6.9714	0.6	0.043	0.8	0.45
0	0.82	-0.0015	0.1	7.5524	0.65	0.049	0.82	0.39
5000	0.1	-0.0021	0.1	8.1333	0.7	0.054	0.84	0.38
5000	0.2	-0.0018	0.1	8.7143	0.75	0.062	0.86	0.37
5000	0.3	-0.0017	0.1	9.2952	0.8	0.07	0.88	0.36

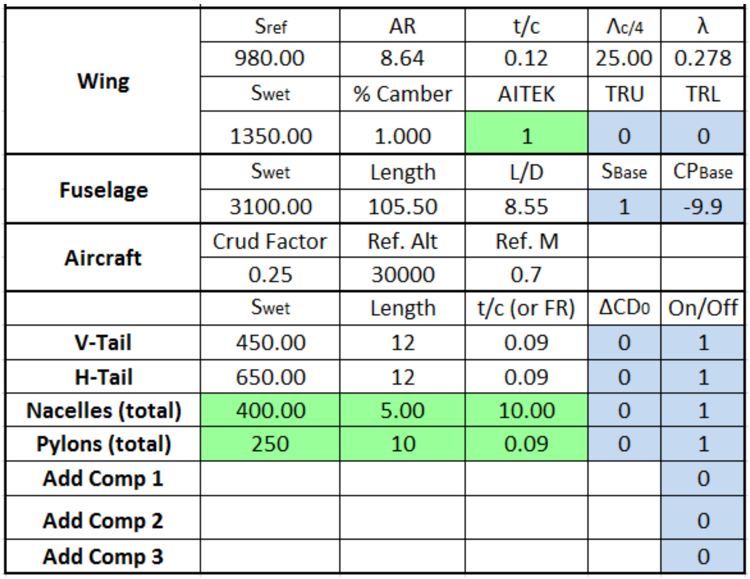
Figure 12. Example EDET Data



MACH	ALT	PLA	THRUST	TSFC
0	0	1	10000	0.38703
0	0	0.98	6788.37	0.34362
0	0	0.96	5657.08	0.33357
0	0	0.9	2262.79	0.33523
0	0	0.85	2240.17	0.33523
0.1	0	1	9200	0.38703
0.1	0	0.98	6788.37	0.34362
0.1	0	0.96	5657.08	0.33357
0.1	0	0.9	2262.79	0.33523
0.1	0	0.85	2240.17	0.33523
0.2	0	1	8296.02	0.47284
0.2	0	0.98	6788.41	0.45081
0.2	0	0.96	4405.94	0.43486
0.2	0	0.9	1534.42	0.5009
0.2	0	0.85	1519.07	0.5009
0.3	0	1	7698.46	0.51795
0.3	0	0.98	6788.55	0.50408

Figure 13. Example NPSS "5 Column" Data

By taking dimensional data and general performance information about the B737-300, EDET drag data can be calculated. [52] The input information for EDET can be seen in Figure 14 below. EDET applies calculations that derive from basic skin friction equations. To account for additional components like vertical and horizontal tail, the corresponding geometry can be included. The color variation in the figure simply outlines which cells should be manually updated (green) and which cells typically remain the same but should be manually updated (blue).



Wing	S_{ref}	AR	t/c	$\Lambda_{c/4}$	λ
	980.00	8.64	0.12	25.00	0.278
	S_{wet}	% Camber	AITEK	TRU	TRL
	1350.00	1.000	1	0	0
Fuselage	S_{wet}	Length	L/D	S_{Base}	CP_{Base}
	3100.00	105.50	8.55	1	-9.9
Aircraft	Crud Factor	Ref. Alt	Ref. M		
	0.25	30000	0.7		
	S_{wet}	Length	t/c (or FR)	ΔC_{D0}	On/Off
V-Tail	450.00	12	0.09	0	1
H-Tail	650.00	12	0.09	0	1
Nacelles (total)	400.00	5.00	10.00	0	1
Pylons (total)	250	10	0.09	0	1
Add Comp 1					0
Add Comp 2					0
Add Comp 3					0

Figure 14. B737-300 EDET Input

Once EDET runs the input file, the drag characteristics are represented in the form shown in Figure 12 above. Taking this data and plotting the drag polar for the Boeing 737, the resulting performance is shown in Figure 15 below. The plot shows that a B737 experiences drag divergence around Mach 0.75. Knowing that the a typical cruise speed is about Mach 0.74, this value makes sense in regards to its drag characteristics. As well using EDET, lift over drag (L/D) was plotted in Figure

16 below. This data also shows the drag divergence around Mach 0.75. The optimal lift over drag is shown to be around 5 degrees.

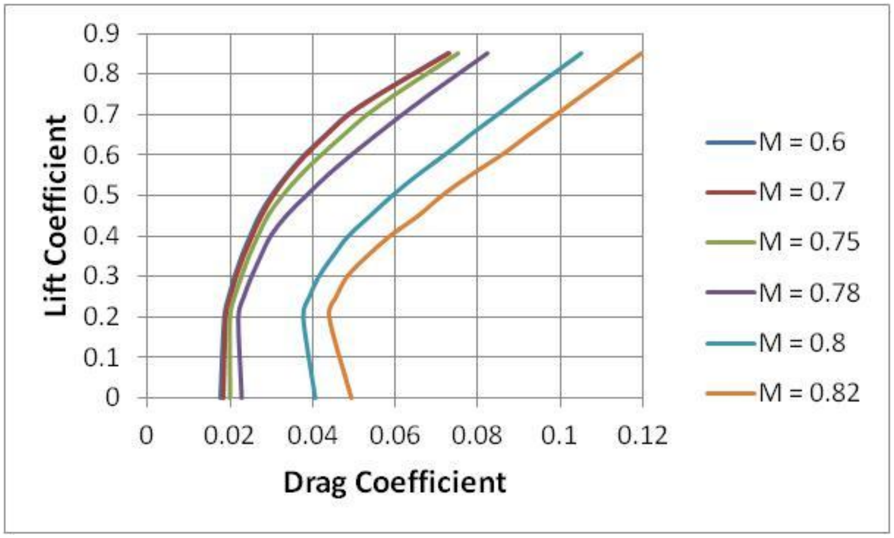


Figure 15. B737-300 Drag Polars (EDET)

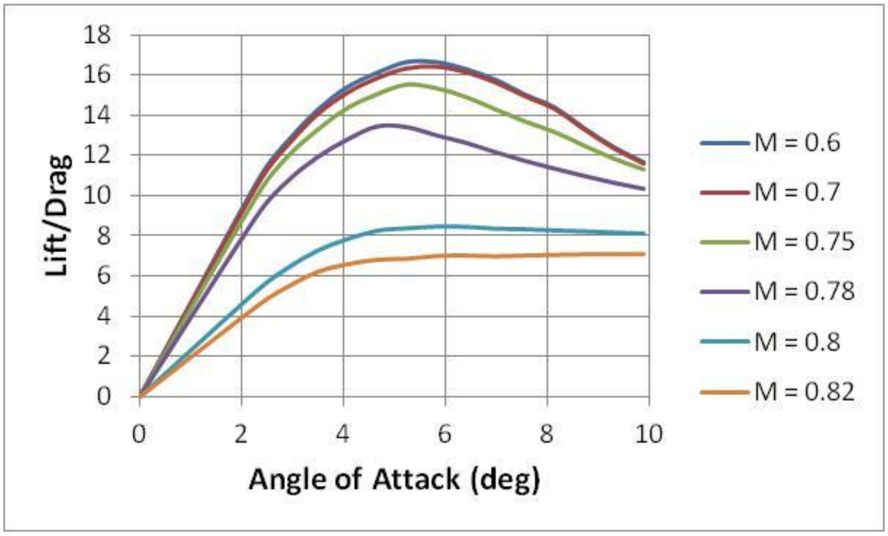


Figure 16. B737-300 Lift/Drag (EDET)

Using NPSS, the engine performance could be adjusted until it closely matched the performance of a B737-300 as outlined in the Southwest Operations Manual. [53] From the outputted "5 column" data, power hooks were created for constant altitude around cruise and constant Mach around cruise in Figure 17 and Figure 18 respectively. For constant altitude, the plot shows that the engine's fuel efficiency diminishes with increasing speed; however the change is not too drastic. For constant speed, fuel efficiency diminishes with decreasing altitude; however the efficiency is about equal at higher thrust conditions.

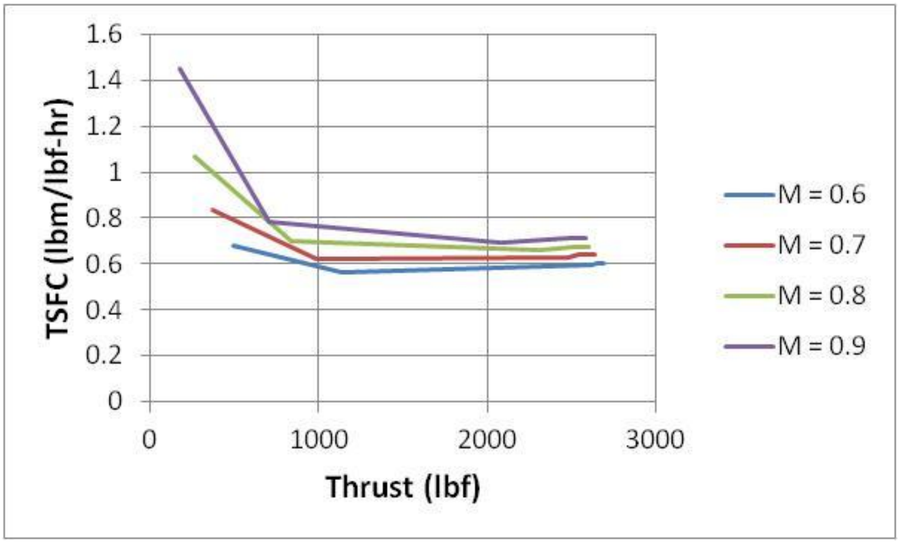


Figure 17. Power Hooks (Altitude = 30,000 ft)

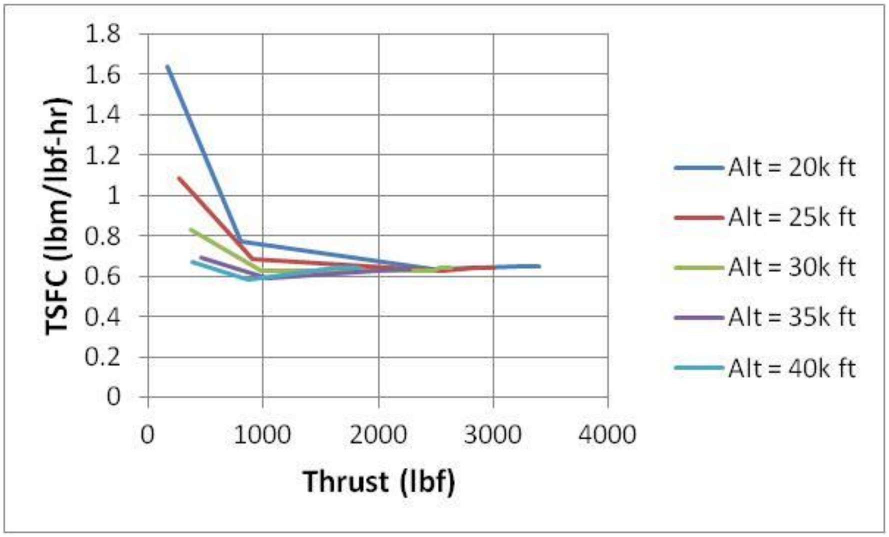


Figure 18. Power Hooks (M = 0.7)

Lastly, “Skymaps” were used to monitor the overall performance and envelope of the aircraft for specific instances along the mission. Typically, “Skymaps” can be created at key instances along the flight plan and the general performance difference can be visually interpolated. For instance a “Skymap” can be created for takeoff weight conditions and end of cruise conditions to analyze the change in performance across cruise. In the case of takeoff weight, Lift over Drag and Mach Lift over Drag are shown in Figure 19 and Figure 20 respectively for a weight of 100,000 lb. From the “Skymaps” the optimum flight condition is around Mach 0.72 – 0.74 at 30,000 ft. This supports the design cruise specifications for the B737-300.

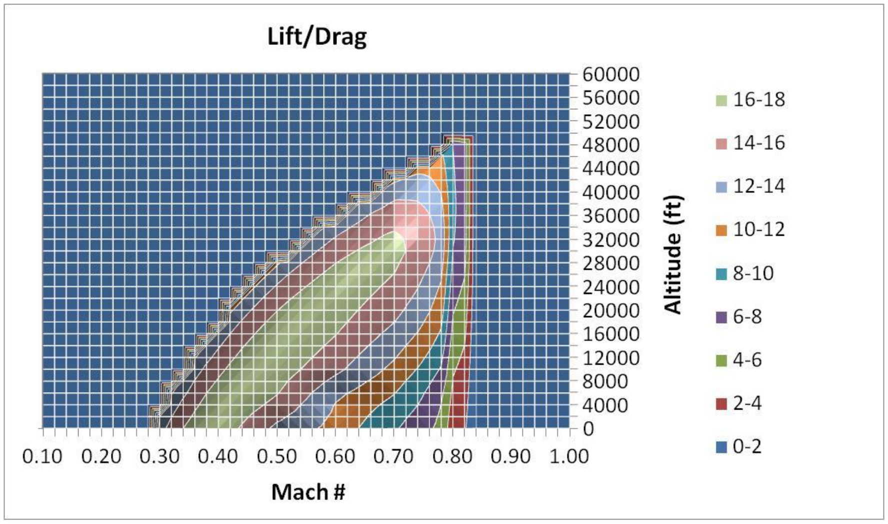


Figure 19. Skymaps - Lift/Drag (W = 100,000 lb)

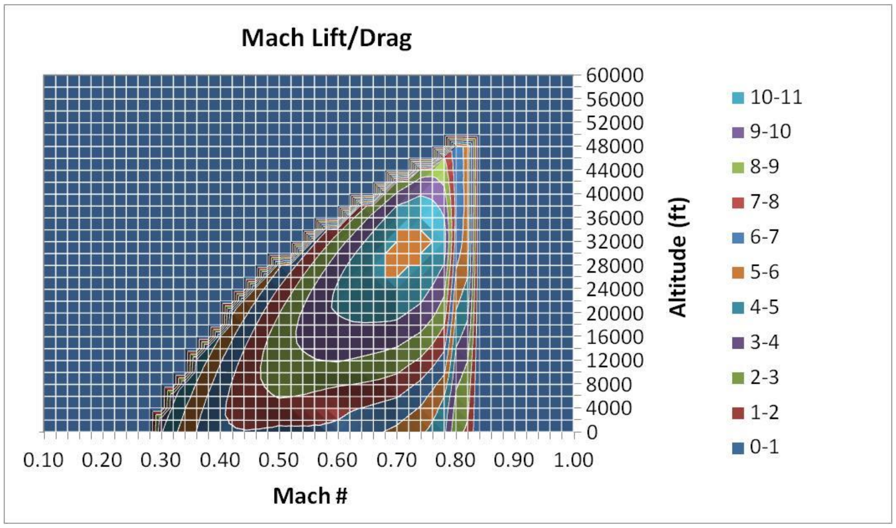


Figure 20. Skymaps - Mach Lift/Drag (W = 100,000 lb)

Furthermore, a very important performance parameter for this study is specific range. Using specific range, the total fuel burn can be analyzed for various missions. Using “Skymaps” a long range mission of 2,000 NM was performed to compare the change in fuel efficiency. The resulting “Skymaps” are shown in Figure 21 below where (a) represents the takeoff weight of 100,000 lb and (b) represents the end of cruise weight of 81,000 lb. By comparing the 2 plots, optimal specific range moved from about Mach 0.7 and 32,000 ft to Mach 0.7 and 36,000 ft. This is the main reason step climbing is so important and must be considered during a flight plan.

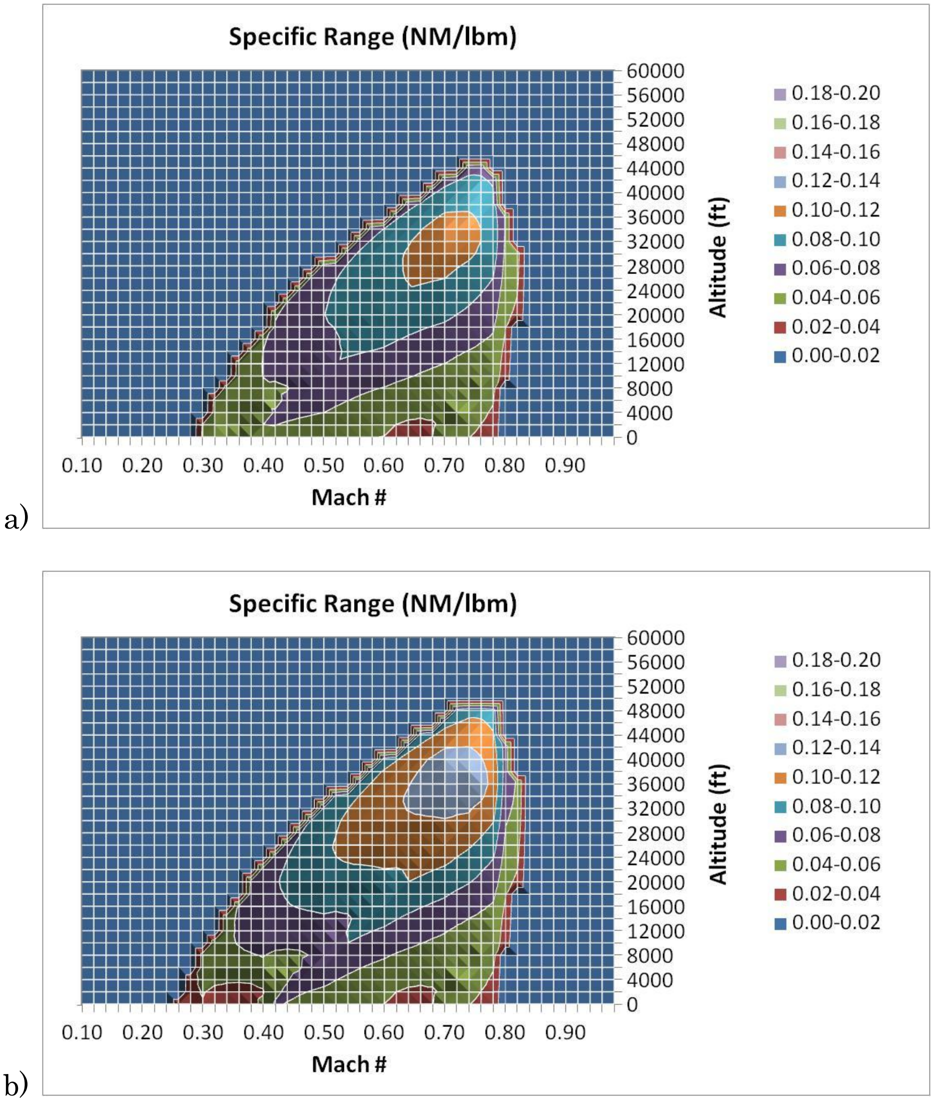


Figure 21. Skymaps - Specific Range a) W = 100,000 lb b) W = 81,000 lb

4.2 DEVELOPMENT OF ITERATIVE FLIGHT PROFILE SIMULATION

Using the analysis tools in the previous section, a full flight profile simulation can be created. The idea behind the simulation is to model a typical flyout with basic flight parameters to analyze various effects on fuel consumption. The simulation inputs, interface, example results, and "Skymaps" are all shown in Appendix D. The mission code was originally written to accommodate any aircraft for the senior design project of an executive business jet. [48] For the application to this study, it had to be adapted to a large jet for commercial flights. Since there was information on the Boeing 737-300 performance data available and the B737-300 is widely used, the mission code was then adapted to this aircraft. By using the general dimensions and characteristics of the 737-300, the drag characteristics were developed through EDET. [52] Then using basic specific range information, 5 column propulsion data was developed with NPSS to closely match the data from a Southwest Airlines Operations Manual. [53] This study is intended to demonstrate trends in fuel consumption for general large commercial aircraft and thus does not need to be a highly cohesive simulation with the B737-300 specifically but simply represent the general characteristics of the aircraft.

In order to develop a realistic flight profile simulation, nearly all the main stages of the flight plan need to be considered. Similar to Figure 22, [54] the simulation performs analysis for the initial climb, departure, cruise, step climbing, descent/approach, and options for two step holds on descent. Additional input parameters include: time step, climb speed, cruise speed, cruise altitude, flight idle power lever for descent, destination airport distance and elevation, two holding times and elevation, balked landing with redirect to alternate airport, head/tailwind, takeoff weight, and an option to takeoff at an adverse direction to destination.

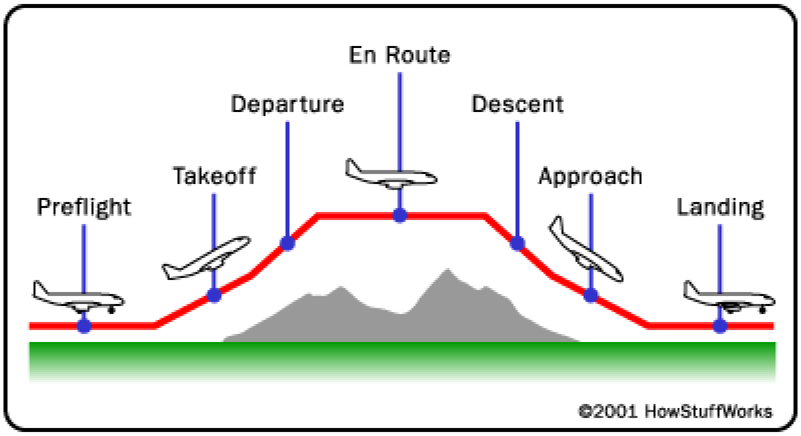


Figure 22. General Flight Profile

As for the actual calculations, the independent simulation is based on a set of basic equations and principles that drive aircraft performance. These methods use simple calculations along with integrated legacy codes (as mentioned earlier) to create the foundation for the aircraft performance. The following process and description is a walkthrough of the steps performed in the mission simulation. To start, a set of independent variables must be defined in order to move on. It is assumed that throughout the flight plan, level flight is maintained. This means that lift equals weight for every instance along the flight. Although the aircraft obviously ascends and descends throughout the flight, the change in rate of climb is considered minimal for the purpose of simplifications. This means that we can use the basic equation for the lift coefficient throughout our whole process:

$$C_L = \frac{L}{qS} = \frac{W}{qS} \qquad (1)$$

For all atmospheric calculations such as dynamic pressure and speed of sound, a method of altitude varying values was used for the current altitude in question. For dynamic pressure, Mach number was used to adjust for the aircraft velocity. This leads to the following calculation of indicated airspeed and Mach number:

$$KIAS = 660.8\frac{NM}{hr}\sqrt{\left(\frac{q_h}{q_0}\right)} \qquad (2)$$

and

$$M = \sqrt{\left(\frac{q_h}{(q/M^2)_h}\right)} \qquad (3)$$

Where subscript *0* implies sea level and h is the current altitude of the aircraft. The value (q/M^2) is an altitude dependent property of the standard atmosphere. Using this ratio, an appropriate Mach number can be found for its particular altitude. For initial climb below 10,000 ft, a KIAS value is chosen at 250 knots or smaller in order to adhere to Title 14 CFR § 91.117. Once above 10,000 ft, the equation is swapped around to make KIAS the dependent variable and Mach number the independent variable. The aircraft can then accelerate to cruise Mach number as it climbs to cruise. For each instance of time calculated, the following equations were used to monitor the aircraft performance:

$$KTAS = Ma \qquad (4)$$

$$C_D = C_D(C_L, M, h) \qquad (5)$$

Coefficient of drag is calculated using EDET. A particular aircraft drag can be found in terms of coefficient of lift, Mach number, and altitude. By simply linearly interpolating between the data outputted by EDET, a particular CD can be found for these three parameters.

$$D = C_D S q \qquad (6)$$

$$Thrust = Thrust(PLA, M, h) \qquad (7)$$

$$TSFC = TSFC(Thrust, M, h) \qquad (8)$$

Thrust and thrust specific fuel consumption (TSFC) are calculated using the data provided by NPSS. As with the coefficient of drag; thrust and TSFC can be found by linearly interpolating between the parameters defined in each function. For climb performance, a power lever angle (PLA) of 100% is used to represent full throttle to cruise. Once at cruise, with the assumption of zero acceleration, thrust is simply found by setting it equal to drag in order to maintain constant cruise Mach number.

$$FF = (TSFC)(Thrust) \qquad (9)$$

$$SR = \frac{KTAS}{FF} \qquad (10)$$

$$ROC = \left(\frac{Thrust - D}{W}\right) KTAS * K_{accel} \qquad (11)$$

These equations help model the engine performance of the aircraft. Fuel flow and specific range are found by simply comparing the current status of the fuel consumption of the engine with consideration of flight performance. As for the rate of climb, the assumption is made that the climb gradient is directly proportional to the ratio of the aircraft's longitudinal and lateral axis forces and since the aircraft is not climbing at constant speed there is an additional acceleration factor added to the equation.

$$\Delta x = (KTAS)(\Delta t) \qquad (12)$$

$$\Delta h = (ROC)(\Delta t) \qquad (13)$$

$$\Delta W_f = (TSFC)(Thrust)(\Delta t) \qquad (14)$$

Since these equations are being used for an iterative numerical simulation, the results will be discrete. Thus, each instance of performance must be calculated for steps in time and space. An independent time step is used to define all parameters changing in linear time. The above equations show these changes in reference to the change in time. By calculating the change in fuel burn for each increment, the change in aircraft gross weight can also be re-calculated for each instance of time. The final results revolve around the change in fuel burn and the total fuel burned for each particular mission or flight profile.

To compare this method to an actual flight profile, the simulation was applied to actual flights gathered from FlightAware, a live flight tracking website. [31] FlightAware provides data for altitude, speed, rate of climb, and location in increments of one minute. Using this data, the simulation can be compared in terms of speed and distance approximations. The first flight compared was from Phoenix to Los Angeles. Figure 23 below shows an example straight line path between the two airports at 370 miles [55] and two corresponding flight patterns from LAX to PHX and PHX to LAX respectively.

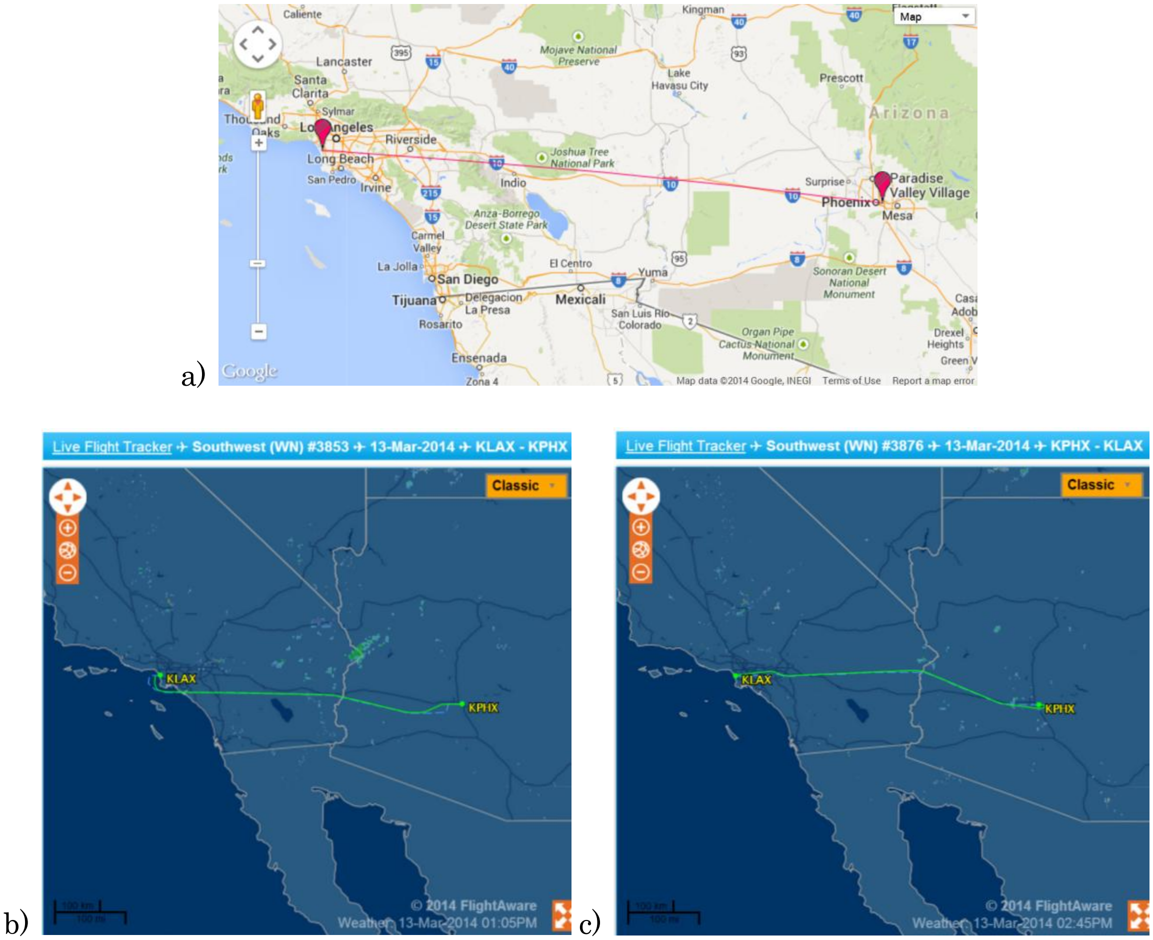


Figure 23. a) PHX/LAX Straight Line Path. b) LAX to PHX, Actual Flight Pattern. c) PHX to LAX, Actual Flight Pattern.

By taking data from both directions, an average wind speed can be calculated. Using this approximation and information that the flights flew a total of 400 miles, a simulation was created to represent a flight from Phoenix to Los Angeles. Figure 24 below shows the comparison between the actual flight and the simulation. The simulation shows a better initial climb speed however the total climb speed is about the same. After cruise, there is one step off during the descent which shows a slightly different trend in descent. This is mostly because the simulation performs the descent with a constant power lever angle. As described in earlier chapters, actual flights may vary greatly as ATC provides the inconsistent descent speed. Overall, the speed and distance are similar to provide a fairly good representation of the flight.

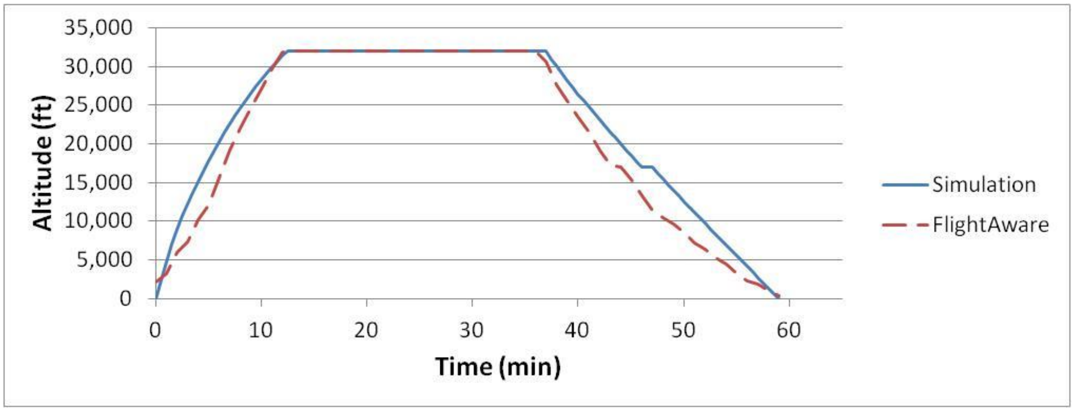


Figure 24. Flight from PHX to LAX (400 Miles)

Short flights were shown to be fairly accurate with the exception of some climb and descent differences but now a medium range flight is compared with the simulation. Figure 25 below shows a straight line path between St. Louis and Los Angeles at 1,590 miles, [55] as well as the corresponding flight patterns between the two cities. This shows a little more deviation between the cities in comparison to the straight line path.

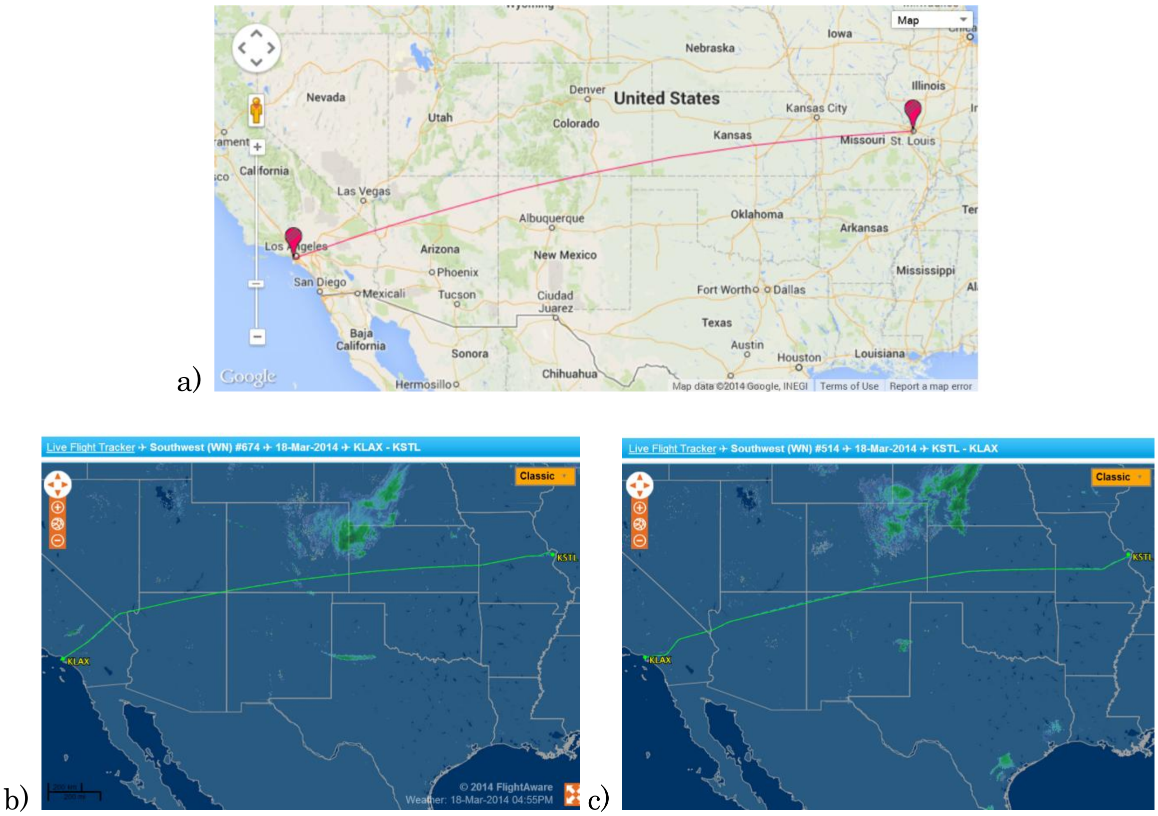


Figure 25. a) STL/LAX Straight Line Path. b) LAX to STL, Actual Flight Pattern. c) STL to LAX, Actual Flight Pattern.

Once again, using both direction data, the wind speed and direction was found and implemented into the simulation. Figure 26 shows the comparison of the simulation to the actual flight data. In this case, the simulation has an overall faster climb speed. Both flight profiles begin descent about the same time and match fairly well with the step descent pattern. In the end, both flights end at the same time confirming the overall speed was accurate. An interesting note is the difference between actual distance flown and straight path is 60 miles since the straight line path is 1,590 miles. In comparison to the short range, the deviated length doubled as the range quadrupled.

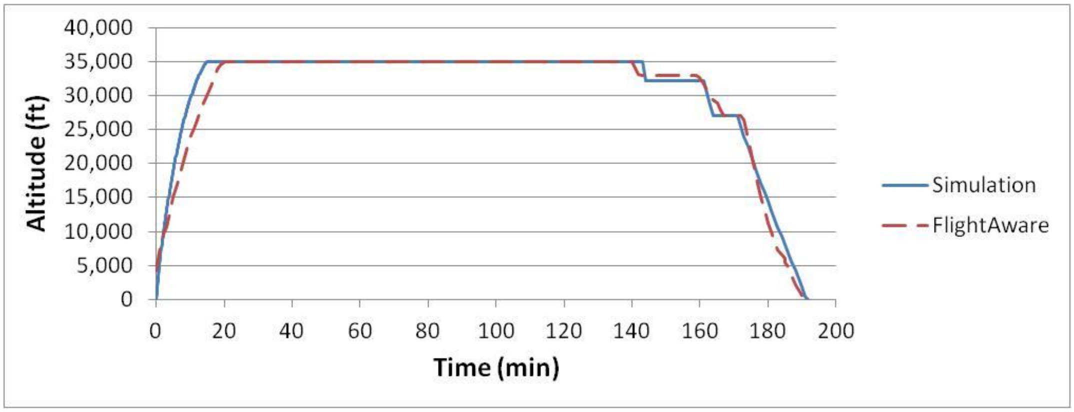


Figure 26. Flight from LAX to STL (1,650 miles)

Lastly, for the interest of long range flights, a comparison was done for flights from Baltimore to Los Angeles. Surprisingly, the actual distance flown was only 15 miles longer than a straight line path of 2,330 miles. [55] This supports the fact that some airlines can achieve nearly optimized routes in the right situations. Ideally this would be the case for all flights but that is unrealistic. Figure 27 below shows the straight line path between the airports and two corresponding flight patterns from FlightAware.

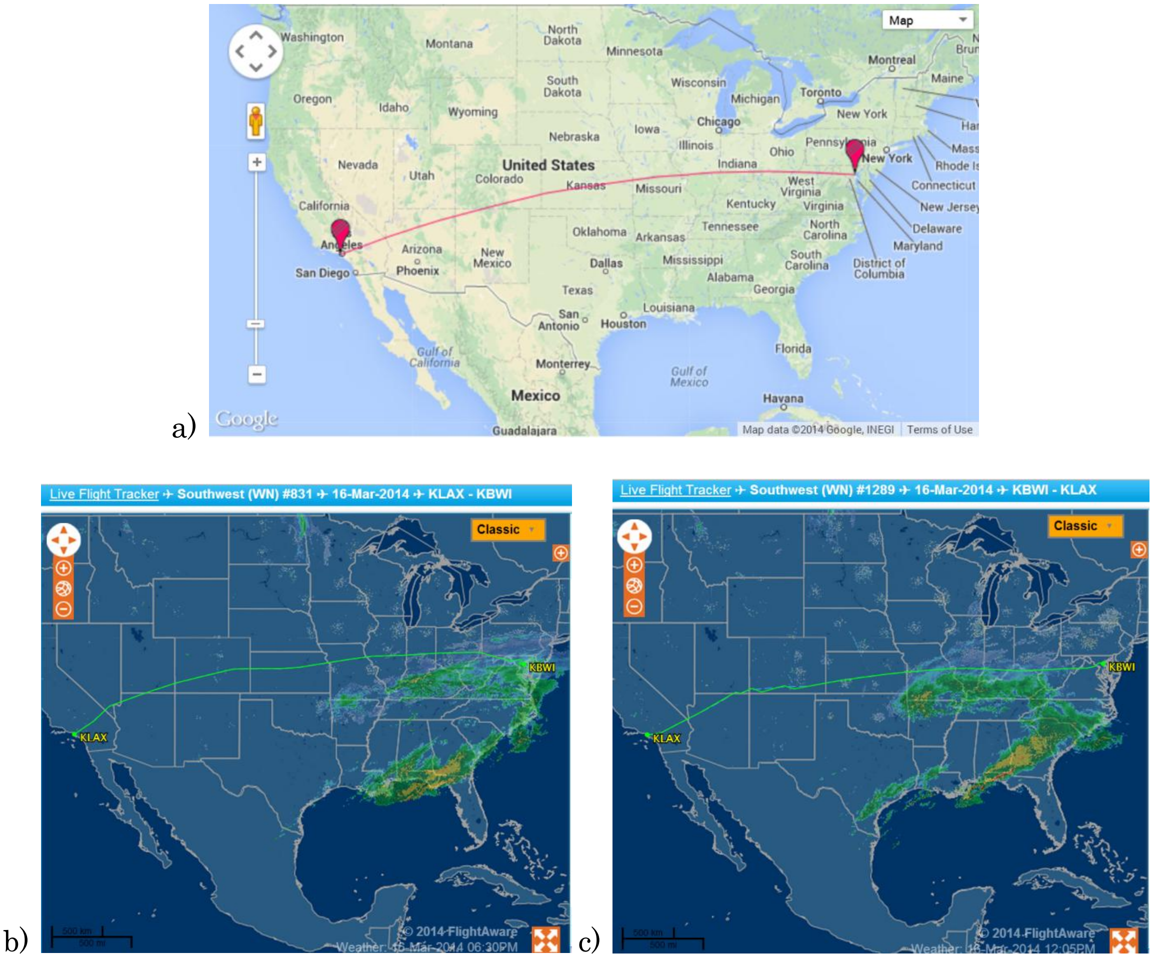


Figure 27. a) BWI/LAX Straight Line Path. b) LAX to BWI, Actual Flight Pattern. c) BWI to LAX, Actual Flight Pattern.

It is important to note that this flight used a B737-800 and the simulation is intended for a B737-300 model. Although this distance falls within the B737-300's range of 2,700 miles, an airline is most likely not going to push the aircraft's capabilities to the edge when longer range aircraft are available. Either way, for a long range mission, Figure 28 shows the comparison in flight profile. Just as before, the simulation climb speed is faster than the actual flown. As well, since the B737-300 does not have as high of a ceiling as the B737-800, the aircraft step climbed once during the mission while the simulation did not find a step climb to be optimal.

Overall, the descent and total time match fairly well and thus support the feasibility of the simulation for analysis purposes.

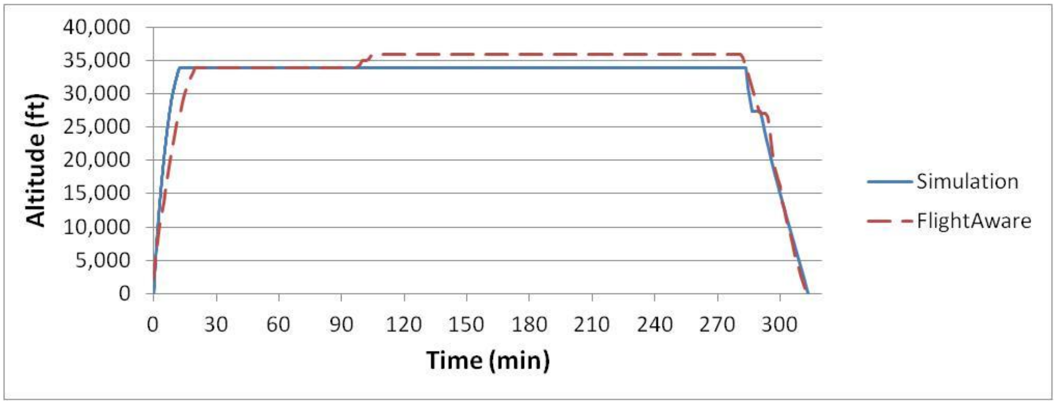


Figure 28. Flight from BWI to LAX (2,340 miles)

The range of the B737-300 is about 2,400 NM or 2,700 miles. The advertised cruise speed is about Mach 0.74 and a maximum speed of Mach 0.82 which is supported by the "Skymaps" from Figure 19 through Figure 21. As well, it is advertised with a service ceiling of 37,000 ft which is not represented in the "Skymaps" because they do not include the buffet coefficient of lift which is about 40,000 ft. Although the ceiling is about 3,000 ft higher than the advertised, it is expected to have some slight variation. Lastly, the B737-300 is advertised with a fuel capacity of 35,900 lb or 5,300 gallons of fuel. The simulation was ran at Mach 0.74 and 32,000 ft for 2,400 NM to yield 32,500 lb of fuel required. As well, it was ran at 35,000 ft for the same mission and yielded 33,300 lb of fuel. In comparison, the simulation is off by about 2,600 lb of fuel however with the consideration that the capacity does not necessarily match the fuel usage and that the model is not a perfect representation of the real-life aircraft. The model is intended to be close to a B737-300 like aircraft but not expected to match it exactly.

CHAPTER 5

FLIGHT PROFILE SIMULATION RESULTS AND ANALYSIS

Using the tools developed above, a full flight profile analysis can now be done to model various missions. Assuming the flight simulation is accurate as supported in the previous chapter, parameters of interest will now be tested to analyze the effects on fuel consumption. Most of the following trade-studies will focus on the topics introduced during the interviews. The intent of this chapter is to show the impact of each topic and how it relates to the change in fuel consumption. This chapter acts as a mixture of test results and test analysis. Since the interviews produce topics of interest, the results are then "tested" in this chapter.

Firstly, to show the importance of fuel consumption and the benefits of reducing fuel loads, a simple trade-study was performed on fuel burn vs. takeoff weight. Assume for a second that an aircraft has some particular operational empty weight (OEW) and an additional payload weight, not including fuel loads. By increasing the levels of precautionary contingency fuel, fuel reserves, and payload weight, the initial takeoff weight will increase. A larger weight directly correlates with more fuel burn. Figure 29 below shows the results for a typical 1,000 NM mission using the B737-300 model. The results are nearly linearly above 90,000 lb takeoff weight, yielding a slope of 0.115 lb of fuel per lb of gross weight. This means that for every pound of fuel that is added to the aircraft, 11.5% of its own weight must be burned solely to adjust for its own additional weight to the aircraft. The effects of reducing weight through fuel loads can be significant and extremely beneficial for other aircraft purposes. The B737-300 has an OEW of about 70,000 lb

[52] so with the introduction of payload and takeoff fuel load, the figure is not truly valid until a takeoff weight of about 80,000 lb.

Takeoff Weight (lbm)	Varies
Climb KIAS	250
Cruise M	0.74
Cruise Alt (ft)	32,000
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	0

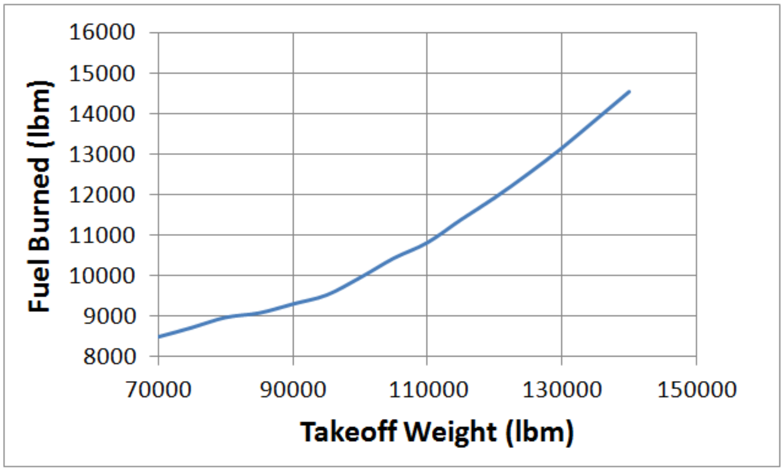


Figure 29. Fuel Burn vs. Takeoff Weight

Since each pound added to the aircraft at takeoff will require an extra 0.115 lb of fuel burn for a 1,000 NM mission, fuel loading can significantly increase operational costs in the long run. The current price of jet fuel is approximately \$2.90/gallon but keeps fluctuating with the market as seen in Figure 30. At its peak in July, 2008 the price was \$4.10/gallon. [33] To relate these to fuel burn, jet fuel is about 6.79 lb per gallon. This means that the current market is about \$0.427 per lb or \$0.43/lb for simplicity. Based on the fuel consumption of 0.115 lb, one pound of payload costs about \$0.0491 of fuel for a 1,000 NM mission. This does not seem like a lot but over a long period of time with thousands of flights, it can make a large difference. As discussed in the interviews, if a pilot were to add 1,000 to 2,000 lb of fuel, each flight fuel cost would increase by about \$49 to \$98. Over a span of a year, this can really add up. According to a report by the National Air Traffic Controllers Association, the U.S. may have up to 70,000 flights per day. [56] This may be a large approximation and only represent the maximum traffic a year. As well, not all of these flights are 1,000 NM. To estimate, let's propose every flight has a takeoff weight of 100,000 lb and burns 10,000 lb for a 1,000 NM mission. Observing Figure 30, about 25 billion gallons or 169.75 billion lb of jet fuel was consumed in 2013. At 10,000 lb per flight, there would be 18,600 flights per day that can be modeled by the 1,000 NM mission with 100,000 lb takeoff weight. With a slight underestimation then of 18,000 flights per day with an average of 1,000 NM, one pound of payload costs about $884 per day. This means that one pound of payload per year would be about $322,587. Now consider every flight contained an excess of 500 lb per flight, the annual total cost would be $161,300,000 of excessive fuel burn. This of course is spread out among the industry and with all the assumptions mentioned. In some cases, 500 lb is a very small estimation. Either way, even smaller assumptions would yield millions of dollars per year.

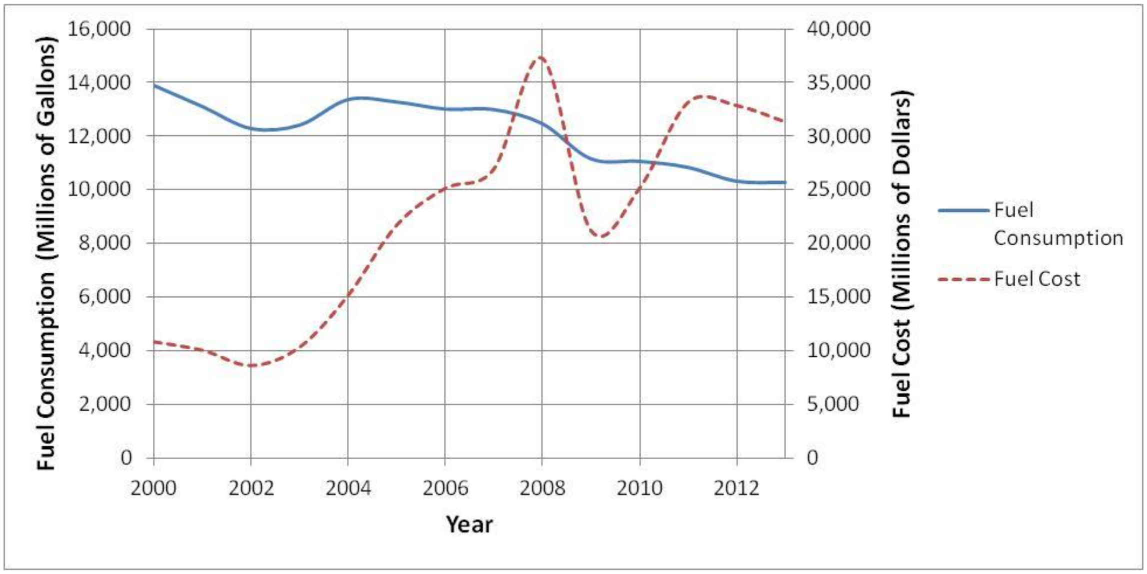


Figure 30. Annual Domestic Fuel Usage Since 2000

5.1 TRADE-STUDIES

By performing trade-studies, the most influential parameters to fuel burn can be outlined and highlighted for areas of interest. Just as additional takeoff weight may affect fuel consumption, other parameters will positively or negatively influence fuel consumption. With the combination of all these non-optimal conditions, one flight may experience an absorbent amount of fuel burn. Most of the trade-studies will follow a consistent flight mission for easier comparisons. A short to medium range distance of 1,000 NM will be used with a climb speed of 250 KIAS, cruise Mach 0.74, cruise altitude 30,000 ft, takeoff weight of 100,000 lb, no holding, no step descents, and no adverse winds. As well, since it is an iterative method, the climb time steps will always be 5 seconds and the rest of the mission will be 30 seconds. This is done to keep the time spacing small and maintain accurate results. Overall, these will be the standard conditions unless otherwise mentioned. This does not represent a real flight but the consistent mission is intended to outline only the fuel consumption changes caused by the parameter in question. With this in mind, the following topics and trade-studies will be shown:

- Fuel Burn vs. Climb Speed (w/ Flight Time)
- Fuel Burn vs. Climb Speed during adverse takeoff direction (w/ Flight Time)
- Fuel Burn vs. Cruise Speed (w/ Flight Time)
- Fuel Burn vs. Cruise Altitude (w/ Flight Time)
- Fuel Burn vs. Distance (w/ Flight Time)
- Fuel Burn vs. Wind Speed (w/ Flight Time)
- Fuel Burn vs. Wind Speed vs. Distance
- Fuel Burn vs. Wind Speed vs. Cruise Speed

- Fuel Burn vs. Wind Speed vs. Cruise Altitude
- Fuel Burn vs. CDA and Conventional Step Descent
- Fuel Burn vs. Stop and Non-Stop (w/ Flight Time)

From the interviews, it was found that climb speed in general is flown at 250 KIAS as defined in the CFR. This can also be affected by ATC during heavy congestion. A trade-study was performed to vary climb speed from 190 to 400 KIAS (Figure 31). As mentioned by multiple pilots, the regulated 250 KIAS is not optimal at all. For a climb to 30,000 ft, there is a fuel difference between 250 KIAS and optimal climb of about 125 lb. As well, there is about a 136 lb difference in total mission fuel consumed between the optimal climb flyout and the 250 KIAS climb flyout. In terms of flight time, there is only about a 2 minute difference.

Takeoff Weight (lb)	100,000
Climb KIAS	Varies
Cruise M	0.74
Cruise Alt (ft)	30,000
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	0

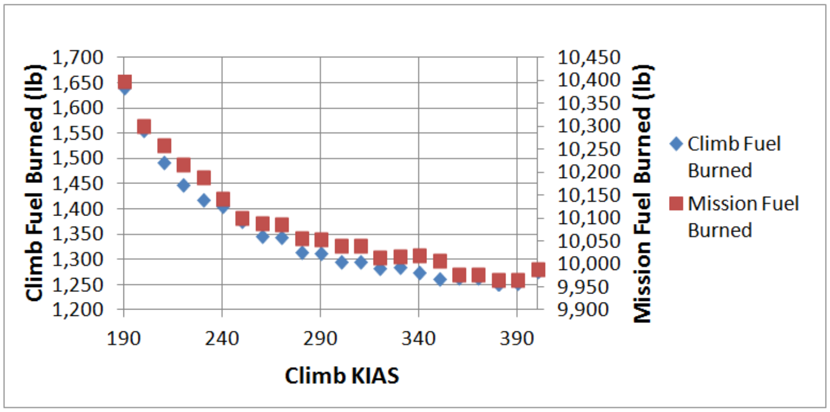


Figure 31. Climb Speed Trade-Study

From the trade-study above, the optimal climb speed would be implied around 390 KIAS. Using the rate-of-climb (ROC) and indicated airspeed "Skymaps", an optimal path can be analyzed. Figure 32 below shows the rate-of-climb contour superimposed over the indicated airspeed contour. The filled in contour and legend represents the KIAS for each Mach and altitude while the "see through" contour shows how ROC correlates with the climb speed. It is a bit difficult to tell on the figure, but ROC generally decreases with altitude. The yellow line represents the climb profile of 390 KIAS while the dotted yellow line represents the climb profile of 250 KIAS. From these two lines, the 390 KIAS profile utilizes better ROC for a longer period of time. Clearly, a faster climb speed would be more optimal but is unlikely to be allowed until better technologies. Likewise, it would be unwise to back track design efforts to improve climb gradients just to match the regulations, ATC limitations, and outdated situational awareness capabilities. On the other hand, climbing at 400 KIAS may not be realistic since this means that cruise Mach is reached around 10,000 ft. This is quite fast and may lead to potential unforeseeable dangers.

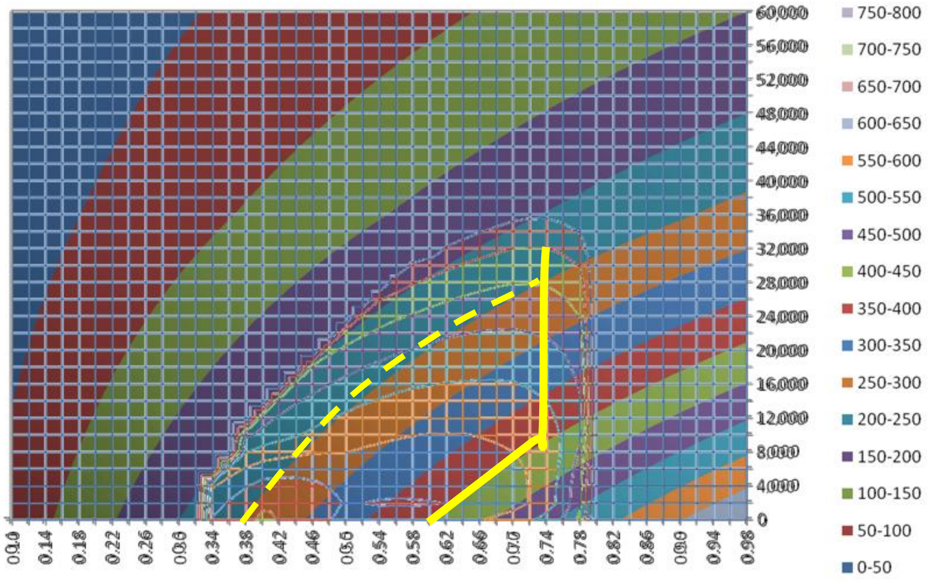


Figure 32. Rate-of-Climb Superimposed Over Indicated Airspeed for Takeoff

Another climb speed topic includes the technique of altering the climb speed during takeoff when the direction of flight is opposing the direction of the destination airport. The participants had a mixed reaction on this topic. Figure 33 shows the effects of climb speed on fuel consumption with the condition of flying the wrong direction until an altitude of 15,000 ft was reached. For a slow scenario at 190 KIAS, the aircraft climbed for about 8 minutes and resulted in a positive distance traveled of 12.5 NM. For the fast scenario at 400 KIAS, the aircraft climbed for about 5.5 minutes and resulted in a positive distance traveled of only 3.75 NM. However the total mission flight times had a negligible difference. This would suggest that reaching cruise sooner but farther away ends up balancing out with a slower climb but farther flight in terms of total flight time. Fuel consumption wise, there is a general trend that a faster climb is more optimal. In Figure 33, the total mission fuel burn does not have a smooth result most likely due to the small inaccuracies caused by the time steps. If the time step were infinitesimally small, the trend should produce a smoother result. Either way, the trend shows that it is more efficient to stick with the regulated 250 KIAS then reduce the speed any further.

Takeoff Weight (lb)	100,000
Climb KIAS	Varies
Cruise M	0.74
Cruise Alt (ft)	30,000
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	0

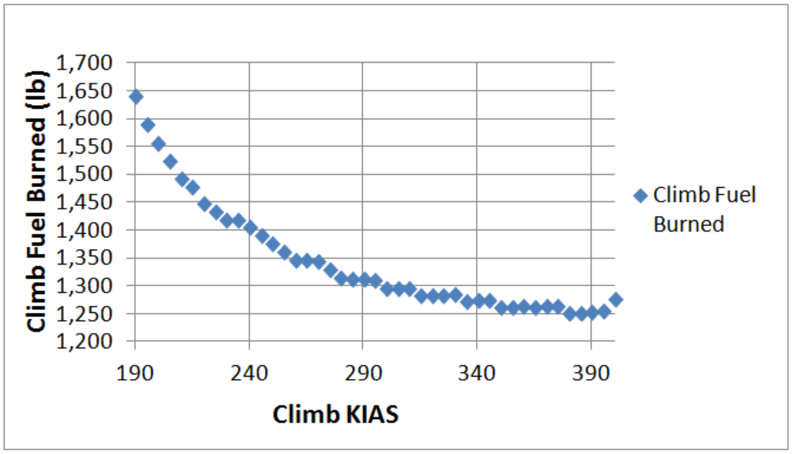


Figure 33. Climb Speed During Adverse Takeoff Direction Trade-Study

After climb, a trade-study was performed varying cruise speed from Mach 0.65 to 0.78. Figure 34 shows that fuel consumption is mostly affected by speeds greater than Mach 0.74. Pilots had expressed that some pilots ("5 - 10%") fly too slow and some fly too fast to increase their pay, additional pilots may alter the cruise speed for legitimate reasons. For pilots who fly fast, assuming speeds around Mach 0.78, the 1,000 NM mission burns about 1,200 lb more fuel than the standard Mach 0.74. As for the pilots who fly slowly, speeds of Mach 0.7 actually improved fuel consumption by about 300 lb with some variation in the lower speeds. In general though, the fuel consumption is only adversely affected by faster missions. On the flip side, a faster mission means shorter flight time as shown in the figure. There is a general correlation of about 19 minutes per tenth of a Mach. For scheduling purposes this can actually improve the operations, for example in the case of Mach 0.78, a 1,200 lb difference costs about $512 in fuel at $0.427/lb. If arriving 8 minutes earlier means less labor costs or reduction in passenger re-imbursement then it may be worth $512 to fly faster. Design wise, it is non-optimal however since flight operations are fundamentally business oriented, the Cost Index is the final deciding factor. Since aircraft speed is highly dependent on drag divergence, the design side is inevitably holding back the operational desire to fly faster.

Takeoff Weight (lb)	100,000
Climb KIAS	250
Cruise M	Varies
Cruise Alt (ft)	30,000
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	0

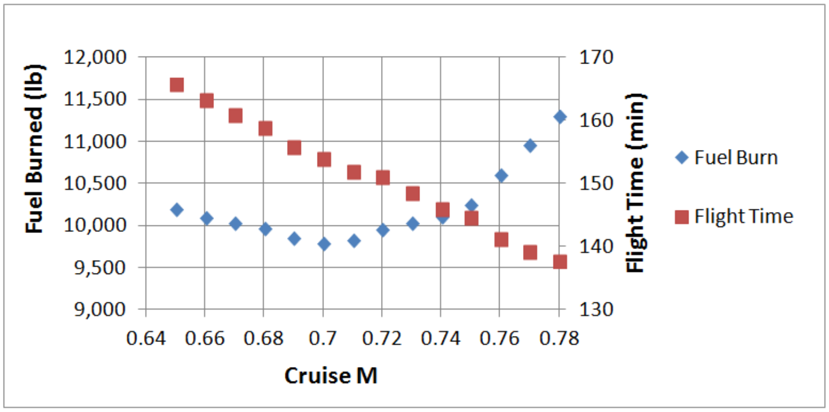


Figure 34. Cruise Speed Trade-Study

Additionally, cruise altitude can be a very influential parameter in flight planning. Figure 35 below shows the trade-study for variation in cruise altitude. The plot shows that there is an optimal altitude around 33,000 ft. The fuel consumption for this altitude is about 9,860 lb while the fuel consumption for 38,000 ft and 28,000 ft are 10,430 lb and 10,570 lb respectively. Although the trend is parabolic, this represents a general trend of 128 lb per 1,000 ft fluctuation. As well, the altitude variation suggests that in terms of flight time, it more optimal to fly at lower altitudes than higher altitudes. For operations, it would be wise to error on the side of less than 33,000 ft if need be. Unfortunately, cruise altitude can often be defined by weather and ATC which will cause a fluctuation from the optimal altitude.

Takeoff Weight (lb)	100,000
Climb KIAS	250
Cruise M	0.74
Cruise Alt (ft)	Varies
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	0

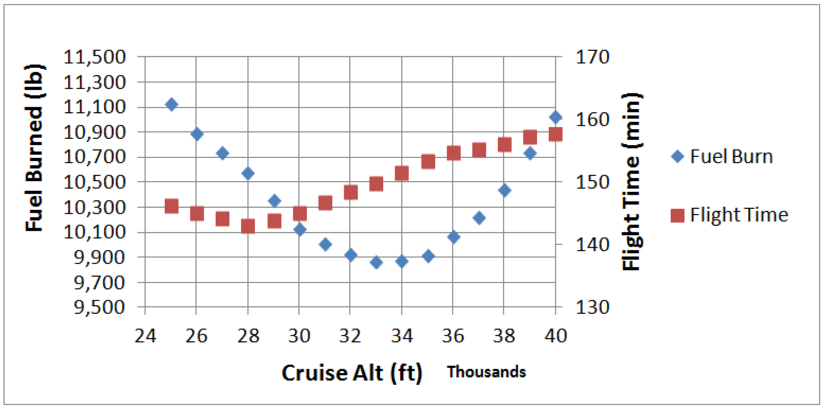


Figure 35. Cruise Altitude Trade-Study

As for the total mission distance, it is obvious that fuel consumption and flight time will greatly change. The objective of this trade-study is to examine how much of a difference that it. With the current rNAV system, the flight plan may not be as direct as it can be thus leading to extra travelled distance. Figure 36 below shows that the linear trend for fuel consumption with respect to Mission distance is about 9 lb per nautical mile. While the time relationship is about 0.14 minutes per nautical mile. This means that a non-direct route with 50 extra nautical miles would result in 450 lb extra fuel burn and about 7 minutes of extra flight time. An extra 50 nautical miles may not occur every flight but there is definitely a 5 -10 nautical mile difference for rNAV approaches and RNP approaches which means that the descent profiles are off optimal by about 45 to 90 lb per flight.

Takeoff Weight (lb)	100,000
Climb KIAS	250
Cruise M	0.74
Cruise Alt (ft)	30,000
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	Varies
Mission Distance (mi)	Varies
Avg. Tailwind (kts)	0

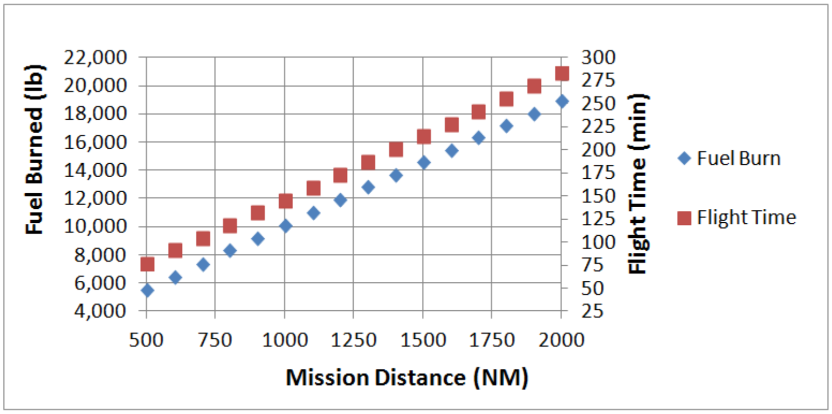


Figure 36. Mission Distance Trade-Study

Based on the interviews, a typical 45 minute reserve fuel load for a B737 or A320 is about 4,500 lb. As mentioned before, defining this reserve is highly dependent on the air carrier's policy. Using the simulation for an additional 45 minutes at Mach 0.74 and 32,000 ft, the results suggested a reserve fuel load of about 3,000 lb. By changing the simulation to Mach 0.74 and 20,000 ft, the results then yielded about 4,400 lb of reserve fuel needed for 45 minutes of flight. This suggests that air carrier's may typically over define the regulation in order to carry a larger precautionary fuel requirement for 45 minute reserve. Based on the interviews, an air carrier may generally value higher safety standards than better performance operations. This is not necessarily a bad decision but should be considered in fuel load design. Overall, an additional 4,500 lb fuel payload would equate to about $220 per flight

The mission distance can often be determined by a non-direct flight into better winds or to avoid adverse winds. Using head/tailwinds to optimize the flight plan is huge factor for fuel consumption. Figure 37 below shows that for extreme wind conditions, a difference of 200 kts can be a difference of 4,600 lb of fuel. Of course this extreme conditions so a difference of 20 kts may be more realistic, resulting in a 430 lb difference in fuel consumption. This is still a large factor for a more realistic scenario. At the same time, the 20 kts wind difference can a flight time difference of about 7 minutes. It is clear that utilizing the correct winds is highly advantageous. Multiple participants expressed that there is significant effort to optimize the winds available with the limited weather forecasting available.

Takeoff Weight (lb)	100,000
Climb KIAS	250
Cruise M	0.74
Cruise Alt (ft)	30,000
Flight Idle	0.85
Holding (ft)	N/A
Holding Time (min)	N/A
2nd Holding (ft)	N/A
2nd Holding Time (min)	N/A
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	Varies

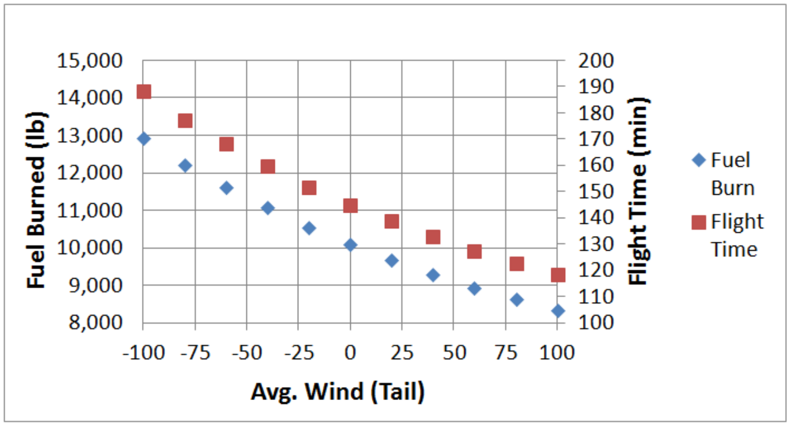


Figure 37. Wind Speeds Trade-Study

Considering how influential the winds can be for fuel consumption, it is important to observe how these changes occur with respect to other parameters as well. For instance, Figure 38 below shows the affects of wind with the consideration of mission distance. In order to maintain constant fuel consumption, on average, an aircraft can fly an additional 2.5 NM per knot of tailwind advantage. For example, if a flight plan is 25 NM farther than direct, the wind speeds should be at least 10 knots better. Of course this is for fuel consumption consideration but the flight time will increase.

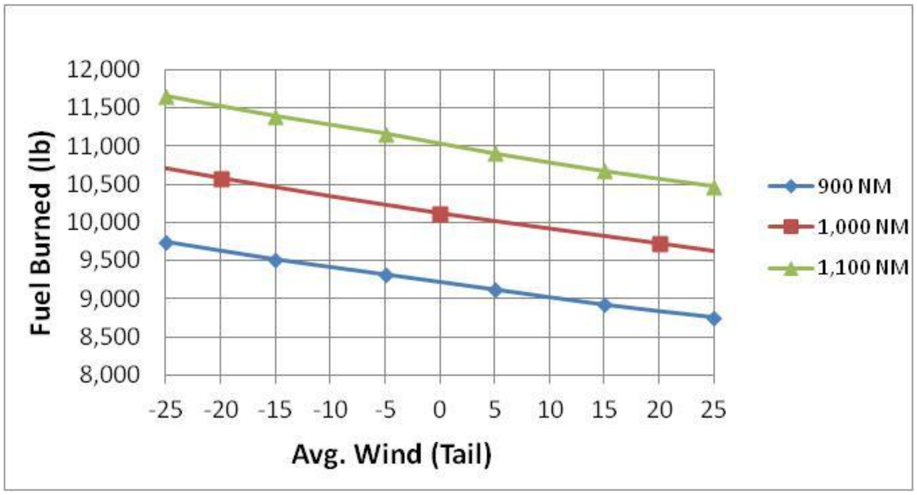


Figure 38. Wind Speed with Varying Mission Distance

As for variation in cruise altitude, Figure 39 shows the effects of wind and altitude on fuel consumption. This is important for considering step climbing and choosing an appropriate altitude for not only design performance but drag performance from wind as well. The plot shows the same trend as seen in Figure 35 where the altitude is optimal around 33,000 ft for any particular wind condition. More importantly this shows that there for constant fuel consumption, the winds are not significantly different between 33,000 ft and its neighboring altitudes, 32,000 and 34,000 ft. However for more significant changes and utilizing a non-intuitive technique, an aircraft can step down from 31,000 ft to 30,000 ft if there are 5 knots better tail winds. Anything greater and it is optimal to actually drop to lower altitudes. The reverse is the same for altitude comparisons above 33,000 ft. Unless the aircraft is flying at a non-optimal altitude, it may not be beneficial to step climb into worse altitudes due to better winds.

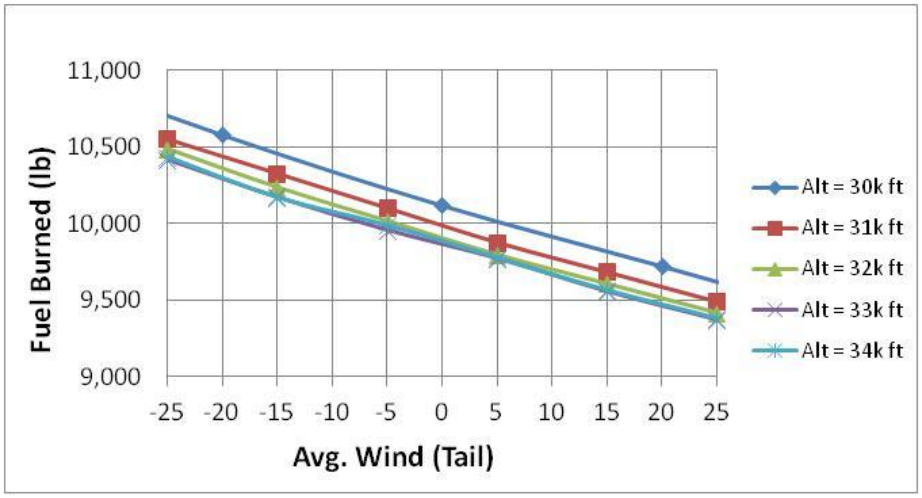


Figure 39. Wind Speed with Varying Cruise Altitude

Finally, cruise speed is another factor that may be affected by wind conditions. One pilot explained the practice of reducing cruise speed if there was an advantageous tailwind. Figure 40 shows that similar to Figure 34, the spacing between speeds is exponential as Mach increases. At a cruise altitude of 30,000 ft, a difference of 12 kts correlates to a speed difference of 0.02 Mach. In this case, if there is tailwind of 15 kts then the aircraft can be reduced to a cruise setting of 0.72 Mach and still arrive on time with a savings of 240 lb of fuel. This trend suggests that an aircraft can reduce its speed in relation to how strong the tailwind is. For large headwinds, the aircraft will have to speed up to remain on time however this only results in a larger fuel burn. It is a close tradeoff between prioritizing flight time and fuel consumption.

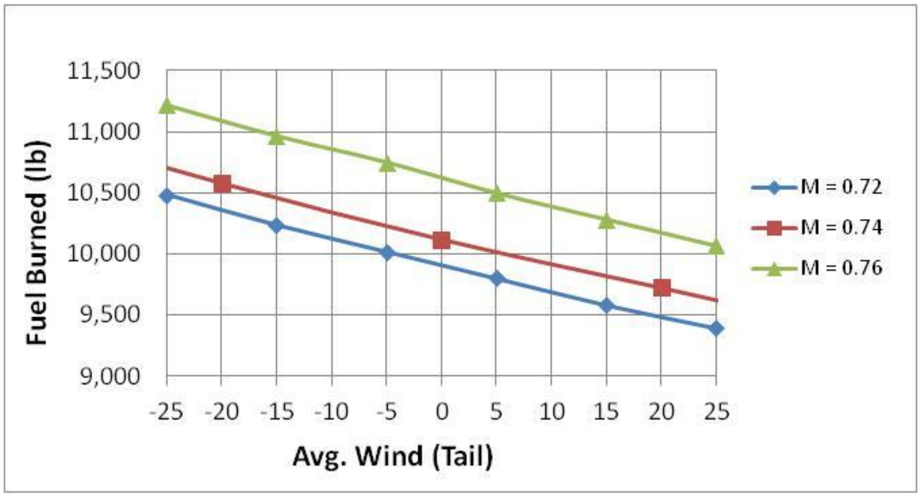


Figure 40. Wind Speed with Varying Cruise Speed

After cruise, the descent and approach was found to be very un-optimized. Multiple participants expressed that there is a lack of clean approaches like CDA and RNP approaches. A trade-study was performed to compare the effects of step descents and a continuous descent. The variation is shown in Figure 9 earlier. For the trade-study, two step holds were performed during descent with increasing duration in the hold time. Figure 41 shows the trend of increasing fuel consumption during descent because of the longer descent time while the total fuel consumption actually decreases with hold time. This result is unexpected and does not support the concept of the non-optimal step approach. Since the simulation assumes constant power lever setting and lack of speed changes during the step holding, it is believed that the simulation is not sufficient enough to realistically demonstrate a step descent. With this understanding, the descent trade-study will be considered unusable.

Takeoff Weight (lb)	100,000
Climb KIAS	250
Cruise M	0.74
Cruise Alt (ft)	30,000
Flight Idle	0.85
Holding (ft)	10,000
Holding Time (min)	Varies
2nd Holding (ft)	20,000
2nd Holding Time (min)	Varies
Mission Distance (NM)	1,000
Mission Distance (mi)	1,151
Avg. Tailwind (kts)	0

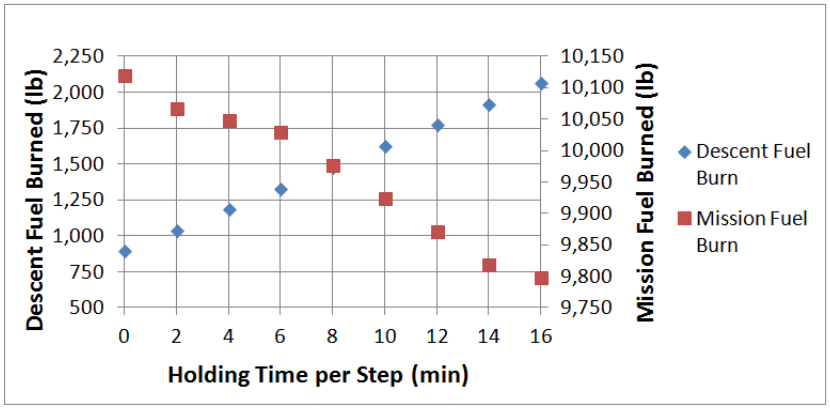


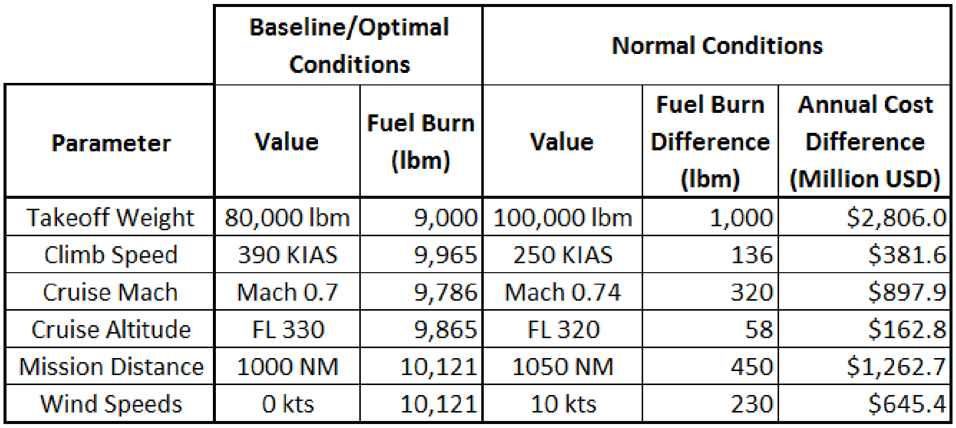
Figure 41. Descent Step Holding Trade-Study

Finally, in many scenarios, an aircraft's daily mission will not consist of one flight but multiple legs on the way to a final destination. This is usually beneficial for dropping off and picking up passengers at each leg, however for connecting flights with majority of the passengers remaining on the aircraft; a stop-over may cause large fuel consumptions. A stop may also be caused by weather or adding additional passengers at the last minute and a re-fueling is needed on the way. To demonstrate one example of its effects, a 1,000 NM non-stop flight was compared to two 500 NM flights with a reduction in takeoff weight for both flights. It was found that including a landing added 600 lb of fuel in comparison to the non-stop flight. As well, there needs to be some consideration for taxi and ground fuel usage so the expected difference in fuel consumption will be greater than 600 lb. Depending on its application, it may be found that the operational fuel consumption costs more than the service benefits.

5.2 KEY RESULTS AND ANALYSIS

Each trade-study shows the magnitude and impact each parameter has on fuel consumption and flight time. These values are intended to be trends and not usable performance data. Since all trade-studies were done with a generic 1,000 NM mission, the values obtained only adhere to a specific mission type. However, the magnitude and relationship of each parameter can be analyzed to see which factors are the most influential. Table 2 below shows a general overview of the trade-studies and how they compare to a normal flight. The baseline/optimal section is intended to show how the normal condition may vary from an ideal condition. As well the normal condition annual cost difference assumes that this condition applies to every 18,000 flights per day at $0.427 per lb. This of course is unrealistic but provides an option to compare the various parameters to each other and their potential for extra cost.

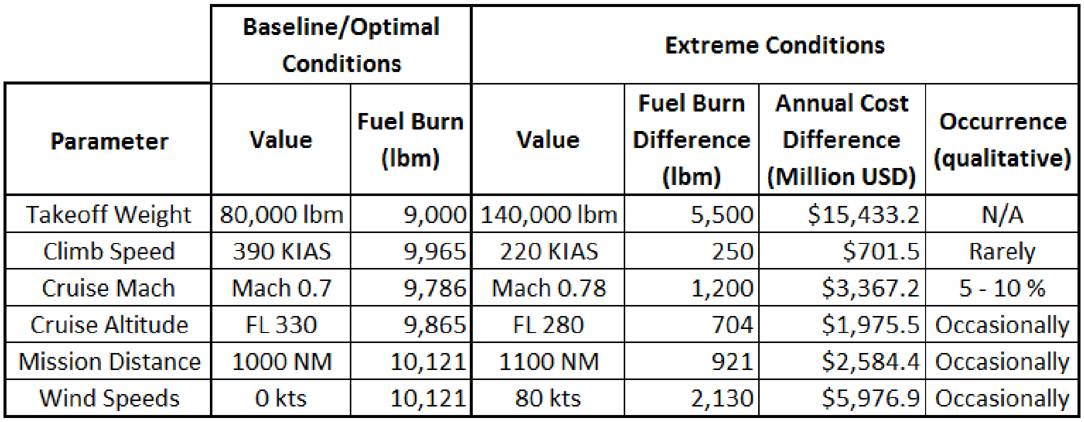
Table 2. Trade-Study Overview and Normal Condition Comparison



	Baseline/Optimal Conditions		Normal Conditions		
Parameter	**Value**	**Fuel Burn (lbm)**	**Value**	**Fuel Burn Difference (lbm)**	**Annual Cost Difference (Million USD)**
Takeoff Weight	80,000 lbm	9,000	100,000 lbm	1,000	$2,806.0
Climb Speed	390 KIAS	9,965	250 KIAS	136	$381.6
Cruise Mach	Mach 0.7	9,786	Mach 0.74	320	$897.9
Cruise Altitude	FL 330	9,865	FL 320	58	$162.8
Mission Distance	1000 NM	10,121	1050 NM	450	$1,262.7
Wind Speeds	0 kts	10,121	10 kts	230	$645.4

From Table 2, the magnitude of weight will inevitably be the largest factor because of the large influence it has on performance. When the regulations cannot be changed, this must be highly analyzed by the air carrier itself and look for other options to reduce weight. As well, a non-optimal cruise speed, distance, and wind speed all have large effects on fuel consumption. All three of these may vary differently depending on the weather, ATC, and pilot factors. Lastly, the climb speed and cruise altitude have less influence but are still substantial enough that further analysis on these parameters should be considered. Climb speed is unfortunately unable to be optimized due to CFR regulations and ATC system restrictions. Aside from assumed normal flight conditions, Table 3 shows the effects of extreme flight conditions. These values should be highly questioned due to the uncertainty of when they actually occur. The annual cost difference is not to be used for any analysis because it assumes these conditions occur on every 18,000 flight a day but this is highly unrealistic.

Table 3. Trade-Study Overview and Extreme Condition Comparison



	Baseline/Optimal Conditions		Extreme Conditions			
Parameter	**Value**	**Fuel Burn (lbm)**	**Value**	**Fuel Burn Difference (lbm)**	**Annual Cost Difference (Million USD)**	**Occurrence (qualitative)**
Takeoff Weight	80,000 lbm	9,000	140,000 lbm	5,500	$15,433.2	N/A
Climb Speed	390 KIAS	9,965	220 KIAS	250	$701.5	Rarely
Cruise Mach	Mach 0.7	9,786	Mach 0.78	1,200	$3,367.2	5 - 10 %
Cruise Altitude	FL 330	9,865	FL 280	704	$1,975.5	Occasionally
Mission Distance	1000 NM	10,121	1100 NM	921	$2,584.4	Occasionally
Wind Speeds	0 kts	10,121	80 kts	2,130	$5,976.9	Occasionally

The table shows that along with takeoff weight, cruise speed and wind speed are large factors in flight planning optimization. When these parameters are not addressed properly, large fuel consumption loses will occur. As well, non-direct flight distances and cruise altitudes have the next highest magnitude on fuel consumption while climb speed remains the smallest. To reiterate, the occurrence rate of these conditions are completely unknown and the influence of each parameter is intended to be a hypothetical understanding of extreme fuel burn.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Flight operations are a very complex system that cannot be viewed as black and white. There are countless factors that affect operational performance and decision making. This study highlights the efforts made by flight operators to reduce fuel consumption as well as introduce opportunities to minimize fuel consumption and thus operational costs. In the end, flight operations are a business and that business is defined by more than just performance optimization. As well, the operation is restricted through regulations, ATC, unpredictable weather, the surrounding environment and air carrier policy and practice. Through flight operator interviews, specific topics are addressed and analyzed via regulations and a flight profile simulation in order to better connect operations with design performance

The first area of interest was the Code of Federal Regulations. Participants introduced the new amendment to ban personal-use of electronic devices for non-essential tasks. This amendment will not have negative effects if air carrier's properly outline the use of newer technology like tablets. Among the performance regulations, ETOPS is a growing and largely used tool for optimizing flight path distance. The current regulations are sufficient for domestic operations but farther over-seas missions may be on the edge of the flight safety. For the 45 minute rule (14 CFR § 91.167, and 121.639), participants had a hesitant response to reducing the regulation to less minutes. In general, the participants felt that the regulation was fine as it. At a typical 4,500 lb, a 1,000 NM mission costs about $220 extra to carry the reserve fuel. For all cost values presented, a mission of 1,000 NM and a takeoff weight of 100,000 lb was used as the standard. As for the “123” for determining an alternate (14 CFR § 91.167 and 121.619), the participants felt that this regulation was sufficient as is. In terms of domestic operations, one individual with pilot and dispatch experience suggested the regulation should actually be stricter in favor of standardizing domestic, flag, and supplemental operations however this would only hurt future operational performance and most flight operators are satisfied with its current status.

One of the largest and overwhelming consensuses for improvements in flight operations was the Air Traffic Control system. Nearly all participants agreed that the system is out dated and needs an immediate modernization. The FAA has an on-going project to implement the future National Airspace System called NextGen. This would include new systems like ADS-B, Data Comm, CSS-Wx, NVS, CATMT, and SWIM. However, participants have expressed strong pessimism toward the current progress and do not think it will be implemented by 2025, as the FAA claims. The current ATC system is the source for many poor performance operations. Some of the largest improvements of NextGen would be the ADS-B system for improved traffic and weather monitoring by pilots. As well as more streamlined and clear processes for various operations like communication, navigation, and information management. Required Navigation Performance (RNP) and Continuous Descent Approaches (CDA) are highly desirable systems that would also come with NextGen. RNP allows the use of satellite GPS to perform more precise, direct, and optimized flight paths. With the addition of CDA, descent approach procedures would become more optimized and potentially reduce 5 – 10 miles of unnecessary flight patterns.

Aside from the much needed ATC improvements, one individual with pilot and dispatch experience stressed the importance of internal air carrier policy. A company culture can do more harm to flight operations than any regulation. For example, air carrier's should focus on load scheduling, weight and balance, reduction in unnecessary payload weight, and improving center of gravity management for better flight performance. As well, air carriers can minimize the regulation limitations may intelligently defining flight conditions like normal cruise defined as flight condition at the end of cruise instead of heavier low altitude conditions. This would benefit regulations like 14 CFR § 91.167, 121.617, 121.639, 121.643, and 121.645 where the requirement is vaguely defined. In the end, airlines should implement intelligent Cost Index systems and constantly monitor flight performance to optimize their CI.

As for fuel management planning during flights, there are a lot of unique flight characteristics that affect various stages in the flight plan. Starting in pre-flight planning, it is not uncommon for pilots to add 1,000 to 2,000 lb of fuel load before takeoff. The occurrence varies by pilot but is usually due to weather, expected delays, adding passengers, runway limitations, and simply to play it safe. For every pound of additional fuel load or payload, about 0.115 lb of fuel must be burned to compensate the additional weight. Reduction in weight is very important to avoid burning fuel to carry fuel. For fuel consumption concerns, an additional 1,500 lb can cost an additional $75 per flight. The value of this additional cost is all dependent on the company's priorities. An interesting flight parameter after takeoff is climb speed. The main consensus was that pilots typically climb at 250 KIAS no matter what unless otherwise instructed by ATC. After performing a trade-study on climb speed, it was confirmed that optimized climb is closer to around 390 KIAS. This goes against the 14 CFR § 91.117 that limits the speed to 250 KIAS. It is unlikely that this regulation would change in the future due to the safety of mid-air collisions but with the NextGen system, higher speeds may be authorized. For the time being, flights can experience up to $58 of additional fuel burn due to the slower climb speed. Although $58 does not seem like much, after thousands of flights a day for a whole year, the unnecessary cost can add up.

The cruise portion of the flight plan was highly analyzed for any opportunity to improve fuel consumption. The main response from flight operators were the efforts to get direct routings and optimize winds aloft. Unfortunately these two cannot always be both optimized but a combination of the two may improve the overall flight plan. Non-direct flight paths with an extra 50 NM can cost an additional $192 per flight. However adverse winds aloft of 10 kts can cost $98 per flight or upwards of $500 in better headwind conditions. It was found that pilots request directs almost every time unless otherwise prompted not to due to weather or wind conditions. Although it is often optimal to get direct, weather conditions can greatly change that. As well, it is difficult for dispatch to create direct flight paths every time because the ATC system may limit the path to a non-optimal route. This is where RNP will become very beneficial in comparison to the current area navigation (rNAV) system. Additionally, the participants expressed that a there is effort to select the best altitude for wind aloft. Pilots are able to communicate to ATC and dispatch to gather more information on wind speeds at neighboring altitudes in order to step climb to the best cruise condition. Poor altitude selection of even 2,000 ft off optimal can lead to costs of $65 per flight. Once again, although an optimal cruise may be found, ATC often limits the aircraft to a specific flight condition off optimal.

As for cruise speeds, the participants expressed that pilots typically follow the flight plan except for certain situations including weather, late departures, scheduling, and ATC intervention. On the other hand, a small portion of pilots ("5 – 10%") do not comply to the flight plan and may deviate by 0.04 Mach from the requested speed. This is mostly due to improving the pilot's personal pay. It is not well monitored by air carriers and is often overlooked for various reasons. For fast flights, other flight operators are accepting because it keeps scheduling in order and does not affect other flights. From the trade-studies performed, slowing down the aircraft is more beneficial for fuel consumption considerations and hardly affects the amount of fuel burn. On the other hand, fast flights of 0.78 Mach from 0.74 Mach may increase the fuel consumption by 880 lb or $375 per flight. These issues vary by company but are still present and have an affect on fuel economy. It is too difficult for air carriers to crack down on this practice and so the most that can be done is improve leadership and respect from these select pilots.

After cruise, descent and approach are largely influenced by ATC limitations. The current descent and approach follows an rNAV non-direct routing with inefficient step descents. With the potential NextGen system, RNP and CDA landings may be implemented to greatly improve descent optimization. As of now, poor approach patterns are still used. Lastly, the fuel loads at landing often consist of about 5,000 lb of unused fuel. Most of this is for the 45 minute reserve fuel and some contingency. Depending on the pilot's initial fuel addition before takeoff and the overall flight performance, this may fluctuation by about 1,000 lb.

Operational performance is highly dependent on ATC limitations, weather, and air carrier policy. In general, the regulations do not hold back safe optimization and more efficient flight planning cannot be redefined in the regulations until newer technology is freely utilized. As long as the ATC system remains un-updated, the flight operations industry will remain poorly optimized in various aspects. For the time being, it is recommended that air carriers re-evaluate their company culture and efforts to minimize performance issues in all aspects of operations from pre-flight planning to landing. A lot revolves around a company's ability to create positive policies, efficient procedures, and finally perform accurate practices. After the completion of the flight operator interviews, it is clear that a lot is being done to optimize flight performance but organizational influences are holding back the industry. The final recommendation is for air carriers to focus more support internally and on the progress of FAA to implement NextGen.

REFERENCES

[1] *14 CFR § 25.111*, 2014.

[2] *14 CFR § 25.121*, 2014.

[3] *14 CFR § 91.117*, 2014.

[4] E. Torenbeek, Synthesis of Subsonic Airplane Design, Delft, Holland: Delft university Press, 1982.

[5] J. Anderson, Aircraft Performance and Design, WCB McGraw-Hill, 1999.

[6] D. Kuchemann, The Aerodynamic Design of Aircraft, Reston, VA: American Institute of Aeronautics and Astronautics, 2012.

[7] *Getting to Grips with Fuel Economy*, Airbus, 2004.

[8] *14 CFR § 121.624*, 2014.

[9] *14 CFR § 121.646*, 2014.

[10] *14 CFR § 121 Appendix P*, 2014.

[11] *14 CFR § 25*, 2014.

[12] *14 CFR § 91*, 2014.

[13] *14 CFR § 121*, 2014.

[14] "The Single Point Reference for Aviation Safety Knowledge," 2014. [Online]. Available: http://www.skybrary.aero.

[15] D. J.-P. Clarke, "En Route Traffic Optimization to Reduce Environmental Impact," The Partnership for AiR Transportation Noise and Emissions Reduction, MIT, Cambridge, 2008.

[16] L. Jin, Y. Cao and D. Sun, "Investigation of Potential Fuel Savings Due to Continous-Descent Approach," *Journal of Aircraft*, vol. 50, no. 3, May-June 2013.

[17] "Aeronautical Decision Making," [Online]. Available: http://www.ultraflightradio.com/segmenthelp/aeronautical-decision-making.html.

[18] *14 CFR § 91.167*, 2014.

[19] *14 CFR § 121.619*, 2014.

[20] *14 CFR § 121.542*, 2014.

[21] *Docket No. FAA-2012-0929; Notice No. 13-02*, 2014.

[22] *14 CFR § 121.639*, 2014.

[23] "ETOPS Diversion Times," 2013. [Online]. Available: http://www.dutchops.com/Portfolio_Marcel/Articles/Flight_Operations/Appendix/ETOPS_diversion.htm.

[24] "Accident Overview," 2014. [Online]. Available: http://lessonslearned.faa.gov/ll_main.cfm?TabID=4&LLID=73&LLTypeID=2.

[25] *14 CFR § 121.645*, 2014.

[26] *14 CFR § 121.643*, 2014.

[27] "Wright Amendment," Wikipedia, the free encyclopedia, February 2014. [Online]. Available: http://en.wikipedia.org/wiki/Wright_Amendment.

[28] "Ronald Reagan Washington National Airport," Wikipedia, the free encyclopedia, March 2014. [Online]. Available: http://en.wikipedia.org/wiki/Ronald_Reagan_Washington_National_Airport.

[29] *14 CFR § 91.135*, 2014.

[30] "NextGen," 2014. [Online]. Available: http://www.faa.gov/nextgen/.

[31] "Live Flight Tracking," 2014. [Online]. Available: http://flightaware.com.

[32] *14 CFR § 121.617*, 2014.

[33] "Airline Fuel Cost and Consumption," 2014. [Online]. Available: http://www.transtats.bts.gov/fuel.asp.

[34] *14 CFR § 121.647*, 2014.

[35] *14 CFR § 121.101*, 2014.

[36] "National Weather Service," 2014. [Online]. Available: http://www.weather.gov.

[37] *14 CFR § 121.471*, 2014.

[38] "Alaska Cuts Plane Emissions by 35 Pct with Smoother Landings," 26 July 2010. [Online]. Available: http://www.greenbiz.com/news/2010/07/26/alaska-cuts-plane-emissions-35-percent-smoother-landings.

[39] "Air Traffic Bulletin," March 2001. [Online]. Available: https://www.faa.gov/air_traffic/publications/atpubs/atbarc/01-3.htm.

[40] "The GE Show," 2014. [Online]. Available: http://www.ge.com/thegeshow/flight/.

[41] A. Hartley, "Airspace: Aircraft Speed Limits," Smart Flight Training, 2013. [Online]. Available: http://smartflighttraining.com/airspace-aircraft-speed-limits.

[42] "History of Flight," 2014. [Online]. Available: http://www.flyingaccidents.com/view/CHI03FA291.

[43] *14 CFR § 119-3*, 2014.

[44] "Wind Map," 2014. [Online]. Available: http://hint.fm/wind/.

[45] "National Digital Forecast Database," 2013. [Online]. Available: http://ndfd.weather.gov/technical.htm.

[46] *14 CFR § 121.161*, 2014.

[47] *14 CFR § 121.621*, 2014.

[48] N. Mora, N. Heitzman, S. Scoville and T. T. Takahashi, "Conceptual Design of a N+1 Transonic Executive Jet," in *AIAA SciTech*, National Harbor, 2014.

[49] R. C. Feagin and W. D. Morrison, "Delta Method, An Empirical Drag Buildup Technique," Lockheed-California Co., Burbank, CA, 1978.

[50] *NPSS, Numerical Propulsion System Simulation, Software Package, Ver. 2.3.0.1.*, Cleveland, OH: Ohio Aerospace Institute, 2010.

[51] T. T. Takahashi, "Aircraft Concept Design Performance Visualization Using an Energy Maneuverability Presentation," in *AIAA 2012-5704*, 2012.

[52] "Technical Specifications," February 2014. [Online]. Available: http://www.b737.org.uk/techspecsdetailed.htm.

[53] *Southwest Airlines Flight Operations Manual*, 1995.

[54] C. Freudenrich, "How Air Traffic Control Works," 2011. [Online]. Available: http://www.howstuffworks.com.

[55] "Distance Calculator," 2014. [Online]. Available: http://www.daftlogic.com/projects-google-maps-distance-calculator.htm.

[56] P. Rinaldo, "A Review of FAA's Efforts to Reduce Costs and Ensure Safety Efficiency Through Realignment and Consolidation," National Air Traffic Controllers Association, Washington, D.C., 2012.

APPENDIX A

TITLE 14 CFR PART 25 – AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

14 CFR §25.111 Takeoff path.

(a) The takeoff path extends from a standing start to a point in the takeoff at which the airplane is 1,500 feet above the takeoff surface, or at which the transition from the takeoff to the en route configuration is completed and V_{FTO} is reached, whichever point is higher. In addition—

(1) The takeoff path must be based on the procedures prescribed in §25.101(f);

(2) The airplane must be accelerated on the ground to V_{EF}, at which point the critical engine must be made inoperative and remain inoperative for the rest of the takeoff; and

(3) After reaching V_{EF}, the airplane must be accelerated to V_2.

(b) During the acceleration to speed V_2, the nose gear may be raised off the ground at a speed not less than V_R. However, landing gear retraction may not be begun until the airplane is airborne.

(c) During the takeoff path determination in accordance with paragraphs (a) and (b) of this section—

(1) The slope of the airborne part of the takeoff path must be positive at each point;

(2) The airplane must reach V_2 before it is 35 feet above the takeoff surface and must continue at a speed as close as practical to, but not less than V_2, until it is 400 feet above the takeoff surface;

(3) At each point along the takeoff path, starting at the point at which the airplane reaches 400 feet above the takeoff surface, the available gradient of climb may not be less than—

(i) 1.2 percent for two-engine airplanes;

(ii) 1.5 percent for three-engine airplanes; and

(iii) 1.7 percent for four-engine airplanes.

(4) The airplane configuration may not be changed, except for gear retraction and automatic propeller feathering, and no change in power or thrust that requires action by the pilot may be made until the airplane is 400 feet above the takeoff surface; and

(5) If §25.105(a)(2) requires the takeoff path to be determined for flight in icing conditions, the airborne part of the takeoff must be based on the airplane drag:

(i) With the takeoff ice accretion defined in appendix C, from a height of 35 feet above the takeoff surface up to the point where the airplane is 400 feet above the takeoff surface; and

(ii) With the final takeoff ice accretion defined in appendix C, from the point where the airplane is 400 feet above the takeoff surface to the end of the takeoff path.

(d) The takeoff path must be determined by a continuous demonstrated takeoff or by synthesis from segments. If the takeoff path is determined by the segmental method—

(1) The segments must be clearly defined and must be related to the distinct changes in the configuration, power or thrust, and speed;

(2) The weight of the airplane, the configuration, and the power or thrust must be constant throughout each segment and must correspond to the most critical condition prevailing in the segment;

(3) The flight path must be based on the airplane's performance without ground effect; and

(4) The takeoff path data must be checked by continuous demonstrated takeoffs up to the point at which the airplane is out of ground effect and its speed is stabilized, to ensure that the path is conservative relative to the continous path. The airplane is considered to be out of the ground effect when it reaches a height equal to its wing span.

(e) For airplanes equipped with standby power rocket engines, the takeoff path may be determined in accordance with section II of appendix E.

14 CFR §25.121 Climb: One-engine-inoperative.

(a) *Takeoff; landing gear extended.* In the critical takeoff configuration existing along the flight path (between the points at which the airplane reaches V_{LOF} and at which the landing gear is fully retracted) and in the configuration used in §25.111 but without ground effect, the steady gradient of climb must be positive for two-engine airplanes, and not less than 0.3 percent for three-engine airplanes or 0.5 percent for four-engine airplanes, at V_{LOF} and with—

(1) The critical engine inoperative and the remaining engines at the power or thrust available when retraction of the landing gear is begun in accordance with §25.111 unless there is a more critical power operating condition existing later along the flight path but before the point at which the landing gear is fully retracted; and

(2) The weight equal to the weight existing when retraction of the landing gear is begun, determined under §25.111.

(b) *Takeoff; landing gear retracted.* In the takeoff configuration existing at the point of the flight path at which the landing gear is fully retracted, and in the configuration used in §25.111 but without ground effect:

(1) The steady gradient of climb may not be less than 2.4 percent for two-engine airplanes, 2.7 percent for three-engine airplanes, and 3.0 percent for four-engine airplanes, at V_2 with:

(i) The critical engine inoperative, the remaining engines at the takeoff power or thrust available at the time the landing gear is fully retracted, determined under §25.111, unless there is a more critical power operating condition existing later along the flight path but before the point where the airplane reaches a height of 400 feet above the takeoff surface; and

(ii) The weight equal to the weight existing when the airplane's landing gear is fully retracted, determined under §25.111.

(2) The requirements of paragraph (b)(1) of this section must be met:

(i) In non-icing conditions; and

(ii) In icing conditions with the takeoff ice accretion defined in appendix C, if in the configuration of §25.121(b) with the takeoff ice accretion:

(A) The stall speed at maximum takeoff weight exceeds that in non-icing conditions by more than the greater of 3 knots CAS or 3 percent of V_{SR}; or

(B) The degradation of the gradient of climb determined in accordance with §25.121(b) is greater than one-half of the applicable actual-to-net takeoff flight path gradient reduction defined in §25.115(b).

(c) *Final takeoff.* In the en route configuration at the end of the takeoff path determined in accordance with §25.111:

(1) The steady gradient of climb may not be less than 1.2 percent for two-engine airplanes, 1.5 percent for three-engine airplanes, and 1.7 percent for four-engine airplanes, at V_{FTO} with—

(i) The critical engine inoperative and the remaining engines at the available maximum continuous power or thrust; and

(ii) The weight equal to the weight existing at the end of the takeoff path, determined under §25.111.

(2) The requirements of paragraph (c)(1) of this section must be met:

(i) In non-icing conditions; and

(ii) In icing conditions with the final takeoff ice accretion defined in appendix C, if in the configuration of §25.121(b) with the takeoff ice accretion:

(A) The stall speed at maximum takeoff weight exceeds that in non-icing conditions by more than the greater of 3 knots CAS or 3 percent of V_{SR}; or

(B) The degradation of the gradient of climb determined in accordance with §25.121(b) is greater than one-half of the applicable actual-to-net takeoff flight path gradient reduction defined in §25.115(b).

(d) *Approach.* In a configuration corresponding to the normal all-engines-operating procedure in which V_{SR} for this configuration does not exceed 110 percent of the V_{SR} for the related all-engines-operating landing configuration:

(1) The steady gradient of climb may not be less than 2.1 percent for two-engine airplanes, 2.4 percent for three-engine airplanes, and 2.7 percent for four-engine airplanes, with—

(i) The critical engine inoperative, the remaining engines at the go-around power or thrust setting;

(ii) The maximum landing weight;

(iii) A climb speed established in connection with normal landing procedures, but not exceeding 1.4 V_{SR}; and

(iv) Landing gear retracted.

(2) The requirements of paragraph (d)(1) of this section must be met:

(i) In non-icing conditions; and

(ii) In icing conditions with the approach ice accretion defined in appendix C. The climb speed selected for non-icing conditions may be used if the climb speed for icing conditions, computed in accordance with paragraph (d)(1)(iii) of this section, does not exceed that for non-icing conditions by more than the greater of 3 knots CAS or 3 percent.

APPENDIX B

TITLE 14 CFR PART 91 – GENERAL OPERATING AND FLIGHT RULES

14 CFR §91.117 Aircraft speed.

(a) Unless otherwise authorized by the Administrator, no person may operate an aircraft below 10,000 feet MSL at an indicated airspeed of more than 250 knots (288 m.p.h.).

(b) Unless otherwise authorized or required by ATC, no person may operate an aircraft at or below 2,500 feet above the surface within 4 nautical miles of the primary airport of a Class C or Class D airspace area at an indicated airspeed of more than 200 knots (230 mph.). This paragraph (b) does not apply to any operations within a Class B airspace area. Such operations shall comply with paragraph (a) of this section.

(c) No person may operate an aircraft in the airspace underlying a Class B airspace area designated for an airport or in a VFR corridor designated through such a Class B airspace area, at an indicated airspeed of more than 200 knots (230 mph).

(d) If the minimum safe airspeed for any particular operation is greater than the maximum speed prescribed in this section, the aircraft may be operated at that minimum speed.

14 CFR §91.135 Operations in Class A airspace.

Except as provided in paragraph (d) of this section, each person operating an aircraft in Class A airspace must conduct that operation under instrument flight rules (IFR) and in compliance with the following:

(a) *Clearance.* Operations may be conducted only under an ATC clearance received prior to entering the airspace.

(b) *Communications.* Unless otherwise authorized by ATC, each aircraft operating in Class A airspace must be equipped with a two-way radio capable of communicating with ATC on a frequency assigned by ATC. Each pilot must maintain two-way radio communications with ATC while operating in Class A airspace.

(c) *Equipment requirements.* Unless otherwise authorized by ATC, no person may operate an aircraft within Class A airspace unless that aircraft is equipped with the applicable equipment specified in §91.215, and after January 1, 2020, §91.225.

(d) *ATC authorizations.* An operator may deviate from any provision of this section under the provisions of an ATC authorization issued by the ATC facility having jurisdiction of the airspace concerned. In the case of an inoperative transponder, ATC may immediately approve an operation within a Class A airspace area allowing flight to continue, if desired, to the airport of ultimate destination, including any intermediate stops, or to proceed to a place where suitable repairs can be made, or both. Requests for deviation from any provision of this section must be submitted in writing, at least 4 days before the proposed operation. ATC may authorize a deviation on a continuing basis or for an individual flight.

14 CFR §91.167 Fuel requirements for flight in IFR conditions.

(a) No person may operate a civil aircraft in IFR conditions unless it carries enough fuel (considering weather reports and forecasts and weather conditions) to—

(1) Complete the flight to the first airport of intended landing;

(2) Except as provided in paragraph (b) of this section, fly from that airport to the alternate airport; and

(3) Fly after that for 45 minutes at normal cruising speed or, for helicopters, fly after that for 30 minutes at normal cruising speed.

(b) Paragraph (a)(2) of this section does not apply if:

(1) Part 97 of this chapter prescribes a standard instrument approach procedure to, or a special instrument approach procedure has been issued by the Administrator to the operator for, the first airport of intended landing; and

(2) Appropriate weather reports or weather forecasts, or a combination of them, indicate the following:

(i) *For aircraft other than helicopters.* For at least 1 hour before and for 1 hour after the estimated time of arrival, the ceiling will be at least 2,000 feet above the airport elevation and the visibility will be at least 3 statute miles.

(ii) *For helicopters.* At the estimated time of arrival and for 1 hour after the estimated time of arrival, the ceiling will be at least 1,000 feet above the airport elevation, or at least 400 feet above the lowest applicable approach minima, whichever is higher, and the visibility will be at least 2 statute miles.

APPENDIX C

TITLE 14 CFR PART 121 – OPERATING REQUIREMENTS: DOMESTIC, FLAG, AND SUPPLEMENTAL OPERATIONS

14 CFR §121.101 Weather reporting facilities.

(a) Each certificate holder conducting domestic or flag operations must show that enough weather reporting services are available along each route to ensure weather reports and forecasts necessary for the operation.

(b) Except as provided in paragraph (d) of this section, no certificate holder conducting domestic or flag operations may use any weather report to control flight unless—

(1) For operations within the 48 contiguous States and the District of Columbia, it was prepared by the U.S. National Weather Service or a source approved by the U.S. National Weather Service; or

(2) For operations conducted outside the 48 contiguous States and the District of Columbia, it was prepared by a source approved by the Administrator.

(c) Each certificate holder conducting domestic or flag operations that uses forecasts to control flight movements shall use forecasts prepared from weather reports specified in paragraph (b) of this section and from any source approved under its system adopted pursuant to paragraph (d) of this section.

(d) Each certificate holder conducting domestic or flag operations shall adopt and put into use an approved system for obtaining forecasts and reports of adverse weather phenomena, such as clear air turbulence, thunderstorms, and low altitude wind shear, that may affect safety of flight on each route to be flown and at each airport to be used.

14 CFR §121.161 Airplane limitations: Type of route.

(a) Except as provided in paragraph (e) of this section, unless approved by the Administrator in accordance with Appendix P of this part and authorized in the certificate holder's operations specifications, no certificate holder may operate a turbine-engine-powered airplane over a route that contains a point—

(1) Farther than a flying time from an Adequate Airport (at a one-engine-inoperative cruise speed under standard conditions in still air) of 60 minutes for a two-engine airplane or 180 minutes for a passenger-carrying airplane with more than two engines;

(2) Within the North Polar Area; or

(3) Within the South Polar Area.

(b) Except as provided in paragraph (c) of this section, no certificate holder may operate a land airplane (other than a DC-3, C-46, CV-240, CV-340, CV-440, CV-580, CV-600, CV-640, or Martin 404) in an extended overwater operation unless it is certificated or approved as adequate for ditching under the ditching provisions of part 25 of this chapter.

(c) Until December 20, 2010, a certificate holder may operate, in an extended overwater operation, a nontransport category land airplane type certificated after December 31, 1964, that was not certificated or approved as adequate for ditching under the ditching provisions of part 25 of this chapter.

(d) Unless authorized by the Administrator based on the character of the terrain, the kind of operation, or the performance of the airplane to be used, no certificate holder may operate a reciprocating-engine-powered airplane over a route that contains a point farther than 60 minutes flying time (at a one-engine-inoperative cruise speed under standard conditions in still air) from an Adequate Airport.

(e) Operators of turbine-engine powered airplanes with more than two engines do not need to meet the requirements of paragraph (a)(1) of this section until February 15, 2008.

14 CFR §121.471 Flight time limitations and rest requirements: All flight crewmembers.

(a) No certificate holder conducting domestic operations may schedule any flight crewmember and no flight crewmember may accept an assignment for flight time in scheduled air transportation or in other commercial flying if that crewmember's total flight time in all commercial flying will exceed—

(1) 1,000 hours in any calendar year;

(2) 100 hours in any calendar month;

(3) 30 hours in any 7 consecutive days;

(4) 8 hours between required rest periods.

(b) Except as provided in paragraph (c) of this section, no certificate holder conducting domestic operations may schedule a flight crewmember and no flight crewmember may accept an assignment for flight time during the 24 consecutive hours preceding the scheduled completion of any flight segment without a scheduled rest period during that 24 hours of at least the following:

(1) 9 consecutive hours of rest for less than 8 hours of scheduled flight time.

(2) 10 consecutive hours of rest for 8 or more but less than 9 hours of scheduled flight time.

(3) 11 consecutive hours of rest for 9 or more hours of scheduled flight time.

(c) A certificate holder may schedule a flight crewmember for less than the rest required in paragraph (b) of this section or may reduce a scheduled rest under the following conditions:

(1) A rest required under paragraph (b)(1) of this section may be scheduled for or reduced to a minimum of 8 hours if the flight crewmember is given a rest period of at least 10 hours that must begin no later than 24 hours after the commencement of the reduced rest period.

(2) A rest required under paragraph (b)(2) of this section may be scheduled for or reduced to a minimum of 8 hours if the flight crewmember is given a rest period of at least 11 hours that must begin no later than 24 hours after the commencement of the reduced rest period.

(3) A rest required under paragraph (b)(3) of this section may be scheduled for or reduced to a minimum of 9 hours if the flight crewmember is given a rest period of at least 12 hours that must begin no later than 24 hours after the commencement of the reduced rest period.

(4) No certificate holder may assign, nor may any flight crewmember perform any flight time with the certificate holder unless the flight crewmember has had at least the minimum rest required under this paragraph.

(d) Each certificate holder conducting domestic operations shall relieve each flight crewmember engaged in scheduled air transportation from all further duty for at least 24 consecutive hours during any 7 consecutive days.

(e) No certificate holder conducting domestic operations may assign any flight crewmember and no flight crewmember may accept assignment to any duty with the air carrier during any required rest period.

(f) Time spent in transportation, not local in character, that a certificate holder requires of a flight crewmember and provides to transport the crewmember to an airport at which he is to serve on a flight as a crewmember, or from an airport at which he was relieved from duty to return to his home station, is not considered part of a rest period.

(g) A flight crewmember is not considered to be scheduled for flight time in excess of flight time limitations if the flights to which he is assigned are scheduled and normally terminate within the limitations, but due to circumstances beyond the control of the certificate holder (such as adverse weather conditions), are not at the time of departure expected to reach their destination within the scheduled time.

14 CFR §121.542 Flight crewmember duties.

(a) No certificate holder shall require, nor may any flight crewmember perform, any duties during a critical phase of flight except those duties required for the safe operation of the aircraft. Duties such as company required calls made for such nonsafety related purposes as ordering galley supplies and confirming passenger connections, announcements made to passengers promoting the air carrier or pointing out sights of interest, and filling out company payroll and related records are not required for the safe operation of the aircraft.

(b) No flight crewmember may engage in, nor may any pilot in command permit, any activity during a critical phase of flight which could distract any flight crewmember from the performance of his or her duties or which could interfere in any way with the proper conduct of those duties. Activities such as eating meals, engaging in nonessential conversations within the cockpit and nonessential communications between the cabin and cockpit crews, and reading publications not related to the proper conduct of the flight are not required for the safe operation of the aircraft.

(c) For the purposes of this section, critical phases of flight includes all ground operations involving taxi, takeoff and landing, and all other flight operations conducted below 10,000 feet, except cruise flight.

Amendment(s) published February 12, 2014, in 79 FR 8263
EFFECTIVE DATES: April 14, 2014
Amend §121.542 by adding paragraph (d) to read as follows:

14 CFR §121.542 Flight crewmember duties.

* * * * *

(d) During all flight time as defined in 14 CFR 1.1, no flight crewmember may use, nor may any pilot in command permit the use of, a personal wireless communications device (as defined in 49 U.S.C. 44732(d)) or laptop computer while at a flight crewmember duty station unless the purpose is directly related to operation of the aircraft, or for emergency, safety-related, or employment-related communications, in accordance with air carrier procedures approved by the Administrator.

14 CFR §121.617 Alternate airport for departure.

(a) If the weather conditions at the airport of takeoff are below the landing minimums in the certificate holder's operations specifications for that airport, no person may dispatch or release an aircraft from that airport unless the dispatch or flight release specifies an alternate airport located within the following distances from the airport of takeoff:

(1) *Aircraft having two engines.* Not more than one hour from the departure airport at normal cruising speed in still air with one engine inoperative.

(2) *Aircraft having three or more engines.* Not more than two hours from the departure airport at normal cruising speed in still air with one engine inoperative.

(b) For the purpose of paragraph (a) of this section, the alternate airport weather conditions must meet the requirements of the certificate holder's operations specifications.

(c) No person may dispatch or release an aircraft from an airport unless he lists each required alternate airport in the dispatch or flight release.

14 CFR §121.619 Alternate airport for destination: IFR or over-the-top: Domestic operations.

(a) No person may dispatch an airplane under IFR or over-the-top unless he lists at least one alternate airport for each destination airport in the dispatch release. When the weather conditions forecast for the destination and first alternate airport are marginal at least one additional alternate must be designated. However, no alternate airport is required if for at least 1 hour before and 1 hour after the estimated time of arrival at the destination airport the appropriate weather reports or forecasts, or any combination of them, indicate—

(1) The ceiling will be at least 2,000 feet above the airport elevation; and

(2) Visibility will be at least 3 miles.

(b) For the purposes of paragraph (a) of this section, the weather conditions at the alternate airport must meet the requirements of §121.625.

(c) No person may dispatch a flight unless he lists each required alternate airport in the dispatch release.

§121.621 Alternate airport for destination: Flag operations.

(a) No person may dispatch an airplane under IFR or over-the-top unless he lists at least one alternate airport for each destination airport in the dispatch release, unless—

(1) The flight is scheduled for not more than 6 hours and, for at least 1 hour before and 1 hour after the estimated time of arrival at the destination airport, the appropriate weather reports or forecasts, or any combination of them, indicate the ceiling will be:

(i) At least 1,500 feet above the lowest circling MDA, if a circling approach is required and authorized for that airport; or

(ii) At least 1,500 feet above the lowest published instrument approach minimum or 2,000 feet above the airport elevation, whichever is greater; and

(iii) The visibility at that airport will be at least 3 miles, or 2 miles more than the lowest applicable visibility minimums, whichever is greater, for the instrument approach procedures to be used at the destination airport; or

(2) The flight is over a route approved without an available alternate airport for a particular destination airport and the airplane has enough fuel to meet the requirements of §121.641(b) or §121.645(c).

(b) For the purposes of paragraph (a) of this section, the weather conditions at the alternate airport must meet the requirements of the certificate holder's operations specifications.

(c) No person may dispatch a flight unless he lists each required alternate airport in the dispatch release.

14 CFR §121.624 ETOPS Alternate Airports.

(a) No person may dispatch or release an airplane for an ETOPS flight unless enough ETOPS Alternate Airports are listed in the dispatch or flight release such that the airplane remains within the authorized ETOPS maximum diversion time. In selecting these ETOPS Alternate Airports, the certificate holder must consider all adequate airports within the authorized ETOPS diversion time for the flight that meet the standards of this part.

(b) No person may list an airport as an ETOPS Alternate Airport in a dispatch or flight release unless, when it might be used (from the earliest to the latest possible landing time)—

(1) The appropriate weather reports or forecasts, or any combination thereof, indicate that the weather conditions will be at or above the ETOPS Alternate Airport minima specified in the certificate holder's operations specifications; and

(2) The field condition reports indicate that a safe landing can be made.

(c) Once a flight is en route, the weather conditions at each ETOPS Alternate Airport must meet the requirements of §121.631 (c).

(d) No person may list an airport as an ETOPS Alternate Airport in the dispatch or flight release unless that airport meets the public protection requirements of §121.97(b)(1)(ii).

14 CFR §121.639 Fuel supply: All domestic operations.

No person may dispatch or take off an airplane unless it has enough fuel—

(a) To fly to the airport to which it is dispatched;

(b) Thereafter, to fly to and land at the most distant alternate airport (where required) for the airport to which dispatched; and

(c) Thereafter, to fly for 45 minutes at normal cruising fuel consumption or, for certificate holders who are authorized to conduct day VFR operations in their operations specifications and who are operating nontransport category airplanes type certificated after December 31, 1964, to fly for 30 minutes at normal cruising fuel consumption for day VFR operations.

§121.643 Fuel supply: Nonturbine and turbo-propeller-powered airplanes: Supplemental operations.

(a) Except as provided in paragraph (b) of this section, no person may release for flight or takeoff a nonturbine or turbo-propeller-powered airplane unless, considering the wind and other weather conditions expected, it has enough fuel—

(1) To fly to and land at the airport to which it is released;

(2) Thereafter, to fly to and land at the most distant alternate airport specified in the flight release; and

(3) Thereafter, to fly for 45 minutes at normal cruising fuel consumption or, for certificate holders who are authorized to conduct day VFR operations in their operations specifications and who are operating nontransport category airplanes

type certificated after December 31, 1964, to fly for 30 minutes at normal cruising fuel consumption for day VFR operations.

(b) If the airplane is released for any flight other than from one point in the contiguous United States to another point in the contiguous United States, it must carry enough fuel to meet the requirements of paragraphs (a) (1) and (2) of this section and thereafter fly for 30 minutes plus 15 percent of the total time required to fly at normal cruising fuel consumption to the airports specified in paragraphs (a) (1) and (2) of this section, or to fly for 90 minutes at normal cruising fuel consumption, whichever is less.

(c) No person may release a nonturbine or turbo-propeller-powered airplane to an airport for which an alternate is not specified under §121.623(b), unless it has enough fuel, considering wind and other weather conditions expected, to fly to that airport and thereafter to fly for three hours at normal cruising fuel consumption.

14 CFR §121.645 Fuel supply: Turbine-engine powered airplanes, other than turbo propeller: Flag and supplemental operations.

(a) Any flag operation within the 48 contiguous United States and the District of Columbia may use the fuel requirements of §121.639.

(b) For any certificate holder conducting flag or supplemental operations outside the 48 contiguous United States and the District of Columbia, unless authorized by the Administrator in the operations specifications, no person may release for flight or takeoff a turbine-engine powered airplane (other than a turbo-propeller powered airplane) unless, considering wind and other weather conditions expected, it has enough fuel—

(1) To fly to and land at the airport to which it is released;

(2) After that, to fly for a period of 10 percent of the total time required to fly from the airport of departure to, and land at, the airport to which it was released;

(3) After that, to fly to and land at the most distant alternate airport specified in the flight release, if an alternate is required; and

(4) After that, to fly for 30 minutes at holding speed at 1,500 feet above the alternate airport (or the destination airport if no alternate is required) under standard temperature conditions.

(c) No person may release a turbine-engine powered airplane (other than a turbo-propeller airplane) to an airport for which an alternate is not specified under §121.621(a)(2) or §121.623(b) unless it has enough fuel, considering wind and other weather conditions expected, to fly to that airport and thereafter to fly for at least two hours at normal cruising fuel consumption.

(d) The Administrator may amend the operations specifications of a certificate holder conducting flag or supplemental operations to require more fuel than any of the minimums stated in paragraph (a) or (b) of this section if he finds that additional fuel is necessary on a particular route in the interest of safety.

(e) For a supplemental operation within the 48 contiguous States and the District of Columbia with a turbine engine powered airplane the fuel requirements of §121.643 apply.

14 CFR §121.646 En-route fuel supply: flag and supplemental operations.

(a) No person may dispatch or release for flight a turbine-engine powered airplane with more than two engines for a flight more than 90 minutes (with all engines operating at cruise power) from an Adequate Airport unless the following fuel supply requirements are met:

(1) The airplane has enough fuel to meet the requirements of §121.645(b);

(2) The airplane has enough fuel to fly to the Adequate Airport—

(i) Assuming a rapid decompression at the most critical point;

(ii) Assuming a descent to a safe altitude in compliance with the oxygen supply requirements of §121.333; and

(iii) Considering expected wind and other weather conditions.

(3) The airplane has enough fuel to hold for 15 minutes at 1500 feet above field elevation and conduct a normal approach and landing.

(b) No person may dispatch or release for flight an ETOPS flight unless, considering wind and other weather conditions expected, it has the fuel otherwise required by this part and enough fuel to satisfy each of the following requirements:

(1) Fuel to fly to an ETOPS Alternate Airport.

(i) Fuel to account for rapid decompression and engine failure. The airplane must carry the greater of the following amounts of fuel:

(A) Fuel sufficient to fly to an ETOPS Alternate Airport assuming a rapid decompression at the most critical point followed by descent to a safe altitude in compliance with the oxygen supply requirements of §121.333 of this chapter;

(B) Fuel sufficient to fly to an ETOPS Alternate Airport (at the one-engine-inoperative cruise speed) assuming a rapid decompression and a simultaneous engine failure at the most critical point followed by descent to a safe altitude in compliance with the oxygen requirements of §121.333 of this chapter; or

(C) Fuel sufficient to fly to an ETOPS Alternate Airport (at the one engine inoperative cruise speed) assuming an engine failure at the most critical point followed by descent to the one engine inoperative cruise altitude.

(ii) Fuel to account for errors in wind forecasting. In calculating the amount of fuel required by paragraph (b)(1)(i) of this section, the certificate holder must increase the actual forecast wind speed by 5% (resulting in an increase in headwind or a decrease in tailwind) to account for any potential errors in wind forecasting. If a certificate holder is not using the actual forecast wind based on a wind model accepted by the FAA, the airplane must carry additional fuel equal to 5% of the fuel required for paragraph (b)(1)(i) of this section, as reserve fuel to allow for errors in wind data.

(iii) Fuel to account for icing. In calculating the amount of fuel required by paragraph (b)(1)(i) of this section (after completing the wind calculation in paragraph (b)(1)(ii) of this section), the certificate holder must ensure that the airplane carries the greater of the following amounts of fuel in anticipation of possible icing during the diversion:

(A) Fuel that would be burned as a result of airframe icing during 10 percent of the time icing is forecast (including the fuel used by engine and wing anti-ice during this period).

(B) Fuel that would be used for engine anti-ice, and if appropriate wing anti-ice, for the entire time during which icing is forecast.

(iv) Fuel to account for engine deterioration. In calculating the amount of fuel required by paragraph (b)(1)(i) of this section (after completing the wind calculation in paragraph (b)(1)(ii) of this section), the airplane also carries fuel equal to 5% of the fuel specified above, to account for deterioration in cruise fuel burn performance unless the certificate holder has a program to monitor airplane in-service deterioration to cruise fuel burn performance.

(2) Fuel to account for holding, approach, and landing. In addition to the fuel required by paragraph (b)(1) of this section, the airplane must carry fuel sufficient to hold at 1500 feet above field elevation for 15 minutes upon reaching an ETOPS Alternate Airport and then conduct an instrument approach and land.

(3) Fuel to account for APU use. If an APU is a required power source, the certificate holder must account for its fuel consumption during the appropriate phases of flight.

14 CFR § 121.647 Factors for computing fuel required.

Each person computing fuel required for the purposes of this subpart shall consider the following:

(a) Wind and other weather conditions forecast.

(b) Anticipated traffic delays.

(c) One instrument approach and possible missed approach at destination.

(d) Any other conditions that may delay landing of the aircraft.

For the purposes of this section, required fuel is in addition to unusable fuel.

Appendix P to Part 121—Requirements for ETOPS and Polar Operations

The FAA approves ETOPS in accordance with the requirements and limitations in this appendix.

Section I. *ETOPS Approvals: Airplanes with Two engines.*

(a) *Propulsion system reliability for ETOPS.* (1) Before the FAA grants ETOPS operational approval, the operator must be able to demonstrate the ability to achieve and maintain the level of propulsion system reliability, if any, that is required by §21.4(b)(2) of this chapter for the ETOPS-approved airplane-engine combination to be used.

(2) Following ETOPS operational approval, the operator must monitor the propulsion system reliability for the airplane-engine combination used in ETOPS, and take action as required by §121.374(i) for the specified IFSD rates.

(b) *75 Minutes ETOPS*—(1) *Caribbean/Western Atlantic Area.* The FAA grants approvals to conduct

ETOPS with maximum diversion times up to 75 minutes on Western Atlantic/Caribbean area routes as follows:

(i) The FAA reviews the airplane-engine combination to ensure the absence of factors that could prevent safe operations. The airplane-engine combination need not be type-design-approved for ETOPS; however, it must have sufficient favorable experience to demonstrate to the Administrator a level of reliability appropriate for 75-minute ETOPS.

(ii) The certificate holder must comply with the requirements of §121.633 for time-limited system planning.

(iii) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(iv) The certificate holder must comply with the maintenance program requirements of §121.374, except that a pre-departure service check before departure of the return flight is not required.

(2) *Other Areas.* The FAA grants approvals to conduct ETOPS with maximum diversion times up to 75 minutes on other than Western Atlantic/Caribbean area routes as follows:

(i) The FAA reviews the airplane-engine combination to ensure the absence of factors that could prevent safe operations. The airplane-engine combination need not be type-design-approved for ETOPS; however, it must have sufficient favorable experience to demonstrate to the Administrator a level of reliability appropriate for 75-minute ETOPS.

(ii) The certificate holder must comply with the requirements of §121.633 for time-limited system planning.

(iii) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(iv) The certificate holder must comply with the maintenance program requirements of §121.374.

(v) The certificate holder must comply with the MEL in its operations specifications for 120-minute ETOPS.

(c) *90-minutes ETOPS (Micronesia).* The FAA grants approvals to conduct ETOPS with maximum diversion times up to 90 minutes on Micronesian area routes as follows:

(1) The airplane-engine combination must be type-design approved for ETOPS of at least 120-minutes.

(2) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(3) The certificate holder must comply with the maintenance program requirements of §121.374, except that a pre-departure service check before departure of the return flight is not required.

(4) The certificate holder must comply with the MEL requirements in its operations specifications for 120-minute ETOPS.

(d) *120-minute ETOPS.* The FAA grants approvals to conduct ETOPS with maximum diversion times up to 120 minutes as follows:

(1) The airplane-engine combination must be type-design-approved for ETOPS of at least 120 minutes.

(2) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(3) The certificate holder must comply with the maintenance program requirements of §121.374.

(4) The certificate holder must comply with the MEL requirements for 120-minute ETOPS.

(e) *138-Minute ETOPS.* The FAA grants approval to conduct ETOPS with maximum diversion times up to 138 minutes as follows:

(1) *Operators with 120-minute ETOPS approval.* The FAA grants 138-minute ETOPS approval as an extension of an existing 120-minute ETOPS approval as follows:

(i) The authority may be exercised only for specific flights for which the 120-minute diversion time must be exceeded.

(ii) For these flight-by-flight exceptions, the airplane-engine combination must be type-design-approved for ETOPS up to at least 120 minutes. The capability of the airplane's time-limited systems may not be less than 138 minutes calculated in accordance with §121.633.

(iii) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(iv) The certificate holder must comply with the maintenance program requirements of §121.374.

(v) The certificate holder must comply with minimum equipment list (MEL) requirements in its operations specifications for "beyond 120 minutes ETOPS". Operators without a "beyond 120-minute ETOPS" MEL may apply to AFS-200 through their certificate holding district office for a modified MEL which satisfies the master MEL policy for system/component relief in ETOPS beyond 120 minutes.

(vi) The certificate holder must conduct training for maintenance, dispatch, and flight crew personnel regarding differences between 138-minute ETOPS authority and its previously-approved 120-minute ETOPS authority.

(2) *Operators with existing 180-minute ETOPS approval.* The FAA grants approvals to conduct 138-minute ETOPS (without the limitation in paragraph (e)(1)(i) of section I of this appendix) to certificate holders with existing 180-minute ETOPS approval as follows:

(i) The airplane-engine combination must be type-design-approved for ETOPS of at least 180 minutes.

(ii) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(iii) The certificate holder must comply with the maintenance program requirements of §121.374.

(iv) The certificate holder must comply with the MEL requirements for "beyond 120 minutes ETOPS."

(v) The certificate holder must conduct training for maintenance, dispatch and flight crew personnel for differences between 138-minute ETOPS diversion approval and its previously approved 180-minute ETOPS diversion authority.

(f) *180-minute ETOPS.* The FAA grants approval to conduct ETOPS with diversion times up to 180 minutes as follows:

(1) For these operations the airplane-engine combination must be type-design-approved for ETOPS of at least 180 minutes.

(2) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(3) The certificate holder must comply with the maintenance program requirements of §121.374.

(4) The certificate holder must comply with the MEL requirements for "beyond 120 minutes ETOPS."

(g) *Greater than 180-minute ETOPS.* The FAA grants approval to conduct ETOPS greater than 180 minutes. The following are requirements for all operations greater than 180 minutes.

(1) The FAA grants approval only to certificate holders with existing 180-minute ETOPS operating authority for the airplane-engine combination to be operated.

(2) The certificate holder must have previous ETOPS experience satisfactory to the Administrator.

(3) In selecting ETOPS Alternate Airports, the operator must make every effort to plan ETOPS with maximum diversion distances of 180 minutes or less, if possible. If conditions necessitate using an ETOPS Alternate Airport beyond 180 minutes, the route may be flown only if the requirements for the specific operating area in paragraph (h) or (i) of section I of this appendix are met.

(4) The certificate holder must inform the flight crew each time an airplane is proposed for dispatch for greater than 180 minutes and tell them why the route was selected.

(5) In addition to the equipment specified in the certificate holder's MEL for 180-minute ETOPS, the following systems must be operational for dispatch:

(i) The fuel quantity indicating system.

(ii) The APU (including electrical and pneumatic supply and operating to the APU's designed capability).

(iii) The auto throttle system.

(iv) The communication system required by §121.99(d) or §121.122(c), as applicable.

(v) One-engine-inoperative auto-land capability, if flight planning is predicated on its use.

(6) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

(7) The certificate holder must comply with the maintenance program requirements of §121.374.

(h) *207-minute ETOPS in the North Pacific Area of Operations.* (1) The FAA grants approval to conduct ETOPS with maximum diversion times up to 207 minutes in the North Pacific Area of Operations as an extension to 180-minute ETOPS authority to be used on an exception basis. This exception may be used only on a flight-by-flight basis when an ETOPS Alternate Airport is not available within 180 minutes for reasons such as political or military concerns; volcanic activity; temporary airport conditions; and airport weather below dispatch requirements or other weather related events.

(2) The nearest available ETOPS Alternate Airport within 207 minutes diversion time must be specified in the dispatch or flight release.

(3) In conducting such a flight the certificate holder must consider Air Traffic Service's preferred track.

(4) The airplane-engine combination must be type-design-approved for ETOPS of at least 180 minutes. The approved time for the airplane's most limiting ETOPS significant system and most limiting cargo-fire suppression time for those cargo and baggage compartments required by regulation to have fire-suppression systems must be at least 222 minutes.

(5) The certificate holder must track how many times 207-minute authority is used.

(i) *240-minute ETOPS in the North Polar Area, in the area north of the NOPAC, and in the Pacific Ocean north of the equator.* (1) The FAA grants approval to conduct 240-minute ETOPS authority with maximum diversion times in the North Polar Area, in the area north of the NOPAC area, and the Pacific Ocean area north of the equator as an extension to 180-minute ETOPS authority to be used on an exception basis. This exception may be used only on a flight-by-flight basis when an ETOPS Alternate Airport is not available within 180 minutes. In that case, the nearest available ETOPS Alternate Airport within 240 minutes diversion time must be specified in the dispatch or flight release.

(2) This exception may be used in the North Polar Area and in the area north of NOPAC only in extreme conditions particular to these areas such as volcanic activity, extreme cold weather at en-route airports, airport weather below dispatch requirements, temporary airport conditions, and other weather related events. The criteria used by the certificate holder to decide that extreme weather precludes using an airport must be established by the certificate holder, accepted by the FAA, and published in the certificate holder's manual for the use of dispatchers and pilots.

(3) This exception may be used in the Pacific Ocean area north of the equator only for reasons such as political or military concern, volcanic activity, airport weather below dispatch requirements, temporary airport conditions and other weather related events.

(4) The airplane-engine combination must be type design approved for ETOPS greater than 180 minutes.

(j) *240-minute ETOPS in areas South of the equator.* (1) The FAA grants approval to conduct ETOPS with maximum diversion times of up to 240 minutes in the following areas:

(i) Pacific oceanic areas between the U.S. West coast and Australia, New Zealand and Polynesia.

(ii) South Atlantic oceanic areas.

(iii) Indian Ocean areas.

(iv) Oceanic areas between Australia and South America.

(2) The operator must designate the nearest available ETOPS Alternate Airports along the planned route of flight.

(3) The airplane-engine combination must be type-design-approved for ETOPS greater than 180 minutes.

(k) *ETOPS beyond 240 minutes.* (1) The FAA grants approval to conduct ETOPS with diversion times beyond 240 minutes for operations between specified city pairs on routes in the following areas:

(i) The Pacific oceanic areas between the U.S. west coast and Australia, New Zealand, and Polynesia;

(ii) The South Atlantic oceanic areas;

(iii) The Indian Oceanic areas; and

(iv) The oceanic areas between Australia and South America, and the South Polar Area.

(2) This approval is granted to certificate holders who have been operating under 180-minute or greater ETOPS authority for at least 24 consecutive months, of which at least 12 consecutive months must be under 240-minute ETOPS authority with the airplane-engine combination to be used.

(3) The operator must designate the nearest available ETOPS alternate or alternates along the planned route of flight.

(4) For these operations, the airplane-engine combination must be type-design-approved for ETOPS greater than 180 minutes.

Section II. *ETOPS Approval: Passenger-carrying Airplanes With More Than Two Engines.*

(a) The FAA grants approval to conduct ETOPS, as follows:

(1) Except as provided in §121.162, the airplane-engine combination must be type-design-approved for ETOPS.

(2) The operator must designate the nearest available ETOPS Alternate Airports within 240 minutes diversion time (at one-engine-inoperative cruise speed under standard conditions in still air). If an ETOPS alternate is not available within 240 minutes, the operator must designate the nearest available ETOPS Alternate Airports along the planned route of flight.

(3) The MEL limitations for the authorized ETOPS diversion time apply.

(i) The Fuel Quantity Indicating System must be operational.

(ii) The communications systems required by §121.99(d) or §121.122(c) must be operational.

(4) The certificate holder must operate in accordance with the ETOPS authority as contained in its operations specifications.

Section III. *Approvals for operations whose airplane routes are planned to traverse either the North Polar or South Polar Areas.*

(a) Except for intrastate operations within the State of Alaska, no certificate holder may operate an aircraft in the North Polar Area or South Polar Area, unless authorized by the FAA.

(b) In addition to any of the applicable requirements of sections I and II of this appendix, the certificate holder's operations specifications must contain the following:

(1) The designation of airports that may be used for en-route diversions and the requirements the airports must meet at the time of diversion.

(2) Except for supplemental all-cargo operations, a recovery plan for passengers at designated diversion airports.

(3) A fuel-freeze strategy and procedures for monitoring fuel freezing.

(4) A plan to ensure communication capability for these operations.

(5) An MEL for these operations.

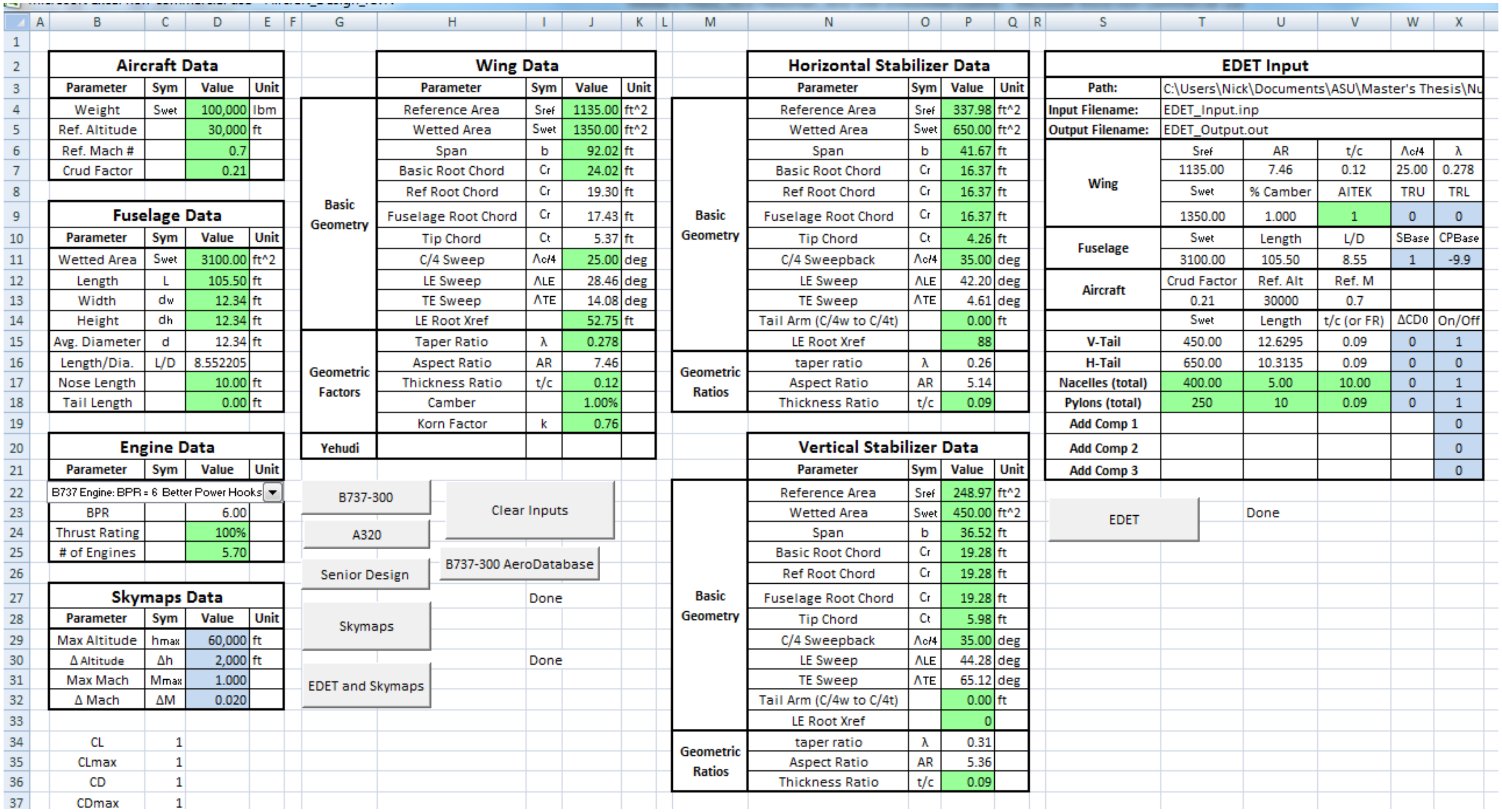
(6) A training plan for operations in these areas.

(7) A plan for mitigating crew exposure to radiation during solar flare activity.

(8) A plan for providing at least two cold weather anti-exposure suits in the aircraft, to protect crewmembers during outside activity at a diversion airport with extreme climatic conditions. The FAA may relieve the certificate holder from this requirement if the season of the year makes the equipment unnecessary.

APPENDIX D

FLIGHT PROFILE SIMULATION



Aircraft Data

Parameter	Sym	Value	Unit
Weight	S_{wet}	100,000	lbm
Ref. Altitude		30,000	ft
Ref. Mach #		0.7	
Crud Factor		0.21	

Fuselage Data

Parameter	Sym	Value	Unit
Wetted Area	S_{wet}	3100.00	ft^2
Length	L	105.50	ft
Width	d_w	12.34	ft
Height	d_h	12.34	ft
Avg. Diameter	d	12.34	ft
Length/Dia.	L/D	8.552205	
Nose Length		10.00	ft
Tail Length		0.00	ft

Engine Data

Parameter	Sym	Value	Unit
B737 Engine: BPR = 6 Better Power Hooks ▾			
BPR		6.00	
Thrust Rating		100%	
# of Engines		5.70	

Skymaps Data

Parameter	Sym	Value	Unit
Max Altitude	h_{max}	60,000	ft
Δ Altitude	Δh	2,000	ft
Max Mach	M_{max}	1.000	
Δ Mach	ΔM	0.020	

CL	1
CLmax	1
CD	1
CDmax	1

Wing Data

	Parameter	Sym	Value	Unit
Basic Geometry	Reference Area	S_{ref}	1135.00	ft^2
	Wetted Area	S_{wet}	1350.00	ft^2
	Span	b	92.02	ft
	Basic Root Chord	C_r	24.02	ft
	Ref Root Chord	C_r	19.30	ft
	Fuselage Root Chord	C_r	17.43	ft
	Tip Chord	C_t	5.37	ft
	C/4 Sweep	$\Lambda_{c/4}$	25.00	deg
	LE Sweep	Λ_{LE}	28.46	deg
	TE Sweep	Λ_{TE}	14.08	deg
	LE Root Xref		52.75	ft
Geometric Factors	Taper Ratio	λ	0.278	
	Aspect Ratio	AR	7.46	
	Thickness Ratio	t/c	0.12	
	Camber		1.00%	
	Korn Factor	k	0.76	
Yehudi				

Horizontal Stabilizer Data

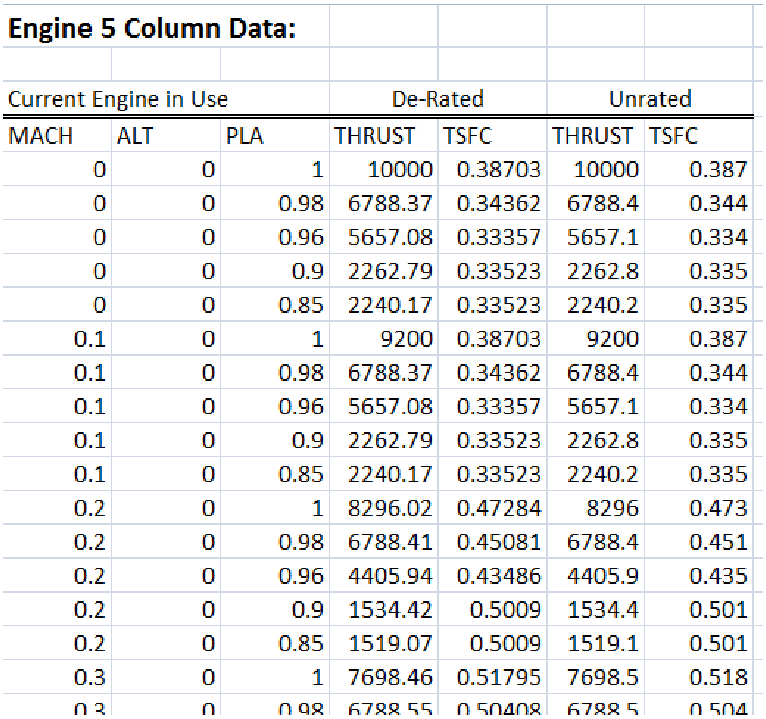
	Parameter	Sym	Value	Unit
Basic Geometry	Reference Area	S_{ref}	337.98	ft^2
	Wetted Area	S_{wet}	650.00	ft^2
	Span	b	41.67	ft
	Basic Root Chord	C_r	16.37	ft
	Ref Root Chord	C_r	16.37	ft
	Fuselage Root Chord	C_r	16.37	ft
	Tip Chord	C_t	4.26	ft
	C/4 Sweepback	$\Lambda_{c/4}$	35.00	deg
	LE Sweep	Λ_{LE}	42.20	deg
	TE Sweep	Λ_{TE}	4.61	deg
	Tail Arm (C/4w to C/4t)		0.00	ft
	LE Root Xref		88	
Geometric Ratios	taper ratio	λ	0.26	
	Aspect Ratio	AR	5.14	
	Thickness Ratio	t/c	0.09	

Vertical Stabilizer Data

	Parameter	Sym	Value	Unit
Basic Geometry	Reference Area	S_{ref}	248.97	ft^2
	Wetted Area	S_{wet}	450.00	ft^2
	Span	b	36.52	ft
	Basic Root Chord	C_r	19.28	ft
	Ref Root Chord	C_r	19.28	ft
	Fuselage Root Chord	C_r	19.28	ft
	Tip Chord	C_t	5.98	ft
	C/4 Sweepback	$\Lambda_{c/4}$	35.00	deg
	LE Sweep	Λ_{LE}	44.28	deg
	TE Sweep	Λ_{TE}	65.12	deg
	Tail Arm (C/4w to C/4t)		0.00	ft
	LE Root Xref		0	
Geometric Ratios	taper ratio	λ	0.31	
	Aspect Ratio	AR	5.36	
	Thickness Ratio	t/c	0.09	

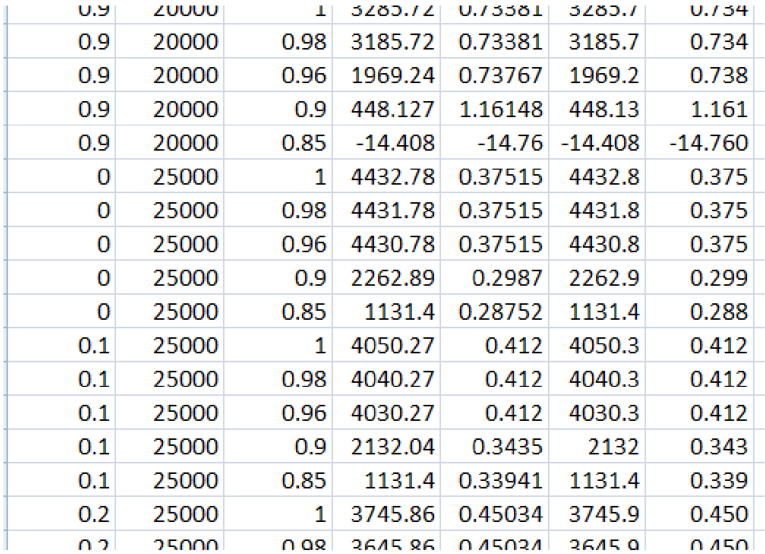
EDET Input

Path:	C:\Users\Nick\Documents\ASU\Master's Thesis\Nu				
Input Filename:	EDET_Input.inp				
Output Filename:	EDET_Output.out				
Wing	S_{ref}	AR	t/c	$\Lambda_{c/4}$	λ
	1135.00	7.46	0.12	25.00	0.278
	S_{wet}	% Camber	AITEK	TRU	TRL
	1350.00	1.000	1	0	0
Fuselage	S_{wet}	Length	L/D	SBase	CPBase
	3100.00	105.50	8.55	1	-9.9
Aircraft	Crud Factor	Ref. Alt	Ref. M		
	0.21	30000	0.7		
	S_{wet}	Length	t/c (or FR)	ΔCD0	On/Off
V-Tail	450.00	12.6295	0.09	0	1
H-Tail	650.00	10.3135	0.09	0	0
Nacelles (total)	400.00	5.00	10.00	0	1
Pylons (total)	250	10	0.09	0	1
Add Comp 1					0
Add Comp 2					0
Add Comp 3					0

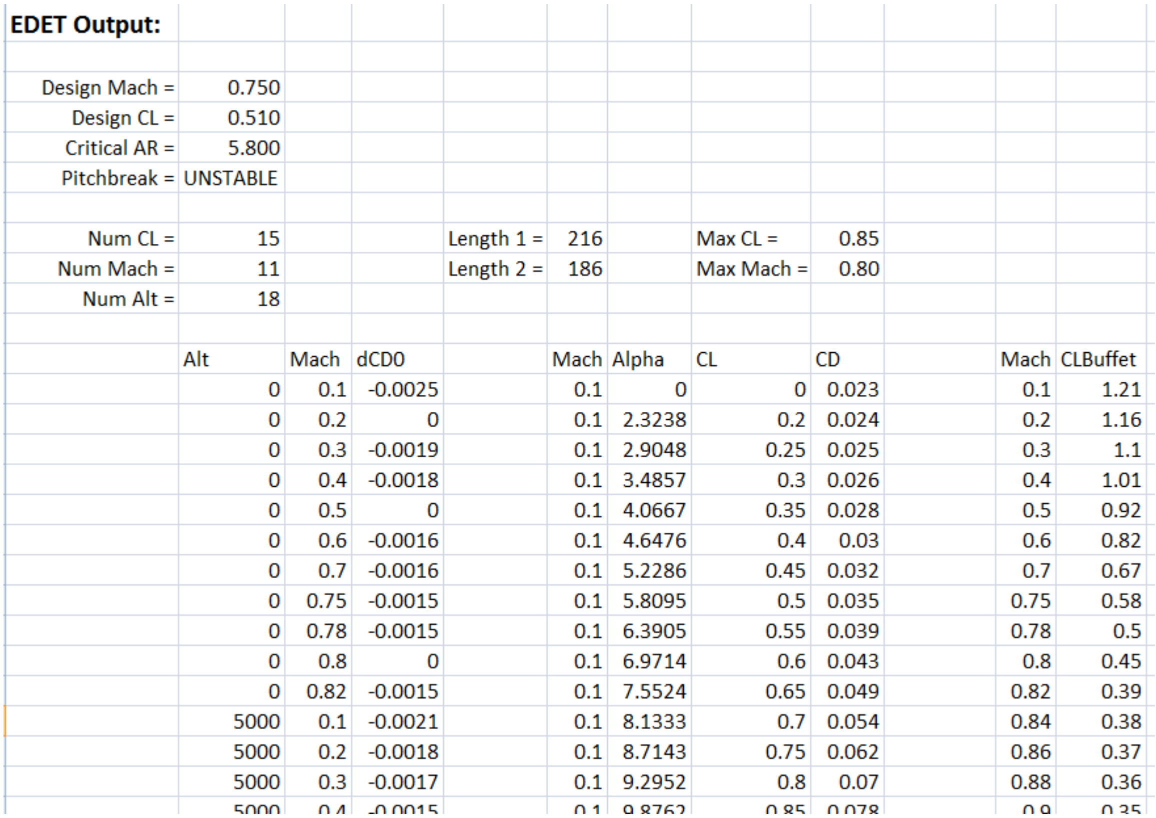


Engine 5 Column Data:

Current Engine in Use			De-Rated		Unrated	
MACH	ALT	PLA	THRUST	TSFC	THRUST	TSFC
0	0	1	10000	0.38703	10000	0.387
0	0	0.98	6788.37	0.34362	6788.4	0.344
0	0	0.96	5657.08	0.33357	5657.1	0.334
0	0	0.9	2262.79	0.33523	2262.8	0.335
0	0	0.85	2240.17	0.33523	2240.2	0.335
0.1	0	1	9200	0.38703	9200	0.387
0.1	0	0.98	6788.37	0.34362	6788.4	0.344
0.1	0	0.96	5657.08	0.33357	5657.1	0.334
0.1	0	0.9	2262.79	0.33523	2262.8	0.335
0.1	0	0.85	2240.17	0.33523	2240.2	0.335
0.2	0	1	8296.02	0.47284	8296	0.473
0.2	0	0.98	6788.41	0.45081	6788.4	0.451
0.2	0	0.96	4405.94	0.43486	4405.9	0.435
0.2	0	0.9	1534.42	0.5009	1534.4	0.501
0.2	0	0.85	1519.07	0.5009	1519.1	0.501
0.3	0	1	7698.46	0.51795	7698.5	0.518
0.3	0	0.98	6788.55	0.50408	6788.5	0.504



0.9	20000	1	3285.72	0.73381	3285.7	0.734
0.9	20000	0.98	3185.72	0.73381	3185.7	0.734
0.9	20000	0.96	1969.24	0.73767	1969.2	0.738
0.9	20000	0.9	448.127	1.16148	448.13	1.161
0.9	20000	0.85	-14.408	-14.76	-14.408	-14.760
0	25000	1	4432.78	0.37515	4432.8	0.375
0	25000	0.98	4431.78	0.37515	4431.8	0.375
0	25000	0.96	4430.78	0.37515	4430.8	0.375
0	25000	0.9	2262.89	0.2987	2262.9	0.299
0	25000	0.85	1131.4	0.28752	1131.4	0.288
0.1	25000	1	4050.27	0.412	4050.3	0.412
0.1	25000	0.98	4040.27	0.412	4040.3	0.412
0.1	25000	0.96	4030.27	0.412	4030.3	0.412
0.1	25000	0.9	2132.04	0.3435	2132	0.343
0.1	25000	0.85	1131.4	0.33941	1131.4	0.339
0.2	25000	1	3745.86	0.45034	3745.9	0.450
0.2	25000	0.98	3645.86	0.45034	3645.9	0.450



EDET Output:

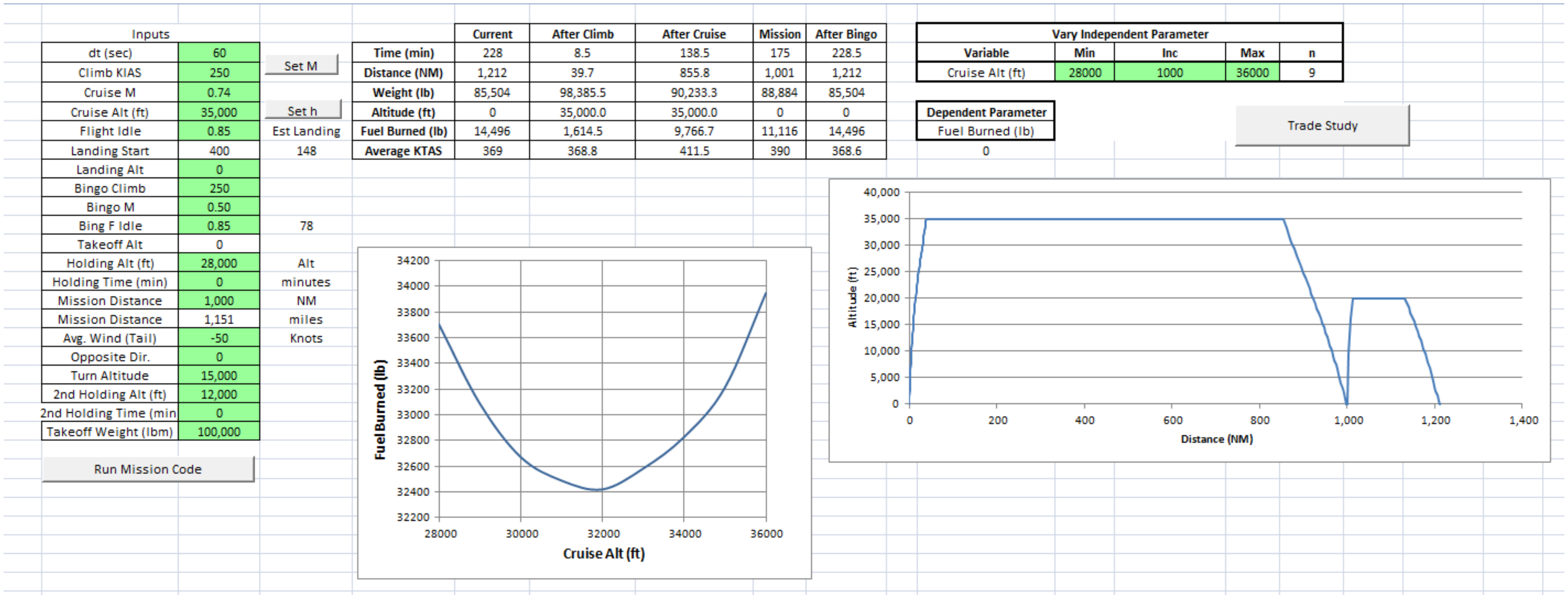
Design Mach = 0.750
Design CL = 0.510
Critical AR = 5.800
Pitchbreak = UNSTABLE

Num CL = 15
Num Mach = 11
Num Alt = 18

Length 1 = 216
Length 2 = 186

Max CL = 0.85
Max Mach = 0.80

Alt	Mach	dCD0		Mach	Alpha	CL	CD		Mach	CLBuffet
0	0.1	-0.0025		0.1	0	0	0.023		0.1	1.21
0	0.2	0		0.1	2.3238	0.2	0.024		0.2	1.16
0	0.3	-0.0019		0.1	2.9048	0.25	0.025		0.3	1.1
0	0.4	-0.0018		0.1	3.4857	0.3	0.026		0.4	1.01
0	0.5	0		0.1	4.0667	0.35	0.028		0.5	0.92
0	0.6	-0.0016		0.1	4.6476	0.4	0.03		0.6	0.82
0	0.7	-0.0016		0.1	5.2286	0.45	0.032		0.7	0.67
0	0.75	-0.0015		0.1	5.8095	0.5	0.035		0.75	0.58
0	0.78	-0.0015		0.1	6.3905	0.55	0.039		0.78	0.5
0	0.8	0		0.1	6.9714	0.6	0.043		0.8	0.45
0	0.82	-0.0015		0.1	7.5524	0.65	0.049		0.82	0.39
5000	0.1	-0.0021		0.1	8.1333	0.7	0.054		0.84	0.38
5000	0.2	-0.0018		0.1	8.7143	0.75	0.062		0.86	0.37
5000	0.3	-0.0017		0.1	9.2952	0.8	0.07		0.88	0.36
5000	0.4	-0.0015		0.1	9.8762	0.85	0.078		0.9	0.35

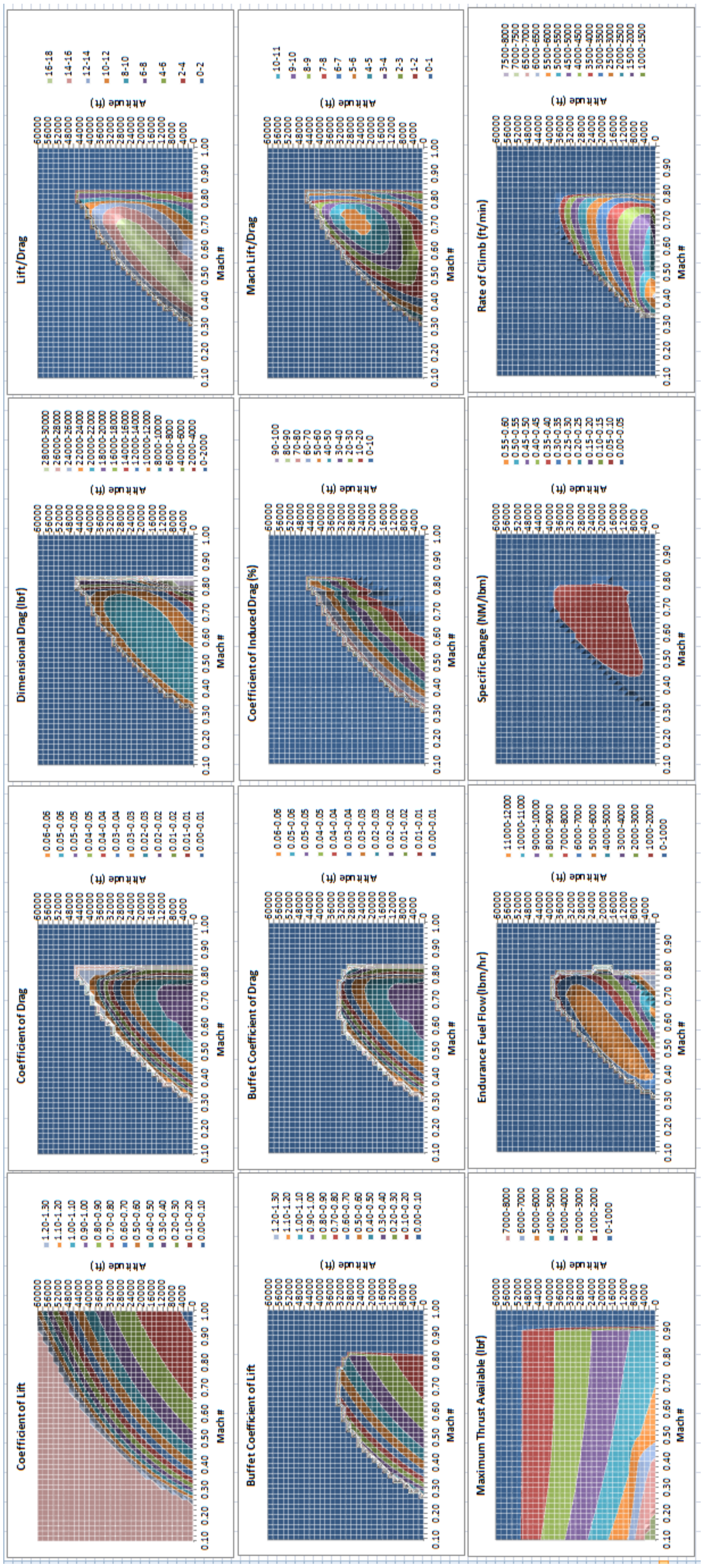


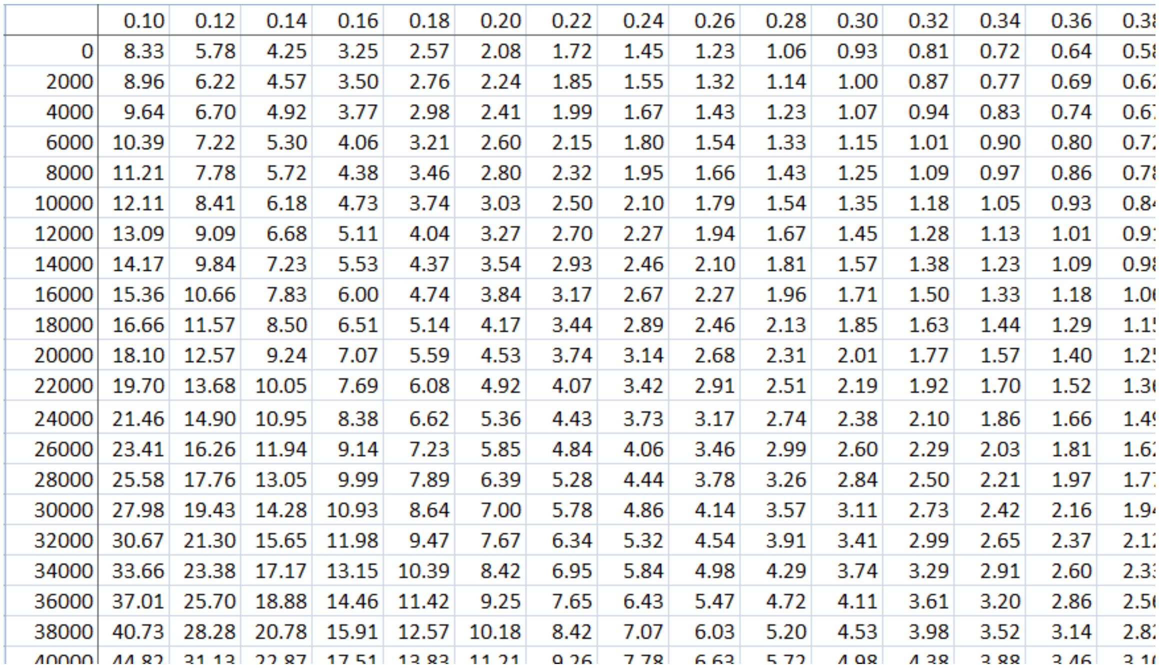
Inputs		
dt (sec)	60	
Climb KIAS	250	Set M
Cruise M	0.74	
Cruise Alt (ft)	35,000	Set h
Flight Idle	0.85	Est Landing
Landing Start	400	148
Landing Alt	0	
Bingo Climb	250	
Bingo M	0.50	
Bing F Idle	0.85	78
Takeoff Alt	0	
Holding Alt (ft)	28,000	Alt
Holding Time (min)	0	minutes
Mission Distance	1,000	NM
Mission Distance	1,151	miles
Avg. Wind (Tail)	-50	Knots
Opposite Dir.	0	
Turn Altitude	15,000	
2nd Holding Alt (ft)	12,000	
2nd Holding Time (min	0	
Takeoff Weight (lbm)	100,000	

	Current	After Climb	After Cruise	Mission	After Bingo
Time (min)	228	8.5	138.5	175	228.5
Distance (NM)	1,212	39.7	855.8	1,001	1,212
Weight (lb)	85,504	98,385.5	90,233.3	88,884	85,504
Altitude (ft)	0	35,000.0	35,000.0	0	0
Fuel Burned (lb)	14,496	1,614.5	9,766.7	11,116	14,496
Average KTAS	369	368.8	411.5	390	368.6

Vary Independent Parameter				
Variable	**Min**	**Inc**	**Max**	**n**
Cruise Alt (ft)	28000	1000	36000	9

Dependent Parameter
Fuel Burned (lb)
0


Coefficient of Lift
Coefficient of Drag
Dimensional Drag (lbf)
Lift/Drag
Buffet Coefficient of Lift
Buffet Coefficient of Drag
Coefficient of Induced Drag (%)
Mach Lift/Drag
Maximum Thrust Available (lbf)
Endurance Fuel Flow (lbm/hr)
Specific Range (NM/lbm)
Rate of Climb (ft/min)
Mach #
Altitude (ft)



	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.3
0	8.33	5.78	4.25	3.25	2.57	2.08	1.72	1.45	1.23	1.06	0.93	0.81	0.72	0.64	0.5
2000	8.96	6.22	4.57	3.50	2.76	2.24	1.85	1.55	1.32	1.14	1.00	0.87	0.77	0.69	0.6
4000	9.64	6.70	4.92	3.77	2.98	2.41	1.99	1.67	1.43	1.23	1.07	0.94	0.83	0.74	0.6
6000	10.39	7.22	5.30	4.06	3.21	2.60	2.15	1.80	1.54	1.33	1.15	1.01	0.90	0.80	0.7
8000	11.21	7.78	5.72	4.38	3.46	2.80	2.32	1.95	1.66	1.43	1.25	1.09	0.97	0.86	0.7
10000	12.11	8.41	6.18	4.73	3.74	3.03	2.50	2.10	1.79	1.54	1.35	1.18	1.05	0.93	0.8
12000	13.09	9.09	6.68	5.11	4.04	3.27	2.70	2.27	1.94	1.67	1.45	1.28	1.13	1.01	0.9
14000	14.17	9.84	7.23	5.53	4.37	3.54	2.93	2.46	2.10	1.81	1.57	1.38	1.23	1.09	0.9
16000	15.36	10.66	7.83	6.00	4.74	3.84	3.17	2.67	2.27	1.96	1.71	1.50	1.33	1.18	1.0
18000	16.66	11.57	8.50	6.51	5.14	4.17	3.44	2.89	2.46	2.13	1.85	1.63	1.44	1.29	1.1
20000	18.10	12.57	9.24	7.07	5.59	4.53	3.74	3.14	2.68	2.31	2.01	1.77	1.57	1.40	1.2
22000	19.70	13.68	10.05	7.69	6.08	4.92	4.07	3.42	2.91	2.51	2.19	1.92	1.70	1.52	1.3
24000	21.46	14.90	10.95	8.38	6.62	5.36	4.43	3.73	3.17	2.74	2.38	2.10	1.86	1.66	1.4
26000	23.41	16.26	11.94	9.14	7.23	5.85	4.84	4.06	3.46	2.99	2.60	2.29	2.03	1.81	1.6
28000	25.58	17.76	13.05	9.99	7.89	6.39	5.28	4.44	3.78	3.26	2.84	2.50	2.21	1.97	1.7
30000	27.98	19.43	14.28	10.93	8.64	7.00	5.78	4.86	4.14	3.57	3.11	2.73	2.42	2.16	1.9
32000	30.67	21.30	15.65	11.98	9.47	7.67	6.34	5.32	4.54	3.91	3.41	2.99	2.65	2.37	2.1
34000	33.66	23.38	17.17	13.15	10.39	8.42	6.95	5.84	4.98	4.29	3.74	3.29	2.91	2.60	2.3
36000	37.01	25.70	18.88	14.46	11.42	9.25	7.65	6.43	5.47	4.72	4.11	3.61	3.20	2.86	2.5
38000	40.73	28.28	20.78	15.91	12.57	10.18	8.42	7.07	6.03	5.20	4.53	3.98	3.52	3.14	2.8
40000	44.82	31.13	22.87	17.51	13.83	11.21	9.26	7.78	6.63	5.72	4.98	4.38	3.88	3.46	3.1

The above is an example of the point performance data used for “Skymaps”