
BOLTER, BOLTER, BOLTER!
A Flight Siumlation & Carrier
Landing System
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Contents

Intent Statement

By creating a jet fighter operation system that uses realistic cockpit heads up display controls and reticles, visual and auditory feedback to indicate the speed, orientation & fuel supply of the plane, and realistic flight physics all within a carrier landing scenario, I intend to create an immersive and realistic flight simulation and carrier landing experience where players feel like an ace Navy pilot.

Research, Thesis, & Process

My goal is to create a highly immersive flight and carrier landing simulation system which revolves around the player controlling an F/A-18 Hornet fighter jet in order to take off from the starting runway, fly towards the carrier, and land on it successfully before running out of fuel, all while using realistic flight physics and cockpit heads up display information to guide the landing. The main objectives with this system are to **make the player feel like a real pilot** in the cockpit with visual and auditory feedback from the flight controls display and control surfaces, **provide a diegetic cockpit heads up display** the provides the player with all the information they need to take off, fly, and land successfully without breaking immersion, **use realistically calculated forces of flight** to provide immersion through simulation, and **emulate a real carrier landing process** with visible "arresting wires" and "optical lenses" to guide the player towards a successful landing.

A lot of games revolving around flight and airplanes (that aren't full blown simulations) often use more "arcadey" controls for flying the planes, which is a useful design choice for making the player feel more empowered, but can hurt immersion for many players looking for more realistic feeling controls. These sorts of games also usually revolve around combat and neglect things like realistic landings, especially when it comes to aircraft carriers. I wanted to do the opposite of this with my system; instead of providing immersion through combat, I aimed to fully immerse players through the feeling and visuals of the plane and cockpit as well as more realistic simulations of take off and landing.

To do all this, I planned to place the player inside the cockpit of a common navy plane (the F/A-18 Hornet) and allow them to look around from a fixed position to see the cockpit HUD, the flight stick and throttle, as well as out the back of the plane to see the wings and such. Players would be able to move the plane forward and steer it in all directions, but it would not be easy and smooth; real physics forces of lift, gravity, drag, and thrust would all be applied to the plane in real time, making flight more of a balancing act to provide immersion. I also planned to give players the ability see their inputs reflected on the throttle and flight stick inside the cockpit as well as on the various control surfaces on the outside of plane to provide even more immersion. The cockpit HUD displays information such as speed, pitch angle, altitude, and orientation in real time to not only provide immersion but also assist landings. Lastly, to give the player an objective to use these immersive flight mechanics and HUD with, I aimed to make the context focused on returning to the carrier before running out of fuel, which provides both a win and loss state as well as immersion, since the plane is stopped by arresting wires instead of just landing on the deck and the optical lenses of the carrier assist players with getting a level slope to the deck.

After thinking about how to implement these mechanics, I turned to one of my favorite games to see how it handles realistic military vehicle interiors: *Squad*. I deconstructed the vehicle immersion systems within the game in order to find out how immersion could be provided through a diegetic interface and visual and audio feedback, as well as camera positioning and angles. Since the game doesn't feature planes, I investigated the mechanics that make the tank simulation so immersive. I came to the conclusion that the heads up display being diegetic and providing actually useful information to the player was a main mechanical cause of this, as well as the limited camera view and "lens" like filter affect applied when looking through the various turret cameras. I used what I learned from this deconstruction process to inform the decision to make the heads up display not only useful and accurate (i.e, not just for show) but also diegetic to preserve immersion.

With the deconstruction done, I was faced with a problem; I knew the bare basics of aircraft physics but had no idea how to program them. I conducted further research into the forces acting on a plane and how they work and eventually stumbled upon a book called *Physics for Game Programmers*, which has an entire chapter dedicated to airplanes and the physics that drive them as well as information on how to program them. The chapter gets very in detail about all of the forces acting on planes and includes the various and complicated physics formulas needed to calculate such forces. I learned quite a bit about lift, drag, thrust, and gravity from this chapter and used pretty much everything I learned from it in the design of my system. While not all of the complicated physics are at play in my system (I'm not calculating the air density for example), this chapter gave me a great overview of the physics as well as an idea of how to implement them programmatically.

Now that I had an understanding of flight physics and knew how to implement them into Unity, I wanted to learn more about carrier landing procedures and the various plane metrics and data that were useful in helping pilots land on carriers. My research yielded two informative articles about the subject, one titled "How Aircraft Carriers Work" which takes a more third person perspective and the other titled "How To Land A Fighter On An Aircraft Carrier On A Dark And Stormy Night", which is told in a story format by an actual pilot. Both of these articles provided me with what I was looking for; the speed at which landings are conducted (around 150 knots), how pilots are guided to the carrier deck (the "meatball" from the Fresnel Lens Optical Landing System, or IFLOLS), and what actually stops the fast moving planes in an instant before they can fall off of the other side of the deck (the landing hook snagging an arresting wire). I used all of this information to inform the design of the carrier landing mechanics, trying to model them as accurately as possible. I also used some of the information to inform the information I wanted to display on the HUD that was relevant to this scenario: speed in knots, altitude in feet, pitch angle, roll angle, angle of attack value, and angle of attack index.

System & Mechanics

Explanation

The system gives the player control of an F/A-18 Hornet fighter plane in a first person, cockpit perspective that features a fully functioning and accurate heads up display, as well as a flight stick and throttle. The heads up display has readings for airspeed, altitude, pitch angle, roll angle, angle of attack, angle of attack index, velocity vector, and fuel supply. The throttle and flight stick move according to player input. Players can look around inside of the cockpit to observe the terrain around them as well as the cockpit interior and the sides of the plane. There are also two other cameras, one that follows the plane from outside and a freelook camera that allows players to look at the plane model, which has fully operating control surfaces and jet effects. These cameras can be switched between by pressing the C key. The plane starts in a stationary position on a runway on land and must successfully perform a carrier landing before fuel runs out.

Players control the pitch and roll of the plane using the WASD keys on their keyboard. Yaw is controlled with the left and right mouse buttons. Holding down the spacebar causes the throttle to increase, while holding left control causes it to decrease. Higher throttle values produce more thrust and drag, while lower values decrease thrust while still maintaining drag from gravity, meaning players must carefully balance their thrust to not fall out of the sky. Pressing the F key will lower the flaps by 15 degrees, while pressing the G key will raise them by 15 degrees. These are used to provide additional lift and drag when landing.

To take off, players must be at full throttle. The plane will naturally lift off of the runway once the thrust is high enough to produce enough lift to exceed the weight of the plane. Once in the air, pitch, roll, and yaw can be controlled to move the plane around. Rolling causes the plane to automatically perform a slight banking turn, which can quickly force the plane’s altitude to decrease if the rolling angle is too sharp. Pitching while rolling can provide tighter and more controlled turns at the risk of increasing drag. After an understanding of the flight model is achieved, players proceed to fly towards the carrier in order to perform a carrier landing.

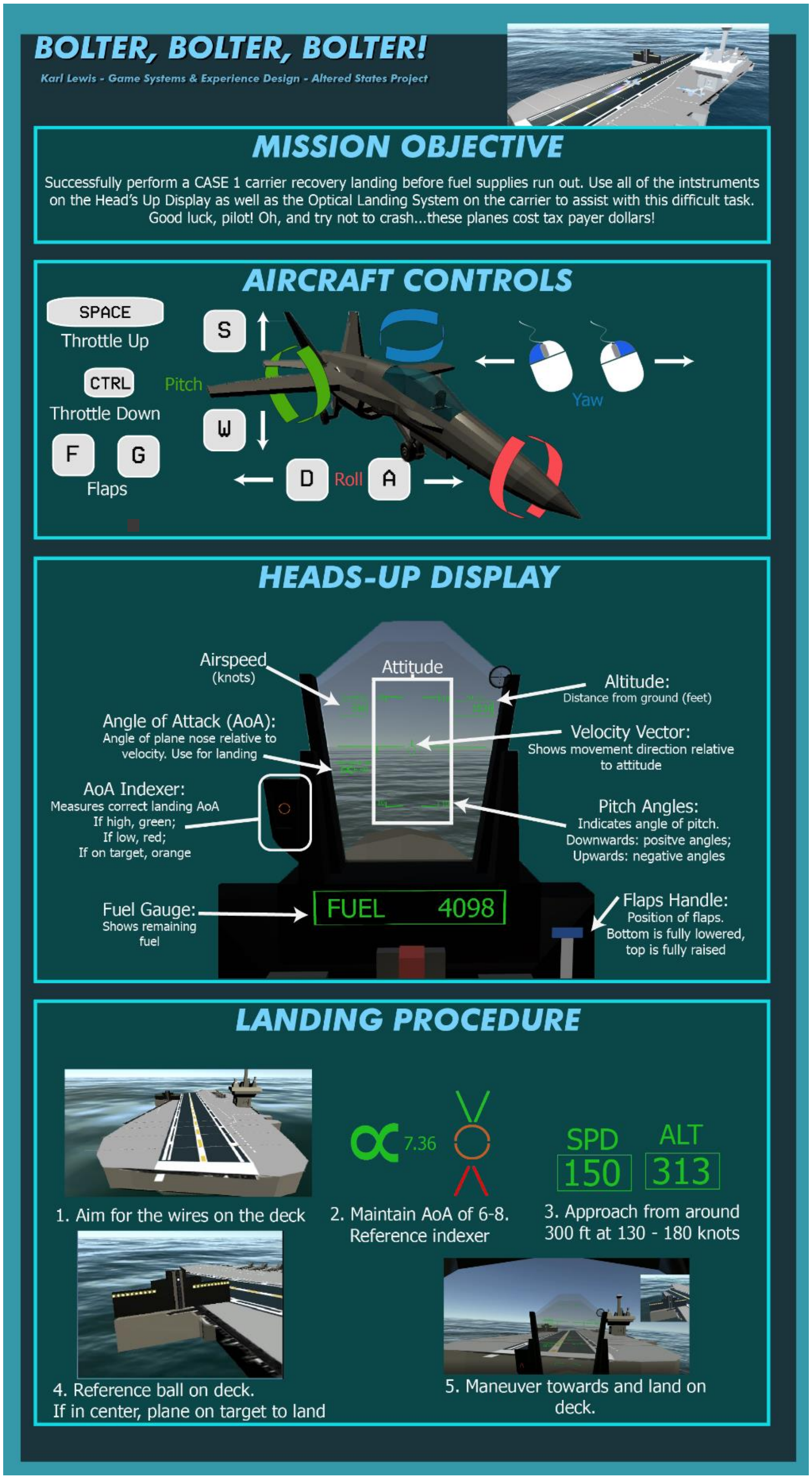
The carrier landing procedure requires the following: firstly, the player wants to be going around 130-180 knots in order to touch down without crashing, meaning careful throttle balance will need to be maintained during the entire process. Putting down the flaps also helps control the descent. Secondly, a balanced angle of attack must be maintained in order to stay angled appropriately to the carrier deck. This is achieved by monitoring the angle of attack indexer: if the green upwards arrows are displayed, the angle is too high; if the red downwards arrows are displayed, the angle is too low; if the orange circle is displayed, the angle is on target.

Thirdly, players must also use the altimeter on the HUD and the meatball from the optical landing system on the ship to indicate their altitude relative to the plane; if the ball is above the center, the altitude is too high; below the center, too low; in the center, on target. Finally, the roll angle must be on center with the deck, which can be easily monitored with the rotation of the attitude meter; when it is in the center, the roll angle is centered

Once the speed, angle of attack, and altitude are all on target, landing the plane is as simple as touching down on the deck, as the arresting wires should be snagged by the hook and stop the plane. When the plane is landed, the win state is achieved. If all fuel is used or any part of the plane besides the landing gear touches another object, the loss state occurs.

Video Overview Storyboard

Visual Design Document



QA Testing

Test Plan

Test Intent: The goal of this test is to determine if the desired intent of my altered states prototype has been successfully achieved in a playable form. Survey questions relate to the testers' sense of immersion while piloting the plane, using the heads-up display, and landing the plane on the carrier. The prototype will be considered a success if players report having enough visual and auditory feedback to feel like they are in the pilot seat, if the heads-up display and cockpit controls are both useful and contribute to immersion, if the flight model made the plane feel like an actual physical object, and if the HUD information and the meatball were used for the carrier landing. I plan to get feedback from at least 4 different people, and will hold the test informally outside of the testing lab.

Testing Setup & Procedure:

1. Explain concept of the system and controls to tester
2. Launch game and observe if tester notices instructions in game world. Record observation.
3. Observe tester behavior as they play the system until they are finished.
4. Have tester fill out form
5. Thank tester for their time and feedback

Test Questions:

1. Did the cockpit view make you feel like you were in the pilot's seat?
2. Which of the following factors contributed to the feeling of immersion, if any, when in the cockpit view: heads-up display indicators, flight stick and throttle movement, camera shake, audio, movement of the plane?
3. Was there enough feedback to feel immersed in the cockpit view?
4. Did you understand the various parts of the heads-up display?
5. How often did you reference the heads-up display information and throttle/flight stick movement in the cockpit?
6. Did the heads-up display and throttle/flight stick movement contribute to immersion? Why or why not?

7. Did the plane feel like a physical object with weight to it? Why or why not?
8. When attempting a carrier landing, did you reference the heads-up display information?
9. When attempting a carrier landing, did you reference the moving "meatball" light on the deck of the ship?
10. Did you successfully land the plane?
11. Would you describe the overall experience as an immersive simulation?

Survey: **https://docs.google.com/forms/d/e/1FAIpQLSdbn6K51FpuczIAbIqg2Bo6Y-TO94g4bja8_pfT-A6GV4JJaw/viewform**

Test Results

Summary: Overall, the test was a resounding success based on the criteria for success. I got four testers to play the game and leave feedback. One of the testers is a game production major at Champlain College, while the other three are from outside the school. All of the testers have little to no knowledge of piloting an aircraft or the physics behind it. Despite this, all of the testers seemed to have fun with the system and reported it as an immersive and detailed simulation, but also had difficulty landing the plane on the carrier due to the complexity of the controls.

Survey Responses:

1. Did the cockpit view make you feel like you were in the pilot's seat?
   A) Yes: 4
   B) No: 0
2. Which of the following factors contributed to the feeling of immersion, if any, when in the cockpit view?
   A) heads-up display indicators: 4
   B) flight stick and throttle movement: 3
   C) camera shake: 4
   D) audio: 4
   E) movement of the plane: 4
   F) control surface movement: 2

3. Was there enough feedback to feel immersed in the cockpit view?
   A) Yes: 4
   B) No: 0
4. Did you understand the various parts of the heads-up display?
   A) Yes: 4
   B) No: 0
5. How often did you reference the heads-up display information and throttle/flight stick movement in the cockpit?
   A) 1 (Not at all): 0
   B) 2: 0
   C) 3: 0
   D) 4: 0
   E) 5: 1
   F) 6 (All the time): 3
6. Did the heads-up display and throttle/flight stick movement contribute to immersion? Why or why not?
   A) yes because it made me feel like i was actually controlling a place
   B) yes, very sensitive to movement
   C) Yes the heads up display made me feel like I was flying.
   D) Yes
7. When attempting a carrier landing, did you reference the heads-up display information?
   A) Yes: 4
   B) No: 0
8. When attempting a carrier landing, did you reference the moving “meatball” light on the deck of the ship?
   A) Yes: 3
   B) No: 1

9. Did you successfully land the plane?
    A) Yes: 0
    B) No: 4
10. Did the plane feel like a physical object with weight to it? Why or why not?
    A) yes because it felt heavy and that you needed skill to control it
    B) Yes, as it moved it seemed realistic
    C) It did because of the audio and the shaking; and of course when I crashed!
    D) Yes, controls were good.
11. Would you describe the overall experience as an immersive simulation?
    A) Yes: 4
    B) No: 0
12. Additional comments and feedback?
    A) this is a well put together experience, however i am no pilot
    B) Very cool!
    C) This was very detailed and I could tell a lot of work was put in to make the experience as real as possible.

Resulting Observations:

1. Testers felt immersed in the pilot's seat because of the visual and auditory feedback
2. The heads-up display information was not only useful but also contributed largely to immersion
3. Flying felt realistic, as the plane was reported to feel like a physical object because of the realistic physics
4. None of the testers were able to land on the carrier in the time they spent playing despite the usefulness of the HUD and the optical landing system
5. The experience was a successful simulation of flight and was detailed enough to provide immersion

Analysis: Based on the survey responses, the prototype was a complete success in regards to the criteria for success, but had a singular major issue with the gameplay objective. The prototype succeeded in immersing players into the game world, largely due to the detail in the flight model, heads-up display, visual effects, and sound effects, as well as the detail in the carrier landing simulation. The HUD was useful both for flying and attempting a landing, and testers were all able to understand how to use it despite its complexity and lack of experience with aircraft. All of the real physics forces acting on the plane made the plane feel like a physical object in the world with weight to it. The HUD information and the optical landing system were used for attempting carrier landings, meaning they were successful in their function and immersive qualities.

The problem with the system lies in actually landing on the carrier itself. While testers seemed to understand the process, the current controls made it too difficult for them to do it successfully without playing the system for longer and adapting to the controls. There are several ways to correct this. An “arcade style” flight model could be made that reduces the impact of drag forces on the plane and tightens up the controls so they’re not as sensitive, and players could choose between “arcade” or “simulated” flight before starting. The current flight model could also be tweaked to reduce the sensitivity of the flight stick movement related controls to make the plane easier to control and recover from too much drag.

Survey Results:
https://docs.google.com/forms/d/14BQg4bDp33XT87FI1Spo0kI_pPXWIVnNl4wj-Zd6Nto/edit#responses

Post Mortem

Based on the test results and from watching the testers play the game, I can conclude that this system was a resounding success. It succeeded completely in delivering an immersive experience that accurately simulated the flight of an aircraft as well as the procedures and details surrounding a real-life carrier landing. While there are some visual bugs, bugs with the game loop, and it may be too difficult for an inexperienced player to land on the carrier, the system managed to induce players into an altered state where they felt like they were piloting a real fighter jet.

What Worked:

1. The flight model accurately replicated the forces acting on a plane
2. The visuals, sounds, controls, and interface of the plane simulated the real thing accurately and were the primary sources of immersion
3. Flying the plane was easy to understand yet difficult to master

4. The heads-up display accurately reflected its real functions and helped immerse players in the experience
5. Landing the plane was easy to understand despite its complexities due to the accuracy of the HUD
6. Deciding to add the optical landing “meatball” was a wise choice since it added even more authenticity to the experience

What Didn’t Work:

1. The fact that testers never managed to land the plane is troubling from a “game” standpoint. While I didn’t bill this experience as a game when explaining it to testers (instead as a simulation), the objective of landing on the carrier was crucial to the immersion of the experience, and the fact that testers understood how to do it but couldn’t because of the complexity/skill ceiling of the flight model took away from the experience to some degree.
2. I spent a lot of time and energy on this project, mostly because I got really into all of the physics and equipment surrounding the simulation. While this isn’t a bad thing (I had an absolute blast making this), I feel that I put way too much time into some of the smaller details like the meatball. I could’ve used that time to polish up the win state surrounding the landing, which is currently really buggy. Which brings me to my next point…
3. Getting the cables to accurately stretch when the hook collided with them was extremely difficult and didn’t work entirely as I wanted it to in the end. This is partly due to limitations with Unity; there isn’t any sort of “rubber” like system, meaning I had to use the cloth component to make the wires stretch. Additionally, I had to bootleg the slowdown of the plane when it hits the wires due to time constraints. It currently just applies the force of the plane back on itself, but nothing stops it from doing this when the plane halts, causing it to either fly forwards or backwards off of the deck. More time would be needed to get this whole thing working correctly.

What I Learned:

Perhaps my biggest takeaway from the experience of designing this system was that **modeling simulations after their real life counterparts is the core of creating an immersive simulation**. While this may seem like an obvious takeaway (a simulation exists to simulate reality, after all), I never understood the importance of this until actually building a simulation myself. It takes a true understanding of and appreciation for the real thing in order to succeed in making an immersive simulation, and I feel that I conducted the research necessary in order to do so. My second biggest takeaway was that **making an interface part of the game world goes a long way in immersing players into the experience**. Choosing to make a fully diegetic UI that accurately replicated the real thing was perhaps the most immersive part of the experience, and it was a far more effective way of conveying information than placing UI on an overlay. Overall, I learned that creating an immersive experience takes a keen attention to detail and relies heavily on visual and auditory feedback, as well as a clean and unobtrusive interface to relay important information.

Annotated Bibliography

Offworld Industries. *Squad.* Offworld Industries. 15 December 2015. Video Game

Squad is a tactical multiplayer simulation FPS available on Steam in Early Acces. The gameplay revolves around working together with large teams of players divided into 9 man squads to complete objectives and create bases and spawn points in a realistic and immersive simulation setting.

Key takeaways:

- Vehicle immersion created through the heads up display
- First person perspective inside of a vehicle gives a sense of place
- Diegetic UI through the vehicle turret heads up display gives information while keeping immersion intact

The expertly crafted vehicle immersion was the main design influence I took from *Squad*. While the game doesn't feature any planes, the way the game handles the tank gunner perspective by using a realistic depiction of the heads up display is integral to not only providing players with information but also keeping them immersed in the experience. I learned the importance of keeping the interface grounded in the reality of the game world in order to create immersion, which is reflected in the HUD panel and instruments featured in my F/A-18 cockpit as well as the movement of the various control surfaces and input devices.

Harris, Tom. "How Aircraft Carriers Work." HowStuffWorks Science, HowStuffWorks, 28 June 2018, science.howstuffworks.com/aircraft-carrier4.htm.

Page 5 of this article discusses the various parts of aircraft carriers that are designed to assist pilots with carrier landings. The article provides details and specifications about arresting wires, optical landing systems, the 'meatball", and how all of these items work. Diagrams and pictures are provided to give visual reference.

The relevant page of the article begins by explaining how planes need a "tailhook" in order to land on the flight deck of a carrier using the deck's "arresting wires", which slow the plane down instantly when the tailhook snags one of them. The article then discusses how pilots aim for the third arresting wire and how air traffic controllers help them orient themselves to land on the deck. The article concludes with a detailed description of the Fresnel Lens Optical Landing system, specifically how the lights move depending on the pilots orientation to the deck and how the "meatball" signifies that the pilot is on target.

Key takeaways:

- Navy pilots don't just land straight onto the carrier deck, they have to precisely target a wire with a hook on the back of the plane
- The wires can stop a plane moving at 150mph in 2 seconds.
- Pilots push the throttle to "full military power" when the plane hits the deck in case the wire isn't snagged so they can take off again, or "bolter"
- "If the plane is right on target, the pilot will see an amber light, dubbed the "meatball," in line with a row of green lights. If the amber light appears above the green lights, the plane is coming in too high; if the amber light appears below the green lights, the plane is coming in too low. If the plane is coming in way too low, the pilot will see red lights."

This article was the first thing I looked to when I decided I wanted to focus the system around landing on a carrier deck. It provides real world information and metrics that I used when designing the system and interface, as the plane has to be moving around 150mph in order to stop when it hits an arresting wire for example. I learned about some of the science and metrics required to land a plane on a carrier as well as how it looks from a visual standpoint both inside and outside of the cockpit.

Palmer, Grant. "Chapter 10: Airplanes." Physics for Game Programmers, by Grant Palmer, Apress, 2005, pp. 275–319.

Chapter 10 of this book breaks down step by step the various different forces acting on an airplane and how they work, as well as the equations required to find calculate them effectively. Lift, drag, thrust, gravity, air density, and more are discussed at length, providing a detailed overview of the physics behind aircraft.

The chapter begins with an overview of the early days of flight and leads into various terminology about airplanes (wings, ailerons, fuselage, etc). After this the chapter explains the various forces acting on an airplane, what airfoils are and how they generate lift, how engines generate thrust, aerodynamic drag, and stability. The chapter gets in depth about all of the various physics calculations and curves that cause planes to act the way that they do, finishing off with a programming example flight simulation.

Key takeaways:

- Lift, gravity, thrust, and drag are the four main forces acting on an airplane
- When a plane produces enough thrust to counteract drag and enough lift to counteract gravity, it is in balanced flight
- Once lift exceeds gravity, the plane takes off.
- Flaps are used to increase lift for takeoff and landing procedures
- Drag increases as airspeed increases

This book was fundamentally important in the design of the flight simulation part of this system. It helped me understand how airplanes fly and how the various forces present contribute to the flight. It also allowed me to see an example implementation in a game sense that helped me create my flight model. I learned all about flight physics, terminology, how different components work, the four forces acting on a plane, and more from this book.

Ruzicka, Joe. “How To Land A Fighter On An Aircraft Carrier On A Dark And Stormy Night.” The Drive, 19 May 2016, www.thedrive.com/the-war-zone/3559/how-to-land-a-fighter-on-an-aircraft-carrier-on-a-stormy-night.

This article is a hands-on explanation from a navy pilot of the procedures followed during a carrier landing. It is told in a story like form and has several diagrams and videos to visually illustrate what the pilot is describing.

The article begins with a description of the various types of landings, or “CASE”s that can take place depending on the weather, an explanation of the 4 arresting wires and which ones are most optimal to aim for, and the different flight patterns (bolter, tanker, marshall) related to carrier landings. The article then provides details about radio conversations with air traffic control, interface to the pilot about their conditions and location relative to the deck, descending, missing the wire and “boltering”, refueling, coming back around, and finally landing the plane by hitting one of the wires.

Key takeaways:

- Communication between the carrier personnel and pilots are key during a landing
- Various flight patterns are used to keep the pilots on track
- Importance of the optical systems can’t be understated
- Information about flight speeds needed for landing

This article influenced the design of the immersive aspects of my system, mainly the radio audio that plays to help immerse players as well as the optical systems HUD indicators that help players stay on target. I learned about just how much of an involved and dangerous process landing on a carrier can be, and how various types of technology are used to mitigate the risks and help the pilots as much as possible.

Additional Sources

- Ocean effect made using CREST Open Source Ocean Renderer for Unity: https://github.com/huwb/crest-oceanrender
- Terrain, jet particle effects, and throttle sound effect from Unity Standard Assets package