Maseeh College of Engineering and Computer Science

PORTLAND STATE UNIVERSITY

Capstone Project Proposal

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Executive Summary

Portland State University's Department of Electrical and Computer Engineering has partnered with Galois, a leading innovation company in the field of research and development of new technologies, to model and simulate a small-scale F-16.

By the beginning of June 2021, Cam Osborn, Minh Le, Qingchuan Hou, and Christopher Mersman will design a software package that runs parallel with an advanced autopilot, stores data in real-time, and determines an accurate flight dynamics model of an RC F-16. Determining the flight dynamics model will be accomplished by defining flight dynamic variables necessary to model a ducted F-16 model aircraft, testing the flight dynamic model variables, creating an accurate State-Space representation of the model F-16, performing HITL and SITL system testing and validation, and finally, instrumenting the F-16 model to gather real flight data. Furthermore, the final product has stretch goals of performing real flight validation, designing an autopilot to adjust flight characteristics of the F-16 model, which will improve the ease of use of the RC F-16, and finally, performing an autonomous flight.

Product Design Specification

Concept of Operations

The objective of this project is to develop a dynamic model of a scaled-down Radio Controlled F-16 Falcon jet and perform flight simulation as well as a real flight. Galois, the industry sponsor, plans to use models to circumvent the inconvenience of flight testing real aircraft. This project is open-source, so the Cyber Physical System Research Community and some hobbyists can also use the data and information our team collects for flight simulation. It is possible to collect research data by adding other sensors that will not be fitted to our RC F-16. In this project, our team needs to use the supplied Pixhawk software stack to determine the flight dynamics of a small-scale model RC F-16 aircraft to develop trusted flight control software. Based on the model, our team will have stretch goals of creating an autopilot for autonomous flight of the scaled-down F-16.

Stakeholders

Open source: Hobbyists, Cyber Physical System Research Community

Industry Sponsor: Galois, Michal Podhradsky, Matt Clark, Ethan Lew

Project Team: Cam Osborn, Minh Le, Qingchuan Hou, Christopher Mersman

Faculty Advisor: Dr. James McNames

Requirements

To have a successful project, the team will implement the following list into the final project. This list is essential to the capstone sponsor and our team:

- Must identify appropriate flight control variables that need to be observed and recorded during simulation and real flight.
- Must develop a static test plan that describes how to excite the system such that the aerodynamic coefficients may be observed or calculated.
- Must develop a dynamic test plan that describes how to excite the system such that the aerodynamic coefficients may be observed or calculated.
- Must develop a flight test plan that describes how to excite the system such that the aerodynamic coefficients may be observed or calculated.
- Must use the supplied Pixhawk software stack and identify where the particular input variables within the stack can be processed and logged.
- Must instrument F-16 with Pixhawk PX4 for data logging and state estimation.
- Must validate governing system equations and variables through the use of data gathered from flight tests with trained personnel.
- Must perform SITL simulations using JSBSim or Flightgear.
- Must perform HITL simulations with the help of Galois getting the Pixhawk to communicate with JSBSim or Flightgear.
- Must compare scaled-down F-16 model with a real flight test to quantify the accuracy of the model.

The following list is optional. The team will evaluate the following list and implement each as the team sees fit.

- May measure and calculate aerodynamic coefficients and other variables using equations found in the textbook, “Aircraft Control and Simulation” by Brian L Stevens.
- May use a system identification approach instead of the aerodynamic equations found in the textbook, “Aircraft Control and Simulation” by Brian L Stevens.
- May perform real flight validation to compare to simulated flight data.
- May design an autopilot to adjust flight characteristics of the model to assist in real flight.
- May perform an autonomous flight with the model.

Specifications

There are two main parts to this project.

The first part was to create a scaled-down F-16 flight mathematical simulation system to perform the simulation and collect data. In this simulation flight system, they identify the appropriate flight control variables that need to be observed and recorded must be identified at first. These data include, but are not limited to, the scale F-16 model gravity, the power of the generators and the thrust they can provide, and the angles of the individual wings. The aerodynamic coefficients and other variables using equations can be found in the textbook, “Aircraft Control and Simulation” by Brian L Stevens. These coefficients and equations will be used to determine the magnitude and angle of the forces applied to the model aircraft in the simulation. These parameters will be verified in the simulation and record the required data. In this accurate model. The dynamic model needs to be within 15% of the real system. Our team has identified a 15% deviation from the real system as an acceptable performance because of the number of variables our team is working with. Working with a nonlinear state-space equation will be a real challenge, so 15% gives our team room to work with.

The second part is to build and test the accurate F-16 model. During the flight of the aircraft, some flight status information needs to be obtained in real-time. Flight state information includes position/altitude, heading, speed, orientation (attitude), rates of rotation in different directions. Therefore, some sensors must be installed to perform real-time detection. First of all, a GPS needs to be installed to determine the position information of the vehicle. Pixhawk-series controllers include an internal compass. The GPS should be able to obtain the relative ground speed. The aircraft also needs to install a barometer to detect its altitude. A compass and gyroscope are to be installed to obtain the real-time direction of the vehicle. All these sensors used must be built based on the Pixhawk software stack. Our team also needs to test each component individually in a simulated environment.

A larger list of broken down specifications is below.

- The real flight data and HITL simulation must be within 15% of each other while performing the same flight plan.
- The real flight data and SITL simulation must be within 15% of each other while performing the same flight plan.
- The HITL and SITL simulation must be within 15% of each other while performing the same flight plan.
- All real flight data must be stored on the capstone teams’ Github repository.

- All SITL simulation data must be stored on the capstone teams' Github repository.
- All HITL simulation data must be stored on the capstone teams' Github repository.
- The Flight Dynamic Model should account for the added weight of the PX4 and additional sensors.
- The Aerodynamic Coefficients must be estimated or realized within 15% of actual values, through the use of static, dynamic, or flight testing.
- The Input vector must be realized within 15% of actual values, through the use of static, dynamic, or flight testing.
- The State Vector must be estimated or realized within 10% of actual values through the use of static, dynamic, or flight testing.
- The RC F-16 will operate from a 3200–4000mAh 6S 22.2V LiPo flight battery with an EC5™ or IC5® connector.
- The costs for developing the system must not exceed 1.5 times the budget listed in the budget section of the project proposal.
- The Airspeed sensor will have a 1 psi measurement range (roughly up to 100 m/s or 360 km/h or 223 mp/h), with a resolution of 0.0145 m/s, and data delivered at 14 bits from a 24 bit delta-sigma ADC.

Deliverables

- Project Proposal
- Weekly progress reports
- Final report
- ECE Capstone Poster
- Submit separate Test plans for the project; The first will focus on the dynamic model, verifying the accuracy and correctness of the flight coefficients. The second will focus on operational flight checks both in simulation and physical. Verifying the accuracy of the dynamic model with real operation.
- A dynamic model that includes accurate aerodynamic flight coefficients that have passed our Test plans and effectively and accurately simulate real flight of the scaled-down F-16.
- A model F-16 fitted with instruments to record flight data
- The project Github repository contains all deliverables (logs, data, equations, model coefficients, videos, and all other applicable data) not including the physical model.

Initial Product Design

What are you proposing to make?

Our team is proposing to design a mathematical model of a model F-16 for simulation and to fit a model F-16 with instrumentation to gather inflight data to compare against and use in our mathematical model.

How are you going to make it?

Our team will make this by first understanding the equations involved and then creating state-space models that will be used to describe the model F-16 in simulated flight.

What are the big risks? How are you going to answer them quickly?

Deeply understanding the way the state space models are working individually and as a whole to create a realistic model of the F-16. Also, correctly accounting for all the variables involved in the mathematical model to reflect flight. These will be mitigated through our test plans and associated readings on how to model flight.

How much of this do you think you can get done in 5 months?

Our team believes the creation of the simulation model up to the verification and gathering of the flight data is very achievable in 5 months. Our team also believes that the stretch goal of assisted autonomous flight is also achievable in that timeline if the project runs "smoothly".

Our hardware architecture and systems can be seen in the following figures.

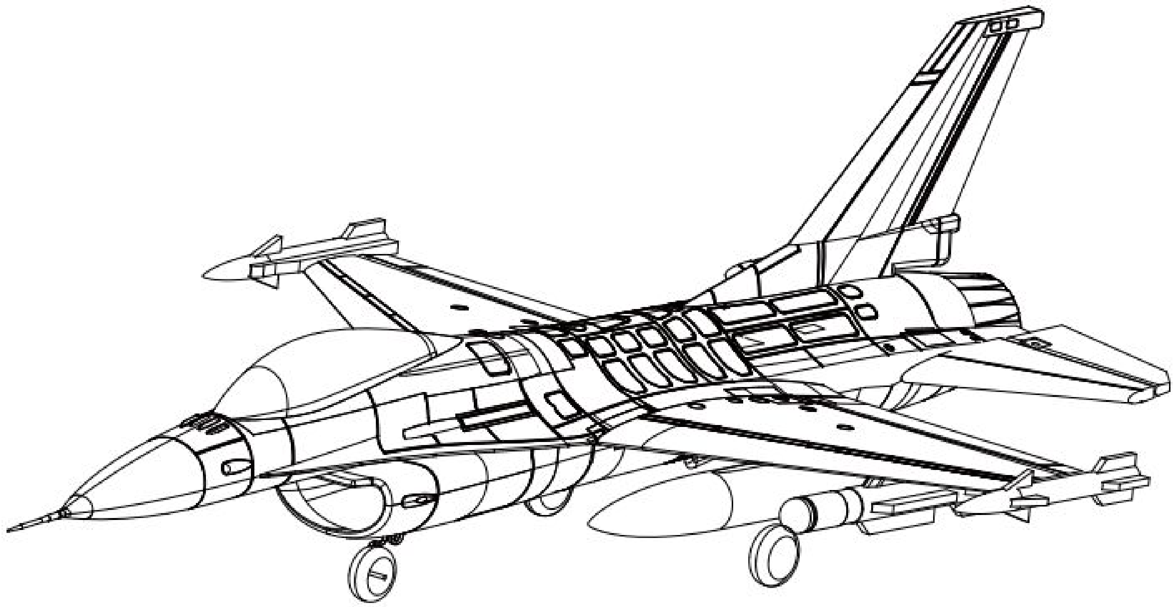

Figure 1: Model F-16 a 64mm ducted fan model

Figure 2: Pixhawk PX4

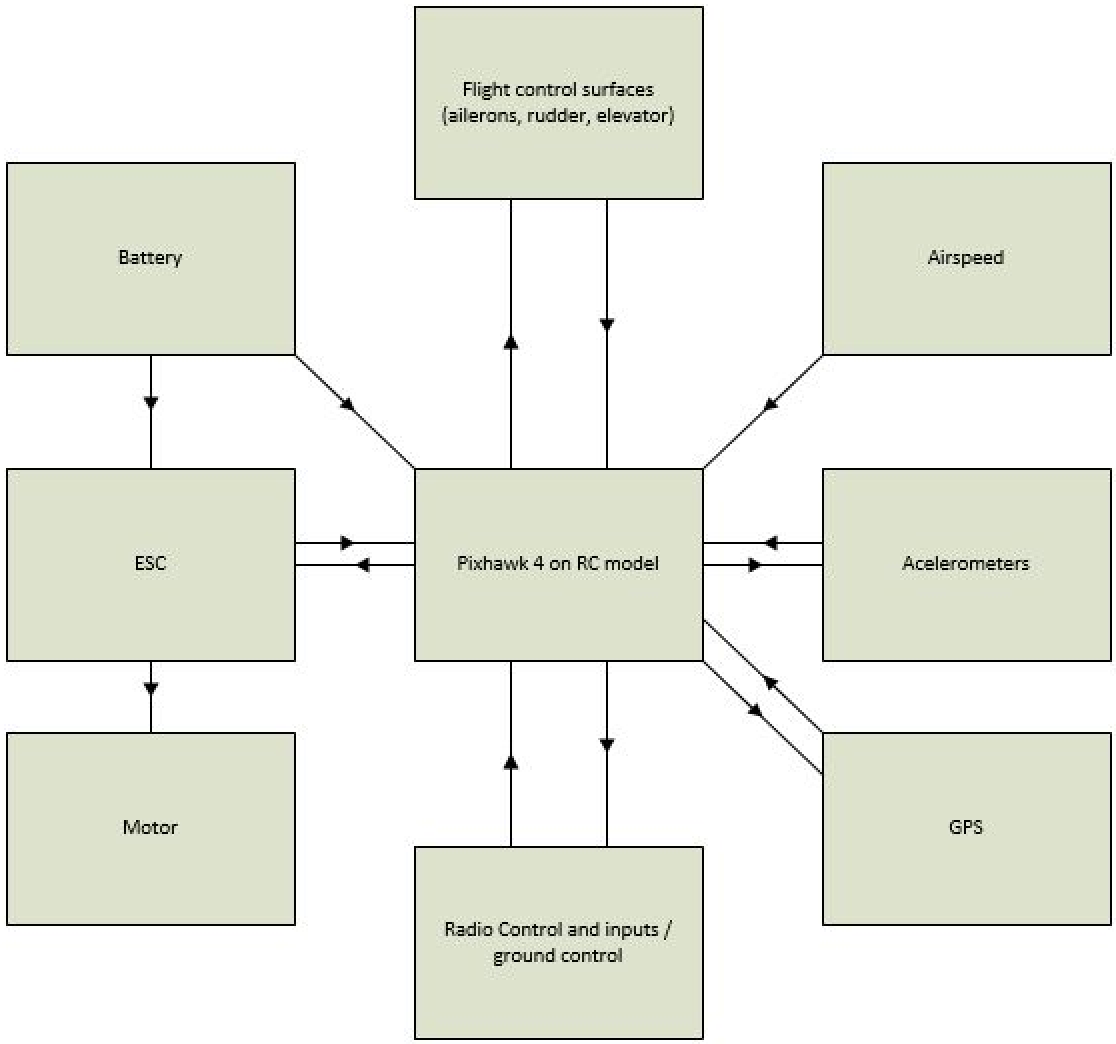

Figure 3: Level 0 block Diagram

Software architecture :

For our software architecture, our team will be using Ground Control and JSBsim to manage our flight data for simulated and actual flight.

Languages and development environments:

Our team will be using Python, with a stretch goal of transitioning to JSBSim.

User interface / experience:

The output data from the model must be presentable and the code well documented. The use and operation of model F-16 will be conducted from the radio controller and ground control environment.

User stories of how the end-user uses your product:

The end-user of our project is our sponsor, Galois and they will be using our collected data and dynamic model as part of the CSAF framework. To be integrated by them after the end of the project.

Other considerations:

Our team will only be considering safety considerations that include operator and observer(s) safety during flight operations.

Back up plans:

1. If the model does not fit the flight data, our team will look at the equations, and ask ourselves why the model doesn't fit. What did our team not account for while designing the model? Our team will take steps to find out why the model doesn't fit and determine what our team can do to help adjust the model to fit the real flight data.
2. If data our team gathers from the PX4 stack is faulty, our team will try to narrow down the causes for the bad data. And attempt to fix or replace the component at fault.
3. Our team will not be operating the RC model primarily, our team will operate the RC model with caution when allowed to do so. If parts break our team will attempt to repair the components and assess on a case by case basis the need to replace the component. Component and RC assembly and storage will primarily be done at Galois.
4. If flight data can't be collected by the RC model during the life of the project a more detailed substitution for the data will be discussed with Galois at the point flight data collection is deemed not viable.

Testing Plans

For our dynamic model to be successful it will need to represent the real flight dynamics of the scaled-down F16, with a variation tolerance of 10%. This will be accomplished by comparing gathered inflight data with simulated data. To test the dynamic model during the life of our project our team will be using Software in the Loop (SITL) testing to verify the correctness of the individual algorithms driving the dynamic model using the aerodynamic coefficients our team will define and refine. Our team will next conduct Hardware in the Loop (HITL) testing to improve the model as a whole system. This stage will have the model simulate communication with associated hardware systems in response to stimulation of input variables. The HITL testing will check the functionality of the dynamic model as a whole under different operating conditions. The dynamic model will then be tested on how it handles simulated flight and its response to maneuvers and various inflight conditions.

The physical F16 model will also need to be tested for functionality along with the associated instrumentation. This will include operating limits of the scaled model such as alerion, rudder, and elevator range limits and thrust provided by the model. Our team will also conduct unit testing on the Pixhawk system to ensure real-time collection of accurate inflight data. Our team will then conduct inflight maneuvers to collect data of normal flight operations and use this data to verify the correctness of our dynamic model. This will most likely be an iterative process that will involve refining the dynamic model through the collection of gathered inflight data.

Project Management Plan

Timeline

Timeline	**Milestones**	
January	Research	
Week 1	Write Project Proposal	
Week 2	Review PDS	
Week 3	Revise PDS	
Week 4	Approve Project Proposal	
February	Software Development	
	Simulation	Instrumentation
Week 1	Develop mathematical equation, model coefficients	3D CAD model, block diagrams
	Develop static test plans	Develop dynamics model of an RC F-16
Week 2	Develop dynamic test plans	
Week 3	Develop flight test plans for validation	
Week 4	Setup & configure Pixhawk	Setup & configure Pixhawk

March	Testing + Collect Data	
	Simulation	Instrumentation
Week 1	Perform Software-in-the-loop simulation	
Week 2	Perform Hardware-in-the-loop simulation	Installation of parts on RC
Week 3	Analyze data for both SITL and HIT	Installation of parts on RC
	Adjust mathematical model	Ground Testing
Week 4	Second phase test to validate the accuracy of the model	Ground Testing
April	Testing + Collect Data	
	Simulation	Instrumentation
Week 1	Analyze data and adjust the model	Operations pre-flight checks w/ Pixhawk
Week 2	Conduct tests	Flight testing and collect data
Week 3	Deliver fitted model within the goal	Analyze data
Week 4	Analyze real flight data with the simulated model	Flight testing and collect data
May	Flight testing & tuning the model	
	Simulation	Instrumentation
Week 1	Adjust coefficients, equations, and the mathematical model	Analyze real flight data and compare with the simulated model
		Adjust the model
	Simulate SITL & HITL	Tune the model
Week 2	Analyze/Compare data	Conduct flight testing and validate
Week 3	Update/Adjust model	Adjust/Tune
	Simulate SITL & HITL	Conduct flight testing
Week 4	Finalize model	Deliver final physical model
June		
Week 1	Review & Final Report	
	Poster and Presentation	

	Design an autopilot to adjust flight characteristics of the F-16 model	Measure and calculate aerodynamic coefficients and other variables
Week 2	Design an autopilot to adjust flight characteristics of the F-16 model	Perform an autonomous flight with the model
Week 3		

Table 1: Major Tasks

Budget and Resources

Hardware	Price ($)	Link
F-16 Thunderbirds 70mm EDF BNF Basic with AS3X and SAFE Select	$299.99	https://www.horizonhobby.com/product/f-16-thunderbirds-70mm-edf-bnf-basic-with-as3x-and-safe-select/EFL78500.html
Battery: SPMX32006S30	$74.99	Battery
Spektrum Smart S1100 AC Charger 1x100W: SPMXC1080	$89.99	Charger
SPMXCA507 Adapter: IC3 Battery / IC5 Device	$10.99	Adapter
Holybro Pixhawk 4 autopilot flight controller with GPS	$211	https://shop.holybro.com/pixhawk-4beta-launch_p1089.html
Digital Differential Airspeed Sensor Kit	70$	https://store-drotek.com/793-digital-differential-airspeed-sensor-kit-.html
Softwares		
FlightGear	Open-source	
JSBSim	Open-source	https://github.com/JSBSim-Team/jsbsim
QGroundControl	Open-source	http://qgroundcontrol.com/

Optional
Sensors: airspeed, distance, tachometers, optical flow
Data/Telemetry Radios, Radio Control, Battery charger, safety switch

Table 2: Budget and Resources

Team and Development Process

Our team will follow the basic Agile Methodology Development Process, which starts from analyzing requirements and developing specifications for our product, then design test plans for both static and dynamic tests. The next step is to perform a simulation to collect data, verify our design's accuracy for evaluation and revise the design model. By having a combination of electrical and computer engineers, our team is capable of working in both software and hardware designs with sufficient skills. The milestones of the project are to develop a dynamic model of an RC F-16 fighting falcon. Once the final schedule and PDS are approved, Our team will decide to split each team member into different tasks according to our skills to complete the project. Our team decided to use GitHub, Trello, and google drive for our standard collaboration tools, and use zoom, Gmail, discord for communication.