Mechatronic Orrery

Politics Shaping Technological Innovation and the Defense Industry: An Analysis of the Joint Strike Fighter Program

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By
Bjorn Bergloff

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Technical Team Members:

Samuel Montante
Sarah Hemler
George Ardura
Samuel Shepphard
James Pace

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

MC Forelle, Department of Engineering and Society

Gavin Garner, Department of Mechanical and Aerospace Engineering

Introduction

Mechatronics is defined as the "integration of mechanical engineering with electronics, computer systems, and advanced controls to design, construct, and operate products and processes" (Kopacek, 2006). Mechatronics can allow one to create incredible systems, capable of performing complex tasks. For example, advanced fighter aircraft utilize fly-by-wire (FWB) mechatronic systems. Fly-by-wire systems can be defined as "semi-automatic, computer-regulated aircraft flight control systems that replace mechanical flight controls with an electronic interface" ("Fly-By-Wire Systems," 2022). These sophisticated flight control systems are able to convert user input into electric signals before the actuation of moving parts and correct overcompensatory actions, resulting in smoother flight. However, mechatronic applications aren't strictly limited to extremely advanced and complex systems. Another neat application of mechatronics is kinetic art, typically taking the form of a moving sculpture. My technical project is creating a mechatronic orrery. This orrery has several degrees of freedom, all moving together to create a beautiful piece of art. The details of my technical project will be elaborated upon in the following section. Mechatronic applications can range from harmless, beautiful kinetic art to advanced aircraft systems and defense technology. The latter is a prime example of "an inherently political artifact" (Winner 1980). In particular, my STS thesis will examine the F-35 Lightning II strike fighter aircraft, identifying ways in which it is an inherently political artifact.

The F-35 Joint Strike Fighter (JSF) program is the largest procurement program in the history of the Department of Defense in terms of total cost. Its goal is to develop three different versions of the F-35 Lightning II strike fighter aircraft for the United States Airforce, Marines, and Navy (Gertler 2022). A strike fighter aircraft is intended to operate as both an attack aircraft (air-to-ground combat) and an air superiority aircraft (air-to-air combat) ("Strike Fighter," n.d.).

The F-35 Lightning II aircraft is a fifth-generation fighter. The classification of fifth-generation indicates that the aircraft includes major technologies developed during the first part of the 21^{st} century, namely “multi-spectral low observable design features such as radar, infrared sensors, and visual situational awareness tools, along with self-protection and radar jamming capabilities that delay or deny enemy systems the ability to detect, track, and engage the aircraft” (Hood 2017). The JSF program was originally meant to develop an affordable fifth-generation fighter aircraft with very similar versions for the Air Force and Navy. However, in 1994 Congress required that Marine Corps efforts to develop a replacement of the AV-8B Harrier aircraft be merged with the Air Force/Navy program. The Marine Corps and Air Force/Navy programs were merged with the intention of avoiding high costs of developing, procuring, operating, and supporting three separate tactical aircraft designs (Gertler 2022). Eight other nations are cost-sharing partners in this program with the United States: The United Kingdom, Italy, The Netherlands, Canada, Norway, Denmark, Australia, and Turkey (Pike 2022).

The JSF program is an incredibly ambitious program and has faced many problems throughout its lifetime. The complexity of developing three versions of the F-35 to meet different operational requirements created technical challenges, resulting in ballooned costs and longer development time. The program began in 1993 and was scheduled to be completed in 2013; however, this wasn’t the case. The first F-35B (Marine Corps version) entered service in July 2015, followed by the F-35A (Air Force version) in August 2016 and the F-35C (Navy version) in February 2019 (Gertler 2022). The JSF program has drawn much criticism over the years due to its delays and continually increasing costs, leading to questions as to whether the program was a good use of federal funding. Analysis of the complex network of actors invested in the development of this inherently political artifact will shed light on the case for the development of the program and the challenges it faced throughout its lifetime.

Mechatronic Orrery: An Artistic Take on the Motion of the Earth and Moon

Orreries are mechanical models of the solar system that represent the motion of the planets and their respective moons (Cooke, n.d.). For a traditional mechanical orrery, a hand-crank is turned, showing the relative speeds and positions of the planets and their moons around the sun. Traditional orreries are created with complex gear ratios and cantilever arms stemming from concentric shafts (see Figure 1). One limitation to this traditional mechanical design is that dates are not prescribed as the model rotates, meaning that you only get a sense of the planets' positions and speeds, not other phenomena. Traditional orreries will also lose accuracy over time due to imperfect gear ratios.

Figure 1. *Note.* A typical traditional orrery, making use of complex gear systems and lever arms. Reprinted from The Orrery, In *The Observer*, 2019, Retrieved October 27, 2022, from https://brazosvalleyastronomyclub.org/newsletters/summer-2019/orrery.html. Copyright 2019 by Derek & Timothy Staines.

My group intends to create a mechatronic orrery, improving upon the functionality of traditional mechanical orreries while simultaneously creating an artistic display. The purpose of creating this mechatronic orrery is to demonstrate mechatronics in action and inform people about the driving force of seasons and the lunar cycle. Given our time and budgetary constraints, the final design will consist of only the sun, the earth, and our moon. The sun, earth, and moon will be more artistic rather than an accurate representation due to space constraints and the intended effect of our display. Design of the components needed to be assembled into a working mechatronic orrery will primarily be done in SolidWorks. SolidWorks is a computer aided design (CAD) and analysis software, allowing us to design individual 3D parts and assemble these parts into a full system. Our project will employ two types of rapid prototyping that are available to mechanical engineering students: 3D printing and laser cutting. 3D printing is an additive process where an object is created by laying down successive layers of material until the object is created. Extremely complex geometries can be sliced into thin layers and quickly built from the bottom up (Roberson, 2021). Laser cutting is a fabrication process that, “uses a thin, focused, laser beam to cut and etch materials into custom designs, patterns, and shapes as specified by a designer” (Obudho 2019). Using these methods allows us to quickly build parts with complex geometries and identify where changes must be made for the next iteration of the design.

Traditional orreries, while breathtaking, reflect old-school mechanical engineering principles. With the emergence of cheaper electronic components, most notably microcontrollers, over the past couple of decades, antique mechanisms are increasingly being replaced by mechatronic systems. Mechatronic systems improve upon antique mechanisms by simplifying the creation of complex mechanical motions. Our mechatronic orrery will allow us to improve upon antique orrery designs by using electric motors instead of a hand crank and implementing user input. The user will input a date, and the orrery will display the position of the earth and moon in their orbits on that date. This can only be accomplished using servo motors, which use a closed-loop control system to "allow for precise control in terms of angular position, acceleration, and velocity" (Lavaa, 2021). Homing the servo motors with inductive proximity sensors at known locations within the assembly provides them with their absolute position relative to that home position. ("Homing," 2021). Using a servo system with an external homing mechanism will allow the mechatronic orrery to be more accurate than a traditional orrery and remain accurate over a long period of time. Precise motor control that is required to operate our mechatronic orrery is also required in many of the systems within the F-35 Lightning II strike fighter. Further investigation of systems incorporated into the F-35 Lightning II will reveal actors invested in the development of the aircraft.

Actor-Networks Surrounding the Joint Strike Fighter Program

My analysis of the Joint Strike Fighter program will be carried out through the lense of Actor-Network Theory (ANT), with reference to other notable literature within the field of science, technology & society (STS). ANT is notoriously difficult to define since everything is both an actor and a network. ANT primarily focuses on how associations between different actors get proposed, accepted, and rejected. Additionally, Cressman (2009) argues that power within a network is an effect performed by other actors and isn't a permanent condition.

One common critique that ANT faces is that ANT is often a fluid and chaotic means of analysis. However, ANT provides a research trajectory that can reveal complexities and contingencies that are often overlooked, deeming it useful in analysis of large networks (Cressman 2009). Another critique of ANT is that it ascribes agency to non-living things. This, however, I see as perfectly reasonable. Pinch and Bijiker (1984) argue that technology does not determine human action, but that rather, human action shapes technology. This is the basis for the Social Construction of Technology (SCOT) framework. I agree that human action shapes technology. However, once created, technologies can also have agency of their own, sometimes performing in manners unintended by the designers. This is especially true today, with microcontrollers acting as the brain of many technologies and essentially breathing life into them. Because of this, I don't see fault in ascribing agency to nonhuman actors.

There are hundreds of actors, both human and nonhuman, making up the network that led to the creation of the Joint Strike Fighter Program. A good place to start identifying actors is to look at the case for the creation of new fifth-generation and Next-Generation Air Dominance (NGAD) airpower. Deptula, Stutzriem, and Penney (2019) cite five main reasons for the development of the F-35 aircraft: outdated inventory, threat environment, stealth, survivability, and dominance. An outdated inventory of fighter jets potentially puts the United States and its allies at risk. Oppressive regimes such as China, Russia, and North Korea continue to innovate and develop advanced military technologies to rival those of the United States. This forces the United States' hand in creating new fifth-generation and NGAD airpower to keep the upper hand in air-to-ground and air-to-air superiority. Air superiority requires exceptional stealth capabilities and survivability. Both have gotten much better with the technology created in the past couple of decades. Looking at the case for NGAD and fifth-generation fighters has identified the following actors relevant to the creation of the JSF program: The US government, allied nations, enemy nations, outdated fourth-generation fighters, fifth-generation fighters, and US defense contractors.

The United States government must rely on US defense contractors to develop the technology that they need to keep up with hostile nations. Large defense procurement programs like the JSF program are often negotiated as cost-plus-fixed-fee contracts. These contracts offer "cost-reimbursement" to the contractor for research, development, and testing as well as "a negotiated fee that is fixed at the inception of the contract" ("16.306 Cost-plus-fixed-fee contracts," 2022). This kind of contract helps to mitigate risk for contractors but doesn't necessarily incentivize cost mitigation and could be a reason for the extremely high cost of the JSF program. US defense contractors are at the very heart of this network and will be further examined in my STS thesis.

Another effective method of identifying actors is looking at what role the F-35 will play and how its script plays out. Latour (1992) argues that designers are uniquely capable of how to delegate things, and whether to delegate to humans, to words or symbols, or to nonhumans. Given this, engineers within defense contractors are incredibly important actors since they are contracted to design and manufacture the F-35 and its supporting systems. One hot topic within the aerospace industry that I thought would be incorporated into the design of the F-35 is higher fuel efficiency. Interestingly, fuel efficiency isn't a "dominant design requirement" due to "the unique requirements for speed and maneuverability for military aircraft" (Waitz et al., n.d.). Because of this, environmental concerns aren't considered in the script of the F-35. The designers of the F-35 delegated tasks to both computer controlled systems and pilots, so I will identify certain subsystems of the aircraft as nonhuman actors. These nonhuman actors prescribe behaviors of the human actors. For example, fly-by-wire computer control allows pilots to manuever confidently knowing that the control surfaces with adjust to keep the aircraft stable. Complicated systems like this are also actors in that it takes lots of time and money to develop them, so they are partially responsible for the technical challenges that increased the cost and development time of the JSF program.

Other significant events within the timeline of the F-35's development can also serve to identify more specific groups acting within large organizations. For example, the F-35 program appeared "to be in a state of suspended development, with little progress made in 2021 toward improving its lackluster performance" (Grazier, 2022). The Pentagon's Director, Operational Test & Evaluation (DOT&E) concealed many key details of the F-35's poor performance. Officials often attempt to conceal embarrassing details like this by labeling the information as "controlled unclassified" (Grazier, 2022). This example of a group within the Department of Defense (DoD) trying to control important information that would likely affect public view of the program. In my STS thesis, I will provide more examples of significant events that identify more specifically who the key actors are and map out the connections between these actors within the Joint Strike Fighter network.

Research Question and Methods

My thesis will ask the following question: why was the development of a fifth-generation fighter necessary, and how did political forces drive the creation of the Joint Strike Fighter program and shape it throughout its lifetime? I will research how foreign threats and politics resulted in the creation of the JSF program in the first place and assess whether or not Congress lacked vision in recognizing the complexity inherent in combining different operational needs into one common aircraft. The JSF program, by nature, was a politically motivated endeavor and a prime example of political forces driving the development of advanced technologies. It is important to analyze the relationships of actors within the JSF network to identify the cause of the astronomical price tag and development time of the F-35. These problems can then be avoided in the development of future procurement programs.

I will find answers to my research question by reading articles published throughout the lifetime of the JSF program that outline the formation of the program, the need for it, and the challenges faced. There are also numerous public reports on the JSF program. One source in particular I am using is a Congressional Research Service report prepared for members and committees of congress, containing up-to-date, accurate information. Information gathered from my reading will serve as background information and give insight into complex nature of the JSF actor-network. Another useful resource that I will use is interviewing my father. He is an active-duty captain in the navy who is approaching 30 years of service. He has valuable information on the way that the Navy and Department of Defense operate, as well as knowledge of foreign affairs and threats that face NATO.

Conclusion

The defense industry is often the driving force of technological innovation within the United States and around the world. Innovation driven through national defense efforts are, by their very nature, political. The development of the F-35 with the Joint Strike Fighter Program is a perfect example of this. My analysis of the JSF program will expose complexities within the political network that created the program and are responsible for the inefficiencies that occurred during its lifetime. I hope to also expose the reality that high-authority figures within the military-industrial complex welcome huge, politically motivated procurement programs like the JSF program; the consequence of this being long, drawn-out programs that waste tax dollars. The analysis will also emphasize the importance of calculated decision making on behalf of Congress in the creation of future procurement programs, identifying faults in their thought process as a result of outside political pressure, whether that be domestic (national security, defense industry ties, etc.) or foreign (international security, needs of ally nations, etc.). The findings of this paper would hopefully serve to enlighten Congresspeople of the inner workings of the military-industrial complex and help them make good decisions when greenlighting and overseeing large procurement programs.

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