Electrical Discharge Machining on Aluminum Workpiece Sheets
(Technical Project)

The Impacts of CHIPS Act Investments on Domestic Semiconductor Supply Restoration and Electronic Infrastructure Sustainability
(STS Project)

A Thesis Prospectus
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Bachelor of Science in Electrical Engineering

By
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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.

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Introduction

A shortage in the supply of semiconductor chips obtained by the United States has occurred upon the country's emergence from quarantine back into normality. This shortage has formed as a result of foreign-manufacturing impairments created by the COVID-19 pandemic, political tensions arising between the US and China, and a lack of semiconductor-fabrication (fab) material directly available to the US. The World Semiconductor Trade Statistics (WSTS) Corporation reports that the average quarterly revenue for semiconductor trade within the Americas region of the world declined from approximately $35.3 billion in 2022, to $27.4 billion in 2023. Furthermore, the revenue from the most recent (third) quarter of 2023 lies at a grim value of $22.2 billion. This recent low stands beneath even the quarterly average of 2018 that predated the pandemic (Historical Billings Report, n.d.).

In response to this steepening decline, The US has passed The Creating Helpful Incentives for Producing Semiconductors (CHIPS) Act. This legislation invests 52.7 billion dollars of newly devoted, federal money into the endeavor of manufacturing semiconductor-chips domestically. (Moeller et al., 2022) The reinvestment endeavor encompasses not only the actual construction of integrated circuits (ICs) into chips, but also the Research and Development (R & D) of microelectronics in relating areas. Some of these areas include production equipment, process metrology, design and testing, emerging technologies compatibility, energy usage, and establishing "end-to-end wafer-level and die-level prototyping." (Moeller et al., 2022) The CHIPS Act is aimed to restimulate the US's semiconductor industry, which has faded in domestic production over the last three decades. America can neither import a sufficient amount of chips, nor manufacture fabs to make chips at an adequate capacity.

Accordingly, it is important for the US to invest in restoring its supply and revenue of semiconductors. If intervention is not taken in the matter of this shortage, then the US will not be able to sustain its electronic technological-infrastructure. My technical project will address the application of chip integration into an electromechanical, manufacturing machine. The project will use the machine prototype, designed for electrical discharge machining (EDM), to carry out a beneficial function for the manufacturing of small scale, aeronautical rocket-frames. Relatedly, my Science, Technology and Society (STS) project seeks to examine the impact of The Chips Act on the US's domestic shortage in semiconductor supply, and the shortage's looming consequences. As the EDM process is directed by a microcontroller board, my technical project is connectedly enabled by The Chips Act scrutinized within the STS project. I propose to stabilize the shortage situation by assessing the effectiveness of The Chips Act on remedying the US's short term, and long term supply difficulty in semiconductor obtainment. By developing an EDM prototype, I aim to grasp the significance of how important semiconductor supply is to American productivity and progress.

Technical Topic

The EDM Machine arcs and erodes a channel through an aluminum workpiece so that coolant can run through the frames of rockets. This arcing is carried out by placing the workpiece in between a pair of positive and negative, electrode terminals and applying an electrical voltage to the positive terminal end. When this voltage is applied, electron charge-carriers accumulate on the negative terminal and form electrical potential on its end. After the terminal has charged with enough electrical potential-energy that the electrons are able to jump across the terminals' gap distance, an electrical discharge arcs across the terminals and through the workpiece. The arcing of these charged electrons into the workpiece causes the piece material to undergo sublimation at a crystalline level of its physical structuring, and subsequently deposition back into byproduct particles. A channel deepens within the material at the point of arc contact as an outcome of this electrical activity. My team's machine consists of a "wet" design, where the terminals are submerged within a dielectric fluid of distilled water. This dielectric fluid increases the energy required to accumulate on the negative terminal in order for the electron charges to cross the gap medium. In turn, the electric field across the terminals strengthens which increases the drift velocity of the arcing electrons. This increase enhances the collision impulse of the electrons into the workpiece, strengthening and quickening the channel driving. (Kuriachen et al., 2022)

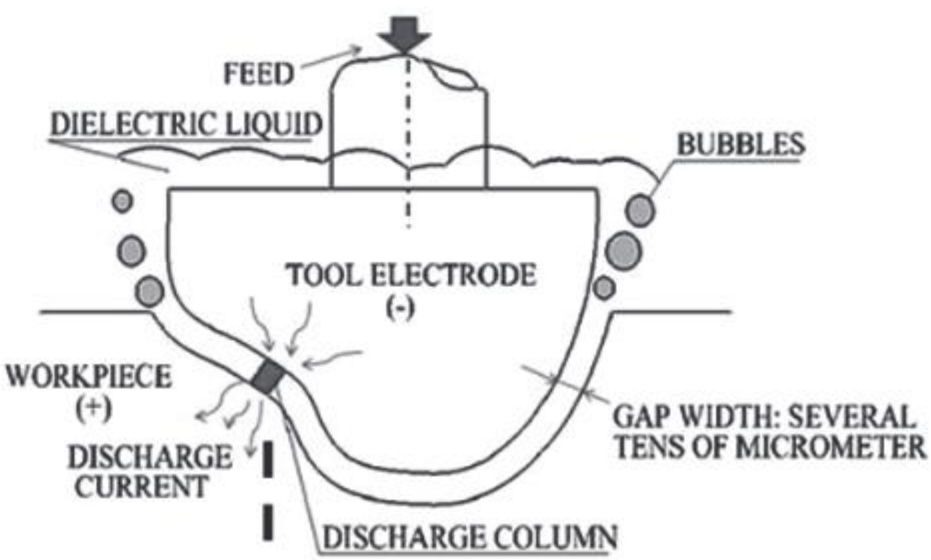

Figure 1: Zoomed Image of EDM process in proximity to terminals gap (Kuriachen et al., 2022)

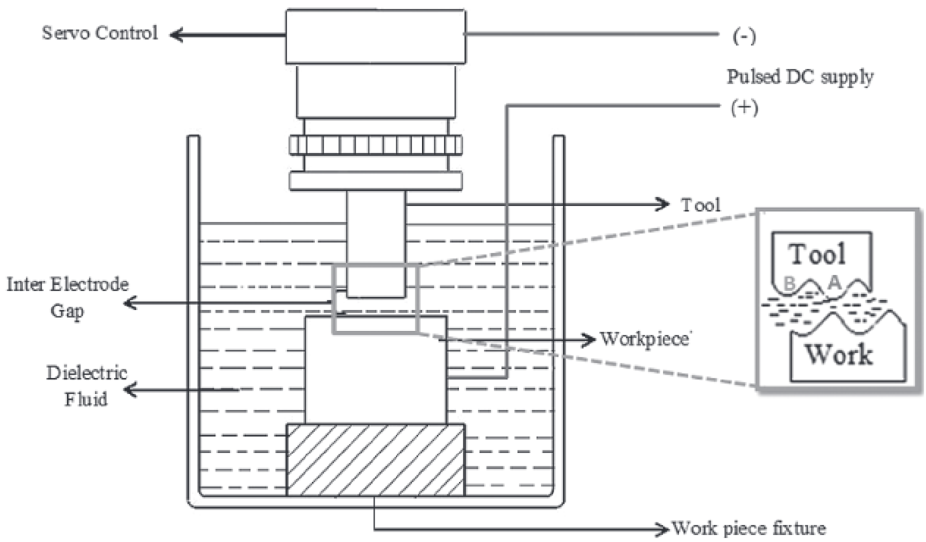

Figure 2: Diagram of "Wet" EDM Process Configuration within Fluid-medium Container

(Kuriachen et al., 2022)

My team, known as The Cathode Blades, aims to develop a nonindustrial, cost-efficient model of a Wet EDM machine by using cheap material and moderate Voltages to arc coolant channels through small-scale aeronautical frames in acceptable time lengths.

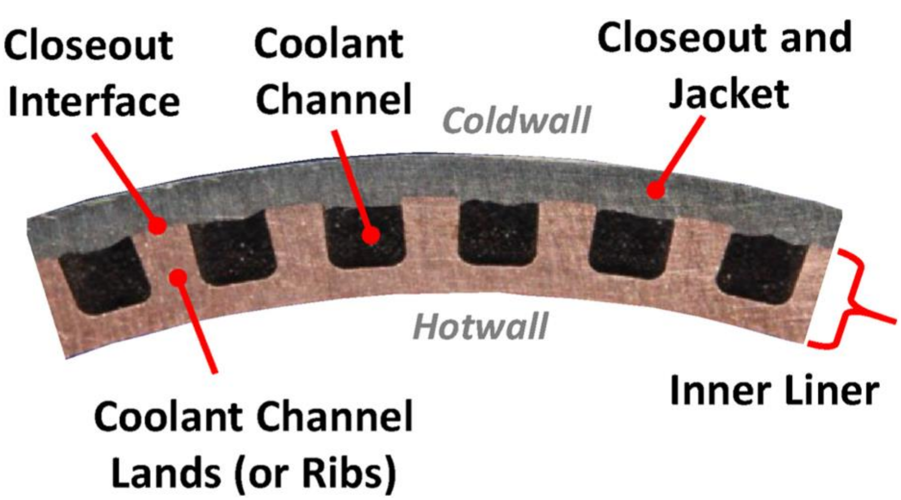

Figure 3: Horizontal Cross-Section of a Nozzle Body's Interior

We will use block diagrams, flowcharts, and multimeter readings to safely and sufficiently test our machine prototype. The undesirable situation that my technical project actively works to prevent is not only the burn destruction of small scale rocket-frames, but also the alteration of a workpiece's physical properties in the process of machining. By circumventing the entire workpiece from undergoing heat treatment to form a channel within the rocket frame, my team's EDM machine enables users to avoid harmful changes to the workpiece material's physical composition.

The coolant channels within the nozzle walls of a liquid-propelled, aeronautical rocket are subject to humungous temperatures and pressures during the process of rocket travel. These conditions place heavy stress upon the structure of the channel walls. In order for the channel structure to withstand this stress, a sturdy channel-frame must be manufactured. Intricate and precise manufacturing techniques, such as EDM, are required to form an internal channel with this necessary level of sturdiness. (Gradl & Protz, 2020) If the coolant channels in the nozzle of a liquid-propelled rocket aren't manufactured with a sufficient level of structural integrity, then they will deform under heat and pressure. Deformation in the coolant channels of a rocket impede coolant from reaching areas of the rocket's nozzle frame, which need to be cooled against overheating. As this overheating occurs, the lifespan of the rocket engine's combustion chamber substantially drops, shortening the lifecycle of the rocket's engine. Transitively, a nozzle's coolant-channel disfunction ultimately leads a rocket to malfunction, die out, and fail. (Marek Fassin et al., 2016) Therefore, the consequences failing to address the problem of adequate channel manufacturing are product deterioration, a loss of supplied energy, and a failed expenditure of human capital in product development.

The reason to think that my team's approach will work is that the EDM process has, previously, been successfully implemented by machinists. (Kuriachen, 2022) Moreover, the fundamentals of electricity and magnetism (E & M), classical mechanics, and fluid dynamics all indicate that it is feasible to develop an EDM prototype on a small scale. The main challenges that my group will face involve designing and developing a functional circuit board, along with achieving a consistent pulse cycle of electrical discharge. This pulse cycle needs to stay within the safety ratings of the board's electrical components. In conjunction, the pulse cycle must be capable of maintaining its magnitude over repeated cycles, for a long duration of time. I anticipate that the deliverable of my technical work will be an operable, effective, and cost-efficient EDM machine. This prototype will be capable of channeling holes through thin workpieces. Its primary application will be to manufacture coolant channels in small-scale frames of aeronautical rockets.

STS Topic

The US's fading in the domestic manufacturing of semiconductors, previously mentioned in the introduction of this Prospectus, can be explained with recent, historical context. This fading has resulted from the American exporting of semiconductor-chip, fabrication materials (fabs) to East Asian countries. Between 1990 and 2020, the percentage of US chips manufactured in domestic factories shrunk to less than a third of its starting value. (Blum et. Al., 2021) The COVID-19 pandemic, at the beginning of the 2020s decade, then severely disrupted the global supply chain of semiconductors. Shutdowns of "chip manufacturing plants," commonly known as foundries, occurred across the entire world as a consequence of “lockdown” quarantining. These halts in manufacturing activity enormously diminished “semiconductors production and inventory,” substantially contributing to the present shortage of chip supply to the US. (Mohammad et al., 2022) Now that the US has exported the bulk of their fab manufacturing to foreign countries, and the COVID-19 pandemic has enlarged a shortage in the country’s chip supply, the US has been left facing harsh difficulty in attaining chips needed for its electronic and technological infrastructure.

The specific uncertainty that my STS research will attempt to resolve is understanding the extent to which The CHIPS Act will aid America in restoring the country’s semiconductor supply, and reattaining a sustainable source of semiconductor materials. Unsustainability will reduce the US’s aforementioned infrastructure to a progressive and consequential standstill. The beginning of this reduction has already been indicated in major American companies. As a result of the shortage in chips supply, Apple lost a value around the range of three to four billion dollars in sales money during the second quarter of 2021. (Voas et al., 2021) Ford Motor Company lost two and a half billion dollars in earnings, over that same whole year, due to that same result. (Blum et al., 2021) Both of these massive companies could not sell to consumers because they did not have enough chips to build their products. Beyond slowing current technological distribution, nonintervention in the US semiconductor shortage will also prevent the country from branching into emerging technologies. Internet of Things (IoT) components need minimal chip dimensions, in order to electronically embed into tiny devices. Nonetheless, IoT components must retain the capability of operating at a power level that is sufficient for proper functionality. (*IEEE IRDS*^{TM}, n.d.) These two conditions for IoT components necessitate maximal power efficiency within IoT semiconductor chips. As minimal dimension-length and maximal power-efficiency form the direction of advancement in semiconductor technology, only the most modern chips are compatible for the development of IoT. (Blum et al., 2021) Similar power and compactness requirements exist for artificial intelligence (AI) functioning. Since the US does not currently have an adequate supply of fabs domestically or internationally to support the expansion of these emerging technologies, the country is consequentially hindered from growing and progressing its electronic technological-infrastructure. (Mohammad et al., 2022)

The present standstill progression, and emergence impediment upon the US's electronic infrastructure, will make America increasingly dependent upon foreign nations for chip supplies. One of these nations, that is a prominent leader in fab manufacturing, is America's adversary China. (Wenhan, 2022) In recent years, this eastern country has been conducting unethical surveillance upon American land, stealing privately-owned data from American entities, and closely threatening American aircrafts with their fighter jets. These behaviors foretell that the US will be extensively subject to endure transgressions from China, as a consequence of elevated dependency upon foreign nations for chip supplies, if domestic intervention in the chip shortage fails to take place.

My work for this project will build on the STS research of Tench Coxe and Langdon Winner utilizing the conceptual structuring of Technological Determinism. Coxe's "technocratic perspective" on mechanical manufacturing will be used to gauge The Chips Act's short-term effectiveness in preventing both the second and third of the previously mentioned consequences, and restoring the US's supply of semiconductors. Inversely, Winner's determinist writings will be used to analyze The Chips Act's long-term effectiveness in regaining source sustainability, and establishing supply consistency for semiconductor fabs and chips. (Marx & Smith, 1994) His "stance" on technological determinism will also be utilized to assess the extent to which the implementations of The Chips Act produce outcomes which are aligned with democratic principles of American society. This assessment is important to avoiding the firstly mentioned consequence, because US workers and consumers may reject capitalizing upon the federal investment, if the money is converted into something that they deem counter to democratic ideals. A rejection of The Chips Act's implementations for this reason would serve to recontinue the present shortage-conflict, and ultimately lead to the consequential infrastructure-standstill. Alongside Technological Determinism, the STS concept of Technonationalism will be used to understand The Chips Act's effectiveness in both the short and long terms. My project will utilize this concept's "innovative approach" to examine how well The Chips Act performs, in reestablishing the US's economic sustainability, by restoring America's chip supply-chain. Moreover, the project will utilize this concept's "strategic approach" to evaluate The Chips Act's impact on the US's international fending, against foreign adversaries like China. (Park, 2023)

I will face two, key challenges in completing my STS research. The first challenge is going to involve acquiring source-material which will reveal indications that are insightful enough to serve as a factual basis for establishing my project's main points. This acquisition will prove challenging because The Chips Act was only passed within the last few years. As such, there are predictions and projections that have been made about the act, but not much data on its actual impacts at this time. This situation may change in upcoming months, when companies and government agencies release their quarterly reports. The second challenge regards forming coherent major-arguments from the findings of my research. Since America's chip supply-chain, and its significant impacts, encompass so many different subjects, the collective topic holds many different aspects to investigate. My diverse findings, from these different aspects, will encumber the discernment of reference-material connections, when constructing valid arguments. Lastly, I anticipate that my deliverable will be an evaluative determination of The Chips Act's effectiveness in restoring America's chip supply-chain, redeveloping economic sustainability in America's electronic-infrastructure, and deflecting America away from consequences linked to the country's domestic chip-shortage. This determination will be based upon solid arguments, which will be derived from an enrichment of factual information that is reputable and current.

Conclusion

The anticipated deliverable of my technical work is a functional, small-scale, and affordable EDM machine that can channel holes through thin aluminum workpieces. My STS work will address a foundational piece of the circuitry within this machine prototype. The anticipated deliverable of my STS research will be an evaluation of The Chips Act's effectiveness in the restoration of America's chip supply-chain, electronic-infrastructure sustainability, and evasions of negatively-related future-consequences. This collective project matters because, in order to navigate an appropriate course of actions for this shortage conflict, and reach the best resolution for the US, actors hampered by the shortage need to recognize that shortage's extensive impact.

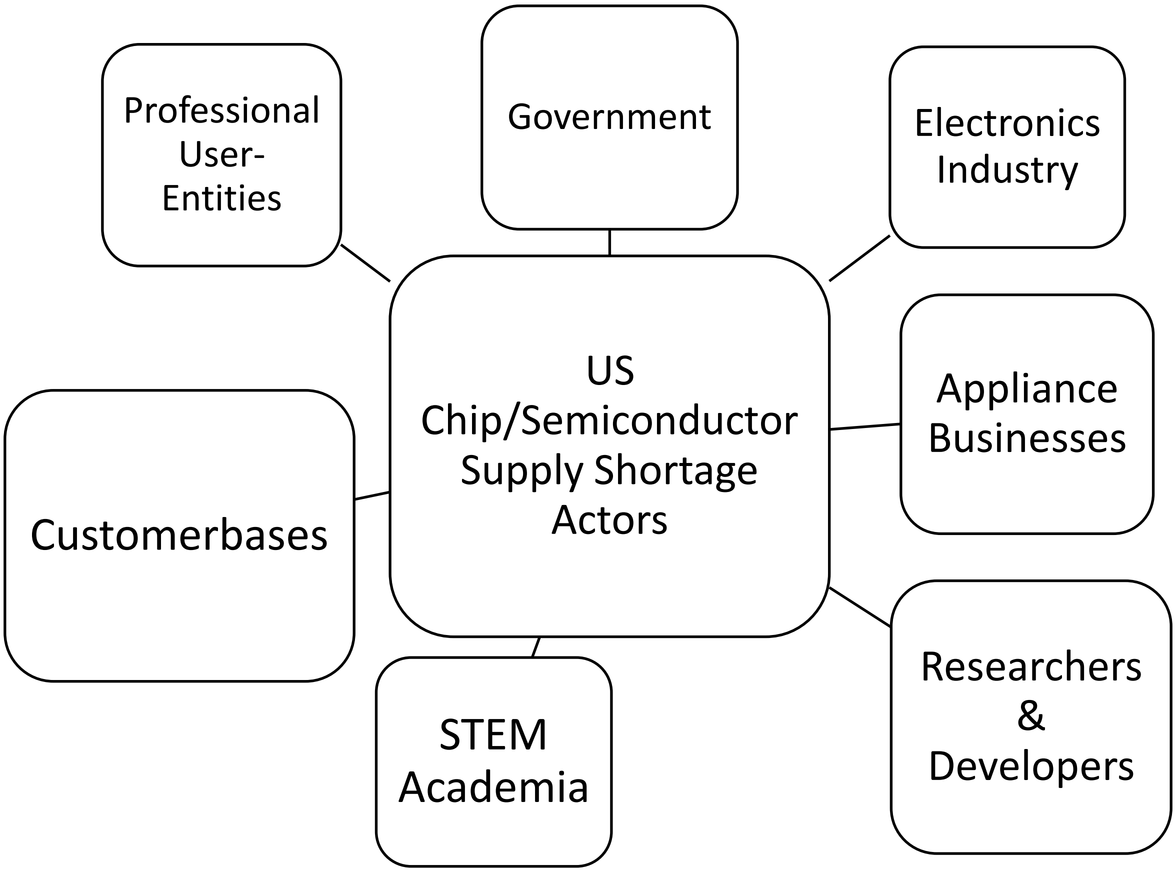

Figure 4: Bubble Diagram of US Actors Encumbered by Chip/Semiconductor Supply Shortage

This combination of projects addresses the domestic problem in semiconductor supply, by accentuating the problem's reach of impacts, and comprehending the US intervention's efficacy in guiding the country to a satisfactory resolution. Overall, the collective project can serve as a point of reference, to actors burdened by the shortage, in making informed decisions to best solve the shortage problem.

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