



# BILKENT UNIVERSITY

## DEPARTMENT OF MECHANICAL ENGINEERING



### INDUSTRY SUPPORTED GRADUATION PROJECTS

2025-2026



**BILKENT UNIVERSITY**  
**DEPARTMENT OF MECHANICAL ENGINEERING**

**INDUSTRY-SUPPORTED GRADUATION PROJECTS**

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# Project Fair Program

## 03 June 2026

13:30 - 13:45	Opening Speeches
13:45 - 14:30	Group Project Presentations
14:30 - 16:00	Project Demonstrations





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University-industry collaborations provide future engineers with a broad understanding of industry and business practices. Such collaborations also provide a platform for students to demonstrate creative design solutions to important problems encountered by industry. We provide this learning opportunity with a two-semester sequence of design courses for the senior-level students. This year, 14 groups, each consisting of five to six students, were provided with design projects from leading industrial organizations. Projects were selected such that students could leverage their undergraduate studies to design a product needed in today's world. Projects were also selected to bring out the students' creativity in both the design phase, which is completed in the first semester, and the embodiment phase normally completed in the second semester. At their final presentation sessions, the students are provided with a unique opportunity to present detailed design specifications of their products and the finished prototypes to the industrial sponsors.

We as a department are grateful to the academic and industrial mentors, instructors and teaching assistants for the continuous guidance and advice they provided.

On behalf of the Mechanical Engineering Department, I would like to thank all those who have generously contributed their time and resources that enabled tomorrow's engineers to gain invaluable experience during this process and demonstrate their capabilities.

**İlker TEMİZER**  
**Professor and Chair**  
**Mechanical Engineering Department**  
**Bilkent University**

 **roketsan**

**METEKSAN**  
SAVUNMA

**aselsan**

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Prof. Dr. Barbaros Çetin, Ela Baycan  
Doç. Dr. Müjdat Tohumcu, Yeşim Gülseren  
Assoc. Prof. Yıldıray Yıldız

Over the years, this program has evolved into a vital bridge between academia and industry. A total of 152 projects have been successfully completed in collaboration with 29 industry partners, providing students with hands-on experience that extends far beyond the framework of a traditional course.

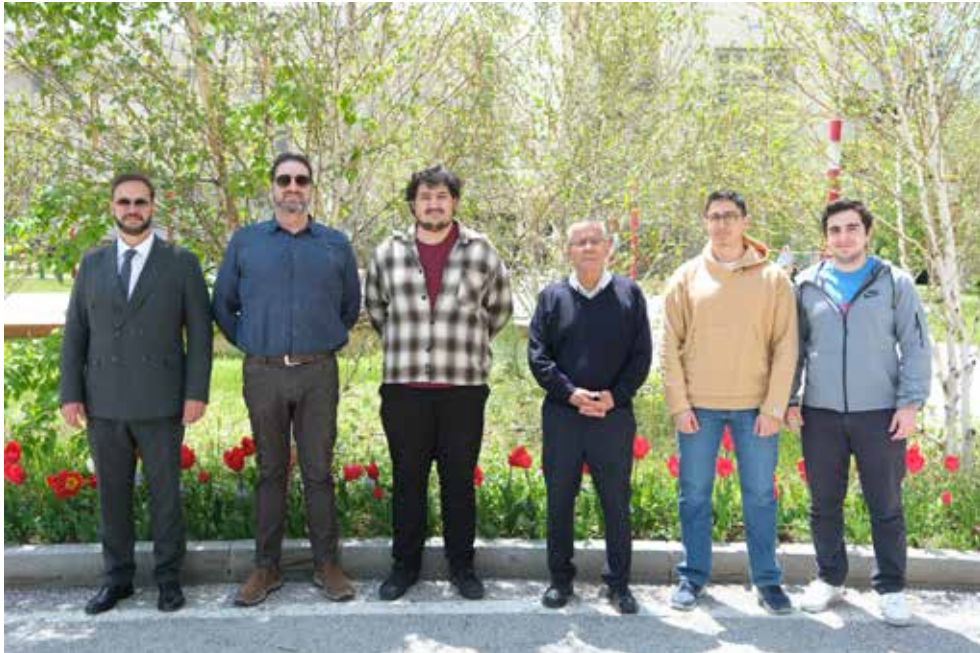
While these projects are formally conducted under ME 481-482 Mechanical Engineering Design I-II, the program itself is much more than just coursework. It serves as a true interface between student life and professional engineering practice, allowing students to engage in similar challenges they will face in their future careers. In essence, industry expertise is seamlessly integrated with the structured learning environment of a university course.

As instructors who have witnessed the program's growth and impact, we are highly satisfied with its progress. This success is the result of the collective efforts of many: students, industry mentors, teaching assistants, faculty members, and departmental staff. Their dedication and collaboration continue to shape this program into a meaningful and transformative experience for all involved.



## Teaching Assistants

Ömer Tarık Mumcu  
Altar Sertpoyraz  
Yunus Selçuk  
Okan Külekçiođlu





Being involved in editing this booklet sparked our interest in our upperclassmen's graduation projects. We gained valuable insight about the type of work our upperclassmen do in collaboration with partners from the industry as we read through each of them. We are now better informed and excited about the possibilities of our own project. We are looking forward to starting our own project and wish the best of luck to our upperclassmen in the rest of their journey as mechanical engineers!

- Elfin Gül, Ömer Gülcü, Sarp Özbek, and Alp Tarcan

### **Editors of the Booklet:**

Müjdat Tohumcu

Barbaros Çetin

Altar Sertpoyraz

Elfin Gül

Ömer Gülcü

Sarp Özbek

Alp Tarcan



# Looking Back: Alumni Memoirs

## A Retrospective Message From our 2022 Alumni



Looking back, we now realize that our graduation project was far more than just another course.

We remember the long nights in the EA building, the deadlines that felt impossible to meet, and the problems we sat with for hours, unsure if we would ever solve them. At the time, it all just felt difficult. Now, we see that those moments were quietly shaping us into the engineers we are today.

During our years in Mechanical Engineering at Bilkent University, we learned a great deal—but perhaps the most valuable lesson was this: being a

good engineer is not only about technical knowledge. What truly makes the difference is being part of a team that thinks together, struggles together, and pushes forward together.

Today, we feel the impact of that education almost every day. The way we approach problems, the importance we place on details, and the way we build solutions all reflect the mindset we developed back then.

For our graduation project, we worked with Roketsan to design a quick coupling system for leak-free missile fuel filling. It was our first real exposure to an end-to-end engineering process—from concept to detailed design. It was challenging, sometimes frustrating, and rarely straightforward. There were moments when we had to go back to square one. But that is exactly what made it such a defining experience.

Today, we are working in different industries. One of us is a mechanical design engineer at ASELSAN, and the other at GE Aerospace. Different fields, different projects—but the same foundation. The perspective we gained during that project still shapes how we think, design, and solve problems.

More than anything, we remember the people. Projects come to an end, reports get submitted, designs evolve—but the bonds you build during those late nights stay with you. When you look back, those are the moments that matter most.

If we could give one piece of advice to students starting their own graduation projects, it would be this: Don't treat it as just another requirement to get through. See it as a chance to challenge yourself, to make mistakes, and to grow. You will struggle at times—you're supposed to. That's where the real learning happens.

And one last thing:

Even the hardest problems become manageable when you have the right team beside you.

**Zeynep Bayar & Özge Kılınç**  
**B.Sc. 2022**

## 2022 Mezunlarımızdan Geçmişe Dönük Bir Mesaj

Geriye dönüp baktığımızda, bitirme projesinin bir bölüm dersinden fazlası olduğunu çok daha iyi anlıyoruz.

EA binasında sabahladığımız geceleri, yetişmeyecek gibi görünen deadline'ları, saatlerce başında oturup çözmeye çalıştığımız problemleri hatırladığımızda, bunların aslında bizi mesleğe hazırlayan en önemli deneyimler olduğunu görüyoruz.

Bilkent Üniversitesi Makine Mühendisliğinde geçirdiğimiz yıllar boyunca birçok şey öğrendik; ama belki de en önemlisi şuydu: iyi bir mühendis olmak, sadece teknik bilgiyle ilgili değil. Asıl farkı yaratan şey, birlikte düşünebildiğiniz, birlikte yorulduğunuz ve birlikte çözüm aradığınız bir ekibin parçası olabilmek.

Bugün meslek hayatımızda, Bilkent gibi bir okulda okumanın farkını neredeyse her gün hissediyoruz. Karşılaştığımız problemlere yaklaşımımızda, detaylara verdiğimiz önemde ve çözüm üretme biçimimizde üniversitede kazandığımız bakış açısının izleri var.

Bitirme projemizde Roketsan için, füze yakıt dolusunda kullanılacak bir quick coupling sistemi tasarladık. Bu proje, bizim için sadece teknik bir çalışma değildi. İlk defa gerçek bir mühendislik probleminin tüm aşamalarına dahil olduk: fikir üretmek, tasarım yapmak, defalarca revize etmek, hata yapmak ve tekrar denemek... Bazen işler planladığımız gibi gitmedi, bazen başa dönmek zorunda kaldık. Ama tam da bu süreç, bize mühendisliğin ne olduğunu öğretti.

Bugün farklı alanlarda çalışıyoruz. Birimiz ASELSAN'da, diğeri GE Aerospace'te mekanik tasarım mühendisi olarak kariyerine devam ediyor. Ama ikimiz de şunu rahatlıkla söyleyebiliriz: bitirme projesinde kazandığımız bakış açısı, hâlâ yaptığımız işin temelini oluşturuyor.

Belki de en önemlisi, o süreçte kurduğumuz bağlar. Her proje bir şekilde biter, raporlar teslim edilir, çizimler değişir. Ama birlikte sabahladığınız, aynı problemi çözmek için saatler harcadığınız insanlar hayatınızda kalır. Geriye dönüp baktığınızda, en çok onları hatırlarsınız.

Bu dersi alacak olanlara söylemek istediğimiz şey çok basit:

Bitirme projesini sadece "bitirilmesi gereken bir ders" olarak görmeyin. Bu, kendinizi gerçekten deneyebileceğiniz, hata yapabileceğiniz ve öğrenebileceğiniz bir alan. Zorlanacaksınız, bazen tıkanacaksınız ama en çok da o anlarda gelişeceksiniz.

Ve şunu unutmayın:

En zor projeler bile, doğru ekiple her zaman bir şekilde çözülür.

**Zeynep Bayar & Özge Kılınç**

**B.Sc. 2022**



# **2025-2026**

# **Industry Supported**

# **Graduation Projects**

# Design of a Control Actuation System for an Underwater Towed Body

## Under Control



**Academic Advisor:** Assoc. Prof. Dr. Yegan Oyman

**Industrial Advisor:** Onur Berk Salcan & Muhammed Raşit Yıldırım

**Teaching Assistant:** Ömer Tarık Mumcu

## ABSTRACT

The aim of this project is to design and produce an active Control Actuation System (CAS) for an underwater towed body. In marine exploration and defense operations, underwater towed bodies are subjected to hydrodynamic disturbances such as tow cable oscillations, current-induced drift, and wave actions. Traditional passive designs with fixed ballasts lack adaptability to these changing conditions, which reduces maneuverability and degrades the accuracy of measurement data collected by onboard sensors. The project aims to actively control the pitch, yaw, and roll of the towed body to maintain a level orientation and stabilize depth without relying on bulky depressor wings. The solution product is a closed-loop feedback control system utilizing an inertial measurement unit, a central microcontroller, and four independently driven control fins arranged in an X-configuration. Since strict dimensional and weight constraints were imposed, a compact, 3D-printed modular hull with an internally adjustable ballast rail system was chosen to optimize passive stability. The proposed solution of the project is to dynamically modify the towed body's hydrodynamics in real-time to eliminate orientation errors, thereby minimizing drag and significantly improving sensor measurement accuracy.

## Problem Definition

Underwater towed bodies are essential tools in modern marine science and defense, acting as mobile platforms for high-precision sonar arrays and environmental sensor modules. These vehicles must be positioned accurately at specific depths and orientations to ensure the reliability of the data they collect. However, maintaining this precision is a significant challenge due to the unpredictable nature of the marine environment and the physical constraints inherent in the towing process.

The primary problem addressed by this project is the inherent instability of towed bodies when subjected to external hydrodynamic forces. Traditional designs often rely on passive stabilization, which is frequently insufficient to counter the disturbances caused by surface wave action, underwater currents, and the mechanical oscillations transmitted through the tow cable. Without an active method to correct for pitch, yaw, and roll, the towed body suffers from increased drag and erratic movement, which ultimately degrades sensor performance and risks the structural integrity of the equipment.



Figure 1: General Structure of the Underwater Towed Body

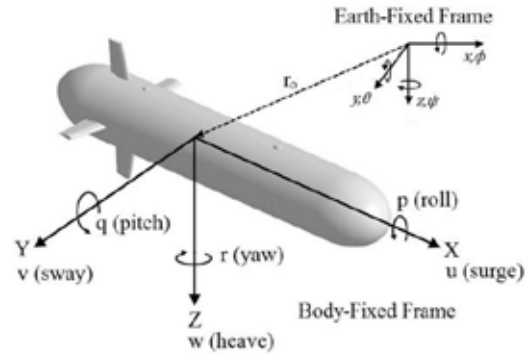


Figure 2: Body and earth-fixed coordinate frames with hydrodynamic loads acting on the underwater vehicle. [1].

To resolve these issues, the development of an active Control Actuation System (CAS) is required to provide real-time adjustments to the vehicle's trajectory. This system must be capable of processing sensor data and driving adjustable fins to maintain a stable flight path regardless of external conditions. The engineering of such a system presents unique mechanical challenges, particularly the requirement for robust sealing to protect sensitive internal electronics, such as the Raspberry Pi controller and servo motors, from high-pressure water ingress at depth. The ultimate goal of this project is to create a fully integrated CAS that enhances the operational capabilities of underwater towed bodies through dynamic stabilization. By utilizing advanced CFD simulations to validate the hydrodynamic responses and implementing a reliable mechanical sealing design, the project aims to deliver a system that offers superior maneuverability and data accuracy. This approach ensures that the towed body can perform effectively across a wider range of maritime conditions, providing a significant improvement over standard passive configurations.

[1] E. Javanmard, S. Mansoorzadeh, and J. A. Mehr, "A new CFD method for determination of translational added mass coefficients of an underwater vehicle," *Ocean Eng.*, vol. 215, p. 107857, Nov. 2020, doi: 10.1016/j.oceaneng.2020.107857.

## Design

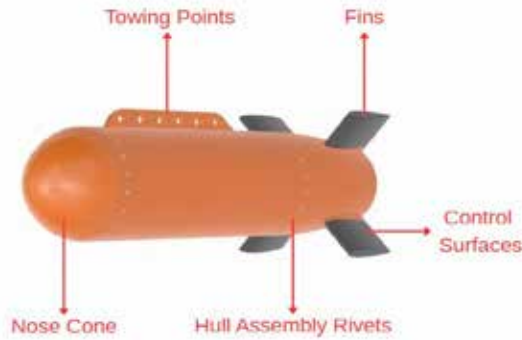


Figure 3 : 3D Model of the System

The design of the system features a modular and hydrodynamically optimized architecture to ensure stability and minimal drag. The main outer structure consists of a streamlined hull and a precise nose cap, designed to withstand external fluid forces while protecting the internal systems. Inside the hull, a 3D-printed electronics tray houses the microcontrollers, sensors and power units. To guarantee reliable operation in submerged conditions, the assembly relies on sealing strategies such as O-rings.

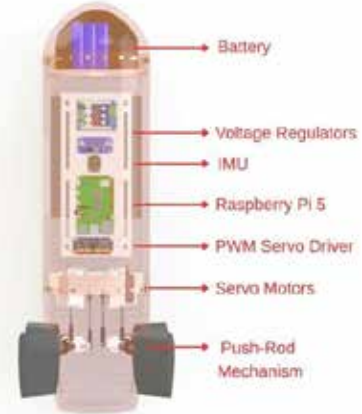


Figure 4 : Hardware Architecture and Electronic Assembly of the CAS Unit

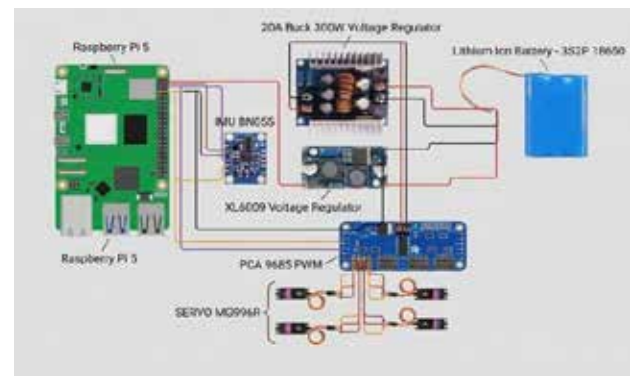
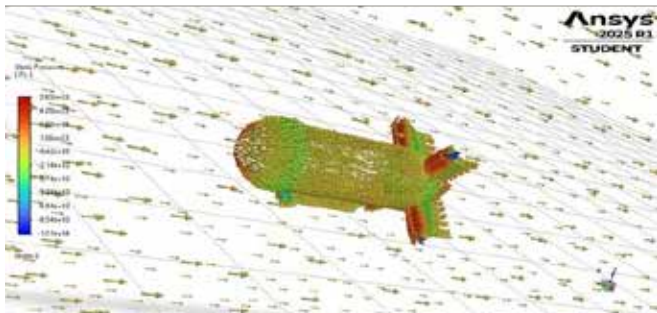
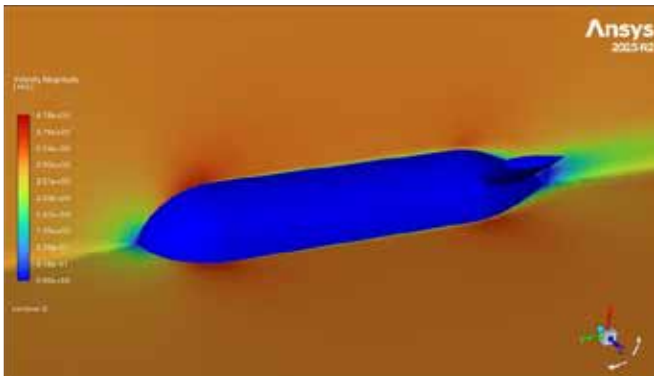
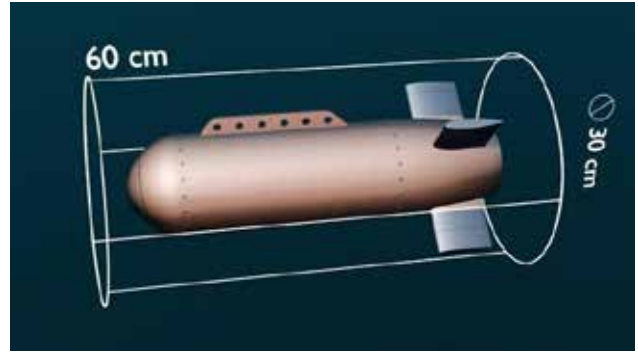
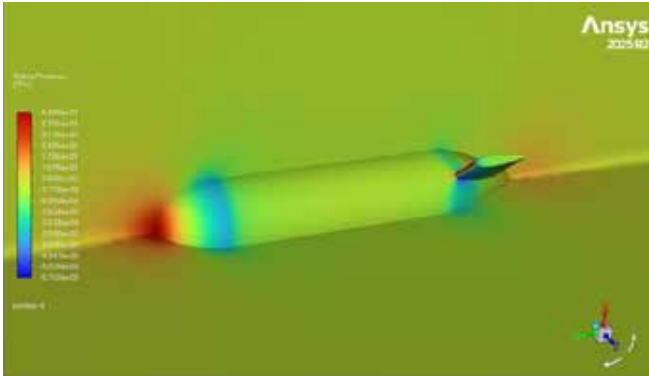
At the core of the system's maneuverability is the independent fin actuation mechanism designed for precise and rapid directional control. A BNO055 IMU sensor continuously tracks the body's orientation, feeding real-time data to the core processing unit, a Raspberry Pi 5. The Raspberry Pi instantly processes this information and commands the onboard PCA9685 motor driver to actuate the high-torque servos. This efficient architecture translates navigational inputs into precise mechanical adjustments, ensuring reliable pitch, yaw, and roll control during submerged missions.

## Outcomes

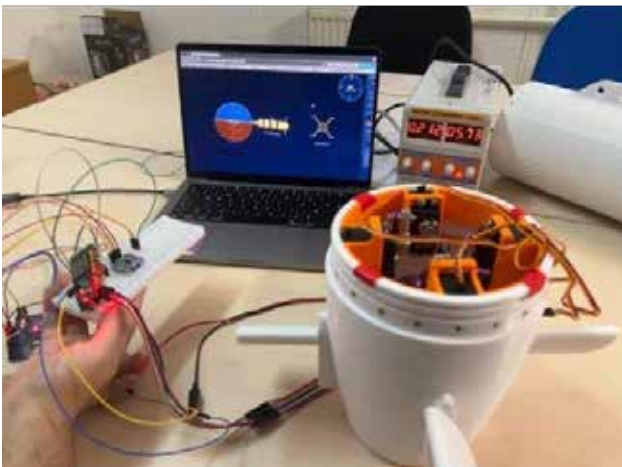
This project applies theoretical knowledge from instrumentation, fluid mechanics, dynamics, and control to the design of an underwater towfish with an active control system, carried out during the 2025–2026 academic year in collaboration with Meteksan Savunma:

- Literature review on towed body dynamics, control theory, and hydrodynamic characterization
- System requirements definition based on Meteksan's specifications
- 3D modeling of the underwater towfish
- Steady-state and transient CFD for damping and added-mass matrices in 6-DOF,
- Linearized 6-DOF hydrodynamic modeling of the towfish and towing cable
- PID controller design for fin deflection and servo actuation
- XFOIL airfoil analysis for NACA lift and drag coefficients
- Detailed CAD design and ASME Y14.5M-compliant technical drawings • Manufacturing, assembly, and verification management

## Various Pictures of The Project



## Various Pictures of The Project



# Design and Implementation of a Multi-DOF Test Rig and Flight Control System for a Model Helicopter

## Hover Dose



Erinç Ada  
Ceylan

Ömer Kaan  
Tekkeli

Ege  
Özbülbül

Tunç  
Akay

Osman Said  
Özgül

Fatih Emin  
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**Academic Advisor:** Assoc. Prof. Yıldırım Yıldız

**Industrial Advisor:** Can Ünen

Ahmet Kara

**Teaching Assistant:** Altar Sertpoyraz

## ABSTRACT

The aim of this project is to design, manufacture, and integrate a comprehensive testing and control system for the Maxi Joker 3 model helicopter. The project addresses the need for safe, reliable, and portable testing of small-scale helicopters under controlled conditions while ensuring high-performance flight control. In the first part, a multi-degree-of-freedom (up to 4-DOF) test rig is designed based on the helicopter's physical properties and operational constraints. The structure is developed to operate safely under specified loads, with adequate ground clearance to prevent damage. Motion-limiting mechanisms are incorporated to ensure controlled operation, and the system is optimized for portability within passenger vehicle limits. Documentation and systematic project management support usability and traceability. In the second part, a robust flight control system is developed using a mathematical model of the helicopter. An inner-loop controller regulates angular rates, ensuring attitude stability within  $\pm 5^\circ$  in pitch, roll, and yaw. The system satisfies robustness criteria ( $\geq 30^\circ$  phase margin,  $\geq 3$  dB gain margin) and includes safety mechanisms and a user-friendly interface.

## Problem Definition

Helicopters operate under highly nonlinear, fast, and strongly coupled dynamics, which makes flight control development and validation challenging. Traditional validation approaches create a major testing gap.

Simulation-only testing cannot fully capture real physical effects such as actuator delays, high-frequency vibrations, and sensor noise.

Direct free - flight testing involves unacceptable risks, including catastrophic crashes and equipment loss.

To address this problem, our project proposes a portable multi-DOF mechanically constrained test rig integrated with a deterministic real-time flight control architecture.

This approach enables safe, repeatable, and hardware-based validation of control algorithms before real-world deployment.



Figure 1: MaxiJoker 3 Helicopter

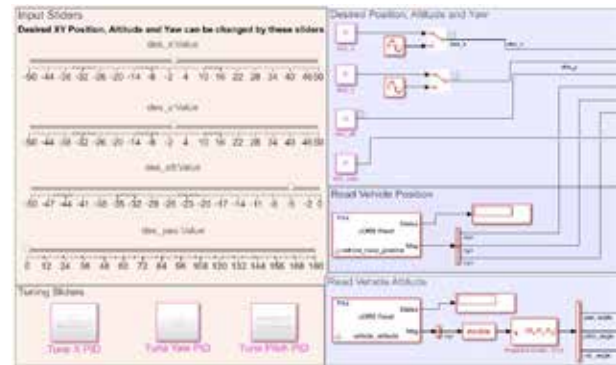


Figure 2: Example Control Architecture from Simulink using PX4 Toolbox [1]

The system is designed under both mechanical and control-oriented requirements.

Mechanically, the rig must provide at least 3 and up to 6 degrees of freedom, while constraining critical motions such as pitch and roll within  $\pm 30^\circ$  to prevent structural collision.

It must also remain portable enough for transport in a standard passenger vehicle, withstand predefined structural load cases with safety margins, and maintain a low-cost, manufacturable, and universally compatible design for helicopter integration.

From the control perspective, execution must support hard real-time signal routing and processing via Pixhawk 6C. The target control performance is defined by an attitude tracking error within  $\pm 5^\circ$  for roll, pitch, and yaw, while robustness requirements include phase margin  $\geq 30^\circ$  and gain margin  $\geq 3$  dB.

[1] MathWorks, "Position Tracking for X-Configuration Quadcopter," *MATLAB & Simulink Documentation*, accessed April 5, 2026.

## Design



Figure 3 : 3D Model of the System

The structure as a whole can move along elevation, yaw, pitch and roll. To be free along yaw and roll, the outer bearing face should move; hence a tight fitting of bearing – shaft assembly and indexing of shafts through bolts achieve the fixed shaft. Two SKF bearings and two CNC-controlled shafts with threads ensure this movement. The elevational movement occurs through telescopic sliders mounted onto sigma profiles which are connected with corner connections and allen bolts resulting in rigid structure.



Figure 4: Power and signal architecture.

The electronic architecture features a deterministic Hardware-in-the-Loop (HITL) setup centered on the Pixhawk 6C flight controller. A Kontronik ESC and high-capacity 6S LiPo batteries manage safe power distribution to the main motor and avionics. For precise attitude regulation, the Pixhawk directs PWM signals to servos actuating the swashplate and tail. Finally, control algorithms are developed using Simulink's PX4 Package, with QGroundControl utilized for planning and real-time data logging.

## Outcomes

This project is a mechanical system design integrating knowledge from dynamics, control systems, mechatronics, solid mechanics, and machine elements. It is carried out throughout the 2025–2026 academic year in the following stages:

- Literature review
- Modeling of sub-assemblies and mechanisms based on TUSAŞ requirements
- Engineering analyses (ANSYS):
  - Static structural analysis for helicopter-induced loads
  - Von Mises stress and safety factor (4-DOF system)
  - Modal analysis for vibration characteristics
  - Verification of theoretical torque values
- CAD drawings with GD&T
- Control algorithm, autopilot, and system architecture (MATLAB)
- Improvement of electronic/mechatronic components (e.g., ESC)
- Manufacturing and iterative structural optimization

## Various Pictures of The Project



Figure 5: Rigid Base Structure with Elevational Mechanism



Figure 7: Maxi - Joker 3 RC Helicopter



Figure 6: Assembly process of base structure with corner bends and allen bolts



Figure 8: Control algorithm and electronic hardware check process

# Design and Realization of an Adaptive Speed Breaker with Dynamic Height Control

## Hump Breakers



**Academic Advisor :** Assoc. Prof. Dr. Onur Özcan

**Industrial Advisors :** Bora Eren & Mehmet Can Gümüş

**Teaching Assistant :** Okan Külekçioğlu

## ABSTRACT

The objective of this project is to design and produce a prototype adaptive speed breaker system. While they are effective at enforcing speed limits, they cause unnecessary discomfort and vehicle wear for drivers who are already compliant, increase noise and emissions due to repeated braking and acceleration, and cannot adapt to changing traffic conditions, vehicle types, or varying traffic demands. This project aims to develop a speed breaker system that provides a dynamic response to the speed of incoming vehicles, and cause discomfort for drivers over the designated speed limit. Unlike conventional or binary adaptive systems, the proposed design is intended to provide at least three discrete response levels, thereby penalizing overspeeding vehicles while allowing vehicles within the speed limitations to pass more smoothly. The proposed solution is a mechatronic prototype with a screw-wedge mechanism that provides user adjustable states, high position locking safety and structural rigidity. This project is designed to align with the human comfort criteria according to BS 6841 standards, by modelling a 1/10 scale prototype that demonstrates the mechanical and control principles of adaptive speed regulation in a repeatable test environment, while also serving as a basis for future analysis and development.

## Problem Definition

### Traditional Speed Control Limitations:

Conventional speed breakers are static physical structures that enforce speed limits by penalizing all vehicles equally. Their fixed geometry causes unnecessary vertical shock, discomfort, and mechanical wear for compliant drivers who are already following the speed limit. Furthermore, these static humps contribute to increased noise and environmental emissions due to the repeated braking and acceleration cycles they necessitate.

### Impact on Vehicle Dynamics and Safety:

Structural impact caused by traditional humps can interfere with sensitive onboard equipment and accelerate the degradation of vehicle suspensions and powertrains. In critical zones like campuses or residential areas, the inability of passive bumps to adapt to changing traffic conditions or vehicle types can negatively affect overall traffic flow and fuel efficiency.

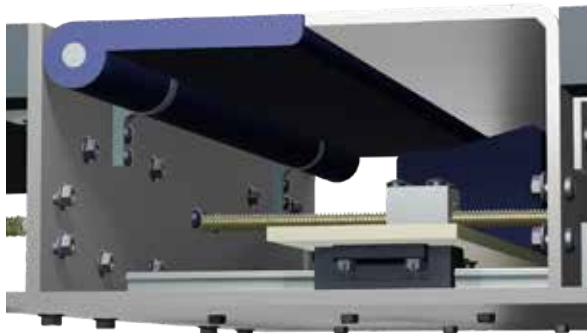


Figure 1: Screw Wedge Mechanism.

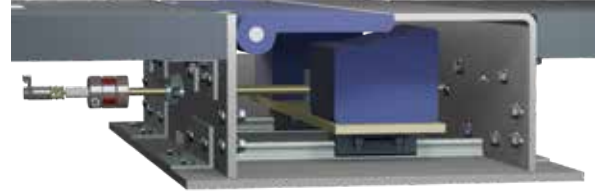


Figure 2: 3D Model of the System.

### The Adaptive Solution:

There is a significant need for intelligent speed control systems that respond dynamically to approaching vehicles. The objective is to implement a mechatronic system capable of:

- **Selective Penalization:** Encountering a higher or stiffer bump only if a vehicle exceeds the chosen speed threshold, while providing a smooth passage for compliant drivers.
- **Multi-Level Control:** Utilizing at least three distinguishable operating states (Low, Medium, and High) rather than a simple binary (on/off) system.
- **Human Comfort Alignment:** Associating vehicle acceleration ranges with target discomfort categories defined by international standards, such as BS 6841, to ensure the system is both effective for enforcement and optimized for passenger comfort.

By demonstrating these principles in a compact, scalable test environment, this project provides a repeatable platform for advanced studies in stress analysis, comfort verification, and adaptive control strategies.

## Design

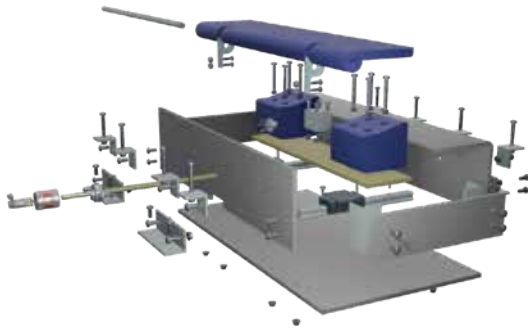


Figure 3 : Exploded View of System

The design of the system was finalized as a scaled mechatronic adaptive speed breaker that dynamically adjusts its height based on the calculated approach speed of incoming vehicles. The system is composed of five aluminum shell pieces, a mechatronic actuation unit, and a 3.5-meter wooden track. The system was designed based on mechatronic principles and closed-loop feedback control that provides at least three discrete operating states: Low, Medium, and High.

Actuation is provided by a DC motor and a screw-wedge mechanism that converts rotational movement into linear translation. The lead screw advances the wedge platform to move the 15-degree wedges, effectively adjusting the height of the top plate. The wedge platform utilizes a flat geometry designed to position the load-bearing wedges directly over the axes of the linear slide rails. This ensures that vertical impact forces are transmitted directly to the carriages and support rails, providing high structural rigidity and preventing mechanical deformation.



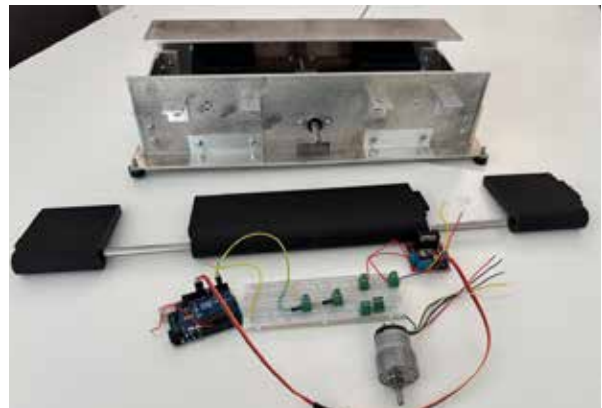
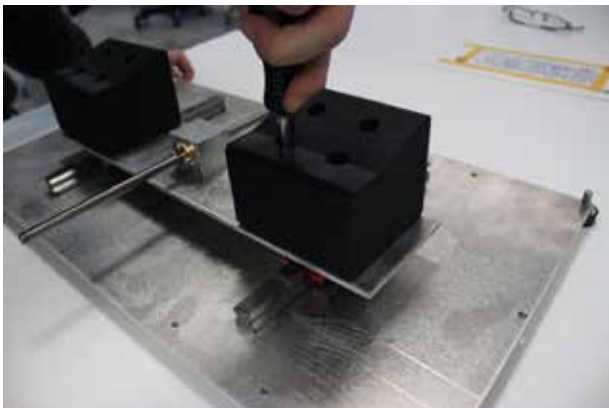
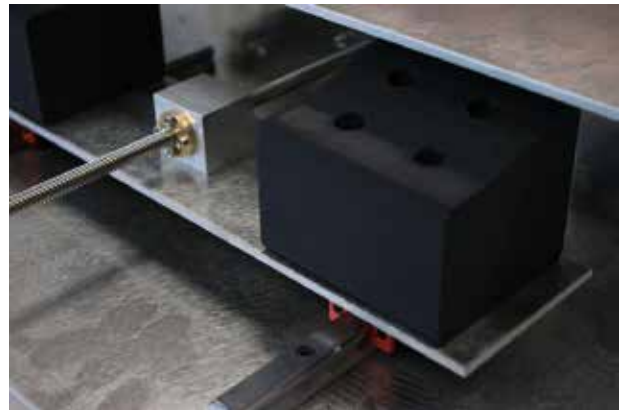
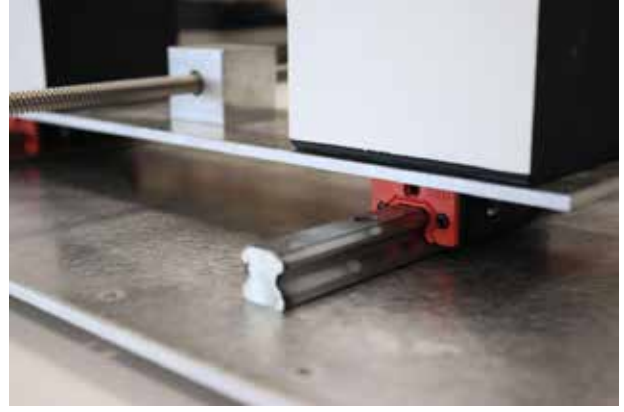
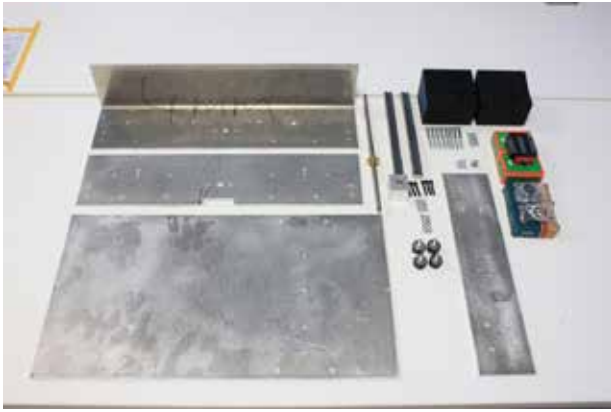
Figure 4 : 3D Model of Wedge Platform and Wedges

## Outcomes

This project is a multidisciplinary mechanical design study that integrates knowledge from dynamics, control systems, and mechatronics courses. The project was carried out throughout the 2025-2026 academic year, following a systematic approach, including:

- Conducting literature and market research
- Performing engineering analysis, including:
  - Control system design,
  - Dynamic modeling for vehicle-speed breaker interaction,
  - Structural analysis for stress evaluation,
  - Kinematic analysis and calculation of system characteristics
- Creating CAD models and technical drawings in accordance with tolerancing standards
- Planning and executing manufacturing processes, assembly and system integration for the 1/10 scale prototype
- Developing a mechatronic system by integrating sensors, actuators, and control algorithms
- Conducting experimental tests and validating simulations through real-life measurements

## Various Pictures of The Project



# Tepe Emlak Duct Inspection and Cleaning Robot

## AREKA-TR



**Academic Advisor:** Assoc. Prof. Dr. Onur Özcan

**Industrial Advisor:** Akif Karakoyun

**Teaching Assistant:** Altar Sertpoyraz

## ABSTRACT

Insufficient cleaning of restaurant kitchen hoods leads to the accumulation of highly flammable grease, creating serious fire hazards and posing significant risks to both life and property. As the NFPA Research (2017) [1] suggests, over 60% of such fires originate either from cooking equipment—particularly fryers—or from the ignition of grease deposits in poorly maintained hood and duct systems. An exemplary incident that occurred at Grand Kartal Hotel in 2025 was one of the motivations behind this project where our co-department graduate Alp Mercan lost his life trying to save victims.

Existing manual cleaning methods require personnel to physically enter ductwork and scrape off grease, a process that is both inefficient and hazardous. Moreover, these methods are often inadequate, as workers struggle to access deep, narrow, or complex duct sections, resulting in incomplete cleaning. To overcome these limitations, this project proposes the development of a compact robotic system capable of navigating complex duct geometries, including sharp turns and vertical transitions. The robot is equipped with a mounted camera for real-time inspection and a spraying mechanism to apply cleaning chemicals directly onto contaminated surfaces using a 360° rotating high-pressure nozzle

[1] R. Campbell, *Structure Fires in Eating and Drinking Establishments*, National Fire Protection Association (NFPA), Quincy, MA, USA, 2017.

[2]“2025 Kartalkaya hotel fire,” 2025 Kartalkaya hotel fire, Wikipedia [Online]. Available: [https://tr.wikipedia.org/wiki/Bolu\\_Grand\\_Kartal\\_Otel\\_yang%C4%B1n%C4%B1](https://tr.wikipedia.org/wiki/Bolu_Grand_Kartal_Otel_yang%C4%B1n%C4%B1). [Accessed:Apr.9,2026].

## Problem Definition

Commercial kitchen ducts are highly susceptible to oil vapor condensation, which gradually forms a thick, solid layer of flammable grease. This creates a critical fire hazard, not only for kitchen employees but also for the building itself and its surroundings. Moreover, strict legal regulations governing the interior cleaning of ducts mean that restaurants and other facilities face severe penalties when employers and managers are found to be non-compliant. Therefore, periodic duct inspection and effective cleaning are essential for human safety.



Figure 1: Manual Scraping of the Ducts[1]

However, traditional manual cleaning operations are both limited and inefficient; workers physically enter the ducts with scrapers, making the process time-consuming, costly, and hazardous. Furthermore, ducts with complex geometries — such as extended vertical sections where the height exceeds several meters, or those with narrow cross-sections — are largely inaccessible to humans for both cleaning and inspection purposes. As a result, grease and dust progressively accumulate in these unreachable regions, further compounding the fire hazard over time.

Consequently, a compact, sustainable, and accessible robotic system capable of entering ducts to perform thorough inspection and cleaning is clearly needed. The proposed solution is a remotely operated robot that can navigate through any duct configuration while simultaneously capturing video footage for inspection and delivering cleaning chemicals precisely to targeted areas.

Furthermore, ducts with significant heights or narrow cross-sections are inaccessible to humans, not only due to physical constraints but also because interior duct temperatures can exceed room temperature, reaching 35–40°C. Therefore, manual inspection and cleaning are inherently inefficient, necessitating a compact robotic solution capable of traversing complex duct geometries—including horizontal and vertical transitions and sharp turns—while reliably operating under such thermal conditions.



Figure 2: Manual Inspection of the Kitchen Hood [2]

[2] Clean Air. "How to manually clean exhaust ducts in a commercial kitchen." *CleanAir.com.au*, Accessed Nov. 4, 2025. [Online]. Available: <https://cleanair.com.au/blog/how-to-manually-clean-exhaust-ducts-in-a-commercial-kitchen/>

[3] Dubai Clean. "Kitchen duct cleaning services in Dubai: A complete guide." *DubaiClean.com*, Accessed Nov. 4, 2025. [Online]. Available: <https://dubaiclean.com/kitchen-duct-cleaning-services-in-dubai-a-complete-guide/>

## Design

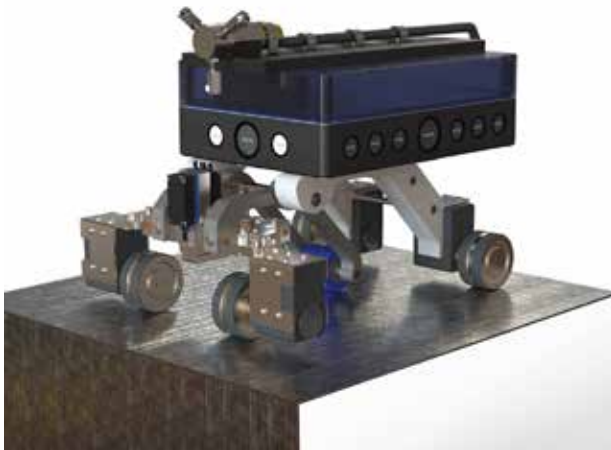


Figure 3 : 3D Model of TheSystem

The proposed final design consists of three integrated subsystems: movement & navigation, cleaning, and electronic. The lower chassis houses four high torque DC motors connected to four magnetic wheels each capable of providing more force than the weight of the robot itself, and two non-magnetic wheels for navigation through 90° transitions. Horizontal turning is achieved through a 6-bar Ackermann steering mechanism driven by a rack-and-pinion assembly. All electronic components are enclosed within an IP68-rated polycarbonate junction box, mounted to the chassis via epoxy adhesive.

## Outcomes

This mechanical design project is a system which requires knowledge acquired from dynamics, control systems, mechatronics, fluid mechanics, and machine elements courses to be implemented. Throughout the design, manufacturing, assembly and testing phases of this robotic system, the team managed to find opportunity to develop themselves at the following areas:

- Systems-Level Thinking and Design Engineering
- Budget management for prolonged engineering projects
- Design for Manufacturing And Assembly Principles
- Integration of Electronic Components into Mechanical Systems
- Manufacturing Processes (turning, milling, additive manufacturing, laser cutting, welding)
- International Procurement Processes and Dealing With Time Shortages
- Crisis Management
- IP Standards Testing and Altering Design to Meet The Test Criteria

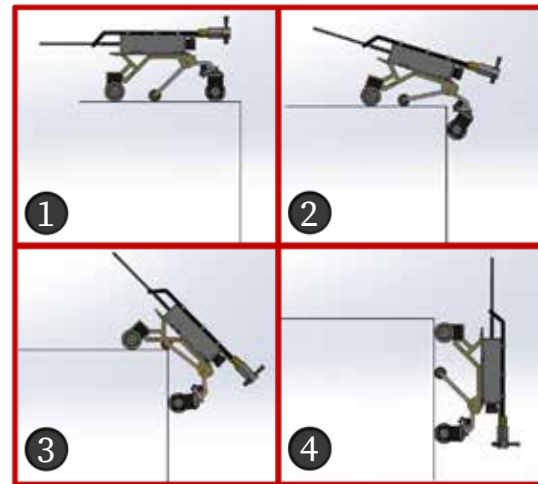


Figure 4 :TransitionBetweenVertical& Horizontal

The cleaning system employs a pressure washer connected to a three-headed, 360° rotating nozzle, delivering pressurized cleaning solution uniformly across duct interior surfaces through a stainless-steel braided hose. The electronic system is built around a single-board computer paired with a depth camera providing live video feed and spatial mapping. Two rechargeable LiPo batteries independently power the drive motors and remaining electronics, with an ADC module enabling real-time voltage monitoring through out operation.

# Design and Production of Motorized Linear Deployable Mechanism

## OrbitExtenders



**Academic Advisor:** Prof. Dr. Barbaros Çetin

**Industrial Advisor:** Barış Temel

**Teaching Assistant:** Yunus Selçuk

## ABSTRACT

The aim of this project is to design, analyze and prototype a motorized linear deployable mechanism for Plan-S Satellite & Space Technologies. The mechanism is intended to provide the required separation of high-gain antennas and sensitive sensors from the main body of the satellites to minimize signal distortion due to interference and ensure optimal operation. In the modern aerospace missions, within the domain of small satellites and CubeSats, volume of the deployment mechanism during launch phase is the most critical design constraint. This project focuses on safely supporting 250g functional payload, exactly 1 meter away from the satellite while satisfying the maximum stowed volume specification of 1U. The team developed a Dual-Hub Storable Tape Spring Boom Mechanism, achieving high packaging efficiency, mechanical reliability against the extreme space environments and orbital thermal cycling, and structural rigidity to mitigate operational vibrations. Additionally, an actuation mechanism that comprises a DC Motor is designed to act as a dynamic brake and provide stable deployment to eliminate the risk of oscillatory tendencies and high-impact structural shock.

## Problem Definition

CubeSats and Nanosatellites have drastically reduced the cost of space access but their strict volumetric constraints (e.g. 3U) severely limit the size of functional payloads such as antennas, solar arrays and sensor booms. Deployable mechanisms have crucial impact on overcoming these limitations by compactly storing large structures during the launch phase and safely extending them once the satellite reaches orbit.

Deployable structures are composed of primarily of stowed elements, containment mechanisms, and actuation systems. Especially, metallic tape springs are widely used in these systems due to their high packaging efficiency. They store significant strain energy when coiled which allows them to act as both the deployment driver and the rigid structural element once fully extended.

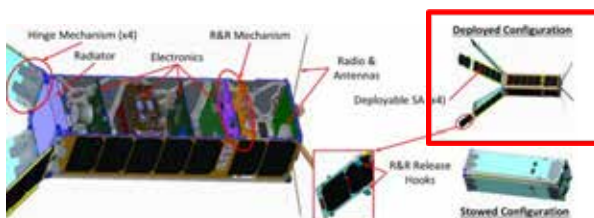


Figure 1: General Structure of the CubeSat [1].

Like all dynamically driven structures, tape springs are affected by the release of their internal strain energy. Therefore, passive deployment of these springs is inherently violent. The sudden, uncontrolled release of stored energy causes unstable, high-speed extension. In terms of operation, relying only on passive deployment is highly risky. Thus, a controlled, motorized deployment system is strictly required to actively govern the release of the tape springs.

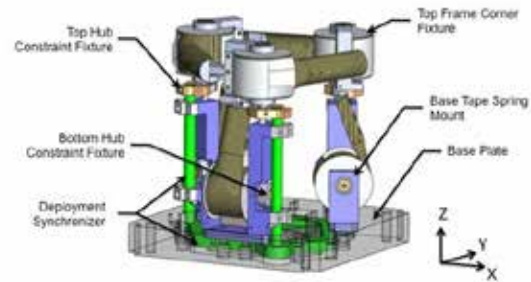


Figure 2: NASA's design of deployment system using tape springs [2]

The system must act as an active damper which provides dynamic braking against the overhauling load of the springs to prevent them from accelerating out of control. The system needs to maintain a constant, regulated deployment speed with utilizing a closed-loop electromechanical control architecture.

The realization of this mechanism presents a complex set of constraints driven by strict CubeSat dimensional standards and the operational needs of Plan-S. The mechanism must be compatible with the extreme space environment (-30 °C to 50 °C ) and operate fully in vacuum medium. It should complete its full extension within an operational time window of maximum 10 minutes and maintain the specified deployed length with self-locking features. Additionally, to comply with standard CubeSat weight restrictions, the mechanism must be engineered to be lightweight.

The solution product will be designed in accordance with the CubeSat Design Specification and will be subjected to aerospace environmental testing standards (such as NASA and GEVS) to ensure structural survivability against launch-induced vibrations and thermal cycles.

[1] Globalspec.com, 2020. <https://insights.globalspec.com/article/11912/how-to-develop-a-cubesat-from-concept-to-earth-orbit>.

[2] J. N. Footdale and T. W. Murphey, "Mechanism Design and Testing of a Self-Deploying Structure Using Flexible Composite Tape Springs," The 42nd Aerospace Mechanism Symposium, May 2014.

## Design

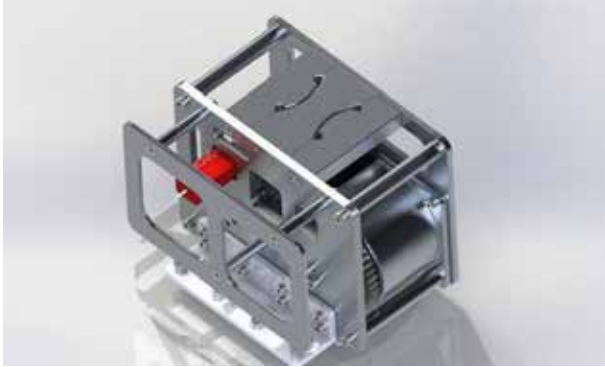


Figure 3 : 3D Model of the System

The working principle of the design relies on the highly controlled release of strain energy stored in the booms, which are flattened and coiled around two different hubs initially. An electrical architecture is designed as a closed-loop system fed by a micro encoder to retain the deployment speed at 5 rad/s, through regulation of the micro-DC motor output for stability. The system is composed of four major subsystems; structural elements, an actuation unit, a transmission system and the deployable tape-spring medium.

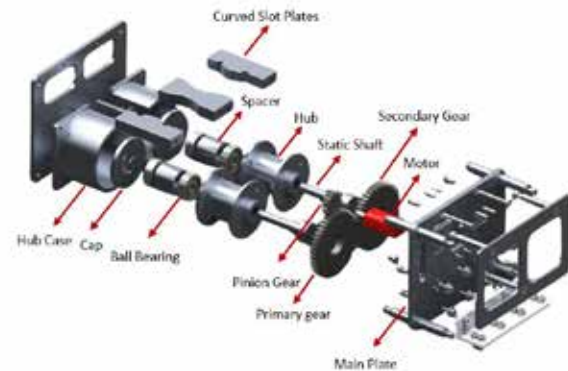


Figure 4 : Components of the System

The system is built on a static framework, composed of a symmetrical main plate and stationary dual shafts. A DC motor and pinion system transmits torque to a primary gear coupled to a single hub which then meshes with a secondary gear with 1:1 ratio, ensuring both hub assemblies rotate in perfect synchronization. Tape springs are attached to the hubs and bounded at tip via epoxy. 2 ball bearings are mounted on each shaft. For precise axial positioning, spacers are located between bearings and assembly caps are tightened to apply specific preload.

## Outcomes

The system interconnects various engineering approaches with distinct applications of mechanical engineering, requiring rigorous product development skills. A synthesis of thermodynamics, dynamics and control, mechatronics and manufacturing courses were used. Systematically, given engineering stages were completed in the 2025-2026 academic year:

- Literature research
- Subsystem definition and architecture for the mechanism and DfM-valued design
- Engineering analysis including:
  - Thermal Cycling Analysis
  - Dynamic Modeling and Analysis
  - Structural and Modal Analyses
  - Kinematics Analysis
  - Control System and Feedback Analysis
- CAD drawings
- Risk & Cost Analyses
- Planning of manufacturing processes, assembly, design verification and testing of the system

## Various Pictures of The Project



Figure 5: All manufactured parts before the assembly procedure begins



Figure 6 : The team begins the assembly process

## Various Pictures of The Project



Figure 7 : Performing additional applications



Figure 8 : The team is hard at work



Figure 9 : Brining the sub-assemblies together



Figure 10 : Two main halves of the system



Figure 11: The finalized assembly of the system

# Design and Production of a ForceGate: Door Opening & Closing Force Measurement and Testing System

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## GateTesters



**Academic Advisor:** Doç. Dr. Müjdat Tohumcu

**Industrial Advisor:** Batur Zafer

**Teaching Assistant:** Yunus Selçuk

## ABSTRACT

The aim of this project is to design and produce an automated test system for measuring the opening and closing force characteristics of dishwasher doors. During product development and quality control, dishwasher manufacturers must accurately determine the force required to open and close the door in order to ensure user comfort, safety, and compliance with standards. Manual measurements are inconsistent and highly dependent on the operator, which reduces repeatability and accuracy. The project aims to develop a mechanism capable of opening the dishwasher door through an angle of approximately  $68^\circ$  in 3 seconds and closing it again in the same period while continuously measuring the force acting on the door. The measured force is always the perpendicular force acting on the dishwasher door surface, ensuring that the results accurately represent the user-applied opening and closing force. The proposed solution is based on a motor-driven circular arc mechanism connected to the dishwasher door through a vacuum suction cup and an S-type load cell. A toothed arc and pinion drive system is used to provide controlled rotational motion while minimizing backlash and ensuring precise positioning. The designed system allows repeatable force measurements under identical conditions and provides a reliable platform for evaluating dishwasher door hinge and spring mechanisms during product development and validation.

## Problem Definition

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The opening and closing force of a dishwasher door has a crucial effect on user comfort, perceived product quality and operational safety. Dishwasher doors are supported by hinge and spring mechanisms which balance the weight of the door and control its motion throughout the opening and closing cycle. If the required opening force is too high, the user may have difficulty operating the dishwasher; if it is too low, the door may open too rapidly and create a safety risk.

Dishwasher doors can be considered as rotating systems whose motion and required force vary continuously with door angle. During the opening and closing cycle, the force required by the user changes because of the variation in the gravitational moment of the door and the characteristics of the hinge mechanism. Therefore, the opening and closing force must be evaluated throughout the entire door motion rather than at a single position.

In current applications, the opening and closing force is generally measured manually by an operator using a force gauge. However, these measurements are highly dependent on the operator and are difficult to repeat under identical conditions. More importantly, the applied force is not always perpendicular to the dishwasher door surface. Since the door rotates during operation, the direction of the true user force also changes continuously. As a result, measurements taken in a fixed direction do not accurately represent the actual force experienced by the user.

For this reason, a dedicated test system is required that can follow the motion of the dishwasher door and continuously measure the perpendicular opening and closing force throughout the complete cycle. In addition to the main problem, the test system must provide repeatable results, operate with sufficient positional accuracy, and be capable of opening the door to approximately 68° and closing it again within a specified time interval. Furthermore, the mechanism should be compact, reliable and suitable for use in product development and quality control environments.

## Design

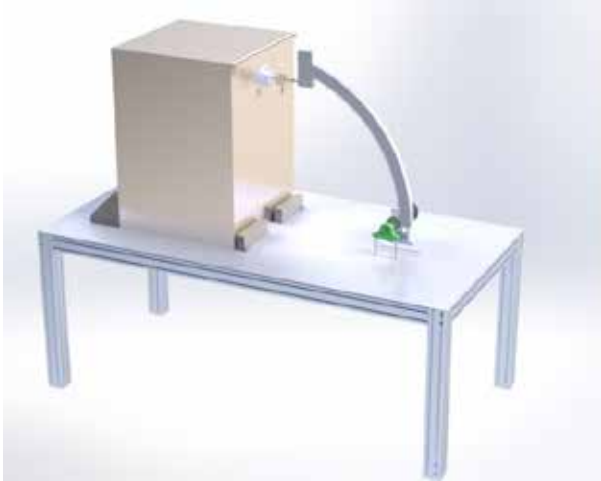


Figure 1: 3D Model of the Dishwasher Door Force Test System

The design of the system was finalized as a motor-driven test mechanism capable of opening and closing a dishwasher door in a controlled and repeatable manner. The system consists of an aluminum profile support table, a fixture that positions the dishwasher, a circular arc mechanism, a drive subsystem and a force measurement subsystem. The dishwasher is fixed on the table while the door is connected to the moving mechanism through a vacuum suction cup.

The motion of the door is provided by a circular arc with internal gear teeth. A stepper motor drives a pinion gear which meshes with the toothed arc and rotates it about its center. In this way, the mechanism is able to open the dishwasher door to approximately  $68^\circ$  in 3 seconds and close it again in the same period. The circular arc geometry ensures that the motion of the mechanism follows the natural rotational motion of the dishwasher door.

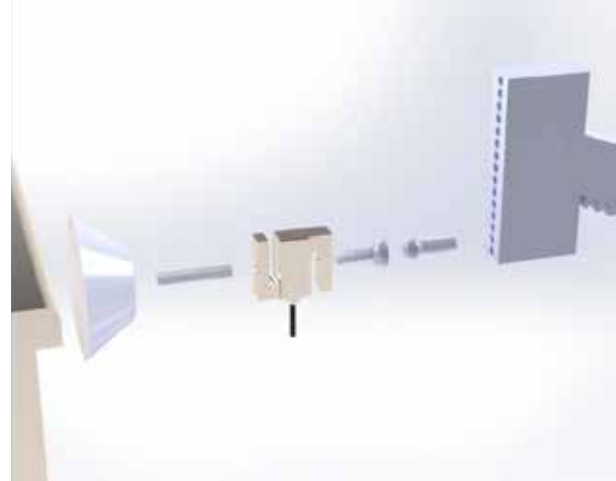


Figure 2: Force Measurement and Arc Connection Subsystem

At the end of the arc, a force measurement subsystem is placed between the mechanism and the dishwasher door. This subsystem consists of a vacuum suction cup, an S-type load cell and the required mounting components. The suction cup is attached to the door surface and transfers the door force directly to the load cell. Since the load cell moves together with the circular arc, the measured force always remains perpendicular to the dishwasher door surface throughout the entire motion. Therefore, the system is capable of measuring the true opening and closing force experienced by the user.

The system was designed to provide repeatable measurements under identical operating conditions. In addition to the main mechanism, bearing supports and rigid mounting elements are used in order to minimize backlash, improve positional accuracy and ensure smooth operation of the arc during the test cycle.

## Outcomes

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This system is a mechanical design project that combines the mechanical engineering knowledge acquired in machine design, dynamics, mechatronics and control courses. The project was completed through several stages, which are summarized below:

- Literature research on dishwasher door opening and closing force measurement methods
- Determination of system requirements including door opening angle, motion duration and force measurement conditions
- Development and comparison of alternative concepts for the door actuation mechanism
- Selection and design of the circular arc and pinion mechanism
- Engineering analysis including:
  - Kinematic modeling of the door and arc motion
  - Determination of the required motor torque and speed
  - Calculation of the circular arc geometry and gear dimensions
  - Analysis of the force transmission mechanism
  - Evaluation of the perpendicular force measurement principle
- Design of the force measurement subsystem including the suction cup and S-type load cell
- CAD modeling and assembly of the complete system
- Design of the aluminum profile table and dishwasher fixture
- Selection of bearings, motor and mechanical components
- Planning of manufacturing, assembly and testing processes
- Verification that the system can repeatedly open the dishwasher door to approximately  $68^\circ$  in 3 seconds while continuously measuring the true opening and closing force throughout the motion.

## Various Pictures of The Project

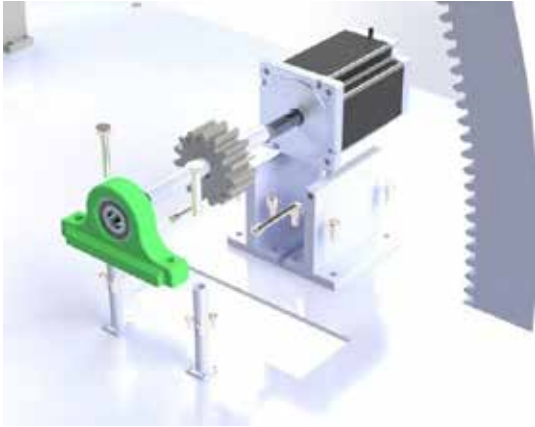


Figure 3: ArcDriver Parts

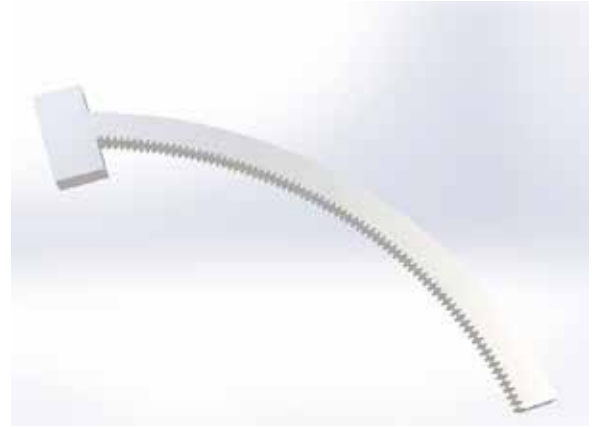


Figure 4: ArcDesign

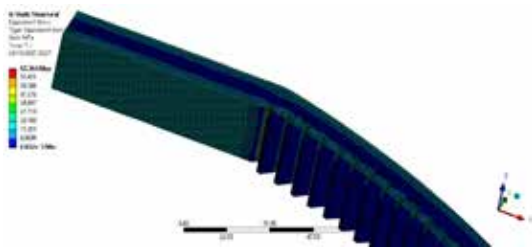


Figure 5: Finite Element Analysis (ANSYS) showing the Von Mises stress distribution on the Arc Rail under maximum loading conditions

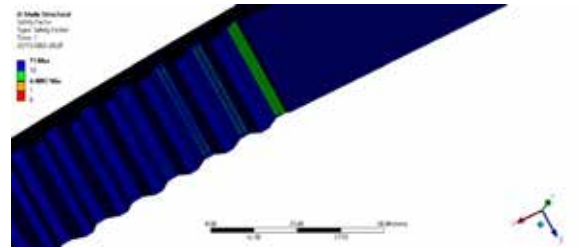


Figure 6: Finite Element Analysis (ANSYS) showing the safety factor on the Arc Rail under maximum loading conditions

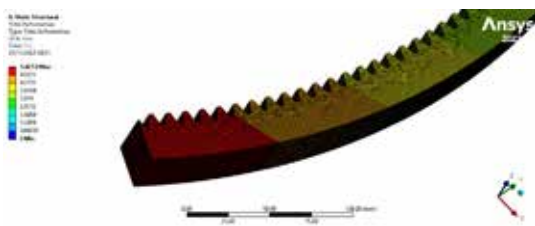


Figure 7: Finite Element Analysis (ANSYS) showing the total deformation on the Arc Rail under maximum loading conditions

## Design and Production of a Reversible Safe & Arm Device for Ammunition

### ARMECH



**Academic Advisor:** Assoc. Prof. Dr. Onur Özcan

**Industrial Advisor:** Utku Akman  
Kadri Onuk

**Teaching Assistant:** Okan Külekçiöglü

### ABSTRACT

This project presents a compact and high-reliability Safe-and-Arm mechanism designed to isolate the detonator from the main explosive in missile systems. The system operates in two states: Safe and Arm. In the safe state, the explosive train is mechanically blocked by two independent electromechanical locks, preventing failures during transportation, storage, and handling. In the arm state, the mechanism aligns the explosive train and enables controlled detonation only upon authorized input. The design meets strict size and weight constraints while maintaining fast response and robustness under high vibration and thermal loads. A key feature is its reversible behavior. A passive return mechanism automatically resets the system to the safe state in case of power loss, ensuring fail-safe operation under unexpected conditions. In addition, a real-time GUI-based monitoring system tracks both the position of the mechanism and the electrical behavior of its components. This enables continuous state verification ensuring that the system remains inert unless all activation conditions are satisfied.

## Problem Definition

Operational safety and mission reliability are critical in tactical missile systems. During transportation, handling, and flight, these systems are exposed to mechanical shocks and varying environmental conditions. The main challenge is to prevent unintended detonation while ensuring reliable activation when required. The warhead must remain completely inactive under all non-operational conditions. At the same time, it must activate instantly and correctly when the mission conditions are satisfied.

To prevent unintended initiation military safety protocols require the detection of at least two independent arming conditions. Parameters such as setback acceleration and elapsed time are commonly used to verify a valid launch sequence. This multi-condition requirement reduces the risk of false triggering caused by noise, vibration, or transient loads.

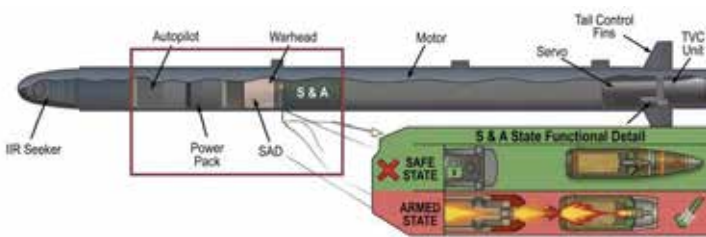


Figure 1: Safe-to-arm transition within missile system [1].

Purely mechanical systems are limited in timing precision and repeatability especially under dynamic conditions. In contrast, fully electronic systems offer higher control accuracy but may lack inherent fail-safe behavior. Therefore, electromechanical systems are preferred during the design.[2]



Figure 2: A Sample S&A Mechanism Housing in Fuze[2].

The size and weight of the system are key design constraints. The mechanism must fit within limited internal volume while preserving the missile's aerodynamic balance, flight range, and structural integrity. In addition, rapid response is required for high-speed engagement scenarios. The system must also remain reliable under harsh conditions, including multi DOF vibrations up to 2000 Hz and temperatures ranging from  $-54^{\circ}\text{C}$  to  $+71^{\circ}\text{C}$ , to ensure consistent performance in extreme environments.

As a final step, real-time GUI integration is conducted to monitor both the position and operational state of the mechanism. This enables real-time fault detection and reliable verification of safe and arm states.

Since high-precision is required in this mechanism, tolerances are a key design constraint, as excessive deviation can lead to misalignment, increased friction, or functional failure. While overly tight tolerances may increase manufacturing complexity and cost. Therefore, ASME Y14.5 is applied to achieve a balanced tolerance design.

[1] "MIL-STD-331D: Fuze and Fuze Components", *QuickSearch*, 2005. [Online]. Available: [https://quicksearch.dla.mil/qsDocDetails.aspx?ident\\_number=35944](https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=35944). [Accessed: 05-Apr-2026].

[2] "Safety and Arming (S&A) Mechanisms", *GlobalSecurity*, 2018. [Online]. Available: <https://www.globalsecurity.org/military/systems/munitions/fuzes-sa.htm>. [Accessed: 05-Apr-2026].

## Design



Figure 3 : 3D Model of the System

The system operates through a rack and pinion mechanism, where an electric motor drives a circular gear (pinion) to slide a linear track (rack). This linear movement is precision-controlled by two solenoids that act as physical "stoppers." By extending metal rods into the rack's path, these solenoids function as electronic gatekeepers, creating a physical barrier that limits the rack's travel to a specific range. Additionally, a third solenoid is positioned to engage directly with the pinion gear.

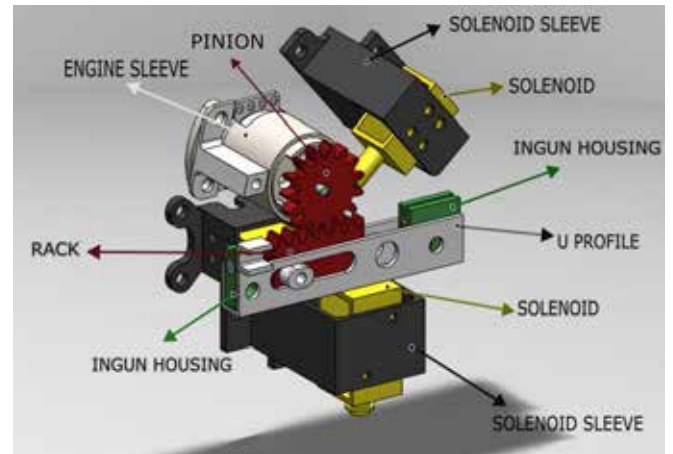


Figure 4 : Main Components of the System

This serves as a directional lock, preventing the gear from rotating in an clockwise direction and ensuring the mechanism stays firmly in its designated state. Safety and reliability are integrated into the design through a "fail-safe" return system. A torsion spring is integrated into the motor assembly, which remains under tension during normal operation. In the event of a power failure or system shutdown, the spring's stored energy is automatically released, forcing the motor and the rack back to their original safe position.

## Outcomes

This system is an electromechanical design project that combines the mechanical engineering knowledge acquired at dynamics, machinery dynamics and mechatronics courses. It is done in several steps through the 2025-2026 academic year given as below:

- Literature research
- Determination of sub-systems according to requirements provided by
- ROKETSAN Engineering analysis including:
  - Mathematical modeling
  - Static Structural Analysis
  - Kinematics analysis
  - Frequency response analysis
  - Thermal Strain Analysis
- CAD drawings
- Safety & Tolerance Analysis
- Electronic System Integration
- Planning of manufacturing processes, assembly, design verification and testing of the system

# Outdoor Robotic Cleaning Apparatus

## ORCA



**Academic Advisor :**Prof. Dr. Barbaros Çetin  
**Industrial Advisor:** Bülent Yalman  
**Teaching Assistant :**Altar Sertpoyraz

## ABSTRACT

This project aims to develop a prototype autonomous cleaning robot capable of detecting and removing dirt, trash, and debris in poolside environments while safely navigating around the pool perimeter. The system integrates multiple sensing modalities, including range-measuring sensors, an Inertial Measurement Units (IMUs), a camera, and LiDAR, to enable accurate perception and real-time decision-making. These sensors operate collaboratively to identify waste materials, estimate distances, and detect obstacles, ensuring reliable operation in close proximity to water and slippery surfaces. The robotic platform is designed to maneuver efficiently along pool edges and surrounding areas, maintaining stability and control under potentially challenging environmental conditions. Sensor data is processed through embedded control systems to support tasks such as obstacle avoidance, path planning, and target detection. Both uninformed and informed search algorithms are implemented to ensure precise navigation and effective cleaning performance, even in dynamic and cluttered poolside settings. The project also addresses system reliability and operational safety by considering environmental factors such as moisture, surface irregularities, and proximity to water. Potential failure modes are analyzed and mitigated through careful system integration and design optimization. Experimental validation is conducted in controlled test environments simulating poolside conditions to evaluate detection accuracy, navigation performance, and cleaning efficiency.

## Problem Definition

Poolside areas in outdoor recreational facilities are continuously exposed to environmental factors such as wind, dust, falling leaves, and user activities, leading to the accumulation of dirt, debris, and liquid spills throughout the day. These contaminants negatively affect both the hygiene and visual quality of the facility, creating an unpleasant and potentially unsafe environment for users. Maintaining clean poolside surfaces is essential not only for aesthetic reasons but also for preventing slip hazards and ensuring overall user safety.

Current cleaning practices primarily rely on manual labor using tools such as brooms, mops, and pressure washers. These methods are time-consuming, labor-intensive, and often inconsistent in terms of cleaning quality. Additionally, cleaning operations are carried out during off-hours, when staff is limited, increasing operational costs and reducing efficiency. Existing cleaning solutions are designed for indoor flat surfaces, making them unsuitable for outdoor poolside environments characterized by uneven tiles, moisture, and obstacles such as sunbeds.



Figure 1:Sports International Outdoor Pool Area

A significant challenge lies in developing a system that operates in dynamic environments while ensuring safety near pool edges. The robot must autonomously remove debris, navigate obstacles, and adapt to surface irregularities.



Figure 2: O.R.C.A.-Poolside Rendered Image

This project introduces an intelligent solution for poolside cleaning to improve hygiene, reduce manual labor, and enhance safety. By integrating advanced sensing and navigation, the system provides reliable, efficient, and safe operation under real-world conditions.



Figure 3:O.R.C.A.-Bottom View

## Design

The finalized design is a compact, circular platform ensuring stability and maneuverability in poolside environments. Its layered structure separates computation from power electronics, enhancing modularity. A Raspberry Pi 5 serves as the main processing unit for data acquisition and decision-making. For perception, a camera utilizes computer vision to detect contaminants, triggering a cleaning subsystem of rotating mops and a pump driven fluid dispenser. For navigation, an RPLIDAR S2 and IMU enable SLAM. Their data is fused via an Extended Kalman Filter for accurate localization and obstacle avoidance. Infrared sensors provide continuous monitoring to enforce safety constraints.

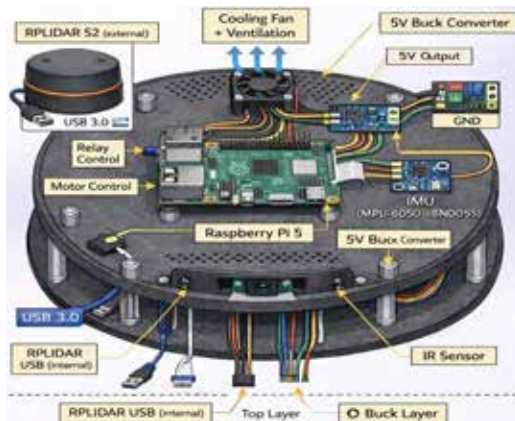


Figure4:O.R.C.A.-Circuit Diagram

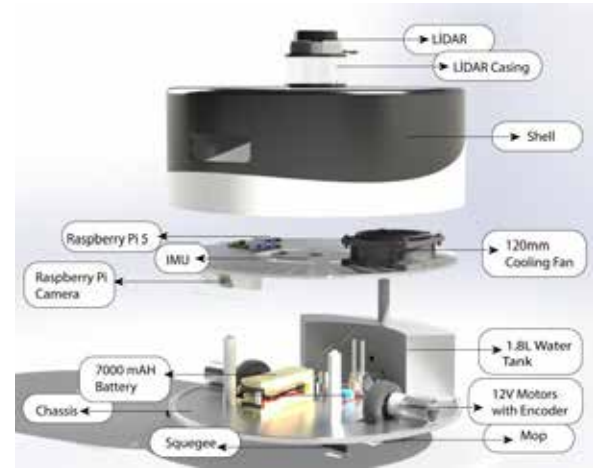


Figure 5:O.R.C.A.-CAD Exploded View

The power system uses a LiPo battery with buck converters for voltage regulation. Two TB6612FNG motor drivers control DC motors, while relay modules manage the pump. The software is built on ROS 2, facilitating modular communication between LiDAR, IMU, and navigation nodes. The navigation stack generates motion commands, and PID controllers ensure smooth motor regulation.

Overall, this cohesive framework integrates perception and actuation, enabling the robot to autonomously navigate and safely clean contaminated pool side areas.

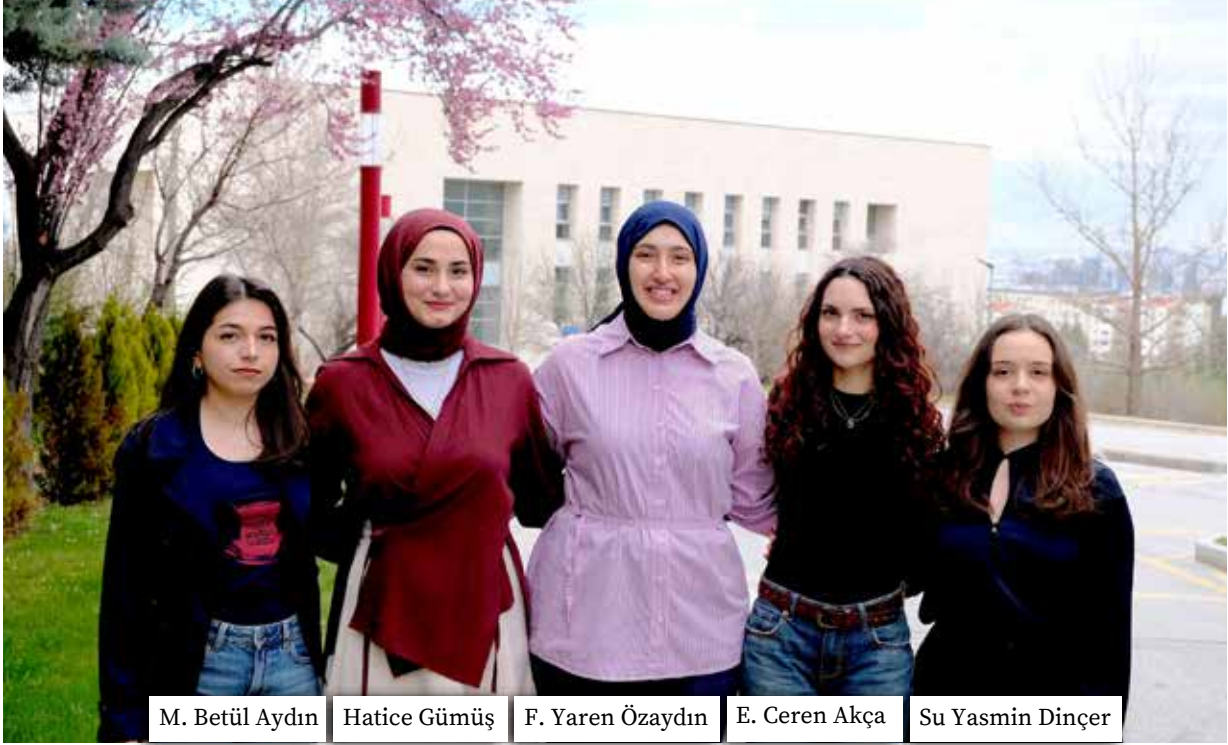
## Outcomes

This multidisciplinary mechatronics project integrates robotics, control, and mechanical design to develop an autonomous cleaning robot prototype. The key outcomes include:

- **System Specification:** Conducted literature reviews and selected appropriate sensing, actuation, and control subsystems.
- **Engineering Analysis:** Performed kinematic modeling, power calculations, PID control design, sensor fusion (LiDAR/IMU), and safety analysis.
- **Mechanical Design:** Created outdoor-ready CAD models integrating the cleaning mechanism (mop, tank, and pump).
- **Software Integration:** Implemented a ROS 2 architecture for SLAM, mapping, and computer vision-based dirt detection.
- **Manufacturing:** Fabricated, assembled, and wired the mechanical and electrical systems.
- **Validation:** Tested navigation accuracy, obstacle/edge avoidance, and overall cleaning efficiency in controlled poolside environments.

# Missile Fin Topology Optimization, Interface and Test Setup Design

## Rockets N'Roses



**Academic Advisor:** Assoc. Prof. Dr. Ali Javili

**Industrial Advisor:** Cengiz Kayahan Özlav

**Teaching Assistant:** Ömer Tarık Mumcu

## ABSTRACT

This project focuses on the design, optimization, and validation of a lightweight and high-performance missile fin under realistic aerodynamic and thermal loading conditions. Traditional solid fin designs introduce significant weight penalties, negatively affecting fuel efficiency, maneuverability, and overall system performance. To address this, topology optimization was applied to a fin with fixed external geometry using CFD-derived pressure and temperature distributions. The optimized internal structure was designed for manufacturability via metal additive manufacturing using Inconel 718. In addition to structural optimization, a mechanically robust and modular fin-missile interface was developed, and a static deflection test setup was designed to experimentally validate numerical predictions. The final design achieved a mass reduction of over 40% while satisfying all structural, dynamic, and deformation constraints, demonstrating the effectiveness of integrating topology optimization, advanced manufacturing, and experimental validation in aerospace applications.

## Problem Definition

Missile fins are critical components that ensure aerodynamic stability and control during flight. They are subjected to high aerodynamic forces, thermal loads due to air friction at high speeds, and dynamic effects such as vibration and potential flutter. These conditions require fins to be both structurally strong and thermally resistant.

Traditional fin designs rely on solid metallic structures, which provide durability but result in excessive weight. This added weight negatively impacts fuel consumption, reduces range, and limits maneuverability. Therefore, reducing structural mass while preserving mechanical performance is a key engineering challenge.

The problem becomes more complex due to multiple simultaneous design requirements. The fin must satisfy strict structural and dynamic constraints, including:

- Weight reduction  $\geq 30\%$
- Maximum stress  $\leq 500$  MPa
- Maximum deformation  $\leq 1$  mm
- Bending mode frequency  $\geq 200$  Hz
- Torsional mode frequency  $\geq 400$  Hz

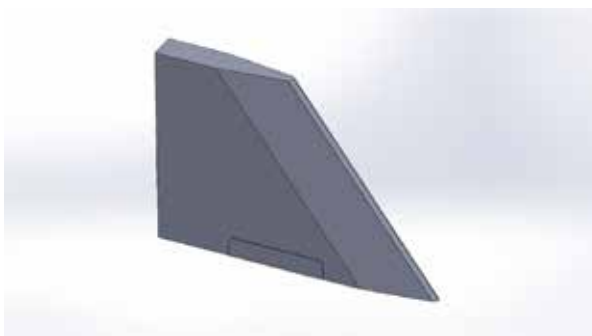


Figure 1: Fin Outer Geometry



Figure 2: Roketsan Missiles [1].

Additionally, the external geometry of the fin is fixed, limiting optimization to the internal volume. The design must also be compatible with metal additive manufacturing using Inconel 718, which introduces constraints such as minimum feature size and support requirements.

Beyond structural design, the fin must be integrated into a mechanically reliable interface with the missile body. In addition to the design, experimental validation is essential to verify the accuracy of numerical predictions. Therefore, a static deflection test setup must be developed to replicate realistic loading and boundary conditions. The system should allow precise measurement of displacement, making the design of a reliable and stable test setup an integral part of the problem.

This project addresses these challenges by combining topology optimization, advanced 3D printing manufacturing considerations, and experimental verification within a unified engineering framework.

[1] "Roketsan Roket San. ve Tic. A.Ş.," *Milli Savunma*, [Online]. Available: <https://www.millisavunma.com/roket-san-roket-san-ve-tic-a-s/>. [Accessed: Apr. 2, 2026].

## Design

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Figure 3 : 3D Model of the Test Setup

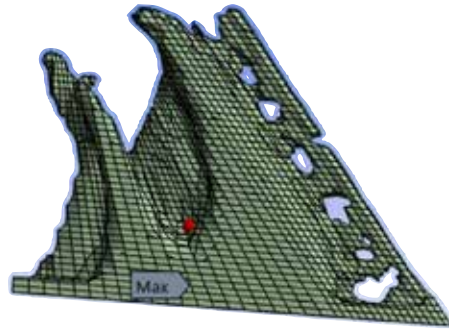


Figure 4 : Optimized ANSYS Result of the Fin

The project consists of the three main components: topology optimization of the fin, interface design, and experimental validation.

### Topology Optimized Fin

The internal structure of the fin was optimized using topology optimization. The external geometry was kept fixed, while material distribution inside the volume was modified to reduce weight and maintain stiffness. Regions with low stress contribution were removed, while load-bearing paths were preserved to ensure efficient force transfer. The resulting geometry was refined to meet additive manufacturing constraints.

### Fin-Missile Interface

A bolted fin-hub-shaft assembly was selected based on strength, manufacturability, reliability, and modularity criteria. The interface was designed using standard machine elements, including ISO 14581 bolts and angular contact bearings, ensuring efficient load transfer and ease of assembly.

### Static Deflection Test Setup

A test system was developed to validate the structural response of the fin. A controlled load is applied using a jack and measured via a load cell, while displacement and strain are recorded using a dial indicator and strain gauges. The setup enables comparison between experimental and simulation results.

## Outcomes

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The final design successfully satisfied all project requirements. All constraints were met with significant safety margins. Experimental validation showed strong agreement with numerical results, confirming the reliability of the design approach.

- Mass reduction: 43.19%
- Maximum stress: 256.6 MPa
- Maximum deformation: 0.25 mm
- Bending frequency: 862 Hz
- Torsional frequency: 464 Hz

## Zero-G and Hindle Mount Approaches for Undeformed Measurement of Optical Mirrors

### OptoMechanics



Atacan Gürlek	Ege Erdoğan	Dicle Sivri	Eren Yılmaz	Melih Fahri Arğalı	Yiğit Uzunoğlu
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**Academic Advisor:** Prof. Dr. Yiğit Karpaz

**Industrial Advisor:** Aykut Bakan

**Teaching Assistant:** Altar Sertpoyraz

### ABSTRACT

High-precision optical mirrors are critical components in infrared imaging, satellite payloads, laser systems, and scientific instrumentation, where even very small surface errors can degrade performance. In ground-based measurements, however, the self-weight of a large flat mirror may introduce gravitational sag when the part is removed from its assembly and placed on a conventional support. This makes it difficult to evaluate the true surface quality of the optic. The aim of this project is to develop a reusable support fixture for ASELSAN's LuphoScan interferometric measurement system that enables undeformed measurement of flat mirrors with diameters between 320 mm and 550 mm. The proposed solution is a 9-point Hindle mount that distributes the mirror weight through kinematically balanced support points to minimize surface deformation under 1g loading. The current study covers the design of the support architecture, prototype development, manufacturing planning, electronic control concept, and risk analysis for precise radial positioning of the support pins.

## Problem Definition

High-precision mirrors are essential in aerospace, defense, and space applications because optical quality directly affects imaging, tracking, targeting, and measurement accuracy. This importance is evident both in space telescopes, where mirror quality controls sensitivity and resolution, and in ASELSAN electro-optical systems such as TOYGUN 100 and ASELFLIR 600, which depend on stable, high-performance optical paths for reconnaissance and targeting. ASELSAN defines TOYGUN 100 as an integrated electro-optical sensor and targeting system for combat air platforms, while ASELFLIR 600 is a precision-stabilized EO surveillance and targeting system with a 325 mm common-aperture input mirror.

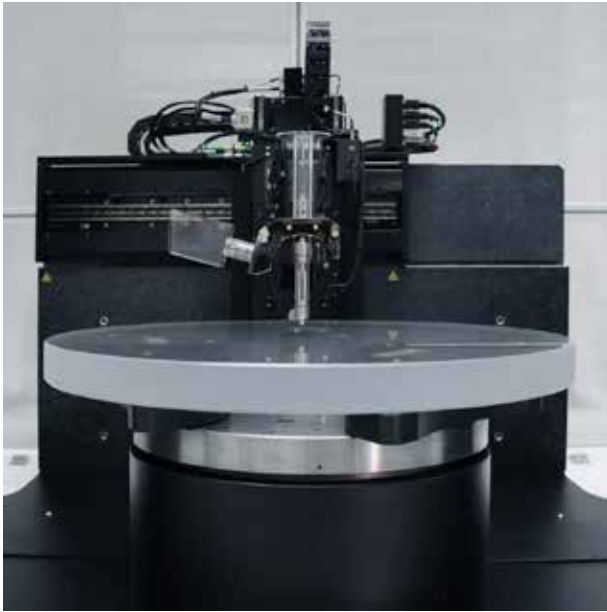


Figure 1: LumphoScan 820 [1]

The main difficulty in this project is that a large flat mirror may deform under its own weight during ground-based measurement. In that case, the measured surface no longer reflects only the manufactured optical quality, but also the deformation introduced by the support fixture. NASA notes that gravity sag in large optics can be orders of magnitude greater than the surface figure error being measured, which means that support-induced sag can overwhelm the very manufacturing defects that inspection is meant to detect.



Figure 2: Toygun-100 on Kızılelma [2]

As a result, it becomes difficult to decide whether a mirror is truly acceptable or whether the test setup is distorting the result. The engineering goal is therefore to develop a support fixture for ASELSAN's LumphoScan system that supports mirrors of 320-550 mm from the rear surface only, minimizes gravitational deformation, and allows reliable acceptance of the product based on its true surface quality.

[1] Taylor Hobson, "LUPHOScan600/850 HD -Non-contact 3D optical profiler," [Online]. Available: <https://www.taylor-hobson.com/products/non-contact-3d-optical-profilers/lumphos/lumphoscan-600-850-hd>. [Accessed: Apr. 3, 2026].

[2] B. Berber, "KIZILELMA TOYGUN EOTS ile havalandı: Dünyadailk," SavunmaSanayiST.com, 17 Nov. 2025. [Online]. Available: <https://www.savunmasanayist.com/kizilelma-toygun-eots-ile-havalandi-dunyada-ilk/>. Accessed: Dec. 12, 2025.

## Design



Figure 3: 3D Render of the Design

The proposed solution is a 9-point Hindle mount developed for the undeformed interferometric measurement of large flat optical mirrors. The system is designed to support the mirror from its non-optical rear surface and distribute its self-weight over carefully selected support points in order to reduce gravitational sag during measurement. The design targets mirrors with diameters between 320 mm and 550 mm and is intended to be compatible with ASELSAN's Lupho Scan metrology system.

## Outcomes

This project is a mechanical design study that integrates knowledge gained from courses such as dynamics, design and manufacturing, machine elements, and mechatronics. It is carried out in multiple stages throughout the 2025-2026 academic year, as outlined below:

- Literature research
- Determination of sub-systems according to requirements provided by ASELSAN
- Engineering analysis including:
  - System modeling
  - Mechatronic system construction
  - Mathematical modeling
  - Optimization
  - Gear design
  - Motor sizing, power and torque calculations
  - Uncertainty analysis
- CAD drawings
- Planning of manufacturing and procurement processes, assembly, design verification and testing of the system

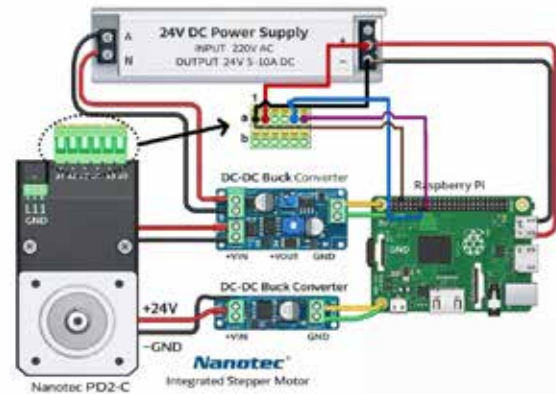


Figure 4: Diagram of the Stepper Motors

The final configuration includes several improvements over the initial concept. The support pins are mounted on linear rails for accurate radial positioning, while each triangular whiffletree plate is carried on a spherical pivot to allow self-alignment. In addition, ball transfer units are used to reduce friction, and bearing-guided centering elements are introduced to improve concentric motion of the main gear. With this arrangement, the mirror load is transferred through the support structure to 27 Delrin-tipped contact points, providing a more uniform and repeatable support condition during measurement.

## Various Pictures of The Project

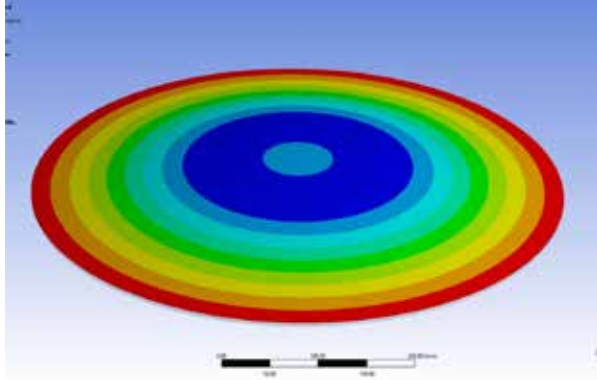


Figure 5: ANSYS Analysis of Current Setup



Figure 8: 3D Printed Prototype

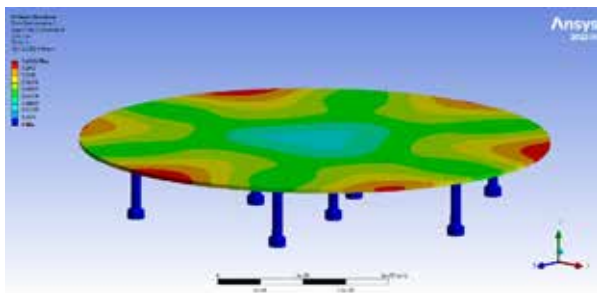


Figure 6: ANSYS Analysis of Proposed Design



Figure 7: Whiffle-Tree Supports

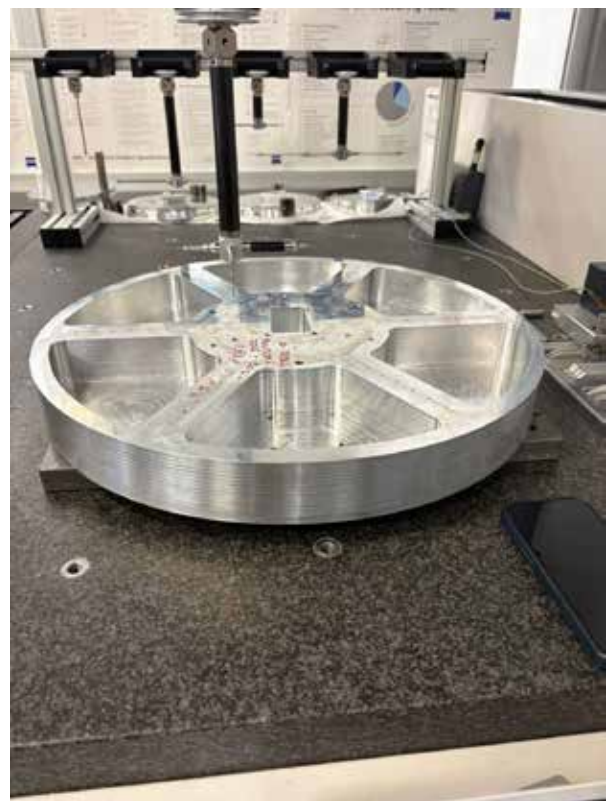


Figure 9: CMM Measurement of the Base Plate

# Design and Optimization of an Upper Spray Arm for Improved Water Distribution in Dishwashers

## Wash ME



**Academic Advisor:** Prof. Dr. Barbaros Çetin

**Industrial Advisor:** Dr. Muhammad Saqib

**Teaching Assistant:** Yunus Selçuk

## ABSTRACT

The aim of this project is to design and develop an upper spray arm to improve cleaning performance and reduce water consumption in the upper rack of dishwashers. Achieving a uniform cleaning performance in the upper rack is a challenging process because the limited design space of the upper spray arm restricts optimal nozzle configuration and spray efficiency. In order to prevent these problems, numerous spray arm geometries, nozzle numbers and nozzle arrangements were investigated to decrease water consumption and minimize blind spots which are particularly in the corners of the upper rack. The proposed solution of the project is to design a multi-component system consisting of a main arm and 3 disks. the arm splits into three branches in a Y-shaped configuration and disks are placed at the ends of the arm and rotate freely to improve spray coverage and eliminate blind spot issues in the corners. This project highlights the importance of nozzle configuration, internal flow design, and iterative prototyping in enhancing dishwasher performance while maintaining compatibility with industrial constraints.

## Problem Definition

Dishwashers are becoming essential home equipment, but maintaining a high level of cleaning performance in the upper rack is still very difficult. Conventional upper spray arms generally fail to clean the corners adequately although there are many advancements in the dishwasher industry such as improved detergents and efficient wash cycle programs. Due to geometric impediment and restricted spray coverage, items like bowls, mugs, and cups positioned in the corners sometimes receive insufficient water impact. Users frequently encounter inadequate cleaning as a result, which necessitates manual pre-rinsing, more wash cycles, and higher water usage.

Conventional spray arms generally have similar nozzle placements and sizes. These arrangements provide little variation in jet trajectories, despite being created using fundamental fluid dynamics concepts to provide rotation and a constant spray pattern. As a result, overlapping trajectories and persistent blind patches within the rack are frequently present in the resulting spray patterns. These restrictions prohibit adequate jet impingement in corner areas. Moreover, physical constraints such as length of the spray arm not exceeding 464 mm and distance between spray arm and top basket being 7.5 mm are essential to guarantee compatibility with Beko dishwashers.



Figure 1: Beko Dishwasher Spray Arm [1].

In this project, several engineering analyses including structural, kinematic and dynamic analyses with a mathematical model were conducted to examine various nozzle numbers, sizes and locations. As a result, the optimal configurations were selected and implemented to address problems like excessive water consumption in dishwashers and inadequate cleaning performance in the corners of the upper rack.

Overall, enhancing internal flow distribution, optimizing nozzle placement, and improving spray coverage while maintaining effective water usage are the key objectives of the spray arm design. The proposed spray arm design aims to enhance upper rack cleaning performance while lowering needless water and energy consumption by decreasing blind spots within the upper rack and boosting hydraulic action on complex dish geometries.

[1] "Beko Dishwasher Upper Wash Spray Arm," *Spares-2-Go*, [Online]. Available: <https://www.spares-2-go.com/products/beko-dishwasher-upper-wash-spray-arm-atlantis-bddn-bden-bdf13-dfn05-din16-din26>. [Accessed: 30-Mar-2026].

## Design

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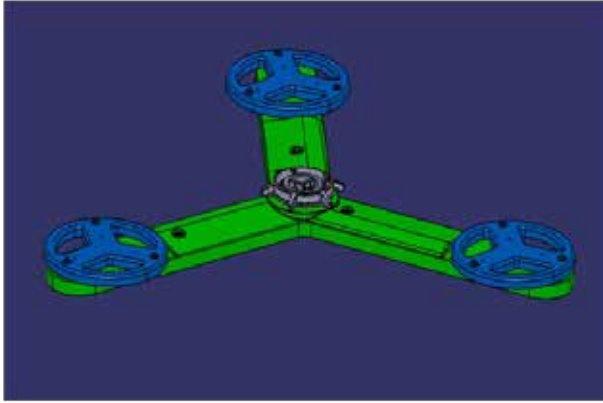


Figure 2: 3D Model of the Spray Arm

The final design is a three-arm design with equal angular spacing, incorporating circular disks. Each of the three equally spaced arms in this design holds a circular disk with several nozzles positioned at various angles. The extensive spray coverage this design offers is its main benefit. Each disk's varied nozzle directions allow the water jets to cover a larger area while rotating, reducing blind spots and improving the cleaning efficiency of the upper rack's corners. As a result, this leads to reduced water consumption by minimizing the need for additional wash cycles.

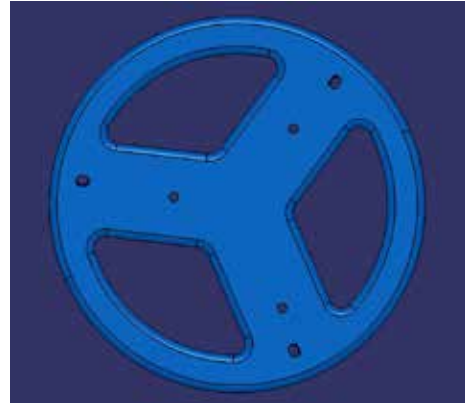


Figure 3 : 3D Model of a Nozzle-Integrated Disk

The main arm design features six nozzles. Three of these are rotating nozzles, positioned at the very end of each arm at a 60-degree angle. The washing nozzles, meanwhile, are located on the body of the main arm. They are positioned at varying distances from the arm's rotation axis. The purpose of this is to ensure the arm can scan the maximum area with each rotation. There are 6 nozzles on the disks, and 3 of these are rotation nozzles. Additionally, the washing nozzles on the disk are positioned at varying distances from the disk's rotation axis, similar to the main arm, to achieve maximum washing performance.

## Outcomes

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This project represents a comprehensive mechanical design effort that combines both theoretical and practical applications that is gained through dynamics, thermo-fluids and mechatronics courses. It is done in several steps through the 2025-2026 academic year given as below:

- Literature research
- Determination of subsystems according to requirements provided by BEKO
- Engineering analysis including:
  - Mathematical model
  - Kinematic and dynamic analysis
  - Structural Analysis
- CAD drawings
- Test setup design
- Planning of manufacturing processes, assembly, design verification and testing of the system

## Various Pictures of The Project

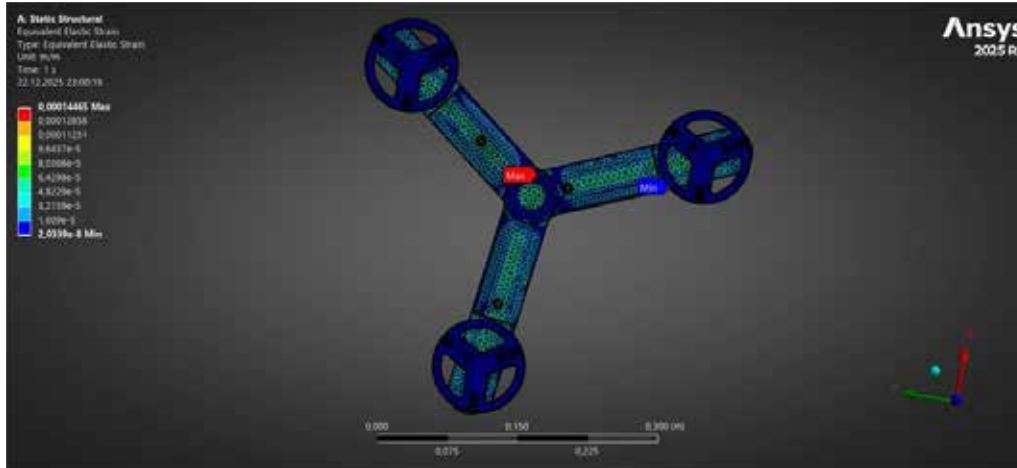


Figure 4: ANSYS Static Analysis



Figure 5: Assembly of the Spray Arm by the Project Team

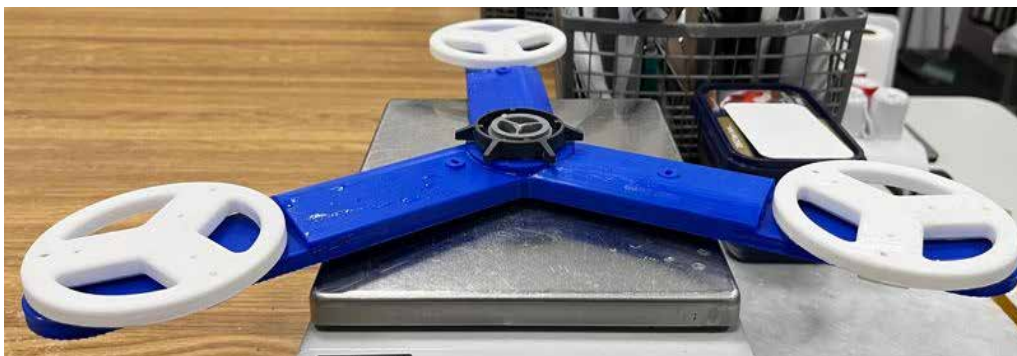


Figure 6: Assembled Spray Arm Design

## Various Pictures of The Project



Figure 7: Spray Arm Testing at Beko



Figure 8: Test Setup with the Spray Arm Installed

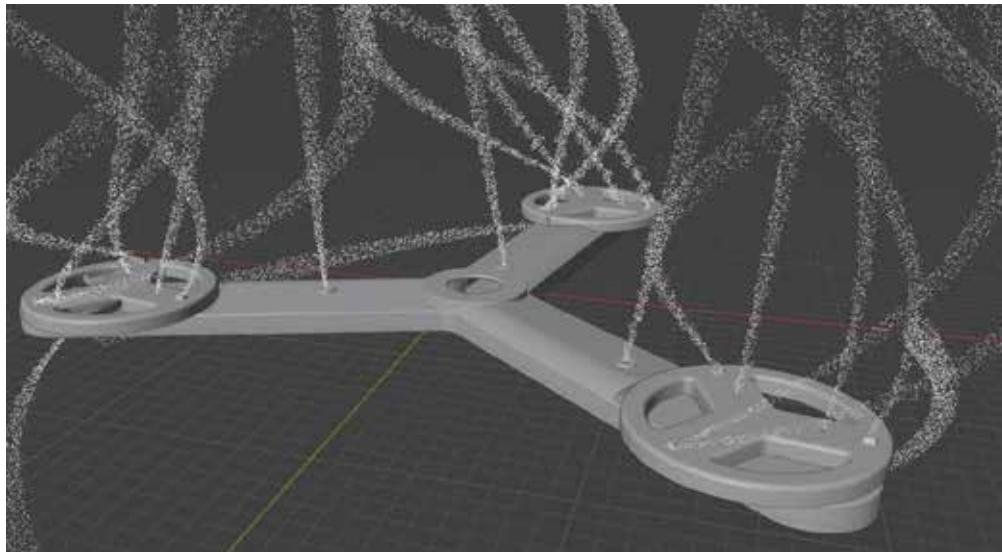


Figure 9: Simulated Spray Pattern of the Proposed Spray Arm Design

# Design and Production of a Sensitive Surface Temperature Controller for Electronic Cards

## Surface Temperature Controller



**Academic Advisor:** Prof. Dr. Barbaros Çetin

**Industrial Advisor:** Cankut Erkaya

**Teaching Assistant:** Ömer Tarık Mumcu

### ABSTRACT

The aim of the project is to design and develop multi zone surface temperature control system for electronic testing applications. In modern electronic system, heat generation on the printed circuit boards (PCBs) leads to hot spots that can negatively affect the performance and the reliability. Conventional cooling methods are often insufficient in providing precise and dynamic thermal regulation under varying thermal loads. The project aims to creating an actively controlled thermal management system capable of maintaining stable and repeatable temperature conditions in different test conditions. The solution product is a four zone thermoelectric cooler (TEC) based surface temperature controller setup. Each of the zones can operate independently, enabling localized temperature control with cooling capacity of 30 W per module. The system integrates a thermal structure consisting of a resistor heater, aluminum plate, TEC modules and heat sink with forced convection. The proposed solution enables active control of heat transfer from a heat source while maintaining stable temperature conditions and ensuring safe operation of the equipments.

## Problem Definition

Modern electrical systems generate significant heat due to high power levels. The generated heat creates local hot spots that can lead to performance instability or permanent component damage in printed circuit board (PCBs). For defense electronics, maintaining stable, reliable and repeatable temperatures is essential for ensuring long term reliability and performance.

Traditional cooling methods, such as air cooling, water cooling, fail to provide precise, dynamic temperature control because they are restricted by the ambient environmental conditions, pressure and the slow reaction time. To address these limitations thermoelectric cooling (TEC) method is utilized in the project. TECs offer a compact alternative solution which is capable of both heating and cooling within a single device. By using Peltier effect the system provide rapid response and high precision temperature regulation by using current with a DC power supply.



Figure 1: Heating of PCBs [1].

TEC modules are highly sensitive to the quality of thermal interface materials, applied contact pressure, and the temperature difference between their hot and cold sides. To prevent the module from overheating, both the transferred thermal load and the internal heat generated by the electrical current (Joule heating) must be continuously and effectively dissipated from the hot side.

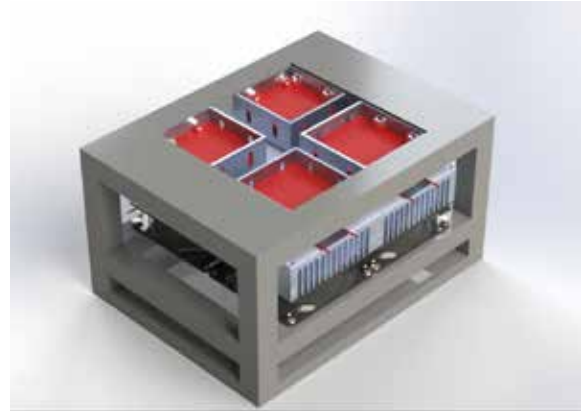


Figure 3 : 3D Model of the System

The proposed system addresses these issues by implementing an optimized heatsink with forced convection, developed using Computational Fluid Dynamics (CFD). To precisely control the temperatures, thermocouples continuously monitor both the hot and cold sides of the TEC modules. This real-time data feeds into a control architecture that utilizes a PID algorithm to dynamically adjust the power supplied to the TECs.

Operationally, the system requires four independent thermal zones, each utilizing a TEC with at least 30 W of cooling capacity. It must maintain a precise  $\pm 0.5^{\circ}\text{C}$  temperature accuracy and manage a minimum 10 W external heat load per zone, all while keeping the hot-to-cold side temperature difference ( $\Delta T$ ) below  $30^{\circ}\text{C}$  to ensure module efficiency

The system offers Meteksan Savunma a compact test set up to better understand the TEC capabilities and performance under varying heat loads.

[1] Burning PCB (Printable Circuit Board) Computer, " Shutterstock, [Online]. Available: [https://www.shutterstock.com/tr/image-illustration/burning-pcb-printable-circuit-board-computer-563629405?dd\\_referrer=ht ps%3A%2F%2Fwww.google.com%2F](https://www.shutterstock.com/tr/image-illustration/burning-pcb-printable-circuit-board-computer-563629405?dd_referrer=ht ps%3A%2F%2Fwww.google.com%2F). [Accessed: 05-Apr-2026].

## Design

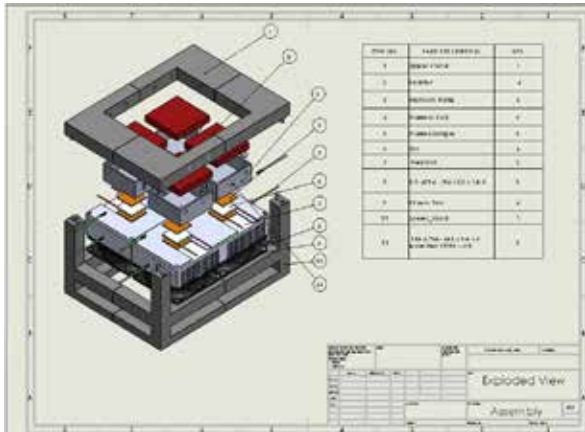


Figure 3 : Exploded View

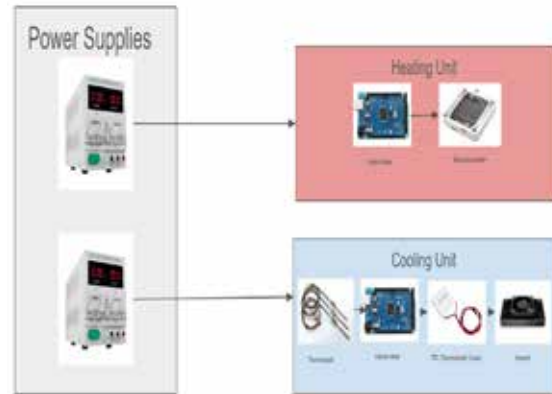


Figure 4 : Electronic Diagram

The final system design features four independent zones, each cooled by a dedicated TEC module. External heat loads are applied via resistor plates on aluminum blocks, while K-type thermocouples monitor both hot and cold side temperatures. To prevent overheating, each zone utilizes an aluminum heatsink and a 92 mm fan for forced convection, with airflow dynamically adjusted by the control system.

Each thermocouple interfaces with an Arduino Mega, which reads the temperature data and dynamically adjusts the cooling capacity of the TEC modules. A custom GUI allows real time control and monitoring. The system is powered by two 30V, 5A power supplies, one dedicated to control the heating and the other to control the cooling.

## Outcomes

This system is a mechanical design project that combines the mechanical engineering knowledge acquired at control systems and thermodynamics courses. It is done in several steps through the 2025-2026 academic year given as below:

- Literature research
- Determination of sub-systems according to requirements provided by Meteksan Savunma A.Ş
- Engineering analysis including:
  - Mathematical modeling
  - Control system construction and analysis
  - CFD simulation to optimize the geometry of heatsink.
  - Temperature response analysis
- CAD drawings
- Safety Analysis
- Planning of manufacturing processes, assembly, design verification and testing of the system

## Fully Mechanical Telescopic Antenna Mast System

### MeğMast—Milspec



Hüseyin Tunç Ahmet Tokdemir Berke İnce Umut Şeker Aslı Bayram Can Arslan

**Academic Advisor:** Prof. Dr. Barbaros Çetin

**Industrial Advisor:** Utku Büyükfidan

**Teaching Assistant:** Yunus Selçuk

### ABSTRACT

The objective of this project is to design a field-deployable, fully mechanical telescopic antenna mast system. Traditional masts often rely on electromechanical, hydraulic, or pneumatic actuation, which are susceptible to electronic failure, fluid leakage, and power dependency in severe environments. This project aims to provide a reliable alternative capable of elevating a 50 kg payload to a height of 7.5 m while withstanding wind speeds up to 90 km/h. The proposed solution is a five-stage structure utilizing graduated aluminum square profiles synchronized via an internal single-belt sequential actuation mechanism. Driven by a self-locking manual winch, the purely mechanical architecture eliminates all active subsystems, ensuring predictable performance with zero electrical dependency. This mechanism supports dual manual and drill actuation modes for operational flexibility. Finally, integrated cast polyamide guides prevent aluminum galling and offer vibration damping, providing a rugged, fail-safe system for repeated field deployment.

## Problem Definition

Portable communications systems are vital for military operations, as they require rapid deployment and high reliability under severe environmental conditions. Existing telescopic mast systems commonly utilize electromechanical, hydraulic, or pneumatic actuation, but these are often prone to complex failure modes that increase maintenance difficulty in the field. Failure to maintain these systems can lead to mission-critical delays in establishing line-of-sight wireless connections.



Figure 1: General Illustration of the Telescopic Antenna Mast System [1].

Fielded systems are specifically susceptible to electronic failure, hydraulic fluid leakage, and battery dependency, while environmental factors like sand, dust, ice, and water frequently cause contamination.

Architectural weaknesses in standard designs such as exposed drive cables make them vulnerable to disablement by shrapnel or bullets, where a single projectile can cause total mechanical failure or decompression. Repairs in remote environments are further constrained by the need for specialized tools or highly trained personnel.

U.S. Patent Jun. 12, 1990 Sheet 4 of 13 4,932,176

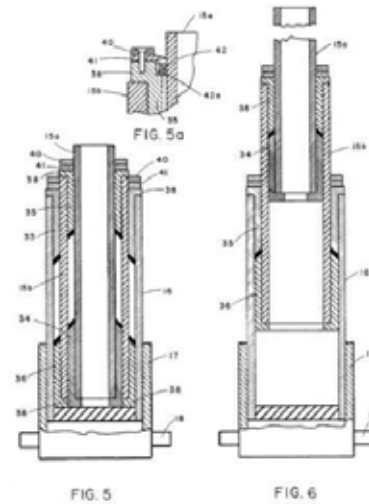


Figure 2: Internal Architecture and Vulnerabilities of Baseline Wire-Rope Mast Patent [3].

In terms of operation, the system must support a 50 kg payload at its maximum elevation and withstand wind loads corresponding to speeds up to 90 km/h. The deployment and retraction processes are required to be quick, typically completed within 5 minutes to meet the needs of time-critical operational scenarios. To ensure flexibility, the design must also support dual actuation modes, allowing for manual operation via a crank mechanism or assisted operation through a cordless drill interface.

The final product must be designed, analyzed, and verified in accordance with several internationally recognized engineering standards to ensure manufacturability and safety. Compliance with ISO 2768-1 defines acceptable dimensional tolerances, while ISO 281 provides the quantitative basis for evaluating the reliability of rolling bearings within the pulley system. Most importantly, the manual operation interface must comply with MIL-STD-1472H to ensure that the required input torque remains within the ergonomic limits of a single operator.

[1] "U.S. Patent 4,932,176 A | Wire-rope capstan mast | General Dynamics," Jun. 12, 1990.

[2] "MIL-STD-1472H | Department of Defense Design Criteria Standard: Human Engineering," U.S. Department of Defense, 2020.

[3] "EN 1991-1-4:2005 | Eurocode 1: Actions on structures - Part 1-4: Wind actions," European Committee for Standardization, 2005.

## Design

The design of the system was finalized as a five-stage telescopic structure that relies on a belt sequential actuation mechanism to provide the necessary operational height. The system is composed of five nested segments, a base-mounted manual winch, and a reinforced top platform where the communications equipment is housed. This cascading architecture was chosen because the internalized serpentine pulley path allows for synchronized movement and stable load transfer throughout the entire extension cycle.

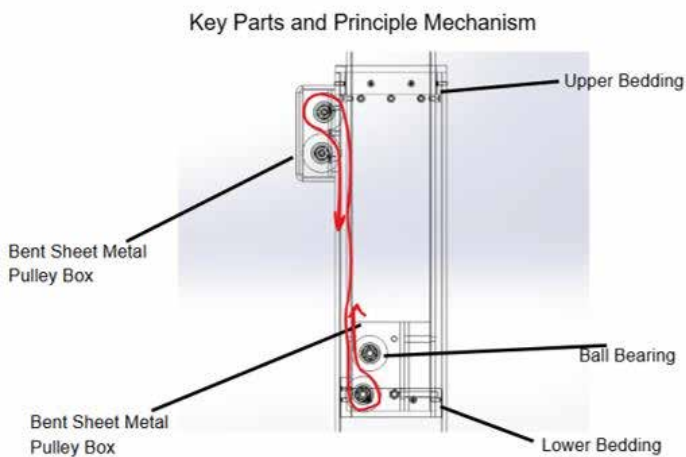


Figure 3: 3D Model of the System

The driving force of the drive train is provided by a manual winch secured to a custom-engineered mounting bracket on the 150 mm base segment. This specific winch was selected for its high load capacity and integrated friction brake, which automatically locks the mast under a 50 kg payload to prevent unintentional retraction.

The motion is transmitted via high-strength seat belt webbing that travels through an S-shaped routing across intermediate segments, terminating at a specialized internal belt clamping component in the top 60 mm stage.

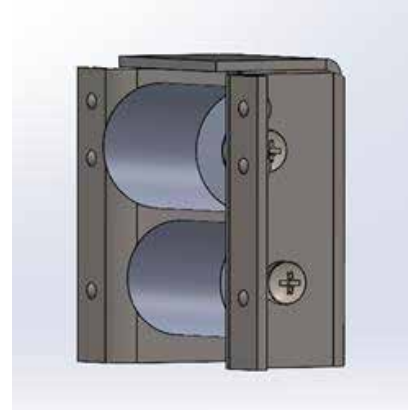


Figure 4: 3D Model of the Pulley Sub-assembly

The primary structural material consists of Al 6061-T6 and Al 6082-T6 aluminum alloys, selected for their high strength-to-weight ratio and corrosion resistance in extreme field conditions. The nested square box profiles provide a progressively increasing second moment of area from the innermost to the outermost segment, ensuring that the Euler buckling capacity scales with the high compressive loads at the base. Stability was further verified through linear eigenvalue analysis, confirming a substantial margin under worst-case wind loads using the critical load formula:

$$P_{cr} = \frac{\pi^2 EI}{(KL_{eff})^2}$$

To ensure precise linear alignment and smooth telescopic motion, specialized cast polyamide bearing Competitiononents are integrated into the system. These bearings are designed in internal and external configurations mounted at the top and bottom of each segment interface, effectively eliminating aluminum-on-aluminum contact to prevent surface galling.

[4] MIL-STD-1472H, "Department of Defense Design Criteria Standard: Human Engineering," U.S. Department of Defense, 2020. [5] ISO 281:2007, "Rolling Bearings -Dynamic Load Ratings and Rating Life," International Organization for Standardization.

By filling the radial gaps between segments, these cestamide guides also provide vital vibration damping and act as a functional seal against environmental debris like sand and dust. Mechanical safety is maintained through the use of high-strength bolt stops that act as physical hard-stops to ensure a mandatory 0.3 m overlap is always preserved between adjacent segments. The system is further optimized for vehicle-mounted operations through custom upper and lower mounting platforms that attach to a chassis or roof rack. This dual-point attachment strategy is essential for counteracting the dynamic bending moments and vibrations encountered during transit, providing a rigid foundation for the base assembly.

## Outcomes

This system is a mechanical design project that combines the mechanical engineering knowledge acquired at dynamics, manufacturing, and structural analysis courses. It is done in several steps through the 2025-2026 academic year given as below:

- Literature research and background procurement
- Determination of sub-systems according to operational requirements and design objectives
- Engineering analysis including:
  - Analytical and CFD wind load modeling
  - Static stress and Euler buckling analysis
  - Tolerance stack-up and thermal expansion shift calculations
- ISO 281 bearing life and MIL-STD-1472H ergonomics verification
- CAD drawings and mechanism layout
- Safety Analysis using Failure Mode and Effects Analysis (FMEA)
- Planning of manufacturing processes, assembly, design verification and testing of the system

## Various Pictures of The Project



Figure 5: Our team in on-site Manufacturing Progress

We performed FEA and CFD analyses using ANSYS to validate the structural integrity at full deployment under worst-case wind and payload conditions. Key results are presented below.

## Various Pictures of The Project

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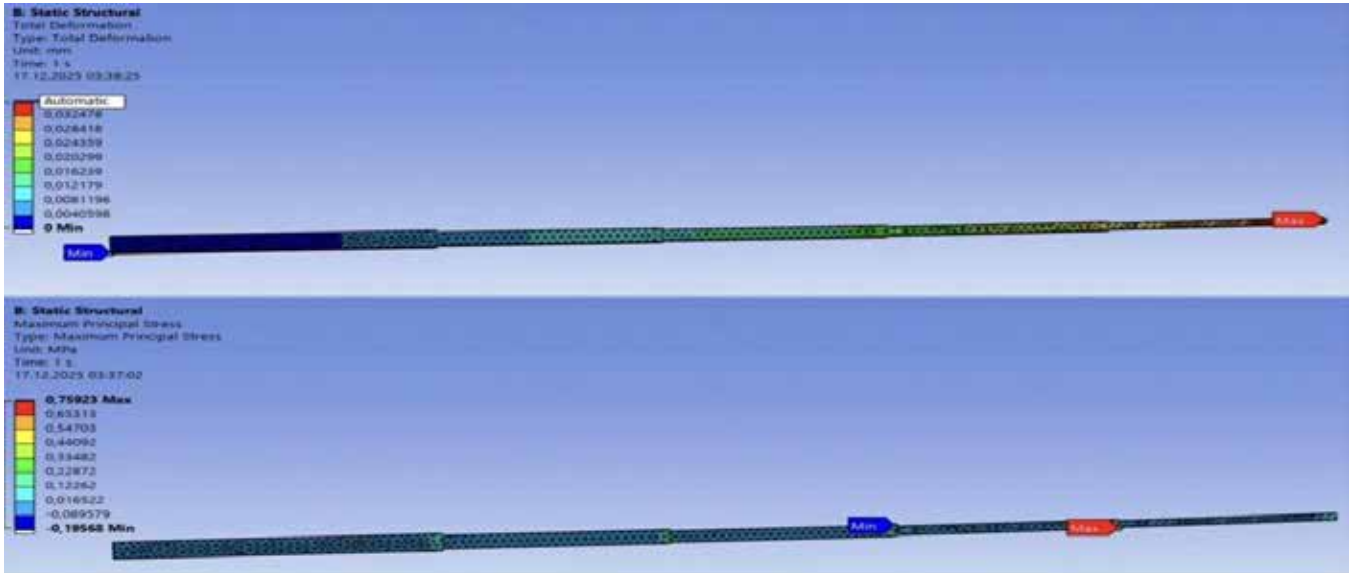


Figure 6: Static deformation and maximum principal stress distribution of the fully deployed mast under combined wind and payload loading.

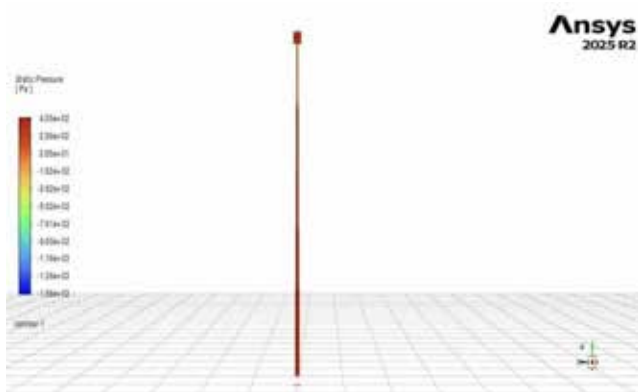


Figure 7: CFD static pressure acting on the mast at 90 km/h wind speed.

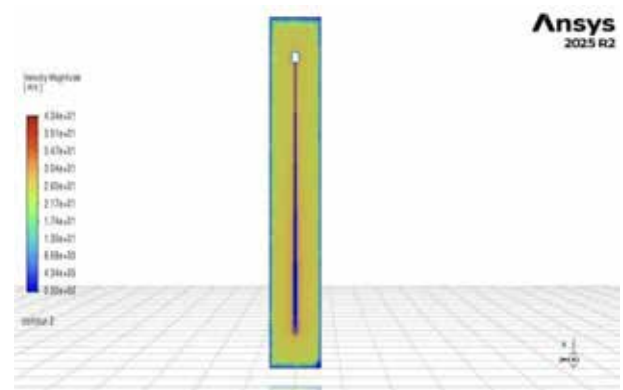


Figure 8: CFD velocity contours and wake region at 25 m/s free-stream velocity.

Our FEA results showed a peak stress of only 0.76 MPa which is well below the 250 MPa yield limit of Al 6061-T6. Also the first buckling mode came in at a load multiplier of 65.1, so structural stability is not a concern. On the aerodynamics side, CFD gave us 367.3 N of total drag at 90 km/h versus the 682.7 N we calculated analytically, which means we have roughly a  $1.9 \times$  safety factor built in.

Overall, the mast sits comfortably within safe limits under the harshest loading scenario we considered.

# 6 Segment Electromechanical Telescopic Antenna Mast System

## MAST-R PIECE



**Alperen  
Yıldırım**

**Tolga Cem  
Kiraz**

**Eylül  
Yeşil**

**Umay  
Uluata**

**Kaan Erdem  
Köse**

**Muhammet Ali  
Akdan**

**Academic Advisor:** Assoc. Prof. Dr. Onur Özcan

**Industrial Advisor:** Utku Büyükfıdan

**Teaching Assistant:** Yunus Selçuk

## ABSTRACT

The aim of this project is to design and produce an electromechanical telescopic antenna mast system for military communication applications, where antennas must be elevated to ensure reliable signal transmission under harsh environmental conditions. The mast is required to reach 6 meters when extended and 1.5 meters when retracted, carry approximately 50 kg payload, withstand wind speeds up to 90 km/h, remain below a total weight of 100 kg, and operate reliably under vibration conditions defined by MIL-STD-810. The solution product is a rope and pulley based electromechanical telescopic mast system driven by a 24 V DC motor, where force is transmitted through an external pulley configuration and separate cable system for each segment. Since the external pulley system provides better maintainability and manufacturability, and the separate cable configuration improves reliability and safety by isolating failures, these approaches were selected. In addition, a steel wire rope and circular tube profile were preferred due to their high strength, durability, and reduced stress concentration. The proposed system ensures controlled and efficient deployment, minimizes mechanical losses, and maintains stable operation under dynamic field conditions.

## Problem Definition

Reliable communication is critical in military operations, where antenna systems must be deployed quickly and operate under harsh environmental conditions. Electromechanical telescopic antenna masts are used to elevate communication equipment; however, these systems are exposed to external loads such as wind, vibration, and dynamic forces during operation. These kind of effects can reduce structural stability, cause misalignment and affect communication performance in a negative way.

The mast structure consist of six telescopic segments, a rope-driven lifting mechanism and mechanical transmission components. During operation, some of the factors such as friction losses, uneven load distribution, and environmental disturbances can give rise to unstable positioning of the antenna mast system or inefficient deployment. Since the system is mounted on military vehicles, it is subjected to continuous vibration and shock, which must meet MIL-STD-810 requirements. In addition, the steel wire rope used in the system must meet DIN 3060 standards to ensure adequate strength and durability.



Figure 1: General structure of the telescopic antenna mast system. [1].



Figure 2: Electromechanical telescopic mast in the field [2].

Another critical limitation is the need for a lightweight and compact design. The system must remain below 100 kg while still being capable of carrying approximately 50 kg antenna load and resisting wind speeds up to 90 km/h. To evaluate these requirements, computational fluid dynamics (CFD) analysis will be conducted to assess wind effects, while structural and vibration analyses have been performed to verify strength and dynamic behavior.

Moreover, the experimental testing will be implemented to validate the load-carrying capacity of the system under real conditions. Therefore, there is a need for a reliable, efficient, and mechanically stable telescopic mast system that provide reliable assurance of steady controlled deployment, withstands environmental loads, and maintains safe and precise antenna positioning in the harsh field conditions.

[1] Mastsystem, *EXB Vehicle Mast*, MastsystemInt'l Oy, 2026. [Online]. Available: <https://www.mastsystem.com/products/exb-vehicle-mast/>. [Accessed: 04-Apr-2026].

[2] Factory Direct, *Vehicle Pneumatic Telescopic Communicate Aerial Street Telescopic TV Aerial Poles Telescoping Antenna Masts*, Alibaba, 2026. [Online]. Available: <https://turkish.alibaba.com/product-detail/Factory-Direct-Vehicle-Pneumatic-Telescopic-Communicate-1600903911692.html>. [Accessed: 04-Apr-2026].

## Design



Figure 3 : 3D Model of the System



Figure 4 : Section View of 3D Model

The design of the antenna mast system was fully finalized as a six-segment telescopic structure developed in the basis of a rope and pulley mechanism to effectively achieve the required deployment height, developed using key engineering calculations including rope tension analysis, aerodynamic drag estimation, and bending moment evaluation under wind loading. Structural dimensioning was performed through stress analysis, with buckling effects considered because of the slender geometry of the tubes.

Each segment of the mast is connected through upper and lower flanges that guide the telescopic motion and provide fixation points for rope routing. The upper flanges act as fixed points, while pulleys change the direction of the applied force. The rope from the motor is routed through the pulleys and wrapped around the lower flanges, creating tension that effectively lifts each segment. This arrangement provides the capability of sequential movement, ensuring smooth and fully controlled extension while maintaining stability and efficient force transmission.

## Outcomes

This project focuses on the design, analysis, and realization of a telescopic antenna mast system by combining principles from mechanical engineering and control systems.

- Literature review on telescopic mast systems and lifting mechanisms
- Determination of system requirements based on operational constraints
- Engineering analysis including:
  - Rope tension calculations and load distribution
  - Aerodynamic drag force analysis (CFD)
  - Structural analysis (stress and deformation)
  - Buckling analysis of slender segments
  - Vibration analysis under MIL-STD-810 conditions
- Control system design, construction, and analysis
- Mechanical system modeling of the telescopic structure
- CAD design and technical drawings of all components
- Planning of manufacturing process, assembly, design verification and testing of the system

## Various Pictures of The Project



Figure 5: Manufactured Upper Flanges



Figure 6: Manufactured Lower Flanges



Figure 7: Six Telescopic Tubes



Figure 8: Pulley housing



Figure 9: (A) Steel Rope (B) Rope loop formed using a rope clamp (C) Pulley

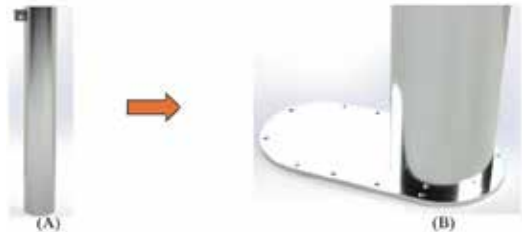


Figure 10: (A) Welding of pulley housing 1, tube 1 and (B) the main body

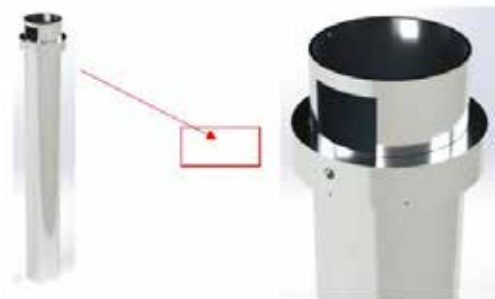


Figure 11: Installation of upper flange 1 onto tube 2



Figure 12: Rope 1 winding around pulley 1



Figure 13: Mounting of pulley 1 into pulley housing

## Various Pictures of The Project



Figure 14: Connection of rope 1 to lower flange 2

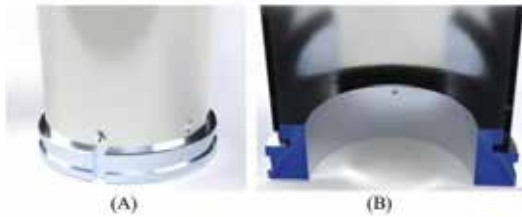


Figure 15: (A) installation of lower flange 2 onto tube 2 and (B) section view



Figure 16: Insertion of tube 2 into tube 1



Figure 17: Mounting of upper flange 1 onto tube 1 and fixing rope 1 to the motor line



Figure 18: Working for calculations



Figure 19: Motor preparation process through partial disassembly of components before installation.



Figure 20: The project team carrying out different tasks collaboratively during the assembly stage of the antenna mast.



Figure 21: Trial of Telescopic Tube Nesting and Fit



## Industry Supported Graduation Projects 2026

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