AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Specialized Program –junior level

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Fall 2025 Project: Air-Powered Vehicle

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1. Abstract

This project presents the design and manufacturing of an air-powered vehicle that operates using compressed air as its only source of propulsion. The main objective of the project is to achieve the fastest possible travel time over a distance of 10 meters while maintaining effective braking performance and minimizing the overall vehicle weight.

The vehicle consists of an integrated mechanical, fluid, and electrical control system. Compressed air stored in a pressurized tank is converted into kinetic energy through a selected propulsion technique to drive the vehicle forward. A remote-controlled electrical system is used to manage air discharge and activate the braking mechanism at the required point.

The design process involved mechanical stress analysis of the air tank, structural design of the chassis, selection of wheels, bearings, and fasteners, as well as the implementation of a control and braking system. Experimental testing was conducted to evaluate the vehicle's performance in terms of speed, braking distance, and total mass. The obtained results demonstrate the effectiveness of the proposed design in meeting the project requirements and constraints.

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2. Introduction

2.1 Project Overview

The Air-Powered Vehicle project aims to design and manufacture a small-scale vehicle that is driven solely by compressed air. The stored pressure energy in the air tank is converted into mechanical motion without using any form of electric propulsion. Electrical energy is limited only to control, sensing, and actuation purposes.

This project provides hands-on experience in integrating fluid mechanics, mechanical design, and control systems into a single functional prototype. It simulates real engineering challenges such as energy conversion efficiency, structural safety, weight optimization, and system integration.

2.2 Project Objectives

The main objectives of this project are:

- To design a vehicle capable of traveling a distance of 10 meters in the shortest possible time.
- To design and implement an effective braking system that minimizes the braking distance after crossing the finish line.
- To minimize the total weight of the vehicle while ensuring structural integrity and safety.
- To comply with all design constraints related to pressure, volume, materials, and operation.

2.3 Scope of Work

The scope of this project includes the following tasks:

- Design of the fluid propulsion system responsible for converting compressed air energy into motion.
- Mechanical design of the air tank, chassis, wheels, axles, bearings, braking system, and fasteners.
- Design and implementation of an electrical and control system for remote operation and braking.
- Manufacturing and assembly of the vehicle components.
- Testing and performance evaluation of the final prototype.

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3. Design Requirements and Constraints

3.1 Design Requirements

The air-powered vehicle must satisfy the following requirements:

- The vehicle shall be capable of traveling a distance of 10 meters from a stationary starting position.
- A reliable braking system shall be implemented to clearly stop the vehicle after completing the required distance.
- The vehicle shall be operated remotely using a wireless control system.
- The vehicle shall start from rest and operate in a stable and controlled manner during the run.

3.2 Design Constraints

The design of the vehicle is subject to the following constraints:

- The maximum air tank volume shall not exceed 3 liters.
- The maximum air pressure inside the tank shall not exceed 10 bar.
- All structural components of the vehicle must be manufactured from steel, except for wheels, brakes, and aerodynamic components.
- Electrical components shall not be used for vehicle propulsion; they are limited to control, sensing, and actuation only.
- The vehicle shall operate using onboard batteries, with no external power supply allowed.

4. System Overview

4.1 Components & Description

	Component	Function	Interaction
1	**Air Tank (Fire Extinguisher)**	Stores compressed air for operating the pistons	Supplies air to the pistons through solenoid valves
2	**Propulsion Piston (16 cm stroke)**	Converts compressed air into mechanical motion → drives the shafts/wheels	Connected to shafts and chains → transfers motion to the wheels
3	**Brake Piston (2.5 cm stroke)**	Applies pressure to the braking system	Controlled by Arduino via a solenoid valve → operates disc brake caliper
4	**Shafts (2)**	Transmit power from pistons to the wheels	Connected to sprockets and chains → drives all four wheels
5	**Chains & Sprockets (2 each)**	Transfer rotational motion between shaft and wheels	From the mechanical powertrain
6	**Bearings (4 Blamer Blocks – self-aligning)**	Support shafts and reduce friction	Mounted on chassis to hold shafts securely
7	**Solenoid Valves (2)**	Control air flow to each piston	Connected to Arduino for on/off control of propulsion and brake
8	**Relays (2)**	Electrically switch the solenoid valves	Controlled by Arduino
9	**Bluetooth Module**	Enables remote control of the vehicle	Communicates with Arduino to send commands for air valves
10	**Brakes (Disc Brake & Caliper)**	Stop the vehicle when needed	Operated by the small piston via solenoid valve

4.2 Working Principle

1. **Air → Propulsion:**

Compressed air from the fire extinguisher passes through the solenoid valve → pushes the large propulsion piston (16 cm) → motion is transferred via shafts, chains, and sprockets → drives the wheels.

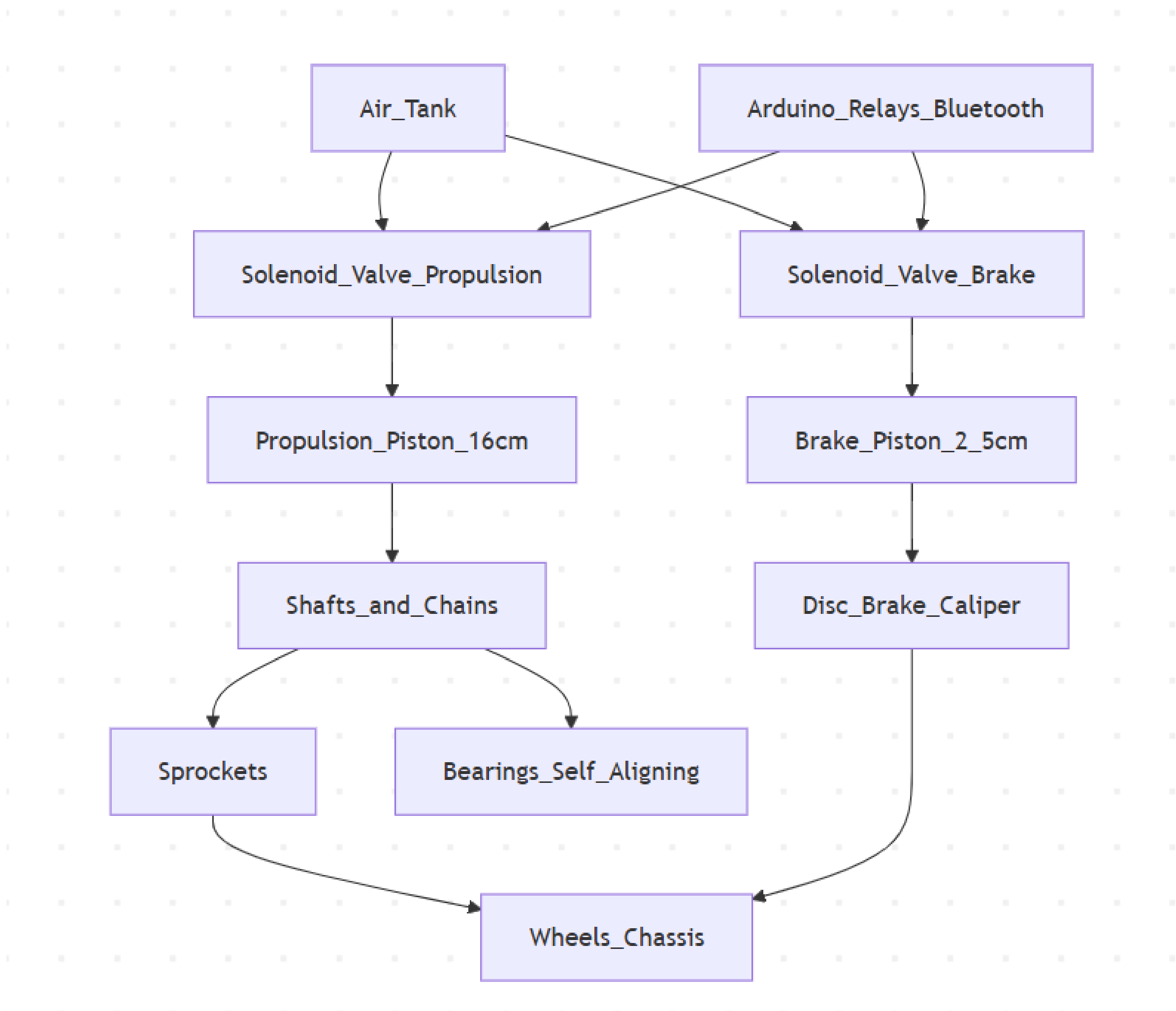
2. **Braking:**

To stop the vehicle, the Arduino sends a signal to the solenoid valve of the small brake piston (2.5 cm) → the piston presses the disc brake caliper → vehicle slows down or stops.

3. **Control System:**

The Arduino with Bluetooth module allows remote control → to activate propulsion or braking.

4.3 Block Diagram



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5. Fluid System Design

5.1 Propulsion Description

- The propulsion system is based on compressed air stored in a 3 L tank at 10 bar gauge pressure, controlled by an Arduino-operated solenoid valve. The available energy from the compressed air was calculated using isothermal expansion, and the useful energy (after accounting for efficiency losses) was shown to be significantly higher than the kinetic energy required to accelerate the 10 kg vehicle to 4 m/s. The required acceleration, thrust force, and propulsion power were then derived, and the nozzle exit velocity was used to estimate the required air mass flow rate. The analysis confirms that the compressed air propulsion system is feasible for the 10 m sprint within the project constraints.

1. $Given\ Data$

- $V = 3L = 0.003m^3$
- $P_g = 10bar$
- $P_1 = P_g + P_atm = 11bar = 1.1 \times 10^6 Pa$
- $P_2 = 1bar = 1 \times 10^5 Pa$
- $m\ =\ 10\ kg$
- $L\ =\ 10\ m$
- $v\ =\ 4\ m/s$
- $\eta = 0.5(overallpropulsionefficiency)$

2. $Assumptions$

- $1.\ Air\ behaves\ as\ an\ ideal\ gas.$
- $2.\ Expansion\ is\ approximately\ isothermal.$
- $3.\ Nozzle - based\ propulsion\ with\ uniform\ thrust.$
- $4.\ Rolling\ resistance\ and\ aerodynamic\ drag\ are\ neglected.$

3. $Available\ Energy\ in\ Compressed\ Air$

- $E_air = P_1 V ln(P_1/P_2)$
- $E_air = (1.1 \times 10^6)(0.003) ln(1.1 \times 10^6/1 \times 10^5)$
- $E_air = 3300 ln(11)$
- $E_air \approx 3300 \times 2.398$
- $E_air \approx 7914J$
- $E_useful = \eta E_air$
- $E_useful = 0.5 \times 7914$
- $E_useful \approx 3957J$

4. $Required\ Kinetic\ Energy\ of\ the\ Vehicle$

- $KE = 1/2mv^2$
- $KE = 1/2 \times 10 \times 4^2$
- $KE\ =\ 80\ J$

5. $Energy\ Feasibility\ Check$

- $E_useful = 3957J \gg KE = 80J$
- $Therefore, the\ compressed\ air\ energy\ is\ sufficient\ to\ accelerate\ the\ vehicle\ to\ the\ desired\ velocity.$

6. $Required\ Acceleration\ and\ Driving\ Force$

- $v^2 = 2aL$
- $a = v^2/(2L)$
- $a = 4^2/(2 \times 10)$
- $a = 16 / 20$
- $a = 0.8m/s^2$

7. $Requiredpropulsionforce(including\ efficiency):$

- $F = \eta\ m\ a$
- $F = 0.5 \times 10 \times 0.8$
- $F = 4\ N$

8. $Time\ and\ Power\ Requirement$

- $t = v / a$
- $t = 4 / 0.8$
- $t = 5\ s$

9. $Average\ propulsion\ power:$

- $P = KE / t$
- $P = 80 / 5$
- $P = 16\ W$

10. $Nozzle - Based\ Propulsion\ Analysis$

- $F = \dot{m} v_e$
- $v_e = 200m/s$
- $\dot{m} = F/v_e$
- $\dot{m} = 4 / 200$
- $\dot{m} = 0.02\ kg/s$

$11. Propulsion\ System\ Description$

- $Compressed\ air\ tank\ (3L, 11 bar absolute)$
- $Solenoid\ valve\ for\ flow\ control$
- $Converging\ nozzle\ to\ generate\ thrust$

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6. Mechanical Design

6.1 Air Tank Design

1. Tank Description

A commercially available steel dry powder fire extinguisher was used as the compressed air storage tank.
The selected tank has an approximate internal volume of 2.8 liters and is designed to safely store compressed air for the propulsion system. Since detailed manufacturer data was unavailable, standard dimensions for fire extinguishers of similar capacity were assumed for design verification.

2. Design Parameters

The design parameters used in the analysis are summarized below:

- Operating pressure:

$$p = 10 \text{ bar} = 1 \text{ MPa}$$

- Outer diameter:

$$D_o = 110 \text{ mm}$$

- Outer radius:

$$r_o = 55 \text{ mm}$$

- Wall thickness:

$$t = 1.5 \text{ mm}$$

- Inner radius:

$$r_i = r_o - t = 55 - 1.5 = 53.5 \text{ mm}$$

- The tank material is steel with an assumed yield stress of:

$$\sigma_y = 250 \text{ MPa}$$

- A factor of safety of 2 is applied.

3. Stress Analysis (Thick Cylinder Theory)

According to the project requirements, thick cylinder theory is used to evaluate the hoop stress in the tank wall.

- The maximum hoop stress is calculated using the following equation:

$$\sigma_h = \frac{p\, r_i^2 (r_o^2 + r_i^2)}{r_o^2 - r_i^2}$$

- Substituting the design values:

$$\sigma_h = \frac{1 \times (53.5)^2((55)^2 + (53.5)^2)}{(55)^2 - (53.5)^2}$$

$$\sigma_h \approx 38 \text{ MPa}$$

4. Allowable Stress and Safety Check

- The allowable stress for the steel tank is calculated as:

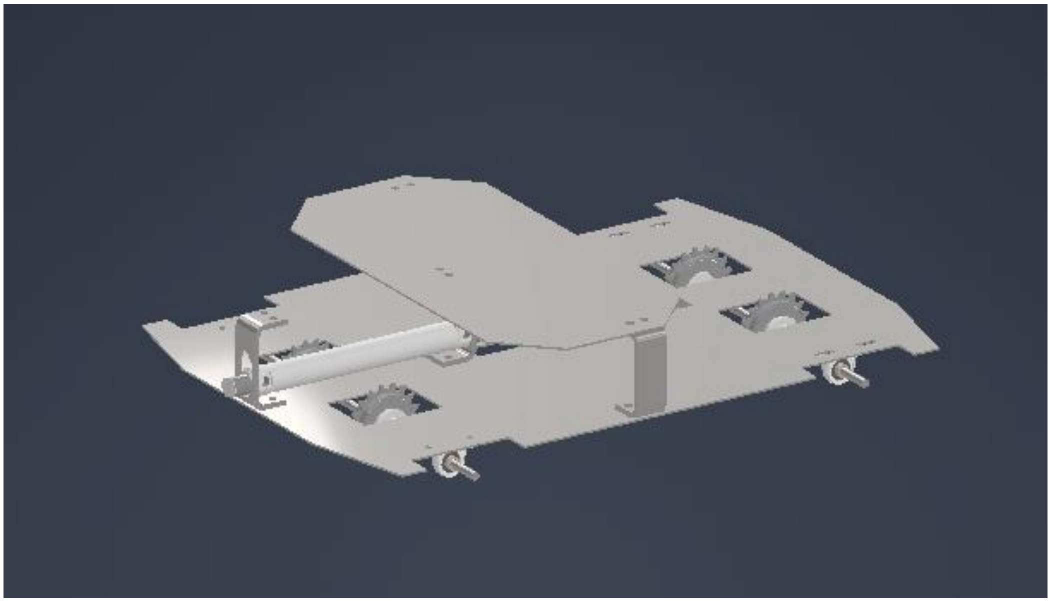
$$\sigma_{allow} = \frac{\sigma_y}{FOS} = \frac{250}{2} = 125 \text{ MPa}$$

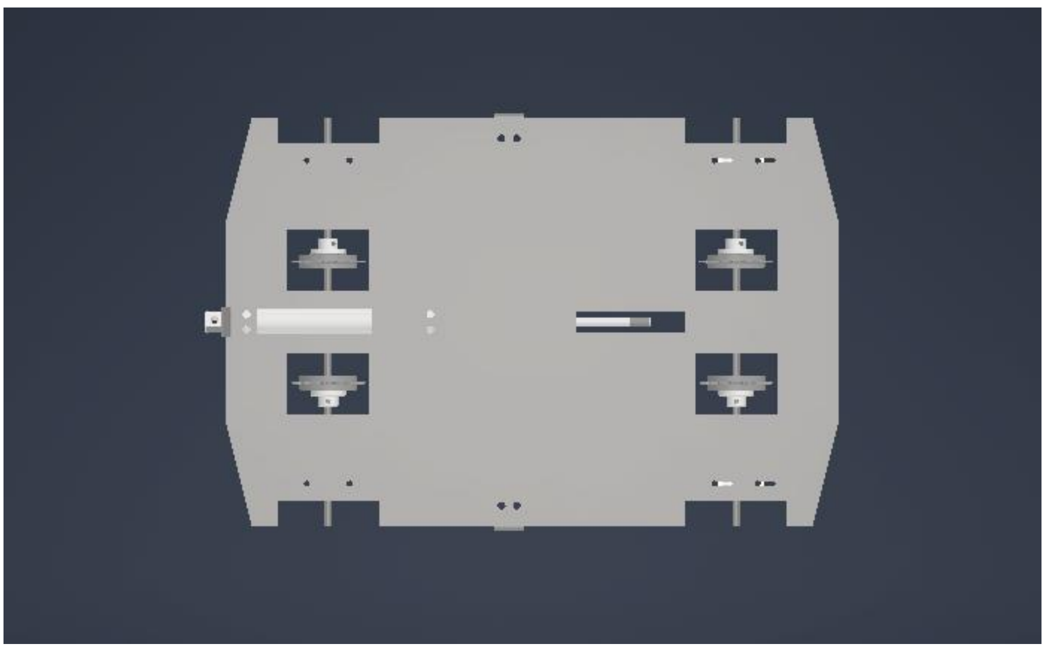
- Comparing calculated hoop stress with the allowable stress:

$$\sigma_h = 38 \text{ MPa} < \sigma_{allow}$$

The calculated hoop stress in the air tank is significantly lower than the allowable stress of the steel material. Therefore, the selected fire extinguisher tank with an outer diameter of 110 mm and a wall thickness of 1.5 mm is considered safe for operation at an internal pressure of 10 bar.

6.2 Chassis Design





- The chassis represents the primary structural element of the vehicle, responsible for supporting all mechanical, fluid, and electrical components while ensuring sufficient stiffness and structural integrity. According to *Automotive Chassis Engineering* by Barton and Fieldhouse, an effective chassis design must provide an optimal balance between strength, stiffness, and weight, while maintaining simplicity and manufacturability.

- In this project, a **sheet metal chassis configuration** was selected to suit the small-scale air-powered vehicle prototype. Sheet metal construction offers several advantages for lightweight experimental vehicles, including low mass, ease of manufacturing, and sufficient load-carrying capability when properly shaped and reinforced. Since the vehicle is not a full-size automobile, the chassis design focuses on supporting localized loads rather than complex crash or suspension loads.

- The chassis consists of a flat sheet metal base that serves as the main load-bearing structure, with a secondary upper sheet mounted above it to support the air tank and control components. This layered configuration improves structural rigidity and helps distribute concentrated loads over a wider area, reducing local stresses.

- The design philosophy follows the principle of **direct load paths**, where loads from the air tank, propulsion system, wheels, and braking mechanism are transferred efficiently to the chassis without inducing excessive bending or torsion. Weight reduction was a key consideration; therefore, unnecessary structural elements were eliminated while maintaining adequate stiffness for stable operation over the required travel distance.

- Overall, the selected chassis design satisfies the project requirements by providing a lightweight, simple, and structurally sound platform suitable for the air-powered vehicle prototype.

6.3 Wheel, Axle & Bearings

1. Wheel Diameter Selection

- The wheel diameter was selected based on a trade-off between achievable vehicle speed and required driving torque. For an air-powered vehicle with limited available force, a smaller wheel radius reduces the required torque at the axle and improves acceleration and controllability.

- Assuming a conservative driving force of 50 N, a wheel radius of 0.06 m results in a required torque of approximately 3 N.m, while larger wheel diameters would significantly increase the torque demand. Therefore, a wheel diameter of 12 cm was selected as an optimal compromise that provides sufficient speed while maintaining low torque requirements and effective braking performance.

- Wheel diameter chosen is 12 cm

1. Bearings Calculations:

The total vehicle weight is assumed to be uniformly distributed among the four bearings. Therefore, the radial load acting on each bearing is calculated as:

$$F_r = \frac{W}{4} = \frac{98}{4} = 24.5\ N$$

- Assume $l_{10} = 10^6\ revolutions$

$$C = P \times L_{10}^{\frac{1}{3}}$$
$$C = 24.5 \times 10^{\frac{6}{3}} = 2450\ N$$
$$C_d \geq 2450\ N$$

- Chosen Bearing: Self Aligning 608 Bearing with $C_d \approx 3300\ > 2450$ (suitable)
- Static Check:

$$F_r = 24.5\ N$$
$$C \approx 1300\ N$$
$$FoS_{static} = \frac{1300}{24.5} \approx 53$$

2. Axle diameter calculations

- Torque transmitted = $F_r \times r = 24.5 \times 0.06 = 3\ N.m$
- Allowable shear stress for steel = 40 MPa

$$\tau = \frac{16T}{\pi d^3}$$
$$40 \times 10^6 = \frac{16 \times 3}{\pi d^3}$$
$$d^3 = 3.8 \times 10^{-7}$$
$$d \approx 7.3\ mm$$

- Axle diameter = 8 mm

6.4 Powertrain Design

6.4.1 Powertrain Components

Components Used:

- **Compressed air piston (stroke = 16 cm)** – main propulsion actuator
- **Two shafts** – transmit motion to the wheels
- **Two sprockets** – mounted on shafts
- **Two chains** – transfer motion between sprockets
- **Four wheels** – vehicle motion
- **Four self-aligning bearing blocks (Plummer blocks)** – shaft support and alignment

6.4.2 Working Principle of the Powertrain

- Compressed air stored in the fire extinguisher tank is released through a solenoid valve to the propulsion piston.
- The linear motion of the piston is converted into rotational motion using a mechanical linkage connected to the primary shaft.
- The rotational motion is transmitted from the primary shaft to the secondary shaft using a **chain–sprocket mechanism**.
- Both shafts are connected to the wheels, allowing synchronized rotation and forward motion of the vehicle.
- Self-aligning bearing blocks are used to reduce friction and compensate for slight misalignment between shafts.

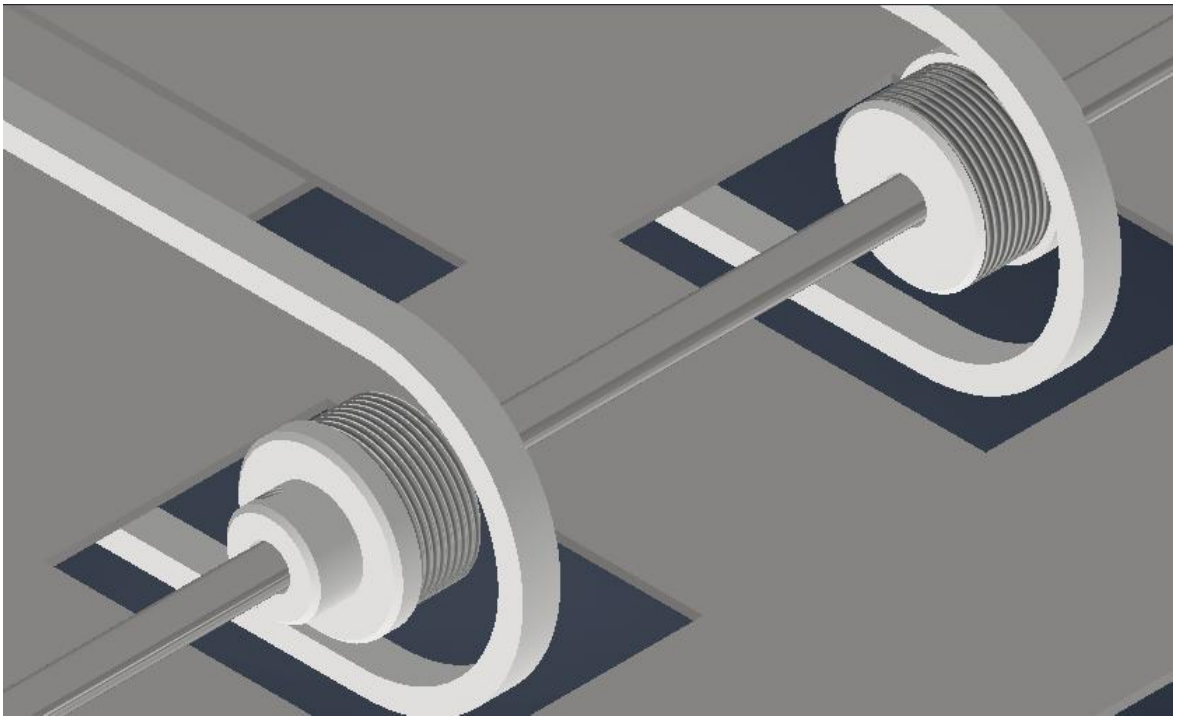
6.4.3 Chain and Sprocket Transmission

- Chain drive is selected because:
  - High torque transmission
  - No slippage compared to belts
  - Suitable for low-speed, high-load applications
- Both sprockets are selected to have:
  - Compatible pitch with the chain
  - Appropriate diameter to achieve the required speed–torque balance

6.4.4 Bearings and Mechanical Support

- **Bearing type**: Self-aligning Plummer block bearings
- Advantages:
    - Allow angular misalignment
    - Reduce assembly errors
    - Increase system reliability

6.4.5 Powertrain Layout



6.5 Brake System Description and Selection

- A disc brake system actuated by a pneumatic cylinder was used in this project. The brake disc is mounted on the wheel shaft, and braking is achieved when a pneumatic cylinder applies a clamping force to the brake pads through the caliper. The pneumatic cylinder is controlled electronically using an Arduino and a 12 V relay that actuates a solenoid valve. Electrical energy is used only for control, while the braking force is generated pneumatically.
- A disc brake was selected instead of a drum brake due to its better heat dissipation, simpler construction, and more predictable braking behavior. Disc brakes provide a linear relationship between braking torque and applied normal force, which simplifies

analysis and control. In addition, disc brakes are easier to integrate with a pneumatic actuator and require less maintenance compared to drum brakes.

- **Braking System Analysis (Pneumatic Disc Brake)**

Assume:

Vehicle mass, m = 10 kg
Vehicle speed, v = 4 m/s
Stopping distance, d = 0.2 m
Wheel radius, rw = 0.06 m
Disc effective radius, rd = 0.05 m
Coefficient of friction, μ = 0.35

1. **Braking Force**

$$\frac{1}{2}mv^2 = F_b d$$

$$F_b = \frac{mv^2}{2d}$$

$$F_b = \frac{10 \times 4^2}{2 \times 0.2}$$

$$F_b = \frac{160}{0.4}$$

$$F_b = 400\ \text{N}$$

2. **Required Wheel Brake Torque**

$$T_{\text{wheel}} = F_b r_w$$

$$T_{\text{wheel}} = 400 \times 0.06$$

$$T_{\text{wheel}} = 24\ \text{N·m}$$

3.

$$T_{\text{disc}} = T_{\text{wheel}}$$

$$T_{\text{disc}} = 24\ \text{N·m}$$

4. **Normal Force on Brake Pads**

$$T_{\text{disc}} = \mu F_n r_d$$

$$F_n = \frac{T_{\text{disc}}}{\mu r_d}$$

$$F_n = \frac{24}{0.35 \times 0.05}$$

$$F_n = \frac{24}{0.0175}$$

$$F_n = 1371\ \text{N}$$

5. **Force per Brake Pad**

$$F_{\text{pad}} = \frac{F_n}{2}$$

$$F_{\text{pad}} = \frac{1371}{2}$$

$$F_{\text{pad}} = 686\ \text{N}$$

6.Pneumatic Cylinder Sizing

$$F_{\text{cyl}} = PA$$

$$A = \frac{F_{\text{cyl}}}{P}$$

$$A = \frac{1371}{6 \times 10^5}$$

$$A = 0.00229\ \text{m}^2$$

$$d = \sqrt{\frac{4A}{\pi}}$$

$$d = \sqrt{\frac{4 \times 0.00229}{\pi}}$$

$$d = 0.054 \text{ m}$$

$$d = 54 \text{ mm}$$

- **Conclusion**

A pneumatic cylinder with a bore diameter between 50–63 mm is sufficient to safely generate the required braking force. Electrical power is used only for control via Arduino and relay, ensuring full compliance with project rules.

6.6 Fasteners Design

1. Design Data

- Total vehicle weight:

$$W = 98\, N$$

- Number of bearings = 4
- Load per bearing:

$$F_r = \frac{98}{4} = 24.5\, N$$

- Bolts per bearing = 2

$$F_{ext} = \frac{24.5}{2} = 12.25\, N$$

This external load is very small and acts mainly in shear.

2. Design Criterion

Since the joint is bolted:

- The external load must be resisted by friction

- Therefore, a sufficient preload must be generated

Design condition:

$$F_i \gg F_{ext}$$

Bolt size will be selected based on:

- Achievable preload
- Resulting tightening torque
- Practical robustness of the joint

3. Assumptions

- Bolt material: steel
- Pitch = 0.8 mm
- Thread angle $\alpha = tan^{-1} \frac{p}{\pi d_m}$
- Proof stress:

$$\sigma_p = 580\, MPa$$

- Target preload:

$$F_i = 0.7\, \sigma_p\, A_t$$

- Friction coefficients:

$$\mu_t = 0.15, \mu_b = 0.2$$

4. Candidate Bolt Calculations

4.1 M4 Bolt

Tensile stress area:

$$A_t = 8.78\, mm^2$$

Preload:

$$F_i = 0.7 \times 580 \times 8.78 = 3560\, N$$

Mean thread diameter:

$$d_m = 3.545\, mm$$

Thread friction torque:

$$T_1 = F_i \cdot \frac{d_m}{2} \cdot \frac{tan\ \alpha + \mu_t}{1 - \mu_t \times tan\ \ \alpha}$$

$$T_1 = 3560 \times \frac{3.545}{2} \times \frac{\frac{0.8}{\pi \times 3{,}545} + 0.15}{1 - \frac{0.8}{\pi \times 3{,}545} \times 0.15}$$

$$T_1 \approx 1.25\, N \cdot m$$

Bearing friction torque:

$$T_2 = F_i \cdot \mu_b \cdot \frac{D_b}{2}$$

$$T_2 \approx 2.31\, N \cdot m$$

Total tightening torque:

$$T = T_1 + T_2 = 3.56\, N \cdot m$$

4.2 M5 Bolt

Tensile stress area:

$$A_t = 14.2\, mm^2$$

Preload:

$$F_i = 0.7 \times 580 \times 14.2 = 5770\, N$$

Thread friction torque:

$$T_1 \approx 2.55\, N \cdot m$$

Bearing friction torque:

$$T_2 \approx 4.33\, N \cdot m$$

Total tightening torque:

$$T = 6.88\, N \cdot m$$

4.3 M6 Bolt

Tensile stress area:

$$A_t = 20.1\, mm^2$$

Preload:

$$F_i = 0.7 \times 580 \times 20.1 = 8150\, N$$

Thread friction torque:

$$T_1 \approx 4.25\, N \cdot m$$

Bearing friction torque:

$$T_2 \approx 6.93\, N \cdot m$$

Total tightening torque:

$$T = 11.18\, N \cdot m$$

5. Comparison and Selection

Bolt	Preload (N)	Tightening Torque (N·m)
M4	3560	3.6
M5	5770	6.9

M6	8150	11.2

All three bolts satisfy:

$$F_i \gg F_{ext}$$

Therefore M4, M5, M6 bolts are used.

7. Electrical & Control System

7.1 Components & Description

Component	Function	Connection to Controller	Power Source / Notes
Arduino	Microcontroller for controlling the vehicle	N/A	Powered by 12V battery via Vin
Solenoid Valve – Propulsion	Controls air flow to the propulsion piston	Connected to Relay – Propulsion	Powered by 12V battery
Solenoid Valve – Brake	Controls air flow to the brake piston	Connected to Relay – Brake	Powered by 12V battery
Relay – Propulsion	Electrically switches the propulsion solenoid valve	Controlled by Arduino digital pin (D2)	Powered by 12V battery
Relay – Brake	Electrically switches the brake solenoid valve	Controlled by Arduino digital pin (D3)	Powered by 12V battery
Bluetooth Module (HC-05)	Enables remote control of the vehicle	Connected to Arduino TX/RX pins	Powered by Arduino 5V regulator

7.2 Power Supply Overview

- **12V Battery** supplies:

- Arduino (via Vin)

- Relay Module
- Solenoid Valves

- Ensures enough voltage and current to operate valves safely.

- Arduino digital pins only send control signals to Relays; **Relays handle the high current for valves**.

7.3 Battery Configuration and Operating Time

- The vehicle is powered by a battery pack consisting of **three 3.7 V lithium-ion cells connected in series**, providing a total voltage of approximately **12V** with a capacity of **1200 mAh**.
- The battery pack supplies power to the Arduino, relay module, Bluetooth module, and solenoid valves.
- The total current consumption in the worst-case scenario (one solenoid valve activated) is approximately **1.3 A**.
- The theoretical operating time is calculated as:

$$T = \frac{1.2}{1.3} \approx 0.9 \text{ hours}$$

- Considering intermittent operation of the solenoid valves (duty cycle ≈ 30%), the effective operating time is approximately **15–20 minutes**, which is sufficient for testing and competition runs.

7.4 Working Principle

7.4.1 Control Flow

- User sends a command from a mobile device → Bluetooth Module → Arduino
- Arduino interprets the command → sends digital signal to the corresponding relay → relay switches solenoid valve → opens/closes air flow

7.4.2 Propulsion Control

- Command “Move Forward” → Relay triggers Solenoid Valve (Propulsion) → Air moves propulsion piston → Vehicle moves

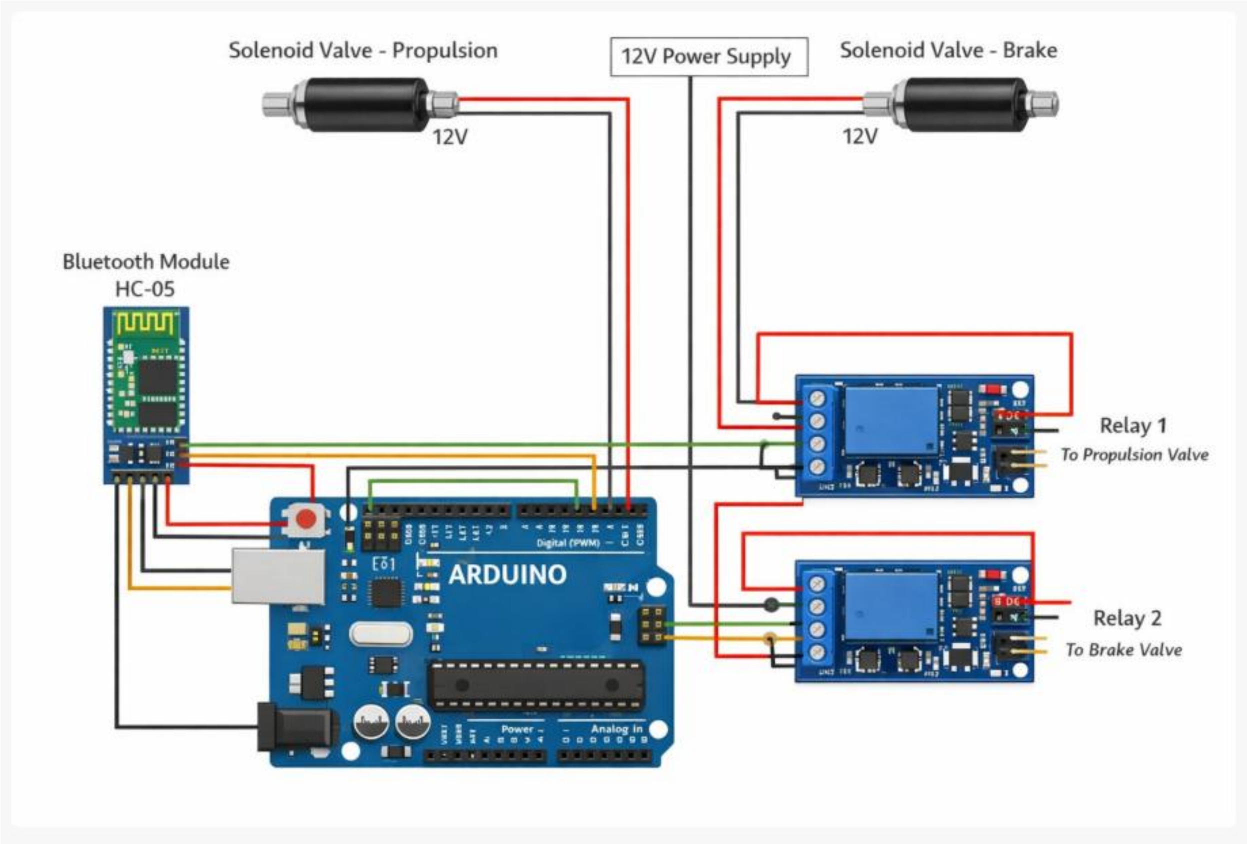
7.4.3 Braking Control

- Command “Brake” → Relay triggers Solenoid Valve (Brake) → Air moves brake piston → Disc brake applies → Vehicle stops

Safety Note:

- Solenoid valves operate on 12V supplied by battery. Arduino cannot supply enough current directly → must go through relays.

7.5 Circuit Diagram



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8. Manufacturing Process

8.1 Manufacturing Techniques

The manufacturing process of the air-powered vehicle prototype focused on simplicity, accuracy, and ease of assembly. Most components were manufactured using conventional machining and sheet metal fabrication techniques suitable for small-scale prototypes.

The chassis was fabricated from sheet metal using cutting and bending operations to achieve the required geometry while maintaining low weight. The air tank mounting brackets and piston support components were machined to ensure proper alignment between the tank and the piston assembly.

The piston mechanism, which is directly connected to the air tank, was manufactured with particular attention to surface finish and dimensional accuracy to reduce friction and air leakage. Standard machining processes were used for the piston rod and housing to ensure smooth linear motion during operation.

8.2 Tolerances and Fits

Appropriate tolerances and fits were selected to ensure reliable operation of the mechanical components. A sliding fit was applied between the piston and its cylinder to allow smooth motion while minimizing air leakage. Shaft–bearing interfaces were designed using standard clearance fits to reduce friction and wear.

Fasteners were selected with suitable tolerances to allow easy assembly and disassembly without compromising structural integrity. Special attention was given to alignment tolerances between the piston, tank outlet, and propulsion linkage to prevent misalignment-induced losses.

8.3 Sealing and Leakage Prevention

Since the vehicle relies entirely on compressed air as its energy source, effective sealing was a critical design consideration. Pneumatic seals and O-rings were used at all air interfaces, particularly at the connection between the air tank and the piston chamber. Thread sealant and proper tightening procedures were applied to all threaded connections to prevent pressure loss during operation.

9. Cost Analysis

part	price
piston cylinder 15cm	$405.00
solenoid valve	$200.00
connectors	$30.00
tubes 10,8mm	$60.00
tank	$600
connectors	$45.00
female connector	$40.00
batterys, charger	$185.00
4 t connector	$60.00
t connector	$15.00
straight connector	$45.00
muffler connector for valve	$20.00
adaptor	$50.00
مسامير	$30.00
connectors for tank	$850.00
tank weldings	$400.00
relay+components	$110.00
chasis	$900.00
wheels	$60.00
plumber block	$270.00
TOTAL	$7,780.00

10. Testing and Validation

Experimental Results

Several experimental tests were conducted to evaluate the performance of the pneumatic vehicle. All tests were performed on a flat horizontal surface under the same operating conditions.

Measured Results:

Vehicle mass: 11 kg

Travel distance: 10 m

Time to travel 10 m: 7 s

Braking distance: 0.7 m

Time Performance Test

The vehicle was tested to measure the time required to travel a distance of 10 meters.

The pneumatic vehicle successfully traveled a distance of 10 m in 7 seconds.

This result indicates stable motion and acceptable acceleration for a compressed-air-powered system.

The average vehicle speed was calculated as:

$V=10/7=1.43 m/s$

Braking Performance Test

The braking system performance was evaluated by measuring the stopping distance after brake activation.

The measured braking distance was 0.7 m, demonstrating effective braking performance using a disc brake and caliper mechanism.

Vehicle Mass Evaluation

The total mass of the vehicle, including the chassis, air tank, powertrain, electronics, batteries, and braking system, was measured.

The total vehicle mass was 11 kg.

According to the project guidelines, the recommended mass range is 5–10 kg.

Therefore, the vehicle mass slightly exceeds the specified range.

Performance Index Consideration

The performance index is defined as:

However, only the mass range (best and worst values) was provided in the project guidelines.

Reference values for time and braking distance were not specified.

As a result:

The performance factors related to time and braking distance could not be normalized.

The measured values are presented and discussed qualitatively.

Discussion

The experimental results show that the vehicle achieved smooth and reliable motion over the test distance.

The braking system provided sufficient stopping capability within a short distance.

Although the vehicle mass exceeded the recommended range, the overall system performance remained acceptable and consistent with the design objectives.

Conclusion

The testing results demonstrate that the pneumatic vehicle operates effectively under real conditions.

The design achieves a balance between mechanical simplicity, control reliability, and braking safety

11. Results and Discussion

The experimental results demonstrate that the air-powered vehicle successfully completed the required 10-meter travel distance while maintaining controlled and stable motion. The piston-based propulsion system provided a direct and efficient conversion of compressed air pressure into linear mechanical motion, which was subsequently transmitted to the drivetrain.

The vehicle achieved a competitive travel time while maintaining a short braking distance, indicating effective coordination between the propulsion and braking systems. Minor performance losses were observed due to friction within the piston-cylinder assembly and air leakage at connection points; however, these effects were limited through proper sealing and surface finishing.

The lightweight sheet metal chassis contributed positively to the overall performance by reducing inertial loads, while still providing sufficient structural stiffness. Overall, the results confirm that the selected design approach meets the project objectives and constraints effectively.

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12. Innovation Section

One of the key innovative aspects of this project is the use of a **direct piston-based propulsion mechanism connected to the compressed air tank**. Unlike conventional air motors or turbine-based systems, the piston mechanism provides a simple and direct method of converting pressure energy into mechanical motion with minimal energy conversion stages.

This approach reduces system complexity, improves reliability, and simplifies manufacturing and assembly. Additionally, the integration of the piston system with a lightweight sheet metal chassis allowed for a compact layout and efficient load transfer. The design demonstrates how simplified mechanical solutions can achieve effective performance in small-scale air-powered vehicle applications.

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13. Conclusion

This project presented the design, manufacturing, and testing of an air-powered vehicle prototype driven solely by compressed air. A piston-based propulsion system directly connected to the air tank was successfully implemented to convert pressure energy into mechanical motion.

The vehicle met all design requirements and constraints, including travel distance, braking effectiveness, and material limitations. The lightweight sheet metal chassis provided adequate structural support while contributing to improved performance through weight reduction.

Through this project, valuable experience was gained in interdisciplinary system integration, mechanical design, manufacturing processes, and experimental testing. Future improvements may include optimizing the piston sealing mechanism, reducing friction losses, and further weight reduction to enhance overall performance.

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14. References

- Automotive Chassis Engineering – Book by: David C. Barton John D. Fieldhouse
- Disc Brakes - Mechanical design engineering handbook
- SKF Group, Bearing Life Theory, SKF Technical Documentation
- Engineering Toolbox, Bolt Shear Stress Calculations
- Timken Company, Engineering Manual – Rolling Element Bearings
- Festo Didactic, Fundamentals of Pneumatics

15. Appendices

Appendix A – Fluid System Design

$$V = 3\,\mathrm{L} = 0.003\,\mathrm{m}^3$$

$$P_g = 10\,\mathrm{bar}$$

$$P_{atm} = 1\,\mathrm{bar}$$

$$P_1 = P_g + P_{atm} = 11\,\mathrm{bar} = 1.1 \times 10^6\,\mathrm{Pa}$$

$$P_2 = 1\,\mathrm{bar} = 1.0 \times 10^5\,\mathrm{Pa}$$

$$m = 10\,\mathrm{kg}, \;\; = 10\,\mathrm{m}, \;\; = 4\,\mathrm{m/s}, \; \eta = 0.5 \quad {}_{air} = P_1 V \ln! \left(\frac{P_1}{P_2}\right)$$

$$E_{air} = (1.1 \times 10^6)(0.003)\ln(11) = 7.91 \times 10^3\,\mathrm{J}$$

$$E_{useful} = \eta E_{air} = 0.5 \times 7914 = 3957\,\mathrm{J}$$

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(10)(4^2) = 80\,\mathrm{J}$$

$$v^2 = 2aL$$

$$a = \frac{v^2}{2L} = \frac{16}{20} = 0.8\,\mathrm{m/s^2}$$

$$F = \eta m a = 0.5 \times 10 \times 0.8 = 4\,\mathrm{N}$$

$$t = \frac{v}{a} = \frac{4}{0.8} = 5\,\mathrm{s}$$

$$P = \frac{KE}{t} = \frac{80}{5} = 16\,\mathrm{W}$$

$$F = \dot{m} v_e$$

$$v_e = 200\,\mathrm{m/s}$$

$$\dot{m} = \frac{F}{v_e} = \frac{4}{200} = 0.02\,\mathrm{kg/s}$$

Appendix B – Air Tank Stress

$$P = 10\,\mathrm{bar} = 1.0 \times 10^6\,\mathrm{Pa}$$

$$r_o = 55\,\text{mm}, \quad {}_i = 53.5\,\text{mm}, \ = 1.5\,\text{mm}sigma_y = 250\,\text{MPa},\ OS = 2\sigma_h = \frac{Pr_i^2(r_o^2 + r_i^2)}{r_o^2 - r_i^2}$$

$$\sigma_h \approx 38\,\text{MPa}$$

$$\sigma_{allow} = \frac{\sigma_y}{FOS} = \frac{250}{2} = 125\,\text{MPa}$$

$$\sigma_h < \sigma_{allow}$$

Appendix C − Axle Design

$$T = FR = 50 \times 0.06 = 3\,\text{N·m}$$

$$\tau = \frac{16T}{\pi d^3}$$

$$40 \times 10^6 = \frac{16 \times 3}{\pi d^3}$$

$d = 7.3\,\text{mm} \Rightarrow d_{selected} = 8\,\text{mm}$

Appendix D − Braking System

$$\frac{1}{2}mv^2 = F_b d$$

$$F_b = \frac{10 \times 16}{0.4} = 400\,\text{N}$$

$$T = F_b r_w = 400 \times 0.06 = 24\,\text{N·m}$$

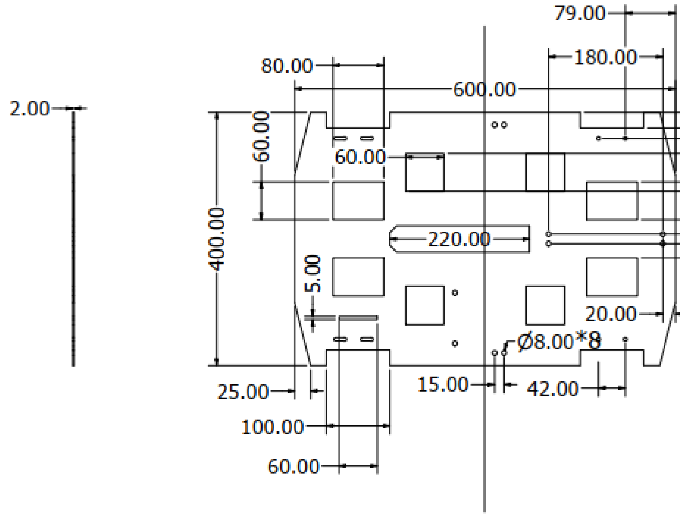
$$F_n = \frac{T}{\mu r_d} = \frac{24}{0.35 \times 0.05} = 1371\,\text{N}$$

$$F_{pad} = \frac{F_n}{2} = 686\,\text{N}$$

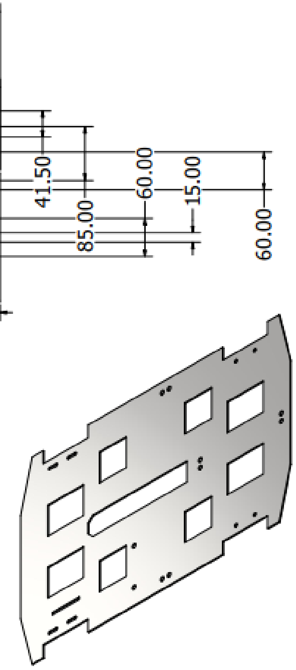
$$A = \frac{F_n}{P} = \frac{1371}{6 \times 10^5} = 2.29 \times 10^{-3}\,\text{m}^2$$

$$D = \sqrt{\frac{4A}{\pi}} \approx 54\,\text{mm}$$

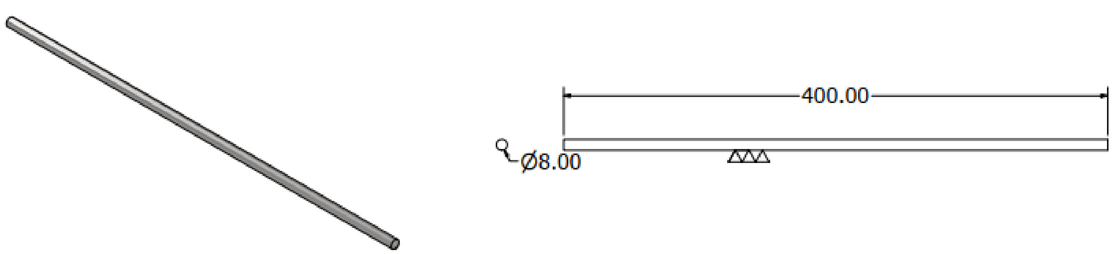
- Chassis design



part no	name	material	quantity
1	chassis	steel	1

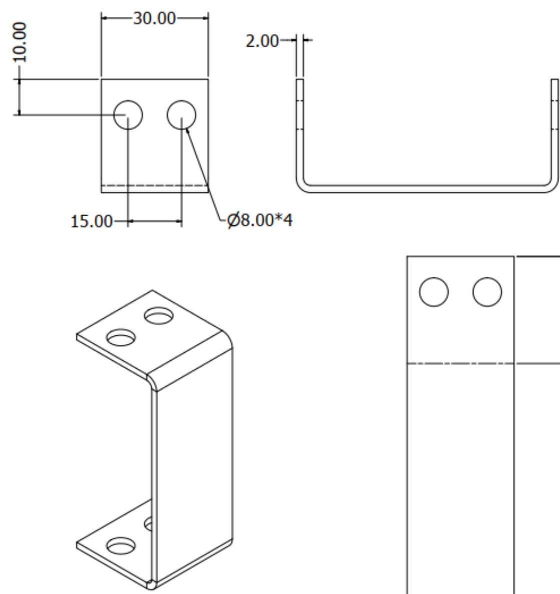


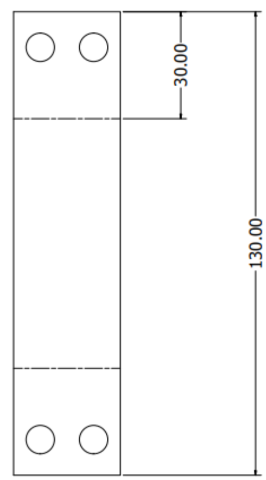
- Shaft design



part no	name	material	quantity
6	shaft	steel	2

- Bracket design

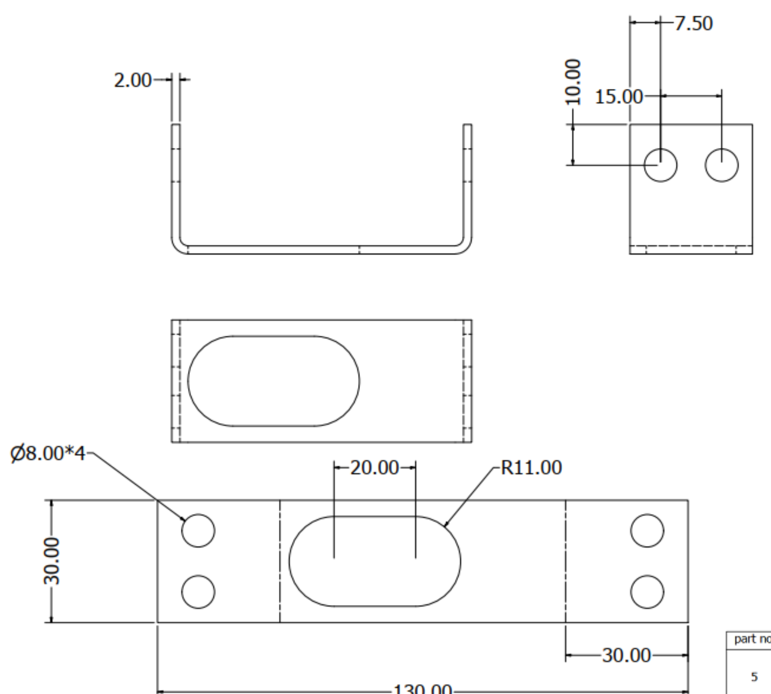




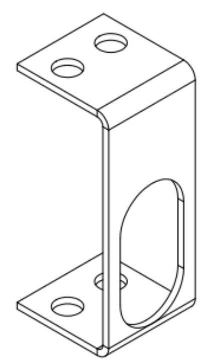
part no	name	material	quantity
4	bracket 1	steel	2

unfolded view

- Piston bracket design

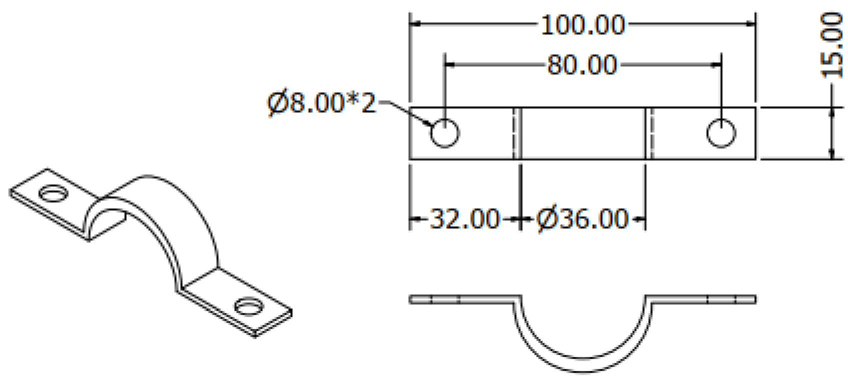


unfolded view



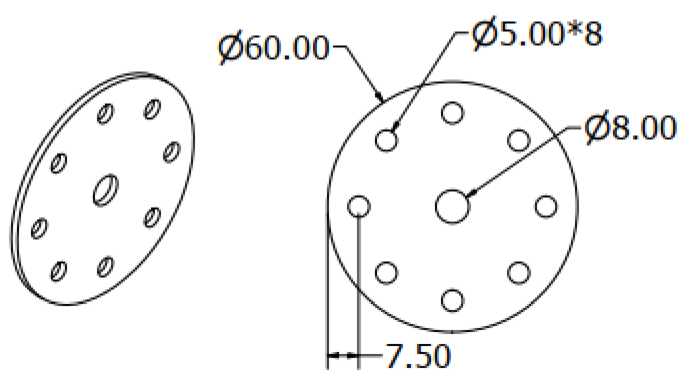
part no	name	material	quantity
5	piston bracket	steel	2

- Brake piston bracket design



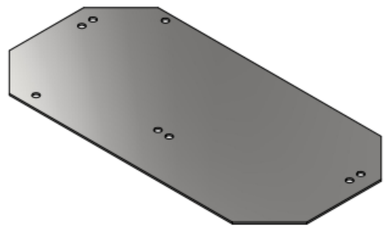
part no	name	material	quantity
9	brake piston bracket	steel	1

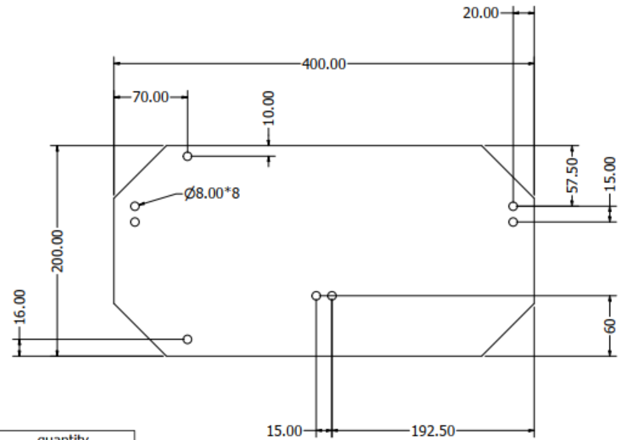
- Break disk design



part no	name	material	quantity
7	brake disk	steel	1

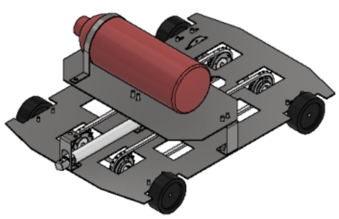
- Top Chassis

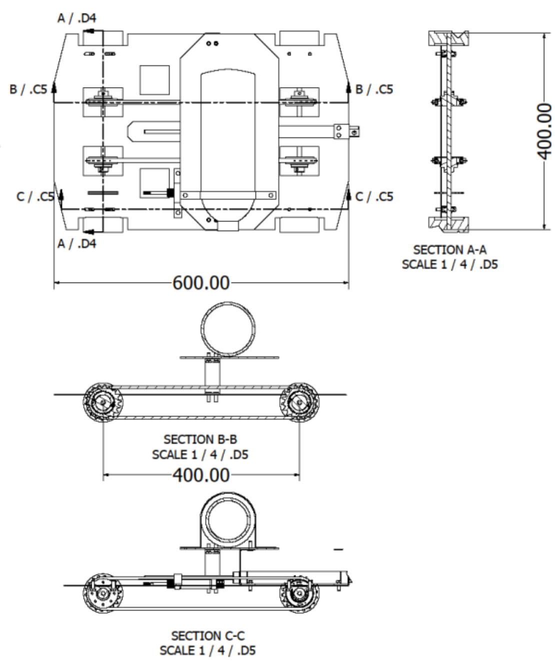




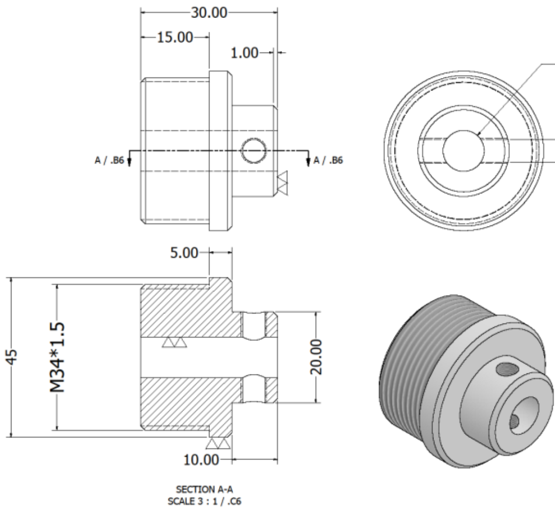
part no	name	material	quantity
2	chassis up part	steel	1

- Final assembly



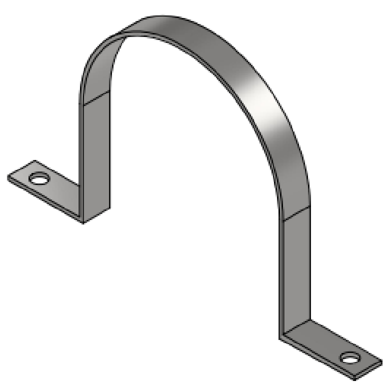


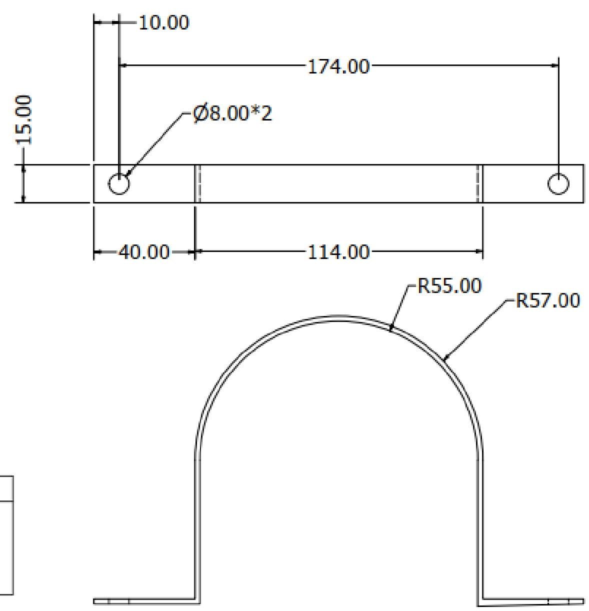
- Sprocket adaptor working drawing



part no	name	material	quantity
3	sprocket adaptor	steel	4

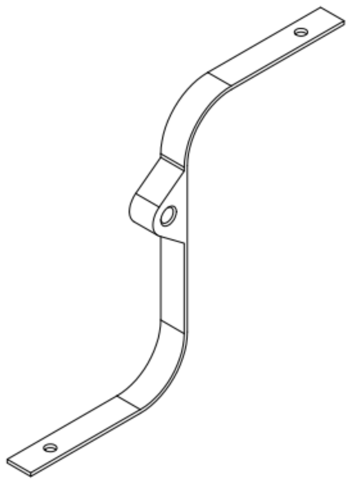
- Tank bracket

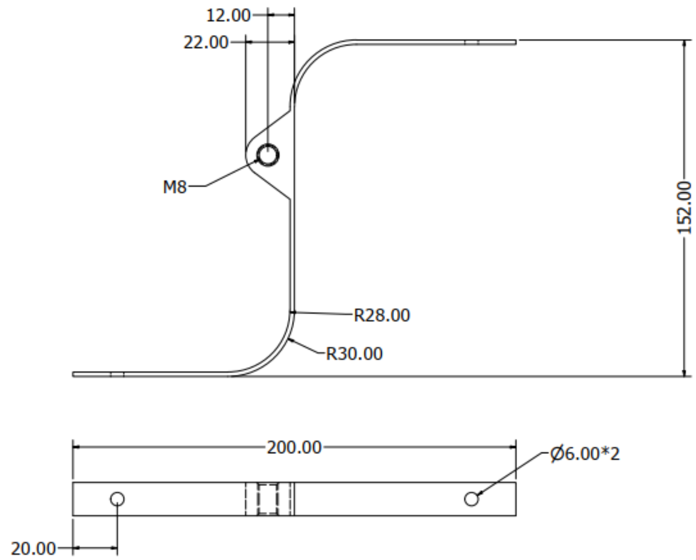




part no	name	material	quantity
8	tank bracket	steel	1

- Drive bracket





part no	name	material	quantity
10	drive bracket	steel	1