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# Design Illustration of a Combat Robot

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**ABSTRACT:** Combat robots are custom-built robots designed to fight similar machines, adapting diverse strategies and incapacitate the combating robots. This paper illustrates the design of a combat robot named *Hades*, which has won in many state and National Level competitions in the 30kg category. The design of Hades is inspired from robots of larger categories, comprising multifarious innovations with regards to drive train and armour design. More often than not, the drive systems of 30kg category combat robots involve the basic off-the-shelf e-bike motors. Though not immensely powerful, it can provide decent performance at low cost, by limiting configurations to a 2-wheel design. However, *Hades* transformed the scenario by using a first in its class Ampflow drive, paired with an equally powerful motor driver, affording an unrivalled performance. The present drive system consists of 2 motors mirrored with each other. Further, the modular nature of the wedge mounts permits varieties of wedges and armours to be mounted. The split wedge setup affords better ramming force during combat with high velocity spinner robots, while a full-length wedge provides greater opportunity to lift the opponent. All this coupled with a robust four-wheel setup with the front and rear wheels connected through a chain provides good traction on both metal as well as wood arena. Major drawbacks of this system for this particular type of wedge robot are yet to be seen since all of our failed battles were due to external factors or random unavoidable events.

**KEYWORDS:** Combat Robot, Drive Train, Armor Design, Ampflow Drive.

## I. INTRODUCTION

Robot Wars is a technical event where teams design and build robots to battle in an arena. The aim is to neutralize the opponent through a series of high-intensity blows, outlasting your opponent, or gaining more points through strategic combat. These robots are mostly radio-controlled but sometimes can be autonomous in the case of Robot Sumo. Since the rules in terms of design aren't definite, a large variety of robots can be seen with varying weapons, drive trains, body armour, frame designs, etc.

Weight classes are what keep the battles fair in combat robotics. As teams can be eliminated from an event solely on the basis of being overweight, it is a critical parameter. Also, the violent nature of robot fighting also requires arenas to be built appropriately. Having these different weight classes allows arena designers to decide whether an arena needs materials such as bulletproof Lexan plastic or a basic wood floor. This is important as robots in the 60-kilogram class can have weapons powerful enough to hurl a robot into the air across a 4-meter area and some even more.

60-kilogram bots, also known as **middleweight class**, is the largest category that is widely run in India due to higher material requirement and much higher quality components. This category mainly consists of bots having machined chassis and significantly higher power.

However, the 30-kilogram weight class is the most popular in India with the colleges openly holding events for 30-kilogram category all over India. This category is also known as the **lightweight class**. Some of the most popular types of bots are the wedge and drum bots, with wedges being the popular starter robot in the category.

15-kilogram bots or **feather weight class**: These bots tend to stay on the compact side with most a large portion of their weight dedicated to offensive power. This class mainly consists of spinners and wedge robots. Wedge robots are also used in Sumo events where, the main goal is to push an opponent out in a small circular arena.

The newest category to India is the 8-kilogram class introduced in Techfest IIT BOMBAY in 2020. It is primarily composed of spinner bots which have a high-speed spinner as the active weapon. Brushless motors are preferred for the weapons as these motors are powerful, light and can fit in the small chassis easily.



After choosing the weight category of your robot, we proceed towards choosing the type of robot. i.e., the type of weapon you wish to use. [1]

In India we mainly use 4 types of combat robots:

- Weapon Robots
  - i) Vertical Spinner
  - ii) Drum Bots
  - iii) Horizontal Spinner
- Wedge robots

A **Vertical Spinner** is a type of weapon robot where a vertical flywheel is used as a heavy rotating weapon. A flywheel is a comparatively heavyspinning disc weapon that spins at high speeds. When the opponent is hit by the weapon, significant damage is caused to the opponent robot, tossing it into the air, and damage is also caused on impact with the ground. This is one of the major advantages of a vertical spinner. If you are building a Vertical Spinner, you will probably want to focus most of your weight on your weapon and make sure the bot has enough support. Because most Vertical Spinners have issues turning while spinning their weapon, we need to be very careful about weight distribution for a Vertical Spinner. That is, try to make your bot as symmetrical as possible, and always keep the spinning weapon balanced in all ways, or it will wobble resulting in lesser stability.



Figure 1: Monsoon, a vertical spinner with an invertible body [1]

**Drum-bots** have a spinning drum with teeth which is usually powered by belts mounted horizontally in front of the robot. Drum robots are more compact versions of vertical spinners and have lesser moment of inertia in the weapon. Drums are generally sturdy, as they are usually constructed from a single block of metal, making them hard to break. They are very stable due to their low centre of gravity, and they take turns more easily than vertical spinners due to the smaller gyroscopic effect. With the use of a reversible speed controller, some spinning drums could work in both directions and still be effective even if the robot was inverted. Pictured below (Figure 4) a 30 kg drum robot built for VJTI.



Figure 2: Centaur, a 30-kilogram drum bot

**Horizontal spinners** are the most lethal type of robots in terms of damage dealt. Also known as bar spinners have heavy rotating blades. As bar spinners do not require an outer ring, they can have larger radius than a spinning disc

(Vertical Spinner). This is an advantage because it means a spinning bar will have a larger reach than an equivalent spinning disc. Because the weight of a bar spinner is distributed in a smaller but denser weapon than a disc, the attack zone can be greater while actually increasing damage output. Their greatest disadvantage is that they are not invertible. They are much more stable as compared to Vertical Spinners.

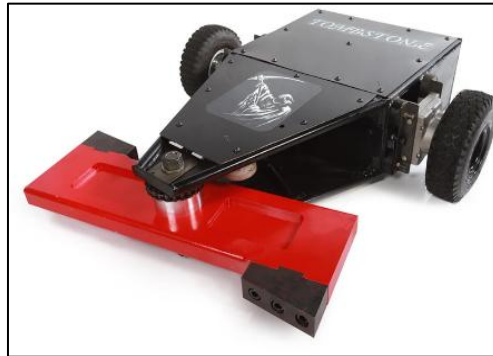


Figure 3: Tombstone, a bar spinner with a high-speed weapon[2]

**Wedge robots** are the most commonly designed robots for any Robot Wars competition as they are easier to design and implement compared to other robot types. A wedge is a body shape or attachment which slopes to the ground and creates a triangular shape from the side profile. Wedges are among some of the easiest weapons to design and build. They usually have 2 or 4 wheels and have one of the most resistant and durable drive systems. Despite not dealing damage directly, they are very effective against spinners causing the spinner to hit the wedge and overturn due to the high impact. Wedge Robots require a highly skilled and tactical controller as they are more defence-favoured robots. Our robot Hades (Figure 4) is also a Wedge robot having two split interchangeable wedges. However, we have also made an arrangement to fix a full wedge.

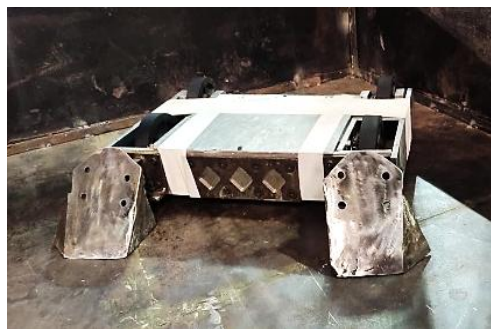


Figure 4: Hades, a 30kg wedge bot with detachable wedge

A well-designed robot [4] can win against a robot of any type, irrespective of the type of weapons used. Each weapon has its own advantages and disadvantages. The wedges tend to flip over the spinners, whereas Drum Robots due to their low centre of gravity can make sharper turns easily. A good design and a good driver can completely change this.

#### Components Used In Combat Robots:

After selecting which type of robots you want to build, you have to spend a considerable amount of time deciding the components to be selected. This depends on various factors including reliability, efficiency, performance, durability, replaceability, and mainly the cost. The following components are used:

Motors can be considered as one of the most important components as mobility can be the deciding factor as to who wins and who loses. One of the most commonly used types is the brushed direct current (DC) electrical motor because it can reach high torques, the speed control is relatively simple, it is easily powered by batteries, and the spinning direction is easily reversed. The three main types of brushed DC motors are the permanent magnet (PM), shunt (parallel) and series. Brushless DC motors are another alternative. A brushless DC motor is a synchronous electric motor powered by DC, with an electronically controlled commutation system instead of a mechanical one based on brushes. In our robot Hades, the driver motors used are 2 A28-150G Ampflow brushed DC motors with a peak HP of

3.0 peak Torque of 1970 oz-in, having 6000 rpm at 24v. The weight of each motor is 3.3 kg (7.3 lbs.). Ampflow motors are designed to give the highest level of performance possible in a brushed DC motor. This is achieved by advanced design and the use of neodymium magnets.



Figure 5: Ampflow brushed motor with gearbox

Electronic Speed Controllers are electronic power systems that are used to control both spin direction and speed of a motor.

In our robot Hades, we use the **VEX Victor 885**. Victor is a family of speed controllers from IFI. Each Victor only controls one motor, so you will need at least two in the robot drive train. The features of the Victor 885 are surge currents of 200A for less than 2s, and 300A for less than 1s, single-channel, forward and reverse, from 6 to 30V, up to 120A continuously. It uses 12 MOSFETs, 6 for each direction [4]. Since the fans are important to cool down the MOSFETs, it is necessary to protect them. Debris or even loosen wires from the electrical system can touch the fan blades, making it stop. To avoid this, you can use a fan grill, which can be made from steel wire or an Aluminium sheet. Another good idea is to use the IFI Stainless Steel PWM Clip, which locks the signal cables onto the Victors, which thus prevents the connectors from popping loose.



Figure 6: VEX Victor 885 speed controller

A radio transmitter allows the driver to send commands to a receiver inside the combat robot. A receiver is responsible to demodulate the radio-transmitted signals and direct the commands to servos and other electronic circuits [3]. In Hades, we use the radio **FlySky FS i6** as the transmitter and the receiver used is the **2.4GHz 6-inch PPM output**.



Figure 7: FlySky Radio transmitter

There are various types of batteries as listed below:

- Sealed Lead Acid (SLA)
- Nickel-Cadmium (NiCd)
- Nickel-Metal Hydride (NiMH)
- Alkaline
- Lithium: Lithium-Ion-Polymer, Lithium-Manganese, Lithium-Iron-Phosphate

Various factors must be taken into consideration in the selection of a suitable battery which includes the following: price, weight, voltage, internal resistance, capacity, shelf life, number of recharge cycles, charge time, self-discharge, discharge curve, discharge rate and de-rating factor. In our robot Hades, we use one **6 cell LIPO battery**. Lithium polymer battery (LIPO) is a rechargeable battery of lithium ion using a polymer electrolyte instead of a liquid electrolyte. These provide high specific energy than other battery types and are used in applications where weight is a critical feature.

Calculation of the current is as follows:

$$1000\text{mAh} = 1000/1000 \\ = 1 \text{ Ah}$$

$$\text{Current that can be drawn safely} = C \text{ rating} \times \text{Ah} \\ = 35 \times 1 \\ = 35 \text{ A}$$

The above calculations are done for a 3-cell battery of 1000mAh with a C rating of 35C.



Figure 8: Different cell types of Lipo battery



You then have to choose the wheels depending on the requirement of the robot. Different sizes of wheels on a single design may be required at times. Also take into consideration the factors like hardness of the wheel, composition, etc. The dimensions of the wheels used in Hades, a wedge robot, are **Diameter-140mm and Thickness-30mm** with a **shore A hardness of 55±5**.

## II. DESIGN PROCEDURE / METHODOLOGY

After selecting the type of robot and weight class, next concern is the cost, designing of a robot, calculations and finally fabrication and testing the robot.

Setting up of a decent budget is of primary importance. A lightweight (30 kg) combat robot has a typical cost ranging from ₹1,20,000/- to ₹2,00,000/- including the transmitter and some spares. For featherweight robot the cost ranges between ₹90,000/- and ₹1,50,000/- including spares and for middleweight is approximately ₹3,00,000/- to ₹4,50,000/-.

Breakup of the major costs is as follows –

COST CATEGORY	MANUFACTURING	ELECTRONICS	MOTORS AND WHEELS
15 Kg	Rs 20,000- 30,000/-	Rs 15,000 -25,000/-	Rs 25,000/-
30 kg	Rs 30,000- 40,000/-	Rs 30,000 -1,20,000/-	Rs 15000 – 1,20,000/-

The above-mentioned cost is a rough estimation and may vary from team to team depending on their budget.

There are even low budget combat robots, this does not mean that they cannot win a competition, it all depends on creativity. The above numbers are fair estimations. The inverse is also true, there is no guarantee that an expensive robot will always win. In general, this is an expensive sport. However, you may compete with the help of sponsors. After gathering funds, we move onto designing the robot. [5]

Designing a robot involves the following steps:

1. Ideation and sketching
2. CAD model development
3. Material selection
4. Design Calculations
5. Manufacturing and weight management.

To distribute the robot's weight, use the 30-30-25-15 rule of thumb [5]. That is 30% of robot weight should be devoted to the drive system, 30% to the weapon system, 25% to the chassis, and 15% to the electrical system. First, you should weigh all the components to be fitted in the combat robot, then you will get an estimate of the weight in which you have to design the chassis (and weapon if it is an attacking robot). In the case of our robot, the components weigh approximately 10Kg to 12Kg. So, 30kg – 12kg = 18kg. In the remaining 18Kg, we designed the chassis, wedges, and armour. We tried designing it within 16-17Kg and kept 1kg for machining tolerance because the weight shown in CAD software may not match with the actual weight after machining.

Choose a suitable material depending on its application in the construction of the robot:

- (a) The chassis needs to be strong and light weight so you can opt for Aluminium alloy. Aluminium 6061-T6 widely used material for robot chassis in the world. Its greatest advantage is its weldability and has lower  $S_y$  and  $S_u$  strength, with similar impact toughness as compared to most aerospace aluminium alloys. [5] It is important to choose proper thickness for the chassis so that it is not overdesigned. 10 mm thickness for side walls, 6-8mm thickness for base plate and 3-4 mm thickness for top plate should be more than sufficient for a 30kg combat robot. There can be two types of chassis: Unibody and Plated. Unibody chases means that the entire body is made up of single block of material machined to its final dimensions usually by VMC. Plated chassis refers to the sides machined separately and then finally joined by fasteners. Unibody has higher strength as compared to plated, but is also expensive to machine
- (b) Next, the wedges or the weapon need to strong to take and give hits. Mostly abrasion resistant steel (AR) is used for wedges and a very high strength steel alloys like EN24 or EN8 are used for Weapon. Abrasion resistant steel provide greater impact strength. However, EN24 or EN8 offers high tensile strength, good wear resistance, easily available and also low cost. However, in case of weapon robots, shaft can be made of high strength steel alloys or Titanium. It is always essential to harden the weapon and the wedges within 35 - 45 HRC to give more strength.

Next, sketch your design on paper various ideas and concepts for your robot. Decide on whether it will have a weapon or a defensive wedge.

Use the limitations and constraints of the physical dimensions of the robot given by the competitions and then model on any CAD software like Solidworks, Fusion 360, Catia, etc. It is important to model the robot on one of the software because it gives you an estimation of space available inside the robot after assembling the components. Keeping sufficient place inside the bot will help you to access the components and wiring in between matches if there is any component damaged. Furthermore, it also helps in performing analysis and subsequently make the required modifications to the weaker parts. Keep the design simple and do not make it complicated. The robot should be as compact as possible, so that its armour can have a larger thickness without exceeding the weight limit.

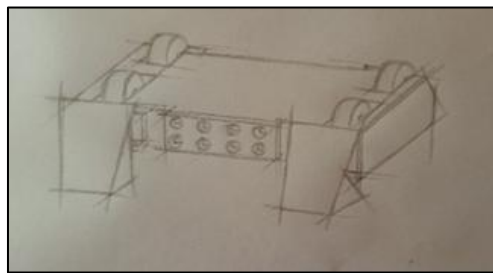


Figure 9: Sketch of 30kg defensive robot

After designing the robot, it is always recommended to perform stress analysis to calculate the resistance of each part. The analysis consists of calculating bending, torsion, tensile, and shear stress in the chassis and components, including stress concentration factors of notches, and then combining them to obtain equivalent stress. Hence having the knowledge of Mechanics of Solids and Machine Design is of great importance. Some software such as ANSYS can be used to calculate the robot's resistance. Besides this, we also calculate the Speed.

**Drive system calculations:**

Following are the calculations of **drive system** of 30 kg defensive combat robot: -

**Weight class** – 30Kg

**Extra weight** –  $2 \times 30 = 60$  kg (To be taken assuming opponent will climb over your robot)

**Wheel diameter** – 139.7 mm = 0.1397 m (You can use a suitable wheel diameter based on your robot size)

**Wheel radius (r)** – 69.85 mm = 0.06985 m

**Gravitational Force (g)** – 9.81 N

**Coefficient of Friction ( $\mu$ )** – 0.9 (Pre-calculated value for the metal surface of the arena and tyre)

**Output Rpm of Drive motor** – 720 Rpm (The rpm varies depending on the type of drive motor)

For ideal condition,

$$1. \text{ Weight on each wheel} = \frac{\text{Weight of the bot}}{\text{Total number of wheels}} = \frac{30}{4}$$

**Weight on each wheel = 7.5 Kg**

$$2. \text{ Force} = m \times g$$

$$= 7.5 \times 9.81$$

**Force = 73.575 N**

$$3. \text{ Frictional force} = \mu \times \text{Force}$$

$$= 0.9 \times 73.575$$

**Frictional force = 66.2175 N**

$$4. \text{ Angular velocity } (\omega) = \frac{2\pi N}{60}$$

$$= \frac{2 \times \pi \times 720}{60}$$

**Angular velocity ( $\omega$ ) = 75.36 rad/sec**





$$\begin{aligned}
 5. \text{ Linear velocity} &= \omega \times r \\
 &= 75.36 \times 0.06985 \\
 &= 5.2638 \text{ m/s}
 \end{aligned}$$

$$\text{Linear velocity} = 11.77 \text{ Mph}$$

**Weapon system calculations:**

Suppose you are designing a weapon robot then the calculation for weapon system would be as follows –

Let us consider a robot in 15Kg class having weapon weight 3.5Kg,

**Weight class** -15kg

**Weapon weight** – 3.5 Kg

**Weapon motor rpm** –13,920 rpm (You can choose any type of motor so accordingly your rpm will change)

For example,

Let us look into some weapon motor for 15Kg weight class.

SR. NO.	NAME	Kv RATING	RPM AT 24 V = Kv rating×24	COST (excluding customs and shipping)
1	Ntm Propdrive 50-50	580	13,920	Rs. 3,435/-
2	Ntm Propdrive 50-60	380	9,120	Rs. 3,800/-
3	Scorpion 4035	560	13,440	Rs. 18,275/-

**Pulley ratio** = 0.7:1

**Tip Rpm** = 0.7×13920=10,000 Rpm (approx.)

$$\begin{aligned}
 1. \text{ Angular velocity } (\omega) &= \frac{2\pi N}{60} \\
 &= \frac{2 \times \pi \times 10000}{60} \\
 \text{Angular velocity } (\omega) &= 1047.19 \text{ rad/sec}
 \end{aligned}$$

$$\begin{aligned}
 2. \text{ Moment of Inertia of the weapon about rotating axis } (I) \\
 &= 5000 \times 10^{-6} \text{ Kg m}^2
 \end{aligned}$$

$$\begin{aligned}
 3. \text{ Kinetic energy} &= \frac{1}{2} \times I \times \omega^2 \\
 &= \frac{1}{2} \times 5000 \times 10^{-6} \times (1047.19)^2 \\
 &= 2.7 \text{ KJ}
 \end{aligned}$$

Kinetic Energy depends on moment of inertia and angular velocity. So, you can vary either of them to get maximum Kinetic energy.

**III. FABRICATION AND TESTING**

The design process usually involves much of the robot development time, around 60% or more. The other 40% would be building the robot [5]. It is always recommended to cross-check the design and make sure that the robot will not undergo major modification after building to save money and material. The fabrication and testing procedure usually involves the following steps –

After the CAD model and analysis are done, you should get the material which you choose at the beginning of designing from any local material supplier. While placing the order, make sure you order at least 10mm extra so that the part can be easy machined under given dimensions. Find a manufacturer and give your robot for machining. Machining operations include lathe, Milling, CNC, Welding etc.

After getting it machined, the next step is to assemble it. There are many things you need to take care while assembling a Robot. Joints can be either threaded or welded joint. Use threaded joint to join parts which may be required to replace in between matches. For Aluminium chases you can use threaded joint. However, you cannot use threaded joints to hold a wedge because it will not sustain the hit by a weapon robot, so you should always weld wedges to remain intact. The angle of inclination of the wedge should be less than 45°. This angle enables easy lifting and pushing the

opponent. Weigh the chases along with the components. If in case it is exceeding the weight limit than make small slots on inner part of the chases.

Now finally place your electronics, connect them and test your robot. It is important to note that electronics should be well covered and placed at the time of matches as small chips may fall on them which may burn the Mosfet or may puncture the li-Po battery.

Get the robot done at least one week before the competition. Many times, due to a tight college schedule robot gets completed just before the competition leaving no time for testing, this is a fatal mistake. Many things can go wrong. With testing, a lot of things can be identified and corrected. Testing also gives the driver the experience of driving the robot. Therefore, it is always good to build the robot before time.



Figure 10- CAD model of 30kg defensive robot

#### IV. CONCLUSION

Robot wars is a technically demanding and challenging event. A lot can be learned from just watching these events and even more so from participating. Teamwork, communication, problem-solving, learning how to deal with pressure, are just some of the things that can be learned from it. [5] Though the barrier of entry might be higher than other technical events, the lessons learned from this and the experience gained with the knowledge achieved is well worth it.

One of our most successful robots, Hades has been a great source of knowledge and we have learned a lot both inside and outside the arena. We have had or shortcomings and failures. But we have learned from them and the successes speak for themselves. We continue to develop Hades as well as or other robots and we hope that the knowledge that we have provided here will be useful for upcoming as well as experienced teams.

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