HELL'S ANGELS FINAL PRODUCT DESIGN SPECIFICATION



EMAE 360 | Fall 2024

Completed: 12/9/2024

Approved:

Product Identification

Product Name

Designed by Hell's Angels, the TR315-r is a motorcycle engine that the Spartan Motorcycle Company is planning to introduce in its new motorcycle model for 2026.

Basic Functions

The TR315-r is an inline 3 engine with a double overhead camshaft. It has been designed to maximize fuel efficiency while maintaining minimum overall dimensions and weight. The engine will run on standard gasoline and have a six speed transmission. Additionally, the TR315-r will be reliable and durable so it can operate in a variety of weather conditions. Finally, the engine will comply with all local and federal emission and noise regulations.

Special Features

This engine will feature an over square bore to stroke ratio of 1.17 and a compression ratio of 10:1. Furthermore, the engine will use a double overhead camshaft and 3 cylinders with a 4 stroke cycle which includes ignition, compression, combustion, and exhaust. The engine will use a port injection system to deliver fuel to the engine's cylinders and the fuel will be ignited using a spark plug. These features will ensure maximum efficiency and reliability to achieve the maximum length of time until service is required.

Key Performance Targets:

This TR315-r will be capable of 5000 rpm of continuous service and 800 rpm when idle. The engine will be able to power a six-speed transmission while maintaining a fuel efficiency of 40 mpg. In order to maintain high customer satisfaction, 95% of all engines will last without significant failure for 100,000 miles or 10 years. Finally, our engine will meet all relevant specifications and standards for safety, fuel efficiency, noise and emissions across the United States.

Service Environment

Use Conditions

The TR315-r will be operated by a person with a class M license. The engine must be serviced every 4000 miles or every 6 months. The engine must not experience prolonged use without service when service is required. Additionally, the TR315-r must be operated in safe riding conditions including weather and road conditions. Any hazardous environmental conditions will stop the riders use of the engine. These environmental conditions include but are not limited to rain, snow, freezing temperatures, and wind above 20 mph.

Storage

When not in operation, the engine should be stored in a dry, secure environment. Storage areas should provide protection against potential damage from wind and rain. Eliminating wind and rain as hazards will prevent engine damage from impacts from debris and corrosion from being wet. Additionally, Humidity of the storage environment should be kept to less than 35 percent. This will ensure that none of the components will experience corrosion while in storage.

Transportation

The TR315-r is transportable by standard commercial vehicles, with appropriate securement measures in place to prevent damage during transportation. The engine may be disassembled for transport to minimize the space it occupies. The engine must be packed in non-corrosive materials that can withstand the vibrations and shocks typically associated with transportation.

Use

The engine should be operated with standard gasoline and in environments that minimize the risk of vehicular collisions. Additionally, the TR315-r should be used in a manner that abides by all traffic laws and regulations.

Predictable Misuse

The anticipated misuse of the TR315-r may involve operating the engine with the incorrect fuel. This could lead to catastrophic malfunction and bodily harm. Additional misuse includes operating the engine until it red lines. This could cause damage to the internal components of the engine. Finally, misuse could occur during transportation or assembly. Failure to completely secure components could

result in unwanted movement which could damage internal or external components. Misuse that results in damage of the TR315-r will not be covered by the warranty.

User Training Required

Motorcycle riders must be trained to operate the TR315-r in conjunction with the entire motorcycle. This training includes but is not limited to achieving a class M license in their respective state.

Market Identification

The target market for the TR315-r motorcycle engine is its use in cruiser motorcycles in the United States with a target demographic consisting of 18-35 year old male riders. Based on Fig. MI.1, about half a million motorcycles have been sold each year in the United States each year for the past decade. Additionally, financial forecasts from Statista predict the US motorcycle market to generate 6.94 billion dollars in revenue in 2024 [1]. The market for motorcycles is a multibillion dollar industry with abundant opportunities for entry into the market by a company like Hell's Angels.

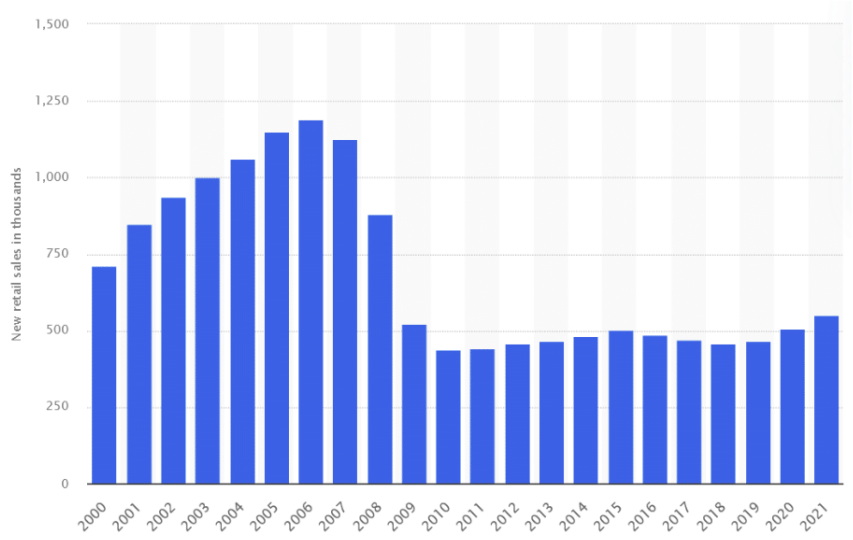


Fig. 1: Number of motorcycles sold each year in the United States [2].

Based on the data from Fig. 1, we predict around 550,000 new retail sales of motorcycles in the United States each year in upcoming years. Hell's Angels anticipates manufacturing and selling 7,500 motorcycle engines by 2026, the first year of production. This would account for approximately 1.4% of motorcycle sales in the United States. In the following two years of production, Hell's Angels anticipates selling 12,000 and 15,000 engines respectively, accounting for 2.2% and 2.7% of United

States motorcycle sales. According to Forbes, a market share of between one to five percent should be a reasonable target for a startup like Hell's Angels [3]. Since our predicted market share of 1.4% to 2.7% fits within the one to five percent range, we believe that these sales ambitions are achievable and reasonable.

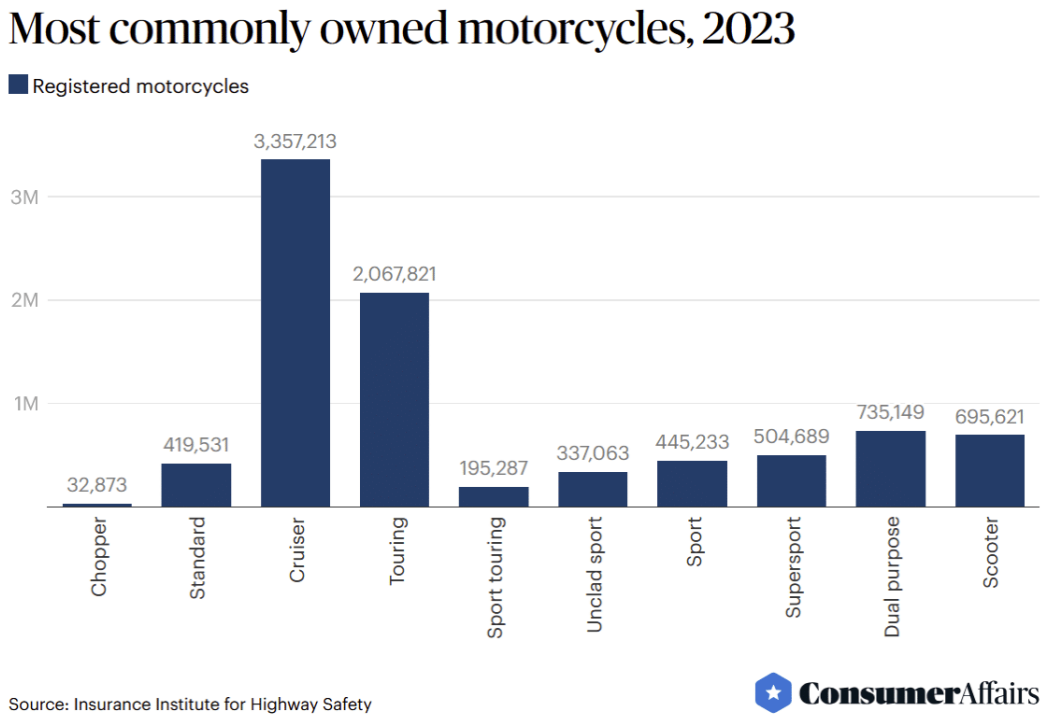


Fig 2: Motorcycle registration by type in the United States [51]

We chose to focus on making a motorcycle for cruiser motorcycles through a combination of our engine displacement size and for the larger market share of cruisers in the United States motorcycle market. Cruisers are characterized by larger displacement, powerful engines which we meet with our 1500cc engine. Based on data from consumer affairs (Fig 2), cruisers are the most popular style of motorcycle in the United States. About 38% of the 8.8 million on-road motorcycles registered in the United States are cruisers. Due to their popularity in the United States, we believe that the cruiser market would be the ideal target for our engine.

The TR315-r will be competing with other heavier motorcycle engines already on the market. Engines with a similar size on the market include the V-twin engines used in the Kawasaki Vulcan cruiser motorcycles [4] or the V-twin engines used in all of Harley-Davidson's line of 2024 cruiser motorcycles [5]. Our engine differentiates itself from these competitors by offering an inline-3 engine with a smoother 120-degree offset firing sequence as opposed to the uneven firing order characteristic of V-twin engines. Hell's Angels hopes that a more even firing order will result in a smoother riding experience for the end-user. We believe that the smoother riding experience characteristic of inline 3

motorcycles will be more appealing to our target demographic of younger motorcycle riders in the Gen-Z to Millenial age-range.

Our main competitor in the inline 3 market is the Triumph Motorcycle company which sells a variety of 3 cylinder engines. Triumph makes a variety of inline 3 motorcycles such as the 1160cc Triumph Tiger 1200 GT Explorer [49] or the 2458cc Triumph Rocket 3 Storm GT [50]. However, they do not make any motorcycles with a displacement in between those. Consequently, we plan to target the market for an in-between displacement of around 1500cc. We hope that this allows us to sell to customers desiring an inline 3 motorcycle with a displacement greater than 1160cc, but not one quite as big and powerful as 2458cc.



Fig. 3 The logo for Hell's Angels.

The Hell's Angels branding strategy consists of a well-known household brand name and a uniquely identifiable logo (Fig. 3. We believe that our branding is well-situated for being associated with cruiser motorcycles in the American motorcycle market. The engine name "TR315-r" acts to describe the characteristic features of the engine: it is a TRiple cylinder with an inline 3 configuration, and it has a displacement of about 1500cc. Additionally, the "-r" suffix to the engine name is a relatively common industry practice for referring to engines which are particularly powerful. The descriptive naming convention will help reduce confusion among consumers about some of the main differentiating features of the engine.

Key Project Deadlines

The following are important deadlines. All deliverables listed must be completed and submitted by the deadline it is assigned to.

September 23rd:

Project Plan Review slides

Team Charter

September 30th:

Draft design scope

Customer derived requirements

October 7th:

Pugh charts, trades studies, and selection criteria for major design decisions

Ideal Otto or Diesel cycle analysis, including thermodynamic states

Ideal CEA combustion calculations

October 14th:

Conceptual Design Review slides

Draft product design specification

October 21st:

Modifications to conceptual design based on CDR feedback

November 4th:

Crankshaft, connecting rod, and piston CAD/FEA

Relevant mechanical calculations

November 11th:

Draft bill of materials

Valves design and selection

CAD and FEA of CAM selections

November 18th:

Materials selections, with justifications

Cooling calculations

Lubrication calculations

November 25th:

Fuel Efficiency

Emission Calculations

Updated Cycle Analysis

December 2nd:

Draft theory of operations

FMEA

Total cost estimate

Draft full engine assembly drawing and CAD

Draft vibration and noise calculations

December 9th:

Detail Design Review slides

Final product design specification

December 13th:

Final Report

A Gantt Chart of Progress Throughout the Semester is Shown Below:

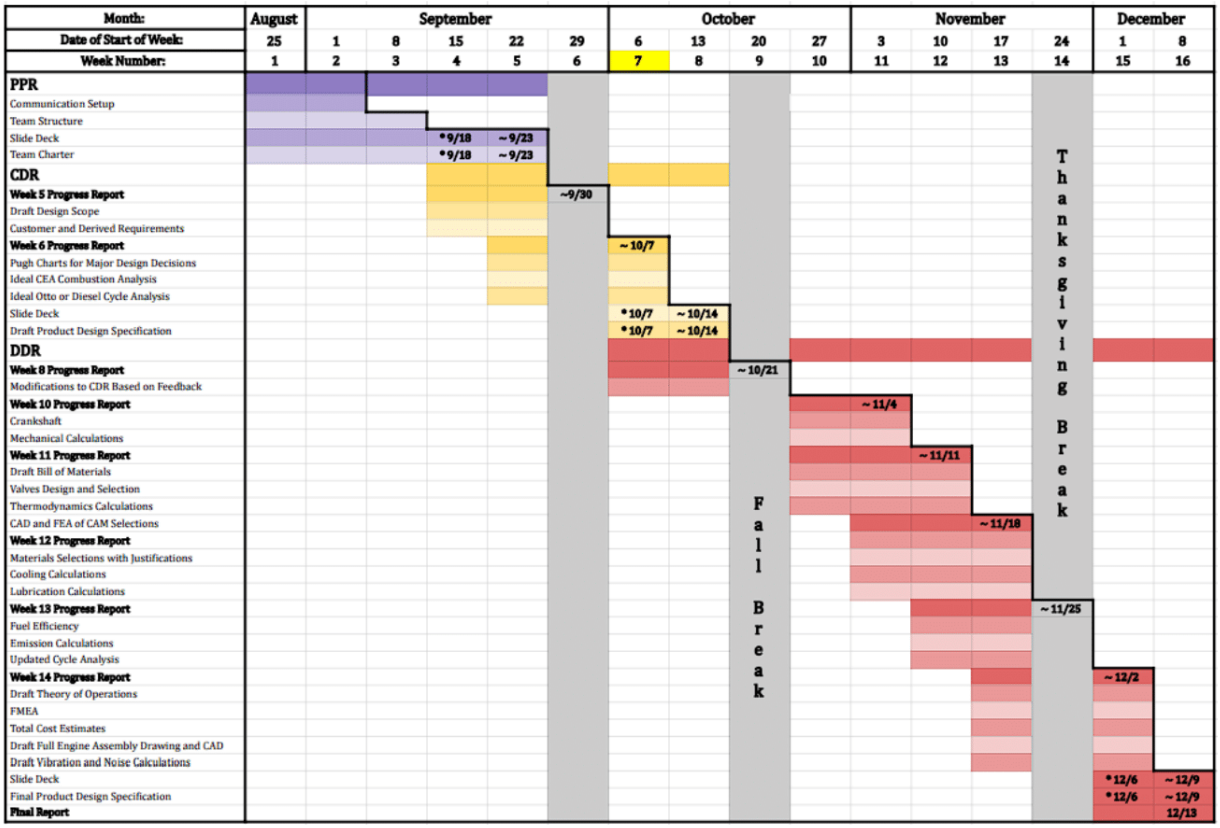


Fig 4: Gantt Chart

Key:

* = Presentation Date

~ = Submission Date

Yellow = Current Date

Red Line = Critical Path

Physical Description

Engine Configuration	Inline 3
Displacement	1502cc
Volume/cylinder	501 cc
Valvetrain Layout	DOHC, 12 valves (4 valves each)
Fuel Delivery	Spark ignition, Port injection
Cylinder Head	Pent-Roof
Bore/Stroke Ratio	1.1667, over-square (.0889 m bore, .0762 m stroke)
Compression Ratio	10:1
Cooling	Water Cooled
Oiling System	Wet Sump
Engine Block	Crank shaft bolted to crankcase, Engine and Crankcase not separate
Envelope	20.32 x 14.50 x 12.75 in
Weight	280.87 lbs
Production Cost Estimate	$3,277.17

Table 1: Physical Description

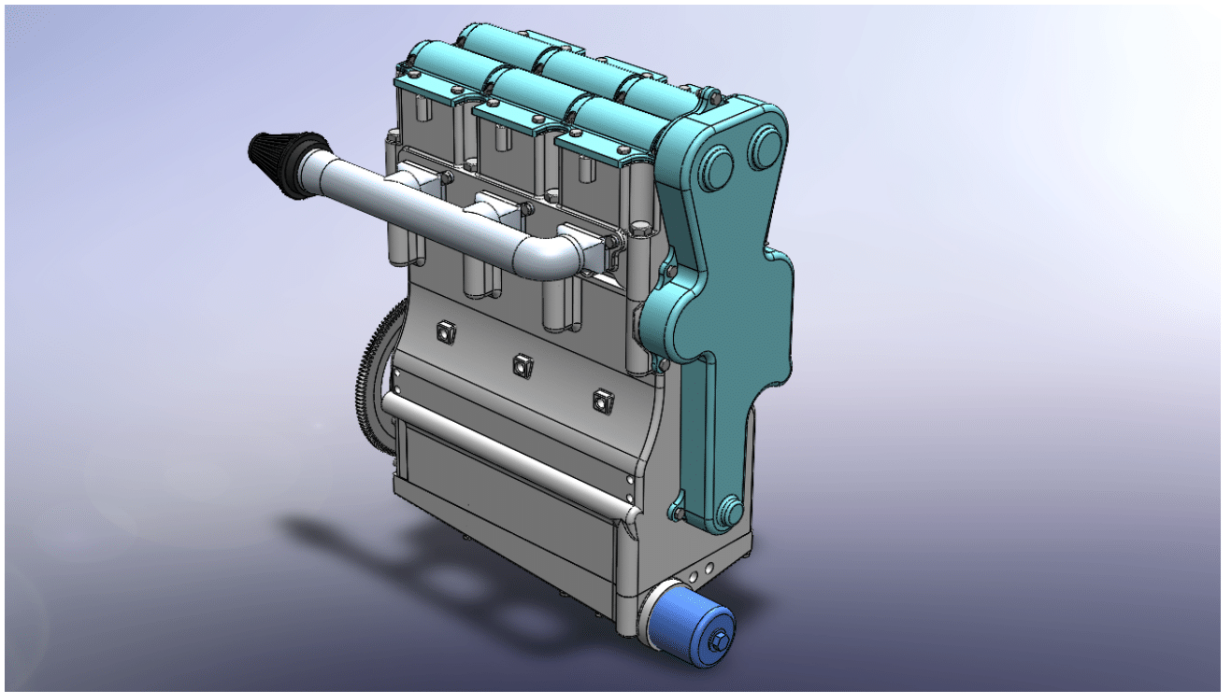


Fig 5: CAD Model of T315-r

Justifications for design decisions:

We have decided on an Inline 3 engine. The inline 3 has a simpler design, lower operation costs, a compact and lightweight design, and smooth power delivery [6]. Keeping consistent with prioritizing low size and weight, we will be using 1502 cc displacement. We will be dividing this up equally amongst the cylinders with a volume of 501 cc/cylinder. For the valvetrain layout we are choosing the DOHC as it has better performance and rev control. It also has more efficient airflow which helps with cooling and efficiency[7]. For fuel delivery, the fuel will be port injected and the engine will use spark ignition. Spark ignition is a given requirement, port injection is preferable as it is less expensive than direct injection, less spacious, and better for emissions [8]. For the cylinder head type, we are using the pent-roof style. This geometry has high volumetric efficiency, and the pent roof combustion chamber also reduces exhaust emissions [9]. We will be using a bore-stroke ratio of 1.1667 (0.0889 bore, 0.0762 stroke): as an over-square bore-stroke ratio has better power and emissions [10]. We will be following the same reasoning of better power and emissions for the selection of a 10:1 compression ratio [11]. For cooling we will be water cooling our engine as it was determined that an excessive amount of fins would be needed for sufficient air cooling, so water cooling would take less space and can move more heat energy [12]. For lubrication, we are using a wet sump system. This is because wet sump

lubrication systems are less complex, smaller, less expensive, and easier for maintenance [13]. Moving onto the engine block, this will be conjoined with the crankcase, with the crankshaft bolted to the crankcase. Having the engine block and crankcase as one part reduces production costs and simplifies assembly [14]. The envelope of the engine is 20.32 x 14.50 x 12.75 in. This size was based on comparing similar engine sizes to produce an estimate [15]. The weight is 280.87 lbs lbs.This was also similarly found by comparing similar engine models [16]. Finally, the estimated cost is $3,277.17.This estimate is at max production (15,000 units) and we plan to sell at $4,099.95 based on a 25% markup. The estimate was created again by comparing the cost of our engine to similar competitors [17].

Financial Requirements

Financial Market Assumptions

To calculate the financial requirements for the engine being developed by the Hell's Angels team, a few assumptions were made to simplify the teams' entry into the motorcycle market. As stated earlier in the market identification portion of the document, the expected production will double over the first three years of operation, starting at 7500 units in the first year and up to 15000 units by the third. We will also assume that our addition to the market will not cause any significant fluctuations in the current market to better understand the expected sales. We will also assume that all of our engines produced will be sold overall, accounting for 2.2% and 2.7% of total United States motorcycle sales. We also assume all engineers and manufacturing employees on the team will receive a fair wage, with mechanical engineers having a salary of 95k annually [18] and engine manufacturers receiving 70k annually [19]. We also will assume that material costs will remain constant over these three years with no significant changes in price.

Corporate Criteria for Profitability

These assumptions allow us to calculate the profitability of our product. Operating expenses are primarily driven by employee wages. Based on the production schedule, 45 workers will be required in the first year, with an annual labor cost of $1.7 million. This scales up to 72 workers in the second year, costing $2.72 million, and 90 workers in the third year, costing $3.4 million. The manufacturing cost per unit decreases with increased production, starting at $3,108.78 for a batch size of 7,500 and reducing to $2,966.07 for 15,000 units, reflecting the benefits of economies of scale. Assembly labor costs and additional overhead remain constant across all batch sizes. Refer to Appendix (1) and (2) For detailed Manufactured and Purchased parts with costs.

Year	Units Produced	Total Labor Hours	Workers Needed
2026	7,500	90,000	45
2027	12,000	144,000	72
2028	15,000	180,000	90

Table 2: Labor Calculations

We chose an engine sale price of $4,099.95 based on a 25% markup of our production costs in our third year, then rounded to the nearest $100. The resulting gross profit margin over our first three years of production is calculated using the Eq. (1) below.

$$Gross\ profit\ margin = \frac{\Sigma(price-cost)*amount}{\Sigma price*amount} \quad (1)$$

Based on Eq. (1), we will have a gross profit margin of about 23.4% over our first three years of production.

Batch size	Manufacturing Cost	Assembly Labor Cost	Additional Overhead (15% of Labor)	Cost per unit	Total Cost	Total Revenue (25% markup of total cost)
7500	$3,108.78	$277.04	$34.06	$3,419.88	$25,649,100	$30,749,625
12000	$3,009.07	$277.04	$34.06	$3,320.17	$39,842,040	$49,199,400
15000	$2,966.07	$277.04	$34.06	$3,277.17	$49,157,550	$61,499,250
Total	-	-	-	-	$114,648,690	$141,448,275

Table 3: Manufacturing Cost

Initial Capital Investment and ROI

The initial capital investment required is the total amount spent on designing the engine, manufacturing prototypes, and associated overhead costs. The capital cost has been determined to be $11.7 million, which only includes purchasing manufacturing equipment and tooling. Prototyping

and testing are also often a large part of the overall production cost, costing up to 80% of the total development cost [23]. From this, our prototype cost will be around 50% of the total capital cost, approximately $5,850,000, which amounts to a total cost of $17,550,000 for our initial investment needed.

From the production data, each engine is sold at a sale price of $4,099.95, with batch sizes planned to increase progressively from 7,500 units in 2026 to 15,000 units in 2028. For the first batch of 7,500 units, the total cost per unit is $3,419.88, leading to a total cost of $25,649,100 and a total revenue of $30,749,625 based on the 25% markup. By 2028, with a batch size of 15,000 units, the total cost per unit decreases to $3,277.17 due to economies of scale, resulting in a total cost of $49,157,550 and a total revenue of $61,499,250. This demonstrates improved profitability as production scales.

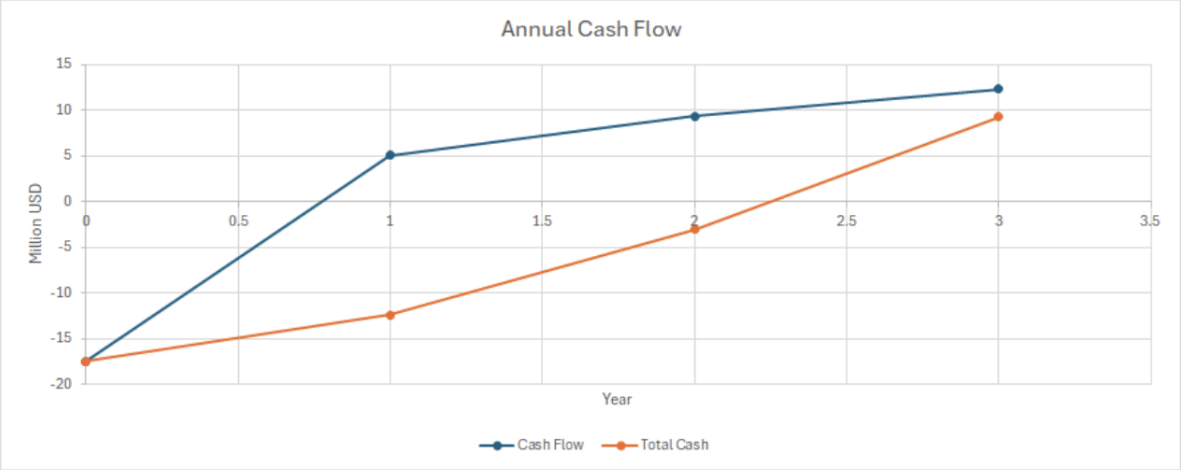


Fig 6: Annual Cash Flow Over Time

Over the three-year production cycle, total revenues are projected to reach $141.4 million, while total costs are estimated at $123.1 million. The expected return on investment (ROI) is calculated as the difference between total revenue and total cost, divided by the capital cost, yielding an ROI of 14.9% for our first three years. These figures highlight the importance of managing economies of scale and production efficiencies while maintaining robust pricing strategies to ensure long-term profitability.

Warranty

The Hells Angels team will supply both a standard and extended warranty on its I-3 motorcycle engine. Based on similar warranty policies on the market [24], The Hells Angels team has a limited-time warranty and an extended warranty. The limited manufacturers' warranty policy has a lifetime of 3 years after the purchase of the engine and a maximum of 40,000 miles ridden [48]. Our fatigue calculations were performed for a lifetime of 10^8 cycles for our parts. Assuming a cruising speed

of 60 mph at 5000 RPM, we expect that 10^8 cycles will last about 40,000 miles. Hell's Angels will repair or replace any manufactured engine components proven to be defective in material or workmanship under normal use during the applicable warranty period. All parts replaced under warranty will be considered as part of the original product, and any warranty on those parts will expire coincident with the original product warranty. Accessories and replacement parts installed by an authorized dealer by Hells Angels to sell them will be repaired or replaced under warranty without charge for parts or labor. If installed by anyone else, accessories and replacement parts will be repaired or replaced under warranty without charge for parts, but any labor charges will be the purchaser's responsibility. This warranty does not extend to the first parts, purchased parts, parts affected or damaged by collision, normal wear, use for which the product was not designed, or any other misuse, neglect, incorporation or use of unsuitable attachments or parts, unauthorized alteration, improper installation, or any causes other than defects in material or workmanship of the product.
As mentioned above, for more information on the conditions for normal operational use, refer to the Service Environment section listed earlier in this document.

Life Cycle Targets

The useful life of our engine is targeted to be between 100,000 to 120,000 miles or 20 years of well-maintained riding. Well-maintained riding is defined as daily riding that takes the engine from ambient temperatures up to operating temperatures for both the coolant and oil. Non well-maintained riding is classified as short term rides that do not increase oil or coolant temperatures to ideal conditions or infrequent rides where the surface layer of oil is allowed to drain to the oil pan. From its manufacturing date, the team assumes that an engine left on the shelf will still be able to be installed with minimum maintenance and replacement parts for 8-12 years. In this case, the minimum maintenance required to recertify an engine for use will be the replacement of any seals or rubber gaskets, as well as replacing any filters that were installed during manufacturing and replacing the initial coat of oil that we cover moving parts with. The engine will be designed such that installation will only require a single person but will be most efficient with two. With two people, the installation of the engine will take no longer than 3 hours and cost approximately $90 in labor. The cost of operating the engine, assuming the engine is used for 8,000 miles a year, will be around $1500 ($1000 for gas plus 500$ in maintenance) plus an additional $100-200 for every additional year the engine is in use. Maintenance is assumed to be done in a service center such as a dealership or certified repair shop. Preventative maintenance should be performed every 4-6 months or 4,000 - 5,000 miles, depending on how the engine is being used.

The mean time to failure of the cylinder block, head, and camshaft cover will be the average lifespan of the engine (100,000 to 120,000 miles). The piston and crankshaft assembly, not including

bearings, will also have a mean time to failure of 100,000 to 120,000 miles. All of our seals and gaskets (intake, exhaust, head) will be designed to fail around 80,000 miles and will therefore be required to be replaced a maximum of twice over the lifespan of the engine. The camshaft sub assembly will be designed to have a mean time to failure of 80,000-100,000 miles. Parts that would result in a catastrophic failure will be designed to have a mean time to failure longer than the average lifespan of the engine. If properly maintained, our engine will not lose horsepower over its lifetime. The cylinders will also be designed to minimize combustion residue and soot on the piston and cylinder walls so that power and fuel efficiency are unaffected over the lifespan of the engine.

Approximately 50% of our engine is recyclable (by part count). Because of this, we will offer a buyback program to the Spartan motorcycle company. In this scenario, TSMC would receive an old bike from a customer and they would send us the used engine and keep the chassis. We would then scrap or sell the used non-metal components depending on their durability and melt down the metal parts to re-use in new engines.

Social, Political, and Legal Requirements

The TR315-r engine will maximize market share by being salable across the United States, ensuring the product can reach the widest customer base. To achieve this, all regulations about the engine must meet the strictest state and national standards across the country. If one state has stricter guidelines than all others, then those guidelines from that state have been chosen, as fulfilling those guidelines will ensure all others across the country are met. If a national law or standards are the only standard present, then that national guideline has been chosen.

Public Safety and Environmental Regulations

Two categories of public safety and environmental regulations will be discussed in this section, as they are the most pertinent to the design of this motorcycle engine. These categories are related to engine noise and emission regulations. Noise regulations are important as they ensure the rider, surrounding motor vehicle users, and pedestrians can all safely listen to noise coming from the motorcycle. Making sure emissions are not outrageously high is important in protecting the environment, and ensuring people using or around the motorcycle are not inhaling dangerous gasses.

The Washington Administrative Code 173-62-030 Standards Vehicle Category is the strictest state law engine noise requirement currently in the US. This Code states that motor vehicles must produce a maximum of 78 dBA below 45 mph, and a maximum of 80 dBA under any other conditions

when measuring 50ft away from the vehicle [25]. Additionally, the Nevada Statute 484D.415 requires all motor vehicles to have a muffler, necessitating this component for noise reduction [26].

These noise requirements have been met by our design after approximating the sound intensity coming from the engine's exhaust, and adding a TRC Quiet Muffler [53]. This assumes that the muffler can reduce sound levels by approximately 35dB. A summary of the results of performed calculations is shown below in Table 4. The Hell's Angels design team was able to calculate these numbers by first solving for the sound intensity of the exhaust without a muffler. The team utilized the maximum and minimum pressure of the exhaust, the density of the exhaust, and the speed of sound [52]. These numbers were used to calculate the sound intensity of the exhaust in W/m^2 at the source. The inverse square law was then utilized to calculate the sound intensity at a distance and that value was transformed into a decibel value. These noise levels were not acceptable under most state regulations so the team added a muffler to bring the maximum noise level at out redline condition within the strictest regulations. The maximum redline condition supersedes the 45 mph noise requirement.

Cruising Condition	Sound Measured 50ft Away from Vehicle
5000 rpm	72.93 dB
8000 rpm (Redline)	77.83 dB

Table 4: Sound Intensity at Different Cruising Conditions

The California Air Resources Board (CARB) has the strictest emission regulation across all states, stating vehicles must not exceed 0.8 g/km of Hydrocarbon (HC) and Oxides of Nitrogen (NOx) combined [27]. Additionally, the United States Environmental Protection Agency (EPA) states that vehicles must not exceed 12 g/km of Carbon Monoxide (CO) [28]. Between these two regulations, all emission standards should be met for this engine across the US.

Without additional filtering components, it was found that initial emissions from the engine would not meet the necessary standards at cruising conditions. The engine requires a reduction of 97% to fulfill the requirement, a reduction made possible through the use of a catalytic converter. The team has selected the PLM High Flow Performance 400 Cell EPA Metallic Catalytic Converter to implement into the engine. After implementation, the nitrogen oxide levels fall below 0.8 g/km and the carbon monoxide emission rates decrease to below 6.4 g/km, therefore successfully meeting the listed emission standards.

It is worth mentioning that maximum surface temperature standards of engines are not spelled out in any specific standard, law, or regulation in the US. As a result, as mentioned in derived requirements, a maximum surface temperature of 120°C will be used, as this is well below the

temperature when plastic shrouding around the engine would begin melting. ABS, a common industrial plastic, begins melting at about 200°C depending on the polymer, which is well above the 120°C maximum surface temperature of the engine, justifying this requirement [47].

Product Standards

There is a nearly endless list of standards that could be used to help develop or conform this motorcycle engine to regulations and laws across the US. However, with the limited knowledge and time of the complexities of law, which should be analyzed by experienced lawyers, a comprehensive list including all of these standards cannot be compiled in this document. Nonetheless, a brief summary of pertinent standards that are most crucial to this engine will be discussed in this section.

The International Organization for Standardization (ISO) has some relevant standards to the motorcycle industry. These include the ISO 26262-1:2018 Road Vehicles — Functional Safety standard, ISO 3046: Reciprocating Internal Combustion Engines — Performance standard, and the ISO 14396: Internal Combustion Engines — Net power standard. ISO 26262-1 specifies Factor of Safety (FOSs) for internal combustion engines, which range from 1.5-3.0 [29]. FEA or manual calculations were performed on all components of the engine to ensure these FOS targets were met. ISO 3046 provides information on how to evaluate combustion engine performance, and ISO 14396 provides standard ways of measuring net power of combustion engines [30, 31]. All of these help to characterize the design, performance, and power of the motorcycle, which is important information for designing an effective engine. These standards were not accessible to Hells Angels for this project, and so it is not understood if they are met with the current engine design, but are listed here for thoroughness. If more time and resources were available for the project, then the purchasing, reading, and updating of the engine design would have been conducted.

The Occupational Safety and Health Administration (OSHA) states several standards that indirectly affect the design of the motorcycle engine. These mainly pertain to the safety of mechanics working on the engines, which falls under the responsibility of the business the mechanic works at. However, these should be kept in mind as the engine design proceeds, to ensure that the design allows mechanics to follow these regulations. These standards and their brief descriptions include:

1. Section 5(a)(1) of OSH Act - General Duty Clause - Driver, pedestrians, and mechanics should be free of general hazards while the engine operates [32]
2. 29 CFR 1910.212 OSHA - guarding over moving components required for the safety of the driver [34]
3. 29 CFR 1910 Subpart 1 - PPE - Mechanics must have PPE for engine maintenance [33]
4. 29 CFR 1910.1200 - Hazard Communication Standard - Safety Data Sheets (SDSs), training, and labeling requires of hazardous chemicals related to engine maintenance [33]

5. 29 CFR 1910.147 - Lockout/Tagout (LOTO) of engine equipment to prevent accidental engine startup [33]
6. 29 CFR 1910.94 - Ventilation required for painting and welding when working on major engine repairs [33]

Section 5(a)(1) of the OSH Act is the OSHA standard that most directly affects the design of the engine, as it requires users and pedestrians to be safe during the engine's operation. The T315-r engine meets this requirement by having been designed to not produce harmful levels of the emissions, be excessively loud to the point of ear damage, and by meeting FOS requirements to ensure the engine does not rapidly disassemble in an unintended manner.

29 CFR 1910.212 also affects engine design by requiring guardian over moving components. This regulation has been met by having a timing belt cover, cylinder head cover, enclosed cylinder head, enclosed engine block, and finally an oil pan that prevents any direct contact to mechanical components in the engine. All these components safely guard the driver from being exposed to moving components, preventing them from being entangled with the mechanical components of the engine.

Other OSHA standards listed above pertain to the maintenance of the engine, and should be met by businesses performing repairs on the T315-r engine. Although these standards do not affect the engine design directly, they have been listed for thoroughness.

Finally, the Underwriters Laboratories (UL) standards provide some additional standards about the material, valve, and electrical considerations that may be needed for this engine. The UL 94 standard gives specifications on plastic flammability, which may be relevant for certain plastic components near the hot engine [35]. The UL 842 standard provides specific information for valves that will interact with flammable and combustible liquids, which directly relates to engine operation [36]. Lastly, the UL 1558 standard provides electrical information regarding low-voltage power systems [37]. Like with ISO standards, time and resources could not be dedicated to ensure these specific standards were met, but have been listed here as standards that should be kept in mind if further work were to be conducted on this engine design concept.

Product Liability

The team promises to deliver a functional and safe motorcycle engine that operates as advertised. As such, it is crucial to recognize and account for sources of liability. The team has prioritized user safety throughout the design process of the motorcycle engine. With rigorous testing, high factors of safety, and adhering to the strictest of standards and regulations, the team is confident in the safety of the engine design. However, liability issues outside of the team's design could be present. For example, instances of product liability may arise in the case of faulty manufacturing

processes. Manufacturing error may lead to defective components that fail to meet quality control standards, and similarly, improper factory assembly may result in malfunctions in the product. In cases such as these, the warranty policy goes into action. Quality control procedures, such as machining checks to appropriate tolerances, help to minimize these instances of liability.

As discussed, it is important to recognize sources of liability, but it is equally as important to recognize potential unintended uses of the product. Examples of unintended uses would be the implementation of the motorcycle engine into a motorcycle that is incompatible, or similarly, a vehicle that is not designed to support a motorcycle engine. In cases such as these, the company is not liable for any incident that occurs, however, it is still in the team's interest to acknowledge these unintended uses to minimize any negative consequences from them.

The best way to inform users of potential dangers from operation of the product is through the use of safety labels. As such, the Hell's Angels team will implement the use of ISO and ANSI compliant safety labels. Examples of safety labels include ANSI warning labels that describe the potential harm and danger of certain methods of operation and ISO pictograms that show the danger with a symbol. Applicable safety labels include, but are not limited to, hot surface warnings, moving parts hazards, electrical shock warnings, fire hazards, and explosion risk.

The Hell's Angels is committed to maintaining a safe working environment at all times in the production of the motorcycle engine. Because of this, it is important to adhere to all relevant company safety standards. Standards set by the Occupational Health and Safety Administration provide guidelines for workplace safety. ISO safety standards such as ISO 45001 establish an internally-recognized standard for occupational health and safety. By following these standards and guidelines, we are making an effort to minimize work related injuries or health conditions and ensure the safety of all involved workers.

Intellectual Property

Considering the design of a motorcycle engine is not new or innovative, it is unlikely that the team would consider the patenting process. It would be presumptuous at this stage of the design to determine if any of the work done will be patentable. However, if a patent is determined to be worth posting, then the appropriate steps should be taken. Firstly, research should be conducted to see if a similar invention does not already exist or is already patented. If not, the appropriate type of patent application should be determined and filed with the USPTO. Once the application has been filed, the team should be prepared to provide any additional information to the patent examiner upon request, and if accepted, pay all required fees. The team may choose to follow the steps independently, or if desired, may consult a patent attorney to aid them in the process.

Developing a licensing strategy is important for protecting the intellectual property of the team, establishing good partnerships, and reaching business goals. The first step would be to file all pertinent patents or trademarks through the process previously described. The next step is to establish all licensing partners, such as motorcycle manufacturers who would be interested in buying the engine. Then, and most importantly, a legal contract should be drafted to outline the conditions, terms, and duration of the license agreement. It will most likely be the case that negotiations will occur, which are necessary to ensure that important business goals are met. As previously mentioned, a lawyer or team of lawyers would be useful in proceeding with a licensing agreement so that all relevant goals and laws are adhered to.

Manufacturing Specifications

Suppliers:

The Hell's Angels team will be utilizing Alro Metals Outlet in Cleveland, Ohio as our primary metal supplier. Our secondary supplier is the North Coast Metal Mart, LLC. We have chosen these metal suppliers based on proximity to CWRU and services available. Both companies are capable of supplying large quantities for our large scale manufacturing plans.

The following is the complete list of major parts we plan to incorporate into our engine and their respective manufacturing specifications. More details on our choices are below.

Part Number	Description	Make/Buy	Material	Primary Manufacturing Method	Secondary Manufacturing Method	Make Vs Buy Justification
25HL01000	Engine Block	Make	Gray (flake graphite) cast iron	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL01002	Engine Block Attachment	Make	Gray (flake graphite) cast iron	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL01003	Oil Pan	Make	Gray (flake graphite) cast iron	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL01005	Cylinder Head v2	Make	Gray (flake graphite) cast iron	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL0100	Timing Belt	Mak	low alloy steel,	Die Casting - High	Machining-CNC	Customizability

6	Tensioner	e	AISI 5115, annealed	Pressure		
25HL01007	Timing Belt Idler	Make	low alloy steel, AISI 5115, annealed	Die Casting - High Pressure	Machining-CNC	Customizability
25HL01009	Tensioner Base	Make	3003 Aluminum Alloy	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL01010	Tension Pulley	Make	3003 Aluminum Alloy	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL01011	Timing Cover	Make	356.0-T6 Permanent Mold (SS)	Hot Closed Die Forging	Machining-CNC	Strength & Durability
25HL01012	Cylinder Head Cover	Make	Gray (flake graphite) cast iron	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL02000	Connecting Rod	Make	AISI 4340 Normalized	Hot Closed Die Forging	Machining-CNC	Strength & Durability
25HL02001	Connecting Rod Cap	Make	AISI 4340 Annealed	Cold Closed Die Forging	Machining-CNC	Strength & Durability
25HL02002	Piston Head	Make	2618-T61 (SS)	Die Casting - High Pressure	Machining-CNC	Customizability
25HL02003	Wrist Pin	Make	AISI 4340 Normalized	Hot Metal Extrusion	Grinding/Honing	Low Cost
25HL02004	Crankshaft	Make	AISI 4340 Normalized	Hot Closed Die Forging	Machining-CNC	Strength & Durability
25HL02005	Counterweight	Make	AISI 1020	Sand Casting - Green Sand	Machining-CNC	Geometric Complexity
25HL02008	Flywheel	Make	Gray (flake graphite) cast iron	Die Casting	Machining	Customizability
25HL02009	Crankshaft Cap	Make	AISI 4340 Normalized	Forging	Machining	Strength & Durability
25HL03001	Camshaft - Intake	Make	AISI 4340 Normalized	Forging	Machining	Strength & Durability
25HL03002	Camshaft - Exhaust	Make	AISI 4340 Normalized	Forging	Machining	Strength & Durability
25HL03003	Intake Valve	Make	Nickel-Cu-Al-Ti Alloy, MONEL 502, hot rolled	Hot Closed Die Forging	CNC Machining	Strength & Durability

25HL03004	Exhaust Valve	Make	Nickel-Cu-Al-Ti Alloy, MONEL 502, hot rolled	Hot Closed Die Forging	CNC Machining	Strength & Durability
25HL03005	Camshaft Caps	Make	AISI 1045 Steel Cold Drawn	Forging	Machine	Strength & Durability
25HL04000	Exhaust Manifold	Make	AISI 316 Stainless Steel	Stamping	MIG Welding	Low Cost
25HL04001	Intake Manifold	Make	AISI 316 Stainless Steel	Stamping	MIG Welding	Low Cost
25HL01008	Timing Belt	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL02011	Crank Timing Pulley	Buy	N/A	N/A	N/A	Special Manufacturing Required
25HL03008	Cam Timing Pulley	Buy	N/A	N/A	N/A	Special Manufacturing Required
25HL04002	Muffler	Buy	N/A	N/A	N/A	Complex System
25HL03007	1/4" Key	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL04004	Air Filter	Buy	N/A	N/A	N/A	Complex System
25HL05000	Oil Dip Stick	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL05001	Thermostat	Buy	N/A	N/A	N/A	Complex System
25HL95001	Connecting Rod Bolt	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL95002	Valve Spring	Buy	N/A	N/A	N/A	Special Manufacturing Required
25HL95003	Camshaft Cap Bolt	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing

25HL95004	Valve Lock	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL95005	Spring Retainer	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL95006	Bucket Tappets	Buy	N/A	N/A	N/A	Easy for 3rd Party Manufacturing
25HL95007	Intake Valve Seal	Buy	N/A	N/A	N/A	Special Manufacturing Required
25HL95008	Exhaust Valve Seal	Buy	N/A	N/A	N/A	Special Manufacturing Required
25HL95009	Water Pump	Buy	N/A	N/A	N/A	Complex System
25HL95010	Catalytic Converter	Buy	N/A	N/A	N/A	Complex System
25HL95011	Oil Pump	Buy	N/A	N/A	N/A	Complex System
25HL95012	Oil Filter	Buy	N/A	N/A	N/A	Complex System

Table 5 - Manufacturing Specifications

The manufacturing methods and materials we selected were chosen to maximize strength and minimize production time and cost. We chose Sand casting - Green Sand, Cold Closed Die Forging, Hot Closed Die Forging, forging, Stamping, Die Casting - High Pressure, and Hot Metal Extrusion, which offer different benefits that make them suitable for other materials and applications. All materials and manufacturing methods were chosen using knowledge from EMAE 160, 260, and sources [38] through [46] below.

Sand casting is versatile, making it ideal for producing complex shapes and components at a relatively low cost. Usually, this method is used with metals that can withstand high temperatures, such as aluminum, cast iron, and steel, and it works well in applications that require intricate designs or big parts. Many of our parts are manufactured using sand casting with green sand because we require relative imprecision in many of them. We will frequently finish with machining processes to ensure precision in necessary areas. We also use a lot of die casting, which provides good dimensional accuracy and smooth surface finishes. Metals that melt easier, like aluminum, are used in die casting due to their

ability to cool quickly, resulting in precise shapes with tight tolerances. We chose to die-cast various parts that required good precision or smooth finishes.

We are also planning to create several components with forging, which is used for more vital components than casting or machining because the process aligns the material's grain structure, which enhances toughness and resistance to fatigue. We chose to forge components in which strength is vital. We are also planning to use welding occasionally when we need to combine parts, but use will be relatively limited because of the difficulties in mass production of welded parts.

Finally we use stamping for parts that need a high strength but also need to be relatively cheap to manufacture. Stamping allows us to make these simple parts quite quickly and reduce both time and cost needed to manufacture. We also chose AISI 316 Stainless Steel rather than our casting metals due to its cost and being simpler to stamp. Hot metal extrusion also follows this principle of being able to cheaply mass produce quality parts.

Finally, various methods are used to create purchased parts, but this will not matter, and we have not elaborated on, except when we need a purchased part to be especially strong or some other factor, in which we will consider to ensure performance and safety.

Material	Properties	Part Requirements
Gray (flake graphite) Cast Iron	Easy to cast, cost effective, vibration dampening, corrosion resistance, high strength, thermally conductive	Used for complex parts that need to be cheap and accurate
Low Alloy Steel, AISI 5115, Annealed	Easy to cast, higher strength, high fatigue life, responsive to heat treatments, resistive to deformation	Used for complex parts that need to be high quality and accurate
3003 Aluminum Alloy	Easy to cast, high strength to weight ratio, corrosion resistant, high thermal conductivity	Used for complex parts that need to be resistant to corrosion and heat while being lightweight
Aluminum 356.0-T6 Permanent Mold (SS)	Easy to cast, high strength to weight ratio, high thermal conductivity, lighter than cast iron	Used for complex parts that need to be resistant to harsh conditions and lightweight
AISI 4340 Normalized	Easy to forge. High strength, durability, and fatigue life. Cost effective, thermally conductive, low thermal expansion	Used for moderately complex parts for high strength and fatigue life
AISI 4340 Annealed	Easy to forge. High strength, durability, and fatigue life. Cost effective, thermally conductive, low thermal expansion. Higher Ductility than normalized	Used for moderately complex parts for high strength and fatigue life
Aluminum 2618-T61 (SS)	Easy to cast, high strength and ductility, high thermal resistance, machinable, weldable, easy to surface treat, corrosion resistant	Used for complex parts that need to be strong and corrosion resistant
AISI 1020 Low	Easy to cast, high strength to weight ratio, high thermal conductivity,	Used for complex parts that need to be

Carbon Steel	lighter than cast iron	cheap and lightweight
AISI 1045 Steel Cold Drawn	Easy to forge, high yield and tensile strength, cost-effective, machinable	Used for moderately complex parts that need to be cheap and strong
AISI 316 Stainless Steel	Easy to stamp, cost effective, high strength, high weldability	Used for simple parts that need to be cheap and strong
Nickel-Cu-Al-Ti Alloy	High corrosive resistance, high yield strength, durability, and fatigue life, high thermal resistance	High durability and corrosion resistant and thermally resistant material needed for valves

Table 6 - Material Justifications

To determine what materials were best we first determined what each part required in terms of properties for the part. For example we needed a high quality material for the valve as it is undergoing large amounts of stress, thermal changes, and corrosive elements[46]. Then we determined what manufacturing process we were using to create that part and what materials could actually be used in said manufacturing process. From possible materials the materials that were best suited for cost, properties, and manufacturability were chosen and justified compared to other available materials. Main concerns were cost, durability, corrosion resistance, heat resistance, part complexity, and accuracy.

Signature Page



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Appendix:

(1) Manufactured parts costs

Part Number	Description	Mass (lbs)	Quantity	Total Mass (lbs)	Unit Cost at 7500 Units	Total Cost at 7500 Units	Unit Cost at 12000 Units	Total Cost at 12000 Units	Unit Cost at 15000 Units	Total Cost at 15000 Units
25HL01000	Engine Block	117.1	1	117.1	$218.04	$218.04	$218.13	$218.13	$218.06	$218.06
25HL01002	Engine Block Attachn	5.45	1	5.45	$11.46	$11.46	$11.37	$11.37	$11.34	$11.34
25HL01003	Oil Pan	19.83	1	19.83	$37.60	$37.60	$37.50	$37.50	$37.40	$37.40
25HL01005	Cylinder Head v2	71.65	1	71.65	$190.12	$190.12	$190.01	$190.01	$189.97	$189.97
25HL01006	Timing Belt Tensione	1.09	1	1.09	$146.61	$146.61	$141.11	$141.11	$138.47	$138.47
25HL01007	Timing Belt Idler	1.21	2	2.42	$23.17	$46.34	$22.30	$44.60	$21.88	$43.77
25HL01009	Tensioner Base	0.37	1	0.37	$2.59	$2.59	$2.52	$2.52	$2.50	$2.50
25HL01010	Tension Pulley	0.41	1	0.41	$2.65	$2.65	$2.58	$2.58	$2.55	$2.55
25HL01011	Timing Cover	1.26	1	1.26	$11.30	$11.30	$10.70	$10.70	$10.50	$10.50
25HL01012	Cylinder Head Cover	13.73	1	13.73	$26.50	$26.50	$26.48	$26.48	$26.45	$26.45
25HL02000	Connecting Rod	1.15	3	3.45	$9.41	$28.23	$8.80	$26.40	$8.58	$25.74
25HL02001	Connecting Rod Cap	0.25	3	0.75	$2.55	$7.65	$2.10	$6.30	$1.95	$5.85
25HL02002	Piston Head	0.95	3	2.85	$9.61	$28.83	$8.24	$24.72	$7.78	$23.34
25HL02003	Wrist Pin	0.29	3	0.87	$0.37	$1.11	$0.37	$1.11	$0.37	$1.11
25HL02004	Crankshaft	19.95	1	22.46	$80.50	$80.50	$79.20	$79.20	$79.70	$79.70
25HL02005	Counterweight	10.89	4	43.56	$22.20	$88.80	$22.10	$88.40	$22.37	$89.48
25HL02006	Crankshaft Gear	4.206	1	4.206	$5.60	$31.36	$5.03	$28.17	$3.22	$3.22
25HL02008	Flywheel	2.93	1	2.93	$9.50	$9.50	$9.04	$85.88	$8.94	$8.94
25HL02009	Crankshaft Cap	0.32	2	0.64	$2.20	$4.40	$1.89	$4.16	$1.77	$3.54
25HL03001	Camshaft - Intake	6.98	1	6.98	$18.00	$18.00	$17.60	$316.80	$17.00	$17.00
25HL03002	Camshaft - Exhaust	7.13	1	7.13	$18.40	$18.40	$17.90	$329.36	$17.80	$17.80
25HL03003	Intake Valve	0.54	6	3.24	$21.60	$129.60	$21.00	$436.80	$20.80	$124.80
25HL03004	Exhaust Valve	0.36	6	2.16	$15.60	$93.60	$15.00	$222.00	$14.80	$88.80
25HL03005	Camshaft Caps	0.09	8	0.72	$1.41	$11.28	$1.09	$1.54	$0.99	$7.92
25HL04000	Exhaust Manifold	3.559	1	3.559	$47.16	$47.16	$45.33	$45.33	$44.67	$44.67
25HL04001	Intake Manifold	1.838	1	1.838	$16.44	$16.44	$16.20	$16.20	$16.08	$16.08

(2) Purchased parts costs:

Part Number	Mass (lbs)	Quantity	Total Mass (lbs)	Unit Cost at 7500 Units	Total Cost at 7500 Units	Unit Cost at 12000 Units	Total Cost at 12000 Units	Unit Cost at 15000 Units	Total Cost at 15000 Units
25HL01008	0.15	1	0.15	$13.78	$13.78	$13.26	$13.26	$13.01	$13.01
25HL02011	0.018	1	0.018	$10.99	$10.99	$10.58	$10.58	$10.38	$10.38
25HL03008	0.038	2	0.076	$9.99	$19.98	$9.62	$19.23	$9.44	$18.87
25HL04002	4.32	1	4.32	$233.99	$233.99	$225.22	$225.22	$220.99	$220.99
25HL03007	0.022	3	0.066	$0.45	$1.34	$0.43	$1.29	$0.42	$1.27
25HL04004	0.25	1	0.25	$22.06	$22.06	$21.23	$21.23	$20.83	$20.83
25HL05000	0.045	1	0.045	$24.99	$24.99	$24.05	$24.05	$23.60	$23.60
25HL05001	0.15	1	0.15	$24.89	$24.89	$23.96	$23.96	$23.51	$23.51
25HL95001	0.01	6	0.06	$0.24	$1.41	$0.23	$1.36	$0.22	$1.33
25HL95002	0.2	12	2.4	$8.31	$99.74	$8.00	$96.00	$7.85	$94.20
25HL95003	0.01	16	0.16	$0.23	$3.64	$0.22	$3.51	$0.21	$3.44
25HL95004	0.0071	24	0.1704	$2.20	$52.80	$2.12	$50.82	$2.08	$49.87
25HL95005	0.013	12	0.156	$4.55	$54.65	$4.38	$52.60	$4.30	$51.61
25HL95006	0.1	12	1.2	$9.99	$119.82	$9.61	$115.33	$9.43	$113.16
25HL95007	0.022	6	0.132	$1.00	$6.00	$0.96	$5.78	$0.94	$5.67
25HL95008	0.022	6	0.132	$1.10	$6.60	$1.06	$6.35	$1.04	$6.23
25HL95009	4.9	1	4.9	$301.45	$301.45	$290.15	$290.15	$284.71	$284.71
25HL95010	2	1	2	$199.99	$199.99	$192.49	$192.49	$188.88	$188.88
25HL95011	3	1	3	$615.95	$615.95	$592.85	$592.85	$581.74	$581.74
25HL95012	0.5	1	0.5	$17.99	$17.99	$17.32	$17.32	$16.99	$16.99