NORTHERN ARIZONA UNIVERSITY

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From: Honda EV Conversion - Team P1

Date: January 29, 2023

Re: Engineering Model Summary

Introduction:

This document outlines the current state of the engineering model for the Honda EV Conversion capstone. Much work has been done to ensure that a thorough and well-designed product will be delivered to the client for the project, and that it meets all customer and client requirements. This includes performing various analyses of the parts included in the design, as well as proper documentation and diagrams to convey this information to the client and show the safety and effectiveness of the design to potential customers.

Top Level Design Summary:

The client for the Honda EV Conversion capstone, Hasport Performance Inc., is an aftermarket auto parts manufacturer that specializes in engine swap kits for Honda vehicles. The company has decided to start making swap kits for electric motors and has enlisted the team to make their first electric swap kit. The vehicle provided by the client is a 1998 Honda Del Sol. This vehicle was selected because the vehicle shares many similarities with other late 1990's Honda vehicles, and the kit could be easily adapted into these vehicles. The kit must include motor and battery mounts, as well as selection and mounting for all other necessary components to make a street-legal commuter electric vehicle.

After 16 weeks of work in the first semester of the capstone, a final design for the motor and battery mounts has been completed. The following figures show the design of the motor mounts in SolidWorks.

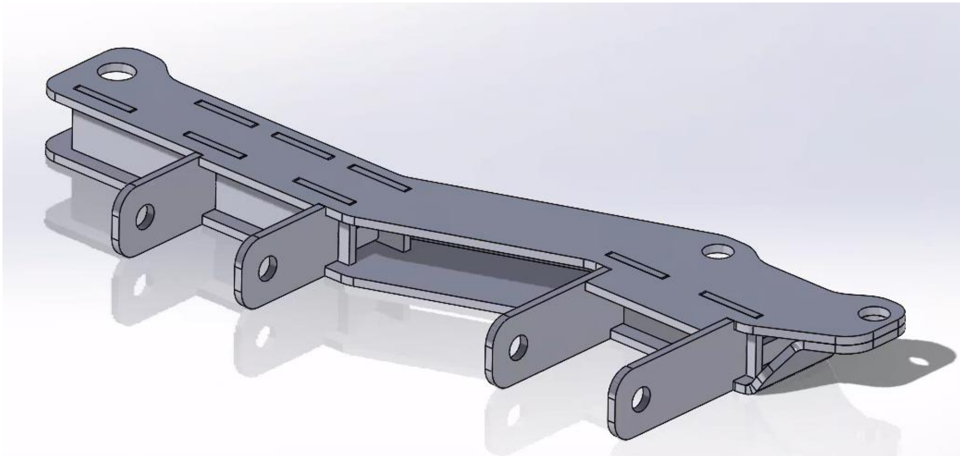

Figure 1: Driver's Side Motor Mount Design

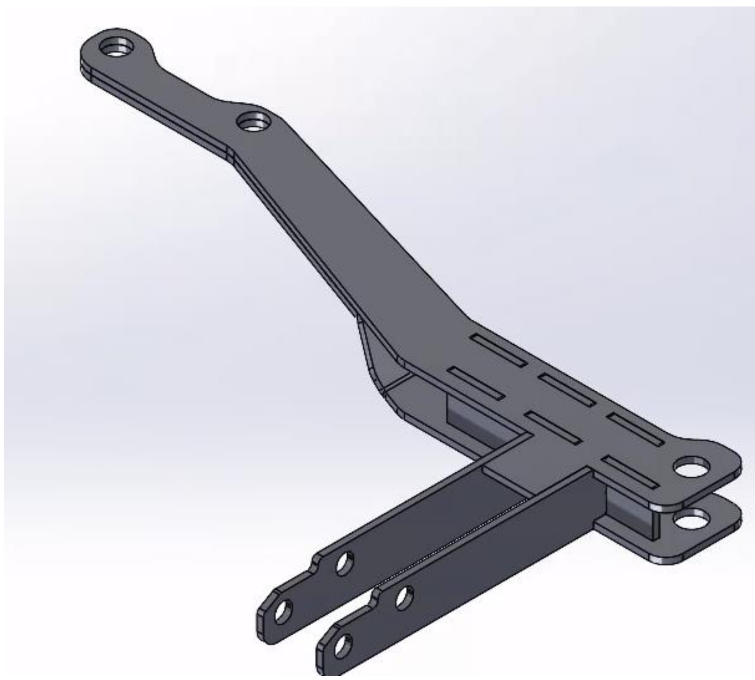

Figure 2: Passenger's Side Motor Mount Design

The motor mounts have two sub-systems: the driver's side mount and the passenger's side mount. Both sub-systems bolt directly into the frame of the vehicle, allowing for easy installation by consumers, and the mounts ensure that the Tesla motor does not move while the vehicle is in motion. The driver's side mount has two sets of bunny ears that connect to two sets of Hasport's K-Flip3 mounts, fulfilling the client's requirement that the design uses a copyrighted part. The K-Flip3 mounts connect to a mounting plate that connects to the motor, securing the motor to the driver's side of the vehicle. The passenger's side mount has a set of bunny ears that connect to the Tesla factory mount, which secures the motor to the passenger's side of the vehicle.

The following figure shows the design of the battery mount in SolidWorks.

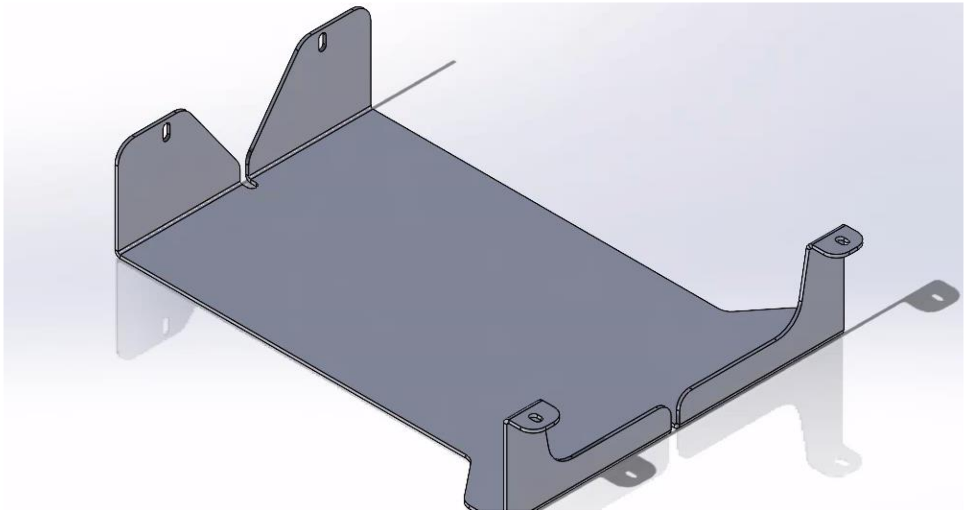

Figure 3: Battery Mount Design

The battery mount functions as a tray that holds the Chrysler Pacifica hybrid batteries in the space formerly used by the gas tank. A metal strap comes over the top of the batteries to keep the batteries stationary during motion. The batteries will be wired in series and will be a part of a circuit that connects to the contactor box, motor, oil pump, and any other parts that may require electricity.

The following figures show the up-to-date QFD, showing the priorities of the customer and client needs.

		1	2	3	4	5	6	7	8
1	Decrease Weight								
2	Increase Battery Capacity								
3	Increase Range	-	++						
4	Reduce cost of production	+	-	-					
5	Reduce # of mounts	++			++				
6	Component cooling		-	-					
7	Maximize power output		++	-			+		
8	Maximize torque		++	-			+	--	

	Customer Needs	Customer Weights	Decrease Weight	Increase Battery Capacity	Increase Range	Reduce cost of production	Reduce # of mounts	Component cooling	Maximize power output	Maximize torque
			Technical Requirements							
1	Battery life sufficient for average commuter	15	3	9	9	3			9	3
2	No modification of existing vehicle frame	5				3	3			
3	Lightweight	10	9	1		9	9			
4	Mount solutions for batteries and electric motor	15	1	9		9	3	1		1
5	Cooling system for electric motor and batteries	10				1		9	9	3
6	Compatibility to similar vehicle models	10				1	9			
7	6 or more batteries in vehicle	15	9	9	9	1	9	1	3	9
8	Consumer sellable product	15			1	3	9	3	1	

Figure 4: QFD

Technical Requirement Units	lbs	kWh	Miles	Dollars	# of items	Degrees Farenheit	HP	Ft-lbs
Technical Requirement Targets	3000	40	100	4000	3	150	300	250
Absolute Technical Importance	285	415	285	365	510	165	150	225
Relative Technical Importance	5	2	4	3	1	7	8	6

Figure 5: QFD Continued

The eight customer requirements all had some correlation with the eight technical requirements for the project. The battery life had to be sufficient for a commuter to make the trip to work and back, while still having a sufficient amount of charge left. This meant that the vehicle should be able to get around 100 miles on a single charge. No modifications to the existing frame means that the kit should only use existing mount points and should not require any additional welding and/or drilling. Lightweight means that the design should not increase the weight of the vehicle by more than what is necessary for the kit. The target weight for the vehicle is 3000 lbs. Mount solutions for the batteries and electric motor means that the motor and batteries are secured to the vehicle, while not allowing for shifting and allowing access for maintenance and electrical wiring. Cooling systems for electric motor and batteries means that the motor and batteries have the space for coolant lines and pumps, those lines and pumps are included in the design, and the lines and pumps are properly mounted. Compatibility with similar vehicles means that the design may be easily implemented into other late 1990's Honda vehicles that have similar frames. Six or more batteries in the vehicle means that the vehicle can meet the minimum voltage of 400 V to run the motor. Consumer sellable product means that the design looks appealing to a consumer who is interested in vehicle swap kits, and that the design has the proper specifications to be appealing to potential buyers. This also means designing more sleek parts with bends and curves, as opposed to a more square-shaped design.

Summary of Standards, Codes, and Regulations:

This project is an entirely new design that is meant to be manufactured for general consumer use on public roadways. Any engineering project must adhere to applicable standards and regulations and given the nature of this EV conversion kit it is no exception; this team must ensure that its design meets the standards put forth by a number of entities that relate to the scope of this project. While there are many different organizations with defined standards that could be related to this design, there are very specific groups with corresponding standards and regulations that the team has identified as critical to ensuring the design is safe and appropriate for wide-scale use on public roads and highways; these include Arizona Department of Transportation (ADOT) [1], International Organization for Standardization (ISO) [2], American Welding Society (AWS) [3], and Society of Automotive Engineers (SAE) [4], [5].

Table 1: Standards and codes of practice as applied to this project

Standard Number or Code	Title of Standard	How it applies to Project

Title 49 Part 396	Inspection, Repair, and Maintenance	Provides the team with Arizona specific and Federal regulations that define the process of vehicle inspection and the requirements that must be met
Title 49 Part 393	Parts and Accessories Necessary for Safe Operation	Comprehensive list of all required automotive parts and additional accessories required for an automobile to be considered road legal in the state of Arizona
ISO/DIS 5474	Electrically propelled road vehicles – Functional requirements and safety requirements for power transfer	ISO documents still under development that provide the base-level requirements for all electric vehicles that are to be operated on public roads, including DC, AC, and conductive power transfer as well as energy storage and charging systems
AWS D8.4:1961	Recommended Safe Practices for Automotive Welding Design	Clear guidelines that dictate the types of welds suitable for automotive applications along with quality and inspection standards
SAE J1634_202104	Battery Electric Vehicle Energy Consumption and Range Test Procedure	Gives the team a set of established uniform procedures by which to conduct its design's performance, range, and battery consumption testing
SAE J-2344	Guidelines for Electric Vehicle Safety	A set of clearly defined safety standards that applies to on-road electric vehicles, meant to ensure the safety of the vehicle operator and those performing service on the vehicle, as well as emergency response protocols in automotive accidents or hazardous situations like battery fires

Summary of Equations and Solutions:

Along with the number of loads being placed upon this team's design, there are also components of subsystems across the vehicle that require analysis to understand if the both the new designs and factory parts will work appropriately for the application. This report will specifically examine the following parts and/or subsystems to check for their validity and suitability:

- The original equipment (OE) drive-axle outboard shafts
  - The reliability of this part has come into question given the significantly higher torque applied by the electric drive unit when compared to the original gas engine, and it is possible that the team and client may need to invest time and resources into strengthening the drive axles. For the calculations performed on this component,

the maximum rated torque of the front Tesla Small Drive Unit (SDU) will be assumed.

- Estimated vehicle range
  - The expected range of the vehicle is important to find, both the safety of consumers and as a major selling point for the design. This will be affected by the total weight of the design and number of batteries included in the design
- The driver side subframe interface
  - This part will be under heavier load than it was from the factory, given that the SDU will be primarily supplying force to it as opposed to the factory mounting positions. The weight of the SDU will not be a concern, as it is much lighter than the factory drivetrain. However, the torque and power it provides will be much higher and faster than the factory drive unit. For the calculations of the forces experienced by the subframe mount, the maximum rated torque of the Tesla SDU will be used.
- The passenger side mounting locations
  - These mounting locations will be under heavier load then when used under factory uses. These locations involve replacing the original subframe spacer as well as two bolt hole locations. Since the passenger side mount utilizes different mounting style to the driver side it requires its separate calculations however the same assumption that the weight of the SDU will not be a concern can be applied. These calculations will be made using the maximum torque the Tesla SDU is rated for.
- Battery plate in fuel tank
  - The plate located in the fuel tank area holds the batteries. Since there are six batteries that weigh 40 pounds each, ensuring that the bolts hold the batteries in place is crucial. The bolts are in shear and axial loading, so they need to be analyzed for proper strength. The bolts will be analyzed for single shear and axial loading along with determining the sizing and strength of the bolts.

Next is a summary of the variety of tools were looked at and used by each team member in performing their respective analysis. Each review will briefly present and describe the most important equation or model that was selected to do the evaluation, and a complete display of the work performed is appended to this report:

The original equipment (OE) drive-axle outboard shafts

To determine the stresses applied to the OE drive-axle outboard shaft and its splines, a machine design resource [6] was sought out to find the appropriate equations that are used to calculate them, along with an online automotive parts retailer [7] to estimate part dimensions and characteristics. The following equations were used (App. A) to find the shear and minimum allowable stress that will be applied to the smaller shaft diameter at the splines (Eqn. 1, 2), and the shear, compressive, and minimum allowable stresses on the spline teeth (Eqn. 3, 4, 5):

$$S_s = \frac{16T}{\pi D_{re}^3} \quad \text{(Eqn. 1)}$$

$$S_s^a \geq S_s \frac{K_a}{L_f} \quad \text{(Eqn. 2)}$$

$$S_s = \frac{4TK_m}{DNF_e t_e} \quad \text{(Eqn. 3)}$$

$$S_c = \frac{2TK_m}{DNF_e h} \quad \text{(Eqn. 4)}$$

$$S_s^a \geq S_s \frac{K_a}{L_f} \quad \text{(Eqn. 5)}$$

First, the shear stress on the shaft itself was found to be 158 MPa. Next, to correctly determine if the OE axles will endure the shear stress on the splined portion of the shaft, the minimum allowable stress was calculated to be quite large, at 947 MPa. Moving on to the shear stress that will be applied to the spline teeth, this was determined to be 76.3 MPa, while the compressive stress on the splines was found to be only 6.1 MPa. Finally, to see if the splines of the OE axles can withstand the anticipated stresses their minimum allowable stress needs to be known, which was calculated to be 458 MPa.

Estimated vehicle range

The continuous load rating for the Tesla small drive unit is 35 kW, meaning this power output is what is required to have the vehicle stay at a constant velocity. Each battery holds 16 kWh of power. The design uses 6 batteries, making a total of 96 kWh of power available from the batteries. Assuming the vehicle is travelling at 65 mph, a standard highway speed for a commute to work, the range may be calculated using the specifications of the batteries and motor. First, the run time of the motor must be calculated using the following equation (Eqn. 6).

$$hours = \frac{kWh}{kW} \quad \text{(Eqn. 6)}$$

Using this equation, the run time of the motor is 2.74 hours. From there, the following equation converts a run time into a total distance the vehicle can travel in that time (Eqn. 7).

$$d = V \cdot T \quad \text{(Eqn. 7)}$$

The calculated distance from the equation is 178 miles, which is 78 miles more than the desired range from the customer needs generated at the beginning of the project.

The driver side subframe interface

To examine the loading on the driver side mounts, machine design principles and mechanics of materials were applied to the system. The total torque applied is already known, as it is just the maximum torque developed by the SDU. This torque is 250 ft-lb according to Tesla documentation. This calculation can be further simplified due to there being two Hasport K-Flip 3 mounts on the driver's side. These mounts are in the same location along the forward axis, meaning the torque is evenly distributed between both. This means the effective force on each mount is found by equation 7 below.

$$\tau_{ef} = \frac{\tau}{2} \qquad \text{(Eqn. 8)}$$

This leaves 125 ft-lb being experienced by the mounts. Using a sum of moment equation, It was found that each mount will be experiencing approximately 426.3 lbf of loading at maximum acceleration. K flip 3 mounts use a M12 bolt to secure to the subframe, which have a maximum load of 33,700 Newtons (7576 lbf). Using this information, it is possible to determine the factor of safety for the system using equation 9 below.

$$FOS = \frac{F_{max}}{F} \qquad \text{(Eqn. 9)}$$

This yields a factor of safety of 17.8, meaning that there is little concern of breaking on the driver side mounts.

The passenger side mounting locations

To determine the loads applied to the passenger side mounting locations machine design and mechanics of materials will be used. The Maximum rated torque of the SDU is 250 ft-lbs and this will be used to find the forces applied to the two mounting locations. Using a sum of moment equation, it was found that the spacer location will experience 910 pounds of force and the two bolt locations will experience 220 pounds of force. To determine if the two bolts are strong enough to experience this force the following equation was used based on a steel M10 bolt thread area (Eqn. 10).

$$F_s = \tau A_s \qquad \text{(Eqn. 10)}$$

This gives the two bolts a strength of 9,000-pound force which is far greater than any force that will be applied to the bolts. Next the force applied to the spacer location, this will be found using the strength of steel over the area of the OE spacer bolt using the following equation (Eqn. 10)

This equation shows that the spacer bolt is capable of withstanding 12,000 pounds of force. This is significantly over the force that will be applied. These values offer the passenger side mount a factor of safety of 13.2.

Battery plate in fuel tank

The initial equation needed to evaluate bolt stresses is the general stress equation shown below (Eqn. 10).

$$\sigma = FA \qquad \text{(Eqn. 11)}$$

There are 4 bolts that the weight of the batteries is spread across, and the weight of the batteries is roughly 250 lb. The density of 3/16” sheet steel is 7.65 lb/ft^2 and roughly adds around 100 lbs to the weight carried underneath the vehicle [10]. The bolts are 10 mm and the cross-sectional area to determine the bolt stress is shown in appendix E. Given that the load is distributed across 4 bolts, the stress acting on each bolt is roughly 2900 psi. The yield strength of steel is 87000 psi, so the FOS of the bolts is 30.2 [9]. This is enough strength to keep the batteries safely in place over the lifetime of the vehicle.

Table 2: Factor of safety for each sub-system or part analysis performed

Sub-System or Part	Load Case Scenario	Factor of Safety
Drive axle shaft splines	Assuming the maximum rated torque of the SDU to be applied at the drive axle outboard joint	0.64
Estimated vehicle range	Load rating for Tesla motor is 35kW and batteries provide 96 kWh to move up to 178 miles range	N/A
Driver Side Mounting Locations	Maximum torque of the Tesla SDU on only the driver side motor mounts	17.7
Passenger Side Mounting Locations	Assuming the maximum rated torque of the SDU on the Mounting locations of the passenger side motor mount	13.2
Battery plate in fuel tank	250 lb battery weight applied to mounting bolts in shear and tension located in the rear of the vehicle	30.2

The analysis of the drive axle shaft and splines show a minimum allowable stress of about 947 MPa, and documentation [8] shows that the standard material in the automotive industry used for axle shafts is 1541 steel which features a tensile strength of 600 MPa; these values give a low factor of safety of only 0.64. Based on these findings, it is clear that the team will need to work with the client to either manufacture a new axle with a stronger material or to look into modifying the wheel hub so that a larger diameter OE Honda axle can be installed.

The analysis of the driver side mount tells the team that the current design exceeds any possible loading by a large margin of safety. The team will move forward with the current design, and only make changes when absolutely necessary.

The analysis of the passenger side mounting locations shows that the current design as well as the current materials offer a factor of safety greater than 10 which means the design meets the team's needs and exceeds the design requests from the client. The team will move forward with this design and continue to optimize it.

Validating the strength of the bolts holding the batteries in the fuel tank of the vehicle is critical to prevent ruining expensive batteries. After running a shear and tensile calculation to ensure the factor of safety is high enough to prevent bolt failure (around 30), the team is confident in the bolt selection of 10 mm that fits underneath in the factory bolt holes.

Moving Forward:

With respect to the drive axle analysis, it has been determined that the OE drive axle will likely fail under the maximum rated torque of the Tesla SDU. As previously stated, this part was in question by the client and this team about its suitability for the new drive unit, so developing a solution for the axles will now take additional work in the form of new design or OE part-swapping to ensure it can withstand the torque of the SDU; the former will require the team to identify a material that is typically used in high-power automotive applications and generate a program to machine a new axle end; and the latter will involve the team identifying a Honda brand steering knuckle with a wheel hub that features a larger diameter axle shaft which can be swapped into the project vehicle. In either case, the team will be working closely with the client to understand their desired solution based on the time and financial cost for each scenario.

The driver side mounts are designed well from an engineering standpoint based on this analysis but a more thorough analysis could be performed. It does seem, however, that they are going to be sufficient for the load the SDU will provide. They are likely not going to see many changes before the final delivery to the client, but further analysis will inform future design decisions by the group.

The design of the battery basin and straps holding down the battery cells can now be lightweighted and further improved to minimize the weight of the basin holding the batteries. The sheet steel thickness used for this project is 3/16", which has a density of 7.65 lb/ft^2 [10]. Decreasing the surface area of material used to hold these batteries will significantly reduce the weight applied to the bolts and will further increase the stability of this sub system and reduce failure risks. Rigidity design considerations can also increase the strength while removing most of the material and is implemented in the design according to the client's specifications.

References:

[1] "Laws and Rules." AZDOT.gov. https://azdot.gov/motor-vehicles/enforcement/new-entrant-program/laws-and-rules (accessed Nov. 20, 2022).

[2] "Road vehicles engineering." ISO.org. https://www.iso.org/ics/43/x/ (accessed Nov. 20, 2022).

[3] "AWS IBR Standards Available." ANSI.org. https://ibr.ansi.org/Standards/aws.aspx (accessed Nov. 20, 2022).

[4] "SAE Standards Development." SAE.org. https://www.sae.org/works/customer.do#TEV

[5] "U.S. National Electric Vehicle Safety Standards Summit." NFPA.org. https://www.nfpa.org/-/media/Files/Training/AFV/Research/rfusnevsssummit.ashx (accessed Nov. 20, 2022).

[6] "Shaft Splines and Serrations." EngineeringProductDesign.com. https://engineeringproductdesign.com/knowledge-base/splines-serrations/ (accessed Jan. 29, 2023).

[7] "1996 Honda Civic del Sol – CV Half Shaft/Axle Shaft." OreillyAuto.com. https://www.oreillyauto.com/detail/c/import-direct-driveline/cv--driveshaft---axle/cv-half-shaft---axle-shaft/ (accessed Jan. 29, 2023).

[8] "Axle Essentials for Racing and Performance, Part 1." MarkWilliams.com. https://www.markwilliams.com/aerp1.html (accessed Jan. 29, 2023).

[9] "AISI 1541 Steel, Cold Drawn Bar (UNS G15410)." MatWeb.com https://matweb.com/search/DataSheet.aspx?MatGUID (accessed Jan. 29, 2023).

[10] Engineering ToolBox, (2009). *Steel Plates - Size & Weight*. [online] Available at: https://www.engineeringtoolbox.com/steel-plates-weight-d_1561.html [Accessed 29 Jan. 2023].

Appendices

- Appendix A: Work performed using Excel to calculate the stresses applied to the splined portion of the OE drive axles.

Shaft shear stress $S_s=16T/(\pi D_{re}^3)$				
Description	*Variable*	*Value*	*Units*	*Comments*
Diameter of the spline	D_{re}	0.022	m	[3]
Torque	T	330	N*m	[1]
Shear stress	***S_s***	***158***	***MPa***	

Shear stress in spline teeth $S_s=(4TK_m)/(DNF_e t_e)$				
Description	*Variable*	*Value*	*Units*	*Comments*
Pitch diameter	D	0.0372	m	Estimated [2]
Torque	T	330	N*m	[1]
Load distribution factor	K_m	1	#	[2]
Effective face width	F_e	0.025	m	Estimated [2]
Chordal thickness at pitch line	t_e	0.0007	m	Approx. D/2N
Number of spline teeth	N	26	#	[3]
Induced shear stress in splines	***S_s***	***76.3***	***MPa***	

Minimum allowable spline stress $S_s^a \geq S_s K_a/L_f$				
Description	*Variable*	*Value*	*Units*	*Comments*
Induced shear stress in splines	S_s	76.3	MPa	
Application factor	K_a	1.8	#	Uniform input, heavy shock load
Life factor	L_f	0.3	#	10^6 fully-reversed cycles
Minimum allowable shear stress	***S_{as}***	***458***	***MPa***	

Minimum allowable shaft stress $S_s^a \geq S_s K_a/L_f$				
Description	*Variable*	*Value*	*Units*	*Comments*
Shear stress	S_s	158	MPa	
Application factor	K_a	1.8	#	Uniform input, heavy shock load
Life factor	L_f	0.3	#	10^6 fully-reversed cycles
Minimum allowable shear stress	***S_{as}***	***947***	***MPa***	

Compressive stress on spline teeth $S_c=(2TK_m)/(DNF_e h)$				
Description	*Variable*	*Value*	*Units*	*Comments*
Load distribution factor	K_m	1	#	[2]
Torque	T	330	N*m	[1]
Pitch diameter	D	0.0372	m	Estimated [2]
Number of spline teeth	N	26	#	[3]
Effective face width	F_e	0.025	m	Estimated [2]
Radial height of the tooth in contact	h	0.0045	m	Estimated [2]
Compressive stress	***S_c***	***6.1***	***MPa***	

[1] Stealth EV, "Tesla Small Rear Drive Unit Kit." StealthEV.com. https://stealthev.com/product/teslalow-power-rear-drive-unit/ (accessed Dec. 3, 2022).

[2] "Standard Spline Shafts." GrobInc.com https://www.grobinc.com/cold-rolled-products/standard-spline-shafts/ (accessed Jan. 29, 2023).

[3] "Replacement axle for a 1996 Honda Civic del Sol." OreillyAuto.com. https://www.oreillyauto.com/detail/c/import-direct-driveline/cv--driveshaft---axle/cv-half-shaft---axle-shaft/7acfacd27274/ (accessed Jan. 29, 2023).

- Appendix B: Battery basin calculations to determine bolt strengths

Metric Bolt Diameter (mm)	Bolt Diameter (in)	Area (in^2)	Force (lbs)	Stress (psi)	Yield Strength (psi)	FOS
10	0.393700787	0.12173696	350	2875.05129	87000	30.2603298

Sheet Steel Size (ft^2)	Density(lb/ft^2)	Weight (lb)
6.45	7.65	49.3425