ME 450 Winter 2006 TEAM 25

Final Design Report for Injection Valve Fluid Supply Housing

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ME450, Final Report
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4/18/06

Abstract

The EPA (Environmental Protection Agency) has been working on a new diesel fuel injector system to address performance and emission issues in clean Diesel engines. The new fuel injectors operate at pressures from 35,000 to 40,000 psi and are hydraulically actuated. The combination of an intensifier and a hydraulic pump will produce these high pressures. This project addresses the issue of how to connect the hydraulic pump to the actuator valve while eliminating leakage. This connector must be feasible for bench testing in a multiple cylinder scenario, and preferably will also be feasible for use within passenger car applications.

1. PROBLEM DESCRIPTION

The EPA is investigating ways to make Diesel engines more environmentally viable. Diesel is currently the European solution to rising prices of crude oil – the engines are typically more fuel efficient than gasoline engines providing the same power. The fuel injectors in lean direct injected Diesel applications require fuel delivered in accurate, short spurts as well as delivered at a high pressure (35,000 to 45,000 psi). This allows the droplets of fuel to be atomized effectively, leading to more complete combustion. This results in less unburned hydrocarbons in the exhaust as well as less particulate matter (commonly known as soot). The fuel injectors rely upon a valve which delivers hydraulic fluid to the end of the intensifier. The hydraulic fluid enters the valve at 3500 psi and is directed into the intensifier when the spool is in the correct position. The fluid is then routed back to the pump for re-use through the two smaller return channels. The intensifier uses a small piston that is 11 ½ times as large at the hydraulic end as at the fuel end to increase the pressure of the fuel and deliver it through the fuel injector. The valve that the EPA is currently using (the Sturman valve) is prohibitively expensive. There is another valve that would work with modification, a die-cast Siemens valve (the Sturman valve is 5 times as expensive because it is precisely machined). They would prefer to use the less expensive Siemens model, but it presents a leakage problem that does not exist in the Sturman model. Our task is to design a connector which delivers the hydraulic fluid to the valve, allows for the return of lower pressure fluid, and seals any leaks from the involved components. Our solution must be small, light, and inexpensive.

Diesel engines are the main type of internal combustion engine classified as compression ignition. As opposed to gasoline (Otto) engines, which initiate combustion with a spark, Diesel engines initiate combustion via compression. There are two primary methods of supplying fuel: port and direct injection. HCCI (homogeneous charge compression ignition) uses port injection, which allows the fuel to fully mix with the incoming air and the mixture is ignited when the pressure and temperature is raised to a sufficient level by the piston. HCCI allows for complete combustion, but is difficult to control. Without proper control of HCCI, combustion can occur too early or too late; too early causes knock, while too late causes incomplete combustion and increased particulate emissions. The other method, the one that we are addressing, is direct injection. A piston compresses air within the cylinder; combustion begins nanoseconds after the fuel is injected into the cylinder a little before top dead center. The timing of the injector is controlled by the ECM (electronic control module). The port injection of the HCCI introduces problems such as environmental factors (temperature and humidity of incoming air, barometric pressure, engine temperature), all of which affect the temperature and pressure of the incoming fuel/air mixture and determine at what point in the piston travel combustion actually occurs. Direct injection eliminates this problem.

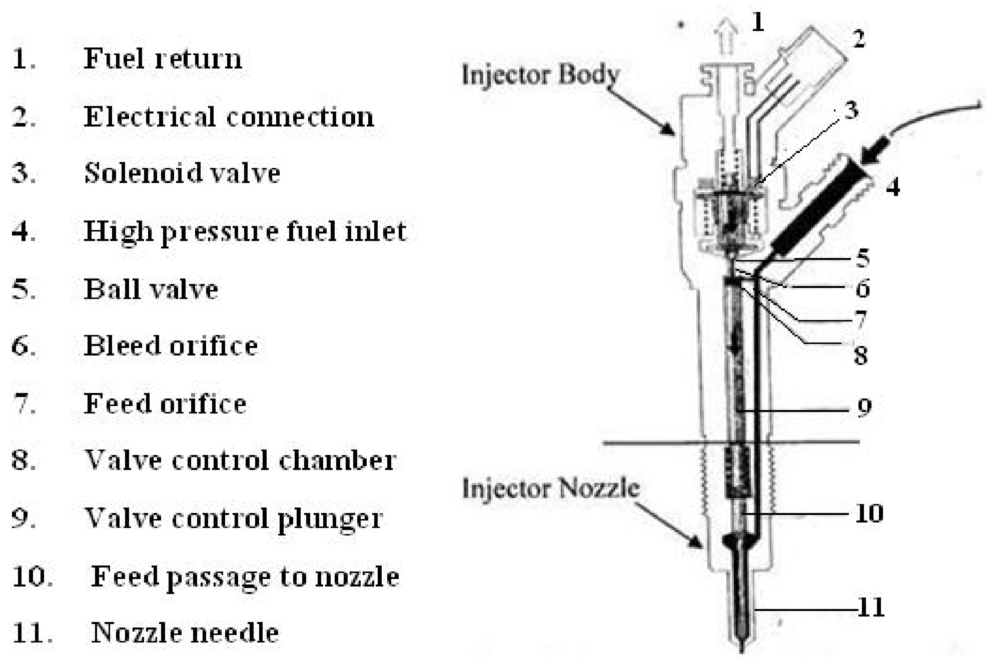

Figure 1: Typical direct injection Diesel fuel injector and its components

While HCCI is difficult to control, when it is properly controlled it fully atomizes the fuel. The EPA’s clean diesel research relies on high pressure fuel injectors to fully atomize fuel in a direct injection format to allow complete combustion characteristic of HCCI while maintaining the controlled combustion advantage of direct injection.

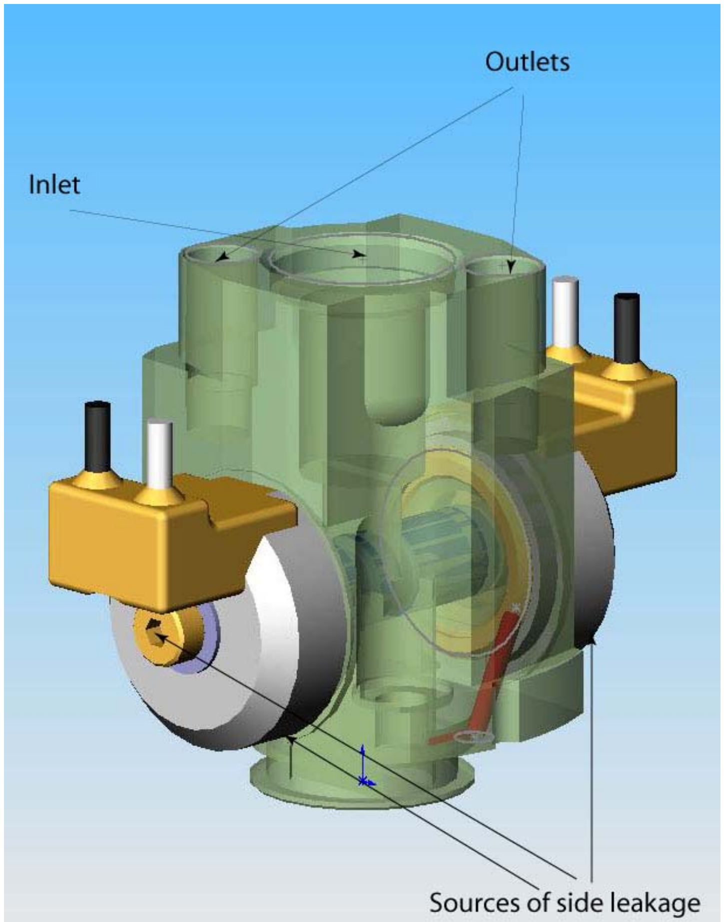

Figure 2: Siemens actuator valve

The high pressure needed to atomize the fuel is produced by an intensifier, which is activated by hydraulic fluid and delivers 11 ½ times that pressure to the fuel. The intensifier is connected to a valve which is activated by the ECM at the precise times when this fuel is required. A pump supplies the incoming hydraulic fluid at the required 3500 psi. Channels return the fluid to the pump to re-pressurize it. The part that is currently needed is one that mates the incoming hydraulic fluid lines to the inlet port of the actuating valve. This part will also direct the returning fluid to the pump. We also need to address the leakage at the sides of the actuator valve.

2. BENCHMARKING

Related Product

In addition to looking into some ways that others have tried to solve our problem, we also looked into other similar products that may not be directly related to diesel engine applications. One product that we found is made by a company called miniBOOSTER Hydraulics. They create many models of a pressure control valve that they make called a miniBOOSTER. The miniBOOSTER Valve Housing is used for mounting various accessory components directly to the miniBOOSTER. MiniBOOSTER is commonly used to supply high pressure to attachments where small cylinders and high force are required. For example, the miniBOOSTER can utilize a low pressure vehicle hydraulic system to operate high pressure tools such as bulldozers, as opposed to using expensive high pressure pumps with flexible hoses. This saves space and reduces the cost of using stand alone components for these functions.

The miniBOOSTER housing material is aluminum. This design incorporates a Pressure Reducing Valve (PRV) to control inlet pressure to the miniBOOSTER, an orifice to reduce inlet flow to the maximum allowed for the intensification ratio selected. Though this is not an exact solution to our problem, the general idea remains the same. Our group has been entertaining the idea of making the housing from aluminum as opposed to stainless steel to reduce weight and machining time. However, we are concerned about the aluminum dealing with the pressures that the valve is under. miniBOOSTER chose to make their housing out of aluminum, and it is made to support anywhere from 300-3000 psi inlet pressure. These pressures are on the same magnitude as the ones for which we are designing.

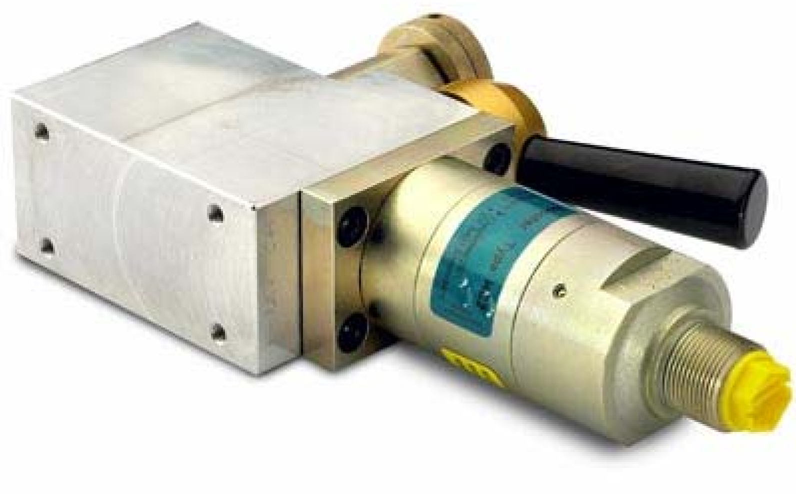

Figure 3: MiniBOOSTER Valve Housing

Existing Solutions

There are two known solutions to this specific problem that we have researched. The first is the original design that the EPA constructed in their lab. The solution is simply to enclose all of the valves in a metal box, with inlets for the incoming hydraulic fluid. It is very large and heavy. It is also difficult to align with all 4 cylinders.

The second solution comes in the form of another valve. This valve is produced by Sturman Industries and solves the problem of delivering and collecting the fluid and returning it to the reservoir. The major downside of this valve system is that it costs about

5 times more then the Siemens valve system. This is because of the precision machining that is required to make each of these valves. Supply is also an issue. While the simpler manufactured Siemens valve is made in hundreds of thousands, there are only a couple thousand Sturman valves for sale in the market.

A past ME 450 team had a project very similar to ours and attempted to solve it by use of a steel lid on the top, which is both less expensive than the Sturman solution and much smaller than the EPA's box solution. Unfortunately, there was significant leakage past the connection gasket. Also, the side leakage problem was not discovered until the project was almost complete and so was not addressed by this design.

3. CUSTOMER REQUIREMENTS

Our task is to design a housing that will enclose the Siemens valve. Enclosing the Siemens valve will contain all injection fluid exiting the valve, including any leakage and injection fluid exiting from the spool after the mixing process in the intensifier. As specified by our sponsor, Dr. Moskalik, the injection fluid entering the housing and valve must be able to withstand at least 3500 psi inlet pressure and less than 300 psi outlet pressure. Any injection fluid that leaves the valve is collected by the housing and should be redirected back to a reservoir. The injection fluid in the reservoir is then channeled back into the valve inlet at 3500 psi, as shown in the diagram below. Dr. Moskalik has also specified that our housing must be light, small and the design must work performance-wise (i.e. no leakage).

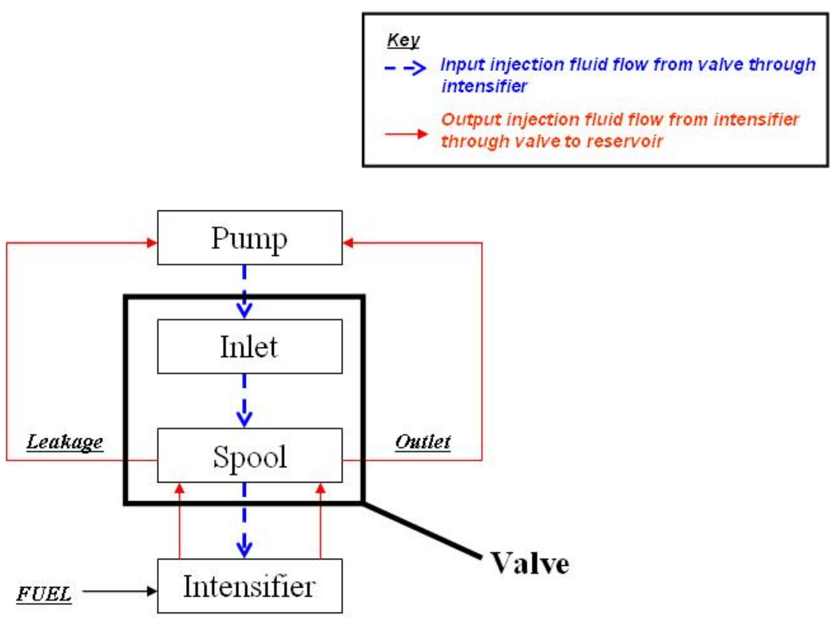

Figure 4: Path of injection fluid flow

4. DESIGN SPECIFICATIONS

As seen in our benchmarking section, current prototypes are impractical, bulky, or too expensive to be mass-produced. Our housing design must be substantially smaller and lighter, as well as more affordable to produce and market.

Size

We have determined that our housing should be no larger than a square box 6 inches by 6 inches by 6 inches in volume. There are also other restrictions to the housing's size that are described in the constraints section on pages 8 & 9. Our housing should only enclose the valve portion of the injector and there should be 1 housing per injector.

Weight

EPA's "box" design (see Benchmarking on page 4) encloses all 4 fuel injectors weighs a staggering 40-50 lbs. Our design will greatly improve upon this weight.

Cost

We intend to design and manufacture our prototype within our $400 budget. The combined cost of our $400 budget and the $600 Siemens valve costs significantly less than the Sturman valve.

To save costs, lean design and lean manufacturing is a priority in our design process. We intend our housing to consist of as few parts as possible. This not only simplifies the manufacturing process for our design, it also helps to save supplies and possibly material costs in the long run. It also makes it easier to open the housing to clean it or to remove the valve for other purposes.

Machining considerations

Besides dimensions, the choice of material for our housing is important. Our sponsor Dr. Moskalik has specified his preference for stainless steel to be used for our housing material. Stainless steel presents many advantages in terms of corrosion, fire resistance, aesthetic quality, as well as providing the least expensive option when overall product life-cycle costs are considered.

We have considered aluminum for parts of the housing that do not involve the injection fluid flow in and out of the valve (e.g. housing sides). Aluminum is less expensive and is more easily machined than stainless steel. However, we have decided to manufacture exclusively in stainless steel because our manufacturing method incorporates welding portions of our design together, which precludes using both. While welding stainless steel to aluminum is not impossible, it is something that is beyond our capabilities and has no significant benefit to the project.

Minimum/ No leakage
The Siemens valve is die cast. While such a valve is inexpensive, it is also prone to leakage. Our housing should contain 100% of the leakage from the valve.

Miscellaneous specifications
The housing must be able to withstand ambient operating temperatures ranging from negative 50°F (very cold winter climates) to positive 170°F (operating temperature of a running engine).

Customer Requirements	Design Specifications
• Contains all injection fluid exiting valve	• Enclosure with dimensions ≤ 6 inches by 6 inches by 6 inches
• All injection fluid exiting housing to be redirected back to reservoir	• Much less than 40 lbs
• Must withstand 3500 psi inlet fluid pressure	• Stainless steel to be used for components involving fluid flow in and out of valve.
• Must withstand ~300 psi outlet fluid pressure	• Aluminum considered for saving weight and ease of machining
• Small	• 0 % leakage from housing
• Light	• Must be able to operate in temperature between 50°F and 170°F
• Cheap	

Table 1: Overview of customer requirements and design specifications

Constraints imposed on housing design
As the figures 5 to 7 on pages 9 to 10 show, the fuel injector and housing will be extruding out of the engine block at about a 70° angle and rising above it pass the engine valve cover. This valve cover extends out to form a lip at the point where it encloses the valve cover gasket. This lip constrains our housing dimensions to a 7/8” radius (from the center of our actuator valve) on the side closest to the valve cover. This constraint only affects the bottom of one side of our housing, since the lip is only ¼” high. However, valve covers frequently extend outward on either side of the actuator valve to accommodate bolts, so we must constrain these sides accordingly. The lip of the valve cover can be minimally filed to allow for our housing, but leaving it intact is preferable. Our sponsor would prefer us to keep this dimension within ¾” if at all possible.

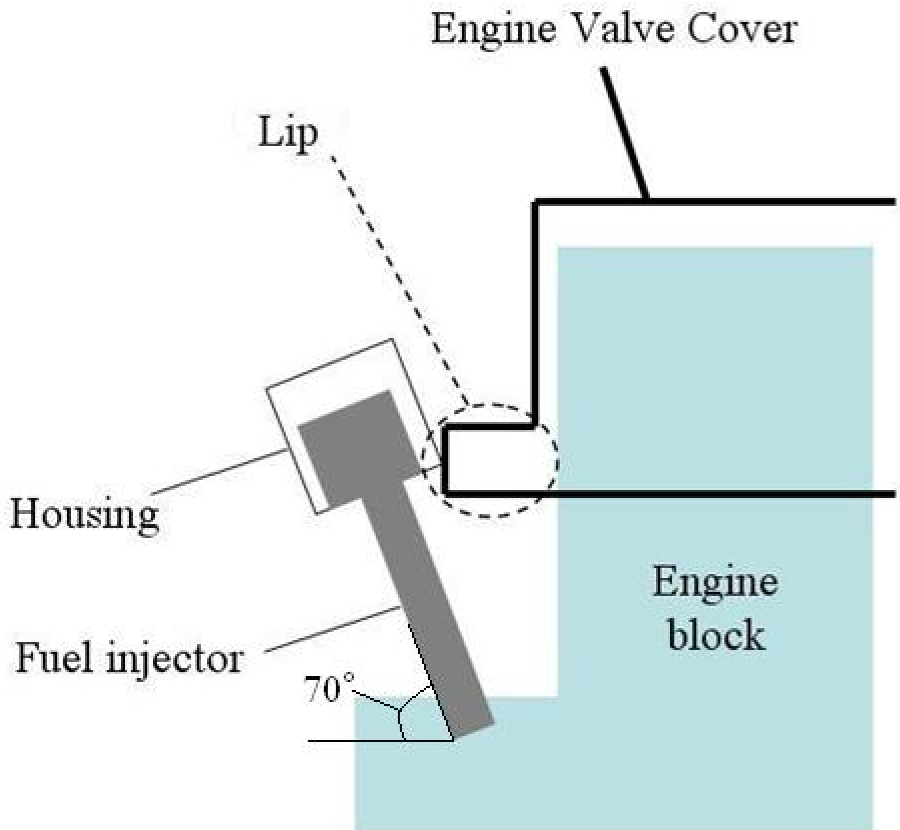

Figure 5: Engine valve cover lip obstructing housing surrounding valve-intensifier mating

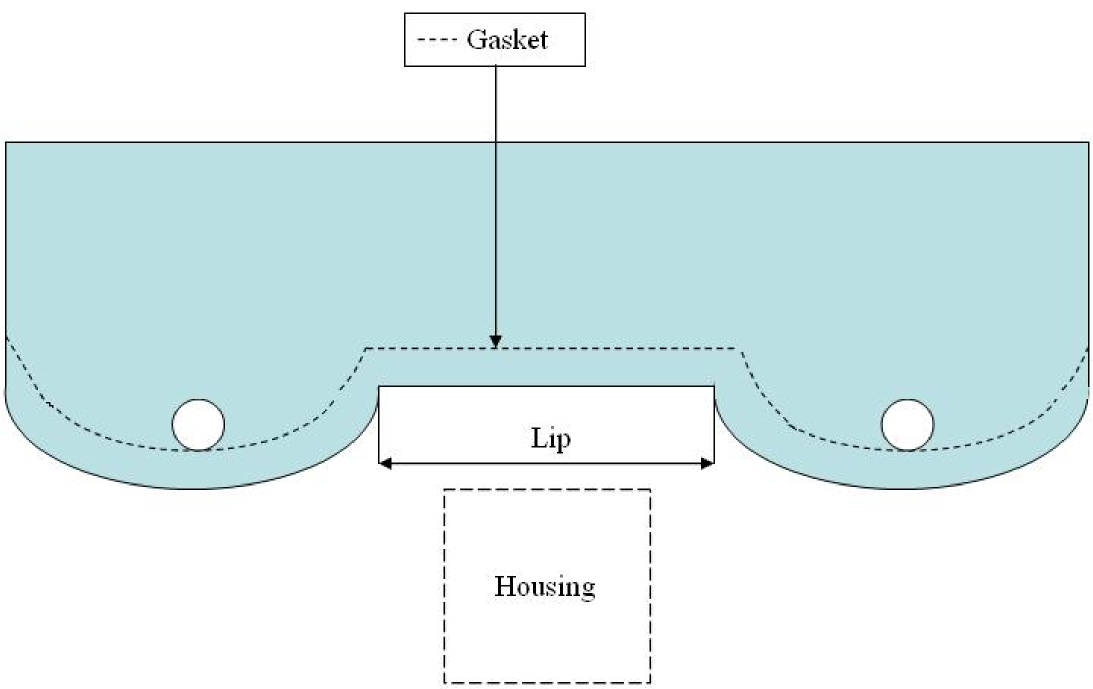

Figure 6: Top view of lip on engine valve cover

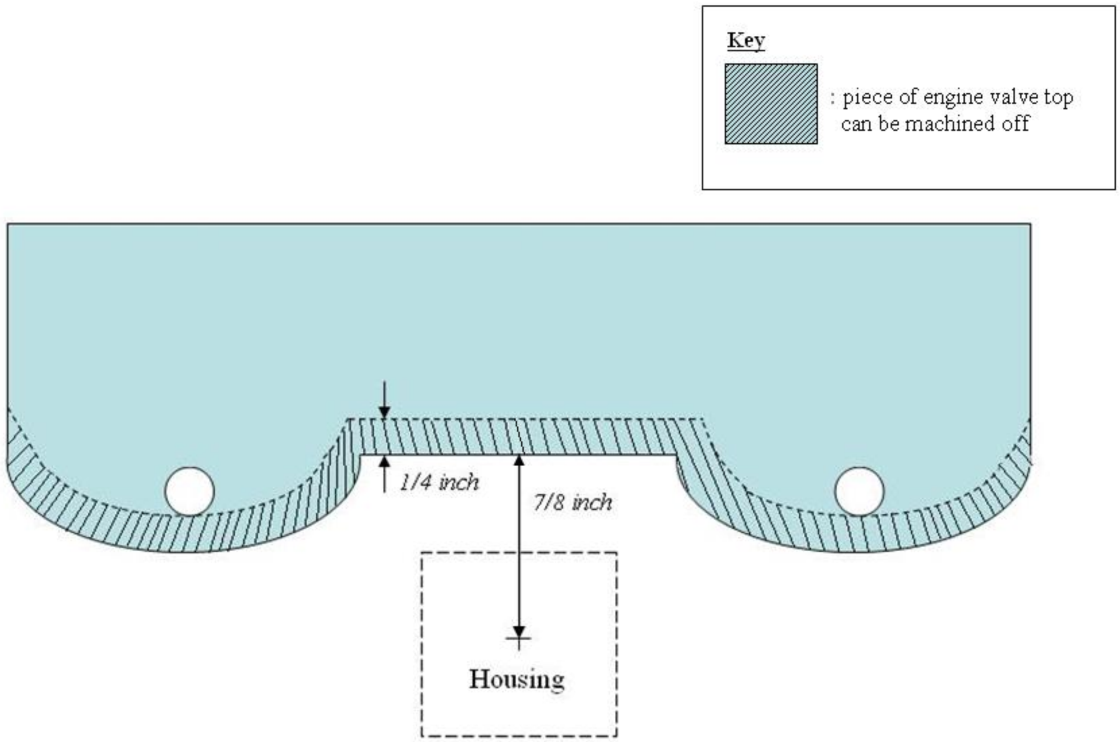

Figure 7: Depending on the exact engine model, up to ¼ inch can be removed from the lip without compromising the gasket

Testing considerations
For testing purposes, we have produced a mock intensifier. It accommodates a Kistler port.

5. CONCEPT GENERATION & SELECTION

The main objective for our housing is to contain and direct the injector fluid flow in and out of the valve. Keeping this objective in mind, we brainstormed a few design concepts that we think might be able to solve the problems that our sponsor is having with the Siemens® valve. All the design concepts are generated by breaking the prototype into 4 component-wise subsystems: the valve outlet (to the intensifier) subsystem, the hydraulic fluid container subsystem, the hydraulic fluid inlet (to the valve) subsystem, the electrical connector subsystem and the hydraulic outlet (from housing) subsystems. We used a Pugh chart for each subsystem to compare existing benchmarks and concepts we generated. We then used the chart to make an informed decision over the best concept in each subsystem that could be used in our prototype. Discussion of these design concepts and the accompanying Pugh charts are in Appendix A.

6. FINAL DESIGN CONCEPT

Figure 8 below shows the illustration of our prototype at the preliminary stage. This illustration is generated by integrating all 4 finalized design concept decisions into one design.

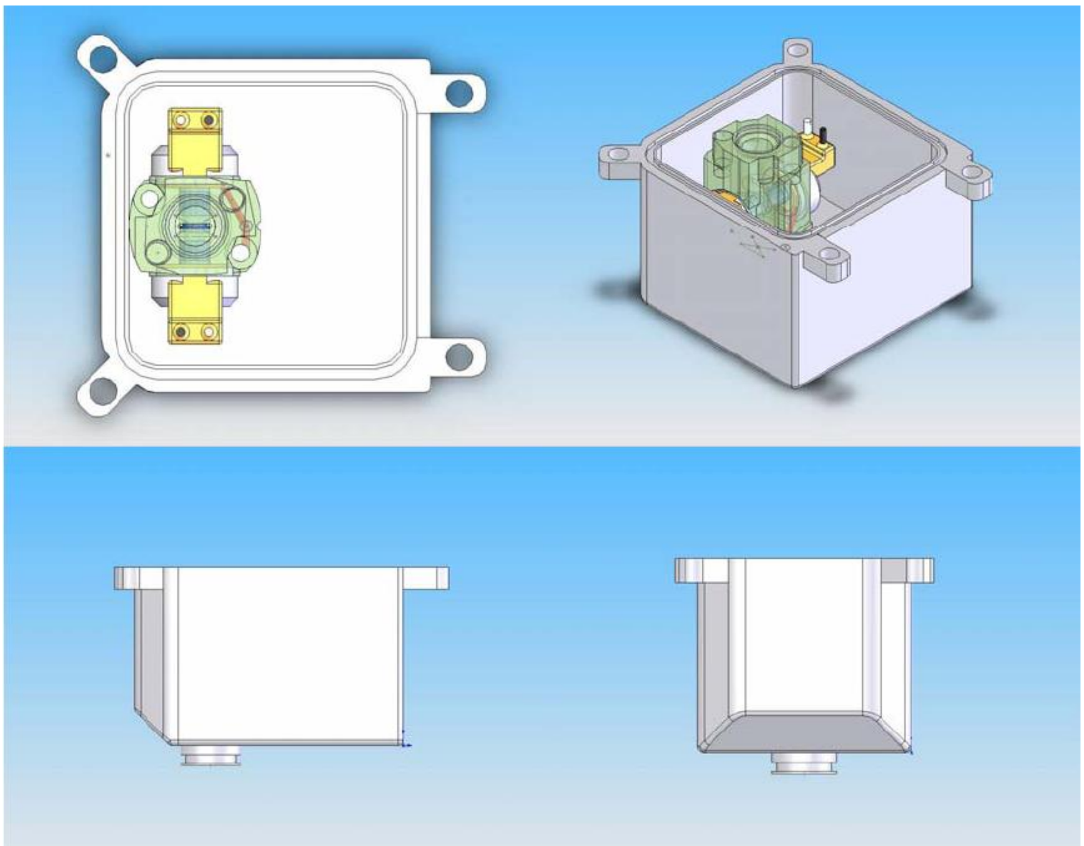

Figure 8: Final design concept.

This design has several locations that present sealing challenges. O-rings seal four locations: one for each housing-to-intensifier bolt (of which there are 2), one for the lid & housing interface, and one for the mock valve outlet that is connected the intensifier. The existing valve has an O-ring already attached which will seal it to the bottom of the housing. The electrical connector is pressure rated, and includes an O-ring. This concept requires precisely size the exit hole for the connector to account for this. The end of the nozzle portion of the lid is chamfered to avoid injuring the internal O-ring in the valve inlet and prevent leakage there. The holes in the lid for the SAE ports are counterbored to accommodate their O-rings to prevent any leakage from there.

7. ENGINEERING ANALYSIS

Engineering Analysis: Wall Thickness

In order to determine the minimum wall thickness of our housing, we had to make some assumptions with regards to properties of materials. We also had to incorporate our design criteria so as to get an accurate estimation of all necessary values. Stainless steel is a generic name for a large number of alloys with varying properties, notably yield strength. We found values ranging from 250-1500 MPa. We decided to design using 250 MPa, the most conservative value. We also determined our thickness with the assumption that the housing would be under an internal pressure of 300 psi (2 MPa). Since the hydraulic fluid will be free to exit once the container is full, we do not realistically expect an internal pressure more than that incurred by the weight of the fluid itself.

1. *Pressure=density*gravity*height*=860kg/m^3* 9.81m/s^2 * .1016m=83037Pa=83KPa

The pressure due to the hydraulic fluid at the bottom of the housing should be no more then 83kPa. This is significantly less than our requested value of 2 MPa.

In order to do the calculations for the wall thickness, we assumed a square geometry with side length L=100mm. We then calculated the principle stresses in each of the walls by way of balance equations.

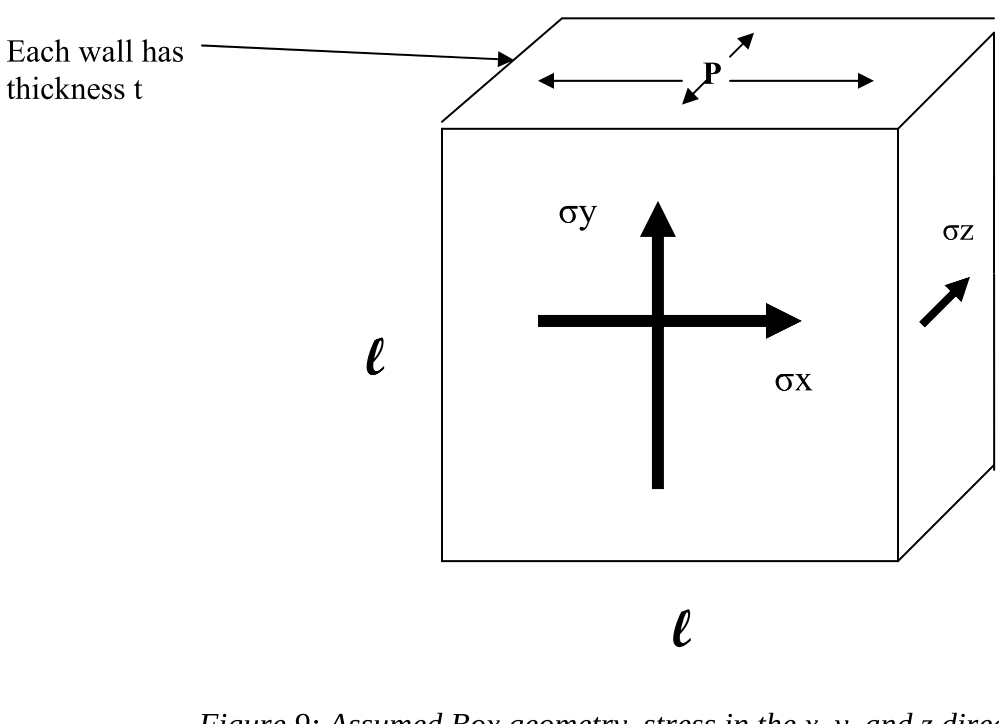

Figure 9: Assumed Box geometry, stress in the x, y, and z directions

2. $\sigma x = \sigma y = \sigma z = P*\ell/2*t$

We then use Von Mises Yield Criteria which states

3. $\sigma yield = (.5*(\sigma x - \sigma y)^2+(\sigma y)^2+(\sigma x)^2))^{1/2}$

Known is the Pressure P, the length of the container ℓ, and the yield strength σyield. Solving for t we find that the minimum thickness we need to protect against yield is .42mm. This is significantly smaller than our actual wall thickness, 3.4mm.

We also wanted to make sure that our housing would leak before it fractured in the case of a critical flaw. In order to do this, we had to analyze the fracture toughness. The fracture toughness of stainless steel ranges from around 70 MPa to 130 MPa depending on many variables. We decided to use 70 MPa as the KIc for our calculations. In order to see of our design would leak before it breaks we had to see if the fracture toughness of our material and design exceeds the critical value of 70 MPa.

Fails before leak if KI>KIc
Leaks before break if KIc>KI
Where $KI=Y\sigma*(\prod*a)^{1/2}$ a-crack length
Y-dimensionless constant

In our case, we calculate KI for a crack length of 4mm, the thickness of our wall. For this length, and using constant Y= 1.12 (geometry specific), we find our KI to be 3.097 MPa which is significantly lower then the 70 MPa we found for KIc. Our housing should leak before catastrophic failure.

8. PROTOTYPE DESCRIPTION

We originally planned to make 2 prototypes: we were going to start with a block of stainless steel and machine it to specifications. Since we planned to use the CNC mill to do so, mindful of our sponsor's need to make additional housings, and aware that stainless steel is expensive in this format, we were going to work out any tooling problems by initially machining an aluminum block. This has the advantage of being able to supply our sponsor with a floppy disk with all of the tool paths already programmed. Dr. Moskalik then let us know that this is not necessary, since he would farm out the project to a machine shop who will create their own toolpaths. As such, he would prefer that we simply make one prototype. To make manufacturing easier and cheaper, he suggested that we instead weld together most major parts and machine important details. Because of this, our prototype is primarily welded 304 Stainless Steel.

9. PROTOTYPE MANUFACTURING

Manufacturing the prototype has led to some significant changes in design. The original prototype manufacturing plan is in Appendix C.

We machined each individual part and ultimately welded them together. What became apparent when we were practicing welding on scrap was that welding takes a lot of practice, it warps the piece, and, depending on the thickness of the pieces joined, it does not necessarily join them through their entire union. Bob Coury advised us that welded joints will not stand up to more than 1 atmosphere of pressure, i.e. 101 kpa or 15 psi. If our assumption about the pressure at the bottom of the container were not accurate, we would only have about 15 kpa additional pressure resistance that we could assume.

Because welding warps pieces (and shrinks them), we had to account for that when machining. The exact amount of warping and shrinking is apparent, but difficult to exactly predict. To ensure exact placement, especially on the bottom where we have the least clearance, we had to drill a through hole to locate the boss on the bottom and a counterbore for it to sit in while it was welded. We also had to drill a hole through the boss for positioning the piece on the lathe after it was welded. Because of the position of the valve within the housing (to accommodate the ¾" to the edge requirement) and the narrow clearance of the walls once installed, any milling on the bottom of the housing had to be complete before the walls and flange were welded on. Had the piece shrunk more than it had, we ran the risk of ending up with the wrong dimensions in one of the places where dimensions are the most critical – where the valve attaches to the housing.

We also had not counted on the weld bead – since welding essentially melts two pieces together, we did not realize that the weld bead needs to remain in place. This turned to our advantage, however – the boss at the bottom of the housing, which originally only partially covered the bolt holes through the housing, needed to be remade to account for the height taken up by the weld bead. We then switched from 1" stock to 1.5" stock, and developed a "shoulder", which somewhat alleviated our concerns about sealing the bolts. The "shoulder" allows for one O-ring around both of the bolt holes instead of two smaller ones on the interior of the cavity.

Because of time constraints, we altered the overall shape. In our original plans, we had angled walls leading from a flat portion at the front of the valve ("front" being the side closest to the valve cover). This would have meant manufacturing an additional piece to clamp the walls onto during welding. The reason these sides were initially sloped was to conserve space near the valve cover; since the most critical dimension (3/4" from the center of the valve to the near end of the housing) was met and the clearance on the sides of the valve was minimal, we were able to confidently alter to the rectangular design, which required no extra part for welding purposes.

Bob Coury tack welded the walls together and to the bottom, and then welded the flange as a plate to the top of the walls. We then had to hollow out the interior of the flange. Removing most of the material over the open interior took about 2 hours. Considering that this space was less than 2.6” by 3.3” and only 0.25” thick, this machining time is considerable.

Valve placement within the housing is critical, as is the location of the nozzle in the lid. To ensure that the lid is properly lined up with the valve when it is installed, we had to leave lid manufacturing until the end. Once we had the flange hollowed out, we were able to use a dial indicator in the counterbore at the bottom of the housing so that we knew the exact coordinates of the center. Once this was completed, we could clamp the lid onto the flange and drill holes for the bolts and locating pins. Bolts will not guarantee placement within a thousandth, and we could ensure this placement with the locating pins. We drilled two locating holes through the flange and lid, one on either side of the housing, so that the lid would only fit on in that orientation. We then reamed the holes to allow a press fit of the locating pins. We returned the mill to the previously determined center and drilled a hole through so that we could bolt the boss for the nozzle onto the lid for welding purposes.

Once all the bosses are welded on, we would not be able to shape the nozzle. We welded the boss for the nozzle and then mounted the lid on the lathe, using the through hole to center it. After the nozzle was precisely placed, we finished up the lid by welding on the other two bosses, shaping them, and drilling and tapping the holes for the SAE ports.

The design critique contains more information about our prototype.

10. VALIDATION

VALIDATION TESTING AND RESULTS

Most of the engineering specifications for the housing can be validated by just observing and operating the prototype. These specifications include its weight, its ease of installation and removal from the engine, and its ability to mate with the Siemens valve and mock intensifier. However, there is one specification that can only be validated through testing; if the housing can withstand 3500 psi inlet pressure and 300 psi outlet pressure. The tests and their results are summarized in Table 2 on page 16:

Specification	Test	Results
Weight of housing	Weigh on electronic scale; compare to existing benchmarks	Housing weighs 4.12 lbs. 4 housings would weigh 16.48 lbs, much less than the 40 lb "box" design
No leakage out of housing	Fill housing with hydraulic fluid (or any liquid) and check for leaks.	No leakage from welds (see explanation below)
Ease of installation and removal	Remove top plate and verify if valve van be taken out or installed with ease.	Housing easy to install and remove. Addition of locator pins to flange was especially helpful for accurately placing lid on top of housing.
Ability to mate with Siemens valve and mock intensifier	Pass pressurized hydraulic fluid through Siemens valve during bench test and check for leakage at mating location	Tight fit between housing bottom and mock intensifier. Unable to perform bench test. (See explanation below)
Withstand 3500 psi inlet pressure and 300 psi outlet pressure	Attach to hydraulic pump, crank up hydraulic pressure and check for leakage.	Unable to perform bench test (See explanation below)
Mock outlet must not contact lip on valve cover, radius from center of actuator valve to housing side wall closest to valve cover must be ≤ 7/8 in	Measure diameter of boss used to make mock outlet	Diameter of boss for mock outlet is 1 ½ in. This boss is flush with the end of the housing that this restriction applies to, and is centered at the valve center. The center of the valve is 3/4 in from this edge.
Cost must be within $400 budget	Add up materials totals	Materials total $70.89 for housing and $10.89 for mock intensifier Price breakdown in Appendix G

Table 2: List of tests for checking targets for engineering specifications

Bench test

There is an existing test bench at the EPA's Fuel and Emissions laboratory (NVFEL). It is a simple hydraulic pump with adjustable pump pressure. The objective of this bench test was to pressurize the housing to a few hundred psi and check for leaks.

However, we were unable to perform this test due to several crucial reasons. First, the housing's stainless steel construction as requested by our sponsor required more time than we had to machine. We completed machining our prototype on the day of the design expo. Secondly, the limited time frame we had to machine and test our product was further hampered by our inability to mate our #4 SAE outlet port to the top lid. This machining problem occurred even though we drilled a 0.25in hole to fit our outlet port onto the top lid of our housing as specified by SAE standards [10]. We also found that we had not left enough of the nozzle boss intact to allow threading far enough down for the inlet port. Correcting problems with the prototype would have required restarting the entire lid, which did not fit into our timeline. We have tested the prototype to the best of our abilities. We have weighed it, measured it, and we plugged the holes in the bottom of the housing and filled it with water to test if the welds leak.

Conclusion

Our inability to bench test our prototype does not mean our housing is a failed design. Theoretically, the housing should work when pressurized hydraulic fluid is passed through it because we have built in safety factors that determined the wall thickness and the overall size of the housing. We carefully machined all fittings in the housing, so there should be no leakage. This was verified when we filled the housing with water, which is denser than the Mobil 1 Synthetic Automatic Transmission Fluid that is the hydraulic fluid used in the valve. As the EPA NVFEL has an existing test bench available, we have attached testing procedures in Appendix D if they still want to perform fluid pressure tests on our prototype.

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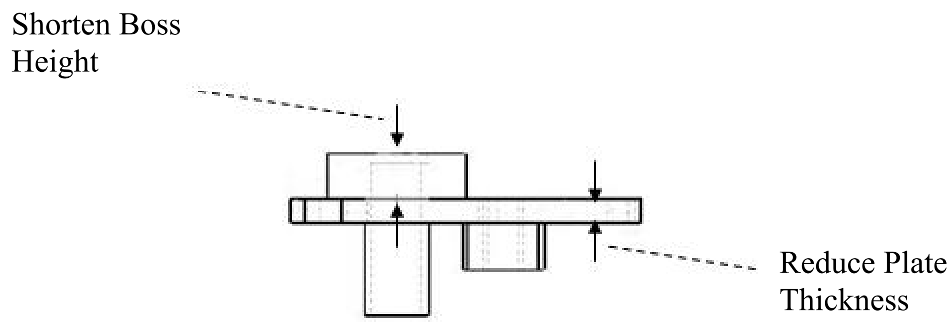
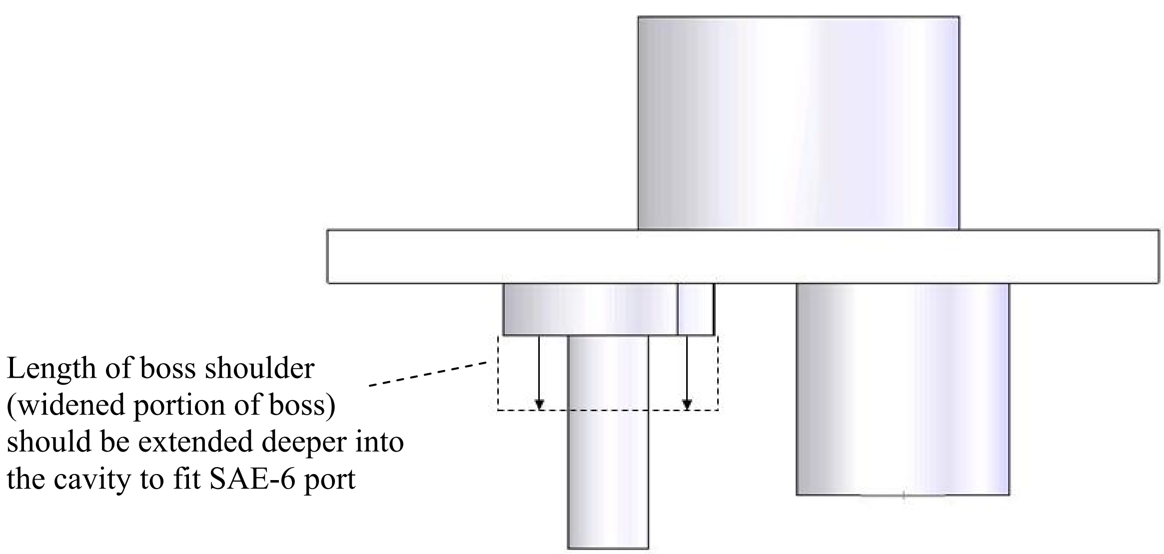
11. DESIGN CRITIQUE

We made our prototype with considerations for warping and shrinking during welding. Since, in practice, it was very easy to melt through 1/8" steel, we did not dare make it thinner. Thinner walls would also have the potential to warp more. As was found from the engineering requirements, the wall thickness could feasibly be virtually paper-thin and still serve the purpose. Every plate used in our prototype could potentially be thinner, if we were to use longer bosses. This would allow us to use thinner plates while at the same time accommodating the necessary depth required for many of the fittings.



Another thing that proved to be a problem with the prototype was trying to incorporate both the electric connector and the hydraulic fluid outlet on the top of the housing. This caused us spacing issues. To fit both bosses into the lid it was necessary to weld one on top of the lid and one on the bottom – this led to a lack of clearance for the outlet port, making it impossible to attach. We could fix this by incorporating either of these bosses in the side or making the bosses smaller initially. Relocation would also allow us to shorten the total length of the housing (by about 0.5") since the length would no longer have to incorporate the 2 bosses sitting side by side. This would make the housing lighter. Originally, it was thought that we would make it easier for the user to access if both bosses were located on the top. However, we now believe that more value is added in reducing total size and making manufacturing easier by having either the outlet port or the electrical connector boss on the side of the housing.

We made a mistake in the manufacturing of the boss that was to mate with the valve inlet. The design called for a boss that was welded to the lid that would be thick enough at the base to accommodate the SAE inlet fitting, and then narrow down to a small tube that would fit snugly inside of the valve and seal within the O-ring. We machined the length of the small tube that fit inside the valves O-ring perfectly, but the length of the thicker part of the boss was too short to accommodate the SAE port that needed to fit inside of it.



As a result, we were not able to thread the SAE hole deep enough for the part to fit. Even if we were able to thread it, the hole would not have been deep enough to fit the port's O-ring. This was simply a manufacturing error and not a design mistake. This could be fixed by simply increasing the depth of the boss that remains the larger size.

The mock valve portion of the housing fit into our mock intensifier perfectly. The inlet tube from the top fit perfectly into the valve. The valve fit exactly into the bottom of the housing. We believe that with corrections to the problems with the lid, our housing would perform well in tests.

Due to time constraints and changes necessary in our design, we were not able to find appropriate O-rings for our design. We have re-evaluated our O-ring requirements and have included our recommendations in the recommendation section, as well as incorporated properly sized glands in our final design CAD drawings.

Because of the amount of time involved in manufacturing the prototype in stainless steel, we believe that any future groups attempting this project should consider prototyping in aluminum. To this end, we have included calculations to determine if aluminum is feasible for the 3500 psi valve inlet and outlet pressures, which was Dr. Moskalik's primary concern when we broached this subject with him originally. Though this material might wear and/or deform after long term usage on an engine, for validation purposes we believe that it would be sufficient. Performing our yield calculations with 6061-T6 Al, we find that even in a small piece subjected to high pressure such as the inlet to the valve that yield strength is high enough that it should not fail. These calculations follow.

Aluminum 6061-T6 Yield Strength = 40,000psi
Hoop Stress (HS) = Pr/2t=40,000*.5/2*.1=8750psi
Vertical Stress (VS) = Pr/t=40,000*.5/.1=17500psi
P=Pressure=3500Psi
R=.5in
T=.1in

$HS^2 - HS*VS + VS^2 \leq \text{Yield Stress}^2$
15,155psi ≤ 40,000psi→√

12. RECOMMENDATIONS

Material

Based on the calculations shown above in Section 11, we would suggest the prototype to be made from aluminum, especially when dealing with the time frame of this class. After perfecting techniques in aluminum, perhaps it would be worthwhile for one of the team members to finish a stainless steel prototype in an independent study capacity; if not, recommendations about a final design would be appropriate after the proof of concept has been completed in aluminum.

Large-scale Manufacturing

Due to the extensive machining required (which is further slowed by the longer time required to machine stainless steel), it will quickly become economically feasible to die cast the housing. If die casting can produce parts with tolerances within a thousandth, no further machining is necessary. If not, specific manufacturing recommendations follow:

Cast the bottom, walls, and flange together, including the bottom boss. The O-ring grooves should be cast, as well as the through holes for the bolts, the counterbore (at least 0.1" undersize diameter-wise) for the valve to sit in, and a 0.5" through hole. The counterbore and the hole should then be finished with a boring bar on a mill. Since the location and smoothness of these features is of tantamount importance, the mill should be zeroed using a dial indicator within the cast hole to indicate relative roundness.

The interior will require a boring bar that is at least 3" long – if this is not available, it will be necessary instead to cast the bottom plate with boss separate from the walls and flange and then weld them together after final machining has been completed on the bottom plate.

The lid can also be partially die cast. The boss that leads into the valve can be cast along with the lid, as well as through hole features for bolting down the other bosses to the lid for welding. For machining and locating purposes, the only boss actually cast onto the lid needs to be the one that leads into the valve. The threads, holes, and counterbores for the SAE ports can be cast into the lid, as well as the through holes for the bolts connecting the lid to the housing.

The housing must be mounted in the mill and the exact center of the valve's counterbore must be located. The lid must then be clamped onto the housing and shaped to match. Bolt holes for the flange can then be drilled, along with holds for locating pins. These holes must be reamed to a press-fit size through both the lid and flange. After returning the mill to the center location of the valve's counterbore, we can then drill a 0.125" hole through the lid and the boss.

This new hole through the boss can be used, with the dial indicator, to precisely locate the lid on the lathe to shape the boss. Take care not to narrow the boss too much too close to the lid – allow for the depth of the SAE port hole. The exterior of the boss must be taken down to a thousandth less than the interior dimension of the valve opening and must be long enough to clear the internal O-ring. The interior of the boss can then be drilled to an appropriate size on the lathe.

Appropriately sized stock for the other bosses can then be welded onto the lid. The necessary through holes can also be drilled. Once the locating holes have been reamed to a slip fit size, the lid should be complete. The bolt holes in the flange portion of the housing can be tapped and the locating pins can be pressed into the flange to finish up the housing. All that remains at this point is to install the O-rings and put the housing into service.

13. CONCLUSIONS

Dr. Andrew Moskalik of the NVFEL division of the EPA has sponsored our team to design a fluid supply housing that corrects leakage problems in their experimental clean diesel fuel injector design. To this end, we have interviewed experts and generated concepts during the design phase. We generated a final design concept that addresses all of the problems with the current design. We have refined this concept into a final design. We developed a manufacturing plan, and made the prototype. We performed most but not all of our validation tests. We have also made some suggestions for alternative housing material and large-scale manufacturing if the EPA decides to make more of our housings for future testing.

REFERENCES

1. Dr. Andrew Moskalik, NVFEL EPA

2. http://www.julien.ca/en/stainless/advantages.asp
   (Website describing the advantages of Stainless Steel)

3. Mechanical Engineering Design, Shigley and Mischke, 6^{th} Edition

4. Dr. Timothy Jacobs, University of Michigan

5. Tim Pott, Proprietor of EuroTec Motors & Automotive instructor, Washtenaw Community College

6. Dr. Ellen Arruda, Professor of Mechanical Engineering and Macromolecular Science and Engineering, University of Michigan

7. Dr. Alan Wineman, Professor of Mechanical Engineering, University of Michigan

8. www.parker.com

9. www.allorings.com

10. SAE 1926-1: "CONNECTIONS FOR GENERAL USE AND FLUID POWER PORTS AND STUD ENDS WITH ISO 725 THREADS AND O-RING SEALING; PART 1: THREADED PORT WITH O-RING SEAL IN TRUNCATED HOUSING"

ACKNOWLEDGEMENTS

- Prof. Steven J. Skerlos, U of M : Course Instructor
- Mr. Ross W. Morrow, U of M : Section Instructor
- Mr. Bob Coury & Mr. Marv Cressey, U of M : Machine Shop Coordinators
- Dr. Andrew Moskalik, NVFEL EPA
- Dr. Timothy Jacobs, University of Michigan
- Tim Pott, Proprietor of EuroTec Motors & Automotive instructor, Washtenaw Community College
- Dr. Ellen Arruda, Professor of Mechanical Engineering and Macromolecular Science and Engineering, University of Michigan
- Dr. Alan Wineman, Professor of Mechanical Engineering, University of Michigan
- ME 450 Team 7 Fall 2005

APPENDICES

APPENDIX A : Design Concepts

(1) Valve outlet (to intensifier) subsystem

The first concept is the valve outlet (to the intensifier) subsystem. We managed to come up with two alternative designs, as shown in the Pugh chart in Figure 8 below. The first design (number 2) fully encloses the valve in a housing that mimics the bottom of the valve for connection to the intensifier. The second design (number 3) is a double threaded boss at the bottom of the housing. The benchmark design (Sturman) has a direct valve outlet-to-intensifier mounting assembly. The precise (and expensive) machining used to produce this valve eliminates the leakage problem.) It does not leak due to the tight tolerance machining of the valve itself. Based on the result of the Pugh Chart, we determined the best design concept for the outlet is to have a mock valve outlet at the housing because it is easier to manufacture and the design itself helps us to reduce the part count.

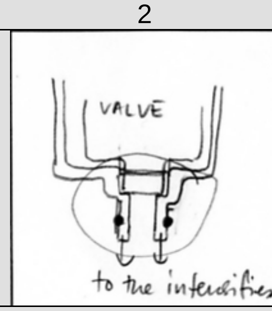
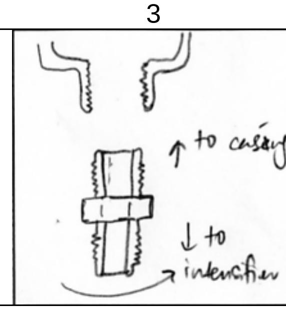
Subsystem: Valve Outlet	1	2	3
			
Assembly Friendly	0	-	-
Leak Free	0	+	+
Minimize Dimensions	0	-	-
Ease of Manufacturing	0	+	-
Cost Effective	0	+	+
Sigma +	0	4	2
Sigma -	0	2	4
Sigma S	7	0	0
Rank	3	1	2

Figure A1: Pugh chart for valve outlet (to intensifier) subsystem

(2) Hydraulic fluid container subsystem

The second concept that we looked into is the hydraulic fluid container subsystem. From this concept, we came out with four alternative design concepts, as shown in the Pugh chart in Figure 9 below. The first design concept (Number 7) is having a cylindrical housing that surrounds the valve. The second design concept is having a rectangular housing instead of cylindrical housing. The third design concept is having 2 small L-shaped tubes that are attached to the ends of the electromechanical actuators (leaking parts). These tubes are used to redirect the hydraulic fluid back to the main flow. The last concept is that having a big block of housing that will encase 4 valve systems instead of having one containing system for each valve, which is a design the EPA is currently using with the Siemens valve. The benchmark (Sturman) does not have any containing system outside of the valve. This is because it does not have any leaking problem from the electromechanical actuator parts. We want the housing to fit to the intensifier without having to interfere with any other engine parts and also we want an ample space for the electrical connector and hydraulic outlet. Therefore, we determined that the second design concept is the best for our prototype design.

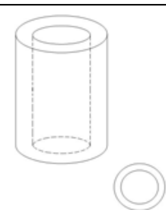
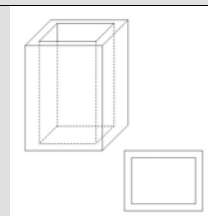
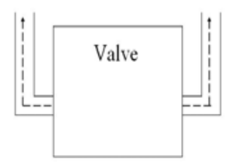
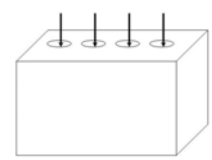
Subsystem: Hydraulic Fluid Container	6	7	8	9	10
					
Assembly Friendly	0	+	+	-	-
Leak Free	0	+	+	+	+
Minimize Dimensions	0	-	+	-	-
Ease of Manufacturing	0	+	+	-	0
Cost	0	+	-	-	-
Sigma +	0	5	6	2	1
Sigma -	0	1	1	4	4
Sigma S	6	0	0	0	1
Rank	5	2	1	3	4

Figure A2: Pugh Chart for Hydraulic Fluid Container Subsystem

(3) <u>Hydraulic fluid inlet (to the valve) subsystem</u>

The third concept that we examined is the hydraulic fluid inlet (to the valve) subsystem. We managed to come out with four alternative design concepts, as shown in Figure 10 below. The first design concept (<u>Number 12</u>) is having a lid with fixtures for bolts and an SAE port. The bolts' function is to mount the lid to the case. The second design concept (<u>Number 13</u>) is also a disk design but it is connected to the housing via threads on the sides. We determined that this design concept might help us to reduce the parts count of our final prototype. The third design concept (<u>Number 14</u>) is a lid that has 2 holes that collect the outlet hydraulic fluid from the valve and directs the fluid to a port. This design concept does not seem to be applicable to our containing objective. The last design concept (<u>Number 15</u>) is having 3 separate fluid lines; 1 inlet and 2 outlets. After going through the Pugh Chart, we chose the first design concept for our prototype design. We chose this concept so the hydraulic flow is straight down from the top of the valve to the bottom of the valve, which minimizes potential pressure drops. This design concept also meets our objective of containing and directing flows.

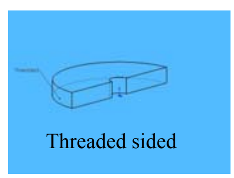
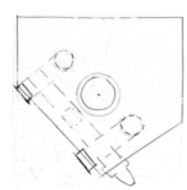
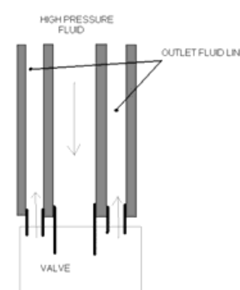
Subsystem: Inlet	11	12	13	14	15
					
Ease of manufacturing	0	+	-	+	-
Ease of Fastening	0	+	+	+	-
Leak Free	0	+	0	-	-
Sturdy	0	+	+	+	-
Minimize Dimensions	0	-	-	+	+
Cost	0	+	-	+	+
Sigma +	0	6	3	6	2
Sigma -	0	1	3	1	5
Sigma S	6	0	1	0	0
Rank	5	1	3	2	4

Figure A3: Pugh Chart for Inlet Subsystem

(4) <u>Electrical connector subsystem and</u> (5) <u>Hydraulic outlet subsystem</u>

The fourth concept that we looked over is the locations of electrical connector (Pugh chart is Figure 11 below) and hydraulic outlet (from housing) subsystems (Pugh chart is Figure 12 on page 14). There are various locations that are possible. However, we wanted the outlet and electrical connector to be easily accessible when the hood of the car is opened. Therefore, the outlet and electrical connector at the housing lid is the optimal location, so we picked design concept Number 17 and 22.

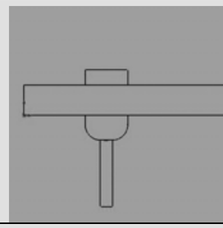
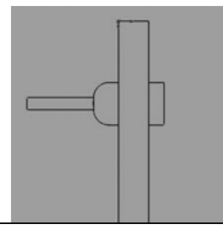
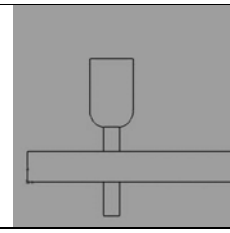
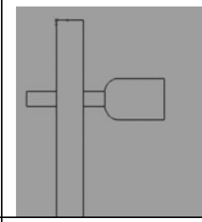
Subsystem: Electrical Connector	16	17	18	19	20
					
Assembly Friendly	0	+	0	+	+
Leak Free	0	0	0	0	0
Minimize Dimensions	0	-	-	+	+
Ease of Manufacturing	0	0	0	-	-
Easy to access	0	+	-	+	+
Sigma +	0	3	1	3	3
Sigma -	0	1	2	2	2
Sigma S	6	2	3	1	1
Rank	5	1	4	2	3

Figure A4: Pugh Chart for Electrical Connector Subsystem

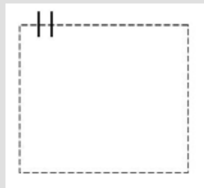
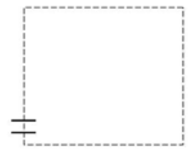
Subsystem: Hydraulic outlet	21	22	23	24	25
					
Assembly Friendly	0	+	0	+	+
Leak Free	0	0	0	0	0
Minimize Dimensions	0	-	-	+	+
Ease of Manufacturing	0	0	0	-	-
Easy to access	0	+	-	+	+
Sigma +	0	3	1	3	3
Sigma -	0	1	2	2	2
Sigma S	6	2	3	1	1
Rank	5	1	4	2	3

Figure A5: Pugh chart for Hydraulic Outlet (Housing) Subsystem

APPENDIX B : Archive - Final Design Description from DR3

The final design consists of 4 major components; housing, lid, fasteners and seals. The housing will have a cavity for a Siemens valve to sit in, a valve outlet end at the bottom, O-rings glands at the top and at the bottom and 4 bolt holes at the top. The lid will have 2 holes for the SAE ports. The following description will help you to understand how our final design works.

1. The Siemens valve will be secured inside of the housing by 2 socket head bolts (T25F1). These two bolts will also secure the housing (T25C1) the intensifier (T25I1). Figure XX shows how the bolt is used to mount the valve to the housing and the housing to intensifier. The size of the bolts are referred to in Appendix XX .

2. Two O-rings (T25SX) will be used to sealing capability to the two bolt holes that will secure the valve to the housing. The interface between the hydraulic outlet of the valve and the inside of the bottom of the housing will be sealed by the O-ring (T25SXX) that pre-fitted at the outlet (See Picture).

3. The bottom part of the valve outlet that mimics the hydraulic outlet will also be fit with O-ring (T25SXX) to provide a sealing capability at the intensifier cavity (See Picture).

4. The lid will be bolted to the housing by using 8 socket head bolts (T25F2). The inlet hydraulic line will be fitted to the valve and there is a pre-fitted O-ring inside of the valve hydraulic intake.

5. In between the lid and the housing, there will be an O-ring (T25SXXX) that will seal the interface between the lid and the housing.

6. Another location where O-ring will be used is the two SAE ports that will be fitted to the lid part. The SAE ports are already pre-fitted with O-rings. O-ring sizes are available in Appendix XX.

In our design, we decided to make the housing and lid of stainless steel. For fasteners, we will be using alloy-steel socket head bolts. This type of bolt has good fastening capabilitues. For the O-rings, we will use Silicone, which is chemically resistant to Synthetic ATF, our hydraulic fluid. It is also rated for operation between -54° C and 204° C.

Our final design will have a total weight of XXkg. This is below our maximum limit weight for the total assembly which is XXkg. Most of the total weight comes from the housing and the lid components which is xxkg. This is due to the material that we chose for the housing and lid (Stainless Steel), as well as our minimal wall thickness.

APPENDIX C: Prototype manufacturing plan

We have developed a step by step manufacturing plan, which follows.

Housing (Part 1)

Bottom of housing (part 1a)

- Made from ½" thick stainless steel
- Machine basic "house" shape

Sides of housing (part 1b)

- Made from 1/8" or 5/32" thick stainless steel
- Weld in sections to the base (part 1a), bending to fit all the way around
- Weld ends together

Lip (part 1c)

- Made from ¼" thick stainless steel
- Mill out basic shape, including open center, but allow ¼" extra clearance
- Weld to sides of housing (part 1b)

Housing finishing

- Fill body of housing with water to check for leaks through any welded areas. If any exist, re-weld. Re-check until satisfactory, then dry thoroughly.
- Machine bottom geometry: mock valve end, external O-ring groove, outlet hole, bolt holes
- Check distance from center of mock valve end to outer edge of closest wall. If more than ¾", remove material no more than 1" from bottom until distance is ¾".
- Flip housing right side up
- Machine top of lip flat, followed with a slow cut to ensure good surface finish.
- Remove any excess overlap material on inner edge of lip (overhanging interior of housing)
- Mill out gland for housing – to – lid O-ring
- Drill bolt holes in lip
- Machine bottom-of-housing geometry (counterbore on bolt holes for O-ring glands)
- Tap bolt holes in lip
- Refine surface finish of glands (sandblasting or, if necessary, electropolishing)

Lid (part 2)

Bosses (parts 2a, 2b, 2c)

- Use a lathe to make rough bosses out of round stainless steel stock for: nozzle into valve, electrical connector, and the SAE outlet port

Lid finishing

- Begin with ¼" thick sheet stainless steel
- Weld bosses in appropriate locations

- Drill holes in bosses, as well as counterbores where appropriate
- Drill holes in lip for bolts
- Machine bottom part of lid flat for mating with top of housing (part 1)
- Refine nozzle geometry to ensure exact placement
- Tap bolt holes and SAE port holes

Assembly:

- Coat Housing –to- intensifier bolts with Loc-tite
- Install O-rings using Parker Super O Lube
- Insert Bolts through valve & carefully place through holes in housing, ensuring O-Rings stay in place
- Line up bolts with holes in intensifier, carefully hand tighten making sure O-Rings remain intact and in place. Tighten down bolts with Allen wrench
- Install O-ring in top of housing using Parker Super O Lube
- Install electrical connector in lid, then place lid on housing, with funnel placed into valve carefully so it does not shear off the O-Ring contained in the valve
- Hand start each lid-to-housing bolt, then tighten in a cross pattern (opposite bolts followed by the other pair) until the lid is flush with the housing.
- Hand install SAE ports and tighten down carefully

Mock Intensifier (part 3)

- Begin with stainless steel block
- Square up all sides
- From top, drill hole for mock valve
- Drill holes for mounting bolts
- Flip piece and drill hole from bottom to fit an SAE -6 port (threads + counterbore)
- Drill 2 holes (& tap) side of block for mounting bolts
- Drill 1 hole in side with counterbore & threads for Kistler port (& SAE port)

APPENDIX D: Validation - Bench Test Procedure

For testing the inlet hole

1. Wear safety goggles
2. Secure the housing/valve/intensifier piece with mounting screws
3. Fill the pump with hydraulic fluid
4. Connect the black hose between the pump outlet nozzle and housing inlet hole
5. Plug mock intensifier outlet
6. Place housing/valve/intensifier into a bucket
7. Turn the pump on
8. Adjust the pump pressure to 3500 psi
9. Purge air out of hydraulic line and manifold/valve/intensifier
10. Leave the pump on for 5 minutes
11. Check for leaks
12. Reduce pump pressure
13. Turn pump off
14. Disconnect the black hose

For testing the outlet holes

1. Wear safety goggles
2. Secure the housing/valve/intensifier piece with mounting screws
3. Fill the pump with hydraulic fluid
4. Connect the black hose between the pump outlet nozzle and pseudo intensifier
5. Plug housing outlet
6. Turn the pump on
7. Adjust pump pressure between 200 and 600 psi
8. Leave the pump on for 5 minutes
9. Check for leaks
10. Reduce pump pressure
11. Turn pump off
12. Increase torque on mounting screws and repeat steps 6-11
13. Disconnect the black hose

Equipment Needed for Testing

1. Housing/valve/intensifier piece
2. Screws to connect the housing/valve/intensifier piece
3. Wrench
4. Bucket
5. Pump with its black hose
6. Watch
7. Hydraulic fluid
8. Digital camera
9. Safety goggles

APPENDIX E: Operational Instruction Manual

Using the housing for the first time:

1. Check the housing assembly to see if it is properly assembled. Make sure all bolts are tightened and the valve/housing is firmly attached to the intensifier.

2. Connect the SAE inlet to the hydraulic pump with hydraulic tubing.

3. Repeat steps 1 and 2 for each assembly.

4. Prime the housings by activating the hydraulic pump.

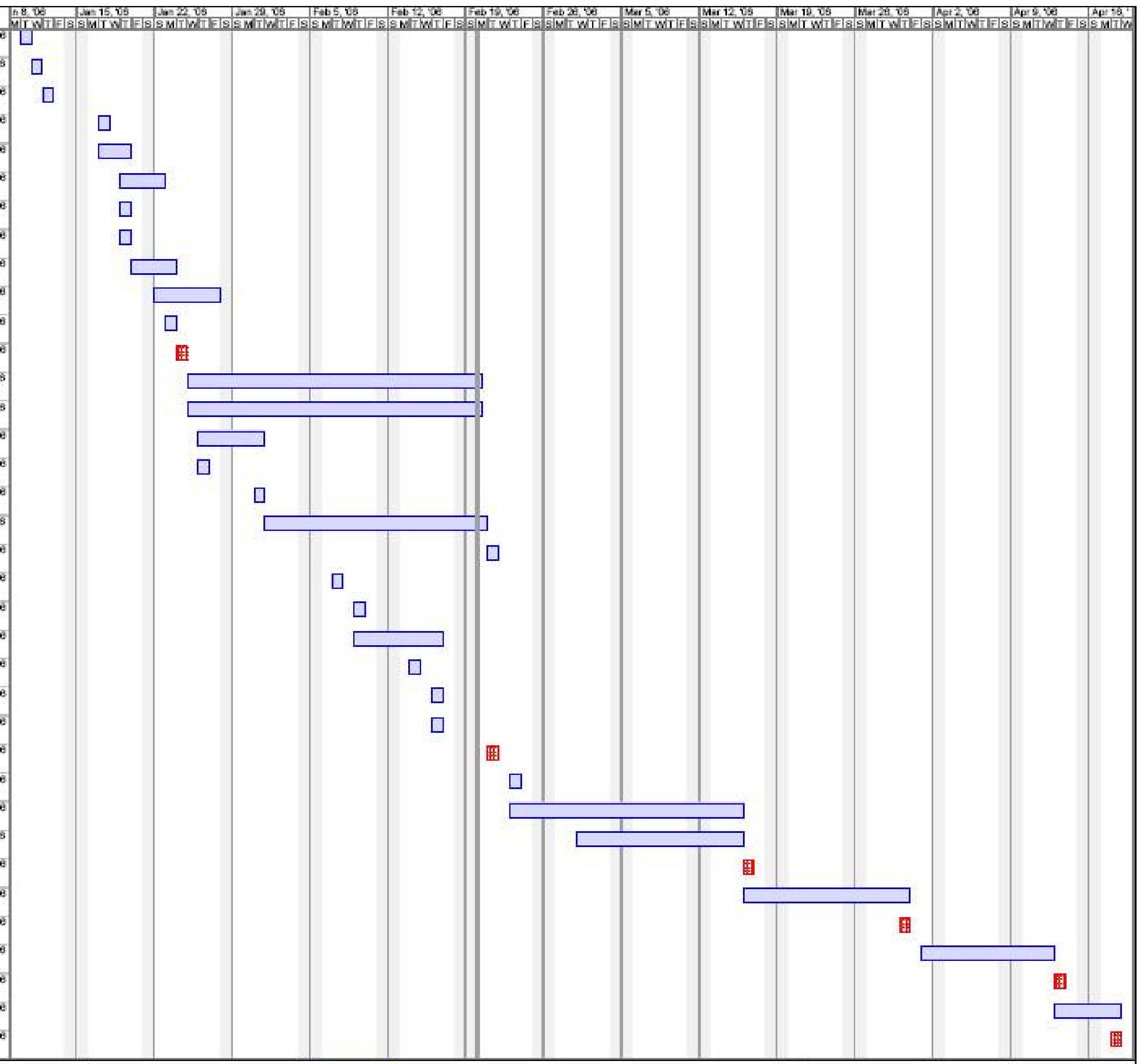
5. The housing is primed when hydraulic fluid starts exiting at the outlet.

6. Connect the SAE outlet to the fluid reservoir with hydraulic tubing.

Once all housings have been installed and primed they should not need further attention.

Appendix F : Gantt Chart (Warning: Due to high resolution, see Gantt Chart on cTools)

ID	Task Name	Duration	Start
1	Lecture 1 - Design Process and IDEO	1 day?	Tue 1/10/06
2	Form Project Team	1 day?	Wed 1/11/06
3	Lecture 2 - Developing Engineering Specification	1 day?	Thu 1/12/06
4	Meeting with Dr. Moskalik	1 day?	Tue 1/17/06
5	Problem definition	3 days?	Tue 1/17/06
6	Generate QFD, Gantt chart	3 days?	Thu 1/19/06
7	Lecture 3 - Concept Generation, Decomposition,	1 day?	Thu 1/19/06
8	Divide Tasks	1 day?	Thu 1/19/06
9	Reverse Engineering	3 days?	Fri 1/20/06
10	Workshop Signup	6 days?	Sun 1/22/06
11	Finalize Design Review 1	1 day?	Mon 1/23/06
12	Design Review 1 - Formal Presentation and Repc	1 day?	Tue 1/24/06
13	Concept Generation	19.5 days?	Wed 1/25/06
14	Generate Pugh Chart Selection	19.5 days?	Wed 1/25/06
15	Preliminary Engineering Analysis	5 days	Thu 1/26/06
16	Lecture 4 - Ethics and Environment in Design & I	1 day?	Thu 1/26/06
17	Lecture 5 - Electromechanical Design: Controls a	1 day?	Tue 1/31/06
18	Material selection Analysis	14 days?	Wed 2/1/06
19	Lecture 6 - Engineering Globalization	1 day?	Tue 2/21/06
20	Lecture 7 - Future of Automotive Manufacturing	1 day?	Tue 2/7/06
21	Lecture 8 - Starting a New Business	1 day?	Thu 2/9/06
22	Finalize Design Concept and Analysis	6 days?	Thu 2/9/06
23	Lecture 9 - Ethics, Liability, and Patents in Desigr	1 day?	Tue 2/14/06
24	Lecture 10 - Design for Manufacture and Assemt	1 day?	Thu 2/16/06
25	Meeting with Dr. Moskalik	1 day?	Thu 2/16/06
26	Design Review 2 - Formal Presentation and Repc	1 day?	Tue 2/21/06
27	Lecture 11 - Shop and logistics, Midterm Evaluati	1 day?	Thu 2/23/06
28	Final Design and Engineering Analysis	15 days?	Thu 2/23/06
29	Finalize Prototyping	11 days?	Wed 3/1/06
30	Design Review 3 - Final Design and Engineering	1 day?	Thu 3/16/06
31	Prototyping	11 days?	Thu 3/16/06
32	Design Review 4 - Alpha Prototype Review	1 day?	Thu 3/30/06
33	Generate Poster/Presentation Materials	9 days?	Sat 4/1/06
34	Design EXPO	1 day?	Thu 4/13/06
35	Write up/Compile report	4 days?	Thu 4/13/06
36	Final Report Due	1 day?	Tue 4/18/06



Project: GanttChart
Date: Mon 2/20/06

Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split | External Tasks | Project Summary | Group By Summary | Deadline

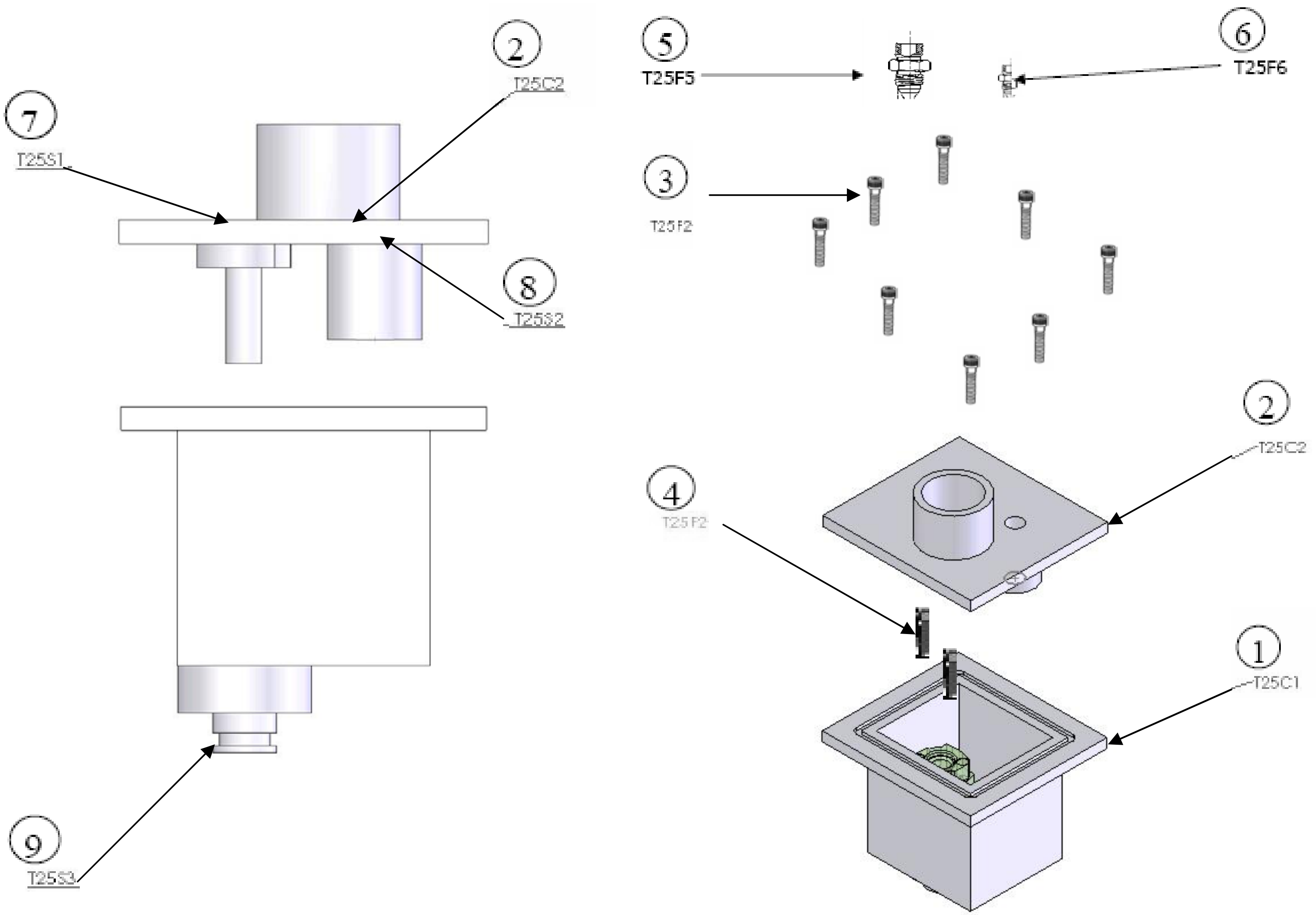
Page 1

APPENDIX G: Price breakdown

Walls	7.92
Lid + Flange	19.22
Bottom Plate	21.74
Intensifier	10.27
1 1/2 " stock	13.00
O-rings	2.50
Bolts	2.50

Labor	Price
140 hours	3500

APPENDIX H : Assembly Diagram



APPENDIX I : Part List

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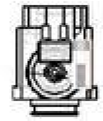
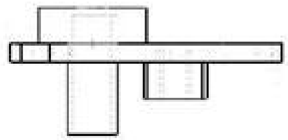
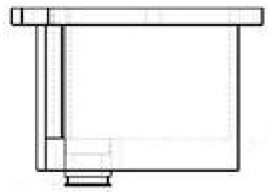
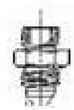
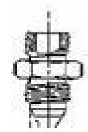
Siemens valve		X 1
Top Lid		X 1
Housing		X 1
SAE-4 port		X 1
SAE-6 port		X 1
8-32X 0.5in Socket bolt		X 8
8-32X 1.25in Socket bolt		X 2

designsafe Report

Application: Injection Fluid Supply Housing
Analyst Name(s): Mohd Ali Anuar Mohd Sani
Description:
Company: Team 25
Product Identifier: Supply Housing
Facility Location:
Assessment Type: Preliminary
Limits:
Sources:

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	mechanical : break up during operation if the pump doesn't pump fluid to the housing.	Minimal Remote Possible	Low	- Out of System -	Minimal Remote Possible	Low	TBD Next Design Team
All Users All Tasks	mechanical : machine instability Vibrations of the engine	Minimal Frequent Probable	High	Dampening mechanism for the housing	Minimal Occasional Possible	Moderate	TBD Next Design Team
All Users All Tasks	mechanical : impact Housing being thrown or during collision when impact from other vehicle being transferred.	Slight Occasional Possible	Moderate	more reliable securing device	Minimal Occasional Unlikely	Low	TBD Next Design Team
All Users All Tasks	electrical / electronic : lack of grounding (earthing or neutral) electromechanical device stop functioning electronically	Minimal None Unlikely	Low	- Out of System -	Minimal None Unlikely	Low	TBD Next Design Team
All Users All Tasks	electrical / electronic : insulation failure insulation of 4 wires from the electromechanical device	Minimal None Unlikely	Low	- Out of System -	Minimal None Unlikely	Low	TBD Next Design Team
All Users All Tasks	electrical / electronic : software errors software/hardware that controls the actuation of the electromechanical device	Minimal None Unlikely	Low	- Out of System -	Minimal None Unlikely	Low	TBD Next Design Team
All Users All Tasks	heat / temperature : radiant heat heat from engine and from cyclic fluid flow	Minimal None Possible	Low	Design a cooling mechanism	Minimal None Unlikely	Low	TBD Next Design Team
All Users All Tasks	heat / temperature : inadequate heating / cooling too much heat from engine being transferred into the housing	Minimal None Possible	Low	suggest a material that has low heat capacity.	Minimal None Unlikely	Low	TBD Next Design Team

User / Task	Hazard / Failure Mode	Initial Assessment Severity Exposure Probability	Risk Level	Risk Reduction Methods /Comments	Final Assessment Severity Exposure Probability	Risk Level	Status / Responsible /Reference
All Users All Tasks	fluid / pressure : hydraulics rupture hydraulics pressure build-up in the housing	Slight Remote Unlikely	Low	Automatic release valve at certain pressure level	Minimal None Unlikely	Low	TBD Next Design Team
All Users All Tasks	fluid / pressure : fluid leakage / ejection Weld / sealings stop working correctly	Minimal Occasional Unlikely	Low	Quality Inspection before shipping to customer	Minimal None Unlikely	Low	TBD Next Design Team