

# Honeywell Reference Pressure Regulator

## Preliminary Proposal

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## **DISCLAIMER**

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

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# **1 BACKGROUND**

## ***1.1 Introduction***

The Honeywell Pressure Regulator Team is assisting in the development of a different type of reference air pressure regulator for use on commercial airliners. Most of the controls and actuators on commercial airliners are pneumatically controlled. For pneumatics to function, they need to reference a specific amount of pressure. This is achieved through the use of a reference pressure regulator. The reference pressure regulator takes in different levels of inlet pressure and outputs at a constant pressure level.

Honeywell has been building upon a legacy reference pressure regulator design for the last 60 years. They have slowly worked out inefficiencies and design flaws in this design. However, their current design has inherent flaws which limit its overall performance. The job of the Pressure Regulator team is to establish a new solution to the reference pressure regulator.

Improving the regulator design would increase the accuracy of pneumatic controls on the aircraft, which could increase economy of the system and safety to the passengers. The economy would also be increased through the improved durability and longevity of the system leading to less replacement parts and maintenance. There are about 15 reference pressure regulators on B737, one of the most common commercial airliners in the world. For a large company such as Honeywell, with products produced on a large scale, the small decrease in maintenance or production cost can benefit the companies' profits greatly.

## ***1.2 Project Description***

The Pressure Regulator team was introduced to the project through the following project description provided by the sponsor, Honeywell.

“In Tempe Arizona Honeywell produces a line of Pneumatic Controls for use in aircraft. These controls take the form of valves that are used for controlling the temperature, pressure, and flow of pressurized air that is extracted either from the aircraft's main propulsion engines, or from a smaller auxiliary power unit (APU). These valves run from small 3/8ths-inch line sizes up to 10 inches in diameter, and carry pressures from just above atmospheric to 600 psig, with temperatures running from -40F to 1300F. The extracted air is cooled and the pressure regulated, and is provided to various “user” systems including wing anti-ice and cabin pressurization and environmental control. Many of the world's aircraft use valves produced by Honeywell, and most aircraft have dozens of these valves. Virtually every valve has a small on-board pressure regulator that serves some controlling function. The purpose of this project is to evolve and improve these pressure regulators.

The pressure regulators in question provide several functions. Some simply limit the pressure in the valve actuator for structural reasons, while others produce a pressure that is used as a reference for control (where other pressures are compared to that reference for the purpose of controlling some function). While it is not quite correct to refer to all of them as reference pressure regulators because they don't all provide that function, it is common to do so, and since the design does not differ, we'll follow that habit.”

## ***1.3 Original System***

The following sections describe the original pressure regulator system as designed by Honeywell.

### 1.3.1 Original System Structure

As previously stated, this project is the redesign of Honeywell's existing reference pressure regulator in use today on many aircrafts. Figure 1 shows the existing design currently in use by Honeywell. The reference pressure regulator works through what is called a pressure balance. The inlet is located at the bottom of the device where the poppet is. The poppet is a small conical closure element that is attached to a guide rod which is attached to the calibration spring. The air flow passes through the inlet, around the poppet, lowering the pressure as it passes through the narrowed passageway. This passage around the poppet effectively acts as a nozzle to increase the velocity of the flow and reduce the pressure. Figure 2 shows the basic pressure regulator design, which is very similar to Honeywell's design.

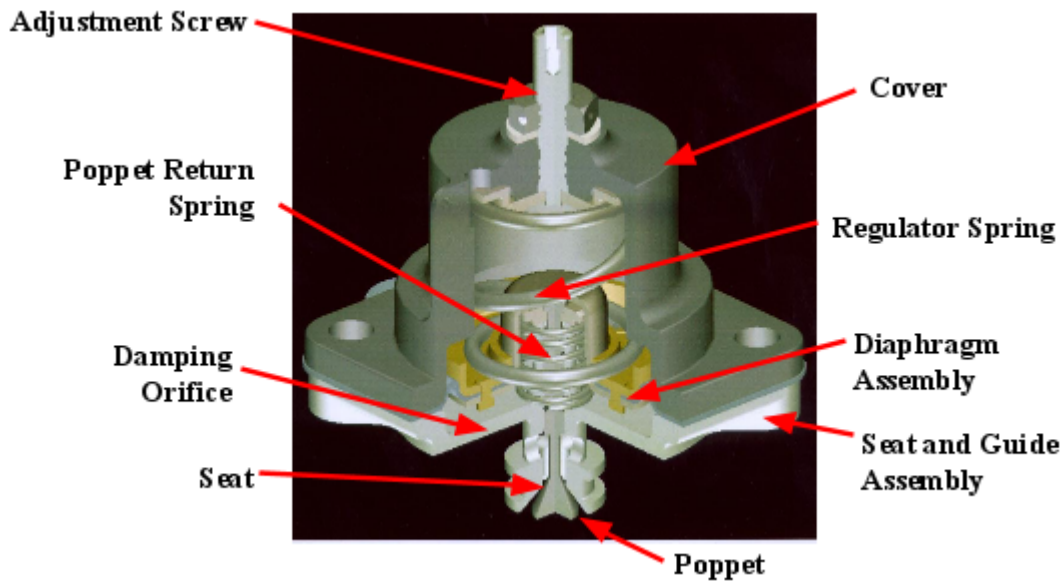


Figure 1: Honeywell Reference Pressure Regulator [1]

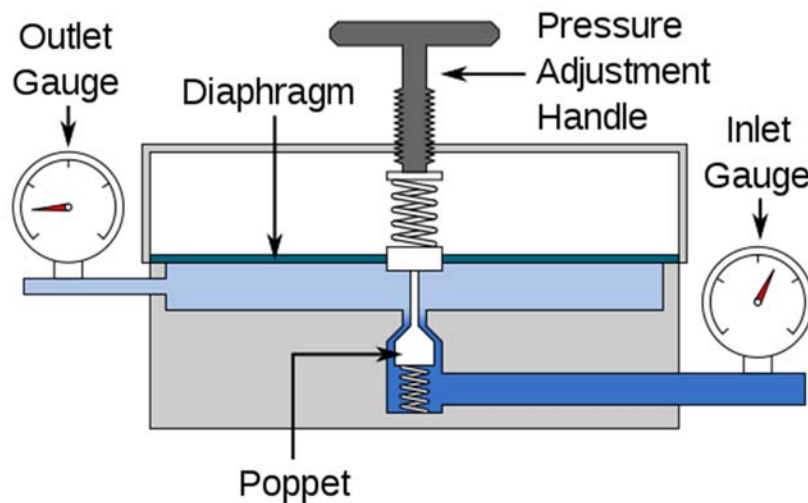


Figure 2: Basic Pressure Regulator Design [2]

Besides the key components of functionality aforementioned, the reference pressure regulator has other components which serve to increase accuracy. The adjustment screw on the top of the device will manually change the height of the diaphragm and spring compression, this will let the user change the desired output pressure. Also, due to the high vibration environment the regulator lives in, the system can become uncalibrated and must be maintained using the adjustment screw. The return spring under the poppet is another element that helps keep the force balance correct by taking some of the force off of the calibration spring. This increases accuracy by making the outlet pressure a function of the displacement of two springs rather than one.

### 1.3.2 Original System Operation

The size of the passage around the poppet is constantly changing, depending on the poppets distance from the seat. If the inlet pressure is increased, the pressure force on the diaphragm will press down on the poppet, guide rod, and calibration spring assembly to close the inlet, in turn reducing the outlet pressure. Vice versa, if the inlet pressure reduces, the calibration spring will overcome the pressure force, allowing the poppet to retreat from the seat, opening the inlet and increasing the outlet pressure. This can be thought of otherwise as the greater the inlet size the smaller the difference between the outlet and inlet pressures. Therefore, the inlet size and pressure difference are inversely proportional.

### 1.3.3 Original System Performance

Since the team does not have experimental data from Honeywell, the basic performance of gas pressure regulators will be evaluated instead. Figure 3 shows the outlet pressure of a pressure regulator as a function of air flow. The plot displays how a pressure regulator works under a different air flow. Note that air flow and inlet pressure are not the same; although they have dependencies, they are not directly dependent. As shown, the outlet pressure of a regulator drops with an increasing air flow, this phenomenon is called “Droop”. This is a common difficulty with all pressure regulators is a difficulty the team will work to solve with the redesign. [3]

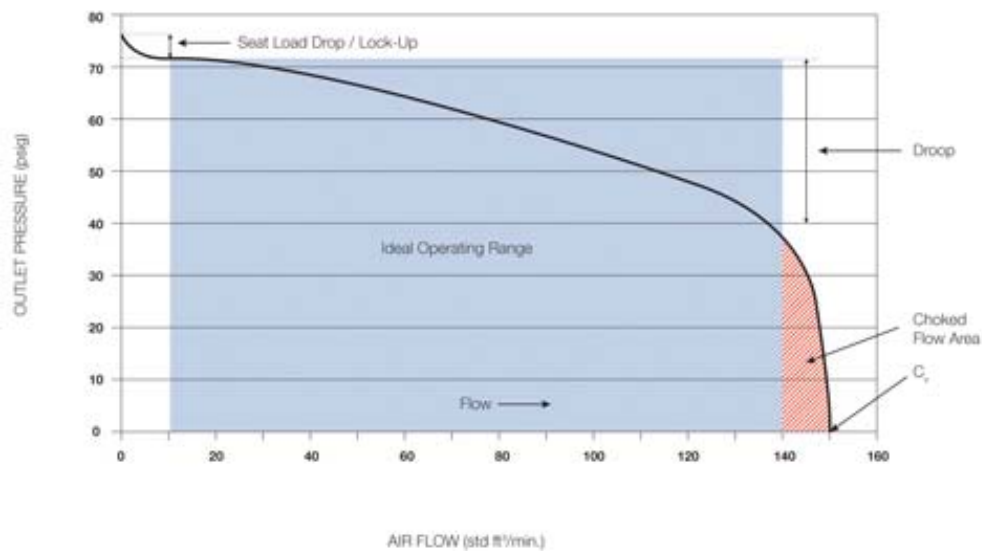


Figure 3: Pressure Regulator Flow Curve [3]

If a pressure regulator were to work ideally, the curve would stay horizontal throughout a changing flow rate. To flatten out the curve, inlet pressure can be increased, which will help decrease droop, shown in Figure 4. Increasing the inlet pressure also increases the capability of the regulator itself in terms of flow rate. Towards the end of the curve the slope becomes exponentially more negative as the flow becomes choked and the outlet pressure equalizes with the inlet pressures. [3]

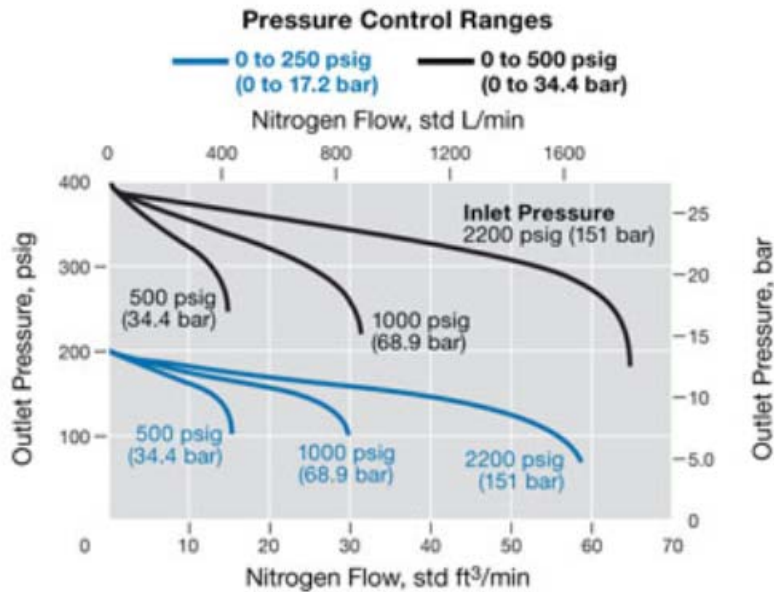
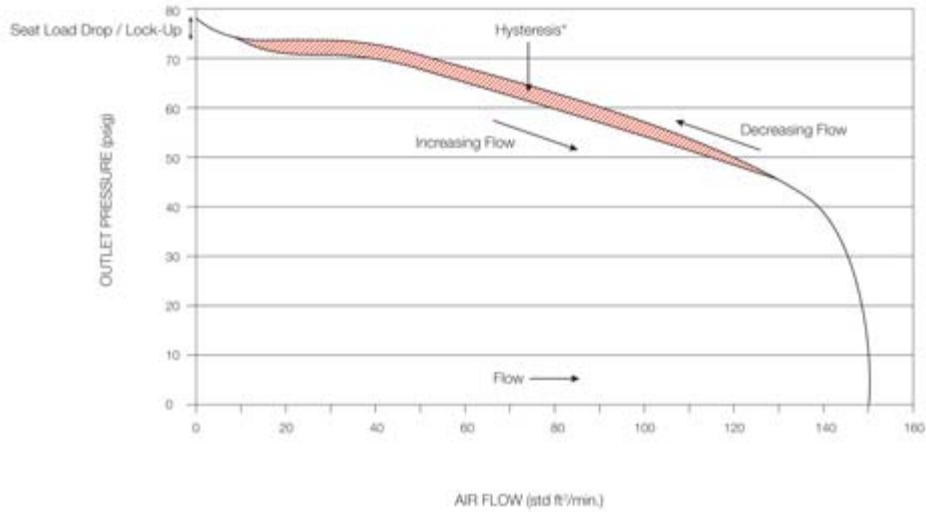


Figure 4: Nitrogen Flow Curves of Multiple Inlet Pressures [3]

### 1.3.4 Original System Deficiencies

One issue brought to attention by the Honeywell Contact is the hysteresis the system shows as the inlet pressure and flow rate change, shown in Figure 5. The hysteresis reduces the accuracy of the system as well as its consistency. For instance, the regulator might output a different pressure at the same inlet pressure depending on the immediate history of the inlet pressure. This can lead to miscalculated actuation in the pneumatic controls on the aircraft. The team will work towards reducing the hysteresis loop area as much as possible to increase consistency of the system. [3]





\*Hysteresis shown larger than actual for demonstration purposes.

Figure 5: Hysteresis Loop from Varying Flow Rate [3]

Hysteresis is caused by friction in the system, which in the case of the Honeywell design, mostly occurs along the guide rod. As shown in Figure 6, the guide rod (gray) is in contact with its housing (orange) the entire time it is moving to adjust outlet pressure. This could be reduced by minimizing the area of contact or by inserting a linear bearing to ease the sliding action. These options could however increase the leakage, which was another issue brought to attention by Honeywell. [1]

The poppet design is one of the best designs to reduce leakage, however it still occurs. Leakage can occur when the closure element is forced against one side and seats/rubs against the seat. This leads to wear and dents on the closure element which causes instability in the system. Originally Honeywell used a ball as a closure element, but leakage was a large problem which was improved using the poppet design. [7]

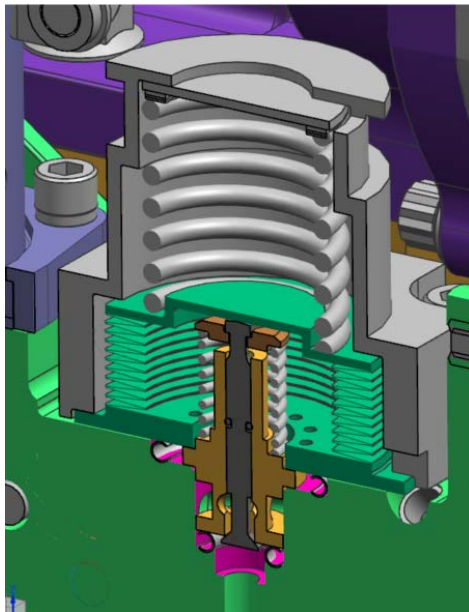


Figure 6: Honeywell Reference Pressure Regulator Design [1]

## 2 REQUIREMENTS

Customer requirements (CRs) and engineering requirements (ERs) were generated from the project description, provided by Honeywell. Customer requirements encompass the scope of the project, and highlight what the final product should accomplish. To ensure that CRs are met, ERs are specified as quantifiable goals. A target and tolerance is assigned to each ER to ensure that all goals are met.

### 2.1 Customer Requirements (CRs)

The following CRs were generated from the project description provided by Honeywell, as well as through conversations with Honeywell representatives. The customer requirements were evaluated for their significance on the final design. Each customer requirement was given a weight out of five.

- Reliability (5.0) & Safety (5.0)

The final product's intended use is to regulate pressure within an aircraft; because of this, the final design must be reliable and safe. The device needs to be able to regulate pressures consistently, without any concern for failure. Reliability and safety have been designated weights of five, and have been deemed to be the most important design considerations.

- Durability (4.7) & Maintenance (3.0)

One of the concerns identified by the client was that current pressure regulator designs are not as durable as they would like them to be. Designing for durability and easy maintenance minimizes the frequency of complete replacement.

- Effectiveness (4.5) & Accuracy (4.5)

Because the redesigned pressure regulator is intended for use in an aircraft, it is essential that the product performs accurately and effectively. The team will be focusing on redesigning the pressure regulator so that pressure is regulated just as well, if not better, than the client's current design.

- Production Time (2.5)

Production time is the lowest consideration for the redesign of the preference pressure regulator. While it is important to keep in mind how long the product will take to manufacture, it is not one of the main design considerations that the client has asked the team to focus on.

### 2.2 Engineering Requirements (ERs)

The table below illustrates the engineering requirements, the target values to achieve, and the tolerances in which the target values are allowed to be between. The engineering requirements are based off of the customer requirements; the ERs provide quantifiable values to each customer requirement in order to ensure that goals are met, and that the client requirements are achieved.

Table 1: Engineering Requirements overview

Requirement	Units	Target	Tolerance	Range
Surface Area	in <sup>2</sup>	1.280	+1	1.28-2.28
Pressure	psi	600	±25	575-625
Strength of Material	MPa	250	±25	225-275
Weight	lbs	1	±0.5	0.5-1.5
Friction	N	1	±0.5	0.5-1.5
Cost	\$	200	±50	150-250
Part Count	#	6	±3	3-9
Accuracy	psi	1	±0.5	0.5-1.5
System Instability	%	1	±1%	N/A
Leakage	cfm	1	±1%	N/A

### 2.3 House of Quality (HoQ)

The House of Quality is used to relate customer and engineering requirements. Each customer requirement and engineering requirement's relationship is assigned a value of either one, three, or nine—one being a low correlation, and nine being a high correlation. Using the House of Quality allowed for identification of which engineering requirements were most important to design for in order to satisfy customer needs. Target values and tolerances for each engineering requirement is also highlighted in the House of Quality. These target values and tolerances are currently tentative, and will be finalized in the coming weeks as research and discussions with Honeywell continue. See Appendix A for the House of Quality spreadsheet.

## **3 EXISTING DESIGNS**

### **3.1 Design Research**

To perform research for different designs the team used many different forms of media searches. The first search method was the compendix and other scholarly articles searches through NAU Cline library. Through this research the team found that the options for pressure regulator designs are very limited. Due to this limitation, benchmarking becomes very difficult, as most data is for different inlet pressures and gases rather than different designs. Therefore, most of the data for the systems and subsystems listed below were taken directly from information given to the team by Honeywell.

### **3.2 System Level**

Most pressure regulators use a similar design but are simply scaled to the needs of the application. Most pressure regulators used are of the same design using a calibration spring, sensing area (diaphragm), closure element, and a guide. This is scaled when the pressure entering the system is either very large or fluctuates with high amplitudes and frequencies. They are scaled by adding more chambers and springs in order to reduce the amount of pressure on each spring and forcing the outlet pressure to be a function of the deformation of more than just one spring. These designs are outlined in the following sections.

#### **3.2.1 Existing Design #1: Single Stage Regulator**

Single stage regulators are a good choice for applications where the supply pressure will be relatively consistent over time, such as when the source is coming from a compressor. High pressure gas is supplied from the inlet valve into the regulator. Gases proceed into the body of the regulator, the body is controlled by the valve, generally a poppet valve. When inlet pressure increases the diaphragm, connected to the inlet valve, closes and prevents any more gas from entering the regulator. The outlet side is equipped with a pressure gauge. When gas is drawn from the outlet side the pressure of the outlet side drops. The diaphragm springs back open and allows more gas into the outlet area because of the force balance between the gas and spring. Therefore, the pressure depends on the spring force and spring force can be adjusted by adjusting a calibrating handle or knob. [4]

The single stage regulator reduces pressure only in one step to produce pressure within a specific range. The corresponding regulator will show noticeable changes in the outlet pressure when the cylinder pressure is lowered. Therefore, single stage regulators are best suited for applications where constant outlet pressure is not important, where an operator can monitor and readjust the pressure, or where the inlet pressure is stable. [4]

#### **3.2.2 Existing Design #2: Two Stage Regulator**

If supply pressure fluctuation is large or decays with time, a two-stage regulator may be better suited for the design. Two-stage pressure regulators are basically two one stage regulators in series. This allows regulators to reduce supply pressure in two smaller steps. In a two-stage design, drooping characteristics of each stage are eliminated. Two stage regulators are designed for stability, even if the inlet pressure or flow rate change significantly the system will provide a stable outlet pressure. [5]

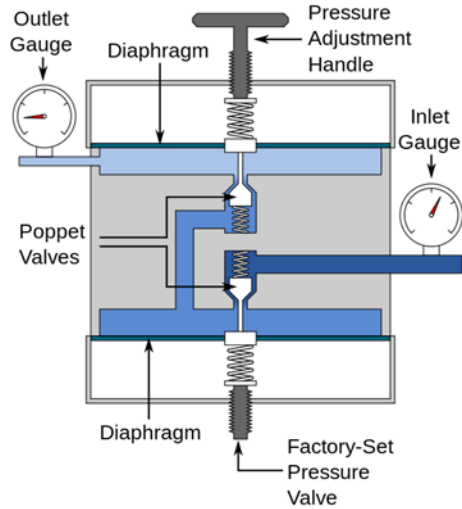


Figure 7: Two Stage Pressure Regulator [2]

Two-stage regulator is two single-stage regulators; its operation is based on two stages gradually reducing pressure. The first stage of the two-stage regulator reduces pressure to an intermediate stage. The intermediate stage then goes through a second pressure regulator to reduce the gas pressure to its final outlet pressure. The two-stage regulator has two safety valves, one for each stage, so that the pressure regulator will not fail catastrophically if inlet pressure is too big. Two stage regulators are more robust in the face of varying inlet pressures. Single stage regulators will require operator observation and input if the inlet pressure varies largely but two-stage regulators are able to handle significant changes in inlet pressure without adjustment. [5]

A two-stage regulator has the same function as a single stage regulator; however, when the cylinder pressure drops, the transmission pressure remains constant. The accuracy of the pressure control is improved because the pressure reduction is performed in two steps. For applications requiring constant outlet pressure in the service life of a gas cylinder, a two-stage voltage stabilizer is recommended. [5]

### 3.2.3 Existing Design #3: Three Stage Regulator

Three-stage pressure regulators provide stability similar to the two-stage regulator outlet pressure, but with significantly higher maximum inlet pressure. Although supply pressures might change drastically, three stage regulators are able to maintain low, stable output pressures. Applications of three-stage regulators are generally higher end lab equipment where accuracy is highly important or portable devices where inlet pressure varies largely. Examples include portable analytical equipment, hydrogen fuel cells, drones, stored high pressure gas cylinders, and medical equipment. [6]

### 3.2.4 Existing Design #4: Scuba Tank Regulators

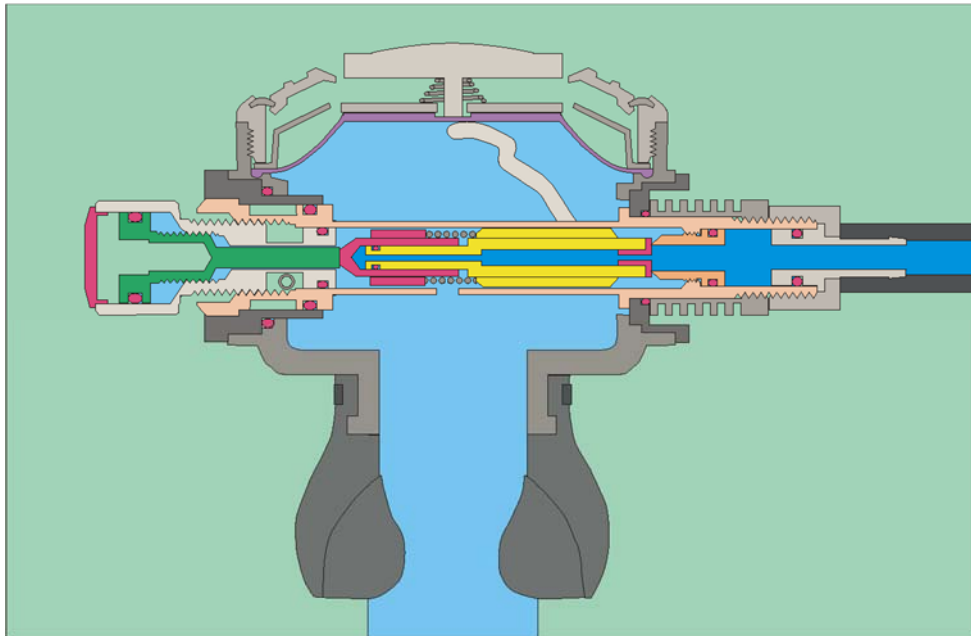


Figure 8: Scuba Tank Regulator [7]

Scuba pressure regulators operate in a similar way to general pressure regulators with only a few exceptions. The scuba pressure regulator has two stages. The first stage regulator (Figure 9) attaches to the tank and allows pressure into an air hose. The second stage regulator (Figure 8) is on the end of the air hose. A user breathes in on the first stage regulator which triggers both the first and second stage regulators in series. Using pressure regulators in series for large pressure reductions is common and not unique to scuba regulators. [7]

The primary difference between a scuba air regulator and other commonly used air regulators is that two liquids are used in the process. Scuba regulators are submerged while in use and use the ambient water pressure to push on the diaphragm and keep the valve closed while the user is not breathing in. Average pressure regulators usually have an atmospheric pressure on the outside of the diaphragm and place force on the diaphragm with a spring, bellows, or some other mechanical device. [7]

The other primary difference between scuba pressure regulators and common regulators is the means of actuation in the second stage regulator. As seen in Figure 8, the diaphragm pushes on the lever which translates the motion of the diaphragm ninety degrees to the poppet valve. This lever action is unique to scuba regulators. Because two separate fluids are used on either side of the pressure regulator, a soft rubber material is utilized for the diaphragm. Using soft rubbers for a diaphragm is not unique to scuba regulators. [8]

Unfortunately, many of the qualities that make scuba regulators unique are impractical to use in the design of an airplane pressure regulator. The pressure regulator will likely not be surrounded by water so using a different fluid to press on a diaphragm is not logical. The lever actuation of the poppet in the second stage regulator is also likely not useful in this design. The lever actuation complicates the pressure regulator mechanically and would likely detract from the regulators reliability. A soft rubber diaphragm is also not practical to use in this pressure regulator because it will likely see temperature extremes which will affect a soft rubber material. [8]

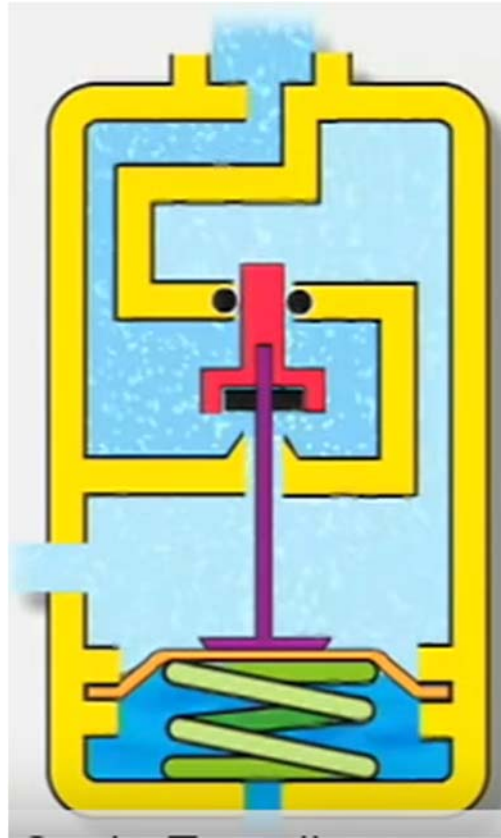


Figure 9: Scuba Tank Regulator [8]

### **3.3 Functional Decomposition**

An initial step in beginning the design process is understanding the underlying concept of the component we are engineering. For this project, it is a pressure regulator. There are many factors that go into the design of the pressure regulator. While there are improvements that could be made throughout the entire design, our client would like the team to focus on the closure element of the pressure regulator. Because of this reason, the team will not be focusing on what material the casing of the regulator is made of. We will more be focused on the mechanical operation and reducing the friction and wear inside of the regulator. While the mechanical operation of the regulator is complicated, it can be reduced into simple input and outputs. The system can be broken down into steps, starting with air entering the regulator, and then exiting the regulator at the desired pressure.

#### **3.3.1 Black Box Model**

The Black Box model below (Figure 10) shows the energy and materials entering and leaving the system, which helps to visualize the function of the component. To the left of the box are the inputs. The top thick line details the material going in and out of the pressure regulator. For a pressure regulator, only air is going in; however, air is at high pressure going in and low pressure coming out. The second line depicts the energy going in and leaving the system. Entering the system is air which contains pressure and kinetic

energy. This energy leaves with different values as well as heat lost through friction. The last dashed line shows the signals in the system. Since a pressure regulator operates autonomously, there is no need for a signal in or out of the system.



Figure 10: Black Box Model

### 3.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

To fully be able to visualize what is happening inside the pressure regulator the team has created a function model. By focusing on what is happening inside of the pressure regulator instead of the physical mechanics of how it is happening the team simplified the process into a step-by-step functional model. The functional model diagram can be seen below in Figure 11. The functional model shows the basic mechanics of the air as the pressure is reduced. The pressure regulator is a balancing device so the functional model is circular. A hand is imported to calibrate the pressure regulator to a desired outlet pressure. Both high pressure air and the calibration spring press on the diaphragm. The diaphragm is connected to the closure valve which reduces the air pressure through friction loss. The functional model then exports reduced pressure air.



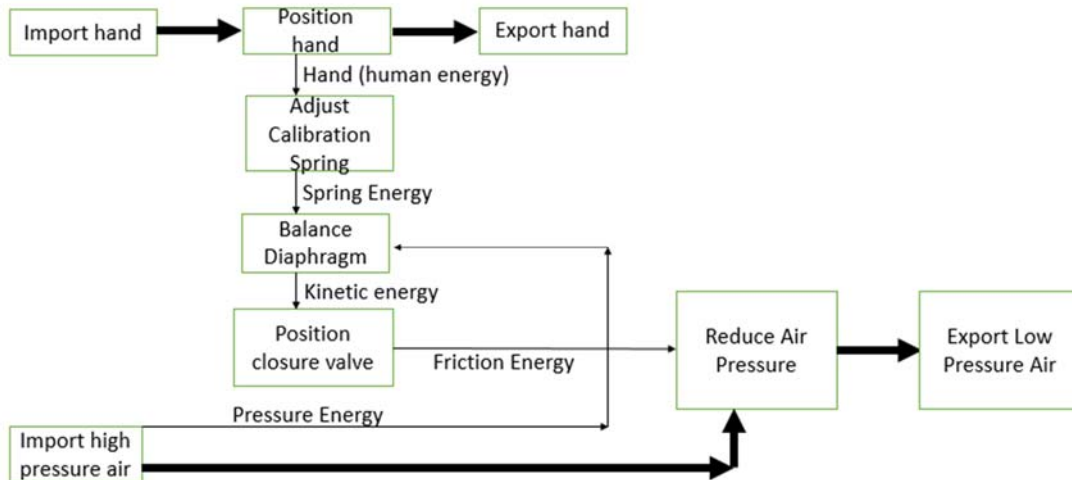


Figure 11: Process Flow Diagram

### 3.4 Subsystem Level

There are many variations of pressure regulators currently on the market; however, despite there being many different providers of pressure regulators, most are comprised of the same elements. Throughout the benchmarking process, there was little variation in design elements. Three elements were analyzed in order to better understand current designs, and to begin to think about elements that could be redesigned: the diaphragm, calibration spring assembly, and closure elements.

#### 3.4.1 Subsystem #1: Diaphragm and Calibration Spring System

The diaphragm serves a large role in regulating outlet pressure in most pressure regulators. When a pressure regulator is functioning properly, the area beneath the diaphragm will have air at the outlet pressure. The calibration spring pushes on the diaphragm and balances the force of the outlet pressure. If the pressure below the diaphragm rises, the air will push on the diaphragm compressing the calibration spring. This will cause the poppet to sink into its seat and restrict the flow of air into the area below the diaphragm, effectively lowering the pressure below the diaphragm. If the outlet pressure becomes too low, the diaphragm will have less pressure holding it in place and the calibration spring will extend. This allows the poppet to rise off of its seat and airflow through the valve increases, increasing the outlet pressure. Diaphragm material, size, and the nature of the calibration spring that presses on the diaphragm all have a large effect on the possible uses of a pressure regulator.

##### 3.4.1.1 Existing Design #1: Hard Diaphragm vs. Soft Diaphragm

Hard Diaphragms and Soft Diaphragms both have several advantages and disadvantages depending on the application they are in. Hard diaphragms are much more resistant to temperature changes. Soft diaphragms are usually made from rubber and have a limited temperature range they can operate in.

Soft diaphragms naturally damp the oscillation of the diaphragm and lead to a system that reaches stability quickly. Hard diaphragms rely on other means to damp the motion of the diaphragm. Systems with hard diaphragms can be just as stable as systems with soft diaphragms but they will be more mechanically complex. [9] Soft diaphragms naturally damp the oscillation of the diaphragm and lead to a system that reaches stability quickly. Hard diaphragms rely on other means to damp the motion of the

diaphragm. Systems with hard diaphragms can be just as stable as systems with soft diaphragms but they will be more mechanically complex. [9]

#### **3.4.1.2 Existing Design #2: Large Area vs. Small Area Diaphragms**

The disadvantage of a large diaphragm area is that it results in a large pressure regulator. The reference pressure regulator assigned to our team has a size constraint depending on the specific application of the regulator. As per conversations with Honeywell engineers, the advantage of large diaphragms is that it results in a more accurate pressure regulator (the variable that affects accuracy is the ratio between the surface area of the poppet and the surface area of the diaphragm, but when all other variables are held constant it becomes the area of the diaphragm). Determining a diaphragm size will require balancing the size restraints of the pressure regulator with the accuracy requirements. Therefore, the ideal size of a diaphragm is dependent on the specific application of the pressure regulator it is a part of.

#### **3.4.1.3 Existing Design #3: High Spring Coefficient vs. Low Spring Coefficient**

High spring coefficients result in an accurate system that has low hysteretic effects. High spring coefficients also require either large airflows and outlet pressures to provide the force to balance the diaphragm or a highly tuned system that has little variation in inlet pressure. If inlet pressure were to drop significantly in a system with a high spring coefficient then the valve might close completely.

Low spring coefficients offer less accuracy and a much higher response time between inlet pressure changes and changes in closure position. However, low spring coefficients offer a much higher range of allowable inlet pressures. [9]

### **3.4.2 Subsystem #2: Closure Elements**

The closure element in the pressure regulator is where most of the reliability and accuracy falls. This element is often under a differential pressure which can affect the system and must be accounted for. An ideal closure element would not move in only one direction, would not wear, and would not be susceptible to pressure. Unfortunately, the closure element must account for all of these factors, therefore they must be researched.

#### **3.4.2.1 Existing Design #1: Gate Valve**

A gate valve, shown in Figure 13, is another possible option to replace the poppet as a closure element. The gate valve opens and closes vertically to decrease pressure and increase flow velocity.

The gate valves motion is similar to the poppet however it acts perpendicular to the flow rather than parallel. This can cause issues because the valve can bend under large pressure and wear unevenly against one side. However, this can improve upon the poppet because the pressure is not directly acting on the closure element, leaving the output pressure to be decided only by the pressure on the diaphragm.

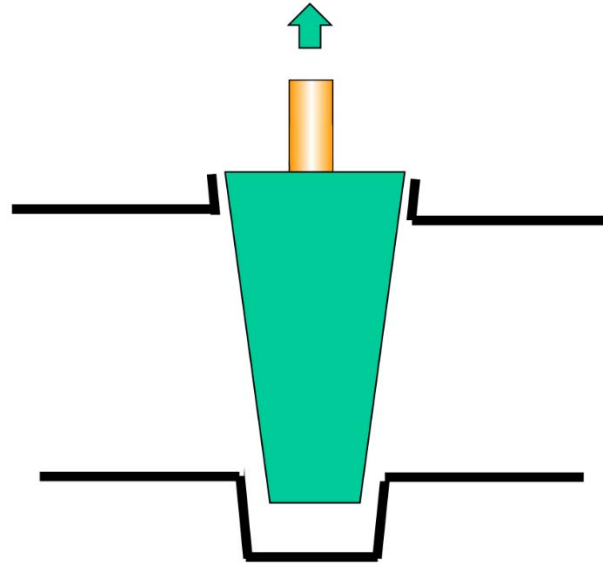


Figure 13: Gate Valve [10]

### 3.4.2.2 Existing Design #2: Shear Block Valve

The shear block valve shown in Figure 14 also can work as a closure element by sliding perpendicular to the flow to open and close the inlet(s). This subsystem improves upon the poppet by not wearing unevenly and always sliding against the same edge. The pressure acting on the shear block also does not affect the inlet size until friction comes into play. The friction on the block is the largest issue with the shear blocks. Under a large pressure, the blocks will not slide perfectly, leading to friction and an even worse hysteresis than the original poppet design. Due to this, the design cannot be considered unless the friction can be solved.

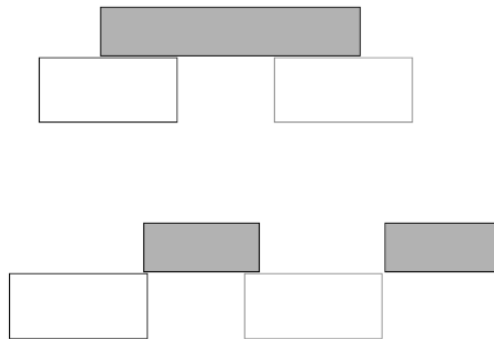


Figure 14: Shear Block Valve [10]

### 3.4.2.3 Existing Design #3: Pinch Valve

The pinch valve shown in Figure 15 can regulate flow by changing inlet area through changing the pipes cross-sectional area. In order for this to work, the pipe needs to be flexible enough to open and close many times easily enough to not fall victim to hysteresis or fatigue. The challenges of using this in Honeywell's pressure regulator design is the system is under very high pressures where strength is necessary for structural integrity. If there is a material that can handle the high pressures of the environment, this system would be effective because the pressure through the system would not act on the closure element at all.

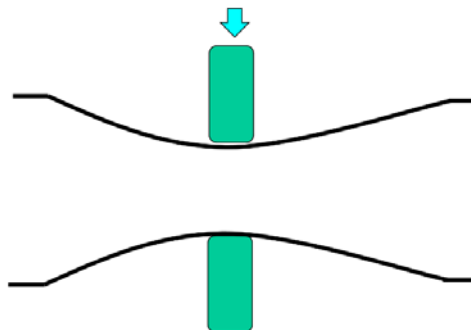


Figure 15: Pinch Valve [10]

### 3.4.2.4 Existing Design #4: Floating Ball Valve

A type of closure element that can be taken into consideration is a ball valve, shown Figure 16. It should be noted that Honeywell has implemented a ball valve closure previously, and found that it did not perform as well as intended. A floating ball valve is comprised of two main mechanical parts: a spherical ball, and a cylindrical hole drilled through it. When the cylindrical hole (which acts as a valve) is aligned with the hole, the valve is considered open and allows airflow through the system; when the flow duct is at a right angle to the flow, the valve is closed. Ball valves are typically used in smaller pressure regulators, as weight of the ball increases significantly with size. The seals of the ball valves are typically made out of Teflon, which are limited to low temperatures; aircraft valves usually exceed the allowable temperatures, making a ball valve ineffective.

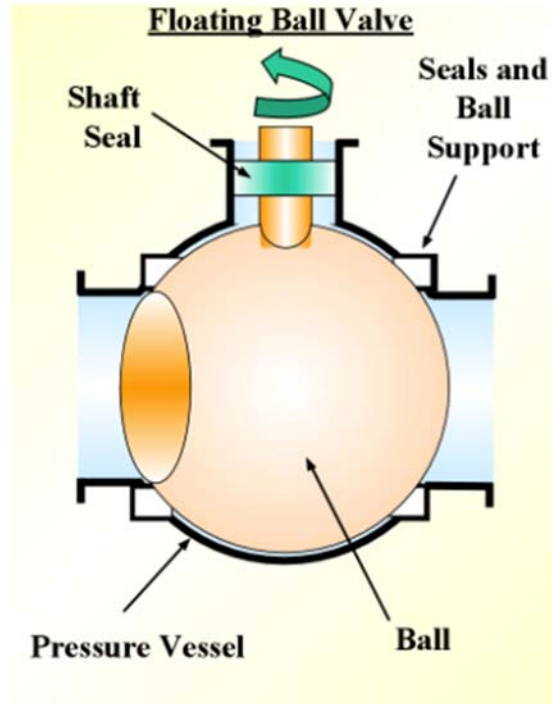


Figure 16: Floating Ball Valve [10]

#### 3.4.2.5 Existing Design #5: Right Angle Poppet

Right-angle poppets house three main parts: an actuator, a shaft, and a pressure vessel. The shaft houses a circular disk, which is used to control the flow of air. When the actuator is aligned with the poppet, the air flows in through the side and out of the bottom of the valve. Though technically valves, right angle poppets can be used as pressure regulators when the inlet pressure is balanced. However, the use of right angle poppets increase friction, and is susceptible to seal failure. Right angle poppets also dramatically increase the weight in larger pressure regulators, and are recommended for use in smaller line sizes only.

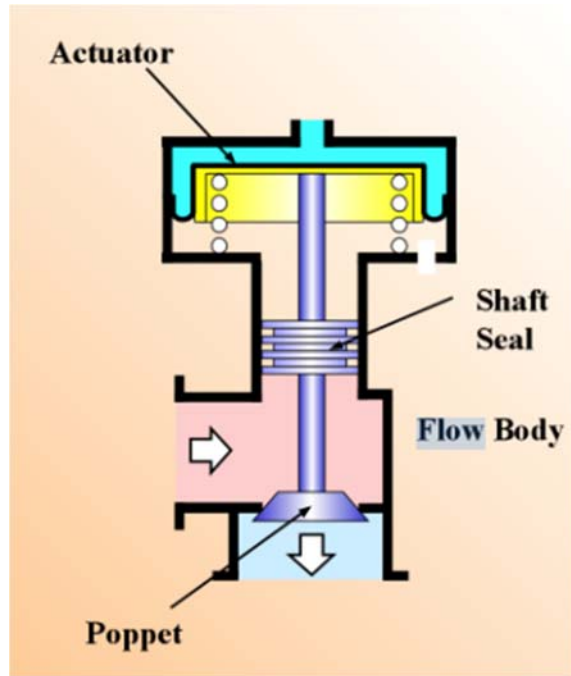


Figure 17: Right Angle Poppet [10]

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# 5 APPENDICES

## 5.1 Appendix A: House of Quality

