Motor Free Air Compressor

ENGR 2050 - Introduction to Engineering Design
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Milestone 5 - System Integration Demonstration + Presentation

Problem Motivation & Background

General Statement: Almost half of Nigeria’s population does not have access to stable, well-functioning power [1]. The goal of this project is to design a product to reduce the time & labor of cleaning a solar panel in the absence of rain.

- Motivation:
  - With one of our team members being from Nigeria, we felt a personal duty to help their country and people all around the world
  - With the Sun being one of the main sources of free energy, implementing solar energy was a no-brainer
  - An air compressor has multiple uses, so our product is extremely inclusive and diverse
- Key Elements:
  - **Users Landscape:** Specifically Low/Middle Class Nigerian Families, but not limited to them
  - **Unsatisfactory State & Symptoms:** Unstable Power & Electricity in Nigeria, Dirty Solar Panels -> Limits Electricity
  - **Impact of Successful Solution/Defining:** Households having access to better power, increasing everyday life productivity, Increase in Percentage of people with access to well-functioning electricity/power
  - **Innovation Opportunities/Design:** Solar powered air compressor releasing pressurized air strong enough to clean any surface with debris, but safe enough for all users while not relying on electricity.

Design Specifications

- Air Leakage Test
  - ~0 Air loss throughout whole device
- Pressure Gauge Accuracy Test
  - Pressure readings are consistent within a 5% margin of error (JEC and Device’s gauge)
- Air Velocity
  - Air speed can reach 30 m/s [2] from the nozzle and can successfully move debris
- Temperature Modeling
  - Pressure increases when device reaches higher temperatures (150°F) [3]
- Cleaning Efficiency
  - Able to clean area of solar panel (1.68 m^2) [4] in 30 seconds

Subsystem & Integration Overview

Subsystems:

- Inner & Outer Chamber (S1)
  - Stores & increases air pressure through solar radiation & mechanical pressure build up
- Pipe (S2)
  - Includes pressure sensor and safety valve to regulate pressure, ensuring user safety
- Valves (S3)
  - Connects hose and air pump to allow input and output of pressure
  - Detachable pump and air hose

Integration

- Connected subsystems aim to have minimal air loss to contain and build pressure.
  - 1” diameter connection between S1 and S2
  - Correct valves/fittings for connections between S2 and S3
  - Tight connections between components

Dependencies

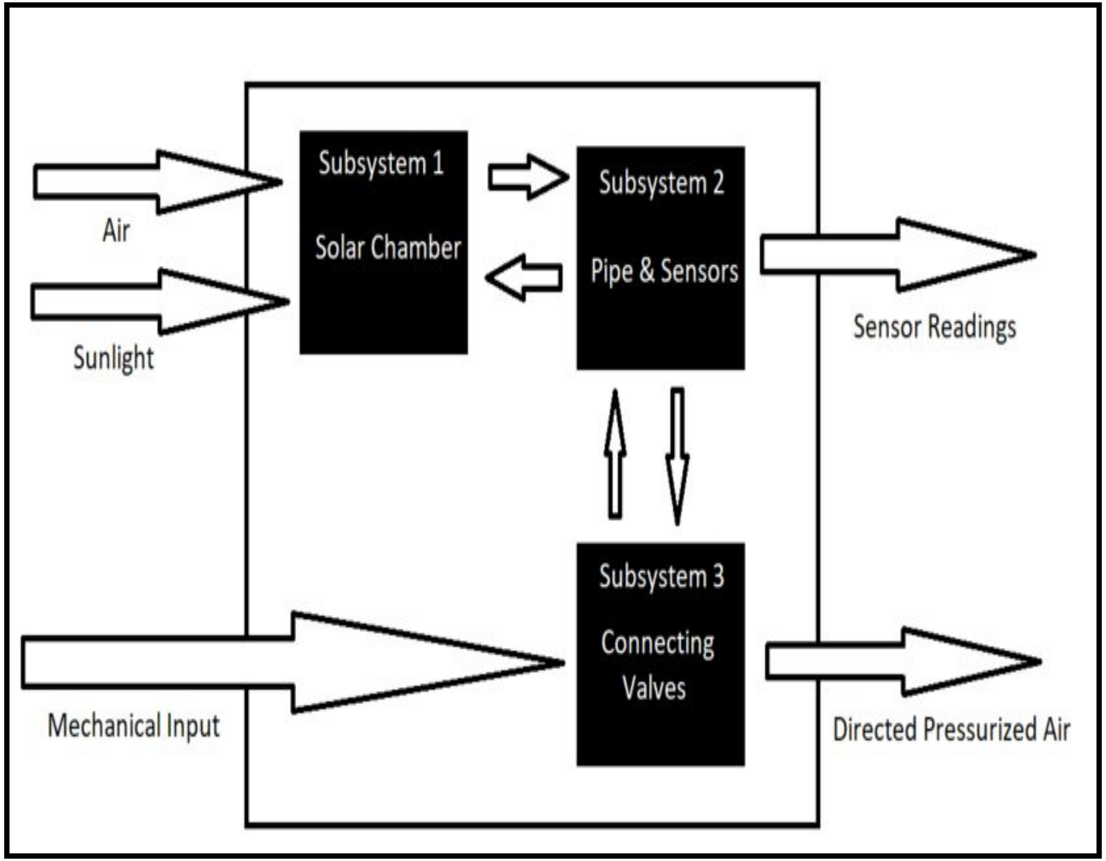
S2 (Pipe) depends on the output of S1 (Inner & Outer Chamber) for increased air pressure.

S2 relies on the pressure sensors to regulate pressure.

S3 (Valve) depends on the pressure readings from S2 to release the built up pressure.

S3 depends on the hose and air pump for the input and output of pressurized air.

S1, S2, and S3 work together to create a functional air pressure regulation system.



System Functionality

- Air is pressurized by both mechanical pumping and heating of air within a chamber by sunlight
  - Mechanically pressurized first. This pressure is then multiplied upon heating
- No motor and no electricity use to eliminate energy cost
- Air is expelled out a nozzle designed to accelerate pressurized air
- Adequate safety and user interfacing

Test #1: Leakage Test

- **Target Specification**: Around 0 PSI decrease over 15 minutes
- **Limitations**: Device was not able to hold air pressure
- **Reasons:**
  - Connection between pipe and solar chamber was not airtight
  - Unable to thread plastic to fit pipe connection while not leaking air
  - Solar chamber material not suitable to house air pressure

Initial Pressure	**1 psi**
Final Pressure	**0 psi**
Total time	**5 min**
Pressure loss	**1 psi**
Pressure loss over time	**0.2 psi per minute or 0.0033 psi per second**

Test #1: Leakage Test (Cont.)

Supplemental Test: Pressure Gauge Calibration

- JEC & project gauge connection was faulty due to continuous air loss
    - JEC showed 10psi, project shows 1psi
    - There was a large drop in pressure between the two valves
    - Our gauge is 200 psi so smaller readings are harder to differentiate

JEC Gauge Reading	**10 psi**
Device Pressure Gauge Reading	**1 psi**
Percent Error	**90%**

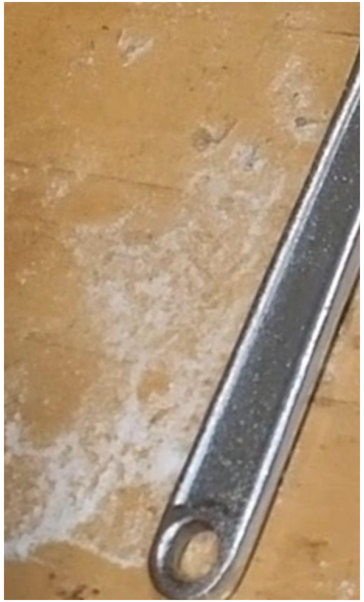
Test #2: Cleaning Efficiency

- **Target Specification:** 1.68 m^2 [4]
- **Limitations:** Inability to hold significant pressure
- **Reasons:**
  - Low pressure results in low velocity which cleans less area
  - Due to quick leakage, output pressure does not last for longer periods of time

Pressure	1 psi
Time	0.15 s
Area	12.9 cm^2 or 0.00129m^2
Pressure Loss	1 psi

Test #2: Cleaning Efficiency (Cont.)

BEFORE



AFTER

Test #3: Air Velocity

By determining velocity of output air, we can estimate the pressure within the container.

To determine velocity, we record the distance traveled by a light object and time taken to travel that distance

Test #3: Air Velocity

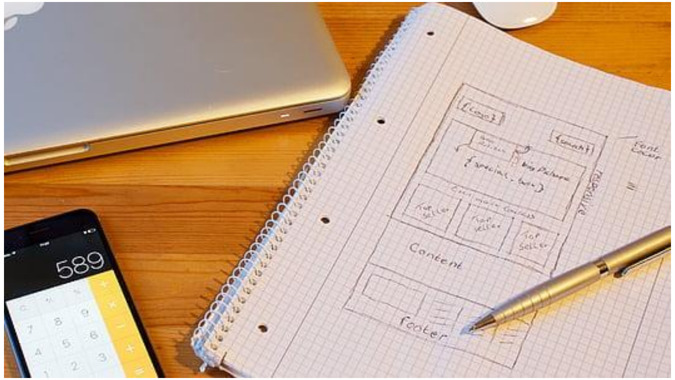
Distance debris traveled taken as straight line

Distance and time were used to compute velocity

(Sawdust) Debris Distance	5.08 cm or 0.0508 m
Time	0.15 s
Velocity	0.34 m/s

Why Modeling?

- Many of our tests failed to meet target specifications
- Modeling through calculations
    - Helps transcend physical/prototype limitations
        - Size, materials, sealing, not a vacuum etc.
    - Produce results for target region
    - Explains prototype performance



Test #3b: Modeling Prototype Air Velocity

Assumptions: $T = 25^{\circ}C$, $\rho = 1.19\ kg/m^3$ [5], inviscid, incompressible, P_2= atmospheric pressure

Knowns: Nozzle diameter = ⅛ in, Valve diameter = ¼ in

$$A_n v_{exp} = A_n v_1$$

$$(7.9173 * 10^{-6} m^2)(0.34\ m/s) = (3.1669 * 10^{-5}) v_1$$

$$v_1 = 0.085\ m/s$$

Use Bernoulli equation to find pressure (P_1) (abs) required

$$\frac{P_1}{\rho} + \frac{1}{2}v_1^2 + gz_1 = \frac{P_2}{\rho} + \frac{1}{2}v_2^2 + gz_2$$

$$z_1 = z_2$$

$$\frac{P_1}{\rho} + \frac{1}{2}v_1^2 = \frac{P_2}{\rho} + \frac{1}{2}v_2^2$$

$$\frac{P_1}{(1.19\ kg/m^3)} + \frac{1}{2}(0.085\ m/s)^2 = \frac{(101325\ Pa)}{(1.19\ kg/m^3)} + \frac{1}{2}(0.34\ m/s)^2$$

$$P_1 = 101325.0645\ Pa\ or\ 14.7\ psi$$

Test #3b: Modeling Prototype Air Velocity (Cont.)

Using Percent Error found in Pressure Gauge Calibration Test (90%), find the actual pressure of the prototype.

$$14.7\,psi * 0.90 = 13.23\,psi$$

$$14.7\,psi - 13.23\,psi = 1.47\,psi$$

$$Actual\ pressure = 1.47 \approx 1\,psi$$

Percent difference due to assumptions when calculating Bernoulli equation (i.e. friction neglected)

$$\frac{|1.47-1|}{\frac{(1.47+1)}{2}} * 100 = 38.1\%\ difference$$

Test #4: Modeling Effect of Temperature on Pressure

Assumptions: ideal, T = 338.56 K [3]

Using Ideal Gas Law, find pressure of device in target region, when heated solely by solar radiation

$$PV = RT$$

$$P(0.00757082\ cubic\ meters) = (287.052874\ Joules\ /\ kilogram\ *\ Kelvin)(338.56\ Kelvin)$$

$$P = 12836736.45\ Pa\ or\ 1861.8\ psi\ per\ kilogram\ of\ dry\ air$$

Absolute pressure

$$P(7.57082\ Liters) = (0.08206\ L * atm/\ moles\ *\ Kelvin)(338.56\ Kelvin)$$

$$P = 3.6696\ atm\ or\ 53.9\ psi\ per\ mole\ of\ dry\ air$$

Absolute pressure

P&S + DEI Specifications

Public Health:

- Motor-free air compressor cleaner contributes to public health by helping to provide reliable cleaning maintenance to solar panels on medical facilities
  - Supports healthcare delivery systems

Global & Cultural Factors

- Providing people across the globe a faster way to clean; not limited to solar panel (ex: leaf blower)
- Device is accessible for diverse populations
- Considers global implications such as international regulations and Nigerian market dynamics

Societal Factors:

- Helps middle & low income Nigerian families unable to access consistent power due to high cost
  - Increase productivity in daily lives

Environmental Factors:

- Energy efficiency (Reliant on Solar Energy) and contribution to mitigating environmental degradation.
- Concerns the impact of human activities on the natural environment.

Economic Factors:

- Total Spent on Design: $160 USD
- Affordable for Low-Middle Class Families
- One time cost, high longevity

Design Inclusivity:

- Accessible to individuals of lower incomes
- Simple design
- Undemanding installation

Citations

[1] “Nigeria to Improve Electricity Access and Services to Citizens” World Bank. Accessed January 31, 2024. [Online]. Available: https://www.worldbank.org/en/news/press-release/2021/02/05/nigeria-to-improve-electricity-access-and-services-to-citizens#:~:text=85%20million%20Nigerians%20don't,access%20deficit%20in%20the%20world

[2] “CFM vs MPH” The Rop Shop.[Online]. Accessed April 1, 2024. Available: https://theropshop.com/rugged-u/blog/leaf-blower-tips-cfm-vs-mph#:~:text=You%20should%20look%20for%20a,and%20150%2D190%20MPH%20ratings.

[3] “How Do Temperature and Shade Affect Solar Panel Efficiency” Boston Solar. [Online]. Accessed April 1, 2024. Available: https://www.bostonsolar.us/solar-blog-resource-center/blog/how-do-temperature-and-shade-affect-solar-panel-efficiency/#:~:text=Residential%20solar%20panels%20are%20generally,150°F%20or%20higher.

[4] “How Big are Solar Panels” NRG Clean Power.” [Online]. Accessed April 1, 2024. Available: https://nrgcleanpower.com/learning-center/how-big-are-solar-panels/

[5] “The density of air at ordinary atmospheric pressure” Pearson. [Online]. Accessed April 14, 2024. Available: https://www.pearson.com/channels/general-chemistry/asset/e63ae059/the-density-of-air-at-ordinary-atmospheric-pressure-and-25-c-is-1-19-g-l-what-is#:~:text=Textbook%20Question-,The%20density%20of%20air%20at%20ordinary%20atmospheric%20pressure,C%20is%201.19%20g%2FL.

Thanks for Listening

Questions?