ECE309 Project: Compressed Air Car

Assigned date: June 22, 2015 Due date: July 22, 2015

INTRODUCTION

Air pollution and rising fuel prices have forced many automotive manufacturers to reexamine the use of the internal combustion engine as the predominant means of powering cars, trucks, and commercial vehicles. Some have promoted the idea of using the expansion of compressed air in a manner similar to using the expansion of steam to power a steam engine. The idea of using compressed air to power a vehicle isn't new. Early prototypes of air-powered vehicles date back to the middle of the 19th century, even before the invention of the internal combustion engine (http://www.aircaraccess.com/history.htm).

More recently, Tata Motors has developed the Airpod, a low cost, light weight urban vehicle powered by a 430cc 2-cylinder engine that develops 7kW at 1,500rpm enough for it to reach 70kph. The latest model comes with a 260-litre tank, with a maximum air pressure of 248 bar and a range between 120km and 150km. Total weight of the Airpod is around 200kg, with 24kg of that accounted for by the engine.

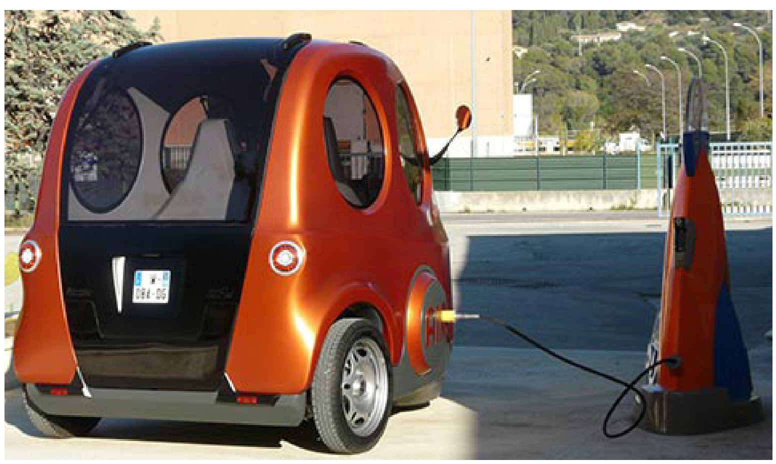

Figure 1: Tata Motors AirPod

THE AIR CAR

Our Air Car is powered by compressed air contained in a storage tank that drives air turbines located at each of the four wheels. Typically the tank is "refuelled" by connecting to a charging station with a maximum operating pressure of $30\ MPa$ ($4500\ psi$ or $300\ bar$). A schematic of the charging station and the Air Car is shown in Fig. 2.

Air is compressed from ambient conditions (state 1) under a polytropic process, $PV^n = const$ in the compressor. The pressure ratio ($r_p = P_2/P_1$) of the compressor varies from 10 to 300 and the ambient temperature can vary from $-10\ °C$ to $40\ °C$. Air is then cooled back to the ambient temperature (state 3) in an air-cooler and stored in the vehicle's air tank. The $300\ L$ air tank is thermally isolated from the surrounding environment. Once the air car is disconnected from the charging station, the compressed air is transferred to the turbines to produce work and and then discharged to the atmosphere. As a result of this expansion, the car starts moving and the pressure in the tank drops. Expansion stops when the tank pressure drops to atmospheric pressure. At this point 99% of the air in the tank has been discharged.

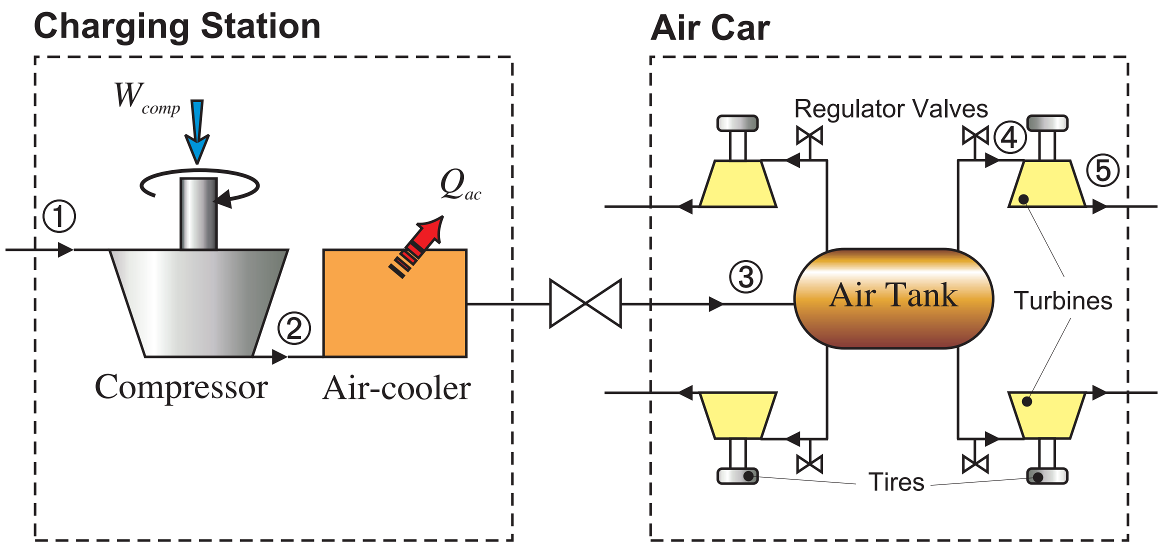

Figure 2: Schematic of the Air Car and Air Compression Process

ASSIGNMENT

1. **Thermodynamics Analysis:** Given a constant ambient temperature of $T_1 = 25\ °C$, an ambient pressure of $P_1 = 100\ kPa$, a pressure ratio, $r_p = 300$ and a polytropic coefficient of $n = 1.51$. Determine

   (a) the amount of work needed to fill the $300\ L$ air tank, $W_{comp}\ [kJ]$,

   (b) the heat transfer from the air-cooler, $Q_{ac}\ [kJ]$, necessary for $T_3 = T_1$,

   (c) the amount of work produced in the turbines to move the car, $W_{turb}\ [kJ]$,

   (d) the mass of air stored in the tank, m_{tank}, and

   (e) the total efficiency of the Air Car, η.

2. **Mechanics Analysis:** The maximum speed of our car is $V_{max} = 100\ km/hr$ (along a flat road) and it requires $12\ seconds$ to reach the maximum speed under constant acceleration conditions. Assume a constant friction coefficient, $f = 0.3$ for the friction resistance between the tires and the road. If the mass of the car is $m_{car} = 200\ kg$ (not including the mass of the air tank) and the mass of the driver is $m_{driver} = 80\ kg$, find:

   (a) the maximum distance (ΔX_{max}) that the air car can travel on one tank of air with only the driver

(b) the maximum distance travelled (ΔX_{max}) on one tank of air if we now add one passenger with a mass of $80\ kg$

Hint: You can consider an average mass of $(m_{full} + m_{empty})/2$ for the air tank over the duration of ΔX_{max}.

3. **Variable Ambient Temperature:** With just the driver in the vehicle let the ambient temperature vary from $-20\ ^\circ C$ to $40\ ^\circ C$, while the ambient pressure, $P_1 = 100\ kPa$ and $r_p = 300$ are constant. Show the effect that ambient temperature has on W_{comp}, Q_{ac}, W_{turb}, η and ΔX_{max}. Summarize your results in tabular and graphical form.

4. **Variable Pressure Ratio:** Perform the same analysis as part (3.) when the ambient temperature remains constant ($T_1 = 25\ ^\circ C$) and the pressure ratio varies from 10 to 300. Show the effect that pressure ratio has on W_{comp}, Q_{ac}, W_{turb}, η and ΔX_{max}. Summarize your results in tabular and graphical form.

5. **Results and Discussion:** Elaborate on your results; make recommendations based on your observations and draw conclusions. What would be the optimum working condition for the Air Car? For parts (3.) and (4.) you should write a program to extract data and plot the results. You can use any of the popular software tools, such as Maple, Mathematica, Excel, Matlab, C++, Java, etc.

REPORTING STRUCTURE

This is an engineering report and should adhere the following structure:

Introduction:

- A brief description of how the Air Car works.
- A summary listing advantages and disadvantages of the Air Car.

Analysis:

- Justify the assumptions and simplifications.
- Control volumes and calculations.
- Plots and tables.
- Discussions of the results.
- Recommendations and suggestions.

Conclusions and Summary:

A bound hard copy of the report (not exceeding 12 pages, appendices extra if needed) should be submitted on the due date. A copy of the computer program used in parts 3 and 4 should be submitted to the Learn Drop box provided.

USEFUL EQUATIONS

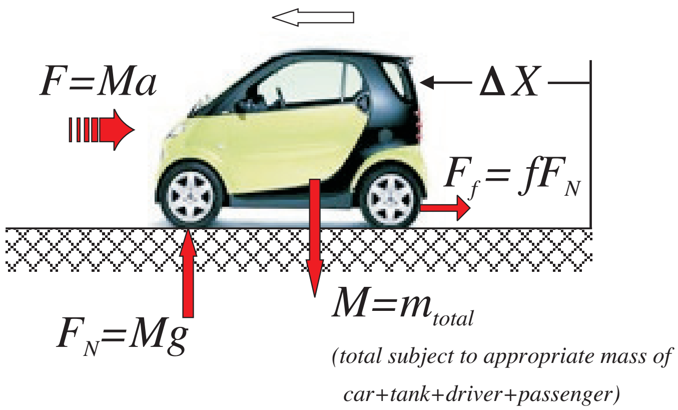

Figure 3: Force Balance

__Work__

Polytropic Compression

$$W_{comp} = \frac{n\, m_{tank}\, R\, T_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

Adiabatic Expansion with Variable Mass

$$\begin{aligned} H_{full} &= \text{enthalpy when the tank is full} \\ H_{empty} &= \text{enthalpy when the tank is empty} \\ W_{turb} &= H_{full} - H_{empty} \end{aligned}$$

__Efficiency__

$$\eta = \frac{\textbf{Benefit}}{\textbf{Cost}} = \frac{W_{turb}}{W_{comp}}$$

__Acceleration__

$$a = \Delta V / \Delta t$$

__Maximum Distance__

$$W_{turb} = (F + F_f)\Delta X_{max}$$

Note (1): When cruising, acceleration is zero, $a = 0$.

Note (2): Neglect the final deceleration in ΔX_{max} calculation.

ASSUMPTIONS

- negligible mechanical losses.
- air is an ideal gas.
- negligible pressure losses in pipes, joints and the air-cooler.
- specific heat is a function of temperature. If you use Table A-2, assume correlations valid over full range of temperature.
- time to reach maximum velocity is independent of the total mass
- when the air tank reaches atmospheric pressure the vehicle stops immediately i.e. no deceleration

SUGGESTED CONTROL VOLUMES