Automotive Engineering Deliverables

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1 Requirements

1.1 Target Segment

Our target segment is economy cars. The main competitors in the economy car market consist of the Mitsubishi Mirage, Chevrolet Spark, Honda Fit, and Suzuki Celerio. These cars averaged to approximately $40,000$ sold units in the year of 2019.

Figure 1: Main competitors: Mitsubishi Mirage(top left), Chevrolet Spark(top right), Honda Fit(bottom left), Suzuki Celerio(bottom right)

1.2 Vehicle Purpose

Economy cars are widely used for commuting short to medium distances. They are excellent means of enjoying another one's company and running daily tasks such as commuting to work or picking up groceries. Also, since they can load several small sized luggage, they are also suitable for traveling nearby places.

1.3 Car Attributes

Our design maintains the affordability of economy cars, but will capture a modern, cutting-edge aesthetic. The design is made for urban settings and for functionality; it is compact and efficient in its build, as well as has immense functionality due to its small and lightweight structure. This allows the automobile to be easily parked and maneuvered in ordinarily difficult parking situations. The car's design is a great balance of refinement and affordability.

1.4 Car Specs

The design we are creating must satisfy several criteria. It must be able to carry $2-4$ passengers. Its cargo carrying capacity is limited to a small load amount (such as groceries or small sized suitcases), and the car's range is limited to approximately 160km. Its climb gradient is maintained at around $30-40\%$. It can accelerate from 0km/h to 100km/h in a time span of $7-8$ seconds. The car can travel approximately 15km/L, and its maximum dimensions are limited to $3-3.5\text{m} \times 1.5\text{m} \times 1.5\text{m}[L \times W \times H]$.

2 Ideation Sketches

Figure 2: Ideation sketches

3 Packaging Plan

Overall

- Length: 3700mm
- Width: 1600mm
- Height: 1500mm

Drivers height

- H30: 250mm

- H5: 450mm
- L113: 440mm
- Forward vision angles: $7 - 14°$ up, $7°$ down
- Front shoulder room: 1400mm
- Lateral location: 350mm

Rear occupants

- Rear shoulder room: 1350mm
- Rear lateral location: 350mm

Powertrain

- Engine: Front transverse, FWD, 4 cylinders
- Engine size: 670×695mm
- Fuel tank: Situated below rear passenger seats

Cargo space

- Maximum cargo width: 1200mm due to suspension
- Minimum cargo width: 1150mm
- Aperture height: 850mm
- Lift over height: 650mm
- Cargo volume: 0.5m^3

Wheel locations

- Wheel outer diameter: 600mm
- Wheelbase: 2500mm
- Front track: 1490mm
- Rear track: 1470mm
- Ground clearance: 150mm at ML3
  - ML1 Curb mass: 950kg
  - ML2 Design mass: 1100kg
  - ML3 Gross vehicle mass: 1400kg

4 Power Requirements

In order to estimate the power requirements of the vehicle, assumptions on resistance force components at the required state must be made. These assumptions include curb weight, payload, drag coefficient and frontal area.

The curb mass m_V of our vehicle is 950kg. Since our vehicle should be capable of taking in 4 passengers and some cargo, the maximum payload m_{PL} is decided to be 400kg. Considering that Honda Fit has maximum payload of 385kg and Mitsubishi Mirage of 408kg, this value is reasonable. The drag coefficient c_D of the vehicle is assumed to be 0.27 at the worst scenario. Lastly, based on the dimensions mentioned above, the frontal area A_x is calculated to be 2.15m^2.

The required performance of the vehicle is as follows. First, the required velocity v_r is expected to be 180km/h(= 50m/s). At this speed, the vehicle is expected to perform an acceleration of 0.5m/s^2 at the climb gradient of 2%. This climb gradient is equivalent to $\theta = 1.146°$

The main resistance forces that impact the power requirements of the vehicle are rolling resistance F_R, aerodynamic drag F_{aero}, climbing resistance F_{Cl}, and acceleration resistance F_a.

4.1 Rolling resistance

The vehicle will be in most times operated on dry concrete or asphalt roads. This assumption can be taken into account by letting the rolling resistance coefficient $f_R = 0.015$.

$$\begin{aligned} F_R(v_r = 50\text{m/s}) &= f_R \cdot (m_V + m_{PL})g \cdot \cos\theta \\ &= 0.015 \cdot (950 + 400)\text{kg} \cdot 9.81\text{m/s}^2 \cdot \cos(1.146°) \\ &= 198.61\text{N} \end{aligned} \tag{1}$$

4.2 Aerodynamic drag

Aerodynamic drag can be computed as follows.

$$\begin{aligned} F_{aero}(v_r = 50\text{m/s}) &= \frac{1}{2}\rho v_r^2 c_D A_x \\ &= \frac{1}{2} \cdot 1.225\text{kg/m}^3 \cdot (50\text{m/s})^2 \cdot 0.27 \cdot 2.15\text{m}^2 \\ &= 888.89\text{N} \end{aligned} \tag{2}$$

4.3 Climbing resistance

Climbing resistance due to the slope is as follows.

$$F_{Cl}(v_r = 50\text{m/s}) = g \sin\theta$$
$$= 9.81\text{m/s}^2 \cdot \sin(1.146°) \tag{3}$$
$$= 0.196\text{N}$$

4.4 Acceleration resistance

Our vehicle will be powered by an internal combustion engine, operating with 5 gears. Assumed values of rotational inertia coefficients k_{m_i} associated with each gear level are tabulated below.

Gear i	1	2	3	4	5
k_{m_i}	1.32	1.15	1.10	1.07	1.06

For each gear level, the acceleration resistance caused by both translational acceleration and rotational acceleration can be calculated as below.

$$F_a = (k_{m_i} \cdot m_V + m_{PL}) \cdot a_x \tag{4}$$

For $v_r = 50$, we assume that the transmission is at 5^{th} gear. Thus, k_{m_5} is used for the calculation of the power requirements.

$$F_a(v_r = 50\text{m/s}) = (k_{m_5} \cdot m_V + m_{PL}) \cdot a_x$$
$$= (1.06 \cdot 950\text{kg} + 400\text{kg}) \cdot 0.5\text{m/s}^2 \tag{5}$$
$$= 703.5\text{N}$$

4.5 Net power requirements

From the analysis above, the net power requirements for the vehicle can be determined.

$$\begin{aligned} P &= F \cdot v \\ &= (F_R + F_{aero} + F_{Cl} + F_a) \cdot v \\ &= (198.61 + 888.89 + 0.196 + 703.5)\text{N} \cdot 50\text{m/s} \\ &= 89.56\text{kW} \end{aligned} \tag{6}$$

4.6 Maximum velocity

Maximum velocity can be determined by excluding the effect of climbing resistance and acceleration resistance.

$$\begin{aligned} P &= F \cdot v_{max} \\ &= (F_R + F_{aero}) \cdot v_{max} \\ &= [f_R(m_V + m_{PL}) g \cos\theta + \frac{1}{2}\rho v_{max}^2 c_D A_x] \cdot v_{max} \end{aligned} \tag{7}$$

Solving for v_{max},

$$v_{max} = 60.21\text{m/s} \tag{8}$$

4.7 Graphical analysis

For the validation and visualization of the calculated data above, force-velocity graph and power-velocity graph are plotted.

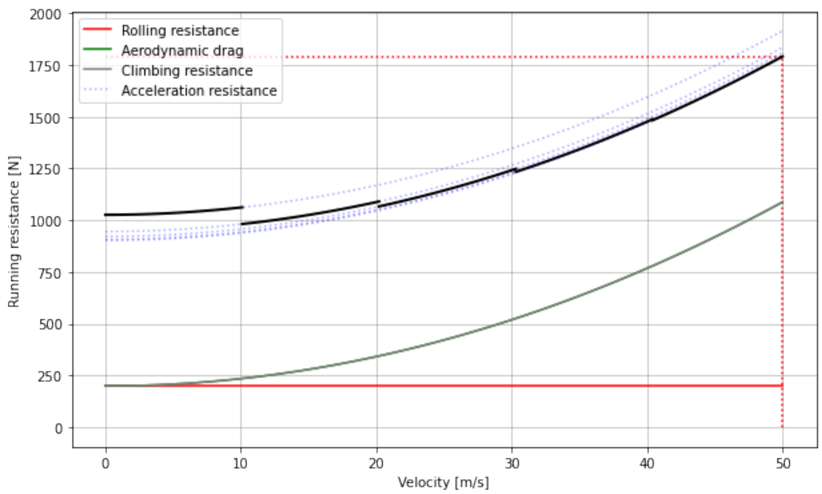

Figure 3: Force-velocity plot

Figure 3 shows how net driving resistance force increases as a function of velocity. Although rolling resistance F_R slightly rises for large enough velocities, it is approximated here as constant, not only for the sake of simplicity but also due to the fact that the increasing in rolling resistance is relatively small compared to the other shares of the resistance forces.

Each blue dotted line indicates different acceleration resistances F_a corresponding with each rotational inertia coefficient k_{m_i}. Velocity domain is roughly split into five sub intervals, each of which represents respective gear level. The discontinuity of the acceleration resistance graph implies change in gear levels.

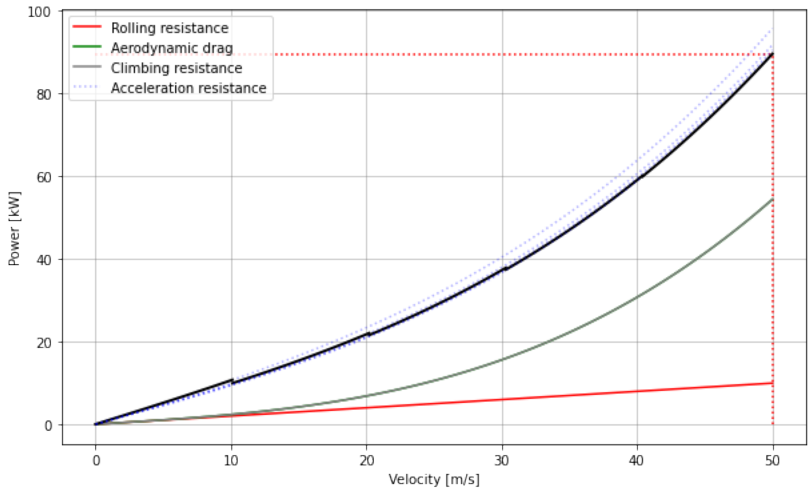

Figure 4: Power-velocity plot

Figure 4 shows how the engine power behaves as a function of velocity. At $v_r = 50$m/s, the power is 89.56kW, as calculated above.

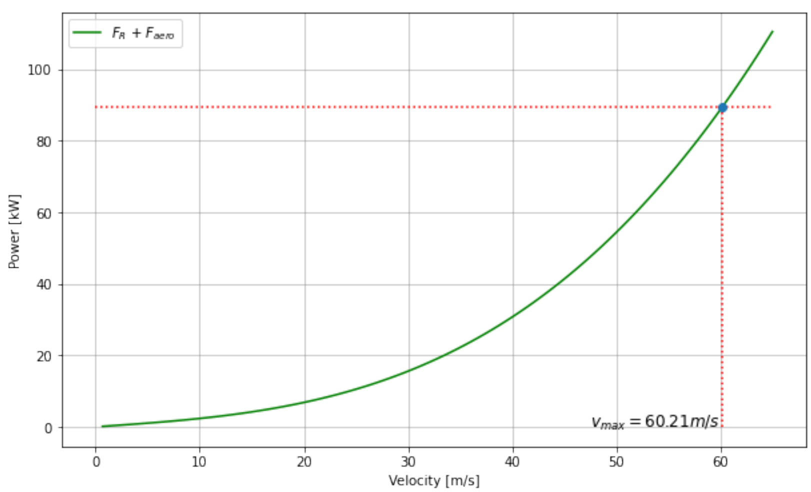

Figure 5: Indication of maximum velocity

Figure 5 indicates the point where maximum velocity occurs. With the restriction of $P_{max} = 89.56$kW, and with the absence of climbing resistance F_{Cl} and acceleration resistance F_a, the maximum velocity is found to be $v_{max} = 60.21$m/s.