Chapter 3

Structural Weight Model

The main function of the structures module is to calculate the structural weight as a function of the vehicle geometry for a nominal fifty person vehicle. It is assumed here that the structure of the MAGLEV vehicle is similar to that of a subsonic aircraft fuselage. Shaw [23] describes the aluminum cabin to have a sheet and stringer structure with internal frames and longerons. This enables use of the empirical equations for aircraft structural weight which are widely available. The structural weight and the design gross weight are found by simultaneously solving the following two equations,

$$W_{fuselage} = 0.3280(W_{dg}N_Z)^{0.5}L^{0.25}S_f^{0.302}(\frac{L}{D})^{0.10} \tag{3.1}$$

$$W_{dg} = W_{fuselage} + W_{magnet} + W_{payload} + W_{misc} \tag{3.2}$$

where the miscellaneous weight includes furnishings, instruments, controls, etc. This weight equation is for a transport aircraft fuselage and was taken from an aircraft design text by Raymer [63].

The design gross weight equation is altered to include MAGLEV specific items. The magnet weight is taken to be $114.4 lbs$ (52 kg) for each of the 24 superconducting magnets (Ref. [22]). The payload weight is taken to be $205 lbs$ (93.2 kg) for each of the 50 passengers and two crew members. This weight includes luggage. The miscellaneous equipment includes the seats and all of the ancillary equipment. Each seat has a mass of 14.55 kg. The ancillary equipment is treated as a fixed weight and is determined to be 47800 lbf. This number was calculated using weight estimations by Allen [26] which states 72000 lbf (320 kn) design gross weight. By subtracting the payload, seats, motor, and estimated structural weight (9000 lbf [23]), one can calculate the remaining fixed weight. These equations can be altered to account for the use of composite materials using a mass modifier. This modifier is currently set at 1.0 for aluminum but can be adjusted to 0.8 for composite material.

The use of this empirical weight equation is correct from a structural standpoint, although, the structural sizing for railed vehicles is handled differently from that of aircraft. Aircraft are structurally sized to handle a specific maneuver by considering the maximum load factor it will have to withstand. Railed vehicles are structurally sized for a longitudinal buffer shock. Shaw [23] specifies a maximum 2g vertical acceleration which is used as the load factor (N_Z) in the weight equation. This is very low compared to maximum load factors for aircraft. For example, a utility category Cessna 152, general aviation aircraft has a maximum load factor of 4.4g. Since aerodynamic loads are very low and the levitation forces are fairly uniform over the length of the vehicle, the MAGLEV structure will be very light. The 3 meter per second bumper impact, specified in the system technical requirements [5], cannot be handled in this preliminary design setting. In addition to the shock load, there are other specifications dealing with impact with guideway obstructions, thrown objects, bird strikes, and bullet strikes.

Weight calculations are very important in the design of aerospace vehicles since the mission profile usually involves carrying a payload over a distance. The weight growth factor is defined in order to determine if the payload can be carried. The definition can be seen in Eq. 3.3.

$$\text{Weight Growth Factor} \quad = \frac{1}{1 - \frac{\text{Empty Weight}}{\text{Gross Takeoff Weight}}} \tag{3.3}$$

It can be deduced from this equation that lower growth factors are favorable, since lower vehicle empty weight increases the possible payload weight. As the weight growth factor increases, the payload weight becomes a smaller fraction of the whole.

Zero payload weight corresponds to a weight growth factor of infinity. The empty weight for a MAGLEV vehicle includes the structure, levitation and guidance system, propulsion system, ancillary equipment, and cabin furnishings. Herbst [64] estimates a growth factor for MAGLEV vehicles of 2.0. This compares to 2.4, which is a common growth factor for transport aircraft. Growth factors for aircraft can be as high as 4.0, while growth factors for launch vehicles can be as high as 20.0. Based on weight estimations presented by Allen [26], the growth factor for the Grumman MAGLEV system is slightly less than 4.0.

The gross takeoff weight can be as much as the available lift which is the combined aerodynamic and magnetic lift. This type of analysis can be used to figure out the maximum potential speed for these vehicles given the current technology. For increased speed requirements, the Linear Synchronous Motor (LSM) propulsion system must be larger and, therefore, heavier. The propulsion system weight increases resulting in a decrease in payload weight. This trade-off can be continued until there is zero payload. This system will give the maximum possible vehicle speed. Likewise, speed can be compromised in order to achieve greater payload capacity.