6-DoF Modeling & Simulation of the *skyTran* MagLev Personal Rapid Transit Vehicle*

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Multibody Dynamics

***Project in partnership with *skyTran*, a NASA Space Act Company, headquartered at the NASA Ames Research Center**

1 Motivation

skyTran is an elevated transportation infrastructure that utilizes a patented method of passive magnetic levitation (MagLev) [1, 2]. Unlike other forms of passive MagLev, the *Bogie* reacts against vertical conductive surfaces. The *Bogie* is the driving portion of the vehicle; the passenger-carrying portion hangs below the track and is called the *Pod*. This design enables the vehicle to control its altitude in software. A strong simulation environment is critical to developing control algorithms without putting hardware at risk.

2 Background

Conventional trains leverage the friction between wheels and rails to drive forward. In contrast, a MagLev vehicle levitates on a guideway, replacing wheels with electromagnets. Levitation is advantageous in numerous ways, such as high speeds, reduction in maintenance costs, reduced noise and vibration levels, quick acceleration and deceleration, and so on. This technology also facilitates emission-free mass transportation [3].

Though the concept of MagLev trains was introduced in the 1930s, the technology reached maturity only in the 1980s. The first practical public MagLev train service was launched in Shanghai in 2003 [3]. Advances in modern technology have enabled full-scale implementation of MagLev trains, which are currently operational in many countries [4]. NASA has investigated the concept of Magnetic Launch Assist, which makes use of both magnetic levitation and magnetic propulsion to propel launch vehicles to 183 meters per second in less than 10 seconds [5].

skyTran is a novel take on the personal rapid transit (PRT) infrastructure, making use of a network of lightweight *Pods* that run on elevated guideways, thus facilitating transportation of people and freight from one place to another without the need for intermediate stops [6].

3 Problem Formulation

3.1 The Vehicle

The vehicle system that will be modeled, simulated and analyzed, is the *Bogie*, which is a cart-like rectangular vehicle with a rotary bearing connecting the front and rear chassis shown in figure [1]. It has four wheels, one at each corner of the body, and four magnetic *wings*, which, at a high-level, function like an airfoil/fixed-wing, with the ability to effect a lift force on the vehicle [7].

The entire *Bogie* can move in 6-DoF (subject to constraints). The front and rear chassis can roll (rotate about x) independently. The *wings* pitch (rotate about y) relative to the chassis, controlled by actuators. The wheels of the *Bogie* are constrained by the floor, and the drive force (loosely) constrains the vehicle to be centered. It is assumed that the track, as defined by motor force direction and reaction plates, is straight [7].

3.2 Dynamics

The vehicle is subject to five important classes of force & torque inputs:

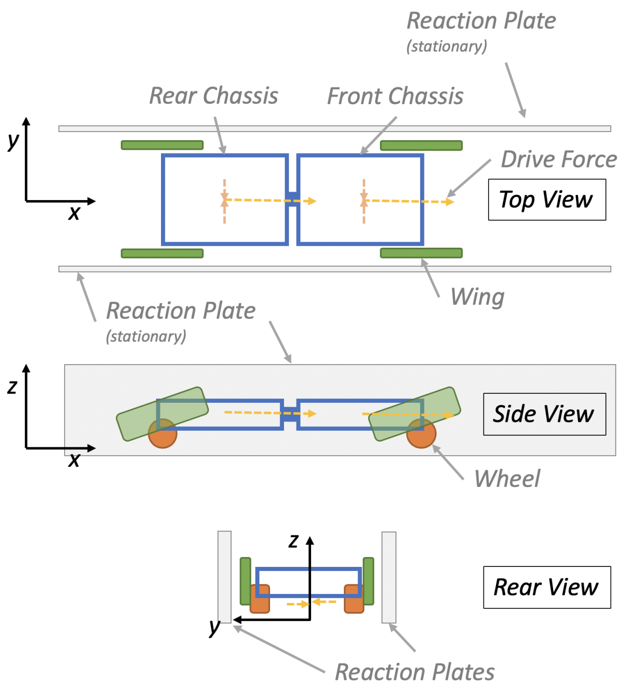

Figure 1: Principal views of the vehicle [7]

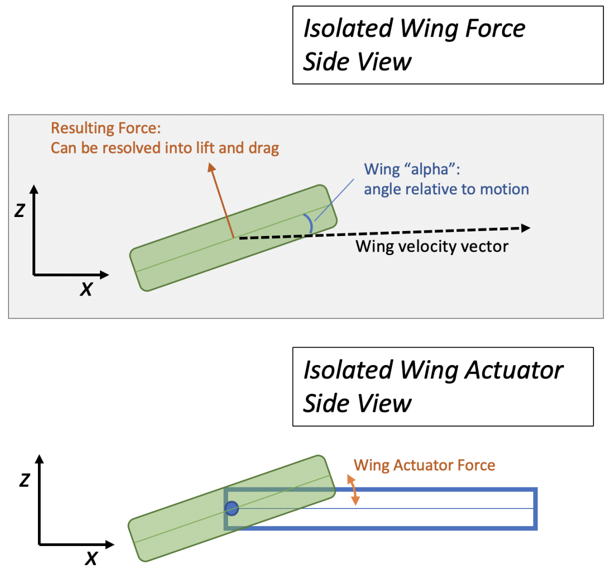

Figure 2: The Magnetic *Wing* [7]

3.2.1 Magnetic *Wing*: Magnetic Lift and Drag Forces

The vehicle has four *wings*, located at the corners of the rectangular *Bogie* body. A simplified black-box model of the *wing* as shown in figure [2] will be considered for the purposes of this project.

The forces effected by the *wing* arise from the interaction of eddy currents that are induced by the motion of the wing, with the conductive track plate (figure [3]).

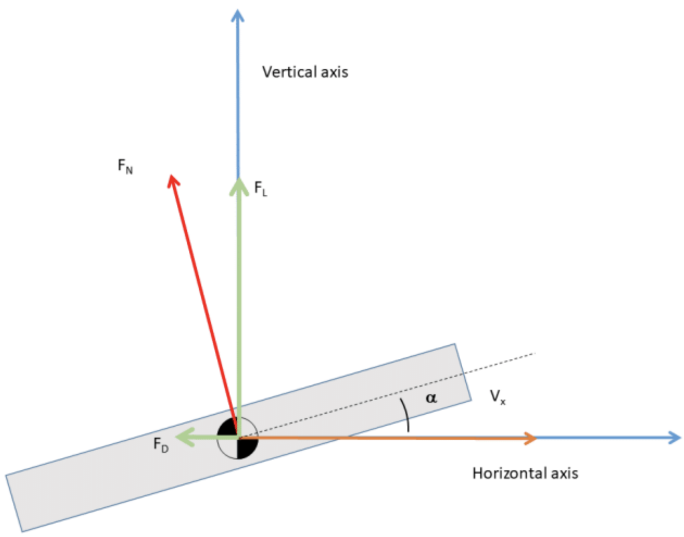

Figure 3: Forces effected by the Magnetic *Wing* [6]

For the vehicle moving in the horizontal direction (along the x axis) at a constant velocity v_x, with the *wings* at a fixed angle of α with respect to the direction of motion of the vehicle, a simplified description of the normal force F_N can be given by equation (1).

$$F_N = C_L V_x sin(\alpha) \tag{1}$$

This normal force can be resolved into *lift*, F_L, and *drag*, F_D, and these components are given by equations (2) and (3).

$$F_L = F_N cos(\alpha) = C_L V_x sin(\alpha) cos(\alpha) \tag{2}$$

$$F_D = F_N sin(\alpha) = C_L V_x sin^2(\alpha) \tag{3}$$

3.2.2 *Wing* Actuators: Pitching Moment

The *wing* actuators cause pitching moments between the chassis and the *wing*.

3.2.3 Wheels: Normal Force

The vehicle has four wheels, located beneath the *wings*. They are active before *lift-off*; *lift-off* is achieved when vehicle reaches critical velocity.

3.2.4 Belt: Drive Force

The belt pulls the vehicle forward (x-direction).

3.2.5 Belt: Centering Force

The belt also provides a lateral centering force, keeping the vehicle very near $y = 0$.

4 Sample Test Run

1. The control system determines the drive force as a function of the vehicle's position in the x-direction. The first objective is to quickly get to *flight-speed* and then maintain velocity.
2. Once at *flight-speed*, the flight control system drives the *wing* actuator force. The next objective would be to follow a desired height and pitch trajectory, while minimizing vehicle roll and yaw.

5 Modeling & Simulation

The vehicle will be modeled to enable analytical characterization of the velocities of the mass-centers of each of the individual rigid bodies that constitute the vehicle. The goal of the project is to answer the following questions using the SymPy/PyDy framework in Python for dynamic simulations of the vehicle:

1. Is the system stable about an equilibrium flying condition?
2. Are there instabilities during the *take-off* regime?
3. How do the vehicle and control system respond to track imperfections?
   - Case 1: reaction plates not centered
   - Case 2: reaction plate location varying versus x
4. How does the point of application of the drive force and the centering force affect the dynamics of the system?
   - The points of application of these forces may be fixed off of the track and not the vehicle. For example, as the vehicle rises, the point of application of these forces would go lower (in z) on the chassis.
5. How best to control the independent rolling of the front/rear chassis?

6 Further Extensions/Future Work

- To model a curved track
- To add a virtual *Pod* that hangs below the vehicle
- To model other types of forces on the *Pod*, such as sidewinds
- To develop more involved control algorithms

References

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