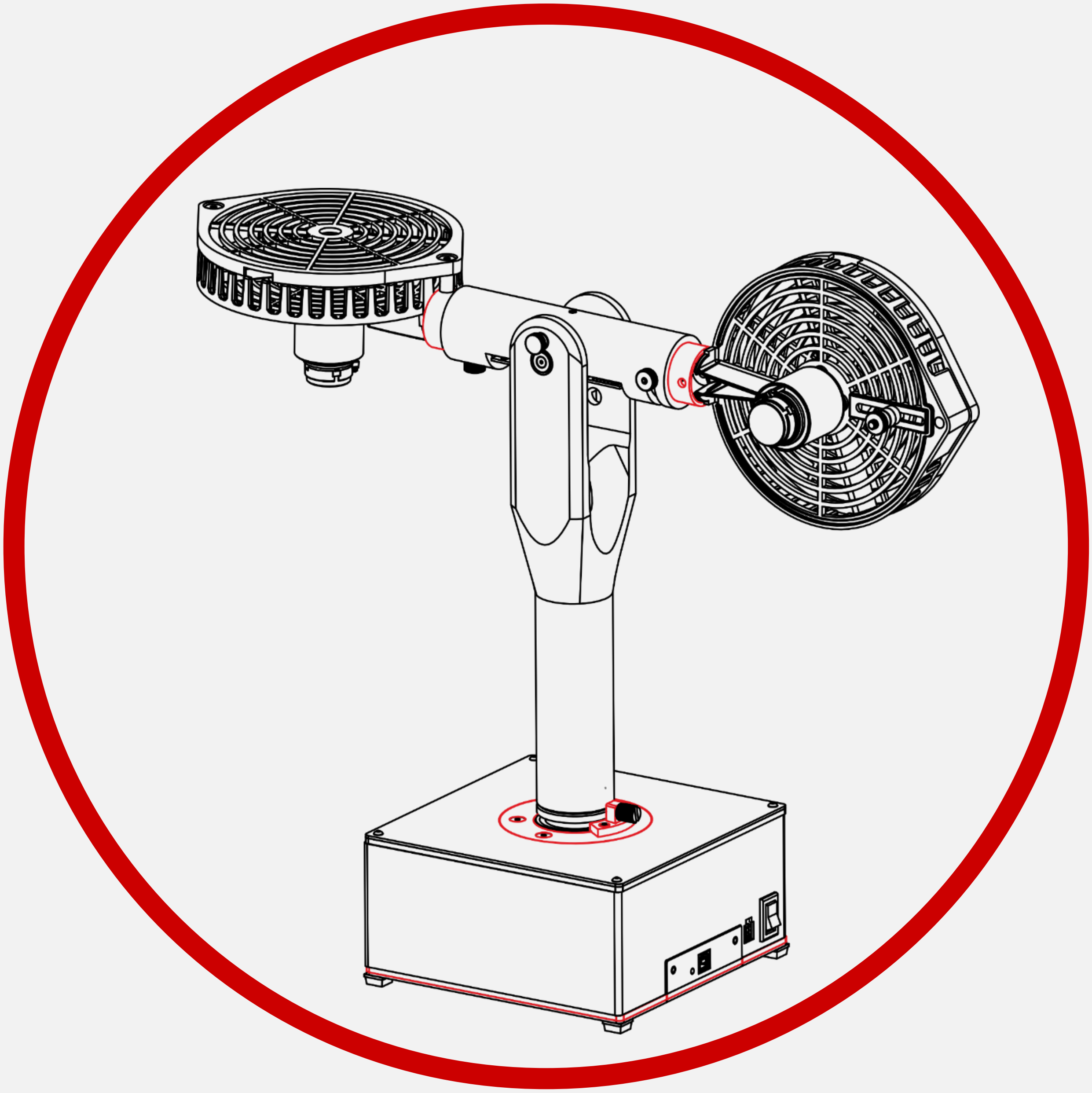

Aero 2

Gain Scheduling

V1.0 – 14th February 2025

Aero 2 – Application Guide
Gain Scheduling

Why Explore Gain Scheduling?

Most closed-loop control strategies such as PID or LQR state feedback are highly linear, meaning that they can only be effectively controlled using controllers that are themselves linear. One of the standard approaches in dealing with such systems is linearizing the system and then using a linear control approach. Linearizing only works in a nominal region, outside of which, the linearized model fails. The control strategy therefore also fails outside this operating region.

A solution to this is to use multiple linear models linearized about different operating points. Multiple linear controllers can be designed for each operating region, a process known as Gain Scheduling.

Nonlinear Systems

Most approaches to feedback control such as PID or LQR state feedback are highly linear, meaning that they can only effectively control systems that are themselves linear. Nonlinear systems are systems in which the output is not directly proportional to the input. One way in which a system may be non-linear is if there are secondary variables that affect the dynamics of the system but which are not under the authority of the controller. In this case, a controller which has been designed and tuned under specific conditions may no longer meet response requirements when those conditions change. The example we will focus on today is introducing asymmetry in the dynamics of the Aero 2 by using a single propeller operating in both positive and negative thrust, as well as intentionally unbalancing the Aero 2 body by shifting the center of mass towards thruster 1.

Linear Approximation

In other labs using the Aero 2 the issue of system nonlinearity has been avoided by simply assuming the system is linear and designing a controller accordingly. The nonlinearity has also been ameliorated by using opposed thrust torques so that each thruster operates only in a positive thrust direction. However, ignoring any factor such as thrust asymmetry ultimately results in suboptimal controllers. One classic solution to the nonlinear properties of a pendulum is to severely limit the range of motion such that θ is very small and use the approximation $\sin(\theta) \approx \theta$ to find a linear system that approximates the behavior of the pendulum within a small range of angles. However since these linear approximations only apply over a limited range, if the system progresses outside this range the error increases and any controller based on the linear approximation will likely become ineffectual, if not completely unstable.

Gain Scheduling

Since any given linear approximation of the system will only be valid under certain conditions, one solution is to approximate the system with a series of several linear system approximations. This way the error in the approximation can be minimized. Controller gains can then be found for each of these approximations, and the gains can be selected based on the current state of the system. This process is known as *Gain Scheduling* and it is used extensively to control both nonlinear, and time-variant linear systems. If approximating the behavior of the system using linear functions is prohibitively difficult, the system may also be experimentally tuned under various conditions, and those tuned gains can be applied whenever the given conditions are present.