



### Metastable States

warn you ahead of time that this article waxes a bit philosophical (sort of like applying entropy to the state of my office).

GeoCue Group is entering the small Unmanned Aerial Systems (sUAS) business with our new subsidiary, **AirGon LLC**. We have been trying to categorize sUAS as to which design is most suited to a particular type of surveying project. There are two fundamental types of sUAS; fixed wing and rotary wing (multi-copters). It is somewhat obvious that fixed wing are most suited to mapping operations whereas rotary wing are more suited to inspection operations where one may need to “stare” from a relatively stationary position.

Within the fixed wing area, there are two common designs; the conventional glider (front wing, tail wing, elevator, etc. of **Figure 1**) and the flying “wings” (such as the SenseFly eBee—see **Figure 2**).

I figured there would be a clear difference between these two fixed wing designs but, alas, this does not seem to be the case. A bit of perusing web sites ([www.flightriot.com](http://www.flightriot.com) is a good place to start) shows what a huge controversy this seems to be! I even saw a few threads where the arguments were getting personal and vitriolic (“I’ve been an aeronautical engineer for 40 years and you think you can...”).

The issue seems to be aerodynamic stability with big arguments about which type of platform is the more stable. This



**Figure 1:** “Glider” style fixed wing sUAS

made me think about control systems and stability in general and how the fellow who has been in aeronautical engineering for 40 years may have a distinct disadvantage as compared to the new young whippersnappers for a reason soon to be explored.

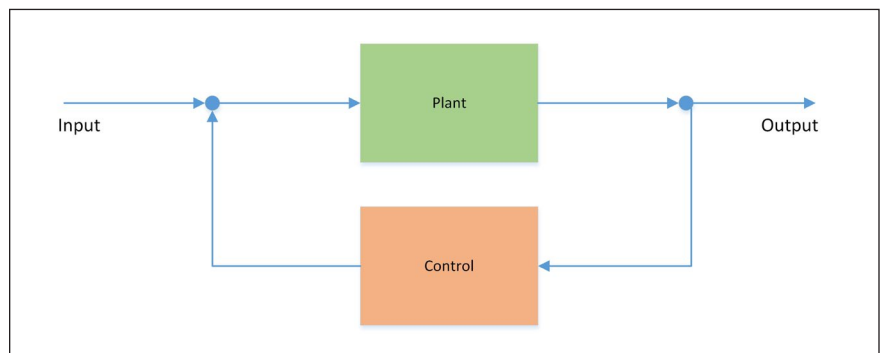
In **Figure 3** is depicted a simplified basic *feedback* control system. The “plant” (as in chemical plant or power plant) is the thing we wish to control (in our example, an airplane) and the “control” is a system of measurements, computations and *feedback* systems



**Figure 2:** SenseFly eBee - a classic “wing” design

used to control the plant. In theory, the operation is quite simple. A sensor (for example a Micro Electro-Mechanical System, MEMS, gyroscope) detects the attitude of the aircraft and provides this information to the control loop. A computation is made and an adjustment signal is sent to correct the attitude. In a simple quad copter, this might be accomplished by changing the rotational speed of one or more motors.

I want to introduce one more concept—that of stability. Consider the simple diagram of balls on a track in **Figure 4**.



**Figure 3:** A basic feedback control system

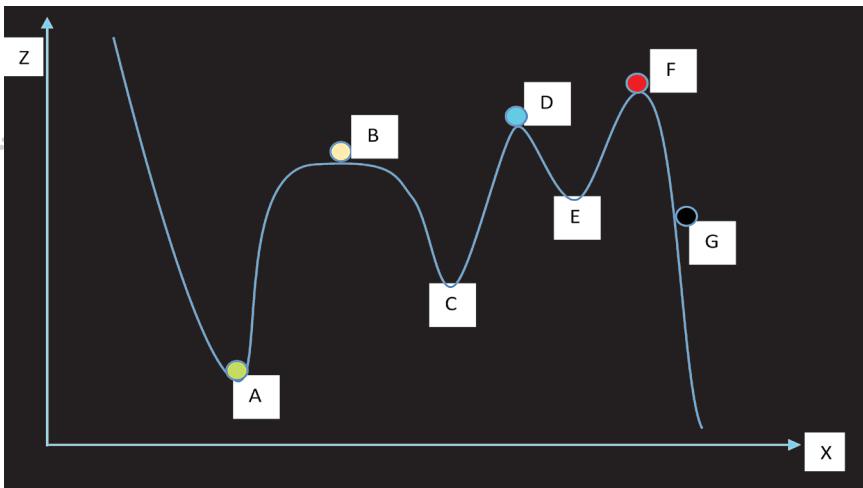


Figure 4: Stability States

We can test stability by displacing the balls a bit along the track. The ball at A is stable. If one pushes the ball slightly to the left or right, it will oscillate a bit but then settle back to its original position. The ball at location B is in a “metastable” state. So long as it remains unperturbed, it will stay at its dicey location. A slight push to the left or right and this ball will (again, after some oscillations), settle to a new state at A or C. F is in a metastable state with the interesting property that a slight push to the right sends it into an unrecoverable unstable state whereas a push to the left will have it ending up in position A. Finally, the ball at G is in a clearly unstable state. As soon as it is released, it will plunge off to the right, into the abyss.

Enter the control system and the point to all of this discussion! A control system monitors the state of the “plant” and takes corrective action to ensure the plant continues to operate within the bounds of the operational envelope (in a simple system such as a thermostat, this is called the “set point”). In our example of Figure 4, we might monitor the position of a ball with a remote measuring technology (a real time LIDAR, perhaps—see, this is a LIDAR article!!) and take corrective action by applying a force to the ball in the opposite direction of its motion. Of course there are all sorts of complications to this that we

will not discuss such as overcorrection, “hunting” and so forth.

Now for the more interesting bit. One of the most common control systems is a human. Consider yourself driving an automobile. The car drifts a bit to the left of lane center. Your optical system (eyeballs, visual cortex and so forth) detects this drift. Your brain processes the situation and turns the steering wheel a bit to the right. This is the same situation in a basic, manually piloted aircraft where feedback signals are being provided by the pilot’s vision, sense of feel (acceleration forces), instruments and so forth. The pilot must be able to react and provide corrective actions prior to the aircraft reaching a state that is not recoverable. This time to react is, of course, critically important.

Consider the points B and D in the graph of Figure 4. Clearly the permissible reaction time is much longer at point B than it is at point D. In fact, we might say that B is a more stable configuration than is D. This sort of idea (at least subconsciously) is what drives the “wing” versus “glider” debate. The stability of the wing can be compared to point D whereas the stability of the glider can be compared to point B. But here is the rub. With the advent in the past 10 years or so of super-miniaturized sensors (for example, the aforementioned MEMS gyroscopes),

very fast memory (for storing state) and ever faster and lower power processors, it just doesn’t matter! With miniaturized sensor and control computer technology, I can control a wing just as easily as a glider. Perhaps it may take more energy to do so (more movement of the control servos) but with the rapid advancements in battery technology, this is not a serious issue either.

This is where the thinking of “old” codgers like myself may be an impediment. Back in the day, the “time to instability” for a system was critical. I might have a control system that can only sense and correct every 20 seconds. If the “plant” can go to unrecoverable instability in 15 seconds, I am doomed. In these old systems, inherent stability was a critical design factor. Today, with electro-mechanical sense and correct chains of thousands of Hz, it just doesn’t matter. We could fly a brick!

One final thought occurred to me on the business side of things. Assume in Figure 4 that the vertical axis is revenue/profit rather than height. We would like to define these “local minimums” of A, C and E for our operations. Moving from A to C requires an input of energy (work, risk, change and so on) but, if we apply these forces correctly, we should be able to get to point C, a quasi-stable state but at a higher energy (revenue, profit,...) level than A. Of course, the trick is to figure out the states and in which direction to apply the forces!

Till next time, focus your optical systems and keep it between the bar ditches! ■

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