Expert Pointers for Better Fixed-Wing UAV Designs

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MicroPilot has been an established authority in the field of professional unmanned aerial vehicle (UAV) autopilots for nineteen years. MicroPilot's combined experience offers the expertise the UAV industry relies on for dependable, applicable advice on how to control a wide variety of UAVs. The experts at MicroPilot have put their heads together to deliver the most essential best practices UAV design teams should follow to produce the most reliable and effective UAVs possible.

From this article, design teams will learn how UAV design decisions impact the performance of their UAVs. Specifically, readers will understand how stall/spin behavior, recovery, launches, and landings affect their UAV autopilots' functionality. Readers will also understand the benefits of redundancy and how to best manage control surfaces and payloads. These ten *design hints* are covered in order of importance, with the most significant tip being at the conclusion.

10. Avoid mixing

In addition to adding redundancy to control surfaces, separating surfaces helps to design the most reliable UAV possible. Design teams should avoid mixing controls and instead include a separate surface for each axis (pitch, roll, and yaw). V-tails and elevons are the two most common instances of a single control surface affecting two axes.

Rolling caused by the inner portion of an *elevon* is not as effective as rolling driven by the portion near the wing tip. Design teams should avoid elevons for this reason. Leaving out the extra servo is not as economical as it seems. In the end, this omission leaves the UAV less dependable; therefore, the design becomes more costly.

In addition, elevons can cause control surfaces to interfere with one another. This happens when a UAV using elevons needs *full elevator* and *full ailerons* at the same time.

V-tails also cause problems, since single control surfaces affect two axes. Specifically, problems occur when a UAV employing V-tail mixing is recovering from a stall or spin. Stall and spin recovery often requires simultaneous application of significant rudder and elevator inputs. Consequently, control inputs often interfere with one another after the V-tail mixing is applied.

9. Pay close attention to recovery

A process for recovering a UAV at the end of a flight is the most difficult challenge UAV designers face. Design teams have many popular recovery options: parachutes, deep stall, capture, belly landings, wheeled landings, and net recovery. However, keep in mind, each comes with its own, often serious, disadvantages.

Parachutes carry UAVs down gently and double as a fail-safe recovery system when other systems fail. However, parachutes add weight to UAVs and take up precious space. Moreover, if operators do not pack parachutes properly, they risk losing their UAVs. Additionally, high winds cause parachutes and their UAVs to drift great distances. Wind can also drag UAVs over harsh ground, damaging or destroying them. In light of these challenges, design teams should include a mechanism to detach the parachute immediately after landing, although this can be challenging for design teams.

Deep stall is a suitable recovery option for small UAVs. During a deep stall recovery, the UAV falls quickly, which minimizes wind drift. Consequently, operators achieve more precise recovery locations with deep stall. On the other hand, quick drops put a UAV's airframe and payload at risk. Design teams should consider airbags if their UAVs rely on deep stall for recovery, carry light payloads, and operate flights within limited ranges. Otherwise, deep stall should not be employed as a recovery option because of possible UAV damage.

Belly landing is fitting for smaller UAVs if onboard cameras are well protected. Belly landings are also appropriate for less expensive UAVs, although not suitable for UAVs carrying payloads positioned under the belly. Design teams often include belly landings in their designs because this recovery solution is inexpensive, although it is important to keep in mind belly landings are hard on airframes and require large landing areas.

Wheeled landing is appropriate for large and long-range UAVs that use runways. Wheeled landings offer flexibility, as they can be performed manually by a highly skilled ground operator; or autonomously with a carrier phase GPS or a laser altimeter. Although, even considering wheeled landings are robust and runways are abundant, design teams are restrained by airspace regulations.

Net recovery and other capture types of recovery require extremely accurate positioning information and can be hard on the UAV.

8. Include approach control

To maximize endurance, most UAV designers minimize a vehicle's drag. Low drag, while desirable in flight, can cause problems during landing. This is because operators need long final approaches to reduce a UAV's altitude during a circuit. In addition, shallow glideslopes make it difficult for UAVs to land in obstructed areas (such as wooded areas or fields bordered by trees). This can be inconvenient since large landing areas are not always available. To remedy this, UAV design teams incorporate an effective means of steepening the UAV's glideslope, such as with flaps or spoilers. With effective approach control, operators can perform belly landings in smaller areas.

Furthermore, shallow glideslopes coupled with seemingly minor altitude errors can cause significant variation in touchdown locations. For example, a 20-foot altitude error on a UAV with a 30:1 glideslope will produce a 600-foot error in landing location. However, with effective flaps or spoilers, operators can generate the drag needed to steepen glideslopes and reduce this error substantially. For instance, flap settings above 45 degrees produce drag effectively. Deploying flaps is the best way to generate lift at low speeds.

Flaps also add lift on launches, allowing slightly lower-speed launches, and can be effective in preventing stalls if they are automatically deployed at low speeds. In addition, flaps provide redundancy, which is covered later in this article. Design teams should include flaps in their UAV designs for all these reasons.

7. Avoid cross-coupling

Cross-coupling of controls reduces a UAV's autopilot performance. This is because autopilots must continually adjust one axis' controls to compensate for inputs on another axis. Cross-coupling can affect a UAV's navigational performance and its ability to hold an altitude. UAV designers should, to the maximum extent possible, design controls that affect only the intended axis.

The most common type of cross-coupling is *adverse yaw*. MicroPilot support teams have witnessed airframes flying with such great adverse yaw that ailerons are of no use to roll into a turn. To minimize adverse yaw, design teams can use upward deflection of the opposite aileron to initiate rolls, or increase drag on the *down-going* wing with Frise ailerons.

The second most common encounter of cross-coupling is between *throttle* and *pitch*. MicroPilot support teams have seen UAVs where the throttle controls pitch more than the elevator. Cross-coupling between throttle and pitch usually results from (a) mounting the engine high above or below the center of gravity, or (b) the prop wash passing over the elevator (especially common in tractor flying wings).

To minimize cross-coupling between throttle and pitch, implement the following:

- Keep the engine near the center of gravity.
- Position all controls out of the prop wash. (This is especially important on flying wings.)

The third most common cross-coupling is between *approach control devices* (such as flaps and spoilers) and *pitch*. These devices are typically used only on final approach and should be conservatively adjusted; therefore, cross-axis effects caused by approach control devices are not as serious as those caused by other devices.

6. Implement both a rudder and ailerons

UAVs with ailerons and a rudder establish turns more effectively and quickly than UAVs that rely only on the rudder or ailerons alone. This arrangement supports inner loop performance, which in turn supports outer loop performance. In the end, robust navigation depends on outer loop functioning. Rudders can be used alone; however, flight test teams must wait one or two seconds for lift differentials to manifest. (Lift differentials are calculated by subtracting the inner wing's slower speed from the outer wing's higher speed.) This difference in speed slowly establishes a bank and entry into a turn.

Ailerons alone can be used to turn, although even the best UAV design will have some adverse yaw. The rudder is the most effective way to overcome adverse yaw. Without a rudder, sideslip will occur for one or two seconds (until the vertical stabilizer starts to turn the nose). This delays the start of the turn in extreme cases.

Rudders and ailerons together add accuracy to waypoint navigation because these controls act together to offer the quickest and most precise turn performance.

5. Position batteries intelligently (electric UAVs)

The bottom of a UAV is most vulnerable during belly landings and deep stall landings because so much energy is absorbed in order to bring the UAV to a stop. Positioning batteries beneath the belly of the UAV absorbs force on impact, minimizing wear and tear on other UAV components.

Therefore, since a UAV's payload and airframe is more valuable than its batteries, design teams should position batteries on the underside of the UAV, letting inexpensive (and sometimes disposable) batteries protect the airframe. Additionally, the weight of the batteries, if placed on top, can cause damage to the airframe. Design teams should also consider that battery loads will most likely increase instead of decrease over the UAV's lifespan. If the UAV is recovered by another means, such as through net or wheel recovery, then batteries should be positioned accordingly.

4. Use a high-energy launch

Many design teams believe that hand launches are the simplest launch solution because UAV operators have been tossing items around since childhood. However, hand launches create complexity and are only suitable for extremely low wing-loaded UAVs. Hand launching heavier UAVs causes a variety of errors. For instance, if an operator throws a UAV too steeply or not steeply enough, then the launch will fail and the UAV will almost certainly be damaged.

Photo from www.trimble.com

Additionally, if the operator does not level wings during a hand launch, the UAV will turn and potentially fly into an obstacle. Stalls and spins can also result when UAVs are not thrown with enough force. Furthermore, as operators gradually add more payload weight and batteries, the UAV becomes less tolerant of a bad launch and endures more force and damage when it hits the ground after an insufficient throw.

Implementing a high-energy launching system, such as a catapult or bungee launch, delivers better stability, accuracy, and reliability. High-energy launches help UAVs clear obstacles and allow operators to launch from smaller areas. In the end, UAVs with high-energy launching capabilities remain intact and provide longer useful life spans.

3. Improve reliability with redundancy

A common source of UAV failure is servo malfunctions. Therefore, redundant servos are especially important on critical control surfaces. Single servo failures that drive control surfaces usually result in complete destruction of the UAV.

Design teams should do the following to support critical components:

- Include individual servos for each aileron, so in the event of an aileron servo failure, operators can continue with at least one functioning aileron.
- Split a UAV’s elevator into two independent control surfaces driven by two separate servos whenever possible.

Please note: If a UAV *has* ailerons, the rudder is not as critical as its other control surfaces; therefore, the rudder does not require redundancy. If the UAV *does not have* ailerons, then two surfaces and two servos are recommended.

Redundancy also satisfies FAA regulations because backup components provide safety. Regulatory authorities recognize the value of redundancy; therefore, spending a couple of hundred dollars on a second servo will impress regulators, while a missing servo may alert regulators to look for more deficiencies.

Autonomous helicopters would highly benefit from redundant controls. Unfortunately, at this time there are no helicopter rotor heads that allow for redundant controls, nor are there redundant servos available. Design teams should avoid multi-rotor configurations that do not allow the vehicle to tolerate propeller, motor, or speed controller failures.

Photo from www.bertin.fr

2. Design for benign stall/spin behavior

Benign stall/spin characteristics are important in UAV design, despite their automated operations. In theory, it is possible to configure an autopilot to avoid approaching flight conditions where a stall/spin could occur. In practice, however, horizontal gusts, configuration errors, clogged static systems, poor launches, and pilot errors can conspire to provoke a stall, or worse a spin.

In addition to the usual stall/spin challenges that *aviation* design teams face, *UAV* design teams must consider typical UAV operational environments. UAV autopilots often exacerbate a stall/spin instead of taking actions to recover for two reasons— UAV design and difficulties in recognizing stalls/spins. When a UAV stalls, the UAV's nose drops. Almost all autopilots correct a nose drop with up-elevator. Up-elevators make the stall worse, which causes the nose to drop further, leading to a vicious cycle of autopilot correction. An ever-worsening stall is established and continues until the UAV is in a deep stall with full up-elevator. In this situation, the only chance of recovery is operator intervention. Furthermore, this type of deep stall develops at such a fast rate the operator does not typically have time to recover the UAV.

In reality, down-elevator is needed to recover from a stall. Some autopilots (e.g., MicroPilot autopilots) can be configured to recognize a stall and react appropriately; otherwise autonomous recovery is not possible. However, configuration alone is not enough. Even if design teams rely on an autopilot that can be configured to recognize and recover from a stall (e.g., MicroPilot autopilot), stall/spin behavior design considerations are still necessary for two reasons:

- Test flight programs normally do not have the resources to thoroughly investigate an airframe's stall/spin behavior and autopilot configurations prior to the first test flights and so a stall could inadvertently develop during initial test flights.
- UAVs flown manually cannot rely on the autopilot for recovery.

Aileron control near the stall can also be problematic. When a stall occurs, invariably one wing will stall first, causing it to drop. Most autopilots correct a wing drop using ailerons; this increases the angle of attack on the lowered wing, which normally generates more lift. However, if the lowered wing is stalled (e.g., the combined angle of attack of the wing and aileron is greater than the stall angle of attack), using ailerons to raise the wing exacerbates the stall. The lift then decreases and the wing drops further. As a result, the autopilot adds more aileron, fuelling a failing cycle of attempted recovery that results in a fully developed spin.

Moreover, stalls caused by mislaunches are difficult to recover from. Unexpected stalls and spins during long, autonomous test flights are also challenging. The reason being the operator likely has been idle for a long period of time and is probably not at his or her best to recognize, let alone skillfully handle, the in-flight emergency that results from an unexpected stall or spin. Safety pilots might be able to perform the recovery; however, it is unlikely they will be looking at the UAV when the stall/spin occurs.

Unplanned repairs and total UAV destruction throw budgets and schedules out of whack. For these reasons, design teams should ensure that their UAV airframes exhibit benign stall/spin behavior. There are a number of design choices that can improve the stall/spin performance of an airframe. Here are three:

- Use an airfoil that exhibits good stall/spin performance.
- Add twist to the wing to ensure that ailerons do not stall, and thereby remain effective when the rest of the wing has stalled.
- Limit the size of the elevator (and/or its travel) to guarantee that the elevator does not have authority to stall the UAV.

Good stall/spin behavior can determine whether your UAV design survives. With proper design, a UAV can recover from a stall unnoticed. Furthermore, good stall/spin behavior helps bring UAVs to market in less time. Stalls and spins during testing are difficult to recover from, especially as the UAV is far away and difficult to see.

Top pointer for better UAV design…

1. Create a sensible location for payloads

Many design teams miss the mark when they invest all their efforts into aerodynamics, endurance, payload, speed, weight, and drag. UAVs are designed with a purpose in mind. Therefore, design teams should prioritize the value and operation of the payload over any other design concern.

> **The most important criteria for any UAV, and the starting point when designing a UAV, is its payload. Without the payload, the UAV has no purpose.**

A UAV's payload is more specific than a typical *aircraft's* payload. When designing an aircraft, design teams are only concerned with accommodating added weight and space. UAV design teams, on the other hand, must consider more factors, such as how the payload will detect objects or how to position a camera system so that it may best capture video.

Photo from www.topivision.com

The carrying capacity of a UAV's payload is important; however, the payload's position is even more essential. Good locations vary depending on payload type.

Still-picture cameras (e.g., Trimble Gatewing X100) are relatively easy to position in the center of the UAV. Design teams should ensure easy access to the camera and provide adequate protection to prevent damage during landing.

Two-axis, pan-tilt-zoom cameras (e.g., Elbit Skylark, Top I Vision, and Blue Bird Spy Lite) are challenging to position and can be mounted in one of two ways*:*

Belly Positioning: If a belly-mounted camera is looking at the center of a circle while the UAV orbits the circle, then the camera's pitch axis is aligned with the UAV's roll axis. The camera's yaw stabilization keeps the lens pointed at the center of the circle. This scenario offers good stabilization in the roll and yaw axis, but no stabilization in the pitch axis. However, if the camera is pointed straight ahead, then the camera's yaw stabilization is aligned with the UAV's yaw axis and its pitch stabilization with the UAV's pitch axis. This scenario offers good stabilization in the pitch axis, yet no stabilization in the UAV's roll axis. Since UAVs roll more than pitch, poor roll stabilization is an issue. Three-axis cameras come at a higher price; however, they provide excellent roll stabilization.

Two-axis, pan-tilt-zoom cameras should be positioned in the belly of the UAV in such a way that the wings do not block the camera's view. Design teams should include a system to retract the payload, since the belly is difficult to protect during a belly landing. Extra failure modes and misalignments will inevitably ensue for arrangements without inertial measurement unit (IMU) control; therefore, in these cases, design teams should plan for such malfunctions.

Nose Positioning*:* Nose-mounted, two-axis, pan-tilt-zoom cameras have several advantages. First, their views forward and toward the center of a circle are unobstructed. Second, the camera's roll axis is always aligned with the UAV's roll axis, which is important as UAVs often roll. When looking forward, pitch and roll stabilization is available. When looking to the center, roll stabilization is available (as it is with the belly mount). With this arrangement, a retraction mechanism is not necessary.

Nose-mounted cameras come with a different set of design challenges:


Photo from www.bluebird-uav.com

- Designs require more restrictions because a nose-mounted camera demands a pusher or an offset engine.
- Design teams cannot adapt most existing designs to a nose-mounted camera. Instead, the camera must be designed in from the start.
- Nose-mounted cameras can affect a UAV's aerodynamics. Generally speaking, UAVs fly more efficiently if the engine and propeller are positioned in front. In most cases, however, efficiency should not be prioritized over the advantages of placing the camera in front, since the purpose of the UAV is to collect images.

UAV design teams should be knowledgeable of the mission their UAV will accomplish. If collecting video or still images is its task then great care should be invested in determining the best position for the camera. Additionally, the specific function of the camera needs to be considered.

Quality resources for design teams

MicroPilot provides the support UAV design teams need to build robust UAVs. MicroPilot's software development packages, simulation tools, and life-cycle management solutions aid organizations to produce quality UAV designs at lower costs and faster rates than they might otherwise be able to achieve. Please contact MicroPilot for more information.

About MicroPilot

With 750 clients in 65 countries, MicroPilot is the world leader in professional UAV autopilots. MicroPilot is the first UAV autopilot manufacturer to bring to market a sub 30-gram autopilot, triple redundant autopilot, and full-function general-purpose autopilot. MicroPilot offers a family of lightweight UAV autopilots that can fly fixed-wing, transitional, helicopter, and multi rotor UAVs. MicroPilot also provides complementary products such as the XTENDERmp SDK, trueHWIL, payloads, and catapults.