Spitzfire 4/2/2022 Crash

The past flight test for the 2022 MIT DBF aircraft, the Spitzfire, ended in a crash. In this report, I want to characterize the flight and explore what I believe to be the main contributing factors: pilot unfamiliarity, poor build quality, and the low-speed instability of the aircraft configuration.

Due to the timing of this report, there are few options to correct this instability without violating the submitted design document and that are feasible in the short time period before competition. The recommendations are at the end of the report, for both the airplane and future pilots, and for a quick glance through, one needs only to read the highlighted portions to understand the gist of the report.

Spitzfire, immediately after lift-off.

From a piloting perspective, the aircraft seemed to handle well in the initial upwind phase after takeoff, with the first stall having been mostly benign. The crosswind turn was similarly as expected for an aircraft with high wing loading and high thrust on a windy day, and the downwind was mostly uneventful as well. It was the turn to final that resulted in such instability before crashing. We can take a closer look at these events in the flight breakdown.

Flight Preparation & Execution

We can break down the flight into its basic components:

- **Pilot Preparedness**
- **Takeoff Procedure**
- **Low Speed Stability**
- **Flight Planning**
- **Coordinated Turns in High Winds**
- **Stall Recovery**
- **The Approach**
- **Spin Recovery**

Pilot & Aircraft Preparedness

Earlier in the day, I practiced on three different STOL airplanes: two 1800mm wingspan Huskies, one front-loaded and one rear-loaded, and a much smaller Cub.

The team waited for lower relative winds at take-off, which were, at T/O about 10G15kts. When I was flying the Husky, the winds got as high as 20 knots on the ground and yet the Husky was relatively easy to fly despite having less wind rejection capability from its lighter wing-loading and lower power (explained further into the report).

Before we started with the test cards, I delegated the pre-flight checklist (detailed in the test card) to two people at the field and then went over their concerns, namely that the control linkages were loose enough on the elevator and ailerons to induce flutter, and that the hinges, made of packing tape, showed minor signs of peeling. Unfortunately, due to pressure I put on myself to continue with the flight (since competition was in two weeks from now), I had the team note these concerns and we continued with the flight test. In hindsight, these issues should have grounded the aircraft, even if the team would have received the news poorly.

Takeoff Procedure & Low Speed Stability

Since I suspected the airplane to be unstable at high AOA and low speed (detailed later in this report), extensive time at the field was used in characterizing the low speed and high AOA stability of the aircraft before the first flight.

I'll explain the test card progression here (the test cards used are in Appendix B). The throttle needed to initiate a take-off roll was found, both with and without braking. Then, starting at that speed, the throttle was further increased slowly until rotation was achieved. The next taxi test started at that rotation speed and attempted to keep the airplane in this pre-liftoff phase to assess the yaw and elevator authority at low speeds and high AOA. It was noted by the pilot (PIC, me) and second-in-command (SIC, Brian) that rudder authority at this rotation speed was poor, that elevator authority was similarly poor, as the aircraft was less "rotated" and was travelling at an airspeed better described as "right before level-liftoff" and small elevator inputs at this speed did not significantly alter pitch. The aircraft had trouble steering at low speeds and needed considerable rudder at high airspeed to keep straight and considerable elevator deflection to rotate. During these high speed taxis, the aircraft would develop a strong left-yaw tendency; the minimum throttle for rudder effectiveness to counter the left yaw was deemed to be ~20% with ~5kts headwind and the rudder deflection percentage was minimal at this speed.

Despite the poor high AOA performance, the team and I decided to achieve first flight due to many factors such as the freezing of aircraft design, the short time window before competition, and general overconfidence in the airframe and in piloting skill. The procedure for takeoff, therefore, was to be conservative in that throttle was not to be punched to full, but rather "punched" to 20%, the minimum speed at which the aircraft can be kept straight, and then linearly increased from there to achieve lift off. Aircraft attitude was relatively level compared to a normal aircraft takeoff, but was as expected after the observations of the high speed taxi where achieving a positive pitch angle at rotation (which leads to a good pitch attitude for climbing efficiently) without liftoff was considerably difficult (i.e. the Spitzfire took off relatively flat). As seen in the picture above and below, the elevator was near, but not at, max deflection (elevator was not maxed out due to concerns of over-rotating the aircraft).

Shortly after take-off with minimal centerline drift (though still non-zero), and relatively flat liftoff despite elevator deflection

Flight Planning

The procedures, as stated in the test card (Appendix B), outlined the field and intended pattern. The information omitted on the card, however, is the exact pattern dimensions. Since the field, from tree line to tree line, is nearly 1000', it was deemed that turns would initiate ~halfway across the field, coming out to about 250'. No persons were out on the field to denote this distance for the first flight, but was intended for subsequent flights. I was familiar with the field length from previous days and the day of, and could judge relative distance for the first flight as to minimize the risk of people at the far ends of the field. Additionally, the aircraft was to stay well within the open field's boundaries as to not overfly or come close to the trees, which would have likely been a source of severe wind shear. This flight path can be verified by the flight video.

Coordinated Turns in High Winds

This flight involved three turns: the upwind to crosswind turn, which changed the heading by more than 90°, a turn from crosswind to downwind which was much less than 90°, and a 180° turn from downwind to final (passing the base turn, since the aircraft pattern was flown too tight to accommodate a proper base leg of the pattern).

Turn to Crosswind

Preceding this turn was a large balloon in altitude while the aircraft kept a mostly level attitude. This could be a result of a strong momentary gust / wind shear from approaching the trees at the west end of the field. Being more reactive than proactive, unfortunately, I eventually stabilized the altitude and performed a right turn which was largely uneventful until the roll back in, when the airplane again gained a lot of altitude, possible due to the wind, but given the pitch up attitude of the aircraft, it was likely an unintentional yet commanded climb by myself.

Turn to Downwind

At a high altitude, I descended and slightly decreased power. There were slight changes in roll angle during this descent, but not inconsistent with wind shear and over-commanded aileron deflection that is here counted as the "turn to downwind" which is a turn that resulted in a small change in heading (~30°) that was necessary to keep the plane parallel to the runway and no more than halfway across the field.

Turn to Final

Since the aircraft was likely angled towards the runway on downwind, and the aircraft ground speed was much faster coming from the downwind leg, the base leg was skipped over to favor a turn straight into final.

The downwind was when multiple people on the ground noticed the tape of the elevator hinge was flapping in the wind. This led to the decision to land on the first lap, elaborated on later.

The downwind unfortunately saw many pitch oscillations, consistent with the same pitch oscillations at the previous flight test on the 6th of February that was due to an oversized tail and error in the aerodynamic analysis. Before this turn, there was another large increase in altitude, likely due to a combination of wind shear from going above the height of the tree line and exacerbated by the already present pitch oscillations.

The turn was initiated with increasing bank and rudder deflection, and those commanded deflections grew as the turn progressed and the aircraft was not turning tight enough to prevent running over the flight line. However, this large bank angle was certainly a result of poor entry into the turn as the pilot should have stabilized altitude and attitude before initiating the turn. The field size and urgency to land contributed to the pilot's reckless endeavor to tightly and quickly turn. This decision, along with others, is a leading contribution to the spin.

Near the end of the turn, the airplane skids in the air as change in yaw angle dominates the turn.

Post-Turn

The aircraft stalls, recovers with a nose down attitude, continues its descent / approach, seems to drift towards people, the PIC overcorrects, and then the aircraft enters a spin.

Stall Recovery

From the previous flight in February (more information in Appendix A), the aircraft is known to enter deep stall at small angles, and that the singularly-tested stall recovery seems to be a moderate (~30%) increase in power first, followed by a restorative elevator deflection. This procedure was used to avoid stalls in the turn to crosswind, turn to downwind, and after the turn to final.

Near-Stall, recovered with an increase in power restoring elevator authority

Contributing factors to this stall-event: PIC unfamiliarity with airframe and a large commanded elevator deflection that did not result in a gain of altitude until a possible wind shear / gust occurred. The aircraft recovered well.

The Stall, recovered with extra power and an uncommanded and lucky pitch down response from the aircraft

Contributing factors to this stall-event were: possible wind shear and commanded pitch up

The third stall event and recovery

Contributing factors to the third stall-event were: likely wind shear.

The successful lessons learned from the previous flight test's intended stall is the major contributing factor to these stalls being recovered with minimal altitude loss.

Stall Recovery – Aside

Following the flight, there has been discourse regarding a few key topics, which will be listed here:

- Intentional stalls Should not be a part of the first flight
- The correct stall recovery for T-Tail Aircraft

Intentional Stalls

Stalls are dangerous events that can result in the loss of an airframe if not properly recovered from. Stall entry and recovery procedure is mostly standardized by the FAA and practiced by instructors and flight test crews nationwide because the two guaranteed maneuvers for every aircraft flight is a take-off and landing. Stalls are most likely to occur at high angle of attack and low airspeed. These two instances are incredibly common ***at*** takeoff and landing.

Every aircraft responds slightly differently to a stall event. Therefore, it is incredibly important to practice stalls on a first flight, even before the first attempted landing. This is true for flight testing a brand new airplane as well as flying an airplane model with decades of history and PIC familiarity. Indeed, most pilots when stepping into a new airplane, first characterize the slow speed, high AOA regime of their aircraft as doing so gives invaluable information for proper landing technique and response.

T-Tail Stall Recovery

It is highly recommended to read Appendix A at this time. It uncovers the stall procedure used in this flight, which is informed from research, consultation with multiple pilots, and practice.

Additionally, after this flight test, while researching for this report, I uncovered another t-tail stall recovery procedure from NASA that is detailed later in this report.

The Approach

The approach was briefed before the flight, in that the approach was to be practice at least once before an actual landing occurred. However, when the elevator hinge seemed to delaminate, I made the decision to land on the next upwind leg. This decision excludes the chance of a go-around, and that decision is usually not a good one. If a pilot continues with an unstabilized approach while trying to make the runway any way they can, the aircraft can definitely be overcontrolled and crash. Therefore, the decision to exclude a go-around must be met with a relaxation of the landing constraints.

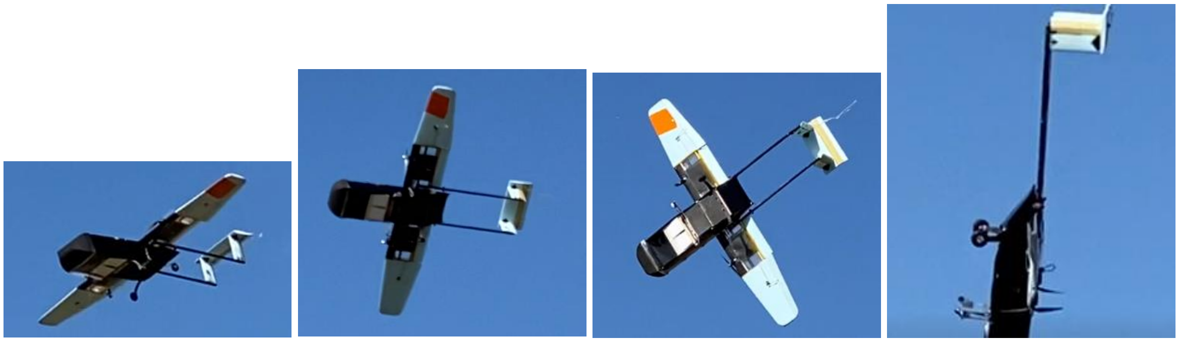
I was familiar with the field and knew that overrunning the runway, which was actually done earlier in the day with the high speed taxi, does not result in much damage to the aircraft other than the gear shearing off from the nylon bolts. Therefore, the priority was to get the airplane down during this upwind leg (due to high likelihood of losing the elevator with continued flight) and do not overfly the no-fly zones. These were the only two landing constraints and could have been easily met.

What actually happened was the aircraft, following the turn to final, was quite high and had just recovered from the third stall-event. Still, the aircraft had enough space before the West tree line of the field to land. After the third stall-event, the aircraft started to descend but also approached the flight line due to wind drift and inadequate wind rejection by myself. I over-corrected and put the aircraft into a spin.

Post-Crash, after disarming the aircraft and disconnecting the battery

Spin Recovery

With the over-correction from the wind pushing the airplane and not wanting to overfly the people on the field, the aircraft spun very low to the ground and crashed nose-first, destroying the fuselage.



The spin that followed from the div: note the rudder initiating the spin in photo 2 and subsequent attempt to correct in photo 3

I followed spin recovery procedure, known as PARE (power idle, ailerons neutral, rudder opposite of spin, elevator to recover from stall). However, there has been discourse over the effectiveness of PARE as a spin recovery procedure. Post-crash, it has been recommended by the team that the procedure could have been increasing throttle, even using some differential thrust, keeping the aileron neutral, or even in the direction of the spin, for the rudder to fully deflect opposite of the spin, and then to use stall recovery.

This procedure is confusing. PARE has been built on the backs of decades of crash investigation, wind tunnel tests, flight dynamics research, aerobatic competitions, and general flight training. This procedure, of course, aims to recover the aircraft and minimize altitude loss. This is because a spin can only follow a stall, and we established that stalls are most likely to occur on landing or takeoff, or when trying to climb to avoid an obstacle. In all cases: spin recovery should minimize altitude loss. The FAA and DOD flight manuals of similar twin counter-rotating engines follow PARE spin recovery. These aircraft are:

- P-38
- DA42-L360
- OV-10
- Duchess 76
- PA-34

There is a question of scale as well. These manuals, clearly, for are full-scaled aircraft. However, in the POH of the heavy Fighter/Bomber 17,500lb P-38 and in the POH of the 17x lighter Quicksilver Ultralight both recommend the PARE recovery for spins. Surely, the consistency of this recovery procedure can be for much larger and much smaller aircraft. Increasing throttle, or even worse, using differential throttle, would certainly flatten out the spin and worsen it.

I mention PARE in this section and defend my use of it because I believe the heavily suggested alternative: to bank into the spin and increase throttle, or even use differential thrust, would worsen any future spin of this aircraft and I want to substantiate what I believe to be the proper procedure.

Final Thoughts on the Flight

The aircraft was handled well despite the wind, sudden changes in orientation, and the pitch instability. Multiple times, stall recovery technique learned from the previous flight (outlined in Appendix A) prevented any major stall events except for the last stall to spin. Overall, the aircraft handled quite poorly in February, and both on the ground and in the air for this flight test. What strikes me is that the handling of the Spitzfire is in contrast to what I warmed up to earlier in the day. I flew a front-loaded light 1800mm Husky, then flew my friend's plane, a different Husky with 50% more weight and a tail-heavy CG, and then I flew a mostly neutral ~600mm Cub, all in preparation for the windy first flight of the Spitzfire. None of these airplanes, and from previous experience, no airplane I have ever flown on a windy day, was representative of the instability I saw of the Spitzfire. This concludes, therefore, that the wind and pilot unfamiliarity with the airplane were contributing factors to the crash, but come alongside general low-speed instability of the Spitzfire.

This low speed instability is derived mostly from the location and configuration of the tail. The Spitzfire will be shown, in the rest of this report, to have subpar low speed and high AOA stability by virtue of its T-Tail design and its specific geometry. The flight mission for this airplane is short take off and landing (STOL). And therefore, the Spitzfire will be compared to STOL airplanes, T-Tail airplanes, and then STOL T-Tail airplanes.

Legacy Design

In the beginning of the year, with the release of the rules, it was clear that a traditional STOL aircraft would perform very well in a competition where short take-off, landing, and ground handling was the priority. Initial analysis should have taken into account what historically STOL aircraft design has been.

Much of aerospace is drawing knowledge from previous engineers, otherwise known as "legacy knowledge." Let's look at a few.

A Collage of STOL aircraft. Shown are, left to right, top to bottom: Draco, Knapp Cub, Twin Otter, C-130, PC-6, and IAI Avara

A Collage of T-Tails. Shown are, left to right, top to bottom: King Air, LS4 Glider, Citation 525, DHC-5, PC-12, A400M

Clearly, the shown STOL aircraft, whose primary mission is short take-off from austere environments, have conventional tails. The Draco and Knapp Cub are competition STOL airplanes, the Twin Otter was designed to take off anywhere, and is a popular skydiving aircraft due to its short runway length; the C-130 and PC-6 are military-designated aircraft whose purpose, as well, are short take off from austere environments, and the IAI Avara is the same and even sports dual rudders. There exist only a few aircraft capable of STOL that have T-Tails, two of which are pictured in the second collage.

The T-Tail aircraft shown all come from very different requirements, and some are indeed STOL. The King Air, PC-12, the LS4 glider, and Citation 525, with the last being a stand-in for the thousands of business jet T-Tails that exist, are T-Tail aircraft whose POHs prohibit stalls, even for training. Therefore, their STOL capability is somewhat nonexistent. Aerobatics, similarly, are explicitly prohibited.

Aerobatic flight, defined by the FAA, 14 CFR 91.303 is a flight with “maneuver[s] involving an abrupt change in an aircraft's attitude.” This is, however, the FAA guidelines for manned aircraft. The DBF competition is for drones. Obviously, manned aircraft can handle landing, taking off, wind correction, stalls, etc. without being deemed aerobatic, but now we get to the nature of subscale flight: small aircraft are more sensitive to pilot input, wind, and changes in stability than their full-scale counterparts. Meaning, with a small airplane, in a small space, such as an R/C field, scale aircraft will maneuver in a way that includes many abrupt changes in its attitude, especially in high winds. Stall training in manned aircraft is incredibly controlled, with many early warning systems, the requirement of an instructor, and with many instruments to ensure minimal orientation loss and maximize the available information to the pilot. Subscale aircraft do not enjoy such information, and their handling absolutely involves sudden changes in attitude. Therefore, T-Tail aircraft may not be suitable for high wind STOL activities.

And specifically regarding stalls: from the FAA's official Pilot's Handbook of Aeronautical Knowledge (PHAK), the textbook culmination of decades of flight research, accident investigation, and training materials, we can read:

> "In comparison with conventional-tail aircraft, the elevator on a T-tail aircraft must be moved a greater distance to raise the nose a given amount when traveling at slow speeds." (6-6)
>
> "the pilot must be aware that the required control forces [and deflections] are greater at slow speeds during takeoffs, landings, or stalls than for similar size aircraft equipped with conventional tails." (6-6)
>
> "Deep stalls can occur on any aircraft but are more likely to occur on aircraft with 'T' tails as a high AOA may be more likely to place the wings separated airflow into the path of the horizontal surface of the tail. Additionally, the distance between the wings and the tail […] may increase the susceptibility of deep stall events." (6-6)

Before the flight, when the high-speed taxis were performed, it was noted that quite a large deflection of elevator was needed to rotate the aircraft. Additionally, the aircraft seemed to stall quite early and often in high winds and sudden orientation changes, all of which are consistent with the PHAK's findings and the nature of subscale flight.

Research from NASA Langley in the "Analysis of Deep-Stall Characteristics of T-Tailed Aircraft Configurations and Some Recovery Procedures" by R. C. Montgomery and M. T. Moul shows that the stall recovery procedure for a T-Tailed aircraft is actually a **dynamic** one, where the pilot needs to rapidly cycle the elevator to induce airflow and correct the trajectory; this stall recovery procedure is counter to what is tested of airmen by the FAA in the PPL knowledge test. Sample systems of recovery procedure in T-Tail aircraft are shown below:

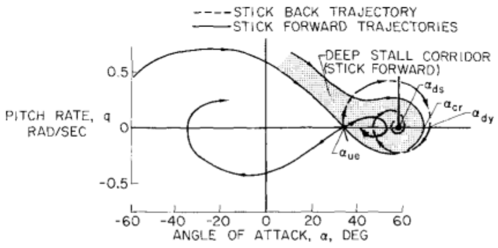


Fig. 4 Phase plane trajectories for both stick-forward and stick-back elevator deflections.

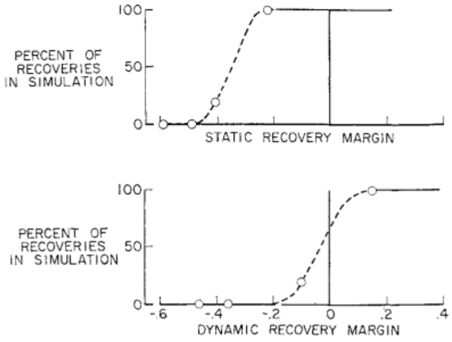


Fig. 8 Comparison of recovery results of simulator and analytical studies.

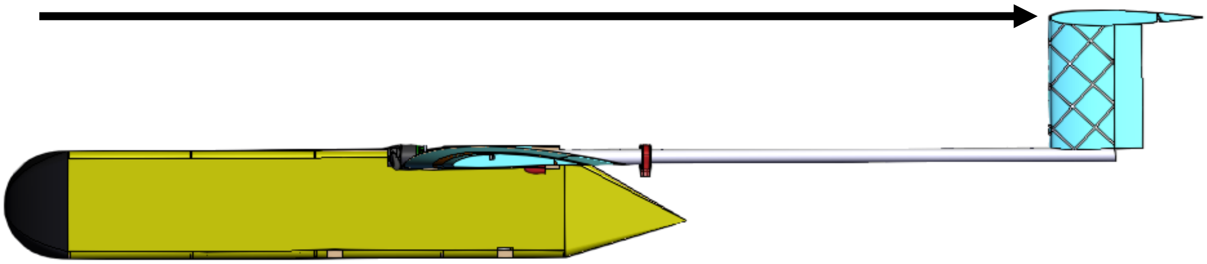
This analysis shows that stalls are incredibly unpredictable in t-tail aircraft. While recoverable, it is indeed the use of non-standard and dynamic control procedures that have a *chance* to recover a t-tail aircraft from a stall, which is further explored in Appendix A.

T-Tail aircraft, however, can operate successfully in STOL applications, such as the DHC-5, A400M, C-5, and C-17 (though the latter two are not primarily built for STOL applications). We will focus on the first two, the DHC-5 and A400M, to compare to the Spitzfire.

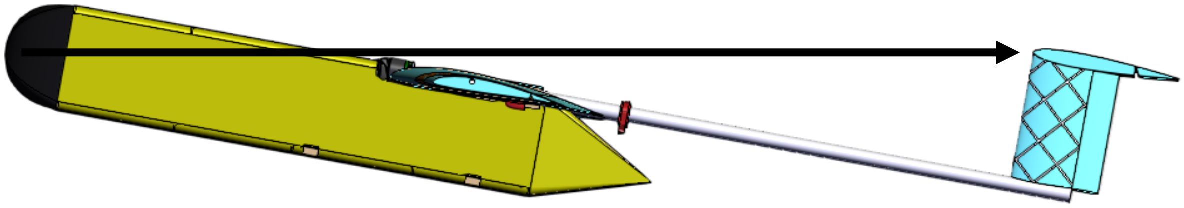
Geometric Considerations in the Spitzfire

Looking at legacy design and research is, in some sense, conjecture. The spirit of DBF is to push the envelope in aircraft design, so let’s look at its design and the aircraft configuration at high AOA and low speed.

The Spitzfire wing is an SD7032 with 0° of incidence. This wing stalls at about 10°. The aircraft position at neutral and stall is shown with a straight arrow depicting airflow pointing to the LE of the tail.



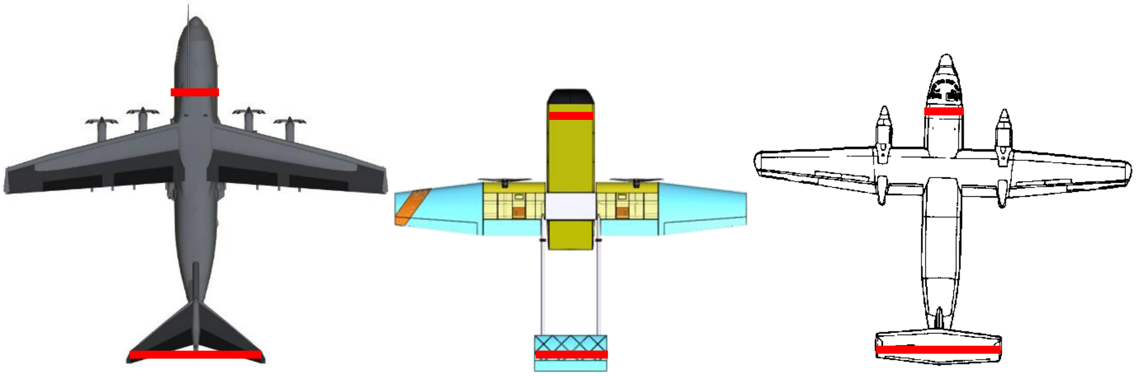
Spitzfire SolidWorks Model, 0° AOA



Spitzfire SolidWorks Model, ~10° AOA

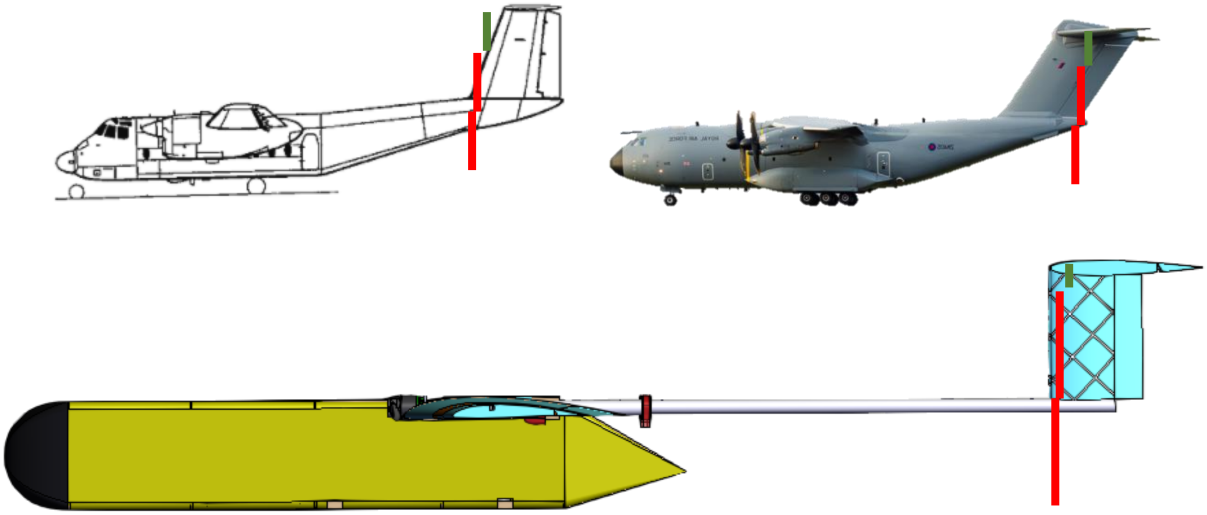
At about 10° AOA, the wing will stall, and the elevator should provide the restoring force to push the nose back down (though to clarify, the elevator needs only to be neutral to push the nose down in a normal stall maneuver, as the high AOA of the elevator is usually enough to generate lift to correct the nose down). At this angle, the long fuselage clearly blocks airflow to the tail, meaning the tail has very little authority to recover from severe pitch upsets caused by stalls and sudden changes in wind or direction.

The fuselage, also, is wide relative to the horizontal tail. Shown below are the two T-Tail STOL aircraft mentioned before, the A400M and DHC-5:



Top Views of STOL T-Tail Aircraft (Left to Right: A400M, Spitzfire, DHC-5)

The horizontal stabilizers of the A400M and DHC-5 are at least a three times the width of the fuselage, whereas the Spitzfire is nearly half that size. These ratios are, left to right: .36, .61, .32. Meaning, for each aircraft, the percent of horizontal stabilizer covered by the fuselage at high AOA is 36%, 61%, and 32%.



Side Views of STOL T-Tail Aircraft (Left to Right: DHC-5, A400M; Bottom: Spitzfire)

These side-views also show that the horizontal stabilizers of these aircraft at least seem to be proportionally higher than that of the Spitzfire, which would affect the stall angle effectiveness of the horizontal tail. All tails are at least one fuselage-height (FH) above (the red lines), but the last parts are slightly different (the green lines) with the DHC-5's tail being 1.645 FH high, the A400M's tail being 1.601 FH high, and the Spitzfire being a much smaller 1.214 FH high.

The DHC-5 and A400M have incidence angles of their main wing and the A400M, famously, has a negative incidence angle of its horizontal tail as well. The side view also shows just how far forward the Spitzfire fuselage is from the main wing, more so than the DHC-5 and A400M, meaning that small angles move the fuselage more, thus hiding the tail more often from clean air. The fuselage of the Spitzfire clearly blankets almost the entire tail at stall angle.

For the Spitzfire, even if airflow is undisturbed at high AOA to the elevator, we get to the second problem with this aircraft: the NACA0010 tail **also** stalls at 10°. The elevator in this stalling configuration is unable to recover the aircraft until the aircraft happens to fall nose down **if** the aircraft's cg is sufficiently front-loaded. And in high winds, whether the aircraft breaks the stall by nosing forward or nosing back, by rolling left or right, is up to a chaotic system, or in other words, by chance.

Spitzfire Wind-Rejection

The thrust to weight ratio and the wing-loading of an aircraft are important numerical values that can compare different aircraft's wind-rejection capability and high AOA performance. In general, aircraft with lower wing-loading can approach stall speeds more safely as the loss-of-lift associated with a slower speed is less pronounced in its possible descent. Therefore, take-off and landing speeds can be slower, leading to better performance and overall better handling at climb and approach speeds, since the speed envelope is larger. (Aircraft Performance and Design, by J.D. Anderson, page 200-36).

Lighter wing-loading and lower T/W, however, decreases an aircraft's wind rejection capability. That is, the wind will push the aircraft around more, and may be harder to control.

For reference, on the same day, I flew an 1800mm wingspan Arrows Husky model plane, with about .91 lb/ft^2 wing loading and a <.5 thrust-to-weight ratio. It was pushed around by the wind quite a bit, but was still controllable. With a higher wing loading of 1.264 lb/ft^2 and higher thrust-to-weight ratio of .622, The Spitzfire should have had greater wind-rejection capability, if thrust was kept relatively high, which it was for most of the flight. This however, was not true based on the handling of the aircraft and subsequent crash, likely due to in part to the low speed and high AOA instability inherent to the Spitzfire's geometry.

Recommendations

The key shortcomings of the flight planning and execution were:

- A lack of proper briefing of likely wind shear above the height of the trees, even if staying within the field boundaries
- A lack of familiarity with twin-engine stalls and with the Spitzfire handling characteristics
- A too tight pattern that allowed the aircraft to come close to the flight line on approach

The key shortcomings of the Spitzfire design are:

- The lack of incidence on the main wing and tail that result in both stalling at the same aircraft angle relative to the wind
- The small sizing of the tail relative to the width and length of the fuselage, causing the fuselage to blanket the tail at high angles
- The vertical location of the horizontal tail that is neither low enough nor high enough to be in free air at high angles

From these shortcomings, we can set a series of recommendations:

- Set a positive angle of incidence of the main wing
- Set a negative angle of incidence of the horizontal stabilizer
- Substantially lower or slightly raise the z position of the horizontal stabilizer, enough to have the tail in free air at high angles
- Make a physical scaled down model to fly in the wind tunnel to characterize high AOA airflow
- Move the fuselage farther back such that at high angles it does not interfere with the tail
- VGs or trips strips on the main wing to improve airflow over the wing at high AOA

- Set a farther forward CG of the aircraft relative to its current position on the wing
- Enlarge the vertical stabilizers and/or rudder surface area
- The pilot should accommodate for error in flight path that could result in over-stepping the no-fly zones, and should better brief possible meteorological events
- The pilot can try a dynamic stall recovery procedure where the elevator is "flapped" to induce an oscillation and increase of airspeed enough to regain elevator authority and pull through a stall.

It is up to the discretion of the team which recommendation or recommendations are followed to better the low speed and high AOA handling characteristics of the Spitzfire that does not substantially conflict with the design document submitted to the AIAA. Additional, miscellaneous, recommendations of the aircraft following the flight test are:

- Make multiple arming plugs so that a loss of one does not ground the aircraft
- A characterization of brake tension and position, since that has not yet been explored despite being incredibly important to competition
- Do not use tape as a hinge on the control surfaces: as suggested earlier in the year, multiple hobby-grade nylon hinges work well, or better layup technique for live hinges
- If using composite/Kevlar hinges, do not layer additional plies of Kevlar or other fabrics/tapes on top, as that will hinder the flexibility of the hinge and/or will result in cracking or delamination
- Build all control linkages to have nearly no "slop" in them, so that there is minimal fluttering of surfaces in flight
- Additionally, control linkages should either be completely straight relative to the control horn and servo arm, or, if angled, should use an angle-tolerant connection, like a ball-link or angled z-bend
- The landing gear should be attached with rigid bolts and washers, such that the load of the gear is uniformly distributed and does not result in the gear shearing off, as has happened in every flight

Conclusion

In terms of flying, future pilots should definitely prioritize airspeed in nearly every maneuver and regime, more so than in other configurations of aircraft, and be wary of high AOA and low airspeed handling.

In terms of design, there was extensive advice to the team given by myself against using a T-Tail for a STOL aircraft, and if so, to use great caution to characterize its high AOA airflow and stability. The T-Tail was seemingly chosen due only to a reduction in drag and increase in elevator authority in level cruise flight. This one aspect: free air at zero AOA, drove the T-Tail design to where it is, but we should make it clear: **there is never one reason to use a configuration: aircraft design is the consideration of every factor of the aircraft both on the ground and in different regimes of flight.**

And in terms of build quality, the aircraft should have solid hinges and control linkages, as this was not emphasized in the report, but the control linkages had significant "play" in them before flight, and multiple hinge materials were layered with some of the Kevlar having been cracked beforehand.

The design can change in subtle but powerful ways, the build quality can improve, and all pilots involved with the team can serve to have better discourse and more practice. I hope these recommendations are followed and report studied so that the Spitzfire can continue the long tradition of MIT DBF aircraft placing well at competition.

APPENDIX A: February and Deep Stalling Practice

Why did the Spitzfire crash on 4/2 and not the previous flight test, 2/6? Wind was definitely a contributing factor as the winds during the previous flight test were roughly half that on 4/2, and thus the aircraft was pushed to the limit in its recoverability and stability. The winds, while rough, only sought to illuminate the characteristics that can be hidden from an observer on a calm day.

In February, the aircraft was still unstable at slow speeds and high angles of attack. Throughout the flight, I was fighting with the elevator to keep the plane straight, which resulted in noticeable pitch oscillations throughout the flight. And, as I had briefed for the first flight, I demonstrated a stall at high altitude to better understand the low speed / high AOA handling of the plane. Before I even got to the field, however, I sought to research deep stalls.

The flat stall recovery from the flight test on 2/6, where there was no elevator authority on the way down.

In preparing for the February flight, I consulted the internet for how to recover a from a deep stall, as that was likely to happen in the Spitzfire. As normal T-Tail airplanes prohibit intentional stalls, and are usually business jets that fly a particular AOA on landing with multiple sophisticated warning and autopilot systems that prevent a stall from forming, there was not much literature available.

Eventually, I encountered a recount of the Boeing 727 flight test program, where the T-Tailed airliner developed into a deep stall (https://www.rbogash.com/Safety/deep_stall.html). This story suggests that rocking the wings can induce a bank that can, alongside some rudder input, can help recover from the deep stall by pushing airflow over the tail.

I also spoke with a friend who is a commercial pilot, and a UPRT (upset prevention recovery training) instructor, and both of them suggested, without any prompt or knowledge of the 727 story, that rocking the wings could change the aircraft orientation and aid in a deep stall recovery.

On the flight test on the 6th of February, when I entered the flaps-up power-off stall at a high altitude, my priorities were to employ general stall recovery procedure as outlined in the FAA flying handbook FAA-H-8083-3C (5-15), which is to push the nose over and increase throttle. The aircraft, however, did not respond to a commanded elevator deflection. In fact, the plane fell vertically without much change in attitude. When that didn't work, I tried to rock the wings like from the 727 story. Likely because forward airspeed was so diminished, this also did not result in a change in pitch or attitude.

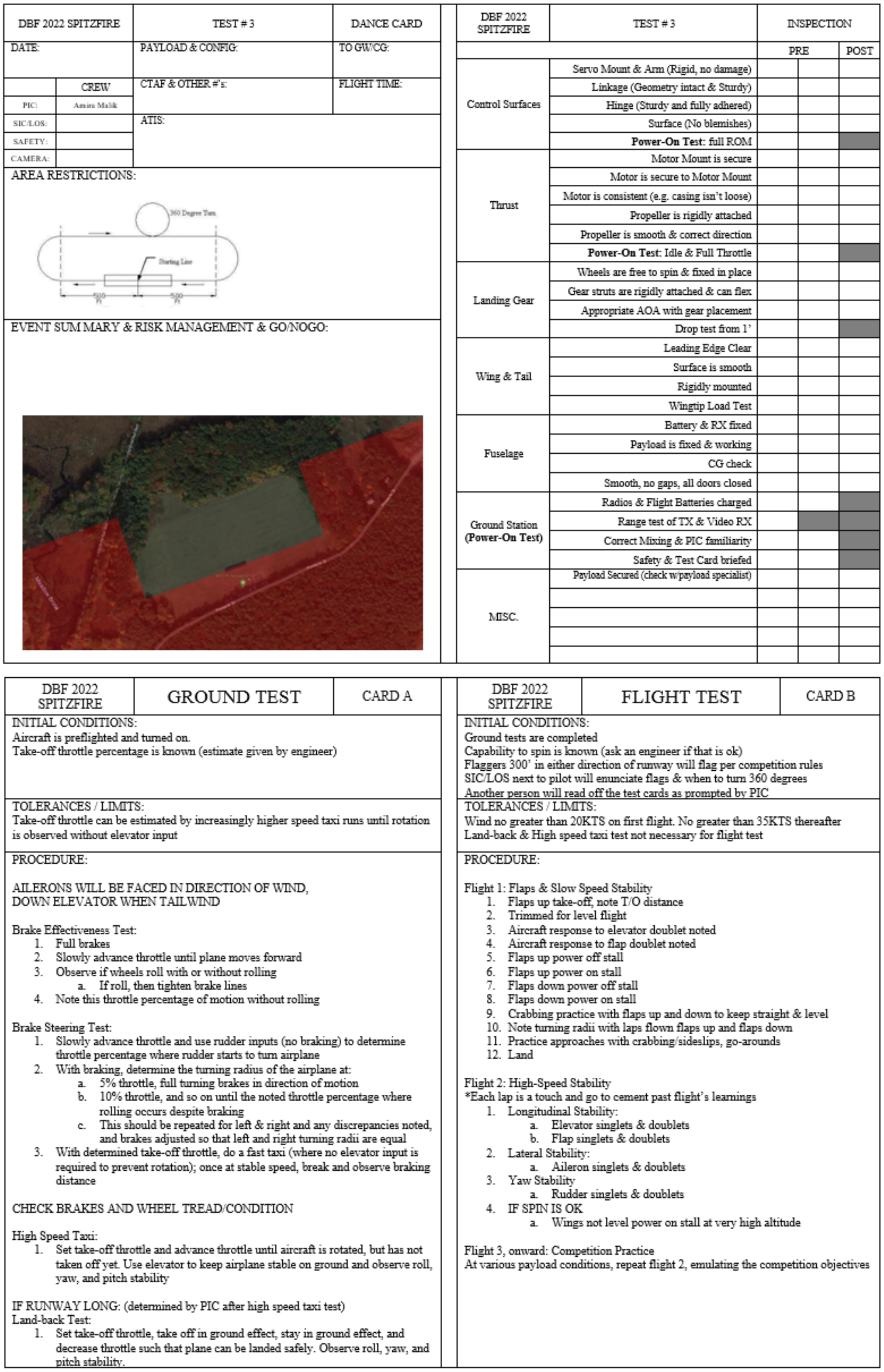
Why did I do a power-off flaps up stall as my first stall practice? This stall practice was to emulate a stall on landing, which was the next required maneuver for this aircraft, so I preferred to practice the power-off stall first. As to not using flaps, I had not yet characterized the flaps deployed handling of the aircraft. Even with the R/C models I fly, there is a considerable increase in pilot workload when deploying flaps on a large, slow airplane. Additionally, given the T-Tail, using flaps to allow a higher AOA may not have been wise due to a deep stall developing even without the higher-allowable AOA of deployed flaps.

Why didn’t I immediately throttle up? Well, in FAA-H-8083-3C, restoring the angle of the main wing takes priority over the increase in throttle, or else the stall could worsen. However, the aircraft was coming close to the trees and I was running out of options, so I slowly increased the throttle, and after a few more moments of falling, the aircraft started to respond to elevator deflection, and the aircraft recovered from the deep stall.

At the end, the aircraft had lost more than half of its altitude, but it is this preparation and experience that has been incredibly valuable and shows just how important researching, practicing, and briefing is in the flight test environment, and that intentional stalls do indeed serve a purpose.

After this test, the team consulted their aerodynamic models and realized that the tail was severely over-sized, which explains the noticeable pitch oscillations.

APPENDIX B: 4/2 Test Card (no notes)



DBF 2022 SPITZFIRE	TEST # 3	DANCE CARD
DATE:	PAYLOAD & CONFIG:	TO GW/CG:
	CTAF & OTHER #'s:	FLIGHT TIME:
	ATIS:	

	CREW
PIC:	Amira Malik
SIC/LOS:	
SAFETY:	
CAMERA:	

AREA RESTRICTIONS:

EVENT SUM MARY & RISK MANAGEMENT & GO/NOGO:

DBF 2022 SPITZFIRE	TEST # 3	INSPECTION		
		PRE		POST
Control Surfaces	Servo Mount & Arm (Rigid, no damage)			
	Linkage (Geometry intact & Sturdy)			
	Hinge (Sturdy and fully adhered)			
	Surface (No blemishes)			
	Power-On Test: full ROM			▨
Thrust	Motor Mount is secure			
	Motor is secure to Motor Mount			
	Motor is consistent (e.g. casing isn't loose)			
	Propeller is rigidly attached			
	Propeller is smooth & correct direction			
	Power-On Test: Idle & Full Throttle			▨
Landing Gear	Wheels are free to spin & fixed in place			
	Gear struts are rigidly attached & can flex			
	Appropriate AOA with gear placement			
	Drop test from 1'			▨
Wing & Tail	Leading Edge Clear			
	Surface is smooth			
	Rigidly mounted			
	Wingtip Load Test			
Fuselage	Battery & RX fixed			
	Payload is fixed & working			
	CG check			
	Smooth, no gaps, all doors closed			
Ground Station **(Power-On Test)**	Radios & Flight Batteries charged			▨
	Range test of TX & Video RX		▨	▨
	Correct Mixing & PIC familiarity			▨
	Safety & Test Card briefed			▨
MISC.	Payload Secured (check w/payload specialist)			

DBF 2022 SPITZFIRE	GROUND TEST	CARD A

INITIAL CONDITIONS:
Aircraft is preflighted and turned on.
Take-off throttle percentage is known (estimate given by engineer)

TOLERANCES / LIMITS:
Take-off throttle can be estimated by increasingly higher speed taxi runs until rotation is observed without elevator input

PROCEDURE:

AILERONS WILL BE FACED IN DIRECTION OF WIND,
DOWN ELEVATOR WHEN TAILWIND

Brake Effectiveness Test:
1. Full brakes
2. Slowly advance throttle until plane moves forward
3. Observe if wheels roll with or without rolling
    a. If roll, then tighten brake lines
4. Note this throttle percentage of motion without rolling

Brake Steering Test:
1. Slowly advance throttle and use rudder inputs (no braking) to determine throttle percentage where rudder starts to turn airplane
2. With braking, determine the turning radius of the airplane at:
    a. 5% throttle, full turning brakes in direction of motion
    b. 10% throttle, and so on until the noted throttle percentage where rolling occurs despite braking
    c. This should be repeated for left & right and any discrepancies noted, and brakes adjusted so that left and right turning radii are equal
3. With determined take-off throttle, do a fast taxi (where no elevator input is required to prevent rotation); once at stable speed, break and observe braking distance

CHECK BRAKES AND WHEEL TREAD/CONDITION

High Speed Taxi:
1. Set take-off throttle and advance throttle until aircraft is rotated, but has not taken off yet. Use elevator to keep airplane stable on ground and observe roll, yaw, and pitch stability

IF RUNWAY LONG: (determined by PIC after high speed taxi test)
Land-back Test:
1. Set take-off throttle, take off in ground effect, stay in ground effect, and decrease throttle such that plane can be landed safely. Observe roll, yaw, and pitch stability.

DBF 2022 SPITZFIRE	FLIGHT TEST	CARD B

INITIAL CONDITIONS:
Ground tests are completed
Capability to spin is known (ask an engineer if that is ok)
Flaggers 300' in either direction of runway will flag per competition rules
SIC/LOS next to pilot will enunciate flags & when to turn 360 degrees
Another person will read off the test cards as prompted by PIC

TOLERANCES / LIMITS:
Wind no greater than 20KTS on first flight. No greater than 35KTS thereafter
Land-back & High speed taxi test not necessary for flight test

PROCEDURE:

Flight 1: Flaps & Slow Speed Stability
1. Flaps up take-off, note T/O distance
2. Trimmed for level flight
3. Aircraft response to elevator doublet noted
4. Aircraft response to flap doublet noted
5. Flaps up power off stall
6. Flaps up power on stall
7. Flaps down power off stall
8. Flaps down power on stall
9. Crabbing practice with flaps up and down to keep straight & level
10. Note turning radii with laps flown flaps up and flaps down
11. Practice approaches with crabbing/sideslips, go-arounds
12. Land

Flight 2: High-Speed Stability
*Each lap is a touch and go to cement past flight's learnings
1. Longitudinal Stability:
    a. Elevator singlets & doublets
    b. Flap singlets & doublets
2. Lateral Stability:
    a. Aileron singlets & doublets
3. Yaw Stability
    a. Rudder singlets & doublets
4. IF SPIN IS OK
    a. Wings not level power on stall at very high altitude

Flight 3, onward: Competition Practice
At various payload conditions, repeat flight 2, emulating the competition objectives