Tamarack Aerospace Group Submission to the National Transportation Safety Board

Regarding

Supplemental Data in NTSB Investigation CEN19FA036

Accident Number:

CEN19FA036

Accident Date:

November 30, 2018

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TABLE OF CONTENTS

Contents

REFERENCES

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[2] H. Gates, *Tamarack Aerospace Group Submission to the National Transportation Safety Board,* Tamarack Aerospace Group, 2021.

[3] C. Cates, *Errata 1 to Group Chairman's Factual Report of Investigation [CVR Transcript],* National Transportation Safety Board, 2021.

[4] M. Moler, *Errata to Performance Study,* National Transportation Safety Board, 2021.

[5] National Transportation Safety Board, *National Transportation Safety Board Aviation Accident Factual Report [CEN19FA036],* NTSB, 2021.

[6] National Transportation Safety Board, *Collins Pro Line 21 Information.*

[7] FAA Flight Standards Service, *FAA-H-8083-3B, Airplane Flying Handbook,* Federal Aviation Administration, 2016.

GLOSSARY

Terms and abbreviations used throughout this submission are presented below, for clarification. Note that references to regulations are made to the amendment level relevant to the certification basis of the 525A, as noted in Type Certificate Data Sheet A1WI [1].

ACU	ATLAS Control Unit, the component in which the load alleviation logic and primary monitoring functions are implemented
AHRS	Attitude and Heading Reference System
AND	Airplane nose-down, specifically a pitch attitude in which the nose of the airplane is pointed below the horizon
ANU	Airplane nose-up, specifically a pitch attitude in which the nose of the airplane is pointed above the horizon
AReS	Aircraft Recording System, a non-required system designed by Textron to record a variety of aircraft parameters and store the data for later review
ATC	Air Traffic Control
ATLAS	Active Technology Load Alleviation System, a Tamarack-patented system designed to alleviate aerodynamic loads on a wing
CAM	Cockpit Area Microphone, which monitors sounds within the cockpit independently of the intercom and radio
CVR	Cockpit Voice Recorder
IMC	Instrument Meteorological Conditions, flight conditions in which it is not possible to fly by external visual references
INOP	Inoperative
KIAS	Knots Indicated Airspeed, the airspeed presented to the pilot
LH	Left hand
LRU	Line Replaceable Unit, a modular unit installed on an airplane
MSL	Mean Sea Level, referring to aircraft altitude
NAV	Navigation, in the context of autopilot modes meaning that the autopilot is configured to control heading to fly a specific course based on GPS or radio navigation aids
PFD	Primary Flight Display, a cockpit screen displaying primary flight data such as heading, airspeed, altitude, and aircraft attitude
PIC	Pilot In Command, in the context of multiple AHRS meaning the unit installed for the left seat in the cockpit
RH	Right hand
RPM	Revolutions Per Minute

TACS	Tamarack Active Camber Surface, aerodynamic surfaces which deploy to alleviate aerodynamic loads on the wing
TCU	TACS Control Unit, an integrated actuator and control board unit designed to convert ACU commands into TACS actuations
TED	Trailing edge down, specifically referring to the orientation of the TACS during deployments
TEU	Trailing edge up, specifically referring to the orientation of the TACS during deployments
UTC	Universal Coordinated Time, also known as "Zulu"
VMO	Maximum operating airspeed, 275 knots calibrated for a CJ2+ below 8000 feet MSL

1 INTRODUCTION

1.1 Submission Abstract

This submission explores a system anomaly or failure of the AHRS as the most likely cause for the uncommanded roll event, autopilot disconnection, and the resulting inflight upset. It is a continuation of the original Tamarack Party Submission [2] based on questions and further analysis of the factual data after errors in the timing of key events were noted and corrected in the factual record.

- This submission stems from the errata correction of the CVR Transcript Report [3] and Performance Study [4] for the accident, which revealed that the autopilot disconnected during the roll event at a bank angle different from what had been initially assumed.
- There is a difference in bank angle between the calculated bank angle at which the autopilot disconnected and the autopilot bank limit. The bank angle at which the autopilot disconnected indicates autopilot disconnect likely occurred as a result of a system anomaly or failure and not due to bank angle or rate of roll exceedances.
- The difference between the actual bank angle at which the autopilot disconnected and the excessive bank angle disconnection threshold does not support an external aerodynamic surface failure as the cause for the initial roll event but suggests an internal system failure first causing the roll and then causing the autopilot to disconnect.
- Factual data and reports made available prior to the release of the NTSB final analysis report have been considered to develop a possible explanation for the onset of the initial roll event and subsequent escalation of the state of the airplane to the high speed spiral dive in which it impacted terrain.
- As of the date of this submission, there are still portions of the factual report which are not developed to the level of detail required to fully support a conclusive finding of the probable cause of the accident.

1.2 Underdeveloped Factual Data Referenced in this Submission

Several key facts in the investigation Factual Report [5] were either not developed or were not fully developed to the level of detail required to prove or disprove their relevance as a cause or contributing factor in this accident. These key facts are critical to fully understanding the context of the accident sequence, and are critical to accurately determining the probable cause and contributing factors of this accident:

1. A thorough discussion of the AHRS system and its relationship to autopilot operation and the pilot's Primary Flight Display (PFD) is critical to understanding the uncommanded roll event and the pilot's delayed or inadequate response to the event after the autopilot disconnected in IMC. Further, it is also important to explore the miscompare or failure of the AHRS as the primary initiating trigger for the roll and autopilot disconnect. There should be discussion of the mismatch between the AHRS 1 and AHRS 2 data that is required to disconnect the autopilot, and the amount of time required for the mismatch to exist before disconnecting. A full understanding of how the autopilot can disconnect is critical to determining what caused the autopilot to disconnect in this case.
2. The pilot's recent experience, specifically in N525EG was not fully examined and is easily determined by comparing the total aircraft flight time during the period from when the accident pilot received his type rating and the accident and subtracting the accumulated flight time of the other pilots who flew the airplane during the same time. This is critical to establish his proficiency in the airplane, but more importantly to determine whether he was properly prepared to handle an inflight upset. In addition, such an evaluation may also support a Safety Recommendation that the company and/or the insurance company should have required the accident pilot to fly with a mentor pilot until the accident pilot's proficiency met a specific standard.
3. Additionally, the factual record is incomplete regarding specific training information because there are no statements available from instructors who provided ground and simulator training to the accident pilot. The factual report also does not expand on the subject of why there were four separate applications by the pilot that all report a total flight time of 3291 hours, despite covering more than two years of calendar time. A more complete understanding of the pilot's actual experience is critical to understanding his preparedness to respond to an unexpected, uncommanded roll event. Also, it is imperative that information from training instructors who worked with the accident pilot be explored, with particular emphasis of his fitness and ability to identify and implement necessary and appropriate corrective actions in an abnormal or emergency situation. Again, this is critical context for evaluating his responses to the unexpected uncommanded roll event.

1.3 Investigation Background

On November 30, 2018 at approximately 1628 UTC, a Cessna 525A airplane was involved in an accident near Memphis, Indiana. The airplane, N525EG, was destroyed and the three occupants were fatally injured. The flight was being operated on an instrument flight rules flight plan as a business flight under provisions of 14 CFR 91. Following the accident, Tamarack Aerospace Group (Tamarack) was invited to be party to investigation CEN19FA036, because the airplane had a Tamarack-designed modification installed at the time of the accident.

1.4 Tamarack Party Submission Summary

The Tamarack Party Submission [2] presents an analysis that concludes that the ATLAS was functioning normally during the event. Post-accident examination of witness marks that were found within the linear electric actuators which drive the TACS were observed on internal surfaces. Because of the design and normal operating parameters, the ball nut cannot contact the upper and lower surfaces of the interior of the linear electric actuator in normal operation, thus suggesting a massive off-axis distorting load factor consistent with a high energy ground impact. In addition, the position of the witness marks within the actuators is consistent with an intermediate deployment, corresponding to a 2g load factor. This aligns with the calculated peak load factor presented in the NTSB Performance Study [4] which indicated the airplane was experiencing a load factor of approximately 2g before the datastream was lost. Further, based on physical evidence, the Tamarack analysis supports the conclusion that at the time of impact, ATLAS was operating as designed and was responding appropriately (as anticipated) to a 2g load factor on the airplane, likely induced during the pilot's attempted recovery. The Tamarack analysis also supports a conclusion that the high energy impact resulted in a force capable of distortion that caused the ball screw to deflect enough to allow the ball nut to contact the inner surfaces of the actuator while the system was still commanding that deployment.

2 AIRCRAFT FLIGHT STATE

As determined by the Safety Board's Performance Study [4], the airplane was at a bank angle of 30° when the autopilot disconnected, which is well within the bank angle limitation noted in the supplemental information presented by Textron to the NTSB [6] for the autopilot disconnection. The Performance Study [4] indicates the airplane was not in either an airplane nose-high (ANU) or airplane nose-down (AND) attitude that would have met the pitch attitude threshold to trigger the autopilot disconnection. This is supported by the fact that the airspeed prior to the onset of the roll event is within a reasonable range for cruise climb and appears to be relatively stable up to the point of autopilot disconnection.

In addition, as stated in the Performance Study [4], the calculated roll rate of the airplane averaged approximately 5-6 degrees per second during the roll event which is also below the autopilot disconnection threshold of 10 degrees per second. The Performance Study [4] presents a peak roll rate of approximately 7 degrees per second, which occurs slightly after the disconnection of the autopilot, and is momentary.

3 DESCRIPTION OF EVENT TIMELINE

Consider the following timeline, extracted from Figure 2 and Figure 3 of the Performance Report [4] and checked against the CVR Transcript Report [3]:

	Event	Time	Altitude	Bank Angle
1	The pilot vocalizes engaging the autopilot in NAV mode.	10:25:06	1100 MSL	0°
2	The bank angle begins to increase.	10:26:45	5550 MSL	-4°
3	The airplane maintains airspeed and a positive climb rate until the autopilot disconnect alert is heard in the cockpit.	10:26:48	5750 MSL	-24°
4	One second later, the pilot is heard vocally reacting to the autopilot disconnection.	10:26:49	5800 MSL	-33°
5	The airplane reaches peak altitude, continuing to increase bank angle.	10:26:57	6100 MSL	-64°
6	The airplane reaches peak bank angle while descending and accelerating.	10:27:05	5400 MSL	-88°
7	The bank angle begins to reverse.	10:27:07	4950 MSL	-88°

Note that the bank angle at which the autopilot disconnects appears to be less than -30° (left wing down), comparing the data trace of the airplane's bank angle with the vertical marker indicating disconnection of the autopilot in the figure.

Approximately three seconds pass between the point at which the performance study notes the start of the roll event and the point at which the autopilot disconnects.

According to recorded information on the CVR, the pilot is heard reacting to the autopilot disconnection annunciation approximately one second after it is activated, while performing checklist items. This indicates that the pilot was aware that a problem was developing. Further, unlike earlier vocalizations of checklist items during normal operation at the start of the flight, no vocalizations of memory items from any emergency procedure are heard following the initial reaction. It is not clear from the transcript whether the pilot was aware of either the operation state of the airplane or the attitude orientation of the airplane at this point. Notably, the pilot does not vocalize recognition of any particular fault indication, including any annunciator panel lights or the ATLAS INOP light.

The data shows the airplane continued to climb and roll following the autopilot disconnect and the pilot's vocalization, peaking in altitude at 6100 feet before beginning to both descend and accelerate while the bank angle continued to increase to a calculated maximum of approximately -88° (left wing down). The airplane remained at that angle for two seconds before beginning to decrease to a final bank angle of -53° left-wing down at ground impact.

4 CONSIDERATION OF AUTOPILOT DISCONNECTION CRITERIA

At the time of drafting the Tamarack Party Submission [2], initially in October of 2020, the data available in the performance report indicated the autopilot disconnected at a bank angle of 45°. Following a revision of the reports to address an error in the timing between events in the cockpit voice recorder transcript and the performance report, it was determined the autopilot disconnected at 30°, rather than 45°. According to Textron's supplemental information regarding the Collins ProLine 21 system [6], the autopilot will disconnect itself for the following reasons:

- Stick shaker activation
- Automatic disengagement of the yaw damper (no action from pilot)
- The flight guidance computer detects an internal failure (yaw damper failure, autopilot failure, AHRS failure or miscompare)
- Excessive or unusual attitudes exist (pitch exceeds +25 degrees or -15 degrees, roll exceeds +- 45 degrees)
- Electrical power to the flight guidance system is lost (In this case, the autopilot warning is canceled automatically after 5 seconds)

The five conditions listed above are taken directly from supplemental information provided by Textron [6] to the investigation party, which was published in the public docket for the investigation. One additional parameter for autopilot disconnection was not included in the Textron supplemental information, but is identified elsewhere in the Factual Report [5]:

- Roll rates exceeding 10°/second.

It is not clear how long each of these conditions must exist for the autopilot to disconnect, but it is likely that some delay is included in the system to prevent nuisance disconnection due to noise in the signal or similar conditions. Regardless, these conditions for autopilot disconnection were not fully explored as possible causes of the initiating roll event.

In addition, the CVR Transcript Report [3] and the Performance Study [4] compiled by the NTSB revealed there was no audible indication that the stick shaker had activated, nor was the calculated airspeed or load factor in a range to activate the stall warning. Likewise, the CVR transcript does not note any audible indication that the yaw damper disconnected, either manually or automatically. It is unclear whether an electrical system anomaly or failure scenario could have resulted in the autopilot disconnect, however it is worth noting that an electrical failure does not explain the initiation of the roll prior to autopilot disconnection.

5 REVIEW OF ATLAS FAILURE CHARACTERISTICS

The two most probable means by which ATLAS may have caused the autopilot to disconnect are either an asymmetric TACS deflection failure which would have caused a bank angle greater than 45° or an asymmetric TACS deflection producing a rate of roll higher than 10° per second. However, at the point of autopilot disconnection, the performance report estimates the bank angle was approximately -30° (left wing down), which is well below the 45° bank angle threshold. The data trace presented in the performance report (Figure 3 within that report) shows that the bank angle trace crosses the autopilot disconnection marker closer to -24° (left wing down).

The Performance Study [4] also estimates the average rate of roll during the accident sequence to be near 5-6° per second. Tamarack flight test data collected during the original ATLAS certification project was provided to the NTSB during the investigation. This data focused on ATLAS failure modes producing an asymmetric TACS deflection and found that the critical failure case was a full dual asymmetry, in which one TACS is fully deflected trailing edge up and the other is fully deflected trailing edge down. This critical case was determined to be controllable by an average pilot during flight test. The full dual asymmetric failure produced a roll rate of approximately 25° per second, significantly higher than the roll rate determined for the accident airplane.

Considering the possibility of a less critical failure mode (i.e., a failure mode in which one TACS is deflected and the other is not), the two most likely causes of autopilot disconnection would still be a roll rate of greater than 10° per second, which the Performance Study does not indicate, or a bank angle exceeding 45°, which the Performance Study also does not indicate.

ATLAS is an autonomous system and does not have a direct link to the Collins ProLine 21 equipment. This makes it impossible for an ATLAS failure to influence the autopilot's internal function or cause an internal failure. Similarly, ATLAS is not powered from the same electrical bus as the ProLine 21 and the TACS are protected by a 15 amp circuit breaker, which would have disconnected the TACS from the rest of the electrical system in the event of an excessive current draw. This makes the likelihood of an electrical failure impacting the Collins equipment low.

Therefore, the facts presented in the performance report do not support an ATLAS failure as an explanation for the initiating roll event, the autopilot disconnection at a maximum of -30° bank (left wing down), or the continuation of the roll to nearly -90° (left wing down) after the autopilot diconnected.

6 CONSIDERATION OF POSSIBLE AHRS FAILURE

Based on the available information, autopilot disconnection due to stick shaker activation, yaw damper disengagement, or excessive bank angle can be immediately ruled out as extremely improbable. The NTSB Performance Study [4] does not support roll rate as an explanation for autopilot disconnection either and there is a lack of evidence to suggest an electrical failure.

It is therefore evident that the one criterion which requires further factual development involves the "the flight guidance computer detects an internal failure (yaw damper failure, autopilot failure, AHRS failure or miscompare)." A failure of this type may have either caused or contributed to the initiation of the roll event, and follow-on effects may have contributed to the airplane's continued roll to nearly -90° (left wing down). This failure mode may also explain why the autopilot disconnected at a relatively shallow bank angle.

Thus, it is suggested that the following possible scenario be considered:

1. The autopilot is configured to receive data from the PIC AHRS unit and is engaged as the airplane enters IMC.
2. The PIC AHRS unit fails and causes a miscompare, also providing the autopilot with erroneous information that causes the autopilot to begin a roll to the left.
3. After three seconds, the failure of the PIC AHRS is detected, causing the autopilot to disconnect automatically.
4. The pilot is alerted to the disconnection of the autopilot and breaks away from the checklist and ATC communication tasks he was performing to address the disengagement, which would require the pilot to immediately begin to hand-fly the airplane.
5. The AHRS displays either faulty data or no data to the pilot, creating a surprise/startle condition that would require the pilot to immediately begin using secondary instruments to determine the airplane state.
6. Without valid AHRS data, the pilot does not initially recognize the airplane attitude state and because of the upset in IMC, and limited valid information, he is overwhelmed because of his limited experience with the particular avionics suite and does not input corrective action.
7. The airplane peaks in altitude and begins to descend and accelerate, entering a spiral dive state as the pilot continues to assess the airplane state.
8. The pilot becomes aware of the airplane state and begins to input corrective lateral inputs, but the near -90° angle of bank creates a secondary surprise condition.
9. In this surprise condition, the pilot does not reduce throttles, despite rapidly rising airspeed due to the descent.

10. The pilot is able to partially recover the bank angle and begin to apply corrective pitch inputs but is unable to fully recover the airplane prior to impact.

The first step in the possible AHRS failure scenario is supported by factual data. The CVR Transcript Report [3] shows the pilot vocalizing activation of the autopilot system at 10:25:29, approximately 1 minute and 16 seconds prior to the start of the roll event. Later annunciation of the autopilot disconnection confirms that the autopilot was indeed engaged.

The next two steps in this possible scenario make the following assumptions:

- The AHRS providing attitude data to the autopilot failed.
- That failure was small, but provided a constant erroneous bank angle reading
- The autopilot commanded a roll to the left, attempting to correct the erroneous bank angle.
- As the airplane continued to roll to the left, the bank angle increased and the difference in bank angle readings between AHRS 1 and AHRS 2 increased simultaneously.

After a certain amount of roll, the miscompare in AHRS readings would reach a value large enough to cause the autopilot to disengage automatically. It is unclear what magnitude of AHRS miscompare is required to trigger an autopilot disconnection, nor is it clear how long the two AHRS units need to be in a miscompared state before the autopilot disconnects, as these parameters were not explicitly stated during the investigation. However, it is reasonable to assume that some small amount of mismatch is allowable for some finite amount of time, to prevent normal fluctuations and noise in the AHRS data from causing excessive nuisance faults during flight.

The fourth step in the failure scenario is directly supported by factual data. The CVR Transcript Report [3] notes an audible click, followed by an electronic voice announcing “autopilot.” These are the audible cues expected in the event of an automatic disconnection of the autopilot. After one second, the transcript notes the pilot vocalizing “whoooaaaaah.” It is likely that this vocalization is in direct response to the autopilot disconnecting, given that the two events occur one second apart, and the autopilot disconnecting would typically not be part of normal operation for this phase of flight. There are no further vocalizations of checklist items, and the pilot does not follow up with Indy Center as instructed following disconnection of the autopilot, suggesting that he shifted his focus from these tasks to address the autopilot disconnection.

On recognition of a failure, it is reasonable to assume that the average pilot will first consult primary flight instruments to determine the state of the airplane and assess the appropriate response. However, if the PIC AHRS had failed, the pilot would have had to move to secondary instruments. The airplane was likely still in IMC, given its altitude and prevailing conditions in the area. Some amount of time would have been required for the pilot to shift focus from previous tasks, to recognize the AHRS failure, and then to appropriately shift focus again to secondary instruments to determine the aircraft state. During this time, the pilot may have either placed his hands on the yoke or not. The performance study shows that the airplane continues to roll following the autopilot disconnection, suggesting that if the pilot did assume manual control of the airplane, he did not immediately input a corrective roll input to counter the left bank. It is possible that he maintained the last position of the yoke during the process of determining the state of the airplane, continuing to increase the bank angle in the process.

As the bank angle continues to increase, the airplane reaches its peak altitude and begins to descend, accelerating as it does so. It is important to note that the CVR Transcript Report [3] does not indicate sounds similar to engine RPM reduction, nor does the pilot vocalize any information regarding throttle position during this time. The rate of acceleration is significant. Based on the data traces presented in the Performance Report [4], the airspeed is increasing by nearly 19 knots per second at approximately 10:27:11. This rate of change is approximately 31 ft/s^2, or nearly the normal acceleration due to gravity. The radar track of the airplane does not indicate the nearly vertical dive that would be necessary to produce this acceleration without thrust. In fact, at 10:27:11, the ground speed appears to be greater than 225 kts, indicating a descent angle less than 60°. Given this descent angle, only a portion of the airplane's acceleration can be attributed to gravity, and the most reasonable explanation for acceleration as high as it was during the descent is that the engines were still developing significant thrust. The Performance Report [4] notes that the airplane continued to climb for 12 seconds, indicating that the engine power was not reduced in response to the roll onset, but does not follow up by estimating the thrust during the high speed descent which developed.

By 10:27:11, the airplane state had developed into a clear spiral dive, as defined by the Airplane Flying Handbook [7], Section 5. It is noteworthy that the first action required for recovery from this state is a reduction of power, intended expressly to control airspeed during recovery. Thus, it appears that the pilot did not reduce thrust at a critical point in the development of the spiral dive condition, contrary to conventional piloting skills and recovery procedures. This may be related to the observation that the pilot did not appear to apply corrective control inputs in response to the bank angle, in that it is possible that he was spatially disoriented, potentially due to a lack of valid information about the aircraft state on his primary flight display.

The final step in the possible accident sequence considered in this report is directly supported by factual data. The airplane bank angle had begun to diminish at approximately 10:27:07, ultimately reaching approximately -53° (left wing down) shortly before impact at 10:27:20. This suggests that the pilot was attempting recovery in the final 13 seconds of available data. It is also worth noting that the airspeed continued to increase during this time. The final airspeed data point is in excess of 375 knots. Note that the calibrated VMO for a CJ2+ below 8000 feet MSL is 275 knots, meaning that at time of impact, the airplane was flying more than 100 knots faster than the maximum allowable airspeed for the plane. Once again, there is no indication in the CVR transcript that the pilot reduced the throttle setting throughout the entire event.

7 HUMAN FACTORS CONSIDERATIONS

There are notable similarities between this accident and other fatal accidents of similar jets which were ultimately determined to be caused by spatial disorientation. Given that, note the flight conditions around the time of the onset of the roll:

1. The airplane was in IMC when the roll began.
2. The pilot had recently responded to instructions from ATC, approximately 12 seconds before the onset of the roll.
3. Specifically, the pilot had been instructed to contact Indy Center and he had acknowledged the instruction but could be heard vocalizing what appear to be checklist items on the CAM immediately after acknowledging.

The pilot was operating the airplane single pilot in IMC and appeared to be responding to ATC instructions and completing checklists around the time of roll onset and autopilot disconnection. It is possible that the pilot was focused on these two tasks primarily, and that any fault annunciation would have required him to shift his focus to respond appropriately.

Given the prominence of the attitude indicator in the pilot's primary field of view, it is unlikely that he would not have immediately noticed the bank angle of the airplane upon looking up from his previous tasks. It is possible that an AHRS failure caused erroneous data to be presented, in which case the pilot would have needed to shift focus from previous tasks, then immediately shift focus again to secondary instruments to regain situational awareness. This possibility is supported by the 18 second delay between the pilot's vocal recognition of the existence of a problem and the first signs of corrective action being applied to counter the bank angle.

Spatial disorientation may also explain why the airplane continued to accelerate. Tamarack flight test experience indicates that the airspeed which the airplane achieved prior to impact required an elevated thrust setting. If the pilot was not immediately aware that the airplane was entering a nose-down attitude it is possible that he was likewise unaware that he needed to reduce thrust, allowing the airspeed to increase significantly. By this point, it is similarly possible that the state of the airplane had produced an excessive workload. This is especially likely if the pilot did not have extensive operational experience in the airplane and was overwhelmed with event to the point of being unable to appropriately respond in the time available. Thus, it is possible that the pilot left the thrust levers in their original position for the climb in a disoriented state, which contributed to the severity of the condition and increased the required effort to correct it.

One further point of note is the following statement excerpted from the investigation Factual Report [5], regarding a vocalization that the pilot made during startup and preflight:

> *He referenced items from the Before Taxi checklist and included in his crew briefing that in the event of a problem after takeoff decision speed, he would handle it as an in-flight emergency and "fly the airplane, address the problem, get the autopilot on, talk on the radios, divert over to Stanford."*

It is not clear how heavily the pilot intended to rely on autopilot in addressing a potential in-flight emergency, but this statement is one of the few available direct insights into the pilot's established operational flows and mental model for response to in-flight emergencies. In the context of an AHRS or autopilot-related failure, it is worth noting that this statement would do little to mentally prepare the pilot for continuing safe flight following the initial "fly the airplane" and "address the problem" steps.

8 OUTSTANDING QUESTIONS

As previously noted, there are still several areas which warrant further developing in the factual record to be able to accurately form conclusions based on the AHRS failure scenario presented in this submission. Three key areas for further development are identified.

1. The failure scenario is predicated on a failure of the PIC AHRS and faulty information being provided to the autopilot. While the factual record provides detail regarding excessive pitch angle, bank angle, and rate of roll thresholds for the autopilot to disconnect, less information is provided regarding the severity of an AHRS miscompare that might cause the autopilot to disconnect, or the amount of time required for the system to confirm that there is a miscompare state and disconnect. It is reasonable to assume that any redundant system will allow some amount of error for some amount of time, as this is required to prevent nuisance faults and unattainable production standards. However, a more complete understanding of these tolerances is required to be able to further evaluate an AHRS failure as a probable cause for this accident.
2. The pilot's recent experience in type is relevant to establishing his proficiency in Cessna 525A operations. An effort to establish experience was made during the investigation, but could be further developed. The airplane was operated by an LLC, which would have most likely kept records of the times and costs associated with each flight, as well as records of payments made to contract pilots. A comparison of the records of operating costs of the airplane vs. contract pilot payment records would provide at least a reasonable estimate of the amount of time the accident pilot accumulated in N525EG prior to the accident. This is important for establishing the pilot's familiarity with the airplane particularly in the context of establishing familiarity with the particular systems and avionics installed on N525EG. A pilot with extensive experience with a particular avionics suite will typically respond differently than a relatively inexperienced pilot when presented with an unexpected failure, and further developing the record on this point may provide insights into the pilot's likely actions during the time between recognition of the autopilot disconnect and the first indication of reversal of the bank angle.
3. Specific information about the pilot's training in the process of adding the Cessna 525 type rating is relevant to establishing both the amount of training provided for responding to unusual attitudes, upsets, and spiral dives and also the pilot's evaluated abilities during such training. The instructor(s) and examiner(s) who worked with the pilot during training may be able to shed light on the pilot's level of proficiency in recognizing, evaluating, and responding to simulated emergencies involving uncommanded upsets, and this insight is critical to evaluating the human factors aspects of the failure scenario presented in this submission.

9 TAMARACK CONCLUSIONS

The AHRS units themselves were destroyed in the crash, preventing functional testing as an option to further explore their role in the accident sequence. Likewise, the AReS memory card was destroyed in the crash, making it impossible to use data from that system to examine the state of the aircraft's systems prior to and during the roll event.

However, examining the possibility of an AHRS failure causing the roll produces a plausible explanation for the entire accident sequence, and addresses several notable discrepancies between conditions and factual data in theoretical explanations for the roll event involving any potential ATLAS failure. This possible chain of events is also more consistent with accident sequences from other fatal crashes involving spatial disorientation in IMC and autopilot failure or mismanagement rather than an induced roll event from an external system failure.

At the time of this submission, there are still incomplete datasets included in the factual record which warrant further study to either support or disprove any theory as to why the airplane began its roll to the left and subsequently continued into an unrecoverable state. In particular, a more thorough understanding of the pilot's experience and the expected behavior of AHRS and the autopilot in potential failure states would greatly improve the factual record from which an ultimately accurate determination of probable cause may be drawn.