

N230BW Accident Report

Introduction

On 12/24/2019 an F1 Rocket with a MK I empennage, manned by a crew of 2, sustained a structural failure to the horizontal stabilizer while maneuvering. The failure resulted in the majority of the starboard stabilizer departing the aircraft. The starboard elevator remained attached to heavily damaged rear spar and to the port elevator through the hinge points and the control horns. The starboard HS that departed the aircraft has not been recovered.

The port stabilizer remained attached, but was severely compromised and was bent downward approximately 30 degrees. Elevator movement was restricted to approximately 1.25 inches, as measured at the top of the rear control stick, allowing a moderate amount of pitch control. The pilot was able to regain control of the aircraft, return to base, and after one aborted landing attempt, was able to land the damaged aircraft successfully.

Background Summary

The pilot/owner had recently purchased the aircraft, and had approximately three hours' time in type. His previous two flights were an acceptance flight at purchase, and a short ferry flight to his home field. The incident occurred when the passenger, a rated pilot, was performing a barrel roll. The estimated weight at the time of the accident was 1830 lbs. The following narrative is derived from the data logging device, a Dynon D180. A more detailed discussion is presented later in this report.

The roll was initiated at 3400 ft (181 KIAS), and reached an altitude of 4000 ft (147 KIAS)

In the descent phase, the aircraft reached 3700 ft, with a pitch low angle of -47 degrees, and an instantaneous rate of descent of -13,000 ft/min at 170 KIAS. It was at this point that the pilot flying initiated pitch recovery, but the aircraft continued to descend and build speed. The aircraft continued to descend to 2000 ft with a pitch angle of -18 deg, and vertical descent rate of -4680 ft/min. Three seconds later the horizontal stabilizer departed and there was a -2.6 G event. At this point the pilot/owner took control and initiated a recovery, but the aircraft continued to descend to 455 ft (approximately 400 AGL) before stabilizing. Peak speeds of 244 KIAS occurred after the failure.

Interviews with the pilot substantiated the data logged data. The pilot stated that he believed he was flying well within the aerobatic specifications of the aircraft, which he believed were +6/-3 G at 2000 lbs., as found in this aircraft's pilot's operating handbook (POH). He believed that they had not pulled more than 2 Gs in the sequence, and the data supports this statement.



Aircraft Inspection

The aircraft was inspected on 1/25/2020 by three individuals. All three have built Rocket variants and are familiar with the aircraft construction. Two of the three are A&Ps with a background in experimental aviation. The third has an engineering background with extensive industry experience.

Approximately 75 pictures were taken both before and during the disassembly of the empennage. The starboard HS had departed the aircraft, but the associated elevator remained attached to the aircraft through the elevator horn and a single bolt. The port HS and elevator were bent down approximately 30 degrees. Control travel was limited to about 1.25 inches at

the rear control stick.

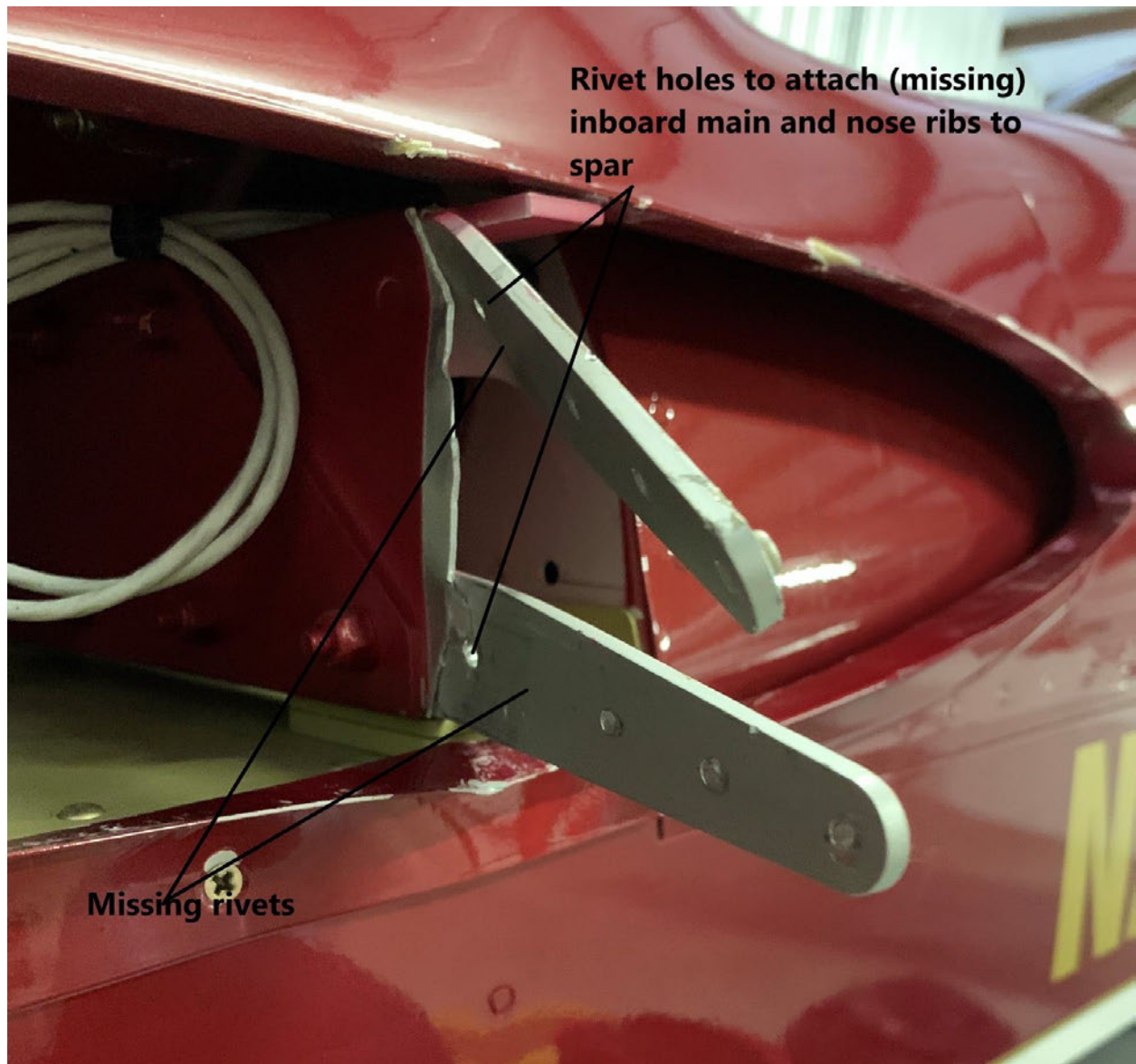


Figure 1

Figure 1 shows the failure of the HS 002 front spar, and the bent legs of the HS 014 spar caps. The failure occurred at the HS 002 bend area as the tapering HS 002 front spar merges with the fuselage.

There was minor damage to the rudder, and no visible damage to the vertical stabilizer. On close examination of the remainder of the aircraft, there was no other visible damage. A story pole was erected to determine if there was any twist in the fuselage front to rear and none was visible.

In general, construction appeared to be excellent. However, there was one significant discrepancy in the build of the stabilizer. One rivet was missing on each of the four spar cap bent legs. There should be five AN470AD4 rivets in this line of fasteners, and there are only four on this build. A total of 4 rivets were never installed, nor were their corresponding holes drilled.

Summary of the Findings

1. The MK I empennage is structurally very similar to that provided by Van's Aircraft for the RV-7. The RV-7 is a lighter aircraft, typically powered by 4 cylinder engines, and has a Vne of 200 KTAS, and a typical gross weight of 1800 lb. The RV series of aircraft have had a series of service bulletins addressing this issue, and the concerns expressed by Van's Aircraft are directly applicable to the accident aircraft.
2. It is possible that this accident was caused by a flutter event, but the analysis indicates aerodynamic overload, at much lower than Vne, could have precipitated the cracking event. The elevator on the port stabilizer was measured on site for balance, and it appears to be balanced correctly. No flutter study was done as part of this investigation, but should be considered for future work.
3. Although it is possible, no evidence of prior cracking in the bend area of the HS 002 was found. A detailed metallurgical examination of the port horizontal stabilizer would be needed to investigate whether pre-existing cracks were present. It thus remains an open question as to whether cracks were present in the aircraft prior to the accident.
4. The aerodynamic loads imposed on the stabilizer were more than sufficient to initiate catastrophic cracking in the bend. At this point the load was transferred to the remaining rivets and the riveted joint failed. It is possible, but unlikely, that the missing rivets would have precluded the loss of the stabilizer.
5. The information transferred to the new owner/pilot was inadequate for flight operations, particularly aerobatics. The owner/pilot believed the aircraft was capable of +6/-3 G at a Vne of 240 KTAS, which is highlighted in the F1 Rocket specification documents. The aircraft, particularly with the MK I empennage, must be flown in accordance with much more restrictive flight speeds.
6. The original POH for the F1 Rocket was placed at the end of the builder's manual, and not broken out as a separate document. The flying portion has a detailed list of V speeds, that appear to be contradicted by the +6/-3 G, 240 KTAS Vne wording, leading to confusion as to how the aircraft is to be flown. Other than the comments on G loading, the V speeds listed in the POH seem reasonable for this aircraft. No analysis was done in this report to confirm the V speeds listed.

[REDACTED]

1.

[REDACTED]

[REDACTED]

[REDACTED]

Design History of the F1 Rocket

The F1 Rocket is a derivative of the Harmon Rocket, which in turn is a derivative of the Van's RV-4. The RV-4 was specified by Van's Aircraft for +6/-3 G at a flying weight of 1375 lbs. These requirements essentially meant it was a single pilot aircraft with minimum fuel for aerobatic flying. The published top speed (Vne) of the RV-4 is 204 MPH (177 KTS), with a maneuvering speed (Va) of 135 MPH.

Harmon Rocket II

The Harmon Rocket II lengthened and widened the RV-4 fuselage, shortened the wing by approximately a foot on each side, but retained the same number of ribs. The wing also used .032" skins for the entire span. The wing modifications increased the torsional and bending stiffness a minor amount, but with no changes to the spar, the strength was essentially unchanged.

The HR II used an IO 540 engine, considerably heavier and more powerful than the power plants originally used in the RV-4. The published specifications for the HR II are a cruise speed (75%) of 230 MPH, and a "Redline" of 275 MPH (240 kTS), and a gross weight of 2000 lbs. The HR IIs typically used the RV-4 empennage. The Harmon conversion kit requires the builder to essentially purchase an RV-4 kit with specific deletions, and then purchase, through Harmon, the necessary replacement parts.

The justification for a Vne of 240 KTS is not known.

Team Rocket F1 Rocket

The Team Rocket F1 Rocket used the Harmon Rocket as an engineering base, but the entire aircraft was placed in CAD by the HPAI group in the Czech Republic. The kits were then shipped as Quick Build Kits from the Czech Republic to customers. There were two wing options, the Sport wing and the EVO wing. This report considers only the Sport wing version.

Team Rocket did provide an extensive build manual and at the end of the build manual (Chapter 9) was a detailed discussion of preparations for first flight, and recommended operating envelope parameters for Phase I flight testing including aerobatics. The final section in Chapter 9 is an example POH. The example POH included in the manual is "Approved" for N252CM, which is a Harmon Rocket II.

From the N252CM POH:

2.2.2 Aerobatic Maneuvers

Aerobatic maneuvers are permitted within the following limitations: Aircraft weight not to exceed 2000 lbs, G limits are +6/-3 Aft C of G limit not to exceed 97.4" aft of datum (where datum is 80" fwd of wing leading edge)

And

2.1 Airspeeds (I.A.S.)

<i>Never Exceed</i>	<i>240 Knots</i>
<i>Normal Operating Limit (Maximum Structural Cruising)</i>	<i>160 Knots</i>
<i>Maneuvering</i>	<i>125 Knots</i>
<i>Maximum, wing flaps extended</i>	<i>95 Knots</i>

Some early F1 Rockets, perhaps 15, used a Van's RV-8 empennage. Team Rocket later produced two different empennages, a MK I and a MK II. The MK I empennage was the empennage on the accident aircraft.

The MK I empennage had early reports of "flutter" at speeds in the 190 KIAS range. In the field modifications were made on several aircraft, and those modifications were incorporated into what became the MK II empennage.

No formal Service Bulletin has been issued, as of February 2020, regarding any possible problems with the MK I. Customers that did encounter problems were told of potential fixes that other customers had employed. It is estimated there are approximately 25 F1 Rockets equipped with the MK I empennage.

The MK I empennage is virtually identical to the empennage supplied by Van's Aircraft for the RV-7. In 2014 Van's Aircraft issued a Service Bulletin for potential cracking of the front HS spar. There was also a retrofit kit available to repair the spar.

Team Rocket under the original owner ceased operating in late 2008. In 2017 the design was put back into production under new management, with a new empennage, the MK III.

N230WB Accident Detailed Narrative

The following charts chronicle the barrel roll accident sequence. The barrel roll took approximately 40 seconds from start to final recovery. Triangles denote areas of interest in the sequence and are discussed below.

Time Marker Sequence

T0: The maneuver begins with an entry speed of 181 KIAS at 3426 ft.

T7: The aircraft pitch attitude becomes negative at a roll angle of 130 degrees. One second later the top of the roll is reached at 3995 ft, for an altitude gain of 569 ft. Airspeed has decayed to 145 KIAS, which is the slowest speed in the maneuver.

T11: In 4 seconds the aircraft pitch angle goes from -.5 deg to almost -48 deg. This is the point at which the descent is first attempted to be slowed, most likely by elevator application. The roll angle is still at 69 deg, and the aircraft is continuing to roll at over 40 deg/sec. This combination of rolling and elevator application can easily result in an over G application ("rolling G"). However, the estimated vertical Gs at this point were approximately -2, so a rolling G failure was considered unlikely. In the interval between T7 and T11 the aircraft is effectively stalled at AoAs less than -12 degrees.

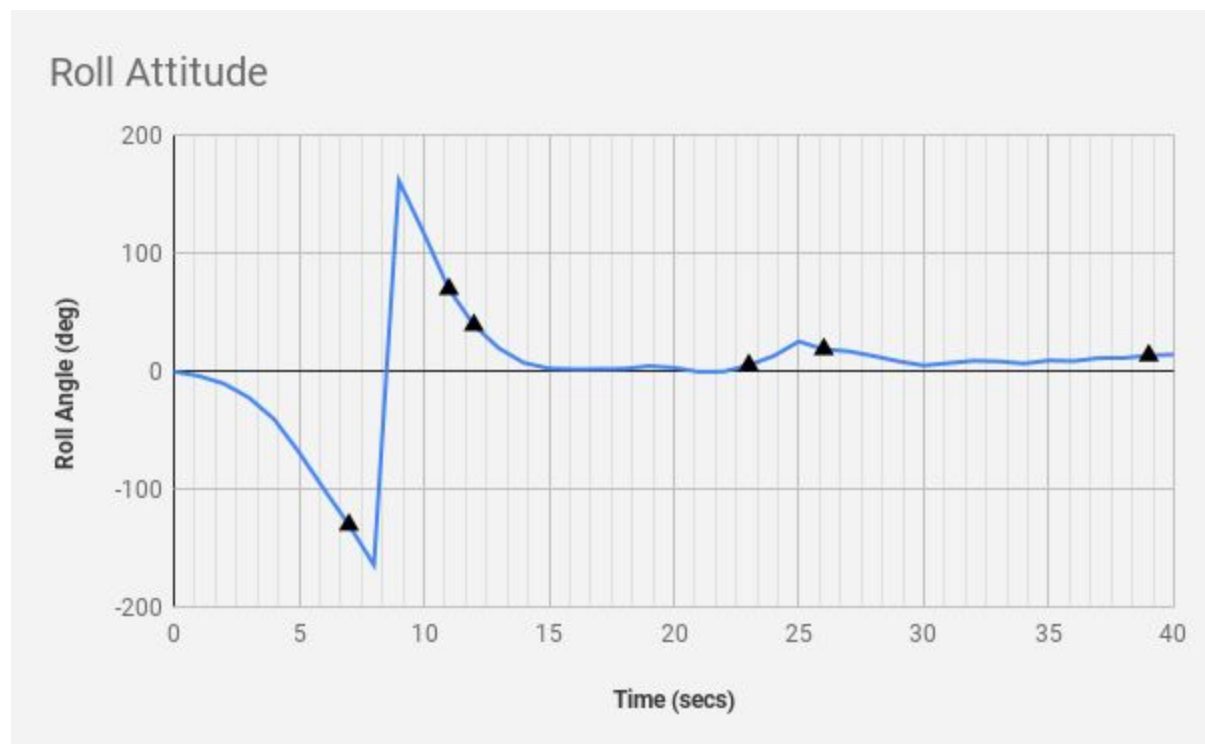
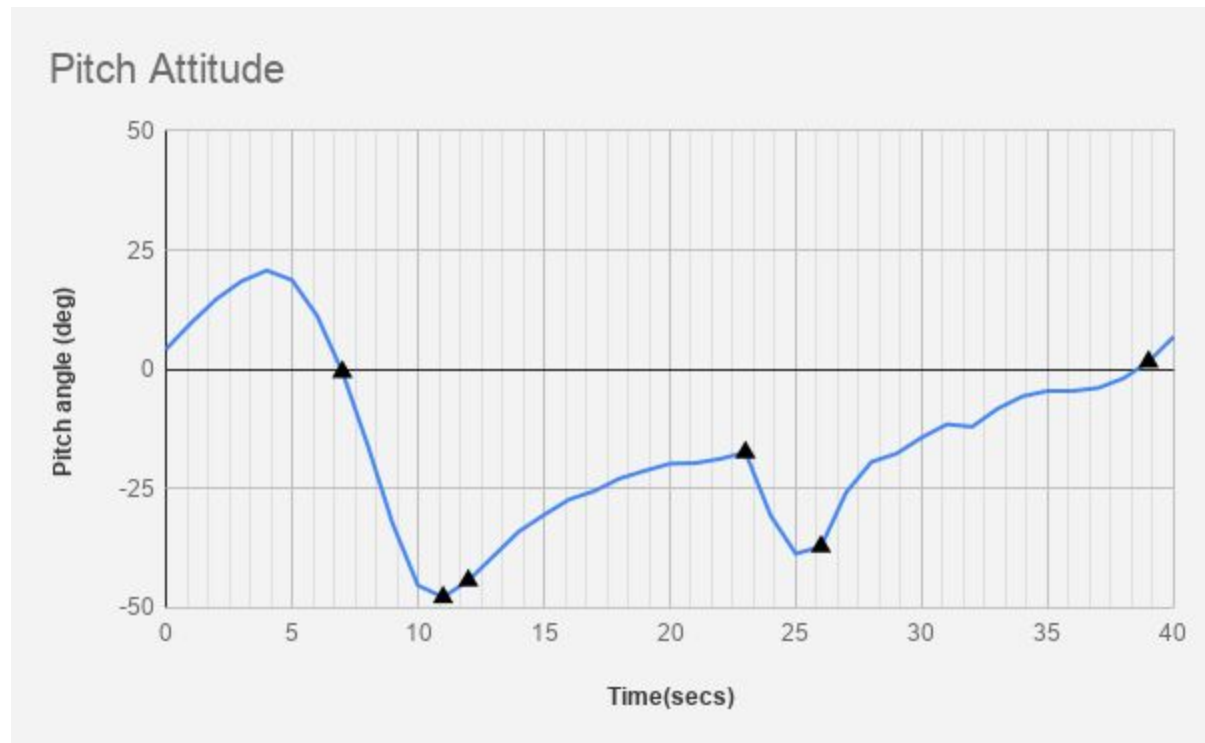
GPS data is lost for the next 5 seconds so it is not possible to estimate AoA. The aircraft continues to roll upright, and the pitch angle becomes less negative in this interval. The descent rate is still approximately -8000 ft/min in this interval. The aircraft reaches 239 KIAS at T19 before beginning a slowdown.

T23: The pitch angle reaches -17 deg and a slowing airspeed of 230 KIAS. The descent rate is -5580 ft/min, and the altitude is 1962 ft. This is the least negative pitch angle in the recovery sequence. At T24, the pitch angle again decreases, and it is believed this is the point where the crew reported "flutter". An aerodynamic flutter event can not be ruled out, however, the sensations encountered by the crew could also be due to a progressive structural failure brought upon by aerodynamic overload.

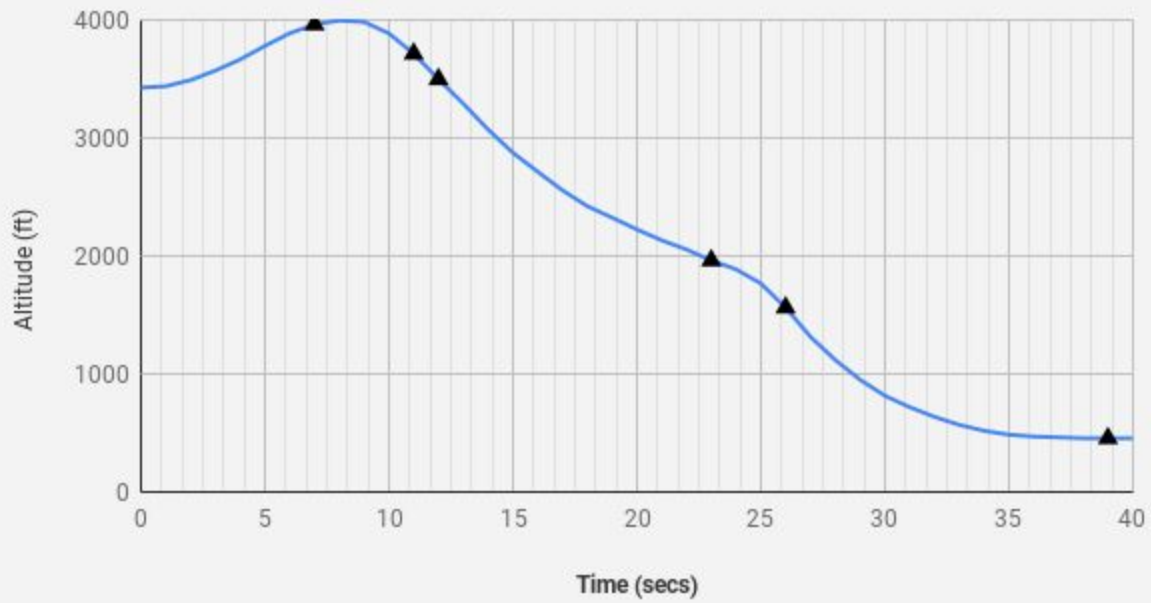
Since this is the point at which the first signs of a structural problem appear, an attempt was made to estimate the loads on the stabilizer. Assuming an AoA of -5 deg, and elevator deflection of 5 deg and a speed of 230 KIAS, the stabilizer would have a bending load of 280 lbf and a pitching moment of 375 lbf-ft.

When this loading condition was placed into the FEA model the Von Mises stress in the bend of the HS002 front spar reached in excess of 600 MPa, or over 50% higher than the ultimate stress for 2024 T3.

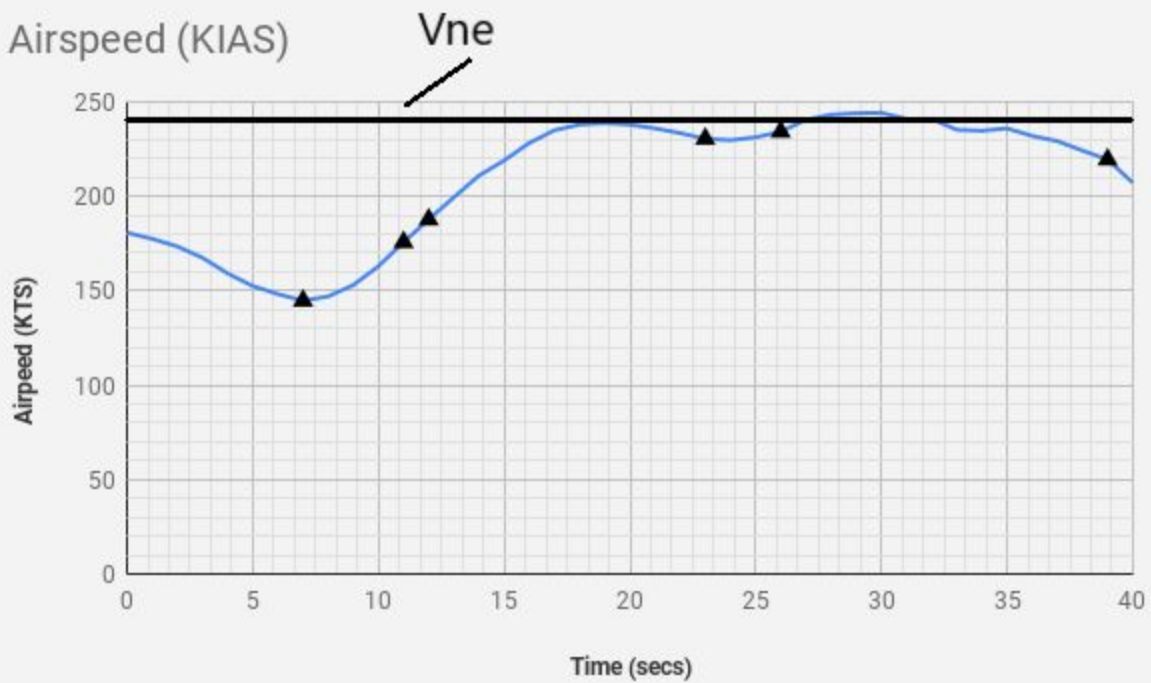
T26: The horizontal stabilizer departs, a -2.6 G event occurs and the peak speed of 244 KIAS occurs at T30. The aircraft descent is stabilized at 450 ft, and the aircraft is successfully landed with no apparent other damage.



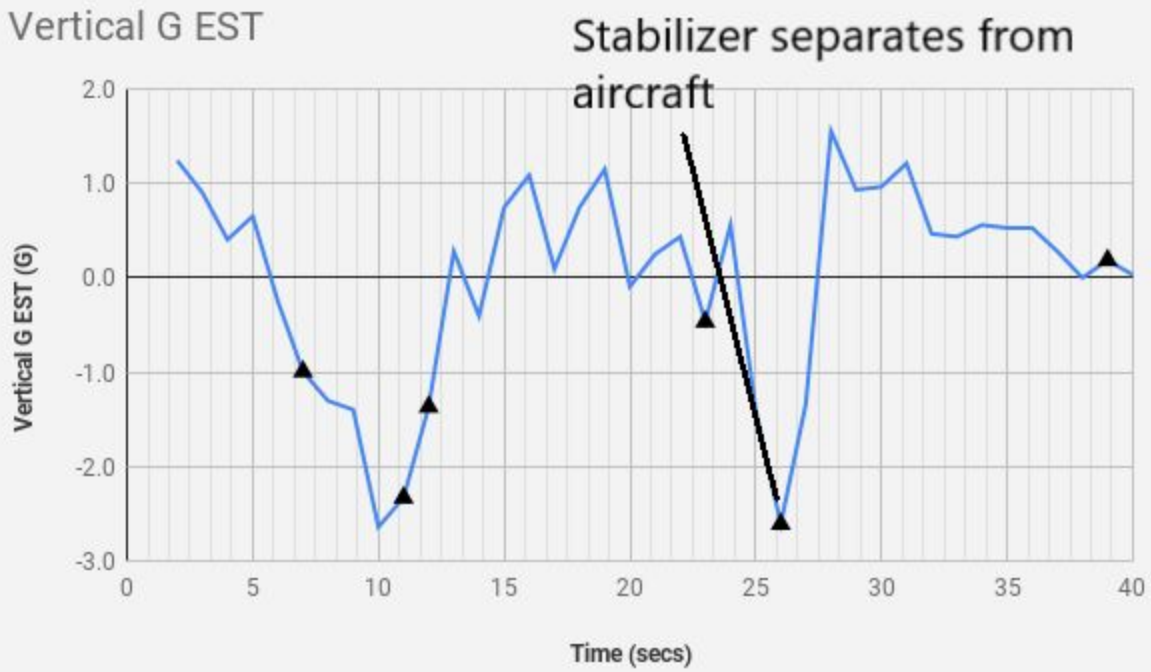
Altitude



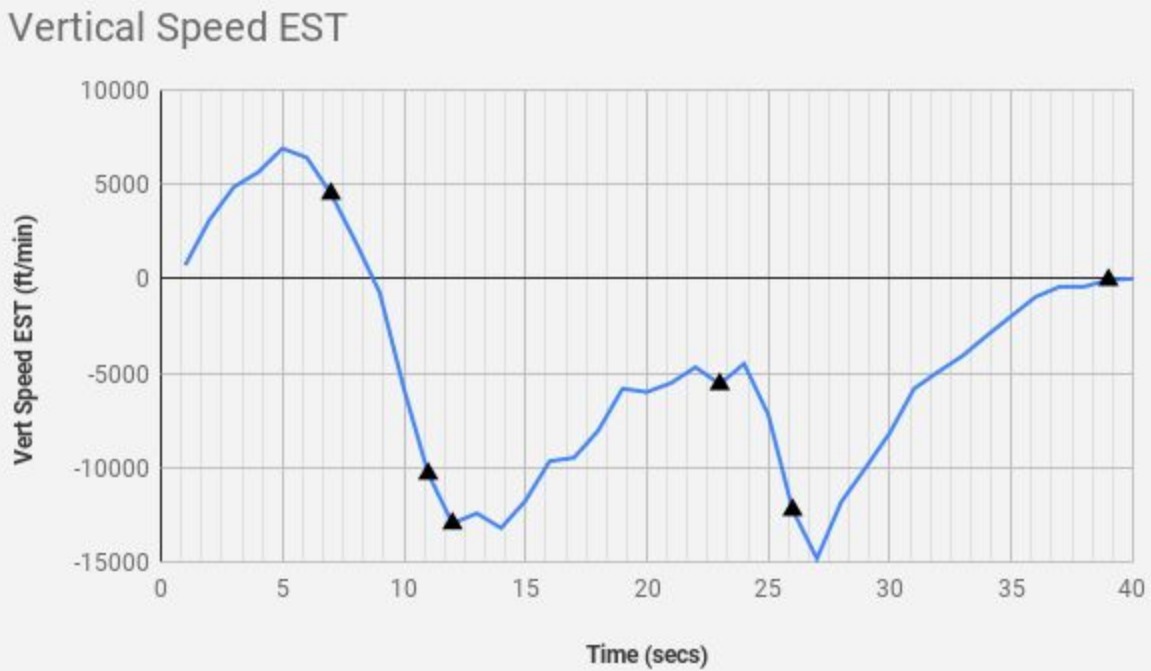
Airspeed (KIAS)



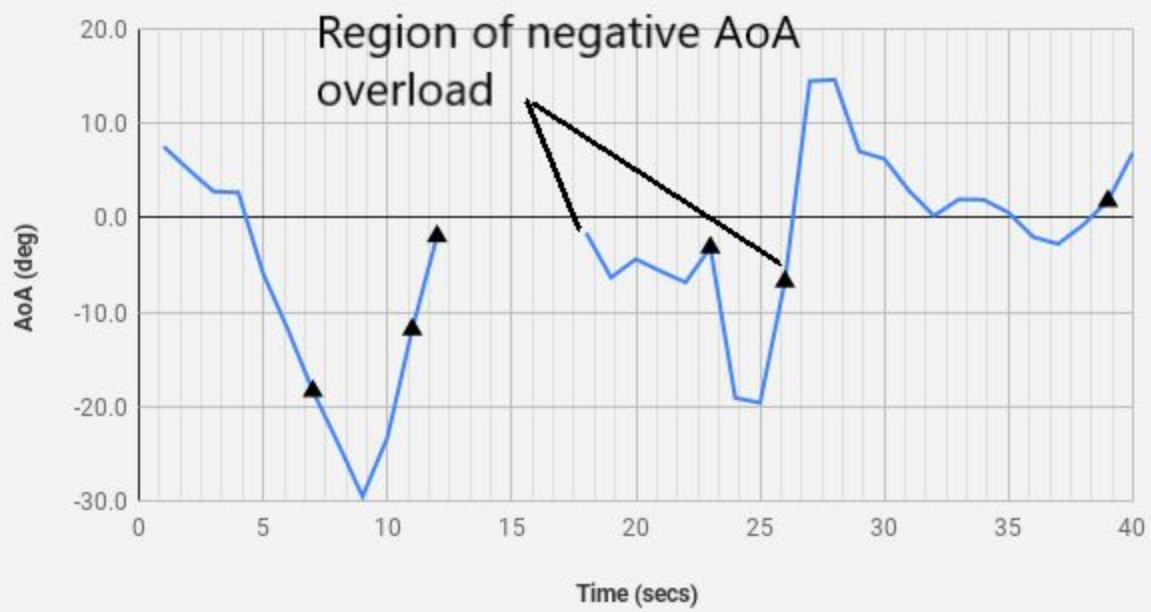
Vertical G EST



Vertical Speed EST



Angle of Attack EST



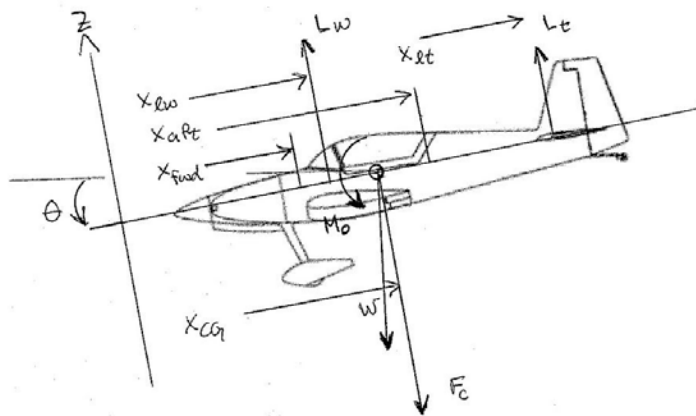
Equations of Motion

The equations of motion for the F1 were derived for symmetric pitching maneuvers. Roll and yaw motion were neglected in the analysis since the data analysis indicated roll accelerations were probably not a factor in the accident (however, the roll angle at which recovery was attempted may be a contributing factor). Thrust and drag were also neglected in the analysis. The wing incidence of the F1 Rocket is approximately 2 degrees, and is also neglected in this analysis.

Figure xx describes an aircraft in a symmetric pitching maneuver. Figure xx illustrates the angle of attack calculation derived from the data log and used in the Detailed Narrative and Analysis sections. All variables used in the analysis are relative to the F1 Rocket POH datum, which is 80 inches forward of the wing leading edge.

The variables are described as follows:

Xlw	The location of the lift vector relative to the datum. Assumed to act at the wing quarter chord. Fixed at 94.75"
Xfwd	The location of the forward cg. Fixed at 87.7"
Xaft	The location of the aft cg. Fixed at 94.75".
Xlt	The location of the horizontal stabilizer lift vector. Assumed to act at quarter chord of the HS, which would place it over the front horizontal stabilizer spar. Fixed at 228.5".
Lw	The lift vector (lbf)
Lt	The tail lift vector (lbf)
Xcg	Calculated value based on POH data. Assumed to act between Xfwd and Xaft. Units are inches
Fc	Centripetal acceleration caused by the pitching maneuver (lbf)
W	Aircraft weight (lbf)
R	Instantaneous radius caused by the pitching maneuver (ft).
G	Gravitation force (ft/sec ²)
Theta	Pitch angle of aircraft relative to the horizon (degrees).
Beta	Angle of relative wind (degrees). Derived from vertical speed and horizontal speed.
alpha	Angle of attack of the aircraft (degrees). $\alpha = \text{Theta} - \text{Beta}$.
V	Aircraft velocity (KTAS)
Vgps	Aircraft ground speed derived from GPS data (KTS).



$$\sum F_z: L_w + L_t - F_c - W \cos \theta = 0$$

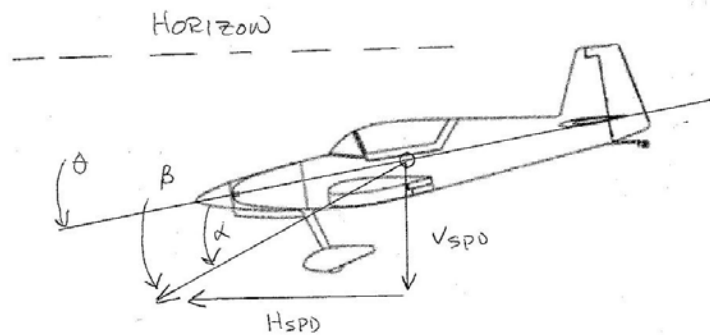
$$L_w = F_c + W \cos \theta - L_t$$

$$\sum M: L_t (x_{lt} - x_{lw}) - (W \cos \theta + F_c) (x_{cg} - x_{lw}) + M_o = 0$$

$$L_t = \frac{(W \cos \theta + F_c) (x_{cg} - x_{lw})}{(x_{lt} - x_{lw})} - \frac{M_o}{(x_{lt} - x_{lw})}$$

$$F_c = \frac{W V^2}{g R}$$

Figure 2: Equations of Motion



ANGLE OF ATTACK:

θ = PITCH ANGLE (FROM EFIS)

β = RELATIVE WIND ANGLE = $\tan^{-1} \left(\frac{VSPD}{HSPD} \right)$

$\alpha = \theta - \beta$

Figure 3: Angle of Attack

The vertical speed (Vspd) and horizontal speed (Hspd) used in the analysis are derived from altitude data and gps data (Vgps).

F1 Rocket in Maneuvering Flight

Negative Angles of Attack

The analysis in the previous section was used to derive Figure 4. The F1 Rocket wing design is based around a NACA 2300 series airfoil. Experimental data was used from the 23015 airfoil documented in Theory of Wing Sections to determine the pitching moment (M_o) used in the

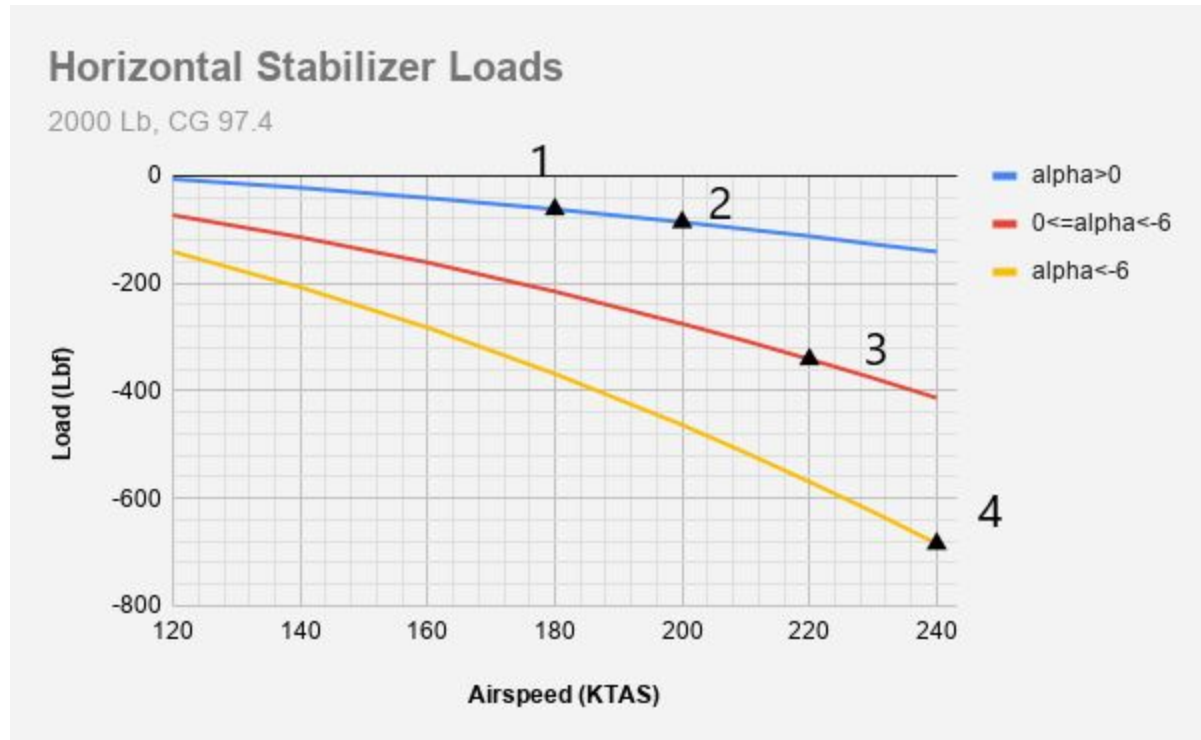


Figure 4

analysis. For positive angles of attack the C_m is assumed to be $-.02$. For negative angles of attack between 0 and -6 degrees, C_m is assumed to be $-.05$. For angles of attack less than -6 degrees, C_m is assumed to be $-.08$. The chart depicts the horizontal stabilizer loads generated for a full aft cg, 2000 lbf aircraft.

For positive angles of attack, the loading of the stabilizer is moderate, even up to V_{ne} . At 180 KTAS (1), the load is 62 lbf, at 200 KTAS (2) it is 86 lbf. However, the load rapidly builds at negative angles of attack.

A typical Rocket with a stock IO 540 will cruise at 180 KTAS on 10 gph. At 180, the load on the horizontal stabiliser is -62 lbf. Pushing the throttle to best power will generally yield about 200 KTAS and a stabilizer load of -86 lbf. However, if any negative angle of attack maneuvering is attempted at these speeds, the loads rapidly build up. A pushover to descend that is faster than

the aircraft can stabilize (and this does not have to be an abrupt pushover) on a new descending trajectory will yield a load of 341 lbf at 220 KTAS (3) at a moderate negative angle of attack of only -5 degrees. Continuing the descent by pushing even a degree or two harder will yield loads of 684 lbf at 240 KTAS (Vne).

The curves shown in Figure 4 will become steeper, with higher loading at the same air speed as the CG moves forward. For example, the 341 lbf load at 220 KTAS discussed above becomes 436 lbf when the CG moves forward to 91". The 684 lbf at 240 KTAS becomes 780 lbf when the CG is at 91".

Positive Angles of Attack

At positive angles of attack the C_m of the 23015 wing is moderate, averaging approximately -0.02 for a wide range of positive α . However, the Rocket design is highly sensitive to CG as shown in Figure 5.

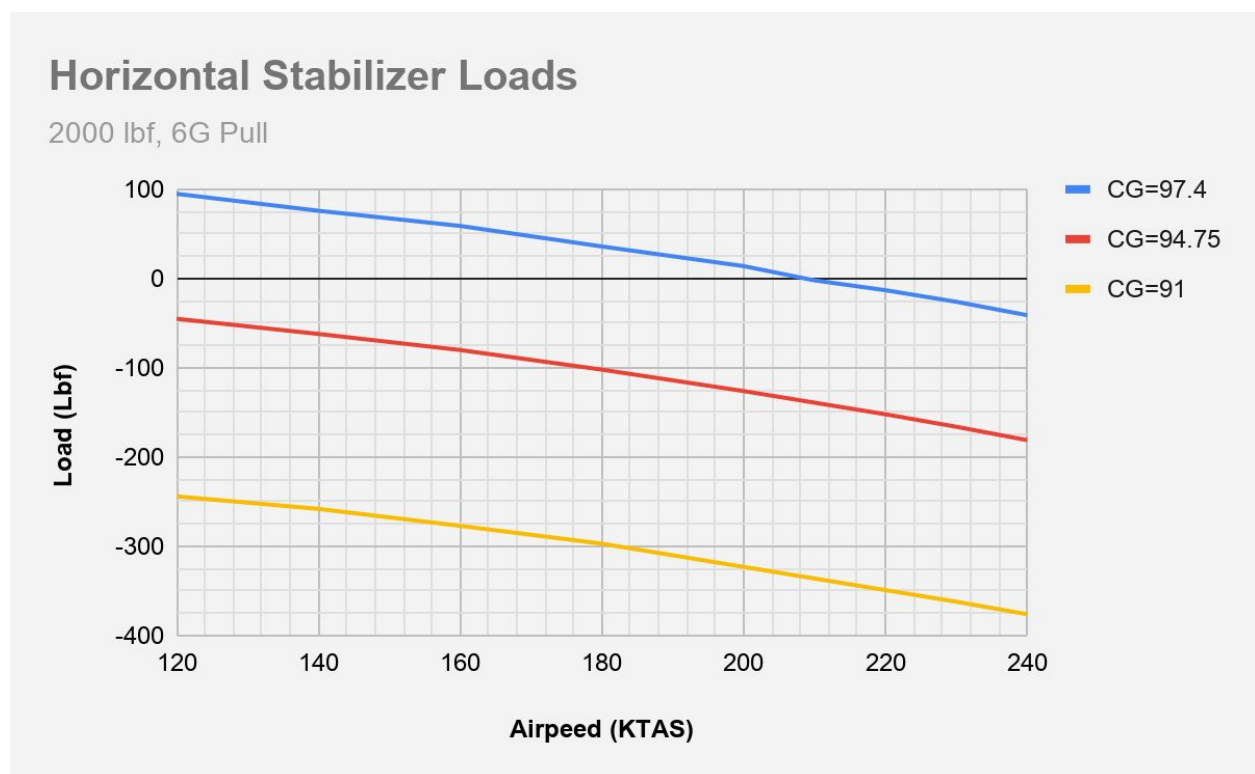


Figure 5

Figure 5 illustrates the effect of CG on the horizontal stabilizer tail load. The curves were generated assuming a 6 G pull at three different CG locations. At aft CG (97.4") the loads are moderate, varying between 95 and -41lbf. At the aerodynamic center (94.75") the loads vary

between -41 lbf and -181 lbf. At a CG of 91" the loads are considerably higher, varying between -244 lbf and -376 lbf. It must be stressed that these are the loads required for equilibrium in a 6 G pull, once the pull was established. The pilot will be modulating the stick in such a way to maintain the forces shown in the figure.

Figure 6 illustrates the loads the stabilizer can create at different lift coefficients (a combination of AoA and elevator deflection). For a 6 G pull, a 2000 lb aircraft needs to generate at least 12000 lbs. Since the wing incidence is about 2 degrees, this will require an AoA of 12 degrees. Assuming the elevator is deflected 10 degrees with an AoA of 12 degrees, the lift coefficient is about 1.2, and the immediate load on the stabilizer semispan is 2500 lbs at 240 KTS. There will be no opportunity to even reach equilibrium before the structure fails.

It needs to be strongly emphasized that the focus here is only on the horizontal stabilizer loads, and while it is true that the loads are lower on the tail at aft CG, the ability to recover from spins, inverted or upright will be severely compromised with these aft loadings.

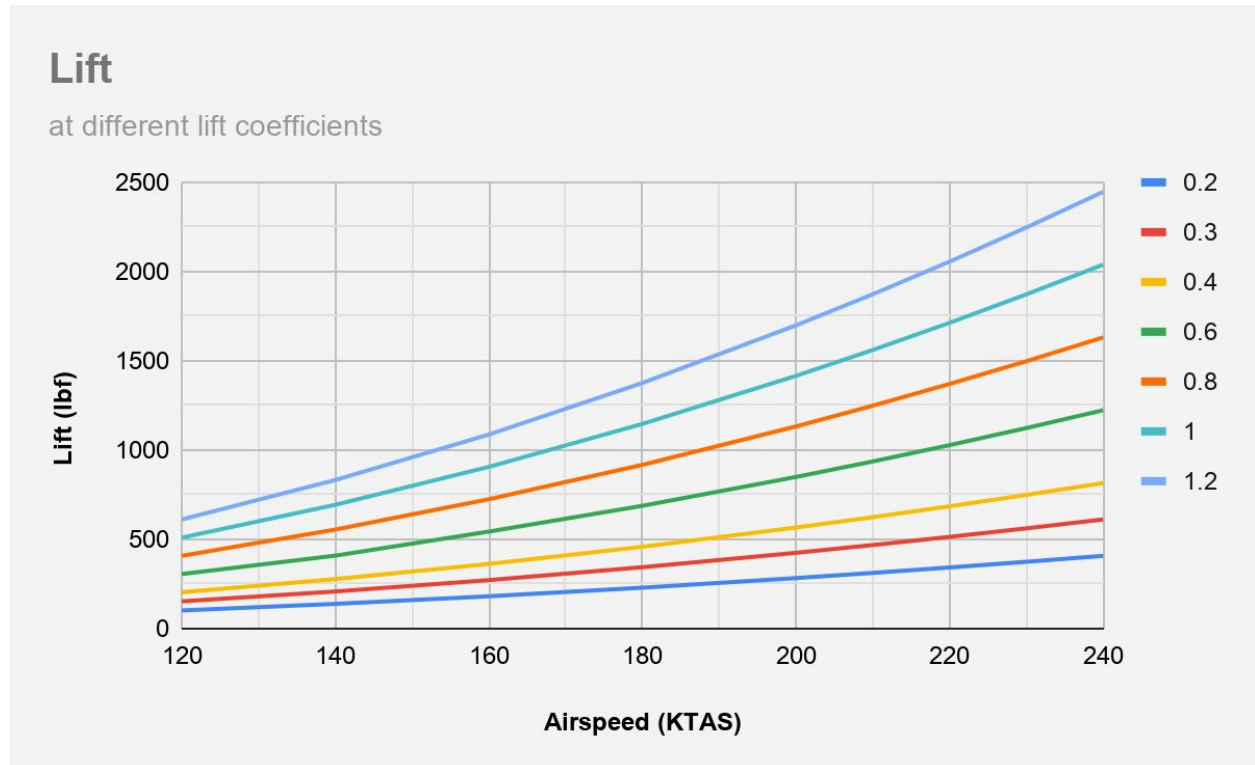


Figure 6

MK I Horizontal Stabilizer

Stabilizer Structure

The MK I horizontal stabilizer is structurally indistinguishable from the Van's Aircraft stabilizer on the RV-7. The MK I has three main ribs which connect the front and rear spars (Figures 7 & 8).

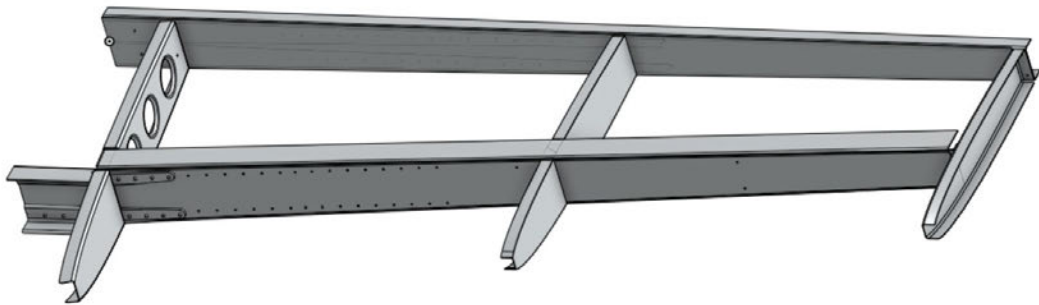


Figure 7

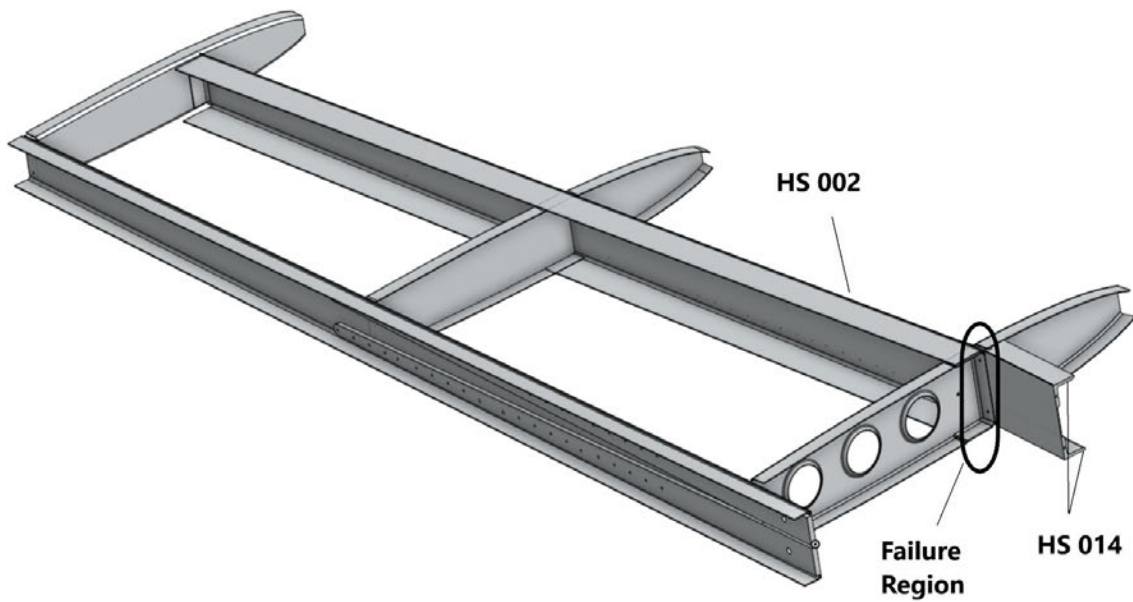


Figure 8

The failure region on the accident aircraft is at the bend in the HS 002 where the root rib, HS 002 and the HS 014s intersect.

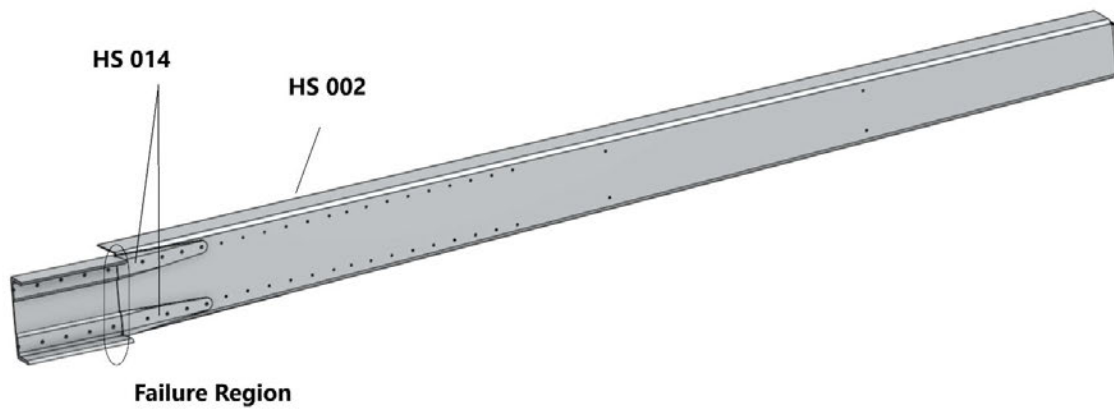


Figure 9

Figure 9 illustrates the region of interest without the root ribs in place. The HS 002 was originally manufactured with 2024 T3 .032" aluminum. Approximately 20 to 25 of the MK I designs were manufactured before transitioning to the MK II design that had an extensive spar assembly added to the back of the HS 002 in addition to the HS 014s. It is believed that either part way through the production of the MK I, or at the start of the MK II production a transition was made to .040" 2024 T3 for the HS 002.

Stabilizer Aerodynamic Considerations

The MK I is a symmetric NACA 0009 airfoil, and experimental data from NACA Report 759 “Pressure Distribution Investigation of a N.A.C.A 0009 Airfoil with a 30 Percent Chord Plain Flap and Three Tabs” was used to generate the Normal Force and Moment Curves for a number of possible angle of attacks and elevator deflections. The results of the analysis are summarized in Figures 10 and 11.

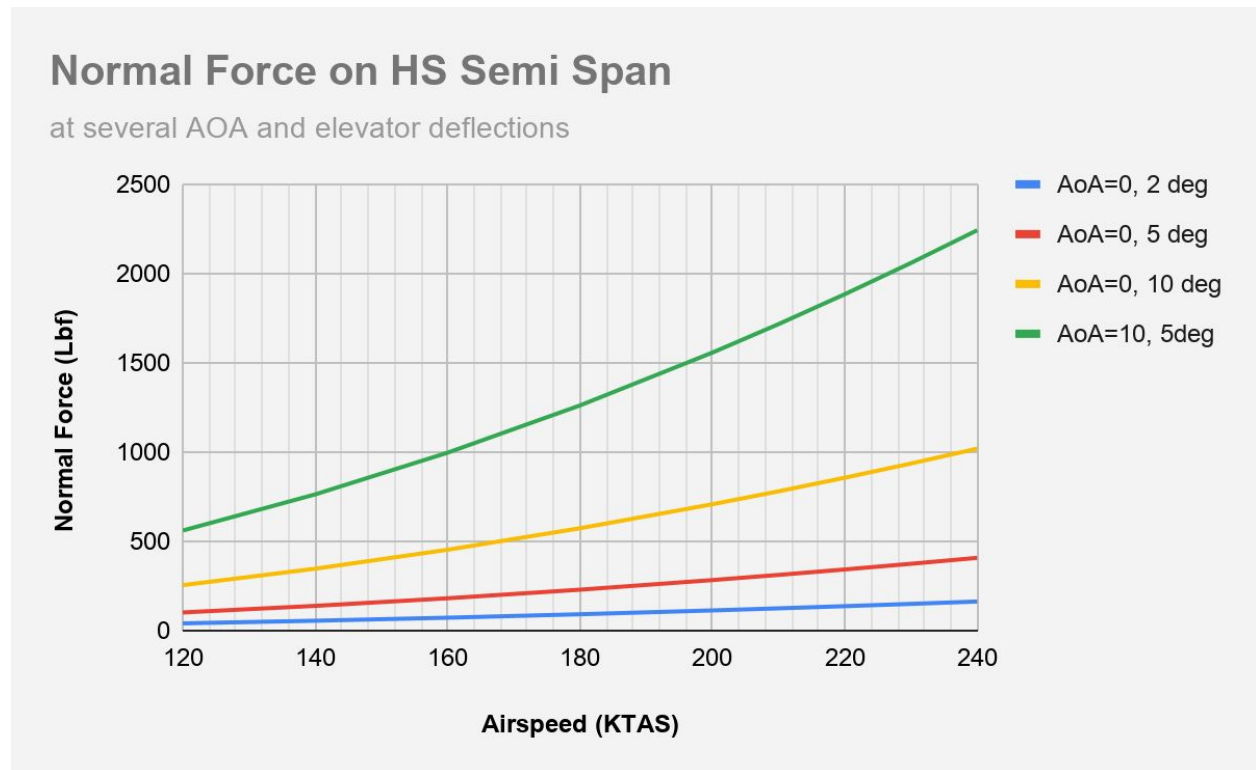


Figure 10

Pitching Moment HS Semi Span

at different AoA and elevator deflection

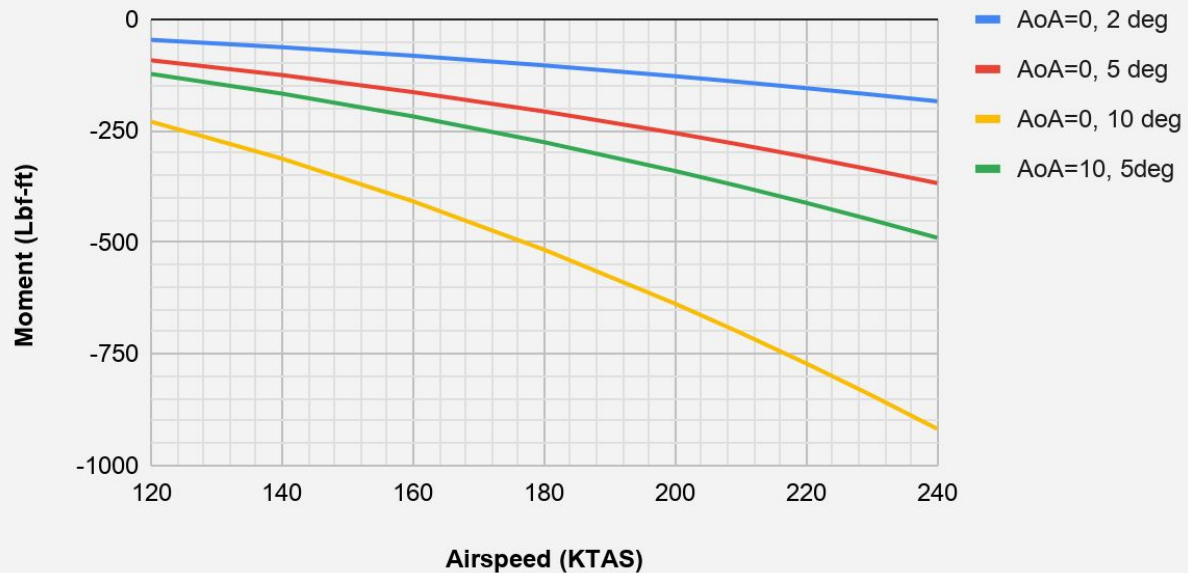


Figure 11

The MK I stabilizer is capable of generating considerable force and pitching moment, as can be seen from Figures 10 and 11. The increased stabilizer area from the original RV-4 stabilizer on the HR II design allows for better performance at low speeds but is problematic at higher speeds. Since both the tail arm on the F1 and the stabilizer area are both significantly greater than on the RV-4, the MK I design if flown aggressively at speed will generate high stress levels not only in the empennage but also in the rear fuselage.

In level flight, a properly trimmed F1 within cg limits needs approximately 100 lbf or less, well within the limitations of the design. However, if maneuvering speeds are not adhered to, it will be very easy to overload the front horizontal spar.

FEA of the MK I Stabilizer

A finite element model of the horizontal stabilizer was created to determine the critical loading areas in the stabilizer. The mesh size was gradually increased until enough resolution was obtained in the critical bend area of the HS 002. The final model had 5.5 million elements.

A number of different loading conditions were used to simulate a range of possible failures during flight. In all cases, the peak loads in the stabilizer were in the bend area of the HS 002. The load concentrations were high, with steep descending stress levels in areas a short distance from the bend. The normal force load was placed above the front spar and uniformly distributed. The moment was placed on the mid rib, at approximately the mean aerodynamic chord (MAC).

Load Case	Load (Lbf)	Moment (lbf-in)	Peak Von Mises Stress (MPa)
1	200	0	350
2	200	50	316
3	200	500	346
4	200	3400	540
5	200	6800	768
6	75	3370	343
7	75	0	117
8	-375	-3360	1130
9	140	0	303
10	375	-3360	497

Table 1

Figure 12 illustrates the Von Mises stress concentration in the bend area. The stress field in the stabilizer has been filtered to show stresses between 45 MPa and 1130 MPa. Note that the average stress level is only 7 MPa, and the nature of the stress concentration at the top and bottom of the HS 002 points to bending loads and not shear or potential buckling loads as the major problem.

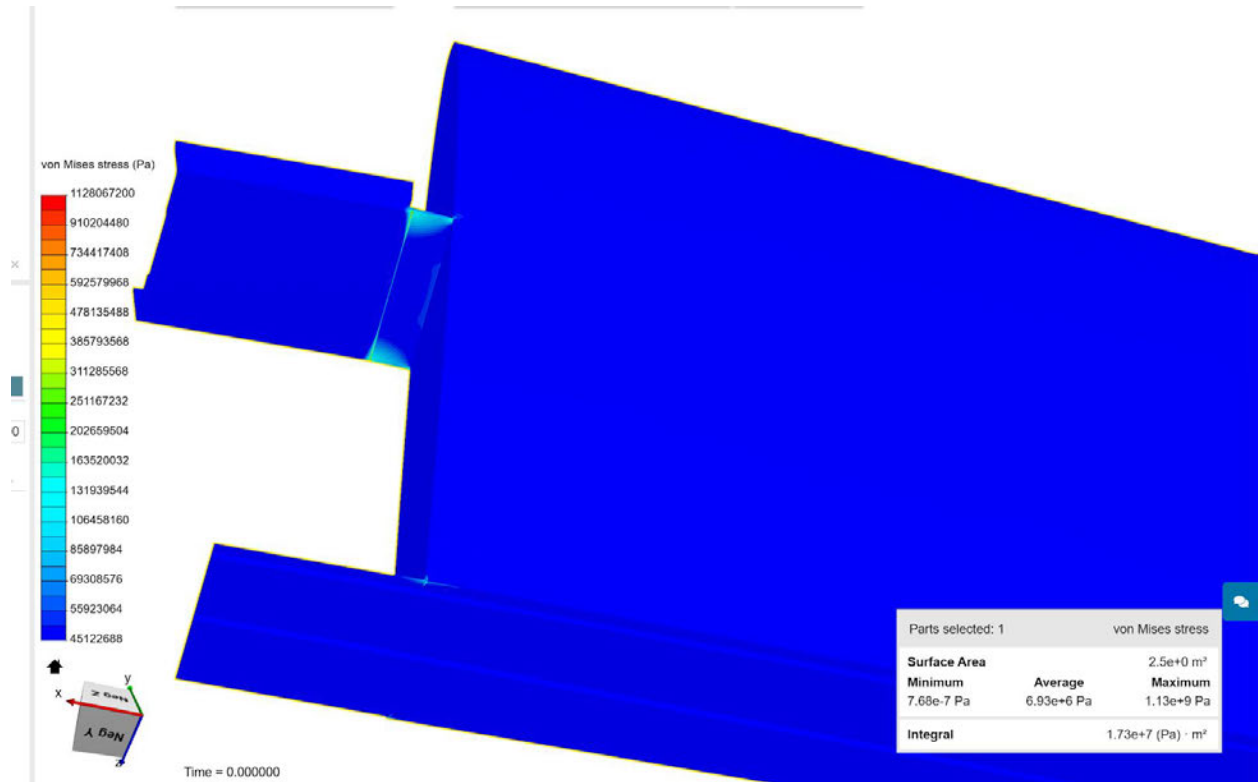


Figure 12

Figure 13 is a closer view of the affected area and shows that in the rivet area the part is fairly lightly loaded but in the bend area the stresses are over twice the limit load (470 MPa) of 2024 T3 aluminum.

The FEA model is a simplified version of the actual part in order to facilitate the computations. A more detailed model of the area in question would refine the peak numbers, and would possibly be lower than shown. The result, however, would be similar. This area is significantly more stressed than any other part of the stabilizer, and given the nature of any bends in highly loaded 2024 T3, this area is prone to cracking.

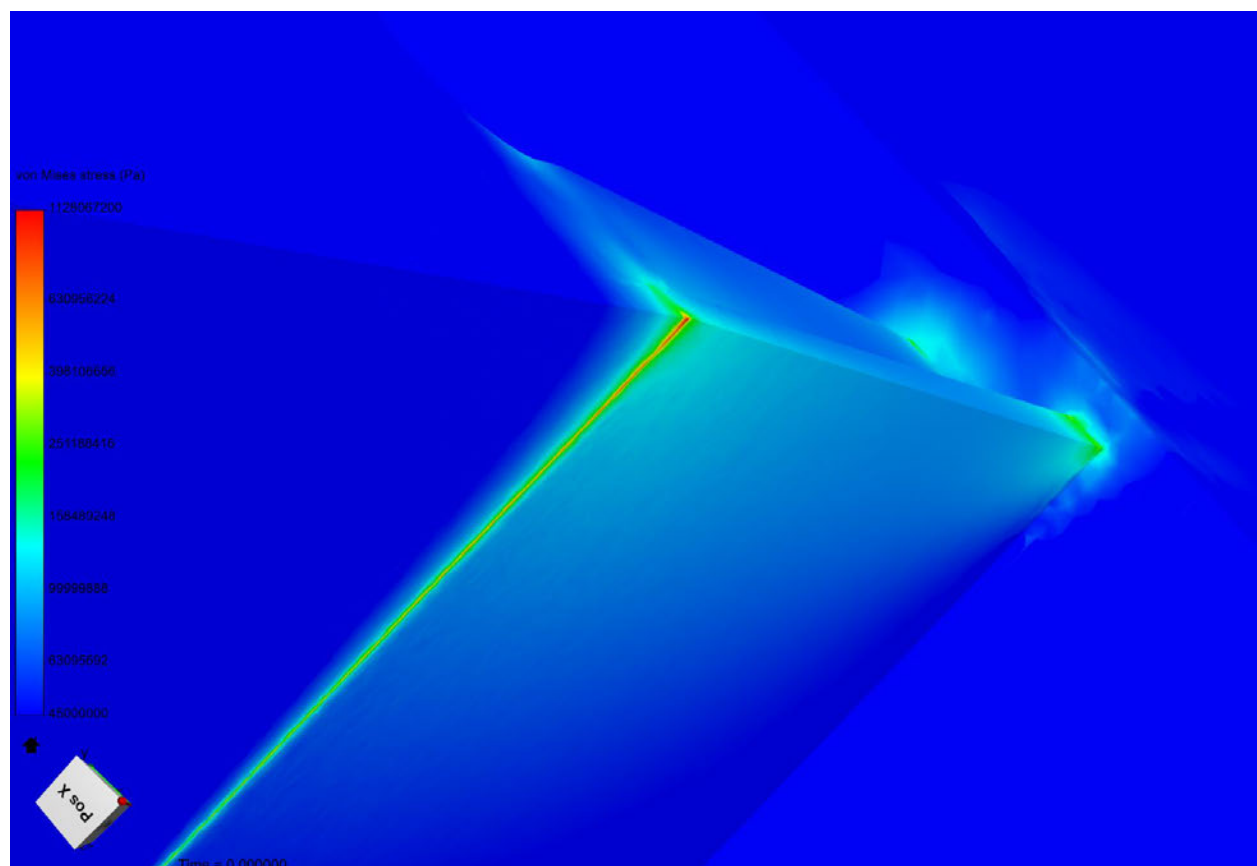


Figure 13

