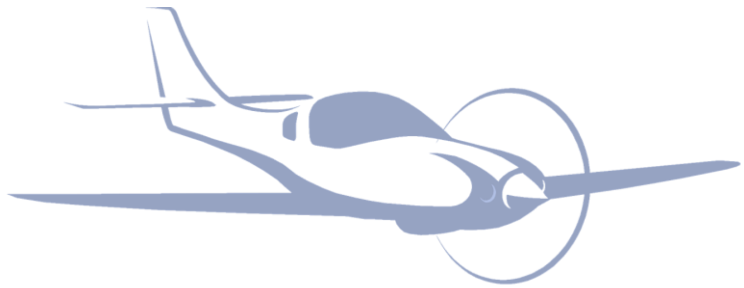

Lancair Legacy Canopy Safety Issue

April 27, 2014

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Preface

This paper was written to help improve the level of safety and reduce risks for pilots flying the Lancair Legacy airplane. Over the Legacy's almost 15 year operational history, there have been periodic accidents resulting from flight with the canopy unlatched/open. As those have occurred, the community debates the causes and preventative measures. The forum where the community comes together for these debates is the Lancair Mail List (LML). The lively debate is wide ranging with many viewpoints represented and always very helpful discussions. After these discussions, it can seem that everyone understands the effective measures for dealing with the issues. Yet, accidents related to flight without the canopy latched continue.

Why is this? Many Legacy pilots do not participate in the LML, might not even know of its existence, and do not have the benefit of the periodic LML debates on this issue. And, even for those on the LML, with all the various views and weeks over which the discussions occur, it can sometimes be difficult to see a focused path forward. The Lancair Company has also not taken an active role in addressing this issue.

So, this "paper" was created, to be placed in the public domain, to provide another communication vehicle to the broader Lancair Legacy community where information on this issue is consolidated for easy discovery and specific recommendations are presented. The completed paper will be posted on several websites, where in time it will come up on website search engines, and will be sent to the email addresses of every Legacy pilot that can be found.

The following fine people have made important contributions to this paper and have my deepest gratitude.

Scott Alair
David Williams
Bill Bradburry
Fred Moreno
Doug Brunner
Art Jensen

Paul Miller
Jim Thomas
John Smith
Jon "Jack" Addison
Dennis Johnson
Allyson Thorn

I believe I speak for us all in saying that it is the hope for other pilots and ourselves that we all enjoy a long life flying the amazing Lancair Legacy airplane and that there be no further losses to our pilot family or damaged airplanes from this open canopy flight hazard.

[redacted]

Valin Thorn

Boulder, Colorado USA
March 21, 2014

Contents

Introduction

One of the great joys of aviation is the visual splendor of flight and the Lancair Legacy's large bubble canopy makes that about as good as it can get.

Carl Lewis and His Legacy over Oregon

The Legacy's canopy, though, can create a catastrophic flight hazard if it is not securely latched for flight. In the Legacy's flight history to date, there have been seven known flights with the Legacy's canopy unlatched resulting in three fatal crashes, two crash landings with significant aircraft damage and/or pilot injuries, one aborted flight immediately after takeoff with minor damage, and one flight without incident. There are also two other fatal Legacy accidents after takeoff without enough evidence to draw conclusions as to their cause though flight with an unlatched canopy is a possibility.

There are several potential root causes of the Legacy's open canopy flight hazard. One is the canopy is large and, if not latched down in flight, it will open to varying degrees and alter the air flow over the tail/stabilizers and under some situations create significant pitch attitude stability and control issues.

Another potential root cause may be the pilot's loss of reliable airplane pitch attitude reference where the canopy's structural frame serves as a key attitude reference line and as the open canopy moves it corrupts the pilot's normal visual pitch attitude reference cues.

There may also be a tendency for pilots flying with the shock and chaos of an open canopy, with severe cockpit wind, noise, and debris flying about, to induce pitch attitude oscillations by their control inputs.

The purpose of this report is to collect the known information on this issue, inform the broader Lancair Legacy community of this catastrophic flight hazard, help understand the hazard and its influences, present strategies for effectively controlling the hazard, and help Legacy pilots enjoy long lives flying their amazing airplanes.

The Evidence

26 August 2005 N345MW Hohenhems, Austria

Source: News report and associates of accident pilot

Pilot Wolfgang Mascheck just wanted to make a short local flight before the airstrip closed and in his haste he forgot to latch the canopy. The Hohenhems, Austria runway is only 2000 ft long, so there was no room for errors.

Maschek's Legacy N345MW

After takeoff the canopy popped open, Wolfgang could not see forward, and the aircraft was very difficult to control. It's unknown if he tried to close the canopy. He reduced power and tried to land directly ahead in fields beyond the runway.

The plane lost the wings on the very hard touch down. The fuselage broke behind the seat and ejected Wolfgang out of the plane. It was a muddy soft grass field and the engine was buried in the mud.

Matscheck suffered serious injuries with two broken legs and bones in his face. The airplane was destroyed. Matscheck fully recovered and has not returned to flying.

N345MW Wreckage

Austrian Legacy builder Helmut Burner was able to contact Wolfgang Mascheck in Austria and get him the second draft of the Legacy Canopy Safety paper for review. Here's Helmut's German to English translation of Wolfgang's letter to him regarding his unlatched canopy accident, below.

Hi Helmut,

Thank you for the mail!

Something about myself: I am now 62 years old, and had an advertising agency in the Switzerland. I learned to fly at 16 (at that time, gliding), and have a CPLII, no IFR, had owned my own planes already before a Mooney and have approximately 2300 h. flying time.

The Legacy Kit No. 52 I started building it in 2001 at Redmond with Lancair and finished it at the spring of 2003 in Hohenems where I made my first flight. The approval was carried out by the FAA with license plate N345MW. I had at the time two FAA controller from Washington here in Hohenems and had with the Legacy till my emergency landing in the fall of 2005 wonderful flights.

The Legacy is an aircraft with really good handling characteristic. The angle of attack system allowed me even in Hohenems on the short airfield (630m) always good landings.

The accident is very well described in your canopy safety report.

To the background of my accident:

The canopy was always very important for me because I knew of the danger. Also the accident in Lake Country got me thinking. I had a built-in warning light and nevertheless I previously briefly made a manual pressure check every time before taking off.

Two years ago I read a US review of two Legacy pilots who dared to open the canopy in cruise flight.

They described that at that time they opened the canopy at 220 kts it moved upwards about 2 inches so 5 cm. that means, the pressure in the cruise is higher compared to the lift, so that the canopy was not raised more than that . Then they tried to close the canopy but couldn't do that during flight.

The two pilots on board were able to land without problems because one was holding the canopy at the present position so that it couldn't move.

At my former misfortune flight, the situation was as followed:

I wanted to start this evening at 07:30PM for a short sightseeing flight. The airfield restrictions are that there are only landings till 08:00 PM allowed. I wanted to fly so only 20 min. Still 10 minutes went by until the run up were done and so I got something under time pressure. The canopy was already closed and locked?

At the start, under time pressure, I did not make the manual pressure canopy check this time unfortunately! Shortly before airborne, it popped up, but I had already too much speed to abort the takeoff. Because of the short runway and knowing after the short paved runway is a small ditch and on the basis of the above report, I thought it will be not so bad to fly with the canopy open -- and flew the airplane.

Because I couldn't see forward I had to hold down with one hand the canopy and of course to climb and the upwards lift forces were very high and I had no view and thus no free hand more to move the suspension, throttle or to use prop, flaps, etc.

And in such conditions I thought it is impossible to land: So full throttle out and into the pasture at the end of the runway. While I tried that I stalled the plane and you know the rest of the report.

But now the question: Why wasn't the canopy locked?

I had an inflatable canopy seal. When I closed the canopy it grazed on this rubber hose something and I had to press it down briefly in order to latch it. If this down pressure was not made the lock could not hook up in the canopy and it then passes below the Canopy latch. Therefore not locked! -because I have not done this short down pressure.

Hey if you should not understand this I will explain it to you at the meeting.

Helmut, I'm looking forward to our meeting in Hohenems.

Many greetings,

Wolfgang

Summer 2006 N495SL Sierra Sky Park, Fresno, California, USA

Source: Pilot Scott Alair (Pvt, ASEL)

Lancair Mail List Post, 7 Nov 2013: On a hot summer day in 2006 at Sierra Sky Park airport in Fresno California, I taxied to runway 30 (2473ft. X 50ft) with my canopy open resting on my arm. When I taxied on to the runway I did not push up on the canopy to check that it is latched (I do now). When I rotated at about 80 kts I was startled by the sudden noise and wind of the canopy coming open about 3 inches at the rear edge. I knew I could not stop on the remaining runway, so I continued with a normal takeoff. I left the flaps at 10 degrees, climbed at 120kts to 1,000 ft AGL and trimmed the plane for level flight (I do not have an autopilot). I then put my hands on the trailing edge of the canopy frame and tried to move it (it had been in a stable open position so far). I could close it about 1 inch and open it about 1 inch farther but that was as far as I could move it. At this point I decided to return to land, I flew a normal pattern, as I flared for landing the canopy opened another 2 inches. Throughout the flight the canopy never oscillated or affected the control of the aircraft.

Email to Author, March 2014: I don't have much to add to my existing "story" but I will try to answer any questions best as I can. Keep in mind this happened almost 8 years ago and at the time I considered it a "Non-event" and did not even make a log book entry about it.

I think the most important thing to remember is my mindset at the time my canopy came open on takeoff. Previous to this event I was a pilot and or passenger when a door came open just after liftoff. This happened twice in a Bonanza and once in a Piper Arrow. On all three occasions we were not able to close the door in flight and returned for a normal landing. I believe because of my previous "open door experience", I was able to remain calm when my Legacy canopy opened.

Here's my best guess at the "numbers" for my open canopy flight. I used the power that was required to maintain 120 kts with 10 deg flaps and the gear down. I don't know what it was. I was solo and no baggage and I normally do local flights with half tanks, so the aircraft weight was probably about 2,000 lbs with a C.G. 35% aft of the FWD limit.

Scott Alair and N495SL

13 April 2008 N1177M Lakeland, Florida, USA

Source: NTSB.

According to witnesses, the pilot was observed having difficulty closing the canopy on the airplane prior to takeoff. During the takeoff climb, a witness said he saw the cockpit canopy moving and believed the pilot was pushing it up and down about 6 to 12 inches. Another witness stated that shortly after takeoff, the engine lost power and the airplane continued straight and level. Another witness stated that she saw a plastic bag float down from the sky shortly after the airplane passed over her location. The bag contained several of the airplane's documents inside of it. The airplane then nosed down about 40 degrees and the left wing dropped as the airplane stalled and collided with the ground. A post-crash fire ensued which consumed part of the engine and the majority of the airframe, including the canopy latching system. Examination of the available wreckage did not reveal any evidence of pre-impact failures or malfunctions. The pilot Gerard Schkolnik, (Aeronautical Engineer, Private, ASEL) age 44, was fatally injured.

Photo of N1177M on takeoff before crash, note open canopy

N1177M crash site, wreckage (Photos: The Ledger.com)

18 October 2008 N151HT Parawan, Utah, USA

Source: NTSB.

During departure, witnesses in the area reported that the airplane appeared unusually low and then entered a left turn. As the airplane entered the turn, items from the cockpit fell from the airplane. The airplane continued in the left turn until it impacted the ground. Examination of the wreckage revealed no evidence of pre-impact mechanical malfunction. The airplane, by design, does not have a cockpit indication for the security of the canopy. Structural documentation of the canopy latching mechanism did not reveal any damage to the latching mechanism, which is indicative of it not being latched when the airplane impacted the ground. Based on post-mortem toxicology results, the pilot had likely recently used two different prescription painkillers that commonly result in impairment, and that may increase risk of seizure, particularly when used together. Based on his height and weight, poorly controlled blood pressure in spite of the use of at least two different medications to lower it, and the presence on autopsy of right-sided heart enlargement, he likely had obstructive sleep apnea, a condition associated with fatigue and cognitive impairment. His response to a real or perceived emergency may have been impaired by the medications themselves, by a seizure induced by the medications, or by the effects of possible obstructive sleep apnea. The pilot did have a single blocked small coronary artery, but the condition had been present and evaluated just over two years prior to the accident, with evidence of good blood flow in spite of the blockage. It is unlikely that the blockage was related to the accident. The pilot had not indicated high blood pressure, use of medications to treat high blood pressure, or use of prescription painkillers on his most recent application for airman medical certificate just over 16 months prior to the accident. The aircraft was destroyed.

The pilot William Grant Phillips (Physicist, ATP, ASMEL, SES, Balloon, Glider, Helicopter, CFI), age 59, was fatally injured. His wife Janice was seriously injured.

N151HT Photo

6 February 2009 N939CB Longmont, Colorado, USA

Source: Pilot David Williams.

Lancair Mail List Post, 9 February 2009: After refueling at the Self Service fuel pump at Longmont Airport (KLMO) at around 5:30 pm, I taxied out the to the run-up area for Runway 29 and did the run-up and take off check on N939CB a Lancair Legacy (LEG2). The takeoff proceeded normally until the point of rotation at which time the canopy popped open slightly. As the runway is short (4800') and I was full of fuel, I continued with the takeoff as I felt that to try to abort was more dangerous than just going around and landing again. Without event, I climbed to pattern altitude, 1000 AGL, and reduced power to prepare for landing. At that time, the canopy assumed a much more open position and started to oscillate up and down (6" to 12" motion) also causing the aircraft to be very difficult control in pitch (at least 6" stick movements where normal is 1" to 2"). I tried to resume the full power climb attitude again as I thought the change of attitude may have caused this, but this only exaggerated the situation. My concerns were the large oscillations of the canopy, my restricted forward visibility, and the violent pitch changes. I continued with the approach and tried to look out the side opening of the canopy to get myself in a position to land on Runway 29 and avoid any other property damage. I kept the airspeed at around 110 knots with significant power to maintain as much control as possible over the oscillations, but only remember trying to minimize them on final when I impacted the ground.

I believe that when the canopy was sucked up far enough that it blanketed the tail causing the aircraft to pitch nose down, causing the closing of the canopy there in turn causing the elevator to become effective again which then allowed me to regain control and level again, which caused the canopy again to open, etc., etc.

Email to Author, 5 March 2014: I think this probably sums it up, other than to say I was full of fuel and no flaps. I know that when I takeoff out of Longmont, I am usually hot as the runway is short and it has flat fields at the end. So the climb would have been at 120+. This means low AOA, which probably kept things under control until I throttled back on downwind slowing, and allowing the AOA to become larger.

Email to Author, 6 March 2014: The most memorable part of this incidence, was when I powered back on downwind and the canopy opened enough that I could see the ground between the lower rim of the canopy and the engine cowling, as I pitched down. And until we held your canopy up to that level, I have not till now realized how far it was open. Definitely a problem here.

From conversation between Dave and the author:

> *David said on final approach, the canopy opened so far that the runway could not be seen straight ahead. When looking to the side for reference, the wind blast was so high that it blew his eye glasses off his face. On landing, his Legacy's landing gear sheared off, skidded through fence posts, with significant damage.*

Pilot David Williams, (Electrical engineer, Comm, Inst, ASEL, AGI, IGI, CFI), had minor injuries.

N939CB After Open Canopy Crash Landing

18 September 2013 VH-ALP Geraldton, Australia

Source: Australian Transportation Safety Board (ATSB).

On 18 September 2013, the owner-pilot of Lancair Legacy aircraft, registered VH-ALP, was intending to conduct a private flight from Geraldton to Newman, Western Australia. At 1545 Western Standard Time1 the pilot taxied at Geraldton Airport for runway 32, an 884 m sealed strip.

The pilot began the take-off roll with substantial engine power and the aircraft was observed to accelerate normally to about halfway along the runway. At this point, smoke from the main wheels indicated that the brakes were applied momentarily, and at about the same time the forward-hinged canopy opened about 15 to 30 cm. No change to engine power was evident and the take-off roll continued.

The pilot lifted off with runway to spare and climbed to about 100 to 150 ft above ground level. The pilot banked to the left and during the turn the canopy opened further so that it was at an estimated angle of 30°. Various people on the ground saw the aircraft flying low and fast with the canopy open.

The pilot appeared to be maneuvering for a landing on runway 08 but the aircraft wheels hit a road curb short of the airport perimeter. The aircraft then collided with the perimeter fence and became entangled as it overturned. Shortly after, an intense fire engulfed the aircraft.

VH-ALP Photo and Crash Site

Bystanders tried to extinguish the fire with handheld fire extinguishers and a water truck but were unable to have immediate effect. The pilot, Gerry Gould, age 60, was rescued from the wreckage and treated for, but later succumbed to his injuries.

N249B Pilot Bill Bradburry

LML Post 9 Sep 2013: The Legacy can NOT be flown safely with the canopy unlatched! If you take off with the canopy unlatched, you MAY survive…I did! You MAY not damage the plane…I did! Several others have not survived. It is a harrowing experience! I now check the canopy latch several times before each takeoff!

When the canopy is closed it takes a little extra force to move it up off the canopy seal, then it is easier to raise and you have the gas struts helping you. So at about 60 knots, the canopy will suddenly pop up and go all the way or nearly to the stops. This action blanks off the elevator and you lose pitch control. The canopy then is blown back down and you temporarily regain pitch control before it is sucked back up for another round. By the time it is headed back up the second time, you had better have the power off and using that short instance of pitch control to get the plane either on the ground or close enough for a hard landing. If this happened at 100 feet or so, flowers would be in order.

It is possible that you could unlatch the canopy at cruise speed and it would only open a few inches, but when you tried to land, the lack of prop blast would put you back into this regime. I don't recommend trying any of it. Latch the damn canopy!

LML Post 20 Sep 2013: It was a stupid pilot trick that I hope nobody else feels the need to do. The surprise of the canopy popping up at such a critical time can be devastating. My first reaction was to reach up to grab it, but I immediately realized the futility of that and pulled power and grabbed the stick and 'put er down!'

The damage was a toe in change on the left main and the operating limitations blew out and were never recovered! Luckily I had made a copy of the limitations.

The Hazard & Potential Causes

The collective evidence of accidents, incidents, and pilot reports suggests three potential root causes, acting alone or in combination, that can make the Legacy's pitch attitude very difficult to control with the canopy unlatched -- potentially leading to loss of aircraft control, inadvertent aerodynamic stall, or insufficient attitude control precision necessary to perform a safe landing.

One can argue that the root cause of this hazard is pilots taking their airplanes into the air without their canopy latched. And, although the Legacy designers surely did not design it for flying with the canopy unlatched – most light aircraft can be safely flown with their doors unlatched. The evidence suggests this is not usually the case with the Lancair Legacy… So this section discusses the potential causes for why flying a Legacy without the canopy latched has a high probability of resulting in injury/death of the pilot and passengers and/or damage to the airplane.

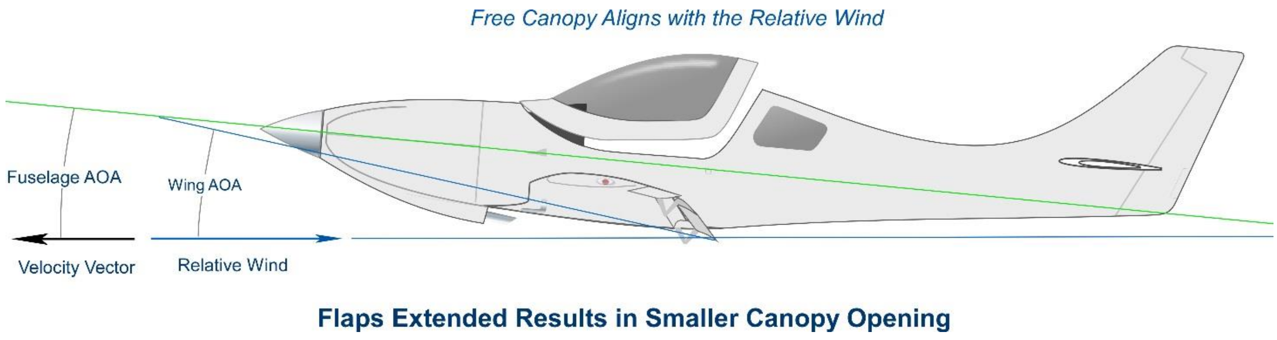
It is useful and relevant to each potential cause to first better understand how the Legacy's canopy responds in flight when not latched.

With the canopy unlatched, it will tend to align with the relative wind with a slightly negative angle of attack as it seeks equilibrium with the aerodynamic pressures acting on it. Its curved surface results in a measure of lifting force that pulls the canopy open until the pressures acting on both sides results in the same torque about its hinge line and it stabilizes in an open position.

The degree of canopy opening is primarily a function of the relative wind the airplane's fuselage sees, to be called here the "Fuselage AOA", with the airplane's Side Slip Angle (Beta) likely playing a role as well. Since the canopy is for the most part aligning with the relative wind, it's the Fuselage AOA that is a key driver in how far it opens.

Lower speeds with higher AOAs will result in the canopy opening farther than higher speeds and low AOAs. Extending the flaps will also result in lower Fuselage AOAs and smaller opening of the canopy. See the following illustrations.

Flaps Retracted Results in Larger Canopy Opening



Illustrations of canopy opening with flaps retracted and extended

Non-zero beta angles/side slip can also be expected to change the canopy pressure distribution and cause it to open farther for the same Fuselage AOA.

One way to visualize the canopy open flight dynamics is to imagine the canopy stays constantly aligned (for the most part) with the relative wind, while the rest of the airplane rotates in pitch about it.

Open Canopy Disrupting Airflow Over Stabilizers

One potential root cause of the Legacy's apparent unlatched canopy pitch instability is the separated turbulent airflow downstream of the open canopy affecting the horizontal stabilizer's angle of attack (AOA), disrupting smooth flow of air over a portion of the stabilizer, changing its effective coefficient of lift, and also reducing the effectiveness of the elevator control surface. When the canopy is open less than about 3 inches, the less separated disturbed airflow has little noticeable effect on the airplane's pitch stability and control. Beyond about 3 inches of canopy opening, the airflow disturbance is large enough to cause unstable pitch control.

David Williams reported that in this unstable condition, about three times the normal control stick movement was required to achieve his desired pitch attitude corrections.

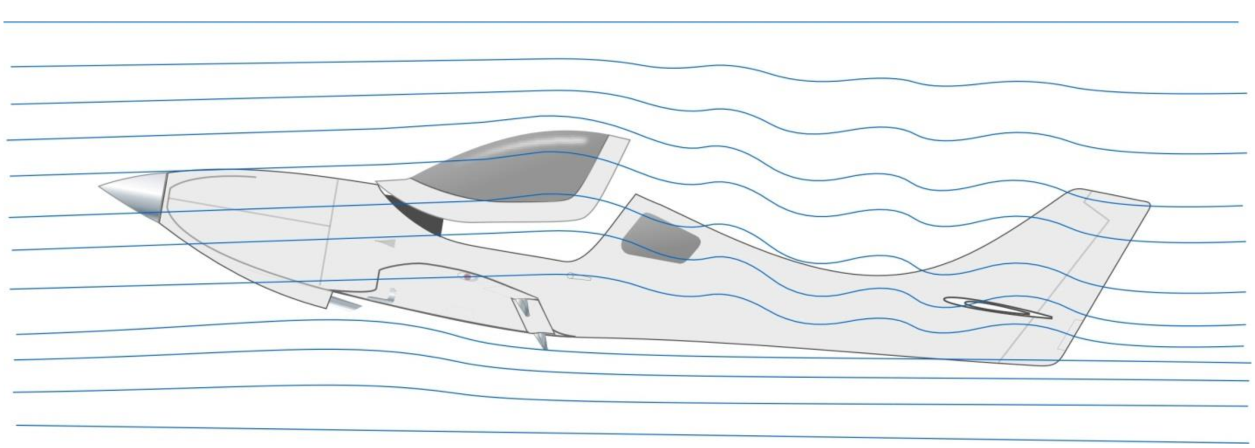


Illustration of disturbed air flow over stabilizers with canopy open

Open Canopy Visual Pitch Attitude Reference Corruption

The principle means of controlling an airplane's flight is by controlling its flight attitude – pitch, roll, and yaw. Pilots depend on key visual cues for precisely controlling flight attitude – the Earth's horizon line (where sky meets the ground) and the lines of the aircraft structure as seen from the pilot's seat looking forward. In the Lancair Legacy, these aircraft structural reference lines are formed by the nose, instrument panel glare shield, and the structural framework of the canopy. Because of the Legacy's relatively low pilot eye point height, the view of the nose/cowling can barely be seen if at all, putting more emphasis on the lines formed by the glare shield and canopy frame.

The illustration below shows an example sight picture of the visual attitude reference for the Legacy.

Legacy cockpit sight picture, visual pitch attitude reference

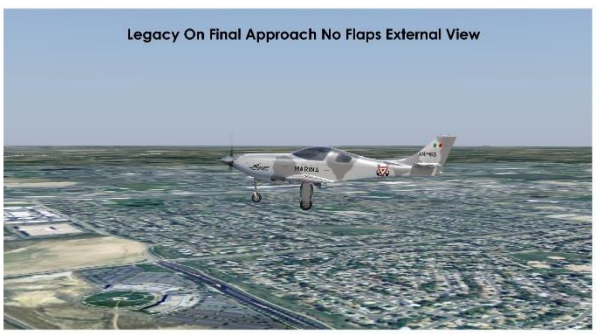
In an unlatched canopy flight case, the canopy structural frame reference moves with changes in Fuselage AOA, airspeed, and side slip angle, corrupting this important visual cue for pitch attitude reference. The images below illustrate the changing sight picture of the pilot with and without the canopy opened and in a flaps retracted and extended configuration. They were created using Microsoft Flight Simulator X with the Real Air Lancair Legacy model, which has accurate enough modeling of the Legacy to be useful in examining these elements.

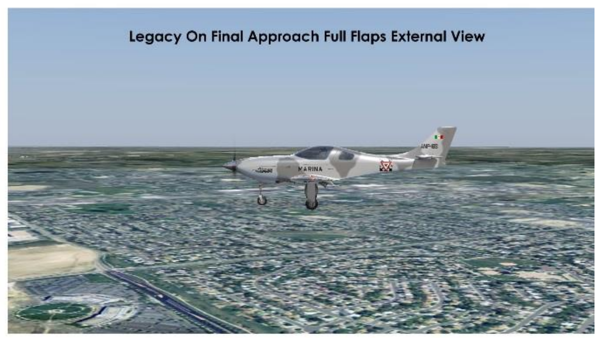

Canopy Closed On Runway External View


Canopy Partially Open On Runway External View


Canopy Closed On Runway Pilot View


Canopy Partially Open On Runway Pilot View


Legacy On Final Approach No Flaps External View


Legacy On Final Approach Full Flaps External View


Legacy On Final Approach No Flaps Pilot View


Legacy On Final Approach Full Flaps Pilot View


Legacy On Final Approach No Flaps, Canopy Open, Pilot View


Legacy On Final Approach Full Flaps, Canopy Open, Pilot View

To understand this dynamic, it's helpful to examine either of the images in the last two rows where the second row from the bottom is the Legacy on final approach with the canopy closed and the bottom images are the exact same airplane location and flight attitude but the canopy is open several inches. The images with the flaps extended are shown in larger scale below. The left photo column is with no flaps and the right is with full flaps. As the canopy moves up, the view of the nose is lost, the instrument panel glare shield reference is obscured, and the canopy frame location can make it seem as if the airplane has been pitched nose down significantly.

Legacy view on final approach with canopy closed and partially open

In canopy open flight, as the airplane's speed, power, and configuration changes, the pilot's visual pitch attitude reference can be seriously corrupted.

Open Canopy Pilot Induced Oscillations (PIO)

"A pilot-induced oscillation (PIO) is an inadvertent, sustained aircraft oscillation which is the consequence of an abnormal joint enterprise between the aircraft and the pilot. In one form or another these fascinating and complex pilot-vehicle interactions have been around since the Wright Brothers." -- Duane McRuer, NASA Contractor Report 4683.

It is worth pointing out that engineering specialists in PIOs often advocate changing the name of this phenomena because it implies faulty pilot control inputs are responsible for the oscillations when in fact it can be the fault of the aircraft, the pilot, or both contributing to the PIO dynamic. According to McRuer quoted above, "some investigators prefer to speak of "Aircraft-Pilot Coupling" or "Pilot-Augmented Oscillations"" to avoid the pejorative implications.

This point is emphasized here – that a PIO does not necessarily mean the pilot provided faulty control inputs – because as PIOs are seen as a potential cause of these tragic open canopy accidents, some tend to discount the need for any action on this issue. They believe that the pilots of the accident aircraft simply panicked, over controlled their airplanes, and they'll make sure if it happens to them they won't do that… PIOs are complicated, with many influences, and if they are the cause of the accidents flying with the canopy open, the accident history indicates simple "don't panic" advice is not going to resolve this issue.

There are several types of PIOs and various causes of the phenomena which won't be explored in this discussion. For those wishing to understand PIOs in more detail, a simple website search engine will provide many educational resources on the subject.

There has been speculation in the Lancair community that the open canopy pitch instability described by surviving pilots was actually PIO because one of the pilots, Scott Alair, did not experience any pitch instability. Also contributing to this speculation, is the fact that the Legacy's ancestor Lancair 360, has a history of numerous canopy open flights without incident. It should be noted, though, that the 360 and Legacy are different enough aerodynamically that drawing conclusions for the Legacy based on the 360's open canopy flight performance is too much of an extrapolation.

Most assume any PIOs are a kind of "panic response" to the startling surprise and chaos of an open canopy on takeoff. Aggressive pilot control responses resulting from the shock of the canopy opening can likely lead to PIOs. There are other factors, though, which can also contribute to PIOs when flying with an unlatched canopy.

For the context of this discussion and the Legacy having direct mechanical linkage between the pilot and flight control surfaces (no electronic flight control system and stability augmentation) PIOs can likely be induced or encouraged by:

- Applying aggressive (high gain) pilot control inputs

- Applying control inputs out of phase with the response of the airplane
  - Changes in the airplanes pitch stability and control with disrupted airflow over the horizontal stabilizer, -- normal pilot response, abnormal aircraft response
  - Corrupted pitch attitude visual cues corrupting pilot control response/inputs
- Excessive latency in the control mechanism response to pilot input
  - Excessive hysteresis (slop) in the control system mechanisms
  - Excessive friction in the control system mechanisms

Disrupted airflow over the horizontal stabilizer and the elevator's effectiveness could alter the airplane's response in pitch from its normal response.

The open canopy changes in the visual cue for pitch attitude can also corrupt the pilot's response to perceived attitude changes. For example, as a pilot pitches up to a higher AOA, the canopy opens farther which can create a visual pitch reference that the airplane's pitch went nose down or at least didn't change as much as expected, causing the pilot to apply additional pitch up control input. The cycle would likewise continue with pitch corrections down where the moving canopy now moves toward closure corrupting the pitch visual cue in the other direction. So the corrupted visual pitch attitude cues and the potential for PIOs could be linked.

The Legacy's mechanical control system using push rods in pitch and roll have very low hysteresis and friction and are not likely to contribute an excessive latent response to pilot control inputs.

PIOs, and the factors contributing to their onset, are a potential cause of the loss of control crashes in flying with the canopy open.

Commentary on Potential Root Causes

How does one look at the evidence and the potential root causes and reconcile that in Scott Alair's open canopy flight, he had normal flight control, was simply inconvenienced in having to return to the airport to latch his canopy down, while several other pilots lost control, crashed, and died?

In terms of the "Open Canopy Disturbed Airflow" explanation, one could argue that Scott's airplane was flown at a lower AOA during its entire flight compared to the other canopy open flights. Scott's airplane was very lightly loaded at only about 2000 lbs gross weight, he kept takeoff flaps down, and maintained about 120 KIAS throughout the flight. David Williams' flight, for example, had just taken on full fuel, flew the approach at around 110 KIAS, and with no flaps – so a higher AOA and Fuselage AOA throughout the flight, perhaps placing him in a high Fuselage AOA region of pitch instability.

In terms of the "Corrupted Visual Pitch Cues" explanation, one could argue that Scott maintained relatively high speed and a constant configuration from takeoff to landing (120 kts, gear down, takeoff flaps) so the canopy didn't move much during the approach and landing (until flare) so his visual pitch cue was not substantially affected. In David William's flight, he retracted flaps, slowed his approach speed, and not only had corrupted pitch attitude visual cues, but could not see the runway ahead given the airplanes attitude and open canopy.

In terms of the PIO explanation, one could argue that Scott continued to apply smooth control inputs while the crash pilots aggressively applied control inputs and induced pitch instability.

There has been much concern from many in the community over just exactly what is going on when the Legacy is flown with the canopy open such that several pilots have been killed or injured and airplanes destroyed or damaged.

I contend that it really does not matter. Whatever the dynamic or "root cause" is, the key to effectively solving the problem is to make sure no one gets a Legacy airborne without the canopy latched.

The point is that no matter what is causing the havoc for most pilots when the canopy opens on takeoff, there are simple options available to just make sure no one gets a Legacy into the air without the canopy latched… How much more energy needs to be spent on figuring out exactly why flying with the canopy open is a serious problem when there are simple, cost effective options available to make sure it doesn't happen again?

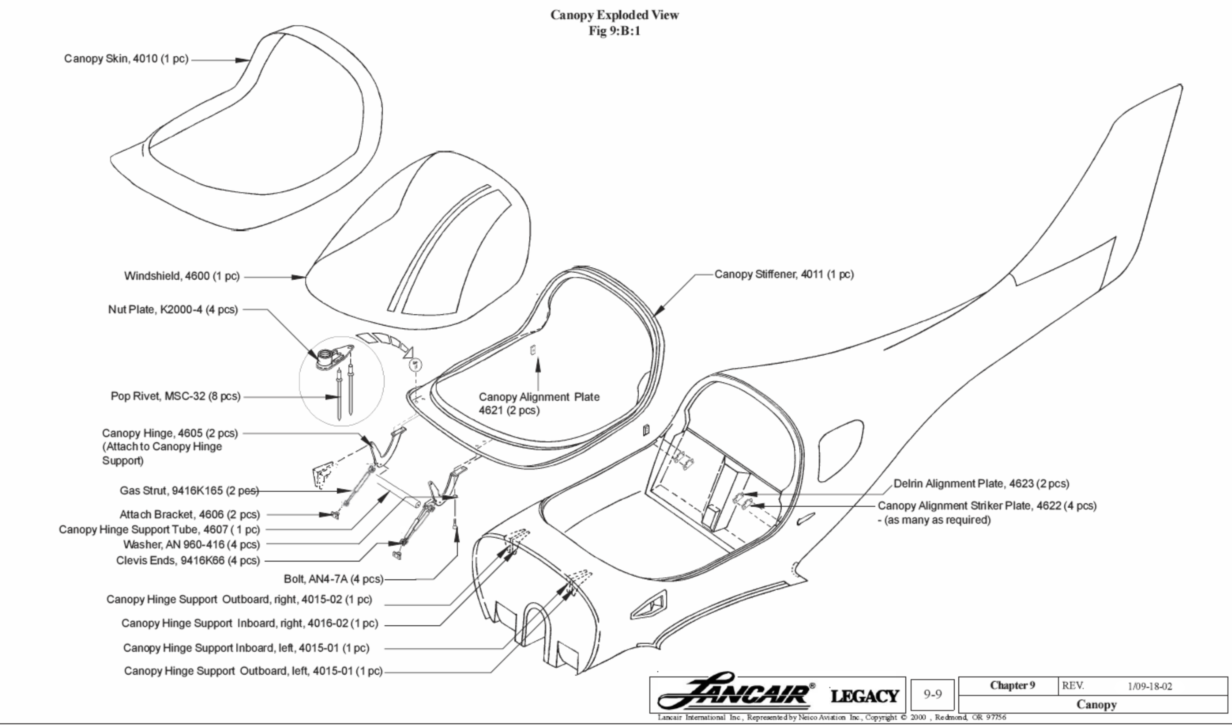
Background -- Legacy Canopy Design

The Lancair Legacy was not designed for flight with the canopy unlatched/open. The Legacy's canopy is hinged at the front with mechanical latching claws on each side of the aft cockpit opening that engage with latching plates on the aft canopy frame. The latching mechanism is engaged and disengaged by a lever between the pilot seats and an exterior control lever on the left side of the fuselage below the canopy. The canopy sits down in its closed position and is latched by lowering the lever between the seats. The design allows the canopy to rest in its closed position without being latched.

Photo of Rob Logan's Tweedy Bird Legacy with Canopy Open
(Rob likely has the highest time Legacy flying)

The following excerpts from the Lancair Legacy canopy construction manual provide detail on the canopy and latching mechanism design.

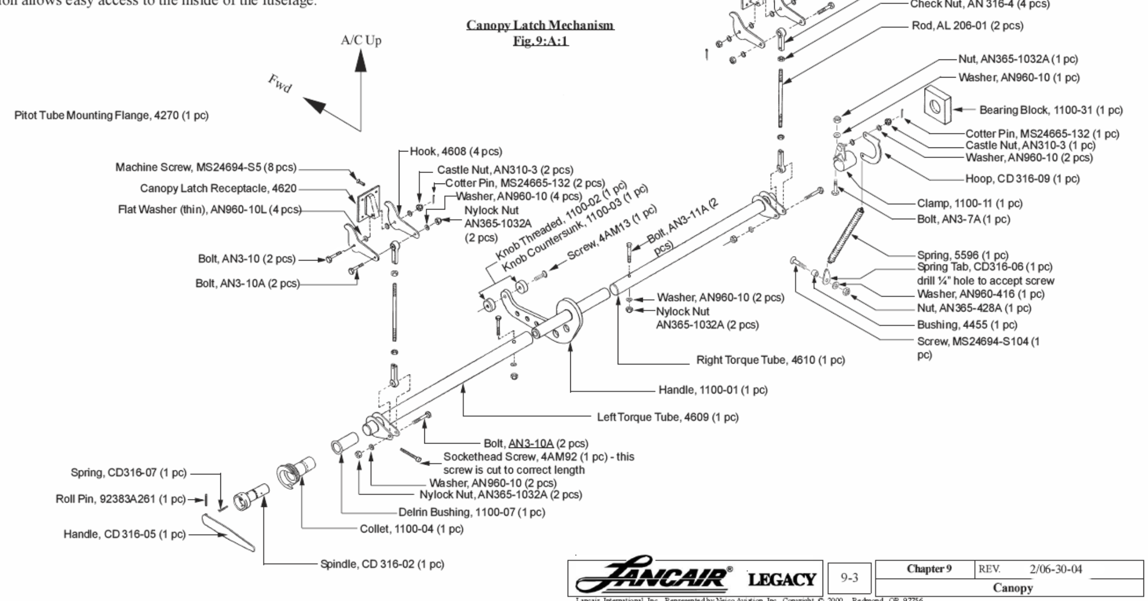
B. Canopy Stiffener Alignment



3. CONSTRUCTION PROCEDURES

A. Canopy Latch Mechanism

The canopy latch mechanism installs along the upper edge of the seat back. It is an over-center type mechanism that draws the canopy down and locked. The canopy is actually the first step in the fuselage construction. Installing the canopy before mounting the center wing section allows easy access to the inside of the fuselage.

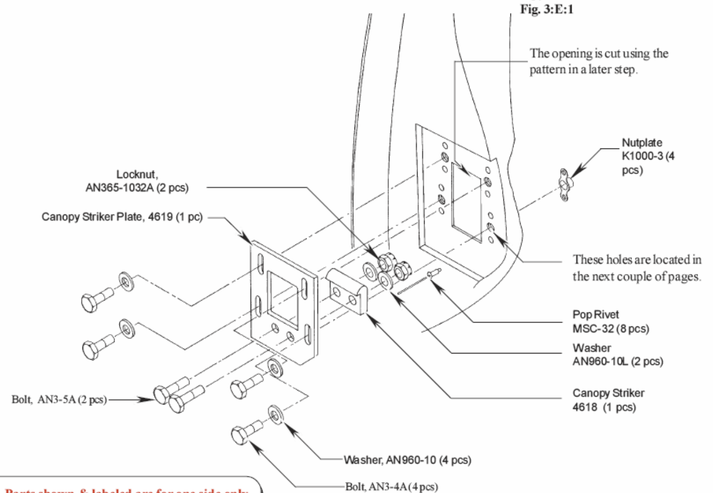


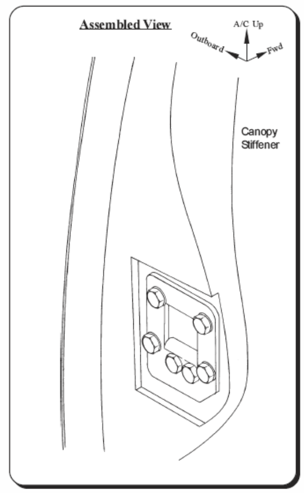
E. Canopy Stricker Metchanism

In section A you installed the canopy latch mechanism in the fuselage. When closed the canopy hooks move out of their slots and "grab: a catch in the canopy stiffener. The alignment of this catch is obviously critical to properly locking the canopy down. We will refer to this "catch" as the canopy striker mechanism.

We supply two parts used to properly align the canopy striker mechanism. The first is a screw that has a #40 hole drilled through the center. This is used to transfer a reference hole in the canopy stiffener by back drilling through the canopy latch receptacle. The second alignment tool is a drill template. The drill template serves two functions, the first

Canopy Strikers
Fig. 3:E:1





Note: Parts shown & labeled are for one side only.

LANCAIR® LEGACY | 9-26 | Chapter 9 | REV. 0/02-15-02 | Canopy

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Hazard Controls

The following strategies are options for reducing the risk of exposing the Legacy's open canopy flight hazard.

Before Takeoff Check List – Canopy Closed & Latched

The first and only intended control of the Legacy's open canopy flight hazard is disciplined use of a pre-takeoff checklist. Human performance history and testing shows the error rate is too high for it to be the only control of a catastrophic hazard. Fred Moreno provided an outstanding discussion of this concept in this LML posting:

Pilot Fred Moreno

LML Post 3 March 2014: Quoting fellow pilot, "Not to put too fine a point on it but, including a pre-takeoff checklist item 'canopy latched??' should cure this issue once and for all."

Let's put this single pilot check list falsehood to bed once and for all, and do it based on tests with real world data collected over many years.

Time for some real world data regarding human performance. I learned this from extensive work on production line quality control in high tech manufacturing. If you take a person in a good environment (temperature, lighting, sound) and that person does a task for which they are trained, experienced, and have the right tools such as assembling a complex piece of machinery, on average (40 hour work week, Monday through Friday, all year round), the error rate in a simple task such as installing a screw to a required torque as you do so is....

About 1%. That is, the measured error rate, over time for a trained and experienced person doing a simple task is about 1%.

This has been verified in airline cockpit tests, production lines and many other environments, and seems to be a rough constant for human beings doing repetitive tasks. For some people having a very good day, it may be a fraction of that rate. For others, harried, tired, end of shift, it may be much more. But figure roughly once per hundred small tasks, an error occurs, averaged over a long period under a variety of conditions.

Same applies to a SINGLE pilot running a check list. Some days you will make NO errors on a 20 item check list. Other days, tired, harried, distracted, you will make a mistake. The most common mistake: you miss the checklist item.

Bingo, you are tired, in a long line of traffic waiting to go, hot day, canopy open to stay cool, suddenly you are "cleared for takeoff without delay" and forget the check list item. For most items, no big deal, the airplane flies. For the canopy, maybe, just maybe, missing the item on your Legacy means you die.

This is the reality of human beings and some of our aircraft, so the record clearly shows.

So what to do? On the production line, standard practice for "six sigma" quality (one error per million operations) you do the following, standard operating procedure:

1) Do the task.

2) Go back and check your work referencing the assembly task list.

3) When you pass the assembly to the next guy in line, he/she checks your work, and then proceeds with the next stage of assembly.

4) People rotate positions so you know you will check his work today, but he will check your work tomorrow.

Error rate is then 1% of 1% (the check) of 1% (checking the check) which yields one error per million. Desired result achieved.

Now look at an airliner cockpit.

1) Check list item called out

2) Check list item repeated by 2nd person

3) Check list item accomplished with call out

4) Confirmed by first person calling out who does not move on until the correct challenge and response are obtained.

Error rate: one per million. Or less.

Now look at YOUR cockpit.

1) As you go down you check list, you get to item X, and miss it. Chance of it happening is 1%

2) You proceed to the next item, not knowing you have missed the item.

Overall error rate: 1%. Repeat 20 times for your 20 check list items.

Your error rate, compared to the target rate of one per million, IS AWFUL. Average single pilot alone operating as an individual in his cockpit without internal checking and observer operates at this level.

Not every day. Not every flight. But on average, year in and year out, you will miss a check list item 1% of the time.

And you could die as a result depending on the item missed and its consequences.

NOT GOOD ENOUGH.

So what is needed is a FAIL SAFE method of protecting you from the fact that you are a human being. If you miss a check list item and it could kill you, you need ADDITIONAL LAYERS OF DEFENSE to assure an adequate level of safety.

A virtually perfect defense on a Legacy canopy is a secondary safety latch that automatically prevents the canopy popping up if the main latch is not secured (auto hood safety latch concept). John Smith's analysis showed that conclusively. (Plug for John's work: he has worked safety issues in the off-shore oil and gas industry. Remember Piper Alpha. Much was learned from that and other accidents.)

Otherwise you are working with layers of imperfect defenses: your own secondary check (push canopy up automatically, muscle memory), audible alarm (different sensory input) warning light (easy to miss with sun behind you), big warning message across EFIS display (hard to miss when you look at air speed indicator prior to rotation) or whatever rings your chimes. These provide vast improvements because they catch you when you miss. Most of the time. They add layers of defense, and reduce the probability of a fatal miss from parts per hundred to down to parts per million

Yes, we should all be good boys and girls and always run our check list, every item, ideally with somebody challenging our work. In reality, we are human and the environment (outside and inside your body) sometimes interferes, and you make errors. Guaranteed.

If it means your life, a checklist is NOT good enough if a missed item leads to a condition that is unrecoverable. DO NOT mislead yourself in thinking that it is. History has proven that checklists without discipline and challenge are not good enough. Humans make mistakes.

Fred Moreno

PS

Recommended for retractable landing gear planes:

1) Check three greens when gear extended - don't take your hand off the handle until you see them. That can be a powerful check by itself.

2) Three greens on base.

3) Three greens on final.

Overall error rate: one per million, until you are distracted. So when distracted internal alarm bells should go off. Then you can stay near one per million, not one per hundred.

Canopy Unlatched/Open Warning System

The risk of takeoff without the canopy latched can be reduced with a prominent annunciator on the instrument panel warning the canopy is in an unsafe configuration – not down and latched and/or with the condition wired to an Electronic Flight Instrumentation System (EFIS) for alerting.

Example Canopy Unsafe Warning Light in Jack Addison's Lancair 360

Example EFIS Warning in John Smith's and Gary Weeks' Lancair Legacys (VH-XTZ and VH-ZYA)

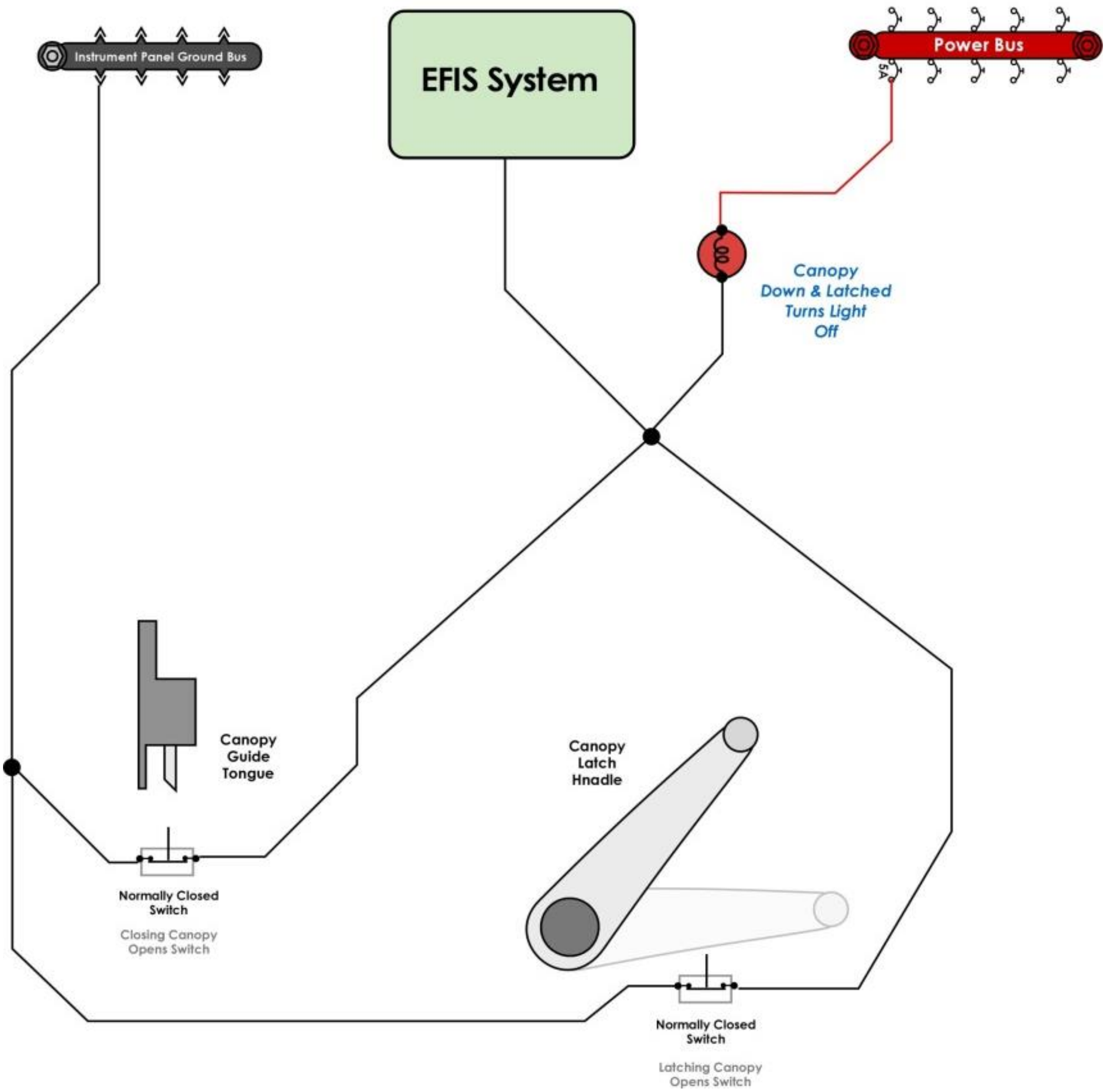
It is not sufficient to measure whether the canopy alone or latching lever alone is in the proper position because both are required to determine the canopy is down and latched. The following wiring schematic shows an example of how to wire micro switches and an annunciator light to provide a simple warning system.

In this example, a micro switch is positioned so that the canopy alignment guide depresses a micro switch and the latching lever depresses a micro switch when it is down. Both the canopy and lever have to be down in order for the warning light to go out. This same signal can be routed to an EFIS system for annunciation.

One could also add a micro switch sensing when the throttle is at full power, activating an aural alert as well.

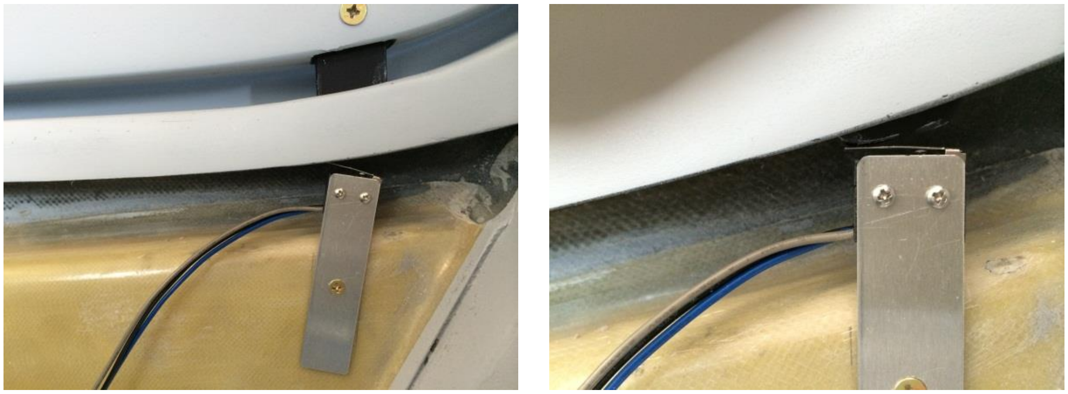
From John Smith:

> Ideally, the warning system should be designed to be FAIL SAFE such that if there is a failure of any part of the system – meaning failure of any micro switch, connector, wire or EFIS interface – the alarm is raised in the event of an "open circuit condition" due a system component failure, or of course an unlatched / improperly seated canopy. Provided the appropriate programmable functionality is available, setting up a FAIL SAFE system should be relatively simple with most EFIS systems providing also that they can be programmed to alarm in response to "hi -> lo" inputs; the Garmin G3X has this capability. Otherwise, simple electronic circuits can deliver the same outcome through use of, for example, switching transistors or other alternatives.
>
> Whilst the following "warning light" circuit example is not a FAIL SAFE solution, it does nevertheless present perhaps the simplest means of setting up a warning light circuit.

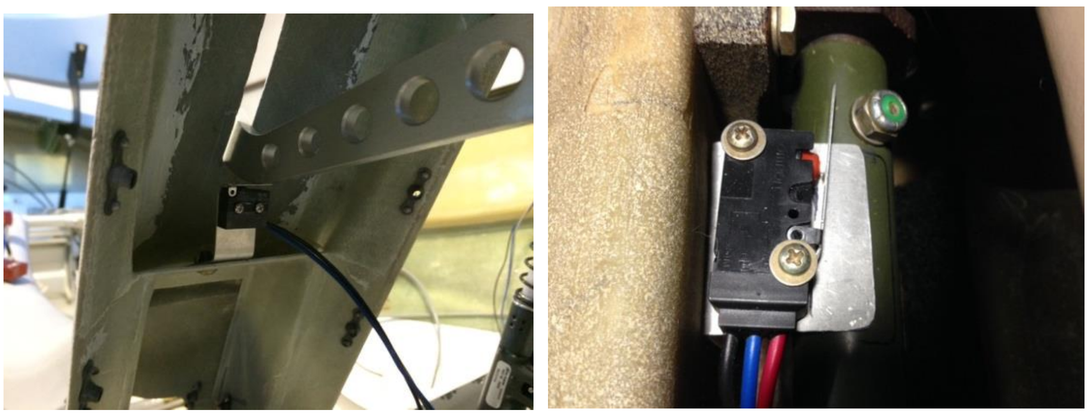


Canopy Safety Warning Wiring Drawing Example

The following photos show examples of micro switch mounting to measure canopy and canopy latch positions. The micro switch is positioned so that the canopy alignment guide depresses the switch. The micro switch mounting shown in these photos are for a Legacy with air ducting below the canopy opening and modifications to the cockpit structure around the canopy latch lever arm. Exact mounting for a stock/unmodified Legacy will be slightly different – but the principle is the same.



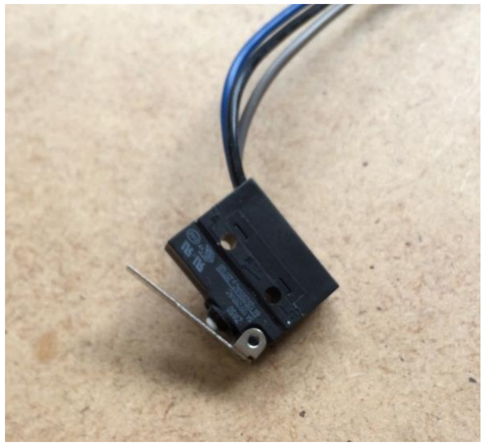
Canopy down micro switch mounting example



Canopy latching lever micro switch mounting examples

The micro switches shown can be wired for "Normally Open (NO)" or "Normally Closed (NC)" switching determined by the wires used. The black wire is the Common line, blue is Normally Open and grey is Normally Closed. The Normally Closed switch position means that when the switch lever arm is not pressed, the switched is closed/completes the electrical connection and allows current to flow. In the example shown, the circuit should be connected to the black and grey (NC) wires. With both switches wired through their NC wires, when their lever arms are depressed, the switches will open, cutting of electrical current to the canopy unsafe annunciator light and the EFIS system. Make sure you adjust the micro switches so they BOTH act within the last 1 to 2 mm or 1/16th inch of movement.

These micro switches are available at Mcmaster.com for $8.11 each:



http://www.mcmaster.com/#8085t15/=qzcvfs

In these examples, the micro switches were mounted to 0.032" aluminum strips cut 0.75" wide and three inches long to facilitate their precise positioning and mounting.

Here are McMaster links to screws, lock washers, and nuts for mounting the micro switches:

Screws: http://www.mcmaster.com/#catalog/120/3017/=r63uo6

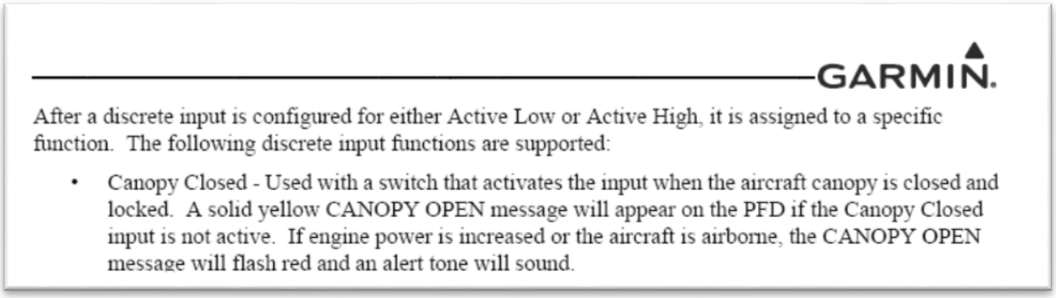
Lock Washers: http://www.mcmaster.com/#catalog/120/3234/=r63v64

Nuts: http://www.mcmaster.com/#catalog/120/3185/=r63vem

The simplest warning system just illuminates a light on the instrument panel. Here's an example of a large annunciator light available at Aircraft Spruce for $15.50:

http://www.aircraftspruce.com/catalog/elpages/legendlights.php?clickkey=4238

Most Electronic Flight Instrumentation Systems (EFIS) support canopy unsafe annunciation. The example below shows how the Garmin G3X system handles the warning.

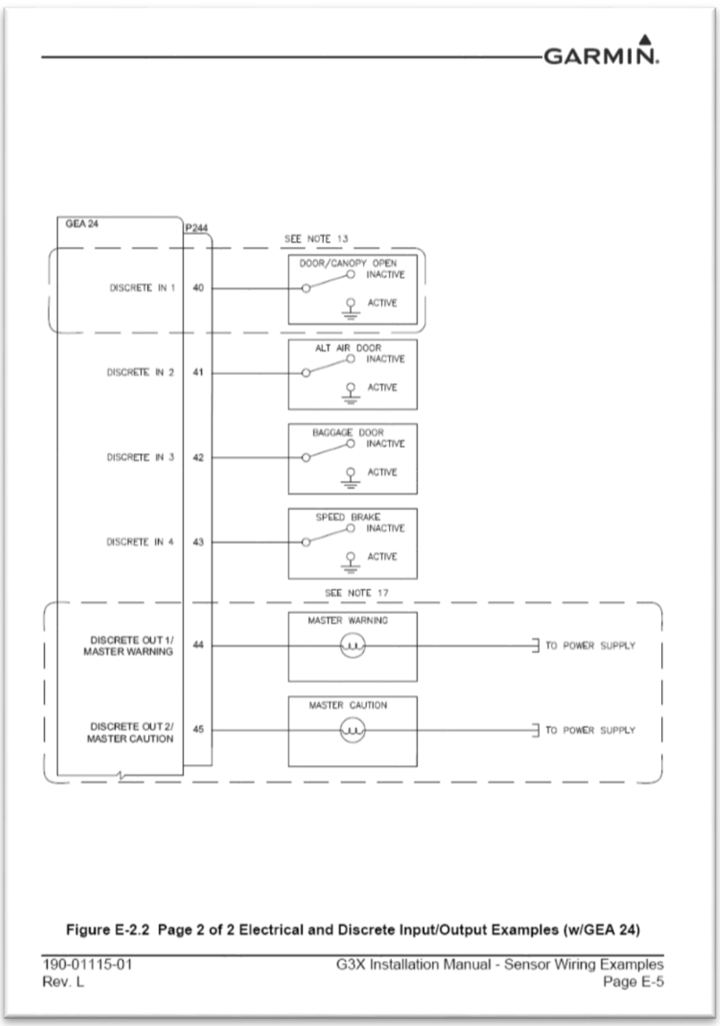

GARMIN.

After a discrete input is configured for either Active Low or Active High, it is assigned to a specific function. The following discrete input functions are supported:

- Canopy Closed - Used with a switch that activates the input when the aircraft canopy is closed and locked. A solid yellow CANOPY OPEN message will appear on the PFD if the Canopy Closed input is not active. If engine power is increased or the aircraft is airborne, the CANOPY OPEN message will flash red and an alert tone will sound.

Garmin G3X Canopy Safety Handling

On the Garmin G3X system, the canopy safety circuit wire connects to the GEA 24 Engine Airframe Unit, Plug 244, Pin 40.



Garmin G3X Canopy Safety Wiring Connection

Canopy Latching Mechanism Modification

The risk of takeoff without the canopy latched can also be reduced by modifying the canopy latching mechanism so the canopy is not allowed to completely close unless the canopy is latched. The baseline design of the Legacy's canopy latching mechanism allows the canopy to close completely without being latched. Pilots must look between the seats to examine the lever to determine if it is latched and/or push up on the canopy for latching confirmation.

Most Legacy airplanes have enough friction between the canopy and canopy seal to hold it closed until the airplane is rotated for liftoff and the aero forces are strong enough to open it. If there is not runway ahead to safely support an aborted takeoff, pilots continue their takeoff.

The author developed this simple modification of the Legacy's canopy latching system, based on a concept suggestion by Graham Nutt many years ago, with the purpose of starting the canopy open to expose an edge to get fingers under to complete the opening. Likewise, it has the benefit of not allowing the canopy to completely close unless the canopy is latched.

The benefits of this latching modification are that the pilot can clearly see that the canopy is not closed, air flows through the opening as a reminder, and the friction with the canopy seal is low enough, in most cases, that the canopy cannot be held down once the takeoff power and/or roll is commenced.

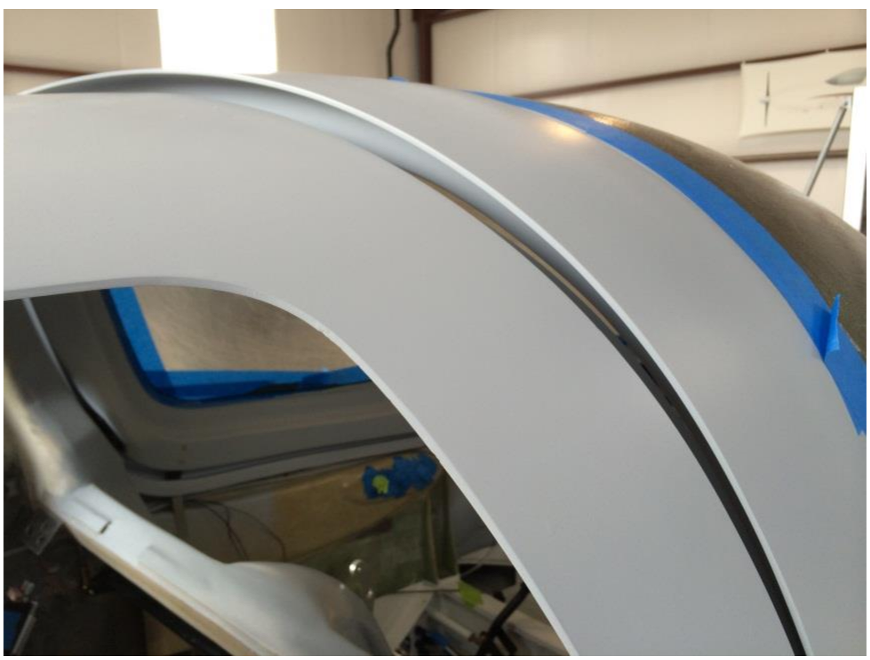


Photo of Canopy Propped Open by Latch Mod

The following are pilot reports of flight experiences related to this canopy latching modification. Doug Brunners' Legacy airplane does not have this modification – but, his friction between the canopy and seal is low enough that on application of takeoff power and at the beginning of takeoff rollout, his canopy will open from the aerodynamic forces. Many Legacy airplanes have too much friction with their canopy seal and if the canopy is not latched, the canopy will not open until rotation for liftoff or later in the takeoff.

N241DB Pilot Doug Brunner

LML Post 5 November 2013: I have gone down the runway with the canopy unlatched. Before I got to takeoff speed the canopy made the fact that it was open known. We simply slowed down and pulled off the runway, taxied back, closed the canopy and took off. A non-event.

Question:

Doesn't the fact that your canopy is unlatched make itself known either during engine run up and/or during the takeoff roll?

N927J Pilot Art Jensen

LML Post 6 November 2013: I have had the same thing happen to me. The fact that the canopy seal was on required more pressure to lift the canopy during the takeoff roll. It actually opened as I rotated. I immediately cut power before becoming airborne. Had this happened on a 3000 foot strip I would have probably gone off the end of the runway. I too had a check list, was properly trained etc. yet because of the very thing a pilot cannot afford to be caught, being in a hurry and distractions almost became a statistic. I'd like to think that this could never happen to me again. I actually double check that the canopy is locked before entering the runway now.

N357V Pilot Paul Miller

LML Post 25 Feb 2014: This mod is excellent (spacer near latch) and easy to implement. My experience has been that at 1800 RPM, the canopy will lift up thereby warning you during mag check. At takeoff power the canopy immediately pops. There is no way to depart with an unlatched canopy with this mod on my Legacy.

N252JT Pilot Jim Thomas

LML Post 10 Feb 2009: I have the Legacy canopy latch modification that props the canopy open about 1.5" as shown on Don Barne's website. The canopy latch must be locked for the canopy to be fully closed. One time I started my take-off roll with the canopy unlatched and because the canopy was propped open the noise and wind made me immediately aware the canopy was not closed. There was plenty of time to pull the power and abort the take-off. Now I believe that this mod not only helps ventilate the cabin on the ground, but it may have also saved my life.

The Canopy Latch Mechanism Modification requires the upper lever stop be moved lower so the canopy latching claws remain extended 7/16" when the canopy lever is in the fully unlatched position.

Photo of Canopy Latch Claws Modified to Remain Partially Extended
When In Full Canopy Release Position

The canopy latching striker plates require installation of 1" x 2" pieces of 1/8" thick Nylon or ABS. The top AN3 hex head bolts are replaced with MS24694 – S54, (10-32) countersunk screws to secure the new "canopy lift plates".

Photo of Canopy Striker Modified with Lift Plate Installed

Photo Showing Claws and Striker Plate with Canopy Propped Open by Latch Mod

Secondary Safety Latch

At the time of this writing, a group in Australia headed by John Smith is developing concepts that may provide a secondary means of latching the canopy to provide fault tolerance for the main canopy latching system. This group has presented several options to Lancair Inc. and is awaiting their assessment. No details have been shared with the larger group at this point. A secondary safety latch system, combined with the other controls for this hazard, could reduce the risk of exposure to this catastrophic hazard to near zero. A key challenge to a secondary latching system is ensuring it does not interfere with crash rescue ability to open the canopy from the outside.

Risk Analysis

John Smith, who has experience with risk assessment and analysis techniques from his oil and gas industry experience, has looked at the Legacy's open canopy flight hazards and provided the following post on the subject to the LML community in February 2014. John is also an active member of a group in Australia working on a secondary safety latch.

Pilot John Smith

LML Post Excerpt 24 Feb 2014: As you know, there has been a fair bit of dialogue on the canopy issue on the forum. And a while back, I invited forum members to join in a working group to look at the issue and, in particular, look at a safety latch. The outcome was no takers other than colleagues here in Oz. Whilst a few of us already had dual micro switch warning systems installed in our Legacy's, but sadly not the Gerladton or

Shepparton Legacys, myself and a few colleagues have been feverishly working on a safety latch design to further reduce risk of the canopy open event.

Cutting straight to where I, and no doubt others may have already got to, but quite likely not all…….

IMHO I believe everyone should have / could easily implement following with substantial benefit to pilots and their passengers in the order of 100 times less risk than the historical average risk of a fatal canopy open event:-

- Make sure you have check lists that include the canopy status at run-up, and then again at the holding point / line-up – and use them
- Develop and acknowledge canopy open on ground and in air procedures
    - if on the ground and it opens, whatever – do not proceed to airborne
    - If it opens in the air – above all else, do not attempt to close the canopy, keep the ball centered
- Add a pair of warning switches in series to check for latch position and canopy seat position – wire so fail safe – audible + big visual warning

Next – look at a safety latch, or something similar or identical to Don Barnes' solution – this sort of device offers the potential to reduce the risk to zip – so why not do it?

A bit more detail below…..particularly around the risk assessment. Read on if you're still interested!

As far as a safety latch is concerned, our group here would have between us come up with dozens of different designs, some of which were sufficiently well developed that one could almost start building the CAD drawings / CNC machine inputs files for fabrication of components. The goal was of course to design something that will operate safely and reliably, not hinder egress or external emergency access, and be simple to install both during a build and after build. We short listed a few options, but all required some penetrations in the structure - so I passed these options to Lancair to see if they could provide guidance as to which would be acceptable from a structural point of view – to date no response (I must follow up…). Once we get that guidance, I will most likely build a prototype and install on my Legacy. I fully intend to publish / share whatever we come up with.

Above said, I had forgotten about Don Barnes' solution where I understand the canopy sits up a little bit unless the canopy latch is in the closed position – that may well largely obviate the need for a safety latch, as I'd presume the noise with even with a slightly open canopy (and even with noise cancelling headsets) would be hard to miss – but may be not 100% fool proof. Anyone know how high the canopy sits up with this mod? 1/2"? 1"?

In order to try and bring a bit of rigour and quantification to the understanding of risk and what measures are useful or not and so forth, I have also done a fair bit of work with event tree analysis to assess how various combinations of check lists, procedures, warning devices and a safety latch effect the risk of a fatal canopy open event. The event tree input assumptions around probabilities of various actions were tuned to match the actual historical risk of a fatal canopy open event. I found it a powerful way to explore what might happen if one does or does not do or have something… Very interesting, and not entirely or always intuitive. There is no doubt that a secondary latch gets straight to a really good outcome – provided such mechanism does not present unintended additional risk or compromise structural integrity. I am happy to share in the detail of this "model" if anyone is interested, but the bottom line messages - and noting the inherent uncertainty around many of the inputs and assumptions - of this work were:-

- At the time I did the work, there had I believe been 3 fatal canopy open events - this equates to a risk factor in the order of 3 x 10-5 (unacceptable cf. a generally understood overall risk target for GA of 10-6)
- This is expressed as risk of a fatal canopy open event per take-off (you can see basis below)
- A dual microswitch warning system (latch position and canopy position) with audible and visual annunciation - in the case of VH-XTZ and VH-ZYA, we have ~3" x 1/2" flashing red warnings in centre of each EFIS screen, combined with the check lists and defined canopy open event flight procedures, get one into the 10-7 event frequency region (again expressed as frequency per take-off) for a canopy related fatal. If it were expressed as a frequency per hour, the number probably wouldn't look different – if avg. flight times were around 1 hour
- So - in theory a Legacy with a decent warning system operated with a decent (and practiced) canopy related check list and acknowledged emergency procedures, may offer the opportunity to reduce the risk by 2 orders of magnitude (100 times less) compared to aircraft without these measures in place
- A big assumption in all this, is that the historical fatal canopy open event aircraft did not have safety switch systems installed – if anyone knows the answer to that question, I'd appreciate it
- A secondary latch (without an alarm) gets one straight into the 10–8 region or better (albeit this is quite sensitive to the secondary latch reliability assumption)
- With a warning system AND a secondary latch, the risk goes to zip

Rolling this up, the picture seems to be:-

- Historical risk of a fatal canopy open event is in the order 10-5

- Add warning devices, check lists for canopy status at run-up and again at holding point => order of 10-7 risk (~ 100 times improvement)
- Add a safety latch alone => order of 10-8 risk (~ 1000 times improvement)
- Add the lot……=> extremely low risk

I'm sure there will be many a clamour about how useful check lists are, or how useful alarms are and how responsive pilots are to alarms… and the work I have done reflects that check lists will not always be done, and that alarms will not always be noticed, and that even if alarms are noticed pilots may not respond or indeed cancel them….. But, in combination – if just some of the measures hit the spot – just one of them alone may well avert a tragedy. Putting it the other way – if none of these things were done – then….?

John Smith

At the time of John's post to the LML Forum, he was not aware of the canopy latching modification as discussed in the preceding section of this report. We since discussed taking a look at the risk benefits that this modification – or "canopy prop open solution" - might offer in the context of the other already identified initiatives. He has provided the following additional commentary:

As always, it is VERY easy to get bogged down in numbers and loose the messages. The other issue of course is that the probability entries that one makes are generally somewhat subjective – although in some instances there is well documented evidence, for example, for check list reliability etc. as Fred Moreno has tabled. So – its perhaps more useful to discuss the risks as a function of "One chance per 1,000,000" or "One chance per 10,000" and not get hung up on whether the number might be "4 in 1,000,000" and so on.

In considering the "canopy prop open solution", I have assumed that there is something like an 80% chance that a pilot will "notice" additional noise / airflow if the canopy is "propped open" – even if noise cancelling head sets are being used.

I have tried to roll up my work to provide some simple high level messages around the benefits of individual measures, or combinations of measures as a function of the indicative risk reduction vs. the reference (historical) chance a fatal canopy open event which is in the order of "One of 100,000 take-offs". The figure I derived from historical data is actually around "3 in 100,000 take-offs", but for the sake of this discussion, we'll leave it as "One chance per 100,000".

Application of a single measure

Incremental to an aircraft with no canopy warning system, secondary safety latch or canopy prop open device with a pilot who always uses check-lists at run up and, most critically, at pre-line up / holding point; this is the scenario for which the inferred reference risk is in the order of “One per 100,000 take-offs”. (It goes without saying that if use of checklists is not practiced – this risk increases dramatically)

Define / rehearse canopy open procedures

Overall risk reduces to “One in 1,000,000” 10 times less risk

Warning system (presumes highly visible / audible annunciation)

Overall risk reduces to “One in 1,000,000” 10 times less risk

"Canopy prop open solution" with 90% chance of being noticed prior to t-off

Overall risk reduces to “One in 1,000,000” 10 times less risk

Secondary safety (automatic) latch with 99% reliability

Overall risk reduces to “One in 10,000,000” 100 times less risk

Secondary safety (automatic) latch with 99.9% reliability

Overall risk reduces to “One in 100,000,000” 1000 times less risk

Whilst putting in place just one of any of these measures gets one into the GA target region of “One chance per 1,000,000), a highly reliable secondary safety (automatic) latch - as Fred Moreno puts it - gets you into very low risk territory in just one step.

Application of combinations of measures

Again, these are assessed as incremental to the reference scenario described above.

Canopy open procedure + Warning system

Overall risk reduces to “One in 10,000,000” 100 times less risk

Canopy open procedure + Canopy prop open solution

Overall risk reduces to “One in 10,000,000” 100 times less risk

Canopy open procedure + Warning system + Canopy prop open solution

Overall risk reduces to "One in 100,000,000"   1000 times less risk

Any of the above + Secondary safety (automatic) latch

Overall risk reduces to at least "One in 100,000,000" 1000 times less risk

So, again, the secondary (automatic) safety latch stands out as the single most effective measure – however, whilst it is the simplest to operate (essentially a passive device that requires no pilot action to bring into effect), it is proving tricky to design at the same time as satisfying the essential design criteria being – simple / reliable, not overly difficult to install, doesn't compromise structure, doesn't overly hinder emergency egress / external emergency rescue. May be with support from Lancair, we'll get something like this over the line. I sincerely hope so.

But – until a secondary safety latch does emerge, right now – if every owner / pilot acknowledged and then defined and rehearsed procedures in the event a canopy opens on the t-off roll or after, there appears to be an immediate win – low hanging fruit that offers ~10 fold reduction in risk.

Opinions will vary greatly, I'm sure, as to the relative ease of installing an alarm system or a "canopy prop open solution" – but to be honest – they are both easy. But – for those that don't like one or the other – well – do at least one which in combination with the procedures seems to offer ~100 fold risk reduction. But – why on earth not do both => ~1000 x risk reduction?

What am I going to do… ? Well – as an interim measure – I'm going to look at adding a prop open solution (in addition to my existing procedures and warning system). BUT – I'm not going to give up on the secondary safety latch. So on latter – I'm waiting on Lancair's contribution around structural issues.

A large part of risk mitigation is understanding what is at stake, and understanding the relative merits of various risk mitigation measures. I think it's pretty clear to everyone what is at stake…. As far as what can be done - I hope my analysis helps put into perspective some of the ideas around what can be done help reduce the risk to pilots and their passengers – as is often said "If you know why you need to do something, there is a far greater likelihood that one might actually do it".

John Smith

Recommendations for Inadvertent Flight with Canopy Open

With the measures discussed in this report implemented to mitigate the risk of flight with the Legacy's canopy unlatched, it is very unlikely that flight with the canopy unlatched/open will occur. Should one be faced with this possible harrowing condition, these procedures and flight techniques may help one survive the ordeal.

These suggestions have not been proven by flight testing and are based on reports of Legacy pilots who've flown with their canopy unlatched, reports of fatal canopy open accidents, and knowledge of airplane aerodynamics and associated conjecture. Follow these procedures at your own risk.

The evidence suggests that minimizing the Canopy AOA and keeping the airplane's Beta near zero (side slip ball in the middle) is key to keeping the canopy from opening far enough that pitch instability is induced, visual cues for pitch attitude are corrupted, or PIOs triggered.

First, do not try to close and latch the canopy in flight – the aerodynamic forces are too great and it will only serve as a distraction from flying the airplane.

Untested Procedures for Flight with Canopy Open

(Follow these procedures at your own risk)

- If canopy opens on takeoff roll and there's sufficient runway for stop remaining, abort takeoff
- If canopy opens on takeoff and sufficient runway for stop is not available, continue takeoff, increase speed, add additional flaps if unstable
- Maintain 120 KIAS
- Extend flaps half way if not completely
- Do Not Attempt Immediate Landing
  - Climb to >6000 ft AGL to test stability in configuration and at lower airspeed
  - In landing configuration with full flaps, level flight, progressively slow to 100 KIAS. If pitch instability ensues, lower nose, add power, and accelerate back to 120 KIAS.
    - The purpose of this is to find out how much airspeed/AOA margin there is below 120 KIAS for landing. You don't want to learn that it is going to go unstable if you slow to 115 KIAS when you're on final approach at 100 ft AGL.
  - If airplane is stable down to 100 KIAS, still fly approach at 120 KIAS, but you'll know you have good airspeed/AOA margin on your pitch stability

- Return for Landing at long runway – minimize configuration changes, gentle control inputs, bank angles, accelerations, etc.
- Approach speed 120 KIAS until inches above runway

Commentary & Advice from the Community

Message to community from Dennis Johnson

A number of Legacy pilots have inadvertently taken off with the canopy unlatched. Some have reported significant (or worse) pitch instability and some have reported no instability. We probably have a better count of the former than of the latter. That raises the important question: Is the Legacy unstable with the canopy unlatched or is the airplane stable and the instability comes from pilot distraction close to the ground or unintentional pilot induced oscillation (PIO)?

Until this basic question is answered, it is prudent to investigate both potential problems. Legacy pilots around the world are actively working on hardware solutions, which are discussed in this paper. While that effort continues, let's also work on solving the pilot distraction or PIO problem.

If you inadvertently takeoff with your canopy unlatched, it may pop open about the time you lift off the runway. If you have adequate runway remaining, abort the takeoff. If you decide to continue the takeoff, be prepared for lots of wind and noise and items blowing around inside the cockpit. A passenger might panic, adding to your distraction and stress.

Remind yourself that some pilots have reported normal stability and handling characteristics with the canopy unlatched. The main thing is to FLY THE AIRPLANE! Do not attempt to close the canopy. Do not become distracted by the wind and noise. Ignore your passenger unless he or she is fighting you for the controls. Duplicate the most thoroughly documented uneventful open canopy takeoff and landing: Leave the flaps at takeoff position (10°) and the landing gear down, maintain 120 knots indicated airspeed, climb to pattern altitude, and fly a normal rectangular pattern back to landing. If you have time, you can declare an emergency, but don't let that distract you from flying the airplane.

You can safely practice this with the canopy closed and latched. Bring an instructor along if you feel that's appropriate. Make a normal takeoff and pretend that the canopy opens the moment your main tires lift off the runway. Try to mentally picture the noise and wind as you fly the airplane, using the procedure in the previous paragraph. Announce a simulated emergency landing on the radio if appropriate, and come back and land. If you've practiced this a few times, you might be better prepared if it ever happens for real. Remember, practice it with the canopy closed and latched the entire time!

Excerpt of message to author from Jon "Jack" Addison

I was one of six engineering-test pilots at NASA, Ames Research Center, Moffett field, CA through the 70's after I completing my combat tour in the F4 over the North. (BS Aero Engr, some graduate work Stanford, grad Naval TPS)

We had 5 or 6 flight simulators, some very, very sophisticated, some of limited specific evaluations for STOL aircraft. The FSAA simulator that was the best the world had and was instrumental in the flight control system design for the Concord. The main frame computers lived in their own large special room.

We did many simulator studies along with flying 6 to 10 aircraft on a regular basis. So, only to say that we were very involved in cockpit design, checklist philosophies, checklist false assumptions, single pilot IFR difficulties, etc. We used many volunteer pilots, many United pilot volunteers, many GA volunteers to evaluate our findings to obviously make sure we were making recommendation that covered the appropriate average pilot, average situation, but including dozens unplanned events . An evaluation team might consist of one engr-test pilot, a couple of what we called engineer-engineers, and possibly a mathematician for statistical analysis. Not to mention the operation staff of the simulators and programmers. Also, many eager outside pilots.

So, my shoot from the hip engineering today is based on those experiences, some specific, some extrapolated. Today I claim no expertise in statistical analysis and my experience with it at NASA was that it formed part of the equation of results, but was never as absolute at some made it out to be. Us pilots, never without lots of opinions, liked to think that our experience and mistakes sometimes trumped pure analytical work from the engineer-engineers. For the most part, they were glad for the oversight of 1000's of hours of flying experience in heavy jets to fighters to twin Cessnas and even gliders and helicopter.

So here are some tidbits of findings and ensuing opinions:

*I don't believe any of the open canopy takeoff events were in a/c with a warning light or horn system, and while not conclusive, it is very noteworthy.

*We demonstrated many times in the simulator that even a command and response checklist is not iron clad. Furthermore, in the single pilot situation a very long checklist can at times be a hindrance to flight safety, and the tendency of pilots to be type A, and to want to expedite to please: their self-image, their passenger's expectations, ATC, and other aircraft operational needs.

*Thus, some before takeoff items are so paramount (ie it's not worth dying, guys), that a visual and/or aural prominent warning is a necessity. But, if it is over used, ie too many lights of red, amber, green; the proper immediately needed response may not happen. But, if only "abort lights" were prominent in front of the flying pilot, then abort fidelity was vastly improved. The other nice to know lights had to be placed in a less prominent location, but still easily seen.

*Extrapolating to today, now that I've remake my panel to all glass, I found that the digital-designers have out done themselves, and have included too, too much in a small space (just because they could....). To that end, I removed 3rd level item of interest from the left pilots EFIS; and the right side EFIS, relegating the right EFIS to only engine and fuel interests. Trim and flap indicators on the right EFIS were replaced with the regular Ray Allen indicators to the lower center panel. The canopy indicator light on the right EFIS was eliminated (as Dynon system allows) in favor of a bright red light above the pilots EFIS, so as to be more prominent and better situated just below the glare shield. Later I hope to eliminate the AOA from the pilots EFIS and put a chevron and donut indicator on top of the glare shield as is standard and proven effective in the Navy and Air Force. (It needs to be in the field of view to be really effective.)

*Thus, over my pilot-side EFIS are a bright red light for canopy (not over center locked), and bright red light for pitot heat on, but not heating. That is a killer situation too. (Ignore the Master On light, as it lights after oil pressure is zero, but the master has been left on and a dead battery will be found after the 2 day visit.... ok, it violates my principal of only abort lights above the EFIS, so shoot me; but 3 lights planned at inception, and I wasn't going to put a patch there.)

*Granted a trained response is appropriate to grant the "abort lights" their full effective authority dictating, "abort NOW without trying to analysis; analysis later with coffee."

*The round Spruce red panel lights are quite bright. But also the rectangular red light you noted looks as or more promising and ironically, I ordered one 4 days ago to further enhance my gear-not-down wailing horn.

Sidebar comment: Holding gear switch as was written, is a good one I'm going to adopt it. Also, I'm very fond of the real-time direct reading hydraulic gages, one for gear up pressure, one for gear down pressure. Works even if the battery is off for electrical isolation w smoke in the cockpit.

*FLOWS. Flows work extremely well. Airlines (I flew for 3 and helped all three go bankrupt....) instruct their use to set all the switches as the Captain knows where they need to be. Then the copilot can expeditiously read the long checklist and the captain just looks at each item and responds quickly. However, one Boeing Captain famously responded "ON" to pitot heat, when it was off, and sadly the plane crashed from a frozen pitot tube and false airspeed reading leading to a deep stall. So checks lists are very fallible even with 2 pilots.

I don't necessarily recommend my very tailored CIGARS and GUMPS basic checklists that I say aloud to myself so that I hear my own voice (very important part). eg C is for Controls, Canopy, Camber (flaps). But, I heartily recommend a short FLOW check, done without a written checklist, upon being cleared onto runway. Mine starts at the canopy handle, sweeps fwd to fuel selector, sweeps fwd to mixture (richen now since taxing on very lean), then on to the low row of switches: fuel boost pump!, pitot heat if req, lights as req. Now is not the time to be waving a hunk of paper around as you are looking and clearing for traffic, etc.

Thus, this is my 2nd or 3rd Canopy check, depending somewhat if temp is cold or hot, but then as I apply TO power, and direct my gaze 12:00, I will see (or not see) a bright red light. Further on as plane picks up speed, and a glance is made to the airspeed indication which is about 5" from the red canopy light, a second opportunity is afforded to see a bright, glaring, sexy, red light. For me this is the clincher. The canopy handle at the entering runway Flow, and the red light warning twice prominent on the takeoff roll. I'll give it a 10 to the minus 8!

*LATCHING. I'm against any latch that requires a second operation from an external ground crew to open the canopy for emergency egress. That said, if the canopy mechanism can be modified that props the canopy open an inch or more at the trailing edge when the handle has not been locked over center, then that would be a comfort to some pilots and worthy of a good development project. The wind noise of an open canopy should tell even a hurried pilot that he just dodged a bullet. However, (here comes the commercial) I will bet a 5th of Jamison that the lucky bastard will have seen the red warning light before he hears from the open canopy!

*Seriously everybody:

- Warnings Light = cheap and NOW
- Flow training upon taking runway = cheap and NOW
- Latching mechanism = could be nice, takes engineering, time, prototypes, money, more time, finalization, agreement, drawings, production, distribution.

Let's all agree to do a light next weekend.... while we wait and watch the latch happen.

*Wind tunnel tests. If anyone is so inclined, I believe getting scheduled into a NASA wind tunnel at Ames or Langley is not difficult. They even have modeling shops that are filled with craftsmen that make beautiful models of high fidelity, and they know all bout Reynolds Numbers. Just to be sure, get a University sponsorship, which probably means find a PHD candidate that is void of a project for his dissertation. Viola Batman!! I'd volunteer my time to contact the few I still know if anyone contacts me.

I also believe flight testing by one Len Fox would be doable, not particularly risky and not too expensive. Only need a volunteer Legacy airplane. Put the call out, it would happen.

*If all else fails. The AF and Navy (and even fearless marines) manuals all advertise that this type of event, often from a survivable midair, requires a through configuration check while airborne at a safe altitude. Use the findings from the configuration check to calmly (by now) figure how you will fly final approach on your long straight in landing. Particular attention needs to be paid to flap position, power setting, airspeed, control effectiveness in all 3 axis, any crossover speeds that ailerons cannot compensate for rudder yaw or visa versa.

One small objection I have to your excellent recommendations is the selection of full flaps, which includes the last high drag portion. If needed for pitch attitude, so be it, but I doubt it. Full flaps will require more power and therefore more slipstream, and more canopy lift. (?) The only configuration change I'd make in such an open canopy event would be: gear raised if needed for climb/raising terrain. And 120 knots sounds right as a worthy target. Slow is not always good. Remember the DC-10 that lost an engine and some of the wing lift devices and followed the book for slower climb out speed and thereby lost roll control. Or one of my bankrupt airlines, USAir, when the 737 north of Pittsburgh lost 132 persons after the rudder went un-commanded hard over, and as they initially tried to hold altitude for ATC, and they slipped rapidly below crossover speed where the ailerons could not counter the roll from yaw. In 28 seconds from 6000' it was all over. (Yes the pilots still had a recovery opportunity from the ensuing "unusual attitude" as the speed increased, but the window was very small and it was all new and unexpected....)

I'm considering installing a traditional "slip ball" in a real race, as I don't find the digital "ball" very effective, not well seen, and lags in yaw. At least for the otherwise excellent Dynon Skyview.

Best Regards,

Jon (Jack) Addison

22,000 hours and still learning

Summary Conclusions & Remarks

The Lancair Legacy can become very unstable if flown with the canopy unlatched/open. There are several potential causes, acting alone or in combination, that likely cause the instability.

No matter what the underlying issue is, flying the Legacy with an unlatched/open canopy is a catastrophic hazard with a high probability of death or serious injury and aircraft damage.

Use of a Before Takeoff Checklist alone does not provide sufficient control of this hazard given the normal error rates of humans and the potential severe consequences after an error. Significant improvements in error rate for before takeoff checks can be expected with use of switch setting "flow patterns" and "pneumonic checks" as well.

Pilots and builders of Lancair Legacy airplanes should install a canopy unsafe warning system and a modification to the latching system that does not allow it to close without being latched. Implementing these three hazard controls – check list, warning system, and latching mod – significantly reduces the risk of exposing this flight hazard.

The accident history shows the risk of a fatal canopy open event is about 1 in 100,000 takeoffs. Adding a canopy open warning system and canopy latching prop open mod reduce the risks to better than 1 in 100 million takeoffs – a reduction in risks by a factor of about 1000.

In case one finds themselves in flight with an unlatched canopy, do not slow down. Low AOA is likely the key to keeping the canopy from opening up wide enough to induce pitch instability, corrupt the visual pitch reference, or start PIOs. Maintain 120 KIAS, extend the flaps, get to altitude, test lower speeds at altitude to get confident in your control margins. Fly the approach and landing to a long runway, with no configuration changes, minimal bank angles, and don't slow down below 120 KIAS until inches above the runway.