Federal Aviation Administration

ZODIAC CH 601 XL AIRPLANE
SPECIAL REVIEW TEAM REPORT
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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) conducted a special review of the Zodiac CH 601 XL and CH 650 to evaluate design and operational details of these nearly identical aircraft. They are available as a special light sport category aircraft (S-LSA) from Aircraft Manufacturing and Design, Inc (AMD) or as amateur-built kits from Zenith Aircraft. Both companies are generically referred as "the manufacturer" elsewhere in this report. The review was a continuation of FAA efforts started in 2006 to monitor the Zodiac after several in-flight structural failures. Data from our prior assessments and the findings from this special review provide information to support FAA action and address safety recommendations issued by the National Transportation Safety Board (NTSB).

FAA review of the in-flight failures did not indicate a single root cause, but instead implicated the potential combination of several design and operation aspects. Our preliminary assessments focused on the strength and stability of the wing structure. Further analysis during the special review found the loads the manufacturer used to design the structure do not meet the design standards for a 1,320 lb (600kg) airplane. Static load test data verifies our conclusion. The special review also identified issues with the airplane's flutter characteristics, stick force gradients, airspeed calibration, and operating limitations.

In September 2009, the manufacturer reanalyzed their wing loads, developed modifications for the wing structure, and completed static tests of a modified wing. The manufacturer also incorporated modifications to the aircraft to address flutter concerns, including balancing the ailerons. To fully mitigate the flutter concern, the manufacturer needs to conduct a new flutter analysis and flight test with the modified design, which had yet to be completed at the time of writing this report.

Following the safety directive process for S-LSA, the FAA worked with the manufacturer to address safety concerns for the S-LSA versions of the Zodiac. Our concerns apply to the CH 601 XL and CH 650 because they use the same wing design. On November 7, 2009, the FAA issued Special Airworthiness Information Bulletin (SAIB) CE-10-08 to inform owners and operators of potential safety issues with the CH 601 XL and CH 650. Concurrently, AMD issued a safety directive for the S-LSA versions of the CH 601 XL and CH 650 to address the situation and to communicate details of modifications required before further flight. Zenith Aircraft also communicated similar information to owners and operators of experimental versions of the CH 601 XL and CH 650.

On November 12, 2009, the FAA suspended issuance of new airworthiness approvals for the CH 601 XL and CH 650 until the applicant submits adequate evidence that their aircraft has been modified to meet the AMD safety directive and SAIB CE-10-08. This action addresses S-LSA, experimental light-sport aircraft (E-LSA), and experimental amateur-built aircraft. This action was taken to ensure no new aircraft with known safety concerns are introduced into the National Airspace System (NAS).

1.0 INTRODUCTION

The FAA special review team was tasked to investigate the causes of in-flight structural break-ups of several Zodiac CH 601 XL aircraft. The team of experts examined the details of the design, manufacturing, and airworthiness certification of the Zodiac CH 601 XL aircraft. The team visited the manufacturing locations for the S-LSA aircraft and the amateur-built aircraft kits to review design data for all CH 601 XL configurations and the CH 650. We also visited Zenair, Ltd. in Ontario, Canada where technical details of the designs are held. These investigation activities were coordinated with European airworthiness authorities, the Canadian airworthiness authorities, and the NTSB.

This report presents the findings of the investigation, a review and evaluation of the safety concerns, a determination whether the S-LSA version of the airplane is in compliance with the ASTM International consensus standards and the status of the continued operational safety (COS) of the CH 601 XL airplane.

1.1 Team Charter

The team was chartered in April 2009, as shown in Appendix B. The intent was to collect specific design, fabrication, airworthiness, and operational data for each Zodiac variant, compare and contrast this information to identify any safety related issues, and recommend appropriate action. The team also sought to identify any relationship between the in-flight structural failures. Appendix C contains more detail regarding the design characteristics of the variants of the CH 601 XL and CH 650. With so many different versions of CH 601 XL and CH 650 (S-LSA, E-LSA, and experimental amateur-built), the team also focused on reducing confusion regarding how the accidents relate to each other. The tendency is to relate issues that may be unique to the amateur-built version of the CH 601 XL with the factory-built S-LSA version, despite the fact they are built, operated, and maintained differently.

To obtain information for this investigation, the team conducted visits, interviews, and evaluations; reviewed the manufacturer's documents; and researched FAA/NTSB accident databases.

1.2 Summary of Team Findings

Based on this detailed review the FAA concluded that potential deficiencies exist in all variants of the CH 601 XL design, including the CH 650, because of common design characteristics. A summary of the Zodiac Special Review Team's significant findings is listed below:

- Wing structure: FAA analysis of the aircraft showed that the loads used by the manufacturer to design the wing structure did not meet the ASTM standard for a 1,320 lb aircraft. FAA analysis estimated that the wing design loads were 20 to 25 percent too low. Static structural tests completed in the Czech Republic, and testing done as part of an investigation by German authorities support this conclusion. Those tests revealed that the wing structure could not sustain the original design loads developed by the manufacturer for compliance to the ASTM standards for a 1,320 lb airplane.

  As indicated below, we also found potential for errors in calibration of the airspeed indicating system and improper or incomplete information in the pilot operating handbook regarding maneuver speed limitations. Our analysis showed that a one mile per hour error in airspeed translates into approximately 0.1g load change on the wing at maneuver speed. Therefore, calibration errors or operating limitation errors could lead pilots to unintentionally exceed the intended wing design envelope by an additional 10 to 20 percent.

  In response to these findings, the manufacturer reevaluated the wing design loads, modified the structure, and tested the modified structure to the new design loads. However, the manufacturer stopped their tests about five percent below the ultimate load estimated by the FAA for compliance to the ASTM design standard. They stopped at a slightly lower load, partly due to their test equipment, and partly because they did not completely agree with FAA estimates. Their modified structure did not fail at the ultimate load they tested to. However, the wing attachment bolts were bent and the attachment bolt holes were elongated, indicating there was permanent damage to the structure at these loads. At the time of this report, the manufacturer was finalizing design details of the modifications to the wing structure. Owners and operators should contact the manufacturer for the latest information on these modifications. The manufacturer needs to perform additional structural testing once a final design is reached to demonstrate the final wing design meets the ASTM standards.

- Flutter: The FAA reviewed available flutter data, but the results were inconclusive. However, it is clear from the evidence from aircraft involved in structural failure accidents that flutter was a causal factor. It is not possible to determine whether flutter was the primary root cause of the structural failure or a secondary cause after some initial structural deformation of the wing. Because of the concerns with the wing structure, it is likely structural stiffness may have influenced the flutter characteristics of the wing. The FAA is aware that some reports of flutter or vibration in the airframe have been traced to improperly rigged aileron cable tensions, and improperly installed flap stops.

  Though changes are being done by the manufacturer to balance the aileron controls and revise procedures reminding operators to check for proper aileron cable tensions before each flight, the FAA has requested the manufacturer perform additional analysis and testing on the revised structure to verify flutter concerns have been mitigated. The flutter characteristics will change once the modifications required by the AMD safety directive are complete. Those modifications will impact the structural stiffness of the wing, which will result in different frequency response and damping characteristics. The manufacturer needs to reevaluate the modified CH 601 XL wing structure with the balanced ailerons to determine the flutter characteristics of the modified design. This should include a complete flutter investigation (ground vibration test (GVT), flutter analysis, and flight test) accomplished by a noted flutter expert. Owners and operators should contact the manufacturer for the latest information on the updates.

- Airspeed calibration: AMD and Zenith Aircraft calibration procedures do not clearly explain how to adequately account for basic pressure source position error due to the location of the pitot-static ports. This error is caused by the flow around the airframe and unless calibrated properly, could lead to potential airspeed indication anomalies; particularly since the CH 601 XL derivatives can be equipped with several different types of pitot-static sources. The situation could lead to operating the airplane above the maneuver speed and/or the design cruise speed, potentially leading to structural failure. Our calculations show a 1 mph error in airspeed provides approximately a 0.1g load change on the wing at maneuver speed.

  The FAA recognizes that similar airspeed calibration problems may exist with other light sport aircraft (LSA) and has begun efforts to improve the ASTM standards to address this problem. To address specific CH 601 XL concerns, the manufacturer has reiterated that proper airspeed calibration procedures are critical and is updating their maintenance manual to document a clear, repeatable calibration process. The FAA recommends that each aircraft be re-tested to verify proper indication of stall speed, maneuver speed (V_A), and maximum speed limits.

- Stick forces: The current ASTM standards simply state, "Longitudinal control forces shall increase with increasing load factors". Available data indicates the stick force gradient for the CH 601 XL meets this standard, and appears to meet the intent of 14 CFR Part 23 within much of its operating envelope, though this is not required. However, flight test data from foreign authorities indicates at aft center of gravity conditions the stick forces do become light. This may be a contributing factor in structural failure accidents if coupled with operating at speeds higher than V_A, especially if flown over gross weight and/or with improperly loaded aircraft. In such a condition, little stick force would be required to dynamically load the CH 601 XL wing beyond its structural load limit, given the inadequate loads used to design the structure.

- Structural Stability: Other aviation authorities have noted the presence of buckling in the wing structure, including in the center section, during static testing. The analysis completed by other aviation authorities suggests buckling may take place at loads significantly below limit load. Buckling is acceptable below limit load provided any deformation disappears when the load is removed and provided the structural analysis and testing properly account for post-buckling behavior. During a visit to the manufacturer's facility in Mexico, MO, the FAA also observed buckling of the local wing skin near the rib containing the aileron bell crank attachment when the ailerons were deflected to their stops. Such structural instabilities can have a significant effect on static strength and flutter characteristics of the wing. The manufacturer has designed modifications to the structure that appear to address the specific areas where buckling has occurred.

- Operating Envelope: Initial review of available static test data indicated the weight and speed envelopes for the CH 601 XL needed to be substantially reduced to limit the potential risk of exposure to subsequent structural failures. The manufacturer published new operating limitations in July 2009 to reduce potential exposure to flutter. However, subsequent analysis by the FAA showed these proposed limits did not adequately address our concerns related to the static strength of the wing. It became evident that reducing the flight envelope based on the loads used to design the original structure may not leave a viable operational envelope for the aircraft. Also, the pilot operating handbook (POH) and the materials provided on the manufacturer's web site need to be more specific regarding the acceptable g-load envelope for the design. Some information could lead pilots to assume the design can sustain +6g and -6g, in flight. LSA airplanes are designed to a design limit load factor envelope of +4g and -2g. Exceeding the design envelope may result in permanent deformation of the structure or catastrophic structural failure. To assure aircraft are operated within their operating envelope after being modified with the structural changes outlined in the safety directive, they must have their airspeed indicating systems properly calibrated. The aircraft must be tested in flight to verify stall speed, maneuver speed (V_A), and maximum speed with appropriate POH changes made so pilots clearly understand all operating limitations.
- FAA Actions: On November 7, 2009, the FAA issued an SAIB to notify the public of the potential safety concerns with the CH 601 XL and recommending owners cease operations until the modifications are made. According to the intent of the ASTM safety directive process, the FAA also worked with the manufacturer to take immediate action to address the potential safety issues with the CH 601 XL design. On November 12, 2009, the FAA also suspended the issuance of all new airworthiness certificates to any and all variants of Zodiac CH 601 XL and CH 650 airplanes, all serial numbers, S-LSA, E-LSA, and experimental amateur-built aircraft until such time that the applicant submits adequate evidence that the applicant's aircraft has been modified in a manner consistent with the AMD safety directive and SAIB CE-10-08. This action was taken to ensure no new aircraft with known safety concerns are introduced into the NAS.
- Manufacturer Actions: On November 7, 2009, AMD issued a safety directive against the S-LSA version of the CH 601 XL and CH 650, effectively grounding those aircraft. Although not required by FAA regulation 14 CFR Part 21 § 21.190(c)(5), the actions in the safety directive may also be appropriate for the E-LSA and experimental amateur-built versions of the aircraft due to common design features. The FAA encourages action by these owner/operators as well, since the wing design is common to the S-LSA. The manufacturer's safety directive addresses modifications needed to improve static strength of the wing, modifications to the ailerons to mitigate flutter concerns, and references the need for proper procedures for pitot-static pressure source calibration and airspeed indicator marking. The modifications specifically incorporated balanced aileron controls, and structural enhancements to the aileron bell crank attachment to mitigate flutter concerns. The aileron changes are based in part on design changes made by the United Kingdom Light Aircraft Association (UK LAA) to alleviate flutter concerns. However, it is not possible to completely rule out the possibility that flutter may exist after

modifications are made. Further testing and analysis by the manufacturer on the modified structure must be done to alleviate any remaining flutter concerns and document compliance to the ASTM standard for flutter. Owners and operators should contact the manufacturer for the latest information on the updates.

2.0 BACKGROUND

In 2004, the FAA issued the light-sport aircraft / sport pilot rule. LSA are small, simple-to-operate, low-performance aircraft. They are limited to a weight of no more than 1,320 lb for aircraft not intended for operation on water, a maximum airspeed of 120 knots in level flight at maximum continuous power, a maximum stall speed of 45 knots, and a maximum seating capacity of two.

Before the FAA issued the LSA rule, an increasing number of ultralight vehicles were being operated outside their applicable regulatory limits. For example, many vehicles either exceeded the 14 CFR part 103 ultralight weight limit, or they had two seats. Seeing the need for training to reduce accidents, manufacturers had built two-place training ultralight vehicles. However, many did not meet the definition of an ultralight and were not manufactured, certificated, or maintained to any standard. The FAA issued exemptions to allow these larger ultralights to be used for training, but not for other sport or recreational flight.

Recognizing a need to remedy this situation and the growing capability of ultralight designs, the FAA issued the LSA rule to increase the level of safety of these aircraft, close gaps in previous regulations, and create a means to accommodate new aircraft designs. Issuance of the LSA rule paved the way for S-LSA aircraft designed, manufactured, tested, and supported according to the ASTM consensus standards. S-LSA aircraft are manufactured under a quality assurance system that meets a specific ASTM standard.

The foundational principles for using the ASTM standards for S-LSA were to leverage existing industry experience through a self-certification process and to provide standards where none existed before. Since the rule was released, the result has been a rapidly growing LSA industry with over 100 new LSA designs recognized under the ASTM International consensus standard process and over 1,100 individual aircraft registered in the S-LSA category.

This rapid growth makes it critical for manufacturers to follow the consensus process, and for them to recognize they are responsible for monitoring and correcting any COS issues related to their designs. The FAA expects the industry to maintain a high level of LSA safety and has begun efforts to support LSA COS. For example, the FAA and the Experimental Aircraft Association (EAA) created the Light Sport Aircraft Subgroup under the General Aviation Joint Steering Committee (GAJSC). This subgroup serves as a vehicle for government-industry cooperation, communication, and coordination on LSA safety issues.

Structural failure accidents are of particular concern to the FAA and we closely follow in-flight structural failures. Between February 2006 and November 2009, the Zodiac Model CH 601 XL was involved in six in-flight structural break-up accidents in the United

States, with several others occurring abroad. To help understand the nature of these LSA accidents, the FAA chartered an internal team to look into details of the Zodiac CH 601 XL aircraft. The investigation was complicated by the fact the CH 601 XL is available as an S-LSA from AMD and as an amateur-built version in the experimental category from Zenith, which are treated differently by the FAA.

These structural break-up accidents gained attention from not only the FAA, but also the media, the NTSB, and other airworthiness authorities. These accidents also prompted the NTSB to recommend the FAA take action to prevent additional in-flight breakups. A link to the NTSB safety recommendations is listed at:
http://www.ntsb.gov/recs/letters/2009/A09_30_37.pdf

2.1 S-LSA, E-LSA, and Amateur Built Airworthiness

Unlike FAA type certificated aircraft neither LSA nor amateur-built aircraft go through an FAA design approval process. Instead, the FAA issues an airworthiness certificate for these aircraft on an individual basis, stating they are safe for operation according to 14 CFR Part 91 using the design limitations set by the manufacturer or amateur builder. More detail regarding the airworthiness of S-LSA, E-LSA, and amateur-built aircraft is contained in this section.

S-LSA aircraft receive airworthiness approval only after the manufacturer asserts the aircraft meets the ASTM International consensus standards and the aircraft successfully completes ground and flight tests. These are considered ready-to-fly LSA and are factory built to ASTM specifications. They do not undergo an FAA design review or approval.

Regarding S-LSA COS, S-LSA manufacturers are required by 14 CFR Part 21 § 21.190(c)(5) to monitor and correct safety-of-flight issues by issuing safety directives. The intent is for S-LSA aircraft manufacturers to be held responsible for monitoring and correcting safety issues related to their designs. They must show that they have a continued airworthiness system that meets ASTM standard F2295. In issuing the LSA rule, the FAA explained that it did not intend to issue airworthiness directives (ADs) on S-LSA aircraft (but would only issue them on type-certificated products incorporated into an S-LSA, such as engines, propellers, etc). The LSA rule requires S-LSA manufacturers, or the group or individual that has assumed COS responsibility for the design, to develop corrective actions for unsafe conditions. Safety directives (or manufacturer-approved alternative methods) must be incorporated into S-LSA aircraft.

The LSA rule also included regulations for E-LSA aircraft. These aircraft have the same limiting characteristics as S-LSA (for example, maximum weight of 1,320 lb, maximum stall speed of 45 knots, etc.). E-LSA aircraft include three different groups of aircraft. Some were originally certificated before the FAA established registration or conversion deadline of January 31, 2008. This provided a path for airworthiness certification of ultralight-like vehicles that were in operation at the time the rule was issued. Other aircraft eligible for E-LSA airworthiness certification are S-LSA that have been converted to E-LSA after being modified by the owner or operator from the original S-

LSA design. The third group is comprised of kit-built E-LSA that comply with the ASTM standard applicable to LSA kits, yet these are not factory-built ready-to-fly aircraft.

Regarding E-LSA COS, the FAA does not issue ADs for E-LSA aircraft. If the aircraft was constructed from a kit, or if an S-LSA version of the aircraft is offered, instructions or safety directives may be available from the manufacturer, but the use of such instructions or safety directives is not mandatory. Owner-developed alterations and repairs are permitted.

Unlike both S-LSA and kit-built E-LSA, amateur-built aircraft do not require a manufacturer's statement of compliance to the applicable ASTM International consensus standards. They are also not subject to any FAA design approval process. Instead, amateur-built aircraft receive experimental airworthiness certificates on an individual basis and may have been built, modified, or maintained in a way that is not controlled by the FAA, an LSA manufacturer, a kit builder, or any other designer.

FAA regulations allow for these aircraft built by people who undertook the construction project solely for their own education and recreation to be operated in our national airspace. The FAA does not require these amateur-built aircraft to meet the airworthiness standards applied to standard certificated aircraft. The regulatory provision for amateur-built aircraft has been in place for more than 50 years. During that time, thousands of people have successfully built and safely flown aircraft for their own education and recreation.

The FAA has several measures in place to protect other people who, unlike the pilot-in-command of an amateur-built aircraft, have not voluntarily accepted the risks associated with their operation. For example, after airworthiness certificate issuance, a newly assembled amateur-built aircraft may not be flown outside an assigned flight test area until the aircraft is shown to be controllable and that it has no hazardous operating characteristics or design features. After this flight test phase, additional operating limitations remain with the aircraft. For example, amateur-built aircraft generally may not be operated over densely populated areas or in congested airways unless sufficient altitude is maintained to allow a safe emergency landing without hazard to people or property on the ground. In addition, the pilot in command of an amateur-built aircraft must advise each passenger of the experimental nature of the aircraft and explain that it does not meet the certification requirements of a standard certificated aircraft.

Regarding amateur built COS, the pilot-in-command has responsibility for determining whether the aircraft is in condition for safe flight, and no pilot may operate a civil aircraft unless it is in an airworthy condition. Owner-developed alterations and repairs are permitted. The FAA does not issue ADs for amateur-built aircraft, but continues to consider ways to deal with amateur-built COS. If an aircraft was constructed from a kit, instructions for addressing airworthiness concerns may be available from the kit manufacturer, but the use of such instructions is not mandatory.

For this special review, it was noted that the CH 601XL design was superseded by the newer CH 650, though the wing structure is nearly identical. The CH 601 XL and CH 650 are S-LSA from AMD. They are also available as amateur-built kits from Zenith Aircraft. The CH 601 XL and CH 650 were not produced as E-LSA kits to the specific ASTM kit standard.

2.2 Airworthiness Certification Regulatory Basis

The airworthiness certification regulations differ depending on whether the aircraft is amateur-built or a ready-to-fly LSA. According to FAA Order 8130.2F the following applies:

For amateur-built aircraft certified under 14 CFR Part 21 § 21.191(g)
Amateur-built aircraft are eligible for an experimental airworthiness certificate when the applicant presents satisfactory evidence of the following:

> **(a)** The aircraft was fabricated and assembled by an individual or group of individuals.
> **(b)** The project was undertaken for educational or recreational purposes.
> **(c)** The FAA finds that the aircraft complies with acceptable aeronautical standards and practices.

For special light-sport category aircraft defined under 14 CFR Part 1 § 1.1 and certified under 14 CFR Part 21 § 21.190
A special airworthiness certificate in the light-sport category is issued to an aircraft that meets the definition of LSA, is manufactured to the applicable consensus standard, and is one of the following five classes of the LSA category: airplanes, gliders, powered parachutes, weight-shift-control aircraft (commonly called trikes), and lighter-than-air aircraft (balloons and airships). When the aircraft meets all the eligibility requirements of 14 CFR Part 1 § 1.1 and 14 CFR Part 21 § 21.190, it may be issued an airworthiness certificate in the LSA category. Appendix D contains the applicable 14 CFR Part 1 and Part 21 regulations applicable to the LSA Aircraft.

Appendix E and F show the total number of S-LSA aircraft built by AMD, and the airworthiness registration date listing for all CH 601 XL and CH 650 aircraft, for reference purposes.

2.3 Applicable Standards and Regulations

This section provides references for the applicable ASTM International consensus standards for the CH 601 XL and CH 650 LSA and the FAA regulations for airworthiness certification of amateur-built and LSA.

The consensus standards are copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. Individual reprints of the standards (single or multiple copies, or special compilations and other related technical information) may be obtained by contacting ASTM at this address, or at (610) 832-9585 (phone), (610) 832-9555 (fax), through service@astm.org (email), or through the ASTM website at www.astm.org. To inquire about standard content, and/or membership, or about ASTM International Offices abroad, contact Daniel Schultz, Staff Manager for Committee F37 on Light Sport Aircraft: (610) 832-9716, dschultz@astm.org.

ASTM International Consensus Standards Applicable to the CH 601 XL:

- **F2245** - Specification for Design and Performance of a Light Sport Airplane
- **F2279** - Practice for Quality Assurance in the Manufacture of Fixed Wing Light Sport Aircraft
- **F2295** - Practice for Continued Operational Safety Monitoring of a Light Sport Aircraft
- **F2316** - Specification for Airframe Emergency Parachutes for Light Sport Aircraft
- **F2483** - Practice for Maintenance and the Development of Maintenance Manuals for Light Sport Aircraft
- **F2626** - Standard Terminology for Light Sport Aircraft

FAA 14 CFR Part 1 and 21 Requirements:

- **14 CFR Part 1 § 1.1** - General definitions. *Light-sport aircraft.*
- **14 CFR Part 21 § 21.190** - Issue of a special airworthiness certificate for a light-sport category aircraft.
- **14 CFR Part 21 § 21.191** - Experimental certificates.

Appendix D contains the applicable 14 CFR Part 1 and Part 21 regulations applicable to the LSA Aircraft.

2.4 Applicable Type Certificate

Since the designs of the CH 601 XL and CH 650 were not reviewed and approved by the FAA there is no type design approval, type certificate, or corresponding type certificate data sheet issued by the FAA. In addition, the FAA does not issue a production certificate to LSA companies for manufacturing duplicate aircraft. The manufacturer's statement of compliance on FAA Form 8130-15 defines the design and production details for each individual S-LSA.

3.0 Specific CH 601 XL Safety Concerns

With the rapid growth in LSA, the primary focus of the FAA is to maintain a high level of COS for the LSA. The intent of the safety directive process, as outlined in 14 CFR Part 21 § 21.190(c)(5), is for S-LSA aircraft manufacturers to be held responsible for monitoring and correcting safety issues related to their designs.

When the CH 601 XL started having structural failures in 2006, the FAA investigated the first accident, viewed the wreckage, and visited the manufacturer to identify a potential root cause. The results of that review were inconclusive. Similar accidents in Europe prompted the United Kingdom, the Netherlands, and Germany to ground the CH 601 XL in October 2008. However, the German authority later opted for a reduced flight envelope, allowing the airplane to continue to fly. At that time, the FAA concluded the accidents were due to improper operations, such as flying beyond the weight and airspeed limits published in the POH, or improperly operating in turbulent conditions. Subsequent structural failures in the US raised additional concern to the FAA, so we began a special review of the CH 601 XL design to identify a root cause.

During this detailed review, the FAA worked closely with the NTSB at a technical level since they had also identified concerns with the airplane. The specific safety concerns shared by the FAA and the NTSB were related to aircraft structure, flutter, proper airspeed calibration, and stick forces. NTSB concerns focused primarily on evidence that seemed to indicate flutter was a root cause for some, if not all, of the accidents. However, from our preliminary analysis of the accidents, a common root cause for the structural failure accidents was not evident. A link to the NTSB safety recommendations is listed at: http://www.ntsb.gov/recs/letters/2009/A09_30_37.pdf

4.0 Design Review & Analysis

The special review team performed a detailed analysis of the CH 601 XL in an attempt to identify a root cause for the structural failures occurring in flight and to further investigate the specific NTSB safety recommendations referred to in the previous section. This section provides the technical results of the special review.

4.1 Loads Analysis

The FAA initially focused on the methods used by the manufacturer to estimate wing design loads. We reviewed the structural loads analysis included in the report 'Zodiac CH 601XLSA Stress Analysis and Tests', available from the manufacturer. Our review focused on whether the manufacturer's structural loads analysis complied with ASTM International F 2245-08a and if the ASTM standard is adequate to ensure an acceptable margin of safety. We limited our review to the analysis of the wing since the accidents of concern involved wing failure.

The FAA identified several significant issues with the manufacturer's structural loads analysis. These issues included:

- The amount of lift produced by the portion of the wing planform covered by the fuselage. The manufacturer's analysis assumes the wing planform covered by the fuselage is as effective in producing lift as an adjacent portion of exposed wing planform. This assumption may not be conservative and may be noncompliant with the ASTM F 2245 § 5.1.1.2 requirement that '…these loads must be distributed to conservatively approximate or closely represent actual conditions.'
- The distribution of lift along the span of the wing. The manufacturer's analysis used an assumption that the lift distribution has a purely elliptical shape. This assumption is often used in academic evaluations, but is incorrect for compliance to ASTM F 2245 § 5.1.1.2. Several more appropriate methods exist for estimating the distribution of wing lift. Some of these methods are listed in advisory circular (AC) 23-19 Airframe Guide for Certification of Part 23 Airplanes.
- The fuel tank capacity. The manufacturer appears to have computed the wing loads assuming a 15 gallon fuel tank in each wing. However, the manufacturer's drawings and advertising materials clearly show that a 12 gallon tank is standard equipment on the CH 601 XL. This small discrepancy in fuel tank capacity underestimates the wing design bending loads by about four percent. This could lead to the structure being designed to a lower capacity than needed.
- The correct definition of the maximum zero fuel weight (MZFW). The manufacturer's analysis defines the MZFW as the maximum takeoff weight (MTOW) minus full fuel. This definition is incorrect. The intent of the MZFW is to design the wing for the condition where airplane weight is at a maximum but the wing fuel tanks are only partially full. Because the fuel load is alleviating for wing bending loads, using the proper fuel load to determine MZFW is important.

For the CH 601 XL, the MZFW case is the condition where two occupants (190 lbs each, according the ASTM standard) are added to the empty weight of the airplane (830 lbs). Then sufficient fuel is added to the wing tanks to reach MTOW. For the CH 601 XL, the MZFW is 1,210 lbs (830 + 380 lbs) and the MTOW is reached with 110 lbs of fuel, instead of the zero fuel weight used in the manufacturer's calculations. This could lead to the structure being designed to a lower capacity than needed.

- The airfoil pitching moment data used to compute wing torsion loads. The manufacturer's analysis was based on estimates of the airfoil pitching moment characteristics obtained from the airfoil designer. The manufacturer then assumed a reduction in the magnitude of the airfoil pitching moment without providing substantiating test data to support it. This assumption could impact the torsional loads used to design the wing structure, possibly leading to a reduction in stiffness and damping characteristics of the wing, which could impact flutter.
- The interpretation of ASTM F 2245 § X1.3.3.3. The manufacturer's analysis assumes that the intent of this standard is to multiply both torsion and wing bending loads by 75%. The manufacturer's interpretation is incorrect. This standard is intended to combine the wing bending loads at ¾ of the design limit load factor, or 3g, with 100% of the torsion loads occurring at V_D. Again, this assumption is non-conservative and could impact the resulting torsional stiffness of the wing structure, which in turn could impact flutter characteristics.
- The correct value for the maneuvering speed, V_A. The manufacturer determined V_A to be 90 knots (103) mph based on a stall speed, V_S, of 44 knots (51 mph). However, the manufacturer's flight test report documents a measured stall speed of 43 knots (49 mph). In addition, the flight test report did not appear to contain proper temperature corrections to convert the measured data to standard atmospheric conditions. Using data in the manufacturer's CH 601 XL flight test report and correcting to standard conditions reduces the stall speed to 41 knots (47 mph), resulting in a V_A of only 82 knots (94 mph). Using a V_A of 90 knots (103 mph) instead of 82 knots (94 mph), a pilot could inadvertently reach 4.8g instead of the intended 4.0g at V_A. The critical importance and intent of V_A is stated in FAA publication FAA-H-8083-3A Airplane Flying Handbook. The handbook defines the design maneuvering speed as the "…maximum speed at which the airplane can be stalled or full available aerodynamic control will not exceed the airplane's limit load factor. At or below this speed, the airplane will usually stall before the limit load factor can be exceeded." Operating below V_A can prevent overstressing the structure from purposeful pitch control inputs, and from vertical gusts from all but the most extreme turbulence. Pilots expect not to be able to exceed the design limit load factor at or below V_A. Unknowingly operating at speeds above the proper maneuvering speed may cause pilots to inadvertently exceed the design limit load factor, particularly at aft center of gravity where stick forces are known to be light and stick force gradients flatten out.
- Errors in the airspeed indication system. In a later section of this report, we describe what may be errors in the airspeed indication system. These errors can be critical to operating the airplane within the intended design envelope. As pointed out in the discussion on V_A, a 9 mph difference between the actual V_A and the V_A

given in the POH can result in exceeding the design limit load factor by 0.8g. Similarly, a 5 mph airspeed indication error at V_C (V_{NO}) would result in exceeding the design gust load factor by 0.33g.

During our review, the FAA developed estimates of the wing bending and torsion loads to determine the relative importance of each of these issues. We estimated the wing loads assuming a minimum value for the MZFW of 1,210 lbs, based on an empty weight of 830 lbs and 380 lbs for the occupants. We also studied the effects of providing an increased MZFW of 1,250 lbs to account for differences in empty weight across the existing fleet, additional installed equipment (e.g. ballistic recovery systems), and for potential structural modifications to the design. Our estimated wing bending and torsion loads are significantly higher than those computed by the manufacturer, as shown in figure 1. (Note: We have removed the actual load values from figures 1 through 4 to protect the manufacturer's proprietary information and data.)

The FAA also studied the importance of the airfoil pitching moment data. As shown in figure 2, the accuracy of this data is critical in determining the torsion loads the manufacturer must use to design the wing. For comparison to the manufacturer's data during the completion of this study, we used wind tunnel test data from the widely used academic publication 'Theory of Wing Sections' by Abbott and Von Doenhoff for an airfoil that appeared to be similar to the one incorporated into the CH 601 XL wing.

The FAA completed its load analysis and provided our comments to the manufacturer in September 2009. Based on our comments, the manufacturer revised their analysis, re-tested the static strength of the wing structure, and provided us with the updated analysis and test results. The manufacturer agreed with the FAA's position on the distribution of lift along the wing span, the fuel tank capacity, and the interpretation of ASTM F2245 §X.1.3.3.3. However, the manufacturer did not agree with, and did not incorporate into their analysis, the FAA position on the distribution of lift between the wing and the fuselage, MZFW, airfoil pitching moment data, and the design maneuvering speed, V_A.

The manufacturer successfully tested the modified wing structure to loads higher than determined in their revised analysis. The wing structure did not fail at the ultimate test loads. However, the wing attachment bolts were bent and the attachment bolt holes were elongated, indicating there was permanent damage to the structure at these loads. We have depicted the loads from the manufacturer's revised analysis and static test in figure 3.

Despite disagreeing with our position on several significant issues, the maximum bending moment achieved in the static test is only a few percent below our estimated maximum required bending moment. The maximum torsion load achieved in the test may only be a few percent below our estimated maximum torsion provided the manufacturer can justify the airfoil pitching moment data with applicable test data. It is possible that if the manufacturer had continued the static test to structural failure, the ultimate test load could have equaled or exceeded FAA estimates of the required load envelope.

Figure 4 presents a history of the manufacturer's loads analysis and static testing. We provide this information to provide a time line of the manufacturer's structural analysis and testing.

Figure 1: Comparison of FAA Estimated Loads with 'Zodiac CH 601 XL Stress Analysis and Tests'

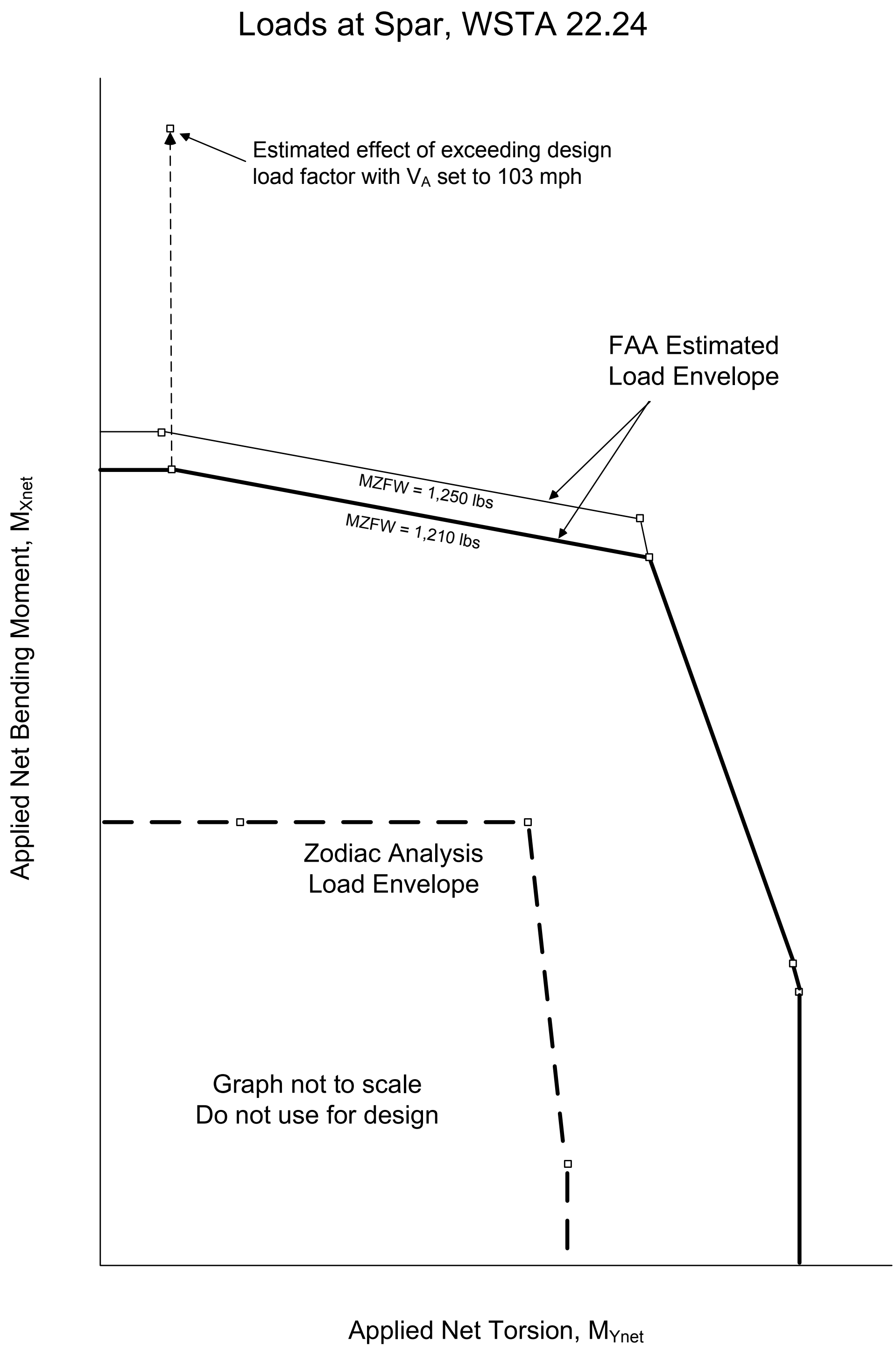


Figure 2: Effect of Pitching Moment Characteristics on Wing Design Loads

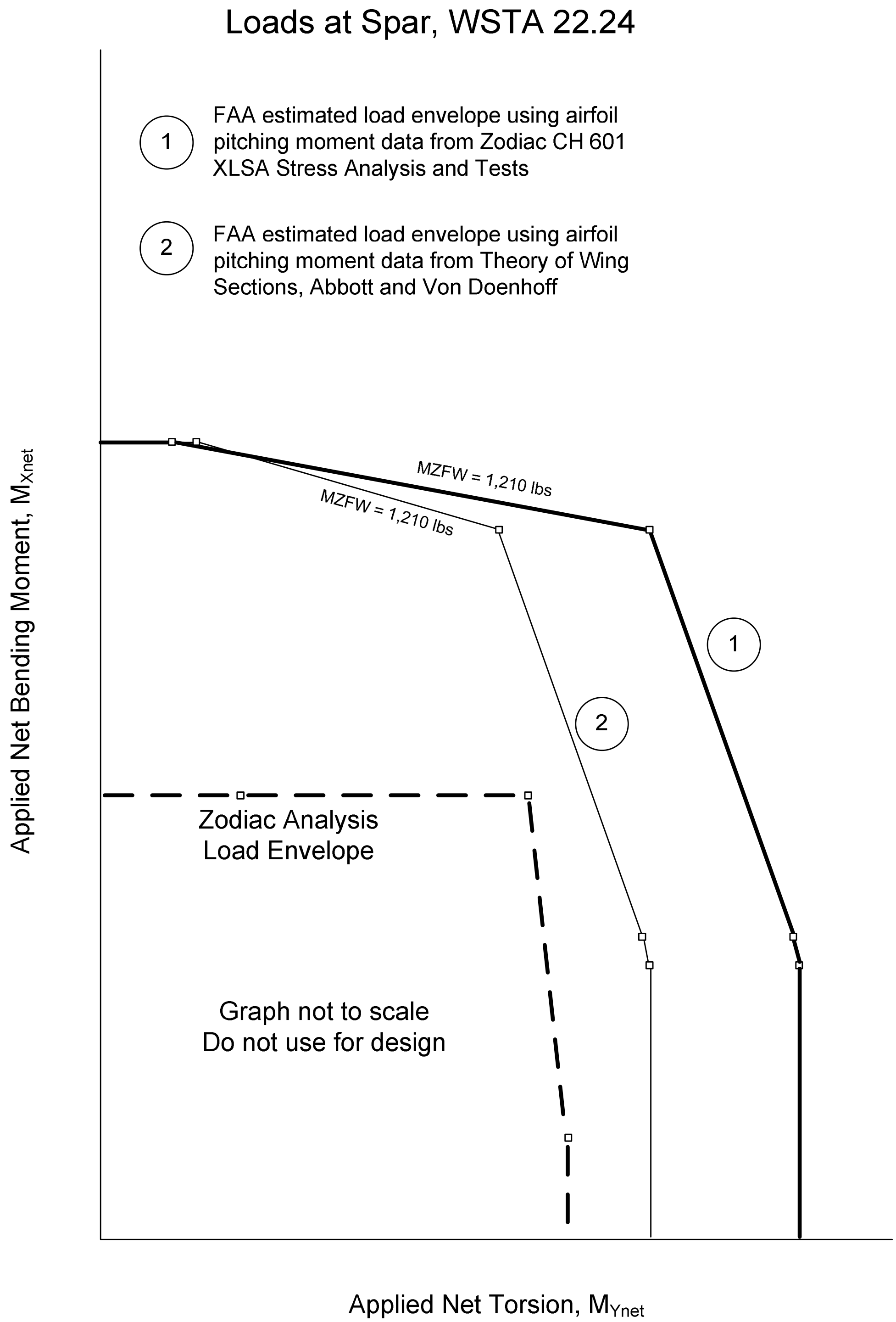


Figure 3: Revised Zodiac Analysis and Static Test Wing Design Loads

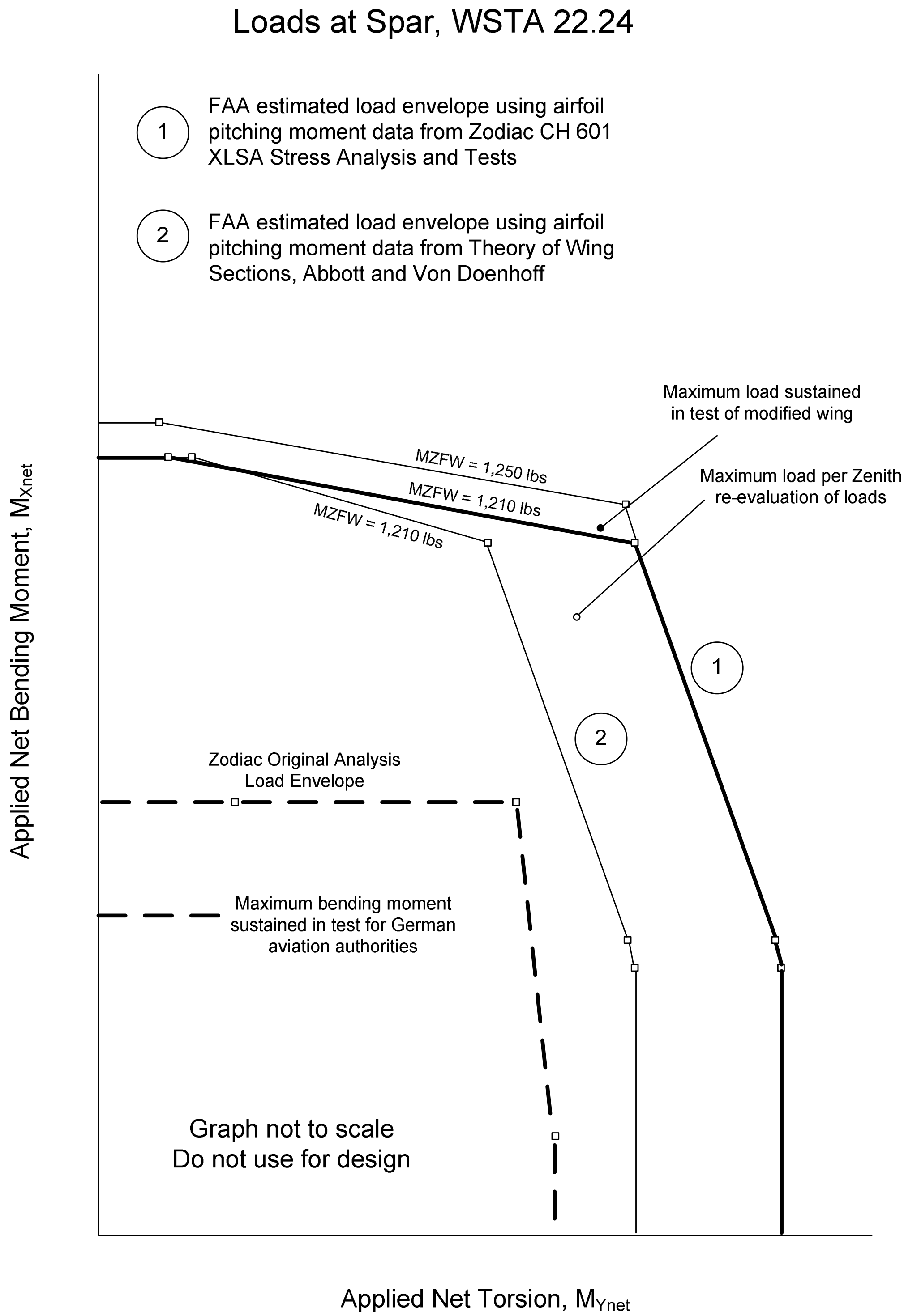
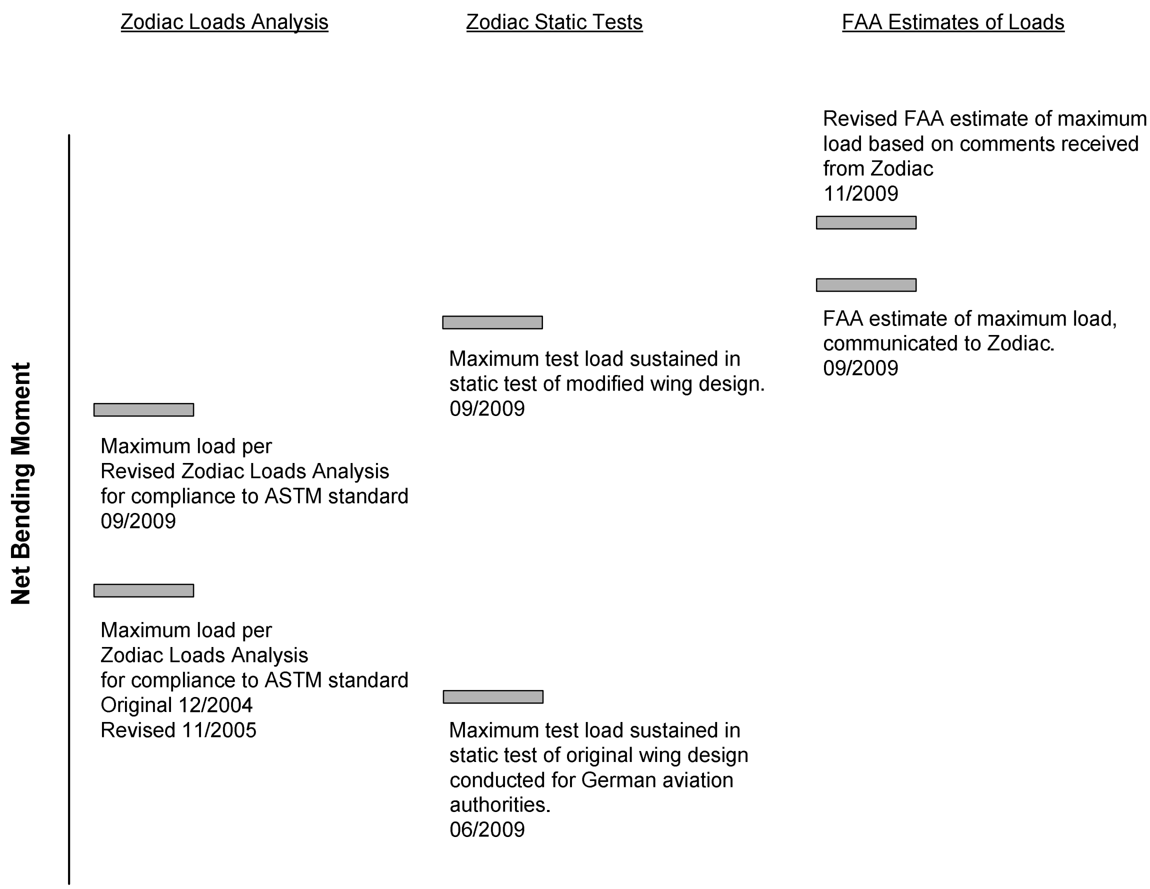


Figure 4: History of Zodiac Wing Structural Loads Analysis and Tests



Recommendations for the Manufacturer:

- The manufacturer stopped the static test of the modified structure approximately five percent below the FAA's load estimates required for ASTM compliance. At the time of this report, the manufacturer was continuing to make modifications to the wing structure and the drawings referenced by the safety directive to provide further improvements. The manufacturer should consider additional structural testing and analysis once a final design is reached to demonstrate the new wing meets the ASTM standards.

- The manufacturer should establish a MZFW for the CH 601 XL. The minimum value for the MZFW is 1,210 lbs, based on an empty weight of 830 lbs. The manufacturer should consider higher values for the MZFW, given the empty weights of the existing fleets, owner's preference for installed equipment including ballistic recovery systems, owner's preference for allowable baggage, and the weight of any structural modifications. The manufacturer should revise the POH and include information on an acceptable MZFW.

- The manufacturer should establish limitations for V_O, V_{NO}, and V_{NE}. Based on the data currently available,

V_O = 94 mph, CAS (See recommended revision to ASTM standard discussed below.)

V_{NO} = 124 mph, CAS (See recommended revision to ASTM standard discussed below.)

V_{NE} = 161 mph, CAS

<u>Suggested Revisions to ASTM International F 2245-07a</u>

- The standard should be improved to clarify the need to consider payload and fuel combinations and to inform the pilot of any limitations on payload and fuel distributions. Specifically, the ASTM standard should incorporate a requirement similar to 14 CFR Part 23 § 23.321 which requires compliance to the flight load requirements for any practicable distribution of disposable load (Use of Appendix A in 14 CFR Part 23 does not preclude the requirements of § 23.321.). Section 9 of the ASTM standard should require inclusion of the MZFW in the operating limitations section of the POH.

- The standard should provide a correct equation for V_{Amin} in F 2245 § X1.1. The definition should be changed to reflect 14 CFR Part 23 § A23.3.

- The standard should incorporate the 'operating maneuver speed', V_O, similar to 14 CFR Part 23 § 23.1507. V_O would replace the value for V_A specified in section 9 of the ASTM standard. The ASTM standard's use of V_O would provide common nomenclature between newly type certificated airplanes and LSA designs. The use of V_O would also provide the pilot with the correct maneuvering speed in cases where the designer has selected a value for V_A other than $V_S \sqrt{n_1}$, such as from ASTM F 2245 § X1.1.

- The standard should provide a correct equation for V_{Cmin} in F 2245 § X1.1. The definition should be changed to reflect 14 CFR Part 23 § A23.3.

- The standard should incorporate the maximum structural cruising speed, V_{NO}, similar to 14 CFR Part 23 § 23.1505. Section 9 of the ASTM standard does not currently provide the pilot with information for the maximum allowable normal operating speed. Use of V_{NO} would provide common nomenclature with type certificated airplanes and ensure that pilot's would not exceed the structural capability of the airplane. Pilots should understand the risk of exceeding V_{NO} and should only consider doing so in smooth air.

- The standard should provide a correct equation for V_{Dmin} in F 2245 § X1.1. The definition should be changed to reflect 14 CFR part 23 § A23.3.

- Section 5.2.4.4 should clarify that the designer has the option to define V_D in terms of the demonstrated dive speed, V_{DF}.

4.2 Flutter Investigation

The flutter investigation consisted of a thorough review of the available accident photographs and physical components of the Zodiac CH 601 XL accident airplanes. We also considered reports and conclusions from external sources, including the NTSB, foreign government regulatory agencies, eyewitness accounts, and independent technical evaluations. Additionally, we reviewed available flutter report summaries and GVT results. The FAA did not perform a formal flutter analysis because our load analysis, as shown in section 4.1, indicated the wing structure would need to be redesigned, impacting the flutter characteristics of the wing. A summary of our flutter evaluation is provided for each source of information in the following sections:

- Photographs and physical evidence:

The FAA evaluated the photographic evidence of several accident aircraft and observed the physical evidence first hand of the Antelope Island accident aircraft. The evidence indicates the presence of compression failures in both the upper and lower aft spar caps (or skins). In some cases the evidence shows a complete wing failure in one direction, yet exhibits compression buckling consistent with bending in the other direction as well. This combined condition is indicative of complete load reversal and provides consistent evidence that flutter occurred in these cases.

- Reports and conclusions from the NTSB, other foreign government regulatory agencies, and eyewitness accounts:

The NTSB identified flutter as the primary cause for several accidents, citing similar evidence to what was stated in the previous section. Their expertise in accident investigation enables them to distinguish between damage that occurred in flight during the structural break-up sequence, and damage caused from impact with the ground. The NTSB has pointed out that the location of the buckling failures on the upper and lower surfaces of both wings has been observed consistently on several accident aircraft. Additionally the direction of the loading that would create those buckles is typically in a direction inconsistent with the loading from the impact with terrain. However the evidence is consistent with wing bending and/or twisting as would be observed during flutter where wing bending and torsion combine with control surface rotation about the wing torsional axis. Additionally the NTSB observed the compression buckling of the lower spar cap was at the lower edge of the hole that allowed the aileron push rod to pass through the rear spar web. The compression buckling of the upper spar cap was several inches inboard of the flap/aileron junction. Both areas should be addressed by the modifications in the safety directive from AMD.

Foreign government agencies have also declared that flutter was their primary concern and evidence pointed to flutter as a primary causal factor for the in flight structural failures. The FAA agrees flutter is a major concern and is pleased the modifications required by the safety directive from AMD will balance the aileron controls to address potential excitation from improperly rigged aileron controls.

Pilots have reported to the NTSB that they experienced what can only be described as flutter. These reports have been documented and pertinent portions of those reports are available on the NTSB web site at: http: www.ntsb.org

- Available flutter report summaries and GVT results:

Several reports were reviewed from the Zenith Builder Analysis Group (ZBAG). They were prepared by a well qualified Civil Aviation Safety Agency aerospace engineer with similar credentials to an FAA DER with experience in flutter testing and analysis. According to these reports, which used a simplified two dimensional flutter analysis, there is an indication of the occurrence of two different flutter modes within the approved flight envelope of the CH 601 XL airplane. At least one of those modes indicated an interaction between wing bending and aileron rotation. However, at the time of the analysis, the author did not have access to the GVT data to fine tune his analysis.

The Hamburg University of Technology (TUHH) was contracted by the manufacturer to perform a complete GVT and flutter analysis. Professor Dr. Ing Uwe Weltin performed this analysis. His report looked at the typical linear flutter analysis and didn't show any tendency for flutter within the CH 601 XL flight envelope. However, his analysis indicated that non-linear flutter analysis could indicate a possibility of flutter or vibration within the flight envelope. Due to the flexibility inherent in the wings (wing skins buckle prior to ultimate load), it may be necessary to consider non-linear evaluation techniques of the flutter characteristics since the frequency and mode shapes may be affected by post buckling effects on wing skin structural stiffness. Link to several reports related to flutter analysis of the CH 601 XL are as follows:
http://www.zenairulm.com/FAQ/pdfdocs/CH601XL-GVT-June6.pdf
http://zenithair.com/zodiac/xl/data/GVT-Report-CH601xl.pdf
http://zenithair.com/zodiac/xl/data/GVT-Report_CH650_V0-EG.pdf

- Conclusion:

Based on the evidence and analysis available, it is clear that flutter appears to be a causal factor to the in-flight breakup of the airplanes. However, it is not clear whether it was the primary causal factor, or occurred after some other initial structural deformation caused local changes in wing section angle of attack. Flutter investigation requires a highly technical, detailed, and complex analysis. The FAA did not perform a detailed analysis to determine the flutter characteristics of the CH 601 XL, recognizing the flutter characteristics would change once the modifications required by the AMD safety directive are incorporated. Those modifications will impact the structural stiffness of the wing, which will cause it to have different frequency response and damping characteristics from the unmodified design.

The manufacturer needs to reevaluate the modified CH 601 XL wing structure with the balanced ailerons to determine the flutter characteristics of the modified design. This should include a complete flutter investigation (GVT, flutter analysis, and flight test) accomplished by a noted flutter expert on the modified design.

It is also important to note that despite efforts to lower the maximum weight, speed, and maneuvering speed to make the current wing design adequate for the design loads, there does not appear to be a single complete flutter analysis that shows the airplane is free from flutter. Of the reports available for the FAA to review, all arrive at different conclusions and none appear comprehensive (i.e., GVT, analysis, and proper flight test), and none were completed by an approved FAA flutter DER, though their involvement is not required. Some consider the ASTM guidance for flutter compliance to be vague. The FAA is working with the ASTM F37 executive committee to determine what additional flutter requirements would be appropriate for the LSA community.

For the CH 601 XL, testing by the UK LAA during their flutter mitigation program seems to indicate that having balanced ailerons greatly reduces any potential for flutter. The FAA's concerns for flutter should be mitigated once the manufacturer has done testing and analysis to validate the revised design. The changes required by the recent safety directive from AMD include:

- Structural modification to the wing;
- The aileron modifications designed by the UK LAA;
- Verification of flap and other control stop installations;
- Modifications to the aileron bell-crank attachment; and
- A requirement to check the control cable tensions before each flight.

4.3 Stress Analysis

An in-depth stress analysis was not performed on the structure of the CH 601 XL. However conclusions regarding the stress characteristics of the design were gathered from the review of the following:

- The manufacturer's report 'Zodiac CH 601XLSA Stress Analysis and Tests';
- Static tests completed by the manufacturer and entities in Europe;
- Structural design drawings;
- Proposed modification drawings;
- Accident reports/photographs; and
- Examination of a representative airplane at the manufacturer's facility in Mexico, Missouri.

Qualitatively, the following observations were made from our review of the available data. A review was performed on the original airplane structure designed to the flight loads that have been identified earlier in this report to be non-conservative. Regardless, it appears that the structure incorporating the required modifications from the safety directive would comply with the applicable ASTM International standards from a stress analysis standpoint.

The original CH 601 XL design is constructed from relatively light sheet aluminum material; typically, 0.016-0.025 inch sheet. This relatively light structural material appears to provide very light integral stiffening, which allows for diagonal wing skin panel buckling even when simply applying an upward force to the wingtip by hand with the aircraft on the ground. Localized buckling at the outer wing skin near the aileron bell-crank support rib was also noted during informal stress evaluations. This rib appears to support both in-flight wing loads and loads from the aileron control system. Several accident photos indicated buckling in this wing skin/rib area as a result of the accident aircraft failure sequence. Having aileron cable tensions too high could also influence the load carrying capability of this particular rib. The modifications required by the AMD safety directive will strengthen this rib and the aileron bell-crank attachment point, and should address FAA stress concerns regarding its strength.

Another item of note is the wing spar construction. The wing spar has three components, two outer sections and a center section, which are spliced together at the side-of-body on both sides of the fuselage. The spar is canted forward nine degrees and the upper and lower chords consist only of thicker straps. The spar chords do not have structural flanges that are usually present on most typical spar designs. Such flanges work to resist buckling, which has been noted in static load tests on the CH 601 XL, and is present in accident photos. For example, structural tests completed by Czech Aircraft Works (CZAW) exhibited buckling in the upper spar chords near the wing tanks that resulted in wing failure at loads below ultimate and at a weight lower than the LSA version of this airplane.

Similar tests were performed by the manufacturer in Canada in September 2009 on a modified structure to the 1,320 lb weight LSA version of this aircraft. During these tests, buckling was noted in the wing structure below ultimate load, so the tests were halted and the wing structure was modified. This modified structure was tested to within a few percent of ultimate load as summarized in the loads section of this report. This modified structure may have been able to handle slightly higher loads prior to failure. A comparison of the two tests indicates the modifications required by the safety directive enhance the design.

The manufacturer provided drawings to the FAA that detailed their modifications to the wing structure required by their safety directive. The modifications include adding angles to the inboard portions of the outer wings, adding a center wing spar doubler, adding wing to body joint attachment improvements, adding reinforcements to the wing rib at the aileron bell-crank, and adding reinforcements to the rear spar at the aileron control rod aperture.

These modifications appear to have addressed and modified all the areas identified by the FAA as potential static-load weak points in the design. This conclusion is supported by the most recent structural tests.

4.4 Stick-Force Characteristics

A manufacturer's flight test report dated November 2005 was used as the primary source of data for the FAA to evaluate the stick-force characteristics of the CH 601 XL against the FAA accepted version of the ASTM International, F 2245-07a, 4.5.2.2. The results were also compared to 14 CFR Part 23 § 23.155. The FAA found the manufacturer's Flight Test Report data is compliant with the ASTM standard. Although not required to comply with 14 CFR part 23, we found the data also meets the standards of 14 CFR Part 23 § 23.155(a) and (c).

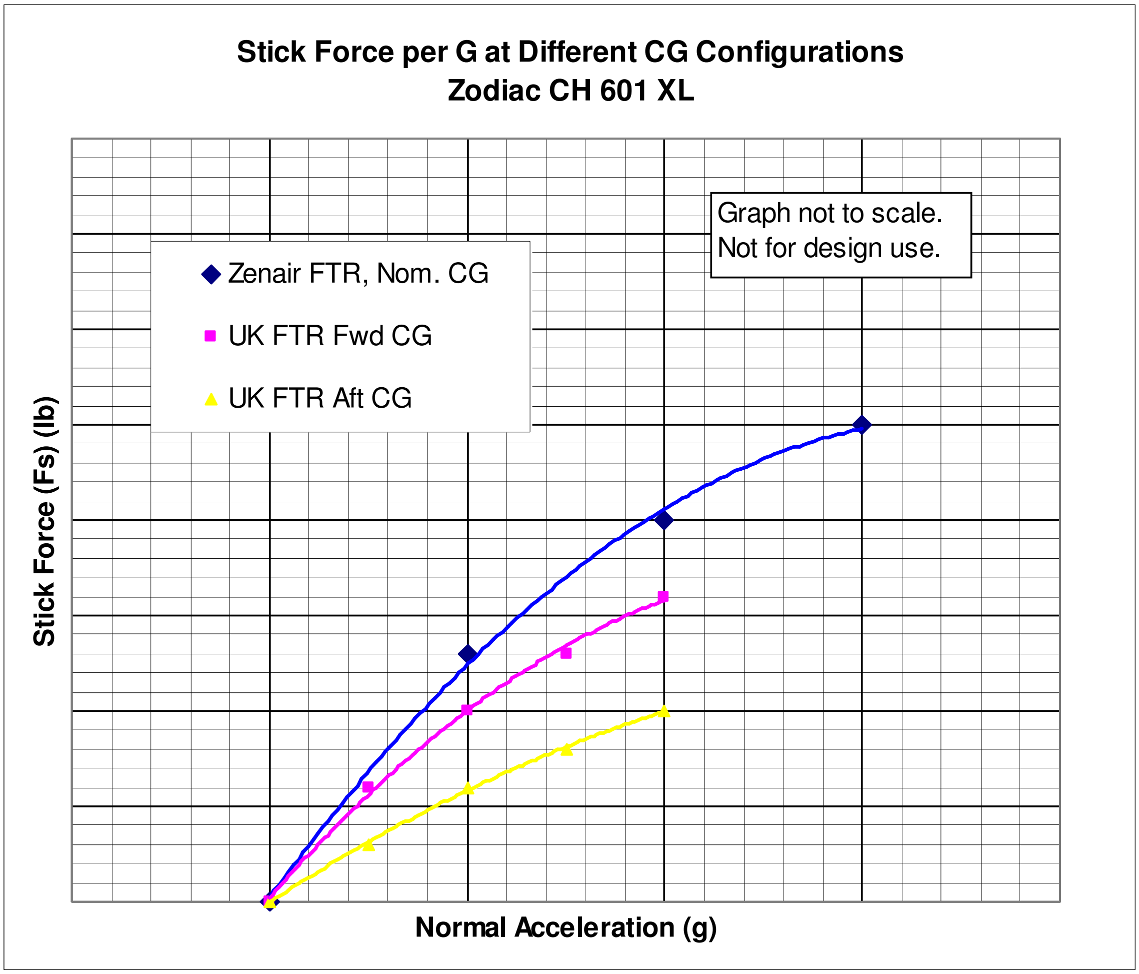
ASTM 4.5.2.2 states, "Longitudinal control forces shall increase with increasing load factors." For reference, 14 CFR Part 23 § 23.155(c) states, "There must be no excessive decrease in the gradient of the curve of stick force versus maneuvering load factor with increasing load factor."

The NTSB recommended testing the aircraft stick force per g at maximum aft center of gravity. However, there is no regulatory requirement for testing in this configuration in either the ASTM standard or in 14 CFR Part 23 § 23.155. For reference, the FAA's applicable guidance in AC 23-8B recommend testing at aft heavy and light center of gravity configurations to verify proper control forces.

The UK LAA performed flight tests for a flutter mitigation program and provided the results to the FAA. Stick force per g evaluations were conducted at both forward and aft cg. Figure 5 shows the data they obtained appears to be compliant with the ASTM standards as well as with 14 CFR Part 23 § 23.155(c). (Note: We have removed the actual stick force and g load values from figure 5 to protect the manufacturer's proprietary information and data.)

Though not required to do so, it appears their tests followed the guidance provided by AC 23-8B. However, when applying this guidance to aft center of gravity data to match compliance with 14 CFR Part 23 § 23.155(a), Figure 5 shows the stick force at limit load appears to extrapolate to a value slightly less than the 15 pound minimum requirement at limit load. Though the CH 601 XL does not have to comply with 14 CFR Part 23, the data does indicate that stick force gradients may not be acceptable for aircraft that are intentionally or unintentionally flown outside the POH center of gravity limits. This is simply presented for regulatory comparison, as 14 CFR Part 23 § 23.155(a) is not currently reflected in the ASTM standards at any center of gravity configuration.

Figure 5: CH 601 XL Stick Force per g Evaluation



The review of the stick force per g ASTM standard generated the following comments and recommendations:

- The current ASTM Standard F2245, 4.5.2.2 is actually more stringent than its 14 CFR Part 23 § 23.155(c) counterpart and may remain unchanged.
- The ASTM standard does not currently require a minimum control force at the limit load factor. ASTM International should amend their standards to require a minimum control force at limit load factor, similar to concepts defined in 14 CFR Part 23 § 23.155(a).
- Just as 14 CFR Part 23 uses AC 23-8B for flight test guidance material, ASTM uses an Appendix to supplement their standard. To better define the increase in elevator control forces in maneuvers, guidance similar to the following in AC 23-8B should be adopted in ASTM's F 2245 Appendix:
  - AC 23-8B, Paragraph 51(a) which describes why testing at aft center of gravity configurations is important to evaluate stick force.
  - AC 23-8B, Paragraph 51(d) which quantifies minimal stick force per g gradients for both stick and wheel controlled airplanes.

4.5 Airspeed Calibration

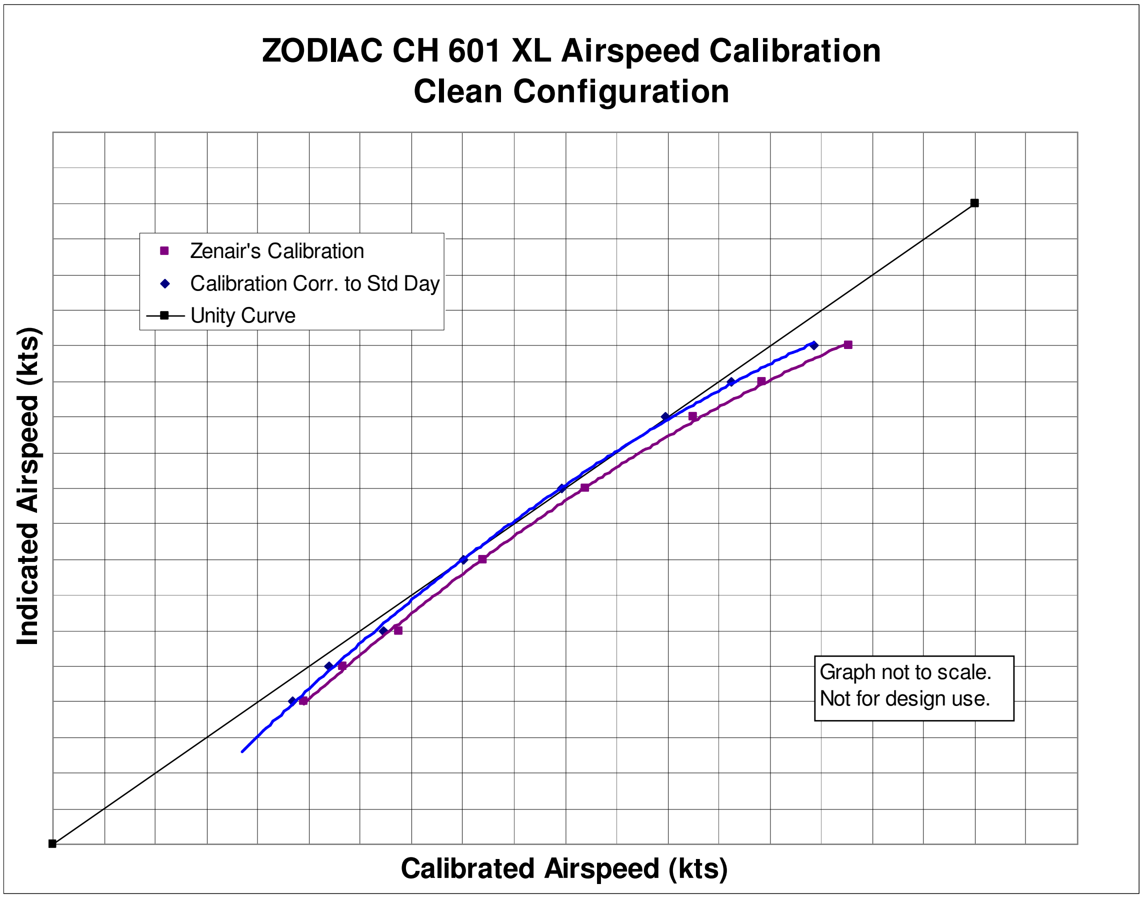
The manufacturer's flight test report was reviewed. It appears the airspeed calibration data presented was only calibrating indicated airspeed to true airspeed. Since this data was collected at a non-standard day temperature of 31°C, and at an altitude other than sea level, a density correction must be applied to the true airspeeds to accurately determine the calibrated airspeeds (compressibility effects are not applicable to light sport airplanes). Figure 6 shows the effect of applying a standard day correction to the airspeed calibration. (Note: We have removed the actual airspeed values from figures 6 through 8 to protect the manufacturer's proprietary information and data.)

The test report states a global positioning system (GPS) reverse course method was used for the airspeed calibration. This method has traditionally been acceptable for airspeed calibrations in this type of airplane. However, to be valid both the airspeed and altitude must be constant while the data is collected. From the data reviewed, it appears there are numerous data points collected above $V_{H,}$ which implies that the aircraft must have been in a dive to reach those speeds. This potentially invalidates the GPS reverse course method.

More accurate airspeed calibration methods are available and are commonly used for modern, more complex aircraft. These include the use of a calibrated static pressure source, such as a pitot-static boom or probe, or a calibrated static trailing cone. In addition, a modified GPS based method flying multiple legs has become the norm for modern aircraft. The FAA suggests the manufacturer work with a qualified technical source to develop a revised calibration method. Advisory Circular 23-8B is available as a reference, and contains suggested calibration methods.

Regarding stall speed, the manufacturer's flight test report determined the flaps up stall speed to be 35 knots indicated airspeed (KIAS) (40 mph) which was reported as 43 knots calibrated airspeed (KCAS) (50 mph). In reality, it was 43 knots true airspeed (KTAS) (49 mph), which after correcting to standard day conditions; the stall speed is calculated to be 41 KCAS (47 mph). The manufacturer's Airplane Flight Manual (AFM) reported a 43 knot (49 mph) flaps up stall speed indicating that standard day corrections were not applied to the flight test data.

Figure 6: Standard Day Correction Effects on CH 601 XL Airspeed Calibration



The design maneuvering airspeed, V_A, is defined per ASTM F2245-07a, Section 5.2.4.1 (and 14 CFR Part 23 § 23.335(c)) as follows:

$$V_A = V_S * \sqrt{n}$$

Where V_S is the stalling speed and n is the limit load factor of the design.

For the Zodiac n =4 so the previous equation resolves to:

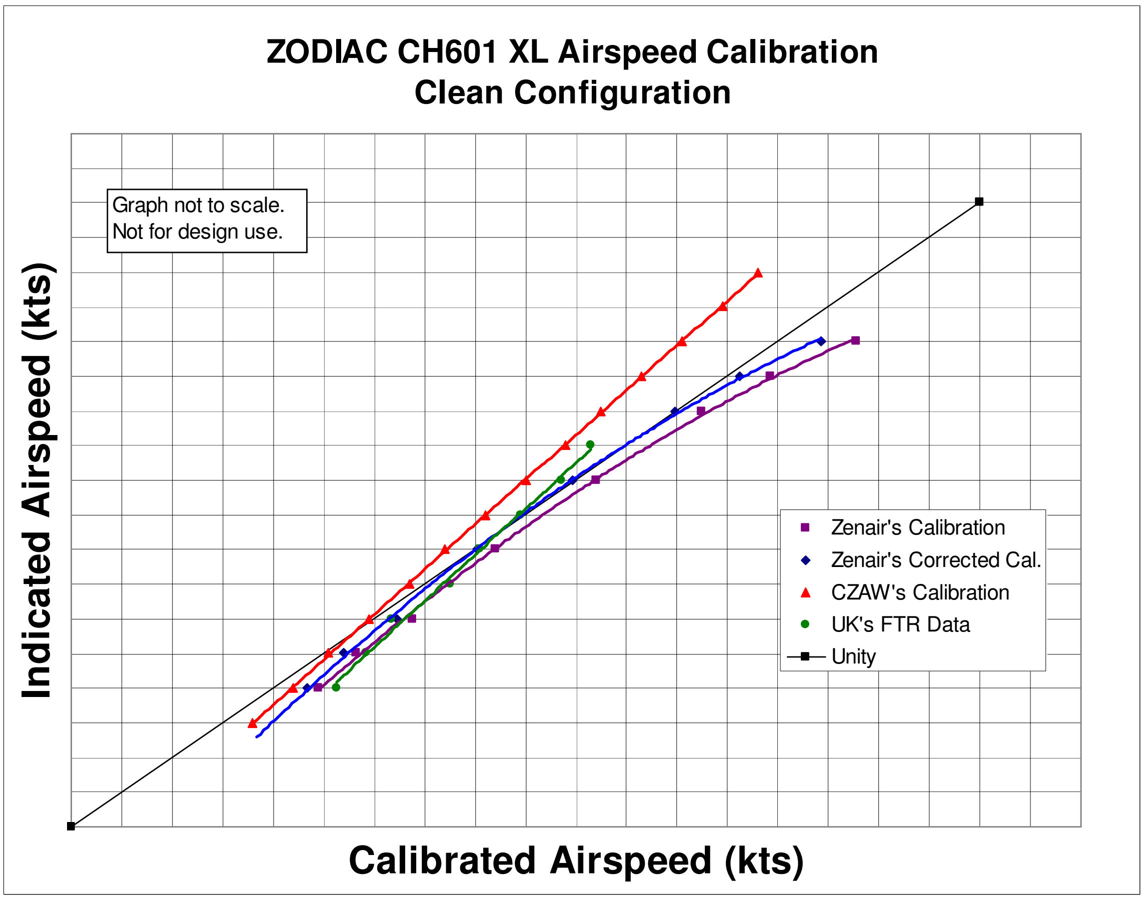
$$V_A = V_S * 2.0$$

The manufacturer determined the V_A 90 KCAS (103 mph) when using what it thought to be its stall speed of 43 KCAS (49 mph) instead of 86 KCAS (43 * 2.0) making it non-conservative by 4 knots (5 mph). However, using the standard day corrected stall speed of 41 KCAS (47 mph) results in a V_A of 82 KCAS (94 mph). Therefore, the manufacturer's stated value of V_A is 8 knots (9 mph) high and non-conservative. The potential to overstress the aircraft by unknowingly exceeding the maneuvering speed and using full control inputs exists. It should be noted that V_A is a function of the airplane weight and the value published in the POH should be based on the worst case.

The FAA did not obtain a copy of the CZAW's flight test report for review. However, CZAW did publish its airspeed calibration within its POH and a copy of that document was collected and reviewed.

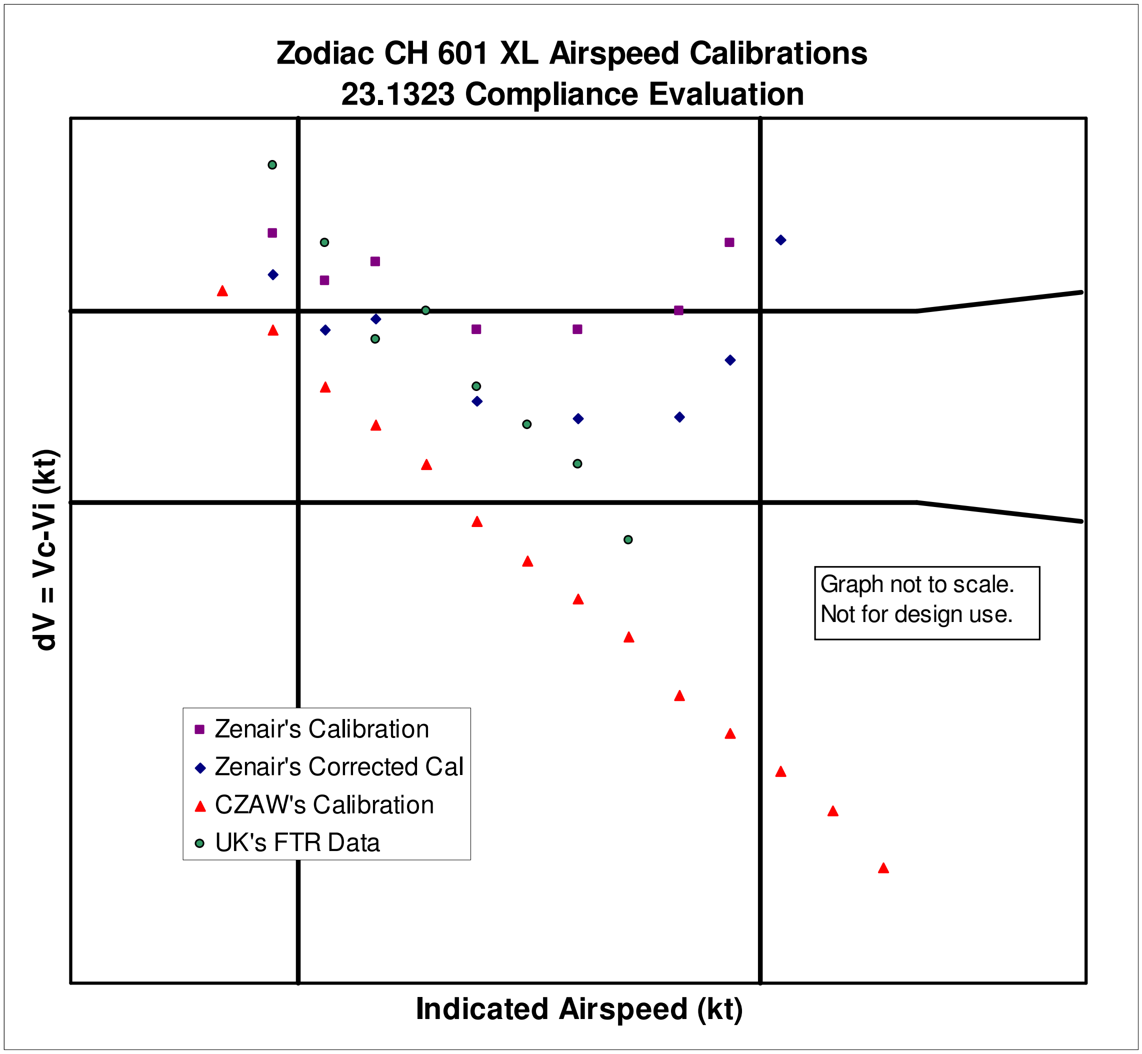
A comparison was made between CZAW and the manufacturer's airspeed calibrations. The calibrations were substantially different in both shape and magnitude. Without the flight test report, it is impossible to say which calibration is correct assuming that both designs are identical. Therefore, the potential to overspeed the aircraft exists. However, as part of the UK LAA flutter mitigation flight test program, an airspeed calibration was conducted and the results were overlaid with those from the manufacturer and CZAW, as seen in Figure 7. (Note: We have removed the actual airspeed values from figures 6 through 8 to protect the manufacturer's proprietary information and data.)

Figure 7: Zodiac CH 601 XL Airspeed Calibration Comparison



The UK LAA's flight test results are similar in magnitude to the manufacturer's data, but trend with CZAW's data making the comparison inconclusive. Using a different approach to determine the validity of the calibration data, a 14 CFR Part 23 § 23.1323(b) analysis was performed on these data sets and shown graphically in Figure 8. It should be noted there is currently no equivalent ASTM standard, and no requirement for S-LSA airplanes to meet 14 CFR part 23.

Figure 8: Zodiac Airspeed Calibration Evaluation per 14 CFR Part 23 § 23.1323(b)



To evaluate the airspeed error per 14 CFR Part 23 § 23.1323(b), the error dV, must be less than ± 5 knots or 3% bounded by a lower airspeed of $1.3V_{S1}$ to a maximum airspeed of V_{NE}. Using the manufacturer's values, this means that to meet 14 CFR Part 23 § 23.1323(b), all the applicable data needs to fall in the enclosed ± 5 knot rectangle.

With these criteria in mind, the manufacturer's original calibration did not meet 14 CFR Part 23 § 23.1323 until after correcting for standard day temperature conditions. For comparison, neither CZAW nor the UK LAA's data meets 14 CFR Part 23 § 23.1323, though they are not required to do so. However it is unusual for a low speed aircraft like the CH 601 XL to need a -24 knot static source error correction, indicating a potential error in the calibration methods used. If corrected improperly, this large airspeed error could translate into approximately a 2.8g load difference at maneuver speed for the CH 601 XL and CH 650. This evaluation suggests the need for an ASTM standard similar to

14 CFR Part 23 § 23.1323 to assist both the LSA manufacturers and kit builders in the proper placement of their pitot-static system to properly account for static source position error.

4.6 Pilots Operating Handbook

We reviewed the POH as part of the operating/airspeed limitations evaluation, with the following comments and/or recommendations:

- There may be some confusion as to what is meant by the design maneuvering speed, V_A. On page 7-1, Airspeeds for Safe Operation, (c) Turbulent Air Operating Speed, should say 'Do not exceed (V_A)'. It currently says, 'Do not exceed (V_C)', which is incorrect.
- Though not defined or required in the current version of the ASTM standard, a proposed update to the ASTM standard would provide definitions for the airspeed indicator markings. The manufacturer's POH provided definitions for the airspeed indicator markings on page 9-1 that are consistent with the proposed ASTM standards. The description appropriately notes the significance of the green arc, but the range is not consistent with descriptions in the comparable Part 23 regulations. It was incorrectly defined as $V_S – V_A$ though this would be conservative. It should be $V_S – V_{NO}$ to be consistent with Part 23 indicating that both the manufacturer's POH and the ASTM standards need to be adjusted so that they are aligned with the Part 23 regulation.
- Similarly, the significance description of the yellow arc is correct but the range is not. It was incorrectly defined as $V_A – V_{NE}$ though this would be conservative. It should be $V_{NO} – V_{NE}$ to be consistent with 14 CFR Part 23.

4.7 Flight Evaluation

Because sufficient flight test data was available from the manufacturer and from other airworthiness authorities, the FAA decided against performing its own flight test evaluations of the CH 601 XL. We deemed these tests unnecessary, as they would have largely been a repeat of tests already performed, with data made available to the FAA.

5.0 OBSERVATIONS AND RECOMMENDATIONS

Previous sections of this document have presented the safety concerns and the data gathered during the special review to address them. This section presents the observations and recommendations developed from this review. The recommendations are based on the Zodiac Special Review Team's analysis and input from all involved, including the NTSB, the S-LSA manufacturer, the amateur-built kit producer, the aircraft designer, and owners/operators.

5.1 General Observations

1) Data gathered by the FAA indicate the structure of the wing for the CH 601 XL was not designed properly to accommodate the full 1,320 lb weight for the US LSA market. Instead it appears, from testing done by other authorities and the company, that the wing structure was not adequately designed, analyzed, or tested to accommodate a 1,320 lb LSA limit. Several other versions of the CH 601 XL are available in Canada and Europe with significantly lower maximum takeoff weights. This may be one of the primary root causes for the structural deformations and subsequent failures of the wing, and may be a potential link to the flutter or vibrations experienced in flight by CH 601 XL operators.
2) Flutter investigation by the FAA was inconclusive for the CH 601 XL. However, the number of in-flight instances reported and data gathered from accident photos and a review of wreckage from several of the in-flight structural failures indicates flutter was present in many of the accidents. Efforts to balance the ailerons may help, but the manufacturer needs to verify through analysis and testing that the final design does not have any flutter related problems.
3) A review of the build records indicated more detail needs to be captured for individual aircraft as they are produced and checked out before flight. The following observations were made during the visit to AMD. These observations were made during the review of the production build records for serial number 601-016S, Reg. # N158MD:
    - Values for the control surface deflections and cable tensions are not recorded in the build records.
    - Left wing inspection does not record check-off for aileron deflection and stop, aileron cable tension, and flap deflection and stop.
    - There were no written production procedures for setting control surface deflections or cable tensions. The production manager is the only person who performs/oversees this function.
4) It is clear that owners and operators may not fully understand the process necessary to properly calibrate the airspeed indicating system, and what markings

are critical to help pilots fly the CH 601 XL according to the limits in the POH. FAA analysis shows that many aircraft, particularly experimental amateur-built, do not have proper airspeed markings to indicate safe speeds for operating in turbulent conditions or to stay within the maximum operating speed. When coupled with the lightly designed structure and the light control forces at aft center of gravity conditions, improper operating speeds may be a significant contributor to the in flight structural failures accidents of the CH 601 XL. The FAA is working with the ASTM F37 committee to create better standards and calibration procedures for LSA.

5.2 Summary of Recommendations

1) According to 14 CFR Part 21 § 21.190(c)(5), owners and operators of S-LSA CH 601 XL and CH 650 must adhere to the requirements of the AMD safety directive, dated November 7, 2009 to address the potential safety issues listed in this report. In a related FAA SAIB CE-10-08, the FAA also recommended that owners and operators of the kit built versions of these aircraft review the SAIB and follow the AMD safety directive. The FAA will continue to monitor the situation to verify the SAIB, Airworthiness Memo, and Safety Directive are having the desired impact on the CH 601 XL and CH 650 fleet.
2) Because the manufacturer's tests stopped at a level five percent below FAA estimates for wing bending load, the manufacturer needs to analyze the additional structural modifications or additional testing and analysis necessary to alleviate any remaining concerns over the adequacy of the airplane design loads and structural capability. The manufacturer has continued to modify the wing structure since their September 2009 tests, so their latest modifications may already address this concern. The manufacturer continues to provide information regarding the situation on their web site, so owners and operators should contact the manufacturer for the latest information.
3) The manufacturer should determine and make revisions to the POH for the correct value of V_A, using the stall speed determined by flight test, with corrections for temperature and airspeed calibration. The manufacturer should also consider renaming V_A and V_C in the POH to V_O and V_{NO}. (See recommended revisions to ASTM standard.)
4) The manufacturer should establish a MZFW and revise the POH to include information on an acceptable MZFW.
5) The manufacturer should reevaluate the wing structure modified per the AMD safety directive to determine the flutter characteristics of the modified design. This should include a complete flutter investigation (GVT, flutter analysis, and flight test) and be accomplished by a noted flutter expert.
6) ASTM standard F 2245-07a should be improved to clarify the need to consider payload and fuel combinations and to inform the pilot of any limitations on payload and fuel distributions. Section 9 of the ASTM standard should require inclusion of the MZFW in the operating limitations section of the pilot operating handbook.

7) The ASTM standard should provide a correct equation for V_{Amin} in F 2245 § X1.1. The definition should be changed to reflect 14 CFR Part 23 § A23.3.
8) The ASTM standard should be changed to incorporate the 'operating maneuver speed', V_O, similar to 14 CFR Part 23 § 23.1507. V_O would replace the value for V_A specified in section 9 of the ASTM standard. The use of V_O would also provide the pilot with the correct maneuvering speed in cases where the designer has selected a value for V_A other than $V_S \sqrt{n1}$, such as from ASTM F 2245 § X1.1.
9) The ASTM standard should provide a correct equation for V_{Cmin} in F 2245 § X1.1. The definition should be changed to reflect 14 CFR Part 23 § A23.3.
10) The ASTM standard should be changed to incorporate the maximum structural cruising speed, V_{NO}. Section 9 of the ASTM standard does not currently provide the pilot with information for the maximum allowable normal operating speed. Use of V_{NO} would provide common nomenclature with type certificated airplanes and ensure that pilot's would not exceed the structural capability of the airplane. Pilots should recognize the risk of exceeding V_{NO} and should only consider doing so in smooth air.
11) The ASTM standard should provide a correct equation for V_{Dmin} in F 2245 § X1.1. The definition should be changed to reflect 14 CFR part 23 § A23.3.
12) ASTM 5.2.4.4 should be revised to clarify that the designer has the option to define V_D in terms of the demonstrated dive speed, V_{DF}.
13) ASTM International consensus standard F 2279, Standard Practice for Quality Assurance in the Manufacture of Fixed Wing Light Sport Aircraft should be reviewed for quality assurance requirements. There was observed at AMD a lack of documented processes and procedures to accurately determine and record critical flight safety data in reference to flight controls. The current consensus standard identifies minimal requirements in regard to written procedures and recording of data. In addition, there is little information on acceptable methods, processes, or procedures for conformance to the requirements. A recent review of several LSA manufacturers done by AIR-200 also indicates improvements are needed in the area of quality assurance and record keeping industry wide.
14) The current ASTM Standard F2245, 4.5.2.2 is actually more stringent than its 14 CFR Part 23 § 23.155(c) counterpart and may remain unchanged. However, it is recommended that the ASTM standard be amended to require a minimum control force at limit load factor. ASTM could use requirements similar to 14 CFR Part 23 § 23.155(a).
15) To better define the flight evaluation of elevator control forces, guidance similar to that contained in AC 23-8B Paragraph 51(a) and 51(d) should be adopted in ASTM's F 2245 Appendix to describe why testing at an aft cg configuration is important to evaluate stick force per g relationships and quantify the minimal stick force per g gradients for both stick and wheel controlled airplanes, respectively.
16) Proper airspeed calibration procedures (acceptable methods and associated corrections) should be added to ASTM guidance for ASTM F2279, or some other

means. ASTM should adopt a standard similar to Part 23 § 23.1323(b) to assist both the LSA manufacturer and kit builders in the proper placement of their pitot static system to properly account for static source position error.

17) The ASTM standards should be revised to require airspeeds in the S-LSA's POH to be given in indicated and calibrated airspeeds. This will complete the airspeed calibration process and provide the recipient with ready-to-fly airspeed limitations. The current ASTM standards only require calibrated airspeeds to be published in an S-LSA's POH placing the responsibility of calibrating the airplane's pitot static system on the recipient. Kit built aircraft would still have to perform the airspeed calibration procedures as they are currently required to do and would be unaffected by this recommendation.

18) ASTM should adopt airspeed indicator marking standards. These standards need to be aligned with the corresponding Part 23 regulations to remove any cockpit confusion between the LSA and Part 23 fleets

19) The manufacturer should conduct a formal risk assessment of the situation, according to the requirements of ASTM F-2295. This data is normally used to identify the risk associated with each safety related issue for a design, indicating the appropriate response. The FAA believes the accidents and the data collected by the special review indicate several of the safety related issues for the design are potentially catastrophic. The safety directive process is meant to deal with potentially catastrophic issues, so the outcome was as desired. However, the FAA did not receive a formal risk assessment from the manufacturer to address the situation.

20) The FAA should define an acceptable level of risk for amateur-built aircraft and consider whether further action is necessary.

6.0 CONCLUSION

The special review team evaluated the design and operational details of the CH 601 XL and variants that share a common wing design. Our review of related accidents did not indicate a single root cause, but instead implicated the potential combination of several design and operation aspects.

Analysis during the special review found the loads the manufacturer used to design the structure do not meet the design standards for a 1,320 lb (600kg) airplane. Static load test data verifies this conclusion. The special review also identified other factors that could contribute to the tendency to overload the wing structure during flight, including airplane's flutter characteristics, stick force gradients, airspeed calibration, and operating limitations.

The manufacturer's test data verified the light weight design of the wing structure was also susceptible to deformation and buckling before reaching limit load, particularly at the aileron attachment rib location. This deformation could weaken the overall strength of the wing structure, and could contribute to the tendency for flutter to occur.

The FAA has taken steps to notify the public of the safety related issues with this design and called for owners and operators to make modifications to their aircraft as proposed by the manufacturer. On November 7, 2009, the FAA issued SAIB CE-10-08 to inform owners and operators of potential safety issues with the CH 601 XL and CH 650. The FAA also issued an action November 12, 2009 to cease issuance of new airworthiness certificates until the safety related issues are addressed. Concurrently, AMD issued a safety directive for the S-LSA versions of the CH 601 XL and CH 650 to address the situation and to communicate details of modifications required before further flight. Zenith Aircraft also communicated similar information to owners and operators of experimental versions of the CH 601 XL and CH 650.

The manufacturer was still modifying the design at the time of this report. The manufacturer needs to re-test the modified wing structure once a final design is reached using loads appropriate for the operating envelope of a 1,320lb aircraft to verify the new design. They need to verify through test and analysis the final design is not susceptible to flutter. They need to publish better information regarding proper airspeed calibration, the light stick forces, and the tendency for this airplane to be loaded to an aft center of gravity and overweight condition for pilots that don't fit the 190 lb ASTM standard for LSA pilots. Finally, they need to provide a statement that the aircraft being altered will still meet the requirements of ASTM F2245 after the changes are made.

With type-certificated aircraft, airworthiness standards play an important role in establishing an acceptable level of safety. The special review team recognizes that if this were a 14 CFR part 23 type-certificated aircraft, it is likely the FAA would have taken airworthiness directive action to address an unsafe condition. Similarly, the consensus standards play an important role in establishing an acceptable level of safety for S-LSA aircraft. Manufacturer's safety directives are used to address S-LSA safety issues.

However, with experimental amateur-built aircraft, the aircraft's design need not meet either airworthiness or consensus standards. Instead, the operating limitations play an important role in establishing the appropriate level of safety for these aircraft. Without design standards for amateur-built aircraft, it is difficult to determine whether in-service airworthiness concerns warrant FAA action.

This situation leaves an open question and possible need for future action by the FAA to define the appropriate level of safety for E-LSA and amateur-built aircraft. The special review team believes this to be a pivotal point for defining an appropriate level of safety for experimental amateur-built aircraft and for the LSA community. The situation has galvanized the need for the FAA to clearly define an accepted level of risk for this segment of the market, and consider what means would be needed to achieve that level of safety.

The actions the FAA has already taken provide some mitigation for the potential safety related issues that are likely to exist in the E-LSA and amateur-built versions of the design. EAA survey data indicates that a majority of owners and operators are well aware of the issues and agree they should not fly until they have further information from the FAA and the manufacturer.

Once the manufacturer has verified the new design through further testing and analysis in support of the statement of compliance to the ASTM standards, owner/operators can make the suggested modifications, and the CH 601 XL and CH 650 should be able to return to safe flight following applicable FAA policy and practice.