THE DUTCH SAFETY BOARD

The purpose of the Dutch Safety Board's work is to prevent incidents or to limit their after-effects. It is no part of the Board's remit to try to establish the blame, responsibility or liability attaching to any party. Information gathered during the course of an investigation – including statements given to the Board, information that the Board has compiled, results of technical research and analyses and drafted documents (including the published report) – cannot be used as evidence in criminal, disciplinary or civil law proceedings.

GENERAL INFORMATION

Occurrence:	2008107
Classification :	Accident
Date, time of occurrence:	14 September 2008 at 12.47[1]
Place of occurrence:	Markermeer, near Hoorn, the Netherlands
Aircraft registration:	PH-4B6
Aircraft model:	Zenair CH601 Zodiac
Type of aircraft:	Micro light aircraft (MLA)
Type of flight:	Recreational flight
Phase of operation:	En route
Damage to aircraft:	Destroyed
Number of crew:	One
Number of passengers:	One
Injuries:	Both occupants fatal
Other damage:	None
Lighting conditions:	Daylight

SYNOPSIS

During flight, at an altitude of 1100 feet, the right hand wing of the aircraft suddenly collapsed upwards. Subsequently the aircraft crashed into the Markermeer. Both occupants were fatally injured.

As a result of the accident near Hoorn, as well as other accidents that happened before with the same type of aircraft, the Safety Board issued a preliminary report on 23 October 2008, that included a warning for operators of this aircraft model. This report was published in both the Dutch and English language on the website of the Dutch Safety Board. This preliminary report caused the Dutch Inspectorate for Transport and Water Management IVW to impose a flying ban on all aircraft of the Zenair CH601XL model registered in the Netherlands, as from 24 October 2008, until further

[1] All times in this report are in local time, unless indicated otherwise.

notice. Aviation authorities in several other countries adopted the flying ban on the Zodiac CH601XL as established by IVW.

FACTUAL INFORMATION

Flight history

On 14 September 2008, at approximately 12.35, the PH-4B6, a micro light aircraft (MLA), took of from the airfield of Middenmeer (in North Holland in the Netherlands). Two persons were on board: the pilot/owner and a passenger.

After take off from runway 05, the aircraft proceeded in a north easterly direction. Near the village of Kreileroord, a left turn of approximately 270 degrees was made and the aircraft subsequently proceeded in a south easterly direction towards Medemblik. Overhead Medemblik a turn of 360 degrees was made. The altitude during this part of the flight varied between 1100 and 1300 feet. From Medemblik the PH-4B6 proceeded in a southerly direction towards Hoorn. The aircraft subsequently crossed overhead Hoorn towards the Markermeer at an altitude of approximately 1100 feet. Witnesses in that vicinity on the ground observed the right hand wing of the aircraft folding upwards and the aircraft subsequently crashed into the water of the Markermeer at approximately 12.47. Both occupants lost their lives in the accident.

The wreckage was found at approximately three meters below the water surface. After recovery, the right-hand wing flap and the vertical stabilizer appeared to be missing. These parts could not be located. After recovery, the wreckage was shipped to the harbour of Lelystad in order to conduct a preliminary investigation.

PH-4B6

The accident aircraft was a Zenair CH601 Zodiac. It is a single-engined, two-seater, metal aircraft with a fixed landing gear. The Zodiac CH601XL can be shipped as an assembly ‘kit’ for subsequent assembly of the prefabricated parts by the owner personally, or in a ‘ready-to-fly’ state after a complete assembly and subsequent delivery by the manufacturer.

The accident PH-4B6 had been prefabricated in the Czech Republic. The owner had acquired the aircraft as a ‘kit’ and assembled it personally. Its maiden flight was performed on 8 September 2007. Until the accident it had logged a total of 92,6 flying hours. No anomalies occurred in that time.

The aircraft had a valid certificate of airworthiness. The periodical maintenance inspection to be performed every 50 hours, had been completed on 6 July 2008 by the owner.

Figure 1: archive picture of PH-4B6

Description of the damage to the aircraft

The damage to the aircraft that, after recovery, visually could be established was as follows:

- The engine and propeller were detached from the aircrafts fuselage.
- The cockpit was destroyed completely.
- The tail section of the fuselage was bended to the left.
- The right-hand wing main spar was twisted and broken.
- The right hand wing was bended near the root and the curve of the bending was similar to the curve of the fuselage top.
- The right-hand wing flap was missing.
- The right-hand wing box assembly was torn apart. Along a considerable distance as from the fuselage, the rivet joints between main spar and wing skin had failed.
- The right-hand wing leading edge had been crushed.
- The right-hand wing to fuselage rear attachment assembly had failed.
- Apart from its leading edge and the area at the right side of the aileron, the left hand wing was damaged comparatively lightly.
- The leading edge of the left-hand wing had been crushed.
- The wing construction near the left- and right aileron drives was heavily damaged.
- The left- and right aileron inboard edges were heavily damaged.
- Both fuel tanks were burst open.
- The vertical stabilizer was torn off.
- The leading edge of the right horizontal stabilizer showed impact damage.

Figure 2: PH-4B6 after recovery

The occupants

Two persons were on board: the pilot/owner and a passenger.

The pilot of the aircraft was a male person of 56 years of age. He possessed a valid recreational pilot licence and a valid medical certificate class II. The passenger did not hold a licence.

Type of licence	Recreational Pilot License (RPL A)
Aircraft classification	MLA
Qualifications	RT (VFR only)
Flying hours total	Approximately 350 hrs
Number of flying hours during last three months	21.40 hrs

Tabel 1: summary of the pilot's flight experience

The weather
According to the KNMI weather report, the weather situation near Hoorn, at the time of the accident was: wind (at 1000 feet) from a direction of 080 degrees with a speed of 15 knots, visibility more than 10 kilometres, and a few cumulus clouds at 3200 feet. The structure of the airflow had an unstable character up to an altitude of 5000 feet.

INVESTIGATION AND ANALYSIS

An investigator of the Safety Board has visited the accident site and conducted, during and after the recovery of the aircraft wreckage, a preliminary investigation. At a later stage, an initial extensive technical investigation was conducted with the assistance of experts.

During this investigation part of the right wing main spar, and the right wing rear spar attachment assembly to the fuselage were removed for further examination. Furthermore the GPS-unit and the airspeed indicator were removed for further examination. The flight data as mentioned in this report are derived from this GPS-unit.
The investigation has been conducted with the assistance of experts in the field of aircraft structures and the theory of strength of materials. Furthermore, specific parts of the investigation have been conducted by the National Aerospace Laboratory (NLR) and an engineering agency specialised in aircraft structures.

Since it turned out that similar accidents with the Zodiac CH601XL also had happened in other countries, close consultation has been maintained with investigation bodies and aviation authorities abroad.

After the recovery, the wreckage was kept in storage for further investigation. At a later stage, several additional examinations have been conducted at the aircraft wreckage.

Witnesses
Statements of witnesses were provided by the Aviation Police. Several eyewitnesses were interviewed. Though their statements varied in detail, the majority of the witnesses had observed that:

- the aircraft came from a north-easterly direction and flew over the water;
- one of the wings was bended upwards and folded over the fuselage;
- the aircraft made a steep dive while turning around its longitudinal axis;
- the engine noise increased during the dive;
- the aircraft hit the water in a vertical attitude.

Investigation of occupants
The remains of both occupants have been subjected to an autopsy. No indications were found that could have been a causal factor in the accident to occur.

Aircraft weight and balance
According to the flight manual, the maximum allowable take off weight of the Zodiac CH601XL is 450 kg. Calculations indicated that the actual take off weight during the accident flight, fuel on board and occupants included, must have been approximately 470-480 kg and that the balance was within the established limitations. This is based on the following assumptions:

Standard empty weight aircraft	270 kg
Occupants	170 kg
Fuel 50 liter	36 kg
Total	476 kg

Tabel 2: calculation of the take off weight

Exact calculation of the take off weight could not be accomplished because the empty weight of the aircraft and the amount of fuel on board was not known precisely. No indications were found that the possible exceeding of the maximum takeoff weight had played a part in the cause of the accident.

GPS

The aircraft was equipped with a GPS-receiver. On the basis of data recorded by this device, a reconstruction of the aircrafts flight path could be provided.

A GPS-receiver calculates the speed by dividing the distance, measured between two registered GPS-coordinates, by the time elapsed between those two positions. Registration is accomplished every six to fifteen seconds. The possible vertical component is ignored in this calculation. The result of this calculation provides the ground speed of the aircraft. To obtain the airspeed, the effect of wind direction and -speed must be included in the calculations.

The data obtained from the GPS were processed and subsequently analysed. From this analysis it appeared that the total duration of the flight was 12 minutes. The aircraft did not execute any unusual manoeuvres and had flown at an altitude of between approximately 1100 and 1300 feet. The ground speed that was flown, varied between 100 and 175 kilometres per hour (km/hr). With a view to the prevailing wind of 15 kt (28 km/hr) the maximum airspeed must have been 203 km/hr.

During the final stage of the flight, the flying altitude, groundspeed and true heading were respectively 1100 feet, 166 km/hr and 212 degrees. Considering the actual wind and altitude, these data resulted in an true airspeed of 146 km/hr.

According to the flight manual of the Zodiac CH601XL, the maximum manoeuvring speed[2] (V_A) is 160 km/hr IAS (Indicated Air Speed) at the maximum allowed take off weight of 450 kg. The prescribed speed limit (V_{NE}) is 260 km/hr IAS.

[2] The maximum speed allowing for maximum- or abrupt control deflections.

Figure 3: flight path as generated by using the GPS-receiver data

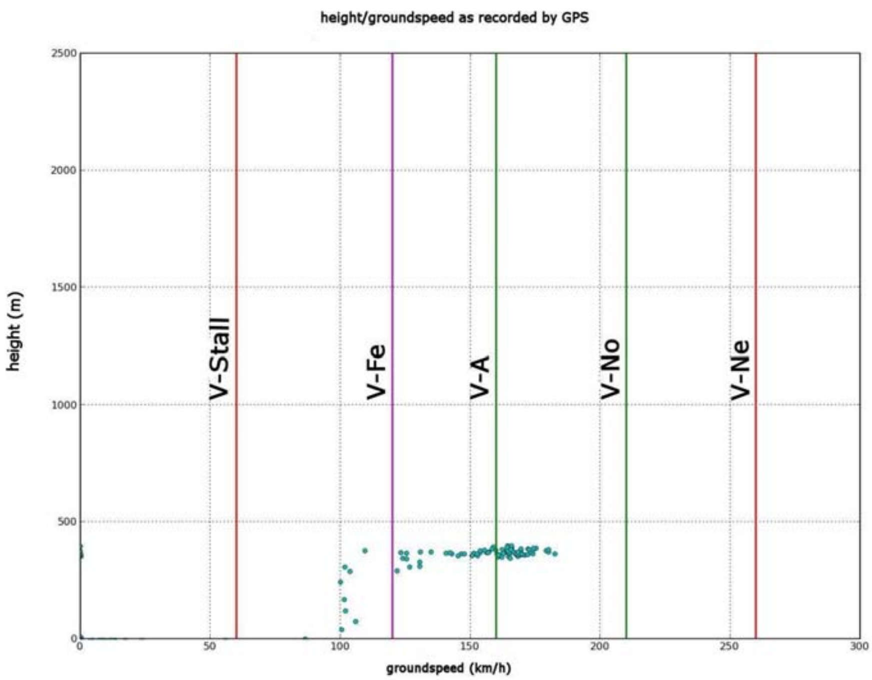

Figure 4: flying altitude and groundspeed as generated using GPS data

Zenair CH601 Zodiac

General

The Zenair CH601 Zodiac has been developed in the United States of America (USA), in the year 2000. There this aircraft is categorized as a Light Sport Aircraft(LSA) and its maximum allowable take off weight is established at 595 kg.

From early 2005 till ultimo 2006 this aircraft model was manufactured in the Czech Republic, in particular for the European Market. In the Czech Republic some modifications were applied to the model, in order to comply with the European requirements regarding the Micro Light Aircraft (MLA). As a result, the aircraft complied with the legal requirement of the maximum take off weight being 450 kg.

If the aircraft is built for the greater part by the owner, this aircraft model also can be registered as a "home-built" aircraft in the Dutch aircraft register and the aircraft is required to comply with the provisions for amateur-built aircraft. In that case the legal requirement of a maximum take off weight of 450 kg is not applicable and is limited to the maximum take off weight as designed, although it is the same aircraft. For the Zenair CH601XL it was 595 kg.

Authorisation

Certification of Light Sport Aircraft (LSA) and Micro Light Aircraft (MLA) aircraft is not accomplished according to the international airworthiness requirements, but according to national requirements. In the USA these are met by the manufacturer to declare that the design is in accordance with the requirements that are promulgated with regard to this category of aircraft, and that construction of the aircraft has been accomplished according to an approved manufacturing process.

With regard to MLA's within Europe, it must be shown that the design complies with the national airworthiness requirements. In accordance with the 'MLA regulation' in the Netherlands (Regeling MLA's) national airworthiness requirements are not provided for. The regulation stipulates that MLA's must comply with (transl.): *"a safety level being equivalent to the airworthiness requirements as established in one of the following countries in accordance with the requirements as promulgated: Germany, the United Kingdom or the Czech Republic."*

The Zodiac CH601XL model, prefabricated in the Czech Republic, has been accepted by the Deutsche Aeroclub[3] on the basis of the German requirements 'LTF-UL'[4] of 30 January 2003. After approval of the test results, a so called 'Gerätekennblatt' was issued, stating that the aircraft complied with the German airworthiness requirements for MLA's. By virtue of this Gerätekennblatt the airworthiness authority in the Netherlands (Inspectorate for Transport and Water Management, IVW) issued a special certificate of airworthiness for this type of MLA's being registered in the Netherlands.

For the issuance of a special certificate of airworthiness for MLA's, no actual inspection at the aircraft is performed by, or on behalf of the Minister of Infrastructure and Environment. The owner of the aircraft merely must declare that the aircraft complies with the applicable requirements.

Other accidents of Zenair CH601 Zodiac

Investigation revealed that with this aircraft model, world-wide, several accidents involving the collapse of one- or both wings upwards had occurred. In the majority of these cases the cause of the wing to collapse was not revealed, but the effect and damage in most cases showed a similar picture.

[3] The Deutsche Aeroclub is an organised interest group, authorized to certify MLA's.

[4] Lufttüchtigkeitsforderungen für aerodynamisch gesteuerte Ultraleichtflugzeuge**.**

Accident date	Country	Synopsis
8 Feb. 2006	United States	The left wing collapsed upwards and backwards. Subsequently the right wing folded upwards against the fuselage (two fatalities).
4 Nov. 2006	United States	The aircraft lost its horizontal stabilizer and both wings in flight; cause unknown (two fatalities).
7 July 2007	France	The left wing collapsed upwards in flight. Pilot survived because aircraft was equipped with a safety parachute. Shortly before the wing folded upwards the pilot heard and felt the wing to flutter.
5 Feb. 2008	Spain	Right wing folded over the left wing in flight (two fatalities).
7 April 2008	United States	Both wings folded upwards in flight (one fatality).
3 March 2009	United States	The left wing folded upwards over the fuselage and the right wing (one fatality). **(accident occurred after the accident near Hoorn)**
6 Nov. 2009	United States	Probably the aircraft disintegrated in flight whilst both wings became detached (one fatality). **(accident occurred after the accident near Hoorn)**

Tabel 3: summary of similar accidents with Zenair CH601XL

Actions taken by IVW after the accident
The preliminary report issued by the Dutch Safety Board caused the Dutch Inspectorate for Transport and Water Management IVW to impose a flying ban on all aircraft of the CH601XL model registered in the Netherlands, as from 24 October 2008, until further notice.

Actions of other aviation authorities
The aviation authorities in several other countries, like Germany, Spain, Great Britain, Sweden and Norway, have adopted the flying ban on the Zodiac CH601XL as established by IVW.

Actions LAA
The LAA (Light Aircraft Association) in Great Britain had conducted its own investigation and developed several modifications, including the balancing of the ailerons, which were made mandatory for all Zodiac CH601XL aircraft in Great Britain.

Actions Zenair
On 28 October 2008 Zenair Europe issued an 'Airworthiness Directive' (ZE-2008-01) which included the statement that a decrease in tension of the control cables can result in flutter[5]. As a consequence owners were required to:

- inspect all control cables on proper tension and adjust it to the correct value if required;
- inspect the ailerons on traces of damage;
- inspect the rear spar to fuselage attachment assembly.

These inspections were to be repeated every 50 flying hours.

Upon request of Zenair, the Technical University Harburg-Hamburg in (TUHH), conducted a static flutter test on a Zodiac CH601XL model. Subsequently a linear flutter analysis was made. This investigation resulted in the conclusion that, if the flap stops were installed according to the

[5] Flutter is an unstable vibration of an elastic deformable construction in an airstream (see appendix A)

applicable directives, and the tension of the control cables would be within the required tolerances, flutter would be unlikely to occur.

Wing construction of the Zodiac CH601XL

The wing of the Zodiac CH601XL consists of, amongst other things, a main spar and rear spar. The main spar is constructed by the manufacturer and delivered in one piece. These spars are interconnected by ribs. On the ribs the wing skin is fitted. The main spar is attached to the centre section, which extends through the fuselage, with six bolts. The rear spar is attached to an attachment bracket protruding out of the fuselage, with one bolt.

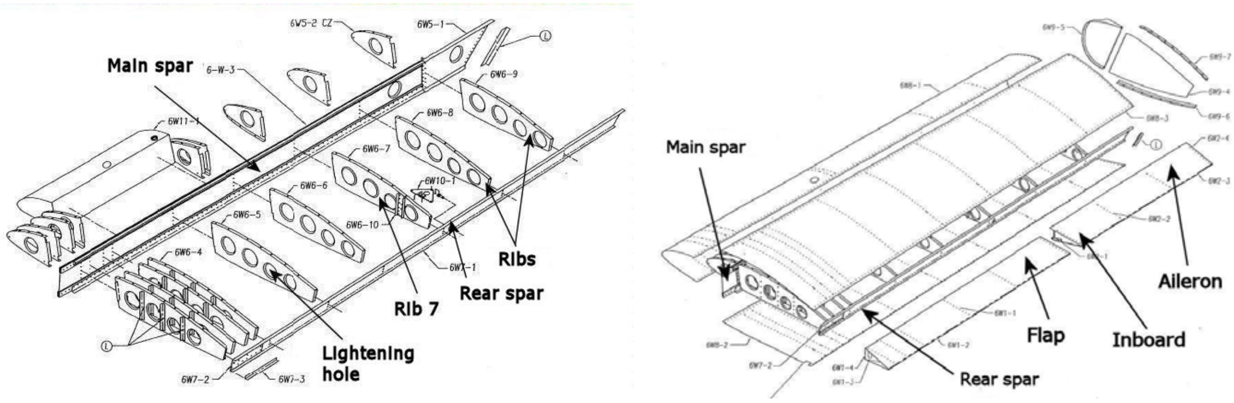

Figure 5: layout of wing construction of the Zodiac CH601XL

Aileron control of the Zodiac CH601XL

The aircraft is equipped with an aileron control system, utilizing steel control cables. The cables run from the control column, through lightening holes in the wing ribs, to a rib (#7) near the inboard area of the ailerons. Driving the aileron is accomplished by a push-pull rod which runs through a passage hole in the rear spar and is moved by the cable via a aluminium bell crank that is attached to this #7 wing rib. The rod is attached, with one bolt, to a bracket fitted to the aileron.
The ailerons are, over their full length, connected to the upper side of the rear wing spar by a piano hinge. The ailerons are not mass-balanced.

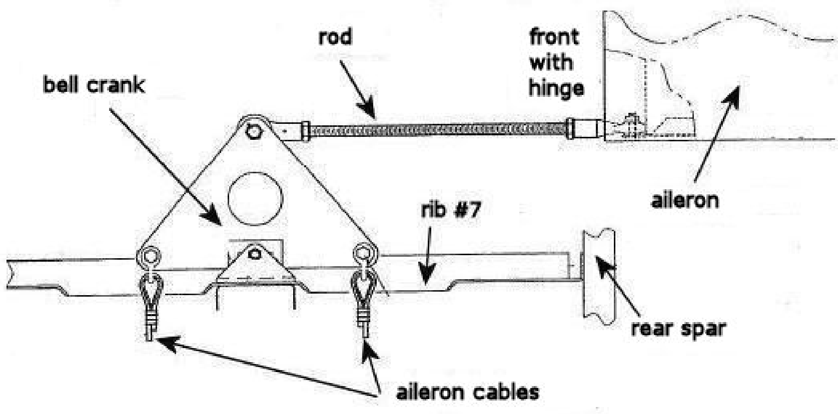

Figure 6: aileron drive of the Zodiac CH601XL

Technical examination of the wreckage

An extensive technical examination was conducted. The examination particularly was focussed on the damage pattern of both wings. The relevant findings are mentioned in appendix B.

Analysis of damage
Apart from the damage at the inboard side of the aileron, the comparatively light damage of the left-hand wing very likely had been caused by impact of the water surface and possibly by recovery actions.

The upper- and lower girders (spar doublers and spar caps) of the right-hand wing main spar were buckled. A similar form of failure indicated exceeding of the permissible bending-moment in this part of the wing spar.

The solid-rivets joining the main spar web plate to the upper- and lower girders, had failed by shearing. This failure mode indicates exceeding of the permissible vertical transverse-force in this part of the spar.

Many of the blind-rivet joints had failed. The rivet holes showed no, or hardly any, permanent distortion, which indicates that failure of these joints was not caused by surface pressure in the wing skin, but by shearing of the blind-rivets. Failure of these joints by shearing, indicated exceeding of the permissible torsion moment in the part of the wing concerned.

It has been investigated if the aircraft was overloaded as a result of a manoeuvre by the pilot or as a result of turbulence. The processed GPS-data indicate that during the final stages of flight, the aircraft proceeded in a straight and level flight. Therefore strong manoeuvres induced by the pilot did not occur.
The weather information provided by the KNMI after the accident, indicates that at the time of the accident there was no turbulence, or at least no heavy turbulence.
The loading factor during the last stages of flight must have been approximately equal to 1. It is therefore very unlikely that overload by manoeuvring or turbulence has caused the accident.

During the last stage of flight the flying altitude, ground speed and true heading were practically constant. They amounted respectively to 1100 feet, 166 km/hr en 212 degrees. In combination with the prevailing wind at 1000 feet (from direction 080 with 28 km/hr) these figures result in a true air speed of 146 km/hr during this stage of the flight.
According to the Zodiac CH601XL flight manual the maximum manoeuvring speed (V_A) [6] is 160 km/hr at the maximum take off weight of 450 kg. Since the actual aircraft weight probably was higher than 450 kg, the actual maximum manoeuvring speed would have been slightly lower then the 160 km/hr as published in the flight manual. It is not likely however that this maximum would have been exceeded. Furthermore the maximum allowed flying speed (V_{NE}) of 260 km/hr has not been exceeded.

Consideration of the damage to the aircraft as a whole, resulted in further investigation regarding the design, stress calculations and certification documents.

Investigation of certification documents
The following documents, that were provided on request to the Safety Board, were examined:

1. *Report of (static) stress calculations*
   title: *Zodiac 601XLSA Stress Analysis and tests*
   date: Nov 11 2005
   author: *unknown, copyright Ch. Heintz*

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[6] Ref. note 2.

2. *Flutter report*
   title: *CH601XL Aircraft Flutter Prevention Analysis*
   date: *February 15, 2004*
   author: *unknown, written by Czech Aircraft Works s.r.o. Four names with signatures on first page.*

3. *Structure Test report*
   title: *CH601XL Strength Tests*
   date: *June 20, 2002*
   issued by: *Czech Aircraft Works SPOL.SRO*
   author: *unknown, signed by: Chip W. Erwin MBA, CEO en Ing. Vaclav Chvala, Director of the technical Section LAA of the Czech Republic.*

The above mentioned reports were accepted by the Deutsche Aero club during certification of the aircraft.

In the course of the investigation, the suspect arose that the above-mentioned documents provided inadequate proof that the Zodiac CH601XL model complied with the strength- and flutter requirements as indicated in the German airworthiness requirements, applicable to this aircraft model. As a result of these findings the Safety Board requested a number of tests to be executed, as follows:

1. *Material testing*
   At five locations at the aircraft, metal samples were taken for material testing, in order to investigate if during construction of the aircraft, material was used that complied with the applicable specifications.

2. *Failure of the right hand wing to fuselage rear attachment assembly*
   Since failure of the wing rear attachment assembly can cause the wing to collapse, the National Air and Space Laboratory was requested to investigate the manner the attachment assembly failed.

3. *Static stress analysis*
   Because the stress report as provided did not show satisfactory proof that the aircraft complied with the strength requirements for certification, investigation was conducted regarding the static strength of some main components. In particular the main spar and the spar to wing skin joints, the centre section of the wing inside the fuselage, the stress lead-in into the fuselage, and the aft fuselage attachment assembly were tested.

4. *Flutter analysis*
   Since it could not be excluded that the accident had occurred as a result of flutter, the NLR was requested to investigate the possibility of flutter as a causal factor. The NLR conducted a linear- and a non-linear flutter analysis.

Analyses and exclusions as a result of the investigations
The conclusions of the above-mentioned investigations, together with further findings, resulted in the following analyses and exclusions:

Ad. 1 Material testing

The chemical composition of the aircraft samples was determined. It was found that the composition of all samples complied with the specified requirements.

Ad. 2 Failure of the right hand wing to fuselage rear attachment assembly

The NLR investigation indicated that the attachment had failed by static overload and that failure caused by fatigue did not occur. The strong transformation (ovalization) of the bolt hole indicated that the attachment had failed by a wing tip directed force. This force made an angle of 30 degrees upwards, relative to the wing. This heavy force being wing tip directed indicates, that this force and the subsequent attachment failure it induced, could not have been the primary cause. The attachment must have failed during or after the wing bending upwards. Failure of the rear attachment assembly therefore cannot have been the primary cause of the accident.

Ad. 3 Static stress analysis

The static stress analysis of the wing and wing-fuselage connection[7], indicated that the strength requirements were not met at all positions. Strength is expressed in terms of 'Reserve Factor, RF[8]'. The RF complies with the requirements if it amounts to 1 or more. Some cases of under strength were identified. However, with a view to the minor loading factor during the accident flight, the under strength of the components concerned was not to such an extent that it could have been the primary cause of the accident.

Ad. 4 Flutter analysis

During examination of the aircraft wreckage, damage was found, indicating that large vertical movements of the right hand wing and of both ailerons had occurred.

- The control cables had caused cuts of up to approximately 3 cm in the edge of the lighting holes in the wing ribs #1, #2 and #3. The damage, as well as traces on the cables, indicates that back-and-forth movements relative to the ribs had occurred.
- At the position where the control cables leave the fuselage, vertical cuts had been pulled in the fuselage sidewall.
- The push-pull rod attachment to the aileron, as well as both aileron to wing connections, showed large distortions and damage. Also the ribs (#7) at these locations showed heavy damage.
- Rib #7 had been wrecked by a high tensile force in the control cables.
- The bell crank of the aileron drive had been bent out of its moving plane by forces in the push-pull rod as well as in the cables.
- The edge of the feed-through passage in the rear spar had been damaged heavily by the fitting at the end of the push-pull rod being pulled through the passage several times. Traces of the back-and-forth movement also were found on the screw thread of the rod.
- The aileron stops on both wings showed damage as a result of ailerons which were moved outside their limits.

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[7] Atkins Nedtech report 090067RP.

[8] RF (Reserve Factor) of an aircraft construction component is defined as the ratio between the components maximum allowable force/load divided by 1,5 times that components actual force/load. For the strength to be satisfactory, the value should be equal to or greater than 1,00. A lower value indicates under strength and is unacceptable.

The distortions and damage as mentioned above only can have been caused by very high- and varying loads in the aileron control drive. Occurrence of varying loads as mentioned above, only can be explained by flutter in the aileron-wing combination.

Flutter analysis
The Dutch Safety Board requested the National Aerospace Laboratory NLR to analyse the occurrence of linear and non-linear flutter.[9] These analysis indicate that, if the rotational-rigidity of the aileron falls below a certain limit value (angular displacement of approximately 1 degree per 0.25 kgf-m moment), flutter can occur. Information of the Technical University of Harburg-Hamburg (TUHH) learns, that this rigidity in particular depends on cable tension, in combination with the rigidity of the aileron drive attachment at the rib, located in the wing. As long as the pre-stress in the control cables is maintained at an adequately high level, it is unlikely that flutter will occur. However, a high aileron load in flight could cause distortion of the control system, and as a result one of the control cables to slack, causing the rigidity being reduced considerably and the risk of flutter to increase.

The non-linear simulations show that flutter also can occur if an aileron rotational-distortion threshold value is exceeded, for instance as a result of turbulence or aileron deflection.

In conjunction with the investigation results as mentioned above, it was considered likely that on the occurrence of several accidents with this aircraft model in the past, one of the above mentioned causes (distortion of the control system or exceeding of the limit value of the rotational rigidity) played a role. Because with regard to the information regarding the accident near Hoorn not enough detail is available, the cause of the accident could not be attributed to flutter for certain.

Since in the linear flutter analysis, flutter does not occur with a completely balanced aileron, nor with a control system with adequate rigidity that is not susceptible to non-linear deterioration of aileron rigidity, the NLR advises to modify the aircraft design by applying an aileron balancing system and increase the rigidity of the aileron control system. Because the most effective prevention of wing-bending/aileron-flutter would be aileron mass-balancing, in particular with a view to the high cruising speed of the aircraft, this option is preferred.

In the course of the flutter analysis being conducted, NLR consulted with the investigators of the Technical University of Harburg-Hamburg (TUHH) on a regular basis. It appeared from these contacts that the investigators in Hamburg only had conducted a linear flutter analysis. Furthermore NLR ascertained some inadequacies in the investigation as conducted by TUHH.

The results of this analysis were made know to other investigation boards that were involved in accident investigations with Zenair CH601XL aircraft. Investigations in those countries, Great Britain, Spain, Germany, Australia and the United States, revealed that flutter probably played a role in these accidents.

Investigation of the American aviation authorities FAA
Following the accidents that had occurred with the Zodiac CH601XL model in the USA, the FAA formed a team of experts to investigate the design, construction end certification of the American version of the Zodiac CH601XL. Their findings were published in a report issued by the FAA in January 2010. The main conclusions were that:

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[9] Report NLR-CR-2009-274.

- a single cause regarding all accidents was not found, but it was very likely that a combination of various design- and operational aspects played a role;
- the design did not comply with the (American) standards of design;
- also other factors were found that could have caused wing overload, affecting of flutter characteristics and of in flight operational limitations;
- the wing was susceptible to distortion and wrinkling in flight before reaching operational limits, in particular in the area of the rib with the aileron system attached.

With regard to flutter it was concluded that flutter was a causal factor in these accidents. However it was 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.

Following these findings the FAA took action to inform the American owners regarding these findings and to urge them to install the modifications as established by the manufacturer. At the time of issue of the report, the manufacturer was still in the process of adapting the aircraft design.

Most probable scenario
The flutter analysis leads to the conclusion that it is very likely that during the last stage of the accident flight, a non-linear mode of wing-bending/aileron-flutter occurred. As a result the distortions, torsion and bending of the wings increased in time quickly. Also this caused the internal forces and material stress in the main spar and its fuselage attachment to increase. During this process the right hand wing collapsed. Buckling occurred in the main spar upper girder and the main- and rear spar rivet joints were torn open upon failure by shearing of the blind-rivets. Subsequently the wing was bended upwards. During this movement the rear wing attachment assembly failed by tension.

Inspectorate of Transport and Water Management (IVW)
With a view to the imposed flying ban, about the middle of November 2009 IVW was informed with regard to the Safety Boards investigation results. This caused the IVW to cancel the flying ban on CH601XL aircraft models as from 21 December 2009, provided that before the first flight of this MLA type of aircraft, the following modifications would have been implemented:

- Install an updated aileron stop.
- Reinforcement of the rib to which the triangular plate (aileron bell crank) has been attached.
- Install mass-balance weights on the ailerons
- Stiffening and reinforcement of the aircrafts wings and wing fuselage connections.

These modifications are developed and described in service letters issued by Zenair.

Government policy
From the investigation it appeared that, within the Netherlands, airworthiness requirements for MLA aircraft are not provided for. The Netherlands accepts all MLA aircraft that comply with the national airworthiness requirements of the United Kingdom, the Czech Republic and Germany. The authorities in these countries delegated the authorisation authority regarding these MLA's, to organised interest groups. The Netherlands does not perform any supervision with regard to these organisations operations and the authorisation process, and accepts the approval of MLA's without any further inspection of the aircraft or aircraft model.

Interviews and information of IVW turned out that this procedure has been established after the Minister of Transport and Water management (nowadays Minister of Infrastructure and Environment) had decided to formalize the supervision on MLA's in 1999. Until the year 2000 all MLA's were operated in a system of exemptions. The pilot was granted an exemption for having a pilot licence. For MLA's an exemption for having a certificate of airworthiness was granted. Operational limitations were related to this exemption, the 'Standaardvoorwaarden' (Conditions for use). In 1999 requirements for the licensing of MLA pilots were made and when the 'Regeling MLA's' (MLA Regulation) was introduced, the system of exemptions for MLA's was lapsed; MLA's got a special certificate of airworthiness. The operational limitations were taken over in the mentioned Regulation. Over the years the MLA Regulation was changed several times at which most of the operational limitations were cancelled.

This policy with regard to MLA's was based on the following principles:

- Within the Netherlands, practicing of aerial sports must be possible.
- Safety protection must be applied only to third parties.
- The policy had to be implemented with minimum governmental effort.

After observing procedures in the surrounding countries, IVW decided that the national airworthiness requirements of the three countries as mentioned, provided adequate assurance with regard to a safe operation of MLA's within the Netherlands. This resulted in a diminished oversight on MLA's by the Dutch authorities.

The identified deficiencies of the CH601XL indicate that, apart from the fact that the airworthiness requirements as applied contain several inadequacies, that this policy does not prevent that MLA's are registered in the Netherlands, which do not comply with the applicable airworthiness requirements. Broadly speaking it can be said that during the use of an aircaft, failings may be discovered. In concert with the manufacturer, measures will be taken to counteract these failings. However, in this case it was a matter of major failings in the design drawings and strength calculations. This could have been discovered if these drawings and calculations were examined thoroughly.

In 2007 the German Bundesstelle für Flugunfalluntersuchung BFU, investigated an MLA accident. One of the conclusions in the report was, that the quality of the certification test was inadequate. The BFU recommended to increase the expertise of the staff of the organisation being responsible for the certification. This recommendation was followed up by appointing more competent staff.

Furthermore investigation of the Dutch Safety board turned out that some tests performed to the model in the Czech Republic, were done incomplete or incorrect. These shortcomings were not noticed by the certifying authorities.

The Inspectorate for Transport and Water Management IVW provides no supervision on the manufacturing and airworthiness of MLA aircraft which are designed in foreign countries. Initial request for a special certificate of airworthiness, or for an extension, merely requires submission of a few documents and completion of a personal declaration form. According to the Inspectorate oversight on maintenance is intensified as a result of several incidents with MLA's.

The number of MLA's registered in the Netherlands in 2010 amounts to 247. To a large extend the utilisation- and operational opportunities of these MLA's are identical to the registered single-engined aircraft, 544 in 2010, that must comply with the international aviation requirements.

With a view to the number of MLA's registered in the Netherlands it is concluded that the assurance of operational safety of MLA's in the Netherlands is inadequate. On the one hand the operational limitations were increased, on the other hand the oversight on the use of MLA's was decreased. This results in an increase in risk for the occupants and for third parties on the ground. With reference to the growth of Dutch MLA, this is seen as a worrisome development.

Conclusion

Since the various other possible causes as indicated and/or analysed in this report could not have occurred or were very unlikely to have occurred, non linear flutter is the most probable cause of this accident. The following factors could have affected occurrence of this kind of flutter:

- Utilizing ailerons that are not mass-balanced.
- Low rotational-rigidity between wing and aileron.

It appeared from the investigation that inadequate proof was provided that the Zodiac CH601XL model complied with part of the German airworthiness requirements as established in LTF-UL of 30 January 2003. Since in the Netherlands, airworthiness requirements for MLA's are not provided for and the Dutch authorities do not perform active supervision on the airworthiness of MLA's, the possibility arose that for this type of aircraft model a (special) certificate of airworthiness was issued.

RECOMMENDATIONS

1. The manufacturer Zenair is recommended to modify the design of the Zenair CH601XL Zodiac so that the shortcomings in the design, both under strength and the possibility of flutter, will be solved and the aircraft will demonstrably comply to the airworthiness requirements.

2. The Minister of Infrastructure and Environment is recommended to revoke the certificate of airworthiness of Zenair CH601XL Zodiac as long as the design does not demonstrably comply to the airworthiness requirements.

3. The Minister of Infrastructure and Environment is recommended to make adequate arrangements in order to increase the oversight on the process of acceptance and the use of MLA's in the Netherlands.

APPENDIX A: THE FLUTTER PHENOMENON

Flutter is an unstable vibration of an elastic deformable construction in an airstream. Flutter involves interaction of air forces being exerted on the construction and inertial- and elastic forces within the construction.
During the unstable vibration, the air forces and the distortion of the construction increase in time. This causes the internal forces and stress to increase and – irrespective of the aircrafts strength – the construction finally to collapse by overload.
Usually, flutter requires a combination of minimum two independent motion possibilities to occur. Two examples regarding a wing: Bending as well as torsion of a wing, or bending of the wing combined with rotation of its aileron. Such combinations can result in flutter if the air forces, generated by one of these modes of vibration (in casu: wing-torsion or aileron-rotation) adds energy to the other mode of vibration (wing-bending).

To enable assessment of the flutter characteristics of an aircraft design, first of all understanding of the vibration characteristics of the aircraft is required. For a given aircraft geometry, these characteristics are determined by mass distribution, distribution of rigidity and structural damping of the construction. Based on these data an arithmetic model can be made that resembles the aircraft. Calculations using this model and, in a later stage measurements at the actual aircraft, enable vibration characteristics affecting possible occurrence of flutter, to be determined. These characteristics are laid down in a list of vibration modes, each with its own frequency and structural damping. The natural frequency decreases with the size of the aircraft. In particular vibration modes in the lower ranges of frequency, are affecting flutter. An essential difference between both examples as mentioned above is, that an aileron can have a zero rigidity (if the aileron is hanging loose, for instance caused by play), whilst a wing, bending or being subjected to torsion, cannot.

The answer to the question if the given vibration characteristics will cause flutter is established beforehand by calculations, using the modelled aircraft in flight. The flying speed is increased step by step, starting at a low speed value up to a final value that exceeds the maximum allowable flying speed. The vibration characteristics of the aircraft change in flight, depending on speed and altitude, because the air forces add extra (or decrease) rigidity and damping. Typical for the occurrence of flutter usually is, that the frequency of the one vibration mode approaches that of the other mode, resulting in the interaction required for flutter to occur. This can cause the stability (identified by damping) to decrease with increasing airspeed, which can result in flutter to occur above a certain airspeed (negative damping, for instance during the classical interaction between wing-bending and torsion during flutter).

In case of an aileron hanging loose, the rigidity in flight is exclusively affected by the air forces. An unbalanced aileron (centre of gravity downstream of the axis of rotation), in general will cause flutter already at lower airspeeds, provided the vibration frequency of the aileron is lower then the vibration frequency of the wing-bending. Because the frequency of the aileron increases with increasing airspeed (increasing air forces) the instability reaches a maximum, and subsequently disappears again above a certain airspeed, approximately at the point the vibration frequency of the aileron exceeds that of the wing-bending. At that point the progression of damping against airspeed reaches a minimum and therefore, more often than not is called the "hump" mode.
During a linear flutter analysis the rigidity of the modelled aircraft (the aero-elastical model) is independent of the loads affecting the aircraft. The air forces are proportionate to the distortion. During a non-linear flutter analysis distortion can affect rigidity (structural non-linearity) and/or air forces can progress disproportionate to the distortion (aerodynamic non-linearity). Non-linear

calculations are more complex then linear calculations and require more calculation effort, involving specific non-linear calculation methods.

Examples of structural non-linearity are play (rigidity is zero as long as the distortion is less than the play) and an aileron drive system utilizing pre-stressed control cables (rigidity decreases if one of the cables is slacking).

APPENDIX B: DESCRIPTION OF THE DAMAGE

Left-hand wing
The left hand wing was damaged comparatively lightly. The leading edge was crushed completely and the fuel tank installed inside, had been burst open at the front side. The underside of the wing had been crushed. The feed-through passage in the rear spar for the push-pull rod to drive the aileron, was heavily damaged.

Right-hand wing
The main spar upper girder of the right-hand wing, had been buckled near the fuselage sidewall. This had caused the right hand wing to be bent upwards. This part of the right hand main spar has been cut off the wreckage for further examination. The main spar lower girder was buckled. Several solid-rivets, joining the main spar web plate with the upper- and lower girders, had failed by shearing.

Figure 7: buckled right wing main spar

Figure 8: removed part of right wing main spar

Blind-rivet joints

Many joints in the aircraft construction were riveted, utilizing Avdel blind-rivets of the Avex type. According to the manufacturers publication, these rivets are “non-structural-rivets”. Two types of blind rivets have been used; type 1682-014 and 1682-0514. These rivets have a shear strength of 130 and 220 Lbs respectively. According to the manufacturer the needed shear strength is 110 and 180 Lbs respectively, so these Avex blind rivets would meet the requirements. The blind-rivet joints between the wing upper- and lower skin and the main- and rear spar, had failed by shearing, over a large distance; more than one meter. The rivet holes showed no, or hardly any, permanent distortion.

Aileron drive

At the inboard side of the ailerons at both wings, the wreckage showed heavy distortions and damage near the aileron drives and rib #7. The left aileron drive showed traces of a back-and-forth movement near the feed-through passage in the rear spar. The triangular plate at the inside was bent, and the connected push-pull rod also showed traces of back-and-forth movements near the feed-through passage in the rear spar.

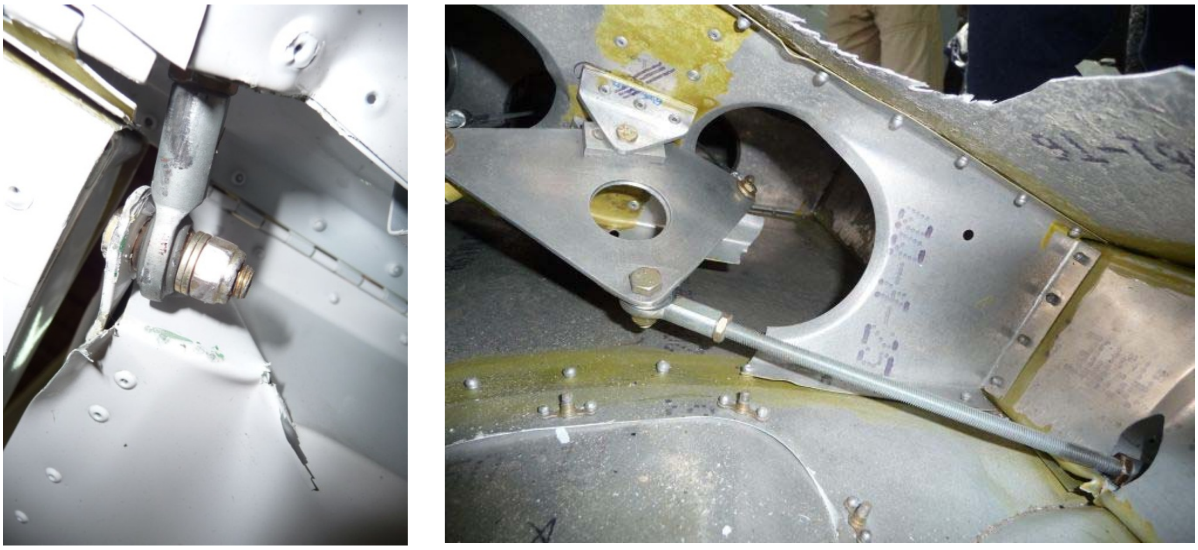

Figure 9: damage to left aileron drive (inboard- and outboard side)

The heaviest damage could be observed at the right-hand wing. The wing rib had been pulled off the wing skin and was torn. The triangular plate of the aileron control had been bent out of its moving plane. The push-pull rod was buckled. The rear spar was, near the feed-through passage for the rod, buckled and cracked. Also the passage itself was heavily damaged. The damage showed traces/indications of strongly varying load and movement. The connection of the aileron to the wing showed indications of heavy overloading near the aileron drive. Both aileron stops on the wings were damaged and showed marks of aileron deflection beyond the limits.

 

Figure 10: damage to the right aileron drive (inboard- and outboard side)

Aileron control cables

The aileron control cables, which are guided through the lighting holes in the ribs, caused tears in the ribs and in the fuselage sidewall. Examination of the tears showed, that they were caused by abrasive action of the cables back-and-forth against the ribs and sidewall. See pictures below.

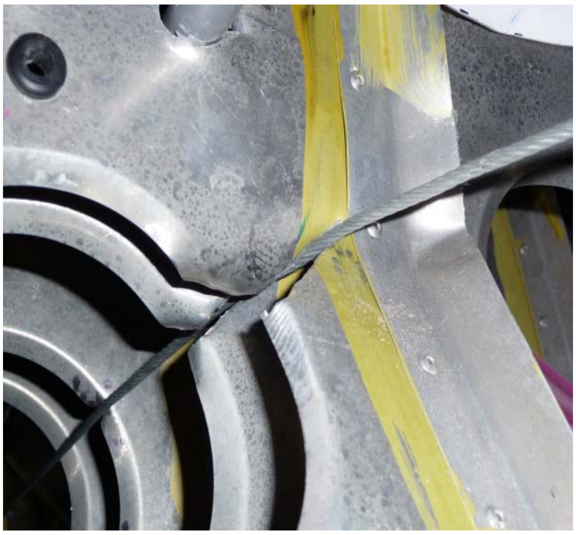 

Figure 11: tears in wing ribs and fuselage sidewall caused by aileron control cables

Aft right-hand wing to fuselage rear attachment assembly

This assembly consists of a bolt, loaded by shearing, connecting a bracket, protruding out of the fuselage sidewall, to the reinforced rear spar. The rear attachment assembly of the right hand wing had failed. The connecting bold was unimpaired and still in its position in the rear spar. The fuselage part of the assembly had been torn across the bolt hole. Part of the fuselage part of the assembly still was in position under the bolt head. The bolt hole in the fuselage part was strongly ovalised. The left attachment assembly was undamaged.

Figure 13: failed right wing rear spar attachment assembly.

Other findings

During the investigation a modification was found for which no approval of the Dutch CAA was granted. An aluminium angle bar was mounted on the back of the left seat. Further double drilling holes, drilling damage caused by a drilling machine and the use of different types of blind-rivets were noticed.

APPENDIX C: COMMENTS OF PARTIES INVOLVED

The Dutch Safety Board has sent the draft report to the parties involved. They may comment in writing. If the comments made should give rise to it, the Board may adjust the report. If the report is not adjusted in conformity with the essence of the comments, the Board shall indicate the reasons for this in the report.[10]

The draft report has been sent to the following parties:

- The Minister of Infrastructure and Environment
- The Inspectorate for Transport and Water Management/ Aviation
- The aircraft manufacturer
- The relatives of the pilot

The General Inspector of Transport and Water Management has sent his comment also on behalf of the Minister of Infrastructure and Environment.

The Inspectorate for Transport and Water Management/Aviation

The General Inspector wrote in her letter, among other things*: "In accordance with your request my reaction on the draft report is concentrating particularly on the factual inaccuracies or indistinct nesses. Hereby my remarks which all refer to page 15."* (Pages 15 and 16 in the final report)

Remark

Finally, the last paragraph of page 15 states that IVW should have the intention to (still) decrease the extend of supervision on MLA's. This is not known by me, could you give an indication what the basis of this statement is?

Response of the Safety Board:
Interviews turned out that this was said by the former Chief Inspector Director of IVW/TCP in an internal meeting with regard to the audit program 2009. Since this intention had not been written down on paper, this text has been removed.

The aircraft manufacturer

The aircraft manufacturer did not respond on the draft report. On 4th October 2010 the draft report was sent by e-mail to the manufacturer for comment. The covering letter stated that the legal term for inspection was eight weeks. The manufacturer did not respond on the draft report within this term. On 20th December 2010 his attention was drawn on the expiring of the term. On 21st December he indicated that the company had the intention to wait until the publication of an American investigation report that was written as a result of an accident with the same type of aircraft in the United States. After publication of that report, the manufacturer should respond on the Dutch draft report. Subsequently the message was sent to the manufacturer that the final report would be published without entering the comments in the report if no reaction was received before 10th January 2011. However, no reaction was received on this date.

[10] Kingdom Act concerning Safety Investigation Board, Article 56.

The relatives of the pilot

Remark
On page 22, head line ‘other findings’, of the draft report it is mentioned that the use of different types of blind-rivet was noticed. I should like to see the text completed with the amount, place and possibly the type of the blind rivets.

Response of the Safety Board:
This remark was not adopted. This finding was mentioned to illustrate the way the aircraft was assembled. No relation with the cause of the accident was noticed.