# AVIATION INVESTIGATION REPORT
# A02Q0098

## IN-FLIGHT SEPARATION OF RIGHT WING

## GILLES LÉGER SUPER CHIPMUNK C-GLSC
## SAINT-STANISLAS DE KOSTKA, QUEBEC
## 14 JULY 2002

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## *Summary*

An amateur-built Gilles Léger Super Chipmunk (registration C-GLSC, serial number 001) took off from Valleyfield Airport, Quebec, at approximately 1745 eastern daylight time for a local flight. On board were the owner-pilot and one passenger. After gaining altitude, the aircraft made several aerial manoeuvres followed by a dive and the beginning of a climb. During the climb, the right wing separated and the aircraft crashed in a cultivated field. A fire ignited after the impact and consumed a substantial portion of the aircraft. The right wing was found in a wood, hanging about 40 feet above the ground in a tree. The two occupants were fatally injured on impact.

*Ce rapport est également disponible en français.*

# *Other Factual Information*

The pilot had received his private pilot licence in May 1997. The report from the last medical examination, dated 20 June 2002, indicates that the pilot had a total of 1200 flying hours. According to his aircraft logbook, he had over 200 hours on the Super Chipmunk. It was also established that the pilot had received training in aerobatics with over 20 hours of practice, including at least one hour in the preceding six months as required by Section 602.28 of the *Canadian Aviation Regulations* (CARs). According to those close to him, he only did manoeuvres for which he had been trained, namely the wing-over, the loop, and the roll. His peers considered him to be a conscientious pilot. Before take-off, he had done a complete pre-flight inspection accompanied by his passenger, who was also a pilot, and who had a keen interest in aerobatics. At the time of the accident, the weather was clear, with excellent visibility and light winds. There was no thermal turbulence.

According to the information gathered, the pilot was making a demonstration flight. Three video sequences filmed by the passenger during the flight, of which the view included the right wing, show that the aircraft first executed a bunt, followed two minutes later by a loop. Four minutes later, a final sequence was filmed. Unlike the other two sequences, which followed the movement until the aircraft returned to level flight, the last sequence ended when the aircraft was in a vertical climb. According to a witness, the aircraft also executed a roll, and these manoeuvres were performed approximately 1500 feet above ground level. The aircraft then climbed to approximately 4000 feet. Unlike the previous aerobatics, the aircraft then executed a manoeuvre described as a Lomcevak, which is a random end-over-end tumble. The aircraft emerged from this manoeuvre in a spin. After three rotations, the aircraft entered a dive, then pulled up somewhat, and it was at this point that the right wing separated. The aircraft did several rolls before crashing in a cultivated field. A fire broke out and consumed most of the fuselage. The aircraft had dual controls, and the builder-pilot was in the habit of letting passengers with pilot licences fly it. This passenger was a pilot who also owned an aircraft. He had always shown an interest in aerobatics and had taken an introductory aerobatics course. It could not be determined who was at the controls at the time of impact.

The Chipmunk was the first aircraft designed and built by the Canadian subsidiary of the British aircraft manufacturer de Havilland. The prototype of this model, designated DHC-1, flew for the first time on 22 May 1946. It was powered by a Gypsy Major four-cylinder inverted in-line engine developing 145 HP. This model had been produced for the basic training of military pilots and had desirable flight characteristics for aerobatics. In all, 1283 DHC-1 aircraft were built under different licences around the world. Over the years, several of these aircraft were modified, particularly to enhance their performance in aerobatics, and were renamed Super Chipmunks.

To modernize the aircraft, increase the interior space, and improve performance, the builder-pilot had totally modified the structure of the fuselage, while retaining the original wings and empennage built by de Havilland. The original motor with a fixed-pitch propeller was replaced with a Teledyne Continental model IO-360C developing 210 HP and was fitted with a variable-pitch propeller. The engine change was based on a one-time approval issued in 1980 by Transport Canada and repeated on several DHC-1s. The document imposed acceleration limits of 4 g[1] at 1930 pounds and 3.5 g at 2000 pounds. The increased power had enhanced the performance of the aircraft, but in level flight, it could not exceed the maximum speed of 202 mph set by de Havilland.

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[1] The symbol "g" represents acceleration due to gravity.

Although the original appearance of the aircraft was unchanged, the cabin was a completely new design. It was more spacious and now consisted of a steel structure to which the wing spars were attached. The cantilever wings were attached with typical fittings, positioned on the upper and lower parts of the main spar, with a third fitting on the front spar. On an original Chipmunk, the attachment of the lower part of the main spar is connected by two connecting links that, on installation, allow shims to be added to fill in lateral space, thereby removing stress on the front fitting. This characteristic was not retained on the Super Chipmunk, whose lower fittings on either side of the central fuselage structure were lengthened to attach directly to those of the wings.

The builder-pilot could not find any original attachment bolts (original reference 06256 then 05179), which were specifically made by de Havilland. These bolts had a diameter of 0.731 inch and were tempered to 150 ksi.[2] The bolts used by the builder (AN10-23) were 0.625 inch in diameter. The hardness standard for these bolts is established at 125 ksi, and the bolts from the accident aircraft were measured at 26 to 28 on the Rockwell scale, which corresponds to 123 ksi to 129 ksi. Therefore, the bolts were in compliance with the AN standard. However, an O-shaped mark on the bolt head indicates a strength of 145 ksi to 165 ksi, according to the National Aircraft Parts catalogue. It was determined that, using bolts tempered to 125 ksi, the strength of the fitting was reduced to 61 per cent of the original strength; using bolts tempered to 150 ksi reduced it to 72 per cent. Bushings were machined to adapt the size of the holes to the bolts. Photo 1 shows the failed bolt from the right main spar. The lower bolt is from the left spar. Its deformation indicates that it was about to fail.

At the conclusion of the project, when the wings were about to be mounted on the fuselage, the builder realized that the fittings of each front spar were off-centre and were about 0.250 inch too low and 1 inch too far outboard. To correct this, a new hole was drilled in the front spar of each wing. On installation, since the ends of the spars struck the bottom of the (U-shaped) fitting, they had to be cut off so they could be inserted far enough to align the new hole with the holes in the fitting. Furthermore, moving the holes required removing a reinforcement, held in place

[2] ksi (kilopounds per square inch) is the equivalent of 1000 pounds per square inch.

by six rivets, from each front spar. The reinforcement was replaced by three larger reinforcements placed one on top of the other, which were attached with nine rivets to the right wing spar and with ten rivets to the left wing spar.

Chapter 549 of the *Airworthiness Manual*, which covers airworthiness standards for amateur-built aircraft, requires that a log be kept of the materials used. Since the builder had decided to market this model in kit form, he produced a series of drawings that documented the characteristics of the construction, including the materials used, which went beyond the minimum requirement of the standard. However, the drawings available do not refer to the diameter of the holes or to the specifications of the main spar attachment bolts, and no drawings could be found to describe the replacement of the bolts or the modification of the front wing spar. The inspections required by Section 549.19 were done by an inspector of the Recreational Aircraft Association (RAA) under delegation from Transport Canada. The role of the inspector is not to evaluate the project engineering or design, but to ensure that the materials and assembly comply with minimum airworthiness standards. The RAA evaluation confirmed that all the modifications made represented 60 per cent of the construction, which exceeded the minimum requirement of 51 per cent to allow the aircraft to be designated an amateur-built aircraft. The project was submitted to two regulatory inspections. The final inspection report contained a list of observations, the corrections of which, confirmed in writing, allowed the issuance of a special airworthiness certificate. The replacement of the bolts and the modification of the front wing fitting were not specifically reported to the inspector and, since the assembly was not in contravention of the existing standards at the time of the second inspection, these changes were not given special attention. However, on the first inspection, point 1 under heading 1.3 Mainplane of the report confirmed that the wing attachments were inspected and found acceptable. Since the modification had been done before the last inspection and before the special airworthiness certificate was issued, it was not necessary for a Transport Canada representative to conduct an inspection as required under Section 549.23 for modifications affecting structural integrity.

According to Section 549.103, in the case of an amateur-built aircraft, the maximum allowable take-off weight is defined by the wing loading, which must not, except for high-performance aircraft, exceed 20.4 pounds per square foot or 100 $kg/m^2$, the aircraft being equipped with flaps and having, in accordance with Section 523.49 (c), a stalling speed of less than 70 mph (61 knots). In view of the above criteria, the representative of the RAA authorized the maximum weight of 2000 pounds for the original Chipmunk to be increased to 2400 pounds for the Super Chipmunk.

The builder had an excerpt from the Chipmunk manual indicating that, at a maximum weight of 1930 pounds and an indicated airspeed of 136 mph, the DHC-1B could withstand a load factor of 9 g. The document also indicated that, at 230 mph, the maximum load factor was reduced to 6.75 g. However, the document was accompanied by a graph indicating that the highest load factor could be reached at 136 mph (120 knots) and that it was limited to 6 g. According to the graph, the load factor decreases to 4.9 g at the maximum indicated airspeed of 202 mph (175 knots). It was not possible to determine from which manual precisely the excerpt was taken (see Appendix A).

Pursuant to Section 523.303 of the regulations, except where otherwise indicated, a safety factor of 1.5 must be applied to maximum loading. The resulting value is referred to as ultimate load.[3] Theoretically, based on the graph at Appendix A, the unmodified wings of the original Chipmunk mounted on the Super Chipmunk could have withstood an ultimate load of 7.2 g before breaking or being permanently deformed. The ultimate load would be calculated as follows: 1930 pounds x 6 g x 1.5/2400 pounds. However, the relationship between the increase in the maximum allowable weight and the load factor is not necessarily linear, and testing it normally required to confirm the strength factor. Since the aircraft was not intended to be certificated for unlimited aerobatics, no strength tests or calculations were required by the regulations. Therefore, the builder was not required to provide a new flight parameter graph. The Super Chipmunk documentation describing the aircraft characteristics indicates that the aircraft will withstand a positive load factor of 9 g and a negative load factor of 6 g.

According to Section 5 (on simplified exceptional demonstration procedure for aerobatics) of Advisory Circular 549.101A (Airworthiness Manual Advisory), for simple manoeuvres like the loop, the roll, and the wing-over, only a demonstration by a qualified pilot is necessary. When these manoeuvres are well executed, the loads applied should be less than 3 g. That section refers to CAR Section 523.337, which sets the minimum strength requirement for a fixed-wing aircraft. It requires a strength of 3.8 g in the normal category and 4.4 g in the utility category (which includes aerobatics). To obtain a waiver, a pilot who does simple aerobatic manoeuvres must document them in his logbook and submit a copy to Transport Canada before a revised special airworthiness certificate indicating the authorized manoeuvres can be issued. Also, Section 549.117 requires that a placard indicating the authorized manoeuvres be posted within view of the pilot. At the time of the accident, the aircraft did not meet any of these requirements; a placard stating that aerobatic manoeuvres are not permitted was still posted on the instrument panel.

The aircraft was put into service on 02 September 1999 and, at the time of the accident, it had accumulated 205 flying hours during which simple aerobatic manoeuvres were regularly executed. For this occurrence, the weight of the aircraft was estimated at 2125 pounds and the centre of gravity at 34.25 inches aft of datum, which is within the limits set for this aircraft.

All the structural elements related to the wing attachments were thoroughly examined at the TSB Engineering Laboratory. The report found that the lower bolt from the right main spar failed first. The initial upward movement of the wing tore the front attachment fitting, and the wing then folded aft, tearing the root of the upper fitting of the main spar from the wing.

Observations made about the bolt indicate that it failed under combined shearing and tension caused by stretching when it was deformed.

Theoretical analysis of the modification to the front fitting showed that, if the rivets had provided their rated strength, the modification would have retained 85 per cent of the original attachment strength. However, using the same diameter rivets to secure three reinforcement plates instead of one was conducive to warping, making the rivets more vulnerable to shearing and not allowing them to retain their rated strength. A pull test was done to compare an original fitting with a fitting modified in the same way as those used on the aircraft. The modified fitting failed at 66.6 per cent of the strength of the original fitting. However, during the test, the rivets

[3] Ultimate load is that load at which a structure breaks or is permanently deformed.

did not shear as they did in the accident; it was the reinforcements that failed with the fitting. Since the failure mode was different, the only acceptable conclusion was that the fitting was able to withstand the maximum load because of the safety factor (66.6% x 1.5 = 100%). However, the aerodynamic loads imposed in flight on these fittings are considerably lower than what the fittings can withstand and, from all the evidence, at the time of design by de Havilland, the strength of the front fittings was established based on drag induced on the ground by wheel braking, and not based on loads resulting from flight. Consequently, reducing the strength of the fittings did not in any way lessen their ability to withstand all loads generated in flight.

Since the force was applied horizontally, all fatigue-induced pre-cracks should normally have developed at a 90-degree angle to the tension axis, in other words, below or above the new hole. No fatigue-induced pre-cracks were found at those locations, and all fractures observed on the bolts or the front fitting were caused by overload.

Documentation on the Lomcevak aerobatic manoeuvre describes it as highly disorienting for the occupants and indicates that the aircraft usually comes out of the manoeuvre in a spin. It further indicates that the Lomcevak generates very high stresses on the aircraft structure, including high centrifugal forces on the wings, causing tensile stress on the wing attachment fittings.

Chapter 8 of *The Pilot's Guide to Medical Human Factors* published by Health and Welfare Canada (catalogue number H34-54/1992E) indicates that, when a pilot is unprotected from g forces, grey-out begins at 2 g and vision dims at the periphery, with blackout occurring at about 4 g. As g forces increase, brain hypoxia develops, and consciousness is usually lost near 6 g. Several factors influence g tolerance, including diet, physical condition, and exposure frequency.

# *Analysis*

The aircraft was equipped and maintained in accordance with existing regulations. The pilot was certified and qualified for the flight. People close to the pilot had often seen him perform simple aerobatic manoeuvres like the wing-over, the loop, and the roll. But this was the first time the pilot was seen doing a Lomcevak. Although the aircraft had been put through simple aerobatic manoeuvres before, and it could have met the criteria for performing these manoeuvres, they had not been documented, and no procedures had been initiated to obtain an airworthiness certificate authorizing such manoeuvres.

The aircraft weight and centre of gravity were within the prescribed limits. The loading limit established for the original aircraft was at least 6 g at a weight of 1930 pounds. Any increase in maximum weight or any reduction in the strength of the structure, such as that resulting from replacing the wing attachment bolts with bolts of a lower diameter and strength, had the effect of decreasing that limit. Assuming that, at full load (2400 pounds), the wings could withstand an ultimate load of 7.2 g, and that this value was reduced by between 61 and 72 per cent by replacing the bolts, the ultimate load was therefore between 4.4 g and 5.2 g at full load (2400 pounds) or between 4.9 g and 5.8 g at the time of the accident, since the weight of the aircraft was estimated at 2125 pounds. However, when the 1.5 safety factor is taken into account, the maximum load is reduced to between 2.9 g and 4.3 g, which is below the 4.4 g level prescribed in CAR Section 523.337 for aerobatics.

The aircraft had often been used for simple aerobatic manoeuvres. Frequent incursions into the zone between the maximum load and the ultimate load are inclined to induce fatigue. Since no fatigue was found, it appears that all manoeuvres executed during the 205 flying hours preceding the accident were done at load factors not exceeding 3 g. Only indications of instantaneous failure were found, which indicates that at the time of the wing failure the aircraft was subjected to loads exceptionally higher than previously experienced.

Following the dive, the recovery could have generated high loads. Using the calculated ultimate load as a reference, loads exceeding a factor between 4.9 g and 5.8 g were necessary to break the wing. These loads could cause a blackout, as well as the beginning of brain hypoxia. A loss of situational awareness could have caused the pilot flying to continue applying elevator to the point where the maximum strength of the wings was exceeded, while the aircraft was still at an altitude that would have allowed the pilot to follow a less pronounced recovery curve, which would have generated lesser loads.

Theoretically, the two wings should have been equally strong and, therefore, should have separated at the same time. However, the aerodynamic stresses on different areas of the aircraft can be different if the flight is not in a perfectly straight line. Given the major deformation observed on the bolt from the lower left spar, the bolt was about to fail, which would have resulted in separation of the left wing as well. However, the separation of the right wing instantaneously removed loading from the left wing.

According to the wording of Chapter 549, the amateur-builder, who by definition must design and build at least 51 per cent of the project, can also modify parts that he or she buys that are already manufactured. Since all modifications were done prior to the last inspection and prior to the issuance of the special airworthiness certificate, there were no other regulatory requirements in this regard. Reducing the strength of the front fitting had no adverse impact because the resulting strength was greater than the maximum loads that could be applied in flight. However, replacing the attachment bolts of the main spars reduced the capacity of the wings to react to loads as great as those estimated by the builder-pilot.

The following laboratory report was completed:

LP 064/2002 – In-flight Wing Separation Engineering Analysis “Super Chipmunk”

This report is available from the Transportation Safety Board of Canada upon request.

## *Findings as to Causes and Contributing Factors*

1. The aircraft was subjected to stresses exceeding its structural envelope, and the bolt securing the right lower spar failed in overload.

2. The four bolts securing the main spars to the fuselage had been replaced with bolts of lesser diameter and strength. The strength of the replacement bolts was approximately 61 per cent to 72 per cent of that of the original bolts.

## *Finding as to Risk*

1. The same load factors were retained despite an increase in allowable weight and a decrease in the diameter of the attachment bolts.

## *Other Findings*

1. The aircraft was not authorized to execute aerobatic manoeuvres.

2. The damages around the fractures showed signs of deformation consistent with failure caused by excessive tension; there were no signs of fatigue.

*This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 07 February 2005.*

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# *Appendix A – Load Table: Chipmunk*

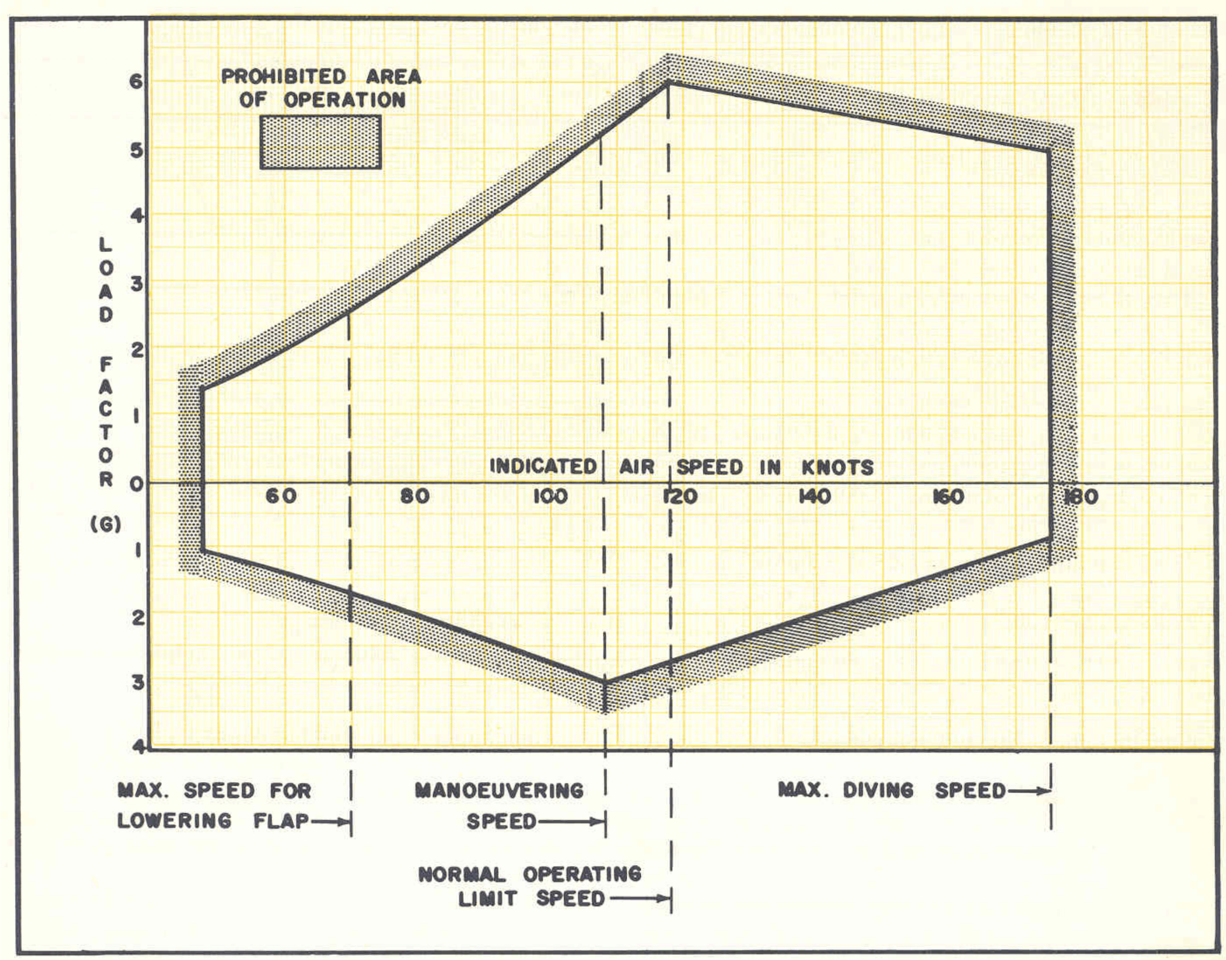


Figure 4-2 Operating Flight Strength Diagram