ACCIDENT

Aircraft Type and Registration:	Hawker Hurricane 1, G-HRLI	
No & Type of Engines:	1 Rolls-Royce Merlin III piston engine	
Year of Manufacture:	1940 (Serial no: 41H-136172)	
Date & Time (UTC):	1 June 2020 at 1203 hrs	
Location:	Duxford Airfield, Cambridge	
Type of Flight:	Private	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Landing gear and lower fuselage damaged	
Commander's Licence:	Private Pilot's Licence	
Commander's Age:	60 years	
Commander's Flying Experience:	850 hours (of which 8.3 were on type) Last 90 days - 1.4 hours Last 28 days - 0.2 hours	
Information Source:	Aircraft Accident Report Form submitted by the pilot and further enquiries by the AAIB	

Synopsis

While landing with a crosswind the aircraft made an uncommanded right turn that was not corrected, and the landing gear collapsed. The landing technique, the pilot's lack of recency and the hard, dry runway surface may have been contributory factors. The operator will require that less experienced pilots do not operate the aircraft with a crosswind component above 5 kt from the right.

History of the flight

The aircraft was returning to land on the grass Runway 06 at Duxford after a 20 minute engine maintenance flight. The pilot observed a crosswind from right of the landing direction and approached at a slight angle to the runway in order to land more into wind. The aircraft touched down on all three wheels as the pilot intended but bounced slightly and began to turn to the right.

The pilot reported that as the aircraft decelerated and rudder effectiveness decreased, he found it necessary to use brake to control direction and was unable to prevent the aircraft from turning further right. There was then a pronounced bounce, during which the aircraft pitched forward into an approximately level attitude and the tailwheel was no longer in contact with the ground. At what he estimated to be around 20 mph, first the left and then the right landing gear collapsed. The aircraft remained upright and there was no fire, but the aerodrome rescue and firefighting service applied a fire-supressing agent as a precaution.

The pilot had been wearing a full harness and helmet and, after switching off the ignition and electrical system, vacated the aircraft uninjured.

Figure 1

G-HRLI after the accident and application of fire-suppressing agent

Aircraft information

General

The Hawker Hurricane is a historic single-engine fighter aircraft of 1930s design with a tailwheel configuration. The main landing gear is located ahead of the aircraft centre of gravity and retracts towards the fuselage centreline. The tailwheel does not retract and castors freely.

Mass and centre of gravity

The aircraft was reported to be below its maximum landing weight, with its centre of gravity (cg) located approximately 55.4 inches aft of datum. The forward and aft cg limits specified in the aircraft's permit to fly were 54.0 and 58.0 inches aft of datum.

Restoration and maintenance

G-HRLI was the subject of a major restoration completed in 2018, since when it had flown 34 hours. The pilot reported no history of relevant defects or occurrences since the restoration, and the maintenance organisation responsible for the aircraft confirmed that its permit-to-fly was valid.

Aircraft and site examination

An examination of the aircraft after removal from the accident site did not reveal any evidence of pre-existing mechanical defects that might have contributed to the loss of control or landing gear collapse.

Ground marks observed after the accident indicated that the aircraft began to slide in approximately the landing direction shortly before the landing gear collapsed.

Meteorology

The pilot reported that the forecast wind was from 080° at 10-12 kt and that on touchdown it was from approximately 100° at 10-15 kt. The wind speed observed in the control tower at around the time of the accident was from 110° at 7 kt. Visibility was more than 10 km, the temperature was 23°C and the QNH was 1007 hPa.

Airfield information

Duxford has two runways, one tarmac and one grass, aligned 06/24. The grass Runway 06 is 880 m long, with a clear straight-in approach, and was dry and hard at the time of the accident. There was no indication that the runway surface was proving hazardous to other aircraft, but the surface was bumpy in places (mainly towards the Runway 24 touchdown end).

Personnel

The pilot had accumulated just over 8 hours flying experience in the Hurricane, all of which were flown solo because at the time there were no examples that accommodated more than one person. Before doing so he conducted a course of training in relevant aircraft, including North American T6 'Harvard' dual control trainers of the type used for this purpose when the Hurricane was in military service.

The pilot also flew a Pitts Special tailwheel aerobatic aircraft, which has different but also potentially challenging landing characteristics. The wing on that aircraft has a symmetrical section whose angle of attack is considerably below the stalling angle of attack when the aircraft lands in a three-point attitude, and it is not usual to apply full tail-down elevator as early in the landing run as might be desirable in a Hurricane. The Pitts Special's brakes and rudder are both effective, and some pilots favour brake as a directional control on landing in circumstances where rudder would be more appropriate in a Hurricane.

The pilot reported that he had not flown the Hurricane for several weeks because private flying had stopped nationally for public health reasons except for specific purposes including maintenance. Recently he had flown a weight-shift microlight in which pitch, yaw and roll control inputs are reversed compared to fixed wing 'three-axis' aircraft such as the Hurricane. He had also flown approximately 15 minutes in the Pitts Special immediately before flying the Hurricane on the day of the accident. He considered that his lack of relevant currency may have reduced his ability to anticipate and make appropriate control inputs on landing.

Operational control

Civil Aviation Publication (CAP) 632 – *'Operation of Permit-to-Fly ex-military aircraft on the UK register'* describes the requirements for this type of operation. Among other things it recommends training and currency criteria for pilots of high-performance propeller-driven aircraft.[1]

In accordance with CAP 632, the operator of G-HRLI specified in its Operational Control Manual (OCM) that pilots with more than 450 hours as pilot in command were considered 'experienced'. In order to self-authorise a flight, they required a minimum experience after training on the Hurricane of five hours on that type or similar types. The operator reported that the pilot had sufficient experience on the aircraft to self-authorise but that the flight was also authorised by its chief pilot. It considered the Harvard to be a similar type for the purposes of its OCM.

Other information

Crosswind handling

When the Hurricane was designed most aerodromes were grass fields on which landings were not constrained to runways and crosswinds could usually be avoided.

On the ground, in the absence of an opposing force, an aircraft's vertical tail surfaces usually tend to turn it into wind or to 'weathercock'.[2] This tendency is pronounced on tailwheel aircraft like the Hurricane whose main wheels are ahead of the aircraft cg, and may become uncontrollable if the cg moves beyond the edge of effective mainwheel contact (Figure 2).[3]

Applying into-wind aileron helps prevent the upwind wing from lifting and may provide some beneficial yaw opposing the turn. Maintaining tailwheel contact can provide a stabilising reaction behind the aircraft cg but, because the tailwheel of the Hurricane castors freely, it does not provide directional control and any resistance is reduced if the surface is hard. Braking tends to pitch the aircraft nose down (tail up), removing any beneficial resistance arising from tailwheel contact.

Diagram (a) shows the wind aligned with the landing direction. Diagram (b) shows a crosswind from the right. The aircraft has turned towards the wind and the path of momentum from the aircraft cg is at the outside edge of effective mainwheel contact. The castoring tailwheel is aligned with its path over the ground and provides little stabilising reaction. Without corrective control inputs the rate of turn to the right will increase. The further aft the cg, the more pronounced this effect will be.[4]

Footnote

1 https://publicapps.caa.co.uk/docs/33/CAP632_02MAY2018_Edition7.pdf [accessed September 2020].
2 In some cases, for example if the main landing gear is sufficiently far behind the aircraft centre of gravity, this effect may be reversed.
3 Based on Thurston, D.B. (1995) Design for Flying, 2nd edition, McGraw-Hill.
4 The aft position of the cg is exaggerated in diagram (b) to illustrate this.

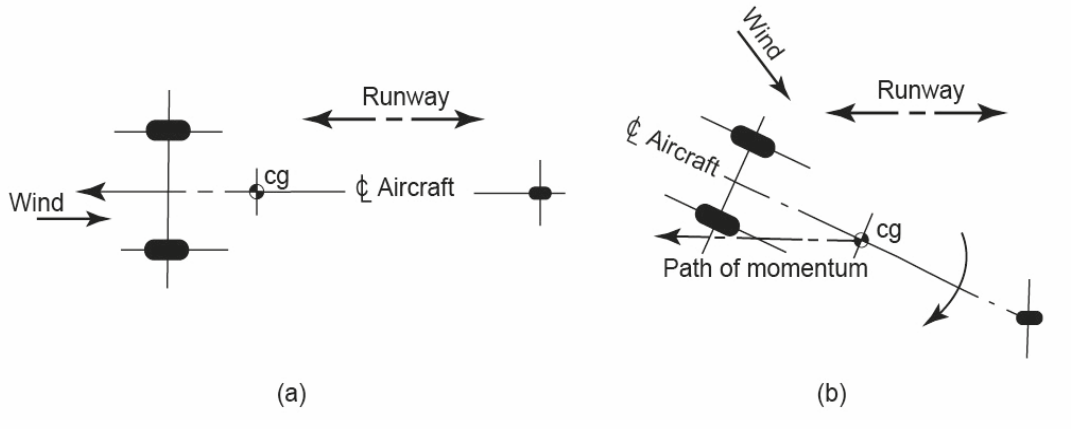

Figure 2

Plan view of landing gear and centre of gravity.
Mainwheels at left of each diagram

Aircraft of similar configuration do not necessarily have similar ground handling characteristics. For example, the contemporary Spitfire and Hurricane both have a tailwheel configuration, but on the Hurricane the cg is considerably further behind the mainwheels than on the Spitfire. Consequently, in the absence of opposing control inputs, a swing on landing will develop more readily in the Hurricane than in the Spitfire.[5]

A tail-down attitude on the ground results in some blanking of airflow over the rudder and fixed fin. Reduced airflow over the fin reduces the weathercock tendency but also reduces rudder effectiveness. If the loss of rudder effectiveness is greater than the reduction of weathercock tendency, the overall effect is to make the aircraft less controllable in yaw when the tail is down.

As airspeed decreases the aerodynamic controls become less effective, and the application of full opposite rudder may be insufficient to maintain directional control if any unintended turn is not corrected promptly, resulting in an increasingly rapid and uncontrollable swing, known as a ground loop. This does not necessarily cause damage if the aircraft comes to rest before hitting an obstacle.

The total wind speed and direction are important factors in a crosswind, as well as the crosswind component itself. A 20 mph wind 30° from the landing direction will produce a 10 mph crosswind but also a 17 mph headwind, whereas a 10 mph wind at 90° to the landing direction will produce the same crosswind but no headwind. The former provides greater control effectiveness throughout the landing roll.

When its engine is running the Hurricane's propeller rotates clockwise when viewed from behind. In the three-point attitude a down-going blade (on the right of the propeller disc)

Footnote

[5] The distance between main and tail wheels is approximately the same for both types, but on the Hurricane the distance from the mainwheels to the cg is approximately double that for the Spitfire.

has a greater angle of attack than an up-going blade on the left, moving the effective centre of propeller thrust to the right and producing a tendency to yaw left. Also, the propeller produces significant gyroscopic effects even at low power, and any tendency for the aircraft to pitch nose down will induce a yaw to the left. Correspondingly, yaw to the right will cause a nose-down pitching moment. Spiralling propeller airflow acting on the vertical surfaces of the aircraft also induces yaw to the left, and is most pronounced at high power and low airspeed.

Whereas these effects of propeller motion are likely to produce a left yawing tendency on the ground, they are most prominent with some power applied and the pilot and operator of G-HRLI stated that in their experience the aircraft was more challenging to land in a crosswind from the right.

The brakes on G-HRLI were of the type originally fitted to the Hurricane. Though adequate for taxiing and powerful enough to produce a nosedown pitch if applied firmly, they are prone to fading in prolonged use and the rudder is considered the most effective means of directional control on landing.[6]

Flight manuals

The permit to fly specified that the aircraft *'shall be operated in accordance with the relevant Pilot's Notes, Aircrew Manual or the manufacturer's prescribed operating limitations and requirements.'*

Air Publication (AP) 1564A – *'Pilot's Notes',* was the original Royal Air Force document for the Hurricane I. The pilot provided the AAIB with a copy of AP 1564B&D, the pilot's notes related to the later Mark II and IV versions of the Hurricane fitted with uprated engines.

Appendix 1 of the operator's OCM described the operating limitations and handling techniques for G-HRLI, based on AP 1564A and with additional material. It specified a crosswind limit of 10 kt for 'inexperienced' pilots and 15 kt for 'intermediate and experienced pilots', with a maximum surface wind of 20 kt.

There are several differences between AP 1564A and AP 1564B&D, partly reflecting the differences between the aircraft themselves, including in operating data and the level of detail provided regarding handling techniques. For example, the two documents recommend different landing speeds. The effect of these differences is that the approach speeds recommended for a Hurricane II are approximately 10% higher than for a Hurricane I.

The April 1940 revision of AP 1564A provides the following guidance on *'landing across wind'*:

> *'The aeroplane can be landed across wind but it is undesirable that such landings should be made if the wind exceeds about 20 m.p.h.'*

Footnote

[6] Source: AAIB discussions with other Hurricane operators.

The edition of AP 1564B&D shown to the AAIB did not contain guidance on crosswind landings. Pilot's notes for the Hurricane produced by the Air Transport Auxiliary in 1944 state:

> *'The aircraft presents no unusual difficulties in taking off or landing in moderate crosswinds, providing the correct cross wind technique is used... No attempt to take-off or land should be made if the cross wind exceeds 20 mph at 30 ° to the runway.'*

The operator's OCM contained the following guidance:

> *'The Hurricane is ground loop prone, but with a right-hand cross wind it is particularly so. When the wind is from this direction during the landing roll the aircraft has the possibility to swing into wind. In right hand wind conditions pilots are to be aware of the ground loop possibility and reconsider the landing runway. The Pilot should be ready to counter the slightest swing which uncorrected will quickly escalate into a loss of directional control. The brakes will not be effective in stopping a ground loop once it is underway but provided there are no obstructions in its path the aircraft should come to rest in a safe position.'*

Landing techniques

Tailwheel configured aircraft can be landed in a three-point attitude, in which touchdown occurs on the main and tail wheels simultaneously; or on the mainwheels first, known as a 'wheeler', in which the aircraft is landed in a level attitude. Landings can also be achieved in any attitude between these and, less conventionally, by touching down on the tailwheel first.

A three-point landing is achieved when the landing attitude is closer to the stalling angle of attack than for a wheeler. A wheeler, being at a shallower angle of attack, must be flown at a higher airspeed and therefore requires a longer landing run, but has the advantage that the aerodynamic controls are more effective at the outset. A 'tail-low wheeler' involves both higher landing speed and less effective controls but is the preferred technique for some aircraft. Landing on the tailwheel first tends to pitch the aircraft nose down and the mainwheels may then touch down with sufficient energy to cause the aircraft to bounce.

Flight manuals sometimes offer guidance on the appropriate technique, but the versions of AP1564 seen by the AAIB did not specify a landing attitude. Other guidance applicable to the Hurricane[7] likewise does not specify the landing attitude but indicates that once the tailwheel is on the ground the control column should be held fully rearwards to offer the best directional control and to counter any nose-down pitching tendency.

Video footage showed that immediately before landing the aircraft was in a 'tail-low wheeler' attitude but rotated quickly into a three-point or slightly tailwheel-first attitude on touchdown. The mainwheels became airborne again briefly and on the next touchdown the aircraft began to turn to the right. The tail lifted several times, followed by a more pronounced

Footnote

[7] Hurricane Aircrew Manual, Royal Air Force Battle of Britain Memorial Flight.

nosedown pitch, and a trail of dust from the mainwheels indicated they were in contact with the ground and probably sliding sideways. The tailwheel then remained off the ground until the landing gear collapsed.

The video is not clear but appears to show the elevator approximately neutral throughout. The ailerons are not in view until quite late in the sequence, when it appears into-wind aileron was applied. The rudder does not appear to be significantly deflected at any time.

Survival aspects

The aircraft's canopy slides rearwards and can be opened in flight. If the aircraft becomes inverted on the ground the escape hatch on the right of the cockpit can only be opened if the canopy is locked fully rearwards. The operator's OCM stated:

> *'To facilitate exit during an emergency it is recommended that the cockpit canopy is locked open during take-offs and landings. Pilots may weigh up the conflicting risks if they consider an open canopy will create a distraction or further hazard and elect to take-off and/or land with the canopy closed.'*

Video footage indicated that the canopy was open during the landing but did not show if it was locked fully rearwards.

Analysis

The aircraft centre of gravity was within limits. The open canopy, if locked fully rearward, would have assisted escape had the aircraft become inverted, and was a significant survival precaution.

The pilot was current for the flight as defined in the operator's OCM and had been authorised to conduct it.

The wind recorded at the aerodrome suggests a crosswind within the limits described in relevant pilot's notes. However, the surface wind reported by the pilot would have involved a crosswind component of up to 11 mph; sufficient to make ground handling more challenging.

Landing speeds recommended in the pilot's notes shown to the AAIB, relevant to the later Hurricane II, are higher than those for a Hurricane I. The tail-low wheeler attitude shown in video footage shortly before touchdown, and the bounce shortly afterwards, indicates that the aircraft was slightly fast for a three-point landing. Accordingly, the aircraft was probably quite light on its wheels during at least the early part of its ground roll, increasing any tendency to bounce and slide. Subsequent braking and the propeller's gyroscopic reaction to right yaw would have tended to raise the tail, and there was no obvious tail-down elevator applied to oppose it. The approximately neutral elevator position is consistent with a technique appropriate to the Pitts Special that the pilot also flew. There was no evidence that the pilot had transferred control input habits from weight-shift aircraft he had flown previously.

The apparent absence of opposing rudder input indicates that additional directional control was available.

When the aircraft bounced while turning to the right the tail lifted and it is likely most of the aircraft's weight was supported on the left mainwheel. The aircraft's momentum being largely in the landing direction, and its cg behind the mainwheels, the swing to the right became more pronounced and the aircraft began to slide in the landing direction. This exceeded the side loads for which the landing gear was designed, and it collapsed.

In the absence of any reported defects, such as a binding right brake, it is likely that the loss of control was a result of insufficient or inappropriate control inputs.

Conclusion

The crosswind on landing induced a turn to the right. The reported application of brake and an absence of tail-down elevator coincided with the aircraft bouncing and pitching forward on the hard, undulating runway surface, aggravating the effects of the swing. In the absence of effective control inputs to oppose the swing, the aircraft began to slide sideways, eventually causing the landing gear to collapse. The pilot considered that his lack of relevant currency may have reduced his ability to anticipate and make appropriate control inputs on landing.

Safety actions

The pilot intends to conduct refresher training in a relevant dual control aircraft such as the Harvard before flying the Hurricane after a significant absence. The operator will amend its Operational Control Manual to require that pilots new to the type with less than 5 hours experience on equivalent types will be limited to a maximum 5 kt crosswind component from the right.