RESULTS OF THE ROYAL AIRCRAFT ESTABLISHMENT STUDIES SUMMARISED

1 Film analysis

Synchronisation of events on both films proved difficult but is estimated to have been achieved to within 0.2 seconds. The error in the ground track is considered to be within ± 25 feet and relative height ± 5 feet, but absolute height above the ground was harder to establish and the possible errors are probably greater than this.

1.1 Speed

The mean speed over the ground shortly after take-off was estimated as 81 knots. After allowing for the headwind component an equivalent air-speed (EAS) of 91 knots was derived, which equated to 72 knots IAS. Just before G-AXAR started its final climb the ground speed was estimated at 102 knots. This equated to 92 knots EAS and 73 knots IAS.

1.2 Sequence of events

The critical point in the flight appears to have occurred between 6 and 6.25 seconds before ground impact. At this time the aircraft had reached a nose-up pitch attitude of 25° to 30° to the horizontal with the pitch rate increasing. There was then an abrupt reversal in the rate of pitch and the nose of the machine started to drop.

At about this time the rotor head moved rapidly nose-down to a position compatible with a fully forward displacement of the control column. The aircraft's subsequent manoeuvres would follow directly from this control movement (Appendix C). The nose-down pitching motion would reduce the normal acceleration and, if sustained, would eventually produce a negative acceleration. It can be seen in Appendix B that zero 'g' was achieved about 4.5 seconds before impact.

The rotor lift forces would also be reduced and eventually drop to zero. A consequence of this would be that the force providing reaction to engine torque would also be reduced, resulting in a roll to the right, this can be seen in Appendix C, when a rapid roll to the right developed 4.3 seconds before impact. Simultaneously the nose-down pitching motion caused the propeller, acting as a gyroscope, to yaw the aircraft to the right, (Appendix C). The combined rolling and yawing motion would be sufficient to bring the aircraft into the vertically nose-down attitude that occurred approximately 4 seconds before impact.

The first rotor strike on the propeller and empennage occurred 3.5 seconds before impact.

1.3 Pilot position

As movement of the pilot's torso could have materially altered the aircraft centre of gravity (C of G) an attempt was made to derive evidence of torso movement from the position, on the film, of the pilot's head.

There was no measurable difference between the position of the pilot's head at the start of the take-off roll and during the pull-up manoeuvre 7 seconds before impact. Although it became increasingly difficult to detect the pilot's head in the later film frames it did not appear to move forward appreciably until very late in the sequence of events.

1.4 Pitching oscillation

It is possible to draw an oscillatory curve through the points used to produce the pitch attitudes curves in Appendix C. This would tend to support the evidence of several eyewitnesses. However, prolonged viewing of the films produced no strong evidence that G-AXAR exhibited an oscillatory motion before it finally pitched nose-down.

2 Appraisal of stability and control

Early in the investigation it became apparent that very little quantitative data about light gyroplane aerodynamics had been recorded. To provide RAE with sufficient information for an effective study of the Wallis WA-117 a relatively simple flight test programme using a similar WA-117 was arranged.

Wing Commander K H Wallis, the designer, flew the programme in G-AVJV, an aircraft identical to G-AXAR except for the dimensions of the cockpit nacelle. It was fitted with a small instrumentation pack and, for some of the tests, an experimental tailplane.

2.1 Theoretical stability and control studies

Reference was made to a derivative mathematical model at the initial level flight speeds of 44, 68 and 95 knots EAS, the latter being approximately the speed at which the accident occurred.

The starting point taken was that of trimmed flight at 95 knots with a rotor speed of 500 rev/min and an aircraft weight of 700 lb. The ensuing estimate of collective pitch was then used at the two lower airspeeds giving the appropriate trimmed rotor speeds. Rotor speed was treated as an independent variable.

The relatively large streamlined cockpit nacelle forward of the C of G produces an unstable pitching movement with respect to fuselage incidence. The overall aircraft movement derivative depends on contributions from rotor, fuselage and propeller side forces. The contribution from the rotor is also dependent on the initial fuselage movement, which it has to trim and which becomes increasingly unstable with fuselage nose-down incidence. The overall effect in the theoretical model 'stick fixed' was to produce an unstable aircraft which becomes increasingly unstable as speed increases.

In the 'stick free' case movement of the pilot's control column tilts the rotor spindle axis which is restrained by a trimmable spring. If the horizontal spindle offset is sufficiently large the moment of the rotor forces about the pivot point becomes stabilising and tends to tilt the rotor disc and stick forward as incidence increases. In trimmed flight a constant force has to be supplied by the spring for equilibrium of rotor and fuselage, but the spring rate is relatively small and has little effect on stability. A modal analysis of the equations of motion by a digital computer programme has been used to give stability and control response characteristics both in the 'stick fixed' and 'stick free' flight conditions. The major derivatives, some geometric parameters, and rotor inertia were varied systematically to study their effect on handling characteristics and to indicate trends and sensitivities.

In the 'stick free' case all modes were found to be stable. The 'stick fixed' theoretical results showed the aircraft to be dynamically unstable in several modes with a readily apparent trend of increasing instability with speed.

2.2 Flight tests

Six parameters were recorded by the instrumentation pack for the tests: Angular rates about the roll, pitch, and yaw axes, longtitudinal and lateral control column positions, and rudder pedal positions.

The test programme included the measurement of:

Position error (airspeed) (using Kine-theodolites).

Control column position to trim in level flight in speed range 26 to 78 knots.

Control column position to trim, constant throttle at 39 knots ± 13 knots and 70 knots ± 13 knots.

Longitudinal control response in speed range 35 to 70 knots.

Dynamic longitudinal stablity 'stick fixed' and 'stick free' in speed range 35 to 70 knots.

Most of the test programme was flown both with and without the experimental tailplane, which had an area of 6 ft^2, an aspect ratio 2:9, and a movement arm of 3.5 feet. Its position was such that it was working in turbulence from the landing gear and instrument pack and was near to, but not in, the propeller slipstream.

The airspeed position error was found to be never greater than 2 knots over the range 35 to 70 knots.

Longitudinal and lateral control column position to trim were progressive and predictable throughout the speed range. At 26 knots the control column was 25 per cent ahead of the rear stop and moved forward to 60 per cent ahead of the rear stop at 78 knots. The lateral control column position to trim was essentially constant with speed at about 60 per cent of available range measured from the right stop.

The measurement of control response using step inputs of control was not entirely satisfactory. However, the control response was similar in shape to that of a single rotor helicopter with an articulated rotor. The response was quite crisp, maximum rate of pitch being reached about 0.75 seconds after initiation.

The tests of dynamic stability using an initial pulse input produced some useful results and enabled comparison to be made of the longitudinal stability characteristics 'stick fixed' and 'stick free' both with and without the tailplane as follows:

(a) *Basic aircraft, 'stick fixed'*

Flight tests indicated that the aircraft was unstable 'stick fixed', but quantitative data on the 'stick fixed' stability was difficult to obtain. Many test results showed apparent dynamic stability, but close inspection of the records often showed small favourable stabilising stick movements. However, some tests indicated that the aircraft was unstable in pitch when the control column was mechanically locked.

(b) *Aircraft with tailplane, 'stick fixed'*

The aircraft appeared to be stable 'stick fixed'.

(c) *Basic aircraft, 'stick free'*

The aircraft appeared to be stable with a prominent short period damped oscillation of period 1.5 seconds.

(d) *Aircraft with tailplane, 'stick free'*

The aircraft appeared to be stable with possibly slightly increased damping of the short period oscillation.

In both configurations the aircraft could be flown 'hands off' for long periods.

3 Comparison of theoretical and experimental results

The unstable mode of the clean aircraft without tailplane, 'stick fixed' at 68 knots, predicted theoretically, is oscillatory, with a period of 8.3 seconds and a time to double amplitude of 1.1 seconds. The nearest flight test result of 70 knots indicates instability, but movement of the controls made it difficult to make a comparison with the theoretical results. The general indication, supported by inspection of other records, is that the aircraft is less unstable than theory predicted.

The most noticeable feature of the 'stick free' stability of the clean aircraft predicted theoretically at 68 knots and 95 knots is a damped short period oscillation with a period of 1.5 seconds and a time to half amplitude of 1.0 seconds. The corresponding flight records exhibit an oscillation of similar characteristics. In the air the aircraft was stable 'stick free' and would tend to produce stabilising movements of the control column in the hand of the pilot. Favourable blade torsional effects possibly contributed to the aircraft's being more stable in the air than theory predicted.

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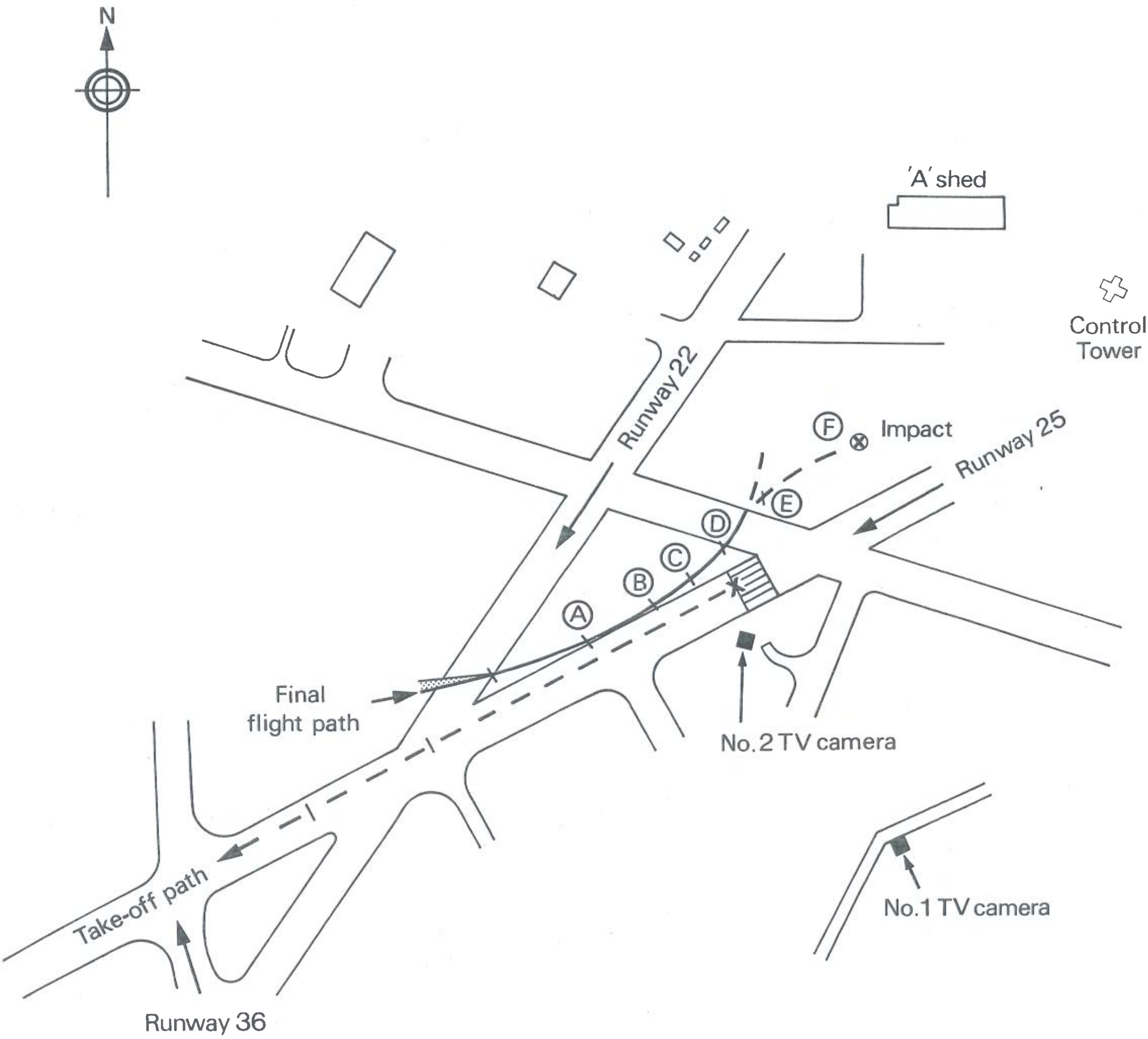
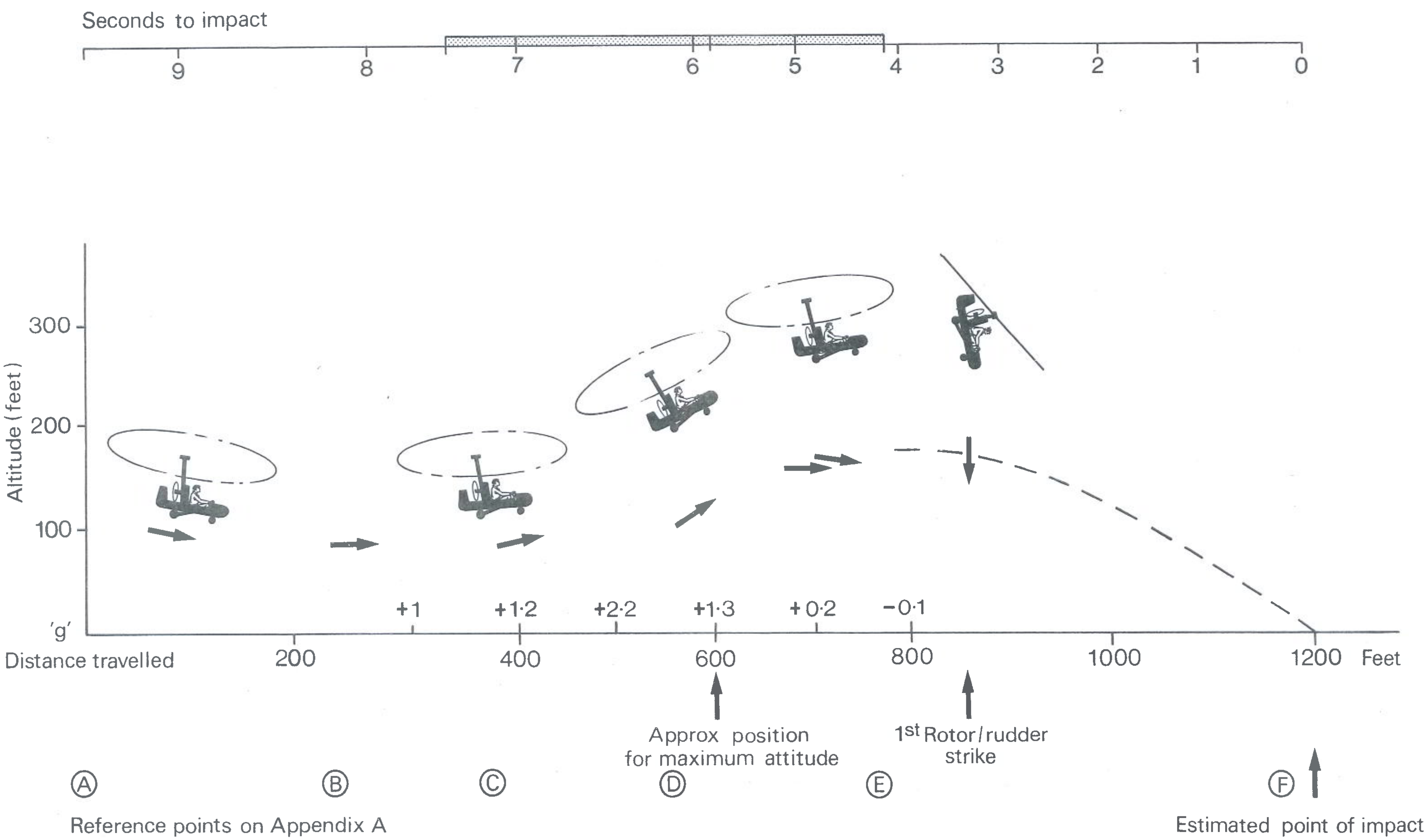
Estimated flight path of G-AXAR

APPENDIX A



Sequence of events in final flight path G-AXAR



Deduced manoeuvres of G-AXAR from TV films