The Gloster E.28/39 -
Fin Arrangement and Spinning Characteristics

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Abstract

Following a 2008 review of the aerodynamic design of the Gloster E.28/39 experimental jet aircraft, newly-located material allows two areas to be clarified and added to the record. It is confirmed that an option for using a twin-finned empennage was retained for some way into the design process, and a probable arrangement of this is presented. Secondly, details of spinning model trials now obtained provide a possible basis for the deletion of the requirement for full-scale spinning trials from the final Specification, agreed for the aircraft in early 1940.

1 Introduction

The original purpose of the Gloster E.28/39, Britain’s first jet-propelled aircraft, was to prove in flight the new turbojet engines provided by Frank Whittle’s company, Power Jets Ltd. But the Chief Designer at Gloster (Wilfred) George Carter realised that engine developments during its life would enable it to enter into the previously-unexplored region of high-subsonic flight. Carter shrewdly interpreted the very limited information about effects of compressibility in this regime available at the time of its conception, and prepared his design accordingly. A study, published in the Aeronautical Journal in 2008, reviewed the aerodynamic design decisions that must have been taken by Carter and his small team, that had enabled it to operate with great success in flight conditions that were far beyond the requirements of its Specification (1).

Inevitably, information from that period in WW2 was either not recorded or had been lost subsequently. What remained, nearly 70 years later, was sparse and widely-dispersed, but when assembled, it allowed a fair picture to be built up of the design procedures undertaken. Among the items that could not be adequately covered before the study went to press were two concerning the empennage. More material on these has subsequently come to light, and is reviewed here as a further contribution to the record.

This paper complements one published in the Aeronautical Journal in 2008. The Editor thanks the Editor of the Aeronautical Journal, Professor Peter Bearman, for permission to reproduce “On the aerodynamics of the Gloster E.28/39 – a historical perspective” from Aeronautical Journal, 117b, 307 – 326, 2008, following this new paper. Because this is reproduced from Aeronautical Journal, the page numbering for this paper does not follow sequentially.

In the course of reviewing this paper it was read by Captain Eric Brown, CBE, AFC, RN, who flew the Gloster E.28/39. A letter from Captain Brown is reproduced after this paper, with his permission.
2 Variants

It is usual for several possible layouts to be generated in the early stages of a project. In the case of the E.28, two possible arrangements for the fuselage were considered, giving rise to what were termed the ‘short jet’ and ‘long jet’ versions. Some early layouts showing these, from October 1939, are outlined in Figure 1 (2). They reflected uncertainty about the best way to accommodate the new turbojet engine, one aspect of which was the potential loss of thrust if a long jet pipe was needed. In due course, it was the long jet arrangement that was preferred, largely through unresolved questions concerning possible entrainment effects of a forward position of the jet efflux on the flow around the tailplane.

In the arrangements shown in Figure 1, both variants have a single fin. However, it is known from some surviving notes by Richard Walker, Carter’s Assistant Chief Designer, that a twin-finned version remained under consideration until a late stage in the design. It seems that Carter had some leanings towards this arrangement, as he had adopted it for his pre-war twin-engined fighter F.9/37, two examples of which began flying in 1939 (3) and again for a project outlined in January 1940 called the Gloster Boosted Fighter (4). This was to have been a mixed power-plant aircraft having a conventional piston engine and propeller at the front, with a turbojet engine, mounted in the short jet configuration, below the rear fuselage. It had arisen from the realisation that a fighter with a single engine of the original Whittle type alone would not have the payload and endurance required for use in the air defence role. However, it was overtaken by the twin-jet F.9/40, which was ordered before the E.28 had flown, to become the Gloster Meteor, the first jet aircraft to enter service with the RAF. For this, Carter reverted to a single-fin configuration.

Figure 1 Schemes I and II (‘short jet’ (upper) and ‘long jet’ (lower) precursors of the Gloster E.28, October 1939 (Reference 2)
Outlines of the arrangements of the twin-fin empennage for the F.9/37 and the Boosted Fighter are shown in Figure 2 for reference later.

Figure 2   Arrangement of empennage, Gloster F.9/37 (upper, Reference 3) and Gloster Boosted Fighter (lower, References 4 and 12)  *not to scale*

No illustration of the possible twin-fin E.28 had been found by the writer prior to the publication of the previous study. But shortly afterwards, a copy of the earliest known representation of the aircraft, dated 26 September 1939, was located at the National Archives, where it had been mistakenly filed with drawings of another type\(^5\). This is from a sketch made by Carter showing a long fuselage arrangement with a single fin, but with a superimposed outline of an empennage with twin fins, shown faintly, probably in pencil on the original drawing. This suggested that this option was under consideration from the beginning. The outline of the fin had a roughly elliptical profile. However, as the chordwise dimension of it drawn in plan is different from the corresponding value in elevation, Carter’s intentions cannot be positively ascertained from that alone.
3 Spinning

Another area for which information was lacking, also with potential relevance to the design of the empennage, had been highlighted by a reference to spinning model trials, made in a letter of 7 August 1940\(^6\). This was found at the National Archives in a former Air Ministry file, headed ‘Wind Tunnel Tests, Gloster Whittle E.28/39’, and gave some favourable results of spinning model trials at the Royal Aircraft Establishment (RAE). Sent by George Douglas, Head of the Aerodynamics Department to Captain R M Liptrot at the Ministry of Aircraft Production (MAP) Headquarters, it concluded by recommending that ‘the aeroplane should be passed for full scale spinning trials’. This would be the normal consequence, after model trials had indicated that the behaviour was likely to be satisfactory in spins at full size.

This recommendation was puzzling, as the usual requirements for spinning tests at full scale had been deleted from the final version of the Specification for the E.28, issued in February 1940 as the formal basis for its procurement\(^1,2\). There had been no reference in Douglas’s brief letter to any report on model trials, which would have given more details and been of interest in the study of the aerodynamic design processes of the time. A search failed to locate one among the RAE reports of that period held at the museum of the Farnborough Air Sciences Trust (FAST). When the two E.28 aircraft were built and flown, there were no indications, either in accounts of tests by the Company or after their transfer for flying at the RAE, that any full-scale spinning trials were ever carried out.

The deletion of the requirement from the Specification thus remained unexplained, but this reference to spinning trials in a file on the E.28 was reported in the earlier account in good faith\(^1\).

As the cataloguing of the RAE reports at FAST progressed subsequently, two relevant reports on spinning model tests came to light, making it necessary to revise that position. The first, on the tests to which Douglas’s letter must have referred, was found to be for models of the F.9/40, indicating that the letter had been wrongly included in the E.28 file held at the National Archives\(^7\). In Douglas’s letter and the report the aircraft is described as the ‘Gloster interceptor fighter’. With hindsight, this might have caused some uncertainty as to which aircraft it referred, though in the early papers the E.28 was often called a ‘fighter’, as it had been thought originally that it might be developed for that role.

It could have been seen also that the reference to spinning model trials in August 1940 would have placed them late in relation to the state of progress on the E.28 at that time. In the only known mention of spinning in records of the design meetings, there is a note of some impatience on the part of the Company, waiting to receive results of model tests from RAE in January 1940\(^1\). In the corresponding position for the design of the F.9/40 the first outlines had been made in April/May, and for it to have already matured sufficiently by August for spinning model trials to be completed would further indicate that Carter and his team expected these to take place at quite an early stage in the process. The F.9/40 model as shown in the spinning report was already much as finalised (though with the short engine nacelles that were installed at first).

The second relevant report proved to be an account of spinning trials with models of the E.28, that had long been hoped for\(^8\). However, it had not been issued until 1944, no doubt the main
reason for its having been overlooked, though no explanation was given for this delay. The
dates when the spinning tests took place are not recorded, though from the design of the models,
it could be conjectured that this had been around the early Spring of 1940. But a 3-view
drawing of the aircraft is included, showing it essentially in its final form, with detailed
dimensions, seemingly taken from a report on the wind-tunnel tests of December 1940. Then in
the title of the report, the aircraft is referred to as the Gloster ‘Tourist’, one of several code-
names used for it when it was on dispersal for flight trials to Edgehill and Barford St John,
which did not begin until early February 1942. (The aircraft was never given an official name;
it was sometimes referred to as the ‘Gloster Whittle’ in official papers, but was known at the
Company only by the number of its Specification, ‘E.28’)

It seems likely, in view of the spread of these dates, that when the report was compiled in 1944
data were taken from a file on the aircraft held in the wind-tunnel section of the Aerodynamics
Department (originally called ‘BA Section’) at RAE. When written at this later time, a certain
amount of hindsight could be expected to enter into the presentation of the spinning test results.

4 The empennage

An unexpected benefit of the use of early designs for the models in the second report was the
inclusion of the twin-fin arrangement, that was feared to have been lost. The models also
included both the short jet and long jet fuselage variants, some with both single- and twin-fin
empennage. The types covered are shown in Figure 3.

Figure 3 Model layouts for tests in the RAE Free Spinning Tunnel (Reference 8)

There had clearly been some developments in the layouts since the first ideas shown in Figure 1.
The twin-fin arrangement, which has not been found anywhere else, has some family
resemblance to those of other Gloster designs, as seen in Figure 2. The arrangement of the
outboard ends of the elevators suggests that for these models, the empennage might have been based on that of the F.9/37. The relatively small size of the fins is a notable feature of the twin-fins models, but it should be recalled that, with the fins in this outboard location, they have a considerably greater effectiveness than a single fin that is operating in the reduced flow over the rear of the fuselage.

A further indication of confusion over the timing is that the one case in this report that includes a single fin shows this feature having the shape and detailing of that in the final version of the aircraft as built, with the fin mounted well forward on the tailplane.

It is notable that, of the four possible combinations of two fuselage arrangements and two fin types, only three were modelled and tested, omitting the long jet and single fin combination that would be nearest to the aircraft in its final form. No reason was given for this omission. In view of the 1944 dating of the report, if there had been a further report that had dealt separately with this case, it would be expected to have been referenced, at least. But no such report came to light and perhaps there is none now remaining to be found.

Before proceeding to a review of the results from the spinning tests with these models, a brief background account is given of the state of knowledge at the time on the behaviour of an aircraft in the spin, and on the measures that could be taken by the designer to obtain satisfactory spinning characteristics and to secure recovery. This is followed by an outline of the technique employed for model tests and the application of these matters to the design of the E.28.

5 Spinning and the designer.

Spinning had been a significant hazard to aviation from its earliest days, and remains one of the factors to be considered in any design. In a spin, the aircraft descends vertically, following a tight spiral path of short radius compared with the span and long pitch. Its centre of gravity does not lie on the axis of this path. The nose is normally pointed well down, perhaps at 60° below the horizontal, though in a ‘flat spin’ this angle can become smaller. (With the downward angle perhaps 20° or less, the rate of rotation is then more rapid, and recovery generally more difficult). The longitudinal axis of the aircraft is inclined at a steep angle relative to its path, so that the wings and tailplane are fully stalled. In moving along a helical path there is a state of continual side-slip, with the balance of forces generally requiring the fuselage to be yawed outwards.

The tasks of the designer in this area are to minimise the likelihood of a spin developing and to provide for recovery if one does. Aspects of the rear fuselage, fin and rudder are the most relevant to this. If the moment of the side forces on these areas when yawed is sufficiently large, the aircraft will not enter a spin easily. If this does happen, application of an additional moment by full deflection of the rudder is the usual means of ending the rotation, and so to begin the recovery procedure. These forces also have a function in maintaining directional stability and control in normal flight, but in the spin their effectiveness can be seriously hampered by the fin and rudder being shielded from the airflow by the rear fuselage and the tailplane when the aircraft is pitched at a large angle to its path.
At the time of the design of the E.28, the nature of the spin was well understood, but its implications for design tended to be based on interpretations of collected data such as those in a 1934 report by the Spinning Panel of the Aeronautical Research Committee (ARC) in its Reports and Memoranda (R&M) series \(^{(9)}\). It was supplemented by a timely review, including more recent measurements, given in an RAE report of May 1940 \(^{(10)}\). This gave an analysis of results from about 40 model tests and 15 spinning trials with a variety of aircraft at full scale, to give limiting values for the two basic coefficients that would be calculated by the designer. These represented respectively the effectiveness of the lateral area of the rear fuselage and fin in regulating the spin and of the rudder area in recovering from it. Minimum acceptable values for these coefficients had been proposed for some time, and were already provided in basic textbooks of the 1930s. The RAE report went further, in reflecting the importance of the inertial couples that balance the aerodynamic ones in the spin. Threshold boundaries for the coefficients were now given as functions of a third one, representing the difference between the moments of inertia of the aircraft about its yaw and roll axes. This is similar to the inertia difference term that appears in the already-developed theory of the steady gyrodynamic motion of spinning bodies. Through this the distribution of mass around the aircraft affects the relative values of pitch, yaw and roll at which it would settle as a rigid body in a steady spin.

6 Pre-flight estimates

The theory available would not yet allow quantitative evaluations to be made of outcomes such as the rate of rotation in the spin or the time to recovery. This was mainly because the relevant aerodynamic derivatives for an aircraft in an orientation of high pitch and yaw and the coupling between them and with roll were quite unexplored at that time. In the procedure outlined, judgments were based on the values of the two leading coefficients for a given aircraft, calculated using the dimensions emerging as the design proceeded. Although this process remains in use at the present time, it is of interest to note how it was employed in the practices available in 1939-40.

The first coefficient, the *yaw damping coefficient*, is a non-dimensional value of the moment about the CG of the aircraft of the lateral area that opposes the rotation in the spin. In evaluating this for a particular layout, the contributions from various parts of the rear fuselage, fin and rudder are given different weighting, according to the extent to which they are liable to be shielded by the wake of the tailplane when the aircraft is stalled at a steep angle to its path. The second coefficient, called the *unshielded rudder volume coefficient*, represents the potential of the rudder to overcome the rotation, when fully deflected in the standard procedure for recovery from the spin. This term is formally a non-dimensional value of the moment about the CG of that part of the rudder area which is not shielded by the tailplane in this condition. The weighting factors assigned to the various areas at that time are shown in Figures 4 and 5 \(^{(10)}\).

Estimates of the minimum acceptable (threshold) values for these coefficients had been determined empirically from those of previously-tested aircraft, according to the level of satisfaction with their observed behaviour in the spin at full scale. These were now expressed relative to the value of the relevant inertia difference coefficient. Although results for a variety of aircraft were available at that time, the level of uncertainty in the threshold values was such that, even where pre-flight estimates of damping in the spin and rudder effectiveness in recovery
Figure 4: Weighting factors for calculation of Yaw Damping Coefficient and Unshielded Rudder Volume Coefficient – central fin (Reference 10)

Figure 5: Weighting factors for calculation of Yaw Damping Coefficient and Unshielded Rudder Volume Coefficient – twin fins (Reference 10)
exceeded them, this would nevertheless be followed by routine testing of scale models at an early stage. If satisfactory, these would give some further confidence in the ability to recover from a spin, and would then normally be considered sufficient to justify entering upon spinning trials at full scale with the prototype. As these coefficients involve leading dimensions of the aircraft, it is readily understandable that designers would wish to investigate them at an early stage in the evolution of a design.

7 Spinning tunnel tests

Tests concerning the E.28 were carried out in the vertical Free Spinning Tunnel at RAE. This had a working section 12ft in diameter, with an enclosed gallery allowing access from one side when in operation. Models were made in balsa wood to a suitable geometric scale, and loaded so as to have the appropriate scaled values of mass and moments of inertia about all three main axes. They were usually represented with the undercarriage up and the CG at its aft limit, though variations in the configuration could be tested if the spin recovery was found to be marginal.

For a test, an arm, pivoted in the gallery, could be swung into the tunnel with the model mounted at its end. A boss in the model could be placed onto a vertical spigot there, on which it could rotate freely. To cause an initial rotation, the axis of the boss was orientated to present the model to the airflow at angles of pitch and yaw that typically occurred in a spin. The development of a spin was further encouraged by attaching a vane to one wing tip. To begin a test the arm was swung so that the model was positioned at the centre of the tunnel, the fan was turned on and the air speed increased so as to cause the model to rotate about the spigot. The speed was then gradually increased until the model was lifted from the spigot and began rotating in a fully-developed spin. Thereafter, the arm was withdrawn and the tunnel speed adjusted so that the spinning model was maintained in a stable hovering position relative to the gallery, where it could be readily observed. The control surfaces on the model were then caused to move to the desired deflections for recovery by an internal clockwork or pneumatic mechanism. The time required for recovery from the spin and the number of turns taken would be observed and recorded. After recovery, the model usually emerged from the spin in a steep dive, then being caught in a net lying across the tunnel below the level of the gallery.

To evaluate the effectiveness of the rudder in this test, the time taken to recover was plotted against the additional pro-spin yawing moment applied by the wing-tip vane. Tests were made with a series of vanes, with increasing applied moment (obtained by calibration), until a value was reached at which recovery was no longer possible. The tests were repeated with the elevators of the model deflected, both up and down, as the elevator position was known to affect the result, and also with the direction of spin reversed, the reported conclusion being the average of the recovery time for spins in opposite directions. For the result to be satisfactory, recovery would have to be demonstrated for values of the applied pro-spin moment in excess of a specified threshold value. This was to represent a margin for safety and to cover remaining uncertainties about how well the behaviour at full scale was represented in testing with models. A conveniently-sized ‘unit’ was devised to represent the applied moment – as the result of a test is obtained simply by comparison with the threshold value, the size of the unit is not material to its interpretation.
8 Significance of results

For the various specified conditions, the outcome of the tests is given by the greatest applied yawing moment that could be overcome when recovery occurred within 10 seconds of applying rudder deflection, together with the limiting value of the moment beyond which recovery becomes impossible. This time, with all other results from model spinning trials, is given as the equivalent full-scale value, assuming the air density to be as at a standard height of 15 000ft. At the time of these tests, the threshold value for recovery after 10s full-scale was 10 units of applied moment, but this was raised to 15 units shortly afterwards.

As an example of successful test results, the summary of those given by Douglas for the F.9/40 are reproduced in Table 1 below.

<table>
<thead>
<tr>
<th>Weight</th>
<th>Flaps</th>
<th>Rudder</th>
<th>Elevators</th>
<th>Applied yawing moment for recovery in 10s</th>
<th>Applied yawing moment for recovery to become impossible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Up</td>
<td>Reversed</td>
<td>Down</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Normal</td>
<td>Down</td>
<td>Reversed</td>
<td>Down</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>Plus 10%</td>
<td>Up</td>
<td>Reversed</td>
<td>Down</td>
<td>17</td>
<td>18</td>
</tr>
</tbody>
</table>

Comparison of this summary with the full account shows that the values quoted by Douglas were slightly optimistic, but there was clearly a good margin over the contemporary threshold value of 10 units, and in fact the later one of 15 units would be exceeded. Hence it was indicated that proceeding to full-scale spinning trials with that aircraft would be justified.

9 Results for the E.28

The spinning trials for the early versions of the E.28 were made with models at 1/16 scale – that is, with a span of about 22in. When compared with the proposed threshold values, the pre-flight calculations of the yawing moment and unshielded rudder volume were only marginal, with those for the single fin layouts being slightly better than those with twin fins. The report states, somewhat cautiously, that these comparisons gave ‘no special grounds for expecting bad characteristics on any version’ at full scale. This was perhaps because in the RAE report (Reference 10) the thresholds from model tests had been found to be somewhat lower than for those at full scale, just one of a variety of ‘scale effects’ in wind tunnel testing, often attributed to the difference in Reynolds number.

Table 2 gives the limiting values of the applied pro-spin moment beyond which recovery was no longer possible for the E28 models. These are the average of results for spins in both
directions, with the elevators in the position found to be the most favourable. An estimated value had been included for the ‘long jet, single fin’ variant, as this was not tested in this series.

Table 2  Spinning model recovery limits for the Gloster E.28/39
probably early Spring 1940

<table>
<thead>
<tr>
<th>Variant</th>
<th>Long jet, single fin</th>
<th>Short jet, single fin</th>
<th>Long jet, twin fin</th>
<th>Short jet, twin fin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied yawing moment</td>
<td>10 ½ (est)</td>
<td>9 ½</td>
<td>14</td>
<td>13</td>
</tr>
</tbody>
</table>

By this measure, the twin fin designs show up better. At the time of the tests, the threshold value for recovery within 10s full-scale was 10 units, so that the single fin designs were at best marginal, but shortly afterwards, the threshold was raised to 15 units, which would have rendered the results unsatisfactory for all layouts.

Some further tests were made with the models fitted with an internal flywheel, given the correct direction of rotation and having the appropriately scaled value of angular momentum to represent the engine. This was a reasonable development, since, as far as was known at the time, the E.28 was to be the first aircraft powered by a turbine engine. In the idling condition, the margin was found to be changed by about 1½ units, being favourable when roll in the spin was opposite to the direction of rotation of the engine, but unfavourable in the other direction. This effect was raised only to about 2 units when the engine was represented at full speed, no doubt reflecting its small speed range. However, it is reported that in practice this would be countered by the moment then needed to provide the (Coriolis) acceleration of the mass of air flowing through the engine. This effect seems to have been recognised for the first time only in the report of May 1940\(^{10}\), so it is probable that this is the first instance of it being evaluated in a spinning tunnel test.

Following the spinning tests, the report records only that ‘As both tail versions appear to be unsatisfactory, the spinning requirement was waived’. The use of ‘as’ here is curious, but the connection indicates that the deletion of the relevant clause from the Specification for the E.28 had been made with full realisation that there would be some risk with the spinning behaviour. The date of the deletion of the spinning clause would require that the tests had been done quite early in 1940, though it remains possible that the reference to waiving the full-scale spinning requirement was an addition made with hindsight when the report was written up in 1944.

10  Factors affecting the result

There are reasons for expecting that the configuration of the E.28 would lead to more than usual uncertainty in estimating its spin recovery characteristics. These had been highlighted in the previous study, in relation to the requirements for ensuring directional stability, in which the same geometric factors enter\(^{(1)}\). The power plant is now located centrally in the fuselage, instead of at the front as in contemporary fighter aircraft with piston engines. Then its centre of gravity was located further aft, so that a greater proportion of the lateral area lay forward of the CG. When the fuselage is yawed, the destabilising effect of this forward area would make it
more difficult to obtain a sufficient value of the damping coefficient. Further, the large diameter of the engine, and the need to accommodate the air intake and exhaust duct, caused the fuselage to be relatively deeper than those of the types on which the standards had been based. On the other hand, at the rear, the presence of the jet pipe would mean that the fuselage could not be tapered as in the manner of contemporary fighter aircraft. All this would be likely to cause different patterns of the airflow over the fuselage in the vicinity of the empennage, especially when the aircraft was descending steeply with substantial angles of pitch and yaw.

Carter had perhaps anticipated these effects. In the final design he located the fin of the E.28 far forward on the tailplane, with its rudder post some way ahead of the leading edge, which would place all of the fin and most of the rudder in an unshielded position according to the method of calculation of the spin coefficients. Also, the rudder was made unusually large, having twice the area of the fixed part of the fin. Even so, a tail parachute had been provided, located in a small compartment behind the base of the fin, presumably as a further safeguard if a spin should occur (2). Carter was evidently persuaded of the value of this forward-fin arrangement, as he used it again later in his design for the single-jet E.1/44.

Interpretation of the available information is hampered by the known test results being only for the earlier forms of the aircraft, and not including the long jet, single-fin arrangement that was finally adopted. Without results for the E.28 as built, all that can be done now to throw further light on the position is to calculate the two spinning coefficients for this form, for comparison with those given for the variants that were tested. This can be done using the proportions of the final airframe, as reproduced from the original Gloster drawings (2). To make the comparison fully, however, it is necessary also to have the values of the moments of inertia about the yaw and roll axes. These cannot be calculated without detailed information on the distribution of the mass, so the values used here are those for the short jet single-fin arrangement cited in the spinning tunnel report, the only source known to the writer at this time. The values required, for calculation of the inertia difference coefficient are then

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moment of inertia, yaw axis</td>
<td>C = 77 970 lb ft²</td>
</tr>
<tr>
<td>Moment of inertia, roll axis</td>
<td>A = 28 200 lb ft²</td>
</tr>
<tr>
<td>Air density, 15 000ft</td>
<td>ρ = 0.0482 lb/ft³</td>
</tr>
<tr>
<td>Wing area, gross</td>
<td>S = 146.5 ft²</td>
</tr>
<tr>
<td>Span</td>
<td>b = 29 ft</td>
</tr>
</tbody>
</table>

These give the value of the inertia difference coefficient for that variant to be 0.288 (0.287 in Reference 8).

Newly-calculated values of the other coefficients are compared in Table 3 with those from the spinning trials (8) and the threshold values as indicated by the RAE report of 1940 (10).
Table 3: Coefficients related to spinning for variants of the Gloster E.28/39

<table>
<thead>
<tr>
<th>Case</th>
<th>Yaw damping coefficient</th>
<th>Unshielded rudder volume coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short jet single fin (reference 8)</td>
<td>0.0416</td>
<td>0.0206</td>
</tr>
<tr>
<td>Short jet single fin (this study)</td>
<td>0.0408</td>
<td>0.0160</td>
</tr>
<tr>
<td>E.28 as built (this study, areas aft of cg only)</td>
<td>0.0461</td>
<td>0.0165</td>
</tr>
<tr>
<td>E.28 as built (full length)</td>
<td>0.0387</td>
<td>0.0165</td>
</tr>
<tr>
<td>Threshold value (reference 10)</td>
<td>0.0431</td>
<td>0.0139</td>
</tr>
</tbody>
</table>

Fair agreement between the values of the first and second cases confirms that the practice of basing the damping coefficient on the area aft of the CG had been followed in the calculations of Reference 8. The value for the third case is increased by 13% by the additional lateral area of the rear fuselage when the long jet arrangement is introduced. On the other hand, the fourth case shows that the coefficient is reduced significantly for the actual E.28, when the part of the fuselage ahead of the CG is included in the calculation (for this case, about a quarter of the fuselage length is ahead of the CG).

Values of the rudder volume coefficient calculated for this study are significantly smaller than that given for case 1 in Reference 8. This might be due to somewhat different assumptions about the area shielded by the tailplane used in the two cases. For the calculations of this study, those of Reference 10 apply.

Comparison of the second and last cases shows the yaw damping of the short jet arrangement to be slightly below the relevant threshold, while the rudder volume would exceed the corresponding one comfortably. But when the values for the E.28 as built are compared, including the destabilisation by the nose section, it is indicated that the shortfall in the damping is about 10%, while the margin in the rudder volume is about 19%. The implication is that the aircraft might fall into a spinning condition if flown in a manner likely to promote it, but that the excess rudder power available should make recovery more likely than not. While somewhat more damping would have been desirable, the predicted risk of serious trouble would not seem to have been high, especially given the provision of the tail parachute as an extra safeguard. It is these results that were the more likely to have led to deletion of the requirement for full-scale spinning trials from the Specification.

11 Experience in flight

The most common occurrence leading to a spin was a stall in which one wing dropped appreciably, leading the aircraft into a spiral dive while stalled. No instances of this are recorded for the E.28. The only time that manoeuvres with a potential to induce spinning were undertaken was in July 1943 \(^{11}\). On this occasion, Sqn Ldr Charles McClure took the second prototype W4046 through loops, bunts, barrel rolls and a stall turn. When emerging from the latter, an aircraft is effectively falling, usually with significant side-slip, and if in the recovery the wing becomes stalled, a spin can be induced, especially if there is any rudder deflection. In
this case, the rudder had become locked hard over, and McClure recalls feeling that the E.28 had been about to spin, though he did manage to make a recovery without that developing.

When at Farnborough, W4046 was flown mainly by Sqn Ldr Douglas Davie, CO of the Turbine Flight, who reported feeling that the aircraft had insufficient directional stability at higher speeds. This was not experienced with the identical W4041, and despite much effort, the cause of the difference was not found. But in preparation for participation in high-speed diving trials, W4041 was fitted with additional finlets outboard of the elevators on the tailplane, increasing the fin/rudder area by about 20%. The increase in lateral area provided by these would also be expected to decrease the propensity to enter a spin. In the available illustrations of the E.28, the finlets are too small for the size and shape to be determined accurately. Calculations given here are based on scaling from an enlargement of the 3-view drawing given by Hygate (12), reproduced in Figure 6. These indicate that the effect of adding the finlets would be to raise the damping coefficient to 0.0423. This is now only slightly below the threshold value, and with a fair margin of unshielded rudder volume, the possibility of trouble from spinning would not be rated very highly thereafter.

![Figure 6](image)

**Figure 6** Auxiliary finlets fitted to the Gloster E.28/39 W4041 (Reference 12)

13 **Postscript : A twin-fin E.28**

Although it is indicated that a twin-finned variant of the E.28 remained under consideration during the Spring of 1940, no documentary evidence has yet come to light that would show the actual arrangement that was being worked on. The illustrations of the spinning tunnel models show them to be very early designs, with an empennage similar to that of the F.9/37, shown in Figure 2. However, as it is known that the Gloster Boosted Fighter was schemed in January 1940, it seems that this more recent design would be more likely to form the basis for the empennage of a twin-finned E.28. Prepared on this assumption for the present paper, the
sketch of Figure 7 would probably be the nearest representation of it that could now be contrived. If the twin-finned variant had been the one chosen to proceed, it seems from this that its appearance would have been no less striking than that of the historic E.28 that was actually built and flown.

Figure 7  Impression of a possible Gloster E.28/39 with twin-finned empennage scaled from the design for the Gloster Boosted Fighter (Reference 4) – after P Moss (Reference 2)

12  Conclusions

From newly-located material the following is concluded :

- an earlier reference to full-scale spinning trials having been made with the Gloster E.28/39 was mistaken. This was due to information about another aircraft being wrongly included in the archived file for the E.28.

- a newly-located report on spinning-tunnel tests with several models of the E.28 confirm that a version with twin fins continued to be an option for some way into the design process. A probable arrangement of that is presented.

- the model tests showed that the spinning characteristics of the aircraft as built were marginal, when compared with the threshold values laid down at the time. This would be expected to follow from the fuselage being relatively deeper than those of contemporary fighter types, and having a larger proportion of the lateral area forward of the CG.

- the effects of these new factors would tend to be countered by the forward placement of the fin relative to the tailplane and the provision of a tail parachute, indicating that they had been recognised and acted upon.
Comparing calculated values with the thresholds of 1940 shows that the yaw damping was lower than desirable, but that ample rudder power was provided. The decision to delete the requirement for full-scale spinning trials from the final Specification indicates that the evidence was considered sufficient to conclude that the risk of trouble from spinning would not be high. There is no record of a spin having been experienced with either of the two machines when flown.

Acknowledgement

Assistance by the late Dr Geoffrey Rowlands and Mr John Binge of the Farnborough Air Sciences Trust (FAST) is gratefully acknowledged.

References

7. Model spinning tests of the Gloster Interceptor. RAE Report BA1636, October 1940. FAST Museum, Farnborough, UK
The author

Brian Brinkworth read Mechanical Engineering at Bristol University. He worked first on defence research at the Royal Aircraft Establishment Farnborough during the 1950s. There, he was assigned part-time to be Secretary of the Engineering Physics Sub-Committee of the Aeronautical Research Council (ARC), and after moving into Academia in 1960, he was appointed an Independent Member and later Chairman of several ARC Committees and served on the Council itself. Thereafter he was appointed to committees of the Aerospace Technology Board.

At Cardiff University he was Professor of Energy Studies, Head of Department and Dean of the Faculty of Engineering. For work on the evaluation of new energy sources he was awarded the James Watt Gold Medal of the Institution of Civil Engineers. In 1990 he was President of the Institute of Energy and elected Fellow of the Royal Academy of Engineering in 1993.

Since retiring, he has pursued an interest in the history of aviation, contributing papers to the journals of the RAeS, which he joined in 1959. He holds a Private Pilot’s Licence.

Correspondence

In preparation for publication, this paper was offered for review to Captain Eric Brown, MBE, OBE, CBE, DSC, AFC, KCVSA, MA, PhD, Hon FRAeS, RN. The following letter dated 19 July 2012 from Captain Brown is reproduced with his permission.

"I was very involved with the Gloster E.28/39 and its stable mate the Meteor. I had quite a few discussions with Dr. Douglas on both these aircraft. I had expected to be asked to spin the E.28, but he had concerns that the jet engine would be snuffed out in a spin, and at that stage relighting was uncertain. In spite of this, I was somewhat surprised as the aircraft was easy to land deadstick and we had plenty of airfields around Farnborough. The same situation applied to the Meteor to a lesser degree.

The other difficult problem which plagued the early jets was directional snaking. This directional instability was created by the removal of the propeller(s) present in reciprocating engines, and its effect was to ruin gun sighting. Much effort was expended by our boffins in trying to cure this, but the answer was eventually found by one of our captured German scientists, Dr. Karl Doetsch, who developed a rudder autopilot. In relation to this I was always led to believe that the finlets fitted at RAE to the surviving E.28/39 was specifically to cure or at least alleviate directional snaking.

I hope these comments are of some help."
Dear David,

I was very involved with the Gloster E.28/39 and its development, the Meteor. I had quite a few discussions with Dr. Douglas on both these aircraft. I had expected to be asked to fly the E.28, but he had concerns that the jet engine would be snuffed out in a spin, and at that stage re-lighting was uncertain. In spite of this, I was somewhat surprised, because the aircraft was easy to land deadstick and we had plenty of suitable airfields around Fairborough. The same situation applied to the Meteor to a lesser degree.

The other difficult problem which plagued the early jets was directional smoking. This directional instability was created by the removal of the propeller(s) present in reciprocating engines, and its effect was to ruin gun sighting. The effort was expended by our engineers in trying to cure this, but the answer was eventually found by one of our re-captured German scientists, Dr. Karl Doetsch, who developed a rudimentary autopilot. In relation to this I was always led to believe that the canards fitted at RAF Leuchars in the following E.28/39 was specifically to cure or at least alleviate directional smoking.

I hope these comments are of some help.

Yours sincerely,

Winkle