On the aerodynamics of the Miles Libellula tandem-wing aircraft concept, 1941 – 1947

B J Brinkworth
Waterlooville, Hants, UK

Abstract

Distinct advantages for the tandem-wing configuration were envisaged by George Miles, initially for carrier-borne aircraft, but subsequently proposed for a wider range of applications, with the generic name of Libellula. Receiving no support from Service and Ministry sources, he designed the M.35, a single-engined 'flying mock-up', loosely based on a naval fighter, to demonstrate the concept at a good scale. Built at Phillips & Powis Aircraft Ltd (later Miles Aircraft Ltd) and flown by him at Woodley aerodrome near Reading, it proved difficult to get airborne and seriously unstable in flight. Persevering, he produced the M.39B, a twin-engined 5/8th scale version of a proposed high-speed bomber of the Libellula layout, which flew successfully and was tested at the Royal Aircraft Establishment, Farnborough.

No serious analysis was made at the time or since of the failures of the first and performance of the second of these examples of the type. Using only very simple procedures, it is shown that the problems of the M.35 were due to its centre of gravity having been placed too far aft, due to neglect of downwash effects. When this was corrected on the M.39B, it proved to be stable and controllable in all phases of flight, but it did not display some of the main advantages claimed for the type. It is shown that this was intrinsic to the layout and could have been foreseen from information available at the time.

1 Introduction
1.1 The concept

Libellulae are species of large dragonflies, characterised by having two pairs of wings of equal size, the front pair and rear pair being mounted on the thorax a short distance apart. In darting flight, they show remarkable speed and agility when catching their prey of smaller flying insects.

This name was adopted for a series of aircraft by George H Miles, who in 1941 had recently been designated Technical Director and Chief Designer of Philips & Powis Aircraft Ltd (later Miles Aircraft Ltd) of Woodley near Reading. He had expected significant advantages for the tandem-wing configuration, and began to consider possible applications for designs with this layout. In the tandem arrangement two wings of similar size were used instead of the more usual form in which there is a main wing and a much smaller tailplane to act as stabiliser. Dragonfly naturally came first to mind in this connection. But this name had already been used for the de Havilland DH90 of 1936, a small passenger aircraft of conventional biplane form. As that was still in service, the name could not reasonably be used, and Miles turned to Libellula when projects with this configuration began to materialise. It is not likely that he
was aware that Louis Blériot's model VI aircraft of 1907, in which he made his first successful flights, had tandem wings and had been called Libellule.

George Miles was as buoyant as his brother Frederick (always known as 'FG' and then Chairman and Managing Director) who was shortly to gain control of the firm, to which they later gave their name. Recognised for the exceptional range of his imagination and determination in following up potential applications, FG had gathered a small but young and enthusiastic team who were 'up for any challenge and not scared of making mistakes' \(^{(1)}\). Both brothers had made the first flights of the firm's new designs and variants of others, and during the war together with Don Brown they all became Ministry of Aircraft Production (MAP) approved test pilots. It is reported that George began thinking about the possibilities of aircraft with tandem wings after seeing a Lysander army cooperation aircraft, which had been modified by the makers Westland Aircraft Ltd to carry a powered gun turret at the rear of the fuselage \(^{(2)}\). This had required fitting a greatly enlarged tailplane to counter the rearward move of the centre of gravity (cg) due to the additional weight. That layout is sometimes identified with Maurice Delanne, who had designed aircraft of a similar form in France before WW2 and later in the US. Though not strictly a tandem-wing arrangement, as the tailplane was not required to be as large as a second wing, it was the kind of initiative that would intrigue George and arouse his imagination in that direction. He was later to insist that his designs were neither of that form, nor canards – those had only one main lifting surface, with a forward stabiliser acting as if a tailplane had been moved to that position.

Under the direction of the Miles brothers, Phillips & Powis Aircraft and its successor Miles Aircraft seemed able to work up submissions for every specification issued by the Air Ministry, for whatever technical application, though the advanced ideas in them were rarely appreciated at the time. They also offered proposals for meeting operational needs that had not yet given rise to specifications, and among these were applications involving the advantages they now expected from tandem wings. The first of those - in the area of carrier-borne operations - was elaborated in a Phillips & Powis brochure of March 1942, with the bold title 'A New Basic Design' in which appears the finely-detailed illustration of a representative naval fighter with this layout shown in Figure 1 \(^{(3)}\). Numerous benefits were envisaged over existing types for this duty, of which the most significant in the present context were that with the engine at the rear and the cockpit placed near the nose, the pilot could be given an open field of view throughout the approach to a deck landing. Existing types had been adaptations of land-based fighter aircraft, from which the forward view was obscured in the nose-up attitude of the final stages, so that guiding signals could not be seen at the most critical moments. There had been numerous accidents and aborted landings with these adapted types.

There would also be no smearing of oil from the engine and consequent accumulation of dirt to obscure the windscreen as was usual in single-engined aircraft. Both wings of the tandem layout would provide lift, and with a similar total lifting area would have a significantly smaller span than a conventional type, so that the aircraft could be fitted into the deck-lift without requiring the complication and weight of wing-folding mechanisms. Also having shorter fuselages, more aircraft of this type could be stowed in a given hangar space and be more easily and safely moved around there. If the two wings were mounted at different
levels, alternate pairs of aircraft could be positioned with wings overlapping, leaving a clear gangway down the centre.

![Figure 1](image.png)

**Figure 1** The tandem-wing concept applied to a projected naval fighter

The Miles Aircraft Collection

There would be no loss of operational effectiveness, but rather improvements. High-lift devices could now be mounted on both wings, providing an ability to change the distribution of the overall lift between them that would allow a wider range of cg position to be obtained. This would provide new opportunities for the carriage and release of stores in offensive operations. The smaller wing loading and power loading would give relatively lower overall induced drag and higher rate of climb. The shorter wings and fuselage would give relatively lower structure weight and moments of inertia, giving superior turning performance during interceptions, with reduced vulnerability and enhanced agility in close combat.

Although the tandem-wing format had been used in the early days of manned flight, it was not much favoured subsequently, having largely given way to the layout with a tailplane as stabiliser. And so when the Libellula concept was proposed by Miles decades later, it effectively offered a fresh contribution to the aeronautical scene as indicated by the novel appearance of the projected naval fighter in Figure 1.

Some specific examples of their approach to this layout and the validity of the claims made for it are considered here. For a relatively small company, Phillips and Powis, and especially after becoming Miles Aircraft in 1943, showed such a remarkable fertility of ideas that there is also historical interest in trying to recapture the circumstances in which the layout came to be favoured there, in relation to the state of knowledge of aerodynamics at the time.
1.2 Preamble

Although the company name was changed from Phillips & Powis Aircraft Ltd to Miles Aircraft Ltd on 5th October 1943, all its aircraft and projects had been known as Miles types and given corresponding numbers from the M.2 Hawk of 1933. In his definitive history of the marque, Peter Amos gives comprehensive descriptions of the principal Libellula tandem wing projects, with works type designations M.35, M.39, M.42, M43 and M.63\(^2,4\).

Some duplication of this cannot be avoided here, though the aim is to give only sufficient detail to support a narrative that concentrates on aerodynamic aspects of the design in its historical context. The unexpected behaviour in flight of the first aircraft in the series seems never to have been analysed previously, so that forms a key item in the review.

This study has been greatly facilitated by reference to the papers of George Miles and of the company's Chief Aerodynamicist Dennis Bancroft, which have not been accessible hitherto (see Acknowledgments at the end of this account). It will be convenient in what follows to refer to the Miles brothers as 'FG' and 'George', as they were invariably called at the time, with 'Miles Aircraft' reserved for the company as a whole or where no particular attribution can be made.

For references to the development of procedures in aerodynamics, the nomenclature adopted by international agreement is used (for example by substituting the definition and symbol \(C_L\) for lift coefficient in place of \(k_L\), which had been current in Britain up to the 1930s). But in quotations from the contemporary literature, and associated analysis, weights and other forces are kept in pounds (lb) and speed in miles per hour (mph), with shorter lengths in feet (ft) and inches (in), units which are still generally understood. And some former practices are retained, such as reserving the term 'incidence' (rather than angle-of-attack) for the angle with which a lifting surface is presented to the free-stream, and 'setting' or 'rigging' angle (rather than incidence) for the part of that due to its inclination to the fuselage axis or thrust line.

References to the Miles 'Black Books' are to collections of papers in hard-back files of that colour, containing data on Miles aircraft and outlines of procedures at the company relevant to aeronautical design.

Some additional clarifications, usually in sections involving theoretical development, are given in the text between square brackets.

2 Proof of concept

2.1 Frustration

Many exhibits and records relating to Phillips & Powis and Miles Aircraft are held in the Museum of Berkshire Aviation (located at Woodley in one of the former Miles Aircraft Technical School 'Robins' hangars from the firm's Davis Farm site). Amos reports that a donation of papers in 2012 included a detailed account by Don Brown, later personal assistant to George, of the interactions between Miles and Ministry representatives on
proposals for developing the tandem wing concept. At first their ideas were received with interest and encouragement by naval staff, who were already feeling that a fresh approach would be needed to the design of aircraft for carrier-borne operations. But it is clear that there were conflicting opinions about the possibilities of the configuration at the Admiralty, and no less at the Air Ministry and Ministry of Aircraft Production (MAP), where they also came to be discussed. This resulted in frustrating vacillation and delays as matters were referred from one recipient to another, or put on hold for lengthy periods, with no firm agreements being reached on moving the idea forward.

This would not have been helped by a lack of firm evidence on the characteristics of tandem-wing machines that Miles could offer in support of their expectations. At this time they could not gather information through model testing on site, though they had designed and were building their own wind tunnel there (with a 5ft 9in x 4ft 3in working section, giving tunnel speeds up to 312ft/s \(^5\)), a half-size replica of one at Farnborough. Until that could be completed, the firm had to rely on tunnel tests that were arranged on various occasions at the Royal Aircraft Establishment (RAE), the National Physical Laboratory (NPL) and Imperial College in London. With no priority to be cited, there would be further delays in securing time on these scarce facilities. That was not acceptable to George, so he decided that the most convincing way of showing the advances envisaged for the concept would be to build a small experimental tandem wing aircraft with which they could be quickly demonstrated at a good scale in flight. This was also in accordance with a guiding principle once stated by FG that 'Full scale tests should precede, run parallel with, and follow all other forms of research'. He had recently completed a similar project to build a 'flying scale model' of a blended-wing aircraft, a configuration about which he had begun thinking in 1936. That had generated a typically far-seeing project for a long-range civil aircraft, known simply as 'X'. Although a bomber version had also been proposed, there was no room for official consideration of the project in the desperate urgencies of the late 1930s. But FG had continued to work on one aspect of the proposal, a representative experimental aircraft, which became the M.30 'X' Minor. The final design, remitted to Frank Robertson, resulted in the elegant machine shown in Figure 2, first flown in February 1942. Though having the novel blended wing/fuselage junction, the layout was otherwise conventional, with an ordinary tailplane as stabiliser.

With George's decision to proceed, Miles would thus be committed to building and flight-testing two experimental aircraft of unorthodox layout – respectively with the blended-wing and tandem-wing configurations. But at this time, Britain had been fully engaged in 'total war' for more than two years, and there were heavy pressures on human and material resources of every kind. The MAP controlled all aspects of aircraft procurement, and unless a contract for an approved project had been issued, permission would not be given for manpower to be assigned, materials obtained for construction, or components and equipment ordered. That still applied even for a private venture where the cost was to be borne entirely by the company concerned. Nevertheless, Miles somehow contrived to complete these projects without formal contracts, in both cases to conclude with testing in flight. This was probably done by using mostly materials and components that they already had in store, or could be recovered from aircraft that had come in for repair but were awaiting disposal as no longer fit for service.
Don Brown wrote later that when the MAP learned of the construction of the tandem-wing model the firm had received a stern rebuke for unauthorised use of resources\(^6\). But in the Woodley Museum document mentioned above he had reported to the contrary that despite its unofficial nature, the project had been well known to them, and that visitors came from several Ministry and service branches and establishments to view progress on it at various stages.

The inconsistency of Brown's reporting is puzzling, but Amos concluded that his later account is the more reliable\(^2\). This is confirmed by documents from the time now made available from George's archives, which are replete with specific dates of meetings, details of visits and names of participants. It is possible that the MAP’s criticism that he recalled had actually been of the previous (M.30 blended-wing) project, for which the Ministry had no interest at all. And further, far from working secretly on the tandem-wing concept, Miles was actively seeking contract support for it.

An outline layout for such a machine was quickly formulated by George and remitted for detail design and construction at an adjunct of the Miles Aircraft factory at Liverpool Road on the outskirts of Reading. Though this was much smaller than the main plant, it had facilities for design and manufacture and its output of novel experimental prototypes was quite significant for the company. George held the overall responsibility for Liverpool Road,
where he was mostly based. Brown describes the aircraft as having been 'designed by Ray Bournon under George Miles' direction'. Bournon had joined P&P in the mid-1930s and was an experienced engineering designer, now the Chief Stressman and Chief Draughtsman at the outstation. Together, they had already designed and flown one new Miles aircraft, and after this tandem-wing machine three other prototypes would follow during the war. Other types were designed at Liverpool Road, to be built later at Woodley (2, 4). It would seem that aspects such as the basic form and dimensions determined by operational considerations would have been George's contribution, then the structural and mechanical design would have been largely down to Bournon. The experimental tandem-wing aircraft, of mainly wooden construction, was begun in February 1942. From its purpose it might have been called a 'demonstrator' today, to provide 'proof of concept', but at Miles it was considered to be a 'flying mock-up'.

2.2 The 'flying mock-up'

The aircraft was not called Libellula from the beginning, but having been given the Miles Aircraft type number M.35, it became recognised later as being the first practical realisation of the concept. It is shown in the outline GA drawing of Figure 3, with photographs of it on roll-out in Figure 4. Brown reported that the building had taken 7½ weeks, though George later gave the construction time as 6 weeks, out of an overall time from the decision to embark on the project of 12 weeks.

![Figure 3 General Arrangement drawing of the M.35, also showing modifications tried during wind-tunnel model trials (alternative front wing, rear wing tip extensions, enlarged rear wing centre-section) The Miles Aircraft Collection](image-url)
The arrangement can be seen to be similar to that of the representative carrier-borne aircraft of Figure 1. The front wing was above and behind the cockpit, giving the pilot the unobstructed view forward that had been emphasised. The rear wing was fitted low down on the fuselage, with outer sections swept back from a straight centre-section, giving the tip-mounted fins and rudders the maximum moment arm required for directional stability and control, while retaining a short fuselage. It was a small aircraft, with both wings having the same span, of about 20ft, though the front one had a smaller area and higher aspect ratio than the rear.

Figure 4  Two views of the M.35 Libellula 'flying mock-up' on roll-out, April 1942
The Miles Aircraft Collection
Flaps were fitted to both wings, with those on the front wing in the unusual outboard position, with the elevators inboard. The arrangement was more conventional on the rear wing, with the ailerons outboard. The flaps were partly on the parallel centre-section of the wing, but continued on the outer, swept-back sections.

The engine of the M.35 was an air-cooled DH Gipsy Major of 140hp rating, an inverted type used in the company's famous Magister trainer. It had first been intended that the pusher propeller would be 4-bladed, with a small diameter of 5.1ft (actually assembled from two 2-bladed ones joined in tandem). A similar one had been used in tractor form on an earlier type with a tricycle undercarriage and had performed well, but the pusher version for the M.35 was found to be badly affected when it was running in the wake of the dumpy fuselage. This was replaced by a 6.23ft diameter 2-bladed pusher propeller, also of the company's own design, as recorded by the Chief Aerodynamicist, Dennis Bancroft (7). A small rear wheel was fitted later, normally clear of the ground, but in a position that would prevent the aircraft tipping back far enough for the tips of the two-bladed propeller to strike the ground.

An example of the re-use of existing components on this aircraft is that of the main undercarriage, which was from a Magister. In the tricycle arrangement of the M.35, the legs were too long for the purpose, but these were not modified, and can be seen projecting for some distance through the top surface of the rear wing, initially fully exposed, but later covered by streamlined fairings. The rudders of the two fins can also be identified as being from the Magister, and it seems probable that many other components and fittings had been recycled from that and existing and former Miles aircraft.

2.3 Initial experience in flight

The M.35 was prepared for flight with 'B' registration marking U 0235. On 18 April 1942 it was brought to Woodley and taxying trials began on the airfield there that day. But when hops were attempted, the aircraft could not be induced to leave the ground, even after the longest runs that could be made on the airfield. A suggestion by Don Brown was then tried, in which runs were started in an adjacent field to obtain some initial momentum, but this required the path to include an L-turn and was still not successful (2, 6). Records show that more than two hours of taxying time was logged in these attempts (8).

Then when a run was being made over as great a distance as possible, and the engine quickly throttled back because field space was running out, it was found that the aircraft briefly left the ground. After this had been repeated, it suggested to George a way of making the first flight, by opening up the engine again as soon as it was airborne. A seemingly rash decision, even for an experienced test pilot, but this was probably felt to be the only way then open that might allow some feedback to be gained from flight with the new configuration, for which so much had been hoped. This was tried on 1 May, when George took the M.35 into the air for the first time. But he found immediately that the aircraft was unbalanced and seriously unstable longitudinally. It was seen to be taken forward at low level (Brown said at only 20ft) and then brought round slowly in a wide circuit and landed, fortunately safely. Though it seems that George made little comment at the time, the first circuit could hardly have been
other than a life-threatening experience, requiring sound instincts and quick reactions to balance the aircraft and prevent the instability from becoming divergent.

Inevitably, the circumstances had been noted in the works, and the cartoon shown in Figure 5 was duly sent to George in a card from the Drawing Office (9). Though he had been the pilot, there is enough resemblance to suggest that he is depicted there as the figure pulling the tow-rope. The tubbier one hastening behind is probably Bancroft, shown carrying an exaggerated version of the 20in slide-rule that was then practically a mark of seniority among engineers. The blended-wing M.30 sailing serenely overhead does little to sweeten the pill. It is perhaps a reflection of the corporate spirit fostered under the Miles leadership that such a serious incident could be represented jocularly without repercussions.

Figure 5  Cartoon depicting the attempts to get the M.35 airborne - via J Pratt
It is known that P&P assistant test pilot Hugh Kennedy also took part in the taxying trials and in subsequent flights. And elsewhere in the Miles archives, there is a reference to one other pilot, who is not named. Presumably, all had to use the same technique of temporarily throttling back to get airborne, as in a report compiled later by Bancroft on the experiences at Miles with the tandem-wing configuration no references are made to modifications to the aircraft, beyond the fitting of the precautionary rear wheel. Brown mentioned only that some limited ballasting had been done. George reported that overheating of the engine had been another distraction on the first flight, so a large air scoop was also mounted below the starboard rear fuselage, to improve the cooling.

In his report, Bancroft's account is quite at odds with Brown's, claiming that 'The aircraft flew successfully the first time; it took off, climbed to about 200ft, circled the aerodrome and landed'. He then reached the inexplicable conclusion that 'The aircraft behaved quite well, with the exception that it was completely longitudinally unstable under all conditions of flight'. Perhaps he had not witnessed the flight himself and had been teased into accepting a typically nonchalant account by George. As to not appreciating the implications of being in charge of an unstable aircraft, he was the only one among the senior staff at Miles Aircraft never to engage in flying himself.

The bulk of Bancroft's report was a purely factual record, which did not include any analysis of the possible causes of this potentially disastrous behaviour. There seems never to have been any serious investigation that might account for it, then or since. And so that is a main item in what follows, made with due regard to the circumstances in which it occurred. As a background to this, a brief account is given of personnel principally involved and their respective contributions to the project, with a review of relevant design practices and of the knowledge of longitudinal stability as it stood at the time.

3 Background to the design decisions
3.1 Personnel and practice

Before joining the company in 1939, initially as a stressman, Bancroft had newly graduated in aeronautical engineering at the then Northampton Polytechnic Institute in Finsbury, central London. The course included three periods of practical experience in industry, two of which were at Handley Page Ltd and the other at Fairey Aviation Ltd. He might also have attended presentations from Frederick Handley Page himself, who is known to have been an occasional visiting lecturer at the Institute. Bancroft duly became an Associate Fellow (now Member) of the Royal Aeronautical Society, and two bound volumes of its Proceedings from the late 1930s were found among his books. There are no reports of the extent, if any, of his involvement in the outline design of the M.35, but as he had become Chief Aerodynamicist by then, it seems unlikely that it had not been discussed with him at some point.

George Miles had joined Phillips & Powis in 1936, though he had been involved with FG in other enterprises since 1928. Nothing is known of formal training on the part of either, but (initially with an active input from FG's wife 'Blossom') the firm had produced a notable sequence of successful aircraft for touring and air racing, then a sport with a very popular
following. Further, they supplied several experimental aircraft ordered by RAE, including a version of their Hawk design, provided with a set of interchangeable wings for flight tests with different taper ratios and thickness ratios (up to 30%). Miles also carried out research for RAE under contract, on such topics as high-lift devices and boundary-layer control by suction\(^{(11)}\). The firm had probably received formal Air Ministry design approval from 1936, when the first aircraft from it were ordered for the RAF.

### 3.2 Observations concerning the basic outline

It would seem then that those involved in design at Miles should have been thoroughly familiar with the routine methods then in use for ensuring balance, trim and longitudinal stability in flight. Much can be illustrated about the requirements for these by considering the simplest case represented by the skeletal airframe in Figure 6, with the weight \(W\) acting at the centre of gravity \(G\), and lift forces from the two surfaces \(L_1\) and \(L_2\), with their respective aerodynamic centres separated by the distance \(l\). Different sources have given various values for primary dimensions of the M.35 \(^{(6,12)}\), so those used here are taken from a 1/12th scale Phillips & Powis drawing dated 9 March 1942, around the time of the start of construction \(^{(13)}\). For example, the values obtained for the gross plan areas of the front and rear wings were 45 and 87 ft\(^2\) respectively, and that for \(l\) was 7.5 ft.

![Figure 6](image)

Figure 6  The forces and dimensions principally involved in the balance of an aircraft

It is apparent that the areas of the front and rear wings are in a ratio close to 1:2. In later designs in the Libellula series and in numerous sketches, the front wing is invariably smaller than the rear, though no case was presented by Miles to indicate that it should always be so.

The design position for \(G\) could not be found from any documents or drawings, until it was mentioned in a later report by Bancroft, on the preparation of models for wind-tunnel testing \(^{(10)}\). This gave \(x = 4.5\) ft.

a) Balance and trim. If the aircraft is in steady, straight and level flight, two basic equalities of forces and moments must be satisfied for equilibrium, namely that

\[
L_1 + L_2 = W
\]  

(1)
and \( L_1 x = L_2 (t - x) \) \hspace{1cm} (2)

from which \( L_1 = W(t - x) / t \) and \( L_2 = W x / t \) \hspace{1cm} (3)

For the dimensions given for the M.35, G was located at \( x / t = 0.6 \). This would be consistent with George's statement that the cg 'would lie roughly just aft of amidships, between the wings', though he gave no rationale for the choice of that position. It would give the lifts of the two wings as \( L_1 = 0.4 W \), and \( L_2 = 0.6 W \). Thus the larger load is carried by the larger rear wing. If their relative areas are taken into account the wing loading is greater for the front wing.

The position of G is determined by the distribution of mass in the aircraft. It would have an initial design location, but this is subject to change for various reasons, such as modification of the airframe, engines and equipment during the lifetime of the aircraft. Variation of the position also occurs in flight, through the consumption of fuel, release of stores, etc. The lift from the wings is similarly affected, and particularly important is the continual variation in flight, as the speed and attitude of the aircraft change. Some means of adjustment of the lift is needed so that the pilot can restore trim by bringing the overall centre of lift, the aerodynamic centre AC, into coincidence with G. In the conventional layout with a tailplane, this was usually done by biasing the median position of the elevators by a small amount via a trim lever or wheel. One of the benefits claimed for the tandem-wing layout was that flaps could be fitted to both wings, allowing much larger movements of G to be trimmed out.

b) Longitudinal dihedral for stability. The basic requirement for stability is that, if an aircraft encounters a disturbance in the air, it must respond in a way that opposes the effect of the disturbance.

A rule, dating from quite early days of flight, was that for longitudinal or pitch stability the 'setting' of the tailplane on the fuselage must be at a lower rigging angle to the thrust line than that of the wing. It was usual for their angles to differ by a degree or two. The chord lines of the lifting surfaces then formed a very shallow 'V', giving what was known as decalage or 'longitudinal dihedral'. The result of this action would be the same when the surfaces were two wings in tandem, as will be described below. The values of the rigging angles were not always recorded in the standard tables of data listed for Miles aircraft, but where they are given, the angle for the rear surface is always less than that for the front one, so there is little doubt that assigning these was a routine practice there (12).

For some previous comments by the writer quoted in Amos's history (2), the rigging angles for the M.35 wings had to be rough estimates made from drawings and photographs, as no other sources were available then, but it has now been established from previously-inaccessible Miles documents that those for the front and rear wings of the M.35 were actually only 2° and 1° respectively.

Now consider an aircraft having two lifting surfaces (these could be a wing and a tailplane or two tandem wings), with the setting of the rear surface lower than that of the front one. If the
aircraft is correctly trimmed for level flight the moments from the two surfaces are balanced about the centre of gravity of the aircraft, such that they are equal and of opposite signs.

Then suppose that the aircraft encounters the commonest kind of disturbance, a gust, in which the air about to be encountered ahead of it is rising or descending. On being reached, this will add a vertical component to the motion of the air relative to the aircraft, so that in level flight it approaches at an angle to the horizontal. If the disturbance is an upgust, this angle is then added equally to the existing incidence of both lifting surfaces. When the rear surface has the smaller setting, the proportional increase in its incidence from the gust, and of the resulting increase in lift, are greater than that for the front one. There is then a nett moment about the cg in the nose-down sense, opposing the response that an upgust would otherwise produce. And if the disturbance had been a downgust, the nett moment would again be in the opposing (now nose-up) sense.

Longitudinal dihedral was evident in the design of the blended-wing M.30. For that, the wing had been set at 1½° to the thrust line, but the tailplane could be adjusted on the ground between 0 and –4°, providing for uncertainty about the effects of the new shape at the wing junction. But its effects cannot provide more than a minimal contribution to stability. The attitude of an aircraft varies in different phases of flight, adding substantial angles to the incidences of wings and tailplanes, so that the addition of a given angle from a gust represents a smaller proportional change than when the base is just the rigging angles. By the 1940s aspects of stability and control in flight had assumed much greater importance, and improved procedures for obtaining these had already come into practice.

It would be expected that these and other considerations would be given particular attention when an unconventional layout was being considered. But neither George nor Bancroft seem to have looked for guidance in relevant material in the literature of the time. If they had done so, they could have found a paper that had shown that the tandem wing arrangement would not have had the aerodynamic advantages that George had expected. This was one by Hermann Glauert of the Aerodynamics Department at RAE, contributed as one of the Reports and Memoranda (R&Ms) of the Aeronautical Research Committee (ARC, later Council), dated 1922, but for some reason not published until 1925[14]. The R&Ms were available publicly through H M Stationery Office and were frequently cited in journals and technical magazines that were read quite widely in the industry.

It was well known that for any wing there is one angle of incidence at which its aerofoil section has the maximum value of the lift/drag ratio (L/D), where it is operating at its highest aerodynamic efficiency. One of the factors in the choice of an aircraft's wing loading would be to ensure that in its most common flight conditions, its L/D ratio would not be too far from the maximum. But Glauert pointed out that if there is longitudinal dihedral, both wings cannot be at that incidence at the same time, so at any attitude the overall L/D ratio for the pair would always be less than the maximum available for wings of that section. [The same applies to the conventional configuration, where the rear surface is the tailplane. But because it is generally much smaller than the wing, its contribution to the overall L/D ratio is of less consequence.] If the difference of incidence of the two wings is as small as a degree or two,
as for the longitudinal dihedral, the reduction in the L/D with tandem wings might not be expected to be serious, but Glauert showed that another factor would greatly enlarge it.

This he had illustrated with an example in which two tandem wings of identical area and span, with an aspect ratio of 6, were mounted in the same plane and separated by a distance equal to their semi-span. Both lift and drag forces were included in the analysis. The attitude of the system to the airstream was varied over a sufficient range to ensure that the condition of maximum L/D ratio had been included. In practice, this variation of attitude would occur as the speed varied over the range specified for the aircraft. That would usually change the trim, and in practice balance would be maintained by using some trimming device. In Glauert's example, this was assumed to be done by adjusting the setting of the rear wing as a whole, in the manner of an 'all-moving' tailplane.

The characteristics of the aerofoil section chosen for the wings in this example, if used in isolation, would have given a maximum L/D of 22, but when used in tandem, the maximum of the value for the combination came out to be about 15, a drop of around a third. This indicated that using the tandem-wing arrangement would always entail a significant fall in the highest aerodynamic efficiency attainable. The additional factor that had enlarged this effect was that of downwash. As this will feature prominently later, a brief outline of the state of knowledge of it at the time follows for further reference.

3.3 Downwash

Glauert's paper was one of many that he published on important developments in aerodynamics (15). In the 1920s he had visited the aeronautics department at the University of Göttingen (later the Kaiser Wilhelm Institute of Fluid Mechanics). There he had been particularly impressed by the simplicity and scope of a representation of Lanchester's circulation theory of lift generation that had been developed by Ludwig Prandtl and associates. This was known as the 'lifting line' theory.

In his consideration of the tandem-wing arrangements, Glauert had included the effects of the interaction of the patterns of air flow over the two wings. One of these is that the rear one is exposed to the downwash from the front one that results from the circulation accompanying the generation of lift there. In practical circumstances this downflow can diminish the incidence of the rear surface significantly. This was taken into account in textbooks of the time giving design calculations for balance and stability when the rear surface was a tailplane.

The simplest procedure for this used a method that had been current for a long time previously. This concluded that, as the lift of a surface is reacted on the air passing around it, this would cause a downward deflection of the airstream behind it by an angle $\varepsilon$ given approximately by

$$\varepsilon = \frac{2C_L}{\pi A} \text{ (radian measure) or about } 36.5 \frac{C_L}{A} \text{ (degrees)}$$

(4)

where $C_L$ and A are respectively the lift coefficient and aspect ratio of the surface. From this, $\varepsilon$ could be several degrees, thus having a significant effect on the incidence at the tailplane.
Equation (4) correctly identified $C_L/\pi A$ as the group of quantities that determine downwash, but the factor 2 arose from an estimate of the mass flow-rate of the air that was influenced when passing over a wing, for which there had been no good physical basis. However, it was found that equation (4) gave quite a good approximation for the downwash behind a wing at a distance about equal to the semi-span. The tailplane was often located in that area and this approximation remained in use.

The lifting line representation of circulation theory provided a more detailed description of the flow, of which the main features of concern here are that:

i) circulation causes both an upwash ahead of the wing and a downwash behind it

ii) ahead of the wing the upwash angle tends to zero at a distance, and behind the wing the downwash angle to a constant value somewhat smaller than that given by equation (4).

iii) the upwash and downwash angles also vary in the spanwise and vertical directions.

Glauert's statement was that for a tandem arrangement the mutual interference between the flows over the two wings 'takes the form of an important downwash in the neighbourhood of the rear wing and of a small, but by no means negligible, upwash in the neighbourhood of the front wing'. His R&M included some calculated values of these quantities. These were obtained from an early simplified representation of the circulating flow, but he later set out the principles and consequences of the theory more fully in his seminal book of 1926 on the aerodynamics of wings and propellers (16).

In addition to access to values for these angles in a practical case, it will be seen below that the first principles of longitudinal stability require an input of how they change with incidence. Except near the stall, $C_L$ varies linearly with the incidence $\alpha$, being given by the product $a\alpha$, where $a$ is the slope of the lift curve, so on differentiating equation (4), the rate of change has the constant value

$$dC/d\alpha = 2a/\pi A$$

With that figure 2 this is also a fair approximation for conventional configurations. It will be seen later that the values from equations (4) and (5) could reasonably be applied to the Libellula layouts also.

3.4 Upwash

For conventional aircraft the tailplane was too small for the upwash due to lift on it to have any significant effect on the flow over the wing ahead of it. And so it was not only neglected in calculations for that configuration, but was likely to slip the mind entirely. But for tandem wings it should be considered, as for two wings separated by a distance as in the M.35, the corresponding values for upwash in expressions like equations (4) and (5) would have a figure of about 0.4 in place of the 2 given for downwash. As in Glauert's example, this is 'by no means negligible'.

25
3.5 Static stability and the Neutral Point

For the M.35 in normal flight, trim was to be managed routinely by the elevators mounted inboard on the front wing. The flaps fitted on both wings were to be used at different settings to vary the distribution of lift between the wings, allowing a much wider range of G position to be utilised (3). There would however be a limit to the rearward limit of G arising from a requirement for stability, as seen next.

This had been mentioned by Glauert in his consideration of the tandem layout but was not emphasised (14). At the most basic level it can be illustrated by using again the simple model shown in Figure 6.

The distance between the lift centres of the wings is \( l \) and the centre of gravity G is located a distance \( x \) behind that of the front wing. The nett moment \( M \) of the lifts \( L_1 \) and \( L_2 \) about G is then

\[
M = xL_1 - (l - x)L_2
\]  

If the aircraft now encounters a disturbance in the air, say an upgust, this is perceived as an increase in the incidence \( \alpha \) to the airstream. The resulting increases in lift cause the overall moment \( M \) to change with \( \alpha \) at a rate

\[
dM/d\alpha = x d_1 - (l - x) d_2
\]  

where \( d_1 = dL_1/d\alpha \) and \( d_2 = dL_2/d\alpha \)

For stability, the overall moment must change in a sense to oppose the effect of the disturbance, so in the case of an upgust, the rate of change in equation (8) must have a negative sign, requiring that.

\[
x d_1 < (l - x) d_2
\]

When that is rearranged, it shows that for stability, G must be located such that

\[
x/l < d_2/(d_1 + d_2)
\]  

The values of the lifts \( L_1 \) and \( L_2 \) to be differentiated in equation (8) are of the form

\[
L = qSC_\text{L} = qSa(\alpha_r + \alpha_0 + \alpha + \varepsilon)
\]  

The first equality in equation (10) is the definition of \( C_\text{L} \), where \( q \) is the dynamic pressure \( \frac{1}{2} \rho V^2 \) of the airflow and \( S \) the plan area of the lifting surface. In the second equality \( C_\text{L} \) is given by the product of \( a \), the slope of the lift curve for the section, and the overall incidence of the surface to the flow, the sum of

\[
\begin{align*}
\alpha_0 & \text{ the off-set of the curve at zero lift} \\
\alpha_r & \text{ the rigging angle of the wing}
\end{align*}
\]
$\alpha$ is the incidence of the aircraft, and $\epsilon$ is the downwash or upwash angle.

$\alpha_c$ and $\alpha_0$ are constants that disappear on differentiating. Hence the derivatives required for equation (8) are

$$d_1 = qS_1a_1 \frac{d}{d\alpha} (\alpha + \epsilon_1) = qS_1a_1 (1 + \frac{d\epsilon_1}{d\alpha})$$

and

$$d_2 = qS_2a_2 \frac{d}{d\alpha} (\alpha + \epsilon_2) = qS_2a_2 (1 + \frac{d\epsilon_2}{d\alpha})$$

(11)

If it is assumed that the dynamic pressure $q$ has the same value for each wing, it will cancel when introducing the derivatives into equation (9).

Then if $X = \frac{d_2}{d_1}$, equation (9) reduces to the convenient form of equation (12) to be solved for the position of $G$:

$$x/l < X/(X + 1)$$

(12)

In Glauert's example, $S$ and $a$ are the same for both wings and also cancel. It was seen in equation (5) that values of the $d\epsilon/d\alpha$ derivatives are readily determined from basic quantities. To be consistent with the conventions, an upwash angle such as $\epsilon_1$ would have a positive sign and the downwash $\epsilon_2$ would be negative.

Glauert took a representative example with equal wings for which the term $(a/\pi A)$ in equation (5) took a typical value of 0.212 per degree for both wings. He then found that for stability $x/l$ must be less than 0.39 when the distance $t$ between the wings was equal to their semi-span. That was with use of his own calculated values in place of the constant 2. Using the approximate values of 2 for downwash and 0.4 for upwash, equations (9) to (12) give about 0.36, in fair agreement for a simplified approach.

Equation (7) shows that the highest value allowed for $x$ (eg 0.39$t$ in the case above) defines a location for $G$ for which the rate of change of moment with incidence $dM/d\alpha$ is zero. The aircraft is then said to be neutrally stable, ie that it offers no restoration or divergence following a disturbance. That location is called the neutral point, NP. For stability $G$ must be located forward of NP and its distance ahead of it is the 'stick-fixed static margin'. This is called 'stick-fixed' because it is assumed that no elevator movement is made. The conditions are 'static' because it takes no account of the dynamic response that follows a disturbance. That might cause an overshoot of the original position, possibly followed by an oscillation. Although having a static margin is a necessary condition for stability, and often satisfactory, it is not sufficient to ensure that. Methods for calculating the motion were available at the time, but quantities required for a given case, particularly the damping, could not be estimated reliably, so the dynamics of the response was not yet generally addressed.

With the above results in mind, the aerodynamic factors involved in the first flight of the M.35 can now be considered.
4 First flight of the M.35
4.1 The take-off

For the M.35 the fast taxying and attempted 'hops' took place at the beginning of May 1942. In the normal course of that the first stage is for the aircraft to be accelerated across the ground, at take-off power, until the stalling speed has been passed by a suitable margin. Next the nose is raised, to give the lifting surfaces the incidence needed at that speed to generate enough lift to exceed the weight, enabling the aircraft first to rotate and then to become airborne. Initially, it was found that the M.35 could not be taken beyond the first stage.

In the tandem-wing arrangement the elevators were on the front wing, which was mounted on the top of the fuselage and well clear of the ground. Being a large lifting surface it would seem to have been adequate for the task of raising the nose at the appropriate stage of the run. However, the tricycle undercarriage had been so arranged that the fuselage had a horizontal stance on the ground, and the wings were set at only small angles to that. During the run the position would be worsened by the compression of the nose-wheel leg by the nose-down moment of the thrust. The characteristics of the leg are not known, but from the geometry of the GA drawing a compression of 1in would give a nose-down pitch of about $\frac{3}{4}^\circ$. This situation was not favourable, but some reassurance might have been felt from experience with the M.30 X Minor blended-wing aircraft, also having a tricycle undercarriage, which had not shown any reluctance to take off when its first flights were made less than three months before.

As it was then found that the M.35 could be made to take off by briefly throttling back the engine, the effects of the temporary absence of the nose-down moment of the thrust were clearly very significant.

4.2 Rotation

a) Principles. To raise the nose in the take-off, the lift of the front wing would first have to equal and then overcome the nose-down pitching moment due to the other forces acting on the aircraft. At this stage a suitable axis about which to evaluate the moments would be one through the point of contact of the main wheels with the ground. [Choosing this point eliminates from inclusion the forces applied by the ground, which are difficult to determine accurately]. The engine having been momentarily throttled back, the thrust from the propeller is taken to be zero and at the beginning of rotation, the forces on the nose-wheel would fall to zero also.

The all-up weight is listed as 1,850lb and the position of G, its effective point of action, as '9in forward of the intersection of the leading edges of the rear wing'$.^{(10)}$ The actual location of the wheels on the M.35 is not listed, but scaled from the 1942 GA drawing on which it is shown gives a value of about 1.7ft for the moment arm of the weight about their contact point. The nose-up moment required to cancel this and begin rotation would thus be 3,150lb ft.
Similarly scaled, the moment arms of the lift centres for the front and rear wings about the main wheel contact point are about 6.2ft and 1.3ft respectively in the horizontal direction. No results from which the lift and drag coefficients could be obtained were given in any of the known Miles documents. However, it is recorded that the aerofoil sections for both wings of the M.35 were from the NACA 230 series. The characteristics of the 23012 (12% thickness ratio) aerofoil from full-scale and wind-tunnel tests had been reported in 1935, and are used here. This section was considered to be a good all-round choice, and notable for its very low intrinsic moment, which will in consequence be neglected.

A modest amount of flap deflection was and is generally used on take-off. For the critical circumstances of the first take-off of the M.35 it might be supposed that the pilot could have selected say 30° of flap on the front wing and then begun to draw back on the stick. As there was difficulty in raising the nose, the point of applying full down-elevator might have been reached. It is not recorded what relevant aerodynamic information Miles might have had about those situations, so for present purposes the required values have to be estimated from sources that were readily available at the time.

Characteristics for a parallel-chord wing of NACA 23012 section, fitted with a full-span plain flap of width 20% of the chord were published shortly after the basic data cited above. Further, lift characteristics of the RAF (Royal Aircraft Factory) 44 aerofoil had been reported in an R&M of 1935, showing them to be virtually identical to those of the NACA 23012 section. Results with a full-span flap at 40° deflection were given, which are very close to those of the NACA section at 45°. These sources provide background data on which some rough estimates for the M.35 wings could be based.

The front wing of the M.35 differed from these test sections in being tapered in plan, with elevators out to about 55% of the semi-span and with flaps beyond that. The presence of taper was offset to some extent by the widths of the moving parts being 25% of the chord throughout. In the absence of anything nearer than that being available at the time, results from these tests have to serve for the present purpose of estimation.

Lift from the rear wing would normally strengthen the nose-down moment. But that was rigged at only 1° to the thrust line, and was subject to the downwash of the front wing over its entire span. From the large-scale GA drawing, it was estimated that the aerodynamic centre of the rear wing lay around 30% of a semi-span below the path of the central plane of the downwash from the front one.

Then from the estimates in Glauert's book the reduction in the downwash angle at the wing due to the height difference would be about 30%. It is then found that the lift of the rear wing prior to rotation would be quite low.

b) Results. At rotation, it is assumed that the fuselage is momentarily horizontal. Using data approximated as above, routine calculations show the combined nose-up moment from the lift of the wings to have an estimated value of 260q lb ft.
Corresponding values for the nose-up moment due to drag forces can be similarly estimated on the basis of contemporary works. The aerodynamic centres of the front and rear wings are found to be distanced vertically from the wheel contact points by about 5.7ft and 2.8ft respectively. Routine calculations of the drags of the wings and fin/rudders could be made and added, but that for the fuselage is subject to more uncertainty. Textbooks of the time refer to the drag of fuselages in two parts, profile drag and 'skin friction' (viscous) drag. The former is covered very sketchily for a few fuselage shapes and the latter is related to the fuselage surface area via Prandtl's equation for a friction coefficient for a flat plate (eg references 20 and 21). A cautious estimate along those lines would give a combined nose-up moment due to drag forces of about 40q lbft, giving a total of around 300q lbft.

Empirical additions to the drag for 'interference' between the flows over the various components of the airframe and minor projections were common practice, based on the accumulated experience of the differences measured in flight from those estimated at the design stage. Typical additions could be applying a factor of 2 on drag terms other than those of the lifting surfaces, though the practice at Phillips & Powis was usually to add 18% to the total drag\(^{(12)}\). The effects represented by that would probably be larger in a tandem-wing layout, so if in the absence of any reliable indications a 20% increase is assumed, the estimated total nose-up moment from lift and drag forces becomes about 308q lbft.

Then equating the total moment to the nose-down moment due to the weight (3,150lbft) gives an estimated value required for \(q\) of 10.2lb/ft\(^2\). The corresponding forward speed \(V\) to begin rotation would then be about 93ft/s (63mph). This is probably as near an estimate as could reasonably have been made of results from methods available at the time.

Regrettably, there is no record of the ground speeds actually reached in the prolonged runs of the M.35. An RAE Technical Note of 1940 found among Bancroft's papers gave a recommended procedure for estimating take-off distances, which shows that only very basic methods were then in use\(^{(22)}\). But to apply that to check the above speed estimate would require further knowledge of the available thrust during the varying speed of the run and the wheel drag terms. The note shows that no standard method of estimating the aerodynamic drag of the extended undercarriage or the rolling resistance on the wheels had been developed at that time. However, although those forces would contribute to slowing the acceleration in the take-off run, being applied low down they would not make a significant contribution to the moment about the ground contact point.

There is no report that even basic procedures of this sort were used to estimate the conditions required for the M.35 to leave the ground. George might have worked from past experience, expecting that the speed would be larger than the 46 mph of the M.14 Magister trainer, which had about the same weight and used the same engine, though it had a larger wing area. Another indication comes from the forward speed of 70ft/s (48mph) used when estimating the thrust and torque for the 4-bladed propeller intended as an alternative to the standard 2-bladed one for the M.35\(^{(7)}\).

It cannot then be said for certain what take-off speed had been expected. But in the repeated attempts to get airborne, including lengthening the path to the limit available at the Woodley
airfield, that expectation was likely to have been exceeded, perhaps by a significant margin. It seems not unreasonable for it to have been taken to a value of over 60mph. That is without the nose-down moment due to thrust from an engine at take-off power, which if that had remained on could have moved the take-off quite beyond reach. As it is known that take-off did occur when the engine was throttled back briefly, it might be concluded that the considerations given above provide at least a plausible technical basis for that part of the behaviour reported.

4.3 Balance

As the nose begins to rise, the incidence of the wing or wings increases and the growing lift causes the rotation to accelerate. In another contemporary case, of the first take-off of the Gloster E.28/39, also with tricycle undercarriage, the pilot Gerry Sayer was surprised by the rapidity of the rotation and had to move quickly to take off the full elevator deflection that he had been holding during the run, to avoid stalling the aircraft\(^{(23)}\). George Miles, piloting the M.35 on its first take-off, would have to do the same, while also being ready to open up the engine to restore the thrust that had been temporarily suspended. A resumption of the forward acceleration would then accompany the rotation, producing a complex, dynamic situation, the analysis of which would go beyond the scope of the present study.

The machine was however seen to have been brought thereafter into a condition of level flight, and if the speed had stabilised, the thrust and drag terms would be balanced in the forward direction, and were probably aligned sufficiently for any moment they might generate to be small. Then the analysis can be resumed by considering the principal requirement of satisfying the two conditions cited in Section 3.2: that the sum of the lifts must equal the weight and their moments must be in balance about the centre of gravity \(G\).

The lifts are evaluated as before, with iteration required because of the interactions between the wings via upwash and downwash. It is soon apparent that the required conditions could not both be satisfied unless there is a transfer of lift from the front to the rear wing. George would probably have sensed the need for this as the rotation developed, first instinctively moving the elevators from down to central, and then perhaps to up to check the motion to avoid a stall from developing. [Because the elevators were on the forward wing, raising the elevators depresses the nose.] To obtain sufficient lift overall, it would also have been necessary to lower the rear flaps, at least to the first stop, perhaps of 10°. Calculations indicate that equilibrium in straight and level flight could then be established at a forward speed of around 70 – 75mph. As the speed increased further, the flaps on the front wing could be raised and the elevators regain their proper role for control in pitch.

It has been the aim here to work only within the state of knowledge at the time, so as to keep in view the contemporary source material that could have been available for use in the design. Then results in this phase can be only approximate, through uncertainties about determining the aerodynamic characteristics of the rear wing and the effects on it of the downwash from the front one.
As seen in Figure 3 the rear wing has a somewhat complex form, having a centre-section with constant chord, and tapering outer sections with substantial sweepback. Estimation of the location of the lift centre for this wing would have to be made by using strip theory, in which the contributions of lift from successive spanwise strips were made by assuming them to be elements having the characteristics of parallel-chord models in wind-tunnel tests, each acting independently of the strips on either side. The effects of the real wing being of finite span would normally be represented approximately by supposing the lift to vary elliptically in the spanwise direction.

The presence of the fins at the wing tips would be a further complication here. For conventional layouts with tailplanes, there had been no great concern for modelling of the flow far from the centre-line, so little can be found to help in representing the downwash on the outboard parts in this case. Nor is there anything helpful on the effects of tip vortices impinging on a wing from another of the same span ahead of it. And so, for the purpose of estimating the effects of the downwash here, strip theory is used without any modifications of the flow towards the tips. The lift centre of the rear wing is then found at about 75% of the semi-span behind that of the front wing. [It is also about 30% of the semi-span below the plane of its wake. That is fortunately in a region where the downwash angles are not varying greatly in the fore-and-aft or spanwise directions].

There were too many uncertainties here for any comprehensive approach to have been taken at the time. It seems likely that for a situation like this the downwash angles would have been calculated only at the centre of lift of the rear wing, and that value assumed to be the effective average for the surface as a whole, as was usual for the familiar case of a tailplane. And so that practice is adopted in what follows.

On the M.35 plain flaps of about 25% chord were fitted below the outer parts of the centre-section of the rear wing and the inboard parts of the tapering sections. As in the case of the front wing, the characteristics, with and without lowered flaps, are again estimated from sources that were available at the time (18, 19, 24).

4.4 Stability

Even while gaining a measure of level flight, George would quickly have become aware that the M.35 was dangerously unstable in pitch. Having a low inertia from its lightweight construction and compact form, it would be readily displaced by disturbances in the air, but would also respond promptly to control movements made to correct the effects. George chose not to climb, remaining at 20ft according to Brown, no doubt with the hope of putting it down immediately if control became impossible. But he then contrived to fly a wide circuit and land safely, despite the further distraction of having to nurse an overheating engine.

The cause of the instability that he managed to contain can be readily established from the first principles given in Section 3.4. These show that stability requires that the centre of gravity G should be forward of the neutral point NP. This would ensure that any disturbance in pitch from level flight would always be countered automatically by an aerodynamic
moment that acted in a sense to oppose it, relieving the pilot of having to make control movements continuously just to maintain straight and level flight. In his example of a tandem-wing aircraft with identical wings, Glauert found that the NP would have to be located 39% of the way aft along the line joining their lift centres. As the position of G was set at 60% of that distance for the M.35, that figure could have alerted attention to downwash as a significant factor, so it must be supposed that Glauert's R&M had not been seen.

The simple approach outlined in section 3.5 gave a result in fair agreement with the corresponding one by Glauert, so it is used again to estimate the position of NP for the M.35. The major change for this case comes from the difference in area of the two wings, though they both still have the same span.

Due mainly to the rear wing having a larger area than the front one, NP is then estimated to be at about 0.54 of the distance between the lift centres. That means that the position of 0.6 chosen for G had been about 5in aft of NP, when for stability it would need to be ahead of it. In a situation in which an inch is a significant amount, this indication of the extent to which the M.35 was longitudinally unstable underlines the skill shown by George Miles in fighting it round to a safe landing.

5 Reasons and responses

5.1 First Aid

After the first flight, the M.35 was not flown again for nine days. The extra rear wheel, seen in the airborne view of Figure 7, was probably fitted during that time. This would limit the extent to which the aircraft could rear up during rotation to protect the propeller from striking the ground. George's reflection on the experience during that phase of the take-off, requiring a hasty reduction of lift from the front wing, would be likely to lead to the early recognition that the centre of gravity had been placed too far aft. There was nothing in the airframe of significant mass that could be relocated to move it forward, so ballasting would seem an obvious palliative. But as the reason for the later instability had probably not been understood at this point, there would have been no guidance on how far forward G would have to be moved to obtain reasonable flying characteristics. That was a critical matter, as ballast would result in an additional nose-down moment during the take-off run, which would nullify some of the effect of the temporary throttling back of the engine. The main wheels could not be moved forward to counteract that, since, as can be seen in the photographs of Figure 4, they were already mounted immediately behind the leading edge of the rear wing.

Regrettably, no data have been recovered that give details of what action was taken, but Brown reported that ballasting was done, though just to a point at which 'the instability, while still present was no longer catastrophic' \(^{(6)}\). As it was necessary for the future of the Libellula concept to have an example to demonstrate in flight, the remaining instability would have to be tolerated.
It is now known that George contacted RAE for advice on 23 May, as among his papers is a letter of that date from F M Green, referring to his telephone enquiry of that morning (25). This was to say in part that ‘... our stability people have looked very roughly into the design of your M.35 aircraft, they tell me that without either rather elaborate calculations or model tests they cannot give you a very exact answer on the fore and aft stability of your tandem wing machine’. But it goes on ‘They think that a movement of the centre of gravity forward of about 3” will make the stability with stick held about neutral and that a further 3” forward will give you a fair margin of stability’. But it also warns that moving the centre of gravity forward would increase the load carried by the front wing. This would raise its tendency to stall, and to limit that it should be made able to develop a higher lift coefficient than the rear one.

At this critical time in the war, it is remarkable that any reply to a technical enquiry could have been given on the same day that it was made. While no great accuracy is claimed for the estimate given above, the value of 5in forward movement found here for G to reach NP was perhaps not incompatible with the 3in that the experts at RAE thought would be sufficient. But even 3in would be hard to obtain. The furthest point ahead in the airframe where the structure might allow some ballast to be located was probably behind the cockpit, where there were frames carrying the loads from the front wing and nose wheel. But to move G by 3in would have required ballast of about 100lb to be placed there. It would not be easy to locate a load of this magnitude safely in a light airframe of mostly wooden construction.

As a pilot, George would have been well aware of the need to avoid stalling the front wing. It had been given a high aspect ratio, and fitted with flaps it would already be providing a good maximum lift coefficient, as now advised. The passing reference to 'model tests' was however something that could be followed up, as reported below.
The M.35 was subsequently flown again by George, by Hugh Kennedy and ‘one other’, so far unidentified. This could have been the Chief Test Pilot Tommy Rose, who reportedly had said when the aircraft arrived at Woodley from Liverpool Road ‘Surely, you don’t expect me to fly that?’ \(^{(2)}\). Now that others had flown it, perhaps he had felt obliged to do so at least once, to save face.

Altogether, there had been seven flights, totalling 2 hours and 20 minutes, the last made on 6 June. No doubt this was much less time than had been hoped, but perhaps enough for George to claim that flight experience had demonstrated that the tandem-wing concept was practicable, together with some compelling photographs of the M.35 in flight. He was already moving on to a bold new application, the M.39, as seen later.

5.2 Research

Reference has been made to the ‘black books’ that provided a record of technical matters at Miles Aircraft. One of these, compiled by Bancroft, was entitled Libellula Research \(^{(10)}\). However, this reports only a programme of empirical work with models, which is reviewed below. Since no analysis of the behaviour of the M.35 in flight appears there or has been found anywhere, it seems necessary first to see if it is possible to identify a design decision that might have led to the basic cause of the trouble – the rearward positioning of the centre of gravity.

Except at low incidence the calculated position of the AC (and thus G when balanced) is not very sensitive to the actual condition assumed. When some typical cases for the M.35 are worked out, it becomes clear that the only factor that could be large enough to cause the position to be found as far aft as 0.6 \( l \) would be the complete omission of the effect of downwash in the calculation. This would result in the lift of the rear wing being significantly over-estimated, and that of the front one somewhat under-estimated, and it is confirmed that it would result in the calculated position being rearward in just the location cited.

Brown reported that while the M.35 was being built, an attempt was made to investigate the flying characteristics of the design with a \( \frac{1}{4} \) scale model glider, which could imply that there had been some misgivings about that before it was flown \(^{(6, 2)}\). As related, the model had been air-launched behind the prototype M.28 (a two or three-seat training and communications aircraft) flown by George, with Brown holding the tow-line out of the starboard window. During the take-off run, Bourron ran behind holding the model up until reaching its flying speed. It then climbed rapidly, and was released only when seemingly nearly above the aircraft. From a considerable height, it proceeded to dive steeply into the ground with no sign of recovery. In this account nothing further of the kind was attempted before the trials with the full-scale aircraft.

Though Bancroft describes a similar occurrence in his report \(^{(10)}\), he places it later, the model now being of the second Libellula type, the M.39, described below. This had been launched at first by ‘an Archimedean pulley system’, which is not described further. The model had climbed quickly to about 100ft, but when the hook disengaged it dived to the ground at ‘great
speed’ at an angle of about 45° and was wrecked. In Bancroft’s account it had been rebuilt, and was launched again with G moved forward, with a similar result except that the dive angle seemed to be considerably less. It was after being repaired a second time that a test was made by air-towing, with the procedure and result just as described by Brown.

In attempting to reconcile these accounts, it is noted that there is no record of concern being felt about possible instability of the M.35 prior to its first flight, making it more likely that the testing of a model glider did not begin until afterwards, as reported by Bancroft. Moreover, Brown said that the model was ¼ scale, which of the M.35 would have made the span only 5ft. Bancroft gives a table of dimensions for the glider, the span of the rear wing being 9ft and of the front one 5.95ft, together with some particulars of its construction. This included being completely ply-covered (which was usual practice for the full-scale Miles aircraft, before being given an outer skin of doped Medapolam fabric). This seems more credible for a large model intended to give a representative performance, but he gives the scale as 1/10th, which would not match either the M.35 or the M.39 at full scale. However, in the same report, he gives a scale of 1/12th for a model of another type, with dimensions that show that it was actually 1/6th. This could have been also the scale of the glider, reasonably matching the M.39, which was to have wings of 55ft and 39ft span (2). But many years later, replying to a query from the well-known aeromodeller P J (Jo) Ivens, George said that there had been 'two large scale towed and free-flight models of the fleet fighter’ [ie. as in Figure 1], though 'both crashed before we could get any worthwhile information from them’ (26).

As no deductions were made from flying model tests, Bancroft had high hopes for others, arranged to be made in a 5ft wind tunnel at Imperial College in London. The model-making skills at Phillips & Powis are illustrated by the 1/8th scale model of the M.35 made for these tests, in the form in which it had flown, shown in Figure 8. Of about 2.5ft span, this had moveable elevators and flaps, and was also tested with three wing modifications, as shown dotted in the GA drawing, Figure 3. Reasons for trying these changes were not given, but they appear to have been intended to increase the lift of the rear wing, by several additions to its area, and finally by moving the position of the front wing from the top to the bottom of the fuselage. This could indicate an attempt to lower the effect of its downwash on the lift of the rear wing, and by giving it a smaller span (while maintaining the area) perhaps to limit the spanwise extent of any remaining downwash interaction.

Figure 8  1/8th scale wind-tunnel model of the M.35 – via J Pratt
Then in Figure 9 are shown the curves of the total moment measured for M.35 models in the tunnel tests for a number of cases over a range of positive fuselage incidence up to 15°. The magnitudes are not important, but it should be recalled that for longitudinal stability the moment curve must have a negative gradient, so that the change in moment will act in a restorative sense.

The solid line of case (i) is for the original form of the aircraft, with controls neutral. This has a positive slope over much of the range of incidence, confirming the instability that was found in the flight tests. The upper, chain-dotted line for case (ii) is purportedly with the elevators 10° up, but the greatly increased positive moment compared with that of case (i) is not consistent with that. More likely, this could be for a test with elevators and flaps on the front wing both lowered. That setting had been anticipated in the analysis of Section 4.2 as a means of bringing about rotation on take-off. To prevent the rotation running away, it would then have been necessary to return quickly to the situation with controls neutral, case (i).

From the curve for case (i), the moment ceases to rise at the higher values of incidence. This is perhaps when the front wing, with its greater setting, approaches the stall, though this is occurring a few degrees earlier than would be expected for that. The stabilising

---

Figure 9  Moment curves obtained with the M.35 model, with various modifications as shown in Figure 4 – via J Pratt
moment from the rear wing is then gaining, and the gradient of the moment curve becomes negative, so there appears to be a region beyond 8° where the model is stable. But for steady flight in practice it would need to be also in balance, a condition which might or might not be attainable. [The point at about 10°, where the curve crosses the horizontal axis and the moment is zero would not be regarded as a reliable indicator of balance. In wind-tunnel testing for stability, especially at small scales, it was generally thought inadvisable to rely on the actual values of the moments measured and to concentrate mainly on the sign of the gradients of the moment curves for the regions below the stall.]

The other curves in Figure 9 are for the model with various control settings, though all now in conjunction with a modified rear wing with the span increased by about 20%, as shown in the GA drawing of Figure 3. While no longer directly relevant to the geometry of the aircraft as flown, these results indicate that with the larger wing and all flaps and the elevators down, a state of nearly-neutral stability (zero gradient) could be obtained over a useful range of incidence. Regrettably, the most likely procedure suggested above, of lowering the flaps on the (original) rear wing only, but with elevators neutral, was not covered here.

Tests were then made with the front wing replaced by one of lower span but the same area. This was not the only change, being accompanied by fitting a modified rear wing in which the central section was enlarged in span and root chord, as also shown in Figure 3. That was tried instead of adding area at the tips, which was found not to be practicable on the aircraft for structural reasons. None of the changes produced a situation in which the stability was satisfactory. The modifications made to the model for these tests clearly reflect a realisation that more lift was needed from the rear wing. However, their ad hoc nature suggests that the particular measures chosen had been based on speculations rather than any analysis made beforehand.

6 The M.39s and M.43
6.1 Project submissions

In the summer of 1942 Brown noticed a reference to the Air Staff specification B11/41, for a two-crew high-speed bomber. Ever the opportunist, without being invited to apply George proposed the twin-engined Libellula-style M.39 for this, with the remarkable claim that for around the same overall dimensions as the twin-engined Blenheim, it would have about the same range and bomb-load as the four-engined Halifax, with a higher top speed than the Hurricane fighter. Probably in anticipation of scepticism, wind tunnel tests were projected and it was proposed that 'a wooden 5/8 scale flying model, the M.39B, should be built and flown to ensure that no time is lost in making available to the services any advantages that may result from the design'. Though the requirement was cancelled in July 1942, George evidently considered that having given notification of the proposals was a sufficient basis on which the wind-tunnel work and building of the M.39B could proceed, and these were put in hand.

It is convenient to consider these developments in conjunction with two other submissions of Libellula designs, responding to the Specification F6/42, for a manoeuvrable single-seat
fighter for attack on ground and sea targets. These were the M.42, a revised version of the M.39 bomber, and the M.43, based on the original carrier-borne aircraft of Figure 1. Models of the M.39 and M.43, both of about 3ft span, were included in the wind-tunnel tests that followed.

6.2 Wind tunnel tests

Views of the M.39 model are shown in Figure 10. The layout is significantly different from that of the M.35, notably that the vertical locations of the wings are now reversed. A high level would be required for the rear wing, to provide ground clearance for the propellers of the underslung engines, so that this does not necessarily show any connection with downwash considerations, as might be thought at first. The front wing was mounted below the cockpit, and with only one-third of the area of the rear one. Its smaller span further compounded the departure from the original dragonfly-like concept.

The wind-tunnel tests were to explore many variants of the layout. Three alternative front wings were provided for the model, all smaller than the first. (It might be noted that the smallest, having an area of only 12% of that of the rear wing, could hardly avoid the appellation canard, so despised by George previously). An alternative rear wing was also provided, of about 20% larger area. There were no moveable control surfaces on this model.

Most of the variants of the M.39 layout gave positive moment-curve slopes, with only the cases shown in Figure 11 providing reasonable pitch stability. It is noted that these are for
the variants with diminishing front-wing sizes, though this was accompanied by moving the centre of gravity progressively forward. The resulting moment curves then turned out to be practically all the same.

As the wind speed in the Imperial College tunnel was only 40ft/s, there had been concerns that results might not be representative of characteristics at full scale. Accordingly, the M.39 model, in its original form, was subsequently tested again in the NPL tunnel at Teddington, at wind speeds from 40 to 200ft/s\(^{(27)}\). The boundary layer transition point on the front wing was fixed by attaching fine trip wires at 0.1 mean chord behind the leading edge. Results still showed a moderate scale-effect, with a tendency for the stability to become lower as the speed increased. The significance of the centre of gravity position had perhaps been realised by this time, as tests were also made at the higher speeds with a forward movement of G. Though the

![Moment curves obtained with the M.39 model (Imperial College) – via J Pratt](image)

Figure 11
distance moved was not small (4.8in at full scale), the results shown in Figure 12 indicate only a modest improvement in stability, but this result was to become the most significant outcome of the wind-tunnel trials.

The NPL test report also gave values of lift and drag. As the tunnel there would have been fully calibrated those results would be sufficiently reliable for determining the overall L/D ratio. This is found to have a maximum value of about 13.

The final tests in the Imperial College tunnel were of the M.43 naval fighter model, shown in Figure 13. These allowed a wide range of flap and elevator deflections to be tried, but all the moment curves had an unstable aspect (see Figure 14).
7 The M.39B flying scale model and after
7.1 A new design

Shown in Figure 15, the M.39B was a single-seat twin-engined aircraft of largely wooden construction, based on the M.39 bomber project at 5/8th scale. Again designed by Ray Bournon under the direction of George Miles, it was built at the Liverpool Road experimental department. Larger than the M.35, with a rear wing span of 37.5ft and initial all-up weight of 2,600lb, it differed by having a shorter span for the front wing of 25ft, and the gross areas of the front and rear wings were in the proportion of 1 to 3 rather than 1 to 2 for the M.35. The relative vertical locations of the wings was reversed. Mounting on the higher rear wing gave clearance for the propellers of the D H Gipsy Major 140HP engines, but the nacelles for these had to be oversize for the scale, and perhaps because of the additional side areas of these, a third fin was added at the rear of the fuselage to assist directional stability, though it was not included in the bomber design.
The longitudinal dihedral was again $1^\circ$, but the rigging settings relative to the thrust line were higher than those of the M.35, $3^\circ$ and $2^\circ$ at the roots, though this time with washout of $1^\circ$ on both wings. [Washout is a twist that involved the setting falling by this amount on moving outboard to the tips. This is usually adopted to ensure that the stall occurs first at the root, allowing use of outboard ailerons to control any tendency for one wing-tip to drop.] A typically ingenious mechanism had been devised by Miles, that allowed the elevators to be operated normally over their full range, but when flap was deflected, the elevator mechanism was activated also, allowing the flap and elevator to work in unison. Another difference, shown in a 1/12th general arrangement drawing of 28 October 1943 (28), was that a longer nose-wheel leg gave the aircraft a nose-up stance on the ground, of about $3.5^\circ$. 

Figure 15 Two views of the M39B Libellula on roll-out, June 1943
The Miles Aircraft Collection
7.2 Trials at Woodley

The first flight was made by George Miles from Woodley towards the end of July 1943, and shortly afterwards it was flown by Hugh Kennedy and Don Brown. From the increased rigging angles and improved stance, the lift during the ground run was greater than had been the case with the M.35, and no special measures were needed at take-off. This took place at 60mph after a run of about 450ft. It was also found to be stable in all phases of flight. However, due to aiming for a low structure weight, it lacked stiffness in the forward fuselage, Brown reporting disconcerting lateral oscillations at the cockpit on encountering turbulence. This was corrected by fitting a heavier gauge ply skin, but the Drawing Office again took the opportunity to lampoon the occurrence, as seen in the cartoon of Figure 16.

Reporting his experiences in flying the M.39B, Brown recalled that it 'showed no sign of longitudinal instability or other undesirable characteristics; on the contrary, it 'handled perfectly normally, like any other twin of its power, and with the additional advantage of no swing on take-off and no wing-drop at the stall' \(^{(29)}\). The first he attributed to the fins being well outside the propeller slipstreams and experiencing no lateral forces from the swirling air in them. In the stall, the front wing always stalled first, and as the aircraft then pitched down, the rear wing never reached the stall so there was no tendency to drop a wing. It seems that this had not been appreciated at the design stage, when washout had been included to achieve the same end.

The design position of G was at 0.614 of the distance between the lift centres of the two wings. That is very close to the position recommended by NPL after the wind tunnel tests there (see Figure 12). It would be easier with the M.39B to obtain a required position for G at the design stage, as the engines were now forward and their fore-and-aft location was to some extent disposable. Brown reported that once flying, tests were made to determine the range of G that could be trimmed \(^{(6, 29)}\). This was done by ballasting, though no details were
given and it is not mentioned in Bancroft's review. The forward limit was set by running out of elevator travel and the aft one by G reaching the position of the main wheels.

7.3 US opinion

Miles made sure that the Air Ministry and MAP were alerted to the good characteristics obtained in these trials, and pressed for a decision on project funding for the Libellula concept. But in the autumn of 1943, they were required to send full details of it to the US Army, with which George complied comprehensively. Records now available show that the purpose had been to obtain opinions 'as to whether it is worthwhile to invest in a development program'.

The reply from Wright Field was that 'There are no known aerodynamic advantages of the Miles arrangement'; just an assertion, with no evidence of any technical evaluation having been carried out. It relied mainly on comparison with a superficially similar US type, the Curtiss-Wright XP-55. This had a rear-mounted engine and swept-back wing with fins near the tips, resembling the features of the M.35, but the front surface was a small canard stabiliser. The first prototype had recently crashed after settling into an inverted stall from which it could not be recovered. It was believed that 'The Miles airplanes would probably exhibit this same characteristic'. Although this could not be 'definitely predicted', it was strongly recommended that 'stalls and stall recovery be demonstrated before any serious consideration be given to the designs'. This should be preceded by model tests in the RAE Vertical Spinning Tunnel.

No record of any Spinning Tunnel testing has turned up. That would have required a dynamic model to be made, in which, as well as a faithful reproduction of its shape, the moments of inertia of the aircraft were represented about its three principal axes. No doubt Miles could have provided one if required, but they were not informed about this response from the USAAF. They were told only that the M.39B demonstrator was to be purchased and be sent to RAE for further testing, where the better facilities than those of the company would allow them to be completed 'more speedily'.

7.4 Trials at Farnborough

After the M.39B was purchased by the MAP, it was given serial number SR392 and delivered to RAE in January 1944. Responsibility for the test flying was assigned to Lieutenant (later Captain) Eric Brown RN, with particular reference to stability and control, but it was also flown by several other pilots. While at Farnborough, it suffered a wheels-up landing and three accidents on the ground, necessitating returns to Woodley for repairs.

Two RAE reports were issued on the results of tests and are included in the Miles black book on Libellula research. They have also been reproduced and reviewed by Amos, so that here the emphasis is mainly on the specific results and conclusions on stability.
The first report confirmed the findings of the Miles tests, concluding that 'No peculiarities of handling of this aircraft have been noted as compared with a conventional aircraft with similar wing and power loading – in fact a pilot flying blind would be unable to detect the difference’. It was also found during investigations of trim that the flaps on the rear wing could not be extended in flight beyond the first two stops (of five) because the front wing at full flap extension could not then provide a sufficient moment to bring the aircraft into balance. To utilise the rear wing more effectively, it was recommended that 'much higher lift is required on the front wing'. This would also provide further help on take-off, where without flap 'the aircraft requires to be pulled off the ground very firmly'.

Perhaps because of the warning from the USAAF it was considered necessary for tail parachutes to be fitted before the aircraft could be safely stalled and the recovery investigated. The second report found, however, that these were not used. In most flight conditions the stall was quite innocuous and recovery straightforward, often with a height loss of 'no more than 100 feet'. If the stick was held back after the stall, a divergent oscillation could follow, with the front wing repeatedly stalling and unstalling, but this did not occur with the normal procedure for recovery by promptly moving the stick forward. A quite extensive range of other performance tests was made from which it is noted that at the limit of the attitude range the L/D ratio was approaching a maximum, with a value of about 16 at this scale.

The flying characteristics were generally benevolent, with the exception that straight and level flight on one engine could only just be held with full throttle on the other and rudder hard over against the swing. Failure to act promptly on a sudden engine cut on one side could lead to the aircraft falling into a steep spiral dive.

7.5 Balance and stability

In the RAE flights, G was estimated to have a range of 1.6in, which is described as 'normal'. It is not usually practicable to move G significantly for test work, and the range is determined from the limits of forward and aft movement of the aerodynamic centre AC. For balance, AC must be brought into coincidence with G, and so the limits are generally worked out from the effectiveness of controls in moving AC in various phases of flight.

The GA drawing from the second RAE report, reproduced in Figure 17, shows the location of the lift centres of the wings, taken to be at the quarter-chord positions of the mean chords, and the design location of the centre of gravity G, at 0.614 of the distance (of 12.6ft) between them. (A value of 0.613 is given in one RAE report, and another of 0.627 was also considered to be 'normal', though that would be about 2in aft of the design position). It was also established in flight that the neutral point NP with stick fixed was at 0.69, with no significant differences between the glide and engine-on conditions. This would give a static margin of about 10in, indicating that very good longitudinal stability would be expected, as indeed had been found to be the case.
In the absence of any record, it is natural to wonder how George, perhaps with Bancroft and others, might have addressed the question of stability for this second flying example of the Libellula concept, after the unhappy experiences with first. In the 'Research' black book (10), Bancroft states that for the M.39B the centre of gravity $G$ had been placed 'as indicated by previous wind-tunnel tests', likely to have been those at NPL, with results shown in Figure 12. Eric Brown subsequently reported that the reversal of the vertical positions of the wings was 'partly to ensure that the aft plane would be free of the downwash effect from the foreplane' (32). That would be an indication that the significance of downwash had been fully appreciated, though as he was not there at the time, it was more likely a case of being wise after the event. For a broader view, some calculations of the positions of $G$ and NP have been made as a check on this, as reported above for the M.35.

Fig 17  General Arrangement drawing of the M.39B, as presented for trials at RAE via J Pratt
The differences between the layouts of the two machines indicated however that simple procedures that were adequate for the first aircraft might not be readily adaptable for the second. The front wing was now shorter than the rear one, so that the latter would be only partly affected by the downwash from it, and both wings had now been given washout. Another uncertainty was the effect of the slipstream from the propellers on the lift distribution. But some trial calculations have been made with the two methods, the first using estimates of the upwash and downwash values from Glauert's book in the procedure as for the M.35, and followed by the second, even simpler approach, resembling that of current practice for finding the positions of AC and G for the conventional layout with wing and tailplane. For the second method upwash on the front wing would be neglected, and the downwash on the rear wing was taken to be as given by the approximate value of equation (4). In both methods the wings were represented just by their respective areas and lift-curve slopes, with rigging angles of 2.5 and 1.5°, the average between root and tip. Thus, downwash was considered to act on the whole rear wing surface, though the part lying in the wake of the front wing was actually about 75% of the area. No account could be taken of the effects of the presence of the engines and their nacelles.

Though Eric Brown reported that the rear wing had now been considered to be clear of the downwash from the front one, in fact, the geometry was not greatly different from that for the M.35. In one case the rear wing was below and in the other above the plane of maximum downwash from the front one, but its vertical displacement from that plane, relative to the semi-span, was similar in the two cases. From the lifting line theory the vertical variation is symmetrical about the plane.

The values calculated for AC for balance and NP for stability were the averages over the range of incidence to the flight path from 4 to 8°. The location of AC, also that of G in trim, was then given as 0.656, compared with the design value of 0.613 (or 0.627 at RAE), and that of NP at 0.687, compared with 0.69 obtained from flight trials. The corresponding static margin was 4.8in, and although less than half the value found in flight, it would still indicate that the M.39B would have good longitudinal stability. With the second method G was found at 0.632 and NP at 0.664, giving the same value of 4.8in for the static margin. Interpretations of these figures are given in the following Section.

It was considered that, despite the approximations, these results had adequately reproduced the values found in flight, so a further case was calculated, one in which downwash had been neglected entirely. This gave a position for G at 0.71, sufficiently distant from the design value to confirm that the latter had not been found by such a calculation, as in the case of the M.35. It is clear that this time, G had been placed as recommended by NPL after the wind tunnel model tests.

7.6 The end of the line

Despite having been required to ‘complete the trials more speedily owing to the superior facilities at RAE’, the M.39B remained there for about a year. According to Bancroft, flight with it was resumed at Woodley in July 1945. It is shown in Figure 18, operating in 1946
with the new post-war ‘B’ mark U4. Modified elevators and extending flaps had been fitted to the front wing to provide the greater lift shown in the RAE tests to be needed to allow more of the rear flap travel to be utilised. Although that aim was not fully achieved, it was found that the range of G was then extended to the high figure of 12in.

In his early consideration of the future potential of the Libellula concept, George had envisaged a jet-propelled version of its high-speed bomber, and the idea was revived in 1946 in the form of a mail-plane. Designated the M.63B, this was the subject of a proposal made to the Ministry of Supply and BOAC in May (4). Though said to have the enthusiastic endorsement of the Postmaster General and interest from BOAC, it was not supported by the Ministry and Miles could not proceed without that.

The M.39B continued to be flown occasionally for display purposes, and is shown in Fig 19 on what was probably its last appearance in 1947, bringing to an end the Libellula enterprise from which so much had been expected.

8. Review

This section brings together briefly the data supporting the technical attributions advanced above for the difficulties experienced on take-off of the M.35 and its instability in flight, and reasons for these not occurring with the M.39B.

Table 1 shows locations of the aerodynamic centre of lift AC and centre of gravity G (which must coincide for the aircraft to be balanced), together with those of the point of neutral...
stability NP; G must lie forward of NP for the aircraft to be longitudinally stable (the actual
distance forward is the stick-fixed static margin). The figures are for the position aft of the
lift centre of the front wing, as a fraction of the distance between the lift centres of the two
wings.

These locations have been measured or calculated as shown in column 1 'Case'. 'Simplified 1'
indicates that the calculation was in accordance with the procedure outlined in Section 3.5,
with upwash and downwash as given in Glauert's book of 1926\(^{(16)}\), including allowance for
the vertical separation between the locations of the wings. 'Simplified 2' indicates use of the
second method described in Section 7.5 above which followed the same principles, but with
upwash at the front wing neglected and downwash at the rear wing as given by equation (4),
previously used for calculating the effectiveness of the tailplane as the stabiliser for aircraft of
conventional layout. Values so obtained are expected to be approximate so those for the
locations of G and NP are rounded to two significant figures, and that for the static margin to
the nearest inch.

Table 1. Compilation of Balance and Stability Factors

<table>
<thead>
<tr>
<th>Case</th>
<th>AC/G</th>
<th>NP</th>
<th>Static margin, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glauert tandem - Glau calculation</td>
<td></td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Glauert tandem - Simplified 1</td>
<td></td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>Glauert tandem - Simplified 2</td>
<td></td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>M.35 - design</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.35 - zero downwash</td>
<td>0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.35 - RAE estimate</td>
<td></td>
<td></td>
<td>-3</td>
</tr>
<tr>
<td>M.35 - Simplified 1</td>
<td>0.51</td>
<td>0.54</td>
<td>3</td>
</tr>
<tr>
<td>M.35 - Simplified 2</td>
<td>0.49</td>
<td>0.52</td>
<td>3</td>
</tr>
<tr>
<td>M.39B - Design</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.39B - NPL advice</td>
<td>0.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.39B - zero downwash</td>
<td>0.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.39B - RAE flight test results</td>
<td>0.63</td>
<td>0.69</td>
<td>10</td>
</tr>
<tr>
<td>M.39B - Simplified 1</td>
<td>0.66</td>
<td>0.69</td>
<td>5</td>
</tr>
<tr>
<td>M.39B - Simplified 2</td>
<td>0.63</td>
<td>0.66</td>
<td>5</td>
</tr>
</tbody>
</table>

'Simplified 1' has been assessed for accuracy by comparing its predictions against four known
values - a calculation of NP for a pair of identical tandem wings by Glauert, an estimation of
the static margin for the M.35 by RAE and determination of the positions of G and NP for the
M.39B in flight by RAE. The agreement can be judged from the corresponding entries in
Table 1. That was considered to give sufficient justification to try 'Simplified 2', the results
from which were expected to be less satisfactory, but in fact proved to be quite similar.
Concerning the M.35, the results show that to obtain the design position for G of 0.6 from aerodynamic considerations would require the omission of any downwash effects. When these are included, the required position would be near to 0.5. If G had been placed there, the calculated position of NP would then give a static margin of about 3in, indicating that the aircraft would have had satisfactory longitudinal stability.

It was not expected that downwash effects could be estimated reliably for the M.39B, as the wings were not of equal span. However, with further approximations both methods gave generally similar values for the positions of G and NP and the same estimate for the static margin. The values obtained by RAE in flight testing are both replicated in the calculated ones, but not in the same combination, so the estimate from the former gives a larger static margin. The longitudinal stability of the M.39B would be excellent by either estimate. And if the in-flight determination of the NP position is assumed to be the correct value, the positions found by either simplified method would predict that the aircraft would be comfortably stable.

A calculation of the position of G without allowing for downwash indicated that this had not been done in the design of the M.39B, confirming that the location had been as advised by NPL after the wind-tunnel tests made there.

9 Assessment

9.1 Expectations

As outlined in Section 1.1, the Phillips & Powis brochure 'A New Basic Design' of 1942 advanced some strong claims for advantages of the Libellula tandem-wing concept over aircraft of the conventional form, having a wing and a tailplane as stabiliser (3). It would be expected that these would be subject to review as practical experience in flight was gained with the M.39B. It is now shown in the papers of George Miles that this was not done until 1947, when he had asked Bancroft to make an assessment.

There was a belated opportunity here for Bancroft to make an aerodynamic analysis of the Libellula layout. This would perhaps start with the evidence from the flight tests of the M.39B that the main (rear) wing had not been able to develop its full capability as a lifting surface before the front wing stalled. Writing later, Don Brown asserted however that 'part of the art of designing a tandem-winged aeroplane' was to choose the relative wing areas and loading so that 'the rear wing cannot be stalled' (29). This is evidently a misunderstanding, as it is a natural consequence of the tandem-wing layout that the front wing stalls first. The rear wing operates at a lower incidence than that of the front one, due to its being rigged at a lower angle to obtain longitudinal dihedral and being subject to downwash. Then as it develops lift, upwash is created at the front wing, further increasing the disparity. As to the effects of the relative areas of the wings, there had been wide variations in this across the range of actual and planned projects of the type, but no argument for selecting a particular ratio had been put forward.

Bancroft returned his assessment in seven 'Minutes' to George over the period from January to July of 1947 (33). Instead of making any fundamental analysis, he sought to make comparisons between the characteristics of the M.39B and other aircraft of the conventional layout. He
found it difficult to decide what would make an aircraft a suitable benchmark machine for
this. His main choice was the Miles M.65 Gemini, also designed by Ray Bournon under
George's direction, the prototype of which had been the last to be built at Liverpool Road [4].
That was a popular 4-seat twin-engined aircraft for private, club and charter use, of about the
same size and weight as the M.39B, and also of largely wooden construction, though fitted
with engines of 100HP rather than the 140HP ones of the latter. Cherished by aficionados,
four aircraft of this type are listed by Amos as being in airworthy condition 70 years later,
and three more undergoing restoration.

Comparing the dimensions showed that the claim for the Libellula of a smaller overall size
for a given duty 'could not be substantiated', and there was 'little information' to support the
claim of a reduced structure weight. Most importantly, the basic expectation that having two
wings would provide lift more efficiently was also not borne out. The take-off and landing
speeds were higher than for the Gemini and the runs correspondingly longer. There had been
an expectation that the lower span loading of tandem wings would give a higher rate of climb,
but this was in fact only 65% of that of the Gemini. The standard measure obtained at RAE
of the profile drag of the M.39B, 66lb at 100ft/s, was 12% lower than the value estimated at
Miles Aircraft for the Gemini, and combined with its greater engine power, an 11% higher
maximum speed had been obtained (164mph). At 4.5in the range of G was less than the 6.7in
for the Gemini, an unusually large figure for a private aircraft.

In later minutes, Bancroft gave new comparisons, after making adjustments to the
performances for various factors such as removing the central fin of the M.39B and fitting
Gypsy Major IC engines to the Gemini. These improved the relative position of the M.39B,
except in the area of take-off and landing.

After the return of the M.39B to Miles, external aerofoil flaps had been fitted to the front
wing, a development of the slotted flaps previously used. This was intended to raise the
maximum lift there as suggested by RAE, to provide a balancing moment allowing greater
use of flap on the rear wing. This type of flap provided increased area and had been used
successfully on several Miles types, but they had not produced a marked improvement here,
and Bancroft could offer no reason for that, other than an unsupported suggestion that it could
be due to 'scale effect' when operating on the smaller front wing. The take-off and landing
runs were still longer than for the Gemini. However, one notable finding of the trials was
that the full range of G that could be trimmed had now been extended to 12in.

Bancroft went on to list some other characteristics of the M.39B that have been traced to a
memorandum from the Company test pilot Hugh Kendall, of 10 January 1947 [34]. The
change of trim with increase of power was safer, by being nose-down, the reverse of the
expected behaviour. Its stall had been gentle, and recovery from it immediate, with no
tendency to fall into a spin. At RAE it had not shown any disagreeable traits except when
there had been a sudden cut in one engine, though Kendall thought that the 'tail arm' for the
fins and rudders was insufficient to cope with asymmetric power loading in general.

He then referred to its 'unpleasant response to gusts', a phrase directly quoted in Bancroft's
review. This he described as consisting of 'a rapid highly damped oscillation in pitch', with
an amplitude that 'seems large in relation to the gust producing it'. He thought that 'the practicability or otherwise of the Libellula layout' would 'depend mainly on whether or not this gust response can be resolved. Tests are necessary to see if this characteristic is fundamental to the layout or merely an individual one'.

Kendall’s memorandum had been sent to Don Brown and George Miles as well as to Bancroft. It must have been unsettling for something claimed to be a central issue to be raised after a considerable test programme, both at Miles Aircraft and RAE, in which it had not previously been mentioned. Kendall does not indicate what type of tests he thought would be required, and nothing has been found to show that any were carried out. As this 'unpleasant' feature was not mentioned again, no further observations about it can be made now.

In a later Minute, Bancroft began an attempt to make comparisons with another Miles type, the M.57 Aerovan. This was a light twin-engined freighter aircraft, which had a large, blunt body to carry ten passengers or a car with its four occupants, a layout that was not really typical of the conventional airframe. However, this served mainly to show uncertainties about how to scale the characteristics of one aircraft for fair comparison with those of another of different weight (in this case about 5,200lb all-up).

Not all the claims that had been made in the brochure for the Libellula concept could be reviewed, as the relevant conditions had not been investigated, either at Miles or during the stay at RAE. An important element, central to the concept, was that the fitting of flaps to both wings would allow compensation to be made for large changes of trim, from the release of heavy stores, for example. But the extra drag produced by flap deflection had not been mentioned at any point, so the possible operational significance of that remained in question. The main drag estimates made by RAE were in the 'clean' flaps-up condition, in partial dives with the engines throttled back, and after being adjusted for the drag of the windmilling propellers. Another drag estimate was based on the maximum level speed, but this too was made approximate by having to assume a value for the propeller efficiency. These results at full scale give a maximum overall L/D value of about 16, and show that the peak had only just been reached at the limit of incidence that could be obtained before the stall at the front wing intervened. A low value had also been found in the wind-tunnel tests of the M.39B model at NPL, where the peak had been about 13. But these results were not included in Bancroft’s assessment, although they had shown that the larger rear wing was not being used effectively. Consequently, it is indicated that factors considered to be of importance in practice would not be competitive with those of conventional types.

A covering note to his Minutes gives Bancroft’s conclusion on his attempts at comparisons, that 'It would appear that a satisfactory answer cannot be obtained unless a detailed design could be developed for a certain specification, both on Libellula and orthodox lines. However, the facilities are not available for this'.
9.2 **Circumstances.**

As Miles Aircraft continued to propose other projects of this nature, it seems likely that it was never fully appreciated that there were technical limitations inherent in the tandem-wing concept itself. That could have been apparent if relevant work that was readily available had been accessed and digested at the very beginning of the programme, so it is pertinent to seek factors that tended to inhibit that in the context of the time.

The Miles brothers have been justly commended for their originality, enterprise and determination, and the atmosphere at Phillips & Powis reflected this. It was in George's character to press ahead with a new idea, and he had the support of a team that was like-minded. Don Brown reported that he ‘had no data on which to work, no idea as to what the relative wing areas should be, or where the c.g. should be initially located. He just went ahead’. The sense of haste implied by the M.35 having moved from conception to rollout in 12 weeks would at any time have left little room for literature search and calm contemplation. But in any case, it has been noted elsewhere that sources like the R&Ms of the Aeronautical Research Committee (later Council) were not likely to be the first to be consulted for guidance by busy designers in the industry of the time. They tended to find these to be ‘too theoretical’ and preferred to be shown results verified in flight and given in graphical form, from which a numerical quantity (such as downwash angle, for instance) could be read off directly for any condition. In 1932, the Society of British Aircraft Constructors (later the Society of British Aerospace Companies, and now part of the ADS Group) asked the ARC to present material specifically aimed at designers, and there was thereafter a definite trend in that direction. This was supported by the appearance of technical journals like Aircraft Engineering which were widely read in the industry. Authors of R&Ms would sometimes provide versions of their work for that and F G Miles was a contributor on developments at the company.

When the M.35 was found to be both unbalanced and unstable in flight, George had consulted RAE Aero Department and this was perhaps his first encounter with a more developed view of stability than had been needed in his previous work. The estimate had been that it would be neutral if G was moved forward by 3 in. If the means of obtaining a specific figure for that had aroused his curiosity, it happens that there were sources at hand that he could consult for further information.

Among Bancroft's papers there was a copy of the well-known textbook on aerodynamics of 1937 by N A V Piercy, of Queen Mary College. (This writer found in it what had perhaps been a place-marker in the form of a 2d tram-ticket clipped at The Angel, Islington, suggesting that this book had been a standard work for the degree course taken by him). References to stability occur in various places throughout the text, beginning with the basic requirement that the gradient of the moment-curve must be negative. It goes on to deal with downwash and the determination of the required tailplane area, though it does not specifically introduce the concepts of the neutral point and stability margins. At one place, Piercy cites the expression given in Glauert's book for calculating the downwash angle behind the centre of a lifting wing, though he advises that a more reliable picture is given by wind-tunnel measurements. Bancroft seems to have followed that advice.
There was also a copy of Glauert's definitive book on hand. Although F G reported that he did not claim to have 'a really intimate acquaintanceship with aerodynamic theory', he is known to have possessed several advanced texts on the subject and Glauert was one of those. That is today included in a display of some of F G's books in the Museum of Berkshire Aviation on the site at Woodley. In fairness, however, it should be said that following this work requires not a little concentration. As a mathematician, working with the conventions of that speciality, Glauert tended to move quickly through a development without showing many intermediate steps.

And so in principle some of the material necessary for a technical evaluation of the Libellula concept had been available for reference at Phillips & Powis, though the Glauert paper on the tandem-wing layout would have been the best pointer towards that. But given the dire national circumstances of 1941-42 it is understandable if time could not be spared for it at that stage. Other participants in the affair were no less remiss than Miles in not turning up these known materials. Seemingly, no reasoned comments about tandem wings in general were ever made by those reviewing the Miles proposals at the Admiralty, Air Ministry, MAP or USAAF, and Glauert's key contribution was not recalled when the M.39B was being tested at RAE, although he had written it while working there.

It is less easy to see why the rear wing of a tandem pair had not been treated from the beginning for stability purposes in the same way as a tailplane of the conventional layout, or at least why that had not been invoked after the M.35 had been found to be so dangerously unstable. A procedure commonly used resembles the 'Simplified 2' method, which is shown above to give quite representative values for the positions of the aerodynamic centre and neutral point. It is poignant to realise from the results in Table 1 that, if just that step had been taken, and the centre of gravity of the M.35 could have been correctly placed, the first aircraft of the Libellula project would have flown and been comfortably stable. An intensive programme of flight testing could then have followed, with at least the prospect that the limitations of the concept would have been recognised at an earlier stage.

Acknowledgements

Material central to this study, much now reported for the first time, was generously made available by
Karen Pratt, née Miles, from the papers of her father George Miles, via Jim Pratt.
Elizabeth Bancroft, from the papers of her husband Dennis Bancroft, and
Peter Amos, for photographs and other material from The Miles Aircraft Collection.

Thanks for help in locating material are due to
Jean Fostekew, the Museum of Berkshire Aviation, Woodley, Berkshire and
Brian Riddle and Tony Pilmer, the National Aeronautical Library, Farnborough, Hampshire
References

1. Pratt, Karen (née Miles), cited J. Pratt. Private communication
5. Wind Tunnel Research. Miles Aircraft Ltd 'black book', via Elizabeth Bancroft
7. Airscrew Research. Miles Aircraft Ltd 'black book', via Elizabeth Bancroft
8. Extracts from flight logs. Papers of G H Miles, via J. Pratt
9. Cartoon – attempts to get M.35 airborne (see Figure 5). Papers of G H Miles, via J Pratt
10. Libellula Research. Miles Aircraft Ltd 'black book', via Elizabeth Bancroft
11. Miles, F G. Aerodynamic design, Aircraft Engineering, 11, 1939, 81-83 and 119
17. Jacobs, E N and Clay, W C. Characteristics of the N.A.C.A. 23012 airfoil from tests in the full-scale and variable-density tunnels, NACA Rept No 530, 1935
Silverstein, A, Katzoff, S and Bullivant, W K. Downwash and wake behind plain and flapped airfoils, NACA Rept No 651, 1939

Green, F M, Aerodynamics Dept RAE, letter to G H Miles, 23 May, 1942, Papers of G H Miles, via J Platt

Miles, George. Letter to P J Ivens, November 1972, Papers of G H Miles, via J Platt


Brotherhood, P and Evans, J R. Flight tests of the Miles Libellula (M.39B) tandem biplane. Part I. Interim note on performance and handling in the original condition. RAE TN Aero 1499(F), Aug 1944.

Aliston, H G and Brotherhood, P. Flight tests of the Miles Libellula (M.39B) tandem biplane. Pt. II. Interim note on stalling characteristics, performance and handling when in the original condition. RAE TN Aero 1687, Sept 1945.


Kendall, H. Miles Aircraft Internal Memo, 10 January, 1947

Performance Data, Vol II. Miles Aircraft Ltd 'black book', via Elizabeth Bancroft


Piercy, N A V. Aerodynamics, English Universities Press, 1937
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.