R. & M. No. 2491
(5520)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Flight Tests on a Falcon with Spoiler Lateral Control

By
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LONDON: HIS MAJESTY'S STATIONERY OFFICE
1950
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Flight Tests on a Falcon with Spoiler Lateral Control

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COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR), MINISTRY OF SUPPLY

Reports and Memoranda No. 2491

December, 1941*

Summary.—Reasons for Enquiry.—As part of a general investigation of the use of spoilers for lateral control, flight tests were required on a Falcon with retractable circular-arc spoilers.

Range of Investigation.—In the first stage of the flight tests pilots' impressions and criticisms of response and stick feel were recorded and used as a basis for improving the control. These tests were made at various speeds, flaps up and flaps down. In the second stage, after improving the control, flight tests were made with full-span flap in operation and landings were made with flap fully down. Finally, some measurements were made of time to bank at various speeds without flap and with flap fully down.

Results.—By reducing the area of the top surface of the spoiler to a minimum and constructing it in the form of a cylindrical arc concentric with its hinge, a spoiler has been produced with zero aerodynamic hinge moment and no tendency to suck out of the wing surface. Provided that the inertia of the spoiler and the friction and backlash in the control circuit are reduced to a small amount pilots do not appear to find the resulting stick feel objectionable after a little experience.

The spoiler provides good response at cruising speeds and rapid though less even response at high speed. At low speed without flaps the response is poor. With a full-span split flap giving a $C_{L\,max.}$ of 2·25 it is very good. For an aircraft fitted with full-span split flap, this type of spoiler appears to offer a satisfactory form of lateral control.

There is no evidence of any time lag in response with these spoilers. Response for small control movements is not good at any speed, but at high speed the contrast between the initial stage of comparatively slow response and the succeeding stage of rapid response appears to become more marked, with the result that when the control is applied in a normal manner the main response does not occur until the stick has been displaced somewhat. This effect is sometimes mistaken for time lag.

1. *Introduction.*—The use of full-span flaps as a means of providing high lift for aircraft is dependent, amongst other things, on the development of a suitable lateral control. Of the devices contemplated spoilers of various types appear to have received most attention, both here and in the U.S.A. The present report describes the results of flight experiments on a Falcon with retractable circular-arc spoilers fitted well aft on the wings (at 0·70c) similar to those investigated in the U.S.A. on a Fairchild monoplane and described in Refs. 1 and 2.

The tests on the Falcon have extended over the period January, 1940 to December, 1941.

2. *Description of Aircraft and Spoilers.*—Fig. 1 shows the general arrangement of the Falcon, and Table 1 gives details of its aerodynamic characteristics. The particular machine used for these tests is fitted with Piercy section wings with the maximum thickness at 40 per cent. of the chord. In addition to the normal partial-span split flap, outboard flap extensions are provided for coupling to the existing flap when full-span flaps are required. With the full-span flap in operation a maximum C_L of 2·25 can be obtained. The tail surfaces are of normal Falcon design, though in the later stages of the flight experiments the upward movement of the elevator was increased by 5 deg. to facilitate landing with full-span flaps fully down.

* R.A.E. Aero. Departmental Note—Full Scale No. 117, received 19th December, 1941.

The general arrangement and dimensions of the spoilers are shown in Figs. 2 to 4. The spoilers are situated at 70 per cent. of the wing chord from the leading edge. Each spoiler is divided into four sections spanwise, any number of which can be incorporated in the control circuit or disconnected as required. When either spoiler is in operation the other is retracted into the wing, a large differential being provided in the control circuit to reduce the travel of the retracted spoiler. With stick central the top of both spoilers is flush with the wing surface.

In their original form the spoilers were constructed of front and rear plates bent in the form of cylinders which intersected at the bottom and were bridged at the top by a flat metal plate (Fig. 3). The front cylinder was concentric with the spoiler hinge.

Flight experience with this design led to its early replacement by a spoiler consisting of a single cylindrical plate with the top edge serrated at intervals along the span (Fig. 4). Apart from some modification of mechanical details of the control circuit and reduction of the weight of the spoilers themselves, this design was retained throughout the rest of the flight programme.

3. *Description of Tests and Results.*—3.1. *The Original Spoilers.*—The original spoilers are illustrated in Fig. 3. The flat upper surface was intended to introduce " feel " into the control system by utilising the increase in pressure on the surface as it rotates into the air stream when the spoiler is operated. The spoilers were made of steel plate and mass-balance weights were fitted. The control column was coupled to the spoilers by a cable circuit, and the full available span of the spoilers was incorporated.

Only very brief flight trials were made with this spoiler. The pilots had difficulty in controlling the aircraft and considered it unsafe. Due partly to the large inertia of the spoilers and their mass-balance weights, and partly to friction in the control circuit, the control force was heavy. The aerodynamic " feel " was too small to be noticeable. The response, though poor for small spoiler displacement, developed suddenly and rather violently when the spoiler was further displaced. The pilots also reported snatching. This type of spoiler, with appreciable upper surface area, may in general be expected to show a tendency to overbalance for small displacements, due to suction on the top surface, but it is possible that the impression of snatching was enhanced in the present case by the violent but slightly delayed response, the absence of the customary stick " feel ", and the effect on stick feel of the inertia of the spoilers and balance weights. Due to this large inertia a considerable force would be required to initiate spoiler movement, after which only sufficient force would be required to maintain the movement against the friction. The resultant stick feel, followed, after the initial stick movement, by a sudden response, may have been the major cause of the apparent snatching.

3.2. *The First Modification.*—In the light of the above experience it was decided to eliminate the flat upper surface of the spoiler and replace the box type of construction by a single steel plate bent in the form of a circular arc. The mass-balance weights were also removed. By these means the inertia was reduced, and if the spoiler arc was made concentric with the hinge the aerodynamic hinge moment would be zero. The small surface area presented by the top edge of the spoiler would reduce any tendency for the spoiler to be sucked out further when displaced slightly above the wing surface. There would be no stick feel with this arrangement, but artificial feel could be provided if found necessary. To reduce the suddenness of the response the upper edges of the spoilers were serrated so that the full span of the spoilers did not come into operation immediately.

The flight tests were made with only the outer three sections of the spoilers in operation. The modifications made a definite improvement in control. The pilots considered that there was still room for much improvement, but no longer regarded it as unsafe provided it was in the hands of an experienced pilot. Their first impression was invariably one of distaste at the lack of stick feel, but it may be noted here that as experience was gained with the control this objection appeared with diminishing emphasis in successive reports.

Cruising at speeds between 100 and 140 m.p.h. the former suddenness with which response occurred was less marked, and provided the control was applied slowly response was considered satisfactory. For high rates of application the suddenness of response and the friction and inertia of the system tended to lead to over control.

At higher speeds, of the order 160 m.p.h., the contrast between the comparatively slow response during the first stage of stick movement (up to about $\frac{1}{3}$ stick displacement) and the rapidity of response for further movement became pronounced, and during one test, when the control was applied quickly at 160 m.p.h. and then held off quickly to correct over control, a sustained lateral oscillation took place as the pilot endeavoured to correct first one way and then the other. This was probably due to a combination of mechanical effects and the suddenness of response. The inertia of the spoilers, though their weight was now reduced, was still noticeable at the stick and there was an excessive amount of friction and backlash in the control circuit. These factors, combined with the suddenness with which response occurred at high speed made it difficult to apply control smoothly and to gauge the amount of stick necessary to bank at a required rate. Examination of the spoilers also revealed that they were not concentric with the hinge line, but later flight tests suggested that the oscillation was almost certainly due to the mechanical features of the control and not to aerodynamic effects. It was in fact found that provided the pilot did not try to correct, but simply centralised the control and released the stick, the oscillation would disappear after four or five periods.

At speeds below 100 m.p.h. with flaps up the lateral control was considered poor, and with partial-span flaps down, at speeds of the order of 80 m.p.h. it was inadequate, the pilots depending to a large extent on the use of rudder and sideslip for lateral control.

In general, it was felt that the modified spoiler showed considerable promise. Though the control was not good at low speeds it appeared to be satisfactory at cruising speeds, and would probably not be objectionable at high speed if the mechanical defects in the control circuit were eliminated.

3.3. *The Second Modification.*—It was therefore decided to make the following further modifications:—

(*a*) The spoilers were made truly concentric with their hinge lines.

(*b*) Their inertia was reduced by constructing them of duralumin instead of steel.

(*c*) The control circuit was redesigned to eliminate friction and backlash. Push rods and ball joints were introduced throughout in place of the existing cables.

Flight tests made after completion of these alterations gave the pilots a much more favourable impression of the control. Inertia and friction were no longer noticeable, even though the full span of spoiler was now in use, and the suddenness of the response at high speeds appeared in consequence not to bother the pilots seriously. There has been no repetition of the lateral oscillation previously encountered. The improvement effected appears to be entirely due to the effect of the mechanical alterations, the response characteristics remaining the same as described in section 3.2.

Experiments with artificial feel provided by springs attached to the control column suggested that on the whole the pilots preferred this control without springs owing to the apparent heaviness which they introduced at low speeds. Possibly a more refined form of artificial feel might prove acceptable.

3.4. *Flight Tests with Full-span Flap.*—In view of the generally satisfactory behaviour of these spoilers it was decided to investigate their effectiveness in conjunction with the full-span split flap, which enabled the aircraft to be flown at a $C_{L\,\max.}$ of 2·25.

With the normal partial-span flap, which extended only to the outer end of the inboard spoiler section, response was very poor and considered inadequate at 80 m.p.h. With the full-span flap

the response showed marked improvement and was considered to be quite sufficient at speeds down to 50 m.p.h., the lowest speed at which steady flight could be maintained with flap fully down.

It was therefore decided to try landing the Falcon with full-span flap in operation. It was found that three-point landings could be made quite satisfactorily with flap angles up to two-thirds of the maximum available angle (80 deg.). Landings were also made with flap fully down, but though they were not at all dangerous, it was not possible to get the tail down. The lateral control, however, remained entirely satisfactory.

By increasing the upward travel of the elevator by 5 deg. it has been found possible to effect three-point landings with flap fully down, but only by landing at speeds higher than those which could be used if sufficient elevator control were available.

3.5. *Measurement of Time to Bank.*—To provide a quantitative record of the response characteristics of these spoilers, measurements have been made of time to bank 45 deg. when half and three-fourths spoiler were applied as quickly as possible and held during the bank, the other controls being kept central. Angle of bank was read from a gyro-horizon and time to bank by stop watch. A typical set of results is given in Table 2 and plotted in Fig. 5 against indicated air speed.

The curves show the rapid rate at which the response declines as the speed is reduced without flap, and the distinct improvement when the full-span flap is employed.

4. *Conclusions.*—The final design of spoiler developed in the course of these tests has provided a lateral control for the Falcon which gives very satisfactory response at cruising speeds and rapid though less uniformly graduated response at high speed. At low speed the response is poor without flap but ample with a full-span split flap. It can be said therefore that it appears to offer a very promising form of lateral control for an aircraft fitted with a full-span split flap, the only defect being due to the contrast at high speed between the comparatively slow response for initial stick movement and the rapid response on moving the stick further. This defect, however, does not seem to be a matter of great concern to pilots provided that the stick feels smooth and light to operate. It is interesting to note also that, provided the stick is smooth and light to operate, pilots, after a little experience, do not appear to offer serious objection to a stick without " feel ".

There is no evidence of any time lag in response with these spoilers. Response for small control movements is not good at any speed, but at high speed the contrast between the initial stage of comparatively slow response and the succeeding stage of rapid response appears to become more marked, with the result that when the control is applied in a normal manner the main response does not occur until the stick has been displaced somewhat. This effect is sometimes mistaken for time lag.

REFERENCES

No.	*Authors*	*Title, etc.*
1	Soulé and McAvoy	Flight Investigation of Lateral Control Devices for Use with Full-span Flaps. N.A.C.A. Report 517. (1935).
2	Wetmore	Flight Tests of Retractable Ailerons on a Highly Tapered Wing. N.A.C.A. Technical Note No. 714. (June, 1939.)

TABLE 1

Particulars of Falcon R.4071.

General	
Weight	2,500 lb.
Rated H.P. at 2,100 r.p.m. at sea level	185
Equivalent power loading	12·7
Wing loading	12·9
Span loading	1·92
C.G. h Aft position	0·29
C.G. h Front position	0·23
Airscrew diameter	7·0 ft.
Airscrew pitch	6·4 ft.

Longitudinal Control	
S' (total tail surface)	25·2 ft.²
Elevator area/S'	0·38
l'/c	2·77
S'/S	0·14
$l'S'/cS$	0·39
Range of elevator angle	± 28°

Directional Control	
S'' (fin rudder area)	11·5 ft.²
l''/b	0·46
$\frac{l''S''}{b\,S}$	0·029
Range of rudder angle	± 24°

Wings	
Wing section. Piercy	Root t/c 0·2 Tip t/c 0·15
Location of max. thickness	0·40c
Mean chord	5·2 ft.
Area (including centre section)	182 ft.²
Span	35 ft.
Aspect ratio	6·7
Dihedral (outer wing)	5°
Sweepback of ¼″ chord line	1°
Root chord/Tip chord	1·6

Lateral Control	
Dist. of spoiler from leading edge/Wing chord	0·70
Spoiler area/Wing area	0·035
Spoiler chord/Local wing chord	0·068 (mean)
Spoiler span/Wing span	0·55 (max.)

Partial Span Split Flaps	
Flap span/Wing span	0·48
Mean flap chord/Mean wing chord	0·154
Max. flap angle	80°

Full Span Split Flaps	
Flaps span/Wing span	0·92
Mean flap chord/Mean wing chord	0·157
Max. flap angle	80°

TABLE 2

Results of Measurements of Time to Bank 45 deg. with ½ and ¾ Full Spoiler

Full-span flap position	Indicated air speed (m.p.h.)	Time to bank 45 deg. (seconds)	
		½ spoiler	¾ spoiler
Fully down	70	3·6	2·5
Up	100	3·9	2·5
Up	120	2·7	1·8
Up	140	2·3	1·4
Up	160	1·8	—

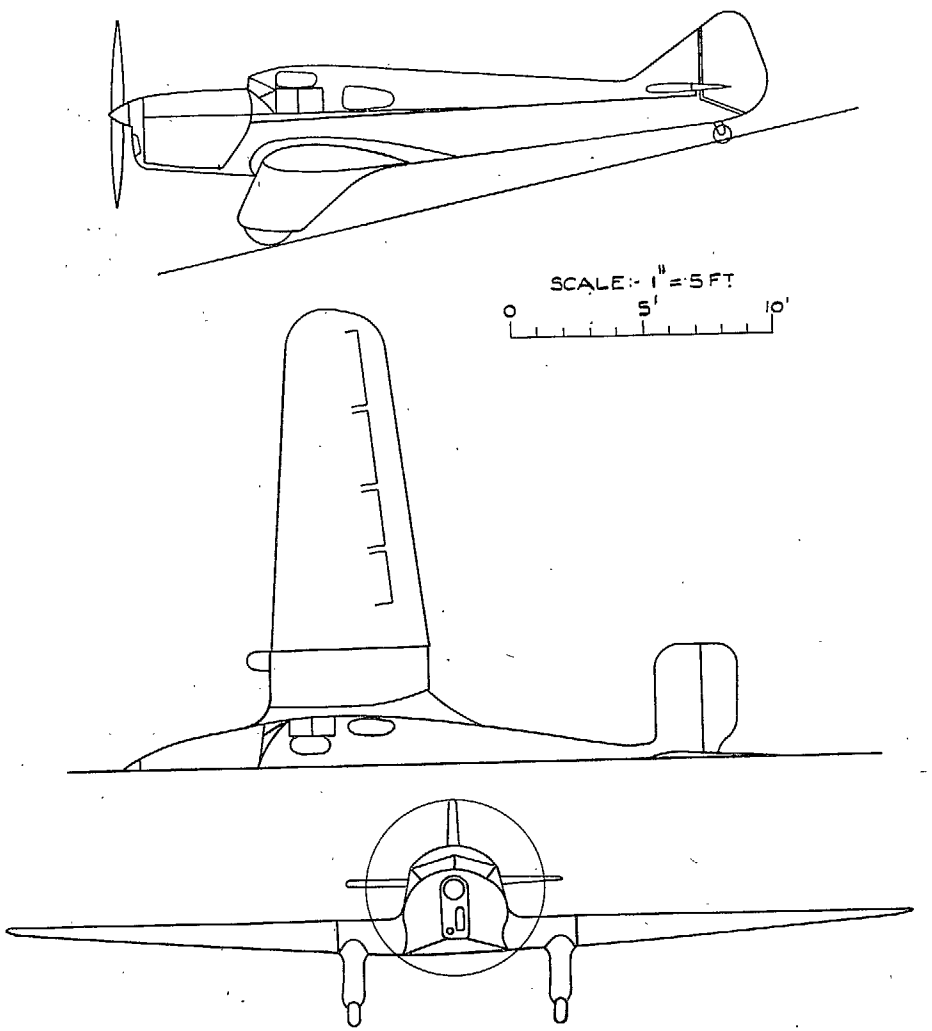
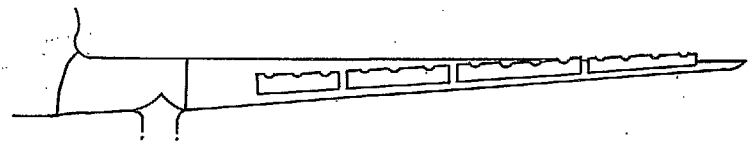
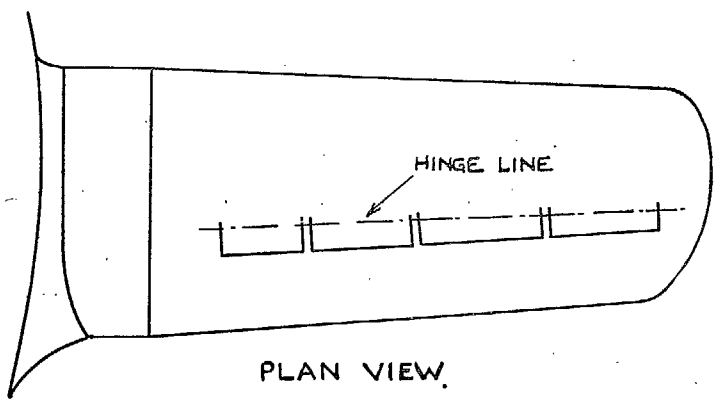


FIG. 1. Falcon R.4071 with Circular-arc Spoilers.

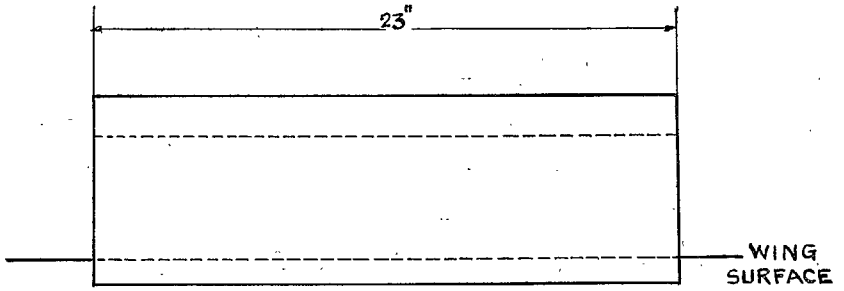


ELEVATION LOOKING FROM REAR
SPOILER FULLY APPLIED.

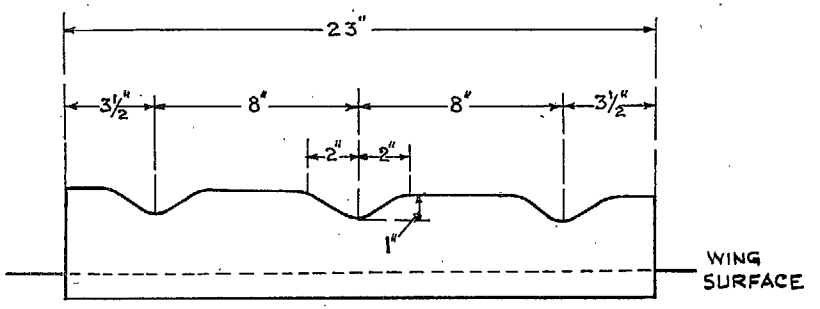


PLAN VIEW.

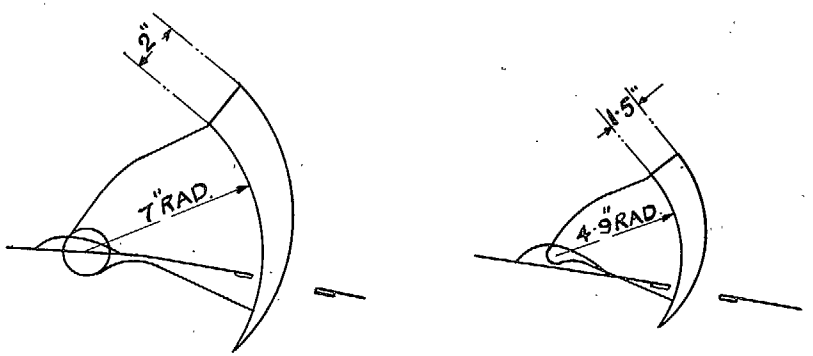
FIG. 2. Diagram Showing Arrangement of Modified Spoiler on Starboard Wing of Falcon.



ELEVATION OF INBOARD SPOILER FULLY EXTENDED

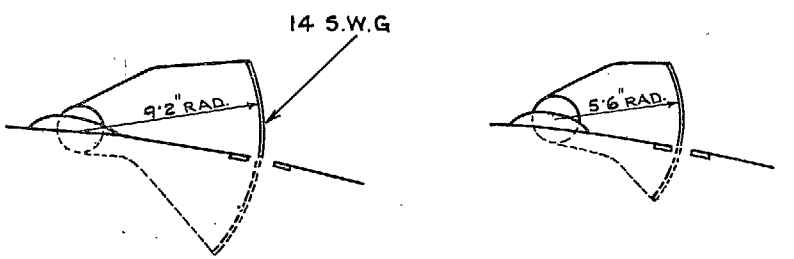


INBOARD SPOILER (ELEVATION)



INBOARD SECTION OUTBOARD SECTION.

FIG. 3. Elevation and End Views of Original Spoiler.



INBOARD SECTION. OUTBOARD SECTION

FIG. 4. Elevation and End View of Modified Spoiler.

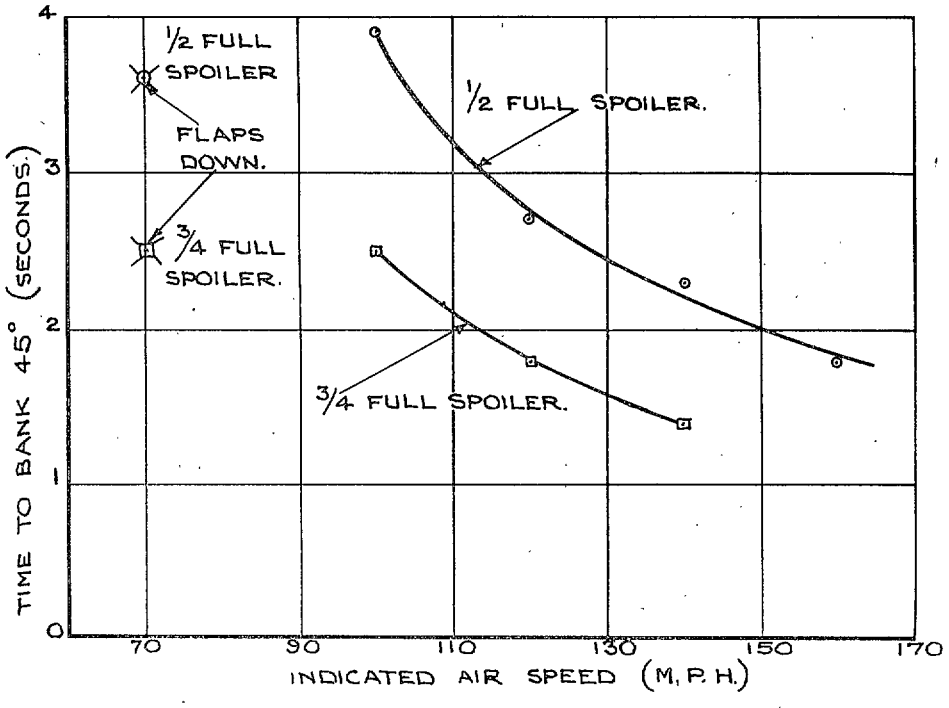


FIG. 5. Curves Showing Time to Bank 45 deg. at Various Speeds with and without Full-span Flaps. (with spoiler lateral control).

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