77012

AERODYNAMIC CENTRE OF WING-FUSELAGE-NACELLE COMBINATIONS: EFFECT OF WING-PYLON MOUNTED NACELLES

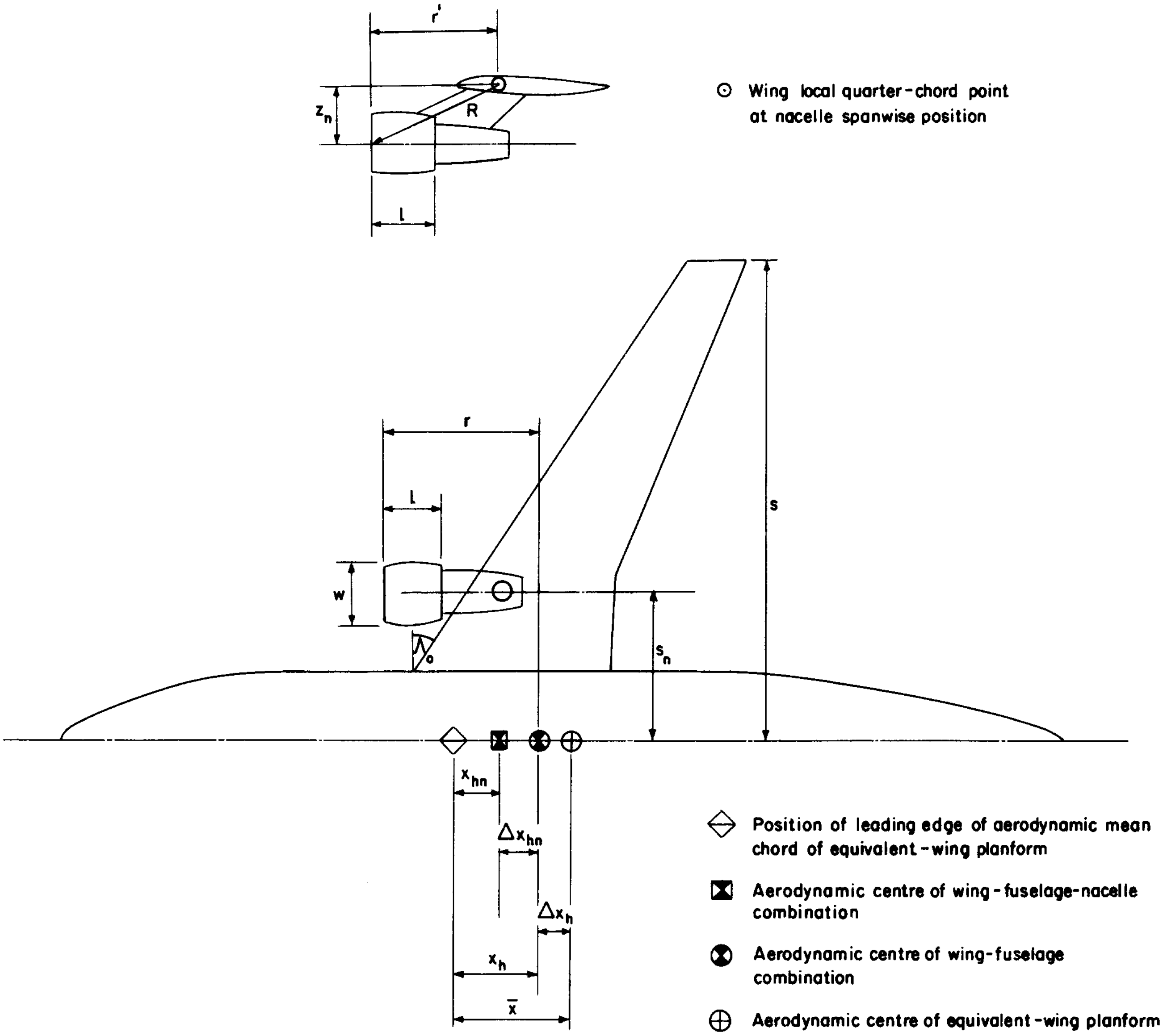
1. NOTATION AND UNITS (see Sketch 1.1)

		SI	*British*
A	aspect ratio of equivalent-wing planform*		
a	lift-curve slope of equivalent-wing planform*	radian^{-1}	radian^{-1}
a_n	lift-curve slope of nacelle, based on area *wl*	radian^{-1}	radian^{-1}
$\bar{c}$	geometric mean chord of equivalent-wing planform*	m	ft
$\bar{\bar{c}}$	aerodynamic mean chord of equivalent-wing planform	m	ft
c_{ref}	general reference chord for stability calculations	m	ft
l	length of nacelle forward cowl or overall length of single cowl nacelle	m	ft
M	Mach number		
R	distance of centre of nacelle inlet from wing local quarter-chord point, $(r'^2 + z_n^2)^{1/2}$	m	ft
r	chordwise distance of nacelle lip forward of aerodynamic centre of wing-fuselage combination	m	ft
r'	chordwise distance of nacelle lip forward of wing local quarter-chord point	m	ft
S	area of equivalent-wing planform*	m^2	ft^2
s	wing semi-span	m	ft
s_n	spanwise distance from fuselage centre-line to nacelle centre-line	m	ft
w	maximum spanwise width of nacelle	m	ft
$\bar{x}$	chordwise location of aerodynamic centre of equivalent-wing planform, measured positive aft from leading edge of aerodynamic mean chord of equivalent-wing planform*	m	ft
x_h	chordwise location of aerodynamic centre of wing-fuselage combination, measured positive aft from leading edge of aerodynamic mean chord of equivalent-wing planform*	m	ft

For footnote refer to end of Notation.

Δx_h	forward shift in chordwise location of aerodynamic centre due to presence of fuselage*	m	ft
x_{hn}	chordwise location of aerodynamic centre of wing-fuselage-nacelle combination, measured positive aft from leading edge of aerodynamic mean chord of equivalent-wing planform	m	ft
Δx_{hn}	forward shift in chordwise location of aerodynamic centre due to presence of nacelles	m	ft
z_n	distance of centre of nacelle inlet below wing local quarter-chord point	m	ft
Λ_0	leading-edge sweep of equivalent-wing planform*	degree	degree

* See Item No. 76015 for definition of equivalent-wing planform and calculation of x_h and Δx_h.



Sketch 1.1

2. METHOD

The forward shift in aerodynamic centre, Δx_{hn}, caused by mounting nacelles on pylons below the wings of wing-fuselage combinations of medium-to-high aspect ratio is calculated, for subsonic speeds, by treating the nacelles as annular aerofoils located in the wing upwash field. This shift is subtracted from the wing-fuselage aerodynamic centre position, calculated from Item No.76015, to provide the location of the overall aerodynamic centre of the wing-fuselage-nacelle combination, x_{hn}, at cruise conditions.

In Item No.76015 the wing-fuselage aerodynamic centre position, x_h, is found by representing the actual gross wing by an equivalent straight-tapered wing, using Item No.70011 to calculate the aerodynamic centre position, $\bar{x}$, of this equivalent wing, and then including a correction term, Δx_h, to allow for the forward shift due to the fuselage. The aerodynamic centre position of the wing-fuselage-nacelle combination, measured positive aft from the leading edge of the aerodynamic mean chord of the equivalent-wing planform, is therefore written

$$\frac{x_{hn}}{\bar{\bar{c}}} = \frac{x_h}{\bar{\bar{c}}} - \frac{\Delta x_{hn}}{\bar{\bar{c}}}, \tag{2.1}$$

where

$$\frac{x_h}{\bar{\bar{c}}} = \frac{\bar{x}}{\bar{\bar{c}}} - \frac{\Delta x_h}{\bar{\bar{c}}} \tag{2.2}$$

and is calculated from Item No.76015.

The effect of nacelles on the position of the aerodynamic centre of the wing-fuselage combination is estimated by adapting to nacelle geometries the results given in Derivation 1 for wind-tunnel tests on isolated annular aerofoils and adding a term to allow for the upwash induced at the nacelle position by the wing. The annular-aerofoil data are adapted by replacing the aerofoil diameter by the maximum spanwise width of the nacelle. The nacelle lift-curve slope, a_n, which results from this procedure is plotted in Figure 1 as a function of *w*/*l*. For nacelles for which a forward fan-cowl surrounds the front of a smaller-diameter afterbody (gas generator cowl, possibly with plug), the forward cowl is considered to have the dominating influence on aerodynamic-centre position and the length of this cowl is used when estimating a_n. The nacelle lift force is assumed to act at the nacelle lip. The effect of the upwash induced by the wing is estimated, approximately, by representing the wing by a line vortex and calculating the increase in incidence this produces at the nacelle lip. The influence of the nacelle and pylon on the aerodynamic loading distribution over the wing is considered to be of secondary importance. The shift in aerodynamic centre position due to nacelles, expressed as a fraction of the aerodynamic mean chord of the equivalent wing, can then be shown to be

$$\frac{\Delta x_{hn}}{\bar{\bar{c}}} = \frac{\Sigma a_n r w l}{S\bar{\bar{c}}}\left[\frac{1}{a} + \frac{r'\bar{c}}{4\pi R^2}\right], \tag{2.3}$$

where $R^2 = z_n^{\;2} + r'^2$, Σ represents the summation of the contributions from each nacelle, and the lift-curve slope of the wing-fuselage-nacelle configuration is taken with sufficient accuracy as *a*, the lift-curve slope of the equivalent-wing planform estimated from Item No. 70011. The first term in Equation (2.3) represents the nacelle-alone contribution, the second term an approximation to the effect of wing upwash.

Normally, aircraft stability calculations will be referred to a point that is not located at the leading edge of the aerodynamic mean chord of the equivalent wing and may be based on a reference chord c_{ref} which is different from $\bar{\bar{c}}$. Item No.76015 describes how to convert aerodynamic-centre positions to a general reference system.

3. ACCURACY AND APPLICABILITY

3.1 Accuracy

The values of Δx_{hn} predicted by Equation (2.3) have been compared with the experimental data contained in Derivations 2 to 8 for 32 conventional wing-fuselage-nacelle arrangements at Mach numbers up to 0.8. The agreement between experiment and prediction is shown in Sketch 3.1 and is better than $\pm 0.02\bar{\bar{c}}$ in almost every case. The mean difference between predicted and experimental values is approximately zero and the root mean square difference is $0.010\bar{\bar{c}}$. The agreement is better at low Mach numbers, being within $\pm 0.015\bar{\bar{c}}$ for Mach numbers below 0.5. Sketch 3.2 shows the values of x_{hn} predicted by Equation (2.1) plotted against the experimental data contained in Derivations 2 to 8. The root mean square error is $0.017\bar{\bar{c}}$, and for 90 per cent of the data the agreement is better than $\pm 0.03\bar{\bar{c}}$, which is the accuracy of Item No.76015 for predicting the aerodynamic centre position of wing-fuselage combinations.

3.2 Applicability

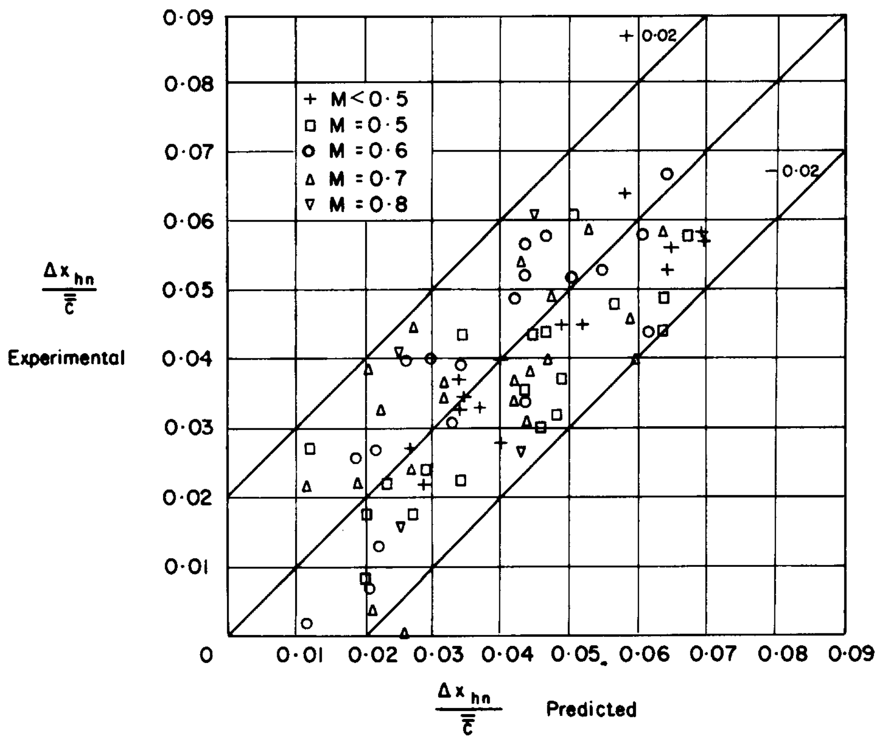
The method calculates the shift in aerodynamic-centre position due to nacelles for conventional wing-fuselage combinations with under-wing pylon-mounted nacelles, with no tailplane fitted and with wing flaps undeployed, at values of lift where the lift-curve slope and rate of change of pitching moment with lift are both essentially linear. The method should only be used when the flow over the configuration is fully attached and wholly subsonic.

The majority of the data studied were from tests with free-flow nacelles, where the mass flow ratio was representative of cruise conditions and fixed by the nacelle geometry. A few data were available from tests in which the mass flow ratio was varied over a range of cruise values. Such variations alter the flow around and through the nacelle, and therefore may be expected to change the position of the aerodynamic centre. However, the experimental values of Δx_{hn} from these tests remained within $\pm 0.02\bar{\bar{c}}$ of the values predicted by Equation (2.3) and changed too erratically for the effect of different mass flow ratios to be determined empirically. Therefore, when predicting Δx_{hn} the mass flow ratio can be ignored, provided it is representative of cruise values.

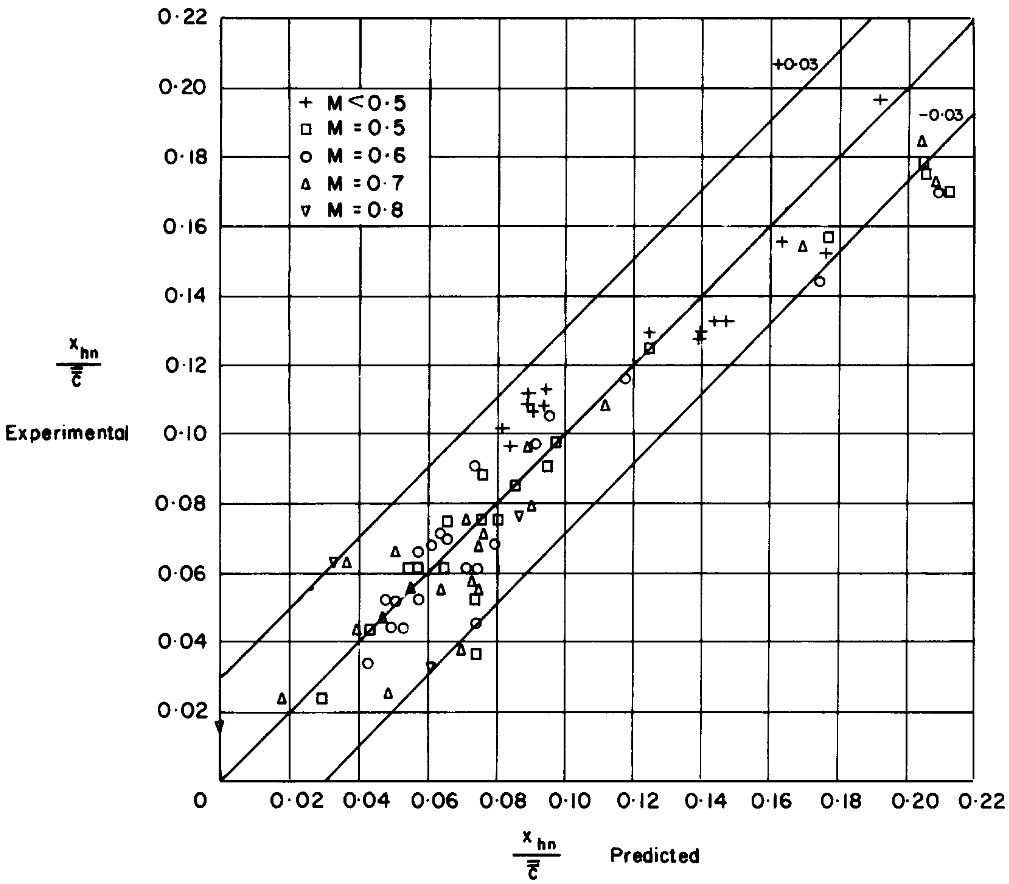
Table 3.1 shows the range of nacelle and wing geometries studied and the method should be used with caution for configurations with geometries that are significantly different. In particular, the effect of nacelles mounted near the tips of wings may be estimated poorly because of the approximation made to the wing upwash.

TABLE 3.1

Parameter	*Range*
A	6.4 to 11.0
Λ_0	5° to 30°
$z_n/\bar{\bar{c}}$	0.22 to 0.48
w/l	0.21 to 0.96
s_n/s	0.22 to 0.52
$w/\bar{\bar{c}}$	0.26 to 0.51
$r'/\bar{\bar{c}}$	0.48 to 1.19



Sketch 3.1



Sketch 3.2

4. DERIVATION

The Derivation lists selected sources that have assisted in the preparation of this Item.

1.	FLETCHER, S.H.	Experimental investigation of lift, drag and pitching moment of five annular airfoils. NACA tech. Note 4117, 1957.
2.	KETTLE, D.J. KURN, A.G. BAGLEY, J.A.	Exploratory tests on an overwing engine installation. RAE tech. Rep.70150, 1970.
3.	MacWILKINSON, D.G. BLACKERBY, W.T. PATERSON, J.H.	Correlation of full-scale drag predictions with flight measurements on the C-141A aircraft – Phase II, wind tunnel test, analysis, and prediction techniques. Volume 2 – Wind tunnel test and basic data. NASA CR-2334, 1974.
4.	–	Unpublished wind-tunnel data from Aérospatiale.
5.	–	Unpublished wind-tunnel data from Aircraft Research Association.
6.	–	Unpublished wind-tunnel data from British Aircraft Corporation (Weybridge).
7.	–	Unpublished wind-tunnel data from Hawker Siddeley Aviation (Hatfield).
8.	–	Unpublished wind-tunnel data from Hawker Siddeley Aviation (Woodford).

5. EXAMPLE

Find the aerodynamic centre of the wing-fuselage-nacelle combination shown in Sketch 5.1 for a Mach number of 0.48, based on a reference chord of 4.5 m and referred to a reference point 20 m aft of the zero datum axis which is 4 m ahead of the fuselage nose.

The aerodynamic centre of the wing-fuselage combination in Sketch 5.1 is calculated as an example in Item No.76015 where the following values are derived: $\bar{c} = 4.674$ m, $\bar{\bar{c}} = 4.874$ m, $S = 149.6\ \text{m}^2$, and, for $M = 0.48$, $a = 4.874\ \text{radian}^{-1}$ and the distance of the wing-fuselage aerodynamic centre from the stability calculation reference point, based on the reference chord of 4.5 m, is – 0.134 (*i.e.* 0.603 m forwards).

From Sketch 5.1 the nacelle lip is 4.2 m forward of the stability calculation reference point. Therefore the distance of the nacelle lip forward of the wing-fuselage aerodynamic centre position is given by

$$\begin{aligned} r &= 4.2 - 0.134 \times 4.5 \\ &= 3.597\ \text{m.} \end{aligned}$$

Again from Sketch 5.1, $z_n = 1.9$ m and $r' = 3.1$ m so that

$$\begin{aligned} R &= (z_n^2 + r'^2)^{1/2} \\ &= (1.9^2 + 3.1^2)^{1/2} \\ &= 3.636\ \text{m.} \end{aligned}$$

The lift-curve slope of the nacelle is obtained from Figure 1 at $w/l = 1.5/3.2 = 0.469$, giving

$$a_n = 1.45\ \text{radian}^{-1}\ .$$

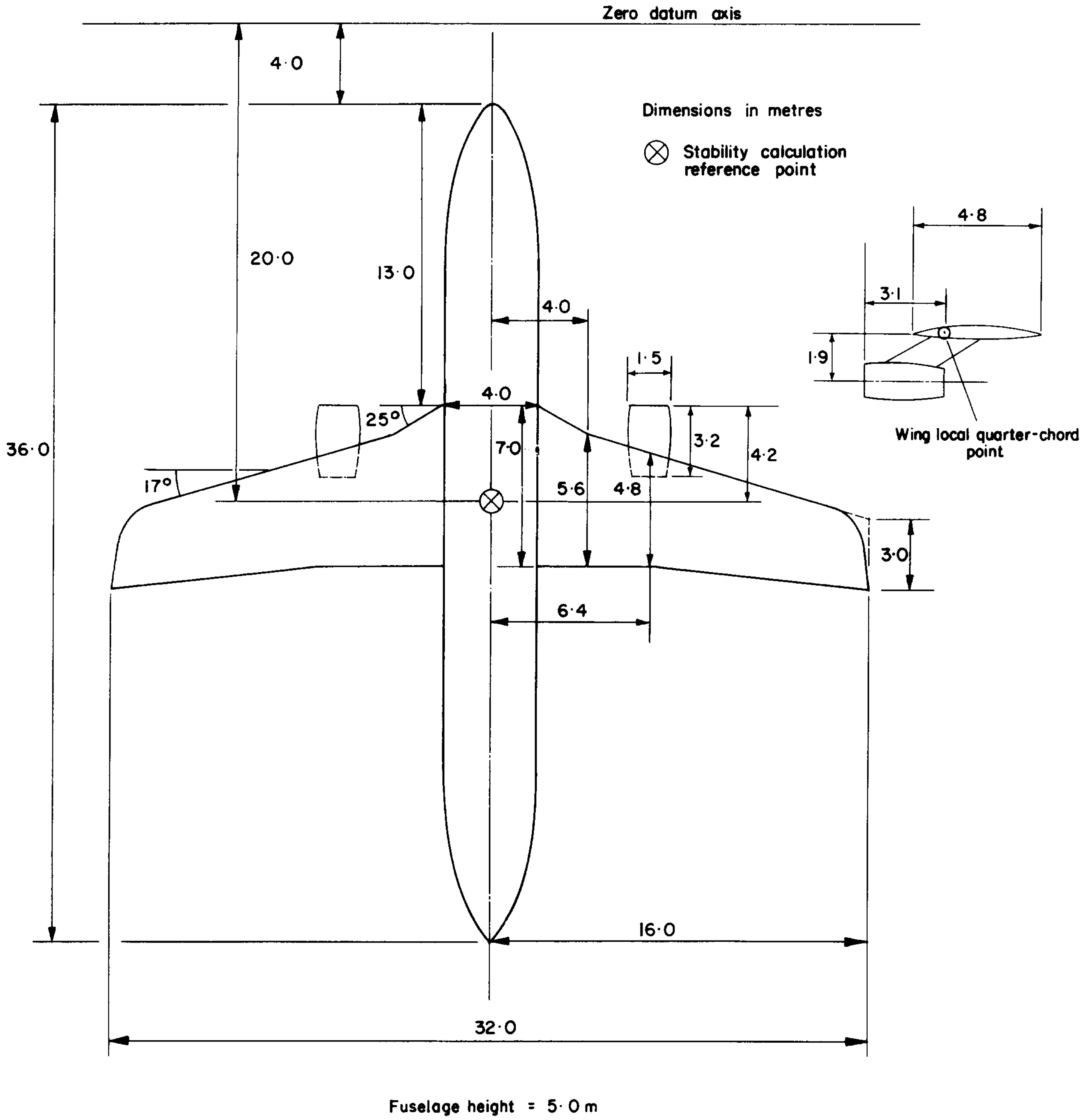
Therefore, from Equation (2.3), the forward shift in aerodynamic centre due to the two nacelles is

$$\begin{aligned} \frac{\Delta x_{hn}}{\bar{\bar{c}}} &= \frac{\Sigma a_n r w l}{S\bar{\bar{c}}}\left[\frac{1}{a} + \frac{r'\bar{c}}{4\pi R^2}\right] \\ &= \frac{2 \times 1.45 \times 3.597 \times 1.5 \times 3.2}{149.6 \times 4.874}\left[\frac{1}{4.874} + \frac{3.1 \times 4.674}{4\pi \times 3.636^2}\right] \\ &= 0.0687[0.2052 + 0.0872] \\ &= 0.0201\,. \end{aligned}$$

Thus the distance of the aerodynamic centre of the wing-fuselage-nacelle configuration from the stability calculation reference point, based on the reference chord of 4.5 m, is

$$\begin{aligned} -0.134 - \frac{\Delta x_{hn}}{\bar{\bar{c}}} \times \frac{\bar{\bar{c}}}{c_{ref}} &= -0.134 - 0.0201 \times \frac{4.847}{4.5} \\ &= -0.156\,. \end{aligned}$$

(The aerodynamic centre is 0.156 × 4.5 = 0.702 m forward of the stability calculation reference point.)



Zero datum axis
4·0
Dimensions in metres
Stability calculation reference point
20·0
13·0
4·0
4·8
3·1
1·9
1·5
4·0
25°
3·2
4·2
Wing local quarter-chord point
36·0
7·0
17°
5·6
4·8
3·0
6·4
16·0
32·0
Fuselage height = 5·0 m

Sketch 5.1

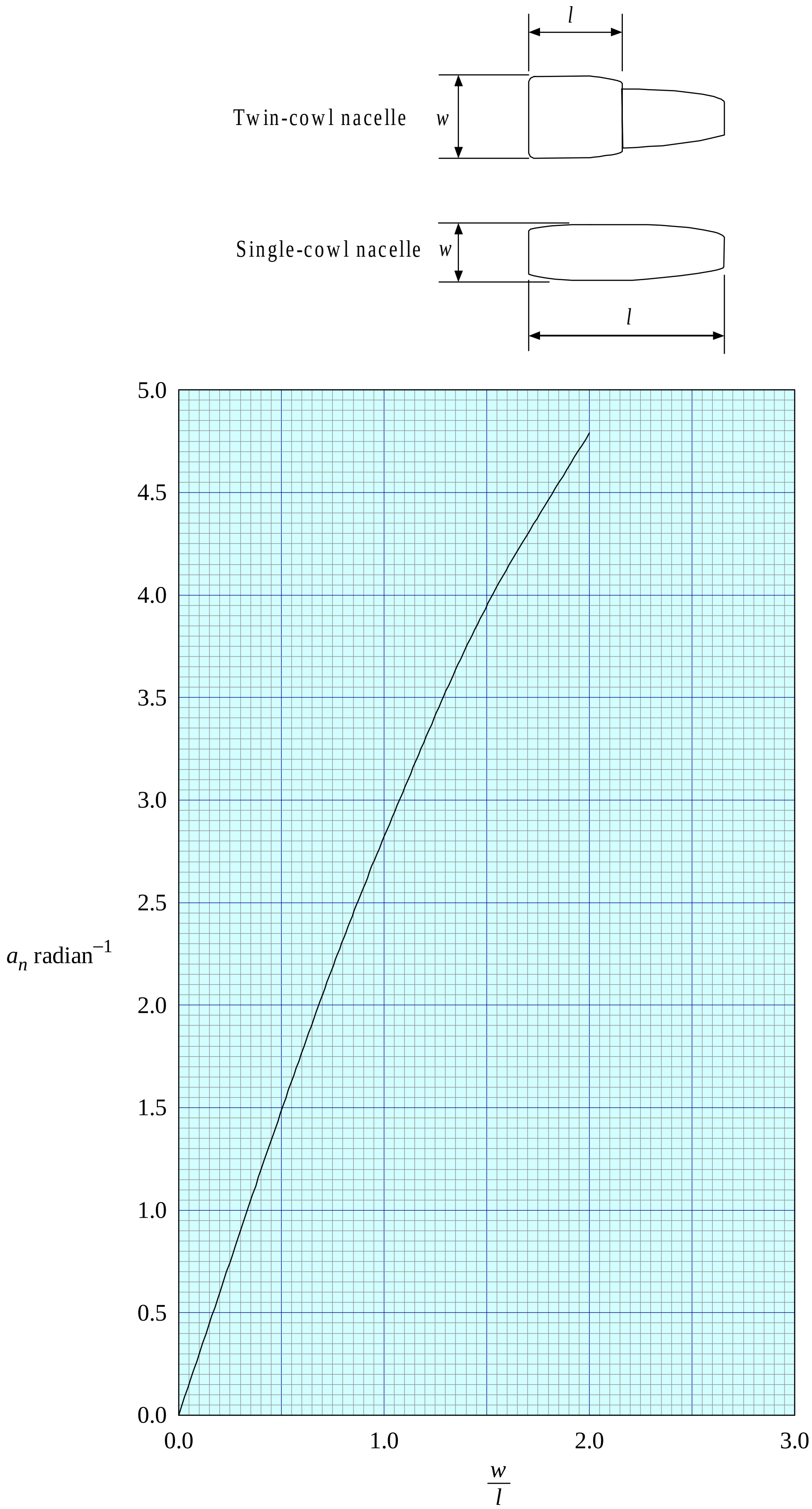


FIGURE 1 LIFT-CURVE SLOPE OF NACELLE

THE PREPARATION OF THIS DATA ITEM

The work on this particular Item was monitored and guided by the Aerodynamics Committee which first met in 1942 and now has the following membership:

Chairman		
Mr J. Weir	–	Salford University
Vice-Chairman		
Mr E.C. Carter	–	Aircraft Research Association
Members		
Prof. L.F. Crabtree	–	Bristol University
Mr J.R.J. Dovey	–	British Aircraft Corporation Ltd, Preston
Mr H.C. Garner	–	Royal Aircraft Establishment
Mr A. Hipp	–	British Aircraft Corporation Ltd, Stevenage
Mr P.K. Jones	–	Hawker Siddeley Aviation Ltd, Woodford
Mr J. Kloos*	–	Saab-Scania, Linköping, Sweden
Prof. G.M. Lilley	–	Southampton University
Mr J.R.C. Pedersen	–	Independent
Mr M.R. Pike	–	Rolls-Royce Ltd, Derby
Mr D. Puyplat	–	Aérospatiale, Toulouse, France
Mr I.H. Rettie*	–	Boeing Aerospace Company, Seattle, Wash., USA
Mr J.J. Spillman	–	Cranfield Institute of Technology
Mr J.W.H. Thomas	–	Hawker Siddeley Aviation Ltd, Hatfield
Mr H. Vogel	–	British Aircraft Corporation Ltd, Weybridge.

* Corresponding Member

The member of staff who undertook the technical work involved in the initial assessment of the available information and the construction and subsequent development of the Item was

Mr R.W. Gilbey – Engineer.