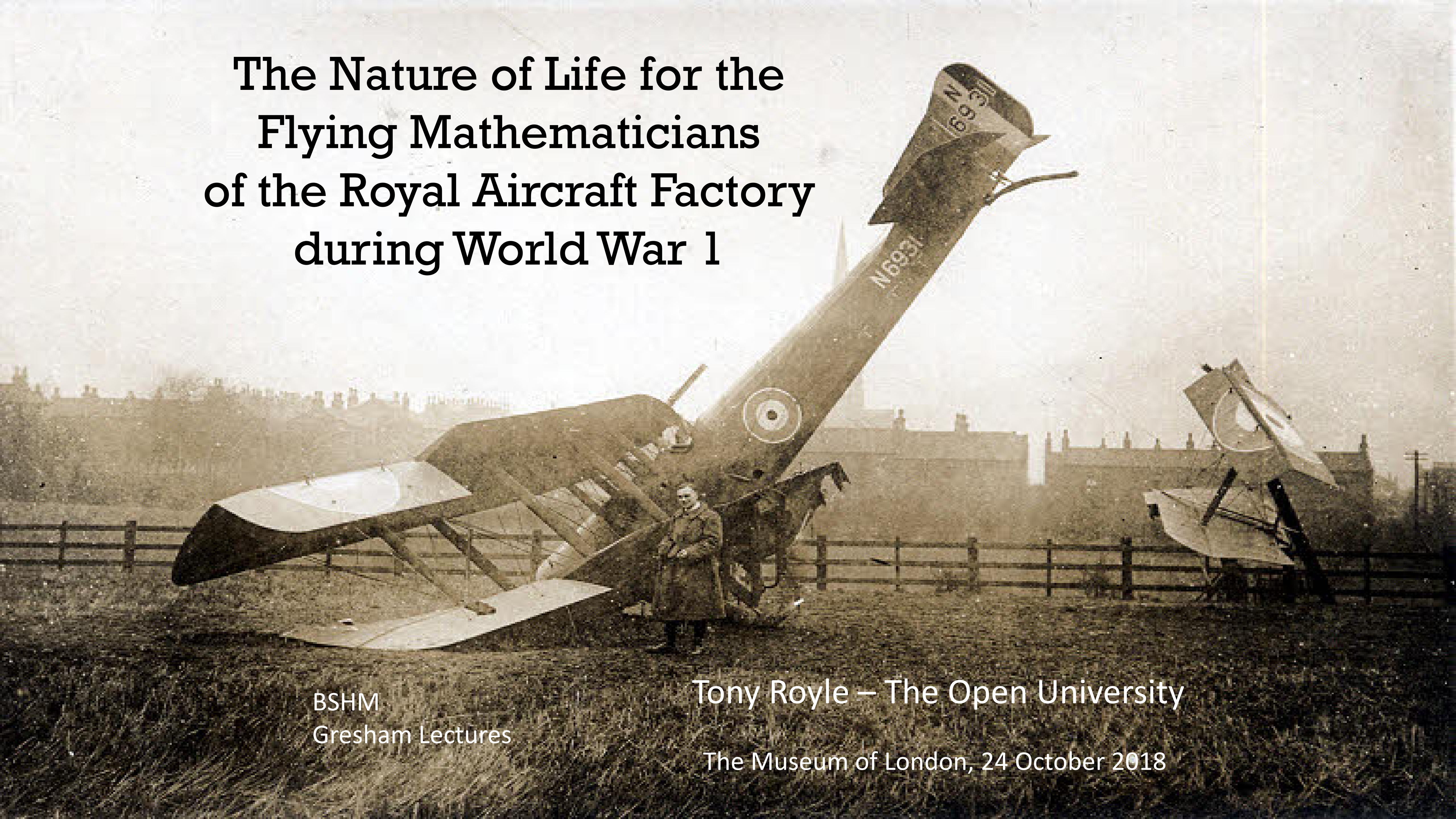
The Nature of Life for the Flying Mathematicians of the Royal Aircraft Factory during World War 1



BSHM
Gresham Lectures

Tony Royle – The Open University

The Museum of London, 24 October 2018

Overview

Brief historical introduction
- **The Flying Monk**
- **The 19th Century**
- **First attempts**

Aeronautical research
- **Landscape in Britain during WW1**
- **The challenges**

The flying mathematicians and scientists

The nature of life – ‘ripping yarns’ with a pilot’s insight

Questions

Eilmer the Flying Monk

MECHANIC'S MAGAZINE.

FLYING IN THE AIR.

Though the science of aerostation is of very modern date, yet there is every reason to believe it was not altogether unknown to the ancients; one of their poets, in allusion to Icarus, says,

at Constantinople, we are told by Knolles, that "amongst the quaint devices of many for solemnizing so great a triumph, there was an active Turk, who had openly given it out, that against an appointed time, he would, from the top of an high tower

Malmesbury Abbey

Malmesbury

Gliders and Balloons

George Cayley

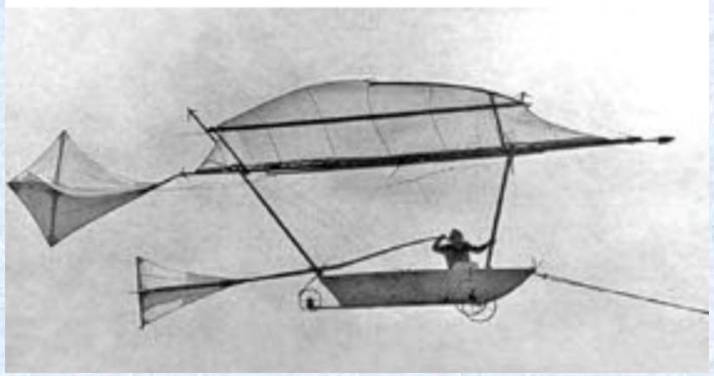
1773-1857

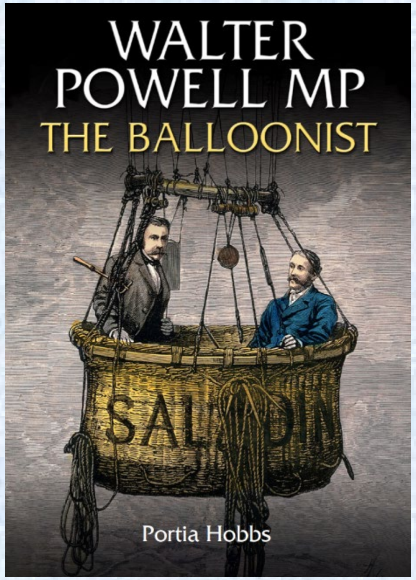
Walter Powell

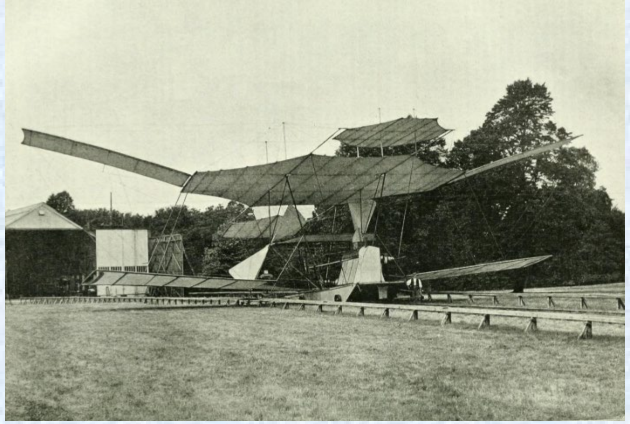
1842-1881

Hiram Maxim

1840-1916







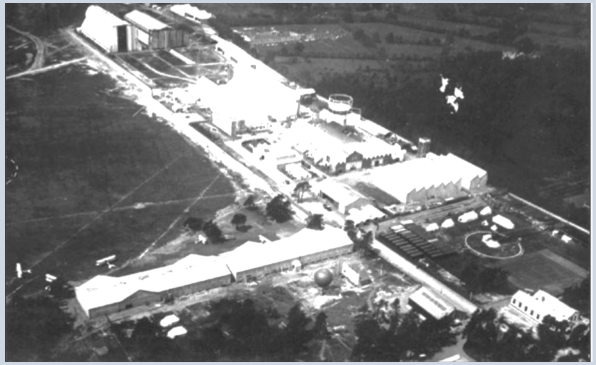
Powered Flight in Britain

John William Dunne

1875-1949

The D4 in Blair Atholl, Scotland
1908

Aeronautical Research in Britain 1914



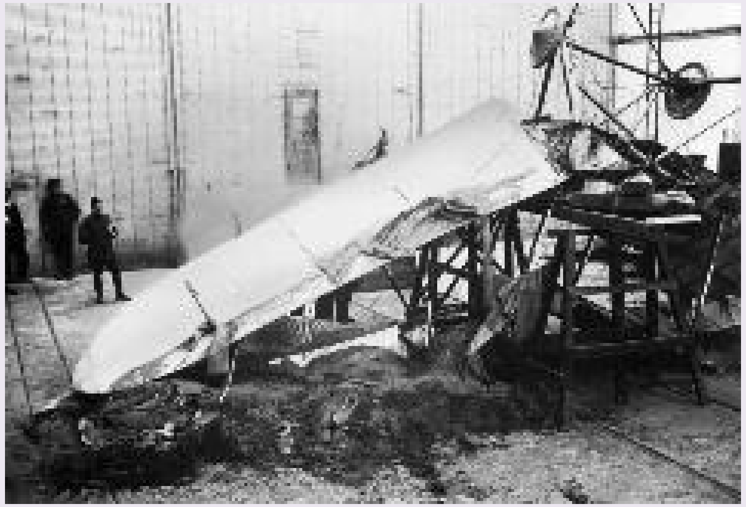
The Royal Aircraft Factory
Farnborough

The National Physical Laboratory
Teddington

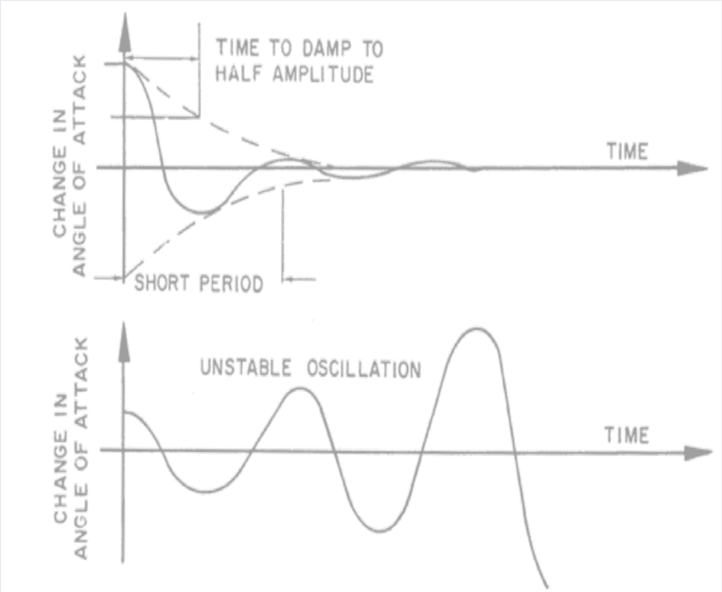
The Admiralty
London

The Challenges Facing Aeronautics

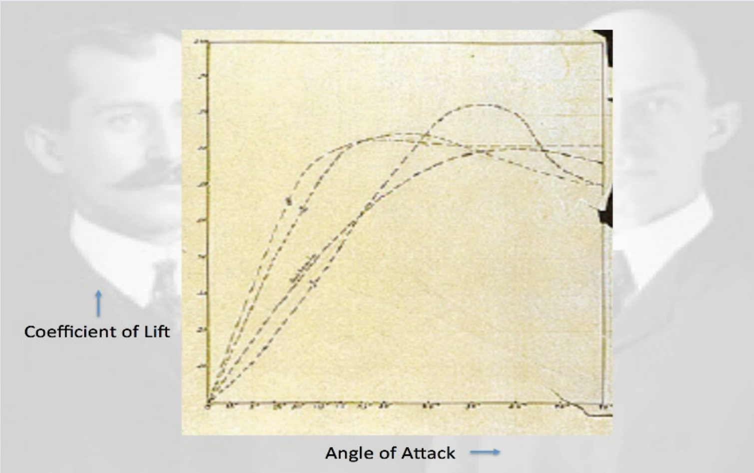
Structural Strength and Resilience



Stability and Control

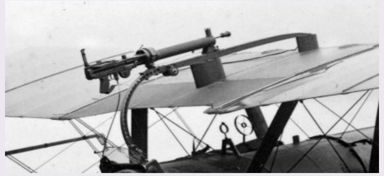


Aerodynamics and Instrumentation



Propulsion

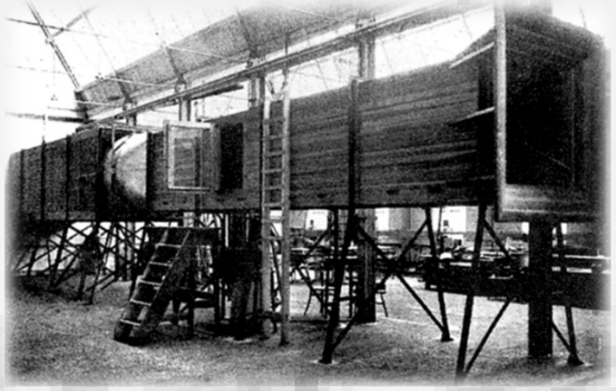
Military
Applications



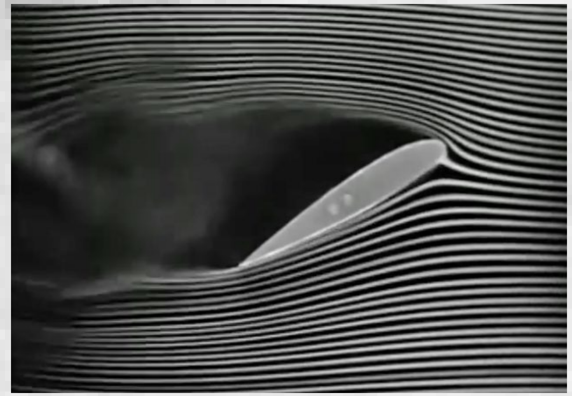
National Physical Laboratory

Leonard Bairstow

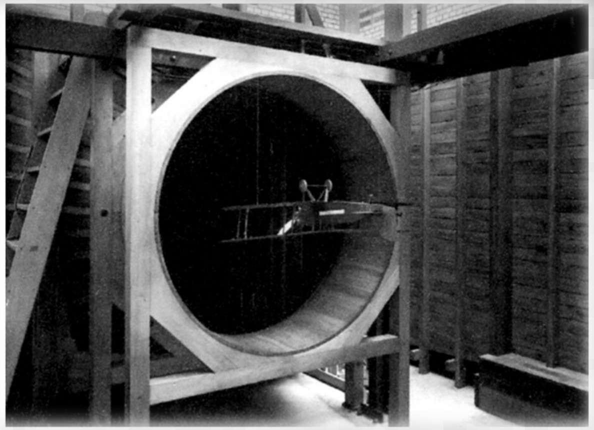
1880-1963



RAF 1907



Wind Tunnel Development and Testing



RAF 1917

Stalling in the Wind Tunnel

Fig:1

Fig:2

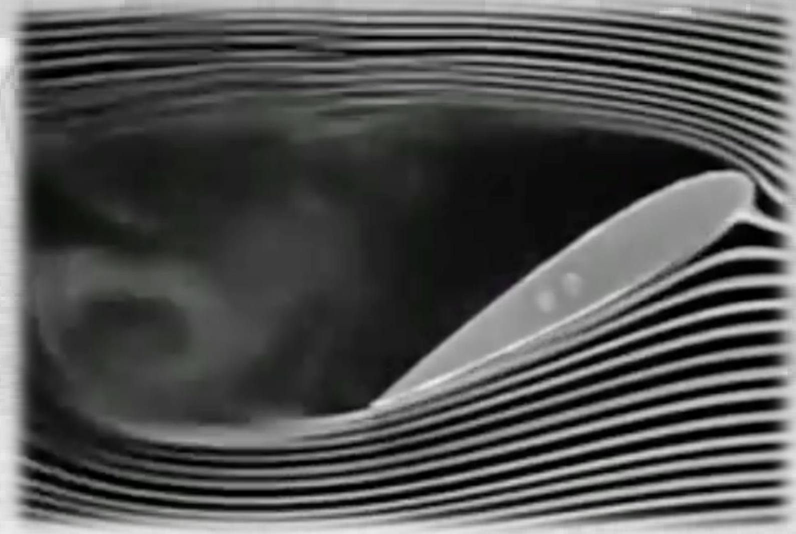
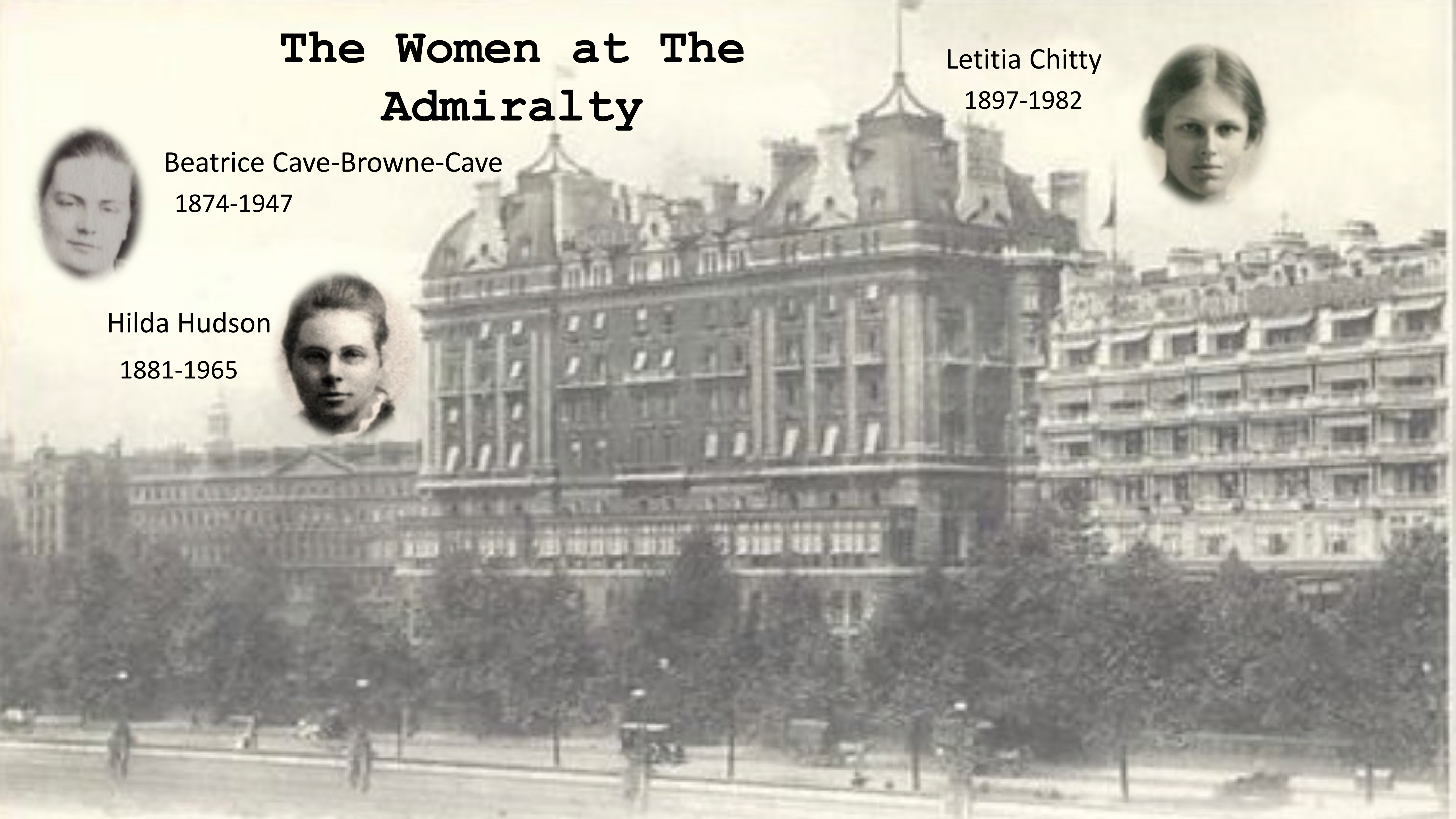


Fig:3

The Women at The Admiralty



Beatrice Cave-Browne-Cave

1874-1947

Hilda Hudson

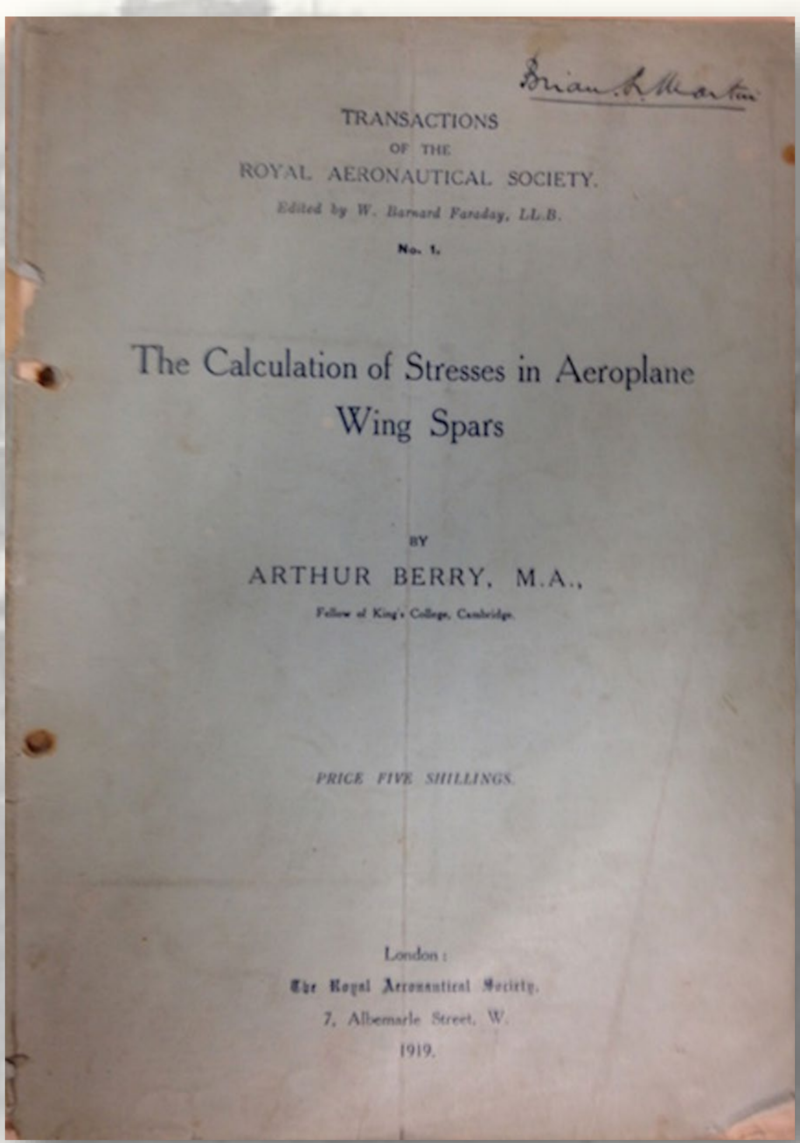
1881-1965

Letitia Chitty

1897-1982

Stressing at the Admiralty

MR. ARTHUR BERRY
(King's College)
Senior Wrangler



Brian L. Martin

TRANSACTIONS
OF THE
ROYAL AERONAUTICAL SOCIETY.
Edited by W. Barnard Faraday, LL.B.

No. 1.

The Calculation of Stresses in Aeroplane Wing Spars

BY

ARTHUR BERRY, M.A.,

Fellow of King's College, Cambridge.

PRICE FIVE SHILLINGS.

London:
The Royal Aeronautical Society,
7, Albemarle Street, W.
1919.

Stressing at the Admiralty

Berry's Re-phrasing of Clapeyron's Equation

$$\frac{a_1}{I_1} M_A \left(\frac{\cot \alpha_1 + \tan \alpha_1}{2\,\alpha_1} - \frac{1}{2\,\alpha_1^2}\right) + \frac{a_2}{I_2} M_C \left(\frac{\cot \alpha_2 + \tan \alpha_2}{2\,\alpha_2} - \frac{1}{2\alpha_2^2}\right)$$
$$+ M_B \left\{\frac{a_1}{I_1}\left(\frac{1}{2\,\alpha_1^2} - \frac{\cot \alpha_1 - \tan \alpha_1}{2\,\alpha_1}\right) + \frac{a_2}{I_2}\left(\frac{1}{2\alpha_2^2} - \frac{\cot \alpha_2 - \tan \alpha_2}{2\,\alpha_2}\right)\right\}$$
$$= \frac{w_1\, a_1^3}{I_1}\left(\frac{\tan \alpha_1}{\alpha_1^3} - \frac{1}{\alpha_1^2}\right) + \frac{w_2\, a_2^3}{I_2}\left(\frac{\tan \alpha_2}{\alpha_2^3} - \frac{1}{\alpha_2^2}\right)$$

$$\text{or } \frac{a_1}{I_1} M_A \left(\frac{3}{2} \cdot \frac{2\,\alpha_1 \operatorname{cosec} 2\,\alpha_1 - 1}{\alpha_1^2}\right) + \frac{a_2}{I_2} M_C \left(\frac{3}{2} \cdot \frac{2\,\alpha_2 \operatorname{cosec} 2\,\alpha_2 - 1}{\alpha_2^2}\right)$$
$$+ 2\, M_B \left\{\frac{a_1}{I_1}\left(\frac{3}{4} \cdot \frac{1 - 2\,\alpha_1 \cot 2\,\alpha_1}{\alpha_1^2}\right) + \frac{a_2}{I_2}\left(\frac{3}{4} \cdot \frac{1 - 2\,\alpha_2 \cot 2\,\alpha_2}{\alpha_2^2}\right)\right\}$$
$$= \frac{w_1\, a_1^3}{I_1} \cdot 3 \cdot \frac{\tan \alpha_1 - \alpha_1}{\alpha_1^3} + \frac{w_2\, a_2^3}{I_2} \cdot 3 \cdot \frac{\tan \alpha_2 - \alpha_2}{\alpha_2^3}$$

Berry's Re-phrased Equations with Functions

This equation may be expressed :—

$$\frac{a_1}{I_1} M_A f(\alpha_1) + \frac{a_2}{I_2} M_C f(\alpha_2) + 2\, M_B \left\{\frac{a_1}{I_1} \varphi(\alpha_1) + \frac{a_2}{I_2} \varphi(\alpha_2)\right\}$$
$$= \frac{w_1\, a_1^3}{I_1} \psi(\alpha_1) + \frac{w_2\, a_2^3}{I_2} \psi(\alpha_2) \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where

$$f(\alpha) = \frac{3}{2} \frac{2\,\alpha \operatorname{cosec} 2\,\alpha - 1}{\alpha^2}$$

$$\varphi(\alpha) = \frac{3}{4} \frac{1 - 2\,\alpha \cot 2\,\alpha}{\alpha^2}$$

$$\psi(\alpha) = 3\, \frac{\tan \alpha - \alpha}{\alpha^3}$$

Berry Functions Table

Appendix IA.

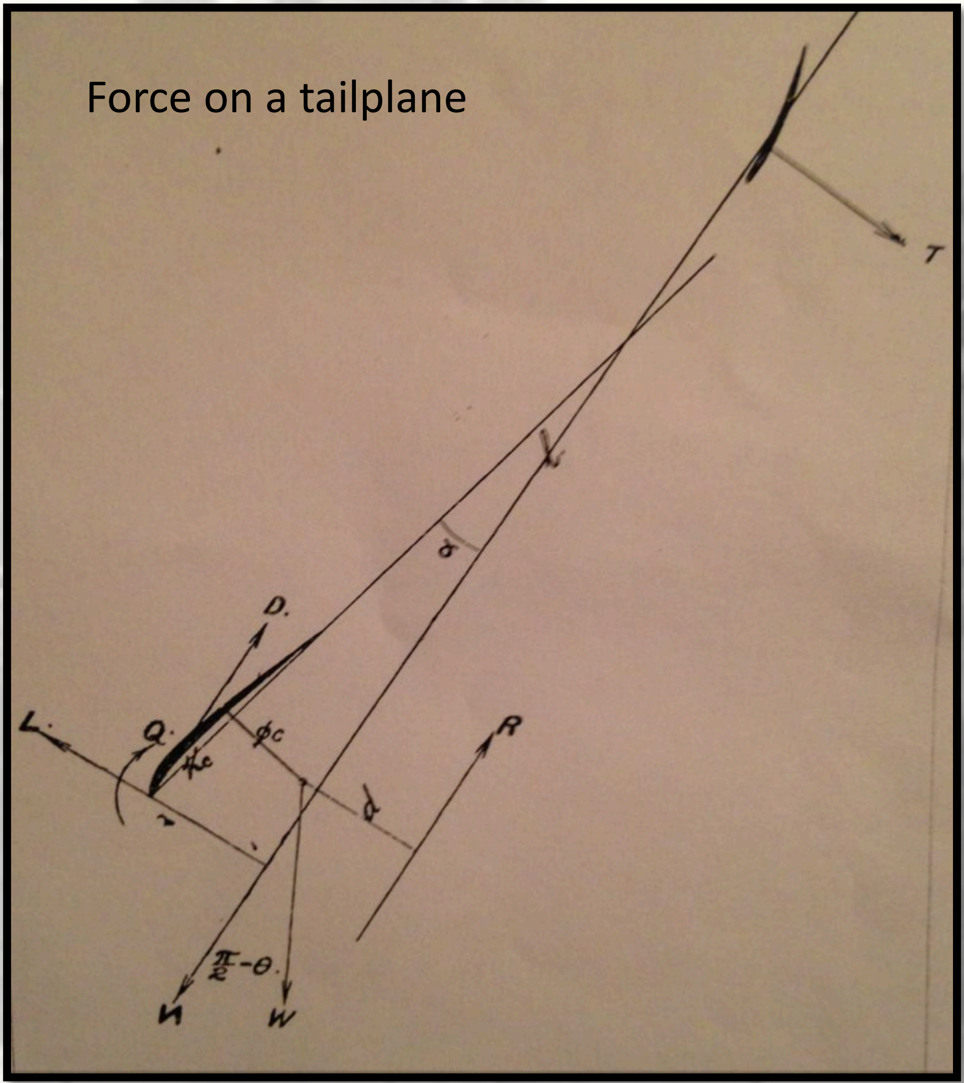
TABLE I.

$f(\theta) = 6\,(2\theta \operatorname{cosec} 2\theta - 1)/(2\theta)^2$, $\varphi(\theta) = 3\,(1 - 2\theta \cot 2\theta)/(2\theta)^2$, $\psi(\theta) = 3\,(\tan \theta - \theta)/\theta^3$.

θ	$f(\theta)$	$\varphi(\theta)$	$\psi(\theta)$	θ	$f(\theta)$	$\varphi(\theta)$	$\psi(\theta)$
0°	1·0000	1·0000	1·0000	50°	1·5211	1·2879	1·4405
1	1·0001	1·0001	1·0001	51	1·5524	1·3048	1·4666
2	1·0006	1·0003	1·0005	52	1·5856	1·3226	1·4944
3	1·0013	1·0007	1·0011	53	1·6208	1·3415	1·5237
4	1·0023	1·0013	1·0019	54	1·6582	1·3615	1·5549
5	1·0036	1·0020	1·0030	55	1·6979	1·3827	1·5880
6	1·0051	1·0029	1·0044	56	1·7403	1·4052	1·6232
7	1·0070	1·0040	1·0060	57	1·7853	1·4291	1·6607
8	1·0092	1·0052	1·0078	58	1·8335	1·4546	1·7007
9	1·0116	1·0066	1·0099	59	1·8550	1·4818	1·7434
10	1·0144	1·0082	1·0123	60	1·9401	1·5109	1·7891
11	1·0175	1·0100	1·0150	61	1·9994	1·5421	1·8381
12	1·0209	1·0120	1·0179	62	2·0631	1·5755	1·8908
13	1·0246	1·0140	1·0210	63	2·1318	1·6115	1·9476
14	1·0286	1·0163	1·0245	64	2·2060	1·6503	2·0089
15	1·0329	1·0188	1·0282	65	2·2865	1·6922	2·0753

Stressing at the Admiralty

Beatrice Cave-Browne-Cave



Farnborough – The Key

The Stability Conundrum

Multiplying by λ to remove λ from the denominator in the upper line and developing the determinant in powers of λ we get an equation of the fourth degree which we write

$$\mathfrak{A}_o\lambda^4 + \mathfrak{B}_o\lambda^3 + \mathfrak{C}_o\lambda^2 + \mathfrak{D}_o\lambda + \mathfrak{E}_o = 0 \quad . \quad . \quad . \quad (17)$$

where

$$\begin{aligned}
\mathfrak{A}_o &= CW^2 \\
\frac{\mathfrak{B}_o}{g} &= CW(X_u + Y_v) + W^2N_r \\
\frac{\mathfrak{C}_o}{g^2} &= C(X_uY_v - X_vY_u) + W\{(Y_vN_r - Y_rN_v) + (X_uN_r - X_rN_u)\} \\
&\quad - W^2\frac{U}{g}N_v \\
\frac{\mathfrak{D}_o}{g^3} &= X_u(Y_vN_r - Y_rN_v) + X_v(Y_rN_u - Y_uN_r) + X_r(Y_uN_v - Y_vN_u) \\
&\quad + W\frac{U}{g}(X_vN_u - X_uN_v) + \frac{W^2}{g}(N_u\cos\theta_o - N_v\sin\theta_o) \\
\frac{\mathfrak{E}_o}{g^4} &= \frac{W}{g}\{-\cos\theta_o(Y_uN_v - Y_vN_u) - \sin\theta_o(X_uN_v - X_vN_u)\}
\end{aligned} \quad (18)$$

$$\mathfrak{A}_o\lambda^4 + \mathfrak{B}_o\lambda^3 + \mathfrak{C}_o\lambda^2 + \mathfrak{D}_o\lambda + \mathfrak{E}_o = 0 \quad . \quad . \quad . \quad (17)$$

Ted Busk – R.E. 1

First R.E. 1 Flight – July 1913

Ted Busk – B.E.2c

First B.E.2c Flight – 30th May 1914

The Tale of the Vertical Dive

Health & Safety?

Ted Busk
B.E.2c Crash

5th Nov 1914

General Sir William Sefton Branker:

"Your son is an irreparable loss to the British Army and, indeed, to the nation, for there are few men available with a like combination of an exceptional brain and scientific knowledge with perfect courage."

The Chudleigh Lot

The Test Pilots

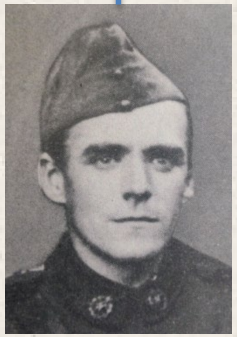
Geoffrey de Havilland

Ted Busk

Goodden

Hill

Farren



Taylor

Thomson

Lucas

Lindemann

The Meteorologist

G. I. Taylor
1886-1975

"…. the aeroplanes used to come in close to the roof making a fearful noise and quite often crashed just outside our windows!"

The Tale of the Darts

The project was cancelled by a senior Army officer who insisted the darts were an "inhuman way of killing people and could not possibly be used by gentlemen!"

"If I had not seen this I would never have believed that it was possible to make such good shooting from the air!"

Melvill Jones
1887-1975

G.I. Taylor

The Tale of the Sewage Farm

"I must confess, however, that I was bad at judging distances. My first landing was too far along the field and ended in the sewage farm just outside it!"

The Tale of the 2000-foot Tree

"I had complete faith in my instruments and did not look at the ground until it was necessary to land on it."

"On one occasion that faith was perhaps misplaced because while I was turning as I thought about 2000' up, the tail of my eye caught sight of a tree quite close to it – it turned out the instrument I was relying on was the rev counter, not the altimeter!"

Cockpit Instruments

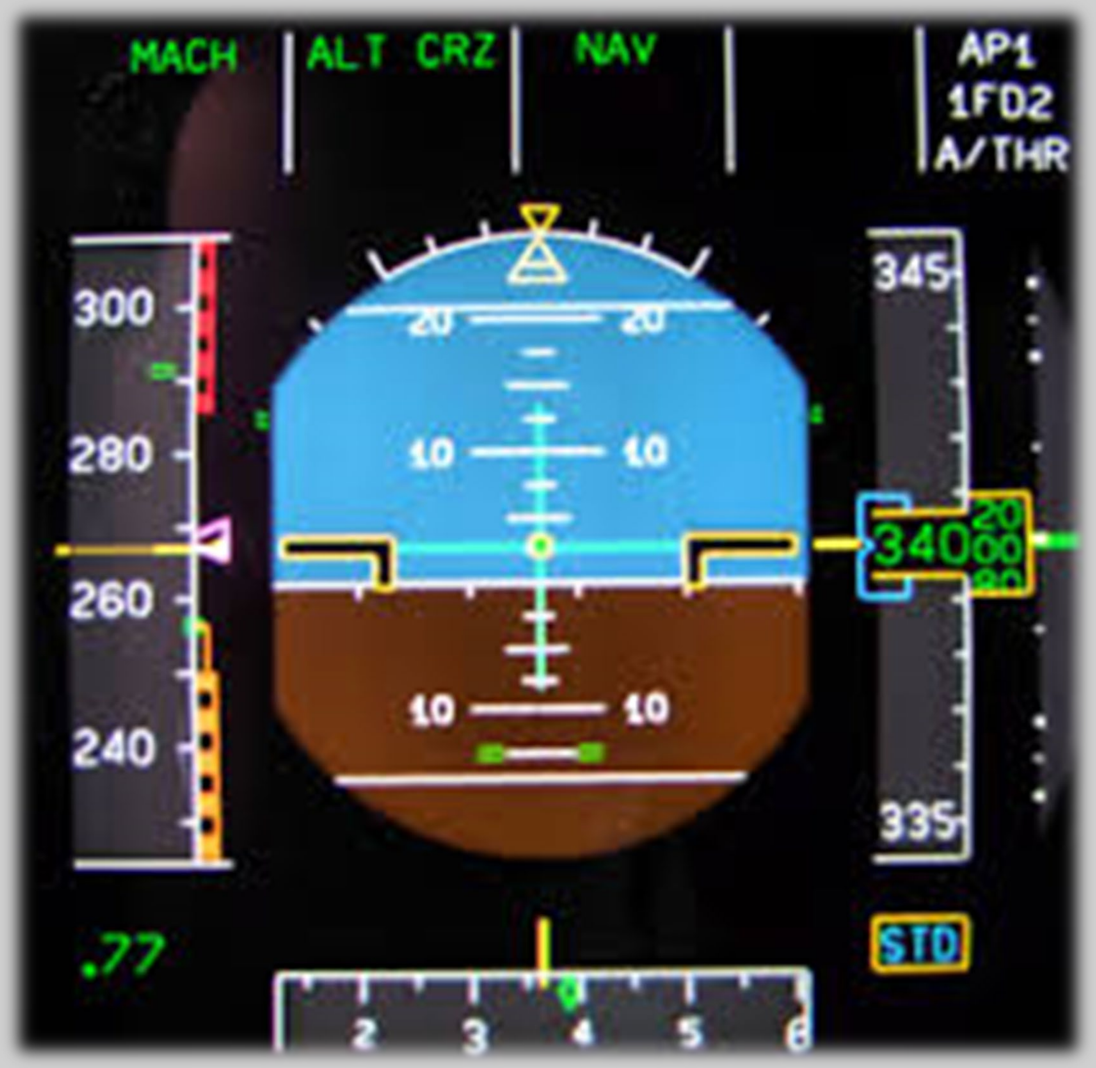
Then

Now

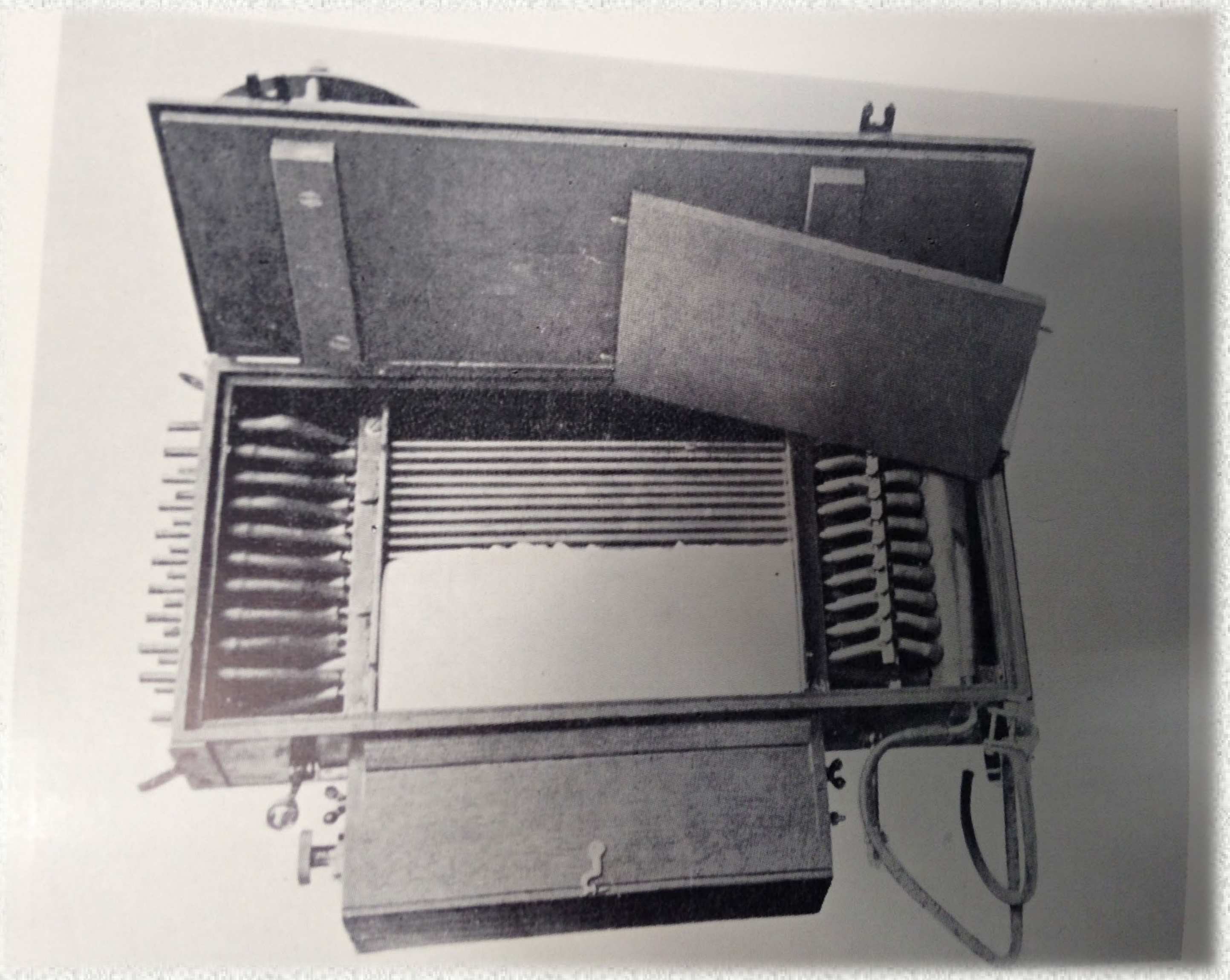
Artificial Horizons

Then

Now



Taylor's Multiple Manometer

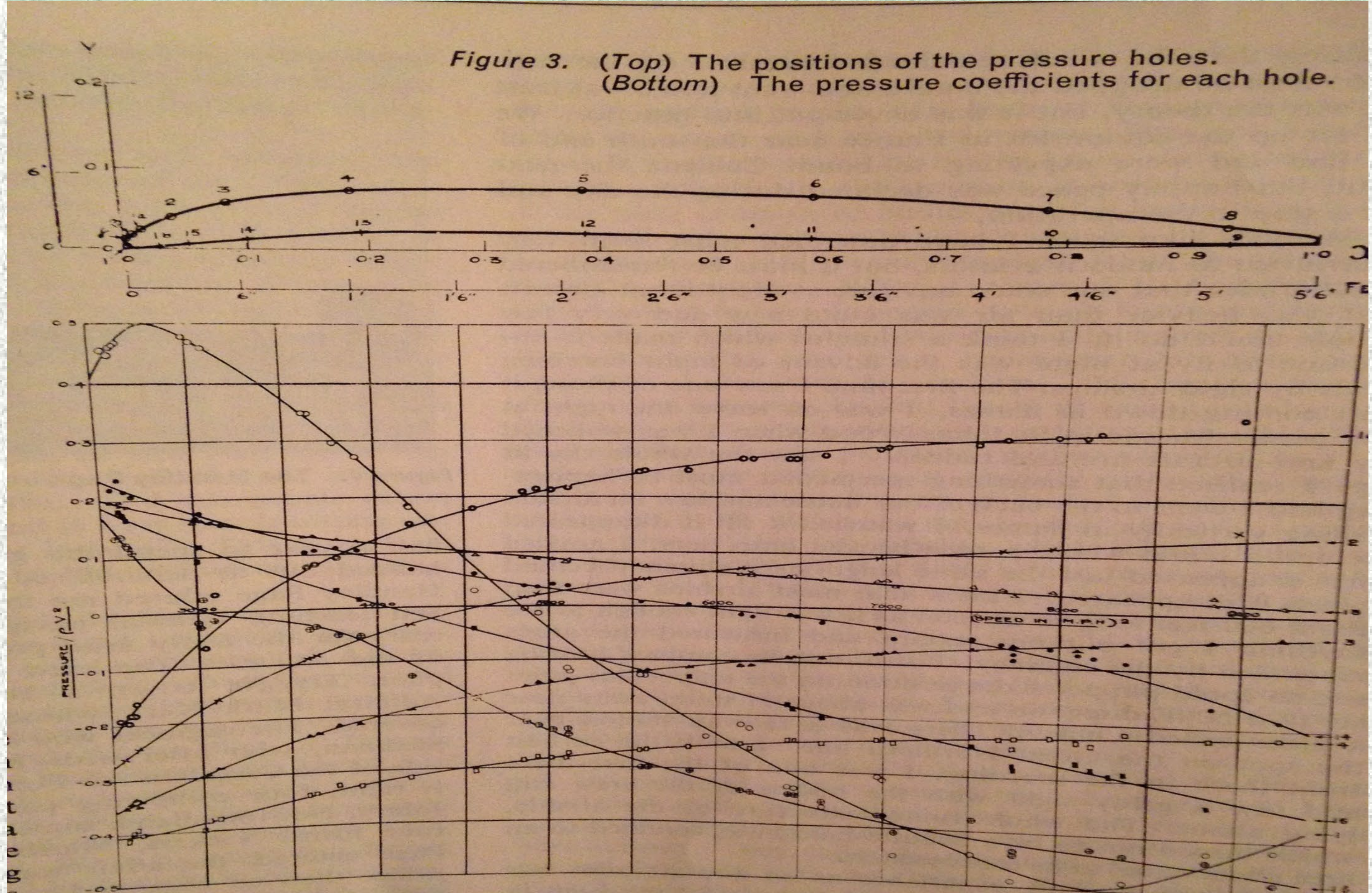


Multiple Manometer Image

In the Cockpit

David Pinsent in a D.H. 1 (front cockpit) with William Farren

Taylor’s Pressure Distribution around a Wing in Flight



The Scourge of the Stall and Spin

Hume-Rothery's Analysis of the Stall

SEPTEMBER 20, 1913.

FLIGHT

THE VOL PIQUÉ.

By J. H. HUME-ROTHERY, M.A., B.Sc.

[FOLLOWING upon a request made at the time of the last Olympia Show, Mr. J. H. Hume-Rothery has been devoting a great deal of his time to the mathematical investigation of the conditions represented by the forced dive as a consequence of being partially stalled in the air. The question as to the least height in which it is possible to recover horizontal flight after being stalled is a matter of first-class importance to pilots, for there is evidence that more than one accident has happened as a consequence of being unable to flatten out in the height available. We trust, therefore, that Mr. Hume-Rothery's article, which represents infinitely more labour than is apparent from the abbreviated and simplified form in which he presents his conclusions, will be read with the interest and appreciation that it deserves.—ED.]

IF an aeroplane loses its velocity relative to the air in which it is flying, the air pressure on its wings is then insufficient to support its weight, and it begins to descend. If this loss of velocity is considerable, the descent will be a more or less headlong dive—a *vol piqué*—in which, like any other falling body, the aeroplane will regain speed. This loss of velocity may be due to the pilot's attempting to climb too steeply, and so bringing the aeroplane almost to a standstill, but it may also be due to causes quite beyond his control, such as sudden changes in the strength of the wind. While ordinary gusts are of very short duration, it is pointed out on p. 217 of the Technical Report of the Advisory Committee on Aeronautics for 1911-12, that not infrequently gusts occur which last for one minute or even longer. If an aeroplane is flying down-wind during such an increase of wind velocity, or flying up-wind during a sudden lull, it experiences a sudden loss of relative velocity, and a dive must follow.

The most important point in practice is to know how great a vertical fall the aeroplane must undergo before it can regain its normal speed and horizontal direction of flight, as if it reaches the ground before this an accident will probably occur. A knowledge of this matter then will help us to form an estimate of the minimum height above the earth at which it is safe to fly.

In order to calculate this, it is necessary to know exactly the air pressures on the aeroplane at all velocities and angles of incidence. The above-mentioned Technical Report gives these very

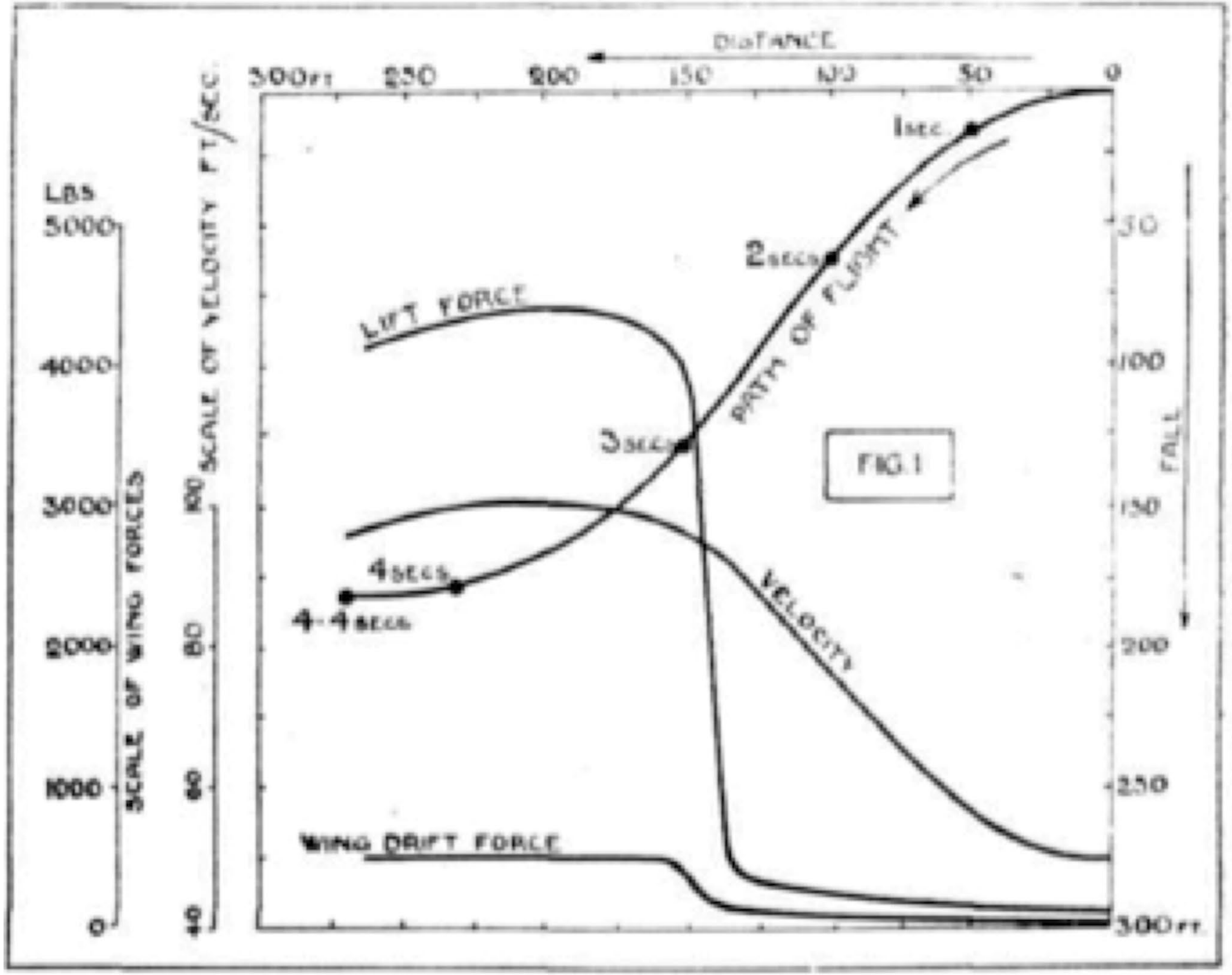
25 sq. ft., which, if deflected 20° at a speed of 62 m.p.h., would give a pressure of about 210 lbs. at a distance of 16 ft. from the centre of gravity, or a couple of 3,360 ft.-lbs. Since the moment of inertia of the aeroplane is given as 1,300 ft.^{2} lbs., this would give an angular acceleration of about 2·6. At a speed of 50 ft. per sec., or about 34 m.p.h., it would give about ·8.

The calculations show that generally this is sufficient for the purpose, but at one or two points where there is a sudden change in the angle of incidence this change may require a fraction of a second more time than has been allowed. Also at the beginning of the dive the aeroplane must make a sudden swing downward, for which the elevator would be insufficient if the gust of wind were absolutely instantaneous, as the elevator would take about $\frac{3}{4}$ sec. to give the necessary downward swing. As, however, no gust is absolutely instantaneous, but takes perhaps $\frac{1}{2}$ sec. or more to develop its full force, the elevator has probably sufficient time for the purpose. In no case can this assumption lead to more than a small error.

While sufficient for the above purpose, it is also assumed (which is only approximately true) that the variations of force on the elevator may, in calculating the motion of the centre of gravity of the aeroplane, be neglected in comparison with the pressures on the main planes.

In the first calculation (the results of which are given in Fig. 1), the aeroplane with velocity of 50 ft. per sec. in a horizontal direction starts from o. The pilot puts the elevator hard down, so as to make

Stall


DISTANCE
300FT
250
200
150
100
50
0
LBS
5000
4000
3000
2000
1000
0
SCALE OF WING FORCES
SCALE OF VELOCITY FT/SEC.
100
80
60
40
1SEC.
2SECS
3SECS
4SECS
4·4SECS
PATH OF FLIGHT
LIFT FORCE
VELOCITY
WING DRIFT FORCE
FIG. 1
FALL
50
100
150
200
250
300FT.

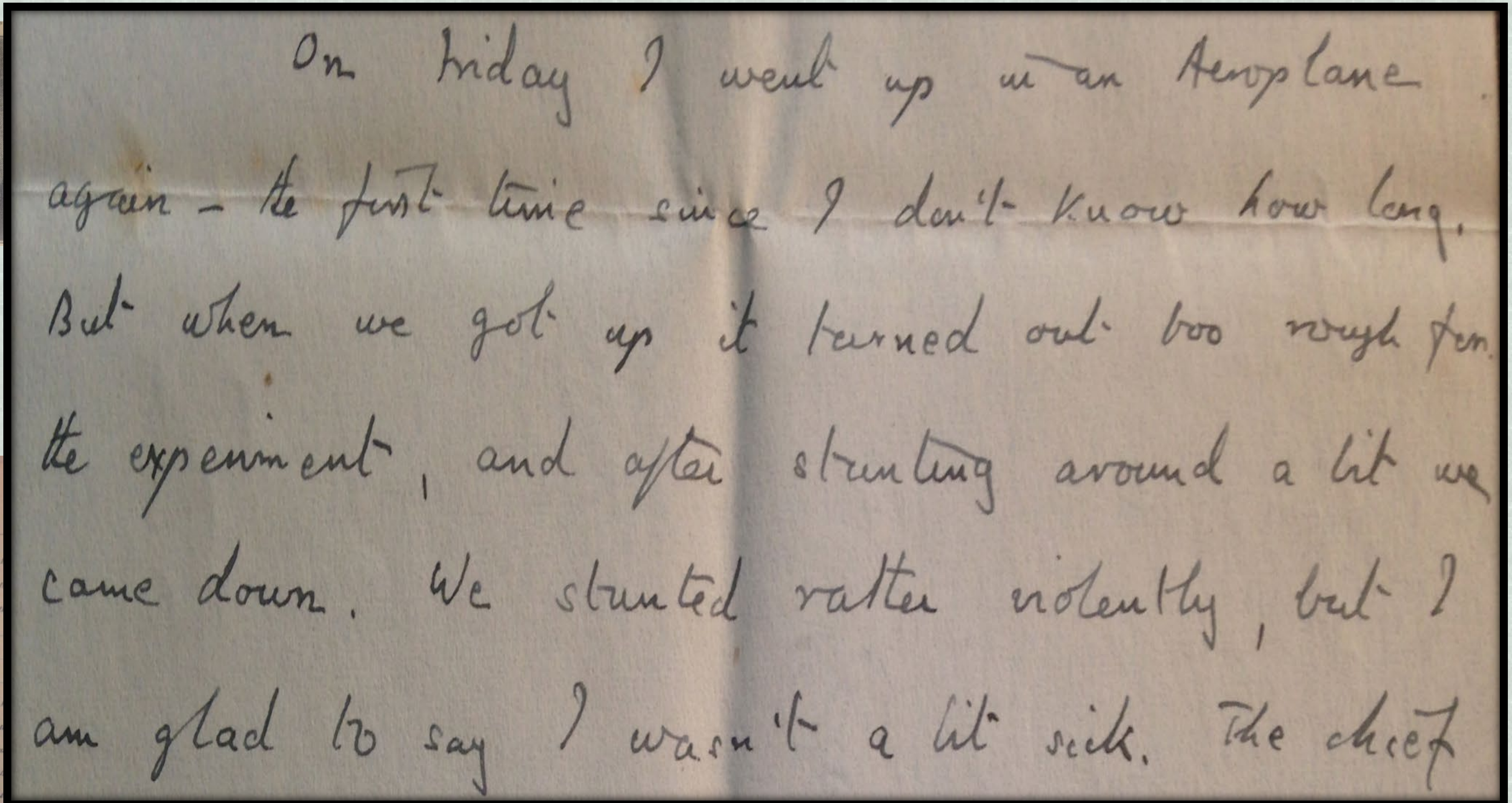
The Spin

Frederick Lindemann (Pillion) –The Prof

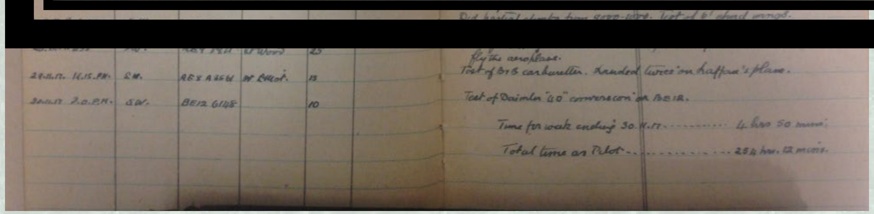
Lindemann and Spinning

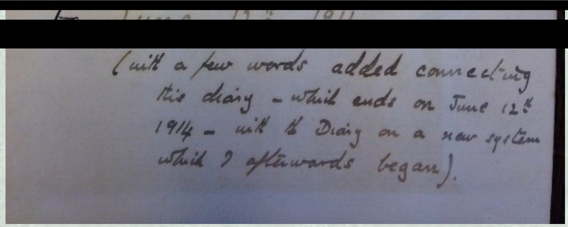
- Height of entry
- Height of recovery
- Air speed
- Number of turns
- Angle of airflow inside wing
- Angle of airflow outside wing
- Yaw
- Elapse time
- Rate of descent

Logbooks, Letters and Loop-the-Loop



On Friday I went up in an Aeroplane again – the first time since I don't know how long. But when we got up it turned out too rough for the experiment, and after stunting around a bit we came down. We stunted rather violently, but I am glad to say I wasn't a bit sick. The chief





Aerobatics

What sort of 'stunting' did these mathematicians get up to?

Wing over

Stall turn

Aileron Roll

Barrel Roll

Loop

Spin

Roll off the top

Roderic Hill

"There are old pilots and there are bold pilots, but there are no old bold pilots!"

HARRY COPLAND

Roderic Hill

1894-1954

Quotes from Hill's Logbook:

'Came down through clouds South of the Hog's Back. Made pancake landing and touched a wing tip.'

'Tried rolling on top of a loop, rather unsuccessfully.'

'Engine very dud. Took a long time to pick up after a spin.'

[Hill's Flying Logbooks held at the National Aeronautical Library at Farnborough]

The Tale of the Interview

Hill: Are you Pinsent’s replacement?

Garner: Yes – Harry Garner - I’m here for my interview.

Hill: Get in that B.E.2b over there!

Hill fires up the aircraft, gets airborne,
and flies three consecutive loops and lands.

Hill: Do you feel sick Harry?

Garner: No.

Hill: You’ve got the job!

The Tale of the Avro and the Shopping Centre

"Unfortunately, we were so engrossed that we came down rather low before unstalling, and the prop would not start again in the short dive that was all that is possible. So we landed in some birch trees at the back of Farnborough's main shopping centre, which did not do the Avro much good!"

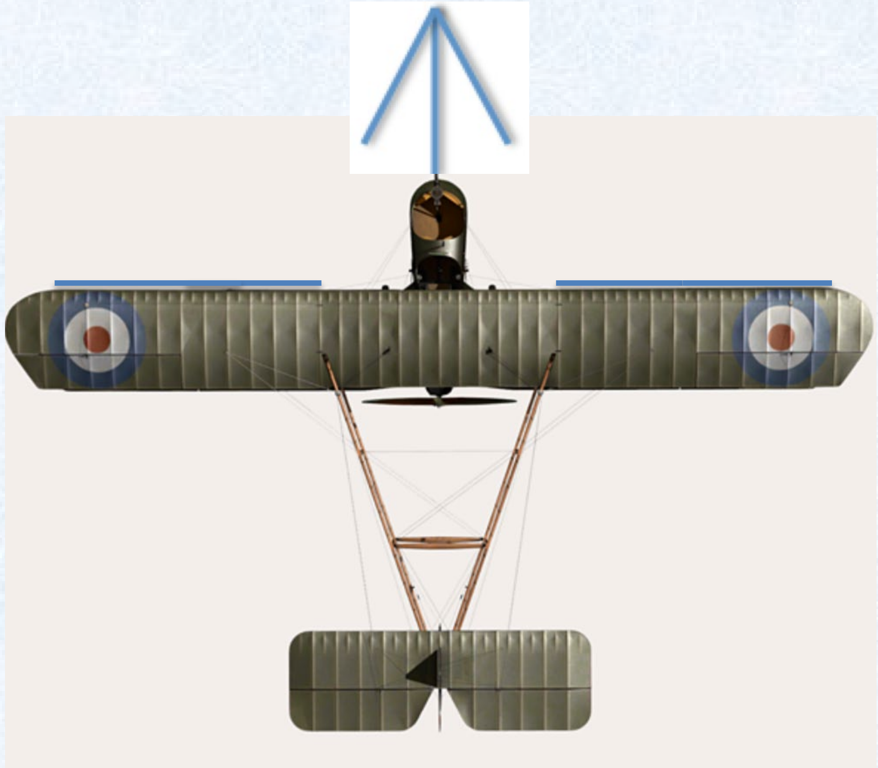
The Tale of the Barrage Balloon Test

(Please do not try this at home)

F.E.2

The Tale of the Barrage Balloon Test

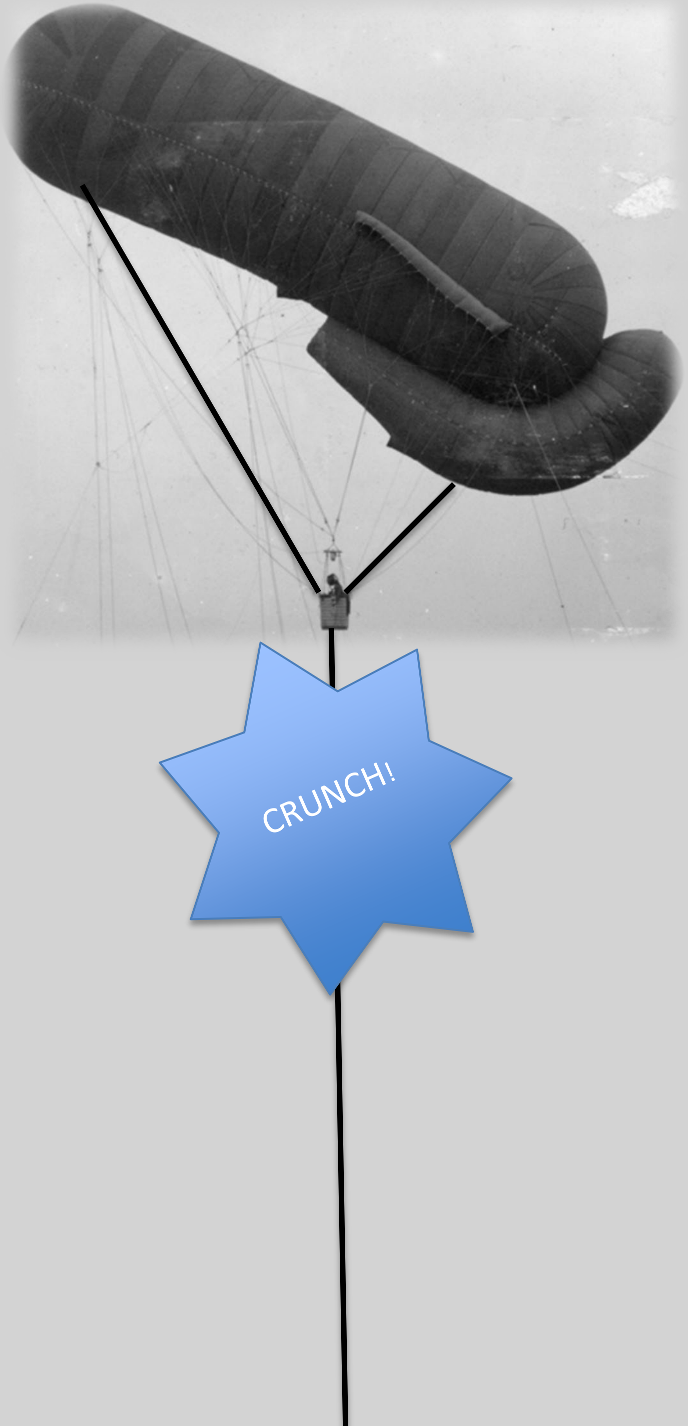
What could possibly go wrong?



The Tale of the Barrage Balloon Test

Remind me again, where did you do your degree Fred?

You'll be just fine Roderic – I've done the maths!



The Tale of the Barrage Balloon Test

NOTE ON THE POSSIBILITY OF COUNTERING BALLOON BARRAGES.

by F.A.Lindemann Ph.D.

S U M M A R Y.

The chances of colliding with a balloon cable while bombing a target protected by a balloon barrage are considered. Experiments on a method for countering balloon barrages suggested by E.F.were a failure and it is shown why this must be so. An alternative method is described and it is shown that this should render flying through a balloon barrage comparatively safe as long as light balloon cables continue to be used as is done at present.

The Mathematicians and Scientists who gave their lives

Bertram Hopkinson

David Pinsent

Hugh Renwick

Ted Busk

Keith Lucas

Benedict Melvill Jones

Structural failures

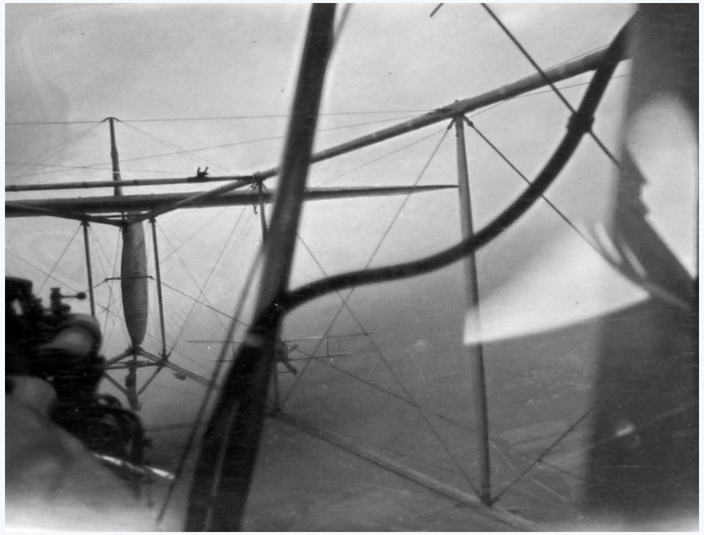
Weather

Bad Luck

Handling errors and poor SOPs

Any Questions?

From one of the new generation of flying mathematicians to the old, complete respect and thanks for your achievements and sacrifices.



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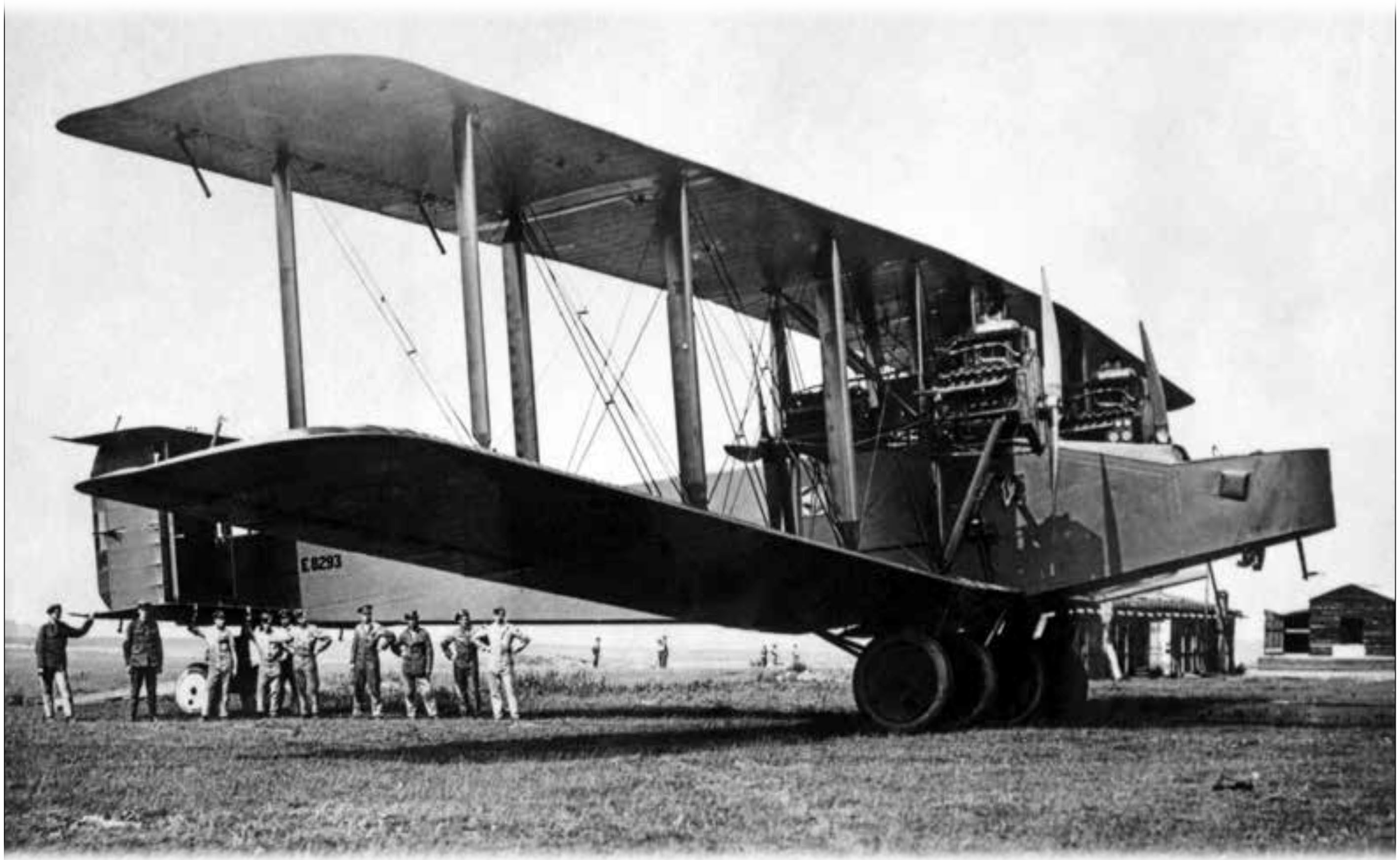

The End