Aircraft Alighting and Arresting Mechanisms.

Paper read by Mr G H Dowty, A F R Ae S (Member), before the Institution in the Lecture Room of the Junior Institution of Engineers, 39, Victoria Street, London, S W 1, on 26th October, 1926 Mr H B Molesworth, M Inst C E, M I Ae E (Hons), in the Chair

MR. CHAIRMAN, GENTLEMEN,

EARLY this month I was invited by your Council to read a paper before you, and it was with some misgivings that I accepted this date on which to do so

The paper and drawings have been prepared very hurriedly, due to the short time available, and I would ask you to make allowances if at any time I fail to make myself perfectly clear

It was my original intention to give a paper entirely on arresting apparatus, but I soon discovered that the arresting and alighting gears were too closely allied to admit of separate treatment

Some of you may not be quite clear concerning the functioning of arresters, and so I will define an arrester as a means for braking the forward speed of the aircraft on landing with the object of minimising the length of run necessary to pull up

With these explanations I will start my paper which I have entitled "Aircraft Alighting and Arresting Mechanisms "

AIRCRAFT ARRESTERS

I now propose to deal with the question of arresting So many impractical schemes have been proposed in the past that many are inclined to doubt the possibility of a practical solution The aeroplane exists under a considerable handicap in that it requires a great space within which to arrive and depart such as no other means of transportation requires The aeroplane is the only vehicle extensively used which does not apply brakes on stopping and yet it is the vehicle most greatly in need of braking, since its speed is the greatest

In the present means of deck landing no arrester is used and consequently only machines with a very low landing speed can be used by the Navy The maintaining of low flying speeds definitely impairs high performances and therefore without an arrester the Navy have to content themselves with aircraft which are inferior in performance to land machines

The velocity of an aeroplane when landing can be divided into two components, the one vertical and the other horizontal I shall take the term " alighting " to mean settling of the aircraft on the ground, which operation includes the absorbing of the machine's kinetic energy due to its vertical velocity and I shall use the term " arresting " to imply the capacity for absorbing the kinetic energy of the machine due to its horizontal component of velocity

It is the function of the undercarriage to absorb the former energy, while up to the present the arresting has been accomplished only by the retarding forces due to aerodynamic resistance of the aircraft, rolling friction of the landing wheels and sliding friction of the tail skid

Following in the sequence of landing operations I will start by considering the case of alighting I think it will be agreed that judging from up to date practice the oleo leg is the accepted method of shock absorbing

Four years ago I read a paper before this Institution on " Oleo Undercarriages," and I trust that you will excuse me if I attempt to bring up to date the more salient points of that paper, because in doing so it will help me considerably at a later stage in explaining the theory of the arrester

The kinetic energy of a machine varies directly as the square of its velocity, and therefore it is essential that any means of energy absorption should be capable of varying its absorbing capacity in a like manner

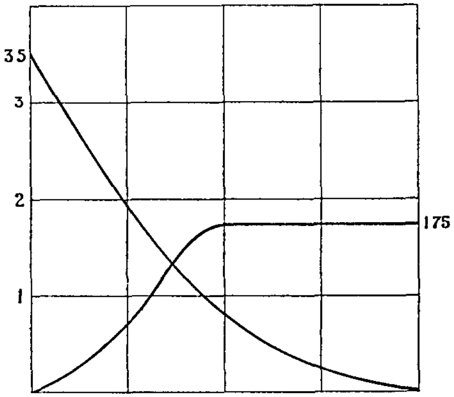

Fig 1

Fig 1, *curve* 1, shows the resistance curve for this type of brake, and it will be noticed that a high peak occurs at the commencement of the travel This peak can be prevented by controlling the leakage area, and this is usually carried out by means of a tapered needle With such a method of regulation the load can be applied gradually, rising to a maximum and then remain sensibly uniform throughout the latter part of the travel The advantage of this system lies in the fact that by keeping the resistance uniform throughout the greater part of the travel a minimum load is imposed on the aircraft structure, and as a case in point it will be seen by reference to *Fig* 1, that for equal energy absorption the maximum load on the uniform resistance leg is less than half that of the fixed orifice type Consequently, aircraft equipped with uniform resistance undercarriages can withstand stalled or high speed landings that would result in a crash with any other type of under-carriage

One of the chief features of the taper needle type of oleo leg is the ability of the leg to absorb the whole of the aircraft's kinetic energy during the up-stroke This is a most desirable condition, because it eliminates rebounding and always gives a perfect landing even in the most severe tests The correct proportioning of the needle is the whole secret of obtaining uniform resistance and total absorbtion of energy, and I propose to show how a very simple formula will give all the particulars necessary to design such a needle

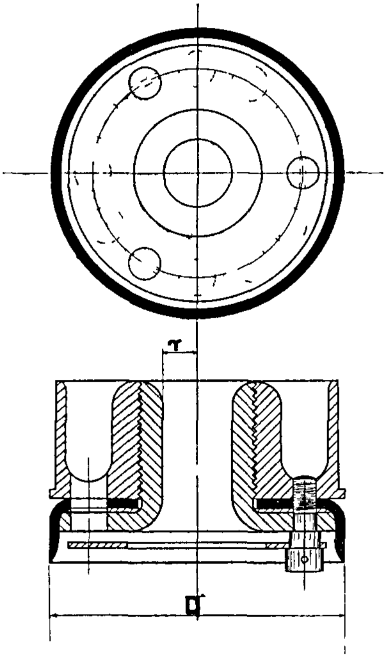

FIG 2

Fig 2 shows a side elevation and plan of the valve, lettered to illustrate some of the terms used in the following formula

The area of leakage required at any point, and consequently the needle diameter, can be readily found from a very simple law The square root of the ratio $\frac{\text{Aircraft Weight}}{\text{Weight of Oil to be displaced}}$ is always the same as that of the $\frac{\text{Piston Area}}{\text{Leakage Area}}$ If, for instance, the aircraft weight was 2,000 lbs and the weight of oil to be displaced was 2 lbs

$$\text{Then} \quad \sqrt{\frac{2000}{2}} = 31\ 6 = \frac{\text{Piston Area}}{\text{Leakage Area}}$$

The above formula although simple, would be somewhat cumbersome to use, and I am therefore going to put the above law into a simple equation suitable for general use

The first step in oleo leg design is to determine the length of travel necessary We are generally asked to design an under-carriage to take a vertical velocity of so many feet per second, without imposing a load greater than so many times the weight of the aircraft on the structure

For instance, let it be required to design an undercarriage to take a vertical velocity of 13 ft per sec , and the load imposed on the structure not to exceed 5 w By reference to *Fig* 3 we find that we shall need a travel of 8 ins minimum

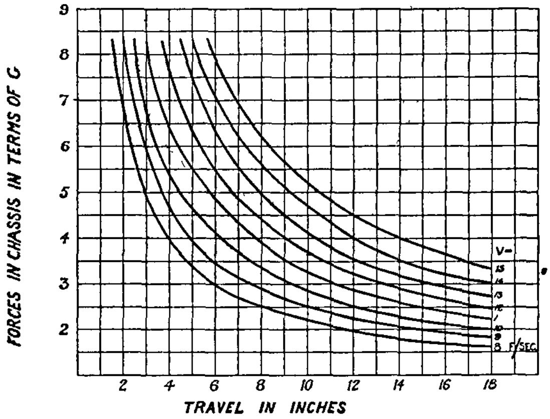

FIG 3

We require six particulars in order to fully determine the size and shape of needle These are —

1 Total weight of aeroplane (lbs)
2 Effective cross sectional area of piston (ft ^{2})
3 Diameter of orifice (ft)
4 Weight of oil (lbs /ft ^{3})
5 No of oleo legs on undercarriage
6 Travel of the leg (ft)

The total weight of machine, density of oil and number of legs on the undercarriage are known before the design is commenced, the travel of the leg can be determined from Fig 5, Piston area is fixed from considerations of tube size required to take the load in the leg and the diameter of the orifice is generally about 0625 ft

Using the following notation —

r = radius or orifice in ft
w = weight oil (lbs /ft ^{3})
y = number of legs on undercarriage
A = Piston area in ft ^{2}
W = Weight of aircraft in lbs
D_n = Needle dia in inches
x = distance of needle section considered from end of travel (in ft) (For instance, at the beginning of the travel of 8 inches, x will be 75 ft and at the end of the travel, x will be zero)

It can be shown (see proof at end of paper) that the needle dia D_n can be determined for any value of x by the following law —

$$D_n = 24 \sqrt{r^2 - \frac{c}{\pi} \quad x^{\frac{1}{2}}} \text{ ins}$$

where c is a constant for any particular machine and is given by the value

$$\sqrt{\frac{w \quad y \quad A^3}{W}}$$

Taking an actual case ,—

W = 10,000 lbs
A^3 = 000162
r^2 = 000976
w = 57 lbs
y = 2

$$\text{Then } c = \sqrt{\frac{57 \times 2 \times 000162}{10,000}}$$

$$\text{and } \frac{c}{\pi} = 0004326$$

$$D_n = \sqrt{000976 - 0004326 \sqrt{x}} \text{ ins}$$

If the travel of this leg is 8 inches then the diameter of the needle should be determined for two positions—say, at 1 inch and 8 inches, and the above equation solved for the two positions by inserting values of x = 666 ft and x = 0835 ft

The taper of the needle is straight, and so from this information a drawing of the needle can be made , see *Fig* 4

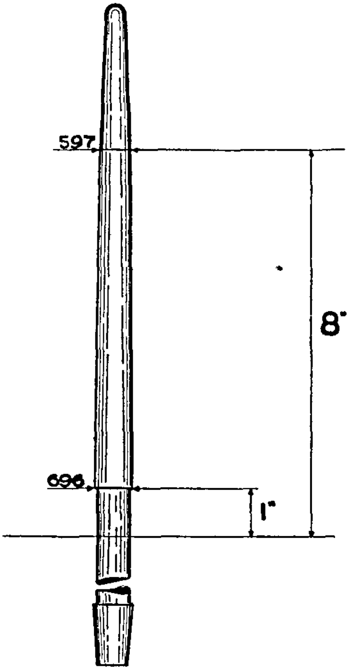

FIG 4

I would call attention to an improvement that can be made The base of the needle over the last inch should be reduced in diameter, because by maintaining the calculated dimensions the diameter would be so large that should the leg bow under load, or the needle and orifice not be quite centralised, then binding would occur

In this work I have omitted all reference to energy stored in the tyres, axle or springing during landing I am aware that some writers have gone fully into this, but in my opinion such investigations are not only laborious but rather futile Generally for that type of calculation a definite vertical velocity is assumed, and it would seem that only under one velocity was the leg operating under maximum efficiency It has been my aim to design an undercarriage that would work at a maximum efficiency under all velocities If compression rubbers or other means of springing work simultaneously with the oil dashpot, then the resistance will not be quite uniform, and the value of loads for various travels and landing speeds given by *Fig* 3 will not strictly apply It will be seen from the nature of the needle formula that the proportions given will be correct even though the springing operates with the oil dashpot, but in this case the energy will not be completely absorbed by the oil, but part will be stored in the springing This will cause oscillating of the landing gear, the magnitude of which will depend on the amount of work stored in the springing, and therefore in good designs this should be kept to a minimum in order that uniform resistance may be approximately obtained and undue oscillating avoided

It was desirable that the truth of this uniform resistance formula should be verified, and therefore an indicator diagram apparatus was fitted to a leg and a typical graph obtained

Fig 5 gives the weights of oleo legs and undercarriages

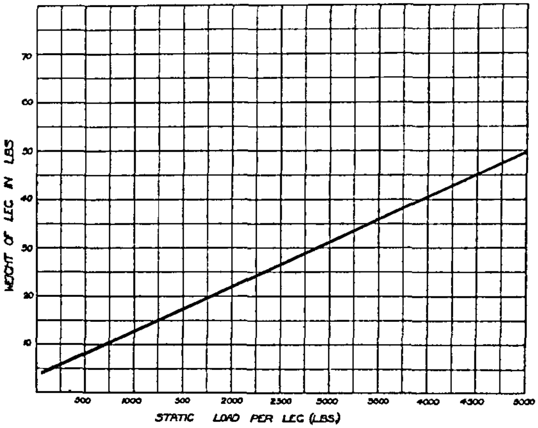

FIG 5

OLEO LEG DESIGN

Proof of formula —

$$D_n = 24\sqrt{r^2 - \frac{c}{\pi} \quad x^{\frac{1}{2}}}$$

NOTATION

W = Weight of aeroplane in lbs
V = Vertical velocity of aeroplane in ft per sec
g = Acceleration due to gravity (32 2 F P S /s)
An = Cross section area of needle in ft ^{2} = a_1 —a
D_n = Diameter of needle (ins)
A = Effective area of piston (ft ^{2})
= (Cross section, Area top cylinder —a_1) approx
d = dia orifice in ft
r = radius orifice in ft
a_1 = Cross section area of orifice in sq ft = $A_n + a$
a = Area of annulus in sq ft = a_1 —A_n
Rh = Hydraulic resistance in lbs
Vi = Velocity of bottom cylinder relative to top cylinder
w = Weight of oil (lbs /ft ^{3})

It may be shown (see Cotterills Applied Mechanics, or any standard work on hydraulics), that the resistance of the oleo leg is given by —

$$Rh = w\,A\left(\frac{A}{a} - 1\right)^2 \frac{V_1^2}{2g} \qquad (1)$$

This formula follows directly from Bernouilli's theorem, where the Kinetic Energy of the aeroplane due to its vertical velocity V is represented by Ke, and the number of oleo legs on the undercarriage by y, then the Kinetic Energy to be absorbed by each leg is given by the value —

$$\frac{W\;V^2}{2g\;y} \qquad (2)$$

If x is the travel of the oleo leg in ft , then —

$$RH\;x = \frac{Ke}{y} = \frac{W\,V^2}{2\,g\,x}$$

If we assume the oleo leg to be vertical, then

$$V_1 = V \text{ and}$$

$$R\,H = \frac{W\;V^2}{2\;g\;xy}\text{and from equation} \qquad (1)$$

$$\frac{W\;V^2}{2\;g\;x\;y} = w\;A\;\left(\frac{A}{a}-1\right)^2\;\frac{V^2}{2g} \qquad (3)$$

$$\text{or }\left(\frac{A}{a}-1\right)^2 = \frac{W}{w\;A\;x\;y} \qquad (4)$$

The value $\frac{A}{a}$ being large, we can neglect the term — 1 and hence equation (4) becomes —

$$\frac{A^2}{a^2} = \frac{W}{w\,A\,x\,y} \qquad (5)$$

$$\text{and } a^2 = \frac{w\,A^3\,x\,y}{W} \qquad (6)$$

The value $\sqrt{\frac{w\;A^3\;y}{W}}$ is constant for any particular machine, and by assigning values to x correspondence values of a^2 may be determined

$$A_n = a_1 - \sqrt{\frac{w\;A^3\,x\;y}{W}} \qquad (7)$$

But the value $\sqrt{\frac{w\;A^3\;y}{W}}$ is a constant as stated above Let us call this term C

Then equation (7) becomes —

$$A_n = a_1 - c\sqrt{x} \qquad (7a)$$

$$D_n = 2\sqrt{\frac{A_n}{\pi}} \qquad (8)$$

Therefore the diameter of the needle at any point x ft from the end of the stroke is given by —

$$D_n = 2\sqrt{\frac{a}{\pi} - \frac{c}{\pi}\sqrt{x \text{ ft}}} \qquad (9)$$

or

$$D_n = 24\sqrt{r^2 - \frac{c}{\pi}x^{\frac{1}{2}}} \text{ ins} \qquad (10)$$

COMPRESSION RUBBERS

It was not my original intention to deal with forms of springing in this paper, but during this past week I have been requested to include some particulars of compression rubbers in this paper

If you will pardon my digressing I will endeavour to give a few particulars of compression rubbers

This form of springing is widely used to-day, and practically all military machines are fitted with compression rubber undercarriages

Fig 6 shows a very simple form consisting of a plain ring

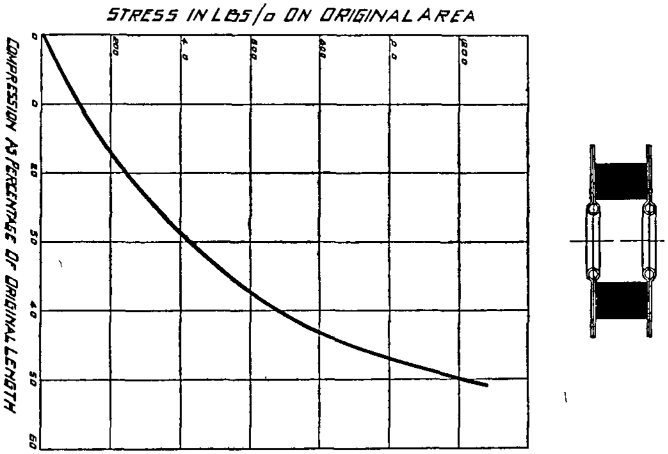

FIG 6.

Fig 7 shows the Parnall type rubber with moulded in stabilising plate

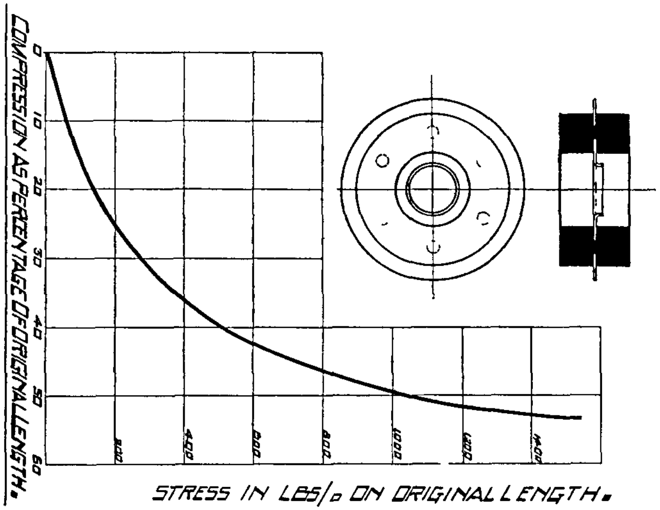

FIG 7

Fig 8 shows the "Gloster" type of compression rubber pad designed to facilitate a good stream lining

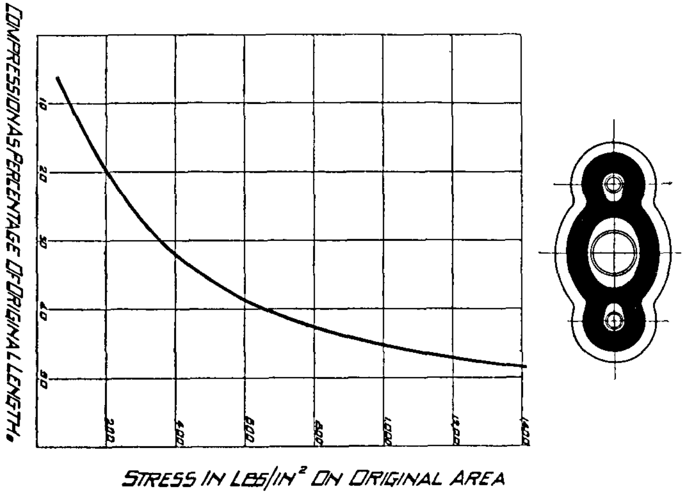

FIG 8

It is essential to stabilise compression rubbers to prevent the column bowing under load, for this would set up uneven loading on the rubbers, and the eccentricity would possibly cause collapse of the leg A further requirement is the addition of separator plates between each rubber This is necessary to enable the rubbers to spread easily under load, so that reasonable deflections may be obtained without the use of an undue length of rubber

In the case of the ring shown in *Fig* 6 the stabilising and separator plates are integral These plates are made from light gauge aluminium plate pressings

With the Parnall type of rubber the stabilising plates are moulded in the rubber, while with the " Gloster " pad the stabilising is carried out by the rubber coming into contact with the two guide tubes

The maximum stress on compression rubber under static load should not exceed 250 lbs /in ^{2}, otherwise the rubber will be harsh in operation during taxi-ing and will quickly take up a permanent set

The most useful data for determining the necessary particulars for the design of the rubber shock absorbers is given in the stress deflection graphs, and in order to demonstrate the use of this data I will work out an example

Total weight of aircraft	10,000 lbs
Required deflection of shock absorber	8 ins

Because the maximum stress on the rubber under static load should not exceed 250 lbs /in ^{2}, then the total area of rubbers will be given by

$$A = \frac{10{,}000}{250} = 40 \text{ ins}^2$$

If the undercarriage is designed to withstand a maximum load of five times the weight of the aircraft, then the maximum stress on the rubbers will be

$$\frac{10{,}000 \times 5}{40} = 1{,}250 \text{ lbs /ins}^2$$

If the compression rubbers are similar in design to that shown in *Fig* 7, then we find that under a stress of 1,250 lbs /in ^{2} that the deflection of the rubber column will be 54 per cent of its original length

The length of rubber required is therefore given by

$$L = \frac{8 \text{ ins}}{54} = 14\ 8 \text{ inches}$$

In order that the outside diameter of the stabilising and separator plates may be determined, it is necessary to know the increase of the diameter of the ring when subject to its maximum compression This information is contained in *Fig* 9

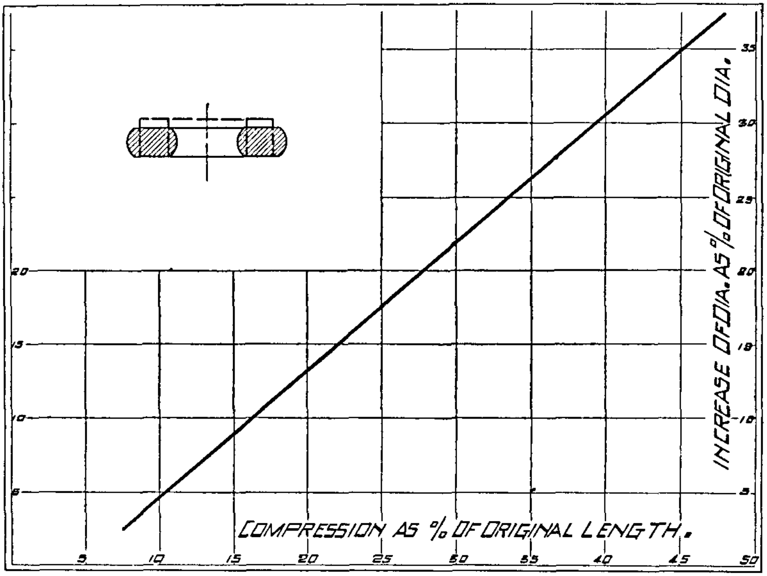

FIG 9

AIRCRAFT ARRESTERS

Coming now to the question of arresting So many impractical schemes have been proposed in the past that many are inclined to doubt the possibility of a practical solution The aeroplane exists under a considerable handicap in that it requires a great space within which to arrive and depart such as no other means of transportation requires The aeroplane is the only vehicle extensively used which does not apply brakes on stopping, and yet it is the vehicle most greatly in need of braking, since its speed is the greatest

There are two aspects from which to view the case of the arrester The one is from a military and naval standpoint, and the other purely commercial

In the present means of deck landing no arrester is used and consequently only machines with a very low landing speed can be used by the Navy The maintaining of low flying speeds definitely impairs high performances, and therefore without an arrester the Navy have to content themselves with aircraft which are inferior in performance to land machines

It would appear most difficult, if not altogether impossible, procedure to land aircraft on deck, using present service methods, if any but ideal conditions prevailed

Ideal conditions are not *Service* conditions, and the present system relies on the ship and aircraft being headed into the wind when landings are made

In the case of a typical landing, with the ship making 30 knots, a head wind of 10 knots, and the aircraft's forward speed 45 knots, we see that the speed of the aircraft relative to the deck is only 5 knots, and hence the possibility of landings under present conditions

In warfare it will certainly not be practical to always steam the ship into the wind, and in adverse circumstances such as in running before the enemy it may even be necessary to land the aircraft while running down wind

In this case it would be quite impracticable to land machines under existing conditions, and it must therefore be assumed that such inadequate provisions can only result in the loss of valuable pilots and machines during hostilities

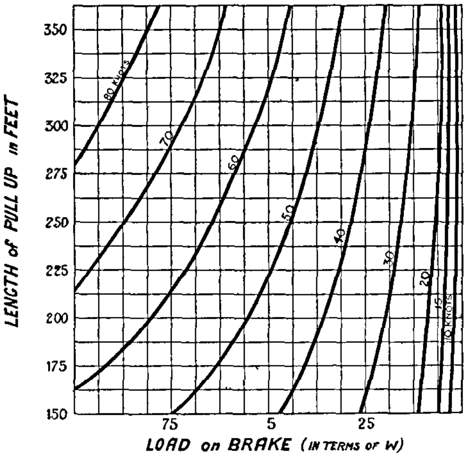

FIG 10

Fig 10 gives a series of curves the ordinates of which are lengths of run to pull up against retarding forces for various landing speeds These curves have been plotted neglecting retardation due to aerodynamic drag, and wheel and tail skid friction It has also been assumed that the retarding force is uniform throughout the period of arresting

The maximum available run on an aircraft carrier is 600 feet, but in order to take a pessimistic case it will be assumed that a pilot takes 300 feet before he engages with the arrester, and that in consequence the machine has to be brought to rest in the remaining run of 300 feet

By reference to *Fig* 10 it will be seen that for this length of pull up, and with a landing speed of 40 knots, the retarding force is 25 W, where W is the weight of the aircraft If we assume a high landing speed of 80 knots (this is not necessarily the forward speed of the aircraft but the speed relative to the deck), then for the same length of run the retarding force will be 93 W

These figures show that the loads imposed on the aircraft by a uniform resistance arrester are of such an order that the present structure would easily stand up to the loads imposed, because even with the highest of landing speeds the aircraft can be arrested in 300 feet without meeting with a greater deceleration than one times that of gravity

In order to carry out this arresting scheme there are two necessary requirements

(1) A suitable brake

(2) A means for quick and safe engagement of the aircraft with the brake

The brake should be designed to give a low resistance at the commencement of operation and then increase gradually to a maximum The resistance thereafter should remain sensibly constant The object of this method of braking is the elimination of large inertia forces which would be set up if the full brake load was suddenly applied

It is further required that the resistance of the brake must vary under different landing speeds as the square of the initial velocity of landing

All these conditions must be obtained quite automatically and without adjustments or manual control, in order that the personal element shall not enter into the mechanical part of the arrester

A type of brake embodying these features is shown in *Figs* 11, 12 and 13

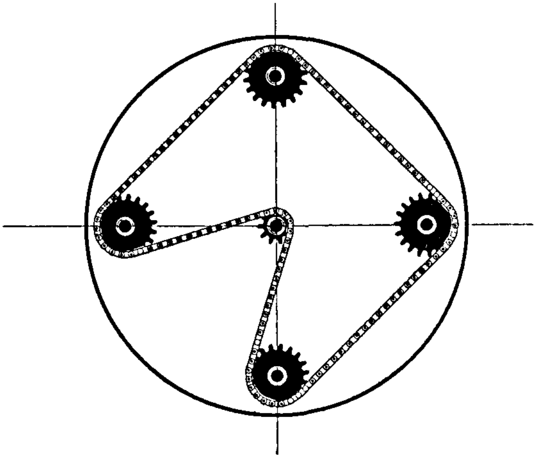

FIG 11

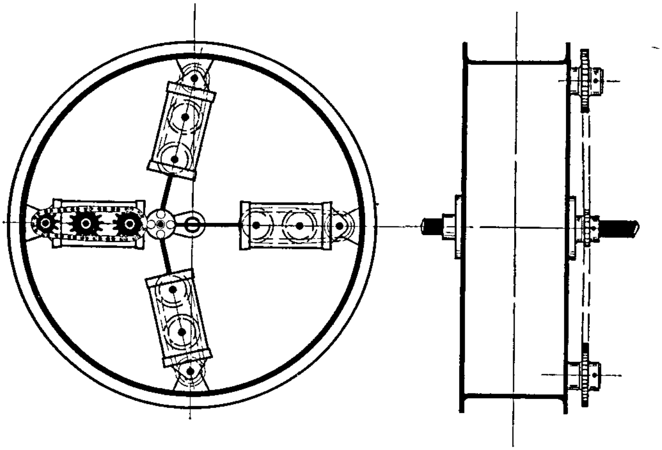

FIG 12

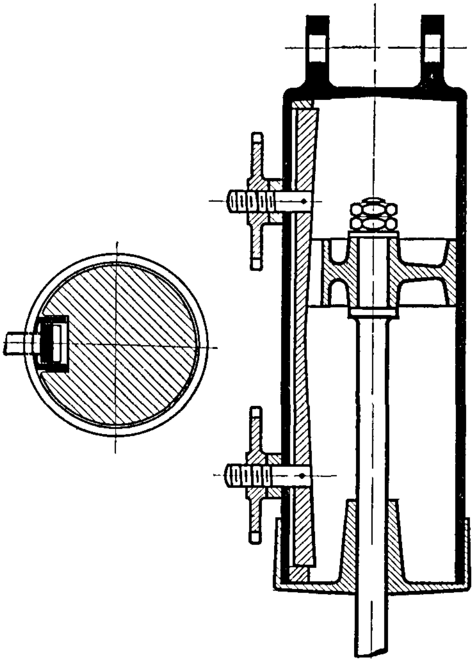

FIG 13

This brake consists of a drum carrying a definite length of cable The unwinding of the cable causes the drum to rotate, and the mechanism for obtaining uniform resistance is contained inside the drum

Four cylinders are pin-jointed to the rim, and their connecting rods are attached to a common crank

The brake is designed to give a uniform torque, notwithstanding that the velocity of the drum is always decreasing, the piston speeds variable, and the connecting rods continually changing their angle with the crank To compensate for the change in piston speed and change in the angle of the connecting rods, a key fitted to the inside of the cylinder is curved in the manner shown in *Fig* 13, such that when the piston speed is greatest the leakage area is a maximum, but when the piston speed is small the leakage area is correspondingly reduced

Provision for decrease of leakage area is also required to compensate for the drop in velocity of the drum during the operation of arresting, and this is obtained by mounting the key on two screwed studs which carry sprockets adapted to engage the screwed portion of the stud as shown in *Fig* 13 The rotation of these sprockets will cause the key to be driven into the cylinder thereby decreasing the leakage area These sprockets are operated by chains driven from a wheel mounted on the main shaft as indicated in *Figs* 11 and 12

A further form of uniform resistance brake can be obtained by modifications to the Heenan and Froude Dynamometer The resistance of the Dynamometer depends upon the volume of water dealt with If the rotator cups are full, the resistance will be a maximum, and by varying the initial supply of water by a governor driven from the main shaft, and reducing this supply throughout the period of operation in proportion to the square root of the remaining travel, the resistance may be kept uniform Putting this in another form

If N = Total number of revolutions of Dynamometer during arresting operation

n = Number of revolutions made by Dynamometer to any intermediate point between the commencement and end of arresting

Then the supply of water should be reduced as

$$\sqrt{N - n}$$

With either of these forms of brake it is claimed that

(1) The aircraft is brought to rest in a definite length of run and quite independent of the velocity at which it lands, and that

(2) An absolute minimum load is placed on the aircraft structure

In designing this mechanism I had in mind the hydraulic buffers used on railway platforms This is an arrester which differs from the brake I have just described in that it has a short travel accompanied with a high resistance, whereas the aircraft arrester will have a long travel and a correspondingly low resistance

Means for providing quick and safe engagement of the aircraft with the arrester are shown in *Figs* 14 and 15

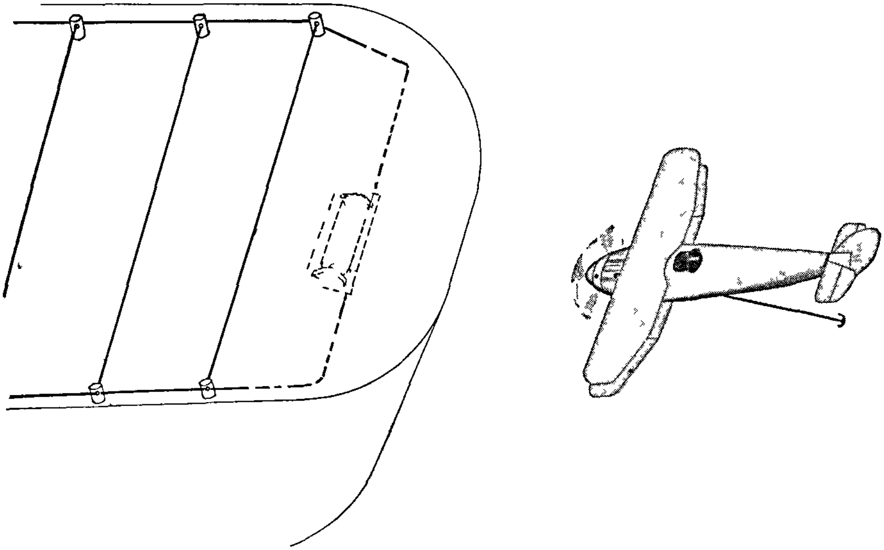

FIG 14

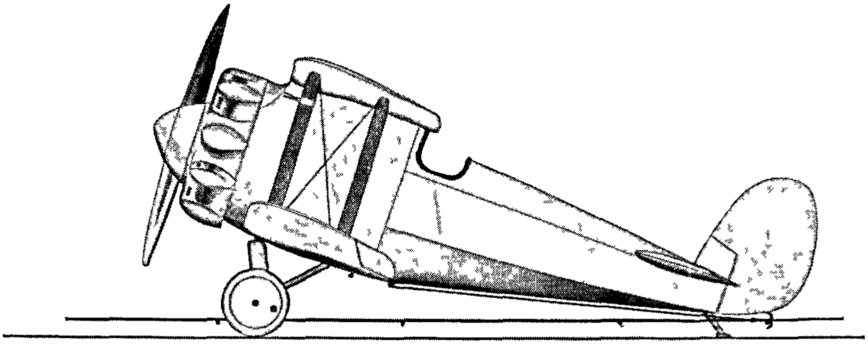

FIG 15

A rod, cable or other means extending obliquely from the aircraft is provided with a hook or anchor to engage cables or ropes which are connected to the arrester It is suggested that the brake should be located below the deck in order that the landing stage can be left free from obstruction The rod is fixed to the aircraft in the rear of its centre of gravity, so that braking may take place without overturning the machine

The mass of the aircraft may be regarded as concentrated at the centre of gravity and the force of momentum as acting at that point As the momentum of the machine is resisted by the retarding force applied, the two forces will work in opposition, the former acting at the centre of gravity and the latter behind the centre of gravity in such a manner as to straighten the aircraft into correct alignment with, and maintain it in its path Thus the application of this retarding force to the aircraft at a point in the rear of its centre of gravity, not only will avoid a harmful tendency, but will produce a positive beneficial effect on the *stability of the machine , resisting any tendency to overturn* caused by other influences, such for instance as obstacles encountered by the wheels of the aircraft when landing

On alighting the pilot can release the rod or cable such that it takes up an inclined position ready for engagement with the cross ropes The cross ropes are connected at their ends to the brake before described, so that as the aircraft runs forward the ropes will cause the brake to be rotated

In another form the brake may be carried by the aircraft For a 5,000 lbs machine the total weight of brake with cable would be 60 lbs (that is, 1 2 per cent of total aircraft weight) An advantage with this method would seem to be the ability of machines to make forced landing in confined spaces providing a suitable grapnel could be designed

In the case of aerodromes, ground ropes could be fitted similar to those suggested for use on board ship

It would also seem that arresters permitting the use of very small aerodromes would be of great use to the Army Catapults (similar in design to those now being successfully used by the U S Navy) and arresters could be designed *for transportation to any small space available for a temporary landing ground* Such a facility might be very valuable in warfare

The whole of the arresting gear for a complete aerodrome could easily be carried in an ordinary lorry The brake with ground fixing would not exceed 400 lbs in weight and a series of 10 cross ropes with fixings could be designed not to exceed 500 lbs It can be safely assumed that the whole outfit would not exceed half a ton

If means were developed whereby commercial aircraft could land and take off in limited areas, the following advantages might be expected Landing grounds as large as are now necessary would not be essential, and this would result in the curtailing of their size with a considerable saving in initial cost and maintenance A more important possibility, however, is the facility given for the providing of auxiliary landing spaces with a resulting increase in safety of commercial flying

It has been demonstrated on many occasions that it is possible to guide an aeroplane flying at high speed within very close limits In this type of arrester, engagement can be made at a good flying speed and the pilot will not be obliged to shut off his engine prior to landing It is the difficulty in determining a quarter of a mile or so in advance of the landing ground the proper moment to shut off the engine, and the proper glide to take which makes it difficult to land at a precise spot A good pilot can guide his machine within close limits to any desired spot, but he cannot glide down with engine off and be sure of making a stall landing within a distance shorter than 200 ft It may be some time before pilots accustomed throughout their flying experience to make stall landings recognise the advantages of a practical method of making high speed landings

In case of failure to engage with the arrester, the properly designed landing platform will offer no obstruction to continued flight and the pilot may return to make another attempt Since the tractive effort of the propeller is of small consequence in comparison with the forces used in arresting, the engine may be left on during the entire procedure of landing The longitudinal ropes used on deck landing schemes are only necessary to hold the aircraft on deck during a high sea or in a gale and are not essential for the operation of arresting

I realise that precautions must be taken in the experimental stages and the work must proceed carefully to avoid any serious accident that would give the project a set back, but if it is successfully carried through, then it would immediately benefit all forms of aircraft, whether Naval, Military or Commercial

I would like to call attention to an article in *Aviation* on July 26th last, entitled "Airplane Arresters and Catapults," by Mr Hazen C Pratt This article clearly set out the advantages and possibilities of the arrester, and in several instances I have quoted from this article

I feel sure that the success of this or any other arresting device depends largely on the brake employed, and if a uniform resistance brake can be satisfactorily adapted to an aircraft carrier there is no reason why high speed aircraft could not be safely landed within the confines of a deck

In conclusion I would like to mention that this arrester mechanism is being developed by the " Gloster " Aircraft Co , and I am indebted to them for giving me permission to read this paper before you

DISCUSSION

CHAIRMAN This is an extremely interesting and novel paper, and has admirably fulfilled the promise given in the paper which Mr Dowty read to us a year or two ago

Regarding an arresting device I do not know whether you remember Sir Hiram Maxim's first flying machine at Dartford It was a huge machine running on rails, and he had an arresting device at the end to stop it He had ropes across in the same way as shown in the model which Mr Dowty has here, wound on vertical capstans with a fan on top The machine ran into these ropes one after the other, and it was most effective

DR THURSTON I think we are all agreed that the paper to-night has been not only a most interesting one, but one of very great practical value Two of the most difficult problems of the present time—as also from the earliest days of flying—are those of landing and getting off Immense strides have been made in every possible direction in the air, but with regard to landing in particular we are more or less still in the early stages, and there are great possibilities in practical devices such as have been shown by our lecturer this evening, and it is up to engineers to devote themselves to this problem and to solve it if flying is to be the really safe thing it must be to bring commercial success

Regarding Maxim's first flying machine, referred to by our Chairman, I did not have anything to do with that particular one, but I helped Maxim with a second machine, and I remember that in designing it he put in an oleo gear for landing, though in those days he did not call it an oleo gear, but an oil dashpot

If a pilot could approach land more or less at full speed, the mere fact that he could so approach land would give landing a greater element of safety, because it is this business of having to slow down and lose speed so as to land without a shock, that is such a handicap if anything goes wrong with the engine or an obstruction suddenly appears I am sure from my own experience that it would bring a greater element of safety into flying if we could only land or rather approach land, at a higher speed

I suppose I should confine my remarks to the two subjects we are discussing, that is, landing and arresting gear, but there is another point which strikes me as important, namely, what is the correct or maximum load factor that should be calculated to be taken by the landing gear? The figure is given as 5 That, I believe, is about the figure laid down during the war, and in that case it was obtained by making many measurements of various landing gears, finding out how they had compressed under various conditions of landing, and how much it took to compress the springs the same amount I do not think that it is really necessary to take the whole weight of the machine as the unit of load , the machine itself is a flexible unit, and quite a large part of the structure is its own shock absorber, but it is the central part which puts the principal shock into the landing gear It is my own opinion that the shock of landing could be eased by certain devices actually in the construction or the structure of the machine , With such a construction the undercarriage would merely have to take the shock of landing perhaps of the central part of the machine, leaving the rest of the machine to look after itself Experience seems to indicate that if the full weight of the machine is taken as the unit of load the designer has a greater factor of safety than the calculated factor Will the lecturer kindly give us the benefit of his experience on that point? In many machines that I have seen the undercarriage has recorded at least five times the weight of the machine, and although in down load those machines when sand tested broke at considerably under five times the load they did not do so in actual practise, so that we know that the shock of landing is eased by the structure itself

It seems to me, apart from the oleo gear, that this business of applying brakes to machines is a matter of very great moment indeed From the earliest times it has been suggested to put brakes on to wheels, or to drop an anchor overboard which will run a cable from a drum—a constant friction drum of one sort or the other Then there was the rope device used by Maxim , I know he was a great believer in that type of arrester, and of course there was the aerodynamic device in which at will a plane is turned at right angles to the wind and offers a heavy resistance It seems to me, however, as an engineer, that the problem is a purely mechanical one, and that is why I personally wish to thank the lecturer very much indeed for giving these specific, very ingenious and very novel suggestions as to certain solutions of the problem I hope it will lead to other experiments with mechanical devices enabling a machine to approach its objective at high speed, and to be brought to rest without the ordinary haphazard conditions which prevail at the present time A motor-car with four brakes is the vogue in these days, but a motor-car without any brakes is unthinkable, and yet that is the present position with aircraft

MR HOLLAND I must thank the Institution for the opportunity of coming to this lecture It is the first, I think, I have had the pleasure of attending, and I have enjoyed it very much

There are one or two points I should like to touch upon

Criticising the paper from a student's point of view—if the taper needle oleo leg is ideal, why bring in " rubber " ?

We use " rubbers " to take " taxying " loads These loads are much greater than many of us give credit for

In a recent issue of *Flight*, Beardmore's give some very high figures

The real object of the leg is to remove all shock from the aircraft, but it is the geometric position of the other members of your undercarriage which determines how much goes into the leg. It is important to realise how much is taken by the leg and how much goes in other members

What does the lecturer consider to be a safe maximum pressure in an oleo leg ?

With reference to the arresting gear, I was connected indirectly during the war with certain of the experiments in deck landings, which throw light on the origin of the longitudinal ropes In those times we used cross wires, as shown on the model, but at the end of each rope we had a sandbag The machine landed into them and was pulled up Difficulty was experienced in getting the pilot to land the machine squarely into the wires, for if he landed at an angle the machine would ricochet off the " outfit " To overcome this difficulty longitudinal wires were introduced

MR R H BOUND It appears to me that the diagram on the board shows rather a lot of mechanism which has been included in the design in order to get constant resistance throughout the complete revolutions of the drum Is it not possible that the same object could be achieved by using a gear wheel type of pump ?

I imagine that the resistance will merely vary with the rotational velocity, whereas in the design just described by Mr Dowty, the pumps give a varying resistance which has to be rendered constant by means of the chain and sprocket device

I am not an authority on oleo undercarriages, but I notice that the lecturer's formula for piston areas and leak orifice areas deals only with the kinetic energy of the aircraft, whereas at the moment of touching the ground the machine has also potential energy Is that not taken into consideration ?

I can fully endorse Dr Thurston's view regarding the difficulty of making slow landings I have been having flying instruction recently, and have found much difficulty in judging the correct moment for shutting off the engine when coming in to land

Landings are made under widely varying conditions , the speed of the wind naturally affects the time of closing the throttle with the result that I either overshoot the aerodrome or have to give another burst of engine Of course, this difficulty would not be apparent to an experienced pilot, but I imagine that if we could always practically land with the engine on, by means of an arresting gear, it would be very helpful to pilots

With regard to Mr Dowty's scheme for putting the arresting gear on the aeroplane itself, I believe that the gear wheel type of pump would cut out a lot of mechanism with a consequent saving of weight and less liability of something "going wrong"

Mr Dowty told us that the advantages of the oleo undercarriage over the ordinary sprung type became obvious when the weight of the aircraft reached 5,000 lbs Am I to understand that below that figure the weight of the oleo undercarriage is greater than that of the ordinary type ?

To the best of my belief, none of the present light aeroplanes is fitted with oleo legs , the Avro Baby is the only exception and that machine was designed several years ago It seems to me that as the oleo undercarriage can absorb landing shocks without rebound that it is the very thing for school machines, and I am surprised that it is not possible to design an undercarriage of this type which would be as light as the more commonly used rubber shock absorber type

MR FOLLAND (Written contribution) I am sorry that owing to an important engagement at the Works I am unable to attend to hear Mr Dowty's interesting paper on "Aircraft Alighting and Arresting Mechanism" I have, however, had the pleasure of looking through his paper and charts, and feel sure that it will be of greatest value to our Institution, and contribute a further step in aviation

The paper introduces a new problem in aircraft and a new sphere for investigation regarding Arresting Mechanisms Mr Dowty has given his subject careful study, and has supplied sufficient ground work to warrant a more serious series of practical tests on Arresting Mechanisms

I have a few remarks to make which I trust will be of interest

Mr Dowty states under the subject dealing with compression rubbers that the "Gloster" type of rubber was designed to facilitate good streamline Whilst this is one of the advantages of the flange type of rubber it is by no means the most important Compression rubbers can vary in deflection for a given load plus or minus 4 per cent , therefore with an oleo leg fitted with two sets of round rings per leg it is possible to get one set of rubbers deflecting more than the other, causing a distortion in the leg With the "Gloster" flange type each rubber can vary in deflection within allowable limits without distortion in the leg I consider this an important point

Under Aircraft Arresters Mr Dowty shows some interesting curves, especially one relating to braking effort (in terms of W) plotted against length of pull up for various landing speeds This certainly indicates that it will be possible to have machines for deck purposes with a performance equivalent, if not greater than land machines, providing that a suitable uniform resistance arrester is developed

It has been mentioned in the paper read that the advantages of this will also assist commercial and land types, but it seems to me that the commercial types will be controlled to a greater extent by the question of the minimum length of run to take off, and that if one took too much advantage of the arrester device it would seriously impair this take off, also in the case of fighting machines the question of forced landing is of vital importance, because working to higher stalling speeds a forced landing without the resistance of the arrester device would invariably mean a serious crash This, however, does not apply in the case of the deck fighter, because in any case, should any trouble develop and forced landing have to be made this of course, will mean coming down on the sea

It appears to one that full advantage can be taken of this new suggestion to use a uniform resistance arrester for ship types, and it will enable one to design for greater stalling which, in turn, should increase the performance of that type, always of course, keeping within the limits of the requirements for taking off the deck within a reasonable distance

There are no doubt a number of points which would call for adverse criticism, but the whole device seems to be one which should be seriously tested out

In conclusion I congratulate Mr Dowty on his excellent paper

CAPT SAYERS (Written contribution) I am in entire agreement with Mr Dowty as to the desirability—I would almost say the necessity—of providing means which will allow of the use of aerodromes of much smaller dimensions than are now found necessary, but I feel that he is mistaken in assuming that an aircraft arresting brake of a type independent of the aeroplane itself will to any large extent meet the case

He refers to the subject of deck landing where no arresting gears are used and suggests that this fact makes it impossible to use machines of high landing speed for alighting on aircraft carriers In this he is, I think, mistaken Aircraft of unusually high landing speed have been landed successfully on deck, and no difficulty has been encountered in arresting them

The real difficulty which makes a slow landing speed desirable is not the lack of length in which to pull up It is the lack of breadth The deck itself is in motion and not only in the line of flight It is in general rolling, pitching and quite possibly yawing The difficulty of deck landing is that of choosing the moment for making contact with the deck at the time when the relative angular velocities of deck and aircraft are a minimum The majority of accidents in deck landing take the form of an attempt by the aeroplane to go over the edge of the deck, not to run past the end of the landing space

The longer the period available to the pilot for choosing the precise moment at which to make contact, the better his chances of landing accurately relatively both to the deck and to the relative wind of the moment, and a machine with a high landing speed—in other words a high speed of approach to the ship—gives the pilot a minimum of time in which to observe the conditions and to choose an appropriate instant of contant A machine which can keep station with the ship gives the maximum choice in this respect

In the earlier days of the War it was assumed that the problem of deck landing was essentially that of arresting the forward movement of the aeroplane and various experimental arresting gears were made and tried Most of them were quite satisfactory on firm ground

All of them when tried on a real deck at sea failed because they limited the control which the pilot could exert on the direction of his aeroplane after he had landed, and they were abandoned because they were found to increase rather than to decrease the risk of going off the deck laterally

Mr Dowty does not disclose the form of the braking mechanism which he proposes , but a generally similar scheme of picking up cross ropes attached to fore and aft ropes running over pulleys at the side of the deck and equipped with braking gear was suggested and designed at the Experimental Station, Isle of Grain in 1916, or 1917, and was abandoned for the reasons stated above

As Mr Dowty points out the ability to use small aerodromes is desirable for both military and commercial purposes Generally speaking commercial machines need a larger aerodrome for taking off than for alighting The first requirement for commercial purposes therefore is some form of accelerator—*i e* , a catapult or the like

I can see no room for doubting that in due course the catapult method of launching will become normal for commercial aircraft at least of the land-going type And having once adopted catapult launching all necessity for wheels disappears and landings can then be made on some form of skids

Tests made with various standard Service aircraft fitted with skids at the Isle of Grain showed that such machines could be landed in all places where they could be landed on wheels, in many where they would have overturned on wheels, and that skids themselves were as efficient arresting gear as many of the devices tried for this purpose They can in most cases be made lighter and of less resistance than can wheels, and since they form part of the machine itself, have obvious advantages over any gear fixed to the earth, if only because they are available at all times and places

Military aircraft are in a somewhat different position to commercial machines With the exception of heavy bombers and a few similar types they are usually of higher performances than commercial types, have a much shorter take off run, and a relatively longer landing run In other words the size of aerodrome necessary is more nearly determined by landing requirements The use of catapults is barely necessary for the high performance types likely to have to operate from advanced bases, and the necessity for carting about arresting gears would seriously limit the mobility of an air force in a war of movement

For machines of very high performance, which in general need the maximum landing runs, skids are perfectly practicable for taking off as well as for landing It is true that the take off run is greater than is needed on wheels, but to nothing like the extent that might be expected The majority of modern single and two seater military aircraft could, I believe, be used from appreciably smaller aerodromes than they can at present use if they are equipped with skid undercarriages, and they could certainly successfully land safely on ground on which as at present equipped they would inevitably crash

If in some future period aircraft power plants, etc , become so completely reliable that a landing away from a prepared aerodrome need never be feared, it may be possible to use commercial aircraft with landing speeds much higher than could at present be contemplated, and to rely on fixed arresting gears at the aerodromes for bringing them to rest in a reasonable space It seems probable that the simplest and most reliable type of arresting gear for this purpose will be a combination of a skid undercarriage giving a high ground friction and of a sloping landing run—or artificial hill

The earliest arresting gear tried at the Isle of Grain during the War was of this type, and certainly no gear subsequently tested gave more satisfactory results as an arrestor

MR DOWTY'S REPLY TO THE DISCUSSION

I was interested to hear Mr Molesworth's remarks regarding Sir Hiram Maxim's landing device and also to learn from Dr Thurston that Sir Hiram was the first user of the oil dashpot on aircraft landing gears

Dr Thurston enquired why the maximum load assumed in the oleo leg was given in my paper as five times that of the static load This value was given in a general way and it should not be assumed that the oleo leg is always designed to this figure It is usual in machines designed for the Air Ministry to be asked to give some definite load factor under a certain vertical velocity of descent The vertical velocity is variously stated between the values of 10 and 13 feet per second, and the load for which the undercarriage must be designed is variously given as between three and five times the weight of the aircraft No particular attention must therefore, be given to the definite figure mentioned in my paper

Dr Thurston makes comment on the elasticity of the structure and the ability of the various parts to take their own inertia loads From such considerations he thought that by designing the undercarriage to take the maximum load then should a light landing be made or the structure itself take part of the shock then there would be a certain amount of reserve work in the dashpot This however, is not the case The most valuable feature of the Taper Needle Oleo Leg is its ability to vary its energy absorbing capacity to suit the needs of the immediate landing The correctly designed oleo leg will always absorb the *whole* of the aircraft's kinetic energy, due to its vertical component of velocity, provided always that the velocity is not above that for which the aircraft was designed The operation of the leg is entirely automatic and the hydraulic gear has been so designed that the resistance of the leg varies directly as the square of the machine's vertical velocity

Dr Thurston refers to various forms of aircraft brakes In the first instance he comments on wheel brakes, but unless the undercarriage is designed with a leading wheel or skid there is a distinct tendency for the machine to turn over on its nose when the brakes are applied Air brakes can never be seriously considered for several reasons, and chiefly that such brakes become quite inefficient at moderately low speeds and do not apply such positive means of braking that it would be possible to draw up an aircraft in a definite length of run irrespective of the landing speed

I agree entirely with Mr Holland's views on the importance of the geometrical position of the shock absorbing member This is a point of considerable importance, and when any aircraft is designed great care should be taken to insure that the main landing loads should be taken in their proper place and avoiding loads of any magnitude in unsprung members

Mr Holland enquires why I deal with the oleo leg and then bring in considerations of rubber I admit that the ideal way of absorbing the energy is entirely on the oil, but there are other functions that an undercarriage has to perform, and unfortunately oil does not possess elastic properties and we are therefore forced to consider some means of springing To-day the generally accepted means is that of compression rubbers and therefore I included some general information on the properties of compression rubber The sandbag method of deck landing, where the aircraft picked up a series of bags and trailed them over the deck, was a very inefficient method The almost instantaneous loading put heavy inertia forces on the frame and under a high speed landing the light structure could never stand up to the loads imposed

Mr Bound remarks on the somewhat complicated nature of the brake illustrated in my arrester scheme It is certainly elaborate, but the requirements of the brake are such that it has been no easy matter to find a solution to the problem With variations both in the piston and crankshaft speeds it is a somewhat difficult matter to obtain constant torque

Mr Bound refers to the gear wheel type of pump as a suitable means for braking Mr S H Evans has also suggested to me the possibility of designing the brake on the same principle as the Fairchild Caminez aero engine Both these suggestions are very useful and I thank both these gentlemen for having brought this matter to my notice Although the difficulties of variable piston and crankshaft speeds would still have to be overcome, yet a simplification in design would result by adopting such a method of construction

Mr Bound has raised a very interesting point in mentioning the question of potential energy Unfortunately it is quite impossible to determine at any particular point how much of the weight is air borne and therefore we are almost compelled to neglect this unknown quantity

I am glad to hear that Mr Bound agrees with Dr Thurston on the benefits to be obtained from landing with a good flying speed

In reply to Mr Bound's question on the weight of oleo undercarriage From my experience I have found that for machines above 5,000 lbs weight the oleo undercarriage has been shown to be the lightest type while under 5,000 lbs the old tension rubber undercarriage comes out lighter There is not the slightest doubt that a long travel oleo leg is admirably suited for the needs of a school machine where novices are apt to test the undercarriage qualities to the extreme limit

I wish to thank Mr Folland for his kind remarks

In reply to his criticism of the oleo leg fitted with two sets of rings per leg I have never experienced or heard of trouble occurring, caused through the unequal deflection of the rubber columns

I fear that I must have created a somewhat erroneous impression in my paper for I did not mean to imply that the use of arrester gears on aerodromes would enable land machines to alight at a higher speed The advantages gained would be, in my opinion, a reduction in the size of landing ground required with a consequent saving in the initial cost and maintenance It will be seen that the case of forced landings is in no way affected and the use of arresting mechanism on the aerodrome does nothing to make forced landings any more serious than they would be without such braking means

In further reply to Mr Folland, I would suggest that the length of take off from the deck of a ship will not be of great importance in the future Catapult launching schemes are now a practical success and therefore the length of run to pull up will be the determining factor when considering ship operating aircraft

Capt Sayers states that aircraft of unusually high landing speeds have been landed on deck and no difficulties experienced in arresting them Such a statement, if taken at its face value, would be very misleading Landing speeds have no real bearing on the ability of aircraft to land on board ship The factor that is all important is the relative speed of the aircraft to the deck Under existing conditions of deck landing it is possible for an aeroplane with a landing speed of say 50 knots to land with a speed relative to the deck of say five knots because the velocities of the ship and the prevailing wind are of assistance I quite agree with Capt Sayers when he remarks that pitching and rolling present great difficulties to the landing of aircraft on deck I would however, point out that landings are never carried out when the sea is such that the ship is subject to any appreciable angular movement I am aware that quite a large proportion of the accidents in deck landing are due to the aeroplane attempting to go over the sides of the ship One of the advantages claimed in the method of arresting that I have described is the tendency of the brake load to always centralise the aircraft should it attempt to deviate from a true fore and aft direction I cannot agree with Capt Sayers when he advocates a very low landing speed for accuracy If the ship was pitching or rolling to any appreciable extent I should agree with him, but knowing that landings are not made under such extreme conditions I have ample evidence to show that a high-speed landing is more conducive to accuracy than a low speed one It calls for exceptional skill on the part of a pilot to come in slowly over the deck, synchronise his speed with that of the ship and then make a stalled landing It is much simpler to fly at the deck with a fairly high speed and then flatten out on approaching the landing ground Furthermore at this higher speed a pilot has full control and in case of any error can quickly get out of any trouble whereas the pilot making a slow speed landing has very nearly reached a point when his control will break down altogether These views are shared by some of our leading test pilots and I therefore give them without fear of contradiction I heartily agree with Capt Sayers when he advocates the use of skids Catapults would definitely alter aircraft landing gears, but there is not the slightest doubt that the wheel type of undercarriage would die a hard death and even if catapults were to be in general use to-morrow I do not believe that we should see any rapid desire to do without wheels I thank Capt Sayers for his criticism even if I do not always agree with his remarks I regret that he does not think this method of arresting will be satisfactory because recent tests have been carried out in America, on similar lines, have proved quite satisfactory, and the scheme has sufficiently interested the American Government that they have spent considerable time and money on this work

The meeting was brought to a close by a hearty vote of thanks to Mr Dowty for his very valuable paper