"The Possibility of the Flight Simulator as a Training Aid to Helicopter Pilots"

By NORMAN HILL, *Sales Manager, Redifon Ltd*,
and
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Two Papers, followed by Discussion, were presented to The Helicopter Association of Great Britain in the Library of The Royal Aeronautical Society, on Friday, 10th December, 1954

NORMAN HILL

The CHAIRMAN, in introducing the first of the two lecturers, said that Redifon, Ltd, to whom Mr HILL was Sales Manager, were very active in connection with the use of the flight simulator as a training aid to pilots Mr Hill was very well known to members, being a Founder Member and a Vice-President of the Association For many years he had been Chairman of the Council He was Sales Manager to the Flight Simulator Division of Redifon, Ltd, and he had held a pilot's licence for both fixed and rotary wing aircraft since 1936 He was commissioned in the General Duties branch of the Royal Air Force in 1941, and served with 1448 Flight and 529 Squadron (Meteorological Flight) After the war he was Air Adviser to British Electric Traction, Ltd, from 1947 to 1950, and he had the distinction of holding the Royal Aero Club's certificate No 8 He was well qualified to speak on this important topic

PIERRE DE GUILLENCHMIDT

Following Mr Hill's paper, the CHAIRMAN introduced Mr DE GUILLENCHMIDT, (who presented the second paper on the same topic), and said he was an extremely welcome guest lecturer Mr de Guillenchmidt had been in the field of helicopters since 1945, when he had entered the S N C A C, one of the French nationalised firms, in research in the Helicopter Division He had published reports on helicopter rotors and bending stresses therein Later, on the winding up of S N C A C, he had joined Giravions Dorand as an associate partner to Mr Dorand himself, together with a group of helicopter specialists, and since 1953 he had been Managing Director of the Company

The presentation of Mr Hill's paper was followed by a short film

MR NORMAN HILL

Mr NORMAN HILL's paper was confined to problems associated with the development of flight simulators by Messrs REDIFON, LTD , for fixed wing aircraft The purpose of the paper was to present an outline of what had already been achieved in Great Britain and to stimulate discussion on the application of the results to rotating wing problems The paper is summarised below

The lecture began by describing the function of the equipment produced, namely the Stratocruiser and Comet flight simulator So far as Mr Hill was aware there had been no development of a simulator for helicopters in this country The purpose of the fixed wing simulator was to reduce to a minimum the process of flight familiarisation, with its attendant hazards and cost The operation of the equipment was based on an elaborate system of electronic and electro-mechanical apparatus by means of which almost any navigational problem or emergency flight condition could be fed into the simulator The crew under training " flew " the machine in the same way as they would fly the actual aircraft and they took the appropriate action to deal with any emergency situations when they arose

The normal familiarisation training was of great value in reducing the time to be spent in the air flying the actual aircraft and, in addition, the ability to confront the crew with abnormal contingencies prepared them for an emergency which they might, otherwise, have to face on the one all-important occasion

Mr Hill concluded his remarks by comparing the cost of training with a flight simulator and with the actual aircraft The detailed figures are reproduced below

TABLE 1

ESTIMATED HOURLY COST OF OPERATING REDIFON FLIGHT SIMULATOR (TYPICAL FOUR-ENGINED AIRCRAFT)

	£	s	d
Inspection and maintenance	5	0	0
Electric power		3	9
Periodic overhauls and spares		15	0
Heat, light, air conditioning, etc		5	3
Senior instructor or check pilot with engineer instructor and radio aids operator	5	15	0
Direct cost/hour	11	19	0
Hourly amortization (40,000 hours in ten years—£187,500 cost = $523,125 at $2 79 (includes building accommodation and installation)	4	13	9
Simulator cost/hour	£16	12	0
or say at $2 79	$46 42		
Utilization 4,000 hours per year			

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TABLE 2

Aircraft	*Comet 3*		*Typical Piston-engined Aeroplane*	
Work capacity millions of ton-miles of payload per annum	12 1		8 1	
Work capacity per £1 of first cost	15 6		14 1	
Direct operating cost	*£ per aircraft flying hour*	*Pence per ton-mile of payload*	*£ per aircraft flying hour*	*Pence per ton-mile of payload*
Obsolescence				
Airframe	24 5	1 4	15 8	1 4
Power plants	6 3	0 4	6 9	0 6
Insurance	13 6	0 8	10 3	0 9
	44 4	2 6	33 0	2 9
Maintenance and overhaul				
Airframe	20 4	1 2	22 2	2 0
*Power plants	40 0	2 4	37 5	3 3
	60 4	3 6	59 7	5 3
Fuel and oil	90 1	5 3	52 2	4 7
Cockpit crew	9 9	0 6	12 0	1 1
Landing fees	6 6	0 4	3 6	0 3
	106 6	6 3	67 8	6 1
Total direct operating cost	211 4	12 5	160 5	14 3

* The overhaul costs for turbine engine power plants are taken at 25 per cent of their first cost (maintenance costs which are small compared with the overhaul costs are also included in this figure)
The overhaul costs for piston-engine power plants and their propellers are taken at 20 per cent of their first cost

An excellent film was then shown to the meeting which depicted the Redifon Comet simulator in action with a trainee crew The story of the film followed a synthetic navigational exercise from start-up to shut-down after landing, and included a number of emergency conditions which were fed into the system by the instructor in charge of the equipment

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The CHAIRMAN said that they had heard a very interesting talk and seen an extremely stimulating film He had not himself seen the Redifon or any other simulator, but the impression conveyed by the film was one of remarkable realism To see what went on inside the cockpit of a modern transport aircraft made one realise that " flying by the seat of one's pants " and " listening to the wind in the wires " were certainly things of the past

As a result of the film and the talk, a considerable number of interesting questions would certainly be put to Mr Hill, whose views would be welcome on how the Redifon simulator could be applied in particular to helicopter problems, and especially to machines of the transport type The discussion would be deferred until the second paper had been presented, but one point which he wished to put to Mr Hill was whether the effects of gravity or acceleration were simulated in any way

MR PIERRE DE GUILLENCHMIDT

Having been invited by Mr Norman Hill to contribute to this afternoon's discussion, I wish first of all to say how much I appreciate the honour of addressing the Helicopter Association of Great Britain

I must also apologise for my poor English and hope that my presentation, which I shall try to make as short as possible, will not strain too much the ears of the audience

The object of my contribution is to give a brief description of what we have been doing in France in the field of helicopter flight simulators and synthetic trainers, but before doing this I would like to express some general views on the value of such devices in helicopter-pilot training

The problem of training comparatively large numbers of helicopter pilots has only recently become a matter of concern as a result of the rapid world-wide development of rotary wing aircraft This fact, together with certain peculiarities inherent in the control of this type of machine, makes it essential that improved methods of pilot training are instituted without delay

Everybody knows what improvements have been introduced in the training techniques of fixed-wing aircraft by the use of flight simulators and ground trainers

The interest of these devices, principally a post-war development, has increased with the complexity and the cost of the flying machines

Owing to the fact that helicopter flying and maintenance are very expensive and that helicopters are more difficult to fly than comparable fixed-wing aircraft, the value of flight simulators and similar devices for training purposes becomes very evident

In my opinion flight simulators and synthetic trainers must play a very important role in the different phases of the training of helicopter pilots, and there is moreover at the present time a definite need for ground primary trainers

Let us consider at first the basic phase of training It is commonly accepted that in this phase a large amount of the teaching time must be devoted to the technique required to handle the helicopter in hovering flight Generally the training begins with the stick only and the control-lag, which is a common characteristic of all helicopters, baffles the pupil in such a way that he cannot relax his muscular control and an overcontrolling of the helicopter inevitably results The difficulty is that there are no straightforward rules to apply The stick movements, when hovering, often appear to be completely illogical and a good part of the instruction must be done by the pupil teaching himself by trial and error

When the instruction advances to the stage of adding first the rudder-pedals, then the throttle and the collective-pitch lever, the problem of a good control co-ordination becomes acute This is not easy as the pupil must do several things at once, always keeping in mind that the handling of the engine is quite critical This phase of training is altogether different from the corresponding phase for fixed-wing aircraft

Here the problem is to educate reactions which are not instinctive, to imbue in the pupil a correct rate response and to develop his skill in co-ordination

Fixed-wing pilots must also unlearn in this phase of training some of the habits contracted in fixed-wing practice which become unacceptable when flying rotary-wing aircraft

For this primary training phase ground trainers incorporating visual conditions and accurately portraying the hovering flight characteristics of the helicopter should be most valuable In this respect I shall relate to you an experiment which we have performed lately

One of our engineers, a glider-pilot, having never set foot in a helicopter, has been trained to hover in our DX 50 helicopter simulator, primarily designed, as you may know, for research work on prototype aircraft and which I shall describe later on

After about twenty hours of training on this simulator during which the flying characteristics of several helicopters including the Bell 47, the Sikorsky S 55 and French S N C A S E and S N C A S O prototypes were introduced in the computer, our engineer was put at the controls of real helicopters He flew successively the Bell 47, the S N C A S E -3120 " Alouette " and the Sikorsky S 55 In every case the instructor has been greatly surprised by the way in which the young man mastered the helicopter in hovering flight after only a few minutes of " on the field practice "

All instructors formed the opinion that the comparison was favourable even with respect to basic helicopter pilots switched from one aircraft to another It is quite clear that such experiments would have to be multiplied before any definite conclusion may be set forward, because the personal aptitude of the pupil may have played some role in the described case, but, however, I think that the indication must not be under-estimated

The use of flight simulators thus appears to be not only an effective means of educating the pilots reactions in the safest manner and the lowest possible cost, but should also permit an early selection of the pupils, as it is during this period of education that the instructor can generally tell whether the man is fit to be a pilot or not Other phases of training could, in my opinion, be also advantageously performed on ground simulators

Such devices would easily be able to familiarize the pupil with peculiarities proper to rotary-wing aircraft such as the following

(1) tendency to lose height when the stick is inclined forward ,
(2) variation of fuselage attitude when accelerating and de-accelerating ,
(3) tendency for the rotor r p m to increase with airspeed ,
(4) increase in torque with power

The necessary procedures in the event of engine failure and other items such as take-offs and landings could equally be simulated Consideration should be given in the same way to conversion of pilots to operational type helicopters, high altitude flying, refresher training and instrument flight training

The comparison of the cost of flight training with and without flight simulators will speak for itself, but since the cost of a flight simulator varies with the amount and degree of simulation of a given aircraft, it is important that serious consideration be given to the subject of exactly what features must be simulated and to what degree

I think that a careful analysis of this subject should be done with the co-operation of all potential utilizers This will result in a realistic approach to the type of simulator or trainer to be considered in this country, bearing in mind that the final form of such a device must be necessity be a compromise between perfection, simplicity and low cost Different trends of thought exist actually on the subject in the United States and in France

In the United States it seems to be desired that, even for primary training, the machine should not only accurately simulate the behaviour of a given aircraft from the standpoint of its performance and its handling characteristics but that it should exactly duplicate it in its internal layout

In France the general opinion is to consider, at least so far as primary training is concerned, that the trainer should merely reproduce an average aircraft

The exact behaviour of a given helicopter is not required, the simulation being limited to the correct dynamics of an average light helicopter, with the possibility of eventually adjusting certain features such as responses in roll and pitch so as to familiarize the pupil with other types of helicopters such as tandem rotor aircraft

It is considered that the trainer should not reproduce only instrument flying conditions, but that the illusion of visual conditions must be introduced Experience will show whether a movable cabin is necessary in order to give a better illusion of flying

Up to now our own experience in this field seems to show that though it gives way to a non negligible increase in cost, the movable cabin (or at least a cabin including a certain ability for motion) should be preferred

We think that the flight conditions to be simulated for a primary trainer should be at least the following

(*a*) hovering flight ,
(*b*) vertical flight (limited) ,
(*c*) horizontal flight (forward, rearward and sideward) ,
(*d*) turns ,
(*e*) passage to autorotation and oblique autorotative descent

Transitions to and from forward flight must be reasonably accurate

A more elaborate trainer which could be used for operational flight training should simulate, in addition to the above flight conditions

(1) take-offs and landings (with ground effect) ,
(2) normal approaches and climbs ,
(3) flare autorotation landings with and without power recovery ,
(4) high altitude flying

Simulation of quick-stops is generally not required nor such items as overload running take-offs, vertical autorotation, flights at extremes of C G or any abusive manoeuvres, which would not be included in the normal training syllabus The flight instruments to be simulated should be those of a standard panel board, that is (i) dual tachometer , (ii) airspeed indicator , (iii) altimeter , (iv) rate of climb indicator , (v) manifold pressure gauge

For instrument and night flying which is still rather restricted on helicopters but which shall undoubtedly be developed in the next few years, an instrument flight trainer would be most valuable

For the time being, however, blind flying of helicopters being conducted only on an experimental basis, it would perhaps be a little premature to talk of an instrument trainer, until a reasonable instrument rating scheme is framed

I shall now give you a brief description of the simulators and trainers produced or under development in our Company

GIRAVIONS DORAND has been active in the field of flight simulation development for several years Previously we have been purely helicopter men, our Technical Director RENÉ DORAND being, as you may know, one of the pioneers in rotary wing aircraft

It is the handling of problems such as stability, manoeuvrability and generally speaking flying qualities of helicopters, which give place to fairly complex mathematical procedures and for which different methods of analysis are still in the stage of early development, that incited us to have recourse to simulators

Up to now, when a prototype helicopter had been designed, there was only one way of verifying the worthiness of solutions choosed and hypotheses allowed for that was to fly it Flight testing, it is known, is a lengthy procedure , further it is costly and sometimes dangerous

When the testing is conducted on a single prototype, damage to the aircraft may lead to months of immobilization Therefore, it appeared valuable to have a machine which would permit the flying qualities of helicopters to be studied without these risks and perform a systematic analysis of all the parameters involved

The problem, as you may conceive, was quite vast and it took us several years to deal with it, though it was decided that hovering being far the most critical flying condition for helicopters, the simulator would be limited to it

After many engineering hours of research work and experimentation, during which we had a comprehensive support from the French Air Ministry, we produced the DX 50 Simulator under Government contract

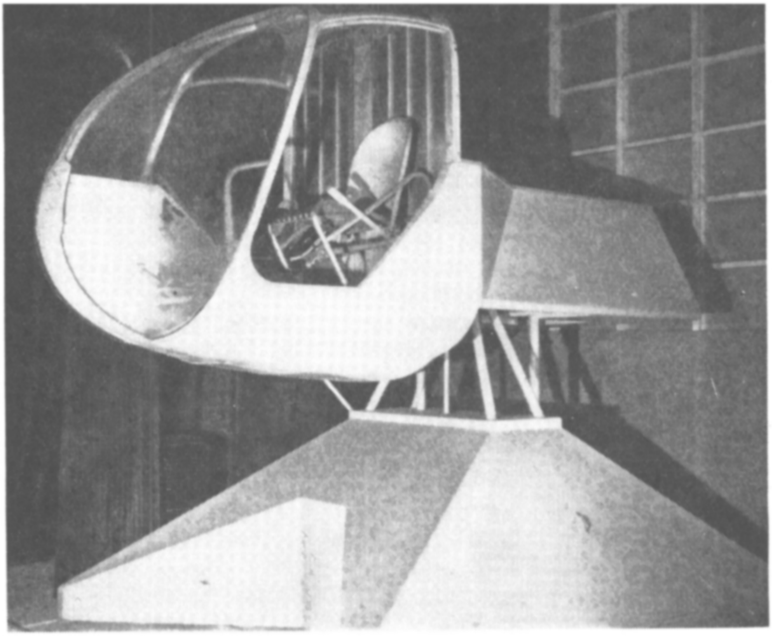
DX 50 SIMULATOR

This simulator permits the study of the hovering flight of any mono-rotor helicopter, either in fixed-stick conditions or with a pilot actuating the controls It thus gives the possibility to appreciate the behaviour in hovering flight of a machine which is still on the drawing-board

The engineer can rapidly investigate the influence of any parameter such as weight, blade characteristics, rotor system, control configurations, response lag and so forth Even an important modification may be performed within a few minutes

The pilot can familiarize himself with the prototype which he is called upon to fly and conduct his training without danger either to himself or to the machine The illusion of flying on this simulator, in the opinion of all those who have tried it, is excellent The pilot has a true impression that he is flying a helicopter

I have told you how one of our engineers has been able to handle real helicopters after a course of training on the DX 50 simulator I want to relate here another experiment to which I myself quite incidentally attended It took place during one of the working sessions we normally have with the DX 50



DX-50 Helicopter Simulator The movable cabin on pylon
(By kind permission of "Flight")

A schematic layout of the DX-32C Simulator
(By kind permission of "The Aeroplane")

The Computer showing Components of the DX-50 Simulator
(*By kind permission of The Aeroplane*)

On this occasion a new prototype was being simulated and the designer of this aircraft wanted to have personal experience of the hovering qualities of his future machine Consequently he took his seat in the cockpit of the simulator by the side of the testing pilot The time was early afternoon and I suspect that he previously had had a good lunch In any case, after a few minutes of flying he signalled to stop the simulation and hurriedly stepped out of the cockpit looking very green in the face ! I don't know whether after that he took any decision about modifying some suitable characteristic of his helicopter against air-sickness, but anyhow he refused to fly the simulator any more

The DX 50 allows for experimenting with such devices as automatic pilots or their components, gyroscopic stabilizers, phase correctors, servo-controls and so forth The dynamic behaviour of these devices and their influence on the handling qualities of the aircraft may be analysed and adjustments may be performed Besides the recording of such variables as stick displacements, angular and linear displacements of the aircraft, the velocities of these displacements and the tilting of the rotor, permits the dynamical study of the helicopter-and-pilot as a whole

Problems relating to human fatigue, standard location of controls and instruments, blind flying, Radio Aids and air traffic control could be studied in conditions of security and time-reduction that the present techniques of flight testing do not allow

In its actual form the DX 50 is built to simulate a wide family of mono-rotor conventional helicopters, but in future models modifications could be made to simulate more complex types such as tandem-rotor aircraft, free-pylon types and so forth Gyration has not been required up to now, but this could be easily added as well as forward flight conditions

The DX 50 simulator is composed of a cockpit representing a S N C A S E helicopter, mobile around its pitching and rolling axis , a visual arrangement on a large screen which comprises an optical system projecting a set of perpendicular stripes which simulate the concrete square blocks of a run-way and an electro-mechanical computer

The Cockpit

The cockpit is actuated in roll and pitch by two electrical split-field D C motors controlled by electronical power servos A three-stage tube amplifier, two h v transformers and four thyratrons are used for each servo unit The cockpit is of the dual-control type The flight controls consist of a stick and collective pitch lever, the latter being used as a means of starting or switching off the simulation The rudder pedals are locked, as gyration is not simulated The actual DX 50 has no instruments nor throttle adjustment as only hovering flight at constant altitude was required However, atmospheric disturbances such as wind gusts can be introduced

The visual system

The visual arrangement is such that the pilot has the impression of hovering at an altitude of about 25 feet over the run-way He sees the latter as a strip, 60 ft wide, extending in front of him over a distance of 120 ft after which it fades away A horizon is projected in front of the cockpit, roughly on the level of the pilots' eyes The projection of the stripes on the run-way figures square slabs of concrete having approximately 6 ft in size The simulated horizontal displacements of the aircraft are not limited, so the pilot sees himself drift in any direction as long as he does not correct

The foregoing projection is effected by means of ruled films, the stripes being located at right angles with each other in a cross-like configuration The lateral stripes are moved longitudinally towards the cockpit to simulate a forward displacement and vice-versa, while the longitudinal stripes converge towards a vanishing point through inclination of the screen and are moved laterally to simulate sideway displacements

Gyration in hovering, though not provided presently, can easily be simulated by rotating the projecting system, which has been designed for this purpose A correction, taking into account the component velocities, must be performed for the simulation of turns with forward speed

This use of a grid-like image on a suitably inclined screen so as to give perspective illusion, is a very simple but highly effective way of simulating displacements in all directions over the ground

Any other system, such as the projection of a map, would be quickly limited by the dimensions of the latter, unless a spheric map is used This would, however, set a serious problem for the rotation of the sphere in three directions without mutual interference Use of magnetic fields would perhaps be an answer to that problem

A change in altitude is also provided in the optical systems, but as no vertical motion was required the system is actually used only in two positions when simulation is stopped the pilot has the impression that the aircraft is stationed on the run-way, when he pulls up the collective pitch lever in order to start flying he goes up to an altitude of about 25 ft

The Computer

The computer of the DX 50 is electro-mechanical, of the analogue type It has been specially designed to handle the equations of motion of helicopters, but appears to be highly suitable for a wide application in all the cases where oscillating systems having a large number of degrees of freedom, multiple couplings and non-linear elastic effects are involved

The originality of this computer consists in the introduction of electro-mechanical double integrating units capable of giving simultaneously and with a high accuracy outputs proportional to the values of a variable and its first derivative in response to an input voltage proportional to the second derivative of the variable

Time would not permit to give here a detailed description of these double integrators, but if anybody is interested in the question I would be glad to give all information requested

The characteristics of the simulated helicopter are fed into the computer by means of dials located on a control panel board actuating potentiometers The computed solutions are given mechanically in the form of rotations which drive the optical system and control the oscillations of the cockpit All the solutions are recorded A security device stops the simulation and brings back to zero all variables when the displacements exceed certain maximum values

The DX 50 can simulate the flying characteristics of a large family of mono-rotor helicopters through a simple manipulation of the panel board dials

The range within which the characteristics can be varied is the following

Gross weight	600 to 20,000 lb
Blade tip-speed	250 to 800 ft /sec
Lock constant of blades	2 to 20
Pendular frequency of the aircraft	1 4 to 12
Periods of natural oscillatory motion	3 to 30 sec

The characteristics which need to be known for the simulation include Gross weight , radii of gyration of the aircraft , distance between C G and hub , rotor speed , collective pitch setting , diameter of rotor , blade characteristics (aerodynamical and mechanical) , ratio of stick travel to swash travel , ratio of swash movement to rotor movement , and several others, particularly if a stabilizer is incorporated in the aircraft Stick-friction may be taken into account

The above characteristics are transformed into coefficients which are fed into the computer This transformation, performed for a given helicopter, takes about one hour of calculations, but further readjustment of these characteristics can be made in a few minutes Special tables are provided for this purpose

The accuracy of the computer is very high where the natural motion of the aircraft is considered the error on the period of oscillation is less than 1 per cent , the error on the damping factor being less than 5 per cent

In forced oscillations, that is with the pilot actuating the stick, the error on the phase angle is less than 2 degrees in the frequency band to be considered This accuracy is entirely satisfactory for all analysis purposes

DX 80 Simulator

Besides the DX 50, our Company has in development a simulator for the training of helicopter pilots, the type DX 80 This training device is derived from the DX 50 but is intended to simulate only one helicopter the Sikorsky S 55

However, the computing characteristics and the cockpit layout could easily be modified if another type of aircraft needs to be considered The DX 80 being designed for training, the flight conditions to be simulated are substantially extended with respect to the DX 50

Simulation concerns here particularly all such items as are normally included in a training course, that is

(1) vertical take-off with control co-ordination ,
(2) hovering flight (accurately performed) ,
(3) forward, backward and sideward flights ,
(4) turns in hovering and in forward flights ,
(5) vertical and oblique climbs ,
(6) engine failure with pitch adjustment

All of these can be performed within the normal operating characteristics of the simulated aircraft

Sound of engine is reasonably reproduced The cockpit panel board incorporates all flying instruments essential to the operation of the aircraft under visual conditions Full flight controls (stick, rudder-pedals, collective pitch-lever and throttle) are provided and control loading simulated An instructors panel duplicates the cockpit flight instruments, and a trouble panel permitting representation of malfunctions commonly encountered with actual aircraft is provided Two versions are considered one with a fixed cockpit, the second with a movable one

We think that this simulator should answer fully the present requirements for all training purposes

DX 32-C Trainer

Another type of trainer is under development at Giravions Dorand, that is the DX 32-C simplified primary trainer This trainer, though simulating the same general flight conditions as the DX 80, is based on a rather different technique which relates to the frequency response of the simulated system

The simulation of the natural motions of the aircraft, though not altogether neglected, is not insisted upon and a reasonable accuracy is only required in a narrow frequency-band corresponding to the pilots reactions

This trainer is composed of separate blocks which build up transfer functions giving a correct rate response The reproduction of these transfer functions is obtained by means of analogy with mechanical and electro-mechanical systems directly available in current practice Though in this way some sacrifices in the accuracy of simulation have to be made, the cost and maintenance should go down in such a way that those trainers should be highly welcomed in primary training schools

The DX 32-C trainer being conceived in an economical turn of mind, no panel is provided for the instructor, who is seated by the side of the pupil The cockpit is of a fixed type and has dual controls Full flying controls and the normal instruments are provided

The type of aircraft simulated is an average light helicopter, having the general characteristics of the Bell 47 The transitions to and from any flight condition to another are being simulated without discontinuity, but no claim is made to their high accuracy

DX 32-B Hovering Trainer

I shall say at last a few words about a highly simplified hovering trainer which has been produced by Giravions Dorand, that is the DX 32-B

The object of this device, which is limited to simulate the dynamics of a hovering helicopter, is to educate the pilots reactions in this particular flight condition The training consists in stabilizing in height (for pitch) and lateral tilt (for roll) a bar projected on a screen in front of the pupil and simulating an artificial horizon Only the stick is provided, but through minor adjustments any given helicopter dynamics can be simulated, and stick frictions introduced No cockpit is provided, the pupil being placed on a pedestal bearing only a seat This is a very simple device, and one of its senior qualities is its low cost In small series its price should be fairly under £1,000 and maintenance negligible One unit is actually in operation at the Fenwick-Bell Helicopter School in Paris

Every pupil begins his training course by a five-hour training on the DX 32-B, and though I have yet no figures concerning reduction of flying hours thus obtained, the Monitors of the School show to be satisfied and assert that its aid is quite effective

Before finishing this review of helicopter flight simulators and trainers developed by our Company, I would like to say a few words about the economics of such devices It is generally accepted that hourly flying costs in helicopter training schools might be considered as the following

Light helicopters (basic training)	30 to 35 £/hr
Medium operational helicopters	around 50 £/hr

Considering that a course of training for pupils being already fixed-wing pilots consists of about 40 to 60 flying hours in primary training, and of something around 30 hours of operational training, we can see that

Every basic pilot costs approximately £1,500 to £2,000
Every operational pilot costs approximately £3,000

If the pupils are not already fixed-wing aircraft pilots those figures should be increased by about 60 per cent

Let us consider now a primary trainer of the simplified type as mentioned above The purchase cost of such a trainer, built in small numbers, would be approximately £20,000 (fixed cockpit)

Hourly depreciation (based on 10,000 hrs in 5 years)	2 £/hr
Direct hourly cost (including maintenance, spares, power and flight instructor)	2 £/hr *approx*
Total hourly cost	4 £/hr

Let us assume that the training time on this primary trainer is 20 hours Actual flying time required for the training course should be easily reduced by 8 to 10 hours This means an annual direct saving of over £20,000 by using a single ground trainer unit The latter would be paid back in less than one year of utilization If a more elaborate trainer is considered and the course extended to operational flying, the saving would be even more substantial

The purchase cost of such a trainer, incorporating a movable cockpit, a system of visual reproduction and a computer handling with good accuracy all the flight conditions normally to be preformed in the training course, would be approximately £60,000 built in few units

Hourly depreciation (15,000 hrs — 5 years)	4 £/hr
Direct hourly—approx cost	3 £/hr
Total hourly cost	7 £/hr
Duration of training on simulator	30 hours

Reduction of flying hours assumed

12 to 15 hours in primary training
Around 6 hours in operational training

Annual direct saving £50,000 to £60,000

No attempt has been made here to evaluate the intangible savings effected by reduction of accidents, overall increased proficiency, reduction of aircraft maintenance, virtual elimination of weather factors and many other items difficult to identify

Thus it is not doubtful that besides cutting the amount of flying hours required, ground trainers and simulators used in conjunction with actual flight would make more precise pilots