Discussion

In opening the discussion, **Mr W H Sear** (*Westland Aircraft Ltd*) (*Member*), said that he would like to give a summary of the pilots' reactions to the results which Mr HARRISON had obtained from the digital computer The examples chosen of the engine-off landing had always been a subject of great discussion in the past between the aerodynamicist and the pilot carrying out the flight tests, especially when establishing the engine failure avoid curve near the ground It had to be remembered that most of this flying was done qualitatively as there were so many variants with cyclic and collective pitch changes, rotor speed variations, pilots' interpretation, etc , which meant generally speaking that the pilot got to the slowest speed and lowest height he felt that he could cope with if the engine were to fail inadvertently This was the point from which the argument started, in that, for example, the pilot considered that the one second delay would be too long at the high all-up weights as the rotor speed would drop too far for him to recover them , and so the argument continued

Looking at the graphical presentation of Fig 7 in the Paper, the pilot in his test work immediately became more at home with this continuous type of presentation, and showed him " what was round the corner " Flight tests carried out after discussion on these graphs showed that these figures could be achieved if approached with an overall picture of what was required It also led to more standard type of testing between pilots For example, it could be seen in the graphs in Fig 7 that the collective pitch lever was continuously being raised after its initial lowering, whereas some pilots raised it in anticipated increments One could always beg to differ from the aerodynamicist, but with the coming of the computer in the aircraft and the computer on the ground the pilot's arguments were getting a bit thin

The situation could be summed up in the joke about the man who was doing test work on the flea The flea was trained to jump over the man's finger when he shouted " Jump " The two rear legs were removed from the flea, and on the order " Jump " it jumped The two middle legs were then removed, and in response to the same order it jumped again When the two front legs were removed, however, the flea did not jump when told to do so In his report, the man stated " When six legs are removed from the flea, it becomes stone deaf "

A question I would like to ask is with the coming of the turbine engine, on engine failure the rotor speed deceleration would vary between engine turbine inertias, which was also variable with the power output when the engine failed Could the digital computer cope with these changes on a decelerating engine, so giving an estimated time period for delay before lowering the collective pitch lever ? Also could the computer deal with the response requirement of a constant speed type rotor to prevent r p m variation not only in ordinary manoeuvres but also during engine failure ?

In reply, **Mr Harrison** dealt first with the question relating to the collective pitch movement immediately after lowering it to the bottom stop His programme showed that it was raised continuously, chiefly because the pilot had to be represented by an automatic type of pilot, therefore giving a continuous input Whether that was strictly characteristic of every pilot he did not know All that had been attempted to do with this type of programme was to show what should be feasible, for instance, in a power-off landing or any other type of manoeuvre In the take-off he had tried to show what space the pilot would need to get the helicopter off the ground and attain 100 feet

The piston engine power-off landing gave a very simple case because the rotor was completely free, and therefore the equation of motion of the rotor was limited to the inertia on one side and the aerodynamic torque on the other In the case of the free turbine the compressor set continued to pour out hot gas and feed positive torque into the rotor This could be simulated provided the necessary information were obtained from the engine manufacturers It had been intimated by several of them that it would be difficult to do a step-by-step basis because the engine equations were rather more elaborate than in the case of the helicopter He thought it could be done if a typical form of response curve were tabulated and if the table look-up facilities were used

The point relating to constant speed controls had already been covered in the paper The feedback could represent a human pilot, and it could also represent a fully-integrated control system

Mr H McGregor Ross (*Ferranti Ltd*), expressed appreciation of the paper and said that it gave a clear picture of the way in which an electronic computer could be used to tackle a real practical problem Because these machines are so novel there are not many descriptions of their practical use, and Mr HARRISON'S paper was therefore of value in giving a clear picture of a typical application

Arising from general experience of using these computers, it had been found the organisation of the sequence of processes inside the machine—which the author called " feedback," and which was covered in real life by the way the pilot handled the aircraft—was much more complicated than carrying out the actual mathematics Speaking very generally, one could say that in preparing work for these computers 80% of the effort and time went into the organisation of the flow of the calculation, while only 20% went into actual mathematics

The paper had shown another interesting point It emphasized the place which the mathematician could have in engineering work Although the techniques which the mathematician uses may be difficult for the engineer to understand, nevertheless with these computing machines it was possible to produce results which could be shown graphically or in other simple forms

The speaker was a little puzzled by the method of integration used in the differential equations, particularly with regard to the accuracy which would be obtained The method described in the paper was regarded as one of rather low accuracy, and he wondered why it had been used

Similarly, with regard to accuracies, the question of the choice of step length was of importance It was stated in the paper that the integration had been carried out in 1/10 sec steps, whereas some of the phenomena which were being studied took only 3/10 sec One would have thought that if these figures were correct, the step length would be too long by a factor of at least 10

Although the computer itself might be expected to make no error, and to work to sufficient places of decimals, nevertheless these points concerning the numerical method were important, and he wondered what checks the author had carried out to satisfy himself in this matter

Another point of interest would be the overall time required to obtain this information from the computing machine, from putting in the problem to getting the numerical data from which one of the families of curves could be plotted It was unfortunate that this was omitted from the paper

Reference had been made to table look-up, whereby tables of numbers had been put into the machine and referred to There was a further facility often used by which a table of numbers could be put into the computer, followed by an interpolation process to find the points in-between the stored values This made it possible to put in tables quite widely spaced and yet obtain a high accuracy at any intermediate point

It would have been of value if the paper had contained a little more information about the manual intervention that the operator of the machine could introduce during the calculation It was important in work of this kind that the operator should be able to work in concert with the machine This was usually done by selecting and operating switches

A similar type of study had been carried out in connection with fixed wing aircraft, involving the flight path of an aircraft after a catapulted take-off, and also for arrested landings In this case a useful feature had been provided in that it was possible to go back to any prescribed point in the flight path and change any parameter, studying the subsequent flight behaviour with the changed parameter

Turning to some general points, the speaker said it seemed rather odd that such limited use was made of computers in connection with helicopter work This contrasted very strongly with the exceptionally widespread use of these machines in other branches of the aircraft industry

It was peculiar that some aspects of computing work in the fixed-wing aircraft industry seemed not to have been adopted for helicopters, even where it might well be appropriate to do so He wondered why this was so The work carried out in the fixed-wing industry covered two broad kinds of calculation first, large-scale calculations of stability, flutter, vibration and stressing , and secondly (an interesting recent development), the use of these machines for quite small calculations such as would involve a morning's work with a slide rule These machines enabled the work to be completed in a few minutes The answers were not only obtained much more quickly, but they were more accurate In addition, when doing a number of small jobs and preparing them for a machine, it was possible to see how they became inter-related This was generally very helpful

The speaker was puzzled by the author's reference to the use of a particular computer as being a matter of Hobson's choice There were at that time four or five computing centres in full action in the country, and by early 1958, taking into account the Universities which were adopting the machines, there would be 14 or 15 computers for use by anyone desirous of doing so The technique was now well established whereby a man who was skilled in his own trade could soon learn to use the machine It was generally found that after a period of two or three months such a man could obtain good work from them This situation would be greatly accelerated by the new techniques which were becoming available for what was called auto-coding These new techniques make it possible for engineers to learn to use computing machines in a day or two Any problem which could be expressed numerically, and which could be precisely defined and worked out by a step-by-step process, could be readily prepared for these machines with these new auto-coding schemes There was no doubt that they would provide most powerful " tin openers " for the design engineer

In reply, **Mr Harrison** said that he would like to settle one point straightaway He was not a mathematician That led to the question why he described the I B M 650 as a Hobson's choice It was because it was the only computer that he knew anything about

Commenting on Mr Ross's reference to auto-coding by which a semi-skilled person could learn to use a computing machine in a few days, Mr HARRISON said that such a method as was used by the I B M 650 had been available for a long time

With regard to the ease of writing the programmes, he stressed that the most difficult and time-consuming part was writing the feed-back He admitted that the first one to be written—that relating to power-off landing—was difficult, and that three attempts were needed before satisfactory responses were achieved However, he was able to write the take-off programme in one attempt and it had worked with the minimum of alteration

Speaking of integration, the author again stressed that he was not a mathematician He had heard of these " fancy " methods of integration, and they did not mean a thing to him Having studied the literature on this type of work, he had found that what was good enough for people in the past was good enough for him He thought that Mr SEAR had made it clear that he was satisfied that the manoeuvres as presented on the curves were reasonably representative As they were not intended to be strictly accurate numerically but merely to represent a manoeuvre on a good qualitative basis, and as there were an infinite number of ways of performing these manoeuvres, he thought this type of integration was satisfactory

A step length of 0 1 per sec had been used because it was the longest that could be used with safety The flapping motion had a very short time constant and that dictated the step length

With reference to the table look-up facility, to which Mr ROSS had referred, it was a method of tabulating functions—usually empirical functions, with curves difficult to fit If Mr Ross required more details, he would have to approach the I B M manufacturers

On the subject of intervention, that had never been attempted The machine was running too fast and it was not possible to intervene quickly enough However, it was probably possible to intervene by stopping the machine and going back to a previous point Mr LAWRIE could no doubt supply technical details He believed that it was possible to arrange to go back to any point in the programme and start from there, with slightly different parameters His *modus operandi* had been to run a series of cases varying what he would describe as phase parameters These determined the point at which a branch instruction on asking, *e g* , " Does the speed exceed so-and-so ?" caused a different type of control input to be applied to make the machine respond in a different way The pilot, for instance, first flared out, maintaining horizontal flight, and when a certain speed was reached, safe enough to land, the nose was allowed to drop and the collective pitch to come up To find the optimum speed, a series of runs could be made varying the changeover speed, starting from some suitable point The programme could then be re-started at this point by a suitable manipulation without going through the whole performance again

The programme ran pretty quickly It took less than 2 secs per cycle, and ran at about one twentieth the speed of real time Referring to the family of curves in the paper, he said that this could be run off in about twenty minutes

Mr N L Lawrie (*I B M , United Kingdom Ltd*), said he did not know whether Mr HARRISON had made a sufficient claim for the accuracy of the programme They were working in the programme to five decimal places They had gone through the computation manually and he thought the accuracy was very good indeed

As far as table look-up was concerned, they had no need in this case to interpolate They were able to store a table of arguments and corresponding tables of functions , there was sufficient room on the drum to do this and to store them with adequate accuracy

Mr Harrison said he thought that Mr LAWRIE slightly misunderstood the point which Mr ROSS had raised He was not stating that the actual numerical accuracy of the computation was in doubt but that the method of integration might be insufficiently accurate

Mr Ross said that an easy way of coping with the situation was to use whatever step length was chosen, and then to do the whole calculation again with steps twice as close together, and to continue halving until it settled down The alternative approach was to double the steps and to discover when it " blew up " That was what he had in mind

Mr Harrison said that in his view, practical experience had shown that it was not necessary in this type of calculation to be any more elaborate than he had suggested A step length of 0 1 per sec gave all the accuracy required

Mr J V Roberts (*Short Bros & Harland Ltd , Belfast*) (*Member*), having apologised for his inadvertent late arrival, said that he would confine himself to some general remarks as he did not know what had been said during his absence

As one who was inclined to whistle the flute music when he came across it in performance, stability or vibration calculations, he had been very glad to see the growth of various forms of computers, both digital and analogue, which to him took the place of the pianola for the poor pianist

The results which the lecturer had obtained with his digital computations of flight paths of aircraft were very encouraging, as they showed that it was now possible to simulate helicopter performance and manoeuvres with a fair degree of accuracy The snag about using digital computers for the job, although it possessed the advantage of rendering it possible to go back to a particular point and try an alternative, was that it was not so easy to " fiddle " the control inputs manually as was possible with an analogue computer which worked in real time, or indeed, when working in condensed time with repetitive traces, which instantaneously show the effect of experimental changes Probably one of the reasons why analogue computers of the general type had not been used so much in the past on helicopter work was that the helicopter possessed more freedoms than the United Nations considered necessary ! For instance, in the case of the Short general purpose analogue computer, which was particularly useful for a wide range of fixed wing problems and had been used for helicopter problems " within the U N Limits," it required one to gang three, four or more of these together in order to get sufficient computing equipment to deal with the larger degrees of freedom involved in detailed helicopter work This is no disadvantage in a large organisation where a number of computers may be directly available or may be collected from different departments Alternatively, one can limit the degrees of freedom, as Mr HARRISON has done Of course, one can go in for a specialist type of analogue computer devoted specifically to helicopter simulation, which might be combined with the inputs from the pilot's controls and associated with a visual presentation which enabled the pilot to see and feel what the aircraft was doing, so closing the loop with his actual reactions rather than an arbitrary one, such as had to be used in the digital computation case His company was working on such a simulator, although apart from the items which had been published in the press he would not like to say any more about it, as further work was likely to be undertaken on the machine which might lead to a more impressive demonstration of its capabilities in the near future (N B See written contributions)

Mr R Annenberg (*Air Trainers Link, Ltd*), said that as one who had to find the quantities which went into the analogical pieces of equipment he was intrigued by one of Mr HARRISON's equations on the blackboard —

$$B_1 = K_1 W' + K \; W' + K_3 \int w' \, dt$$

It appeared that three terms represent one of the effective auto-pilot feedbacks in the loops involving three constants, K_1, K_2 and K_3 As he was interested in a similar type of problem, he was worried about the extent to which one should consider variations in those constants in that problem One can feel bemused while searching around for combinations of sealing levels within the auto-pilot giving satisfactory answers on gear with which one was working , all too often these prove unrealistic by virtue of inadequate basic information in the gear Could the lecturer comment on this state of affairs ?

In reply, the **Author** said he had to confess that he had taken the equation out of a text book on automatic pilots It was a well-known fact among auto-pilot specialists that the first two terms represented an auto-stabiliser If an aircraft of any sort was disturbed from a given path and one required to return it to straight and steady flight, the first two terms were put in If one wanted it to go back to the actual path, one applied the latter term $-K_3 \int w' \, dt$ in addition

With regard to the value of the constants, the actual response was not very sensitive to variations in magnitude within certain limits, provided the ratios were kept sensibly constant He believed that Mr CURTIES might confirm that

Mr M C Curties (*B E A Projects and Development Branch*), said that the point he had made at that time was that it was possible to achieve stability over quite a wide range of the particular auto-pilot constants concerned but he thought it was fairly evident from the flight records that there were definitely some optimum values

The **Author** said he could confirm that viewpoint The constants did not have unique values but they had quite a wide range which gave adequate results

Mr C H Bickerdike (*Miles Electronics, Ltd*), said that it had occurred to him that the author had not attempted to use an analogue computer He wondered whether the only reason was that it was too expensive He had no idea of the price of the I B M digital computer, but he wished to know whether it was impossible to consider the use of analogue computers for this type of work

In reply, the **Author** said he thought he had made it clear that the reason this method had been adopted was to form a complement to the linear approach That linear approach was very satisfactory for certain routine type of manoeuvres, and for checking stability criteria , but for comparatively long period responses—10 secs as against 2 secs —the equations became non-linear, and he did not know of any existing commercial analogue computer which could cope with non-linear equations

Mr Bickerdike agreed, but said that such a computer could be built

The **Author** said that he had not wished to delay the work while an analogue computer capable of this work was built

Mr Bickerdike then asked whether the Author could give some idea of comparative costs

The **Author** said the reason why the I B M 650 had been chosen was that he and his colleagues knew something about it He knew how to programme it, having been taught some time before As to the cost, the use of the I B M 650 cost £27 10s per hour In that time they could produce simulated flights of roughly one-twentieth of that duration When one considered that the average manoeuvre they required to study lasted 10 seconds, one realised that quite a few could be packed into the space of an hour, which was quite satisfactory for his purpose He did not know how much a Short computer fitted with non-linear units would cost That factor did not enter into the argument because when he carried out the work he did not think that computer was available

The **Chairman** said he thought there would be general agreement that Mr HARRISON had made out a very good case for the automatic computer, even if he had not made out such a good one for the automatic aerodynamicist ! It was said of some of the best mathematicians that they were very poor at arithmetic That being so, here was a tool that could perform detailed calculations very precisely and rapidly, and the main function of the mathematical scientist was to act as interpreter in setting the problem and in translating the results He could also now undertake the solution of problems in which the parameters not only had derivatives, but derivatives of derivatives—in other words, problems of a non-linear flavour—and by obtaining answers to these problems he could make a much closer approximation to Nature's Laws

This technique was becoming so important in scientific and technological work that they were very indebted to Mr Harrison for having presented a paper on the subject

A vote of thanks to the Author was carried with acclamation

Written Contributions

From MR JAMES J FOODY (*Short Bros & Harland*) (*non-member*)

Having read the paper with much interest, it strikes me that from the outset we must be quite clear what we mean by the description "Helicopter Flight Simulator" The conventional meaning is that this name describes a piece of equipment which attempts to stimulate a pilot as would an actual helicopter and hence invoke in him the reactions and control movements which would occur in an actual helicopter This involves providing some means of generating information on helicopter movement in real time (this is obviously of primary importance) and presenting it in a suitable form to the pilot

Mr Harrison, however, interprets the term "Helicopter Flight Simulator" quite differently and he describes the use of a digital computer in the solution of sets of linear and non-linear dynamic equations of motion with pre-determined forcing functions This, of course, is a job which is very suited to digital computation and is being done as a matter of routine in most of the aircraft companies on the equivalent fixed-wing aircraft problem which cannot always, as Mr Harrison suggests, be reduced by linearising assumptions We would not, however, consider that these digital computers are doing the job of "Aircraft Flight Simulators" but merely of solving the dynamic equations of aircraft motion

The digital computer as an element in a Helicopter Flight Simulator is, however, something which should exercise our minds and the major problem which will have to be overcome before this is possible is that of speed The digital computers available in this country at present are much too slow to be of any use and at a guess they would have to be speeded up by at least a factor of ten before they come into the right street This has been done in America and is well within the compass of present knowledge but in this country analogue computers have been used exclusively as the computing elements in Helicopter as well as fixed-wing Aircraft Flight Simulators

From MR J V ROBERTS (*Short Bros & Harland Ltd*)

In the discussion following my contribution, the lecturer indicated that one reason for having employed digital rather than analogue computation was the apparent lack, when he started work, of non-linear function units for analogue computers, whereas non-linear as well as linear functions can be applied in tabular form in digital computations As I indicated at the meeting, a range of non-linear units is available for the Short General Purpose Analogue Computer, and I have asked Mr Peter Wright of our Company to write a brief note on these An indication of the cost of both the basic computer and these additional units, which was requested by another contributor to the discussion, has been supplied to The Association and is, no doubt, available on request

From MR P A R WRIGHT (*Short Bros & Harland Ltd*)

"With the Short General Purpose Analogue Computer, there is available a comprehensive range of both linear and non-linear computing equipment, practically all of which is designed to jack in bodily to the standard console, containing the power supplies and the monitoring, timing and display facilities The actual composition of the computer can therefore be varied to suit the problem The "heart"

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of the analogue computer ıs the hıgh gaın d c amplıfier, but ın the Short computer, thıs amplıfier has been built ın and does not appear necessarıly as a separate unıt, *e g*, the lınear functıon unıt contaıns a hıgh gaın d c amplıfier associated wıth a number of resıstors and capacıtors whıch are selected by swıtches and whıch can be connected ın varıous networks around the amplıfier, to perform such mathematıcal functıons as ıntegratıon, addıtıon, dıfferentıatıon, etc

A computer equıpped wıth 18 contınuously drıft corrected lınear functıon unıts and 18 scalıng unıts (gıvıng 36 co-efficıents each of whıch can be set to any value between 0 100 and 1099) can deal wıth problems represented by 4 sımultaneous second order dıfferentıal equatıons , ıf non-lınearıtıes are present then suıtable non-lınear unıts must eıther be mounted ın place of the lınear unıts or ıf the same capacıty ıs requıred they must be fitted ın a second or even a thırd coupled console

The consoles are so desıgned that any number can be coupled together to ıncrease eıther the number of sımultaneous equatıons whıch may be dealt wıth or theır order

The followıng lıst brıefly descrıbes some of the many non-lınear unıts now avaılable for the Short computer —

Unıt	*Equıvalent Sıze*	*Method of Operatıon*
Functıon Squarer Unıt	One Lınear Functıon Unıt	Thıs unıt contaıns a parabola sımulated by 14 straıght lıne dıode sectıons and gıves the square of any ınput
Sıne/Cosıne Unıt	One Lınear Functıon Unıt	Thıs unıt contaıns a 270° cosıne curve wıth the x = 0 poınt swıtched so that the output ıs eıther the sıne or the cosıne ±90°) of the ınput
Dıscontınuous Functıon Unıt	One Lınear Functıon Unıt	Thıs unıt contaıns two amplıfiers, the second beıng used to provıde lımıtıng or dead-zone characterıstıcs
Varıable Tıme Swıtch Unıt	One L F U + One S U	Thıs unıt enables two scalıng sectıons to be swıtched together or ındependently so that the problem can be altered eıther after a gıven tıme or after a gıven amplıtude
Hıgh Speed Multıplıer Unıt	Three L F U + Two S U	Thıs unıt contaıns four 19 segment dıode squarers and sıx plug connected amplıfiers and permıts purely electronıc multıplıcatıon (wıth ıts ınherent H F response) of two varıables
Servo Multıplıer Unıt	One L F U + Two S U	Thıs unıt permıts one common varıable to be multıplıed by four ındependent varıables, and ıs provıded wıth output scalıng on each of the four product terms
Contınuous Functıon Unıt	Three L F U + Two S U	Thıs unıt contaıns 21 dıode segments each of whıch ıs ındependently adjustable for bıas and slope , ıt contaıns 3 plug connected amplıfiers wıth contınuous drıft correctıon It permıts the generatıon of an arbıtrary functıon of a sıngle varıable wıth the hıgh frequency response ınherent ın an electronıc method

Certaın other unıts are also avaılable, such as the Low Frequency Decade Oscıllator, ıncorporatıng prınted cırcuıt amplıfiers, and a Tıme Delay Unıt, ıncorporatıng 20 cascade prınted cırcuıt amplıfiers

These two unıts are constructed on standard 19 racks and do not fit physıcally ınto the standard computer console, but may be connected to ıt by plugs and sockets Prımarıly developed as components for testıng servo systems, these unıts may be used ın computatıon, *e g*, the former for provıdıng sınusoıdal forcıng functıons between 01 c p s and 100 c p s and the latter for representıng transport delays, such as pılot's reactıon tımes, etc "