Discussion

The **Chairman** congratulated the Author on his interesting presentation of so fundamental a subject and for taking members back to first principles and tracing the conception of an integrated aircraft to the flying creatures The history of aviation usually began by looking at what happened in Greek mythology—for example, Icarus, with wings fastened to his arms with wax It was usually considered that the helicopter was first conceived by Leonardo da Vinci, who, however, also envisaged flapping wings for the achievement of human flight Man-powered flight had not yet been practicable, although there were a good many people, including some who were present tonight, who considered that it was now nearly a possibility It remained yet to be seen whether man-powered flight would best be achieved by an ornithopter, a helicopter or an aeroplane

The Author had spoken of the jet-wing principle The discovery that a jet issuing from an aerofoil fundamentally altered the flow pattern around it and could give an amplification of lift had opened a new field in aerodynamics A few days ago, the Chairman had received a communication containing a specification of a device which was described as a bladeless helicopter, in which the objective was to replace the blades by rotating jet sheets Without suggesting that this was even a remote possibility, it would be interesting to hear the Author's comment on the extent to which the jet-wing principle could be applied to the blades of a helicopter rotor Were there likely to be important changes in the helicopter by the application of this principle ?

The **Author** replied that one thing that came to mind concerning the jet flap principle was a device with which to prevent the wing from stalling, so that if on a conventional helicopter there was trouble during its path and the flow might stall on a blade, this would be one way of at least postponing it a little In other words, the speed limitation of the helicopter might possibly be affected by the use of the jet flap

Another aspect that came to mind was that instead of moving the blade about and pitching it, the jet flap was a means of producing lift on a surface even if it was along the stream It might be simpler to have a nozzle near the trailing edge of the blade and swing it about and thereby do what one might otherwise achieve by means of trailing the whole

The **Chairman** asked the Author whether he would do away with hinges

The **Author** replied that there would still be a hinge, but it might be easier to manage

The **Chairman** asked the Author whether he considered that man-powered flight could best be achieved by an ornithopter, a helicopter or an aeroplane

The **Author** (in reply), said that there were in the audience a number of other people who were much more qualified to answer He had not thought very much about it himself At first sight, he had always thought that rotation was preferable to any oscillatory motion, but this was mainly on engineering grounds that it seemed to be simpler Looking at the various animals, some of them appeared to strain themselves to get as close to rotation as possible On the other hand, it was by no means clear whether the unsteady motion of an oscillating wing and interference effects could not be used to advantage, in which case it might be worth while to use the oscillating motion

On the whole, a lot of work needed to be done before even the aerodynamics side of the question could be decided

The **Chairman** announced his intention of calling on a number of discussion speakers, starting with those interested in man-powered flight and helicopters, and then those who might be interested in powered lifting systems incorporating the jet wing principle

Mr H B Irving (*Consultant*) (*Member*), described the paper as most stimulating and the film stimulating as well as beautiful, especially the sequences of the gulls in slow motion and some of the insects too They prompted the wild thought, "Why can we not do likewise ?" The birds certainly seemed to have an instinctive knowledge not only of aerodynamics, but of mechanisms , and human beings had a tremendously long way to go before they could get anywhere near then It would be very well worth while studying bird and insect flight much more than had been done in the past, and one had the desire to see the film a number of times Was the von Holst thrust wing model driven by elastic ?

Speaking of the term " integrated aeroplane,' Mr Irving said that he had come to the meeting with a very vague idea of the meaning of ' integration,' but the paper had not made him entirely clear Was the definition of " integration " altered merely to suit one s purpose ? Before the meeting, for example, he had wondered whether the idea was to award marks to an aircraft according to the degree of fulfilment of its various functions The fixed-wing aeroplane, for example, could travel very fast and would be given a lot of marks for its speed It also had to land fast, however, and it required a big airfield, for which it would get poor marks The helicopter could go up vertically and would get full marks for this particular property, but it could not go very fast—at the moment A silent aircraft could be given more marks than a noisy machine Another factor was its payload as a percentage of its all-up weight Was it possible to talk about an integrated aircraft in this sense, in getting most marks for fulfilment of function ?

It would be of interest to know more about the power/weight ratio of birds and insects It was known that man had a fairly low power/weight ratio Did birds and insects have an enormous figure of power/weight ratio in comparison with the poor human being ? In other words, were human beings at an inherent disadvantage in this respect ?

In the film, the pterodactyl appeared to have a tail and a long boom at the end, whereas one's impression had always been that it did not have a tail At any rate, the Hill pterodactyl aircraft did not have a tail The idea was that it did not need a tail from the very beginning

The **Author**, replying to the suggestion that it would be worth while to study the birds, said that the models had all been made with this specific purpose in mind They were all intended to imitate certain modes of flight In other words, it was assumed that this or that animal would possibly fly in a certain manner and that shape and elasticity of the wing would achieve this or that result, and the models were made accordingly The purpose was then to see whether a model would fly as expected If not, the properties would be changed It was, therefore, a roundabout way of getting a bit more knowledge about how the birds flew, with models trying to imitate each one in turn The models were all driven by rubber, with just a piece of elastic wound up to drive the wings

Admittedly, " integration " was not a nice word The second definition given by Mr Irving could just as well be integration In the paper, its usual meaning was taken in the sense of combining several purposes and using one unit to do several jobs For instance, one could dispense with the fuselage and make a thick wing, in which case there might be an integrated design namely, one in which the provision of stowage space was combined with the provision of a lifting surface In that respect it was unified or integrated , but " integrated " was still not a wholly satisfactory term, because nothing, in fact, had been integrated in the mathematical sense Another example would be to use the wing to serve two purposes—namely, thrust and lift—in which case it might be called engineering integration Nevertheless, the word was not altogether satisfactory

As to the tail of the old pterodactyl, one of the results of the tests by von Holst was that if he made wings of that sort of shape and elasticity, he definitely needed to use a tail , the model would not fly otherwise Since it was a small tail surface only, it had to have a very long arm von Holst had tried various models in which he shortened the tail and enlarged the surface, but an arrangement of the kind illustrated was necessary before it would fly properly Therefore, it must have had its purpose, and Hill's pterodactyl—meaning a tailless aircraft—was probably one of those things which could not be explained, like integration

The question of the power/weight ratio was an important one and there was now a fair body of information from people who had tried to measure it It was, however, difficult to measure on a living bird, and von Holst had made his models to find out something about it In some cases, he had been able to take measurements At the kind of scale of insects or models, the power/weight ratio was relatively low on paper, but when using similarity laws and changing the weight with scale, one found that, in terms of an aircraft, an insect might be very high-powered This was the rough conclusion that the Author had reached at the time, but it was certainly not conclusive

Mr B S Shenstone (*B E A*) (*Member*), who spoke of the wing section of insect wings, said he had noticed under the microscope that insect wings were very rough in sections They were ribbed and had hairs in odd places Using an electron microscope, it could be seen that a gnat's wings were covered with hairs which were short, thick and curly and which obviously must have a definite purpose The purpose mentioned by the Author was to keep the flow turbulent, and this might well be true If it was, one had the feeling that it was, as it were, doing something the easy way rather than the right way If the flow could be kept laminar without separation, one was far better off than by making it turbulent The question is Is this possible ? It would be interesting to have the Author's comments

When looking at the insect wings, they appeared to be so arbitrary in shape and so incredibly crude that one wondered whether they could be considered to be sufficiently developed for production purposes !

A very marked impression derived from the lecture was that the film and the Author s remarks showed that a flapping wing was merely a propeller that did not go all the way round, and that everything was simplified by making it go all the way round The poor insect could be seen trying like mad to make it go all the way round The fact that it could not do so was no virtue It was only the limitation under which the insect suffered because it could not have a fully rotating shaft

Many people seemed to feel that when man flew by his own power, he should use flapping flight, but there was no reason why this should be assumed After all, nobody had flown in aircraft powered by engines with flapping wings, and this would be far easier to do than to hook up a man to it Therefore, until it was possible to fly about in light aeroplanes with flapping wings easily and show that it was more or less efficient than with a propeller, the man-powered flight problem should not be involved with the flapping wings

Some people might feel insulted by remarks of that kind, but, after all, the easiest way to do things was the best If something could be done the easy way, the complications and refinements could be introduced later Unless an effort was made to do it the easiest way, it might never be done at all

The **Author,** referring to the question concerning the section of the insect wings, said that their peculiar shapes had never really been properly investigated But he wished to mention one simple test which had been done with a two-dimensional aerofoil shaped as a smooth curve with a sharp leading edge, as on insect wings At an angle of incidence, it produced a separation which took the form of a bubble, which might then re-attach to the surface and leave a fairly thick wave behind This was probably what it was sought to avoid because large bubbles implied a loss of lift and an increase in drag as well as undesirable changes in the aerodynamic centre and the properties generally

If little additions like spikes were put upon the leading edge of such a wing, they were some kind of vortex generator which broke up the bubbles in its wake completely If they were widely spaced, the bubbles occupied the other spaces, but sufficiently close spacing might eliminate the bubbles altogether This might well be the explanation of why this sort of thing was done by the insects, troubled as they are by the low Reynold's number of flight It was still a flow with a very thick and turbulent boundary layer and a thick wake behind all these excrescences and vortex generators, but it was still better and more efficient than would be obtained without it and could be thought of as approaching attached flow

To keep the flow attached by other means at these low Reynold s numbers would require a change in the leading edge shape and possibly a change of camber during flight The higher the load required, the more camber the wing should assume The insects with their stiff wings, however, were not able to do that, so they had probably to revert to such means as what might be called vortex generators , and the few tests which had been carried out led one to suggest that this was probably effective It would be interesting to do further and more detailed experiments It was an interesting fluid-motion problem, too

The controversy between rotation and flapping motion was one in which the Author did not wish to take sides He wished to be sure, first, that the oscillatory motion could lead to some advantages This could not be excluded *a priori* , but it would have to be proved first and so far no advantages for the flapping motion had been demonstrated In this context, one might also refer to rotating wings such as the Voith-Schneider propeller which is used in the propulsion of ships Although each wing was moving on a circle, it was, after all, an aerofoil in an unsteady motion For ship propulsion, of course, an entirely different purpose was fulfilled which enabled movement in any direction This was a great advantage, so much so that even if it was not as efficient as a means of propulsion, it might still be used It was not, therefore, a conclusive case for the application which was being discussed

Mr D G A Rendel (*R A E*), recalled the Author's remarks concerning the propulsive efficiency of the various types of propulsion and, in particular, the flapping wing, which he had expressed as a ratio between the propulsive efficiency or the forward thrust and the lift Was it possible to express this term in a more fundamental way as the efficiency of the power ratio to the rate of climb—in other words, to the work done by the vehicle ? In considering vertical take-off, for instance, the power to take off could be expressed as weight × rate of rise Could this be related to the power of the engine to get a much more fundamental property ?

Mr Rendel gave a number of figures which he had collected in various ways and which had been reduced to reasonable proportions of accuracy

	Weight	(*Power output*) *Horse-power*
Dragon-fly	0 002 lb	0 002 h p
Gull	4 lb	$\frac{1}{4}$ h p
Man	200 lb	2 h p

The ratios, therefore, were roughly of the order of 1 — 10 — 100

For the same cases the wing span figures were Dragonfly 0 2 ft , Gull 4 ft , and for something of the size of a man, a wing span of about 25 or 30 ft would be needed These dimensions gave ratios of wing area of the order of 1 — 100 — 10,000 It was thus clear that the insect, the bird and the man presented cases of different orders of magnitude and it was difficult to draw any firm deductions from comparison between them

The **Author** replied that another factor in the definition of the efficiency was the rate of advance Only the propulsive efficiency was considered and defined as the thrust multiplied by the forward speed and divided by the power input The work was, therefore, done in the direction of flight In that respect, it was only a partial efficiency It was a sort of aircraft efficiency for level flight, and it would have to be redefined for a vertical motion

He had nothing to add to the figures given by Mr Rendel They were on the same lines as those assumed in the paper and he completely agreed with what Mr Rendel had said

Mr H B Irving, who referred to the figures given by Mr Rendel, said that man could not exert the figure of 2 h p for long, as Mr Rendel would be well aware It was a peak power which man could produce for a short time, but over a steady period it fell to something a little under $\frac{1}{2}$ h p

Mr W Stewart (*R A E*) (*Member*), pointed out that in the paper the Author had insisted on keeping everything general Was this because he was interested in the technical feasibility of doing things or because this still applied when considering a commercial enterprise ? It was quite obvious that the various birds and insects did things in many different ways and that there was a great technical interest in being able to duplicate them When the subject was kept on the general level, however, it was difficult to appreciate whether there was a serious commercial application to all these different forms of flight

As a research worker, the Author would appreciate that in almost all fields of research the scope was so vast that he could not cover it all and it was necessary to pick out what would be the most likely line of successful development Was the

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Author s prime interest the technical achievement of reproducing something else, or did he have commercial possibilities in mind at the end of it all ?

Having made his wonderful comparison, had the Author any intention of now going along to the Automobile Engineers and persuading them that they should not have overlooked the possibility of the mechanical horse ?

The **Author** replied that his interest was on the fluid-motion side and that of Von Holst had been mainly biological That was why he had of necessity kept the subject general, because he could not really say much about anything else In particular, he knew nothing about mechanical horses

It was all very well to pronounce that one should do certain things first , at some stage it was certainly necessary to pick and choose and to make up one's mind and take the risk Probably the big difficulty was in going too far to one side and then concentrating on one aspect too early to the exclusion of other things and possibly throwing away something better On the other hand, there might be the man who was interested only in seeing how things worked and who never got down to making anything at all It would be helpful if somebody would consider the subject from this point of view and would make a few suggestions for things which seemed to be worth looking into and which were not too general, and not too much independent either As he had said in the lecture, it was probably still too early to consider well-defined commercial projects and layouts at this stage , what was required now was more fundamental research

Mr J Shapiro (*Servotec*) (*Founder Member*), added his support to those who considered the word " integrated " rather unfortunate He thought that its origin was in America, where it was borrowed from psychology Integrated personality was a Good Thing and, therefore, an integrated aircraft was a Good Thing In fact, every aircraft which did not fall to bits could be described as integrated ! What really was meant should be expressed by a quite different word What Mr Hafner meant was once expressed by Mr Raymond, of the Douglas Aircraft Company, as the " well tuned " or " well tempered " aircraft, each part being tuned to another

When watching unorthodox forms of aircraft layout or conception, the first thought to enter the minds of those concerned mainly with design was whether the parts were well tuned to each other, in other words, whether it was a felicitous combination One could understand the origin of the attraction that had impelled the Author to commence his studies Mr Shapiro had had the same feeling himself and regarded this design as a well-tuned and felicitous combination

Could the Author say what had happened to the rather advanced and thorough adaptation of the idea by Pabst and Focke, of which there had been some detailed descriptions ? Pabst had tried his very short ram-jets, which were an essential part of the fitting together of the whole combination as an engineering entity Pabst had achieved some results with propane, but he had not got very far with liquid fuels

When having to write on the subject of convertible aircraft, Mr Shapiro had chosen it as one of the best tuned combination A little while ago, he had come across the coleopter conception Although he had approached it with very sceptical eyes, on further examination it seemed to be another " well tempered " proposal This might be a poor phrase to express what was meant by an aircraft incorporating dual purpose components which would do more than one job Of course, the conventional aircraft did not have dual purpose components but flew very well The helicopter did have them and it also flew well

In the case of the helicopter, a distinction should be made between the fundamental efficiency when talking of slow flight—or flight in which speed did not matter, when the power/weight ratio was the fundamental conception—and the proper term " efficiency," which was a non-dimensional conception, could not be applied because it was fundamentally impossible Not having studied the jet flap adequately, Mr Shapiro would be interested to know whether it contributed anything in the direction of improved power/weight ratio To put it at its most fundamental physical level, if it was a fast jet it could not have a very good power/weight ratio, but by a certain amount of entrainment matters could be improved An invention about which he and Professor Bennett had been consulted had something to do with it Mr Shapiro had not been able to tell the inventor that he was on the wrong track, and he would be interested to have the Author's views

Was it possible that the jet flap was a form of producing entrainment under favourable circumstances ? A simple form of entrainment occurs in an ejector

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pump It is used in steam power stations, because of its simplicity but there was no efficient ejector pump The subject had not however, been fully explored

Would the Author say whether the jet flap was, in fact, a form of producing entrainment under exceptionally favourable circumstances ? If so, there was some *interest in the " circular jet flap " invention, because it might be another configuration* which would make use of this phenomenon

Among the Author's ex-colleagues there was also Dr Kuessner, who had produced a combination of flapping and rotation, an idea which on first reading was very impressive The combination was in a sense rather like that suggested by Mr HAFNER It was a particularly well integrated one because it produced the effect of a counter-rotating rotor with a single rotor , it produced rotation by flapping Incidentally, Kuessner himself had admitted that the basic idea had been invented and tried before, namely by Passat in France, in 1921, but Kussner produced a theory of it and made some models Had he gone any further with them ? Certainly, on paper they were most attractive It was only the mechanical side which had caused difficulties, but these might not have been insuperable It was a question of the flapping strength of the blades Certainly, from the viewpoint mentioned by Mr Hafner, it was the most integrated, best fitted conception of a helicopter rotor which made use both of flapping and of rotation

The **Author** replied that the definition put forward by Mr SHAPIRO was quite acceptable He had merely taken the word ' integration " in the sense in which it was nowadays used, but perhaps he should not have done so

The jet flap principle had not been applied to rotating wings or anything of that kind, *but it had* been applied to the *ordinary unswept wing with* large aspect *ratio* The question of what was the corresponding answer to the induced drag to replace it was a very complicated one, and many mistakes had been made in the early stages Quite a number of factors were involved On a finite wing, there was some downwash left at infinity, and this meant a loss of thrust On the other hand, to change the downwash distribution somewhat along the chord would make for improvement It could not possible be explained here and now, but what came out of it, in effect, was that the induced drag was smaller for a given span and given lift by an amount which depended on the jet momentum It was, however, a different matter whether it could really be used with high lift because the induced drag was still proportional to the square of the lift The extent of its usefulness would need a detailed project study The author considered the entrainment effect with jet flaps to be small

The Author was not very familiar with the work of Kuessner but was sure that it had not been followed up What Mr Shapiro had suggested was exactly what one would like to do in order to decide whether a flapping motion was superior to rotation for man-powered flight, because there was just the possibility that with the unsteady motion the work to be done might be arranged in such a way that one was better off on basic principles

The work of Focke-Wulf simply foundered at the end of the war and nothing came of it It was quite correct to say that the work was a definite attempt to go as far as possible *in this* way and to have it " well tuned ' For *instance, the ram-jet* design was definitely done with that in mind To suit the particular application, the engine had to be kept short and, in order to do that, it was necessary to develop a number of burners to keep the combustion chamber short The work had got just as far as doing subsonic wind tunnel tests on a model When worked out in the end, it did very nearly what it was designed to do The gas was nearly burnt out inside , there was no flow separation anywhere , and the drag was as estimated The results could thus be explained fairly well, but they were obtained by burning propane That was a big snag, and the work had simply not gone further The drawings of the whole aircraft had been ready for going to the shops

Commenting on the earlier reference to commercial intentions, the Author said that this scheme might well turn out to be profitable it might well be a card on which somebody could put his money The coleopter, on the other hand, might be another one Both of them appeared to be business-like

Mr T R Nettleton (*College of Aeronautics*), inquired about the possibility of reclassifying the various integrated-lift systems Even the term integration seemed to lack definition The technical literature contained various classifications such as tilt wing and vectored slipstream VTOL, and internally and externally jet augmented flaps Were there not some broader terms such as in the classification of balloons and aeroplanes into aerostats and aerodynes respectively ? Could the systems be re-grouped in terms of the general aerodynamic propulsive principle involved in their operation ? For example, all of the systems employing a wing submerged in a slipstream involve the aerodynamic principle of a wing at incidence to a relative airflow

It would also be interesting to hear a little more about the " instrumentation of birds," mentioned in the lecture A man flying without visual or instrument references experiences difficulty in sensing steady motion and in interpreting accelerated motion How does a bird overcome this ?

The **Author** replied that he could not answer the last part of the question He referred again to an article in the *New Scientist* of 5th December, 1957 To repeat it all would merely be confusing

He wished that there were some standard terms, but he had not discovered any However, people were, in fact, engaged on the task of defining terms for the British Standards glossary It has also been said recently that somebody was even trying to define what was meant by " integration "

Dr S Neumark (*R A E*), said that one thing that the paper had demonstrated, was how little aeronautical engineers knew about birds' flight and, especially, how little the members of the R A E staff knew about their heraldic pterodactyl One puzzling feature was the different use of the wings' inner and outer parts, the former being used mainly to produce lift and the latter to produce thrust This seemed not to be absolutely necessary, but that was how most birds did it Could it not be done so that all elements of the wing did the same job ? How was the problem solved in the various models ?

Could the Author explain whether there was any advantage in separating the functions, as the birds did ? If flight of this kind came to technical realisation, was it desirable to imitate the birds in this respect ?

The **Author** (in reply), said that the question was an interesting one Von Holst had tried to make models of various kinds In some of the models shown in the film he definitely tried to do the same as the birds, and it would have been noticed that the outer wings did a much bigger pitching motion than did the inner wings He had, however, made other models also The differences were not so much in efficiency, although there must be some difference in efficiency The obvious main difference was in the motion of the centre of gravity Using the path of the centre of gravity in relation to the wing tip and using time marks along it, there would be variations according to what was done along the wing span It was, after all, an unsteady motion In one case a lot of lift might be produced during the down-beat, which would whip the machine up into the air , then it would glide down again and get up again, and so on Similarly, there were differences in the thrust Alternatively, either lift or thrust could be made as uniform as possible, in which case the functions then had to be sub-divided along the wing span Within a fairly wide range, it was possible to have what one wanted

It might just be that the birds did the things that they happened to like best Some might like it a little smoother, while others might not object to a rougher flight This might be the nature of the explanation

The only other factor involved would be differences in the spanwise loading and deviations from elliptic loading, but very often these were not very large and one did not notice them a great deal when integrated over a period

Mr R L Maltby (*R A E*), said that he wished to spring to the defence of the word ' integration " before it was too late Integration meant or implied the bringing together of things In tonight s sense, it meant the bringing together of several functions into one component As such, it seemed a perfectly simple and satisfactory word, and it would be a pity to lose it

The **Chairman,** in closing the meeting, proposed a vote of thanks to the Author, not only for his excellent paper, but for all his patience, and expressed his thanks also to those who had taken part in the rather lengthy discussion

The vote of thanks was accorded by acclamation, and the meeting then ended

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