Discussion on Mr. Fielding's Paper

Mr. Stephenson called on Mr. H. Brooks from the Royal Aircraft Establishment to open the discussion. He enlarged on the information in Mr. Fielding's paper, drawing attention first to the American aluminium alloy X2020 containing one per cent Lithium which had room temperature strength comparable with the Al-Zn-Mg alloys and retained its strength at elevated temperatures better than others. He remarked that it was not as tough as some other materials but nevertheless it had secured important applications in at least one military aircraft. The British RR 58 alloy had been chosen and developed in sheet form for the Anglo-French supersonic transport owing to its superior long time creep strength at around 120°C of about 23,000 p.s.i. for 0.1 per cent total plastic deformation in 20,000 hours.

Magnesium alloys with better strength at elevated temperatures had also been developed, but operator resistance to the use of these materials had increased in recent years because of corrosion troubles. Beryllium was now available for use where its low density and high modulus or good thermal properties justified its very high cost, its toxicity risk and its limited ductility.

He thought that the high strength precipitation hardening stainless steels should be classed among the most important recent developments. They were obtainable in sheet and bar form in a soft condition and could be subsequently strengthened by heat treatment. Examples were the British Firth Vickers 520 alloys and the American PH 15-7Mo and AM-350 alloys.

Titanium alloys were the most radically different new materials that had become available in the last decade. They now offered strengths equal to that of S.99 steel with about 40 per cent less weight and without any need for corrosion protection. He added, however, that some elevated temperature applications had been temporarily handicapped by the possibilities of salt corrosion and embrittlement of spotwelds.

Mr. Brooks went on to mention new higher strength nickel alloys which had become available, such as René 41, which had a strength of some 185,000 p.s.i. at room temperature which remained substantially unchanged up to 600°C.

He showed a slide (Fig. A) in which tensile strengths of metallic and non-metallic materials were plotted against elongation at fracture to demonstrate how available strengths were increased when ductility requirements were reduced. If a 1 per cent minimum elongation was demanded it was possible to have an aluminium alloy with a tensile strength of 100,000 p.s.i., a titanium alloy with 200,000 p.s.i. or a stainless steel with 300,000 p.s.i. He expected that still higher strengths would be offered in the future because all the values were well below the ideal theoretical strengths, and alloy development was being stimulated and assisted by advances in the dislocation theory of the strength of metals. If plasticity requirements could be estimated and specified more accurately this would also aid the development of better and stronger alloys.

Finally he reminded the meeting of the attempts being made to utilise the very high inherent strengths of some non-metals and compounds by incorporating fine fibres of the compounds in a binder metal. One such material was the Rolls-Royce Silica-Aluminium material which had recently been in the news.

A speaker from A. V. Roe enlarged on the rôle of the non-metallic materials in structural development.

He thought it should be remembered that fibre-reinforced laminates had very low ductility; they had highly directional properties and the shear to tensile strength ratio in the plane of the sheet was very poor compared with metals. Thus attachment of two members of this type of construction by mechanical means could seriously impair the efficiency of the structure. He thus suggested that such a structure could be made to compete with metals only if it could be made in one piece in which the stress was generally in tension and applied along the lines of the filaments. He envisaged a fuselage made on the filament winding principle, noting that such construction was being considered seriously in the United States for submarine hulls. Considerable enterprise would of course be demanded from the designer to cater for the multitude of cut-outs in an aircraft fuselage.

The speaker then drew attention to structural adhesives, noting that improvements in adhesives had permitted parallel improvements in honeycomb sandwich construction which was being used increasingly in modern aircraft to satisfy high stiffness requirements. Present structural adhesives were limited to a useful temperature of about 200°C but much work was being done to develop systems, usually based on ceramics, which might raise the limiting temperature to about 500°C. He pointed out that processing temperatures would, however, be too high to use these adhesives with aluminium alloys.

M. O. W. Wolfe from the Royal Aircraft Establishment put forward his views on the future trends in specific material properties. He showed a slide (Fig. B) in which specific tensile strengths of seven materials ranging from an aluminium alloy to a tungsten alloy were plotted against temperature. He used this figure to show the great reduction of specific strength which occurred through the temperature spectrum of materials.

Figure C based on a criterion for buckling stability, which, the speaker pointed out, generally designed as much as half of an aircraft structure, again showed the very great penalty which had to be paid at high temperatures, and demonstrated the importance of aluminium at the lower end of the temperature range. He commented that although he was not considering other factors such as fatigue, it appeared that further exploitation of aluminium was well worth while, although in the future it would be important to consider beryllium which would be much better still because of its high modulus.

For these reasons he made a plea for consideration of the question of protecting aluminium alloys by external insulation, as it appeared possible that the weight penalty the good properties of the aluminium would offset the additional weight of the protection. He presented Fig. D showing the results of an investigation made at Farnborough into this problem, noting that the estimates for the weights of the
thermal protective systems were debatable, although conservative values had been used. He remarked that for the system studied (an aircraft about the size of the Concorde, flying at Mach 4 over ranges of 2500 and 5500 miles) the best protection system appeared to be a combination of cooling and insulation. He suggested that using external thermal protection systems, aluminium could well remain competitive with the stronger and more heat resistant materials for quite a long time.

A speaker from Bristol Aircraft commented on the difficulties of introducing new materials, particularly with regard to the effect of manufacturing processes on material properties, and asked if the lecturer had ever tried to prepare a list of the many conditions which had to be satisfied before he could confidently use a new material, and how long the process took.

Mr. Fielding replied that he thought the materials engineer had always been very conscious of the manufacturing problems and the influence of manufacturing processes on properties. When a new material was introduced the manufacturer usually provided proof, ultimate and perhaps some fatigue data, but one of the most important things to remember was the investigation of the effects of all the manufacturing processes on the performance of the material in a structure. He mentioned particularly the importance of stretch forming where undesirable effects such as the Bauschinger effect could affect disastrously the compressive properties, elongation and notch-toughness. Notch toughness was a property of great interest and he thought that insufficient attention was paid to investigating the effect of working processes on the fracture properties. On the question of time he believed it was obviously necessary to do the testing as quickly as possible, but in general any serious shortcomings could be foreseen early in a production programme.

Mr. Stephenson invited Mr. Paul Kuhn (NASA) to comment on notch toughness. Mr. Kuhn thanked the Royal Aeronautical Society for giving him the opportunity of participating in the meeting. Noting that the subject of notch toughness or notch sensitivity was known by as many names as there were people discussing it, he continued that he was particularly interested in the problem in relation to the airworthiness of structures containing cracks, particularly fatigue cracks, although welding cracks offered similar problems. There had been a large amount of work done on the subject, particularly when the related problem of failures in welded ships was included. However, the designer working on the problem found himself confronted with what could only be described as utter chaos. He explained that it seemed that there were people discussing it. Noting that the subject of notch toughness or notch sensitivity was known by as many names as there were people discussing it, he continued that he was particularly interested in the problem in relation to the airworthiness of structures containing cracks, particularly fatigue cracks, although welding cracks offered similar problems.

Mr. Kuhn noted, however, that it would be impossible to standardise completely because the requirements of the design engineer, the requirements for acceptance by the aircraft factory and the requirements for production control by the material manufacturer were different. Nevertheless it was desirable to be able to convert from one type of specimen to another.

He went on to describe with the aid of slides some methods of stress analysis which had been successfully developed for calculating the strength of a cracked structure, which also could be used in correlating tests on various materials and in making a more rational choice of specimen. He put forward the opinion that as the cracked condition was an emergency condition it was not necessary and not rational to aim for the same accuracy of prediction as in the static strength calculation for the basic loading conditions.

Mr. Kuhn concluded by making a plea for the greater use of stress analysis in investigating the notch toughness of materials, and pointed out that the cost of a test on a full-size fuselage or wing for demonstrating to the airworthiness authorities was such that designers would certainly wish to make their demonstration by calculation rather than by testing.

**Discussion on Mr. Atkinson's Paper**

A speaker from Short Bros, and Harland thanked Mr. Atkinson for a most stimulating paper, but expressed doubts on some of the figures given. He did not believe that a 10 per cent saving in structural weight would mean an 8 per cent reduction in direct operating costs. He reported that 25 per cent of the operating costs of the Viscounts operated
by North Eastern Airlines was due to the initial cost of the aircraft. Other contributions, such as insurance, could be related to the initial cost and he felt that maintenance and repairs were also to some extent related to the initial cost. The cost of repairs and maintenance did not always decrease as the structure became more sophisticated, in fact they often increased. These items added up to 50 per cent of the direct operational costs and he therefore found it difficult to believe Mr. Atkinson's figures. He went on to put forward an argument that for certain aeroplanes the idea of ultimate structural efficiency could be relieved in favour of a simpler, but slightly heavier structure, if by so doing the 50 per cent of the direct operational costs that was controlled by first production costs could be reduced.

Mr. Atkinson pointed out that he had referred to 10 per cent improvement in structural efficiency at the design stage, which did not necessarily result in 10 per cent saving in the final project. He had used BOAC and BEA cost figures but there were many assumptions which had to be made to arrive at any conclusion whatsoever.

A speaker from A. V. Roe commented on the figures for the percentage structural weight for the short haul transport aircraft on Fig. 2. He felt that the figures for the Friendship were a little high and for the latest Friendship 30 per cent would be a better value. He noted that nearly all the aircraft fell into the 30 per cent bracket with the exception of the Ambassador and the Viscount. These had been in service for a long time and probably, in the long process of development, the structural weight had been reduced. He noted that the DC-3, however, which was probably older, still maintained the value of 30 per cent. He asked if the DC-3, whether by design or not, went into the category of a "fail safe" aircraft, whereas the Ambassador and the Viscount were "safe life" aircraft? Was 3-5 per cent of the total weight, or about 10 per cent of the structural weight, the price to pay for "fail safe" aircraft?

Mr. Atkinson replied no to this last question and commented that he felt that the life of an aeroplane had a major effect on cost; it would be worth about 10 per cent of the direct operating costs to double the life of the aeroplane.

Referring to Fig. 2, a speaker from Vickers commented on the weight of the Boeing 707. He recalled some old R.A.E. reports which would have shown that such high aspect ratio swept wings alone would exceed the weight of the entire structure. He remarked that there was much percentage error to tip the balance from one form of construction to the other. He mentioned a number of factors which should be considered, such as the number to be made of each part and the time of assembly of joints and surmised that the cost estimates for machining included factory overheads which might include the number of people running about with parts marked out by the previous speaker.

He had found it very difficult to get cost figures with the accuracy of 10 to 15 per cent which designers required to be able to choose between different alternatives. He wondered whether Mr. Williams felt that he really could give the sort of information needed by the designer so that he could see to within a few per cent what the costs really were.

A speaker from Armstrong Whitworth Aircraft supported Mr. Williams' paper from the design side. He had recently been concerned with commercial as well as aircraft designs and was appalled at the cost of aircraft design. He gave examples of comparative costs such as a small bracket costing thirty shillings which could be bought for a few pence in a hardware shop. He felt the structural designer ought to know the comparative costs of various manufacturing processes. Work in the Hawker-Siddeley Group had shown that sometimes integral construction and sometimes fabricated construction was better and the only answer was independent analysis of the structure on a cost basis.

He wished to push for more grading of structural design and felt that standards could be dropped on secondary and tertiary structure to reduce costs. He cited a case of calling for a 15 micro-inch finish on a toilet seat handle.

The speaker also regarded as important the need for the shops to wait for the design to be completed as the demand to get the aeroplane completed meant that there was not always time to consider costs, and contributed to the "mods" which bedevilled the aircraft industry.

He next questioned the need for good surface finish, noting that one saw aircraft flying perfectly well in service with badly damaged surfaces. He wondered if it was possible to lower standards with fail-safe aircraft which were inherently able to withstand trouble.

Mr. Williams agreed except on one point. He felt that no aircraft would ever be built if the production had to await completion of the design!

A speaker from Vickers thought that the most important point which had come out of the discussion was the need for reliable information on manufacturing costs. He also referred to the wing panel of the Lightning with 50 or 60 items compared with the single item if it had been integrally machined and pointed out that there was a contribution to costs, which should not be forgotten, of 50 or 60 people planning the job, attaching the labels to pass the parts through the various departments and so on.

A speaker from Blackburn expressed doubts on the validity of the cost figures given by Mr. Williams, as it did not require much percentage error to tip the balance from one form of construction to the other. He mentioned a number of factors which should be considered, such as the number to be made of each part and the time of assembly of joints and surmised that the cost estimates for machining included factory overheads which might include the number of people running about with parts marked out by the previous speaker.

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Mr. Williams replied that he had been investigating this problem deeply recently and gave as an example the cost of running the skin milling machine, illustrated in the lecture, which worked out at £5 10s. 0d. per hour. For comparison the cost of one man riveting worked out at 25 to 30 shillings an hour. The overheads put on each of these operations were not the same. He explained that in order to determine the cost of an operation it was necessary to examine the conditions necessary for that operation to be carried out. He gave as an example a machine shop building, for which he quoted the cost of services to the building, heating, ventilation, power and the capital depreciation of the machines had all to be considered. On top of this was an administrative overhead cost for the whole factory. But it was possible by investigating deeply enough to determine a cost rate for every machine tool in the factory and this had in fact been done. He considered that for the case of the wing rib considered in his lecture, the cost was the actual money paid out to a specialist sub-contractor for the components so that the comparison was completely valid.
A speaker from the British Welding Research Association was gratified to hear Mr. Williams say that aircraft engineers had not been paying sufficient attention to welding, particularly resistance welding. He thought that this might have been due to their not taking into account the improvements in welding processes which had been made since the early work of Dr. Williams at the RAE on fatigue and static strength of spotwelds. He drew attention to recent work in France which showed that spot welds resisted fatigue better than rivets. A speaker from the Fairey division of Westlands thought that designers should not forget high tensile steel castings. The previous speaker concurred and suggested that an answer might be the welding of castings. A speaker from Vickers observed that they did in fact do this.

### Discussion on Mr. Ashley's Paper

A speaker from A. V. Roe commented on the need for high stiffness honeycomb core under certain conditions. These conditions were met in heavily loaded panels when, irrespective of length or width, core failure could occur by shear instability if for any reason the panel thickness had to be kept low.

He agreed with Mr. Ashley's views on the need for two full scale aircraft for structural test programmes, but after reading Mr. M. Burt's recent RAE Structures Note he thought perhaps one specimen might be adequate and that one of the early prototypes should be used to find out just what the loads were to which the test-specimens should be subjected.

A speaker from the Royal Aircraft Establishment thought it was clear that one full-scale specimen was not sufficient and it could be argued, as suggested by the previous speaker, that two were not enough. He wondered whether it was safe to draw conclusions on fail-safe characteristics from a static strength specimen which had already undergone over 100 per cent of ultimate load and had probably yielded in critical areas.

Mr. Ashley replied that in the course of residual strength testing, where a proportion of the tensile area was cut away, the remaining area under load must have to yield to an even higher degree before it failed, than the level to which it had been subjected previously.

A speaker from de Havilland reviewed the history of full-scale testing and suggested that the development to be expected in future would be to use a single specimen, which would be subjected to a loading spectrum including perhaps static loads up to the maximum limit loads. With this it could be demonstrated that, at any stage in its working life, the structure had sufficient reserve of static strength to carry an unforeseen large load. He asked whether Mr. Ashley had considered this.

Mr. Stephenson pointed out that it was necessary to establish the ultimate strength early in order to obtain a Certificate of Airworthiness, but subjecting a specimen to ultimate loads would invalidate any subsequent fatigue test results. Thus the time factor for obtaining a C. of A. necessitated the use of two specimens. Mr. Ashley agreed.

Another speaker from de Havilland did not find it necessary to use separate fatigue and ultimate test specimens. He advocated a procedure for fail-safe aircraft of fatigue testing, where a proportion of the tensile area was cut away, and using the resulting lightly loaded structure for primary structure in the Shackleton, although it was used extensively in interior furnishing and crew equipment. He had not had any reports of deterioration or corrosion trouble except for one special application near the stove in the galley which suffered from heat damage. The method used for bond testing since 1952 was a testing device which was used to scan the whole surface of the honeycomb structure. A vacuum cup contained three prongs which were pressed down by the external pressure hard onto the skin. A strain gauge probe in the middle of the three fixed prongs sensed any deflection of skin which would be lifted by the vacuum if there were any unbonded portion or any partly bonded portion would be broken away.

A speaker from de Havilland, referring to the method of construction illustrated in Fig. 11 and Fig. 12, contended that to get the best out of a bonded joint the thickness had to be maintained to within 4 to 10 thousandths of an inch. He predicted that when the method went into production the parts would not fit.

Mr. Ashley thought that machining a slot of constant width along a panel to a tolerance of 6 thousandths of an inch should be quite possible, bearing in mind the experience this. Furthermore, he felt that residual strength testing was becoming increasingly important and in doing this type of work there was a great danger in losing an invaluable specimen precipitately. By using two specimens it was possible to apply fatigue test results from one specimen to the residual strength tests on the other, the work going on in parallel, thus saving time.

The speaker from the R.A.E. expressed disappointment that the promises of beryllium seemed as distant as ever. Recent studies in arranging the mass distribution of aircraft such that mass nearly balanced air loads, and pressure stabilising the resulting lightly loaded structure had also proved disappointing. He asked whether Mr. Ashley could foresee any other approaches which were likely to lead to a major breakthrough in structural efficiency. He drew attention to Fig. 4 which emphasised remarks by previous speakers on the benefits to be gained by the elimination of fretting.

Mr. Ashley thought that if anyone had been able to foresee any major breakthrough in structural design he would have applied it by now. Pressure stabilisation was being studied in the space field and any significant conclusions were likely to come from America. He agreed with both Mr. Redmayne and Mr. Atkinson on the importance of fretting and bonding methods were used for testing bond integrity. He also agreed with the factor of 2½ to 3 on fatigue life which Mr. Atkinson had mentioned.

Referring to Fig. 4, a speaker from de Havilland was concerned at the rapid loss of strength with a small loss of thickness area and asked whether the operators were supplied with such a curve so that they could judge when repairs were necessary. Mr. Ashley remarked that there would be something very much lacking in the operator's inspection department if cracks were allowed to develop to anything like the degree to which they were cut in the tests. The curves were not supplied to operators, but were presented here to show the critical effect of loss of area on residual strength.

A speaker from Folland Aircraft commented on Mr. Ashley's remarks on post-stabilised structures and stated that some years ago Follands had built a wing with post-stabilised skin which gave good results on tests, but they had concluded that the extra production complication did not justify it.

A further speaker from de Havilland asked if there were any corrosion problems due to the use of thin skins in honeycomb structure on the Shackleton, and what inspection methods were used for testing bond integrity.

Mr. Ashley replied that honeycomb structure was not used for primary structure in the Shackleton, although it was used extensively in interior furnishing and crew equipment. He had not had any reports of deterioration or corrosion trouble except for one special application near the stove in the galley which suffered from heat damage. The method used for bond testing since 1952 was a testing device which was used to scan the whole surface of the honeycomb structure. A vacuum cup contained three prongs which were pressed down by the external pressure hard onto the skin. A strain gauge probe in the middle of the three fixed prongs sensed any deflection of skin which would be lifted by the vacuum if there were any unbonded portion or any partly bonded portion would be broken away.

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gained in machining integral panels to close tolerances for weight reasons. He drew attention to the taper in Fig. 11(d), by which method the gap could be varied by altering the height of the assembly. He hoped by this method to be able to put the correct pressure in the bonded joint as well as to centre its thickness. He pointed out, however, that this would necessitate allowing a nominal clearance between the ribs and the inside of the panel but he thought such a clearance should be allowed in any case for ease of production.

Discussion on Mr. Taig's Paper

Before opening the discussion on the paper by Mr. Taig, Mr. Stephenson remarked on the capital expenditure involved in buying computers, erecting and fitting out buildings to house them, and the ever-increasing staff required to use these time savers.

A speaker from Bristol Aircraft felt that when dealing with a large complex structure such as a modern supersonic airliner there was no alternative to the use of the computer. He noted that two to three hours machine time would in fact do the work of several man years manual labour with greater accuracy. One of the difficulties, however, was the use of the results. In a particular problem taking not more than two or three hours of actual machine computing time, printing them took five hours, and the paper would stand 8 feet high and be 6 miles long if stretched out fully. This enforced strongly the need for the feedback loop described by Mr. Taig. The computer must produce the results, use them and then sort them. This work could not be done manually.

He recalled that Mr. Ashley had talked earlier on test programmes for a complex structure. There was no possibility of using the results from thousands of strain gauges or temperature gauges except to feed them back into a computer and compare with previous computation. There was no alternative for the analysis of a large structure. A second application of the computer was the solution of a large number of simple problems at a very high rate. A third aspect was one of cost. Cost estimates could be fed through a weight programme, and therefore the production costs could be controlled. He was of the opinion that the computer was essential for future advancement in aeronautics.

Summing up by Mr. Keen

Mr. Keen opened by saying that it had been a most valuable day, and congratulated the Lectures Committee on their choice of speakers. Mr. Fielding in his review of steels had given him the impression that the Americans and even the Japanese were ahead of the United Kingdom in this field, and he asked if Mr. Fielding could clarify the position during the discussion to follow. Mr. Fielding had spoken of the necessary protection of the high tensile steels and this was going to present a very serious maintenance problem in the services. The Navy in particular would be very critical of this aspect. The corrosion problem on board aircraft carriers had to be seriously considered.

With regard to structures at elevated temperatures he felt that something could be learned from the engine people, considering that the modern engines ran continuously at temperatures far higher than those at which a supersonic aeroplane would run.

He agreed with Mr. Atkinson that the structural weight figures given for the Shackleton did not reflect penalties for "fail safe" design. He spoke of the Argosy wing which was based on the "safe life" Shackleton wing. The two wings were identical in aerodynamic and geometric form, and in spite of the fact that the Argosy wing was designed for a more severe flight plan from the fatigue point of view, it was in fact lighter and not heavier than the Shackleton wing.

He agreed with Mr. Atkinson's concepts on structure weight. Having estimated a structure weight in the project stage, this must be maintained. He felt that, apart from any major errors, the structure would always be capable of taking a bigger load than it was originally designed for.

He noted that the controversy on lips or no lips on integral stringers discussed by Mr. Williams had been raging for many years.

On the question of break-down of the increased cost of aircraft, Mr. Keen felt that the aircraft constructor was controlling a smaller and smaller proportion of the total selling cost of the aeroplane. Relatively speaking, engine costs had gone up at a greater rate than the aircraft structure costs and certainly equipment had increased in both cost and weight.

With regard to test programmes, he thought that the United States did not go to the same length on all structural tests as we did in this country. He felt that new methods and new computers could improve the calculation and yet the very fact that we were spending more and more on structural testing seemed to indicate that we were relying less and less on those calculations. There would probably be no more long run production aeroplanes and there was a very strong case for trying to cut down on structural testing because it was very expensive and not always possible. Probably the most powerful reason for carrying on with major structural tests was that often tests showed that a failure which occurred was not in the main design of the structure, but in some small overlooked detail.

General Discussion

A speaker from Vickers felt that although he agreed with much of what Mr. Taig had said, care must be taken in the automation process not to try to use testing just to prove that the computer was right. Both the testing and computation were done to get a better understanding of the behaviour of the structure. Tests were carried out on limited areas, and the testing and structural analysis must go hand in hand. The test results should be used to give greater confidence in the structural analysis, and then the structural analysis techniques might be used to demonstrate the integrity of the structure in those cases which could not be tested. He felt that the representation of the structure was of necessity still very crude. It was also necessary to take the non-linear analysis very much further. At the present time the tendency was for all the analyses to be carried out in the elastic range which was, of course, very important because it gave an idea of where stress concentrations occurred for use in the fatigue analysis.

In reply to a questioner from Loughborough College, Mr. Taig said that it was sometimes possible to get a higher stress by strengthening a highly stressed region, but the convergence on reiterative design of a redundant structure was generally very rapid.

A speaker from de Havillands reinforced Mr. Atkinson's statement that structure efficiency was not the whole key to the situation. In the column of structure efficiencies—structure percentage weight—he noted that the Comet 4 was 21 per cent, the larger Comet 4B was 24 per cent, and the latest of the series, the Comet 4C might be higher still. Of the three versions, however, he suggested that as an overall vehicle for making money the 4C was probably the most efficient. He wondered if more work could be done to show the relative merits of the two philosophies of low basic structure weight versus long endurance. He wondered if an overall concept of the combination of the two opposite types of requirements could be worked out that would provide for a very long life, the economic case for "fail safe" versus "safe life" and he suggested that if an aircraft was designed for a very long life then the two approaches would tend to coalesce. Starting off on the so-called "safe life" approach, and a particularly long life was wanted, the stresses would have to be low to have a good fatigue performance. With low stresses, cracks would take time to propagate, their critical lengths would be longer and there would be a chance of discovery on inspection.
In reply to the question on the ultimate strength requirements, Mr. Atkinson said that the 10 per cent reduction referred to one particular set of requirements, for example, the normal acceleration. He agreed that 10 per cent overall reduction of applied loads would give a very different answer.

Mr. Stephenson remarked on the right specimen for testing materials. With polished notched specimens, fretting and corrosion effects were ignored. He wondered if a simple lug or more elaborate test piece would be more realistic. Structures were not designed with polish and notches were not willingly, deliberately put in, but stress raisers which led to fretting and local strains could break down protective treatment. He felt that the design for long life had to be matched with the protective finish.

Mr. Fielding commented on the development of new materials. In the first series of screening tests all available materials were tested for the relevant properties. The unsatisfactory materials were then discarded and tests which would give the designer more concrete information on crack properties were carried out on the remaining possible materials. He agreed that a lot more fracture testing was needed.

Commenting on the relationship between production costs and structural efficiency, a speaker from de Havilland's said that they had recently carried out an investigation into the design influence on costs and had reached the same general conclusion as Mr. Williams, that integral machining was nearly always more expensive. In dealing with dense structures in large aeroplanes the increase in cost over the traditional fabrication methods was offset by the increased structural efficiency, and cleaner design. In small aeroplanes, however, the integral machining could not compete with fabrication methods on a material waste basis. It was felt that bonded structures when properly designed were very efficient, compared with integral machining. He thought that tape control would save some of the high tooling costs and labour costs, but investment cost in plant and cost of waste material would increase.

Mr. Williams acknowledged that the economic application of integral construction depended entirely on the particular application.

A speaker from the I.B.M. spoke of the need to eliminate some of the difficult and lengthy lofting required to define parts of the structure. He spoke of the "Master Dimension Programmes" techniques being developed in the United States which were aimed at eliminating the lofting process without the use of controlled machine tools, and asked if any work along that line was being done in this country.

In reply to a question on cost of tape controlled tools, Mr. Williams mentioned that the main application was in the production of small or medium sized batches of components. The advantage of this was the elimination of tooling and more rapid machining. He quoted a particular instance of a high tensile titanium alloy component. By putting the machining on to tape control the cost of the component was reduced by half, and also in a very short space of time all the costs of the tooling which had arisen through conventional machining were written off.

Mr. Taig considered that for standardised types of components it was possible to eliminate drawing as well as lofting. The actual design of the fairly large structural component that he had shown (Fig. 10, the simple unflanged integrally stiffened panel) could be performed on a digital computer without any man's intervention. He felt that a programme which in theory was simple, but in practice was large, could be transformed into a set of machining instructions which could be used to provide the drawing, to make sure that the calculations had been performed correctly and also to produce a model in some easily machined material, and finally to produce the actual component.

Mr. Stephenson pointed out that aeroplanes were not simple structures alone. They were filled with equipment, wiring, flying controls, and so on and he thought this would be difficult to design without drawings. It was pointed out that this method would be useful only for a simple type of fairly large component.

Mr. Taig agreed with the comment made by a speaker that the ship building industry was now beginning to leave lofting and introduce the programme method, not only to define the shape of the hull of the ship but to determine where the pipe runs, control mechanisms, rods, and so on fitted in the structure.

A questioner from Vickers asked if anyone was yet engaged in designing the mechanical man to be fed with tape to give him the necessary working instructions.

A speaker from Whitworth Gloster thought that in order to develop better structures it was necessary to have some criteria for the meaning of better structures. He felt that the old one of structure weight ratio as a percentage seemed to have outlived its usefulness and other factors should be taken into account. He would prefer to invert the structure weight ratio and refer to the carrying capacity of passengers or freight. He would like an environmental index in terms of speeds, pressure ratio, and so on, a reliability index and a cost index. There was interplay between these four basic terms and if a customer wanted to put the reliability index or the environmental index up, then the cost index would rise or the carrying capacity be reduced.

Mr. Atkinson thought that this was an excellent idea, but felt that it was not easy to put into practice. He could not see how it was possible to put figures to reliability versus weight, and reliability versus cost figures were even more obscure.

Mr. Stephenson closed the discussion after thanking everyone for their attention to the animated discussions and thanking the speakers who had taken so much trouble in preparing and developing the papers.