200 Rotorsport

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Club Flying—Private Owner Interests—Amateur Construction

Are There Deficiencies in Current Light Autogyro Designs?

THE PRIVATE INQUIRY BY HELICOPTER WORLD

BASIL ARKELL A.F.R.Ae.S.

writes . . .

IN THE 1930's, after the early autogyros had progressed through the initial pioneering years, there was confident expectation of a rosy future ahead among the small band of enthusiasts who had developed this new form of flight to a practical stage.

Most of the development work had been done in England, with other projects in France, Germany and the U.S.A. By the mid-1930's the first direct control autogyro had appeared, the Cierva C-30, and subsequent production of this type by Avro resulted in the building of over 100, several of which found their way into local flying clubs, both in England and overseas, and many private pilots learned to fly them.

The old Hanworth Flying Club, which operated alongside the Cierva Autogiro Company, became a Mecca for rotating wing enthusiasts and thousands of hours were flown in perfect safety. One or two pilots had turn-over accidents, but nobody was ever seriously hurt.

All this growing activity came to an abrupt halt in 1939 with the outbreak of World War II and, in 1945, it was the helicopter that had captured everyone's imagination. The autogyro was forgotten.

However, when it became apparent, in the 1950's, that the helicopter was not likely to offer an inexpensive means of flight, some of those engaged in helicopter development turned back to the autogyro in search of a less costly solution.

What has emerged is the ultra-light autogyro but, for a variety of reasons, its safety record has not been as high as the pre-war autogyros. Those in England who had their doubts as to the safety of these new machines, felt their worst fears had been confirmed when the WA-117 broke up in mid-air in front of some fifty thousand people at last year's Farnborough Air Show.

Since that accident, the companies engaged in manufacture of ultra-light autogyros in the U.K. have been seriously affected by a marked reduction of interest in these aircraft and there has been but little flying activity by amateur private owners. In America it is suggested that England has panicked. If the WA-117 crash had been an isolated case, this might have been valid, but it was one of four successive and apparently similar accidents and as such it gave rise to understandably serious concern.

Since British authorities responsible for air safety appear to be so singularly slow in producing any investigation report, this broad outline of factors believed to be relevant is published here. In future issues, space will be made available according to requirement for the publication of contributions and comments (for or against) from any person or company who feel they have anything to offer towards finding a solution.

Gyro flying can be great fun. Let us all do all we can to get confidence restored and get back into the air again.

Mr. Arkell has been active in aviation for over 30 years, over 25 of which have been devoted to specialisation in rotating wing aircraft. After service with the Royal Air Force, he spent six years engaged in helicopter test flying with Fairey Aviation Company, Cierva Autogiro Company and Bristol Aeroplane Company. He has been a private owner of a Cierva C-30 autogyro and has flown over 40 different types of rotorcraft, ranging from the Bensen gyroglider to 20-ton helicopters. He is currently Director of HELICOPTER WORLD.

WHEN Igor Bensen pioneered his "build-it-yourself" autogyro movement in the United States, he started a fashion that has spread throughout the world. He paid very special attention to the all-important safety aspects and produced a design which, if built and flown meticulously to his instructions, was as safe as any flying machine can be. And he was insistent in all the instructions issued by his company that great emphasis must always be placed on the need to adhere precisely to the instructions provided.

So far, so good. There were a number of accidents it is true but this was hardly surprising in view of the large numbers of inexperienced amateurs who began building and flying the little gyros. In the final analysis most of the accidents could be traced positively to deviations by individuals from the precise instructions with which they were provided, to piloting errors or, in a few cases to downright foolhardiness.

There was a nasty such case in New Zealand. The propeller of a Bensen gyrocopter disintegrated in flight and parts of it flew into the rotor and broke the blades with a predictably fatal result. At the inquest, a friend of the owner-pilot recalled how he had been telling him a short time earlier how he (the owner-pilot) had been spending an afternoon filling up cracks which he had noticed appearing in the propeller and had given it a fresh coat of paint so that it looked as good as new!

Other accidents occurred through similar ignorance or stupidity. In one, a rotor spindle that failed was found to have been made from sub-standard material not in accordance with the building instructions. An American trying to save a few dollars but it cost him his life. In another, the rotor blade bonding failed in flight, probably due to inadequate standards being maintained during construction.

Of the minor flying accidents, from which the pilots often walked away, most were due to inexperience. Some tried to learn too quickly and were caught out by simple little things like gusts (not that an experienced pilot can ever be entirely foolproof), some hit fences or wires and some just misjudged a landing, bumped heavily and rolled over. And of course there was the predictable crop of engine failures which accounted for a proportion of the accidents.

In the eyes of the airworthiness and flight safety authorities, home-built autogyros were beginning to get a bad name. But against this record the manufacturers and many enthusiastic private groups were able to show proof of much higher standards in other quarters—good engineering and intelligent airmanship which combined to produce an excellent safety record. The majority of gyro enthusiasts who were building and flying strictly to the book were doing all right and thoroughly enjoying it. It was the minority who were causing all the trouble and giving gyros a bad name.

In the face of the convincing proof offered, the authorities could only let the movement progress. Much was done to encourage the minority to improve their standards and more stringent regulations were devised. So matters stood with the enthusiasts free to have fun, or trouble, as the case may be, but confined so that if there was trouble it did not endanger anyone else. It was a situation not entirely dissimilar to the early pioneering days of fixed wing flying when enthusiasm ran higher than experience and crashes were not infrequent.

New Problems

The real trouble began where a few of the more adventurous, having gained legitimate experience according to the book, began to become impatient with the operating limitations of the early open-framework gyros. Apart from anything else, the pilot gets very wet if caught out in rain. Adding a racy-looking streamlined fuselage would give weather protection, it was thought, and also permit much higher speeds to be obtained.

One of the first to have aspirations in this direction was a young American named Herman Saalfeld. In the early 1960's he built a light autogyro similar in many respects to the Bensen configuration. It was however a two-seater machine with a streamlined cockpit for the occupants. The engine was a 72 bhp McCulloch fitted as a pusher as in the Bensen and the maximum speed claimed was 85 mph. He named the machine the Saalfeld Skyskooter and formed Saalfeld Aircraft Company to develop the project.

On March 4th, 1962 (*note the date*) he was demonstrating the machine at an airfield in California to a group of prospective investors in the company. What ensued, as quoted from the US Civil Aeronautics Board Accident Report, could almost have applied to the WA-117 accident at Farnborough last September. The report describes the beginning of the flight and goes on:

" . . . After this pass down the runway, a tight 180° left turn was made and the craft proceeded down wind very close to the edge of the runway at approximately 200 ft. altitude. During this downwind leg, the craft was observed to be pitching up and down. At the top of one of these pitch-ups, a blossom of parts was observed to come off the craft and the main

(continued overleaf)

Professor JAMES BENNETT, D.Sc., Ph.D., Hon. LL.D., Hon. F.R.Ae.S., Hon. F.A.H.S.

writes . . .

THE difficulties which some ultra-light autogyro builders currently seem to be facing could be alleviated to a useful degree I think, if more effective means of fuselage stabilization were to be incorporated in the designs they build. Some of these ultra-light autogyros appear to be substantially tailless, with no appreciable damping in pitch or roll. This could also make them undesirably sensitive to slight movements of the pilot's body.

No pre-war autogyro would have been given a certificate of airworthiness without adequate fuselage stabilization and it was necessary to resort to outboard tail fins or dihedral-shaped tailplanes to achieve this.

The instability with fuselage angle of attack is a well known stability deficiency of the conventional tail-less helicopter in forward flight and it is only the freedom of the autorotating rotor to vary its rotor speed that enables it to be less deficient in this respect than the powered rotor. However, it is asking too much from the autorotating rotor to match its unique stabilizing features with a fuselage that is not self-stabilized.

Although the autorotating rotor is "statically" stabilized with changes in fuselage angle of attack, being free to vary its rotor speed, there must still be a transient measure of the stability deficiency of the powered rotor, as "dynamically" the rotor has inertia and cannot vary its speed instantaneously. When rapid manoeuvres are made, there is always a delay between an input and the resulting response.

The combination of a statically stable rotor and a statically unstable fuselage may be good enough for trimmed level flight, but not for rapid manoeuvres. The combination could be lacking in manoeuvre stability.

I would expect that there is a divergent pitch-up at the higher fuselage angles of attack and a divergent "tuck-under" at the lower angles. There is probably a divergence in roll also.

If a machine with such characteristics were brought to zero airspeed at the top of a climb, in simulation of a typical helicopter demonstration manoeuvre, this could possibly result in loss of control.

If an ultra-light autogyro could be designed with blades having augmented flapwise stiffness, to improve control power without excessive rotor tilt, I would imagine that such a machine could have many advantages over one fitted with a teetering rotor. Even so, there would still be a need for independent stabilization of the fuselage, both laterally and longitudinally.

Professor Bennett is one of the world's foremost authorities on the science of rotating wing systems, with over 40 years' design and research experience in this field. In G & J Weir Ltd and the Cierva Autogiro Company he worked alongside James Weir and Juan de la Cierva in the pioneering 1930's. On Cierva's death, he assumed design leadership of the group and designed the C-40 jump take-off Autogiro. Seconded to the U.S.A. during the second world war, he made notable contributions to the early Sikorsky designs and other American helicopters. Later in England he designed his unique Gyrodyne and Rotodyne concept with Fairey Aviation Company. For the last 15 years he has moved into academic spheres of interest, in which he is still active. Professor Bennett has made his unique knowledge available entirely gratuitously to assist in the solution of this ultra-light autogyro problem.

The ill-fated Saalfeld Skyskooter with its glass-fibre cockpit nacelle was one of the first ultra-lights intended for higher speeds. It is quite similar to some of today's machines.

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rotor blade was observed to separate from the craft at the peak of the pitch-up. The craft then tumbled to the ground out of control."

Evidence contained in the remainder of the report indicated that the rotor blades had struck the propeller and also sliced off the upper portion of the rudder. It was further discovered from examination of the wreckage that the main rotor shaft had failed in fatigue.

Instability?

In his own subsequent accident report the Saalfeld Company's Chief Engineer referred to the pitching up and down, indicating that he may have thought that a stability problem might exist. From where he stood, 500 yards from the scene, the aircraft's final climb was abrupt and to the left. He gave it as his theory that the porpoising observed by many witnesses may have been an attempt by the pilot "to counteract a fore-and-aft instability of the rotor."

The Skyskooter project was abandoned. The possibility of the cause of this accident having been a rotor instability does not appear to have been followed up by the official investigator and in the US Civil Aeronautics Board official accident summary for the year the "probable cause" of this accident was attributed to "fatigue failure of the main rotor shaft caused by poor machining of the part and the poor choice of material for the part." There is no question that the rotor shaft did fail, but it is now believed to be more likely that the shaft failure was a secondary cause, induced by the high stresses imposed upon the rotor head by rapid development of an instability of the rotor system which was the primary cause. The next incident in which the porpoising phenomenon occurred was put down to inexperience on the part of the pilot!

Examination of the accident records over the last 10 years indicates that in about 20 cases the reports of the incidents include a reference either to the porpoising phenomenon or to the pilot having been seen to perform an "unusual manoeuvre" in the air immediately prior to the crash. Since all these particular accidents were fatal, it is impossible to know precisely what the pilot was trying to do—i.e., whether he was attempting to initiate an unusual manoeuvre or trying to prevent one.

In the accident records it is not difficult, in most cases, to differentiate between this kind of accident, where there is an element of mystery about the cause, and what could be described as straightforward accidents, such as hitting wires, etc., where in any case many were not fatal, so the pilot could say what had happened.

It may also be significant that a number of these unexplained accidents appear to have occurred during flight demonstrations of the machine when the pilot may well have been aiming at showing off its capabilities to best advantage. Under such circumstances, a pilot might well be flying at the highest possible speed and executing the most rapid turns he could and it could well be that Professor Bennett's observations on "manoeuvre stability" are relevant here.

Two of the four accidents in U.K. occurred while the pilots were actually demonstrating in an air display and a third was while the pilot was believed to be practising for an air show.

In spite of the 20 or so apparently similar accidents that have occurred in various countries, no airworthiness authority ever seems to have made a comprehensive check analysis of the dynamic stability of these two-bladed autogyro rotors, to determine just what the characteristics are.

Yet it has long ago been established that the two-bladed teetering helicopter rotor is particularly susceptible to a form of self-excited oscillation, analogous to wing flutter, especially if it has a high built-in coning angle. The instability is associated with the difference in blade moments of inertia about the flapping axis and the axis of rotation. It makes little difference in the consideration of this particular effect whether one is considering a power driven helicopter rotor or a freely rotating autogyro rotor. The higher blade angle of the helicopter rotor does aggravate the condition somewhat but the principle involved is essentially similar. Although in certain respects the freely rotating autogyro rotor may have advantages, in other respects it has distinct disadvantages.

The so-called gimbal rotor head claimed by its manufacturers to confer stability characteristics on the machine may well do so up to a point. The effect it has though has no direct bearing on the self-excited oscillation effect of the blades which may still be a potential hazard in spite of this form of rotor head geometry.

If the rotor head geometry is such that the blade mass is distributed above and below the feathering axis, as it may be with a high coning angle, the forces affecting the blades in flight are such that the blade masses tend to be forced outward from the rotational axis. This can result in an unstable spring constant. In contrast to the two-bladed teetering rotor, blades having individual flapping freedom (usually in a rotor with three or more blades) will normally have a stable spring constant because the mass is distributed more chordwise than vertically.

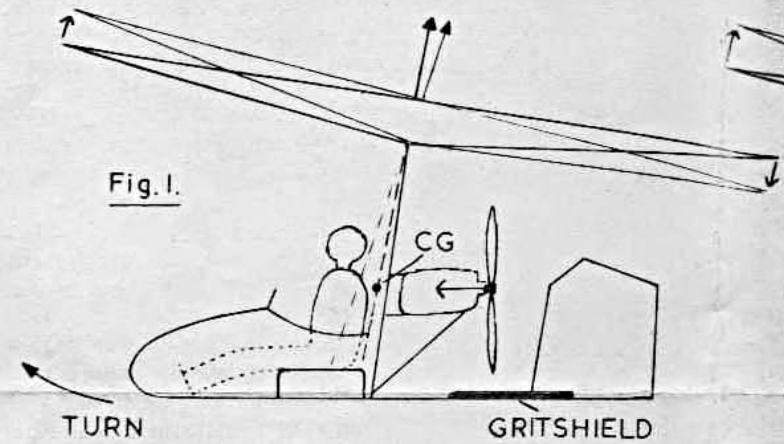
This is not to say that all two-bladed teetering rotors on all ultra-light autogyros may necessarily be liable to instability. In many cases there may be no problem at all. Indeed, if this were not so there would probably have been far more accidents than there have been.

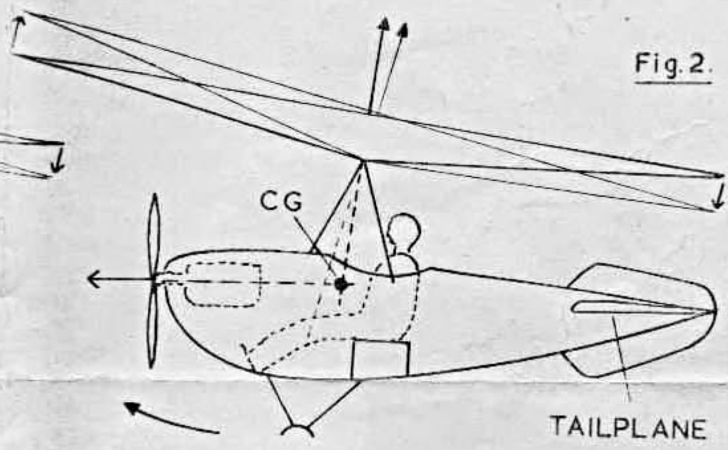
The onset of flutter, for that is what a self-excited oscillation is, can be influenced by a combination of several factors, of which these aeroelastic effects are of great importance. Closely allied is the flapping stiffness and torsional rigidity of the blades and in this respect the autogyro rotor may also be at a disadvantage. Optimum autorotative efficiency which is always a major design aim in autogyros, is inversely proportional to the solidity ratio, amongst other factors. This, being the ratio of blade area to swept area, usually leads to the autogyro designer selecting blades with high aspect ratio. Autogyro blades also tend to have a high fineness ratio to keep drag to a minimum.

The combination can lead to higher flexibility and lower torsional rigidity than is common in the thicker, wider helicopter blades. If rotor head geometry is already such that with high coning angle mass distribution extends into the flapping plane to a degree that the rotational moment of inertia becomes less than the flapping moment of inertia, the rotor has all the ingredients for instability, as higher forward speeds are approached. Flutter can even occur if the blade's chordwise CG is ahead of the 25% chord position which is usually regarded as the safe aft limit of the stable region for this parameter.

This form of instability is sometimes termed blade weaving because of the characteristically wavy path followed by the blade tips as they traverse the disc. If in any particular rotor design some parameters have a destabilising effect and some stabilising, the overall phenomenon can have comparatively mild results and may even be mistaken for poor blade tracking by the uninitiated. If all the parameters are additive in an adverse sense the condition can deteriorate rapidly, with disastrous consequences.

In flight, the flutter could be manifest in a porpoising deviation from the level flight path. In a mild form, the moments generated might be within the pilot's ability to control by stick movement. He might, for example, experience slight porpoising after hitting a patch of air





These two diagrams depict an autogyro in a 90° turn to the right as viewed from above (see text). Considered independently, a rotor system in steady flight is, at best, rarely more than neutrally stable. The fuselage must therefore be used to exert a stabilising influence on what would be the natural characteristics of the rotor. In some current ultra-light pusher configurations it barely achieves this purpose. In contrast, the earlier tractor configuration lends itself much more readily to a higher degree of damping from fuselage influence. A mere superficial glance at these two drawings, depicting the pusher and tractor configurations, is sufficient to appreciate the much greater aerodynamic damping moments to pitching motion that can be induced by the tailplane in the tractor configuration by comparison to that in the pusher. Indeed, in many forms of the pusher configuration the tailplane is merely a "flat plate" which is intended to serve more as a grit-shield to prevent damage to the propeller from stones, etc, on the runway rather than as an aerodynamic surface to provide damping of fuselage motions.

turbulence or after a steep turn and think to himself that the machine took rather a long time to level out again without realising why. If the divergence is great, however, the forces involved could rapidly increase beyond the pilot's ability to control them and the porpoising would become the "mid-air flare" which has been observed in many of the accidents of this nature.

In theory, the porpoising or mid-air flare would be most likely to occur immediately after a rapid manoeuvre had been executed at high speed. This seems consistent with reports available of most of the accidents concerned and it should be taken by pilots as a warning against performance of such manoeuvres.

If the configuration of the autogyro were such that the rotor blades could not possibly strike the propeller and rudder, they would probably shake themselves to pieces anyway once this stage is reached—just as wing flutter in an aeroplane could culminate in structural break up if it reached the "explosive" point. And in the pioneering aeroplane days when wing flutter was a problem, before designers discovered how to overcome it, the aircraft were hardly exceeding speeds of 100 mph. Advancing blade tip speeds on today's light autogyros are more like 400 mph which magnifies the problem considerably.

One particularly unfortunate aspect of the phenomenon is that some factors which most seriously affect the onset of flutter (coning angle being one of the primary ones and rotor speed being another) can change considerably and rapidly during some flight manoeuvres. A pilot may think that his rotor is operating comfortably within the stable region which may well be the case in normal flight conditions. If the rotor is overloaded in flight, however, which can easily be done inadvertently by excessive increase of rotor angle of attack with too much backward movement of the control stick, the effective coning angle will increase immediately, especially if the blade flexibility in the flapping plane is high. Thus the rotor stability characteristics can momentarily move from the stable to the unstable region, with no warning to the pilot that the system he is controlling has suddenly become critically dangerous.

Fuselage Damping

Against this background of potential rotor instability with a two-bladed teetering system, the rotor/fuselage relationship assumes a much greater significance, and in this context, Professor Bennett's separate observations on this aspect merit a careful study.

Rotor/fuselage relationship is illustrated in the two accompanying diagrams which are exaggerated for clarity. Both diagrams depict an autogyro in a 90° turn to the right as viewed from above. This is not intended to represent a common or even feasible manoeuvre but is purely to illustrate the aerodynamic forces involved. Similar forces are present in turning manoeuvres of any degree or, for that matter, in a climb from level flight. And the order of the moments generated can be quite sufficient to have an adverse effect long before the angle of bank or climb reaches 90°.

Even in a steady turn, the load factor (or indicated G), defined as the ratio of lift to gross weight is inversely proportional to the cosine of the angle of bank. Thus if the angle of bank is 60°, for example, the load factor is 2. This overloading of the rotor will increase its effective coning angle through excessive blade bending. In a manoeuvre, the coning angle could be increased to more than twice the built in value.

Figure 1 depicts an autogyro of pusher configuration. The pilot has made his rearward stick movement to initiate and maintain the turn, the rotor tilts backward and relative airflow affecting the machine changes direction in response to the turning motion. The fuselage is now subjected to a combination of forces. Predominantly, since the new rotor tilt will have moved the extension of the rotor lift vector ahead of the centre of gravity, the fuselage will rotate clockwise until the CG is once again on the extension of the rotor lift vector. The effectiveness of this method of control by lift vector tilt is well-known to all rotating wing pilots.

Inertia tends to resist this process but inertia alone is not sufficient to provide stability. Rotation of the fuselage under the influence of lift vector tilt is itself increasing still further the rotor's effective angle of attack by its feathering influence on the blades' flapping axes. A tailplane could provide sufficient damping for stability if it were effective. However, a tailplane fitted to the rear keel member—if one is fitted at all in this configuration—can tend to become ineffective in providing the requisite damping as it becomes increasingly affected by turbulence in the wake of the pilot's body and the engine. It may even provide negative damping.

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in which case the manoeuvre quickly becomes unstable.

In Figure 2, which depicts a tractor configuration in the same conditions, somewhat different considerations apply. The tailplane in this configuration is much more effective owing to reduced turbulence and the moment it can induce about the CG is much higher by virtue of its greater distance from the CG. Thus it will make a more effective contribution to damping fuselage rotation in manoeuvres. Moreover, if, as was common in the earlier designs, a flapping hinge offset were embodied in the rotor head geometry (which cannot be done with the two-bladed teetering rotor) this feature would provide greater control power and damping during manoeuvres.

Thus in the tractor configuration there is no lack of fuselage damping during manoeuvres, no tendency to overload the rotor due to the aircraft rolling into an excessive angle of bank and no destabilising effect because the fuselage itself is aerodynamically self-stabilising, independent of rotor attitude. This is not to say that all pusher configurations are necessarily unstable but it is certainly more difficult to achieve positive dynamic stability throughout the speed envelope in this type of configuration than it was in what used to be regarded as the conventional tractor configuration.

Advantages

Clearly the two-bladed rotor has many attractions, particularly for a light autogyro. Apart from being less expensive to build, a private owner finds such a machine much easier to store in a garage or transport on a trailer and this may well be the deciding factor on whether or not he acquires one. This type of rotor also has similar advantages for commercial and military helicopters but Bell and Hiller, who are the world's principal exponents of the configuration have had to resort to quite a high degree of design sophistication in order to achieve the standards commensurate with the flight characteristics required.

Both Bell and Hiller two-bladed helicopters embody a form of stabilisation gear to monitor the operation of the rotor. Both have high control stiffness and a measure of mechanical damping in the control system. Both use low aspect ratio blades with high torsional rigidity and flapping stiffness which reduces the propensity to coning angle increase during manoeuvre. And both incorporate fixed aerodynamic stabilising surfaces on the fuselage to ensure a satisfactory rotor/fuselage relationship. All these features have been embodied and improved upon over the years as careful design investigation by specialists in a wide variety of engineering skills has shown them to be necessary.

Many if not all of these features are equally essential to a satisfactory light autogyro design if it is to have a two-bladed teetering system and this investigation is concluded with a summary of the stabilising and destabilising influences involved.

It is far too much to expect the average private owner, however enthusiastic and knowledgeable, to have a sufficiently deep insight into all the design complexities to be able to discern from what would normally be a superficial visual inspection, the difference between an inherently safe and a potentially dangerous machine. For one thing, it must be much more difficult for the amateur builder making his own blades to be quite sure that the finished product has the correct degree of flexibility, than for an approved manufacturer working under controlled conditions. Too much flexibility might permit excessive rotor coning. Too little may lead to excessive stresses in the blades themselves.

It is hardly surprising that interest in ultra-light autogyros is currently at such a low ebb among prospective private flyers. The only way to restore confidence, it seems, is for the accident investigation authorities to take some positive action to isolate the cause of the accidents and for the airworthiness authorities to follow this up with steps to ensure that they are not repeated. It is by no means impossible. They have now had more than two years to think about it. Surely it is time that the results of their official deliberations were published.

STABILISING FACTORS

1. Mass distribution arranged within plane of rotation
2. Low coning angle
3. Chordwise CG of blade well forward
4. Low aspect ratio
5. High flapping stiffness
6. High torsional rigidity
7. High control stiffness
8. Mechanical damping of controls

Note: Independent positive aerodynamic stability of the fuselage is an essential prerequisite.

DESTABILISING FACTORS

1. Mass distribution extending into flapping plane
2. High coning angle
3. Chordwise CG of blade too far aft
4. High aspect ratio
5. Low flapping stiffness
6. Low torsional rigidity
7. Low control stiffness
8. Undamped controls

Future Prospects

It is to be hoped that publication of this report will provide an impetus which will get things moving again. If funds are not available to support completion of the official investigation, which is understood to be one of the principal reasons for the extreme tardiness in the publication of any official report, special arrangements should be made for the funds to be provided. It is not as though any vast sums are involved.

More than one university in the U.K. would certainly welcome an opportunity to participate in completion of the investigation and analysis of the results. And there is no lack of expertise. All the requisite knowledge is within the bounds of current rotating wing engineering practice.

In the meantime, private pilots of amateur-built rotorcraft can only be advised to conduct their flying with care and avoid making sudden or excessive manoeuvres, particularly at the higher speeds.

Thousands of hours have been flown by privately owned autogyros of many designs in the past without serious accident. There is no fundamental reason why this should not be possible again.

Footnote : I am very pleased to acknowledge the wholehearted co-operation I have received from the American FAA, CAB and National Transportation Safety Board, which has greatly assisted the preparation of this report. And, of course, Professor Bennett's magnificent contribution.

B.H.A.

Correspondence from Readers on this subject is now invited—in particular it is felt that it would be most helpful to have information for publication from any individual or company who feel they may have personal experience either from the flying or the building points of view. Letters should be as brief as possible consistent with clarity and should be addressed to:—

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