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# The Aircraft Growth Factor

**By GROUP CAPTAIN H. FOOTTIT**

"An airplane isn't really built; it is a process of evolution."
—*Edward F. Burton*
*Chief Engineer,*
*Douglas Aircraft Co.*

IT COULD only happen in pre-war England. The time was 1934 and the drawing office of The Bristol Aeroplane Company were working hard on a new twin-engined airliner, the Model 143. At the same time Lord Rothermere was shopping around for a super-fast personal transport. He discovered the Bristol design. With a cut down fuselage and more powerful Mercury engines in the 143, and his Lordship was sold. The redesign got underway. Thus in 1935 Lord Rothermere's personal transport roared into the air with the challenging name *Britain First* painted on the side of the fuselage.

Following the usual British practice, the aircraft was flown to Martlesham for its airworthiness trials. Here officers of the RAF's Air Ministry heard stories of the outstanding performance of the *Britain First*. Reports trickled back to headquarters. Finally the RAF asked Lord Rothermere if he would lend them the airplane for further tests. In the best spirit of Lady Houston, who, a few years before, had donated the Schneider Cup racing plane to the government, Lord Rothermere graciously gave the *Britain First* to the nation.

**Just the Beginning:** From this magnanimous seed great airplanes were to grow. The RAF trials on the transport led to a specification for a fast bomber. Bristol redesigned their airplane. The result was the Bristol Blenheim bomber of World War II. True to the tradition that there is always growth in every good airplane, the Blenheim went from one "mark" to another. There was the original "short nosed Blenheim", the "long nosed Blenheim", the Canadian "Bolingbroke", and others.

The continual growth of a good airplane, such as the Blenheim, has been repeated over and over again. Spitfire fighters, Lancaster bombers, Constellation transports, Canadair Sabres (which are now coming out as Mark 6s), and Avro Canucks are examples of good airplanes which have grown. Yet in spite of this historical handwriting on the wall, it is only now being recognized that the designer should have this growth factor in mind right from the beginning. W. E. W. Petter, designer of the Folland fighter, the Gnat, told a production conference a few years ago that, from the very first line on paper, "the designer can help by designing for modification."

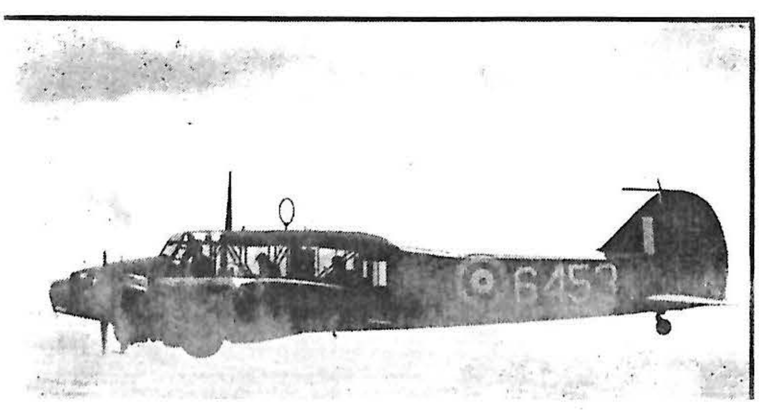
True as this concept is, it obviously takes more than a designer with a growth phobia to ensure growth. The soil must be right, too. From looking over the field of successful airplanes I believe that there are at least four factors that fertilize for future growth. These are (a) a correct operational requirement and concept of the airplane to meet it; (b) a basic design that is adaptable to change without having to scrap everything that has gone before; (c) extensive tests in the wind tunnel and on ground test rigs so that as many design deficiencies as possible can be sorted out as soon as possible; (d) a quick recognition of any defects early in the flight test program so that they can be rectified in a hurry. All these factors are readily recognizable in the early life of the greatest of all transport planes, the work horse of the air world, the Douglas DC-3.

**Number One:** When the company laid down the specification for the first airplane, the DC-1, they did it, as Arthur E. Raymond, Vice President for Engineering has said, "in an atmosphere compounded of equal parts of optimism and ignorance." Nevertheless, the company had a firm grip on what was wanted. They designed from the beginning for passenger comfort with a spacious, soundproofed fuselage. In addition they stressed safety, and planned on enough power in one engine so the airplane could take off and fly between two airports having an elevation of 5,000 feet, with a terrain clearance between them of 7,000 feet.

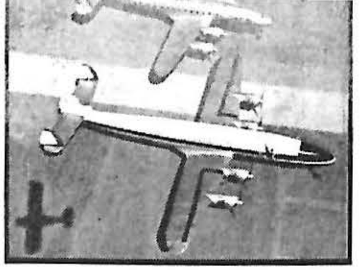
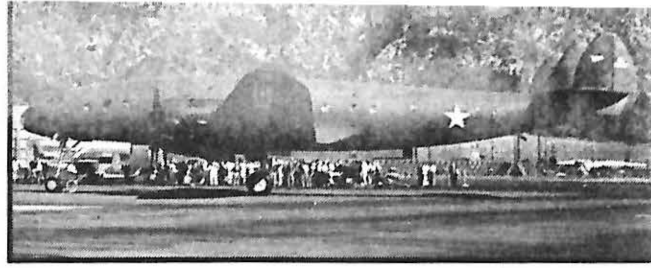
With this requirement and concept the basic design was made adaptable to change. And changes came while it was still in the blueprint stage. As it ultimately turned out, the first aircraft tipped the shop scales 30% over estimated weight. It could never have met the performance demands without two major developments that arrived on the scene and were incorporated into the partly built airplane. These two, which were completely unpredicted at the time of the specification, were the variable pitch propeller and an engine of higher horsepower. Together they pulled the overweight transport through the single engine performance tests.



**After the Cheetah-powered Anson 2 (L) came the Jacobs-engined Mk. 2 (R), shown on MacDonald Bros. wartime line.**





**Spit seemed destined to live forever; Constellation (Super & predecessor, centre; prototype, R) is still growing.**

In designing the DC-1, Douglas did an unprecedented amount of test work for the early 1930s. Models with three different wing types were wind tunnel tested. Then different tail, landing gear and tail wheel configurations were added and went into the tunnel's blast. Several types of ailerons, and six different flap arrangements were tried. But the real pay off centred around stability. Calculations had shown the stability to be satisfactory. But the tunnel tests results disagreed. Even the Douglas company were later to admit that if they had not done these wind tunnel tests, the DC-1 would probably have been unstable and gone to the scrap heap. As it was, they were able to find a satisfactory set up of general configuration, wing sweepback, and center of gravity position—though different than anything that had gone before—that was highly satisfactory.

**Attention to Detail:** A similar painstaking, detail check went into the cabin layout mock-up. Finally the airplane was finished. It first flew in 1933. Deficiencies in the design were quickly recognized. A remodeled DC-2 flew a year later, with a number of changes incorporated, including a 40 inch extension in the fuselage for better balance control and more passenger space. The lengthening of the fuselage was further indication of the adaptability of the design. However, the DC-2 flight tests convinced the company that more modifications were necessary before production. Thus the DC-3 was born, two years later. It was able to better its sister, the DC-2, by being able to carry one and one half times the load for a gross weight increase from 18,560 lb to 25,200 lb.

If this gross weight change can be taken as the growth factor during development, then from DC-1 to DC-3 the growth was 6,600 lb. This was stretched out over a three year period. Consequently, as a percentage of the original DC-1 weight, the average growth per year was about 12%. So the right airplane concept, backed by an adaptable design, extensive tests, and rapid recognition of design deficiencies, and the DC-3 type transport was able to absorb this 12% annual growth during development.

## the harvest

THE SUCCESS of this procedure can be judged from the production record. The company initially planned the tooling for a run of 50 airplanes. This was a daring decision at the time. But the DC-3 was so successful that it threw all competition off balance. Ultimately some 700 commercial transports were built from this tooling and duplicates of it. Then the war came. And nearly 10,000 military cargo Dakotas swelled the production tide.

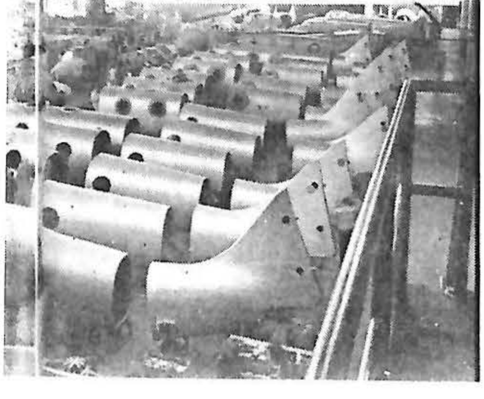
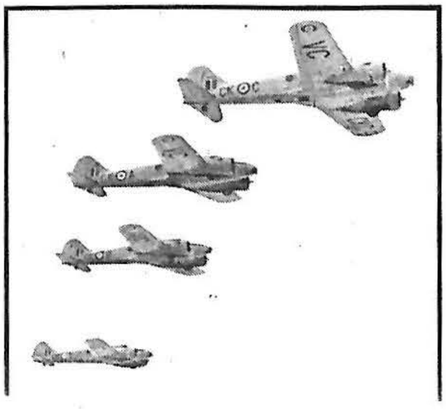
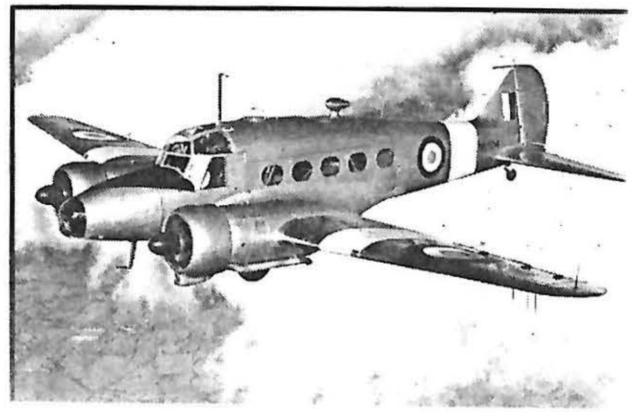
Although the DC-3 and Dakota have been converted for such roles as a radio trainer or a navigation trainer, most of their total life has been logged in the transport field. Their production growth has, therefore, almost been exclusively confined to this area. Other aircraft have changed roles with wide abandon, as they left the prototype stage for a long production run. This changing role is another type of growth that the designer must keep before his eyes from the earliest drawing office days. Here, a typical case is on our very doorstep: the Avro Anson.

Early in 1935 the British aviation magazines were reporting the first flights of a new twin engined transport that had been ordered by Imperial Airways for long distance charter work. This was the A. V. Roe, England, Model 652. About the same time the RAF observed that the newer civil airliners had stepped up performance over the standard military craft. Consequently they decided to write a specification for a coastal reconnaissance airplane that could be built from the conversion of a civil type. By this means they hoped to cash in on the civil success, and get airplanes in a hurry.

**A Career Begins:** Soon proposal brochures were being scanned in Air Ministry offices. A quick evaluation was made. Shortly after a contract was let to A. V. Roe for a reconnaissance version of their Model 652. By the end of 1935 the order had been sealed for 174 airplanes. This was the Avro Anson.

The Anson was soon flying in RAF squadrons. Then came World War II. And from this point on, one branch of the Anson's history is etched in the annals of Canadian aviation. I asked D. A. Newey about the Canadian Anson story. Mr. Newey is presently with Bristol Aircraft (Western) Limited (formerly MacDonald Bros. Aircraft Ltd.), in Winnipeg, but during the Anson program he bore the heavy responsibility of Production Supervisor with Federal Aircraft Ltd., a Crown corporation set up to administer the

**Wasp-powered Anson 5's during assembly (L) at MacDonald Bros. and in flight (centre). Right is a postwar Mk. 20.**

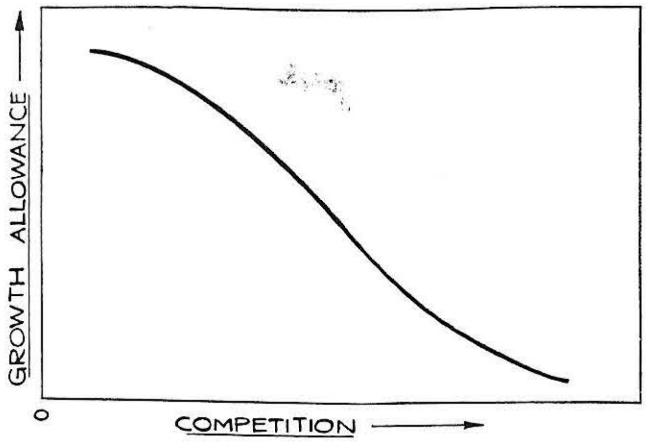



FIGURE 1
GROWTH ALLOWANCE FOR COMMERCIAL AIRCRAFT.

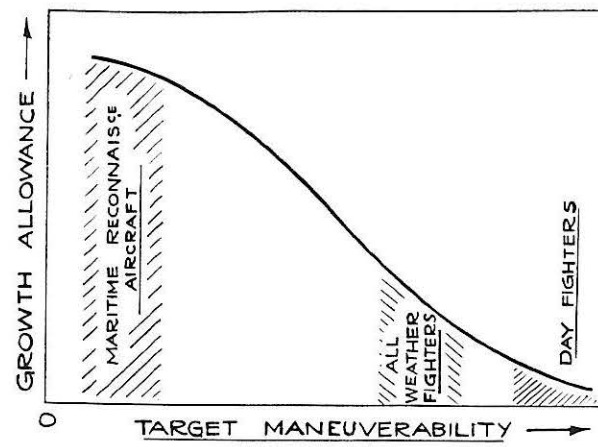



FIGURE 2
GROWTH ALLOWANCE FOR MILITARY AIRCRAFT

contract. Doug. Newey poured out a fascinating tale, well spiked with difficulties, both technical, logistical, and political.

From the aircraft growth side, Canadian production got underway with the Anson II, now converted to a training role instead of reconnaissance. The airplane was essentially a copy of the British Anson with a number of changes. The major ones were the replacement of the British Cheetah 9 and 10 engines with American Jacobs L6MB's, and the incorporation of power to the landing gear retraction system, instead of the torturous hand operated gear. The first Mark II was delivered into the Air Training Plan in the spring of 1941. Before the program finished, 1832 Anson II's were rolled from production lines which were fed by the web of Federal's associated companies stretching from coast to coast.

**The Mark Five:** But this was just the beginning. "With the shortage of materials, particularly steel and aluminum," says Newey, "it was decided to investigate the possibilities of manufacturing a satisfactory fuselage for the Anson out of laminated plywood. After some experimentation this was successfully accomplished and the Anson V came into existence. In addition we substituted the Pratt & Whitney Wasp Jr. engine for the Jacobs." All in all, nearly 2,000 of this trainer were produced, at a rate that finally peaked at 14 airplanes delivered a week. All these came out of the only assembly plant in operation at the time, MacDonald Bros. Though war's end finally brought the military Anson production to a stop, the airplane growth still went on. As Newey points out, "It is interesting to note that the Anson V, with some modifications in fuselage equipment, is still in operation in various parts of Canada, mostly as a bush transport, but in one or two cases on scheduled airline service."

This, then, is the record of one aircraft's growth. A growth that included structural changes, and ran the gamut from civil airliner, to a reconnaissance plane, then a trainer, and finally back to its original occupation. And who knows—the Anson's growth may not be over yet.

There is no doubt that a design team, struggling with the detail design of a new airplane, could never visualize and allow for such growth as finally blossomed in the Anson. Still there are several sign posts along the design highway that point the way for general growth potential in the basic structure.

### room to grow

IN THE FIRST place there is the use of design ingenuity in the structural layout. Since the expensive tooling is usually tied in with the fuselage, wing, tail and landing gear structure, any growth changes, which must be economical, should have the minimum effect on the stressed parts of these components. This does not mean that the basic structure won't change over the life cycle of the airplane. But it does mean that each major step should be a relatively small one as far as the structure is concerned.

An example of this design ingenuity is the straight sectioned fuselage of many modern transports. By keeping the fuselage cross section uniform over much of its length, there is not only an excellent passenger cabin, but, more important from the growth viewpoint, it is possible to add in additional fuselage bays, with minimum structural change, as the design grows. Some present day airliners have had two or more of these sections added as the fuselage has been lengthened through several model changes. There may be an aerodynamic loss with a constant cross sectional fuselage. But it is better to accept this and keep the door open for a long, profitable production run.

There is also the possibility of designing the structure for a higher gross weight than initially contemplated. In this way many modifications can be added, as the airplane grows heavier, without changing the basic airframe. But this is a two edged sword. Any designer that takes it literally can easily end up with a heavy airplane that carries little payload.

**Competitive Factor:** About the only criterion for judging, in general terms, such a growth allowance scheme for commercial airplanes, is to assess the allowance against a "competitive factor." In other words, whatever the airplane has to compete with, will limit the growth allowance in the blueprint stage (Figure 1). For a large transport airplane, being designed for the blue ribbon airlines on the trans-Atlantic or trans-Continental run, there is probably very little initial growth allowance possible. The route is too competitive. On the other hand, there are Ford Tri-motors, of the late

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tion of a new runway at Roberval Municipal Airport. Mr. Marler noted that the DoT operated more than 100 of these and assisted financially "or otherwise" at a great many others.

## CESSNA 172

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threatening to do all day.

Reluctantly we slid into the circuit behind our Twin Bonanza friend. The circuit speed which feels comfortable is 80 mph with a progressive drop off to 65 on finals. The wind on the long runway at the Island Airport was 30 degrees cross and gusty to boot, so an "over the hedge" speed of 60 mph was maintained. Recommended runway threshold speed is 50 mph. There is very little round-out required on this airplane, and we "landed" rather carelessly about three feet above the ground! The undercarriage withstood this treatment handsomely. After lowering the nosewheel to the runway, the 172 stopped in practically its own length. This is not as unbelievable as it would at first seem.

**Powerful Elevators:** The nosewheel can be held off the ground down to very low forward speeds due to good elevator effectiveness. Bob Wong demonstrated this most vividly while proceeding over the grass to the ramp. At fast walking-pace taxi with half elevator up, the nosewheel rose off the ground. We covered a few hundred yards in this unique attitude before reaching the ramp.

The most interesting feature of the 172 is, of course, the tricycle gear, and undoubtedly Cessna's have done a good job with it. As usual, the flying public knows what it wants, and in this case has got it—with a tricycle undercarriage! The docile ground handling of this aircraft will, I am sure, commend it to all pilots.

Cessna's predict that the 172 will *not* oust the 170 from the market that is available for this type of aircraft. But on only 30 minutes acquaintance with the 172, my money is on its being first past the post when the reckoning is made.

## GROWTH FACTOR

*(Continued from page 20)*

1920 era, still operating in South America. The only competition on some routes there are ox-carts or a few automobiles. An airliner or cargo plane designed to operate over this country may have a reasonably large growth allowance right from the first drawing.

For military airplanes the growth allowance on the design gross weight still varies with the commercial "competitive factor", though the latter is more clearly described as a "target maneuverability factor". (Figure 2) Such an airplane as the Canadair CL-28, a redesign of the Bristol Britannia for the RCAF's Maritime Air Command, may have as a target a relatively sluggish, slow maneuvering submarine. Hence, the growth allowance can be reasonably large. In this way any new anti-submarine equipment that arrives during the life of the airplane can be added without any major redesign of the structure.

At the other end of the scale are the fighters. For an all weather fighter the allowance would have to be smaller since the target can be a maneuvering bomber. At the bottom of the curve is the day fighter. Here, the maneuverability of the target, another day fighter, is at a maximum. Consequently a good day fighter, the air superiority weapon, must have practically a zero growth allowance on weight if it is to compete with the enemy.

There are other ways, too, of planting the seeds of growth at the drawing board stage. Although I favor the "design ingenuity" approach, of the two mentioned here, in many cases and in many design details both schemes may play a part. But one thing is certain. Unless the modern design engineer starts worrying about the growth factor from the first line on paper, it is highly unlikely that his brainchild will ever go through the "process of evolution" that Edward F. Burton spoke about. For this process is the hallmark of the successful airplane. And there have been far too many of the other type, in the cheap, romantic days of aviation, which have now gone by.

## COMET

*(Continued from page 22)*

ness. This vibrationless feature has been widely publicized and commented on ever since the first Comet took to the air; nevertheless, it must be experienced to be fully appreciated.

The time from take-off at Downsview to touchdown at Dorval was 1 hr. 12 mins., which includes the time spent circling Toronto and Montreal in order to show the aircraft off to as many people as possible. No attempt at speed was being made of course, and it should be kept in mind that all of the cruising flight was on two engines.

**False Alarm:** The Comet was scheduled to take off for London from Montreal on December 22 and while it did actually make a start, a firewarning which flashed immediately after takeoff, indicating a fire in one of the engine bays, necessitated a return to Montreal. There was, in fact, no fire, but a fitting on one of the tailpipes had failed, releasing hot jet efflux into the engine bays and setting off the firewarning. It is understood that one of the undercarriage doors was also sprung as a result of the pressure build-up of these gases.

The aircraft was returned to the Toronto plant of DH Canada for repairs, which were effected without making use of the spares that were flown out from England. It should be noted that up till the time of this incident the aircraft had been receiving only normal routine servicing throughout its flight and the only maintenance