Kudu with a turboprop....

BIRTH OF AN ANGEL

BORN OUT of "duress" from the United Nations Arms Embargo imposed on South Africa during the 1970s, the Atlas C4M Kudu was spawned in response to an operational requirement from the SA Air Force for a light re-supply/medevac capability during the Angolan conflict.

With the C47-Dakota fulfilling the light transport role and the C160/C130 aircraft fulfilling the medium lift component, the nature of bush warfare required an even lighter airlift capability with the specific ability to get into and out of remote, unprepared strips.

The operational requirement, in fact, called for four different transport roles. The first was for a cargo load of two 44-gallon drums for fuel placements at remote locations to provide mobility to the logistic support lines in what was then South-West Africa (now Namibia) and Angola. The other three were for the casevac role, a stretcher plus medic; for the transport role, four passengers, and for the paratrooping role, six paratroopers.

Contrary to popular belief, the Atlas C4M Kudu was not a spin-off designed from the AM-3C Bosbok by Atlas just modifying the AM-3C Bosbok and replacing the fuselage with the wider and larger volume fuselage of the Kudu. In fact, the prevailing duress left local industry with very little alternative but to take the Italian designed AL-60 light civil utility aircraft of the early 1960s, originally designed by Al Mooney, of Lockheed, and certify it against the SAAF's operational requirements.

The AL-60 had been manufactured in small quantities in Mexico and Argentina and under licence in Italy. Aermacchi then purchased a licence to produce the type, first in its original configuration as the AL-60B, for some African customers, then in a modified version as the AL-60C. This latter version changed from the original tricycle undercarriage to a tail dragger arrangement and it was this aircraft that was manufactured by Atlas under licence.

The basic specification was thus for a general-purpose, light utility transport, accommodating a crew of two and up to six passengers in the cabin or 560 kg of freight. The first civilian prototype (ex SAAF #999) used by Atlas Aviation for the certification of the Kudu to Federal Aviation Regulations Part 23, flew on February 17, 1974, and the first military prototype flew on June 18, 1975, entering SAAF service in 1976.

More than 40 Kudus had been built when production ended in the early 1980s with the prototype, Kudu #999, eventually being assigned to the Test Flight and Development Centre.

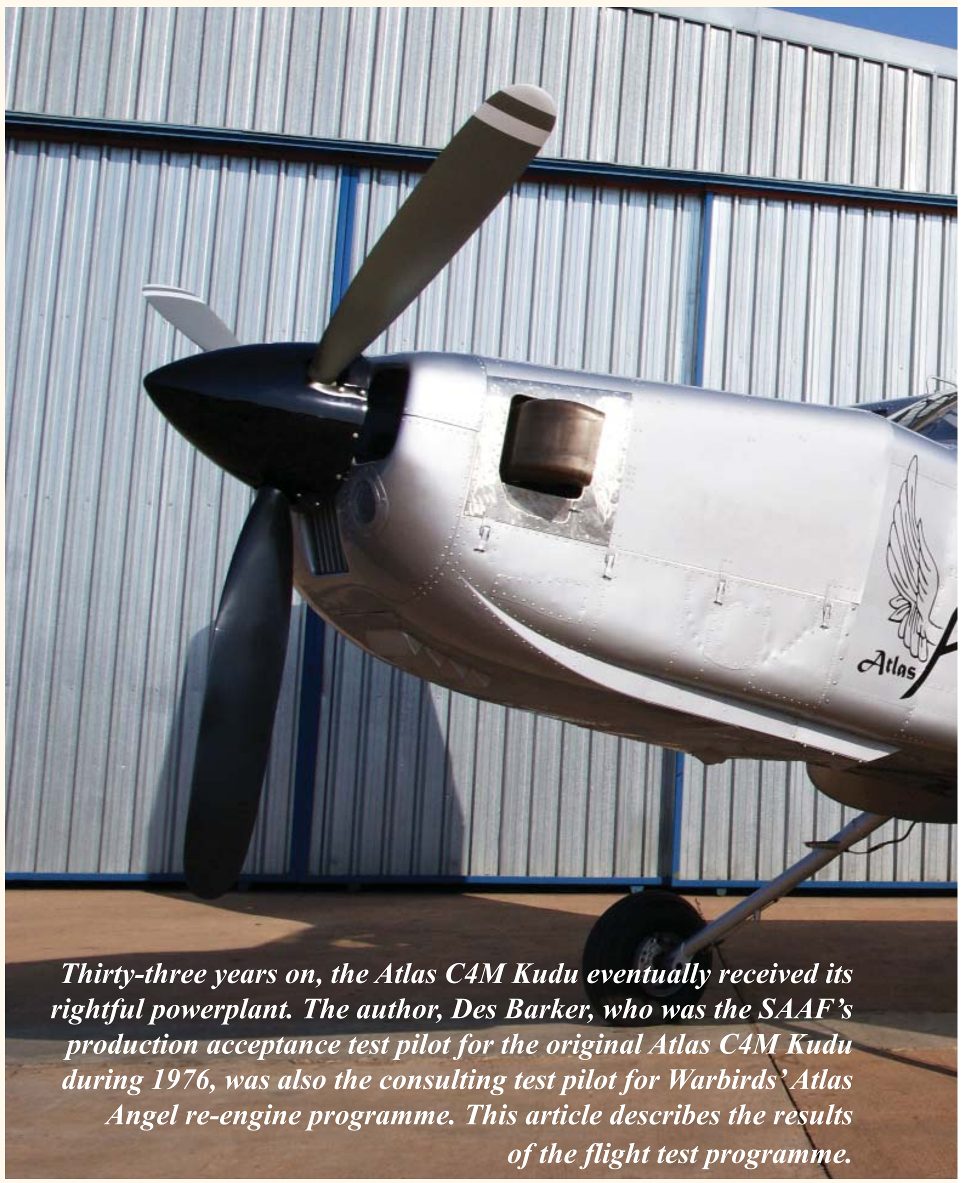
The question within the SAAF at that time was: Was there sufficient excess horsepower to accomplish the mission? In the early 1970s, the then Rhodesian Air Force's AL-60B Trojans, had at odd intervals visited AFB Pietersburg in support of RhodAF weapons exercises on the Roodewal bombing range, and already the Trojan was derogatively referred to by the fighter pilots as a "noise generator, converting fuel into noise". The Kudu and Bosbok were yet to be introduced to inventory.

SAAF Kudu pilots will readily attest to the fact that the Kudu was, in fact, underpowered, which meant that high skills, judgement and knowledge levels were required as was respect for the environmental factors that governed density altitude to safely maximise output from the Kudu in the hot and high conditions that prevailed in Namibia and Angola.

The concept of fitting a turboprop to the Kudu, though, is not new. During 1976, the discussion around the crew room among the fixed wing test pilots and flight test engineers at TFDC often breached the subject and, in fact, Lt Col Arrie Meulman drew up a concept design for a turboprop equipped Kudu.

The flight test fraternity, more than anyone else, understood the implications of releasing an underpowered Kudu to service and expressed empathy with Kudu pilots having to accomplish the mission in hot and high conditions from rough fields in the middle of nowhere.

The logisticians, however, not really understanding the implications, were having none of it – the Bosbok had an Avco Lycoming GSO-480-B1B3 flat-six piston engine and for purposes of standardisation of equipment and training, they



Thirty-three years on, the Atlas C4M Kudu eventually received its rightful powerplant. The author, Des Barker, who was the SAAF's production acceptance test pilot for the original Atlas C4M Kudu during 1976, was also the consulting test pilot for Warbirds' Atlas Angel re-engine programme. This article describes the results of the flight test programme.

were not going to have their world complicated by the logistics support efforts required to provide pilots with a more powerful aircraft.

The Kudu was not only performance challenged, but also in some cases, the flying qualities demanded above average skills. However, despite its performance and handling shortcomings, the Kudu shouldered a large portion of the light utility and transport requirements for the SAAF 'in theatre'.

At the operational level, the slow speed of the Kudu cruising along at approximately 110 KCAS, made it highly vulnerable to enemy ground fire and man-portable surface-to-air missiles. What is certain, though, is that the rather limited performance and handling qualities challenges of the Kudu, produced high calibre pilots. The SAAF's training syllabus adequately prepared the mostly young and inexperienced pilots with the necessary skills to fly the aircraft safely.

On the one hand, survival was ensured by clever utilisation of the aircraft through flight tactics to counter the ground threat and, on the other hand, squadron pilots developed standard operating procedures to deal with performance and handling shortcomings.

The primary challenges posed by the Kudu from a handling perspective, was the landing, particularly in crosswind conditions with its large keel surface area aft of the centre of gravity.

In addition, the downwash from the full flap landing configuration reduced the tail plane's pitch authority to bring the aircraft into the three-point attitude for landing which resulted in squadron pilots 'stealing' two notches of nose-up trim to reduce the pull force required for the round out.

Not a bad idea for compensation, but any balked landing overshoot at full power produced a strong nose-up pitching moment from the all-moving stabilator, that would have to be overcome by a pitch trim rate that was not very quick and, as a result, the cockpit could become very busy trying to get the aircraft trimmed out, flaps raised and deal with the directional control challenges imposed by full power.

Also on landing, closing power to flight idle in the high drag landing configuration, tends to decelerate the aircraft rather rapidly and if the round-out height is excessive, the aircraft will drop out of the pilot's hands.

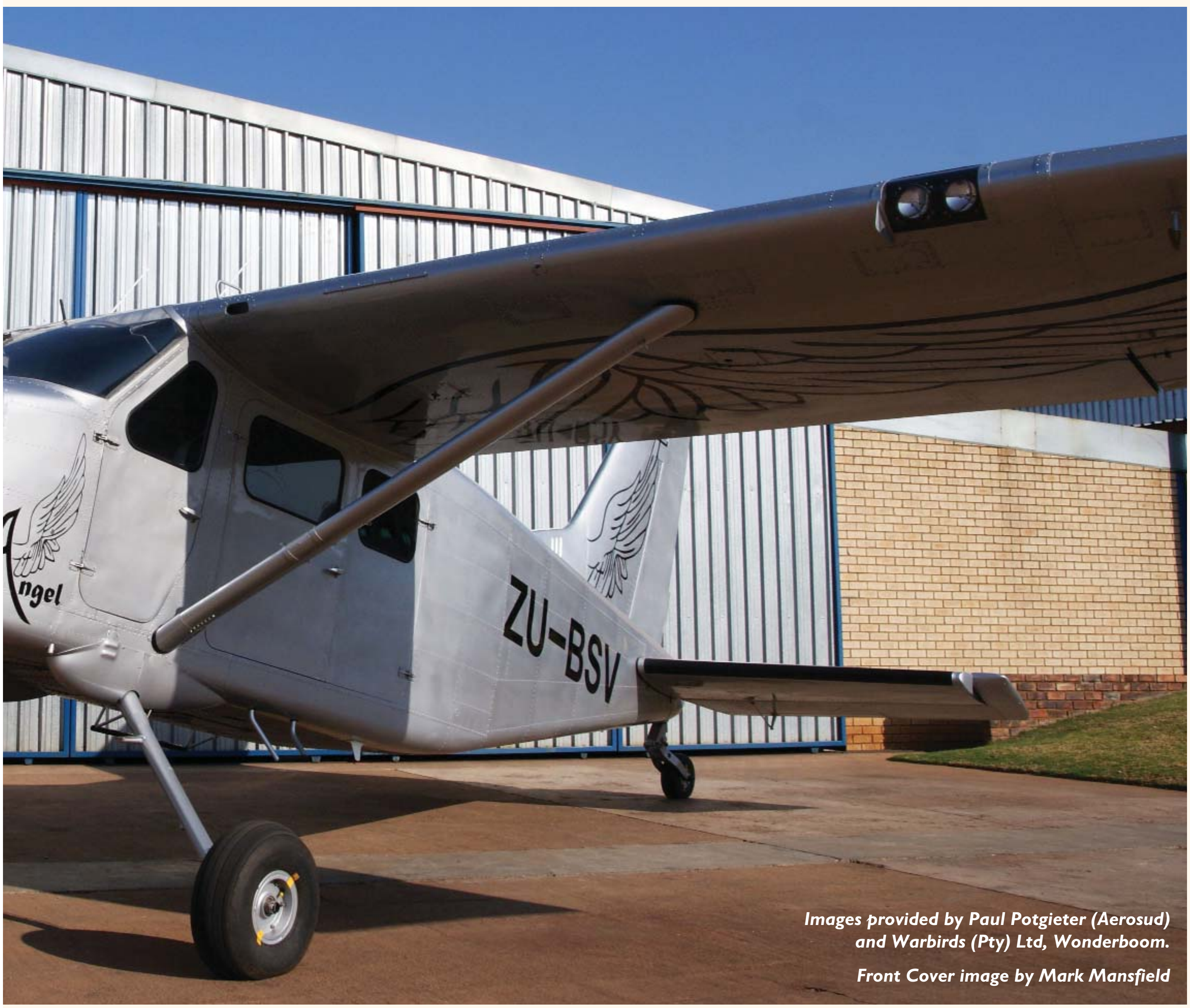
The bottom line is that the Kudu required a high level of coordination in certain flight phases. In accordance with transport aircraft design requirements, the degree of stability about all axes was relatively high, but, inadequate excess power remained the single biggest complaint area by SAAF Kudu pilots.

However, this complaint was heard from most SAAF pilots, irrespective of the aircraft type they flew. There was never a SAAF pilot who had enough excess power; the SAAF inventory aircraft were designed for European conditions, not understanding the stringent requirements for Africa's hot and high conditions.

RE-ENGINE THE KUDU!

So, it took approximately 33 years for someone with insight into the requirements of the skydiving mission to realise that, with the ready supply of the rugged ex-military Kudus, the potential existed to meet the demands of the skydivers, provided a suitable engine could be installed to overcome the power shortcoming.

The skydiving mission essentially requires



Images provided by Paul Potgieter (Aerosud) and Warbirds (Pty) Ltd, Wonderboom.

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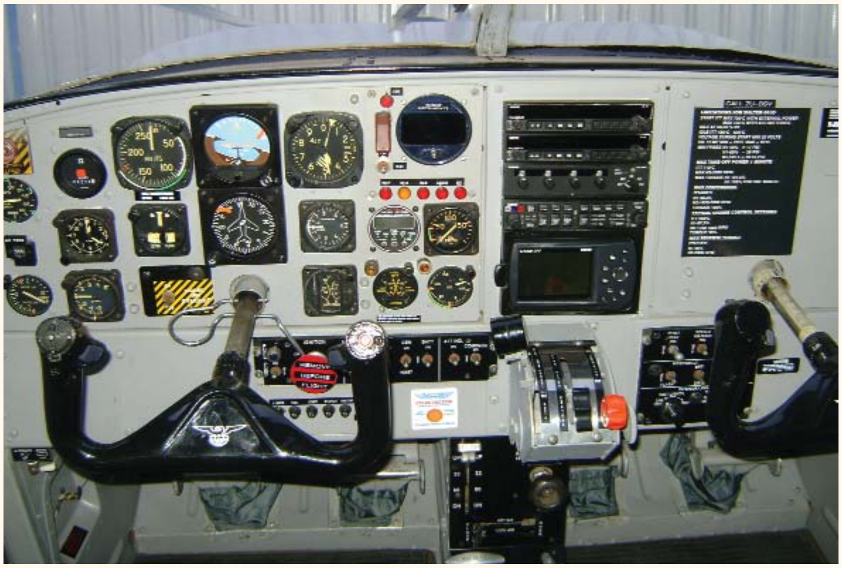


short time to height with a respectable number of skydivers carried, and a minimum time to descend, all in an effort to reduce the cycle time for each drop load.

An added bonus of the Kudu airframe is the cargo doors on the Kudu that provide skydivers with easy ingress and exit. The Kudu was no stranger to the skydiving mission, having been used extensively by the Defence Skydiving Club at Swartkops for many years.

The Kudu airframe met the requirements of volume. What was needed, however, was a ruggedised powerplant to provide the excess shaft horsepower (shp) for short field take-off performance at maximum all up weight – the excess shp to provide quick time to height, and the ability to descend rapidly without the concomitant issues of 'shock cooling' associated with piston engines.

THE ANGEL IS BORN

Several Atlas Aircraft C4M Kudu aircraft were purchased by Rob Taylor (Pty) Ltd and were subsequently earmarked for an engine replacement of the 340 hp Avco Lycoming GSO-480-B1B3 engine and Hartzel 3-blade constant speed propeller, with a Walter M601D engine and Avia V508 3-blade constant speed propeller.

The aircraft in this new configuration was designated the C4M-TP Angel, a non-type certificated aircraft (NTCA) in terms of Part 24 of the SA Civil Aviation Regulations (CARs).

The modification programme was undertaken by Johan Lok's Wonderboom-based maintenance and repair company, Warbirds. Structural analysis and modification planning support from Franscois Jordaan's Aerostruct Consulting and flight test support by Carlos Cabral, a SACAA Class II test pilot, formed the remainder of the project test team.

THE ENGINE

The Walter configuration at 68% of its maximum torque, is equivalent to the 340 bhp maximum of the standard Atlas Kudu.

Built in the Czech Republic, the Walter M601D turboprop was designed for use in remote areas with rugged and minimal field maintenance requirements as top priorities and has been installed in the Let 410 (19-seat commuter) operating in harsh Siberian, African, South American, and Eastern European regions.

Fitted with an AVIA V508 three-blade constant speed propeller and spinner, with full feather and reverse, the modification included the following additions: oil cooler, oil lines, electric fuel pumps, wiring harness, relays, voltage regulator, starter-generator, igniters, exhaust, control cables and switches and annunciators.

In addition, electronic digital gauges (ITT, N_1, N_2, oil pressure, oil temperature, volt and ammeter, torque, fuel pressure/fuel flow), gascolator, power quadrant and baffling kit were fitted.

The engine also included an auto-start system with electro-hydraulic transducer to automatically control the starting process optimally to reduce the risk of "cooking" the engine on start-up. Engine starting is accomplished using a combination starter-generator and electronic ignition (dual low voltage torch igniters).

What makes this engine particularly attractive to the skydiving mission, is the recommended time between overhaul (TBO) of Walter M601 engines which is defined by "cycles" (engine starts), flight time, and calendar time. Factory recommended TBO intervals vary from 2 250 to more than 20 000 cycles, from 1 500 to 3 000 hours flight time, and from five to eight years between overhauls.

Unlike some turboprop engines, hot section inspections between overhauls are not required with the Walter 601. Maintenance between overhauls consists primarily of filter and screen cleaning, compressor wash, oil change, bore scope inspection, igniter replacement, and testing/calibration.

The maximum engine power of the Walter engine is approximately double that of the Lycoming GSO-480 engine. Since the propeller speed of 2 040 rpm is essentially unchanged, this implied double the engine torque and significantly increased helical airflow around the fuselage at maximum engine power which would impact on static and dynamic stability characteristics of the aircraft.

The Walter engine installation resulted in mass and inertia changes which affected the aircraft performance, stability and control. To maintain the static margin at approximately the same range of CG positions as for the standard Atlas Kudu, it was necessary to move the propeller mounting face forward by 305 mm (12 ins).

The military radio equipment weighing 39 kg, was also removed from its original position from the rear racks aft of the cabin, and modern radio equipment weighing 5,44 kg was installed in the cockpit on the instrument panel.

A new battery weighing 44 kg was fitted in the rear to the now unused radio instrument rack aft of the cabin replacing the original battery which weighed 29,5 kg.

The net effect was a mass redistribution which, although the static margin was theoretically unchanged, did change the moments of inertia of the aircraft about both the pitch and yaw axes which impacted on the static and dynamic stability characteristics of the aircraft; the exact amount would have to be determined by flight test.

With the increased propeller mass, the rotational inertia of the propeller was increased by 26% and although the rotational speed was the same as that obtained with the Lycoming engine, the propeller gyroscopic loads had changed.

The considerably increased installed shaft horse power obviously significantly increased aircraft performance, increased the propeller normal force, slipstream, downwash, and mass flow. The exact optimised utilisation of such power was required to be determined in flight test to verify compliance with FAR Part 23, even though the aircraft was to be flown within the NTCA category.

HANDLING QUALITIES

It is not a simple task to just re-engine with a turboprop by fitting the engine to the aircraft. Critical considerations cascade down from the increased mass flow of the three-bladed propeller at 2 080 rpm.

One of the most destabilising effects on a propeller-driven aircraft is the power-on effects, particularly at high angles of attack. This is due mostly to the increased mass flow that develops additional lift over parts of the aircraft, not always for the good though.

The magnitude of engine torque posed another set of challenges. Where do you draw the line regarding acceptable stability and control? Where and how do you make the call for performance increases considering that the aircraft will no longer be flown by military pilots who undergo a comprehensive conversion on to a tail-dragger?

Is the performance and stability and control acceptable for the intended role of carrying skydivers? And the excess power, how usable is it? This could only be determined through flight test.

FLIGHT TEST PROGRAMME

The aim was to conduct a certification flight test programme on the C4M-TP Angel in accordance with the requirements of the Non-Type Certificated Aircraft (NTCA) in terms of Part 24 of the SA Civil Aviation Regulations.

Although certification requirements as a

NTCA do not specifically call for FAR certification standards, the aircraft was nevertheless subjected to the airworthiness requirements of FAR Part 23, which essentially called for evaluation of the static and dynamic stability testing of the aircraft with the turboprop fitted.

The most significant challenge to the flight test programme was to determine the relationship between maximum torque and the inherent aerodynamic stability of the Kudu. Without the hindsight of wind tunnel testing and aerodynamic load testing, a build-up programme, taking each test point, one by one, was required, particularly in determining the optimum power setting for first take-off.

Without getting too technical, the aircraft was subjected to static, dynamic and manoeuvre stability tests including, among others, evaluation of the short period, Phugoid, stick force/g, spiral stability, Dutch Roll response, steady heading sideslips, among the many different flight test techniques.

A build-up programme was adopted, starting at a forward CG/light weight and progressing to near maximum military overload at aft CG. Aspects of performance testing were obviously critical and, as such, take-off, climb, level cruise, descent and landing performance tests were conducted.

Initial aerodynamic analysis raised concerns that the increased torque, slipstream and precession effects could restrict the handling envelope, but these proved unfounded. In fact, such a large amount of inherent aerodynamic stability had originally been designed into the Kudu, that there was sufficient residual stability margins to recommend the clearance envelope be retained as per the original FAR Part 23 certification conducted by Atlas Aviation.

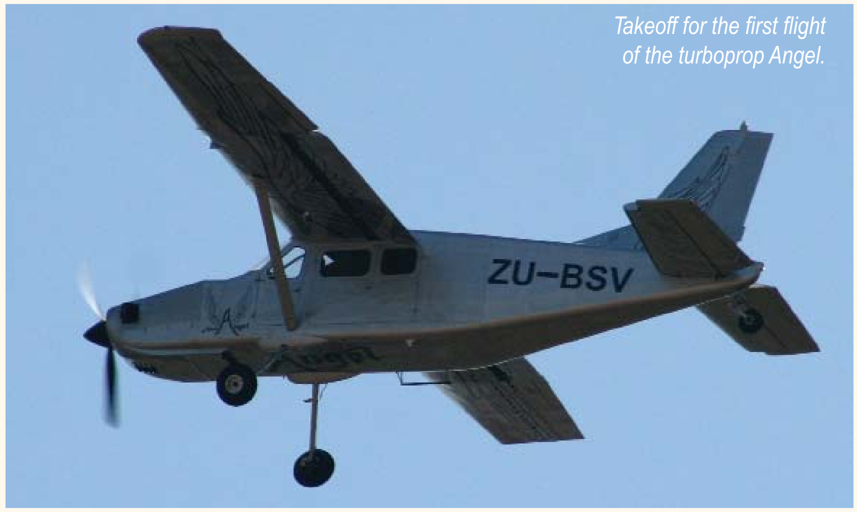
Interestingly, the stalling speed of the C4M Angel, was approximately three to seven knots lower than that for the Atlas C4M Kudu, depending on configuration, namely: the more flap selected, the bigger the difference which implied an effective increase in Cl_{max} of 0,2 at 100% flap setting.

This amount of Cl increase is significant and was most probably attributable to a combination of effects, including increased propeller normal force, increased mass flow over the nose, wings and fuselage, and the residual thrust from the idling turboprop (100 hp at sea-level).

The implications of increased Cl_{max} was the ability to approach and land at a significantly lower airspeed with the consequent reduction in landing distance, particularly the ground roll. Good for the skydiving mission? You bet! Quicker turnaround times are possible if ground taxi distance is decreased.

PERFORMANCE

In an effort to best describe the performance improvements to the Kudu by the introduction of the Walter 601D turboprop, it would make good sense to relate the aircraft's performance to the typical skydiving mission. Simulating a mission weight at takeoff of 2 124 kg (145 kg less than maximum military overload), it represented, in this case, a typical jump load of seven skydivers and 111 kg of fuel.



Takeoff for the first flight of the turboprop Angel.

The first indication to the pilot that the original shortcoming of insufficient power available had been resolved, was with the take-off. Operating from Wonderboom's 1 828-metre long runway at density altitude 3 670 ft, the total takeoff distance over a 50-foot screen height, was 297 metres made up of a ground distance of approximately 232 metres and an air distance of approximately 61,5 m.

A nominal torque value of 105 psi (83%) produced a significant acceleration with the tail wheel lift-up at approximately 35 KIAS after nine seconds (65 metres). The aircraft was rotated at 75 KIAS after 16 seconds (198 m) and airspeed maintained at 75 KIAS until 50 ft agl screen height, which was reached in 18 seconds.

Good enough for the skydiving mission and light transport mission? You bet! This is an impressive distance for any aircraft operating at near maximum all up weight.

Strangely, contrary to expectations of increased torque, slipstream and precession effects from the more powerful engine, trim settings of zero in pitch, roll and yaw, were adequate to maintain control with predictable response about all three axes throughout the takeoff run and adequate aerodynamic control power. Performance, stability and control as well as flying qualities were considered satisfactory for the mission.

The selection of 105 psi torque, was considered the highest that an average pilot should be confronted with in terms of aircraft controllability while monitoring engine performance, aircraft acceleration and control during takeoff. The reserve capacity of 22 psi Tq and 45°C (ITT limit temperatures) would be available for increased rate of climb for the skydiving mission.

As anticipated, and in accordance with theory, maximum climb rate, a direct function of excess power climb performance tests, revealed that the optimum climb speed of the Angel had increased from 85 KIAS for the standard Kudu, to 90 KIAS for Angel.

In fact, the climb performance curve revealed best ROC between 88 and 92 KCAS which at 90 KCAS, presented a climb attitude of approximately 12° which provided adequate forward field of view.

Total time to climb to a drop height of 10 000 ft pressure altitude (approx 6 000 ft agl) was four minutes, 32 seconds from brake release (ISA dev+8,4°C) with total fuel used, was only 22 litres.

Level cruise at 80 KIAS at 10 000 ft pressure altitude, required only 37psi torque (29%) with a fuel flow of 107 litres/hour.

Throttling back to flight idle, descent without the skydivers present at 135 KIAS, was easily accomplished at 2 000 ft/min in three minutes during which time only three litres of fuel was consumed before touchdown.

Landing back at Wonderboom (OAT = 13°C) on R/W 11, in landing configuration of 100% flap, approach speed at 65 KCAS (FAR 23 procedure 1,2xVso) over a 50 ft screen height at a relatively heavy weight of 2 012 kg in calm wind, three-point landing without using beta or reverse, the total landing distance was an impressive 180 metres – impressive, particularly due to the very short ground roll distance of only 66 metres.

Interestingly, the earlier requirement by squadron pilots for the pilot to trim two-divisions nose-up for landing, was not required. Sufficient elevator power was available to generate the required pitching moments for the flare and landing, indicating an increased energy level prevalent. Aircraft handling, stability and control in the landing configuration was satisfactory.

Within the scope of the limited flight test programme, it can be concluded that the fitment of the Walter 601D turboprop on the Kudu, significantly increased the performance of the C4M Angel in the skydiving mission.

Contrary to SAAF pilots' experience flying the Kudu under operational conditions during the Angolan conflict, pilots assigned to fly the skydiving missions can look forward to an aircraft in which the deficient performance challenge to operating the Kudu, has been resolved in the 'C4M Angel.

Never has there been a pilot that has complained about too much power. There is no doubt that, in this case, the aircraft has been provided with adequate power for the mission and many former SAAF pilots who operated the Kudu in the operational area would have given their eye teeth for this engine to reduce their stress levels. ✈