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CONCEPTUAL DESIGN OF THREE ALTERNATIVE CONFIGURATIONS OF NEW-GENERATION 19-SEAT BUSH AIRCRAFT

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Abstract

This paper will describe initial surveys of the design and operational characteristics of current successful bush aircraft, such as the De Havilland Twin Otter and the GAF Nomad. Other classic 19-seaters were also examined. This was followed by the performance of market surveys and derivation of aircraft requirements. The paper will then describe the conceptual design processes of three alternative 19-passenger Bush aircraft concepts:

-A flying boat, with amphibious capability. Particular attention was given to the hydrodynamics of the aircraft, together with the use of a step fairing to improve the aerodynamics of an aircraft cruising at 410 km/hour.

-A Low -Cost conventional aircraft, designed for enhanced comfort and low operating costs. It has a pressurised cabin, with a generous fuselage cross – section.

-A Modern technology landplane, incorporating natural laminar flow, composite construction and a novel propulsion system. It has outstanding fuel burn performance. .

The paper will conclude with descriptions of the three concepts in terms of dimensions, masses, performance, CAD models, drawings and cost estimates. These aircraft are then compared to existing aircraft, to assess their viability. Recommendations are made for future work, including airworthiness clearance issues for one of the designs.

1 Introduction

Design of bush planes reached its peak in the 1960s with the introduction of the DHC Twin Otter. Since this time, little has changed in the standard configuration associated with a bush plane and advances in technology have been weighed carefully against a perceived loss of ruggedness. Yet the Twin Otter, in its time was a highly advanced design and remains one of the lightest aircraft fitted with full span double slotted flaps. This feature allows the aircraft to maintain a significant lead in short field performance to this day. Legacy types still in service include the Pilatus Turbo Porter and the GAF Nomad. Both these types, along with the Twin Otter, are being returned to production, largely unchanged

1.1 Headers and Footers

2 Market Survey

Rojas [1] performed an initial survey of turboprop aircraft in 2006 and produced the data of competing aircraft shown in Table 1. This survey was added to by Ji [2} and Stewart [3} to guide the requirement for their designs in 2013, shown in Table 2. These were slightly different from the earlier amphibian design.

Current roles for the aircraft include short-range passenger and small freight transport, patrol, tourism, agricultural work, medical assistance and relief work. They need to be rugged and able to operate from austere, short airstrips.

Table 1 Survey of small turboprops, 2005 [1]

	In service	**Average**	**Flyable'**	**Average**	**Flyable Production**		**In service percent fleet***
Equipment type	**Number***	**Age**	**Number***	**Age**	**Years**	**Seats**	
Beechcraft 1900	177	18.1	241	17.8	1983-1991	19	3%
Beechcraft 1900D	354	9.64	433	9.7	1990-?	19	5%
Beechcraft 99	157	**31**	**163**	**31.1**	1968-1987	19	2%
BAE Systems J31132	199	17.9	336	17.8	1982-1997	19	3%
Twin Otter	563	30.7	601	30.8	1966-1988	19	8%
Domier Do-228	212	17.2	247	17	1982-?	19	3%
Embraer EMB-110	329	26.1	360	26.1	1972-1992	19	5%
Metro III	694	22.4	738	22.7	1970-1998	19	10%
GAF Nomad	86	26.5	87	26.5	1975-1986	19	1%
Handley Page HP137	26	35.2	27	35.2	1969-1976	19	0%
Short SC-7	90	32.8	92	32.8	1964-1986	19	1%
Total	**2887**	**-**	**3325**	**-**		**-**	**-**
Weighed average		**23**		**22**			

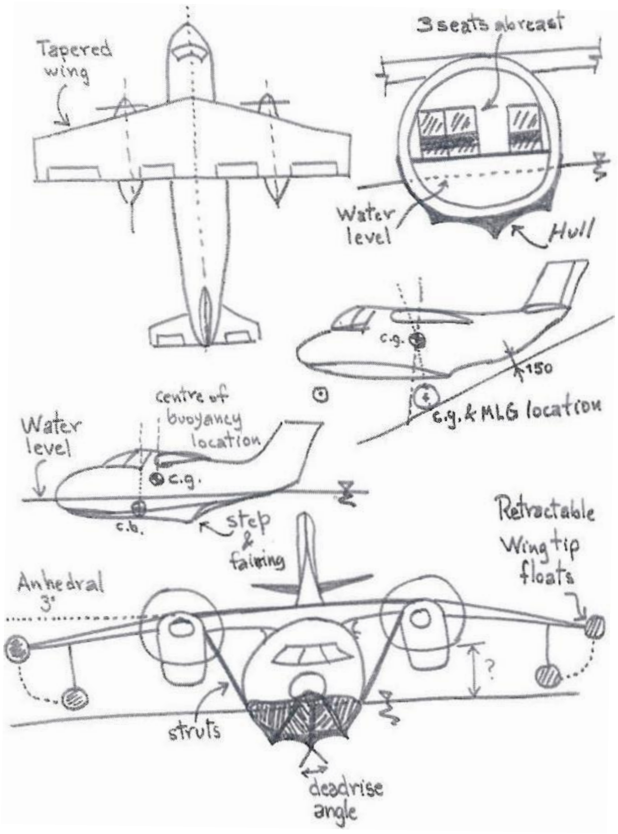
Table 2 Requirements [2]

Description	Requirement
Accommodation	1 Pilot + 19 Pax
Payload	2000 kg
Range with max. payload	1000NM
Cruise speed	250 kts
Take Off Ground Roll	250 m
Take off distance to 35ft screen	350 m
Landing distance from 50ft	<500 m

3 Conceptual design of the New Amphibian aircraft (NA)

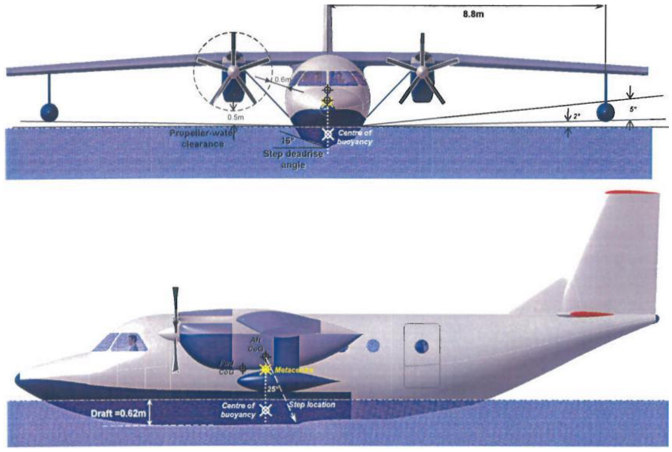
This methodology used a landplane concept as a baseline to convert it into a flying boat. It considered the additional mass due to the hull, step configuration, draft estimation, spray height, hydrodynamic drag, aerodynamic drag, on-water static-dynamic stability and purchase costs. Figure 1 shows the initial sketches of the concept. [2].

Fig. 1 Initial Amphibian concepts



It was decided to use a high – wing, turboprop, design to minimize spray interactions. Extensive calculations were performed to estimate aerodynamic and hydrodynamic performance, as well as mass estimates. Conventional land aeroplane methods were used, but allowances were made for modifications required for flying boats. Chicken [4] provided methods for doing this, as well as for hydrodynamic performance. Considerable efforts were made to design the hull, interior, amphibious landing gear, and the waterborne and airborne stability and control aspects of the design. The results are shown in the comparison section of this paper, whilst the final configuration of the aircraft is shown in fig. 2, below

Fig. 2 Impression of the final New Amphibian aircraft



4 Conceptual design of low-cost Bush aircraft (LC)

Ji [3] performed a conceptual design of a conventional, low-risk aircraft, to the requirements of Table 2. The design process is summarized in the flow-chart of fig.3, below. Conventional aluminium alloy construction was used, with well-proven Pratt and Whitney of Canada PT-6 engines. It differs from aircraft such as the Twin-Otter, in the use of a pressurized cabin and retractable landing gear. This resulted in a superior range and speed

The low – cost design features included:

- Metallic primary structure.
- Conventional configuration.
- Constant – chord inner wing.
- Unswept wing, with simple slotted flaps.
- Single wheel landing gears.
- Mechanical flight control system..

Fig. 3 LC Design process

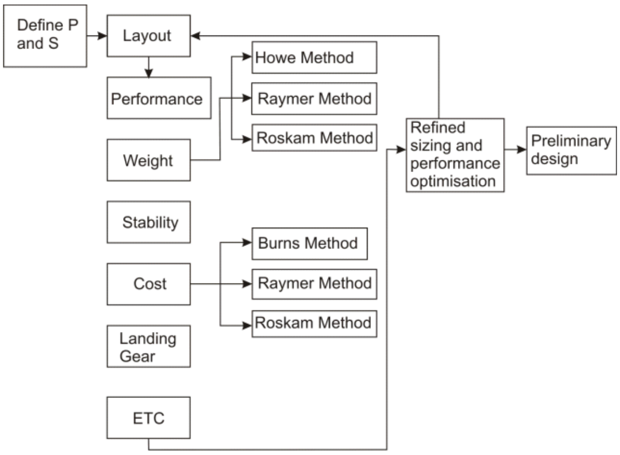


Fig. 4 shows a Computer-aided design model of the aircraft, whilst Fig. 5 illustrates the flexible cabin layouts.

Fig 4 LC CAD model

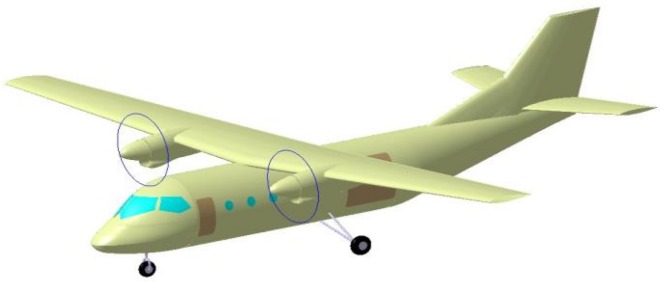
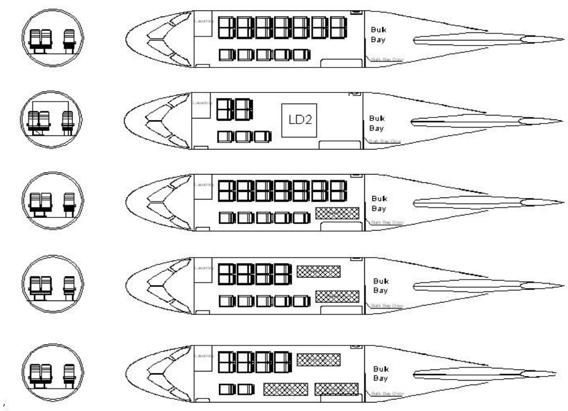
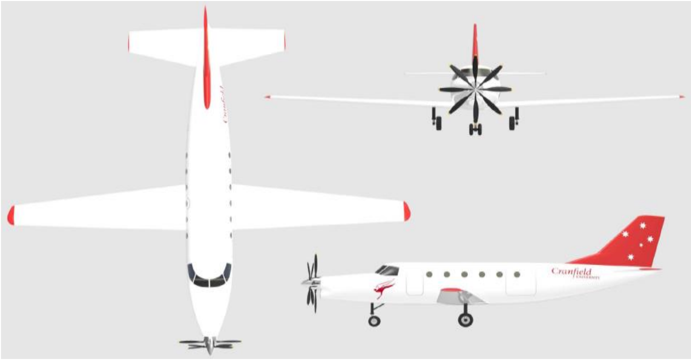


Fig 5 LC alternative fuselage interiors



5 Conceptual design of a Modern Technology aircraft (MT)

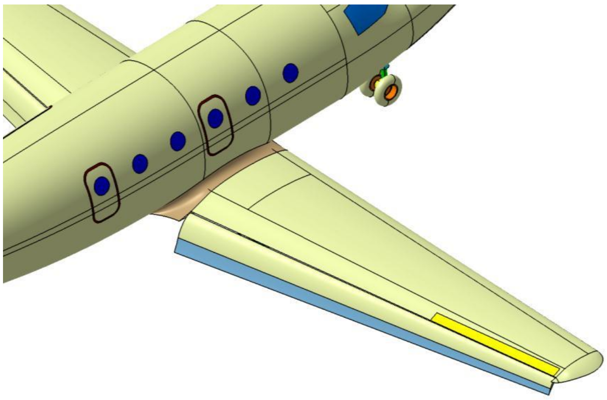
Fig.6 General Arrangement of the MT.



The concept developed for the study was a low wing monoplane with an unswept, straight tapered wing. The configuration breaks with the tradition of mounting the wing high on aircraft intended for utilitarian use. The shortcomings of this configuration in terms of ground clearance were accepted in return for higher cruise efficiency.

The wing comprises a NASA LF (1)- 0414F Natural Laminar Flow (NLF) section along its entire span. This is among the highest performing NLF airfoils in service with a design lift coefficient of 0.4. The airfoil was originally designed for use with a 0.12 chord "cruise flap" that maintains the minimum drag state over a wide range of C_L by controlling the acceleration of the flow. Due to the small chord of this flap, it may be incorporated into a Fowler flap system as a tab, simplifying the practical adoption of this feature (Fig. 7).

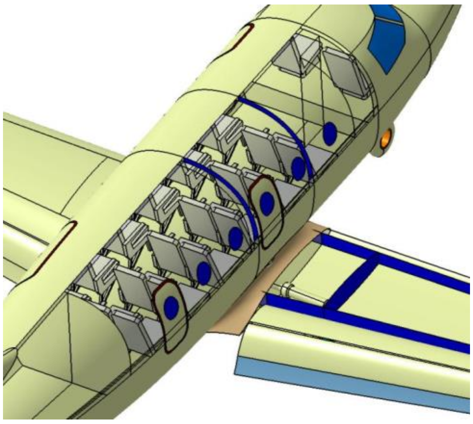
Fig. 7 MT wing layout



The wind tunnel tests conducted by NASA [5] on the NLF(1)-0414F achieved a laminar region equal to 70% of the chord with a 66% reduction in profile drag compared to the same airfoil with fully turbulent flow.

The aircraft is intended to accommodate a single pilot and a passenger on a two seat flight deck with a further 18 passengers in the main cabin (Fig. 8). A 3.5 cubic metre luggage bay is provided at the rear of the main cabin and provides expansion for outsized cargo. Two type A emergency exits are located on the starboard side with emergency egress from the flight deck possible through the side windows. Carriage of up to 8 litters is possible in the high density aeromedical configuration or a combination of litters and seats.

Fig. 8 MT Cabin interior

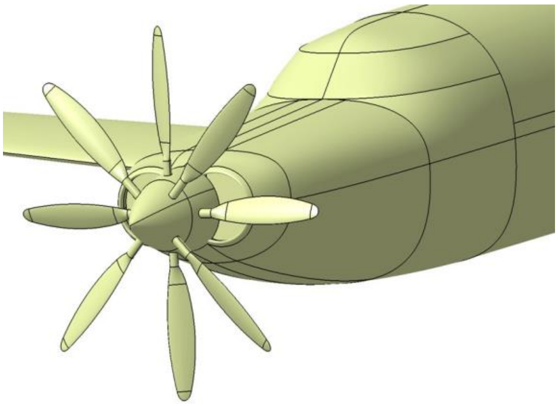


Landing gear is a retractable tricycle configuration, dictated by cruise performance at high speed (Fig.9). Each leg is fitted with oleo-pneumatic shock absorbers with a long travel trailing link arrangement preferred for rough field operations. For operation from airfields down to a California Bearing Ratio of 3, twin 6.50-10 tyres on nose gear leg at 60 psi and a single 9.25-12 tyre on each main gear leg at 40 psi are required. Amphibian and ski conversions are desired, the latter with the landing gear locked in its deployed position.

Fig. 9 Landing gear layout

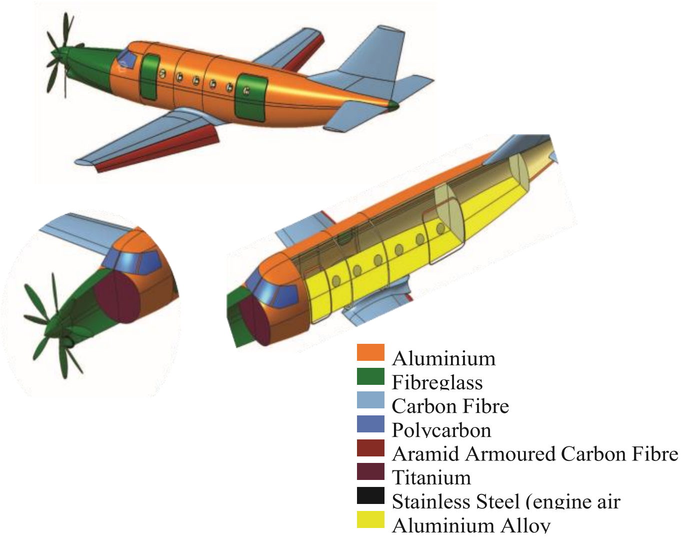
The aircraft is propelled by a single turboprop driving two, four bladed propellers, counter rotating on a common axis. The Counter Rotating Propeller (CRP) is considered an enabling technology which allows the low wing configuration to be adopted while maintaining sufficient ground clearance for rough field operations. The CRP is also critical for minimising the zone of the wing exposed to prop wash (and by extension unable to experience laminar flow). Additional benefits are also realised in lower fuselage drag and improved pitch and yaw response due to the reduction in the swirl component of the prop wash. Preliminary engine selection is the PW127H de-rated to 2400 shp. By concentrating power to a single engine, a larger engine, designed for commercial transports, can be employed. Such power plants often make use of triple spool technology and are significantly more efficient than their CS23 counterparts. Though this configuration of aircraft does not strictly fit within the current limits of the CS23 (which limits single engine aircraft to 9 passengers), the benefits of such an approach are significant enough not to ignore and are presented in detail in the study. An alternative configuration using a dual-pac system is also proposed (Fig. 10).

Fig. 10 Alternative twin-pac powerplant



A number of advanced materials were considered, as shown in Fig. 11, but final choice will be based on manufacturing and operating cost considerations.

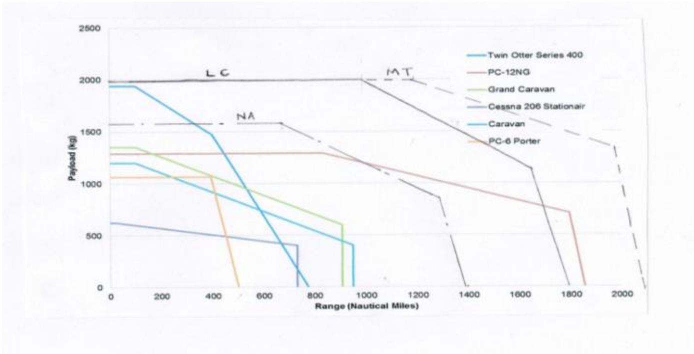
Fig. 11 Proposed material usage



The approximate flyaway cost is estimated to be 35% more than the Twin Otter and 32% more than a PC12. Given that a PC12 retails for approximately 4.5 million (USD, 2012), this puts the price of the concept aircraft at approximately $6 million.

6 Performance comparisons between MT, LC and NA, with current aircraft

Fig. 12 Payload range diagrams



Estimates have been made for the dimensions and field (or water) performance of the three concepts. These have been augmented by payload range predictions as shown in Fig. 12. These have been compared with similar parameters for current existing aircraft, using consistent methods. It can be seen that the new LC and MT concepts have distinct improvements over current aircraft in their payload-range performance. The NA amphibian has smaller benefits, but does have operational flexibility.

Table 3. Comparisons of aircraft leading performance characteristics

	Twin Otter	Beechcraft 1900D	PC-12	MT	LC	NA
MTOW k	5670	7688	4500	7300	8600	6690
Payload kg	1940	1984	1400	2000	2000	1600
Capacity	19	19	9 (1st class)	19	19	19
Max Cruise Speed knots	183	274	260	310	250	210
Landing Length m	320	844	560	746*	447	594 (on water)
Take off Length m	365	1140	700	240	380	465 (om water)
Ferry Range nm	989	1476	1660	2200	1820	1400
Price USD Mil 2013	4.6	4.99	3.3	6.0	4.5-5	4.85

* This figure would be improved on a future design iteration

7 Discussion

Table 3, above gives a summary of the main features of the competing aircraft. The payload – range improvements have already been noted, but the table also shows the speed benefits of the new designs. They also benefit from pressurized cabins, which will allow higher altitude, more comfortable flights. The amphibian can operate on either land or water, but has a rather more restricted range.

The estimated acquisition prices show that the low cost aircraft (LC) price is comparable to the older Twin Otter and Beech 1900D aircraft, but with greater capability.

The amphibian is more expensive, as one would expect, but is very flexible in operation.

The Modern Technology aircraft, has more design risks, reflected in its higher price, but it does exhibit superior performance in most aspects.

8 Conclusions

- The market for 19-seat bush aircraft is a small, but important one. Most current aircraft were designed decades ago, and the time is ripe for more modern aircraft.

- There are still some design issues to be solved for new amphibian (NA), such as hull design, nose-gear design and water spray. This is a multidisciplinary task for aircraft engineers and naval engineers. . The pressurised cabin, however, makes the aircraft able to operate as a regional aircraft for commercial routes.

-The manufacture of the NA aircraft will be predominantly of aluminium alloy. The choice of composite materials for the hull was disregarded due to the cost implications and potential damage, without composite repair facilities in remote regions. A similar choice was made for the low cost (LC) aircraft, but the Modern Technology (MT) aircraft would be hybrid metal/composite because of the performance benefits that would follow.

- The LC aircraft was of limited technical risk, but still offers significant advantages relative to current aircraft.

- Fuel burn penalties have largely been avoided for the MT aircraft due to the use of natural laminar flow, highly – loaded wings. Replacing two engines with one larger one allows a more advanced fuel-efficient turboprop engine to be used, together with mass and complexity reductions. Single – engine 19- seat Part 23 aircraft are not currently allowed, but advances in engine and airframe technologies and reliabilities should prompt changes to this ruling. An alternative twin – pac powerplant has been designed to be used, if this is not the case.

- With a cruise speed of more than 300 kts, the MT aircraft will lead the current class by a significant margin. The speed will ensure the aircraft will be competitive with executive jets in a similar way to the PC-12. This market is driven at least in part by prestige and image and in this regard, the counter rotating prop will ensure the concept stands apart. STOL will be appreciated by mining sector executives and the fuel burn will give the aircraft at least some ‘green’ credentials over immediate rivals.

- All three concepts are worthy of further study.

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