New Design Concept of Compound Helicopter

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Abstract: - The market trends in the design of helicopter have shown that in order to be competitive it is necessary to investigate new design approach which may give an expanding the flight envelope of rotorcraft, but must be shown to be cost-effective. The helicopter has carved a niche for itself as an efficient vertical take-off and landing aircraft, but have limitation on its cruising speed due to restrictions of retreating blade stall and advancing blade compressibility on the rotor in edgewise flight. This is a challenging task, which might be solved by the use of new design approach. It is believed that the application of a compound helicopter design concept would assist in achieving such a task. This work presents the feasibility study of a compound helicopter design concept, allowing for the use of a combined conventional fix-wing aircraft with single propeller in the nose and conventional helicopter to satisfy the above objectives. Description is then given of the concept proposed compound helicopter which incorporated combines main rotor-wing-auxiliary propeller. It concludes with a discussion of the results and recommendations for future work.

Key-Words: - compound helicopter, VTOL (vertical take-off and landing), high speed helicopter, aircraft design

1 Introduction

The first type of VTOL heavier than air aircraft was the helicopter, whish was conceived by Leonardo da Vinci but not regularly used until shortly after World War II. The Helicopter rapidly proved its worth for rescue operations and short-range point-to-point transportation, but its inherent speed and range limitations restricted its application.

VTOL refers to a capability for Vertical Take Off and landing, as opposed to Conventional Take Off and Landing (CTOL). An aircraft, which has the flexibility to perform either vertical or short take off landings, is said to have Vertical or Short Take off and Landing (VSTOL) capability. An aircraft that has insufficient lift for vertical flight at take off weight but which can land vertically at landing weight is called a Sort Take off and Vertical Landing (STOVL) [1].

The conventional helicopter is limited in forward flight performance by the aerodynamic lift and propulsion limitations of the main rotor. These rotor limits arise because of compressibility effects on the advancing blade, as well as stall on the retreating blade. In addition, the relatively high parasite drag of the rotor hub and other airframe component leads to relatively poor overall lift-to-drag ratio of the helicopter. This generally limits performance of conventional helicopters to level-flight cruise speeds in the range of 150 kts, with dash speeds up to 200 kts.

This paper presents the author work as Supervisor of configuration design (Indonesian Aerospace, IAe) when designing the compound helicopter for Arthur W. Loper company [2].

2 The Design Approach

The helicopter has carved a niche for itself as an efficient vertical take-off and landing aircraft. As with any aircraft, however, there is the continuing desire to expand the performance capabilities of the helicopter, particularly its speed. In the case of the helicopter, it is fundamentally limited in the maximum velocity obtainable though by the restrictions of retreating blade stall and advancing blade compressibility on the rotor in edgewise flight. This is created by the combination of the rotor's rotational velocity and the forward motion of the aircraft.

To achieve higher forward velocities alterations to the configuration of the helicopter, to alleviate the problems of retreating blade stall and compressibility effects on the advancing blade at high speed are necessary. One method used to achieve this is to rotate the rotor(s) forward to use them as propellers, while using a wing to provide the lift - the Tilt Rotor. A somewhat less radical solution is to modify the existing helicopter configuration, augmenting the rotor as a form of lift and thrust with the addition of a wing and an auxiliary propulsion source - creating the Compound Helicopter.

A wing increases in lifting effectiveness with increasing velocity, which complements the decreasing effectiveness of the rotor on a Compound Helicopter, off-loading its thrust requirements. The auxiliary thrust of a Compound Helicopter also off-loads the rotor of its thrust requirements, but more importantly eliminates the need for the aircraft to tilt forward in flight to supply a rearward component of rotor thrust. The reduction in rotor thrust therefore reduces the required rotor collective pitch and hence moves the boundaries of stall and compressibility to higher overall aircraft velocities. By keeping the large diameter rotor the compound helicopter also maintains the helicopters good hover and low speed maneuverability characteristics, unlike the tilt rotor aircraft. The combination of the rotor and wing also give the compound helicopter two sources of lift to call upon at high speed, so the aircraft has improved maneuverability over its conventional helicopter cousin. In addition the off-loading of the rotor reduces the main vibration induction at its source, much reduced levels of vibration being achievable, which should result in significant reductions in maintenance costs and crew fatigue. The Compound Helicopter has the advantage over the tilt rotor aircraft that it is a straight evolution of the conventional helicopter design and hence the technical difficulties should be less.

The addition of the wing adds weight and rotor wake blockage to the aircraft for the hovering portion of the flight, which can impact on the payload that can be lifted - critical for aircraft productivity. There is also the added complexity of the wing structure and the transmission or power supply for the auxiliary propulsion source. The Compound Helicopter designer also has to deal with the complexities of the interactions between the rotor, wing and stabilizer, which can severely affect the performance of the wing in particular if care is not taken. Hence, the Compound Helicopter designer's task is to minimize hover and payload penalties and the increase in complexity over the conventional helicopter, whilst also maximizing the cruising speed, maneuverability and range of the aircraft to give it a distinct advantage.

2.1 Requirement

The major objective of this compound helicopter design is to combine a conventional helicopter with a conventional propeller driven aircraft. This compound helicopter will have hover capability like and helicopter, and have cruise performance like a propeller driven aircraft. The hover capability and high speed in cruising condition is major requirement of the design.

The penalties of this design are increasing of empty weight, reduced of hover performance, transmission system to distribute the power from engine to rotor or propeller. To eliminate this penalties will used newest technology, like new material for structure, fly by wire system, efficient high lift device to reduce wing vertical drag, and new engine and transmission system.

2.2 Potential Mission

The potential mission of the compound helicopter is more like a conventional helicopter, but with addition in flight range and time to reach its destination. It can have mission as VIP aircraft, regular transportation used by airline, SAR/EMS even as a military transportation or war machine.

2.3 LCH Compound Helicopter Design Feature

- Maximum cruise speed : 250 knots
- Maximum range : 700 nm
- Cabin can accommodate 12 economic class passengers. Pressurized cabin to reach service ceiling of 25000 ft.
- Wing have high-deflected flap to reduce vertical drag during hover condition.
- Transmission system can transfer power from engine to main-rotor during hover and low speed flight condition and to propeller during cruise condition.

3 Technologies

To achieve the optimum design of this compound helicopter, several newest technologies will be applied.

3.1 Aerodynamics

The aerodynamics major problems that occur in compound helicopter design are wing blockage effect during hovering and main rotor drag during cruising. The best effort to eliminated wing blockage is rotate wing 90^o, but with complexity in structure mechanism and increase weight, so this concept not applied. In this design, to reduce the wing blockage during hover will be used high deflected flap (df = 80^o) and "umbrella" installed in wing leading edge. With this configuration, the vertical drag of wing reduces until 30%. Main rotor will auto gyrating during high speed cruising. to reduce main rotor drag will be used blade pitch control.

3.2 Structure

Compound helicopter has the empty weight heavier than pure helicopter because of installed wing, transmission system, and reinforced structure. The structure must be reinforced to accommodate transmission torque. The 3000 shp that transfer from powerplant to nose installed propeller make the under floor structure more complex and heavy. To reduce empty weight will used composite material to replace metal material in all possible places. Wing, front fuselage, aft fuselage, and empennage will use composite material. The possibility of using composite material in center fuselage is under calculation.

3.3 Propulsions

Because of additional drag, both of vertical and horizontal drag, this aircraft need more power compare to pure helicopter or conventional airplane. To reduce fuel consumption and increase cruise efficiency, will used newest engine that most efficient. Beside that, engine reliability also the critical problem, because of one engine out condition. This compound has a saver configuration compare to tilt rotor, because have auto rotate capability during all engine out, since its can landing safely.

New concept of transmission system that transmit power to main rotor, tail rotor, and propeller.

3.4 Systems

This compound helicopter will used fly by wire system. The system is used to make the pilot jobs easier, because of complexity of this aircraft transition mode from helicopter to airplane.

New concept of flight control system that accommodates helicopter mode and airplane mode control systems.

4 LCH Configurations

The LCH Compound Helicopter combined conventional fix-wing aircraft with single propeller in the nose and conventional helicopter. This configuration had chosen because of the difficulty and failure that occur on Tilt Rotor Configurations. Combine the conventional airplane and helicopter is making reasonable to have a possible and safe configurations.

This specification describes the Compound Helicopter with a twin-engine design for 12 passengers, 700 nm range, and 250 knots cruising.

General arrangement of LCH Compound Helicopter is shown in figure 1.

During cruise-flight conditions, the tractor type propeller would use approximately 70% of the power available under cruise condition to produce a cruising speed 250 kts, max speed would be approximately 275 kts. As the air speed increased from 150 kts to 250 kts the main/tail rotor speed is auto-gyrating to approximately 70% NR, while the wing and horizontal stabilizer would carry 70 % of the lift.

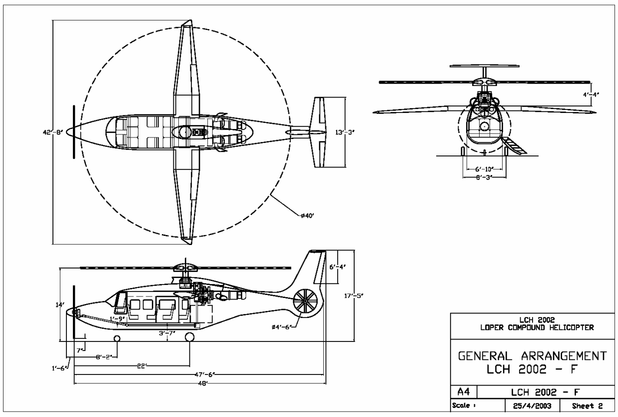

Figure 1. General arrangement of LCH Compound Helicopter

4.1 LCH Specifications

A. Dimension (external) :

Main rotor diameter	40 ft
Tail rotor diameter	4 ft 6 in
Length overall (w/o spinner)	48 ft
Height overall	18 ft 8 in
Wing span	42 ft 8 in
Wing aspect ratio	10
Tail plane span	13ft 3 in
Propeller diameter	10 ft
Propeller ground clearance	1 ft

B. Dimension (internal) :

Cabin: Length (excl. cockpit)	12 ft
Max width	6 ft
Max height	6 ft
Seats arrangement	3-2-3-3 abreast

C. Areas :

Wings, gross	161.5 sq ft
Vertical tail plane	31.7 sq ft
Horizontal tail plane	31.47 sq ft
Main rotor disc	1256 sq ft
Tail rotor disc	15.9 sq ft

D. Weights and loading :

Empty Weight	9000 lb
Max T.O weight	14000 lb
Useful Load	5000 lb
Max fuel weight	2600 lb

E. Performances :

Max speed (helicopter mode)	175 kts
Max cruising speed (helicopter mode)	160 kts
Max cruising speed (airplane mode)	250 kts
Max range (airplane mode)	700 nm
Service ceiling (airplane mode)	25000 ft
Hovering ceiling OGE	10000 ft

F. Powerplants :

PWC PT6C-67D twin or Rolls Royce twin pack CT800-50

4.2 Aerodynamics & Flight Control Systems

Wing will be carrying out 70 % lift during cruise condition. Beside the main rotor that carries out 30% lift while outogyrating. Cantilever high wing installed above cabin. Wing aspect ratio is 10 to reduce induced drag during cruise in high speed. Wing area is 161.5 sq ft. Wing incidence is 3 deg. to reach C_L required during cruise. This wing only designed for cruising condition, see Figure 2 and Table 1. Flap design based on the need of low vertical drag during hover condition, see Figure 3.

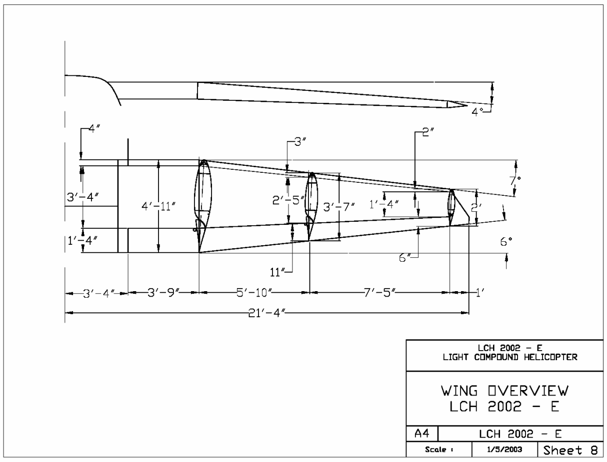

Figure 2. Wing Layout of LCH Compound Helicopter

Wing section is NACA 653-218. This aerofoil have aerodynamics characteristics :

- Low profile drag at trim c_l , (c_d = 0.007 at c_l = 0.4)
- High $c_{l\ max}$ = 1.5
- Gentle trailing edge stall characteristics
- Sufficient maximum thickness (18 percent) and favorable chord wise thickness distribution for structural efficiency and low weight.

	Wing.	Vertical Tail	Horizontal Tail
Area	161.5 ft^2	31.7 ft^2	31.47 ft^2
Span	42 ft 8 in	7 ft 3 in	13ft 3 in
Aspect ratio	10	1.66	5.6
Taper ratio	0.4	0.56	0.5
Root chord	4 ft 11 in	5 ft 7 in	3 ft 2 in
Tip chord	2 ft	3 ft 2 in	1 ft 7 in
M A C	3 ft 9.4in	4 ft 4.5 in	2 ft 2.5 in
Incidence angle	3°	0 °	0 °
Twist	0 °	0 °	0 °
Leading edge sweep angle	7 °	27°	9 °
Aerofoil	653-218	63A012	63A012
High Lift device	35.3%	25%	-
Max. HLD deflection	+80°	±25°	±25°

Table 1. Geometry characteristic of wing, vertical tail plane and horizontal tail plane.

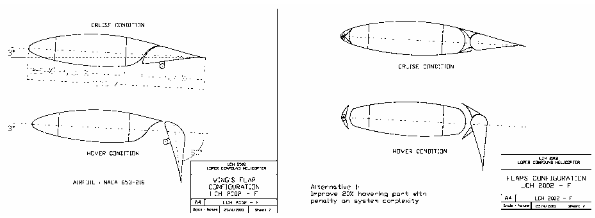

Figure 3. Two alternative of flaps configuration

During hover condition, there are two alternative of flaps configuration :

a. Wing with 35.3 % chord single slotted flap deflected 80 deg. This configuration will reduce

vertical drag 30% compare with bare wing. This configuration has simple mechanism to move flap.
b. Wing with leading edge flap and 30 % chord plain flap with "umbrella". This configuration will reduce drag 70 – 75% compare with bare wing. However, have penalty in complexity of mechanism.

4.3 Propulsion & Transmission System

The powerplant would either be Rolls Royce twin pack CT800-50, or Pratts & Whitney twin pack PT6C- 67D, located on aft-top of the fuselage, aft of the main rotor shaft. Engine air intake will be located on top left and right side above the engine fairings. Exhaust will be located on left and right side of the engine.

Propeller is the state-of-the-art, 10 feet diameter, 6 composite blades, slightly forward of the main rotor blade tip to prevent contact under high flap angles.

The fuel tank with capacity of 2600 lbs is placed well behind the cabin.

In order to optimize the CG distributions, as well as the powerplant and drive train compactness, the vertical shaft is located behind the cabin compartment, this also eliminate any obstruction in the cabin.

The Drive Train system that transfers power from powerplant to propeller, main rotor and tail rotor is shown in figure 4.

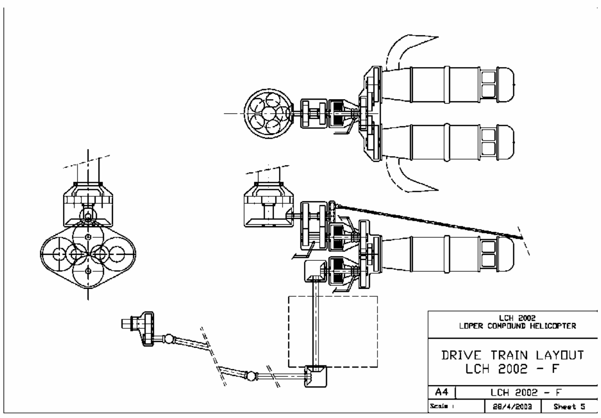

Figure 4. Powerplant and transmission system

5 Discussion

Probably the most critical subject on designing this compound helicopter are the complexity of this aircraft transition mode from helicopter to airplane mode and to define/develop a new concept of flight control system that accommodates helicopter mode and airplane mode control systems.

6 Conclusion

A new design approach has been developed for the design of compound helicopter, allowing for the helicopter to cruise at higher speed.

The conclusion can be drawn, that the compound Helicopters concepts is feasible for a transport aircraft from aerodynamic and configuration point of view, with the reservations that the economic and safety aspects depend on aerodynamic, performance and operational data.

Before the compound Helicopters can be used as a transport aircraft, a large multidisciplinary research effort is needed in order to master the concept and demonstrate it as flying test-beds and in-service operational tests.

Acknowledgement

This work was carried out with the excellent team work of the LCH 2002 group of Indonesian Aerospace (IAe) at Bandung, West Java, INDONESIA and support from Loper Company.

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