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CONCEPTUAL DESIGN OF AN AMPHIBIOUS VEHICLE: VECTOR

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ABSTRACT

This work is to present conceptual design of an amphibious vehicle named "VECTOR" that has great high-speed and long range capabilities. The vehicle is designed to carry up to 50+ personnel or 14 tons of payloads in a range of 1800 km at nominal speed of 360 km/h. The VECTOR not only possesses pros of current helicopter technology, that is, efficient vertical flight and hover capability, but also is capable to take-off/land on water, land, grass, and other relatively flat surfaces. It also introduces a brand new concept of fuselage and chassis design. Tilt rotor continues to be the best candidate for diverse field and rescue operations. All the important aspects, including material, power, propulsion systems, aerodynamics and stability are thoroughly studied and analyzed. Capabilities of the VECTOR can fulfill the ever-expanding civil requirements and contribute to the current search and rescue teams in any part of the world.

Keywords: VECTOR, helicopter, tilt rotor, propulsion, aerodynamics, stability.

1. INTRODUCTION

In contrast to fixed-wing aircraft, helicopter is a type of rotorcraft which is arguably the most versatile aircraft today, capable of vertical, horizontal, and stationary flight [1, 2]. The helicopter and its versatility have shown superiority in transportation, construction, firefighting, search and rescue, and military uses [3, 4, 5]. Helicopters have many pros but speed is not one of them. In a moving helicopter, the speed of the blades relative to the air depends on both speed of the helicopter and blade rotational velocity. The airspeed of the advancing rotor blade is much higher than that of the helicopter itself. It is possible for the blade to exceed the speed of sound, and thus produce vastly increased drag and vibration. At the same time, the retreating blade experiences high angle of attack and may stall [6]. The current design aims to improve the effectiveness of rotorcraft to meet civil needs, responding more quickly, rescuing more people, and being able to operate on water, with high speed and long range [7, 8].

A vector is what is needed to "carry" the point A to the point B; the Latin word vector means "one who carries". This is the essence of the design. So, the project is named after VECTOR. In this paper, construction of the vehicle and its subsystems was described first; then, Material and aerodynamics of the vehicle were analyzed; stabilities on water and in air were evaluated; a conclusion was drawn finally. The conceptual design will serve to expand and improve the capabilities and civil benefits of rotorcraft.

2. IDEA AND CONSTRUCTION

Figure-1 shows the specific resistance of air vehicles based on Von Karman's definition [9, 10]. Few helicopters can cruise faster than 100 m/s, which are attributed to the way it works. Some seaplanes can reach a high cruise speed. Amphibious helicopters can takeoff and landing on water, but can not operates on water. Seaplanes don't posses capacity of vertical takeoff and landing. There is a need to design a vehicle which can operate on water and in air and is able to vertical takeoff and landing. Compared with wing-based crafts, tilt rotors are the best candidates for design of a high speed amphibious vehicle [11]. Another unique feature is that self-lifting fuselage is used. The body has airfoil-shaped section so as to provide good aerodynamics. The VECTOR has characteristics of both airplane and helicopter. In Cruise, it is more like an airplane what ensures perfect aerodynamics and sufficient efficiency. Horizontal tail and vertical tail were also used to further improve stability. The design introduces ducted nozzles with contra-rotating propellers resulting in high performance and low induced energy loss [12]. Searchlights attached on the front make looking for people easier and fluorescent orange coating body ensures great visibility of the vehicle during rescue operations. The 3D model is shown in Figure-2.

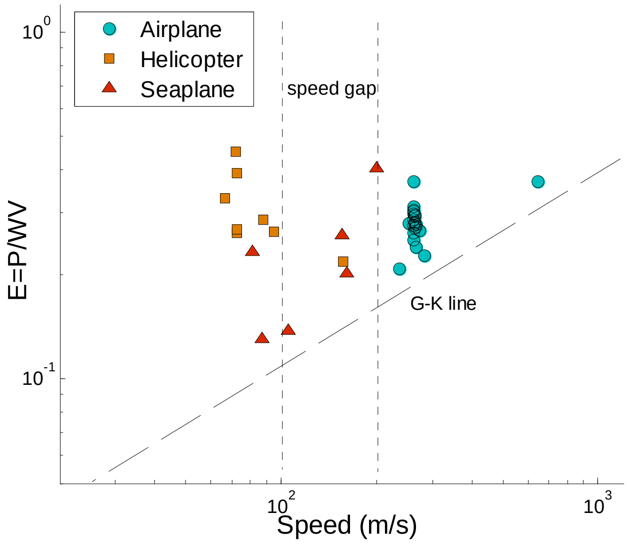

Figure-1. Air vehicle transport efficiency.

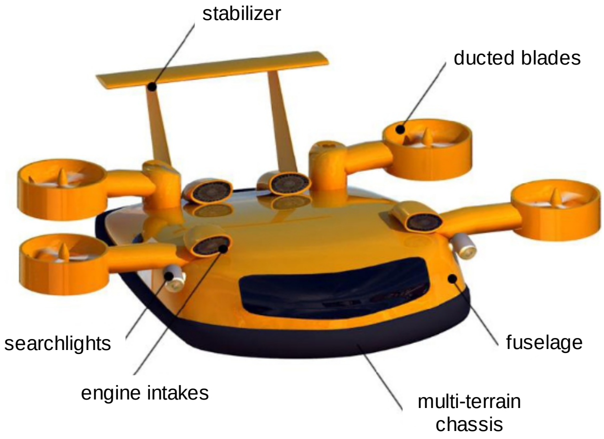

Figure-2. 3D presentation of the VECTOR.

Main characteristics

Crew: two (pilot, copilot)
Capacity: 50 passengers or 14 tons cargo
Length: 12 m
Width without blades: 8 m
Height: 2.5 m
Disc area: 4 × 2.7 m²
Body area: 96 m² (top view)
Empty weight: 11 ton
Inside payload: 14 ton
Max takeoff weight: 30 tons
Powerplant: 4 × Honeywell's T55 engine, 4 × 3,631 kW [13]

Performance

Maximum speed: 400 km/h
Cruise speed: 360 km/h at sea level
Power/mass: 484 kW/ ton
Range: 1800 km

Material

Material selection is a very important part of the whole design. A vehicle used for rescue missions has to be able to work in various, possibly hazardous conditions (high temperature or moisture). To make sure the vehicle is safe and reliable, it needs to be constructed using carefully chosen and well tested materials.

The composites are used for vast majority of the construction, particularly CRP (Carbon fiber-Reinforced Plastics) and FRP (Fiberglass Reinforced Plastics). Comparing to widely used aluminum, composites have stronger structure, are lighter, cheaper, faster and easier to manufacture. Moreover, they have already been field-tested. Composites have proven to be highly successful in the field of aeronautics numerous of times and much of the fuselage of aircrafts like Boeing 787 Dreamliner or Airbus A350 XWB is made of them [14, 15]. FRP and CRP are corrosion resistant which is great for a vehicle that's going to have much contact with water.

3. AERODYNAMICS OF VECTOR

The aerodynamics of VECTOR was estimated by using Computational Fluid Dynamics method (CFD) on basis of simplified model. The simplified model is shown in Figure-3. Nozzles were omitted in CFD study, No propulsion system was employed into the numerical simulations. The numerical simulations were conducted at a Reynolds number of 6×10^7 based on the chord length (body length). The use of computational fluid dynamics codes to simulate the flow around geometrically complicated shapes such as airplanes, cars and ships has become standard engineering practice in the last few years. A number of commercially available codes can be used to perform these studies. The finite volume codes FLUENT [16, 17] was employed in the present study. It has been performing well in aerodynamic prediction for craft [18]. The aerodynamics is shown in Figure-4. The pitch moment is in respect to 1/4 of the chord (for the body).

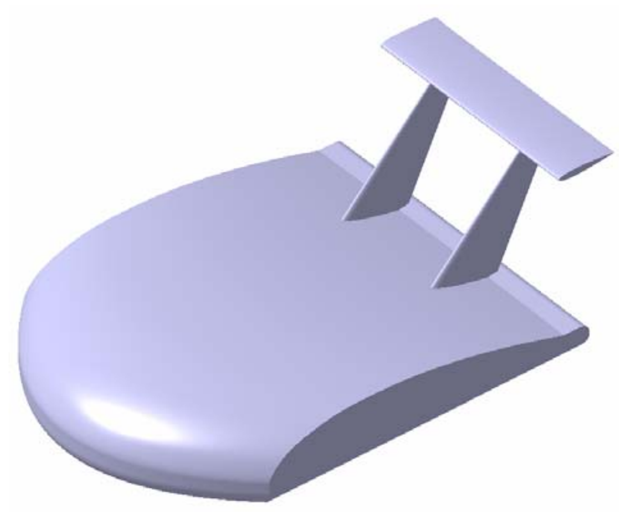

Figure-3. Simplified model.

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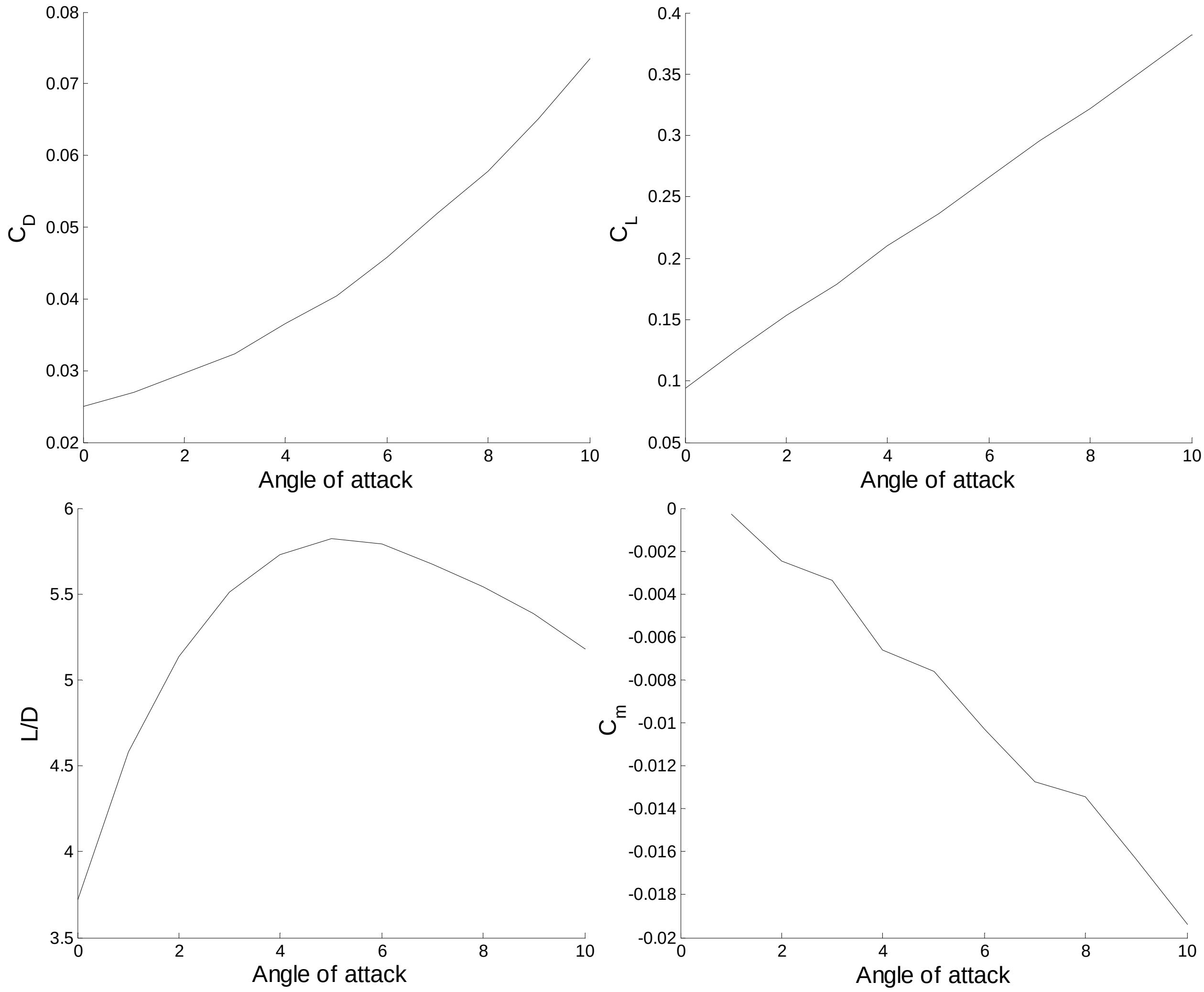

Figure-4. Aerodynamics of VECTOR.

4. STABILITY

On water

There are in fact two Metacentric heights of a ship, one for Rolling and the other for Pitching. The former will always be less than the latter and unless otherwise stated, the Metacentric given will be for Rolling. The essence of stability calculations is finding the force couple between buoyancy and weight [19, 20]. This is the moment of force which a stable ship develops to counteract the overturning moments arising from external forces. From the configuration of the body, KB = 0.16 m, KG = 1.0 m. Then, GM = 16.2 m. The VECTOR has positive stability for the meta center is above the center of gravity (Figure-5).

Stability curves (GZ curves) are used to show graphically the stability levers (GZ) exerted by a vessel to return itself to a position of equilibrium from the various conditions of heel. Figure-6 shows the typical stability curves. The blades of VECTOR should not kiss water, so the heel angle is no more than 12 degrees for rolling motion. It is indicated that the VECTOR can only float on calm water.

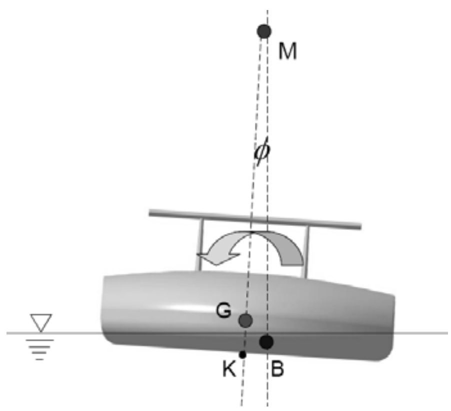

Figure-5. Ship roll motion.

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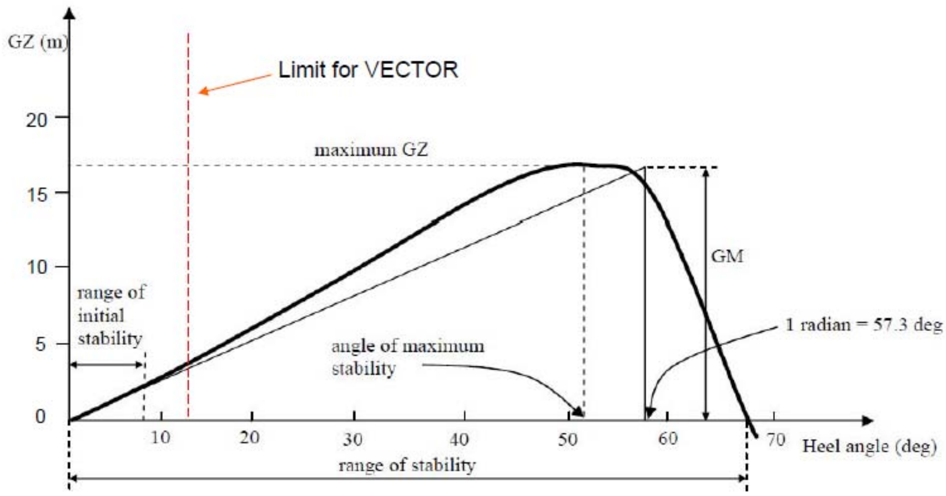

Figure-6. Typical stability curves.

In cruise

Static longitudinal stability

Longitudinal static stability is the stability of an aircraft in the longitudinal, or pitching, plane during static (established) conditions. This characteristic is important in determining whether an aircraft will be able to fly as intended. The stability axes are shown in Figure-7.

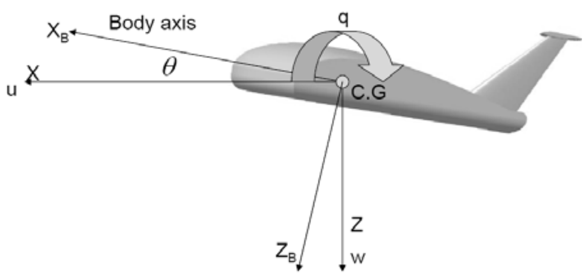

Figure-7. Stability axes and body axes.

If an aircraft is longitudinally stable, a small increase in angle of attack will cause the pitching moment on the aircraft to change so that the angle of attack decreases. Similarly, a small decrease in angle of attack will cause the pitching moment to change so that the angle of attack increases [21]. That is,

$C_{m,\alpha} < 0$

Obviously, the VECTOR is statically stable.

Longitudinal dynamics

Newton's second law requires that the sum of all external forces acting on the aircraft be equal to the time derivative of its momentum. To simplify the analysis, the Newtonian vector equations are recast in scalar form consisting of 3 force and 3 moment equations. Due to the complexity of the non linear EOM, it becomes necessary to linearize the equations. The linearization is based on perturbation theory with the assumption that the aircraft is flying in an equilibrium condition [22].

The linearization yields a set of first order Linear Time Invariant (LTI) differential equations with constant coefficients. The LTI are only valid over a narrow range of flight conditions. The constant coefficients reflect the aerodynamic stability derivatives, control derivatives, mass and inertia of the aircraft. These in turn embody the flight condition parameters, control inputs, and geometric characteristics of the aircraft.

RESULTS

Short Period

$\zeta_{sp} = 0.692$

$\omega_{sp} = 3.2347$ rad/s

Phugoid

$\zeta_{ph} = 0.1221$

$\omega_{ph} = 0.0867$ rad/s

Eigenvalues are:

-2.2384±2.3351i, -0.0106±0.0861i

The VECTOR is a passenger carrying one, so it should be designed to satisfy the flying quality of Level I at the cruising conditions. Level I requirements for MIL-F-8785C and MIL-STD-1797A are given in Table-1.

Table-1. Level I requirements for MIL-F-8785C and MIL-STD-1797A.

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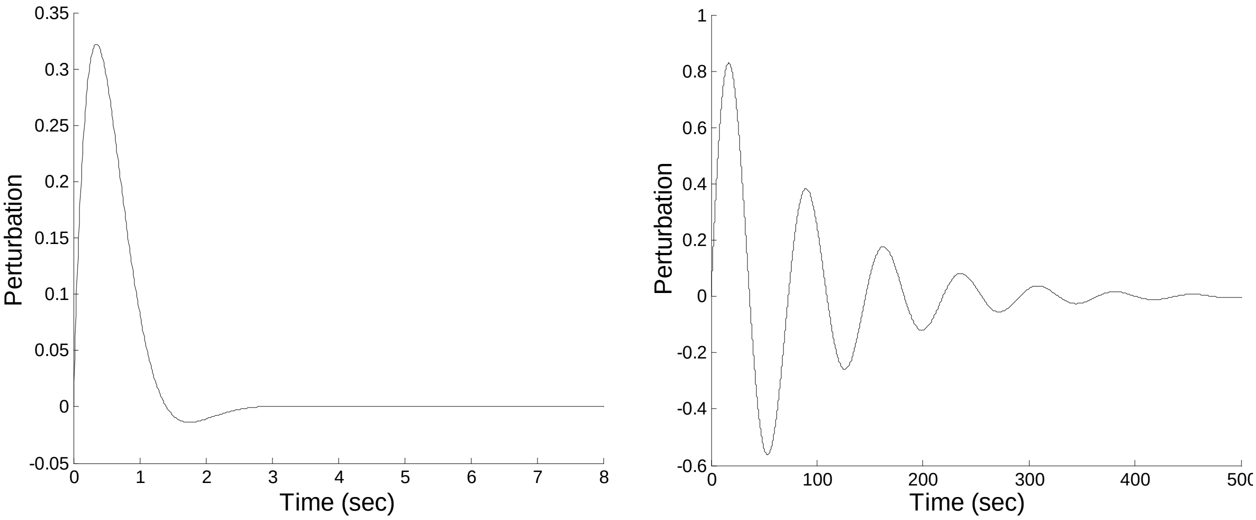
Phugoid damping requirements	$\zeta_{ph} \geq 0.04$
Short period damping ratio limits	$0.35 \leq \zeta_{sp} \leq 1.30$
Short period undamped natural frequency	$0.28 \leq \frac{\omega_{sp}^2}{n_\alpha} \leq 3.6$
	Note $\frac{\omega_{sp}^2}{n_\alpha}$: CAP (Control Anticipation Factor)



(a) Short Period (b) Phugoid

Figure-8. VECTOR cruise open loop response.

The handling quality criterion presented here is base on the research presented by O'Hara [23]. The flying qualities when a pilot experiences when hand flying the craft depends very much on the damping ratio and natural frequency of the short period response. It is indicated that the vehicle has satisfactory handing qualities. The control anticipation factor (CAP) also satisfies Level I requirements. The time responses are shown in Figure-8. The perturbed quantity is the dimensionless pitch motion.

5. CONCLUSIONS

The increasing demand for more efficient vehicle in rescue, transportation and search promotes the design of VECTOR. Next-gen configuration, materials and advanced rotary technologies were applied into the design. Capabilities of VECTOR can fulfill the expanding civil requirements in any place of the world.

A concept of self-lifting was introduced into fuselage design. Large and airfoil-shaped body provides not only the lift, with which 30 ton weight is hovered, but also on-water and in-air stability and spacious cabin for the passengers. Ducted propellers take the place of open propellers considering harsh operating conditions, such as cruise approaching the ocean surface in very high speed. Tail as stabilizer like in a conventional airplane shows good performance for stability of the VECTOR. As the VECTOR behaves like an airplane in cruise, control of flight could be based on sophisticated control strategy of the airplane. The VECTOR is supposed to meet the needs of efficiency, productivity, versatility and to ensure that life and safety comes first.

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