Take off simulation and analysis of aircraft with twin floats

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Abstract. Amphibious aircraft is a multi-function aircraft which can be operated on land and water. This type of aircraft helps transportation sector due to its ability to reach remote areas. Indonesia as the largest archipelago in the world has problems in connecting remote areas. Land transportations and conventional aircraft have difficulties to reach remote areas due to lack of facility. Hence, small aircraft capable of operating on land or water with take off and landing distance less than 1000 m are required. This study conducted take off simulation and analysis for DHC-6 Twin Otter Series 400 equipped with twin float. It tries to propose a simpler method to initiate the analysis of take of performance for float planes with limited data constraints. Several programs were used to generate required data, such as DatCom and SolidWorks. Float plane take-off simulation used in this research utilized Gudmundsson’s method. Results showed that the method is suitable and correctly produce take off distance and time similar to those of the real aircraft. Aircraft weight and thrust affect take-off distance and required time, as well as hydrodynamic forces produced. Reduction of weight 10% reduces the distance approximately 17%, while 10% thrust reduction increases take off distance about 15%. In the future this research will be expanded to include other float shapes and sizes, as well as flying boats.

Keywords: take off, twin floats, simulation, DHC-6 Twin Otter

1. Introduction

Indonesian Aerospace Industries (PT. DI) is currently developing a 19 passenger turboprop aircraft. As requirements increase, this aircraft is then developed to fulfil the need of float planes in eastern Indonesian area. The development was performed by simply replacing landing gears with two floats to enable it to take off and land on the water.

Just like any other aircraft, comprehensive analysis is required to assess the performance of this new flying vehicle. Especially for float plane, take off performance analysis is more challenging because of the involvement of water characteristics in the process. Water tunnel testing is also required, in addition to thorough wind tunnel testing. These tests will take a lot of time and money. This paper tries to propose a simpler method to initiate the analysis of take of performance with limited data constraints such as those usually encountered in the beginning of such research.

Gudmundsson’s method [1] is recently used in more and more research related to amphibian aircraft design and analysis, such as in [2]. This method is used as the baseline simulation algorithm in this research. Aircraft modelled in this study is the de Haviland Canada DHC-6 Twin Otter which is very similar to PT. DI’s aircraft in terms of size and configurations. Simulation were performed for three
values of aircraft weight and two throttle settings. Results were then analyzed to check for consistency and accuracy of the method compared to available trusted data.

2. Materials and Methods
This chapter describes the float components of float plane, float plane in take-off maneuver, aerodynamic forces, water forces and aircraft data for simulation.

2.1 Floatplane in Take off
Typical floatplane is given in Figure 1. Floatplanes are conventional landplanes that have been fitted with separate floats or pontoons in place of the wheels. The de Havilland Canada DHC-6 Twin Otter is an example of twin-float plane used widely around the world.

Figure 1. DHC-6 Twin Otter float plane [www.airplane-pictures.net]

Float components are shown in Figure 2. A keel along the bottom center guides the float in a straight line through the water and resists sideways motion. The keel under the front portion is intended to bear the weight of the floatplane when it is on dry land. A step in the middle of the float reduces water drag during take off and high-speed taxi. The step is located slightly behind the center of gravity, approximately at the point where the main wheels are located on a landplane with tricycle gear. The sharp break along the underside of the float concentrates structural stress into this area, and the disruption in airflow produces considerable drag in flight. Without a step, the flow of water aft along the float would tend to remain attached all the way to the rear of the float, creating unnecessary drag. Skeg located behind the step makes it more difficult to tip the floatplane backward when it is on land. Chine guides the water out and away from float, reduces spray and increases hydrodynamic lift. Two sister keelsons add strength to the structure and also function as additional keels. The front of float has a rubber bumper to cushion minor impacts with docks, etc. Spray rails along inboard forward portions of chines reduce the amount of spray hitting the propeller [3].

Figure 2. Float components [3]
For light propeller-driven airplanes take off can be defined as the maneuver by which the airplane is accelerated from rest to climb out speed $V_c$ over a 50 ft obstacle [4]. Floatplane take off maneuver can be divided into four distinct phases, i.e. displacement, plowing, planing and lift off phases [3].

**Figure 3.** Displacement phase.  **Figure 4.** Plowing phase.  **Figure 5.** Planing phase.

When taxying at low RPM, floatplane will be in displacement condition similar to being at rest on the water (Figure 3). In this phase the floats support the weight of the airplane through buoyancy where they displace a weight of water equal to the weight of the airplane.

When the power is increased, the floatplane will be in nose-up or plowing position (Figure 4). In this phase pilot holds elevator control in full aft position. Aerodynamic and hydrodynamic lift begins to support a certain amount of the weight, while the rest is still supported by buoyancy. Hydrodynamic lift increases with speed, but hydrodynamic drag increases more quickly.

Accelerating the aircraft faster makes it passes through the hump speed where the water drag is maximum. To minimize water drag, pilot relaxes elevator back pressure, thus allowing the seaplane to assume a pitch attitude that brings the aft parts of the floats out of the water. The step makes this possible. The floats are now riding the water in a level position on the step (Figure 5). Higher speed will increase aerodynamic lift, while hydrodynamic lift will decrease as the float displacement lowers. When running on the step, a small part of the front float supports the seaplane.

Lift off phase transfers support from floats to wings by applying back elevator pressure. The seaplane will lift off the water and become airborne. To avoid porpoising, proper pitch angles need to be maintained. Too much back elevator pressure will force the aft part of the floats to dive deeper into the water and retard the take off. On the contrary, insufficient back elevator pressure will cause the front part of the floats to remain in the water and result in excessive water drag.

### 2.2 Aerodynamic forces

Aerodynamic forces acting on aircraft are lift and drag. These forces will depend on the air density, airspeed, as well as the shape and configuration of wing, fuselage, etc. Equations for lift and drag forces are as follows [4]:

$$L = \frac{1}{2} \rho V^2 S C_L$$

$$D = \frac{1}{2} \rho V^2 S C_D$$

where $\rho$ is air density, $S$ is aircraft wing area, $V$ is aircraft airspeed, $C_L$ is lift coefficient and $C_D$ is drag coefficient. Values of aircraft’s $C_L$ and $C_D$ as function of angle of attack, airspeed and aircraft configurations can be predicted using software such as DatCom or AAA.

### 2.3 Water forces

Two water forces acting on floats are also lift and drag. Water lift is generated from buoyancy (hydrostatic) and movement of float above the water (hydrodynamic force). Buoyancy or displacement $\Delta$ is experienced by any object immersed in a fluid and equals to the weight of the displaced fluid [1]:

$$\Delta = \rho_w g V$$
where \( \rho_w \) is the water density, \( g \) is the gravitational acceleration and \( \nabla \) is the volume of displaced fluid. The \( \nabla \) value as function of the depth of float immersion or draft can be calculated using SolidWorks.

Hydrodynamic lift can be formulated similar to equation (1). However, the development of water lift coefficient will be very complicated since it involves various factors such as the float shape, angle of attack, air-water interaction, etc. Prediction of this lift coefficient should use methods such as computational fluid dynamics or water tunnel models. Furthermore, since the water density is approximately one thousand times the air density, water lift will quickly build up as the speed increases. This water lift can overcome aircraft weight, while actually the aerodynamic lift is not yet ready to support the weight. This condition will lead to porpoising phenomenon in which the airplane is thrown several times to the air by the water. Actual take off of floatplanes is such that the transition from full water support to full air support can be performed smoothly. This can be achieved when the take off maneuvers are performed such that the lift of water can be maintained as small as possible, so that only the aerodynamic lift and buoyancy support the weight of aircraft. Transition from floating to flying occurs only by an exchange between the two forces. This approach will be used in this simulation.

In [1] it is assumed that the water drag can be represented by water resistance and Froude resistance. Water resistance depends on the design and shape of the float, water density and speed. Typical example of water resistance from NACA tank test is given in Figure 6 for two types of float. Water resistance will increase from zero at rest to maximum at hump speed. It will then decrease to zero again at lift-off speed when aircraft move from plowing to planing attitude.

![Figure 6. Typical values of resistance coefficient as function of speed coefficient [5]](image)

Based on such experiments, water resistance \( R_w \) can be calculated as follows [1]:

\[
R_w = C_R \frac{\Delta}{C_{d0}}
\]  

(4)

where \( C_R \) is water resistance coefficient and \( C_{d0} \) is displacement coefficient at zero speed. The speed coefficient \( C_V \) is defined as:

\[
C_V = V (g B)^{-\frac{1}{2}}
\]  

(5)

Froude or hydroplanning resistance depends on immersed area and type of float, as well as water speed. As the name implies, this resistance is taken into account when hydroplanning occurs and the float is getting on the step, i.e. from hump speed to lift-off speed. This force can be formulated as [1]:

\[
R_F = f S_{wet} V^n
\]  

(6)
where \( f \) is coefficient of frictional resistance, \( S_{wet} \) is wetted area of the float and \( n \) is a constant which depend on surface quality. The \( f \) coefficient varies depending on surface quality, but values between 0.012 – 0.010 can be applied for smooth surfaces such as floats. The \( n \) value of 2 is accurate enough for most applications.

2.4 Data for Aircraft Simulation Model
General configuration for DHC-6 Twin Otter amphibian is given in Figure 7. It is a high-wing, twin-turboprop aircraft with twin float and retractable landing gears. The floats do not have water rudder.

Table 1 shows some key data for the aircraft. The first 4 data are used in simulation, while the last 3 are used to compare the results.

| Data                        | Value | Unit |
|-----------------------------|-------|------|
| engine power                | 750   | shp  |
| engine efficiency           | 0.85  | -    |
| specific fuel consumption   | 0.06  | kg/s |
| wing area                   | 39    | m²   |
| take off distance to 50ft   | 599   | m    |
| \( V_{LOF} \)               | 35.8  | m/s  |
| \( V_2 \)                   | 41.15 | m/s  |

2.5 Aircraft Modeling in DatCom
Figure 8 shows the modeling of Twin Otter and its float in DatCom.

Typical result from DatCom is shown in Table 2. DatCom is capable of estimating values of aerodynamic lift and drag coefficients as function of aircraft angle of attack, airspeed, altitude and
aircraft configurations. Such values are used to compose aerodynamic database to calculate aerodynamic lift and drag in simulation.

### Table 2. Example of aerodynamic coefficients [7].

| Flap deflections [°] | C_L | C_D |
|----------------------|-----|-----|
| 0                    | 0.317 | 0.0270 |
| 10                   | 0.446 | 0.0290 |
| 15                   | 0.497 | 0.0300 |
| 20                   | 0.540 | 0.0320 |
| 25                   | 0.579 | 0.0350 |
| 30                   | 0.614 | 0.0390 |
| 37                   | 0.647 | 0.0440 |

#### 2.6 Float Modeling

Based on [1] the resistance coefficient of the float can be expressed as:

\[
C_R = 0.0011 C_V^3 - 0.0221 C_V^2 + 0.1062 C_V - 0.0149
\]  

(7)

However, in this case care must be taken, so that C_R values are always positive. Depending on the type of float, water tunnel result such as [5] can also be employed.

SolidWorks software is then used to model the floats as represented in Figure 9.

![Figure 9. Modeling twin floats in SolidWorks [7].](image)

Based on SolidWorks result, the draft d in [m] and wetted area S_wet in [m^2] of the float are then formulated as functions of displacement \( \Delta \):

\[
d = -1 \times 10^{-9} \Delta^2 + 6 \times 10^{-5} \Delta
\]  

and

\[
S_{\text{wet}} = -6 \times 10^{-9} \Delta^2 + 8 \times 10^{-4} \Delta
\]  

(9)
2.7 Engine Modeling
Using equation in [8] the maximum thrust obtained from the two engines can be estimated to be 13.8 kN. Variation of engine thrust with airspeed can also be modeled using approach described in [9]:

$$T = T_s \left(1 - 0.96(M_0 - 0.1)^{1/4}\right)$$

where $T_s$ is the maximum static thrust. Note that equation (10) is only valid for Mach number $M_0$ higher than 0.1.

2.8 Simulation
The take-off simulation algorithm as described in [1] can be summarized in Figure 10. Unique characteristics for float planes in take off is shown in the presence of buoyancy, water and Froude resistance calculation. Take-off simulation was started with the aircraft at maximum take-off weight where pilot apply full thrust for take-off until the obstacle height of 50 ft was achieved.

The aircraft weight is then varied to 90% MTOW and 80% MTOW. The last value of weight represents flight condition with 2 crews and some amount of fuel. Engine thrust is also varied at 100% and 80% of its maximum value.

3. Result and Discussions

3.1 Effect of Weight on Take-off Performance
Twin Otter’s take-off performance for various values of weight is shown in Table 3. From this table it is clear that Gudmundsson method is consistent in estimating the take off distance and time. The heavier the aircraft, the longer the distance and time required to achieve obstacle height, as well as other variables. Heavier weight requires higher lift-off speed and $V_2$. Heavier aircraft will also result in higher water and Froude resistance, since the floats will be immersed deeper in the water. The resulted values of take off distance, lift-off speed and $V_2$ shown in this table are quite close to those in Table 1.

| Variables | Unit | MTOW | 0.9 MTOW | 0.8 MTOW |
|-----------|------|------|----------|----------|
| Distance  | m    | 603  | 494      | 399      |
| Time      | s    | 24.5 | 20.8     | 17.5     |
| $V_{LOF}$ | m/s  | 36.3 | 35.3     | 33.8     |
| $V_2$     | m/s  | 42.1 | 41.0     | 40.3     |
| $R_w$ max | N    | 2767 | 2649     | 2507     |
| $R_F$ max | N    | 347  | 287      | 232      |

Figure 10. Flowchart for float plane take-off simulation.
3.2 Effect of Thrust on Take-off Performance

Take-off performance of Twin Otter for two values of thrust is given in Table 4. The table shows that the method gives consistent simulation results. The higher thrust applied, the shorter take off distance and time required to clear the obstacle. Other variables are also consistent with previous results. Lift-off speed almost unaffected by thrust, since it is very much dependent on the aerodynamic lift. \( V_2 \) will be lower for lower thrust, since the aircraft flies slower. Slower speeds also give higher water resistance since more amount of water will be plowed in front of the floats.

| Variables    | Unit | 100% thrust | 80% thrust |
|--------------|------|-------------|------------|
| Distance     | m    | 603         | 789        |
| Time         | s    | 24.5        | 32.5       |
| \( V_{LOF} \) | m/s  | 36.3        | 36.8       |
| \( V_2 \)    | m/s  | 42.1        | 40.9       |
| \( R_w \) max| N    | 2767        | 2824       |
| \( R_F \) max| N    | 347         | 347        |

3.3. Take-off Distance of Other Float Planes

Comparison of take-off distances for 5 float planes is shown in Table 5 assorted according to their weight. Smaller float planes tend to need longer distances since they have smaller and less powerful engine with lower power loading.

| Aircraft type                        | Weight [kg] | Power [hp] | Power loading [kg/hp] | Take off distance [m] |
|--------------------------------------|-------------|------------|-----------------------|-----------------------|
| DHC-6 Twin Otter \(^6\)              | 5670        | 620        | 9.1                   | 599                   |
| DHC-6 Twin Otter simulation          | 5670        | 620        | 9.1                   | 603                   |
| Cessna Grand Caravan \(^{10}\)       | 4110        | 867        | 4.7                   | 610                   |
| DHC-2 Turbo Beaver \(^{11}\)         | 2721        | 680        | 4.0                   | 635                   |
| Airshark \(^{12}\)                   | 1598        | 300        | 5.3                   | 610                   |
| Cessna 172 \(^{13}\)                 | 1007        | 160        | 6.3                   | 658                   |

4. Conclusions

Gudmundsson method is suitable to be used as simple scheme to analyze take-off performance of float planes. It can be applied for take off analysis of other float planes in early design phase. However, to obtain accurate results the simulation still need to be supplied with correct data particularly for float used. Weight of aircraft affects the take-off distance and time, as well as water resistance produced. Reduction of weight by 10% will result in decrease of distance approximately 17% and time about 15%. Thrust also affects take-off distance and time. Thrust reduction of 10% gives approximately 15% longer distance and about 16% more time to reach obstacle height. Smaller float planes tend to need longer distances since they have smaller and less powerful engine with lower power loading. In the future this research will be expanded to include other float designs, configurations and sizes, as well as flying boats.

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