Analysis and Conceptual Design of a Novel MAV Rotorcraft

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Abstract

This paper examines the development of an analysis package for use within the design process of small coaxial MAV rotorcraft. The analysis tool has been formulated to analyse the rotor dynamics and performance of a Proxflyer type rotorcraft. The analysis tool has been benchmarked against the base Proxflyer vehicle, and is therefore suitable for use with this platform type. Subsequently, a new platform configuration has been proposed which will provide better stability and controllability. The new design utilises the base elements of the original platform as well as a novel flapping feedback mechanism. This mechanism allows conventional rotor control as well as the Proxflyer rotor flapping. And in turn provides a much better method for controlling this platform type. Due to the flexibility of the design tool and the general design concept any sized platform can be designed.

Symbols

B - number of rotor blades
c - chord of blade section
C_L - coefficient of lift
C_D - coefficient of drag
dT - elemental thrust component
F, f - Prandtl Tip Loss Factor
J - rotational moment of inertia
M - moment about rotor hub
r - radial location
V_H - horizontal velocity component
V_V - horizontal velocity component
W - resultant section velocity
α - angle of attack
ϕ - inflow angle
θ - geometric angle
β - flap angle
υ - induced velocity
ρ - air density
Ω - rotor rotational velocity
ψ - rotor azimuth location

Introduction

Unmanned Aerial Vehicles (UAVs) are a much preferred choice where a pilot would be placed in danger, or the length of the mission would strain the pilot both physically and mentally. Removing the requirement of a pilot from the design process places the emphasis on carrying out the mission rather than protecting the pilot. Although this reasoning only applies for larger aircraft, the use of UAVs in smaller application has always been a natural choice.

Use of UAVs has now been well bedded within the aircraft industry for both large and small craft[1], such as the Global Hawk or Predator. However UAV design has reached a point by which only small performance gains can be made redevelopment of conventional aircraft designs. Now the focus of UAV development must be firmly placed on optimising existing designs, as with manned aircraft, as well as developing novel platform concepts.

One area in which the development of novel platform concepts has developed quickly is within smaller Mini Air Vehicles (MAVs). An MAV is generally classified as an aircraft which normally has a major dimension no bigger than 450mm. The size of these platforms allows trial of various concepts which would be difficult to implement on a larger platforms. Tail sitter VTOL vehicles such as the Bidule[2] and T-Wing[3,4] from the University of Sydney display a similar concept difficult to implement on a larger vehicle. In addition to fixed-wing platforms, rotary-wing MAV platforms provide an extremely effective autonomous aircraft configuration. This platform type can also be used as a basis for a variety of new ideas to be trialled.

As the design of MAVs is generally a smaller overall project than a UAV or manned aircraft, they often suffer as a result of the smaller project size. A large number of these platforms are developed from existing radio controlled aircraft. By relying on the design of an existing platforms rather than developing one from scratch, the platform is never a completely optimal design for its given mission. This can give problems with systems integration and more importantly flight performance. By approaching the platform design as a process which is seamlessly integrated with the ultimate mission goal, a more optimal platform can be produced. This design methodology is well established within manned aircraft design, and should be transferred to the design of UAVs and MAVs.

This paper presents work on the Concept, Analysis and Design of a novel rotary-wing platform. Design of this platform is benchmarked against similar existing vehicle concept which performs well. However, the existing vehicle can be improved upon by approaching the design process from a mission oriented stance. An analysis tool which models the base platform well has been developed. By using this analysis tool, the process of developing the platform from concept to design is stepped through showing the benefits of the Novel Platform Concept.

Platform Type Background

A new rotary-wing concept which showed potential to be used as an autonomous platform is the Proxflyer[5] type platform, shown in Fig. 1. By using the flapping hub design and coaxial rotors the Proxflyer has excellent stability can easily maintain a steady hover within a relatively gust-free atmosphere. However, its control is provided only through an external tail rotor which tilts the aircraft. This control method results in translation which pendulums and does not provide a smooth motion. Should this platform type be used as an MAV extra effort needs to be placed upon the control system, which needs to provide smooth motion for onboard sensors.

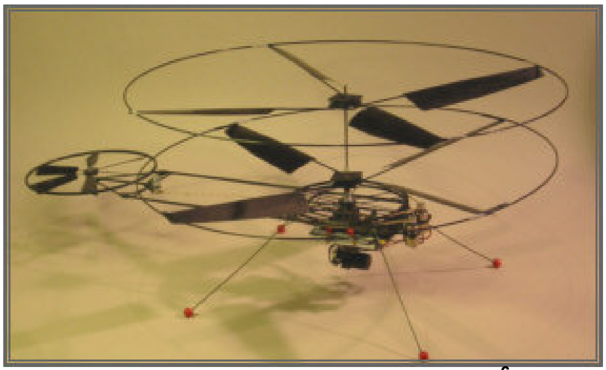

Figure 1. Proxflyer Type Vehicle[6]

Although this design provides excellent stability, its control authority and translation does not perform as well. To provide more control authority direct control over the rotor motion is needed. This can be achieved by changing the configuration to include control in the form of incorporating both collective and cyclic control to both rotors. If this platform concept can be altered to allow better control over the platform motion, whilst maintaining its stability, an overall better performing aircraft can be made.

Analysis Tool

Developing a novel rotorcraft concept based on the basic Proxflyer requires that an analysis model of the basic platform be used. By developing such a tool, the analysis of the basic design can be performed, as well as modifying the analysis to include new design concepts. The motion of this type of platform is almost entirely dominated by the loading and motion of its rotors. Thus new designs can only be adequately analysed if the dynamic motion and loading of the rotors can be adequately modelled. Being able to model flight performance changes of new design concepts would allow comparison to the baseline design thus allowing more optimal designs to be developed.

To reduce the complexity of the analysis, only the dynamics of the rotor motion and its loading are modelled. The coupling between the dynamics of the vehicle and that of the rotors can be ignored, allowing the focus to remain on accurately modelling the rotor motion. To model the dynamic motion and loading of a Proxflyer type rotor, separate analysis methods for both dynamics and loading need to be used. Blade Element Momentum Theory (BEMT) is used to model the rotor loading; and Rotational Equations of Motion (REoM) are used to model rotor flapping dynamics. To refine the model further, tip losses are modelled with a Prandtl tip loss factor, and a model for coaxial rotor interaction is used. These analysis techniques have been outlined in previous papers by the author[7,8] and are briefly discussed in the following sections.

Blade Element Momentum Theory

Blade Element Momentum Theory is a commonly used technique to accurately analyse rotor and propeller loading[9]. By breaking the rotor up into radial elements,

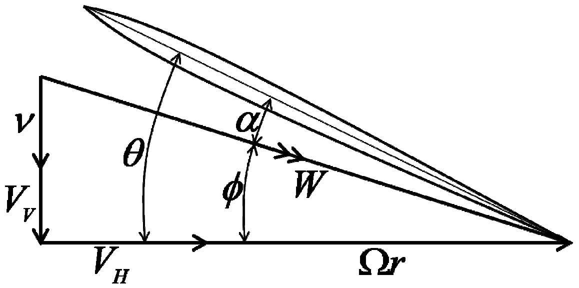

Figure 2. Element Aerodynamic Diagram

BEMT can determine a distributed loading over the entire rotor. Each element is analysed separately by Momentum and Aerodynamic theory used to determine an induced velocity flow, v, over the element. This is shown in Fig. 2 with rotational, horizontal and vertical velocity components.

Momentum and Aerodynamic theories are used to converge upon an elements induced velocity. Aerodynamic theory uses an estimate for the induced velocity to calculate a corresponding estimate of the elements thrust, shown in Equation 1. Momentum theory is then used to model the flow over the element as a continuous streamtube, and the thrust produced by the elemental section is found with Equation 2. This equation is then rearranged to form a quadratic which can be solved to find a new estimate for the elemental induced velocity. From the converged induced velocity, aerodynamic theory is then used again to find the Lift, Drag and Pitching Moment of the element.

$$dT = C_L \frac{1}{2}\rho W^2 c dr \tag{1}$$

$$dT = \frac{4\pi\rho r dr\left(V_Z + \upsilon\right)\upsilon}{B} \tag{2}$$

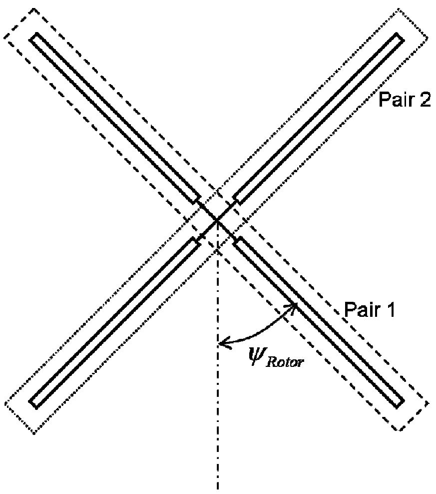

Figure 3. Blade Pair Breakup

Rotational Equations of Motion

By studying the rotor response of a Proxflyer type craft to external disturbances, it can be seen that the rotor flaps as two blade pairs, shown in Fig. 3. To model this motion simple Rotational Equations of Motion (REoM) have been chosen. REoM can easily be utilised to model the free and forced response of the rotor blade pairs to external inputs through a simple relation shown in Equation 3. As there is no spring or damper acting on the rotation of the blades, their response is governed by the moments applied to them. This equation can then be integrated to map the rotational response of the rotor blades.

$$J\ddot{\beta} = \sum M \tag{3}$$

Prandtl Tip Loss Modelling

BEMT models the load across a rotor blade as a continuously increasing load from root to tip. In its basic form, it has no account for losses that are expected at the blade tip. Accounting for this loss in lift is especially important when constructing the rotational forcing moment. If it is not taken into account there will be a notable over-prediction of the forcing moment. To account for this, Prandtl Tip Loss Modelling can be used which is an empirical fit to the loading data which accounts for losses experienced at the tip. To implement this method a simple scaling factor, F, is generated and applied to the aerodynamic calculations[10,11]. These are generated with Equations 4 and 5.

$$F = \frac{2}{\pi}\cos^{-1}(e^{-f}) \tag{4}$$

$$f = \frac{B}{2}\frac{R-r}{r\sin(\phi)} \tag{5}$$

Coaxial Rotor Interaction Model

Two rotors or propellers in close proximity will have an effect on each other. BEMT does not take this into account in its simplest form. A method for modelling the interaction between

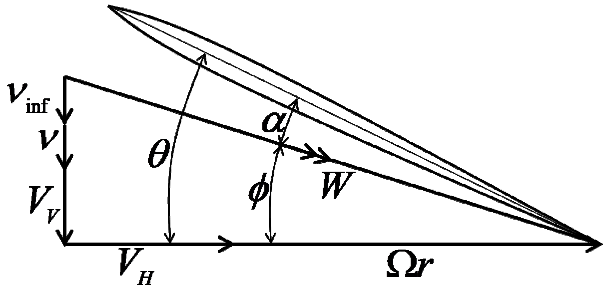

Figure 4. Influenced Element Aerodynamic Diagram

two rotors with BEMT has to be developed. This model applies a second induced velocity, v_{inf}, to a blade element to account for the counter-rotating rotors influence. Figure 4 shows the influence velocity within the aerodynamic diagram. A mapping function is used to geometrically map the induced velocity from an element on the opposing rotor onto the analysed rotor. This parameter is transformed to account for stream development and applied directly within the BEMT process. This additional velocity component will have an effect on the convergence of any element, therefore a second outer convergence loop is used to ensure that the entire coaxial rotor setup has converged.

Implementation and Results

The analysis techniques described above have been combined into a total analysis package. This analysis package can be used to model the rotor dynamic response of Proxflyer type platform as required. A more detailed explanation of the implementation of the tool is shown in other papers by the author[7,8].

To demonstrate the analysis tool, a test case was developed in which a Proxflyer type rotorcraft is subjected to a wind gust. The geometry of the platform and gust data are shown in Table 1. While Fig. 5 shows the craft rotor response in disc pitch and roll to the pulse gust input. Each rotor disc responds to the gust by pitching up to meet the gust. Furthermore, in preparation to meet the gust the advancing side of the disc rises. The two rotors are rotating in opposite directions, thus the roll response is also in opposite directions. It can be seen that the response of each rotor is different due to the interaction modelling within the analysis. Differences in the magnitude and damping of the rotor response show that the upper rotor is receiving less of an influence due to the interaction. This is due to the upper rotor being upstream if its influencing rotor, whereas the lower rotor is downstream of its influencing rotor, where the flow is more developed.

Table 1. Platform Geometry

Parameter	Value
B	4
r_{root}	0.045 m
r_{tip}	0.145 m
c_{root}	0.025 m
c_{tip}	0.015 m
θ_{root}	35°
θ_{tip}	25°
Blade Mass	2 g
Platform Mass	100 g
Section per Blade	10
Blade Section	Cambered Plate
Rotor Speed	~1000 RPM
Gust Magnitude	$3ms^{-1}$
Gust Duration	0.1s

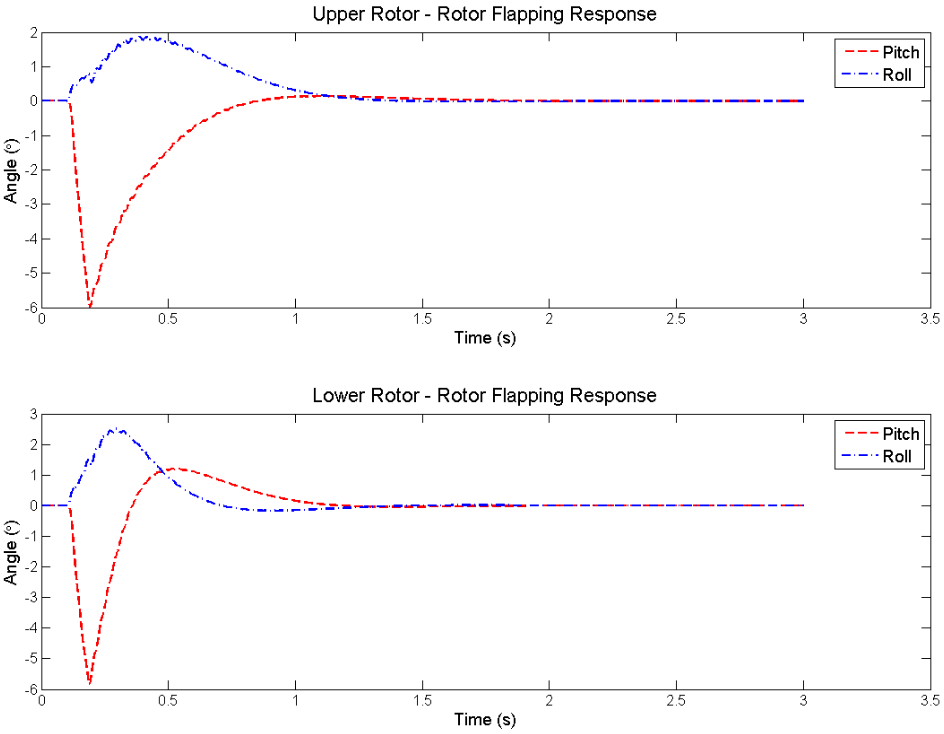

Figure 5. Rotor Response to Test Gust

Novel Platform – Concept

Proxflyer type rotorcraft exhibit favourable stability characteristics around hover, when flying in still air. However they lack any real ability to control the motion of the platform. Forward control is provided by applying a pitching moment to the platform through the tip of the tail boom. This method of control only allows very slow translation, and provides little authority over the attitude of the platform. Although this does provide a certain degree of control, it does not provide enough authority to make the platform useful. A rotorcraft which displays similar stability characteristics, as shown in Fig. 5, and also features good control authority would provide a platform with much better flight characteristics.

In contrast to the Proxflyer, rotorcraft with higher control authority (either manned or unmanned) use changes of the rotor itself to control the aircraft. UAV coaxial rotorcraft such as the AirScooter[12] (shown in Fig. 6), use conventional rotors with cyclic and collective controls. This method of control provides a higher degree of control authority for the aircraft, which in turn allows better overall flight characteristics. Having full control of a Proxflyer style rotor, with collective, and more importantly cyclic, produces a platform with much better stability and controllability.

From observation of the rotors of a Proxflyer under an external disturbance, the rotor-planes adopt a steady deflected flapping state. If direct control over the pitch angle of the blades is used, control over the flapping of the rotor can be subsequently actuated. Actuation of the rotor flapping angle can then be used to translate and rotate the platform. By varying the level of control authority over the rotors, a balance between stability and controllability of the platform can be reached. The balance between these factors can be varied to suit particular in-flight conditions or overall platform configurations.

Actuation of the change in blade pitch will generally require use of external control through use of a swashplate. Externally controlling the blade pitch is simple for a conventional rotor however, when the blades experience a large range of flapping angles control of the blades differ. As the blades flap and the control rod remains stationary, the actual pitch of the blade will change proportionally with the flap angle. At first this may seem to be counter-intuitive, but if implemented correctly this can be beneficial to controlling the flapping motion. The addition of 'Flapping Feedback' to the rotors can increase the ability of the rotors to maintain a rotor disc plane flap angle when actuated by control. In contrast it can also help to reduce the magnitude of the flap response to an external disturbance.

Figure 6. AirScooter G70 UAV[13]

Overall benefits of developing a platform with fully controlled flapping rotors can be seen in general terms, through the addition of direct control. However specifics of how this manifests itself within the response of the platform need to be defined.

Motion Control

Pitching and rolling the rotor disc will change the orientation of the lift vector, thus applying forces to the platform. The combination of two rotors can lead to a very effective platform control mechanism which also has the benefit of inherent stability. To control the flapping of the rotors, conventional control of RPM, Collective and Cyclic is used. This gives a total of four controls per rotor, and eight controls for the platform. As the number of platform controls exceeds the six degrees of platform freedom, the platform can then be directly controlled about all axes. Controlling each of the six degrees of freedom directly requires an explanation on how it is implemented.

Controlling the platform motion in the Z direction is as simple as changing the collective on both rotors simultaneously, while keeping the rotor speed constant. The change in collective on both rotors will change the lift produced, and thus will change the crafts Z

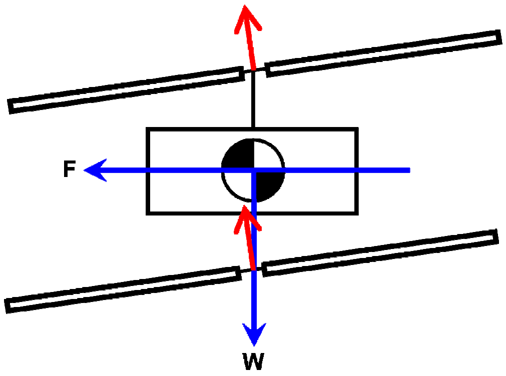

Figure 7. X or Y Craft Translation

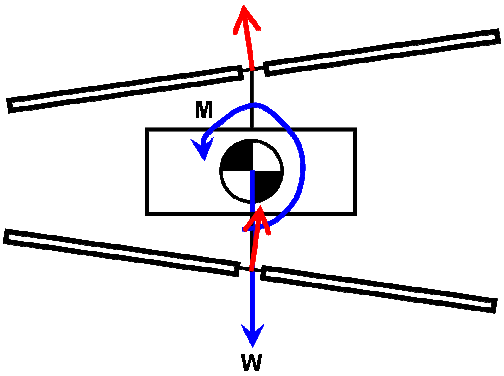

Figure 8. Pitch or Roll Craft Rotation

position. To affect this both rotors will also need to have a constant speed maintained, as with conventional helicopter designs. Z control can be also effected by using only speed control, should collective be unavailable. This is similar to many existing helicopters.

To translate the platform in either the X or the Y direction, a combination of cyclic commands on both rotors is used. By actuating each rotor to either Pitch or Roll in the same direction, both of the rotors' thrust vectors are tilted in the same direction. This will then apply a net force on the platform in the direction of tilt, as shown in Fig. 7, thus producing platform motion in the desired direction. However, when each rotor is flapped in a given direction there will be subsequent flap residue 90° out of phase. This can then be simply cancelled by applying cyclic to the opposite control direction. Applying control in this manner will allow the platform to be translated in the direction required with little or no platform tilt. As a consequence, this will only produce a slow translation in the desired direction and generally this is not how a normal rotorcraft translates.

As with conventional coaxial rotorcraft, a yawing motion is performed by applying differential collective. This will apply different torque reactions about the rotor mast, therefore applying a moment about the Z axis. Changing the collective also changes the rotors' thrust as well as the torque of the rotor. Therefore, the reduction of thrust on one rotor must be balanced by an equal increase in thrust on the opposing rotor.

To rotate the platform about either the X or Y axis, a combination of rotor flapping is also used. Similar to the slow translation motion described above, manipulation of the rotor flapping can apply a moment about the platform. Figure 8 shows the top and bottom rotors flapping in opposite directions to offset the thrust components in opposite directions. This produces a moment about the X or Y axis causing rotation. The opposite flapping directions will also produce subsequent flapping out of phase with the desired flapping direction. However, in this case they will both be in the same direction, thus causing platform translation rather than rotation. This must also be remove by applying an opposite cyclic control.

A second type of platform translation is which produces a faster platform response by increasing the force in the required direction of travel. Instead of deflecting the rotors in a similar direction, the platform is firstly rotated about the appropriate axis then the whole platform thrust is used to direct a force in the direction of travel. This procedure is shown in Fig. 9. Platform motion can then be controlled further through manipulation of the rotors as described above.

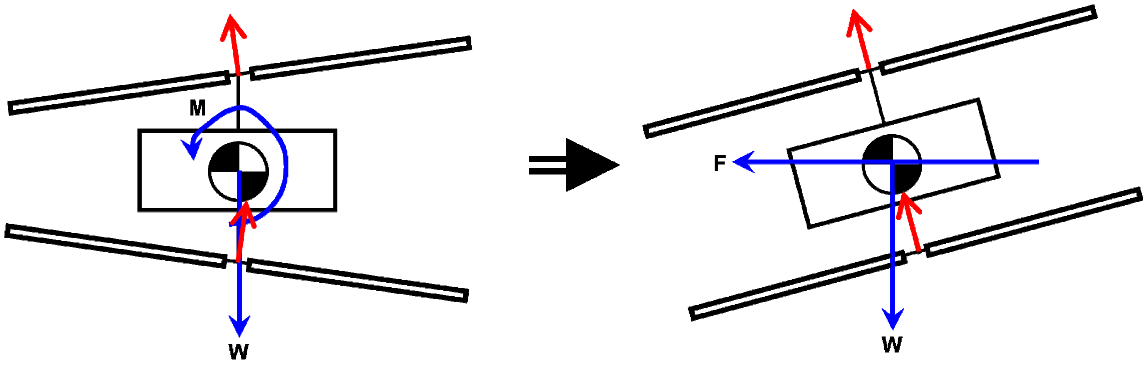

Figure 9. Fast Craft Translation from Craft Rotation

Novel Platform – Analysis

The goal of any rotorcraft design process is to develop a platform which has favourable flight characteristics. It has clearly been shown through an earlier section that the basic Proxflyer design has favourable stability characteristics. The concept described within this paper builds on this basic inherent stability by providing significantly better control characteristics.

To verify the addition of beneficial control characteristics, the original design must be compared to the new concept. Specifically, tests must be performed to ensure that the stability (Gust Response), control authority (Control Response) and overall efficiency of the new platform outperforms the original platform. Once the new concept has been proven to meet these tests, a more detailed design process can begin.

For a given platform mass, a trim algorithm is run to obtain the rotor speeds required to maintain steady hover. Efficiency can be gauged by examining the relative power requirements of each configuration. The control of collective and rotor speed can be tested by making a sweep about the trim condition. To test the cyclic control authority, a standard control input is commanded and the rotor flapping response is then found. Finally, to ensure that the platform still remains gust tolerant, the rotors are subjected to a characteristic gust. This allows the overall rotor response to be examined. Example profiles of the cyclic and gust inputs are shown in Fig. 10.

To make changes to the performance of this helicopter type, variations in blade design and control linkage system can be considered. Blade variations can be made through changes of either aerodynamic or mass properties. Aerodynamics changes are carried out by varying the Tip and Root values for Radial Location, Chord and Twist. A plot of a base geometric blade distribution of the Proxflyer is shown in Fig. 11. As well as the blade geometric design, the blade mass can be changed. As the total blade mass is assumed to be evenly distributed across all blade elements, thus a simple change in total blade mass applies evenly to the entire blade. Blade configuration and mass distribution changes are not considered within this paper. As flapping feedback is included within the simulation, variations in control linkage configuration locations are made, which changes the gain of the flapping feedback. A schematic of the control linkages are shown in Fig. 12. Variations in l_1 and l_2 allow the gain in the flapping feedback system to be varied, and thus have an effect on the rotor motion.

The above tests are used to define the

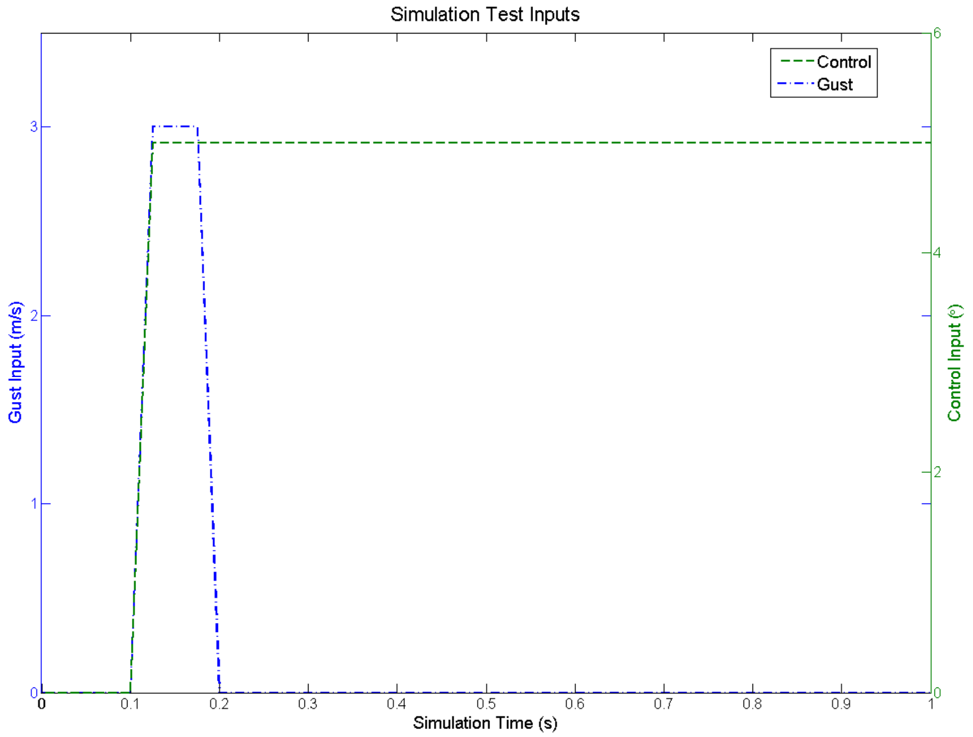

Figure 10. Gust and Control Test Simulation Inputs

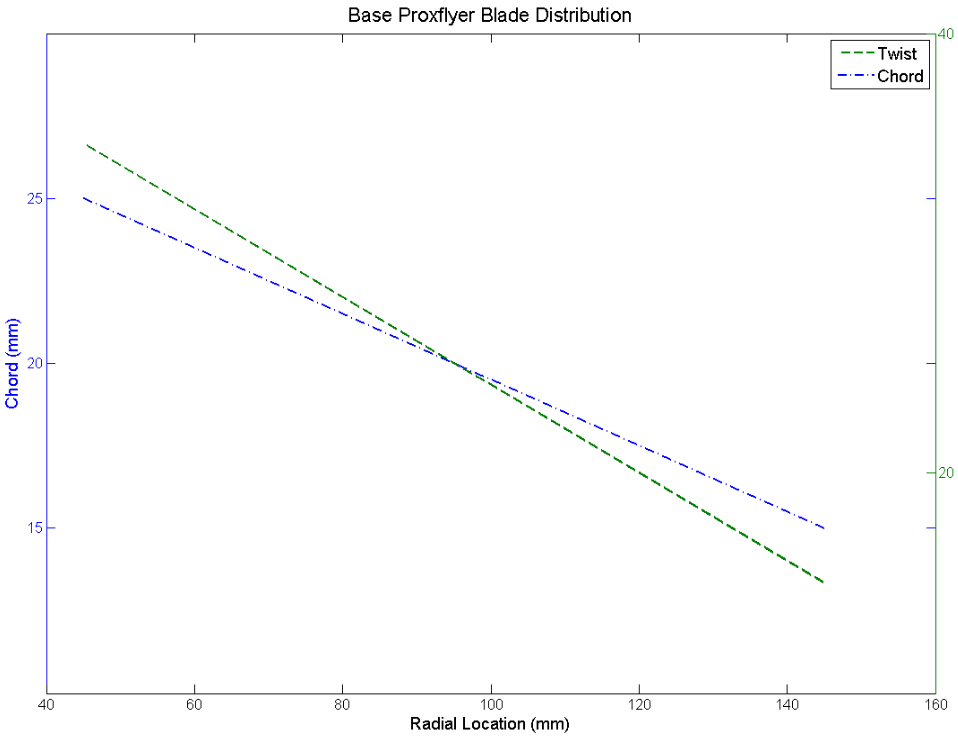

Figure 11. Base Proxflyer Blade Chord and Twist Distribution

performance of new designs with respect to the existing design. Therefore a base platform configuration, such as a 200g platform, must be used. This initial platform design is designed to have exactly the same design as a basic Proxflyer platform. Following an initial analysis, differing combinations of the new designs are applied to the analysis model. Results from these analyses allow a better performing platform to be produced.

Novel Platform – Design

To demonstrate the benefit of the new platform, an initial analysis of that design concept is made. This analysis requires that the geometry of the base platform be defined, which has been modelled from a Proxflyer type platform approximately the size of the Bladerunner[6]. The geometry of the test platform is similar to the geometry used to illustrate the analysis tool, shown in Table 1.

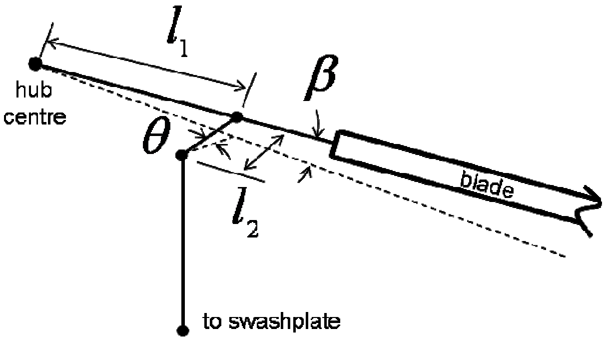

Figure 12. Control Linkage and Flapping Feedback Schematic

Benchmarking the new platform concept against the base design allows benefits of the new design to become immediately apparent. A standard set of analyses is used as a benchmark between the original platform and the platform with new design features. The standard set of analyses is generated from the analysis suggested above, and is summarised below.

1. Trim platform for steady hover at given platform mass.
2. Perform RPM sweep around hover condition.
3. Perform Collective sweep about hover RPM.
4. Simulate Rotor Response to 3ms-1 Wind pulse input.
5. Simulate Rotor Response to 5° Cyclic Control input.

Table 2. Base Craft Geometry

Parameter	Value
B	4
r_{root}	45 mm
r_{tip}	145 mm
c_{root}	25 mm
c_{tip}	15 mm
θ_{root}	33°
θ_{tip}	15°
Blade Mass	2.0 g
Craft Mass	200 g
Elements per Blade	10
Blade Section	Cambered Flat Plate

Of the five tests described above, only the first four tests will be performed on the base platform design, as no rotor control is present. As well as the gust simulation testing new designs against the base platform, a cyclic input simulation is used to gauge the control authority of new designs with respect to each other. Table 2 shows the geometry and analysis parameters of the base platform configuration.

To begin, the base configuration must be examined to set a baseline for further comparison. As with any set of tests, the base configuration is firstly trimmed to define a hover rotor speed. The trimmed conditions for the base craft are summarised in Table 3. These trim values are also the same for any of the new craft as no blade changes are being considered. Using this trim configuration as a base, Fig. 13 shows the variation of output thrust, and total required power, with rotor speed about the trim condition. As would be expected, the total thrust and power vary proportionally with rotor speed. However if Fig. 14 is examined, the variation of thrust and power with rotor Collective, it can be seen that the blades are operating near blade. Thus, a small increase in collective, or any other angle change, can cause the blades to stall giving sub-optimal performance.

Table 3. Trim Configuration

Parameter	Value
Upper Rotor Speed	1479 RPM
Upper Rotor Power	5.16 W
Lower Rotor Speed	1479 RPM
Lower Rotor Power	4.99 W
Residual Torque	0.001012 Nm

To compare the base design to the new platform configuration, dynamic performance of the rotor is examined. The performance of the base vehicles rotors with respect to gusts needs to be found. A standard gust profile shown in Fig. 10 is used to generate the

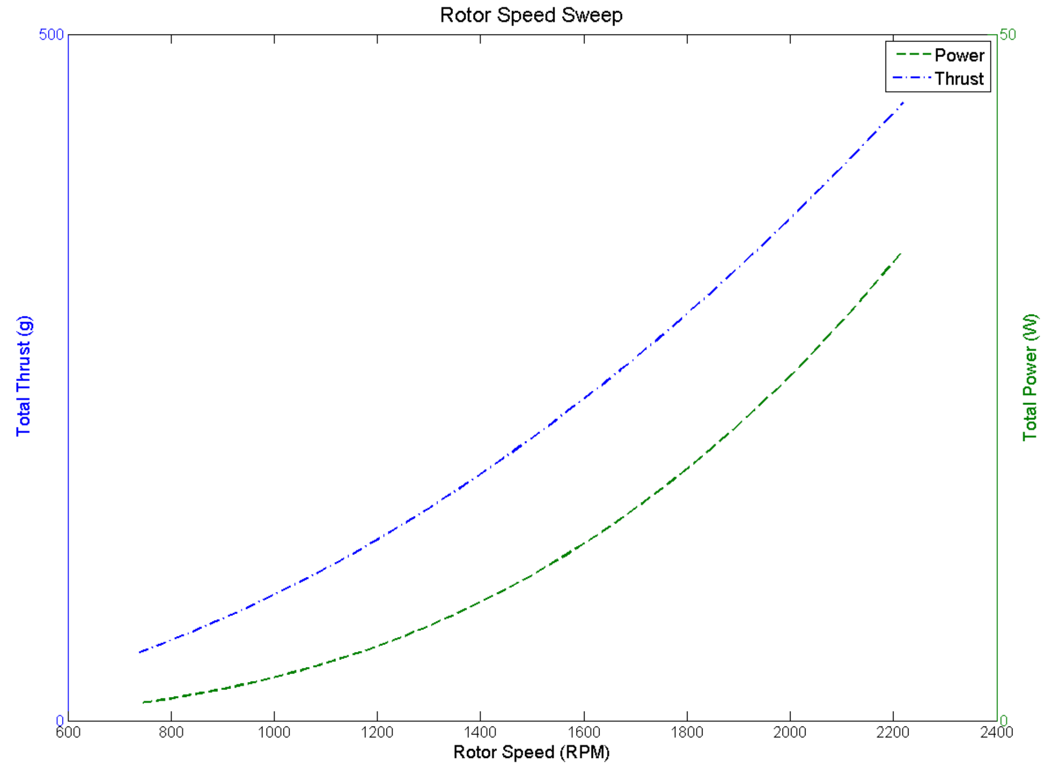

Figure 13. Base Craft – Rotor Speed Sweep

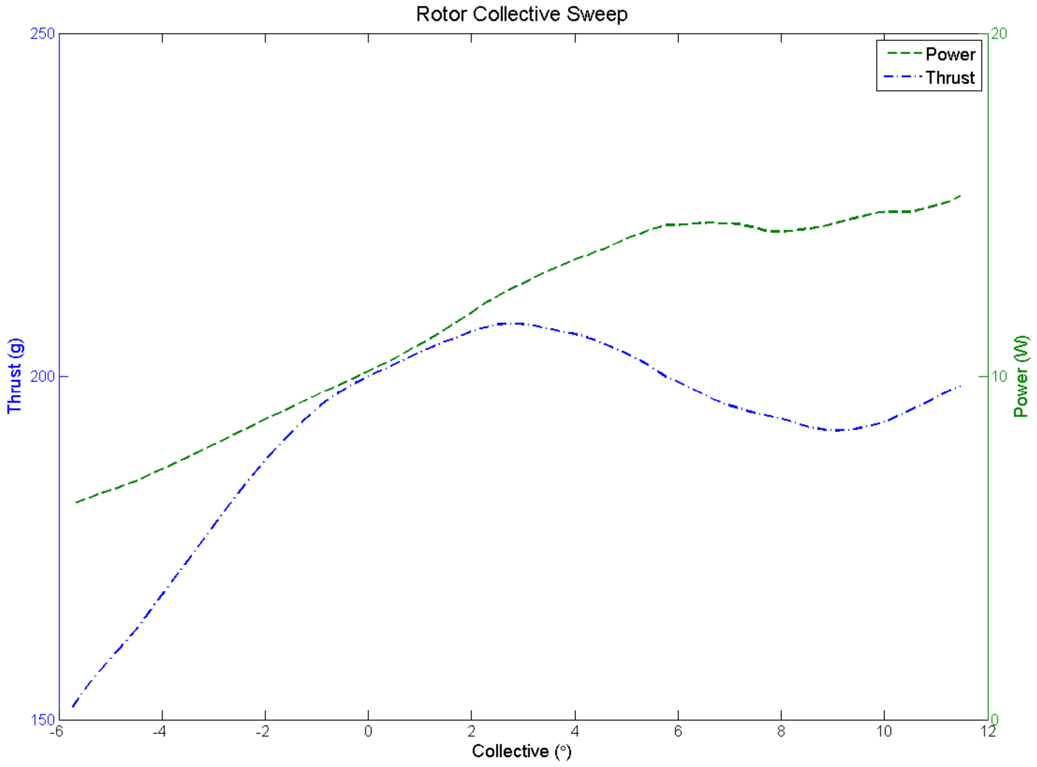

Figure 14. Base Craft – Rotor Collective Sweep

required response to external disturbances. Figure 15 shows the rotor flapping response in pitch and roll as a response to the gust disturbance. As the gust strikes the rotor, it responds through a large initial disturbance in the pitch direction. Following the cessation of the gust, the rotors return to there steady-state positions. The deflection magnitude reflects the gust energy, thus can be used as a measure of the rotors stability performance. A lower deflection showing the rotor is better at absorbing a gust, and will place less force onto the platform itself.

Once control of the platforms rotor is used, both the gust response and control response can be used as a benchmark. Figures 16 and 17 show a flapping feedback rotors response to a gust and control input simulation. This rotor exhibits gust response characteristics which are comparable to, or better than, the base configuration. Control authority of this craft is shown through the steady-state flapping angle which the rotor adopts. In this case, the control response that the platform provides will be able to actuate platform motion.

Table 4 shows a summary of the gust and control simulation flapping response magnitudes for varying combinations of control linkage lengths. For comparison of these configurations, gust response is gauged by the maximum rotor deflection, while control

Table 4. Analysis Results

	Parameter	Units	Base Craft	Feedback 1	Feedback 2	Feedback 3	Feedback 4	Feedback 5
	l_1	mm	-	25	15	25	15	15
	l_2	mm	-	15	25	-15	-25	15
Upper Rotor	Max Pitch	°	-5.64	-5.03	-5.53	-5.65	-5.40	-5.40
	Max Roll	°	0.35	2.82	1.12	-1.59	-3.23	1.86
	SS Pitch	°	-	1.39	3.87	2.51	0.93	2.73
	SS Roll	°	-	-2.53	-2.26	1.86	1.91	-2.82
Lower Rotor	Max Pitch	°	-5.55	-4.32	-5.21	-5.61	-5.11	-4.93
	Max Roll	°	0.38	3.16	1.76	-1.79	-3.76	2.47
	SS Pitch	°	-	0.86	2.74	3.34	1.04	1.67
	SS Roll	°	-	-2.32	-2.76	2.61	2.32	-2.83

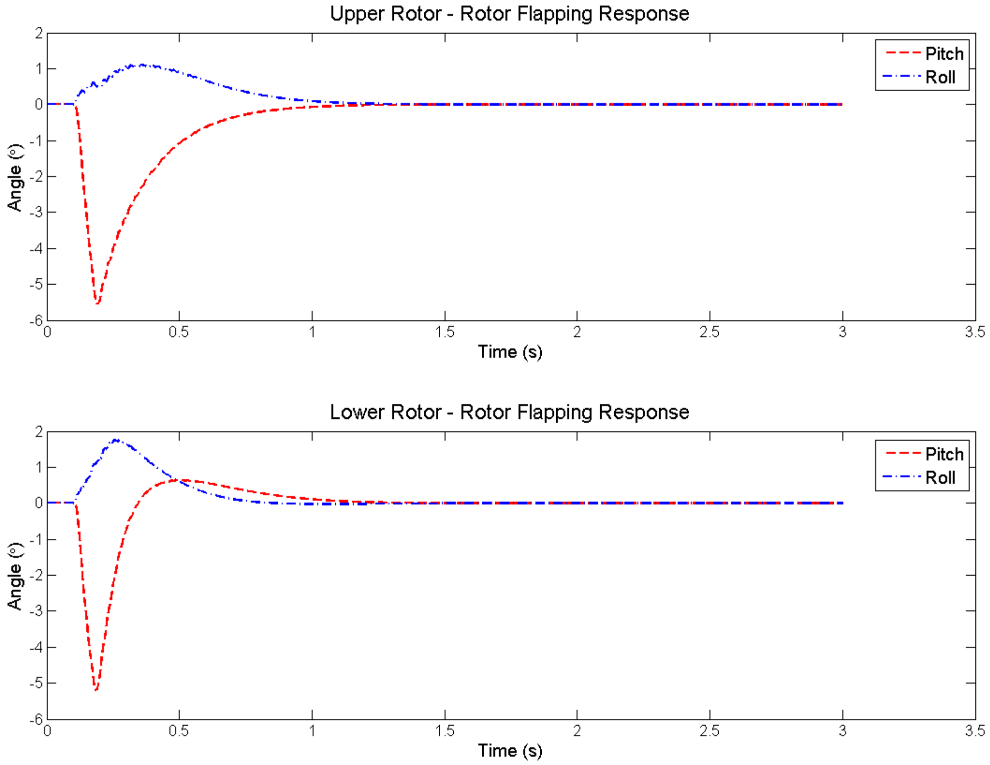

Figure 15. Feedback Craft – Rotor Gust Response

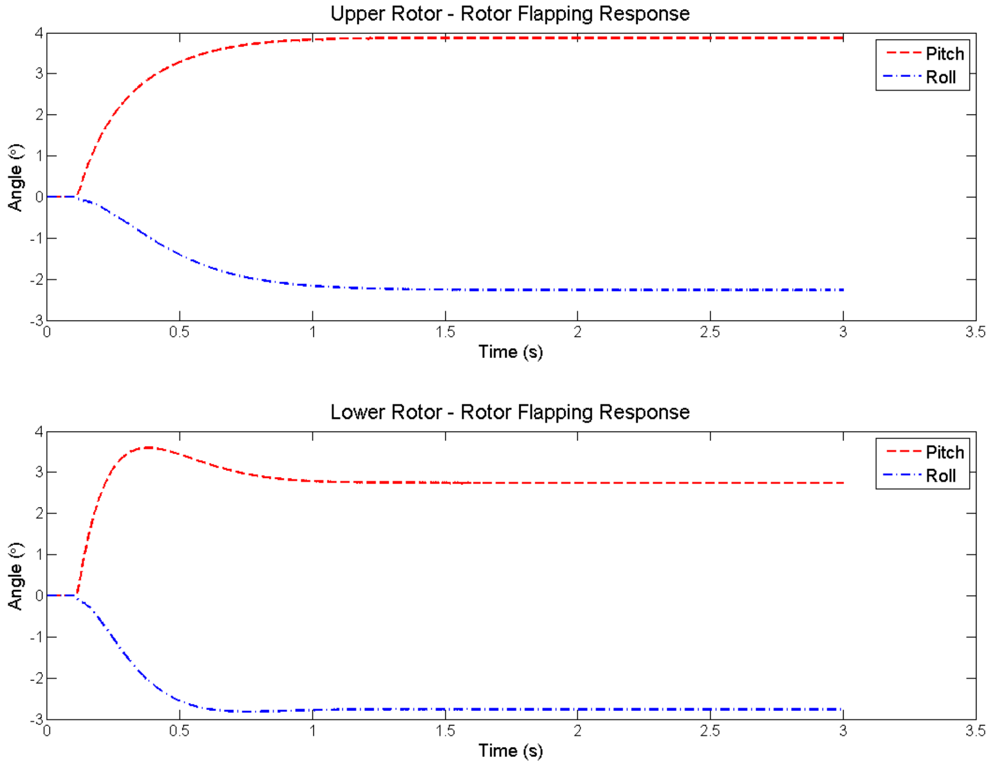

Figure 16. Feedback Craft – Rotor Control Response

response is gauged be steady-state flapping deflection. The gust and control response of the rotor varies widely with variation of the control lengths. When the ratio of the control linkage lengths (l_1 and l_2) is large, the change in blade pitch with flapping angle is also large. Thus, as the blades are already operating near stall they can easily reach stall. This will manifest as a degradation of the overall rotor performance, as can be seen by the lower magnitudes in the Feedback 1 and 3 configurations. To ensure that the rotor remains below stall, a low change in pitch angle and thus low linkage ratio is required. The results of a lower linkage ratio are shown on the Feedback 2, 4 and 5 configurations. Each of these configurations has a gust response which is comparable to the base design, while also displaying excellent control authority. The performance of a platform design around the base configuration can be improved by applying a flapping feedback control configuration with a control linkage ratio less than 1. By providing control authority as well as the base stability, a new platform which far surpasses the original can be designed.

Conclusion

An analysis tool which accurately models the rotor dynamics and performance of a platform with similar configuration to the Proxflyer has been developed. This tool allows the rotor flapping dynamics as well as its performance to be examined for a wide range of rotor and blade configurations. In addition, it also allows new configurations to be created and tested with special attention paid to the effect on rotor dynamics. In particular it has allowed the conceptual design of a new platform.

Analysis of the base and flapping feedback platform configurations shows that the new design exhibits excellent stability and controllability characteristics. Flapping feedback augments the blade pitch angles as a function of the flapping angle, resulting in gusts being absorbed more efficiently. As well as displaying positive stability characteristics, use of flapping feedback allows direct control of the rotors. Direct rotor control provides significantly better control authority than the base Proxflyer configuration. For this base configuration, a basic flapping feedback design has been presented which shows the benefits of using this design feature.

Further analysis of these design features will result in a platform configuration with better flight characteristics. This future design study will include changes to the blade configuration, as compared to keeping it consistent with the base design. Allowing both the blade design and the flapping feedback mechanism to be varied will provides an analysis which contains a larger range of possible configurations. This versatility will allow a global optimisation of the platform configuration to be performed, and result in an efficient rotorcraft platform which can be designed around any takeoff weight and mission specifications.

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