Optimization of the Longitudinal Stability of Unmanned Aerial Vehicle (UAV) UX 004

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Abstract— *Improper longitudinal weight distribution within any air vehicle cuts down the efficiency from the standpoint of altitude, manoeuvrability, rate of climb, endurance, and speed. It may even be the cause of an uncontrollable accident because of the excessive loads exerted upon the control surfaces of an improperly trimmed air vehicle. Even control surfaces can become ineffective below certain speeds to compensate the counterbalancing forces due to air vehicle CG forcing out of the specified limits. The distance of the elevator control surfaces from the trailing edge, elevator area, deflection angles and rate of deflection are also factors that directly contribute to the longitudinal stability when the air vehicle is operating closer to the forward or aft limits of the designer specified CG range. This paper presents procedures and methodologies of data collection, analysis and precision adjustments that can be carried out optimizing the aerodynamic performance of the air vehicle thereby incorporating enhanced performance and operational safety.*

Keywords— Centre of Gravity, Longitudinal Stability, Unmanned Aerial Vehicle and Aerodynamic Stability

I. INTRODUCTION

The Center of Gravity (CG) is the point at which the total weight of the aircraft is assumed to be concentrated, and the CG must be located within specific limits for safe flight. Both lateral and longitudinal balance are important, but the prime concern is longitudinal balance; that is, the location of the CG along the longitudinal or lengthwise axis.

II. LONGITUDINAL MASS DISTRIBUTION

The designers of the UX 004 UAV have designated the exact station for each component achieving the accurate weight and balance by positioning the CG within the range of 28% to 33% of the Mean Aerodynamic Chord (MAC). However, due to the inadequacy of testing facilities it is mandatory to measure the dynamic performance while in flight and make required adjustments (Fig 1).

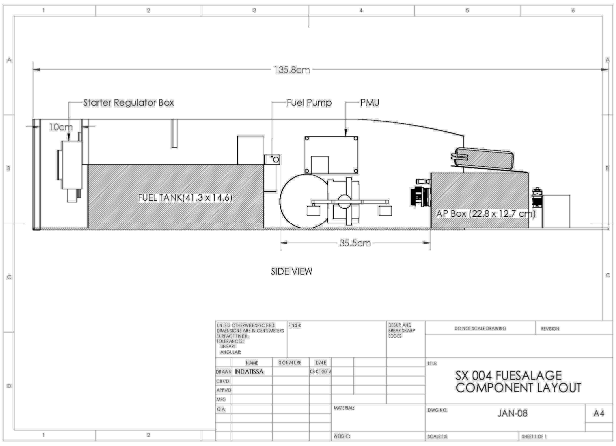


Figure1. Forward Section of UX 004

A. *Positioning CG and Center of Lift (CL)*

Longitudinal stability is maintained by ensuring the CG is slightly ahead of the centre of lift. This produces a fixed nose-down force independent of the airspeed. This is balanced by a variable nose-up force, which is produced by a downward aerodynamic force on the horizontal tail surfaces that varies directly with the airspeed.

B. *Longitudinal Equilibrium*

If a rising air current should cause the nose to pitch up, the airplane will slow down and the downward force on the tail will decrease. The weight concentrated at the CG will pull the nose back down. If the nose should drop in flight, the airspeed will increase and the increased downward tail load will bring the nose back up to level flight. However, the determination of the exact distance between the CG and CL remains a computational challenge due to the decimal inaccuracies in calculation of the CL in its dynamic behaviour primarily with variable Angle of Attack (AOA).

C. *CG Position of UX 004*

Table 1 depicts the calculation of the CG station of UX 004 taking the Datum Line at forward most edge of the nose cone.

Component	Weight (g)	Arm (inch)	Moment (g*inch)
Fuselage with fuel tank	3576	31.94319771	114228.875
Tail with 4 servos	1962	107.5326835	210979.125
Tail connecting rods	100	107.5326835	10753.26835
Wing	6806	48.3125	328814.875
Main landing gear	1300	51.0625	66381.25
2 Tyres	1500	51.0625	76593.75
Nose landing gear	1200	5.25	6300
Propeller	133	61.9215	8235.5595
Engine with generator	3350	57.3935	192268.225
Engine mounting bolts	124	53.0625	6579.75
Wing mounting bolts	52	40.6875	2115.75
Wing mounting bolts	54	49	2646
Data link	700	16.969	11878.3
Electronic box	3300	12.5	41250
Bus bar	143	20.157	2882.451
Nose landing gear rods	47	5.88	276.36
2 Booms	620	80.625	49987.5
GPS module	99	28.5	2821.5
Fuel	8640	41.06	354758.4
Camera payload	1500	28.346	42519
Ballast	2100	2	4200
Total weight	**37306**	**41.07301611**	**1532269.939**
Position of C of G		41.06	

Table 1. CG Calculation

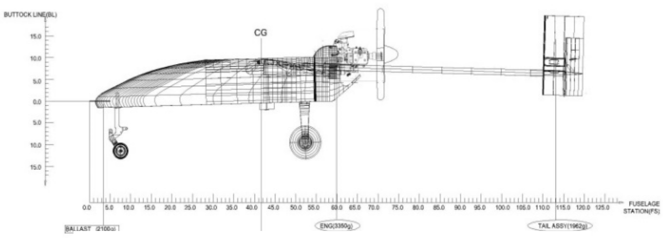


Figure 2. CG Position on Longitudinal Axis

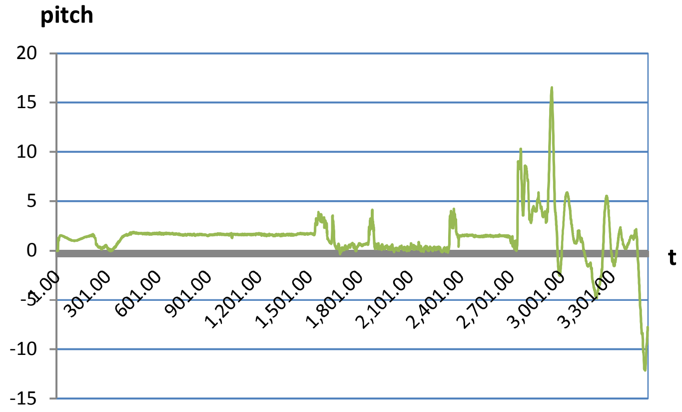
III. ANALYSIS OF FLIGHT TEST DATA

During the first air test of the UX 004 carried out on 05/04/2016, the air vehicle was flown into a determined flight profile to test the dynamic outcome of the CG which was positioned through the calculation based methodology as depicted in Table 1. Created flight profile was controlled with following conditions and limitations.

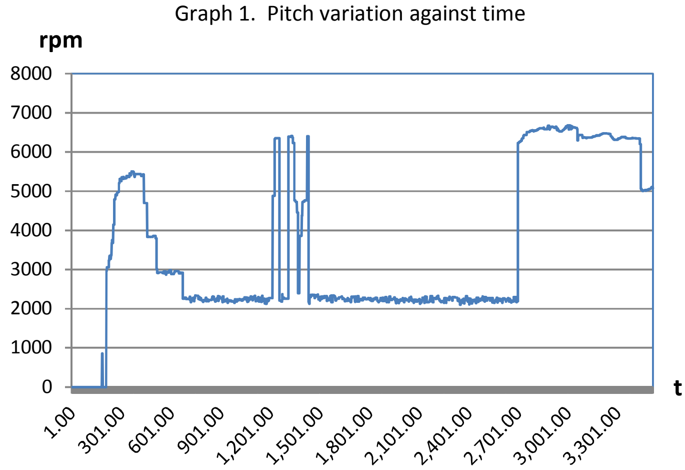
- Throttle was retarded to the lowest limit in which the air vehicle could hold the altitude
- Auto Pilot disengaged
- Air Vehicle on straight and level flight (elevator controlled by external pilot)

A. The Dynamic Test Profile - 01

The elevator control was released by the external pilot under above conditions and the recorded data is plotted in Figure 2 and 3.



Graph 1. Pitch variation against time



Graph 2. Corresponding rpm value during pitch variation

1) Variable Pitch Data: The variable pitch data depicted in Graph 2 indicates the air vehicle starting its climb rate with a positive pitch after the 540th second (a frame = 200 mili seconds) which means the air vehicle taking off from ground. The variation of the pitch indicates a rapid fluctuation between 17° to -5° within the short period of 180 seconds. Another reason for this variation is the manually controlled flight by the External Pilot (EP) who controls the air vehicle from visual inputs instead of sitting inside the aircraft.

2) RPM Data: The corresponding engine RPM is taken instead of the throttle position to determine the thrust exerted by the power plant producing the adequate lift to keep the air vehicle afloat in the air. At 6300 rpm, the air vehicle seems to hold the altitude controlled by the elevator, but increasing the Indicated Air Speed (IAS) in response to the excessive power delivered by the engine. Therefore, power was slowly retarded to 5000 rpm in which the air vehicle could hold the altitude and IAS both with elevators controlled by the EP. At this setting, the elevator control was released by the EP making its deflection 0°. The air vehicle drops the nose rapidly passing -13° which was immediately arrested by EP by increasing the power and pulling up the nose, on acting upon the audio warning given by the Internal Pilot (IP). The rate at which the pitch dropped, could have even led the air vehicle to go into an uncontrollable dive in which all control surfaces, especially elevators ineffective to recover from a fatal crash.

3) Analysis of the Test Profile 01 – Pitch Data: The rapid drop of pitch value in the minimum lift power setting is clearly indicative of the excessively forward position of the air vehicle CG. Although this condition could be sustained with increased power and deflected elevator, the condition is not acceptable in terms of the operational safety, fuel economy and air vehicle glide ratio with zero thrust. The first dynamic test profile analysis delivered a result contradicting the validity of the calculated CG position of the air vehicle. It demanded the re adjusting of the CG and recalculating the new CG position.

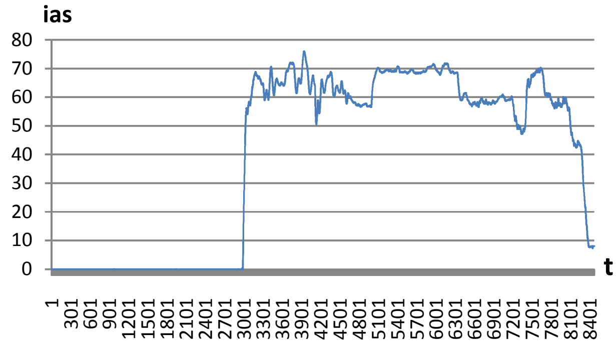
B. The Dynamic Test Profile - 02

The CG of the air vehicle was re adjusted pushing it further aft wards from 41.06 inches to 42.47 inches. The purpose of this adjustment is to reduce the force couple between the CG and Centre of Lift CL in order to increase the longitudinal stability. The plotted graphs of pitch, indicated air speed (IAS) and corresponding rpm against time are cascaded together for easy referencing of corresponding values.

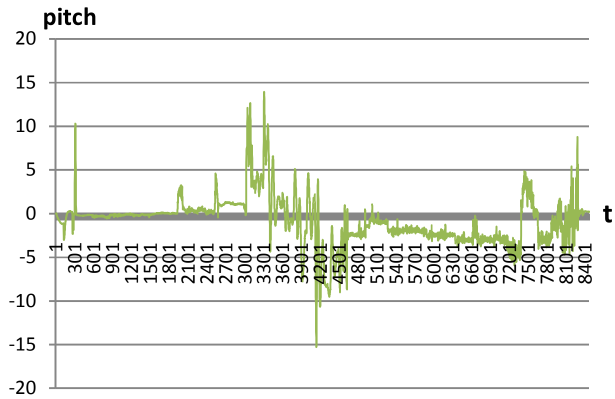
1) IAS Data: The IAS variation remains within 50 to 75 knots as per Graph 3. Though it's well above the stall speed, the variation with in a small time frame is excessive. Pitch variation from +15° to -15° with in the same time frame while the rpm remains in maximum range is indicative of excessive elevator corrections by the EP.

2) Variable Pitch Data: The rapid pitch variation remains a concern in the first segment of the air test, but it stabilizes towards the latter part of the flight indicating a positive improvement from the first air test. But, mostly operates in the negative (0° to -4°) despite the stabilized IAS and rpm from time segment 4801 to 6301 which is also a concern that has to be investigated.

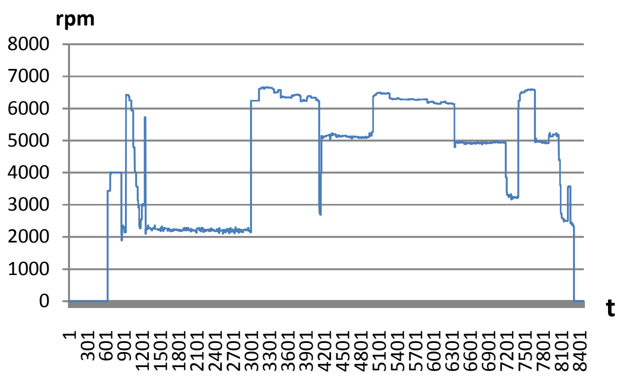
3) RPM Data: The RPM drop to 2800 at time segment 4201 is followed by a rapid drop of pitch to -15° which indicates the requirement of further pushing the CG aft ward to improve the longitudinal stabilization.



Graph 3. Indicated Air Speed (IAS)



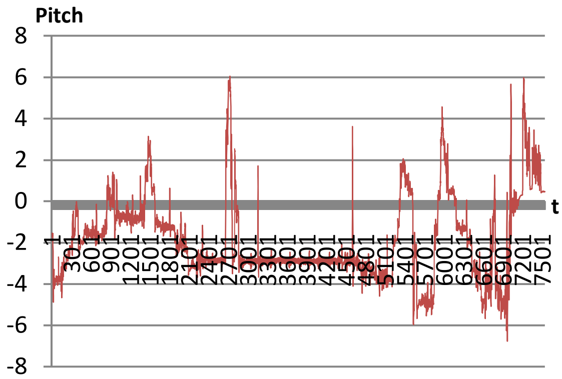
Graph 4. Pitch Variation



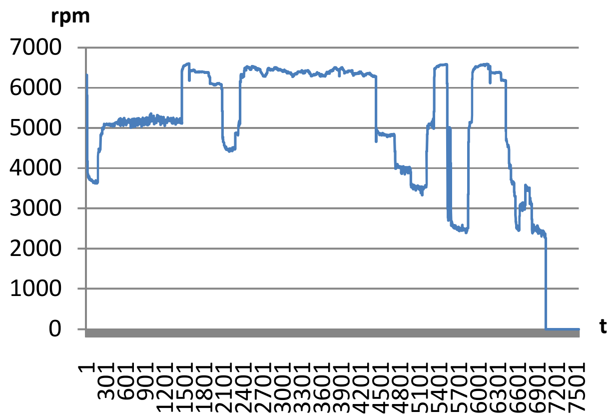
Graph 5. Corresponding rpm

C. The Dynamic Test Profile – 03

As proven imperative from the second test profile analysis, the CG of the air vehicle was shifted towards the aft from 42.47 inches to 42.94 inches. This adjustment has to further reduce the force couple between the CG and Centre of Lift



Graph 6. Pitch Variation



Graph 7. Corresponding rpm

1) RPM Data: The rpm had been retarded by the EP during four segments of the test flight envelop and the corresponding rpm drop had been limited to maximum of -6° in each. The test result had been positively influenced by the last shift of CG aft wards by 0.47 inches achieving a significantly better level of longitudinal stabilization.

2) Variable Pitch Data: Both, the negative and positive pitch variation maximum values have been reduced from approximately 15° to 6° which can be considered as a significant improvement in the longitudinal stabilization compared to the level the air vehicle was at during the first air test.

3) Analysis of the third test Profile: The rapid variation of the pitch remains a concern in the first segment of the air test, but it stabilizes towards the latter part of the flight indicating a positive improvement from the first air test. But, mostly operates in the negative (0° to -4°) despite the stabilized IAS and rpm from time segment 4801 to 6301 which is also a concern that has to be investigated.

IV. CONCLUSION

The common aerodynamic notion of establishing the air vehicle CG ahead of the CL makes an air vehicle capable of making a safe flight, but more intricate analysis of the longitudinal stability indicates a dynamic behaviour that re quires further refining of the CG point to improve the stability.

V. RECOMMENDATIONS

A. The calculated CG position of the air vehicle has to be re adjusted through real time aerodynamic stability profile analysis.

B. The tendency of this particular air vehicle, UX 004 operating in most test profiles in a negative pitch range has to be investigated.

VI. REFERENCES

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VII. ACKNOWLEDGMENT

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