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The Flying Wing UAV Using Classical Control Theory

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Abstract: This paper describes modeling design procedure of a flying wing UAV which is a tailless fixed wing aircraft and has no definite fuselage, with respect of the crew, payload and equipment being housed inside the main wing structure. In this thesis a 6 degree-of-freedom mathematical model describing the aircraft dynamics is first presented, then using these equations, the derivatives of the parameters and system identification of simplified, linear lateral and longitudinal models are estimated for the tailless aircraft. A detailed modeling procedure of flying wing UAV and stability analysis results using the linearized model at trim condition are represented. Finally, we have designed the flying wing UAV using classical control theory.

Keywords: Control, Designe, Model, UAV.

I. Introduction

Unmanned aerial vehicles commonly referred to as UAVs are powered aerial vehicles sustained in flight by aerodynamic forces (lift) without pilot. It can fly autonomously or remote controlled. An unmanned aircraft system is shown in Fig. 1 which includes ground station and other elements besides the UAV. UAVs are playing a vital role in modern world in the form of air reconnaissance, attack, air defense, surveillance and delivery vehicles, rescue and in future this is going to take place of various flying vehicles. The military role of UAV is growing at unprecedented rate and the advancement in technology is enabling more and more capability to be placed in similar airframe which is spurring a significant increase in the no. of UAVs in the battlefield has been expanded in the areas like:

Electronic countermeasure is the part of electronic attack. This is used to deceive radar, sonar or other detection system of enemy like infrared or lasers. It may create pseudo targets or make real targets disappear. This is a plan used by air force to establish immediate air control prior to possible full-scale conflict. For the suppression of enemy air defense the UAVs are equipped with radar seeking missiles and tasked with destroying the radars and Surface to Air Missiles (SAM) installed at enemy air bases. Battlefield Airborne Communication Node (BACN) is an airborne communication relay and gateway system hosted by aircraft that provides flexible radio connectivity across the battle space for airborne and surface operators. BACN enables real time information flow between similar and dissimilar tactical data link and voice system through relay, bridging and data transmission in line of sight and beyond line of sight situation.

UAVs can be as small as an insect to that of a commercial aircraft. They are relatively easy to maintain, have a durable life span, low cost as compared to manned aircraft and based on their capability these can be categorized as Short Range (SR), Medium Range (MR), Medium Range Endurance (MRE), Low Altitude Long Endurance (LALE), Medium Altitude Long Endurance (MALE), High Altitude Long Endurance (HALE), Unmanned Combat Aerial Vehicle (UCAV), Naval UAVs and Civil UAVs.

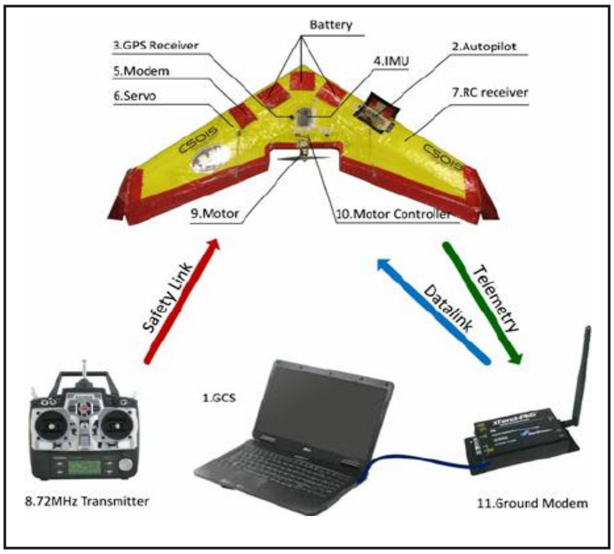

Fig. 1: UAV System

Flying wing UAV is a tailless design that integrates the wing and fuselage in a common structure. This configuration shows some aerodynamic advantages over conventional configuration of UAV like lower wetted area to volume ratio and lower interference drag. It may increase the maximum lift to drag ratio. Flying wing UAVs have more payload capacity and flight range for same engine configuration than conventional UAV.

But this is not the monoplane wing deep chord, as the first demonstrated by Hugo Junker's firm as early as December 1915, that the opportunity to discard any form of fuselage arose and the true flying wing could be realized. Frenchman Charles Fauvel designed the first self-stabilizing airfoil on a straight wing (AV3 glider) in 1933. The German fighter aircraft Horten Ho 229 was the world's first twin jet engine pure flying wing flown in 1944. In 1948 BICh-26 was one of the first attempts at a supersonic jet flying wing aircraft. But these designs did not offer a great advantage in range and presented a number of technical problems, leading to the adoption of "conventional" solutions like the Convair B-36 and the B-52 Stratofortress.

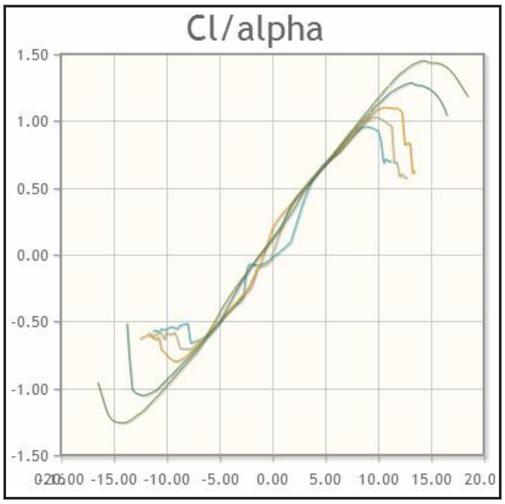

Fig. 2

Interest in flying wings was renewed in the 1980s due to their potentially low radar reflection cross-section. This approach eventually led to the Northrop B-2 spirit stealth bomber. In this case the aerodynamic advantages of the flying wing not the primary needs. However, modern computer-controlled fly-by-wire systems allowed for many of the aerodynamic drawbacks of the flying wing to be minimized, making for an efficient and long-range bomber.

II. OBJECTIVES

Objectives of present thesis work are to develop autopilot for flying wing UAV. The objectives are listed as follows:

1. Design of flying wing model.
2. To estimate the aerodynamic parameters of the model using analytical methods.
3. To developing Six DOF equation of motion for the model.
4. Simulation of Six DOF model in MATLAB.
5. Development of control laws and determination of control matrices for the model.
6. Simulation of controls in SIMULINK.

This paper presents the details explanation of 6 DOF equations of motion. It deals with the approach how to write 6 DOF equations. Starting from equation of motion of rigid body the equations for conservation of linear momentum, conservation of angular momentum, flight path equations and kinematic equations are derived for both steady state and perturbed flight.

This provides the detailed analysis of longitudinal dynamics under steady state condition as well as perturbed condition. This chapter also deals with modeling of aerodynamic coefficients associated with longitudinal dynamics, modeling of aerodynamic forces and moments associated with longitudinal motion, determination of longitudinal stability derivatives, state variable modeling of longitudinal dynamics and determination of longitudinal state matrix.

III. PROCEDURE

A. Geometric Characteristic

In this chapter the wing platform of aircraft, geometry of control surfaces, airfoil selection and relevant geometric characteristic namely aerodynamic center, center of pressure and characteristic related to airfoil are determined.

Fig. 3

B. Airfoil Selection

Flying wings are having sweep and sweep causes a performance loss which can be minimized by choosing airfoils with Cmc/4 close to zero. The other characteristic is low drag values.

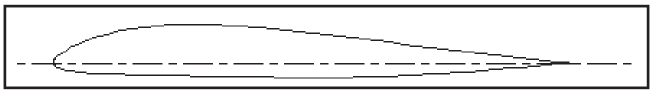

Fig. 4

This airfoil has a nose heavy moment. The center of gravity is also the center of rotation of the wing. When it is shifted behind the C/4 point, the air force L* in front of the c.g. counteracts the nose heavy moment M* to achieve equilibrium. The distance between c.g. and c/4 point is depending on the amount of M*. A symmetrical airfoil has M*=0, which means we have to place the c.g. at the c/4 point.

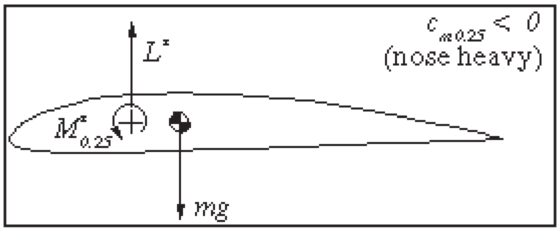

Fig. 5

The reflex camber line makes the moment coefficient positive, which means, that the moment around the c/4 point is working in the tail-heavy direction. Therefore, the center of gravity has to located in front of the c/4 point to balance the moment M* by the lift.

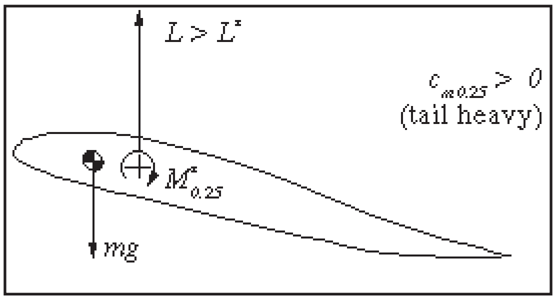

Fig. 6

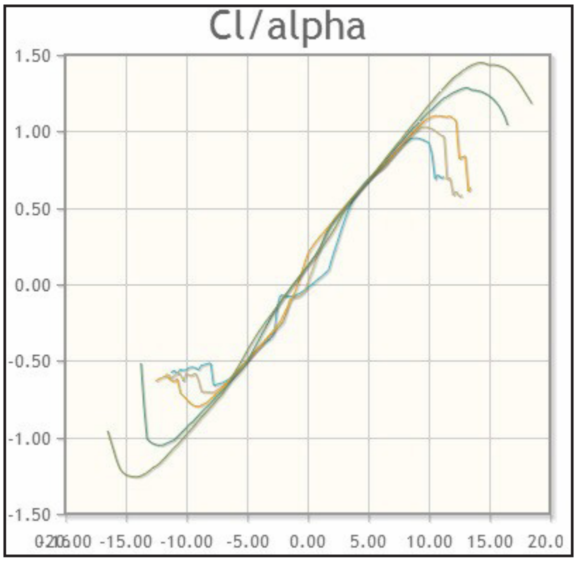

Fig. 7

IV. Results and Discussions

The state vector defines the appearance of the coefficients matrix A and the driving matrix B in equation

The state vector x has to be defined first for the longitudinal motion.

$$x = \begin{Bmatrix} v \\ \alpha \\ \theta \\ q \end{Bmatrix} \tag{1}$$

And input vector

$$u = \begin{Bmatrix} \delta_{el_{11}} \\ \delta_T \end{Bmatrix} \tag{2}$$

$$C_{D_\alpha} = \left(\frac{2C_{L_1}}{\pi.AR.e}\right) C_{L_\alpha} \tag{3}$$

Equation of motion for rigid body is derived from Newton's second law, which states:

The sum of all external forces acting on a body is equal to the time of rate of change of the momentum of the body, and the sum of external moments acting along on the body is equal to the time rate of change of moment of momentum.

The velocity of mass element can be expressed in terms of velocity of center of mass of body frame with respect to fixed frame, angular velocity of body frame (ω) and position vector of mass element.

Any two coordinate systems can be related through a sequence of three rotations. The orientation of the body frame with respect to the fixed frame can be determined in the following manner:

For dynamically stable aircraft the longitudinal characteristic equation has two pairs of Complex conjugate roots. Each pair is associated with a specific dynamic mode related to a second Order system. Longitudinal dynamic modes are called short period and phugoid modes.

The output equation is an algebraic equation, which depends solely on the state vector x and control vector u. It is expressed in the following equation.

Where, C is output matrix and D is forward matrix. The C matrix determines the relationship between the system state and the system output. The D matrix allows for the system input affecting the system output directly. A basic feedback system as used in this UAV does not have a feed forward element, and hence the D matrix is a null matrix. The state vector x has to be defined first for the longitudinal motion.

The used state vector for investigation of the stability behaviour of the longitudinal motion is

$$x = \begin{Bmatrix} v \\ \alpha \\ \theta \\ q \end{Bmatrix} \tag{4}$$

$$u = \begin{Bmatrix} \delta_{el_{11}} \\ \delta_T \end{Bmatrix} \quad (5)$$

V. CONCLUSION

The initial part of this thesis deals with the scope of UAVs and state of art in this field of research and development. This was followed by the design of tailless flying wing, estimation of parameters, determination of control matrix and final portion of this thesis deals with the design of autopilot.

The altitude hold loop has the maximum overshoot of 8% and settling time is 5 seconds which is good.

The altitude hold pilot has settling time of 8 seconds and maximum overshoot of 8% which is desirable and good for practical implementation. The steady state error is 5% which is acceptable. This steady state error can be improved by adjusting the loop gain and compromising the maximum overshoot.

The velocity hold loop is also performing satisfactorily; it has maximum overshoot of 15% and has no steady state error.

The autopilot for automatic take-off and landing can be implemented, and the autopilot can be improved for coordinated turn and pull-up maneuver.

When the elevons are deflected at higher angles the nonlinearity is introduced in the system. To overcome this problem any algorithm for nonlinear control like nonlinear dynamic inversion or gain scheduling may be implemented.

The autopilot for automatic take-off and landing can be implemented, and the autopilot can be improved for coordinated turn and pull-up maneuver. When the elevons are deflected at higher angles the nonlinearity is introduced in the system. To overcome this problem any algorithm for nonlinear control like nonlinear dynamic inversion or gain scheduling may be implemented. Some other instruments like camera, thermal image sensor or any transponder may be installed on this UAV to take some practical applications. It may be coated with some radar absorbent material to reduce it radar cross section which will be a step towards making it stealth.

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