Advances in Aircraft and Spacecraft Science, *Vol. 5, No. 1 (2018) 73-105*
DOI: https://doi.org/10.12989/aas.2018.5.1.073

Constant speed, variable ascension rate, helical trajectories for airplanes

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(Received August 25, 2017, Revised August 28, 2017, Accepted August 29, 2017)

Abstract. A particular type of constant speed helical trajectory, with variable ascension rate, is proposed. Such trajectories are candidates of choice as motion primitives in automatic airplane trajectory planning; they can also be used by airplanes taking off or landing in limited space. The equations of motion for airplanes flying on such trajectories are exactly solvable. Their solution is presented, together with an analysis of the restrictions imposed on the geometrical parameters of the helical paths by the dynamical abilities of an airplane. The physical quantities taken into account are the airplane load factor, its lift coefficient, and the thrust its engines can produce. Formulas are provided for determining all the parameters of trajectories that would be flyable by a particular airplane, the final altitude reached, and the duration of the trajectory. It is shown how to construct speed interval tables, which would appreciably reduce the calculations to be done on board the airplane. Trajectories are characterized by their angle of inclination, their radius, and the rate of change of their inclination. Sample calculations are shown for the Cessna 182, a Silver Fox like unmanned aerial vehicle, and the F-16 Fighting Falcon.

Keywords airplane helical trajectory; automatic trajectory planning; banked turn; airplane equation of motion; helical arc connection

1. Introduction

The work reported in this article is a contribution to the enterprise of endowing unmanned aerial vehicles (UAVs) with the ability to accomplish missions without human intervention. It is concerned in particular with providing airplanes with the means to re-plan their trajectory when unforeseen circumstances require them to modify their flight plan.

An efficient approach to constructing trajectories was introduced by Frazzoli *et al.* (2005). It consists in concatenating elementary trajectory segments, called motion primitives, taken from a finite library. The most often used segments are rectilinear, circular and helical. The properties of these segments could have been determined beforehand, and stored in the memory of the airplane computing device. The main advantage of this approach lies in its minimizing of the calculations since then only the connection between the segments and a few adjustments to the motion

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http://www.techno-press.org/?journal=aas&subpage=7 ISSN: 2287-528X (Print), 2287-5271 (Online)

Cylinder 80cc (ZENE80T). It weighs 34 N and outputs 4045 W at 7500 rpm. (Horizon Hobby 2017). We shall consider a Silver Fox-like UAV with such a motor.

Table 8 Characteristic parameters of the Silver Fox-Like airplane.

W_1 = 100.0 N	W_0 = 148.0 N	W_F = 19.1 N
b = 2.4 m	S = 0.768 m^2	e = 0.8
C_{Lmax} = 1.26	C_{D0} = 0. 0251	n_{max} = 5.0, n_{min} = -2.0
P_{Amax} = 4.413 kW	RPM = 7500	
Fixed pitch propeller	Diameter = 0.56 m	h_{max} = 0.77

A.3 Lockheed martin F-16

The General Dynamics/Lockheed Martin F-16 Fighting Falcon is a single-engine fighter aircraft originally developed for the United States Air Force. Its characteristic parameters can be found in Lockheed-Martin (2015), Filippone (2000) and Sadraey (2009). The maximum value of the lift coefficient and the maximum negative load factor were estimated from those of other similar fighter airplanes.

Table 9 Characteristic parameters of the F-16 fighter airplane

W_1 = 90,237.4 N	W_0 = 213,365.6 N	V_{max} = 605 m/s
b = 10.0 m	S = 27.87 m^2	e = 0.8
C_{Lmax} = 1.8	C_{D0} = 0. 026	n_{max} = 9.0, n_{min} = -3
	T_{Amax} = 131,222.5 N	