The Full – Controller for On Board Directly Platform

OCTAVIAN GRIGORE
Department of Aerospace Engineering
University "Politehnica" of Bucharest
Splaiul Independentei 313, RO-77206, Bucharest
ROMANIA

OVIDIU GRIGORE
INESC Porto
Prc, da Republica, 4050-497, Porto
PORTUGAL

Abstract:– It is known that on board of an aircraft exists some directly platforms which must to track a satellite or a fixed ground radio station for solving the navigation problem, or to track some mobile target to solve the guidance problem. In those systems that finally are automatic control systems (a.c.s.) usually the output value is the position. With the developing of the digital circuits appears the digital automatic control system. For these it was necessary to develop an especially family of actuators compatible with the digital data processing. In this paper a full directly platform controller on board of a B767 AWACS aircraft is illustrated.

Key-Words: – automatic control system (a.c.s.), directly platform, digital actuator, servomotor.

1. Introduction

Historically speaking the first a.c.s. on board an aircraft was the analogue one [5,6]. Because of the disadvantages of these (a small reliability and precision, the difficulty of a complete automation of the process due to the impossibility to memorize the analogue signal, sensitivity of the environment action) appears the necessity to implement a new category of a.c.s. Those have the data processing part made it digital and the actuators part made it analogue devices. For these the advantages are a better reliability, the increasing of the precision, the compatibility with the data buses, but the most unfavorable is the impossibility of analogue power conversion in the digital power.

By extending of the data buses on board the aircraft create the possibility to apply the actuators compatible with the digital data processing that means the stepping motors, the low-inertia DC servomotors. Because of the best speed of rotation control quality the most actuator used in a digital a.c.s. on board of an aircraft is recommended to be the DC servomotors, which usual was developed for ground domestically applications like the printers, plotters, in washing machines [9].

2. The DC servomotor used like automatic position controller

It is well known that the most a.c.s. of the position are in fact the speed regulating systems, which have the classical command schemes shown in Fig.1. [5].

Starting from the dynamical equation which characterize each part we can made the analysis of the automatic system between two-start impulse [6,7]:

- in Part 1 block, the equation of the amplifier is:

$$u_a = k_A \, u_å; \tag{1}$$

where k_A is the amplifier constant.

- in Part 3 block the equations of the DC servomotors and the mechanical load are:

$$\begin{aligned} u_a &= k_e \, \Omega + R_a i_a + L_a \frac{d i_a}{d t} \\ M_e &= M_r + J \frac{d\Omega}{d t} + B\,\Omega \\ M_e &= k_m \, i_a ; \end{aligned} \tag{2}$$

where k_e is the e.m.f. constant, R_a and L_a the resistance and inductivity of the induce, M_e the electromagnetic couple, M_r the resistance couple, J the inertia moment and B the viscous torque constant.

- in Part 2 block the equation of the speed transducer – the tacho-generator is :

$$u_{\mathrm{T}} = \mathrm{k}_{\mathrm{T}}\,\Omega. \qquad (3)$$

where k_T is the gradient factor or transfer factor of the taho-generator.

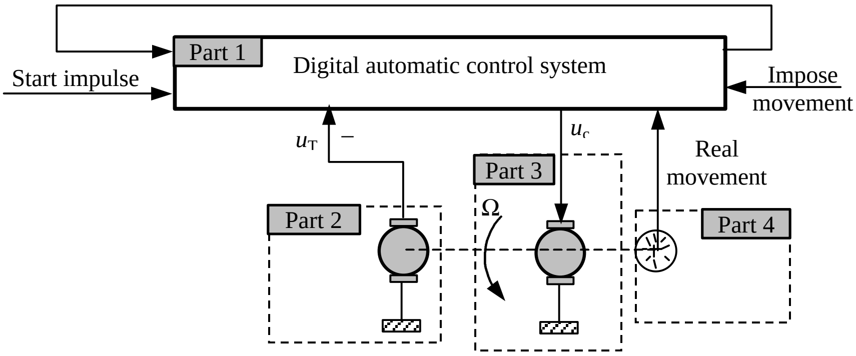


Fig.1 – The speed regulating system with impose speed profile
Part1– the digital automatic control system; Part 2 – the part of load and DC motor; Part 3– the speed transducer; Part 4– the position transducer.

How the mathematics model is linear we could apply the Laplace transformation obtained the results, in condition of using a low-inertia DC servomotors, that means $L_a \approx 0$:

$$F(s) = \frac{\Omega(s)}{u_{\mathrm{c}}(s)} = \frac{\frac{1}{s}\cdot \text{è}(s)}{u_{\mathrm{c}}(s)} = \frac{\dfrac{\mathrm{k_A}}{\mathrm{k_e}\left(1+\delta+\dfrac{\mathrm{k_A k_T}}{\mathrm{k_e}}\right)}}{1+s\,\dfrac{T_{\mathrm{m}}\,\mathrm{k_e}}{(1+\delta)\mathrm{k_e}+\mathrm{k_A k_T}}}, \qquad (4)$$

where $\delta = \dfrac{R_{\mathrm{a}}\,\mathrm{B}}{\mathrm{k_e k_m}}$ is a damping factor and $T_{\mathrm{m}} = \dfrac{R_{\mathrm{a}} J}{\mathrm{k_e k_m}}$ the motor's mechanical constant. We can see that the DC motor behave like an inertial element by first order, having a variable exponential response (Ω) in appearance of the step input (u_c). From the Eq. (1)(2) and (3) result the following:

- the incremental motion system is absolutely stable, thus the amplifier factor can be increase theoretical however much;
- the damping introduced by the viscosity braking factor *B* decrease both the DC motor's constant of time and the total damping factor;
- the amplifier factor k_a decrease the constant of time and increase the global amplifier of the system, action which lead on the extension of the system's pass band and therefore to get a faster response.

In the conclusion it can be say that intermittent positioning represents a discrete control of the position, though positioning cycle is controlled by an automatic control system of the speed. The explanation of these is that each positioning cycle is an exactly movement quantity, an incremental change of place, calling sometime step. To reduce the positioning error it must decrease the mechanical time constant, by introducing the negative speed loop, and the cancellation of the positioning errors from a cycle to another is made by the positioning loop.

3. The full control of a directly platform on board the B767 AWACS aircraft

In this paper the full control of a directly platform on board a B767 AWACS aircraft is illustrated.

The input of the incremental motion control system that command the directly platform for tracking a satellite is determined by designing first an automatic flight control system that track the mobile target (assumed in our case to be a satellite). Also it assumes that the motion of the jet transport aircraft is uncoupled, means that we can study the motion independently in vertical plane and in horizontal plane, planes where it can define a line between the aircraft and satellite which it called the line of sight plane (Fig.2).

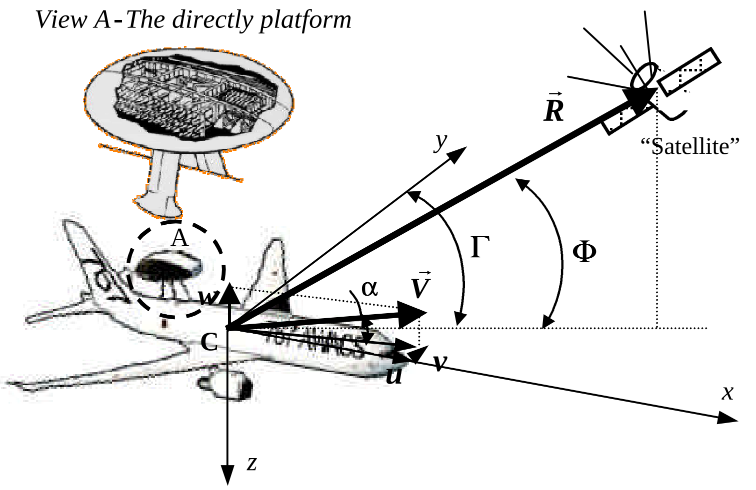


Fig.2 – The kinematics system and the parameters needs in a tracking scenario

In figure above Φ is the line of sight angle in vertical plane and Γ in longitudinal plane, *R* the distance between aircraft and target (satellite). For the motion equations of the aircraft I considered the following conditions: the flight is cruising in horizontal flight at approximately 40000 ft at Mach number 0.8. For these conditions the relevant data of B767 AWACS jet aircraft are shown in [3,10].

With these data it can be calculated the system matrix $\boldsymbol{A}$ for the state vector $\boldsymbol{x}^T = [u \quad w \quad q \quad \theta]$ for longitudinal mode and the state vector $\boldsymbol{x}^T = [v \quad p \quad r \quad \phi]$ for lateral mode:

$$\boldsymbol{A_{long}} = \begin{bmatrix} -0.00725 & 0.02012 & 0 & -28.2 \\ -0.08125 & -0.2191 & 653.98 & 0 \\ 0.000187 & -0.0026 & -0.2285 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix};$$

$$\boldsymbol{A_{lat}} = \begin{bmatrix} -0.0832 & 0 & -197.9 & -28.2 \\ -0.00468 & -0.3421 & 0.3163 & 0 \\ 0.00286 & -0.0041 & -0.3482 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix},$$

where: *u* is the *x* component of airspeed vector of airplane mass center ***V***;

w – the *z* component of airspeed vector of airplane mass center ***V***;

q – the *y* component of angular velocity vector of the airplane ω;

θ – the *y* component of attitude angles – pitch angle;

v – the *y* component of airspeed vector of airplane mass center ***V***;

p – the *x* component of angular velocity vector of the airplane ω;

r – the *z* component of angular velocity vector of the airplane ω;

ϕ – the *x* component of attitude angles – bank angle,

and the command matrix ***B*** for the command vector $\boldsymbol{u}^T = [\delta_e \quad \delta_t]$ for longitudinal mode and $\boldsymbol{u}^T = [\delta_r \quad \delta_a]$ for lateral mode:

$$\boldsymbol{B_{long}} = \begin{bmatrix} -0.000237 & 7.58 \\ -13.25 & 0 \\ -2.58 & 0 \\ 0 & 0 \end{bmatrix};$$

$$\boldsymbol{B_{lat}} = \begin{bmatrix} 0.12 & 6.82 \\ -0.1354 & 0.2434 \\ 0.00745 & -0.8157 \\ 0 & 0 \end{bmatrix},$$

where: d_e is the elevator command of airplane;

d_t is the throttle command;

d_r is the ruder command;

d_a is the aileron command.

As it known the stability of the airplane is governed by the real parts of the eingenvalues, the roots of the characteristic equation of the state matrix $\boldsymbol{A_{long}}$ and $\boldsymbol{A_{lat}}$. Also from these equation it could be calculated the characteristics of the movement which are represented in Table 1.

Table 1 The Modes characteristic of B767 AWACS Aircraft

Mode	Name	T(s)	$t_{response}$(s) / $^*t_{half}$(s)	ζ
1	***Phugoid***	87.34	954.16	0.035
2	***Short-period***	5.67	8.94	0.29
3	***Spiral***	–	* 75	–
4	***Rolling***	–	* 1.3	–
5	***Lateral oscillation***	4.64	* 19.5	–

From Table 1 it can see that the natural modes are two damped oscillations, one of long period and light damped and the other of short period and heavily damped, two convergence's, one very slow and one very rapid, and the latest mode is a lightly damped oscillation. This result is quite typical for a jet transport aircraft.

Like commands I choose for the elevator $\delta_{e,max}$ = 2°, for the throttle $\delta_{p,max}$= 2, command which corresponds to a thrust increment of 0.5 W, for the ruder $\delta_{r,max}$ = 5° and for the aileron $\delta_{a,max}$ = 1°.

In figures 3, 4, 5 and 6 are represented the aircraft trajectory, the line of sight angle Φ in longitudinal plane and line of sight angle Γ in lateral plane, angles which command the directly platform in longitudinal plane, respectively in lateral plane. First to verify the automatic control system of the position we consider in Fig.3 for R_0=480 km that Φ_0=0° and Γ_0=15° case unreal (the B767 aircraft couldn't flies at the same altitude with the satellite) [7,10]. The next step is to simulate in Fig.5 a real case that means R_0=480 km, Φ_0= –60° and Γ_0= –25°.

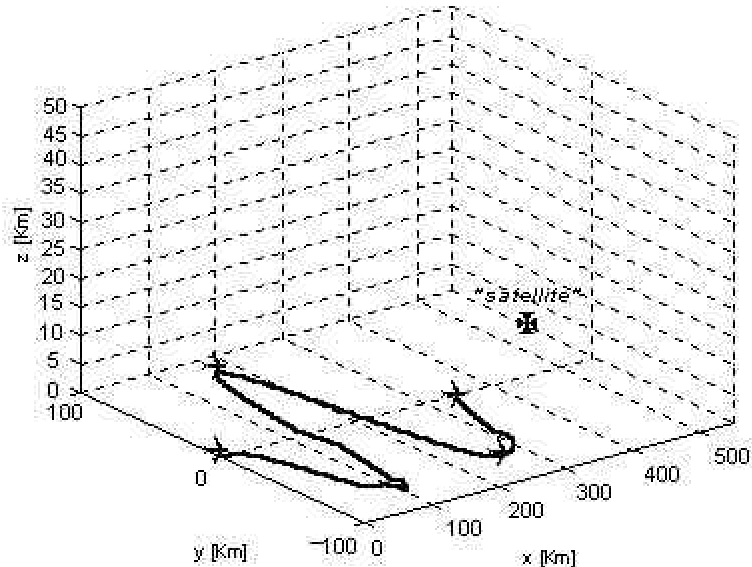
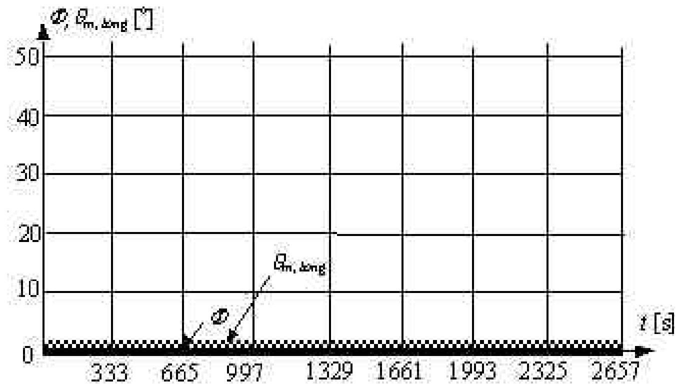
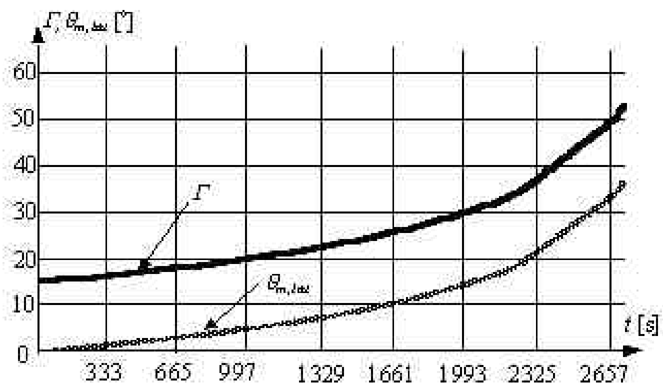


Fig.3 The trajectory of B767 AWACS aircraft for R = 480 km, Φ_0 = 0° and Γ_0 = 15°





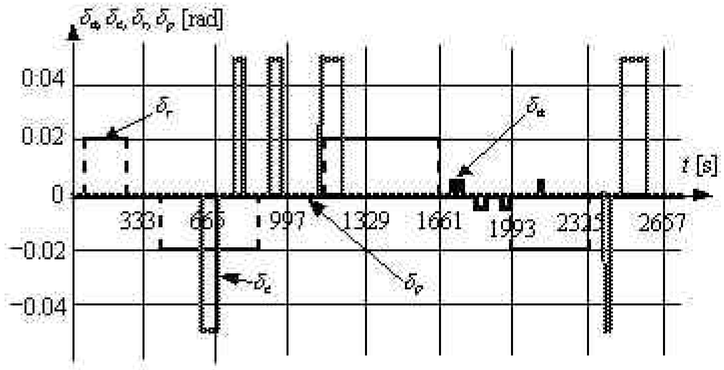


Fig.4 The tracking system parameters for R = 480 km, Φ_0 = 0° and Γ_0 = 15° with command (δ_p= 0°, $\delta_a \neq 0$, $\delta_e \neq 0$ and $\delta_r \neq 0$)

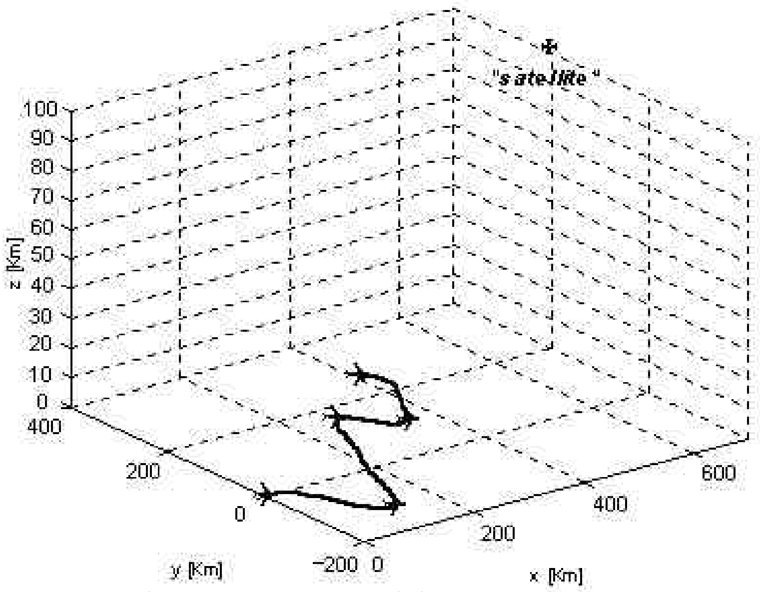


Fig.5 The trajectory of B767 AWACS aircraft for R = 480 km, Φ_0 = –60° and Γ_0 = –25°

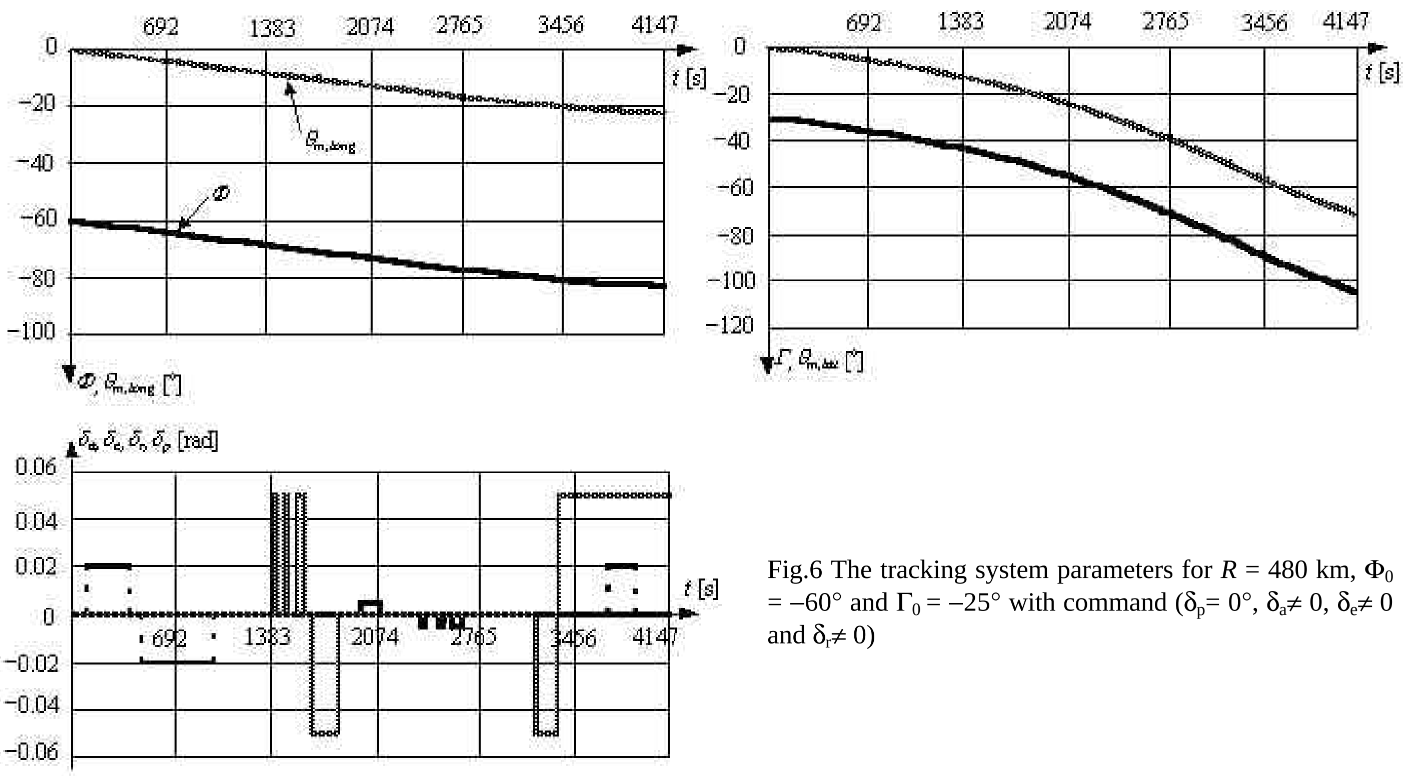


Fig.6 The tracking system parameters for R = 480 km, Φ_0 = –60° and Γ_0 = –25° with command (δ_p= 0°, $\delta_a \neq 0$, $\delta_e \neq 0$ and $\delta_r \neq 0$)

These angles (Φ and Γ) with aide of a taho-generator, that has the constant k_T= 2°/V·s, are transformed in the command tension u_c. The characteristics of DC servomotor are the following:

- the resistance of induce: $R_a = 1.64\ \Omega$;
- the inductance of induce: $L_a << R_a \Rightarrow L_a \approx 0\ \Omega$;
- rated voltage: $U_a = 28$ V;
- the inertia moment: $J = 3.5 \cdot 10^4$ kg/m^2;
- viscous torque constant: B = 0.013 N·m;

The others characteristic from the command schema are (Fig.1):

- the amplifier constant: $k_A = 100$;
- the couple constant: $k_m = 10,5$ V;
- the constant of position transducer: $k_p = 0.5°/V$.

With these the DC servomotor rotation speed (4) are:

$$\grave{e}_m(s) = \frac{1}{s}\frac{\dfrac{100}{6\left(1+0.0003+\dfrac{100\times 2}{6}\right)}}{1+s\dfrac{820\times 6}{(1+0.0003)6+100\times 2}}u_c(s) = \frac{1}{s}\frac{\dfrac{100}{6\left(1+\dfrac{100\times 2}{6}\right)}}{1+s\dfrac{820\times 6}{6+100\times 2}}u_c(s) = \frac{1}{s}\frac{0.48}{1+23.88s}u_c(s) =$$

$$= \frac{1}{s}\frac{0.02}{s+0.04}u_c(s) = \frac{0.5}{s} - \frac{0.5}{s+0.04}u_c(s)$$

Applying the inversion of Laplace transformation we obtain the variation of DC servomotor rotation speed in time:

$$\grave{e}_{m,long}(t) = 0.5\left(1-\mathrm{e}^{-\frac{t}{0.04}}\right)u_c(t) =$$

$$= 0.5\,\mathrm{e}^{-\frac{t}{0.06}} \cdot 1.8 \cdot 57.2 \cdot \Phi(t)$$

for longitudinal plane and

$$\grave{e}_{m,lat}(t) = 0.5\left(1-\mathrm{e}^{-\frac{t}{0.04}}\right)u_c(t) =$$

$$= 0.5\,\mathrm{e}^{-\frac{t}{0.06}} \cdot 1.8 \cdot 57.2 \cdot \Gamma(t)$$

for lateral plane, which are represented in figures 4 and 6.

4. Conclusion

Speaking from the quality point of view it can see from figures above that the DC servomotors tracking well the line of sight angles, that means in the end the satellite target. So these drives (DC servomotors) with digital command can substitute the old continue system of drives and position, which use the gyroscope.

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