ZESZYTY NAUKOWE AKADEMII MARYNARKI WOJENNEJ
SCIENTIFIC JOURNAL OF POLISH NAVAL ACADEMY

2015 (LVI) 2 (201)

DOI: 10.5604/0860889X.1172066

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ANALYSIS OF SELECTED VARIABLES CHARACTERISING THE MANOEUVRE FOR MOVING OBSTACLE AVOIDANCE

ABSTRACT

The article is focused on the results of analysis aimed at selected variables, which are found to be important for the automatic flight control in case of passing by a moving obstacle. Considerations are focused on parameters describing an aircraft — moving obstacle system. Numerical simulation of the selected anti-collision, automatically controlled manoeuvre has been carried out. On the basis of this example, the effect has been analysed that parameters, found to be necessary for the realisation of such a manoeuvre, exert on state variables and variables describing the relations between discussed objects. The results obtained can be treated as the source of information opening the deeper insight into a behaviour of the controlled aircraft in case of known scenario of obstacle's motion.

Key words:
obstacle avoidance, anti-collision systems, computer simulation, flight dynamics.

INTRODUCTION

In order to get the on-board anti-collision system satisfying high requirements, among others a precise analysis of motion of either flying object or the obstacle's is necessary. This is of fundamental significance for synthesis of algorithms and structure of automatic flight control covering an appropriate reaction to collision threat [3, 7]. A manoeuvre carried out by the aircraft to avoid a moving obstacle is a complex task due to a considerable number of variables defining the process of

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manoeuvre execution. On one hand, these variables influence in several degrees on threat conditions [3]. On the other hand they are related by complex relationships. In the article the proposition is taken up to present a choice of essential variables. The analysis has been carried out on the basis of an example of complex manoeuvre performed to avoid a moving obstacle. Its course has been discussed for the selected scenario of aircraft — obstacle configuration. An approach proposed in the article, makes use significantly of results obtained by numerical simulation of obstacle avoiding manoeuvre. The work is a continuation of the research on the development of anti-collision system cooperation with other on-board automatic control systems.

ANALYSED VARIABLES DETERMINING AN EVASIVE MANOEUVRE

Cooperation of elements of analysis of an obstacle avoidance manoeuvre are presented in scheme (fig. 1).

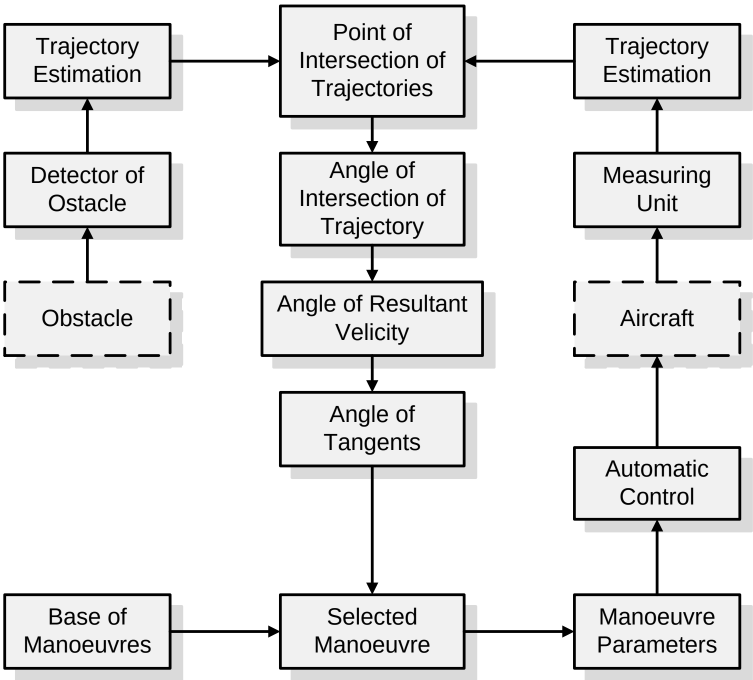

Fig. 1. Block diagram illustrating the cooperation between units of the analysis of evasive manoeuvre against a moving obstacle

Detection and identification of previously unknown obstacle by the obstacle detector [2] with estimation of both aircraft's and obstacle's trajectories define the necessary phase of safety manoeuvre selection process. This selection should be preceded by the analysis of variables characterising the motion of both: the aircraft and the obstacle. The analysis of the following variables is proposed: angle and crossover point of trajectories, angles of resulting velocities of the aircraft and obstacle and angles of tangents to the circle of r_{CMB} radius (fig. 2). This analysis was carried out on the basis of computer simulation of mathematical model of aircraft's motion with several values of object's forward speed. The details of simulation process are presented further. Complementary variables subjected to analysis were time-error (time delay) of the moment the evasive manoeuvre starts as well as, angles and components of angular rate describing the spatial attitude of the aircraft.

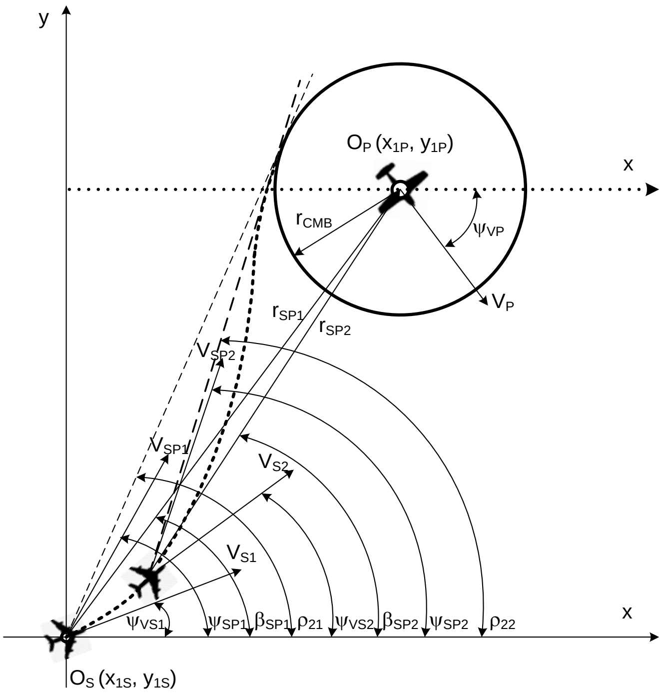

Fig. 2. Variables describing the aircraft — obstacle configuration;
O_Sxy — Earth reference systems (O_Sx — E, O_Sy — N)

Mathematical relationships describing selected variables [1], illustrated in figure 2 for two positions of the aircraft (indices 1 and 2), are presented in further part of this paragraph. Angles of tangents to the circle with the radius r_{CMB} are:

$$\rho_1, \rho_2 = \beta_{SP} \mp \arcsin(r_{CMB} / r_{SP}), \quad (1)$$

where the following relationship describes the line of sight angle β_{SP}:

$$\beta_{SP} = arctg((y_{1P} - y_{1S})/(x_{1P} - x_{1S})). \quad (2)$$

The distance between objects:

$$r_{SP} = \sqrt{(x_{1P} - x_{1S})^2 + (y_{1P} - y_{1S})^2}. \quad (3)$$

The angle of resultant velocity vector (for both: the aircraft and the obstacle) is:

$$\Psi_V = arctg((\dot{y}_{1S} + \dot{y}_{1P})/(\dot{x}_{1S} + \dot{x}_{1P})). \quad (4)$$

When the information of obstacle is obtained, the important question remaining to be solved is the analysis whether the collision threat appears. To do this, we check whether the following three inequalities are satisfied:

$$\Psi_V > \rho_1 \quad \wedge \quad \Psi_V < \rho_2 \quad \wedge \quad r_{SP} > r_{CMB}. \quad (5)$$

First two conditions are equivalent to the requirement that the resultant velocity vector V_{SP} lies between tangents to the circle. Limits of position of this vector are on one of tangents. The third inequality (5) defines the condition of minimum distance to the obstacle.

TRAJECTORY OF PASSING-BY A MOVING OBSTACLE

Determination of the shape of trajectory to evade a moving obstacle is aimed at getting a more effective control over the safety of anti-collision manoeuvre. Among others, the questions of restricting the number of elementary manoeuvres to the minimum and reaching the most possible unification were considered. This last demand is aimed at simplification of trajectory shaping process, while carried out on the basis of relatively small number of parameters. A scenario illustrated in figure 3 was selected to show the trajectory evading a moving obstacle and then returning to previously realised flight plan. Two parameters were used above all for trajectory shaping: a desired roll angle and desired change of yaw angle, both defined for turning manoeuvre. Three turns were necessary to execute the presented manoeuvre: the first and the third to the left and the second to the right, each one with 60° roll angle (fig. 3). The first turn, executed in time interval from t_{PM} to t_{RT1} assured the collision avoidance — it results in about 40° change of yaw. The second one, executed in time interval from t_{RT1} to t_{RT2}, assured the safe passing by the obstacle — it results in about 90° change of yaw. The third one, lasting from t_{RT2} to t_{KM} assures returning to the flight trajectory, which was planned before the first turn. During the last turn the change of aircraft's yaw is about 40°. During this complex manoeuvre the maximum distance between the aircraft and the trajectory of previously planned flight plan equals: d_{OT} = r_{CMB}, where the radius is a sum of aircraft's and obstacle's dimensions plus safety margin.

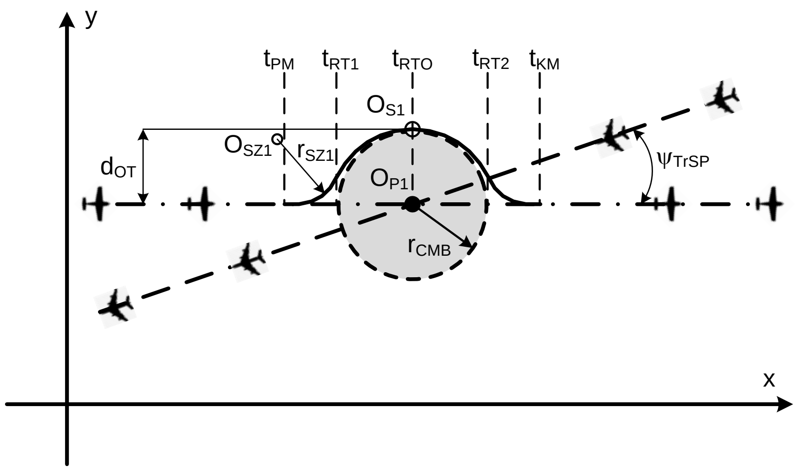

Fig. 3. Trajectory of the manoeuvre to evade a moving obstacle

RESULTS OF NUMERICAL SIMULATION OF PERTURBED FLIGHT

The mathematical model of I-23 Manager aircraft was used in numerical simulations (see e.g. [4, 6]). The actuating units of flight control system were represented by simplified models of linear, first order inertia forms. For all of control surfaces the appropriate limits for the rates of deflection were introduced. The system of equations of motion were solved by MatLab software environment, using the 'rk4' numerical procedure with 0.01 s time step. The object was flying with constant velocity at constant altitude $H_S = 200\,m$. The obstacle was moving at the same altitude with $V_P = 72\,m/s$ velocity, along the trajectory crossing the aircraft's trajectory with the angle Ψ_{TrSP} = 50°. All of elementary turning manoeuvres were completed with the desired value of roll angle: Φ_{ZS} = 60°. Simulations of flights with three velocities: 40 m/s, 50 m/s and 60 m/s were carried out.

The described motion of aircraft is characterised by the illustrated variations of roll and yaw angles (fig. 4) and angular roll rate (the first curve in fig. 5).

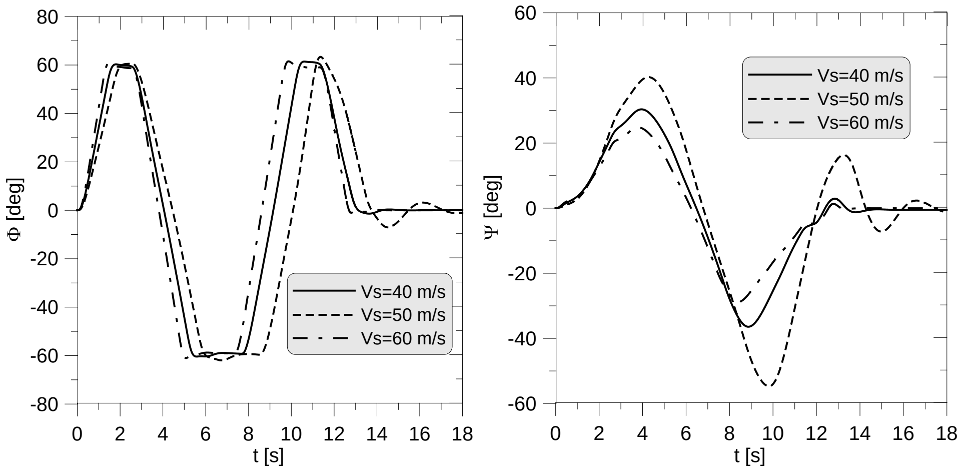

Fig. 4. Roll and yaw angles of aircraft's motion

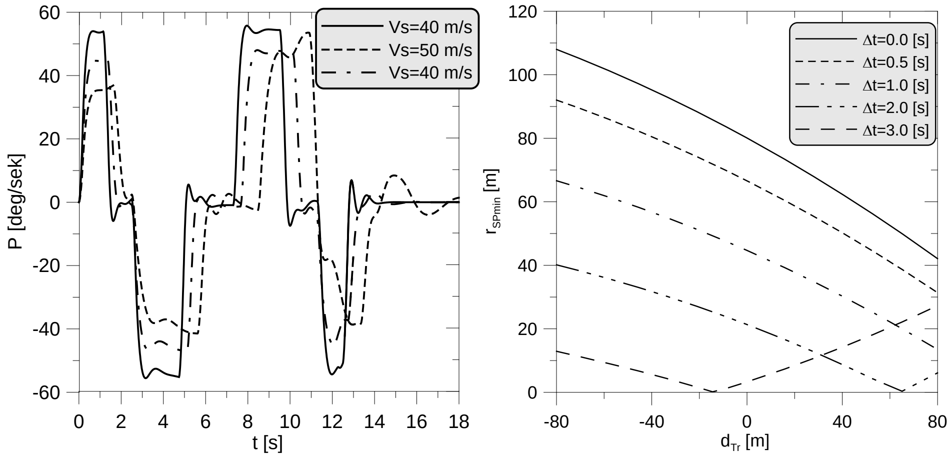

Fig. 5. Angular rate of pitching motion and minimum distance to the obstacle

From the perspective of flight safety, a minimum aircraft to obstacle distance (r_{SPmin}) is a crucial parameter for a flight threaten by collision. It depends, among others, on a difference between real and recommended moments the execution of manoeuvre starts. Curves (the second diagram in fig. 5) represent some selected cases of a start of manoeuvre delayed in relation to recommended moment. In passing-by manoeuvre the r_{SPmin} value also depends on position of the intersection point O_{P1} of both trajectories (fig. 2). The axis of abscissae (fig. 5) represents the distance d_{Tr} from O_{P1} point to the point, which the aircraft reaches with no anti-collision manoeuvre executed at the moment when the obstacle reaches the O_{P1} point. The key point for a passing-by process is the relationship between of ρ_1 and ρ_2 angles of tangents do the circle of r_{CMB}=80 m radius (fig. 6) and the angle of resulting velocity vector Ψ_V. The assumed safety margin equals 60 m and determins the value of radius. The first diagram in figure 6 illustrates the case, where the collision threat was eliminated temporarily after 3.25 seconds from the start of the passing-by manoeuvre. However, an attempt of returning too early to previously realised trajectory, results in repeating of collision threat after 5.5 seconds and, as a cosequence, in a drop of safety margin below the demanded level. The second diagram in figure 6 illustrates the correctly executed passing-by manoeuvre, where the collision threat was rejected once for all during the time interval of similar length 3.25 seconds, keeping a demanded safety margin. Trajectories of the aircraft and the obstacle (fig. 7) illustrate the case. Subsequent positions of both: the aircraft (smaller circles) and the obstacle (bigger circles) are marked every two seconds.

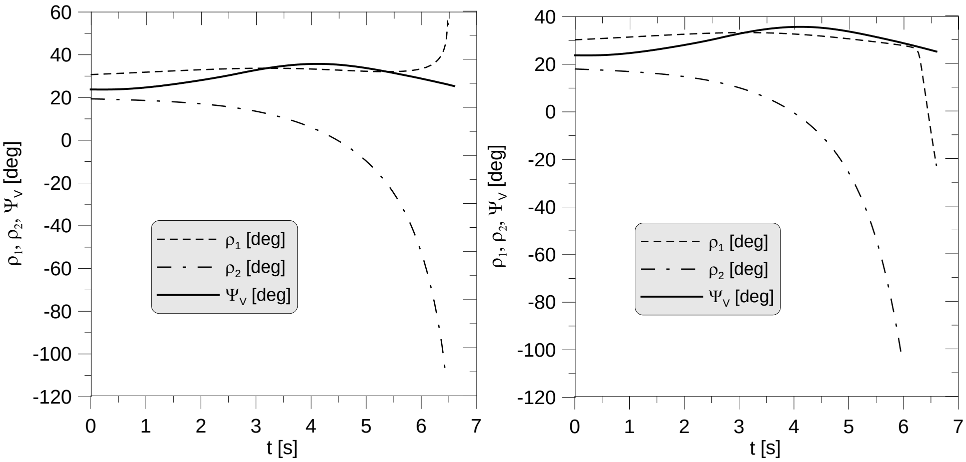

Fig. 6. Angles of tangents and angle of resulting velocity vector:
I — incorrect manoeuvre, II — correct manoeuvre

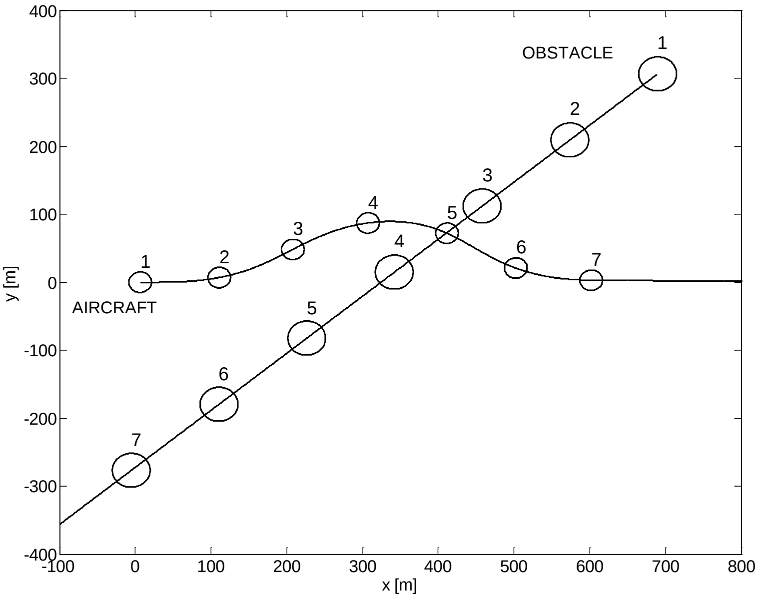

Fig. 7. Trajectories of the aircraft and the obstacle

CONCLUSIONS

The article describes a selected class of complex manoeuvres, that can be used to avoid a moving obstacle and return to execution of interrupted flight plan. Presented guidelines enable a choice of parameters characterising the selected manoeuvre. Presented proposition facilitates a selection of manoeuvre's run by making this process depended on two parameters as well as on similarity of elementary manoeuvres.

Results of flight simulation covering the evasive manoeuvre against moving obstacle have shown regularities characterising the behaviour of variables which are important from the flight safety point of view. Relation between the angle of resulting velocity vector and the angle of tangent ρ_1 has turned to be decisive in considered case. Keeping the Ψ_V value bigger than ρ_1 for a some time-interval do not guarantee a rejection of collision threat once and for all. A proof for elimination of collision threat for sure is the time interval t_{SW}, long enough, with the condition (5) being satisfied. When the sudden drop of ρ_1 value occurs, the t_{SW} value is sufficient. Further numerical simulations are necessary to specify the last thesis precisely.

REFERENCES

[1] Ariyur K. B., Lommel P., Enns D. F., *Reactive in flight obstacle avoidance via radar feedback*, Portland 2005.

[2] Graffstein J., *Anti-collision system with radar obstacle detector*, 'Pomiary, Automatyka, Robotyka', 2013, No. 2, pp. 171-175.

[3] Graffstein J., *Elementy procesu wykrycia zagrożenia kolizją i automatycznie sterowany manewr awaryjny*, 'Pomiary, Automatyka, Robotyka', 2012, No. 2, pp. 383-387 [*Elements of collision threat detection process and automatically controlled emergency manoeuvre* — available in the Polish language].

[4] Graffstein J., *Wpływ wybranych zmiennych stanu na dokładność toru lotu samolotu podczas automatycznie wykonywanego manewru*, 'Prace Instytutu Lotnictwa', 2009, No. 202, pp. 51–64 [*An influence of selected state variables on accuracy of aircraft trajectory during automatically controlled manoeuvre* — available in the Polish language].

[5] Lalish E., Morgansen K. A., Tsukamaki T., *Decentralized Reactive Collision Avoidance for Multiple Unicycle-TypeVehicles*, American Control Conference, St. Louis 2009.

[6] Maryniak, J., *Ogólny model matematyczny sterowanego samolotu*, conference 'Mechanika w Lotnictwie', PTMTiS, Warszawa 1992, pp. 575-592 [*General mathematical model of a controlled aircraft* — available in the Polish language].

[7] Shim D. H., Sastry S., *An evasive maneuvering algorithm for UAVs in see-and-avoid situations*, American Control Conference, New York 2007, pp. 3886-3891.

ANALIZA WYBRANYCH ZMIENNYCH CHARAKTERYSTYCZNYCH DLA MANEWRU OMIJANIA RUCHOMEJ PRZESZKODY

STRESZCZENIE

W artykule przedstawiono wyniki analizy wybranych zmiennych istotnych z punktu widzenia automatycznego sterowania samolotem podczas omijania ruchomej przeszkody. Rozważania dotyczyły przebiegu parametrów opisujących układ samolot — ruchoma przeszkoda. Przeprowadzono numeryczną symulację wybranego automatycznie sterowanego manewru antykolizyjnego. Na tym przykładzie przeanalizowano wpływ parametrów niezbędnych do jego realizacji na zmienne stanu lotu samolotu i zmienne opisujące wzajemne relacje omawianych obiektów. Uzyskane wyniki stanowią źródło informacji pozwalających na lepsze zrozumienie zachowania sterowanego samolotu dla znanej konfiguracji ruchu przeszkody.

Słowa kluczowe:
omijanie przeszkód, systemy antykolizyjne, komputerowa symulacja, dynamika lotu.