MATHEMATICAL MODELING FOR STUDYING THE CONDITIONS OF AIR AMMUNITION WARFARE

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Abstract

Experience of ammunition warfare has shown that a store at the start leg of its flight toward a target when relative velocity of the store with respect to the aircraft is small and the store moves inside the compartment or near the aircraft, the store experiences additional aerodynamic forces and moments due to interference with the aircraft. The magnitude of these forces (depending on different conditions) can exceed 3 to 5 times its own weight for small caliber stores (air guided missiles or unguided rockets) and can amount to as much as 80% of the own weight for large caliber stores (air bombs, heavy air-to-surface or air-to-air guided missiles). Interaction of • store and disturbed airflow near the aircraft yields significant oscillations of the store. This can lead to the following effects: store reentry into a compartment; store-to-store collision; store-to-aircraft collision; gas dynamics stability loss of the aircraft power plant due to the store jet engine entering into the aircraft air intake; thermo-damage of the aircraft surface due to the store jet engine action; deterioration of unguided rocket accuracy performance; violation of conditions for normal functioning of the store control and guidance systems, for example, crossing of the admissible limits for load factors, angular rates, target aspects, etc.
All these phenomena have occurred in practice, and thus reinforces the inportanse of improving air ammunition safety and performance by modeling its start regimes.

Most of the known approaches to store separation simulation can be divided into four large groups: computer simulation; simulation in wind tunnels; combined methods based on computer simulation of store dynamics using experimental information on aerodynamic disturbances near the aircraft; and flight experiment.

Since store separation conditions depend on various factors (including the aircraft maneuver type, ACC flight regime, store location types, store separation process, etc.), experimental investigation of store separation trajectories in the aircraft warfare operating range is very bulky, expensive, and sometimes dangerous. Therefore, in Russia and in other countries, mathematical methods of store separation simulation are being devised intensively.

Most approaches to mathematical simulation of store separation are based mainly on steady aerodynamic models and consider only unilateral aerodynamic influence of the aircraft on stores. For this reason they cannot be used for store separation process investigation in the wide range of aircraft warfare.

For solution of the problem the authors have developed store separation calculation methods for internal and external placement of stores. These methods are adapted to conventional and new (from the upper side of wings and the rear hemisphere of the aircraft) procedures of store separation and are based on the synthesis of the following theories: unsteady dynamics, aerodynamics, and aeroacoustics of the aircraft (calculation of aerodynamic disturbances); unsteady aerodynamics of a store; unsteady aerodynamic interaction of a store with nonhomogeneous airfield disturbed by ACC; and store ballistics.

1 Introduction

The contemporary phase of aviation development is characterized by increasing types of aviation stores of various purposes. Widening the aircraft (A/C) flight range for store separation adds to the complexity of the problems related to necessary safety and accuracy of hitting targets.

Investigations show that aerodynamic characteristics and kinematic parameters of air ammunition (AA) near A/C considerably differ from the corresponding characteristics and parameters of AA far from A/C. For example, the magnitude of aerodynamic forces can exceed 3 to 5 times its own weight for small caliber stores (air guided missiles or unguided rockets) and can amount to as much as 80% of the own weight for large caliber stores (air bombs, heavy air-to-surface or air-to-air guided missiles). The conditions of AA movement near A/C influence also the rest part of the AA trajectory. Numerous cases of impacts of AA with A/C resulting in accidents and incidents could be seen in practice.

As store separation conditions depend on numerous factors (A/C maneuver, its flight mode, store position and separation mode, etc.), the experimental study of store trajectories in the whole range of A/C flight conditions is extremely bulky and expensive. The mathematical methods give the possibility of reducing experiments in wind tunnels and in real flights. Most of the known approaches to store separation simulation can be divided into four large groups: computer simulation; simulation in wind tunnels; combined methods based on computer simulation of store dynamics using experimental information on aerodynamic disturbances near the aircraft; and flight experiment.

The traditional approaches to simulation of store motion under aerodynamic interference with A/C have some disadvantages. First, to evaluate aerodynamic forces and moments acting on AA one must solve the corresponding aerodynamic problem at each timestep of integration of the store motion equations. This leads to increase of calculation time, complicates the code debugging and testing, and requires high qualification of the users. Secondly, evaluation of aerodynamic forces and moments is performed commonly according to steady aerodynamic models, and it is not necessarily adequate to the real processes. Thirdly, the A/C disturbed motion caused by store separation does not receive proper attention. Finally, it should be noted that experimental studies generally give no way of deducing the contribution of each of the different factors in the integral effect.

The above disadvantages are eliminated in the approach developed by the authors. The approach gives the possibility of dividing the aerodynamic and dynamic problems and use in full measure most comprehensive aerodynamic and dynamic models.

In accordance with the proposed approach, the AA aerodynamic forces and moments necessary for the closure of the motion equations are evaluated using the authors' method of decomposition of the disturbed flow velocities near the AA with respect to the given set of base functions. The use of the method reduces to evaluation of the disturbed velocities at some points fixed on the AA surface. The summation of some known linear functions of these values gives the AA aerodynamic forces and moments.

As a result of the authors' studies, a set of aerodynamic and dynamic models of the both AA and A/C has been developed for solution of the wide range of problems. In particular, the following investigations have been performed: bombing and launching air rockets (AR) from aircraft flying with subsonic and supersonic speed, launching AR from helicopters, launching AR from aircraft rearward, and launching missiles from the upper surface of aircraft wings. Some, most interesting from the authors' view results are presented in this paper.

2 Launching Rockets from Helicopters

Simulation of launching AR from helicopters shows the increase of the AR pitch and flight path angle owing to the helicopter rotor flow.

This is due to the fact that the vertical flow induced by the helicopter rotor generates the downwash on the AR surface. As the AR is aerodynamically stable, it turns in the direction opposite to that of the flow. Therefore, the effect of the helicopter rotor flow leads to the shot over the target if this effect does not take into account by the helicopter sight. It should be noted that the rotor effects depend on the AR position on the helicopter.

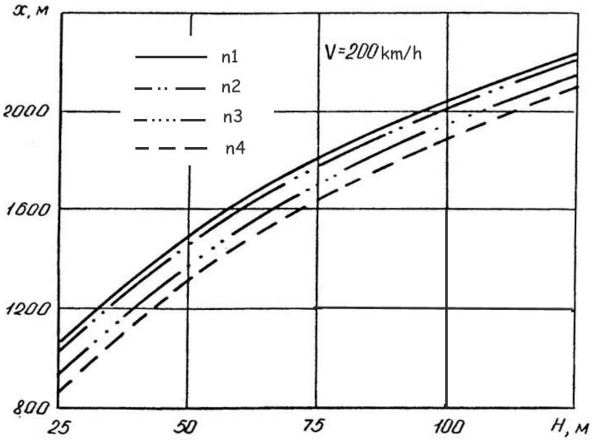

Fig. 1

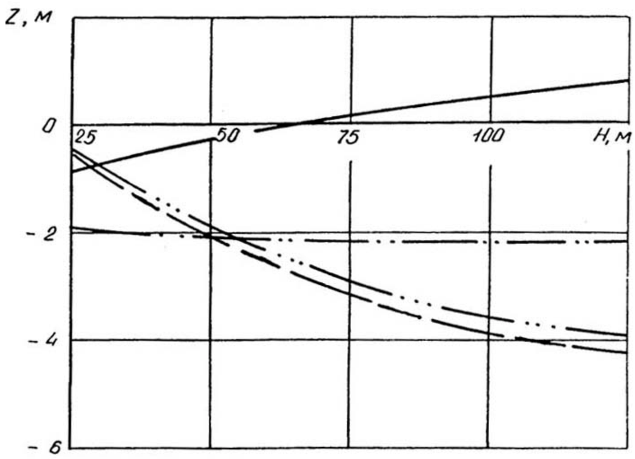

Fig. 2

Figs. 1 and 2 show the ground hitting coordinates, the longitudinal coordinate *x* and the side coordinate *z*, of the small caliber AR in the ground fixed coordinate system (the *x*-axis is in the helicopter flight direction and the *z*-axis is in the starboard direction; the coordinate origin is at the point of projection of the helicopter mass centre on the ground at the moment of the rocket launching) for different helicopter flight altitudes and different positions on the helicopter: n1 is for the port outboard point, n2 for the port inboard point, n3 for the starboard inboard point, and n4 for the starboard outboard point. The helicopter flights horizontally with the speed 200 km/h. The difference in the ground hitting coordinates *x* for different initial AR positions is up to 160 m. The side variations are rather small: in the presented case they do not exceed 5 m.

Among the helicopter flight parameters (speed, altitude, diving angle, etc.), the speed and diving angle have the maximum influence on the disturbed flow structure, and hence, on the ground hitting coordinates *x*. The calculations show that the increase in *x* (with respect to the value of *x* without account of the disturbed flow) decreases with the increase of the helicopter flight speed. For example, the increase in the flight speed from 100 km/h to 300 km/h for AR launching at the distance 2000 m decreases the difference in shots over the target from 280 m to 30 m.

To study AR serial launches from helicopters one must take into account effect of kickback forces on helicopters. These forces lead to reduction of the helicopter fuselage pitch by several degrees. Such a ‘peck’ leads to reduction of the ground hitting coordinates *x* for each of the following rocket in the series. A typical image of the ground hitting point distribution for small caliber AR serial launching is presented in Fig. 3. Here the coordinate origin is at the point of projection of the helicopter mass centre on the ground at the moment of launching the first rocket and *n* is the rocket number in the series of total 64 AR. The saw-tooth shape of the graphs is due to AR launching from different rocket blusters.

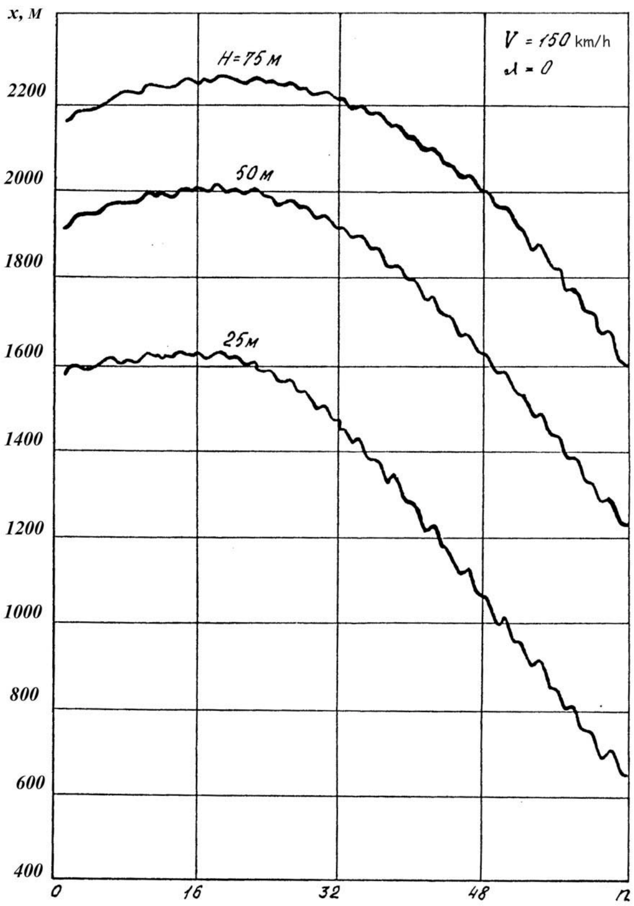

Fig. 3

3..Launching Rockets from Aircraft Rearward

One of the interesting AR launching modes from aircraft is the launching rearward. Such the mode generates several problems, in particular, AR are unstable when moving rearward (the AR speed vector is from the AR nose to its tail) at the start leg leading to their poor accuracy. Therefore, it is necessary to have some means for providing the reasonable level of accuracy. Aerodynamic disturbances near the aircraft considerably change the distribution of the ground hitting points of AR and add to the problem complexity.

Figs. 4 and 5 show the simulation results for AR trajectories without aerodynamic disturbances (Fig. 4) and with them (Fig. 5). The aircraft flights horizontally with the altitude 300 m and the angle of attack α = 7°. The aircraft Mach numbers, M, are shown in the figures. Here *X* and *Y* are the coordinates of moving rockets in the coordinate system fixed at the rocket initial position at the aircraft (the *X*-axis is in the aircraft flight direction and the *Y*-axis is upward). One can see that for M = 0.35 the difference in the ground hitting point values with aerodynamic disturbances and without them is about 200 m. This difference increases with M and gains 1200 m for M = 0.65. Hence, aerodynamic interference of the AR and the aircraft should be necessary taken into account.

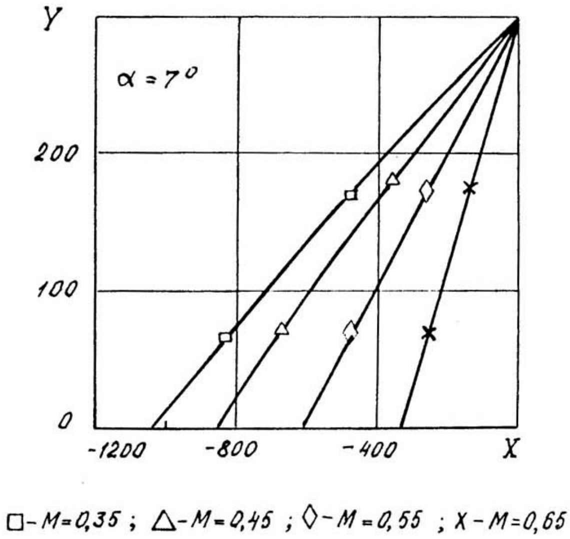

Fig. 4

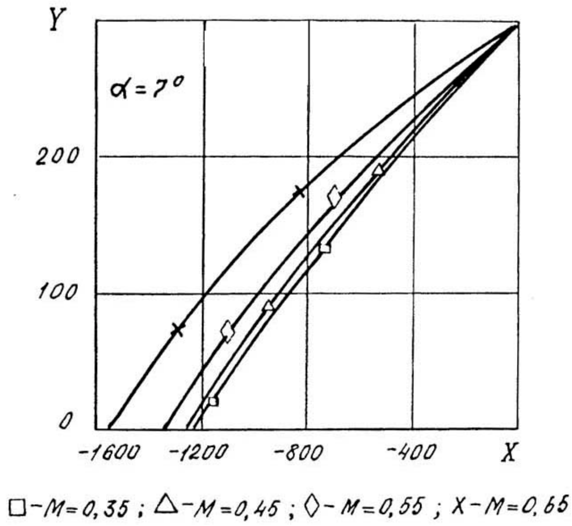

Fig. 5

The similar picture is for the change in the aircraft angle of attack, α. Figs. 6 and 7 show the results for M = 0.55. The difference in the ground hitting point values with aerodynamic disturbances and without them is small for low values of α. For example, it is about 200 m for α = 2°. This difference increases with α and is more than 700 m for α = 7°.

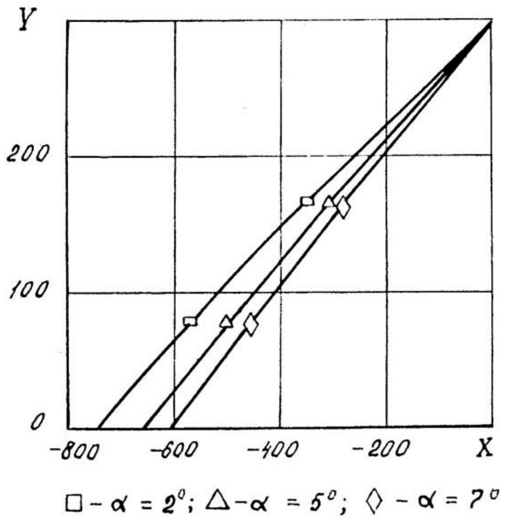

Fig. 6

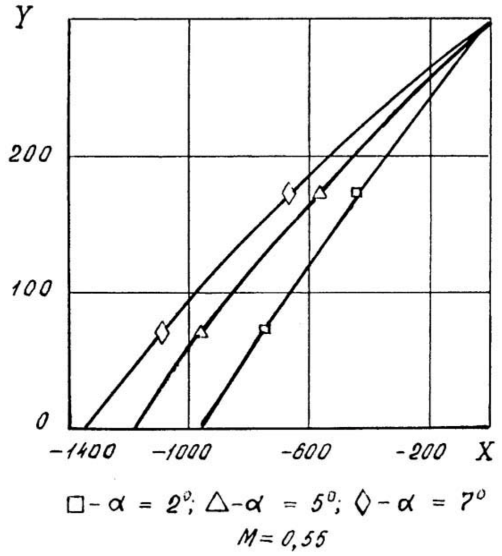

Fig. 7

4 Launching Missiles from the Upper Surface of the Aircraft Wing

Consider one more example of the developed model application. This is a case of missile launching from the upper surface of the aircraft wing.

Figs. 8 and 9 show the process of missile launching from the upper surface of the aircraft wing simulated with aerodynamic disturbances (Fig. 8) and without them (Fig. 9). The aircraft Mach number M = 0.4. The aircraft system for missile forced separation generates the missile additional normal velocity V = 4 m/s. Here aerodynamic interference of the missile and the aircraft also considerably changes the missile motion at the start leg.

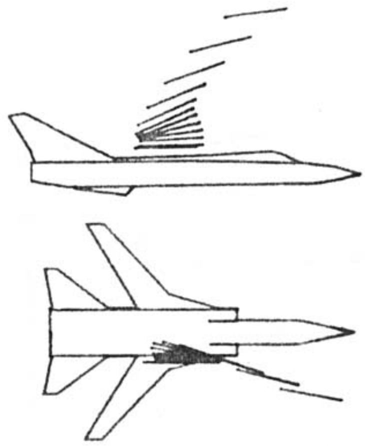

Fig. 8

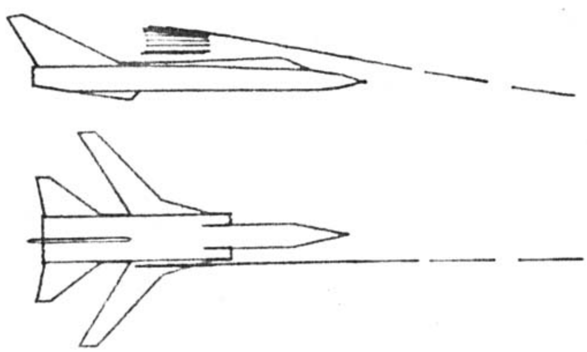

Fig. 9

Fig. 10 shows the missile launching process for different additional normal velocities. One can see that the missile additional normal velocity considerably changes the missile separation process. The abrupt increase of the missile pitch for the additional velocity of V = 2 m/s can lead to the impact of the missile tail with the aircraft.

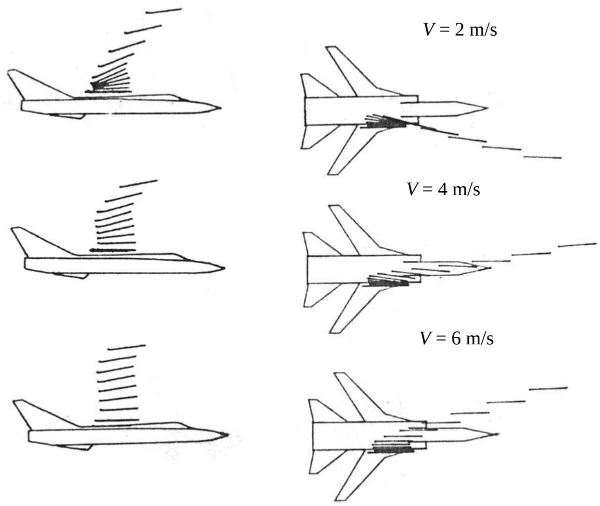

Fig. 10

5 Conclusions

The presented results show, on the one hand, the considerable influence of the aerodynamic interference of AA and the aircraft or helicopter on the AA separation and, on the other hand, a rather wide range of possible applications of the presented approach for studying the problems related to the aerodynamic interference.