MISSILE DYNAMICS

presented by

6- by 6-Foot Supersonic Wind-Tunnel

In our demonstration today, we are going to try to explain certain difficult aspects of missile research with which we are concerned, not only here, but in various other sections of this Laboratory and in other Laboratories of the NACA. Specifically, we are concerned with the interrelation of the aerodynamic properties of the missile provided by its wings, body, and control fins, and the target-seeking properties of its electronic and hydraulic components. There are, of course, numerous problems in this category of varying degrees of complexity. In our demonstration today, we have chosen one of these problems to try to show the general nature of all these problems and to illustrate the necessity for the intensive research being applied.

In order to convey the basic ideas involved, let us examine this missile model.[1] For this particular missile, the lift, which is required to produce accelerations, is provided almost entirely by these rear wings which are fixed rigidly to the missile body. In order to develop lift, these wings must be inclined to the relative wind. The inclination of the body and wings is provided by the adjustment of these forward control fins. These fins are operated by hydraulic motors which act in accordance with signals supplied by the electronic guidance system. The deflection of these control fins depends, in essence, on the measurement by the guidance system of the error in heading of the missile relative to the target. The greater the error in heading, the greater the deflection of the control fins.

It is possible, of course, to design a missile which resembles an airplane with wings and control fins in one plane only. These vertical wings would, therefore, be missing. Such a missile, however, is required to bank in order to make a turn and, because of this, there is a very stringent requirement as to the proper bank attitude. There are problems, of course, associated with either the planar or cruciform-wing arrangement. In our discussion today, however, we will concern ourselves solely with the problems of a missile equipped with a cruciform arrangement of wings and control fins. Such a missile has essentially the same maneuvering ability regardless of the bank angle. In order to utilize this advantage, however, it is necessary to design the actuators for the control fins so that the fins always tend to produce a change in heading that is independent of the angle of bank of the missile. In order to do this, the signal from the guidance system to the hydraulic motors operating the control fins must be commutated or resolved so that each set

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[1]A missile model, with movable control surfaces, is mounted on a stand to the left of the speaker.

of fins seeks its appropriate deflection as the missile is banked. This model has been designed to illustrate this point. This vector is a schematic representation of the radar signal reflection from the target to guide the missile. Notice that as I rotate this signal and hold the missile fixed at one angle of bank, the forward control fins move in such a manner as to always provide a lift on the nose tending to pitch the missile in the direction of the radar signal. Furthermore, as I hold the radar signal fixed in space and rotate the missile, note that the control fins again move in such a manner as to provide a lift on the nose tending to head the missile in the direction of the radar signal. It is evident then that the missile can be rolling continually and still respond properly to guiding signals if the relationship between the radar signal and the angle of bank is properly interpreted by the electronic guidance system and the correct adjustment of the control fins is given by the hydraulic motors.

In flight, the missile will be subject to certain rolling moments which will cause it to roll about its longitudinal axis. In particular for this missile arrangement, very large induced rolling moments will occur at times when the missile is developing acceleration in one plane as shown by this schematic acceleration vector and the radar signal suddenly calls for a change in heading in another plane. Such a condition may occur frequently during one flight due to evasive maneuvers on the part of the target or because of errors in launching.

The first chart here shows why these rolling moments occur. The missile on the left in this chart is accelerating in the vertical plane to attack the bomber from below. The acceleration produced by the loading on these rear wings is coincident with the signal from the target to the missile. In this condition, these two horizontal control fins are deflected and their lift produces two vortices which trail rearward over the rear wings and which cause some change in the lift distribution on these wings. The vertical fins are undeflected and carry no load. Since these vortices are symmetrical with respect to the vertical plane passing through the center of this pair of wings, their influence is symmetrical and no rolling moment exists. The missile on the right, however, is accelerating in the same plane as the missile on the left but, in this case, the bomber has made an evasive maneuver so that, temporarily, the direction of the radar signal from target bomber to the missile is not coincident with the acceleration direction. Again the horizontal control fins are deflected and the vortices shed from these fins are symmetrical about the vertical plane but, because of the change in the radar signal due to the bomber's evasive maneuver, the vertical forward control fins are now also displaced to provide a change in heading to direct the missile toward the target. The vortices shed from the vertical control fins, however, are asymmetrical with respect to the cruciform rear wings and, as a consequence, the lift of the wings is momentarily asymmetric. This transient asymmetric loading tends to roll the missile in this direction. Extensive research on this subject of induced rolling moments has been underway in this wind tunnel and we have correlated our experiments with theoretical considerations. We have found that it is possible to calculate these rolling moments so that a designer can make allowance for their effects prior to building the missile.

To summarize briefly, we have noted that for missiles of cruciform arrangement, it is necessary to design the guidance system so that the signal to the hydraulic motors driving these control fins is resolved in such a manner that the fins always take the proper setting to give the required change in heading. We have shown that such a missile will generally, during some portions of its flight, have a tendency to roll because of the induced rolling moments that occur under certain conditions. If the relationship between the direction of the radar signal and the instantaneous angle of bank of the missile is perfectly resolved, these control fins will always take the correct position to give the required change in heading and the accuracy of the missile will not be impaired by the rolling motion. It's impossible, of course, to build a perfect system and therein lies the problem with which we are concerned. Mr. __________ will now illustrate how the induced rolling moments, when coupled with the imperfections of the guidance system, may result in a serious impairment of the guidance qualities of the missile.

In order to illustrate the effects of imperfections in the resolution of position of the radar signal relative to the missile bank angle, we have developed this model[2] (speaker removes picture in front of shadow box). We have designed this model to simulate this imperfection which we informally call a phase lag or, simply, a lag in the system. The model represents a rear view of this missile and shows the rear cruciform wings, depicting the acceleration of the missile, and this vector which depicts the guiding radar signal. You will recall that the previous speaker pointed out that if the directions of the acceleration and of the radar signal are not coincident, the missile tends to roll. This point can be illustrated with this model by rotating the radar signal clockwise with respect to the acceleration in this manner. Notice that as I rotate the radar signal away from the acceleration direction the missile begins to roll, and that there appears here another vector which is the ghost of the true radar signal. Furthermore as the radar signal is moved further away from the acceleration direction the missile rolls faster and the deviation between the true radar signal and the ghost signal increases with increasing rolling velocity. Now this ghost signal represents the heading to which the missile actually tends to respond. The appearance of the ghost signal is due to the lag or imperfections in the resolution of the position of the forward control fins with reference to the true radar signal. It is evident that since the missile seeks a heading indicated by the ghost signal, the accuracy will be impaired seriously by excessive rolling.

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[2]Inside the shadow box is mounted a model depicting a rearview of the missile with appropriate vectors denoting the radar signal and the missile acceleration.

In order to illustrate this point, we have prepared two charts showing an attack utilizing a guided missile. The first chart consists of a plan view of the attack showing the target bomber, the pursuing airplane and the missile in flight. This chart shows the relative positions of the bomber, missile, and fighter at three separate times during the attack. At this time, the fighter airplane has just released the missile which is flying toward a point on the target's path. In the next view, the missile has progressed toward this point and the fighter airplane has begun to turn away to avoid the defensive fire of the target bomber. At this time, the missile has almost intercepted the bomber. Notice again on this chart that throughout the time of flight the missile is heading for a point on the bomber's flight path and will reach that point simultaneously with the bomber. You should note, however, that in this view we cannot tell whether the attacking missile passes over, under, or strikes the target. In the next chart, we have a view of this same attack at a time shortly after the fighter pilot has launched the missile. We are viewing the attack as though we are seated in the cockpit of the fighter airplane and the missile has just been launched from under our left wing. If the missile flies true the bomber and missile will collide at this point. You will recall that with the rolling model we showed that the phase lag due to rolling causes the missile to follow the ghost signal which lies counter-clockwise from the true signal. The missile, in following the ghost signal, will develop accelerations to the left of the true radar signal. It will therefore follow a path which will carry it ahead of and over the top of the target bomber. It is apparent then, that the induced rolling moments which act on the missile have a detrimental effect on the over-all guidance. This is the relationship between aerodynamic properties and guidance qualities which was noted by the first speaker.

As was stated previously, it is impossible generally to eliminate all induced rolling moments for these missiles. The influence of the induced rolling moments, in causing the missile to roll, can be suppressed, of course, by the use of additional control fins actuated by an additional component of the guidance system sensitive to roll rate. Such a solution to the problem is feasible but results in an undesirable complication of the missile which may impair its reliability and, certainly, will add to the difficulty and cost of manufacture. In our research, we have found means of minimizing these induced rolling moments which may give roll rates that are entirely acceptable. Through the application of this research the designer can select an arrangement of wings and control fins that have acceptable induced rolling moments. This missile could be redesigned to give smaller and acceptable induced rolling moments with some sacrifice in the efficiency of performing lateral maneuvers. The designer will have to weigh this sacrifice against the alternate complication resulting from the introduction of roll control fins and additional guidance components. Either solution requires an integrated study of the guidance system and missile aerodynamics. The designer must calculate the induced rolling moments of the missile in the various conditions of flight, calculate the rolling rates that result and compare these rates with acceptable values determined from knowledge of the phase lag of the guidance system. With this solution in hand, acceptable target seeking trajectories can be obtained so that the missile will follow a path such as to meet the target bomber at this point and destroy it.

The problem we have discussed is only one of a number of complex studies that are underway in the field of missile aerodynamics. We have selected this problem to point out to you that the aerodynamics of the missile and the properties of its electronic and hydraulic guidance components must be studied together. Such studies require personnel who are versed in both guidance and aerodynamics in order to supply research information for the development of accurate and reliable guided missiles. A significant portion of the work of the NACA is concerned with this difficult problem of relating guidance requirements and aerodynamic capabilities.

Display for presentation of "Missile Dynamics"


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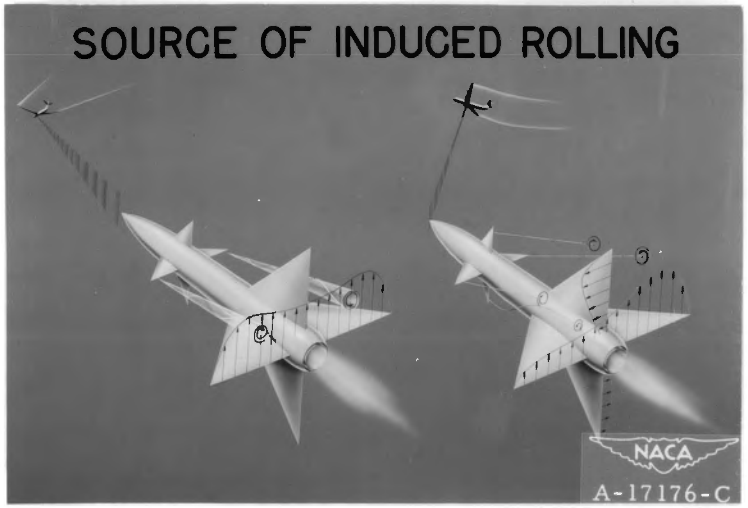
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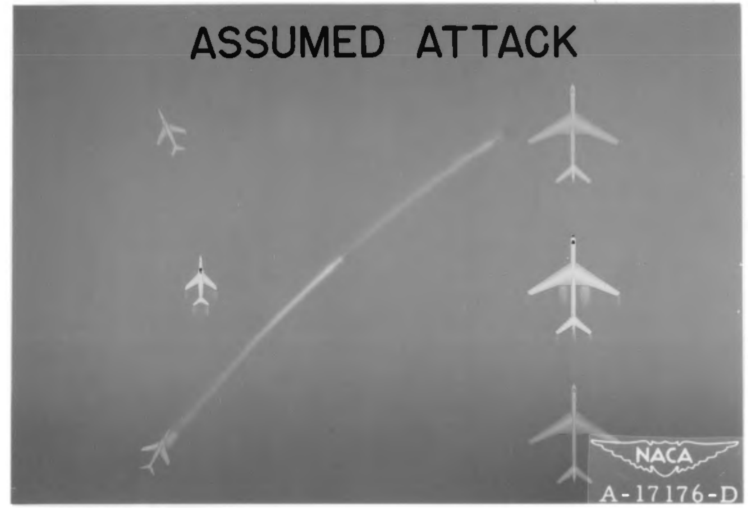
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