High-Speed Store Separation—Correlation Between Wind-Tunnel and Flight-Test Data

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The problems associated with separation of stores from high-speed aircraft can be studied by the use of several wind-tunnel test techniques. Attention is given to the three most useful of these techniques: 1) dynamically scaled drop-model testing, 2) flowfield survey testing, and 3) captive trajectory testing. A description of each method is given, and data obtained are shown to approximate full-scale flight-test data within acceptable limits.

I. Introduction

SEPARATION of stores such as bombs and tanks from military aircraft has been a problem for design engineers since the advent of the high-speed airplane. The flowfield interaction between the myriad of store-aircraft combinations demands individual attention to insure acceptable separation. Indeed, the separation characteristics must be ascertained over the complete range of airplane flight conditions that will be experienced whether it be a weapon or fuel tank store. Additional flight conditions are created if the aircraft is of the variable sweep-wing type, thus multiplying by several times the areas of required investigation. When considering the number of different stores that would be released from a variable sweep-wing series aircraft such as the F-111, for example, it is no wonder that store separation has become of major concern to aircraft and weapons designers.[1]

The use of the wind tunnel as a tool to obtain valid separation information has been well established and represents the most economical means of generating separation data. There is, however, concern over the increasing test costs which reoccur for each new tactical system where the stores increase in number with each new system. Quite frequently, questions of separation also rearise when existing stores are modified or when new stores have been devised which are to be dropped from existing aircraft. Advances in wind-tunnel technology in the store separation field have been made in an effort to reduce the test cost per system. The question then arises as to the validity of the data produced. Its true test is its agreement with full-scale flight-test separation data.

There are several methods used in a wind tunnel to simulate experimentally full-scale flight tests to determine store-parent separation characteristics. Three such methods are 1) dynamically scaled drop-model testing, 2) flowfield survey testing, and 3) captive trajectory testing. Each of these methods has advantages as well as disadvantages; however, it will be shown that all three produce satisfactory correlation with full-scale flight-test data.

II. Drop Models

The drop-model wind-tunnel data are an important source of information used in determining store separation characteristics. For the drop-model wind-tunnel tests, dynamically similar models of the stores are built to simulate the motions of the stores when released from the aircraft. The model of the aircraft is suspended from the ceiling of the wind tunnel, and the store models are ejected with a scaled ejection force to simulate full-scale ejection forces. High-speed motion picture cameras take pictures of the model to record its trajectory as it separates from the aircraft. The cameras are located so as to look at the aircraft from the side and bottom. Each frame of film is then analyzed and reduced to three-dimensional trajectory data. This is done using a film analyzer to translate the XY coordinates of the store on the film to card form, which is then used as input to a digital computer program.

The drop-model scale may make it impossible to simulate exactly the mass characteristics of the store; i.e., high-density stores may not be heavy enough. This weight deficiency is taken into consideration in the analysis, and an additional ejection force (mass deficiency make-up) is applied to the model to help it pass through the correct flowfield as it separates from the aircraft. That is, the store, being too light, must have an additional eject force applied such that it enters the flowfield matching the scaled momentum rather than the scaled velocity. The critical local airplane geometry is made to accurate dimensions in order to produce properly the flowfield for the store to experience. A multiple-exposure still camera is used to give a quick record of the store separation (Fig. 1) and is useful in immediate comparisons between drops.

The method used for ballistic store separation analysis begins with the results of the drop-model test. The motion

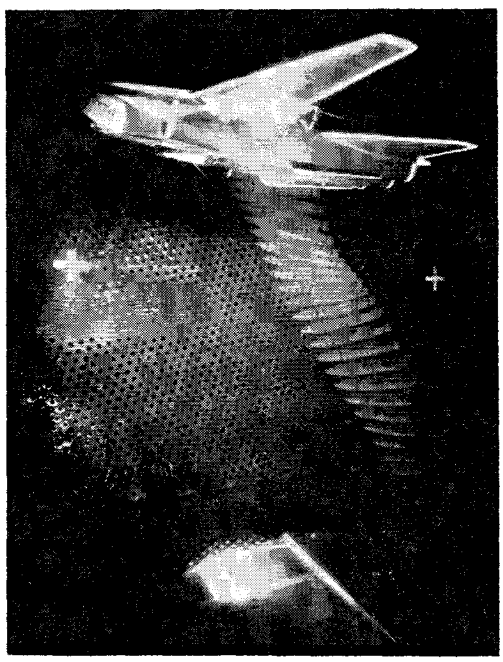

Fig. 1 Drop model, multiple exposure photograph.

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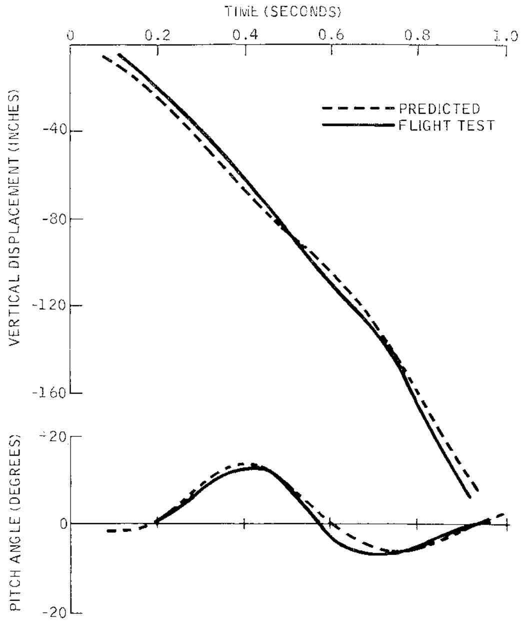


Fig. 2 Comparison of flight-test and drop-model prediction: sweep-wing carrier and fin-stabilized, free-fall bomb.

pictures of the drop give a general view of the store separation characteristics, but because some models cannot be made or tested to simulate completely the full-scale quantities, further analysis must be made. This begins by making a digital computer solution of the drop-model separation on a procedure using 6-degrees-of-freedom total equations. These digital solutions use the actual release conditions, Mach number, altitude, angle of attack, ejection velocity, etc., and the actual physical characteristics of the models dropped in the wind tunnel along with the free air aerodynamic characteristics and an interference library. The interference library varies the pitching moment, yawing moment, rolling moment, normal force, and side force as a function of store separation distance from the airplane.

Based on attached loads data, experience from past store separation programs and theoretical analysis, the interference library is then adjusted until the digital computer run matches the drop-model test results as closely as possible. This is then the final interference library, which is used to make the predictions of the full-scale separation characteristics. Figure 2 is an example of the results of such a method as compared to actual full-scale flight-test results of a fin-stabilized, free-fall bomb.

III. Separation Simulation Utilizing Flowfield Surveys

The gathering of the necessary information as input to the simulation program involves the use of the wind tunnel as a tool. The flowfield survey technique of obtaring separation data makes use of a ceiling-mounted parent aicraft model as is used for drop-model testing. The store model, however, is supported independently of the parent. It is moved to various positions under the parent in the vicinity of the field of flow influence. This is done to obtain a grid of data for defining the flow effect on the store aerodynamic coefficients. A generalized store (or probe) can not be used since the flowfield is generated not only by the parent aircraft but by the combination of parent and store. This makes it necessary to use the particular store and parent under study at the time.

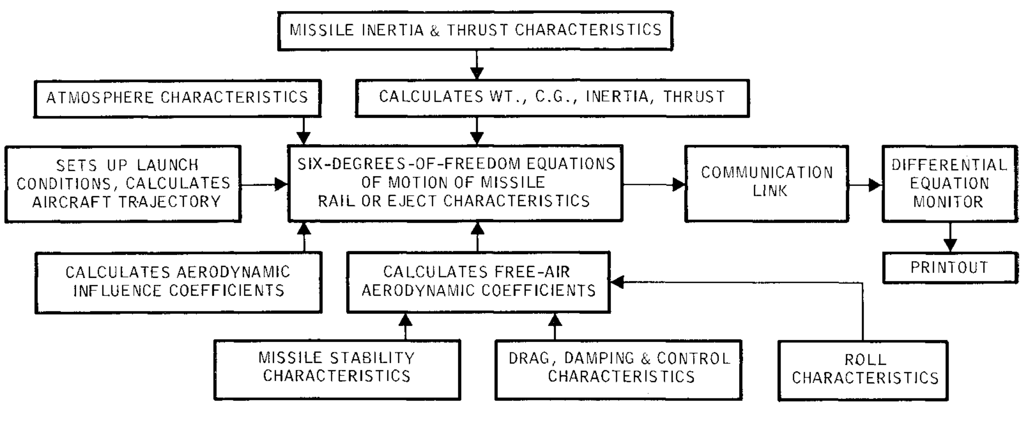
Evaluation of store aerodynamic characteristics in the vicinity of the aircraft indicates that a method of aerodynamic influence coefficients may be used to evaluate the effects of the aircraft on the store. By combining these influence coefficients with store-alone aerodynamic characteristics, formulation of the interference effects is accomplished. This is done utilizing a 6-degrees-of-freedom simulation on a digital computer. The mathematical method employs a differential equation monitor that controls the evaluation of the variables and their integration, and the presentation of the variables. This method has the advantage that once the aerodynamic data are generated, analytical studies of separation can be made without the use of additional wind-tunnel testing. Figure 3 shows the separation simulation block diagram used by the Pomona division of General Dynamics.

So-called "free air" or store-alone aerodynamic characteristics are obtained in the normal way; that is, the store model is mounted in the wind tunnel on a six-component strain gage balance. By measuring the aerodynamic forces and moments while varying speed, angle of pitch and yaw, etc., the store stability and control characteristics are ascertained. Influence coefficients are obtained by traversing the store model through the aircraft flowfield, again with the store mounted on a strain gage balance. It is immediately evident that, without special equipment, the traversing movement alone could be very cumbersome and time consuming in a wind tunnel. The most efficient method of obtaining this movement is the utilization of the captive trajectory mechanism discussed in more detail in the following section. By employing the mechanism, capable of six independent movements (pitch, yaw, roll, vertical, lateral, and longitudinal), with an analog computer to direct its preprogrammed travel path, a continuous recording may be made of the flowfield influence pattern upon the store model. A typical traverse run in a blow-down-type wind tunnel may be as shown in Fig. 4. Other patterns frequently used are single vertical or axial traverses at various pitch, yaw, or roll attitudes of the store.

IV. Captive Trajectory

The newest and most sophisticated technique now in use for separation testing (a technique pioneered by M. J. Bamber of the David Taylor Model Basin) is known as a "captive trajectory" system.[2] This technique utilizes the 6-degrees-of-freedom mechanism, mentioned earlier, in com-

Fig. 3 Six-degrees-of freedom separation simulation block diagram.



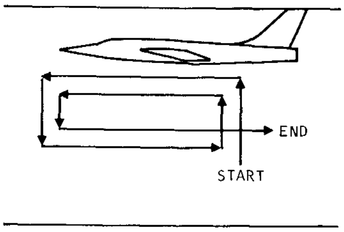


Fig. 4 Typical flowfield traverse.

bination with an analog computer to simulate the store trajectory. A digital computer may be used in place of the analog in which case an iterative point-by-point movement rather than a continuous feedback loop movement is used. The parent model, again supported from the wind-tunnel ceiling, is used to produce the flow of the area of interest. The store is mounted on the support mechanism as described in the flow survey discussion. To obtain a trajectory, the store is positioned on the aircraft model in its normally carried location. After wind flow has been established, control of the mechanism is switched to the analog computer. By sensing the loads on the store through the strain gage balance and converting them to mechanism control signals, the analog computer then "flies" the store on its trajectory. Store full-scale characteristics such as weight, center of gravity, drag, thrust, etc., are programmed into the computer also. Figure 5 is a picture of the Convair captive trajectory support. This support, an electromechanical positioning system with all axes of motion contained within, is independent of the launching aircraft mode. As shown in Fig. 6, the envelope of translation is a cube approximately 30 in. on a side. Drive motors are printed-armature electric motors with extremely fast response characteristics. The control system for the support serves both as a positioning control and as an interface between the analog computer and support.

The major components of the system shown in block diagram form in Fig. 7 are the support mechanism, controller, analog computer, digital data acquisition system, and digital computer. The strain gage balance outputs are processed by the analog computer and converted into aerodynamic coefficients which in turn are used in the analog simulation of the equations of motion. The rates thus calculated are converted to called-for support rates which, through the controller, drive the support at the prescribed velocities. The back electro-motive force (EMF) of the motors in the mechanism is used as a velocity feedback. As a further control, a position feedback loop between the support and the analog computer is utilized.

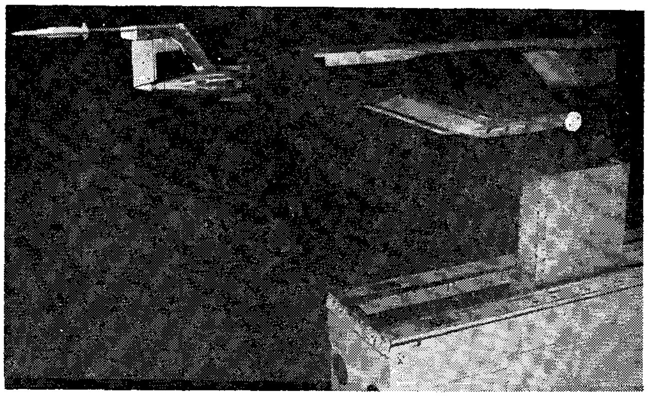


Fig. 5 Convair captive-trajectory mechanism.

The analog program is time-scaled, so that what is seen is an apparent slow-motion movement of the store through its separation trajectory. During the run, the position and angle outputs and the balance outputs and tunnel test parameters are recorded on a data acquisition system. The balance outputs are converted to coefficients, and the actual position and angle outputs are evaluated and processed into full-scale parameters on the digital computer. These are called analog trajectory data. The coefficients of the analog trajectory data are used in a digital simulation on the digital computer which calculates the trajectory that should have been made based on the forces and moments on the store. These are called digital trajectory data and provide a check of the validity of the trajectory by comparison with the analog trajectory data.

In order to evaluate the flowfield survey and captive trajectory methods of determining store separation, several different launch conditions were chosen for use in computing the trajectory on the digital computer and the results compared with captive trajectory tests of the same conditions. All conditions showed excellent agreement between the flowfield digital simulation and the captive trajectory tests. The maximum discrepancies in all comparisons were less than 3° in angles and less than 2 ft (full scale) in positions. Thus, it

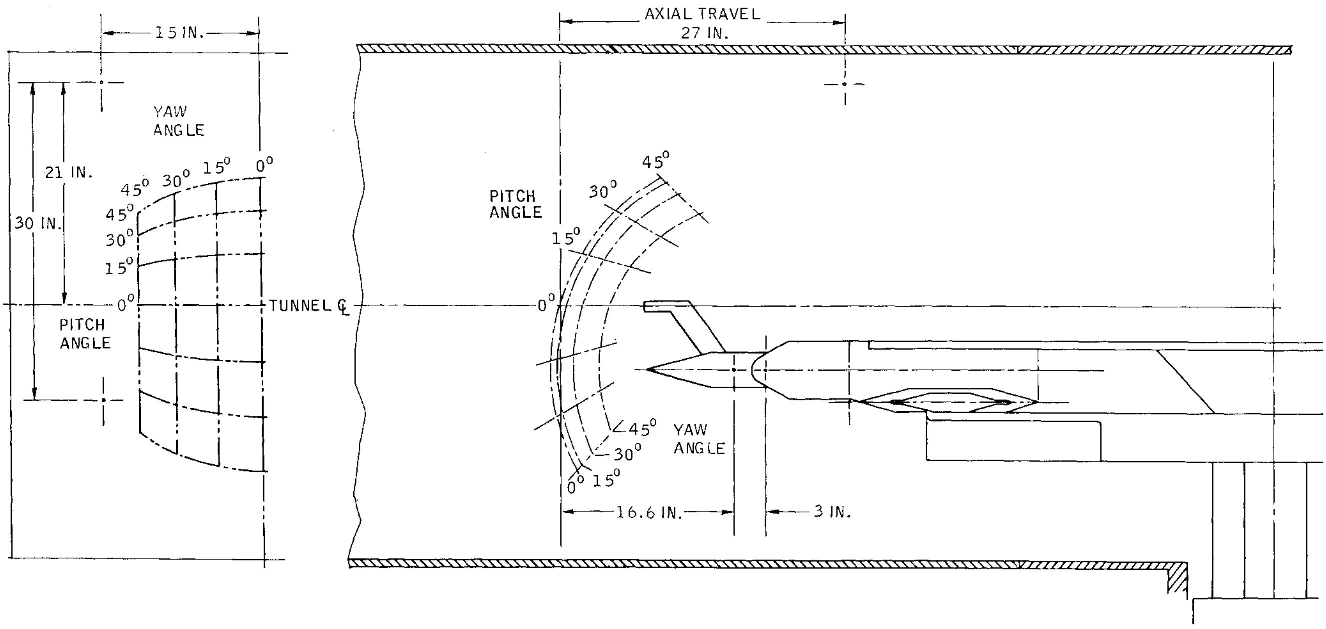


Fig. 6 Envelope of motion, captive trajectory mechanism.

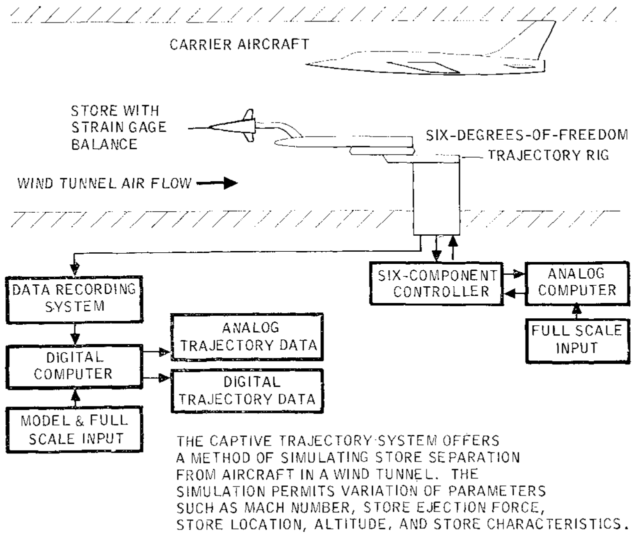


Fig. 7 Captive trajectory system.

was apparent that these two mutually independent approaches to air-launch trajectory simulation could arrive at the same results.

How closely they approximated the actual full-scale flight-test results, however, was of prime importance. Figure 8 is a comparison of flight-test, captive-trajectory, and digital simulation flow survey data of a fin-stabilized store released from two different parent aircraft. When taking into consideration the degree of accuracy associated with the reduction of full-scale flight-test data, it is apparent that the data fall within the scatter band of the wind-tunnel data.

V. Summation

Wind-tunnel generated store-separation data compare favorably with actual full-scale flight-test data. Several methods may be employed by the wind-tunnel engineer to generate these data; however, these methods have many common factors. First, the flowfield must be accurately simulated in the wind tunnel. In addition, the characteristics of the store itself must be duplicated and the application of release conditions properly employed.

Choosing the method of obtaining the wind-tunnel data is dependent upon the following: 1) wind-tunnel availability, 2) equipment availability, 3) relative cost per unit of data, 4) lead time, 5) type of separation data required, etc. The drop model has the advantage of being a free-falling body and, as such, has no aft-end modification to accommodate a support system, thus eliminating the possibility of being adversely affected. It cannot be tested, however, in a wind tunnel where damage would occur with pieces of heavy metal flying down the tunnel. Cost is a factor since expensive ($500–$1,000) models are dispensed, one or more, on each drop sequence. Single models with multiple configuration capability are used on the flowfield and captive trajectory tests; model costs are thus greatly reduced over the drop-model system.

As with the drop model, the captive trajectory testing yields a trajectory for each run, but only for the condition of the run. If anything is changed (store characteristics,

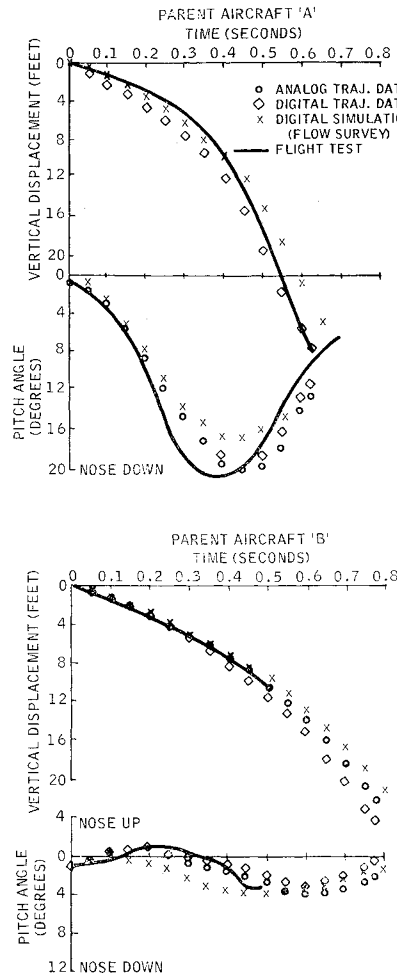


Fig. 8 Comparison of flight test, captive trajectory, and digital simulation.

launch or parent flight conditions, etc.), the trajectory must be re-established with another wind-tunnel test. On the other hand, the flowfield method yields little information on one traverse. Several traverses covering the field of influence interest must be made in the wind tunnel at several hundred dollars per traverse. With these interference data available, many trajectories may be simulated using a computer, without the need for additional testing unless a physical change is made to the store.

The aircraft or store designer most certainly should take advantage of wind-tunnel model testing techniques in solving the separation problem associated with high-speed aircraft. The cost advantage alone of model over full-scale testing is sufficient justification, and the advances in the state-of-the-art make valid the results obtained.

References

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[2] Bamber, M. J., Aero Repts. 970, Jan. 1960; 981, Sept. 1960; 1011, July 1951, David Taylor Model Basin Aerodynamics Lab.