New Analysis Tool for Tow Target Trajectory Predictions

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Abstract

ALTHOUGH tow targets have been flown for many years, until recently no method existed to predict analytically the target's trajectory separation characteristics. Conventional store separation techniques could not be applied because the cable tension foce, which dominates the trajectory, was not accounted for. Two new programs, termed the Tow Target Trajectory Prediction (3TP) codes, have now been developed. One, 3TP1, was developed for trajectories where cable tension time history data are available. The other, 3TP2, which was developed for trajectories where no a priori cable tension data exist, calculates the target's separation characteristics by constraining the total acceleration to a fixed value. Both codes have been validated by comparing predicted target trajectories with flight and wind tunnel test results.

Contents

Aerial tow targets are used worldwide in support of the test and evaluation of weapon systems and operator training. They are towed by both military and civilian aircraft. A typical tow target system as shown in Fig. 1 consists of a tow target, a reeling machine launcher system, and cable. The tow target system modeled in this analysis is the U.S. Navy standard tow target system consisting of the TDU-34A/A aerial tow target and the A/447U-44 reeling machine launcher system.

A conventional 6-degree-of-freedom store separation trajectory code was used in this effort. Five sets of data are normally required as inputs to this program. These are the aircraft initial conditions, store freestream aerodynamics, ejection system time history, store carriage loads and incremental store loads in a grid under the aircraft.

The six-degree-of-freedom program had to be modified to account for the effects of tow cable tension on the trajectory. The assumption made in the two new versions of the code was that the tow cable effectively is a straight line connecting the target to the aircraft attachment point. This formulation was chosen because, for short cable lengths, this not only is a reasonable representation of the actural behavior of the system but also would lend itself to straightforward verification in a wind tunnel test. It is anticipated that a wind tunnel test could easily measure the effect of cable tension on the trajectory by modeling the cable tension as a force vector acting at an angle through the target center of gravity. The angle at which the cable force acts can be estimated by measuring the X, Y, and Z (called XREL, YREL, and ZREL) displacements of the target relative to the aircraft attachment point.

Flight test data, consisting of cable tension time histories and movies of the corresponding trajectories, were obtained for the TDU-34A/A tow target, which consists of the baseline TDU-34A configuration with a 20-in. extension, separating from the F-4 aircraft at $M=0.42$, 0.45, and 0.48. The freestream aerodynamic characteristics for this extended body target were unchanged from the basic configuration. Since it unexpectedly hit the A-6E aircraft during its first launch and because the $M=0.42$ data for the F-4 exhibited the largest pitch variation, these flight conditions were selected for further analysis.

Two separate launches were available at the same flight Mach number and initial conditions. The TDU-34A/A aerodynamic forces at launch were predicted using the influence function method (IFM) technique. The trajectory was initiated

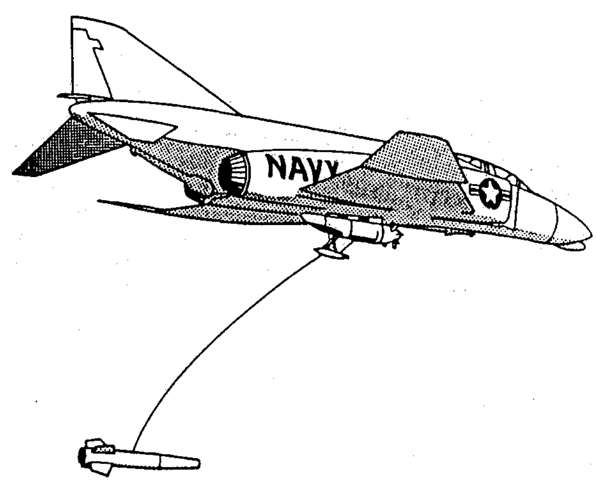

Fig. 1 TDU-34A/A aerial tow target.

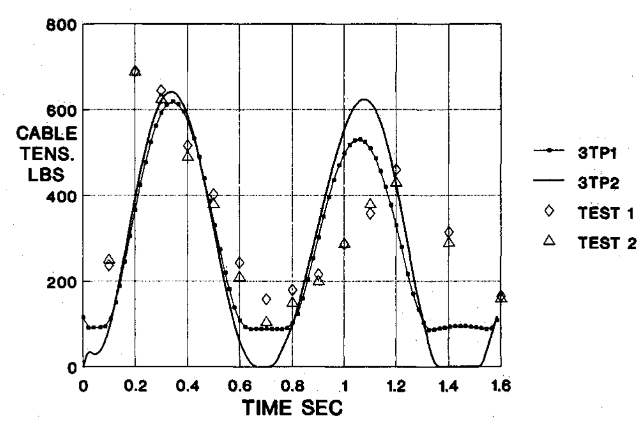

Fig. 2 Cable tension time history for TDU-34A/A separating from F-4.

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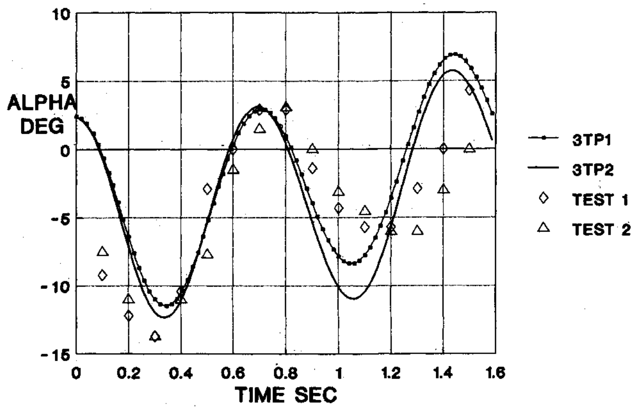

Fig. 3 Pitch oscillation for TDU-34A/A separating from F-4.

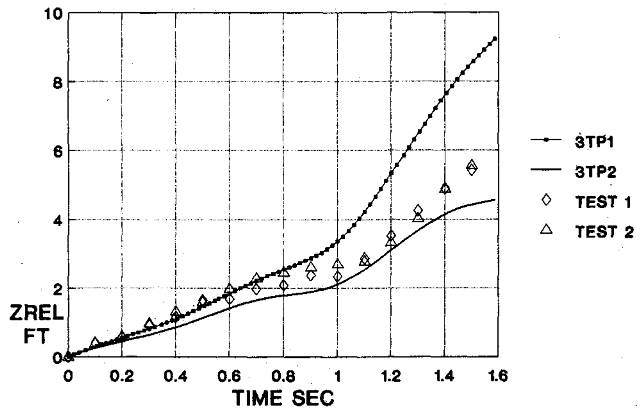

Fig. 4 Vertical displacement for TDU-34A/A separating from F-4.

about three-tenths of a second after separation from the saddle since that appeared in the films to be the time required for the cable attachment bolt to clear the saddle release mechanism. At that time the tow target was 4 deg nose down relative to its initial condition, or 6 deg nose down relative to the aircraft FRL. This orientation was used to estimate the target's initial carriage loads, while IFM predicted grid loads at the launch positions as well as 10 in. below were used to predict their decay.

The cable tension time history for these two launches is shown in Fig. 2. Also shown in Fig. 2 is a plot of the vector sum of the forces that the 3TP1 program predicts act on the target. Since these forces are the cause of the tension in the cable, they should correspond to the actural cable tension. Although the magnitude of the forces is in reasonably good agreement with the flight test data, the frequency of the predicted response appears to be about 0.1 s greater than that of the flight tests. Also shown is the cable tension calculated by 3TP2. Since the target not only pitches about its tow point but also swings at the end of the cable, which is accounted for only in 3TP2, the close agreement in the tension values calculated by the two programs indicates the validity of both approaches. The minimum tension value predicted by the two versions of the program do not agree since in 3TP2 the cable tension cannot exceed the vector sum of the aerodynamic and inertial loads. Note that both the flight test data and the prediction indicate that the minimum tension occurs between 0.6 and 0.8 s. That means that the target tends to fly up toward the aircraft and represents the critical condition for this launch.

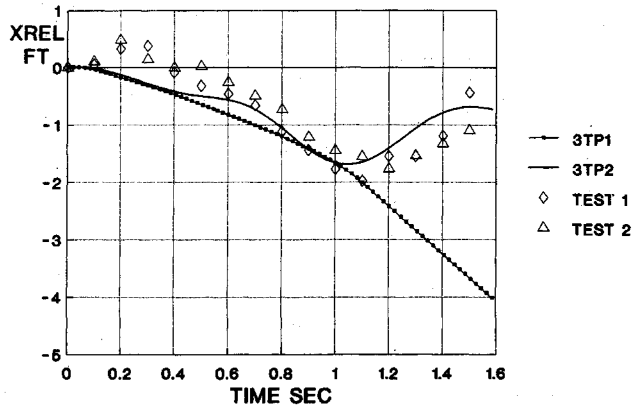

Fig. 5 Horizontal displacement for TDU-34A/A separating from F-4.

The pitch oscillations are shown in Fig. 3. Considering the uncertainty in the initial conditions and that the pitch angle could only be estimated to ± 2 deg from the movies, both predictions are in remarkably good agreement with the test data. As for the tension time history, the frequency of the oscillations is about 0.1 s faster than indicated by the flight test data. However, this makes the prediction more conservative, since the predicted maximum pitch angle occurs sooner (and therefore when the target is closer to the aircraft).

The vertical displacement of the target is shown in Fig. 4. The prediction was initiated with a vertical velocity of 2.5 ft/s to match the cable velocity at the release point. The 3TP1 prediction departs somewhat from the test data after 1 s. The reason can be attributed to the fact that the target-reeling mechanism restricts the maximum acceleration to 1.2 ft/s^2. That corresponds to about 6 lb in cable tension. Obviously, the only way to match the displacement is to constrain the acceleration in the six-degree-of-freedom program and calculate the tension force required. This feature as well as the ability to solve the rotational equations of motion at the cable attachment point are both incorporated in 3TP2, which accounts for the excellent agreement with test data shown.

The horizontal displacement is shown in Fig. 5. Note that 3TP2 predicts the forward motion of the target, attributed to cable swinging effects, 1 s after the trajectory calculation was initiated. The forward motion of the target at $t=0$ probably was caused by an initial forward velocity inparted by the saddle; since the magnitude of this effect cannot be estimated, it was not modeled.

Conclusions

A store trajectory prediction program has been modified to account for the effects of tow cable tension. Comparisons with flight tests data indicate that the 3TP codes can be useful tools for evaluating target trajectories.