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Aerodynamic Design of an Extended Range Bomb

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Randall C. Maydew*
Sandia Laboratories, Albuquerque, N. Mex.

Abstract

THE extended range bomb (ERB) is designed to provide a low altitude, 15 km stand-off or a 2.5 km turn radius, return-to-target (RTT) delivery capability from aircraft at release speeds of 330-800 KCAS. The boosted, 41.9 cm diameter bomb utilizes two orthogonal pairs of pneumatically actuated canards for attitude control and lift. The guidance and control (G&C) system consists of a strapdown inertial measurement unit (IMU) and a digital computer containing an autopilot and navigator. Extensive wind tunnel tests were conducted to optimize the canard design. Two flight tests of instrumented full-scale vehicles were conducted to verify the design. The wind tunnel data are compared with theory and the verification flight tests are discussed.

Contents

The ERB is designed for external carriage on wing or fuselage pylons on F4, F111, A4, A6, and A7 aircraft. Carrier aircraft compatibility (ground and aircraft clearance, ejector racks, release and separation, etc.) severely constrained the size and shape of the aerodynamic lifting and control surfaces on the 3.68 m long bomb. The design[1] which evolved (Fig.1) utilizes four extendable fins (for increased lift), fin-tip mounted rollerons, a solid fuel rocket motor, and four canards. Preliminary estimates (1974) of the ERB aerodynamics indicated that lift/drag ratios of 3-5 were achievable. Digital 6 deg of freedom simulations and real-time flight parametric studies on the flight simulator (analog/digital computer) indicated the ERB must pull about 5 g (trim angle of attack of about 15 deg) for the RTT maneuver at Mach 0.9. The simulations also indicated the canards must provide high lift with nearly linear characteristics up to angles of attack (α) of 20 deg.

Six component force and moment tests[2] of a 0.3 scale 18 deg sweep canard model (Fig. 1) were conducted in the Calspan 2.44 m transonic wind tunnel. The canards were remotely actuated and the canard loads were measured with individual three component balances. Typical normal force coefficient (C_{N_c}) data for the 18 deg sweep canards are presented in Fig. 2. The effective angle of attack, as modeled from potential theory and cross-flow considerations, is defined as:

$$\alpha_e = \alpha + 0.65\,\delta_y$$

where δ_y is the canard deflection in model pitch plane.

The canard normal force data collapse to a single curve for various canard deflections when plotted vs α_e. The data indicate the 18 deg sweep canards partially stall at $\alpha_e = 12$ deg and do not provide sufficient lift. Hence, it was decided to conduct a parametric test in the Sandia 0.3 m transonic wind tunnel of 0.09 scale canard/forebody configurations. Forty-one models were tested to evaluate the effects of nose shape (ogive, hemisphere cone, and hemisphere biconic), canard planform (swept, deltas, and clipped deltas with and without strakes), canard location, and canard cross section. These test data indicated the sphere-cone-cylinder, 60 deg delta-canard forebody was the optimum configuration.

Extensive tests were then conducted of a 0.3 scale 60 deg delta-canard model (Fig. 1) in the Calspan transonic wind tunnel. The canard normal force data in Fig. 2 correlates well with the vortex flow theory of Polhamus[3]; a similar correlation at $M = 0.90$ is shown in Ref. 1. The correction to the wing-alone vortex theory for the effect of the body on the canard normal force was taken from Nielsen.[4] Figure 2 illustrates the canard normal force was increased over a factor of two and is nearly linear up to $\alpha_e = 20$ deg. The lift contributions of the fins, body, and canards are about 54, 23, and 23%, respectively, for canard deflections of 15 deg at the nominal bomb design trim angle of attack of 15 deg.

Approximately 100,000 six-component data points were obtained for the baseline configuration at Calspan at $0.65 \le M \le 1.25$, $0 \le \alpha \le 20$ deg, and -15 deg $\le \delta \le 15$ deg. Power series equations were fit to these data using Maple-Synge theory and were then input to the flight simulator (hybrid computer) for preflight simulation with evaluation of

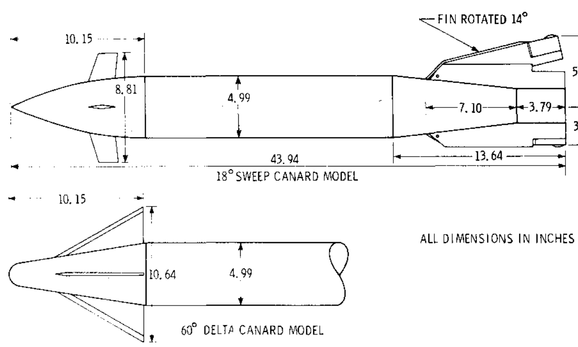

Fig. 1 Calspan wind tunnel models (0.3 scale).

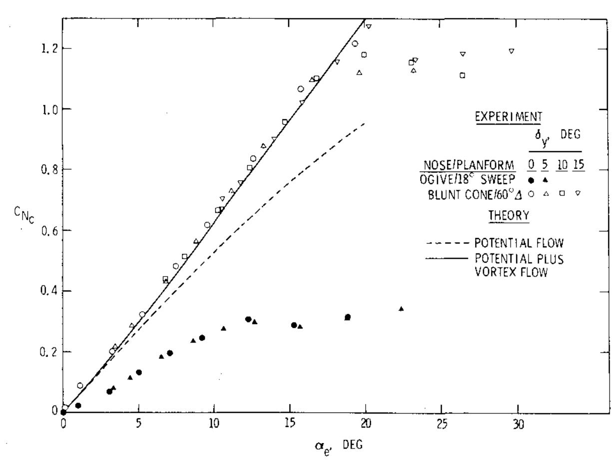

Fig. 2 Comparison of canard normal force wind tunnel data with theory for $M = 0.65$.

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*Manager, Aerodynamics Department. Associate Fellow AIAA.

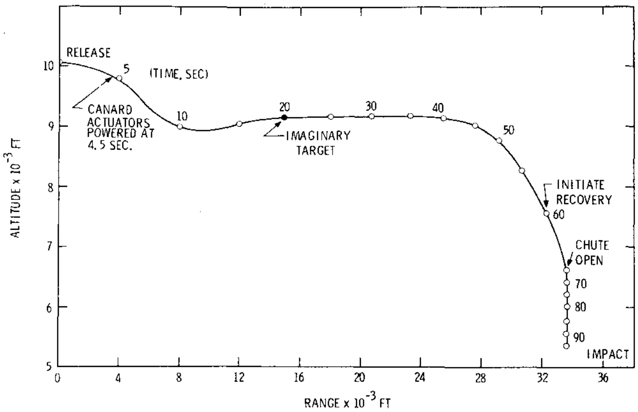

Fig. 3 Flight performance of FTU-1.

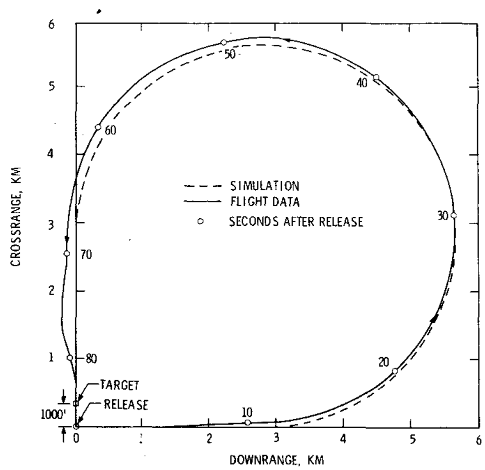

Fig. 4 Flight performance of FTU-2.

the G&C system. Initially, the simulations were run with the IMU and canard actuator hardware mathematically modeled on the hybrid. Later simulations included the IMU hardware mounted on the three-axis motion simulator to generate the expected flight angular rates; the IMU signals were then fed to the G&C computer which generated commands for the canard actuators. Typical preflight design change requirements identified were rocket ignition timing, canard actuator gains and damping, and radius-of-turn trajectories for RTT delivery. Further, the compatibility of flight hardware was demonstrated.

Two ERB flight tests were conducted with an A-7 aircraft at the Sandia Tonopah Test Range, Nev., in 1977. The test units were released at $M = 0.84$ at about 10,000 ft altitude and tracked by radar and cinetheodolites. Rate gyro, MARS stable platform (roll, pitch, and yaw), triaxial accelerometer, canard position transducer, etc., data were telemetered to the ground receiving station. The payload sections were parachute recovered.

The unpowered 493 kg FTU-1 demonstrated the aerodynamics and G&C for the standoff mission. At 4.5 s after release (Fig. 3), the canards were actuated and the guidance system flew the ERB to an imaginary target position 4.57 km (15,000 ft) north of the release point. The autopilot maneuvered the ERB to within 24 ft east error and 6 ft altitude error of the imaginary target. FTU-1 trimmed at $\alpha = 8$ to 10 deg with canard deflections of about 4 deg. The flight lateral accelerometer data agreed with wind tunnel normal force data within 1-7%.

The powered 544 kg FTU-2 demonstrated the aerodynamics and G&C for the RTT mission. The rocket motor provided 4700 lb thrust for 2.7 s followed by a sustainer with thrust of 675 lb for about 50 s. At 4.5 s after release the canards were actuated and the unit was programmed to dive about 1000 ft. The rocket motor was ignited at 15 s, and the guidance system flew the unit in a near circular trajectory back to the imaginary target near the release point (Fig. 4). The unit maintained a nearly constant altitude from 20 to 75 s. The trim angle of attack gradually increased from about 15 deg at 20 s to about 20 deg at 75 s; the unit stalled at 32 deg at 80 s. The unit missed the imaginary target by about 15 m (50 ft). The target was offset 305 m (1000 ft) in cross range from the release point (see Fig. 4), i.e., the autopilot commanded the FTU-2 to seek the target. Figure 4 illustrates the good agreement of the FTU-2 RRT simulation with the flight data.

Acknowledgment

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References

[1] Maydew, R.C., "Aerodynamic Design of an Extended-Range Guided Bomb," Sandia Laboratories, Albuquerque, N. Mex., SAND79-0836, Oct. 1979.

[2] Reid, C.F., "Transonic Wind Tunnel Force Tests of the Sandia ERB/RTB Model in the CALSPAN 8-Foot Transonic Wind Tunnel," Calspan Corp., Buffalo, N.Y., Calspan Report AA-4034-W-1, Nov. 1975.

[3] Polhamus, E.C., "Charts for Predicting the Subsonic Vortex-Lift Characteristics of Arrow, Delta, and Diamond Wings," NASA TN D-6243, April 1971.

[4] Nielsen, J.N., "Nonlinearities in Missile Aerodynamics," AIAA Paper 78-20, AIAA 16th Aerospace Sciences Meeting, Huntsville, Ala., Jan. 16-18, 1978.