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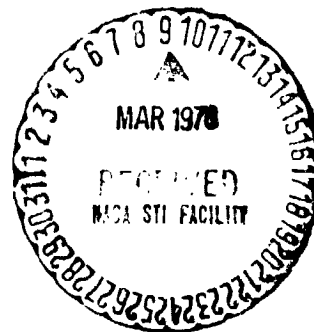
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INTRODUCTION

The free-wing concept is an unconventional attachment of a wing to a fuselage such that the wing is free to pivot about a spanwise axis forward of its aerodynamic center and is subject only to aerodynamic pitching moments imposed by lift and drag forces and a control surface. An expected benefit of this concept is gust alleviation due to the greatly reduced inertia in the pitch axis. Inherent in this concept are numerous other benefits not found, and in many cases not available, in conventional designs. Previous studies have shown that the angle of attack of a free wing can be controlled by a trailing edge flap (refs. 1 and 2) or by a trailing edge surface at the wingtip (refs. 3 and 4). In addition, these studies have indicated a weight penalty for the static balance of the free wing at its pivot.

The use of a trimmable free surface to control the angle of attack of a free wing had not been investigated previously. Boom installation of a free canard would allow conventional landing flaps to be used (a capability that is lost when trailing edge flaps are used for control) and would also tend to offset the ballast required for static balance of the free wing at the pivot. A radio-controlled model airplane with a 1.74-meter (6-foot) wingspan was modified to this configuration and flown to assess its flight characteristics, controllability, and potential operating problems. Eight flights were made to obtain a limited amount of quantitative and qualitative data. The flights were conducted during the spring of 1977 at the NASA Dryden Flight Research Center at Edwards, California.

This report describes the test program and presents a limited amount of data on trimmed flight characteristics.

TEST VEHICLE

A three-view drawing of the test vehicle is shown in figure 1. The canard flap was used for longitudinal control, while the elevators were used for fuselage pitch attitude control. Full-span strip ailerons were used for roll control. No provision was made for landing flaps. The rudder and nose wheel were interconnected for directional control, and the engine was throttleable for speed control. The radio system was a commercially available seven-channel digital proportional control system. Physical characteristics of the test vehicle are given in table 1.

DATA ACQUISITION

To obtain velocity data, the test vehicle was flown from the back of and "in formation" with a moving pickup truck. Large protractors were installed on the test vehicle (fig. 2) so that the angles of the wing and canard relative to the fuselage could be read in flight from about 6 meters (20 feet). A duplicate of the airborne radio receiver, two servoactuators, and a strip recorder (fig. 3) were carried in the back of the truck to record the canard flap and aileron positions. Before flight, the measured control deflections on the test vehicle were recorded. Flight data points were acquired when the truck driver stabilized on a given speed and the test vehicle was stabilized relative to the truck. Wing angle, surface position, and velocity were recorded, and fuselage attitude relative to the horizon was estimated. Because of the limited instrumentation, 16-millimeter motion pictures were used as much as possible to support the qualitative evaluation.

TEST PROCEDURE

The flight characteristics to be evaluated were identified, and a series of maneuvers was determined that would allow observation of each characteristic. These flight characteristics and maneuvers are listed in table 2. A baseline vehicle with a conventional wing configuration was flown to establish a basis for evaluation of the free-wing concept. Where applicable, the baseline vehicle was flown through the same series of maneuvers in identical wind conditions. The test vehicle pilot conducted the maneuvers while engineers observed the vehicle dynamics and test conditions.

RESULTS AND DISCUSSION

Except for the trim curves, the results and discussion that follow are based on the authors' and consultants' observations of the test vehicle in flight. The flights were conducted in winds generally less than 10 knots; however, one demonstration flight was completed without difficulty during winds of 15 knots with gusts to 20 knots.

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Flight Characteristics

The test vehicle exhibited generally normal stability and control characteristics throughout the flight envelope for all the maneuvers listed in table 2. The test vehicle's response to control inputs in the pitch axis appeared to be faster than that of the conventional airplane, apparently because the inertia of the free-wing assembly was lower than that of the total airplane. The handling qualities were judged to be as good as or better than a similar fixed-wing design. Finally, the separate control of a decoupled fuselage appeared to provide benefits that tended to enhance vehicle performance through pseudo-thrust vectoring. The conclusion reached was that the free-wing, free-canard concept was workable.

Trim curves. - The wing and canard angles of attack and the canard flap deflection, as functions of velocity, were determined for the test vehicle and are shown in figure 4. Each data point represents an average of several readings taken at a particular velocity. The wing angle of attack data were derived from the observed wing deflection angle corrected for estimated fuselage attitude error. The canard angle of attack is the sum of the observed canard deflection and the wing angle of attack. The canard flap deflections were measured directly from the strip recorder.

The plots in figure 4 show that the canard angle of attack and canard flap deflection increase steeply with decreasing velocity, thus indicating strong speed stability.

Stall/spin. - With the test configuration, stall prevention can be achieved by at least two methods: (1) by limiting canard flap travel, or (2) by balancing the canard's maximum lift with the hinge moment required to stall the wing. Stalls were prevented on the test vehicle by the first method, which gave highly repeatable results. With the canard flap at full travel, the test vehicle appeared to sink in a constant wings-level attitude with power off, or appeared to climb steeply with good lateral-directional control with full power. The apparent lack of power effects on the stall is thought to be due to the decoupling of the wing-canard assembly from the fuselage and the placement of the canard well clear of the propeller slipstream.

The test vehicle demonstrated no tendency to spin during stalls. When full rudder with or without aileron was applied, the test vehicle would roll and pitch downward into a spiral dive and would not spin.

The stall/spin characteristics of the test vehicle were considered to be excellent.

Gust alleviation and ride qualities. - During flight in turbulence, a considerable amount of rotational motion of the wing-canard assembly about the pivot was observed. This angular motion is expected in the presence of gusts. In addition, some fuselage pitch oscillations were observed. The test vehicle pilot commented that the flightpath was easy to control in gusty conditions. Lack of onboard instrumentation precluded any conclusions about gust alleviation or ride qualities.

Center of gravity changes. - The wing-canard assembly was balanced at the pivot, which was located at 5-percent mean aerodynamic chord. The fuselage also was balanced at the pivot. When the fuselage center of gravity was moved to approximately 25-percent mean aerodynamic chord, there were no significant changes in the flight characteristics of the test vehicle. When the wing center of gravity was varied 0.5-percent mean aerodynamic chord forward or aft of the pivot, no changes in flight characteristics were observed. However, when landing with the wing center of gravity aft of the pivot, the vehicle tended to lift off after touchdown. This was apparently caused by the inertia of the wing at touchdown which caused the angle of attack to increase, but was easily compensated for by piloting technique. It was concluded that center of gravity changes in the fuselage over the range examined had little or no effect on the longitudinal stability of the test vehicle.

Fuselage attitude control. - Fuselage attitude was controlled independently by use of the traditional elevator control surface. This allowed the fuselage attitude to be controlled over a range of about 15°. The effects of this control were most noticeable during takeoffs and climbs, where the upward thrust effect of a full nose-up elevator position shortened the ground roll noticeably and seemed to cause a steeper climb. The relatively high horsepower-to-weight ratio of the test vehicle exaggerated these effects. The preset elevator control also caused a galloping motion during the takeoff roll and a fuselage pitching motion after the landing touchdown. A preset nose-down elevator position caused considerable "wheelbarrowing" during takeoff and seemed to degrade climb performance. Takeoffs and landings performed with the elevator set at neutral (for a three-point ground attitude) did not exhibit the peculiar ground rolling characteristics.

In addition, the test vehicle was observed to have an apparent absence of power effect (that is, the effect of the propeller slipstream on the tail of the aircraft) to enhance control of lift during flare and landing. Because the fuselage is decoupled from the wing, small increases in power (as used on aircraft with conventional wings) with the elevator up tended only to change fuselage attitude. The use of power for effective thrust vectoring for landing was not investigated.

A separate control for fuselage attitude is a departure from conventional controls and results in an added control with which the pilot must cope. There appear to be a number of benefits to be gained by the use of this controller, such as pseudo-thrust vectoring that could enhance low-speed performance; however, determination of the best method of control was not within the scope of this investigation.

DEVELOPMENTAL PROBLEMS

Some unique and unexpected, but interesting, problems were encountered during the test program.

Canard deflection limits. - During early flight tests the free-wing deflection relative to the fuselage was limited to 20° trailing edge up or down. The free-canard surface deflection relative to the wing was also limited to 20° trailing edge

up or down by mechanical stops designed to prevent the winding up or binding of the electrical wires used to power and control the canard flap servoactuator which was mounted on the canard. During an early flight, the wing suddenly deflected to the full nose-up position, causing a semicontrolled descent to a hard landing. Although the airplane was completely unresponsive in the pitch axis, the remaining roll control was sufficient to maintain a wings-level attitude. The upset was apparently caused by the canard's encountering the trailing edge up position limit, thus aerodynamically locking itself in that position as the wing continued to pitch leading edge up until it encountered its position limit. The assembly was then locked into a stalled condition, which was irreversible in flight.

The problem was eliminated by increasing the free-canard deflection limits to 90° trailing edge up or down. Subsequently the locked condition was not encountered, even in extreme maneuvers such as spin entries, aerobatics, and unplanned tail slides.

Control sensitivity. - Difficulty was encountered in providing an acceptable match between the wing hinge margin (the distance from the wing's aerodynamic center to the pivot) and the canard control effectiveness. In the preliminary design, the size and location of the canard surface were determined based on the requirement that the aircraft be trimmed with full-span landing flaps deflected to 30°; however, the model was not equipped with these flaps. It was not realized until flight testing that the canard flap position for trimmed flight changed only 1.5° for a lift coefficient range from zero to maximum for the landing flaps up condition. Thus, the usable range of the trim lift coefficient was spanned by only 21.5 percent of the control stick throw, which proved to be excessively sensitive. Reasonable handling qualities were achieved by increasing the wing hinge margin from the design value of 6.5-percent mean aerodynamic chord to 20-percent mean aerodynamic chord, increasing the canard area aft of the canard pivot to effectively increase the canard hinge margin from 6.5-percent mean aerodynamic chord to 12-percent mean aerodynamic chord, and decreasing the canard flap area by approximately 50 percent.

Canard pivot friction. - The strongly destabilizing effects of canard pivot friction were observed when the test vehicle was parked and headed into a light breeze such that the free wing would oscillate from stop to stop. When the free wing is unrestrained, canard pivot friction causes the wing-canard assembly to assume a canard-fixed aerodynamic center that is well forward of the wing pivot. The system is thus unstable for small angle of attack changes, but stable for large changes since the friction eventually becomes small compared to the aerodynamic restoring moment on the canard. A limit cycle of fairly large amplitude resulted during taxiing; however, the magnitude of the limit cycle diminished rapidly during the takeoff run and was not noticeable to observers while the test vehicle was in flight.

Piloting difficulties. - Wing-fuselage decoupling caused some control difficulties for the test vehicle pilot, who was accustomed to judging approach and landing speeds by visual acquisition of the attitude of a conventional vehicle. With the test vehicle, the fuselage attitude was no longer helpful, and the wing

angle of attack was extremely difficult to judge. It was necessary to use relatively rigid piloting procedures to avoid having either excessive or insufficient airspeed during approaches and landings.

It is expected that the wing-fuselage decoupling would not be a problem for a pilot flying a full-scale version of the test vehicle because normal flight instrumentation, including airspeed indicators, would be available.

CONCLUDING REMARKS

A radio-controlled airplane model with a free-wing, free-canard configuration was flown to assess its flight characteristics, controllability, and potential operating problems. The flight results discussed are based mainly on observations. The free-wing, free-canard concept was demonstrated to be workable. The stall/spin characteristics were considered to be excellent. Center of gravity changes had little or no effect on longitudinal stability. Fuselage attitude control is an added parameter with which the pilot must cope. The lack of onboard instrumentation precluded any conclusions about gust alleviation or ride qualities.

*Dryden Flight Research Center
National Aeronautics and Space Administration
Edwards, Calif., October 11, 1977*

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TABLE 1.—PHYSICAL CHARACTERISTICS OF TEST VEHICLE

Weight, kg (lb)	5.5 (12.1)
Wing—	
Span, cm (in.)	174.0 (68.5)
Chord, cm (in.)	30.0 (12.0)
Area, m ² (ft ²)	0.52 (5.70)
Loading, kg/m ² (oz/ft ²)	10.58 (35.3)
Pivot location, percent of mean aerodynamic chord	5
Deflection, maximum, deg	±20
Canard—	
Span, cm (in.)	72.0 (28.5)
Chord (average), cm (in.)	15.0 (5.8)
Area, m ² (ft ²)	0.11 (1.15)
Pivot location, percent of mean aerodynamic chord	13
Flap area, cm ² (in ²)	42 (6.5)
Deflection, maximum, deg	±90
Boom—	
Length (pivot to pivot), cm (in.)	58.5 (23.0)
Angle, deg up	15
Engine displacement, cm ³ (in ³)	10 (0.61)

TABLE 2.—MANEUVERS USED TO EVALUATE FLIGHT CHARACTERISTICS

Flight characteristic	Maneuver
Trim	Formation with ground vehicle
Stall/spin	Powered and unpowered stalls, spins
Fuselage center of gravity changes	Takeoffs and landings, stalls
Wing center of gravity changes	Takeoffs and landings, stalls
Separate attitude control, thrust vectoring	Straight flight with cycling canard flap and elevator, takeoffs and landings, stalls, slow flight
Gust alleviation	Flybys at approximately 3 meters (10 feet) from observer during turbulent conditions
Maneuvering	Loops, rolls, Immelmans

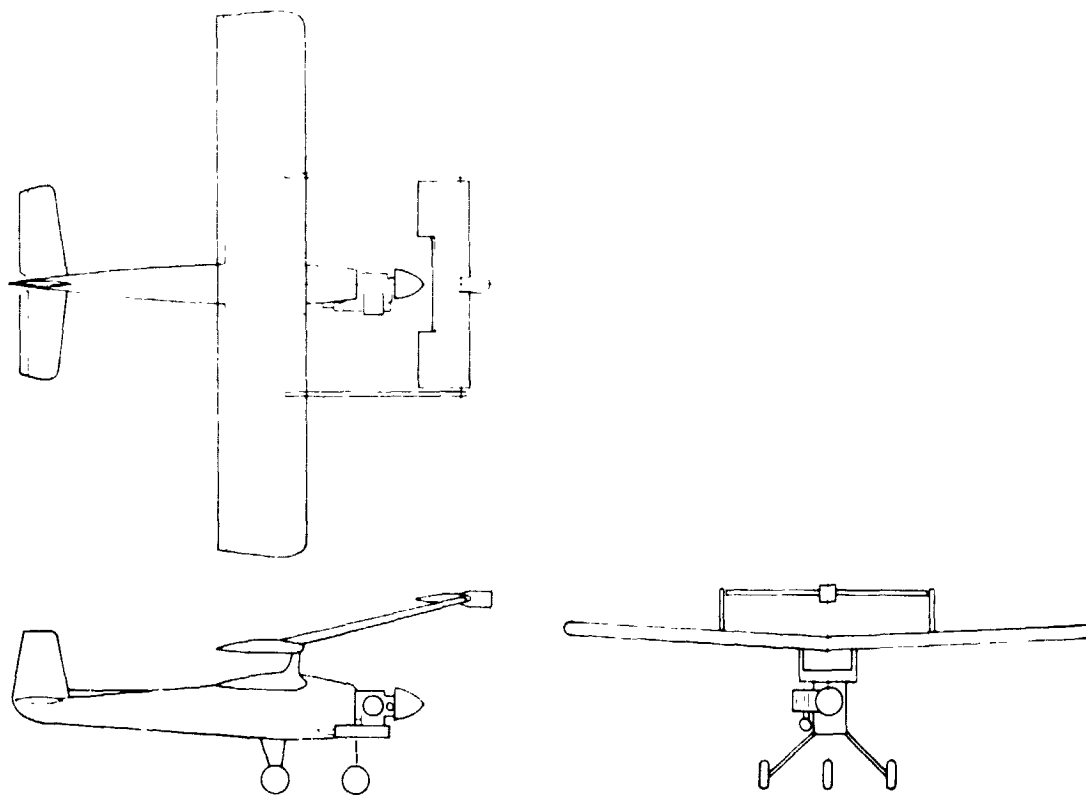


Figure 1. Three-view drawing of test vehicle.

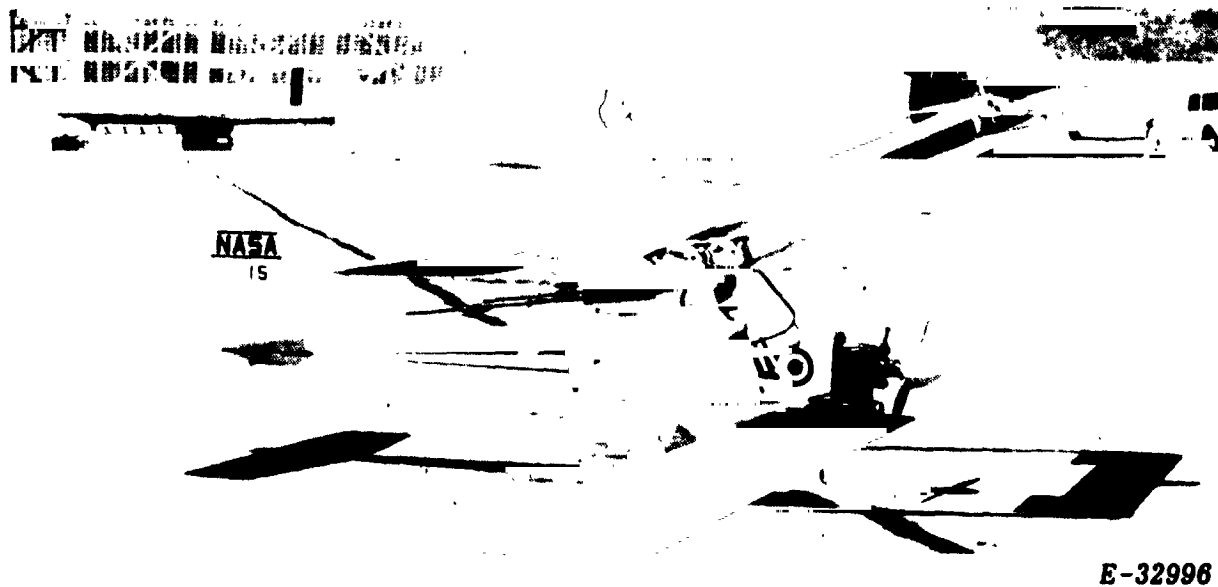
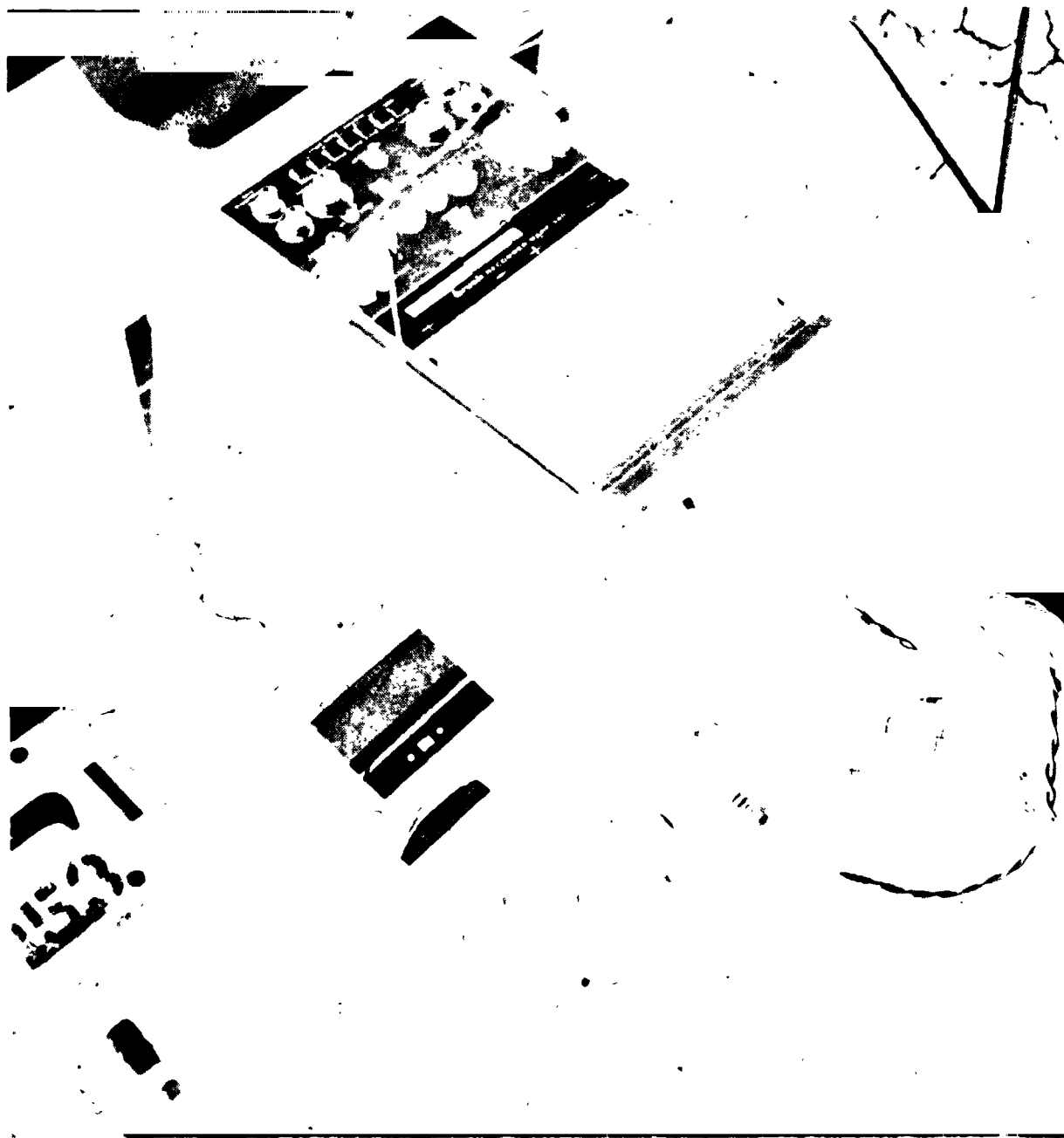


Figure 2. Test vehicle.



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Figure 3. Recorder in pickup truck.

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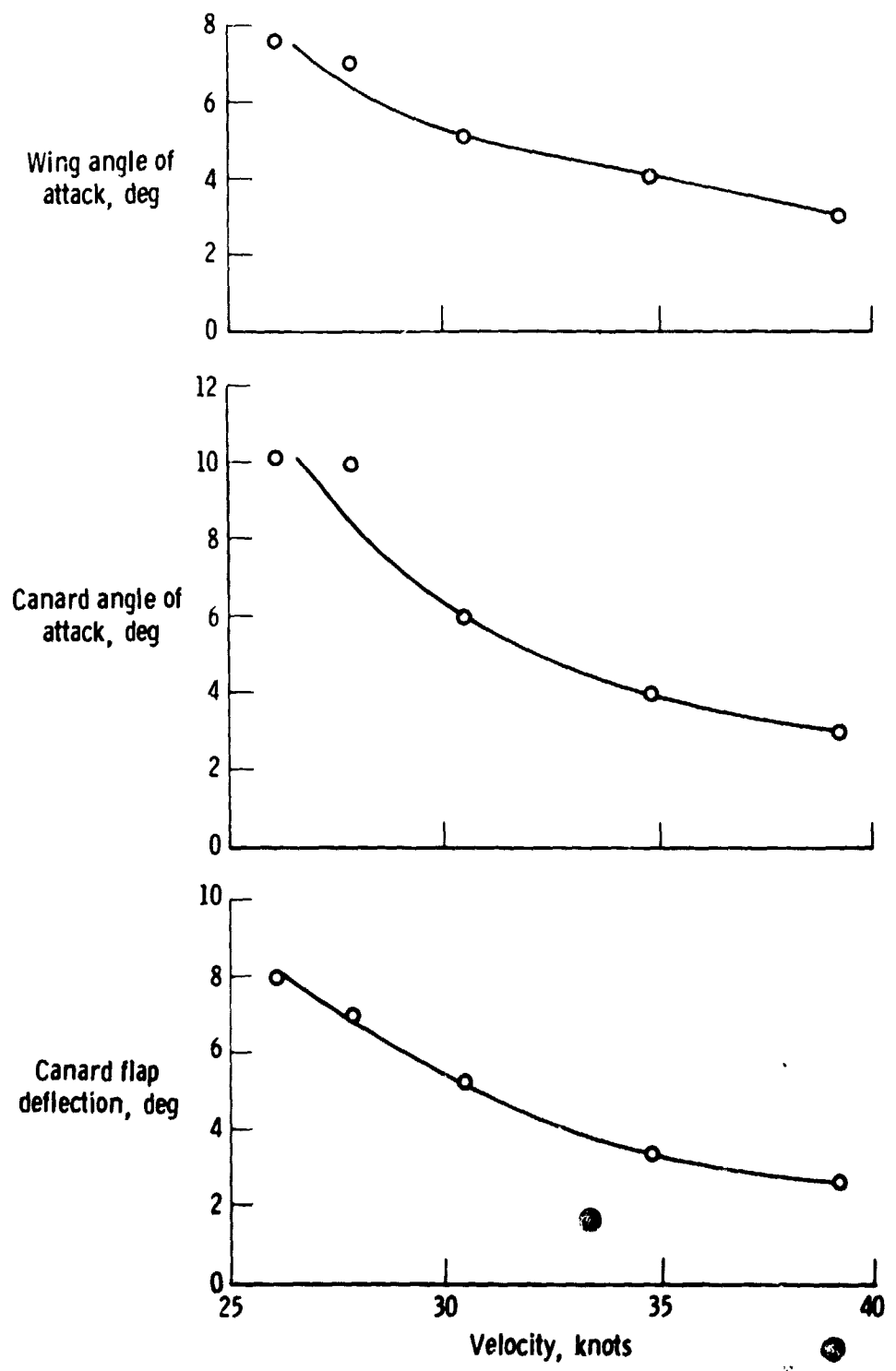


Figure 4. Wing and canard angle of attack and canard deflection characteristics of test airplane.

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16 Abstract A radio-controlled airplane model with a free-wing, free-canard configuration was flown to assess its flight characteristics, controllability, and potential operating problems. A simple technique of flying the test vehicle "in formation" with a pickup truck was used to obtain trim data. The test vehicle was flown through a series of maneuvers designed to permit evaluation of certain characteristics by observation. The free-wing, free-canard concept was determined to be workable. Stall/spin characteristics were considered to be excellent, and no effect on longitudinal stability was observed when center of gravity changes were made. Several problems were encountered during the early stages of flight testing, such as aerodynamic lockup of the free canard and excessive control sensitivity. Lack of onboard instrumentation precluded any conclusions about gust alleviation or ride qualities. ORIGINAL PAGE IS OF POOR QUALITY			
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