tem. If the flutter control system required separate dedicated components, the weight would be significantly greater.

Conclusions

These studies have shown that wing/store flutter can be stabilized with adequate stability margins using an active flutter control system which shares the aileron actuation hydraulics with the lateral control system. The flutter control system can be adapted to different store carriage configurations by adjusting the phase and gain characteristics of a generalized electronic compensation network. Control of a flutter mode can be maintained even though the hydraulic actuators are rate saturated for a significant portion of their stroking cycles. Before a flutter control system can be implemented on current aircraft actuator bandwidth should be extended and hydraulic flow rate increased. These improvements are within the current state-of-the-art. It is estimated that the flutter control system with triply redundant components will add about 270 lb to the aircraft weight.

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An Omnidirectional Gliding Ribbon Parachute and Control System

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An omnidirectional gliding, guided ribbon parachute and control system has been designed and tested. A 24-ft-(7.3-m)-diam ribbon parachute has been modified by incorporating four controllable glide flaps 90° apart at the skirt region and two roll flaps 180° apart. The design includes a control system consisting of a remote command transmission site and an on-board sensing and receiving station and control line operation. Four drop tests of a 2600-lb (1179-kg) test vehicle have demonstrated that the system is feasible if the parachute is carefully modified, if glide flaps are provided for omnidirectional control, and if an on-board sensor is used for roll control.

Introduction

RIBBON parachutes[1] are often used to control down time, impact velocity and impact attitude of bombs. The accuracy for parachute retarded delivery of stores is about an order of magnitude worse than a free-fall delivery due to wind drift and drag-area variations. The three sigma dispersion is about 100 mils based on trajectory length for parachute retarded weapons. This dispersion does not include release point error or errors in wind prediction.

It has been demonstrated[2-4] that a ribbon parachute will glide with a lift-to-drag ratio of about 1/3 if the skirt region is lined with solid cloth. Only two glide flaps in the skirt region of the parachutes were used on these original, similar tests.[2,3] It was believed desirable to introduce four glide flaps 90° apart at the parachute skirt so that the vehicle could be glided in any direction without rolling the system appreciably.

The data from four drop tests of a 2600-lb (1179-kg) vehicle released at 130 knots (67 m/s) true air speed at a 13,000-ft (3962-m) altitude to evaluate the four-flap system for guiding a 24-ft-(7.3)-diam ribbon parachute are presented herein.

History

Development work on the feasibility of guiding a store by means of a ribbon parachute began at Sandia Laboratories in early 1969. These early drop tests, along with wind tunnel tests,[5] established that a ribbon parachute with a lined skirt could achieve a glide ratio‡ of 1/3 if an opening of proper size was introduced into the lined portion. Subsequent tests showed that simple and reliable

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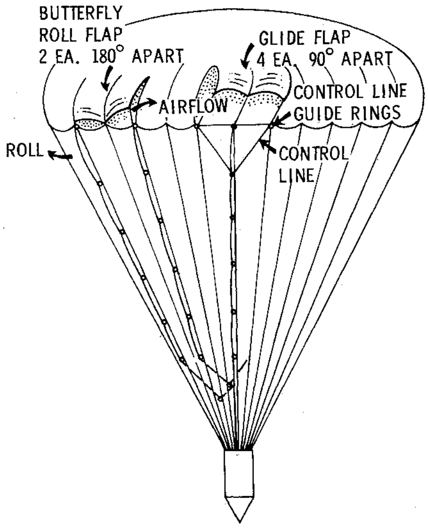

Fig. 1 Sketch of glide and roll flap rigging.

rigging could be achieved for controlling the openings by motor driven drums in the drop test vehicle. The motors were controlled by signals sent from a remote ground location by means of an RF link. The parachute used on these early tests had two glide openings 180° apart, with two roll control butterfly openings 180° apart, but transverse to the glide openings (similar to four glide openings shown in Figs. 1 and 2).

On early tests, the method employed for defining the positional error of the drop test unit relative to the target was a TV camera mounted in the nose of the vehicle with the video picture transmitted to the operator (controller) at a remote site. The TV camera was held in a fixed position in the vehicle nose for the first few tests. Due to the motion of the test vehicle at the end of the parachute, the positional error could not be determined with sufficient accuracy. A gimbaled camera also proved ineffective. Finally a TV camera mounted on a stable platform coupled with a rate gyro to automatically damp out vehicle roll proved very effective. The rate gyro was used in the latest drop test series reported herein.

Even with the stable-platform-mounted TV camera, several obstacles remained to successfully guide the vehicle to the target. The first problem was to uncage the

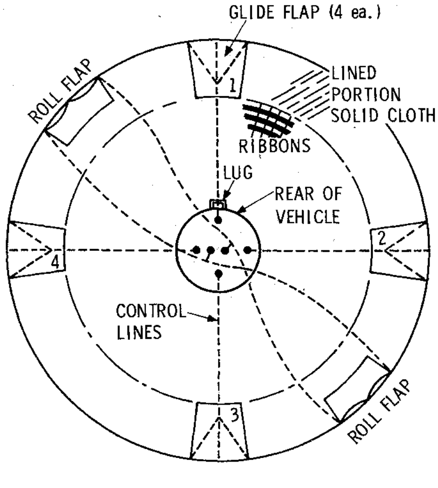

Fig. 2 Rigging of control lines.

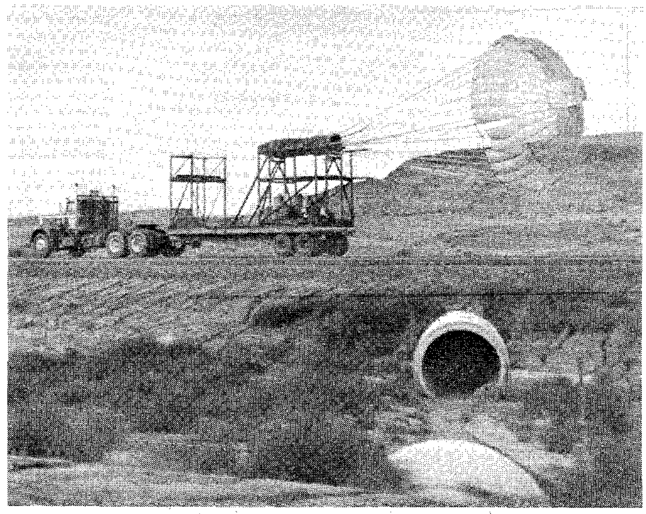

Fig. 3 Truck tow tests of control system.

camera in a vertical position. The controller accomplished this by studying a priori how the picture should appear at verticality and then transmitting an uncage signal to the drop unit according to his analysis of the TV picture. From this point on, circuitry in the system would integrate all motion of the vehicle and apply a signal to torque motors on the stable platform to bring it to the focal point of this motion. This system worked satisfactorily for a known target; however, it would present problems for an unknown target. An additional problem with the system was that the parachute glide capability was bidirectional resulting in a costly time lag if the unit was blown off the target in such a way that it would have to be rolled before gliding. This problem was encountered on one drop test.

An additional factor contributing to impact dispersion concerned lag time. The operator response to observations from the TV monitor in combination with system response led to overcontrol. Also, the resolution of the TV system was such that small disturbances were not noted and consequently no corrective action was taken.

A further drawback to the system was the cost of the TV camera in the expendable drop vehicle. Even on the

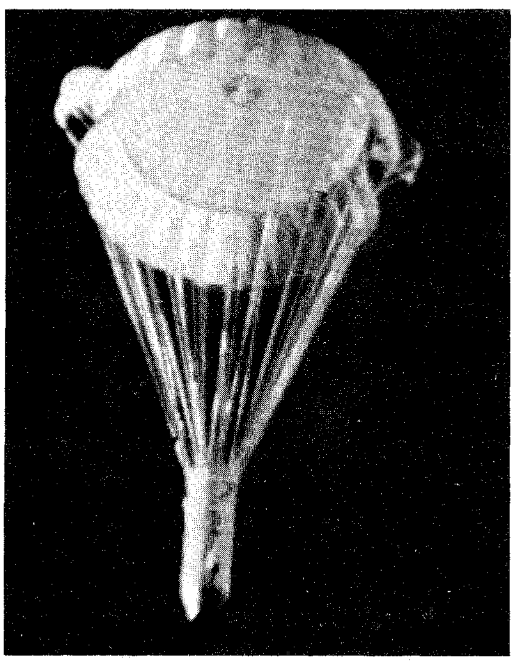

Fig. 4 Free-flight photograph of gliding ribbon parachute.

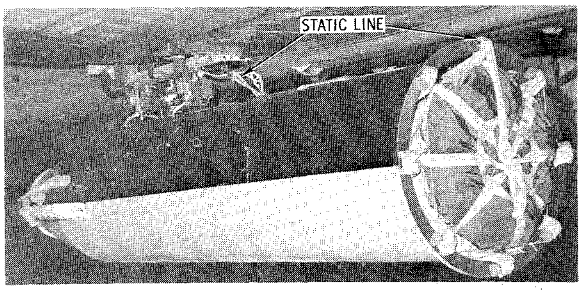

Fig. 5 Rear view of vehicle on C-54 aircraft.

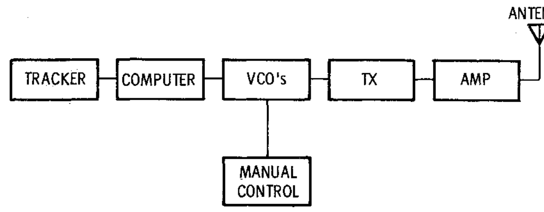

Fig. 6 Remote sensing, logic, and RF command block diagram.

test drops where the rest of the equipment survived, the unprotected TV system in the nose of the vehicle was lost.

Four separately-controlled, glide flaps 90° apart (omnidirectional glide control system) were incorporated in the 24-ft-(7.3 m)-diam ribbon parachute system for the test series reported herein to improve the guided performance.

Parachute Design

The parachute used for four recent tests was a standard heavy duty, flat-circular, 24-ft-(7.3 m)-diam, 32-gore ribbon parachute modified for controlled gliding flight as shown in Fig. 1. The parachute canopy has been lined on the inner side, from the skirt band up radially for 5 ft (1.5-m), with 1.6-oz/yd^2 nylon cloth. Four glide flaps, each 5 ft (1.5-m) square, are located 90° apart around the canopy. Each flap is connected by a control line to a motor driven windlass.

Roll control is achieved by two "butterfly" flaps 180° apart, located 45° from the glide flaps. The roll flaps are interconnected, as shown in Fig. 2, so that, as the clockwise half of both flaps close, the counterclockwise portions open. At neutral roll, all four halves are half open. When the clockwise sides of the flaps are open, the system will roll counterclockwise due to the reaction effect of outflowing air.

A truck tow shown in Fig. 3 was used in early testing to check control action. A flight photograph (Fig. 4) taken of the two-glide-flap design shows the flaps half open.

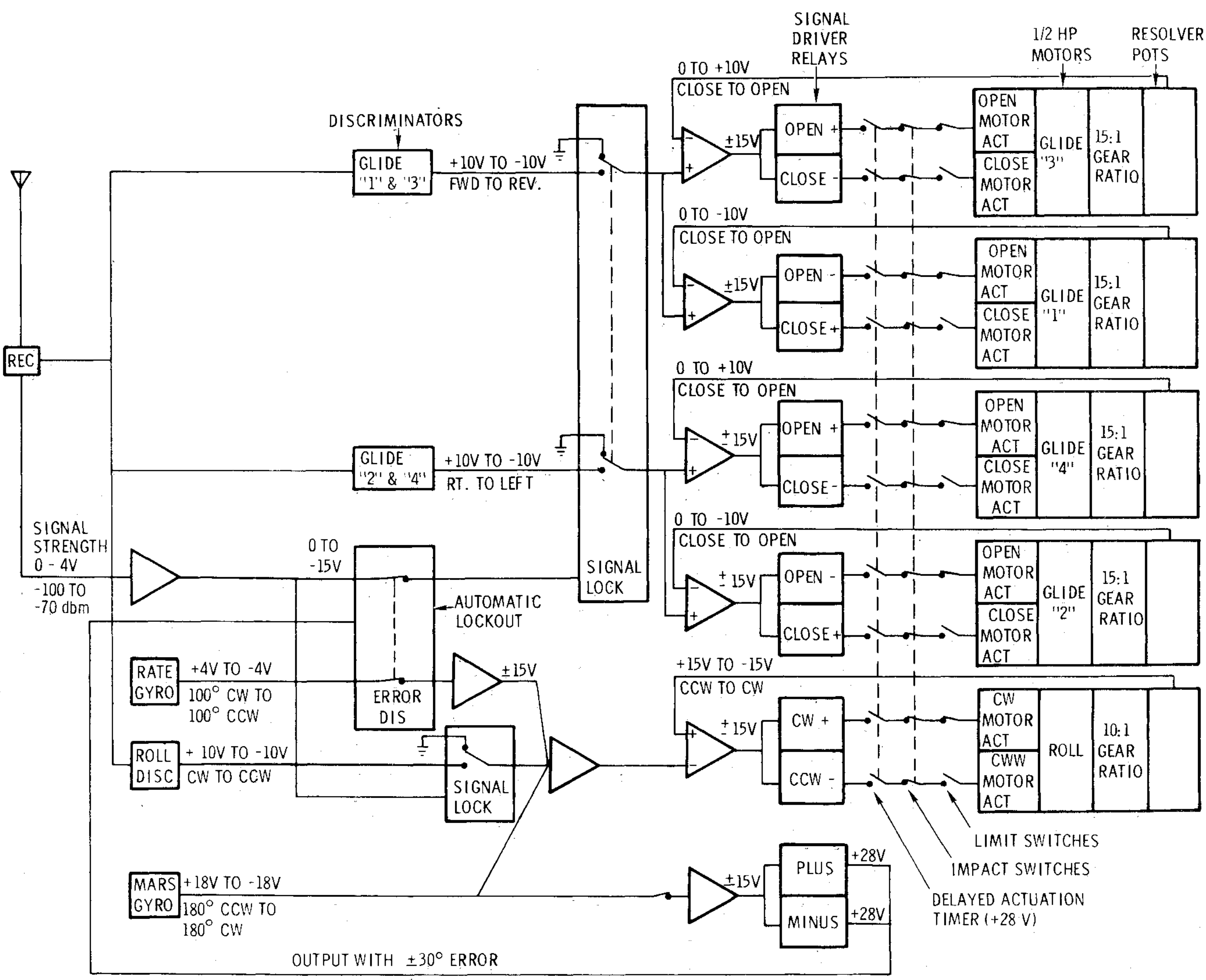

Fig. 7 On-board control system signal flow chart.

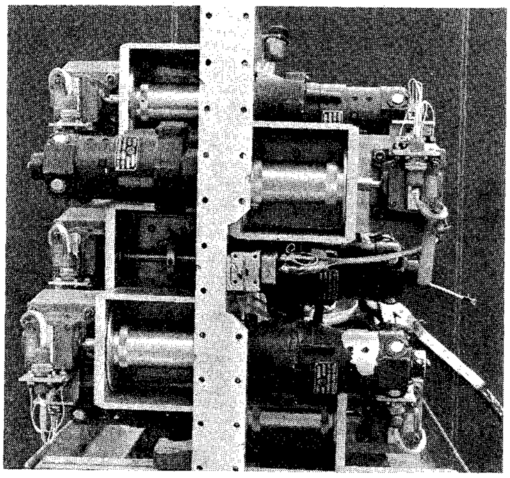

Fig. 8 Control motors and drums.

Parachute Rigging and Packing

The control lines, fabricated of 4000-lb (17.8-kn) 1-in. wide nylon webbing, were laid out along the 6000-lb (26.7-kn) suspension lines and cut to proper length under 40-lb (0.18-kn) tension. As shown in Fig. 1, the control lines were passed through standard 1⅛-in. (2.86 cm) I.D. reefing rings at the skirt of the parachute and at 8-ft (2.44-m) intervals along the suspension lines. After the first drop test, asymmetries were noted that required stretching the parachute out approximately to the inflated shape (while attached to the drop vehicle) and making adjustments to the suspension-line and control-line lengths. Stretching the parachute was accomplished by tying 550-lb (2.45-kn) cord at four points on the skirt 90° apart and anchoring the ties to beams in the laboratory.

The parachute was packed loosely into a bag incorporating canopy locking flaps and 90-lb (0.4-kn) tape line ties. A 5-ft-(1.5-m) -diam guide surface pilot chute was used with a static line attached from the pilot chute bag to the C-54 bomb rack (Fig. 5). The packed parachute weighs about 150 lb (68-kg).

Control System Description

Figure 6 shows a block diagram of the remote sensing, logic and RF command systems proposed and partially used on the program. The tracker is a postulated radar or other system which could acquire an object in space and determine its azimuth and range from the antenna. The computer would determine the flight path and generate correction signals for transmission to the drop test vehicle, gliding it along a wind-corrected trajectory to the target. The manual control is used for vehicle checkout and was also used on the four test drops.

Figure 7 is a signal flow chart of the vehicle's on-board control system used in the last four tests. The rate gyro signal was used to damp out roll oscillations while the stable platform (MARS gyro) signal maintained the vehicle in a constant roll orientation. The system could then receive the remotely generated command signals and glide to the target. The flap-control motors and control-line drums are shown in Fig. 8.

Drop Test Results

Four drop tests of the 2600-lb (1179-kg) test vehicle shown in Fig. 5 were conducted. A mobile radar van was used to position the C-54 drop aircraft at 13,000 ft (3962-m) msl and at a speed of 130 knots (67-m/s) TAS. Mobile cameras were used to obtain documentary data. Preliminary drops of smoke bombs were used to verify windage corrections.

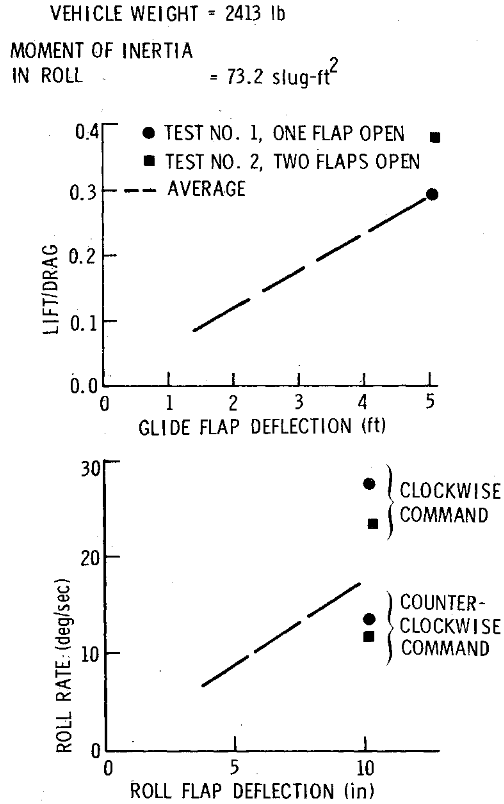

Fig. 9 Lift-to-drag ratio and roll rate variation with control opening.

The first two drops were made to adjust the control-line lengths and eliminate rigging asymmetries, as well as to evaluate the on-board roll control and stable heading systems and to obtain glide ratio data. Lift-to-drag ratio and roll rate as a function of control flap openings are shown in Fig. 9 for the first and second drop tests where control settings were maintained for 10 sec. No roll or glide data could be obtained on the last two drops because the control settings were not constant. Data from the four drop tests indicate the average vertical velocity was about 100 ft/sec (30-m/s) and the horizontal glide velocity was about 33 fps (10-m/s), with the measured wind subtracted. On the fourth and last drop test the operator used position data from a radar plotting board to direct the vehicle to a ground reflector. The impact error, which includes the effects of wind and release-point errors, was 80 ft (24-m) or about 10 mils based on trajectory length.

Conclusions

An omnidirectional gliding parachute and control system has been designed. A 24-ft (7.3-m) diam ribbon parachute has been modified by incorporating four controllable glide flaps 90° apart at the skirt region and two roll flaps 180° apart. A control system consisting of a remote command transmission site and an onboard sensing and receiving station has been designed. Four drop tests of a 2600 pound (1179-kg) test vehicle conducted from a C-54 aircraft demonstrated that: 1) Satisfactory guidance and control was obtained. 2) Four glide flaps will provide omnidirectional control.

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Fracture Mechanics Applications in Materials Selection, Fabrication Sequencing and Inspection

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Structural component failures associated with military aircraft have caused both operational limitations and concern over the current approach to assurance of structural integrity. Failures attributed to the presence of crack-like defects raised special concern over the probability of other defects existing in similar parts. For this reason, critical parts are being subjected to additional screening to evaluate their integrity when containing crack-like defects. This paper illustrates the use of fracture mechanics concepts to quantitatively compare the effects of various alternatives involved in design, manufacturing, assembly and quality assurance for a critical part.

Introduction

MATERIALS selection and structural design in the aircraft industry are based on five basic considerations of material response to loading,[1] namely:

1) Static ultimate strength and stiffness of undamaged, flaw-free material (σ_U, E, no flaws or damage).

2) Fatigue of undamaged, flaw-free material (safe-life design).

3) Residual static strength and stiffness of damaged structure (fail-safe, damage tolerance).

4) Fatigue of damaged, flawed material (inspection criteria, intervals and repair procedures).

5) Time dependent material behavior (creep, stress rupture, thermal fatigue, stress corrosion, etc.).

Safe-life design concepts require analysis or testing to show that the probability of any catastrophic fatigue failure is extremely remote for the assumed life of the structure. Increasing demands on materials to fill new or modified mission requirements, while maintaining high performance characteristics at minimum weight and cost, have brought about the use of high strength materials in safe-life designs for both military and commercial aircraft. The problems that are being experienced in fracture of aircraft components today are somewhat disturbing because they are now occurring in safe-life design components such as wing fittings and attachments, landing gears, and carry-through structure. Thus, use of high strength materials in components where safe-life design has traditionally and reliably been applied has produced service failures. Simply stated, this is because the increase in strength requirement very often brings a concomitant loss of toughness. Thus, where tough materials previously had been employed, materials that are subject to failure by small flaws are now being used. Often, the flaw sizes involved are not detectable by current nondestructive inspection (NDI) procedures.

The aircraft industry has effectively minimized the seriousness of the fracture problem by fail-safe design concepts for several years. Fail-safe design concepts require that a damaged structure continues to perform satisfactorily until discovery and remedial action can be accomplished. In employing this practice, the following items have been used in an attempt to prevent premature failure of components: 1) tough materials (large visible cracks prior to failure), 2) multiple load paths (redundancy), 3) crack stoppers, and 4) subcritical flaw growth prediction techniques (use of inspection intervals and crack propagation laws).

The fail-safe concept was developed as a result of failures encountered in the Comet series aircraft in the early 1950's. Current fail-safe design criteria specify the load requirements for structures having obvious damage and specify appropriate inspection intervals. In all cases the intent is to provide for sufficient damage tolerance so that fatigue cracks or other damage will be discovered before catastrophic failure becomes probable.

In the past, methods of calculating residual strength of damaged structures included effective width,[2] notch analysis[3] and fracture mechanics[4,5] techniques. In tough materials such as 2024-T3 aluminum, high residual strengths (near net section yield) have been obtained by proper use of crack stoppers such as properly placed straps, stringers or frames. When using materials that are lacking in toughness in relation to inherent flaw sizes and operating stress levels, it often becomes impractical to attempt arresting crack growth by adding structural reinforcements, since these reinforcements would need to be very close to one another, resulting in weight and cost penalties. When this is the case, redundancy and thus fail-safe conditions are most economically obtained by providing alternate load paths. However, in many applications even this tech-

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