The use of reflection coefficient R in place of k provides more insight to jet wave patterns and permits one to draw a neat map in $M_j - M_\infty$ plane.

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Development of a Gliding Guided Ribbon Parachute for Transonic Speed Deployment

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Introduction

PARACHUTE retardation is often a necessity on some drop vehicles to help control performance and trajectory. With the increased time of fall, dispersion suffers from unknown winds. A guided parachute system could be used to improve accuracy in many applications.

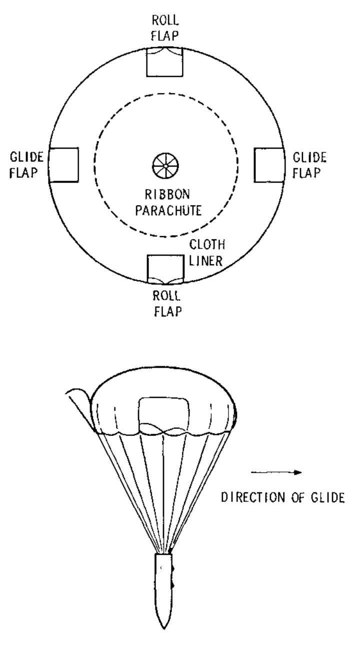

Fig. 1 Sketch of gliding ribbon parachute.

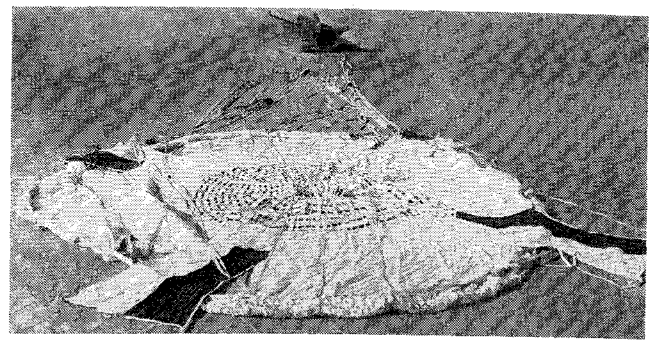

Fig. 2 Gliding parachute after drop test at Tonopah Test Range, Nevada.

Earlier work with guided parachutes at Sandia was done with solid chutes with one gore missing,[1] or with the parafoil.[2] Both of these systems were suited for low-speed deployments only. To develop a system for higher-speed deployments, recent research has been directed at using conventional ribbon parachutes,[3] modified to provide a glide and turn capability without materially affecting opening reliability, structural integrity, or effective drag.

Parachute Design

The system presently being tested consists of a standard heavy duty flat circular 24-ft diam, 32-gore, ribbon parachute that has been modified, as shown in Fig. 1, for controlled gliding flight. The canopy has been lined on the inner side from the skirt band up radially for 5 ft with 1.6 oz/yd^2 nylon cloth. Two glide flaps, 2 gores wide and 5 ft high, have been made diametrically opposite each other. These flaps are interconnected so that as one opens, the other closes, and for neutral glide, they are each half open. This way, either forward or backward glide can be commanded.

Roll control is obtained by making two roll flaps on the skirt located 90° from the glide flaps. Most effective control has been obtained by the "butterfly" arrangement shown. Again, the flaps are interconnected so that as the clockwise portion of both flaps close, the counterclockwise portions open. At neutral roll, all four portions are half open. When the portions that are physically located on the clockwise sides are open, the system will roll counterclockwise.

Development

The system has been developed by wind-tunnel testing,[4] vehicle tow tests, and full scale drop tests. Wind-tunnel tests were conducted to investigate gliding performance. Several combinations of glide flap size and amount of flap movement were tested. Ribbon canopies with differing amounts of a solid inner lining were also tried. From a visual analysis and determination of the zero moment point, the results indicated a glide angle of 25° off the vertical could be obtained. Cloth lining in the skirt area of ribbon chutes was found to increase glide capability.

Drop tests using the 24-ft chute and a 2500-lb vehicle, shown in Fig. 2, were conducted from a C-54 aircraft at the instrumented AEC Tonopah Test Range, Nevada, and the predicted glide angle of approximately 25° was verified.

Radio-controlled flights were then made using two motors to open and close the flaps on command. Each motor drives a windlass wound to reel out one line while pulling in another. One windlass is attached to both glide flaps, and the other is attached to both roll flaps. Using reversible motors, both forward and reverse glide and clockwise and counterclockwise roll can be obtained. The parachute and vehicle after drop test are shown in Fig. 2.

The "bang-bang" type of control originally employed caused stability problems by forcing full glide too fast, making it difficult to hold a given heading; therefore, proportional

Received August 10, 1970; revision received October 15, 1970. This work was supported by the U.S. Atomic Energy Commission.

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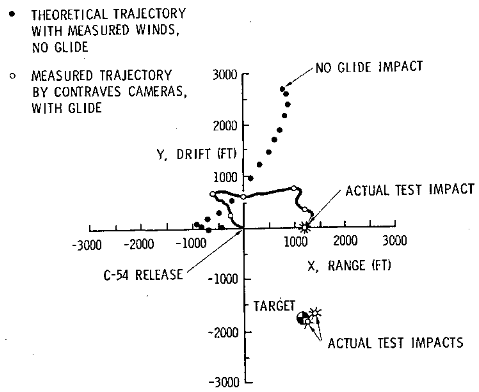

Fig. 3 Plan view of guided gliding drop tests.

control was incorporated. An analog computer program was devised‡ to study the effects of proportional control on stability and steering accuracy and on the effects of using a fixed camera and gyrostabilized camera as steering aids. The proportional control system was evaluated through another series of drop tests. Controllability was greatly improved.

To get a shorter "turn around" time and to visually observe the effects of rigging changes, a platform was built on a diesel truck trailer, and tests were conducted at speeds of 50–60 mph. Better methods of routing control lines and improving stability were developed during these tests at considerable savings.

Further drop tests were then made to verify the rigging changes and the use of a downward-pointed TV camera in the nose of the vehicle to help the operator steer toward a selected impact point. Both fixed and gyro-stabilized cameras were used. This improved operator accuracy and allowed remote operation desirable for certain applications. No radar or visual acquisition of the vehicle was necessary, allowing a simpler over-all system.

Results

A plan view of the flight path of a representative drop test is shown in Fig. 3. The no-glide impact shown was computed by using the measured winds and the actual vertical speed measured on the drop. Drop altitude from the C-54 aircraft was 20,000-ft MSL, and target altitude was approximately 5500-ft MSL. Nearly 3000 ft of wind drift was cancelled by using the controlled glide capability of the parachute.

Circular errors of 1800 ft, 240 ft and 111 ft have been obtained, as shown in Fig. 3, for a release altitude of 20,000-ft MSL. It is believed that accuracy of this system can be developed to 50-ft CEP, or better. Operationally, the controller with a television monitor would be located in an aircraft above the desired impact point.

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‡ This work is done by H. R. Vaughn, Supervisor of Aeroballistics Division, Aerothermodynamics Projects Department.

Calculation of Supersonic Compressor Losses

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Nomenclature

A_I/A_{II} = $S/S + \tau$ = dump area ratio
c = chord
f = correction factor
g = $(P_t)_2/(P_t)_1$
h = radial blade length
M = Mach number
P = pressure
S = blade spacing
γ = ratio of specific heats
ϵ = $f_n - f$
θ = blade camber angle
η = stage adiabatic efficiency
σ = c/S = solidity
τ = trailing edge thickness
ξ = cascade stagger angle, measured from axial direction

Subscripts

0 = subsonic conditions
1 = conditions upstream ahead of cascade inlet
2 = condition's downstream of cascade
n = nominal conditions
s = conditions behind shock wave
t = total conditions

I. Introduction

THE theoretical prediction of supersonic flow properties in a curved channel or between adjacent blades of a cascade presents a formidable task because of the complex nature of the interaction of shock waves, the vortex sheets, and the boundary layer.[1,2] A more reliable means of obtaining the performance of these compressors is experimental testing, as described in Refs. 3–7. For design purposes the idea of a simple analytical or semiempirical means of predicting the performance is attractive. Several papers along these lines have appeared recently in the literature, among them is the work of Balzer[8] in which the boundary-layer blockage effect and change in shock position are accounted for. A semiempirical method for predicting the performance of high reaction supersonic compressor blade sections is given by Boxer.[9]

The present analysis is an attempt to supplement the previous analyses with still another semiempirical performance estimation that is believed to be simpler in application and more widely applicable to a large family of cascade geometries. The success of the method is due, in part, to the manner in which the experimental data was used to determine the initial Mach number influence on a key parameter in the efficiency expression. This method extends a successful formulation developed for subsonic compressors by Losey and Tabakoff[10] to the cases of supersonic compressors in which shock losses are present and accounted for. Other effects, such as dump losses and errors in the shock structure model used, are partially accounted for through the use of the experimental data.

II. Mathematical Flow Model

The purpose of this analysis is the development of a simple realistic means to compute the adiabatic efficiency of a super-

Received October 26, 1970. This work was sponsored under Project Themis Contract Number DAHC-04-69C-0016, U.S. Army Research Office—Durham.

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