Engineering Notes

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Documentation of the Feasibility Research on a Destructible Parachute

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Nomenclature

C_D = drag coefficient of system based on S
d = constructed parachute diameter, ft
F_{max} = maximum parachute load at deployment, lb
h = altitude, ft
Δh = vertical fall, ft
q = dynamic pressure, lb/ft^2 = $\frac{1}{2}\rho V^2$
S = parachute constructed area, ft^2 = $(\pi/4)d^2$
V = velocity, ft/sec
W = total payload weight, lb
x = dynamic load factor
γ = flight path angle from horizontal (negative below horizontal), deg
ρ = air density, slugs/ft^3

Subscripts

ej = downward ejection velocity at release
T = total velocity
r = release conditions

Introduction

In September 1971, a study was initiated to develop a parachute that would decelerate a 37.2-lb terradynamic penetration store from transonic release speeds. A 4-ft-diam nylon ribbon parachute was known from previous tests to be capable of producing the necessary drag and stability characteristics. It was specified that the parachute leave no recognizable trace that would reveal the presence of the store.

In February 1972, a project was authorized to prove the feasibility of the entire system within a period of 3 months. The short time scale eliminated the possibility of developing any new parachute fabric that would be easier to destroy than nylon. This report documents the activities related to the destruction of nylon and the events that lead to the issuance of United States Patent No. 3,814,355.[1]

System Analysis

The system operation consisted of delivering a 37.2-lb store from a high-speed military aircraft. Design conditions were a maximum release speed of 550 knots CAS at an altitude of approximately 250 ft above terrain. A ribbon parachute decelerated and turned the vehicle over to the proper angle for implant in the ground. Figure 1 shows point mass theoretical trajectory angles and velocities after 190 ft of vertical fall. At this point, the parachute would be separated and ignited and a rocket fired to increase the vehicle speed to approximately 230 ft/sec for proper implantation. The knee of the curves (see Fig. 1) occurs at the selected parachute size of 4.5 ft. Assuming a 50-lb total system weight, the velocity at rocket fire was 67 ft/sec and the trajectory angle was 68.5 deg from the horizontal.

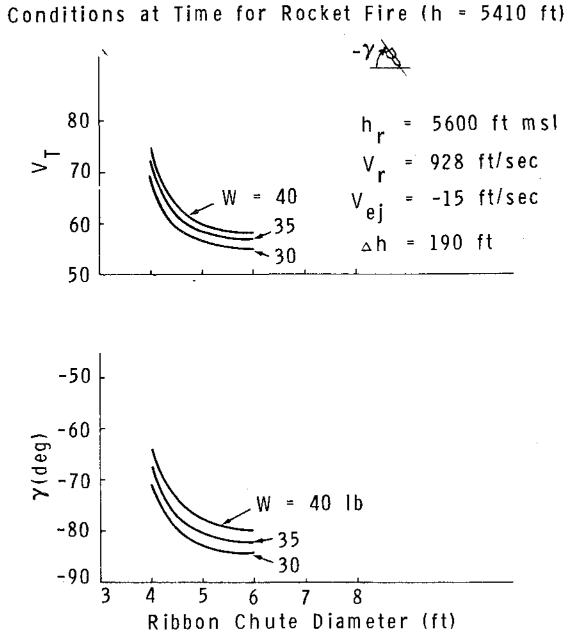

Fig. 1 Theoretical trajectory results for maximum speed release.

Parachute Design

A 4.5-ft-diam 20-deg conical ribbon parachute[2] made of nylon was selected for the project. Based on the desired maximum release velocity at sea level of 550 knots CAS the design dynamic pressure was 1000 lb/ft^2. The maximum opening load was

$$F_{max} = C_D Sqx = 8(1000)(0.5) = 4000 \text{ lb}‡$$

Twelve 6-ft suspension lines of 750-lb breaking strength would give an ultimate line rating of 9000 lb, producing a safe design factor of 2.25. Nine 2-in. wide ribbons of 460-lb breaking strength spaced at 1 in. were used for the canopy. The gore length from the bottom of the skirt band to the top of the vent band was 26.125 in. Pocket bands were used at the intersection of each suspension line with the skirt band to aid initial inflation. The finished canopy, untreated, weighed 1 lb 11 oz. The twelve suspension lines formed six load loops, which were attached to an aluminum load ring.

Materials

Early experiments with fast-burning materials like collodion and airplane dope resulted in parachutes that were stiff and could not be packaged. These materials also were too viscous to penetrate the ribbon nylon. Therefore, only surface coating resulted, not impregnation. Consequently, there was only surface charring of the nylon when it was ignited. Oxidizers like potassium perchlorate were added, but

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‡A drag coefficient of 0.5 was assumed for the ribbon parachute, and the dynamic factor of 0.5 was determined from prior tests of a lightweight vehicle.

Table 1 Final mixture proportions for impregnating one ribbon parachute

Material	Mixture no. 8 component wt., g	Mixture no. 9 component wt., g
Viton	150	150
Acetone	900	900
TNT	225	225
Aluminum	150	...
Titanium	75	...
Magnesium	...	150
Total weight	1500	1425

granularity and packaging difficulties discouraged this approach.

The approach that appeared most satisfactory for this application was the use of deeper penetration fuels having greater elastomeric characteristics to facilitate packaging. Mixtures 8 and 9 described in Table 1 satisfied these requirements. Even so, the need for particle size control was evident. The 3 to 5 μm magnesium particles were the most successful. Two other magnesium particle sizes, 19 μm and atomized were tested and found inferior to mixture 9. The trouble with larger particle size lies with the inability of the material to stay suspended in the slurry during impregnating, thus complicating the impregnating process.

The elastomer Viton A proved to have slow solubility in acetone. Usually an overnight dissolving was required for 150 g Viton A in approximately 900 ml acetone. It is likely that other elastomers may have been applicable here, but the short time allotted for completion of this project required that materials on hand, if remotely acceptable, should be investigated. Viton A was one of those materials.

Other metals often found in pyrotechnics were investigated to substitute for magnesium and reduce some of the hazards associated with magnesium's use. Two of these were aluminum and titanium. Zirconium was considered, but rejected because of its hazardous handling characteristics in the dry, finely divided state.

The use of TNT proved to be the pivotal component, which assured success in the parachute impregnation. TNT appears to melt and burn well during the nylon decomposition as well as penetrate the nylon ribbon in Viton-acetone solution, thus allowing greater surface burning.

Drop Tests

Four preliminary drop tests were made from a Beaver aircraft. The first drop test was made to determine the vehicle stability without a parachute. Three drop tests were made using untreated 4-ft-diam ribbon parachutes. The deployed parachute after the fourth drop is shown in Fig. 2.

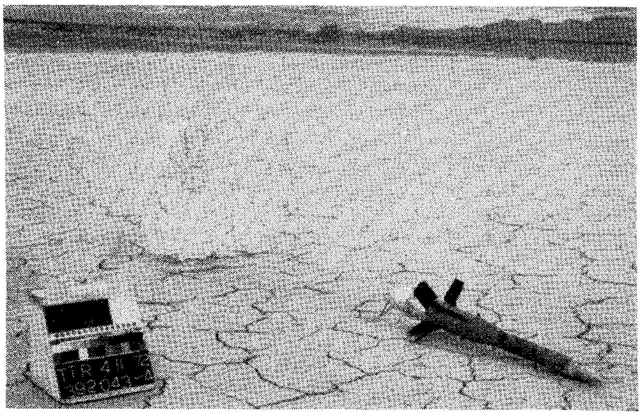

Fig. 2 4-ft-diam untreated nylon parachute after drop test at Sandia Labs., Tonopah Test Range, Nevada.

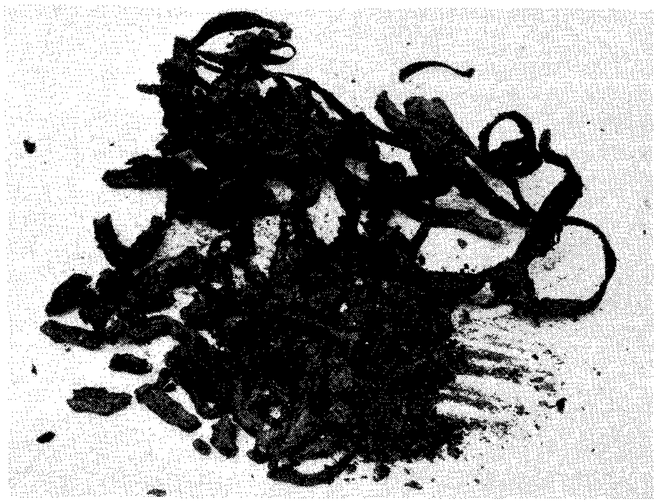

Fig. 3 Charred remains of parachute after ignition during drop test at Sandia Labs., Tonopah Test Range, Nevada.

Three successful deployment drop tests were conducted to demonstrate that deployment of magnesium/TNT/Viton (mixture no. 9, described in Table 1) impregnated 4.5-ft-diam ribbon parachutes could be achieved. These were in preparation for the final demonstration tests with live rocket units at Tonopah Test Range.

Data for the final live demonstration drops are shown in Table 2. On four of the five tests, the 4.5-ft-diam ribbon

Table 2 Tests of 4.5-ft-diam treated nylon ribbon parachutes[a]

Test no.	Pack weight, lb[c]	Coating no. (see Table 1)	Rocket fire time, sec	Chute ignition time, sec	Trajectory angle, deg	C_DS avg, ft^2	V, fps	Igniter installed
1	4.47	9	10.31	10.02	−76.8	10	70	Yes
Remarks: All ribbons were burned off. Lines and radials were charred. No burn on ground.								
2	4.46	9	10.21	10.13	−78	10	66	Yes
Remarks: All ribbons were burned off. Lines and radial were charred. No burn on ground.								
3	4.94	9	9.92	9.92	−70.8	7.5	80	No
Remarks: Still burning after impact. Small amount of char left. Rocket ignited the chute.								
4[b]	6.94	8	10.02	10.02	−80	10	68	Yes
Remarks: Burned on ground well. Pilot chute burned. Bag charred black.								
5	4.37	8	10.25	10.29	−87	10	70	Yes
Remarks: Igniter fired but did not ignite chute. Igniter may not have been anchored against the canopy securely.								
Theoretical trajectory	...	...	10	...	−87.9	8	74.5	...

[a] 3-ft-diam. guide surface pilot chutes used on all tests. 4.5 ft R = 1 lb. 11 oz (untreated) bag = 1 lb. Release altitude was 800-1000 ft, AGL.
[b] Bag and pilot chute were also impregnated and tied permanently to the apex of the 4.5-ft ribbon chute to burn both.
[c] Pack weight included 9.5-oz aluminum load ring and 4-oz loaded igniter (except no. 3 had no igniter).

parachutes were ignited and burned well as shown in Fig. 3. Test no. 3 demonstrated that the rocket blast could ignite the parachute, even though the rocket burn time is very short.

Two suitable pyrotechnic formulations, mixtures nos. 8 and 9, described in Table 1 were developed and used successfully to disintegrate the 4.5-ft-diam ribbon parachutes after completion of the deceleration phase. It is believed that pyrotechnic disintegration of lighter weight parachutes, such as solid cloth personnel canopies, would be a more complete disintegration because of the lighter material. Safe methods of treating and handling were devised and used with no inadvertent ignition incidents.

If further work is conducted with pyrotechnic parachutes, the packed parachutes should be evaluated for premature ignition hazard characteristics. Degradation of materials with respect to compatibilities and shelf storage should also be investigated.

Conclusions

A flammable impregnant has been developed which when applied to a nylon parachute will promote disintegration of the parachute after the deceleration phase of a drop has been completed.

Drop tests of a 50-lb total weight low-level delivery sensor delivered by a parachute impregnated with the flammable pyrotechnic have made possible the following conclusions:

1) An impregnating mixture of powdered metal such as magnesium, Viton A, and TNT can be used to produce a disintegratable parachute. A mixture of titanium powder and aluminum powder may be substituted for the magnesium powder. In either case, the use of finely divided powder is required. Precautions should be taken during handling to prevent accidental ignition, which is inherent with the use of finely divided pyrophoric metals.

2) Treating, packing, handling, deployment, and ignition have been shown to be feasible. All were successfully accomplished during the development of this program.

Acknowledgment

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References

[1] Pepper, W. B., Jr. and Buxton, R. J., "Destructible Parachute," United States Patent No. 3,814,355, June 4, 1974.

[2] Pepper, W. B., Jr. and Maydew, R. C., "*Aerodynamic Decelerators – an Engineering Review,*" SC-R-61-3156; also, *Journal of Aircraft*, Vol. 8, Jan. 1971, pp. 3-19.

Vortex Lattice Prediction of Subsonic Aerodynamics of Hypersonic Vehicle Concepts

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Introduction

A JOINT USAF/NASA study is underway to define the vehicle requirements for a hypersonic research aircraft which is currently designated the National Hypersonic Flight Research Facility (formerly the X-24C).[1] The vehicle will be air-launched from a B-52, rocket-boosted to the cruise condition of Mach 6, and will then glide to an unpowered landing. The constraints imposed by the launch aircraft result in low-aspect-ratio vehicles, and the high drag associated with certain experiments such as the research scramjet cause the unpowered approach and landing phase of the flight to be a critical design problem. This problem is associated with the high angles of attack required to develop the needed L/D. At these angles of attack, vortex flows are expected. Several configuration concepts have been developed by USAF and NASA studies, some of which have been tested at subsonic speeds. The majority of them have either marginal or unacceptable subsonic performance. Therefore, a requirement exists for a reliable analytical method which could determine the subsonic aerodynamics of candidate concepts.

The vortex lattice method of J. E. Lamar and B. B. Gloss,[2] with unpublished improvements in the leading-edge suction computation by Lamar, was used to estimate vortex flow aerodynamics. The suitability of this method was investigated by comparing calculated and experimental aerodynamic characteristics of two National Hypersonic Flight Research Facility (NHFRF) concepts at Mach 0.2. The unpublished experimental data were obtained in the Langley Research Center Low Turbulence Pressure Tunnel at a Reynolds number of 10×10^6. The comparisons presented are for a lifting-body concept (12I) and for a distinct wing-body concept (L16) which was developed at NASA-Langley (Fig. 1).

Configuration

Each of the concepts have several features in common. At high speeds, the underbody ahead of the engine inlet acts as a precompression surface for the research propulsion system, whereas the underbody aft of the exit acts as an external exhaust nozzle. The requirement for precompressed inlet air results in negative wing incidence in order to increase the underbody angle of attack at cruise. The blunt base is primarily the result of the rocket boost system.

Computer Model

The fuselage-wing combination is represented by two coplanar lifting surfaces where the dividing line between the lifting surfaces is taken at the body-wing leading-edge juncture and drawn normal to the centerline. The "no flow" constraint is applied simultaneously to each elemental panel at its control point.[3] This constraint is equivalent to requiring that the flow be tangent to the real mean-camber surface. This surface, which can be highly irregular for this class of vehicles, is represented as the local slope of the mean-camber surface at each control point. The process of determining the local slopes of the mean-camber surface is straightforward and could easily be converted to an automated process utilizing any suitable three-dimensional numerical model.

Results and Discussion

Hypersonic configurations are atypical in that the flow around the total vehicle is greatly influenced by interference effects from the massive fuselage. This represents a situation for which the vortex lattice method was not designed.[4] Also, due to the high sweep angle of the fuselage forebody, it was not known whether vortex flow, if generated from the forebody, would be effective in generating forces and moments due to the inclination of the body sides. Comparisons of the data and theory showed that the resulting aerodynamic forces and moments could be modeled by only accounting for vortex flow on the wing leading edge and tip. This procedure was applied to several other NHFRF concepts with good results. Past studies[4,5] have shown that the application of the augmented vortex lift improved the lift and

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