ENERGY ABSORPTION IN SUSPENSION LINES

E. A. Gimalouski
Pioneer Parachute Company, Inc.
Manchester, Connecticut

Introduction

Designing a parachute consists of satisfactorily meeting the requirements of drag, strength, stability, volume and weight. Once the canopy size and type to provide the desired drag and stability is established, the strength of the canopy and lines will govern the minimum weight and volume.

The strength, in turn, is usually dictated by the magnitude of the forces encountered in the first few seconds of the opening. The problem of calculating these forces with any degree of accuracy is much more difficult than that of reducing the forces by using existing deployment techniques and the elasticity of the lines.

Initial impact force at line stretch, known as snatch force, may be reduced by the use of deployment bags and, to a lesser degree, by skirt restraining devices such as skirt hesitators. The purpose of the investigation conducted by Pioneer Parachute Company for the WADC Materials Laboratory was to find how much line elongation contributed to reduction of opening forces. The Parachute Branch saw an opportunity to collect drop test data on the newly developed 30 foot Extended Skirt Canopy and suggested that deployment bag launchings, using this canopy, be included in the program. Most of the test progam was devoted to free type launchings using the 24 foot Solid Type Canopy.

The Air Force Parachute Handbook contains a simplified formula for calculating snatch force. This formula includes a term for the load-stretch factor of the lines that will yield resultant lower forces. It is useful for determining the approximate force with a minimum amount of calculation.

These forces do not vary in direct ratio to line elongation alone. Other parts of the parachute also influence the time, distance covered, and relative velocity of the moving bodies to retard the force of final impact.

Measured canopy opening forces are known to vary widely even in a group of tests where a single canopy and weight load are continually dropped at the same speed. Upper and lower extreme snatch loads in such tests would be apt to exceed load difference due solely to suspension line elongation.

Several precautionary steps were taken to prevent extraneous factors from affecting the test data.

Material Tested

Table I shows the material, construction, tensile strength and ultimate elongation of the cords tested. The woven tubular cord in Group II does not gain any appreciable elongation by virtue of its construction. Other cords gain some elongation due to the geometric pattern of the braided sleeve and the twists in the cord thread. Although this feature of the Group II cord had no effect on its relation to the others in the static tests, it showed symptoms of very low elongation in the dynamic tests.

Table I

Group No.	Material	Construction	Tensile Strength	% Elong. @Br. Str.
I	Rayon Fortisan	Sleeve & Core	420#	8.7
II	Nylon	Woven Tubular	450#	23.1
III	Nylon	Sleeve & Core	550#	39.3
IV	Nylon	Sleeve & Core	320#	41.8
V	Nylon - Formic Acid Treated	Sleeve & Core	550#	52.8

Standard 24 foot Flat Type Canopies were selected for the greater percentage of tests because they open rapidly and develop high opening forces. Pocket bands were installed on the skirts of the canopies to cut down the opening time even further. Forces resulting from these rapid openings provided tension in the lines in excess of 50% of the total line strength.

Static Tests

The static test results are plotted in Figure 97

Group V, formic acid treated nylon cord, has 1% less elongation than Group IV, nylon cord, in the zero to 300 pound load range. According to the static tests, these two cords should produce almost identical opening forces.

Note that Group I fortisan line stretches 5% under a 90 pound load and only 3% for the next 350 pounds. Calculations will yield abnormally high snatch forces if the ultimate load-elongation ratio is used.

Deployment System vs. Snatch Force

Before reviewing the test results, a comparison of the deployment systems is in order. See Figure 98.

The 24 foot canopies were packed into containers that remained in the load. Thus, the pilot chute pulled the main canopy away from the load, vent first, followed by the suspension lines.

Upon launching, the deceleration of the pilot chute will be very rapid because its drag area is relatively high and its inertia is small. At the other end of the system, the inertia of the load is large and its drag area very small, thus its velocity is affected very little by aerodynamic drag. Consequently, a larger differential velocity is produced between the pilot chute and the load. The dotted lines in Figure 98 enclose the portion of the parachute which is moving at the same speed as the pilot chute and will be a part of the total mass to be accelerated after the lines have straightened.

The 30 foot canopies were packed into deployment bags. See Figure 99. In several respects, the launching sequence for these is the reverse of that shown in Figure 98. Instead of the pilot chute pulling the canopy and the lines away from the load, as in Figure 98, the load pulls the lines and canopy away from the pilot chute.

Dotted lines enclose the mass whose velocity is equal to that of the pilot chute. Full lines enclose the mass of the lines and canopy whose velocity equals that of the load. A more detailed analysis of the changes in inertia, velocity and forces will be made later.

Test Load

The dummy used in the Whirling Tower tests is a metal framework to which one end of a tensiometer is attached. The other end of the tensiometer is attached to a light sliding bar equipped with "D" ring for connection to the risers from the canopy. The total weight of the dummy and tensiometer is a little under 250 pounds. The outer 30% of the flexible tie rods attached to the rotating tower arm are also added to the dummy load, bringing the weight to approximately 260 pounds. It was intended that the dummy weight should be as high as possible for the 200 MPH speeds in order to create high stresses in the lines.

Test Results

Average measured snatch loads for the five groups of cord appear in Figure 100. Tests at 100 MPH are shown in solid color, the higher forces at 150 MPH extend above into the shaded area and the 200 MPH forces extend into the outlined area.

Results are not entirely consistent with the static elongation properties of the lines. Since only six tests were made at each speed with each type of line, it is quite possible that results do not reveal the true averages. With a free type deployment, an immeasurable amount of air is trapped in the main canopy during line straightening and stretch. This is the greatest single factor responsible for abnormally high loads. The effect of line elongation on the reduction of snatch forces may be judged by comparing the two low elongation cords at the left of the graph with the two high elongation cords at the right. A 30% average reduction in force is evidenced for 24 foot canopies and 20% reduction for 30 foot canopies using deployment bags.

Any explanation of test results shown in Figure 100 must be tempered with certain assumptions. If it is assumed that the six tests on each type of line represent a true average, then the low elongation, Group I, line develops lower forces than the Group 2, high elongation line. It may now be surmised that the woven structure of the Group II line lacks the elasticity of the braided sleeve construction. In other words, it may lack the bounce-back quality at high speeds, even though recovery rate is satisfactory in static tests and at lower speeds. Test results on the Group I cord are questionable.

Group IV cord, second from right, exhibits the lowest average force at 200 MPH; corresponding to its highest elongation, at other speeds the results are inconsistent.

Thirty foot Extended Skirt Canopy forces are shown in the lower part of Figure 100. The same scale is used for both 24 and 30 foot canopies. The great reduction in forces, due to bag deployment, is self-evident but it should also be noted that the average load on the individual lines was less than 60 pounds, placing the location of the tests in the optimum load-stretch area of the static test curves.

Opening shocks did not follow in the order of line elongation of the various cords. See Figure 101. There was little variation in the average forces at the different speeds, which is strong evidence that suspension line elongation plays a secondary part in the reduction of these forces; opening time, canopy shape and other factors having greater influence than line stretch.

Analysis of Snatch Force

By today's standards for speed, 200 MPH falls into the low speed category, yet the stretching of the suspension lines at this speed can take place in less than 10 milliseconds.

A study of this action should begin at the launching of the load and parachute. Figure 102 shows that the two may be treated as a system, with pilot chute and main canopy forming one Body "A" and the load Body "B" joined together by the lines. The time, velocity and distance traveled by each body are plotted on the left. The curves show calculated values for the four variables with respect to time. This action takes place in .23 seconds. During this time, there is no load on the lines. The lines have merely been straightened out - not stretched. Note how rapidly the velocity of Body "A" has decreased.

In Figure 103, the development of the snatch force is continued from the .23 second mark on Figure 102. The time scale has been expanded to show what happens during the first 30 milliseconds of line stretch. Effect of apparent mass is omitted despite the fact that its influence on force and velocity is greatest during sudden changes in velocity of Body "A".

The action seen here is both sudden and violent; it will account for many broken pilot chute bridles and lost pilot chutes.

Body A is accelerated to a velocity higher than the original parachute release velocity.

The snatch force builds up from zero to approximately 4000 pounds in 24 milliseconds, after which it quite likely drops to zero and possibly builds up to another peak load before the canopy starts to open.

The tractive force T reaches its maximum when the relative velocity between A and B reaches zero.

Suspension lines will stretch in approximate proportion to the tractive force acting on them. The product of the force T times the total line stretch e is the amount of work done on the lines or the potential energy stored in them. This will be transformed into kinetic energy which will accelerate A to some velocity greater than that of B.

The energy absorbed on the lines may be the product of a small force times a large distance (high elongation) or a large force times a small distance (low elongation); thus, to reduce the force, a high elongation is essential.

In the test illustrated, the maximum line stretch was approximately 2.4 feet and maximum force was 4000 pounds equal to 9600 foot pounds of stored energy. Calculations have not been continued beyond 30 milliseconds; at this point, Body A was moving 40 feet per second faster than the original launching speed and still accelerating.

Calculated Results

In most cases, calculated forces did not compare closely with measured forces. The greatest difference appeared in the Group 1 lines. See Figure 104. The spring modulus for this cord is abnormally high.

For standard elongation cords, the results were as close as could be expected, considering that assumptions had to be made for the drag area of pilot chute and uninflated canopy. There is no way to predict how much the skirt of the canopy will open while lines are paying out.

Elastic Lines

No discussion of line elongation would be complete without some mention of rubber core elastic suspension lines.

The Air Force and a few private concerns did a limited amount of work between 1945 and 1951. It was concluded that natural rubber would still be classed as a critical material in times of emergency and that additional research was needed to determine its ability to withstand the effects of tropical and arctic environment.

During the past few years, Mr. S. W. Severance, of Thomas Taylor and Sons, and Mr. E. R. Boland have been experimenting with improved elastic cord. Three to five foot length suspension lines with 250 to 300% elongation, canopies combining elastic vents with elastic suspension lines, line constructions and new methods of attachment are being studied. Recent tests on Pioneer's Whirling Tower show that snatch force and opening shock may be effectively reduced through use of elastic cord. Table II shows the results of five tests at 175 MPH.

Table II

Elastic Line Tests

Launching Speed MPH	Opening Time Sec.	Snatch Force Lbs.	Opening Shock Lbs.
175	1.9	1825	1275
175	2.3	1825	1400
175	3.0	1275	1275
175	3.0	1900	1275
175	4.2	1400	890
Average	2.9	1645	1223

Dummy Weight - 220 pounds

Elastic Vent - 24 foot canopy

Canopies equipped with short rubber core lines show promise for improved deployment, good stability, low opening forces and rapid spilling of canopy after touchdown. Airplane drop tests are planned to check these characteristics together with the opening time and descent rate. Opening time must be held below maximum limits for the safety of the jumper and above minimum limits to obtain the low opening forces. Comparison of free type, bag and elastic line deployments is shown in Figure 105. Note that the dummy load for the elastic line is 220 pounds and speed is 175 MPH.

Probably the most important feature of the elastic line record is the multiple traverse of the scriber during the snatch load with the corresponding longer elapsed time and lower peak force. This is shown in the bottom of Figure 106(c). The snatch force rises from zero to 1000 pounds twice and from zero to 700 once before opening shock of 1400 pounds occurs. After a long, easy opening, the elastic collar closes, producing a smaller secondary opening shock.

The record in the middle, Figure 106(b), is from a deployment bag drop test. Here again, the multiple peak force is developed. It is suspected that these peaks are caused by pulsing forces due to elasticity of the lines.

At the top of Figure 106(a) is a free type deployment record. The film has been badly gouged by moving the scriber over the record two or more times. Any force that occurs in less than 20 thousandths of a second should be traced at a film speed of more than one inch per second. By the same token, motion pictures should be taken at speeds higher than 128 frames per second to show the action in complete detail.

In concluding this review, it is evident that line stretch reduces snatch forces in both free and bag type deployments.

Indications are that elasticity should receive full consideration whenever new cord or webbing is being developed for parachute use.

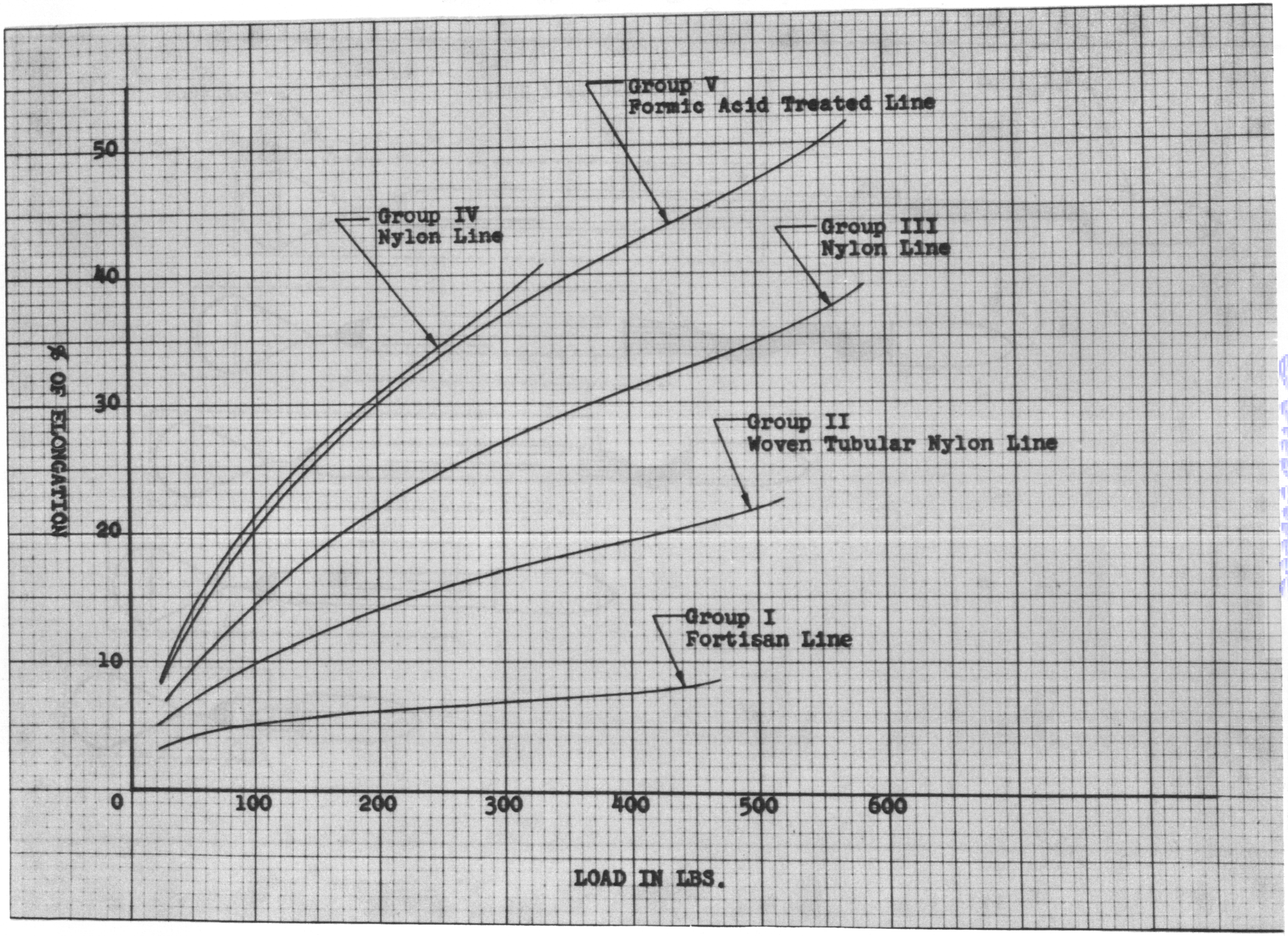


Figure 97. Static Test Results.

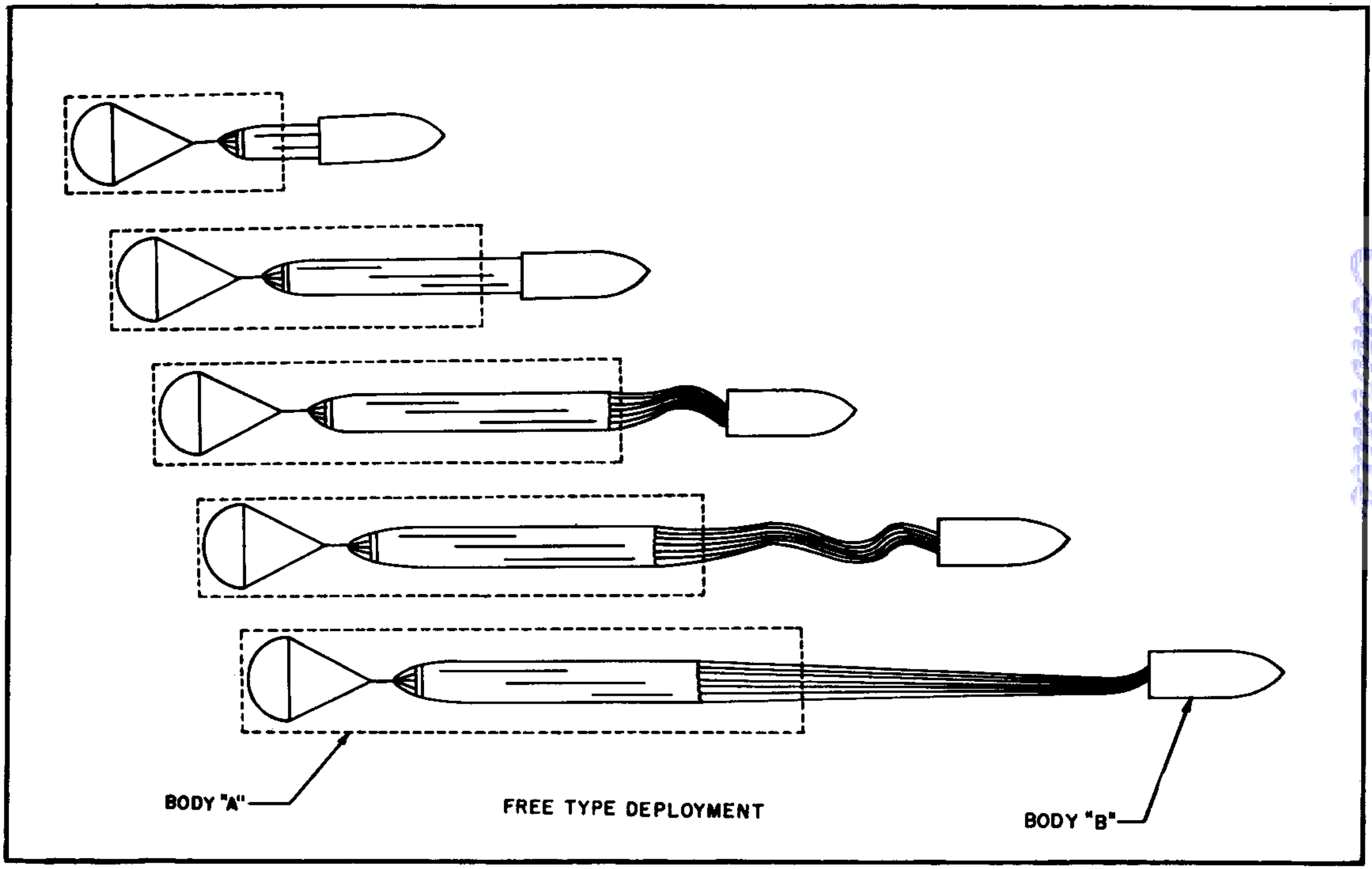


Figure 98. Free Type Deployment.

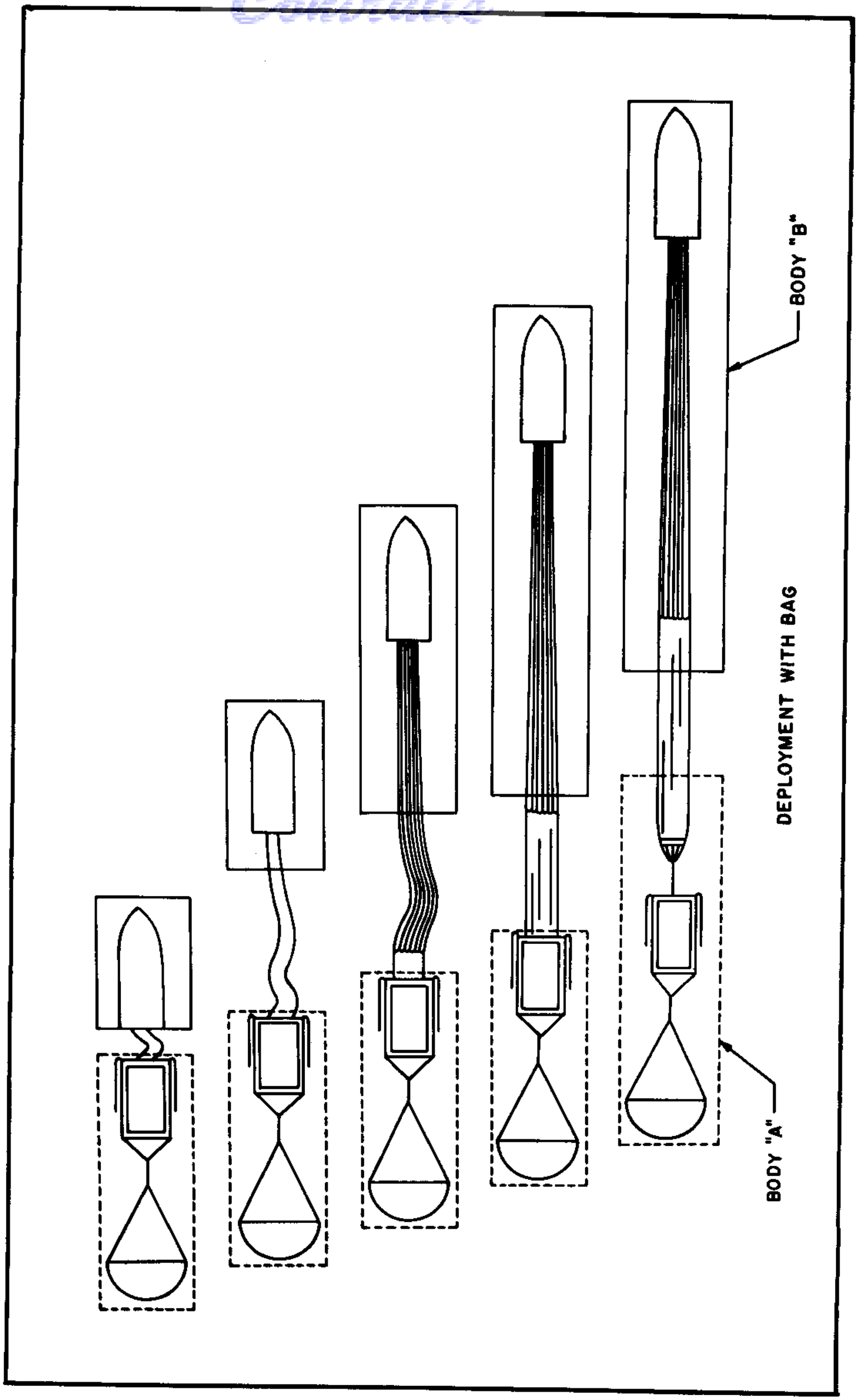
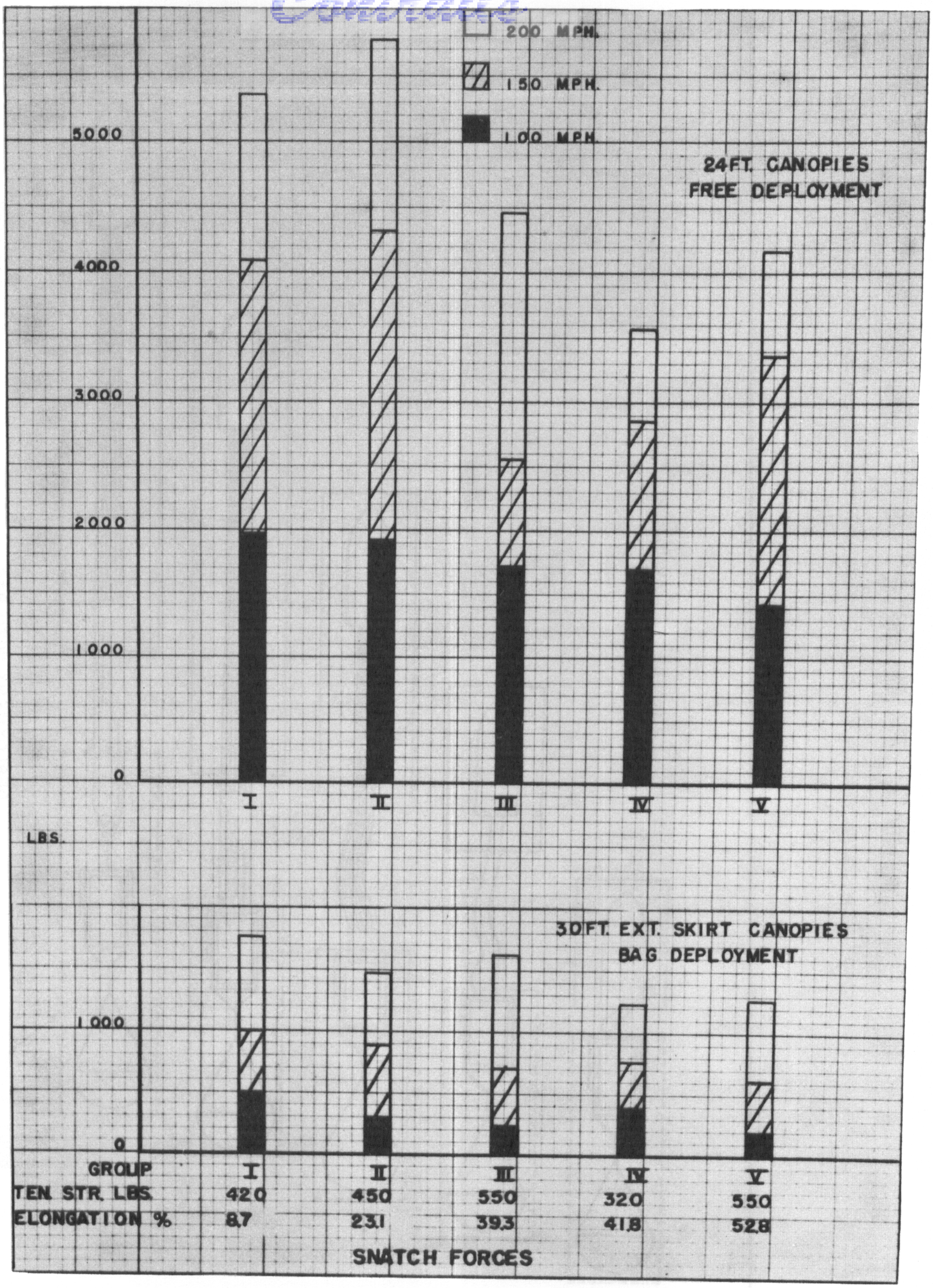


Figure 99. Deployment with Bag.



GROUP	I	II	III	IV	V
TEN. STR. LBS.	420	450	550	320	550
ELONGATION %	8.7	23.1	39.3	41.8	52.8

Figure 100. Snatch Forces.

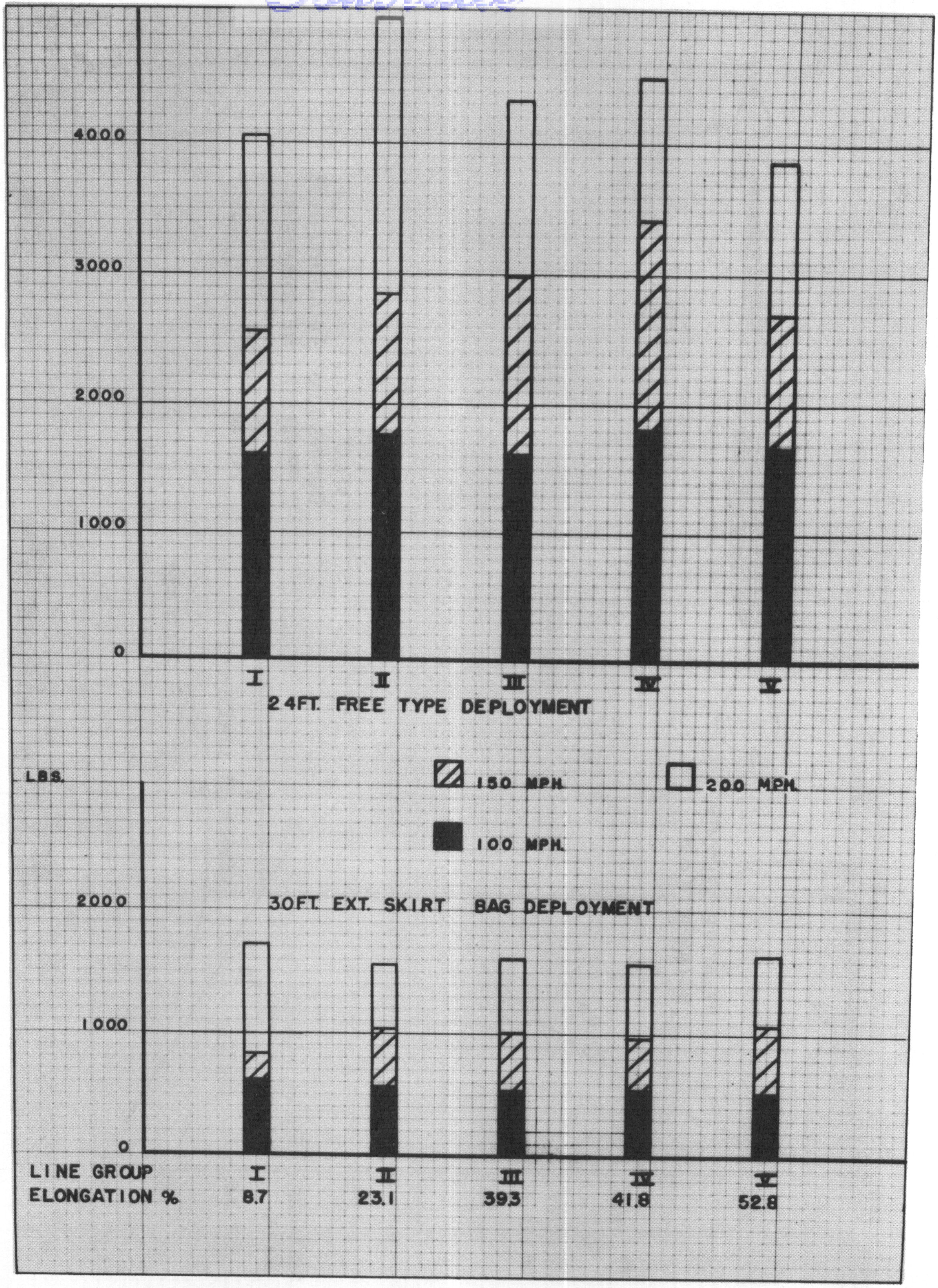


Figure 101. Opening Shock.

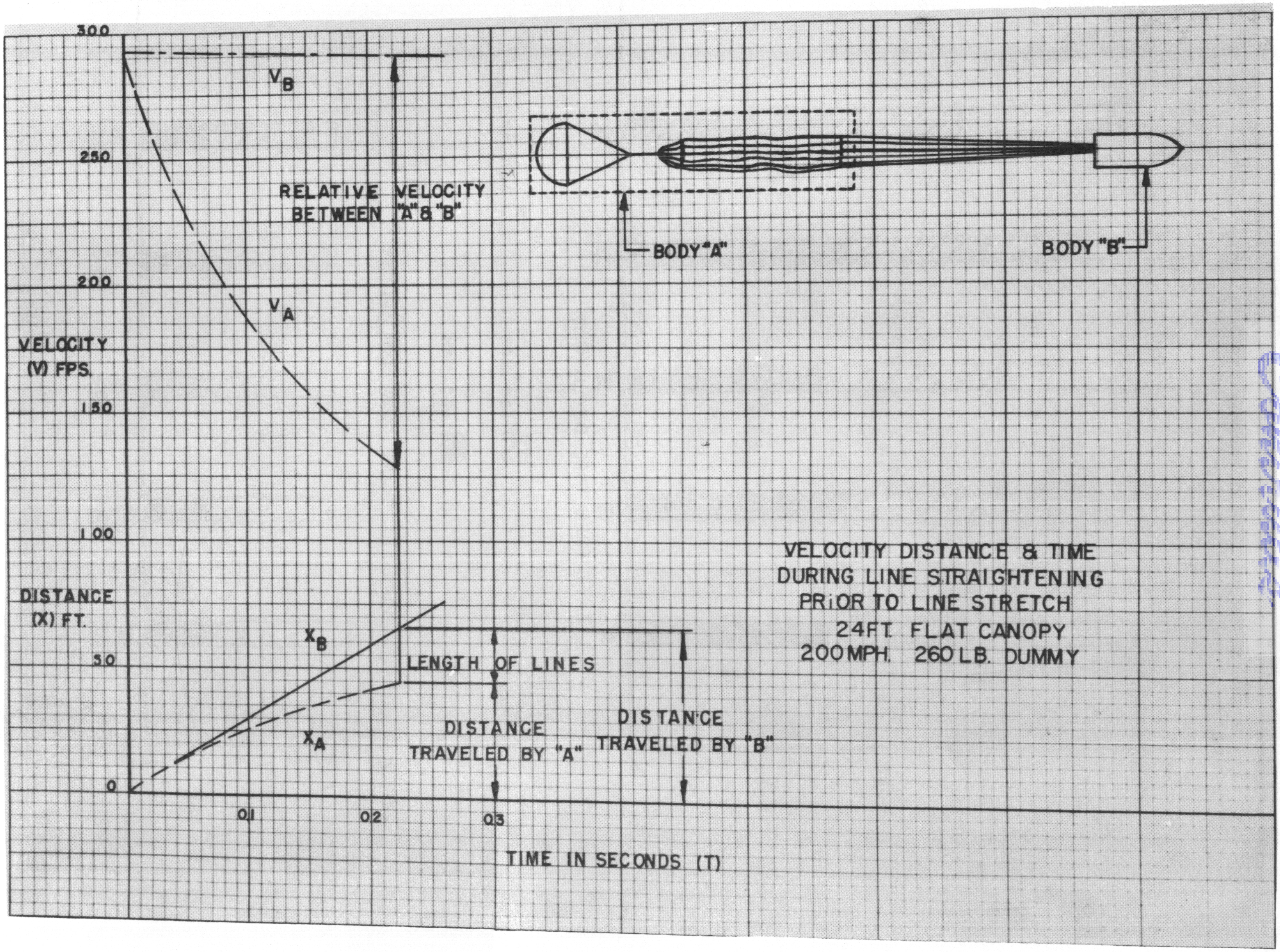


Figure 102. Velocity, Distance and Time During Line Straightening Prior to Line Stretch, 24 ft. Flat Canopy, 200 MPH, 260 lb. Dummy.

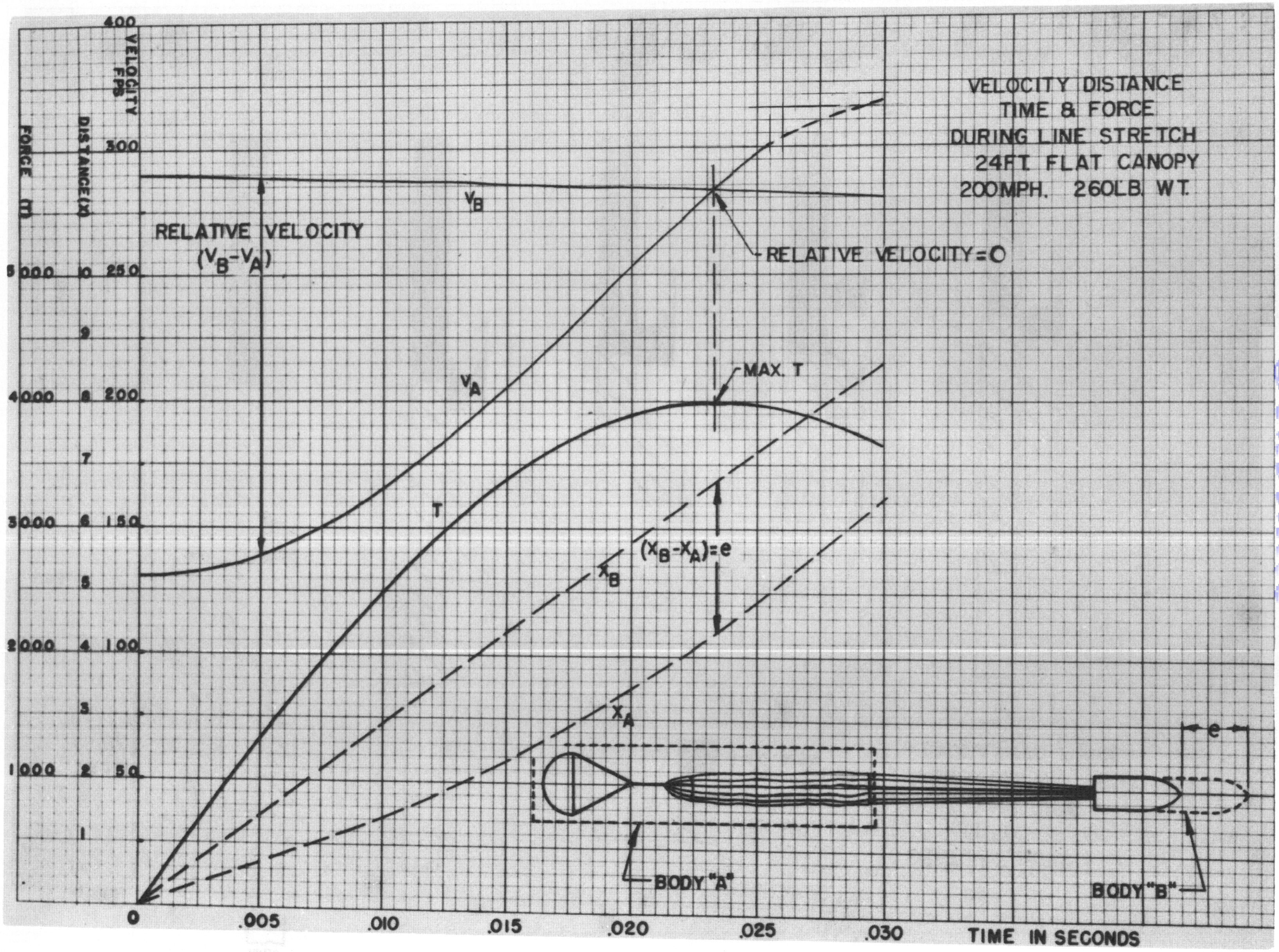


Figure 103. Velocity, Distance, Time and Force During Line Stretch, 24 ft. Flat Canopy, 200 MPH, 260 lb. wt.

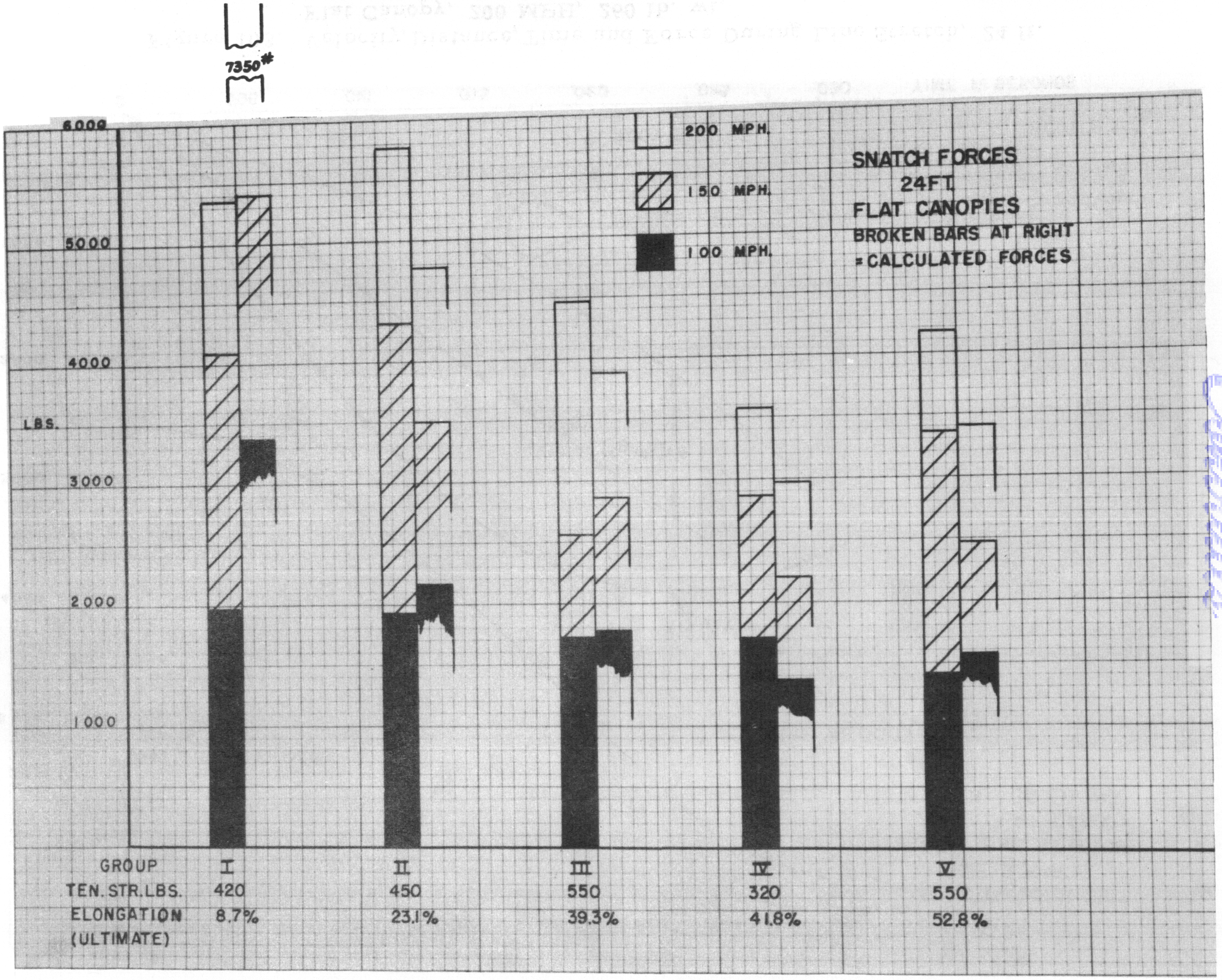


Figure 104. Snatch Forces, 24 ft. Flat Canopies.

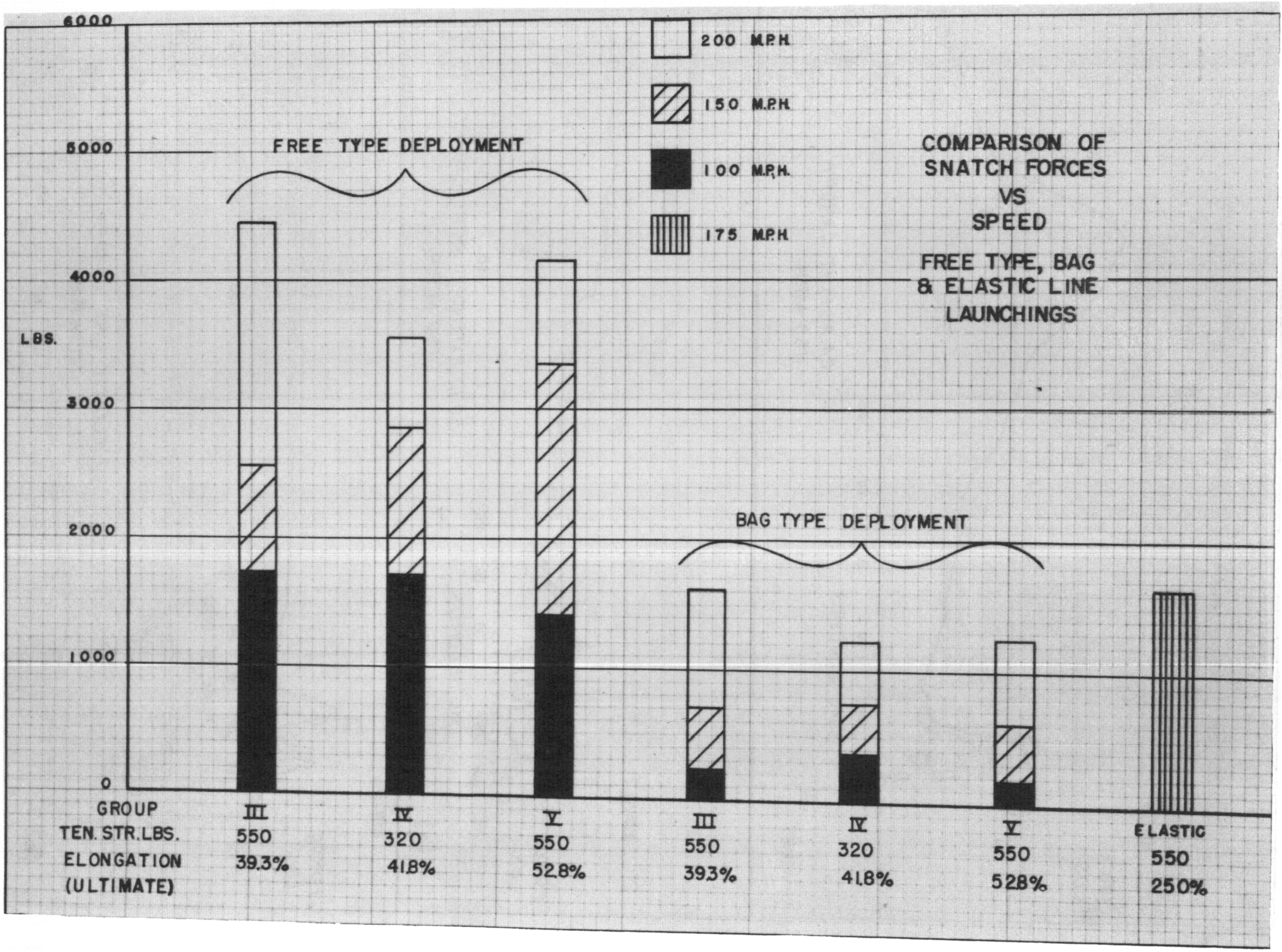


Figure 105 Comparison of Snatch Forces vs. Speed, Free Type, Bag and Elastic Line Launchings.

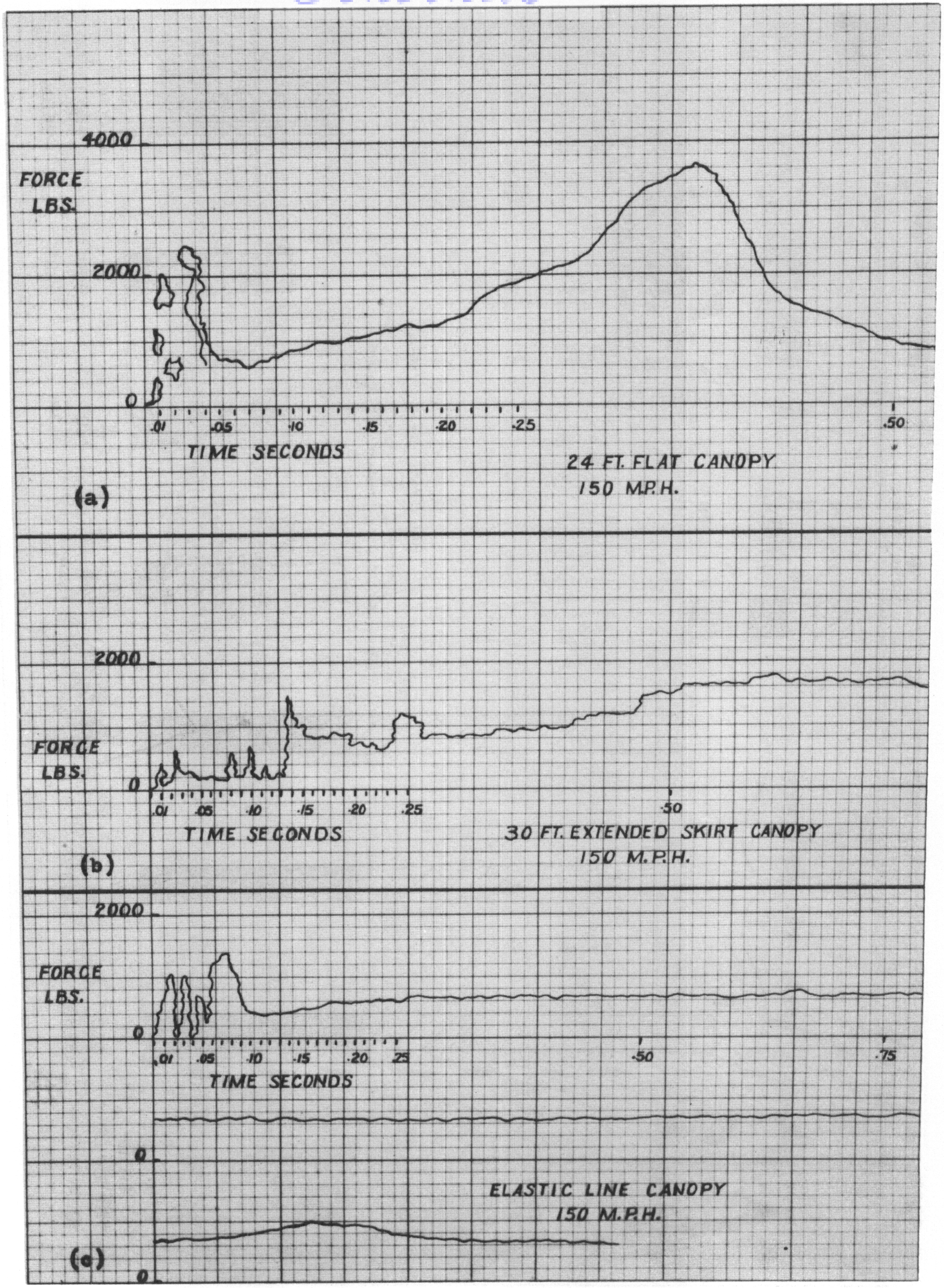


Figure 106. Time vs. Force for Various Canopies.