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Free-Flight Test Results of Scale Models Simulating Viking Parachute/Lander Staging

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SUMMARY

This report presents the results of Viking Aerothermodynamics Test D4-34.0. Motion picture coverage of a number of scale model drop tests provides the data from which time-position characteristics as well as canopy shape and model system attitudes are measured. These data are processed to obtain the instantaneous drag during staging of a model simulating the Viking decelerator system durinr parachute staging at Mars. Through scaling laws derived prior to test (Appendix A and B) these results are used to predict such performance of the Viking decelerator parachute during staging at Mars.

The tests were performed at the NASA/Kennedy Space Center (KSC) Vertical Assembly Building (VAB). Model assemblies were dropped 300 feet to a platform in High Bay No. 3.

The data consist of an edited master film (negative) which is on permanent file in the NASA/LRC Library (Reference 1).

Principal results of this investigation indicate that for Viking parachute staging at Mars:

1. Parachute staging separation distance is always positive and continuously increasing generally along the descent path.
2. At staging, the parachute drag coefficient <u>is at least 55%</u> of its pre-stage equilibrium value. One quarter minute later, it has recovered to its pre-stage value.

I. INTRODUCTION

As the lander approaches the Martian surface, it descends at an equilibrium speed suspended by the parachute decelerator operating at a subsonic Mach number less than 0.35. The aeroshell has since been released and the parachute ~~base~~ cover is about to be separated from the lander.

Two (2) seconds prior to the parachute release from Terminal Descent Engines (TDE) fire and settle into a thrust level equivalent to 85% of the lander's weight on Mars. During the period after TDE ignition until soon after parachute release (a period termed parachute staging) the behavior of the parachute decelerator with relation to the lander could not be confidently predicted by MMC — LaRC had confidence

A fundamental concern was whether the sudden unloading of the parachute at staging would cause it to collapse. If collapse should occur, recontact with the Viking Lander is conceivable with an obvious threat to mission success. Another important concern needing resolution, centers about the parachute image seen by the radar altimeter. This image might be falsely interpreted as a terrain feature introducing "False Targeting" as a staging hazard. Judgments regarding these concerns are best founded on test data.

Two parachute models, 10% and 21% scales, were rigged and loaded to simulate the Viking parachute staging weights. These were drop tested at NASA-KSC in High Bay #3 of the Vertical Assembly Building (VAB) in June 1973. Several movie cameras recorded the motion of the parachute models during their descent to the platform of the resident Launch Umbilical Tower (LUT). Range time was simultaneously coded onto the film record. These movies comprised the source of time-position data subsequently processed to provide model velocity and acceleration data.

A brief discussion on scaling relationships is presented in Appendix A. A particular scaling relationship from which the conditions of this test are selected is presented in Appendix B. These scale guidelines were established by analyses utilizing information obtained from References 1 through 9. The Terminal Descent Engine (TDE) simulator design and positioning analysis depended on applicable information contained in References 10 through 14. The experience of Reference 15 was used to specify the test facilities and required support apparatus described in Reference 16.

This report concentrates on establishing fundamental parachute performance characteristics for the Viking parachute staging event are Mars.

II. SYMBOLS AND NOMENCLATURE

SYMBOL	DESCRIPTION	DIMENSIONS
a	Acceleration - aligned with gravity vector	(ft/sec^2)
A_o	Denotes parachute reference area 2205 sq. ft. (full scale)	(ft^2)
C_D	Drag coefficient	
D	Diameter or Drag	(ft),(lbs)
N_i	Scale Factor - Ratio of a model property divided by that for the full scale vehicle. Unless indicated otherwise. (See Appendix A).	
g	Acceleration of gravity--subscripted to denote gravity system.	(ft/sec^2)
m	Mass	$\left(\frac{lb\text{-}sec^2}{ft}\right)$
R	Radial distance measured in horizontal plane between camera lens and nominal drop axis (Appendix D).	(ft)
t	Time	(sec)
$T, \Delta T$	Time constant--time required for an exponential velocity change to progress 63.2% toward the new equilibrium between initial and final conditions.	(sec)
W	Weight--subscripted to denote gravity system or vehicle component.	(lbs)
X	Camera location in horizontal plane measured along LUT ℄ $_{sym}$ toward camera station (Figure D1).	(ft)
Y	Camera location in horizontal plane measured perpendicular to LUT ℄ $_{sym}$ toward camera station (Figure D1).	(ft)
$\xi, \Delta\xi$	Ratio of C_D to a reference, $C_{D_{ref.}}$; usually equilibrium C_{D_o} prior to initiation of a staging sequence - also $\xi = \frac{C_D\ A_o}{(C_D A)_o}$ - - - when subscripted refers to an instant of time.	
$\tau, \Delta\tau$	Ratio of time to time constant for staging, T_s - - when subscripted refers to a specific event.	

SYMBOL	DESCRIPTION	DIMENSIONS
ρ	Mass density of air	$(lb\text{-}sec^2/ft^4)$
σ_w	Ratio of actual gross weight to ideal kinematically scaled gross weight.	

SUBSCRIPT	DESCRIPTION
C	Deployed canopy (Figure C1)
D	Drag
i	Arbitrary element of a related series of components, events or situations. (See Appendix A).
L	Simulated lander.
o	Pre-stage equilibrium state.
s	Linear scale factor reference (other scale references are self-contained in Appendix A), stage.
T, T_S	Time constant, time constant applicable specifically to lander staging.
$(\ )_-$	Refers to state before the instant implied by the subscript.
$(\ )_+$	Refers to state immediately following the instant inferred by the preceding subscript.

NOMENCLATURE	DESCRIPTION
BC	Base Cover
Int.	Wake interference effect on parachute canopy performance
KSC	NASA-Kennedy Space Center
LUT	Launch Umbilical Tower
Min; Max ρ	Minimum/Maximum Martian atmospheric density
P+BC	Parachute and Base Cover
SLS	Simulated Lander System
Syst.	Gross System Effect including TDE Thrust
TDE	Terminal Descent Engine (Also STDE for simulated TDE)
VAB	Vertical Assembly Building

III. APPARATUS AND PROCEDURE

Two types of tests were performed. Type I was designed to evaluate the effect of sudden canopy unloading by only simulating lander release. Type II tests include simulation of the Terminal Descent Engine (TDE) operation during the staging period. The functional distinction between these types of tests lies in the additional disturbance to the decelerator canopy due to the simulated TDE operation. Wake effects behind the TDE reduce the effective "q" on the trailing parachute canopy, thus reducing to an unpredictable degree the drag coefficient of the canopy (based on freestream q). Though a drag device simulating TDE is not ideal it does afford a ~~close~~ worst case approximation of the effect as rocket engine would impose on the trailing parachute thus the Type II tests yields a slight over-simulation (conservative) of Viking parachute staging at Mars than does the Type I test.

The models were positioned over the drop zone by the service crane (part of the LUT). A cross-arm rig and release system (Figure 1) held the canopy partially deployed before the test. The pre-deployment was devised to gain the most useful data from available drop height. This was achieved by avoiding an indefinite canopy fill distance along with the excess distance due to over-acceleration followed by deceleration to pre-staging system equilibrium velocity (common to the deployment of an initially collapsed-trailing canopy).

Schematics of the two model types are presented along with dimensions in Appendix C. Figures 2(a) through 2(d) are a sequence of pictures from immediately following the drop to post-landing for a typical Type II test. Details of the various components identified in the schematics (Figures C1 and C2 in Appendix C), are shown in more detail in Figures C3a thru C3d.

Camera locations for the movie-records are described in Appendix D.

Staging of Type I models is simulated at the instant the ballast contacted the LUT platform. Type II model staging sequence was initiated by a radio signal which resulted in TDE simulator deployment. A variable onboard timer was set to sequentially release the simulated lander after TDE simulator deployment. Nominal timer delay was set at about 2 seconds which resulted in about 1-1/2 second delay between effective TDE deployment and lander staging.

TDE simulation is based on the principle that any drag device properly located and producing the same force as a scaled rocket engine thrust produces equivalent effects at the canopy. Thus proper application of this principle requires that two conditions be met. The first produces the desired wake or momentum defect (drag force). The second, TDE simulator position relative to the P+BC model properly simulates the wake distribution about the model canopy. Reference 10 establishes a nominal stand-off distance for such a simulator at about 70 feet (full-scale) ahead of the BC.

The test procedure and a description of the test site is specified in Reference 16. This document contains the detailed count-down procedure for each drop.

The test was terminated subsequent to the 37th drop. A structural member of the release system failed causing the 10% TDE simulator to be destroyed after it fell to the LUT platform without deploying. By then all but the 10% heavy Type II testing was complete. It was concluded that there was sufficient data to satisfy the test objectives; <u>the cost and time to recover test capability could not be justified</u>. After running 37 drops?

IV. DATA REDUCTION AND ACCURACY

Model motion varied amongst tests as a function of model type and load condition. Slight unavoidable differences in the symmetry of release in combination with a small amount of swinging would induce slight system elastic-aerodynamic harmonics. These usually persisted until actual staging took place. The natural frequency of these harmonics for the 21% model would periodically reinforce one another for a few cycles so that the effect noted prior to staging (while tracking the B/C) could be clearly detected in the velocity-time plot. Other sources of variance in results may have been due to differences in staging details such as slight asymmetry of the TDE deployment reaction vector (opening shock force).

Keep [illegible] in mind — affects [illegible] results

These disturbing factors are believed to have caused variances in the data. Because of limited data samples it is not considered worthwhile for the purpose of this investigation to evaluate these effects in detail. Instead, an averaging data processing procedure is adopted.

motion interpretation & Δv are arbitrary & question

The data obtained from the movie record is in the form of average velocity over each successive five-foot nominal descent path segment. Adjustments are made where appropriate for loaded suspension line stretch and for slight model offsets from the ideal flight path. These data are then plotted to produce a faired velocity-time curve for each drop.

The velocity-time curves are comprised of data segments taken at several levels and for several tracked points on the model system. These segments usually plot slightly off the faired components curve. Thus, transfer of information from the film to ~~the velocity-time format is another minor source of~~ variance. The variance of the faired curve through these velocity data segments is of the order of ±5%.

The movie projection equipment was a 16 mm data analyzer projecting onto a gridded screen. The frame count was noted for a tracked item to pass vertically through an equivalent 5' grid interval.

The next step in data processing was to record the velocities from the faired curves. These were points where the TDE was deployed, where the parachute was staged and where accelerations were measured from the faired curves. Accelerations were measured at TDE deployment, 1/4 second later, at staging, and at the time constant interval after staging. The chute post-stage velocity, V_F, did not always reach a stable equilibrium within the drop interval evaluated. Thus, a value of V_F occasionally depended on a calculated value.* It is likely that secondary field effects traceable to the staging sequences influence the canopy in varying degrees to cause the long period variances and apparent delay in achieving V_F.

Acceleration is determined by measuring the tangent slope to the faired velocity-time curve at an arbitrary point. Of course, this procedure may lose precision in an interval whenever a large velocity change occurs within the chosen five foot interval. However, the results show that the objective of the Viking Project is adequately served by the distance interval chosen for data processing. This is to say that more precision, regarding the motion of a particular point, may be available by re-processing from the data source (the movies) with improved projection equipment and with shorter sample intervals. A more complex scale-size correction procedure which considers a time (position) variable correction may also improve precision of extracted data.

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* V_F could be calculated with confidence. It had been demonstrated (Re 15) that the drag coefficient of the parachute is practically identical for pre-stage and P+BC post-stage flight (minimal TDE wake influence).

The velocity and acceleration data thus acquired is used to calculate the drag coefficient based on the parachute reference area. The C_DA is computed according to formula E2 presented in Appendix E. Comparable drag coefficient values are then averaged for each model type and load conditions to produce the results which lead to the conclusions of this report.

The procedure just described yields a statistical result. These results should be regarded as most likely, representative data to be used in a conservative** analysis for predicing Viking parachute staging performance at Mars.

** Conservatism means that the recommended result will yield a slower L+BC and Lander separation rate estimate than would probably occur at Mars.

V. DISCUSSION OF RESULTS

A. Objective Comments

The purpose of this test is to resolve fundamental concerns relative to Viking parachute staging at Mars. Principle among these is to resolve the question of whether staging in combination with TDE start can precipitate a parachute collapse. Further, if the parachute does not collapse at TDE start, the parachute performance subsequent to staging has no firm analytical basis. Basically, it is intended to demonstrate that separation between these bodies is both positive and continuous. NO INDICATION OR REASON TO BELIEVE IT WOULD NOT BE — m/C_DA etc, etc & etc

Test criteria were developed whereby results in an Earth environment could be projected to the environment of Mars. The basis of this criteria was kinematic scaling according to the Froude Rule, (See Appendix B). Two parachutes were each loaded to provide different degrees of scaling. The measure of scaling variation was determined to be the weight ratio parameter σ_w.

The actual situation at Mars and modeled on Earth is a loaded parachute descending near equilibrium velocity. The TDE start and warmup mode introduces a braking assist to the system. Two seconds later the Lander including the TDE is staged from the P+BC. This series of events is followed by a continuously diminishing unsteady flow field about the parachute canopy. INCREASINGLY MORE STEADY — BETTER FLOW CONDITIONS. The parachute drag throughout the staging interval is compared to its value for the steady condition prior to these staging events. This comparison is defined by the symbol ξ. $= \frac{C_{D_S}}{C_D}$

It was anticipated, based on the Reference 15 results, that the parachute drag coefficient would be the same a long time after staging as it was before staging (both of these flow regimes are steady). Thus it becomes clear that the purpose of this test specifically identifies with how the drag coefficient might be altered for the unsteady case during the transition from the initial to the final velocity of parachute operation. It was also anticipated that the effect would be emphasized with increasing departure from ideal kinematic scaling (decreasing σ_w -- see Appendix B). As already mentioned, there was concern that the transient effects of staging would cause parachute collapse and no canopy reinflation. This collapsing effect was never demonstrated during this test nor during the test of Reference 15. Thus, the method of evaluating these test results became a correlation between the degree of time dependent transient drag (ξ) and the degree of kinematic scaling (σ_w). The following discusses that evaluation.

NO DATA OR REAL INDICATOR!

B. Discussion

The drag coefficient was determined during the parachute velocity transient phase of staging as already discussed in Section IV. This was done for each test drop and averaged results for repetitive drops are presented in Figures 3a and 3b. To assist in clarifying Figure 3, Figure 4 is sketched to point out its significant features.

Table I lists the tests in chronological order, and it includes descriptions and remarks concerning each test, or group of tests. This table is supplemented with Table II which relates each model loading condition to its degree of kinematic scaling. Columns 3 and 4 of Table I are correlated with columns 1 and 2 of Table II and with the legend of Figure 3a.

In Figure 3a, the instant of parachute release is chosen for the time reference. As mentioned earlier, the instantaneous drag coefficient for each test group is referred to the systems drag coefficient during pre-stage equilibrium (ξ). Real time is normalized in terms of time constant*** increments τ.

*** Time constant, τ, of an exponetially changing characteristics is the period of time required for $\frac{e-1}{e}$ or 63% of the complete change to occur following its initiation.

ξ = DRAG RATIO
σ_ω = WEIGHT RATIO

It will be noted in Figure 3a that there appears to be a random scatter of ξ trends among scale weight (σ_w) groups prior to parachute staging (pre-stage interval). Yet, after parachute staging and until ξ recovers to pre-stage value of unity, (post-stage interval) the ξ characteristic among σ_w groups is consistent and orderly. Apparently the choice of staging interval and stand-off distance had no important bearing on the post-stage drag properties of a simulated Mars parachute staging.

Type I and Type II tests are comparable after P+BC staging (Figure 3b vs Figure 3a) when $\tau \geq 0$ and $\xi \leq 1$. Again, in Figure 3b we see that the minimum value of ξ occurs at $\tau = 0$ and that its magnitude is nearly the same whether the σ_w group is a Type I or a Type II model.

In all cases the ξ plot, post-stage, is characterized by a most extreme decrease below unity at $\tau = 0$ followed by a recovery to unity after 7 to 9 periods. The principle characteristic is the ξ_{min} occuring at $\tau = 0$. Then a straight line drawn from this value of ξ_{min} to ($\xi = 1$, $\tau = 8$) represents a conservative prediction of ξ vs τ for the Viking model parachute staging.

In Figure 3a, the legend shows that T_{TS} the real time value of $\tau = 1$ is about 1/2 second. Then the 7 to 9 periods required for the real time model recovery to $\xi = 1$ always takes place in within about 4 seconds. Through the time scaling relationship presented in Appendix A and evaluated in Appendix B, a basic model projected to a Viking vehicle at Mars predicts that the Viking parachute will require 4 x 3.3 = 13 seconds to recover its pre-stage drag coefficient. Now we have to determine the appropriate value of ξ_{min} for the Viking chute at Mars.

It was anticipated that at staging, the Type II test would not be as disturbing to the parachute canopy as the Type I test. The reasoning came from recognition that the parachute canopy would be operating in the TDE system wake and

Study based on a real [illegible] plume with gaseous [illegible] The simulation [illegible] a solid plume [illegible] simulation does not allow for proper mixing and flow [illegible] characteristics [illegible]

would have already begun to slow before the simulated lander staging. The results do support this, but not as distinctly as expected from the study from which the approximate proper STDE stand-off was determined. This ξ_{min} detail is illustrated by comparing the Figure 3a ξ_{min} with that in Figure 3b. Figure 5 is a summary of ξ_{min} and it distinguishes Type I and Type II ξ_{min} characteristics. The Type II model is considered most representative of Viking operation at Mars.

Figure 6 will be recognized as a plot taken directly from Figure 5b in the local region between Max ρ and Min ρ of Mars for Viking parachute staging. Two lines are identified; one labeled "conservative" and one labeled "very conservative". Referring again to Figure 5b the distinction is apparent. The very conservative line in Figure 5b passes closer to the "+" point at σ_w = 0.07 than does the conservative point. Both lines pass through the "Δ" point at σ_w = 0.007 (an anchor point). The "very conservative" line represents a trajectory through the σ_w, ξ_{min} field of Figure 5b that is obviously biased low.

Since the slope of either ξ_{min} line in Figure 6 is shallow the Mean ρ point could be taken as representing an overall atmosphere, ξ_{min} condition. For a most critical design condition the ξ_{min} at Max ρ may be more appropriate than for Mean ρ. The slope of ξ_{min} vs. σ_w affords an evaluation of the atmosphere density effects for an assortment of atmospheres.

VI. CONCLUSIONS AND RECOMMENDATIONS

The objective of this test was to enable an analytic representation of the Mars parachute staging sequence. We can conclude that the C_D versus time is well represented by the ξ_{min} curve presented in Figure 6. This characteristic emphasizes the initial minimum value of ξ occurring at staging. A suitable allowance for TDE start and warmup operation on $C_D A_o$ may precede the staging value of ξ_{min} within region of TDE influence (Figure 7).

It is suggested that, at staging, the minimum value of ξ (Figure 7) for the appropriate H , ρ is followed by a linear recovery to $\xi = 1$ during 14 seconds of post-stage Martian time*.

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* At Mars, in a Min atmosphere, time intervals measured or calculated on Earth with the 10% heavy model should be adjusted by a factor of about 3.3. This factor is obtained using the formula for Kt given in Table A1, Appendix A.

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TABLE 1

VIKING MODEL PARACHUTE STAGING TEST SUMMARY

June 1973 at KSC VAB

TEST NO.	TYPE (1)	SCALE N_S (2)	WT. CLASS (3)	REF. 16 TABLE 1 RUN NO. (4)	DATE	REMARKS
1	I	.1	B	021	6-20	All tests in this block are good--length of line between B/C and SLS is 75' at zero load.
2	↓	↓	B	21	↓	
3			B	22		
4			H	19		
5			H	20		
6			L	23		
7	I	.1	L	24		
8	II	.1	L	13	6-21	TDE staging with 7' standoff line between B/C and TDE--2 sec. Delay between deploy and staging command.
9	↓	↓		14	↓	
10	II	.1	L	15A		
11	II	.1	L	15B		11' standoff - 2 sec. deploy.
12	II	.1	L	15C	6-22	4' standoff - 2 sec. deploy.
13	II	.1	B	01	↓	4' standoff - 2 sec. deploy. All TDEs suffered broken TDE strut wires--terminated these tests until fix is found. (Test 37)
14				02		
15	II	.1	B	03		
16	I	.2	B	27		All tests good--75' line length at zero load between B/C and SLS.
17	↓	↓	B	28		
18			L	29		
19	I	.2	L	30		
20	II	.2	L	16	6-25	15' TDE standoff line and 2 sec. delay.
21	II	.2	L	017	↓	15' TDE standoff line - TDE failed to deploy.
22	I	.2	H	25		All tests good - 75' line;
23	I	.2	H	26		All Type I tests completed.
24	II	.2	L	17	6-26	15' TDE standoff - 2 sec. delay.
25	II	.2	L	18A	↓	
26	II	.2	L	18B		15' TDE standoff - 4 sec. delay.
27	↓	↓		18C		15' TDE standoff - 1 sec. delay.
28	II	.2	L	18D		15' TDE standoff - 1/2 sec. delay.

TABLE 1 (Concluded)

TEST NO.	TYPE (1)	SCALE Ns (2)	WT. CLASS (3)	REF. 16 TABLE 1 RUN NO. (4)	DATE	REMARKS
29 30 31	II ↓ II	.2 ↓ .2	B B	04 004 0004	6-26 ↓	TDE did not deploy--filled flutes of stowed canopy (TDE) and excessive "q" is probable cause
32 33 34	II ↓ II	.2 ↓ .2	B B	4X 05X 5X	6-27	15' TDE standoff. Pre-deploy mode employed to continue testing.
35 36	II II	.2 .2	H H	7X 8X		Pre-deploy mode with 15' stand-off.
37	II	.1	B	1R		7' TDE standoff and 2 sec deploy - nylon struts replace steel.
38	II	.1	B	02R	↓	Stage release mech. failure led to crash of undeployed TDE--no data.

(1) I -- Type I test; II -- Type II -- See Figure C1 and C2, Appendix C.

(2) .1 -- 10%; .2 -- 20.7% scale model.

(3) L -- light; B -- basic (dynamically loaded) (Nom.); H -- heavy. (Table 2)

(4) "O"s before run no. indicates faulty test; letters after run no. denotes special test series as explained in the Remarks; "X" denotes pre-deployed TDE simulator; "R" denotes steel TDE "umbrella" struts replaced by nylon--This column correlates with Column 2 of Table 1, Ref. 16.

TABLE 2

MODEL WEIGHT LISTINGS -- RELATED TO IDEAL WEIGHTS

MODEL		GROSS WEIGHT (LBS)		KINEMATIC OFF-SCALE FACTOR $\sigma_w = W/W_{ideal}$	
	WT.* CLASS	$\rho = 0.006$ MIN, ρ	$\rho = 0.012$ MAX, ρ	MIN, ρ	MAX, ρ
$N_s = 0.1$	IDEAL	307.0	69.5		
	H	70.4	70.4	0.229	1.021
	B	36.7	36.7	.120	.528
	L	21.0	21.0	.069	.302
$N_s = 0.21$	H	70.4	70.4	0.0247	.0963
	B	34.1	34.1	.0120	.0467
	L	21.0	21.0	.0074	.0288
	IDEAL	2850	730		

* H - Heavy; B - Basic - Dynamically scaled; L - Light

The P+BC and lander were dynamically proportioned for all tests. The basic weight condition also dynamically proportioned the parachute and BC weights. A light and heavy class of weights had the BC lighter or heavier respectively than they should be for proper dynamic scaling relative to the parachute subsystem.

When considering operations in the minimum density Martian atmosphere, reference is simply made to "MIN ρ". Likewise, for operation in a maximum expected Martian atmosphere density, reference is made to "MAX ρ".

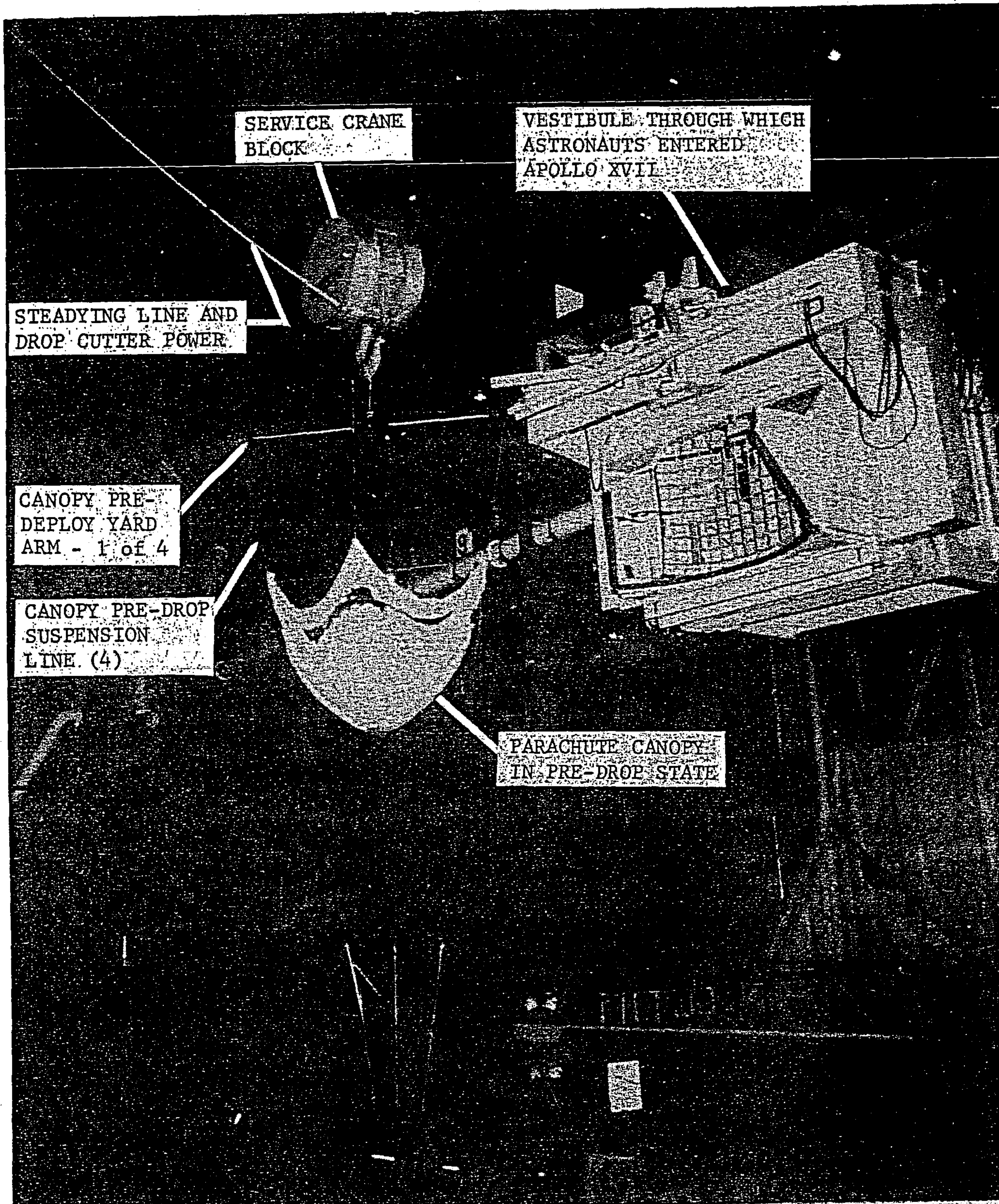


FIGURE 1. MODEL SUSPENDED OVER DROP ZONE READY FOR RELEASE

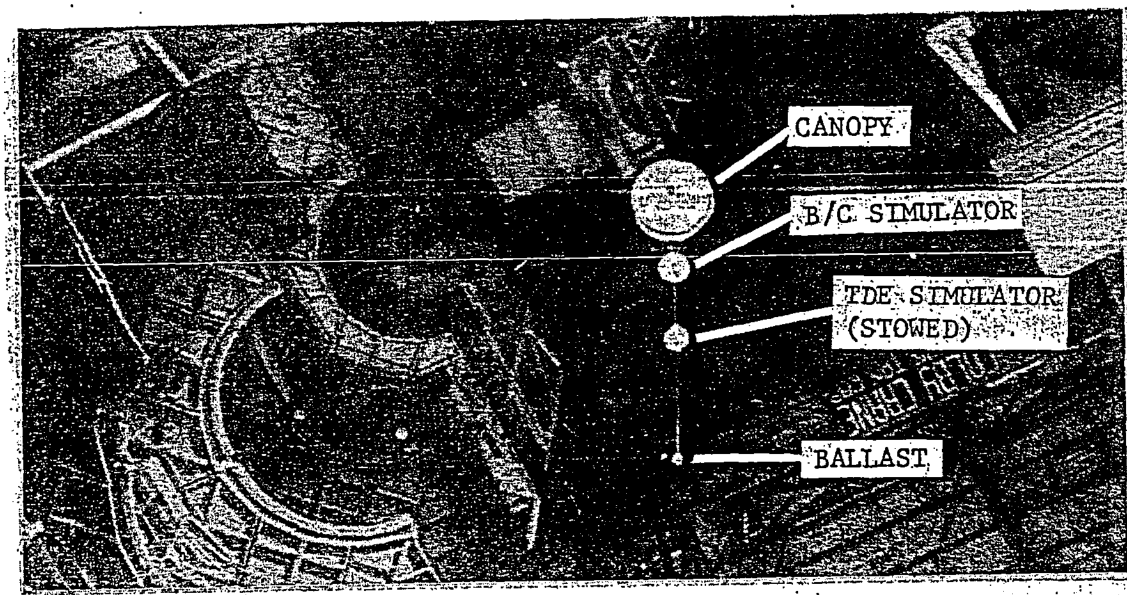
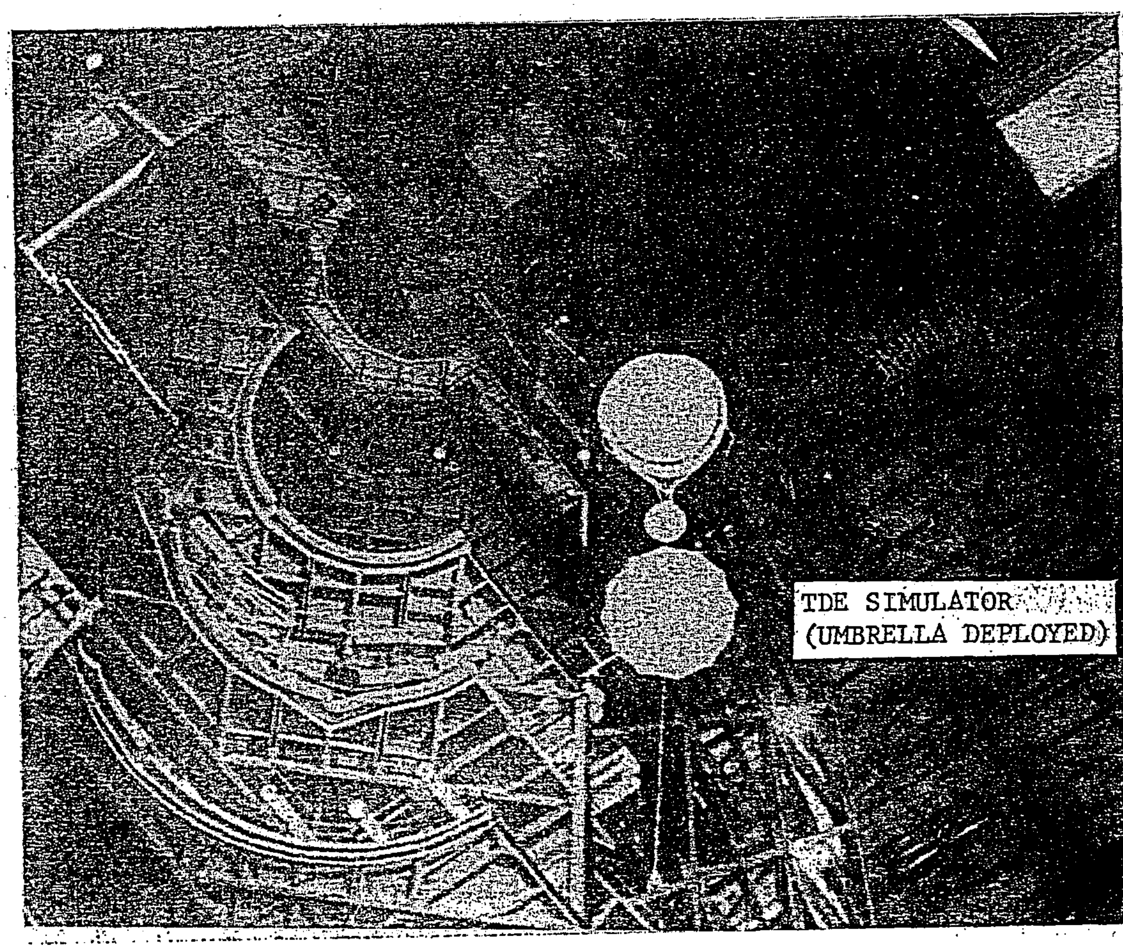


FIGURE 2 TYPE II -20.7% MODEL VIKING PARACHUTE IN FLIGHT
(a) POST RELEASE WITH TDE SIMULATOR STOWED



(b) TDE SIMULATOR IS DEPLOYED AND PRIOR TO SIMULATED LANDER STAGING

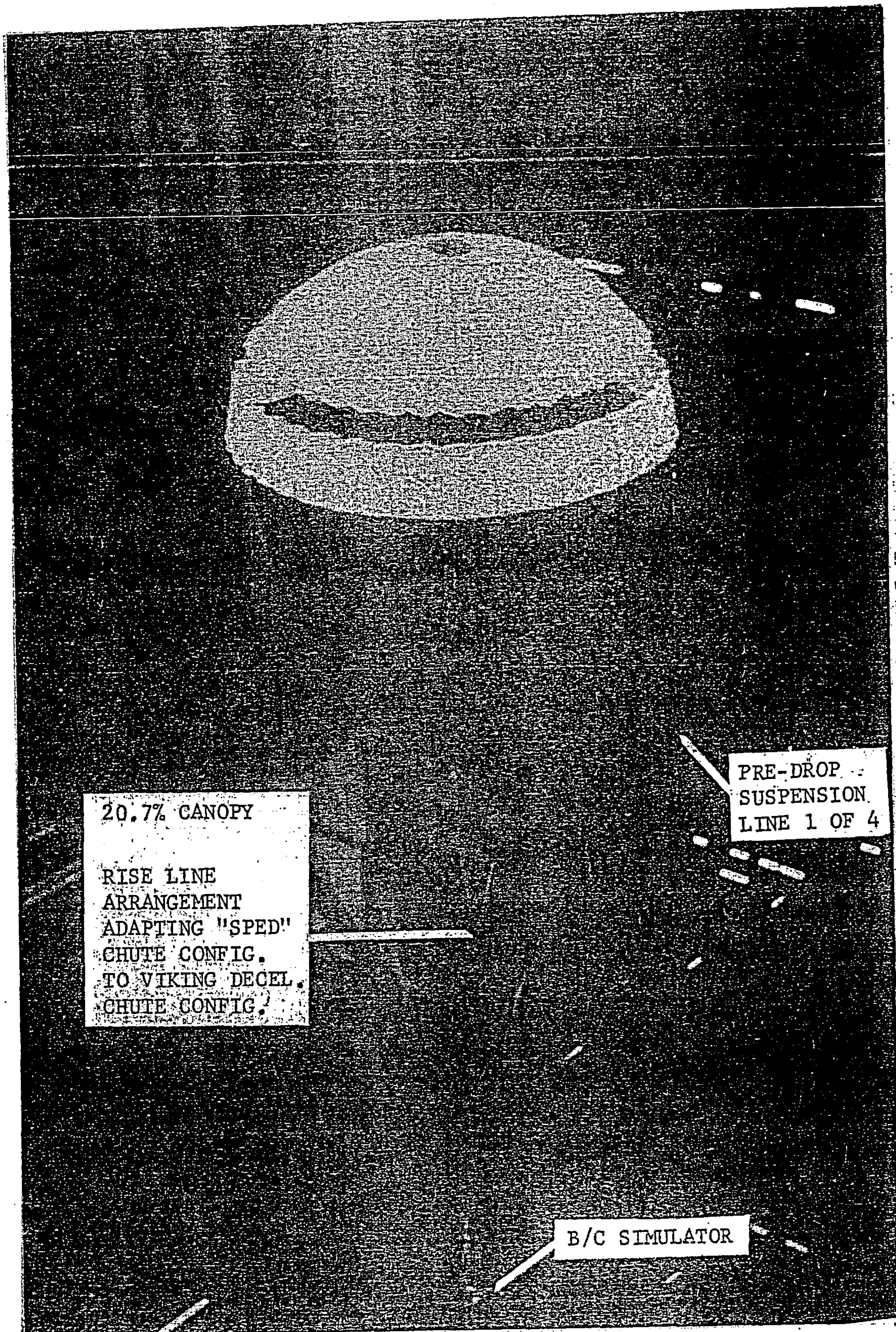


FIGURE 2 (Continued)

(c) PARACHUTE IN FLIGHT AFTER STAGING.

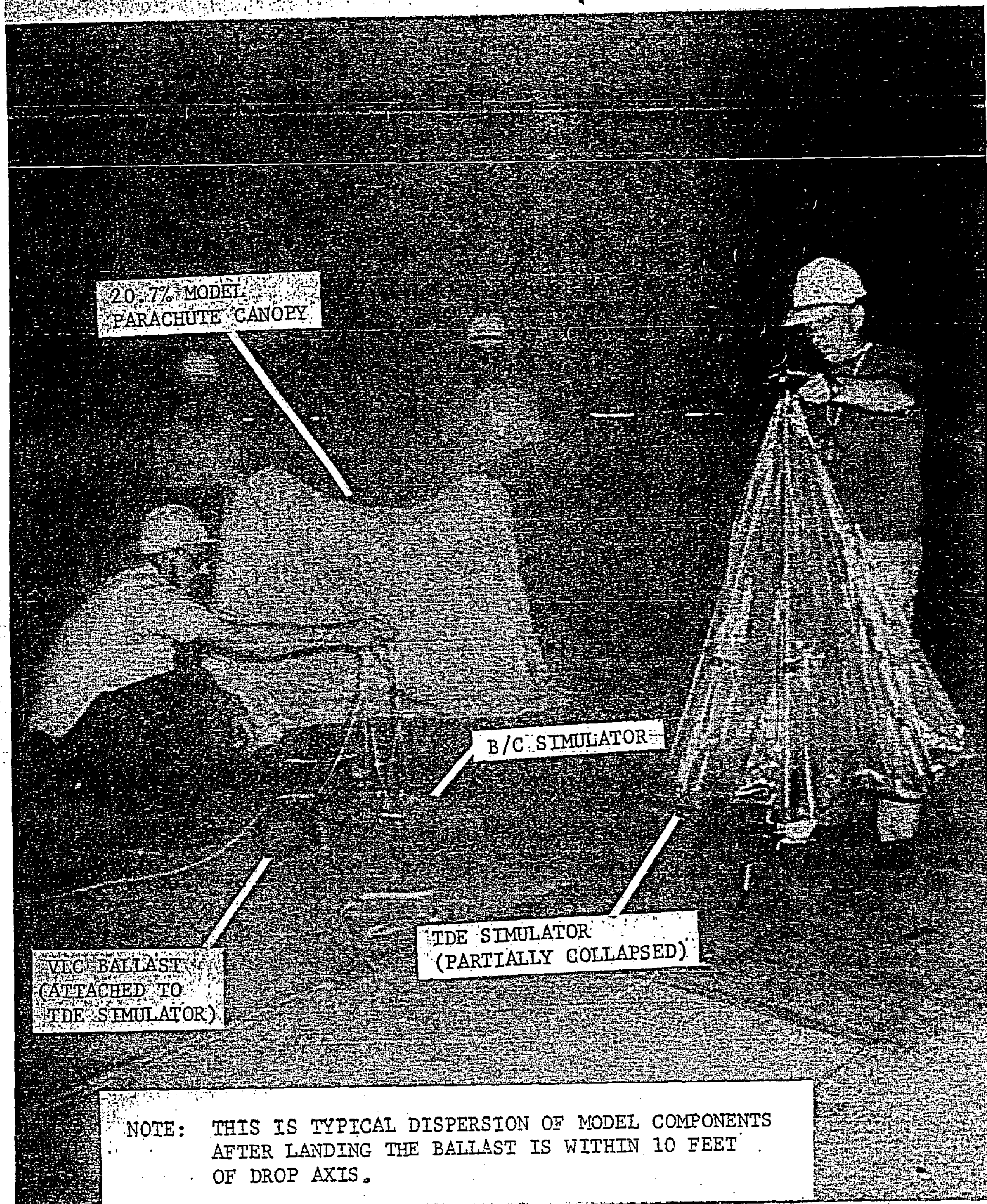
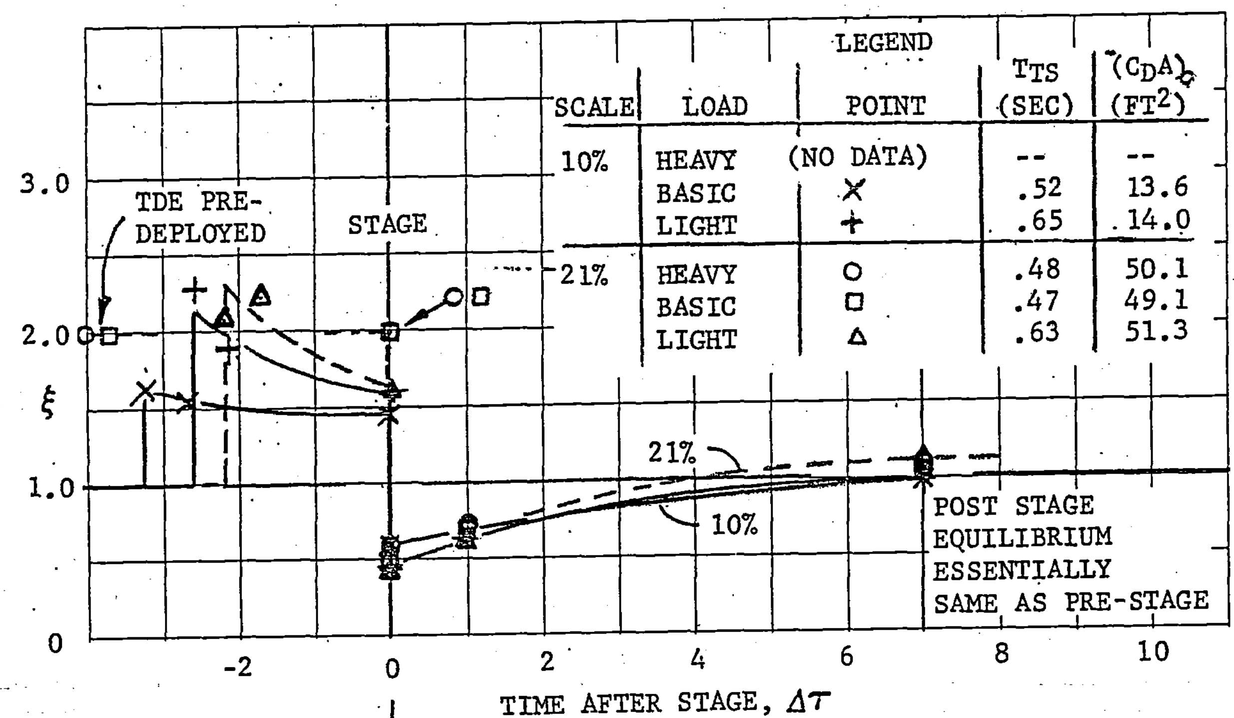


FIGURE 2 (Concluded)

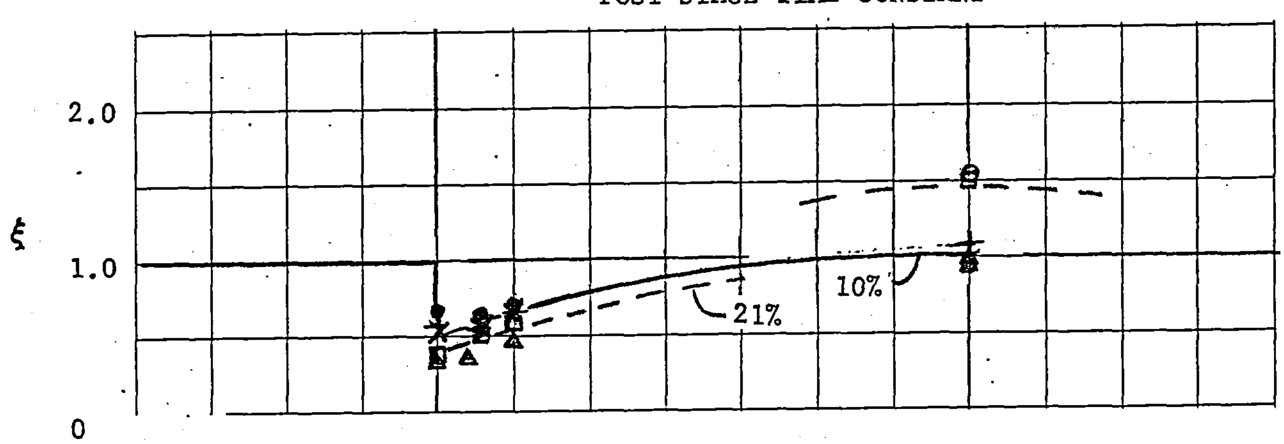
(d) TYPE II, 20.7% VIKING PARACHUTE AFTER LANDING ON THE L.U.T. PLATFORM



(a) Type II Model

NOTE: 1) $\xi = \dfrac{C_D \text{ DURING STAGING}}{C_D \text{ BEFORE STAGING SEQUENCE}}$

2) $\tau = \dfrac{\text{REAL TIME}}{\text{POST STAGE TIME CONSTANT}}$



(b) Type I Model

FIGURE 3 DRAG CHANGE VS. TIME ASSOCIATED WITH SIMULATED LANDER STAGIN

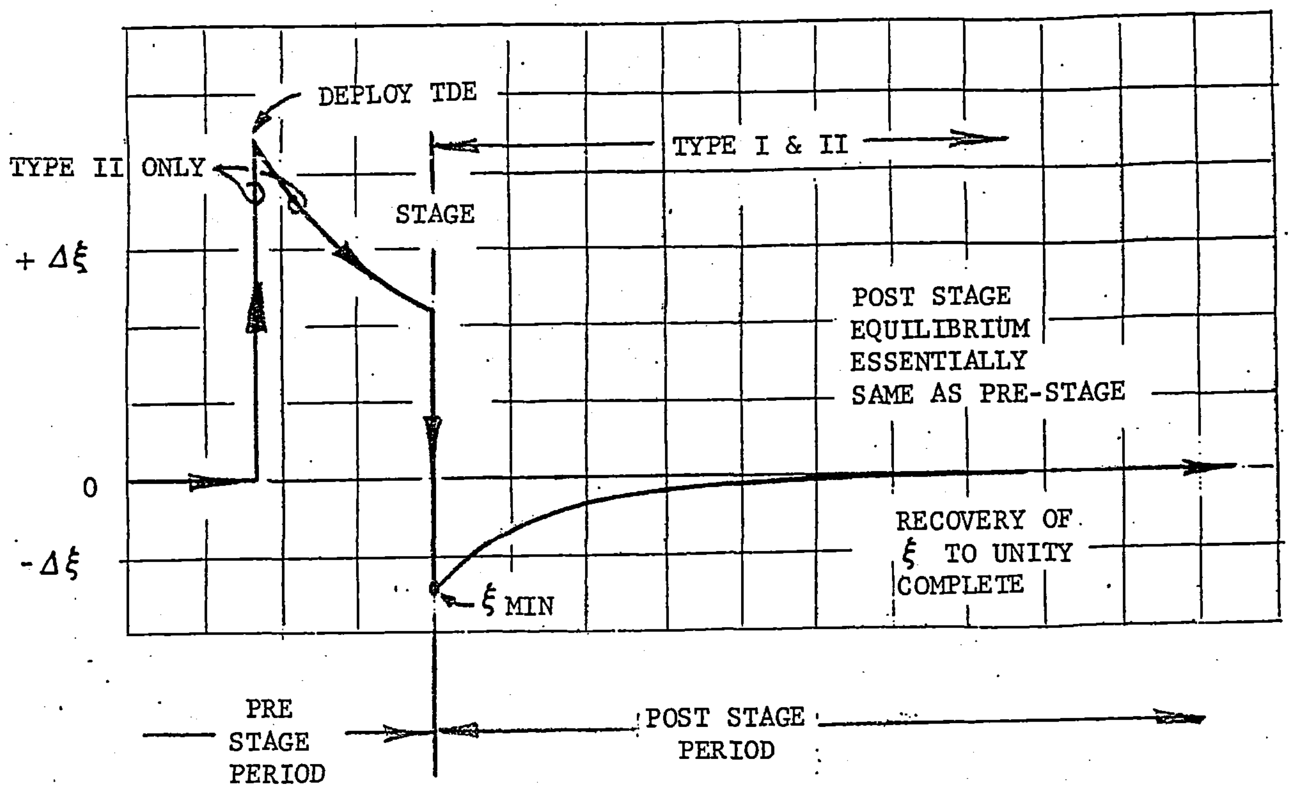


FIGURE 4 TYPICAL TYPE II STAGING SEQUENCE INFLUENCE ON NORMALIZED DRAG

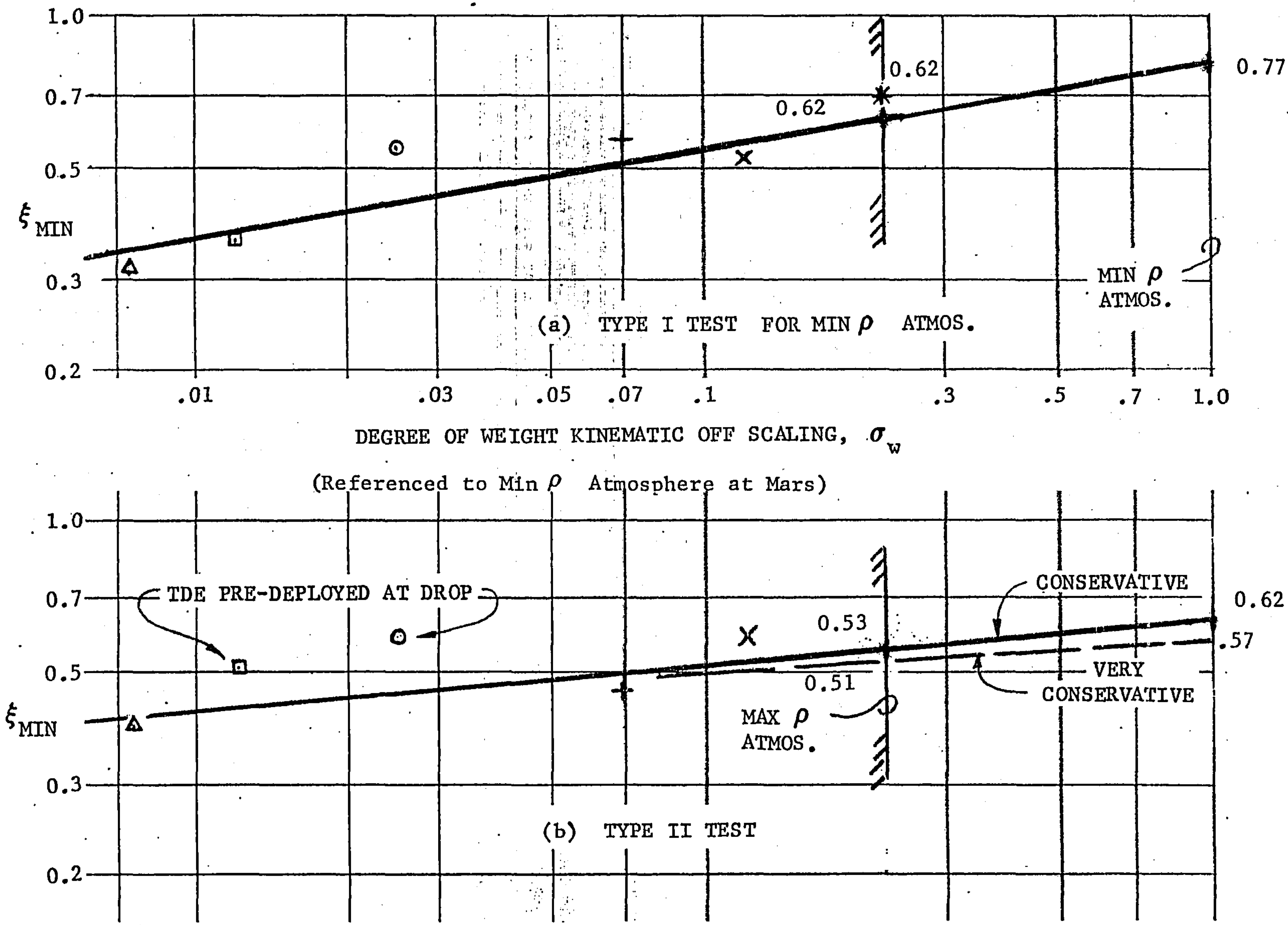


FIGURE 5 MINIMUM ξ_{S+} VS. σ_w

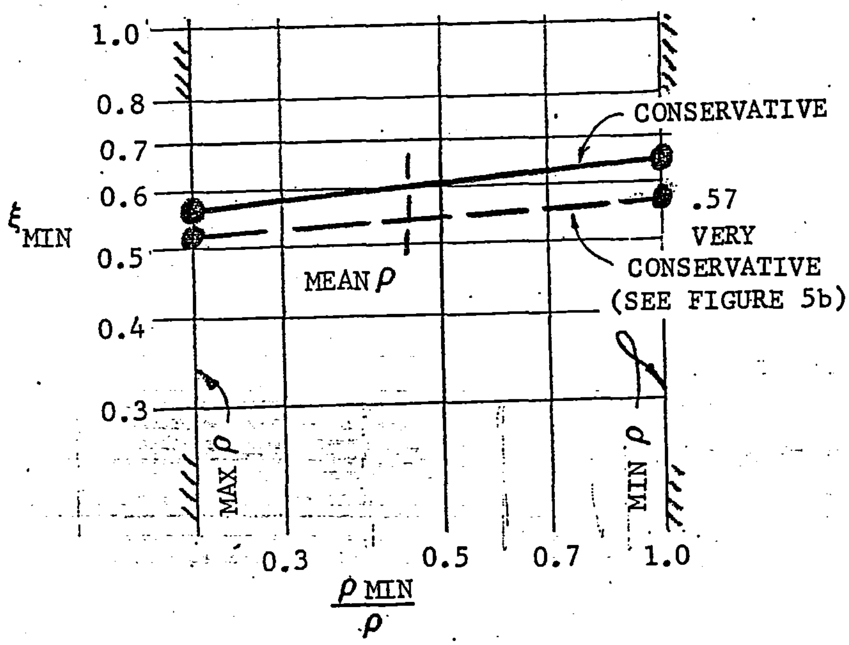


FIGURE 6 RECOMMENDED VARIATION OF STAGING ξ_{MIN} FOR VARIOUS MARTIAN ATMOSPHERES

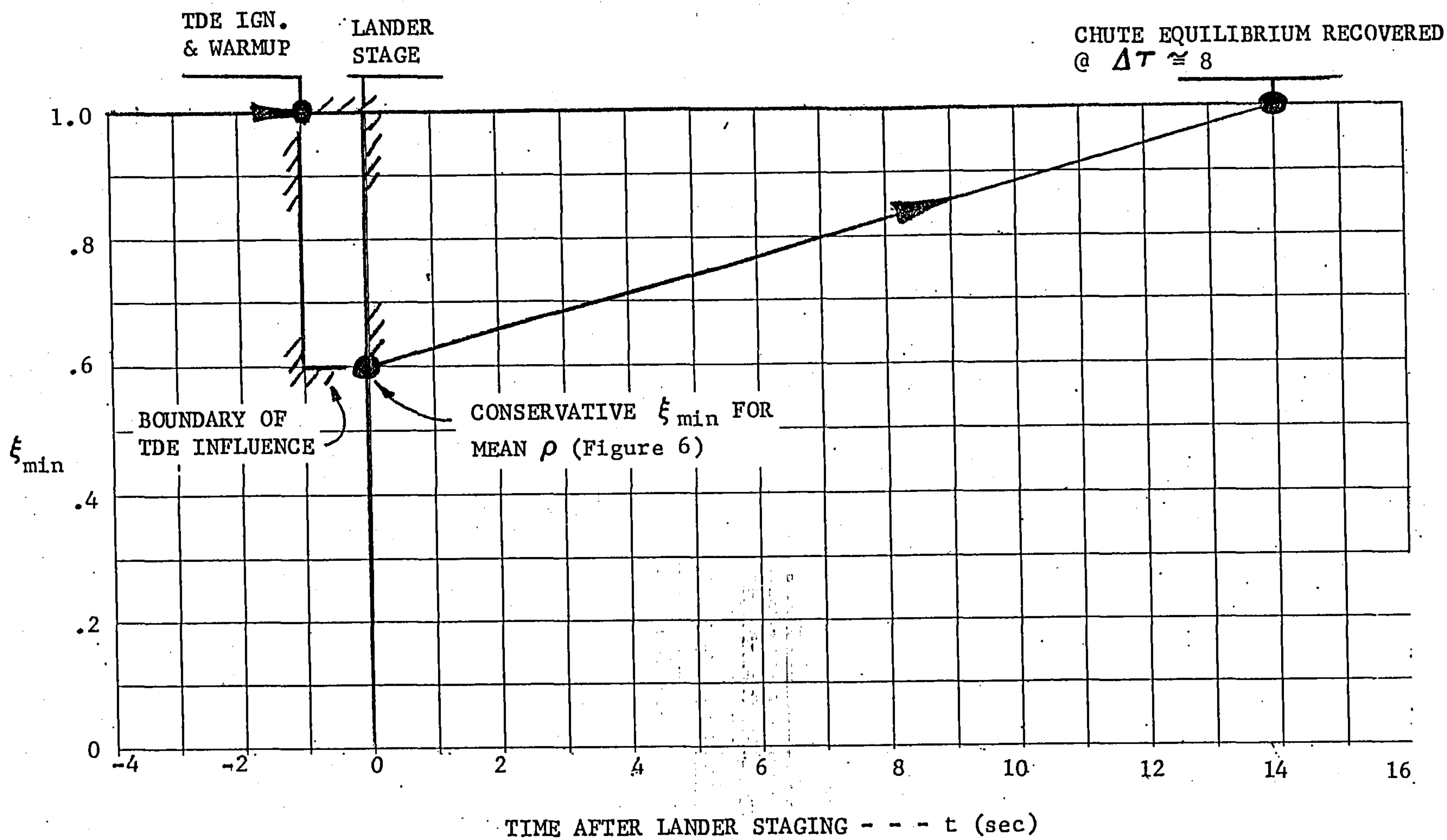


FIGURE 7 A SUGGESTED MODEL OF VIKING PARACHUTE STAGING AT MARS FOR MEAN ρ ATMOSPHERE & CONSERVATIVE ξ_{min}

APPENDIX A

GENERAL REMARKS ON SCALING

In the course of analytically exploring the criteria of scale modeling the Viking Parachute Staging situation, (References 2-7), a set of scaling relationships was developed (Table A1). These have been generally organized as Fundamental, Defined and Combinations of fundamental and defined, (Extended). Once the reader is acquainted with the table presented here he will be able to add to it using the "algebra of subscripts".

One caution is necessary at this point. Note (Table A-1) that N_a and N_g are inversely defined in the strict sense. All other scale factors are defined as Model $\div$ full scale whereas these atmosphere and gravity scales are Mars $\div$ Earth which reduces to an inverse of the model $\div$ full scale ratio.

Subscript Algebra

It can be simply shown that the subscripts of an algebraic scale factor relation will result in a dimensionally consistent relation. The following illustrates this statement.

The velocity scale factor is defined as the ratio of model velocity to full scale velocity under the comparable conditions. Thus, for an aerodynamic situation the drag equations bring out the physical elements that are important. Accordingly, the velocity scale factor will become:

$$N_v = \left\{ \frac{N_{\rho_a} \cdot N_{ms}}{N_g \cdot N_s^2 \cdot N_{C_D}} \right\}^{1/2}$$

If we assume that $N_{C_D} = 1$, as we do in this report, the following velocity scale factor results:

$$N_v = \left\{ \frac{N_{\rho_a} N_{ms}}{N_g \, N_s^{\,2}} \right\}^{1/2}$$

The numerator subscripts are g and ms: (recall the inverse relationship for ρ_a and g), the denominator subscripts are ρ_a and s. Now simply ignore the N's and the result is a dimensionally correct relationship:

$$V = \left\{\frac{ms \cdot g}{\rho_a \cdot s^2}\right\}^{1/2} = \left[\frac{\text{lb-sec}^2}{s} \cdot \frac{s}{\sec^2}\right]^{1/2} \div \left[\frac{\text{lb-sec}^2}{s^4} \cdot s^2\right]^{1/2} = \left[\frac{s}{\sec}\right] .$$

Thus, many scale factors can be described using the fundamental elements such as length, gravity, mass and (on Viking) atmosphere density. This suggests the class name <u>Fundamental</u>. In the illustration above, a definition leads to a scale factor composed of fundamental factors, and so, the class name <u>Defined</u> is suggested. Other scale factors may be derived by applying subscript algebra to combinations of "defined" and "fundamental" scale factors. This third group is labeled "Extended" definitions -- combinations of fundamental and defined scale factors.

As an example consider the factor for volume. It is $N_s^{\,3}$ by assuming shape similarity in three dimensions (ie., $N_x = N_y = N_z = N_s$). Also time scale factors may be derived from the relationships:

$$N_t = \frac{t_{model}}{t_{f.s.}} = N_s / N_v \quad \text{or} \quad = \frac{N_v}{N_{\dot{v}}} \text{ , etc.}$$

Other applications of the subscript algebra are to check on results of defined scale factor relationships and to derive extended scale factors.

TABLE A1

MODEL - PROTOTYPE SCALE FACTORS APPLICABLE TO VIKING MODEL PARACHUTE STAGING TESTS

	FACTOR	RATIO	EQUIVALENTS
Fundamental	N_s	Lm/Lp	x_m, x_p; y_m/y_p - - x_m/x_p; - - model scale factor.
	N_g	g_p/g_m	g_m/g_e - Mars - Earth gravity ratio
	$N_{\rho a}$	ρ_{ap}/ρ_{am}	ρ_{am}/ρ_{ae} - Mars - Earth Atmos. density ratio.
	N_{m_s}	m_m/m_p	Model - Prototype Mass Ratio
Extended	N_t	t_m/t_p	$N_s^2\left\{\frac{N_g}{N_{\rho a} \cdot N_{m_s}}\right\}^{1/2} = N_s/N_v = N_v/N_{\dot{v}}$
	$N_{\dot{v}}$	$\dot{v}_m/\dot{v}_p$	$N_s/N_t^2 = \left(\frac{N_{\rho a} \; N_{m_s}}{N_g \; N_s^3}\right) = \frac{N_v}{N_t} = \frac{N_v^2}{N_s}$ - - etc.
	N_{A_o}	S_m/S_p	N_s^2 - Area ratio
	$N_{\mathcal{V}}$	$\mathcal{V}_m/\mathcal{V}_p$	N_s^3 - Volume ratio
	$N_{\bar{\rho}_s}$	$\bar{\rho}_{s_m}/\bar{\rho}_{s_p}$	N_{m_s}/N_s^3 - System Mean Density Ratio
	N_{w_s}	W_{s_m}/W_{s_p}	N_{m_s}/N_g - System or Component Weight Ratio
Defined	N_v	V_m/V_p	$N_s/N_t = \left(\frac{N_{ms}}{N_g \; N_s^2}\right)^{1/2} = N_u = N_v = N_w$
	N_{C_D}	C_{D_m}/C_{D_p}	C_D (Re, M, - - -) Ratio = 1

APPENDIX B

SCALING APPLIED TO PARACHUTE STAGING TESTS

The purpose of this section is to help the reader gain perspective on scaling relationships underlying the structure of the Viking Parachute Staging Tests. A few scaling laws we use commonly, perhaps without realizing it, are reference to the Reynolds and the Mach Numbers. We confidently rely on visco-dynamic testing when the Reynolds number is the same for the model as for the full scale vehicle. If the Mach numbers are the same the pressure fields will be duplicated. The key word is "same". This word in scaling discussions is synonomous with the phrases "is preserved" and "has 1:1 correspondence".

It was determined that the Froude number* is the appropriate measure of the Viking parachute staging activity. Thus, if the Froude number associated with staging is preserved the test results bearing on the question of parachute staging performance are directly projected to the full scale vehicle at Mars. Thus an ideal test preserves Froude number or, (reference to scale factor discussion in Appendix A).

$$\frac{N_{\dot{v}}\, N_s}{(N_v)^2} = 1. \qquad \text{(B1)}$$

When this criteria was applied to the Viking parachute staging test, it was found that B1 translated to the more specific form:

$$\frac{N_{ms}\, N_{\rho_a}}{(N_s)^3} = 1. \qquad \text{(B2)}$$

---

* The Froude number is commonly used to measure wave phenomena as influenced by gravity. Thus the velocity vector is usually at right angles to the acceleration or gravity vector. In this application the velocity and acceleration vectors are aligned. Even so, we refer to this velocity-acceleration-distance relationship as a Froude number.

First recall that N_{ρ_a} is $(\rho_{a_{Mars}} / \rho_{a_{Earth}})$ and $\frac{N_{ms}}{(N_s)^3} = (\bar{\rho}_{model}/\bar{\rho}_{full\ scale})$. Then equation B2 states that the ratio of densities of vehicle to atmospheric test medium must be preserved. That is, $\left(\frac{\bar{\rho}_{model}}{\rho_{a_{Earth}}}\right) = \left(\frac{\bar{\rho}_{vehicle}}{\rho_{a_{Mars}}}\right)$.

Then to simulate Martian atmosphere density (about 1/100th that of Earth) a model tested in earth atmosphere must be impracticably dense if at all possible. An ideal test with a reasonably constructed model must be tested in a facility such as the Lewis Zero "G" facility (a long, evacuated, vertical tank) or at an altitude of 80 to 100 thousand feet. Though these are technically feasible concepts, the expense of such tests is not justified. Alternates were sought utilizing available models in the sea level ambient atmospheres. From this effort, the philosophy was adopted of testing at lower than ideal model-atmosphere density ratios; off-scale testing.

The measure of off-scale testing is the ratio:

$$\frac{\text{Actual Model Weight}}{\text{Ideal Model Weight}} = \sigma_w.$$

The same analysis which points to σ_w as the off-scale measure also predicts that tests at σ_w less than 1 will, for our objective, yield conservative results. That is, we would measure more extreme acceleration effects due to staging than would be experienced by the Viking parachute at Mars.

A wake oriented influence was anticipated affecting parachute performance degradation after staging. Exactly how this would be manifest in the measured performance awaited the outcome of testing reported here.

Test results showed that the property to be compared with the off-scale test measure, σ_w, was ξ_{min}. The evidence presented in the text of this report suggests a fundamental property of the drag devices of this test is a portion of intimately associated atmosphere that must be included in the mass term of the dynamic equilibrium equations describing the parachute system (disussed in more detail in Appendix E). (This evidence is consistent with the reasoning behind the philosophy of this test effort. So by deduction, the philosophy of this testing is supported by the results).

A final remark concerns the distribution of model mass elements to achieve the assortment of σ_w required for testing with two model parachutes. Equation B1 is being applied to a very flexible system. So dynamic scaling must be carefully considered. Ideally, the model mass distribution would be preserved.

It was anticipated and later demonstrated that a reasonable variance of off-dynamic scaling in the test would not materially interfere with the test results. Thus, we accepted a reasonable degree of dynamic off-scaling relative to the <u>basic</u> tests which were nearly dynamically scaled. Again, the results would appear to endorse this judgment since fabric pliability would be related more to internal dynamic (deformation) phenomena which were observed to be a minor feature of this test series.

A formula for scale time is derived and listed in Appendix A (see Table A1, Factor N_t). This relationship for scale time is used to determine the time scale factor (3.3) given in the discussion. (Chapter V). Other projections of model time oriented events to comparable situations in specific Martian environments will be evaluated using this formula for N_t.

APPENDIX C

VIKING PARACHUTE STAGING MODELS

Two parachute models were available. One was a 10% model previously used in wind tunnel tests. The other was an adaptation of a SPED model parachute. This second 20.7% (SPED) model, from the standpoint of canopy venting and pliability, is the more representative model of the Viking decelerator parachute.

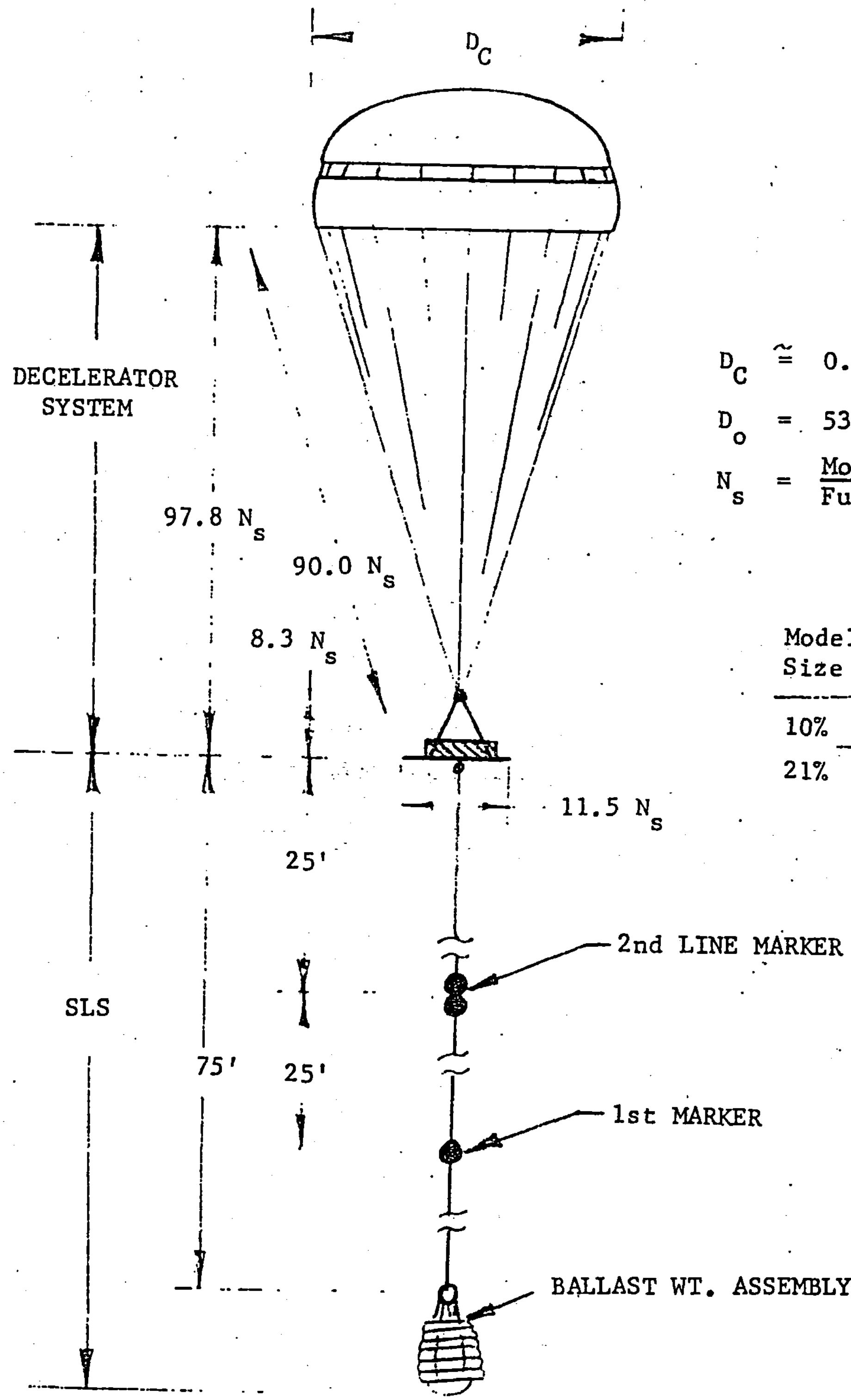
Figures C1 and C2 illustrate how these parachutes were rigged for the Type I and II tests. In these figures the principal decelerator system dimensions (parachute) are given in reference to the full scale system. Those dimensions for the Simulated Lander System (SLS) are nominal makeup dimensions. Because of operational considerations manifest during the test, special adjustments were necessary in order to properly account for line stretch and set due to load and load repetition.

Model weight was adjusted through a ballasting system. Metal slugs and trim weights were secured to the B/C simulator (an aluminum disc). Ideal dynamic scaling within the decelerator system was achieved by proportioning the parachute and B/C subsystem weights. For all model configurations the SLS gross weight was dynamically proportioned to the decelerator system by adjusting the lead shot load in the ballast bag.

TDE Simulation

Terminal descent engine (TDE) simulation, as mentioned in the text, was based on producing a drag of the order of thrust produced by a properly scaled TDE at STDE deployment. One other important factor was the TDE simulator position relative to the BC. Accordingly the standoff distance and the deployed TDE simulator drag disc (umbrella) diameter are referred to the full scale system. Several discussions regarding the TDE simulation are contained in References 10 through 13.

Operation of the TDE simulator (STDE) was initiated by a radio command. A disc at the bottom of the STDE mast served to attach and to protect the radio controlled actuator system. A servo motor released the "umbrella" rib tips and the relative wind deployed the umbrella against the steel restraining strut wires resulting in the working configuration illustrated (Figure C2). Another servo at the top of the mast actuated the staging (release) mechanism. Photographs of these details are Figures C3(a) through C3(d). Figures 1b and 1c contrast the stowed and deployed STDE drag areas.



$D_C \cong 0.71\, N_s\, D_o$

$D_o = 53'$

$N_s = \dfrac{\text{Model Dimension}}{\text{Full Scale Dim.}}$

Model Size	N_s
10%	0.100
21%	0.207

FIGURE C1 SKETCH OF TYPE I SIMULATED VIKING DECELERATOR MODEL SYSTEM

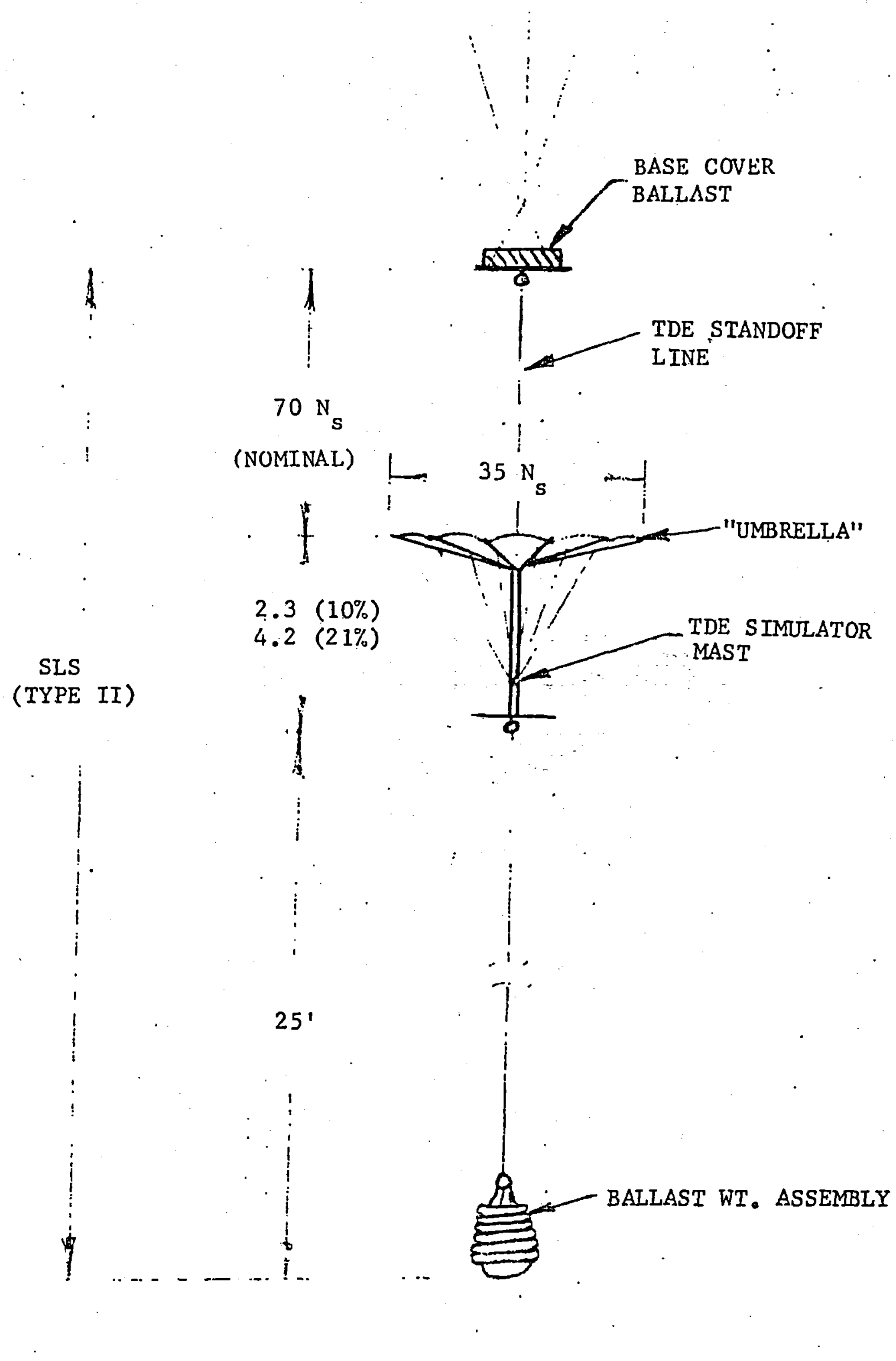


FIGURE C2 TYPE II SIMULATED TDE SYSTEM SKETCH

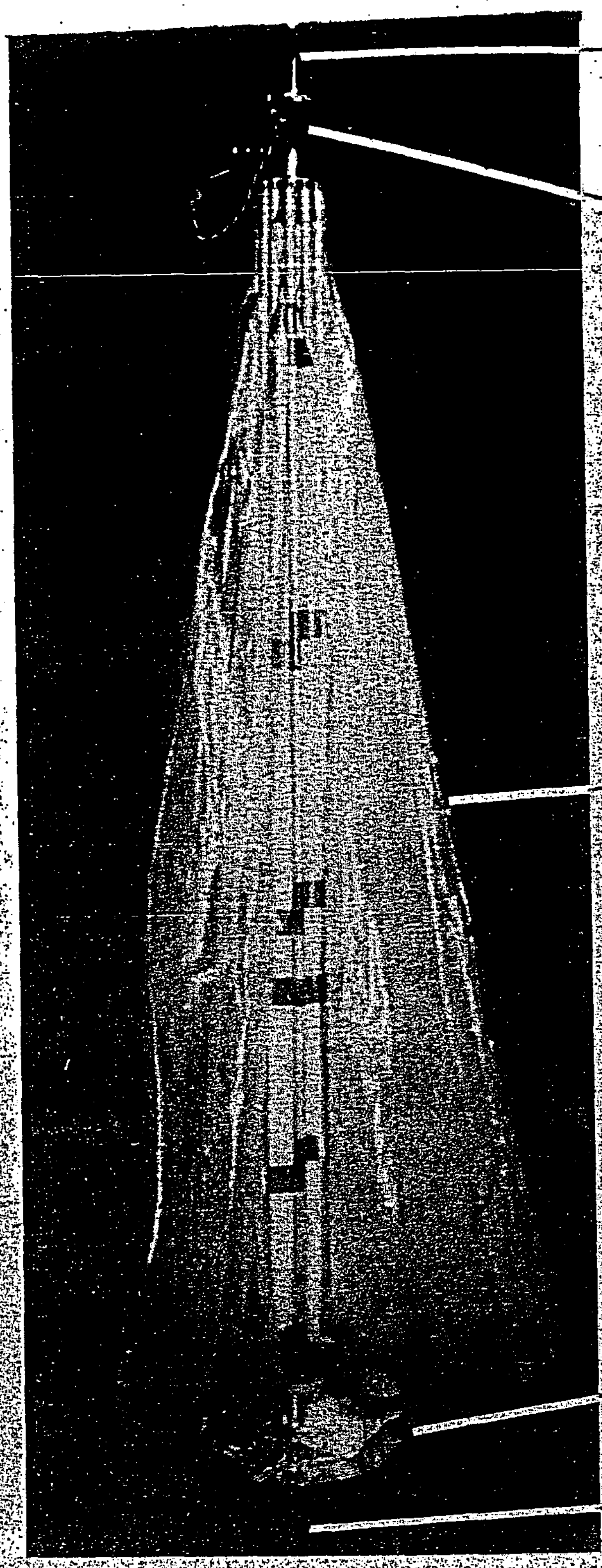


FIGURE C3 TYPE II 20.7% VIKING PARACHUTE STAGING MODEL ASSEMBLY
(a) STOWED TDE SIMULATOR ASSEMBLY

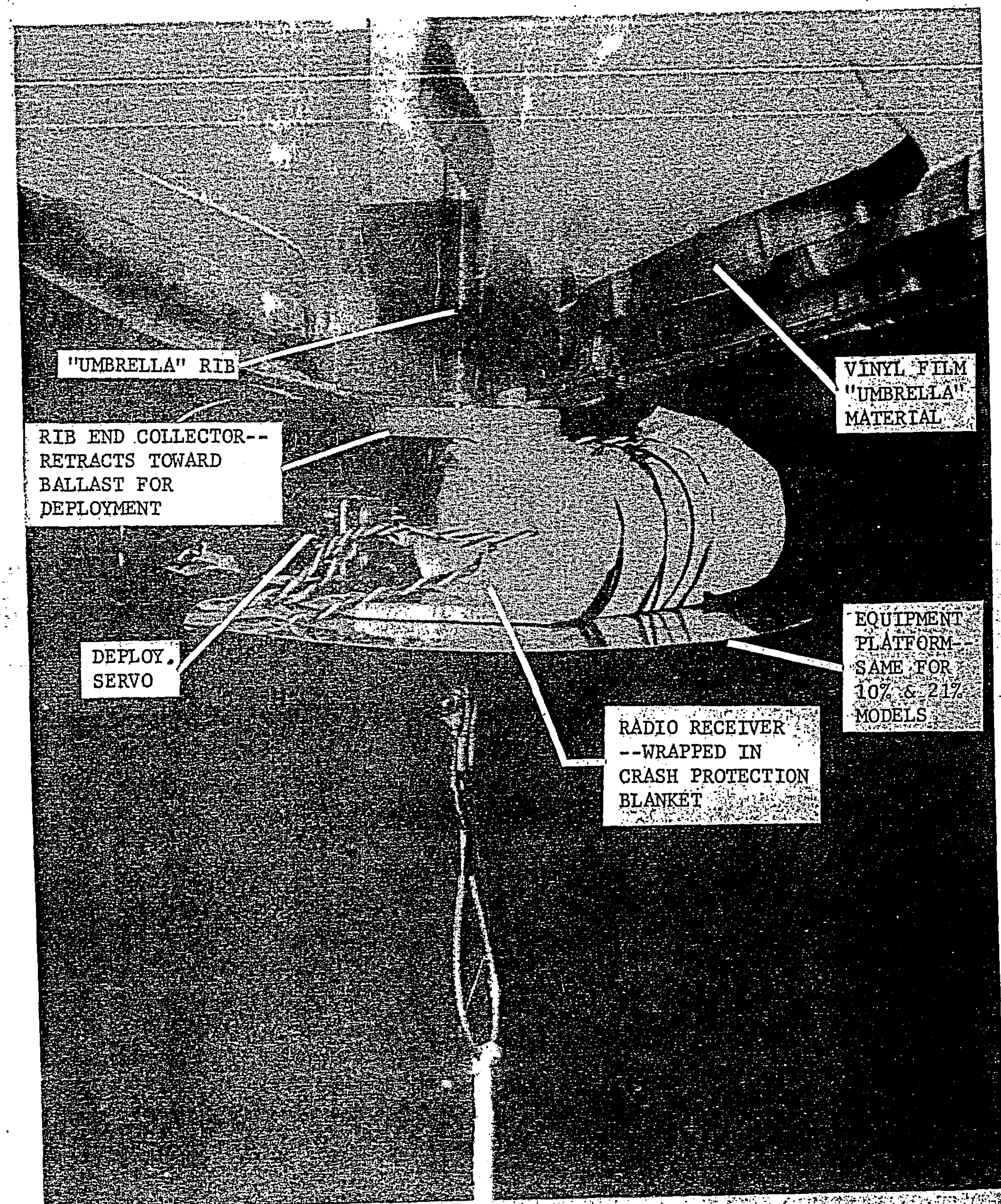


FIGURE C3 (Continued)

(b) BOTTOM DETAIL OF TDE SIMULATOR SHOWING DEPLOYMENT SYSTEM

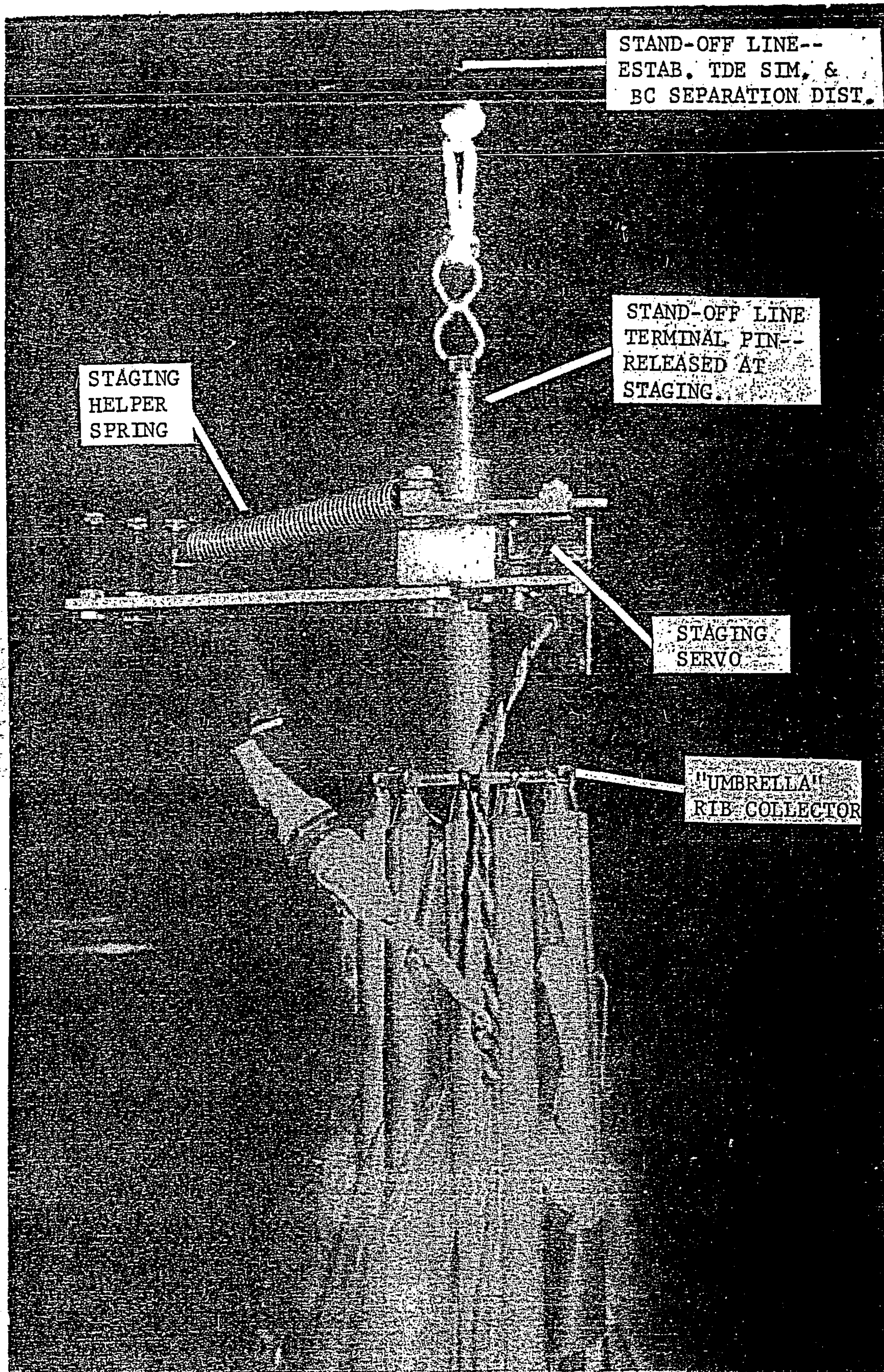


FIGURE C3 (Continued)

(c) TOP DETAIL OF TDE SIMULATOR SHOWING STAGING SYSTEM

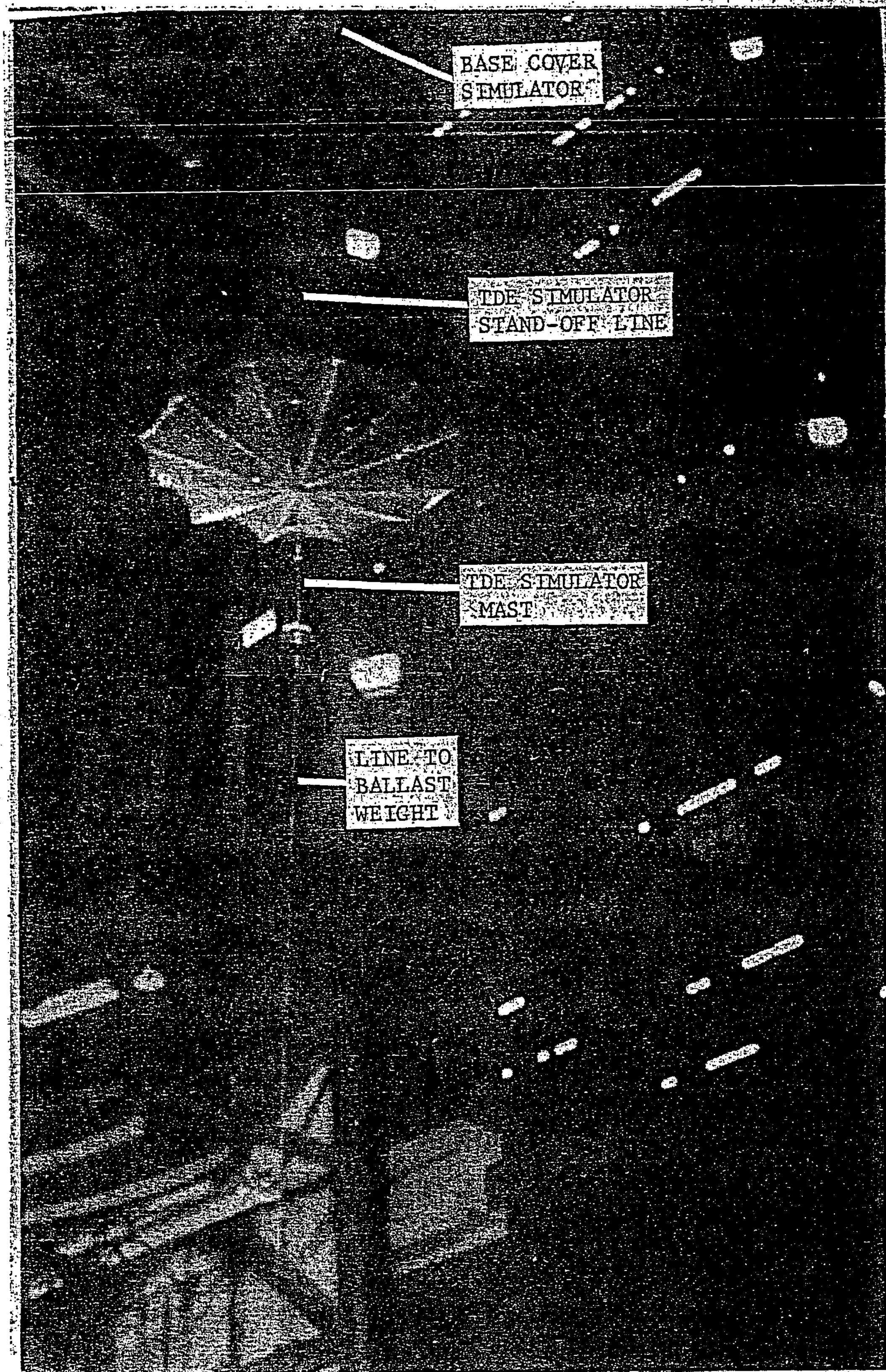


FIGURE C3 (Concluded)

(d) CLOSE VIEW OF TDE SIMULATOR AND SIMULATED LANDER IN FLIGHT PRIOR TO STAGING

APPENDIX D

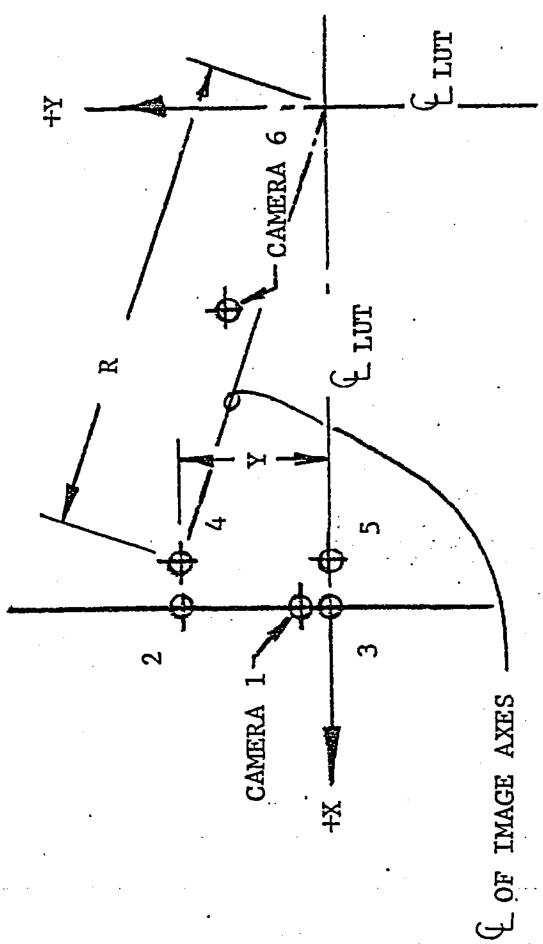
MOVIE DATA CAMERA LOCATIONS

A comprehensive description of the test operation is contained in Reference 17. Information necessary for data reduction but not contained in this reference are the exact aiming and operating details for six movie cameras. (The data source).

Cameras

Figure D1(a) illustrates the elevation station of each of the six (6) cameras on the Launch Umbilical Tower (LUT). The intersection of the centerlines of the mobil launch platform (the drop target area) at zero level is the coordinate reference center. The plan layout locating the camera is Figure D1(b). Figure D1(c) is a summary table furnishing the space relationship of all six cameras.

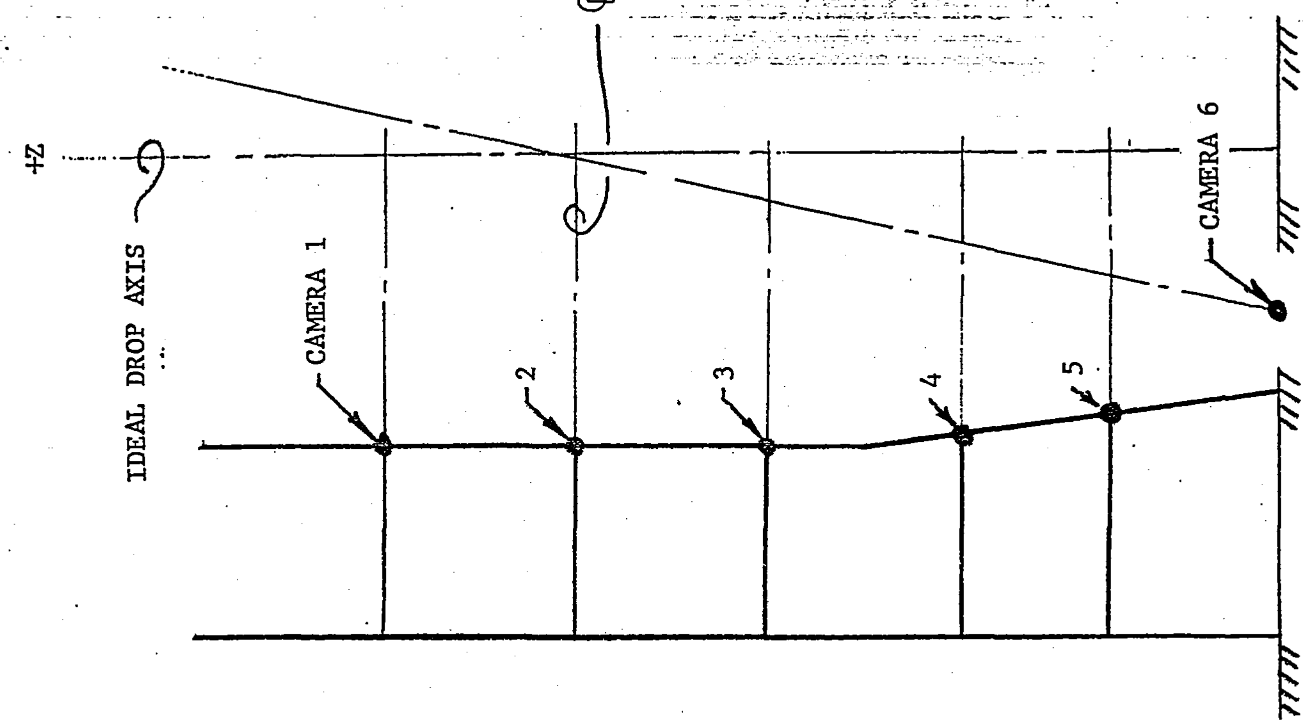
Cameras 1 through 5 operated at about 200 frames per second. Range time was coded on all film so that camera time phasing and film speed could be determined to within a few milliseconds. Camera No. 6 recorded the general features of the test, but the time position data for the model during flight was derived from cameras 1 through 5.



b. PLAN SKETCH.

(c) TABLE OF CAMERA LOCATIONS

CAMERA NO.	ELEV. (FT)	Y (FT)	R (FT)
1	185	1.7	60.0
2	150	21.5	64.0
3	105	0	60.5
4	61	21.6	60.2
5	34	0	57.0
6	1	14.0	33.5



a. ELEVATION SKETCH

FIGURE D1 CAMERA LOCATIONS AND AIMING DIAGRAMS

APPENDIX E

Analysis of ξ

A model of the Viking Lander on parachute is analytically represented by a statement of dynamic equilibrium. This relationship is:

$$W - D = m \cdot a \tag{E-1}$$

Here the gross weight of the model system, W, acts downward and equals the upward reactions drag, D, and inertia, m · a. Of course, velocity and acceleration are also positive downward.

If we define drag in the usual way (i.e., $D = C_D A_o \rho/2\ V^2$) and let $m = W/g$, E-1 is re-arranged to become:

$$C_D A_o = \frac{W\ (1-a/g)}{\rho \frac{V^2}{2}} \tag{E-2a}$$

This expression relates the instantaneous $C_D A_o$ to the corresponding velocity and acceleration at that instant. By setting a = 0 the usual form of $C_{D_o} A_o$ for steady pre-stage flow results (i.e., $C_{D_o}A_o = 2W/\rho V^2$). The normalized form of Equation 2a is the quotient $C_D A_o / C_{D_o} A_o$ or:

$$\xi = \left\{1 - a/g\right\} \cdot \left(\frac{W}{W_o}\right) \cdot \left(\frac{V_o}{V}\right)^2 \tag{E-2b}$$

Equation E-2b was used in processing the drag data resulting from the Viking model parachute staging test.

The test results indicate that the system mass includes more than the hard tangible mass of the system. Preliminary analysis led to the idea that during an accelerated flow some of the fluid mass immediately about the vehicle is accelerated with the vehicle. A first order approximation of the magnitude of such fluid mass involvement would relate to the vehicle's characteristic dimension as:

$$m_f = k\ D_o^3 \tag{E-3}$$

where m_f is the mass of involved fluid and k is a constant which considers the fluid mass density and a factor representing the vehicle shape.

Though k might itself vary with the state of flow (i.e., R_e, M, etc.) it is reasonable to assume here that k is practically a constant. We will proceed on this premise.

In order to expand (ma) it would better to arrange E-3 so that its addition to the "m · a" term in E-1 would result in a factor times the vehicle weight. Thus, letting the vehicle mass be represented by m_V and k' = kg/W, we may write:

$$m = (m_v + m_f) = \frac{W}{g} (1 + k' D_o^3) \tag{E-5}$$

Now we will extend equation E-2 by including the factor k'. The result is:

$$\xi' = \left\{1 - \frac{a}{g} \quad (1 + k' D_o^3)\right\} \cdot \left(\frac{W}{W_o}\right) \left(\frac{V_o}{V}\right)^2 \tag{E-6}$$

The difference between E-6 and E-2b is the factor containing k' modifying the acceleration intensity, a/g.

Recall from E-1 that the weight associated with ξ is the instantaneous weight when ξ is evaluated. But the magnitude of 'a' at staging depends on how much change of system weight takes place. The proportions of the initial gross weight to the staged weight for each parachute model system was always the same as for Viking staging at Mars. Thus, the initial acceleration (slow down) due to staging was also constant. On the other hand, the term k' D_o^3 is directly related to the canopy loading (see definition of k'). Thus, from the definition of σ_w it is seen that σ_w and k' are related.

Evaluation of E-6 for ξ'_{min}, (which applies to the instant following staging, t = 0) shows that its magnitude does appear to depend on the sign and magnitude of acceleration intensity (a/g). This is also supported by the results of a quick check on the STDE acceleration at staging. Unfortunately, the test did not provide data from which k' could be evaluated. Such would have required another dimension, namely, variation of acceleration intensity (a/g).

This discussion of ξ and ξ' is submitted to close the loop of pre-test analysis and test results. The reasoning behind the test procedure appears to be all right. The test results confirmed what was reasoned to be essential physical differences between Earth-models parachute performance and Mars-Viking parachute performance. Now, based on the test results, we see that the tests did not provide a means of quantifying k'. The test results presented reflebt k' in effect by presenting the variation of ξ with σ_w. It should be emphasized that the physical differences between Type I and Type II tests would necessarily lead to a different value of k' for the TDE operation.

The test reported here meets the objective for which it was designed. Now we see how more precise results can be obtained in the future by evaluation of k' for each specific parachute staging configuration. This technique is basically applicable to all problems of transient drag evaluation.