MDC-TR-66-23

AIR FORCE MISSILE DEVELOPMENT CENTER TECHNICAL REPORT

EFFECTIVENESS OF NYLON DRAG STRAPS FOR BRAKING MONORAIL SLEDS

Daniel J. Krupovage

Distribution of this document is unlimited

November 1966

HOLLOMAN AIR FORCE BASE
NEW MEXICO

UNCLASSIFIED

MDC-TR-66-23

EFFECTIVENESS OF NYLON DRAG STRAPS FOR BRAKING MONORAIL SLEDS

Daniel J. Krupovage

November 1966

AIR FORCE MISSILE DEVELOPMENT CENTER
DIRECTORATE OF TEST TRACK
AIR FORCE SYSTEMS COMMAND
HOLLOMAN AIR FORCE BASE, NEW MEXICO

FOREWORD

Monorail sleds are being used for many different kinds of testing on the Holloman track. The weight efficiency and small drag area of these vehicles allows their application for missions with speed requirements up into the hypersonic Mach number regime. Unfortunately the same characteristics which are most essential for reaching high speeds, and detrimental to efficient braking during free-run after burnout, and effective low speed recovery methods are mandatory to keep the coasting distance in consonance with the length of the existing track. The braking method discussed in this report is one of several approaches to this problem used at AFMDC. The technique itself was first tried out at Holloman in 1958, and has been in operation since. The need for the tests, the results of which are covered in the following pages, arose from the requirements to provide numerical data for performance calculations of hypersonic sled runs with marginal recovery distance.

PUBLICATION REVIEW

This technical report has been reviewed and is approved.

CHARLES E. CARSON
Colonel, USAF
Director, Test Track

ABSTRACT

Velocity versus coast distance measurements on two monorail rocket sleds were conducted on the Holloman track to obtain numerical information on the braking effectiveness of nylon drag straps. The data were obtained from ribbon frame camera readings and reduced to the form of drag area ($c_D A$) of the sleds and the drag straps. The straps as described are shown to increase the effective drag area of the monorail sleds used by approximately one square foot and to be an effective means for reducing recovery distance in the speed range below approximately 700 ft/sec.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

A	ft^2	Reference area for aerodynamic coefficients of vehicles: Frontal area of sled not including the frontal area of the drag straps picked up.
c_D		Drag coefficient
$c_D A$	ft^2	Drag area
c_F		Slipper friction coefficient
F	lb	Frictional force
F_{pickup}	lb	Maximum force exerted on sled structure by pickup of drag strap
ℓ	ft	Length of strap (see Figure 3)
m	slugs	Mass of sled after burnout
q	lb/ft^2	Dynamic pressure
s	ft	Distance along the track
t	sec	Time
V	ft/sec	Velocity of sled relative to ground
$\dot{V} = \frac{dV}{dt}$	ft/sec^2	Acceleration of sled
V_w	ft/sec	Component of wind velocity in direction of sled motion
W	lbs	Burnout weight of sleds
$\frac{W}{c_D A}$	lb/ft^2	Ballistic coefficient
ρ	$slugs/ft^3$	Air density

SECTION I

INTRODUCTION

1. Nylon drag straps, picked up and dragged along during coasting, are being used on the Holloman track as a means to reduce recovery distance of monorail sleds. One attractive feature of this method is that relatively little structural weight is needed for sled components to pick up the straps. Another important feature of this braking technique is the capability to stop more than one sled simultaneously approaching on the same rail; for instance, several stages of a multi-stage system. This is accomplished by supporting a strap above the rail, so that the first sled passes under the strap but cuts a cord, which allows the strap to be dropped on the track for engagement by the second sled. The first sled continues on and engages another strap or straps further down track. This braking technique can be extended to more than two sleds by proper location of the support fixtures.

2. It has been determined by previous tests that this braking method is applicable up to safe maximum engagement velocities of 700 feet per second. Engagement speeds higher than this in many cases broke the straps.

3. This report presents the results of sled tests which were conducted on the Holloman track to obtain numerical data on the braking effectiveness of such drag straps.

SECTION II

DISCUSSION OF METHOD

4. The nylon drag straps used in the tests were free to trail behind the vehicle and were not restrained from traveling with the sled by any ground side fixtures. The braking effects produced by such straps are attributed to momentum exchange between sled and straps, and to the aerodynamic drag generated by the straps. In the speed range under consideration (i.e., $0 < V < 700$ ft/sec) the aerodynamic braking is by far the more important portion of the braking effect of the straps. However, the structural loads during pickup determine the layout of the sled components designed to accommodate the braking forces.

5. The phenomena involved are briefly described as follows:

a. Momentum exchange between sled and strap. When a sled of weight W traveling at a speed V, picks up a strap of weight W_{strap} which is at rest with respect to the ground, its speed is decreased by momentum exchange from the speed V_1 to

(1) $$V_2 = V_1 \frac{W}{W + W_{strap}}$$

and the force exerted by the strap on the sled structure is described by

(2) $$F_{Pickup} = m_{strap} \frac{V_2}{\Delta t}$$

The strap pickup time Δt may be estimated by the following considerations: Assume the strap is laid out ℓ feet forward of the initial engagement point and the sled is traveling at the speed V_1. Then the total length of the strap is accelerated to the speed V_2 within the time increment:

(3) $$\Delta t = \frac{2\ell}{V_2}$$

For example:

For $V_1 = 500$ ft/sec, $W = 70$ lbs, $W_{strap} = 7.5$ lbs, and $\ell = 25$ ft, the sled is decelerated by momentum exchange to

$$V_2 = 500 \frac{70}{77.5} \approx 450 \text{ ft/sec}$$

within the time increment

$$\Delta t = \frac{50}{450} \approx 0.111 \text{ sec}$$

b. Increase in aerodynamic drag due to the strap. While being carried along with the sled, the straps are fluttering violently in the air stream and produce a sizeable increase in aerodynamic drag of the sled-strap system. In the equation of motion

$$(4) \qquad m \frac{dV}{dt} + \left[c_D A + c_D A_{strap}\right] \frac{1}{2} \rho (V + V_w)^2 + c_F W = 0$$

the term $c_D A$ is applied to the drag area of the sled by itself. The term $c_D A_{strap}$ designates the apparent increase in drag area caused by the air drag of the straps themselves and by the interference drag generated by the straps in the vicinity of the sled flow field. While the drag area of a given set of straps can be expected to be essentially independent of the sled on which the strap is used, the interference drag depends strongly on the local geometry of the sled flow field and may vary from sled to sled.

SECTION III

TEST EQUIPMENT AND PROCEDURES

6. Sleds. Two vehicles were used to obtain the data in this report. The reason for using two vehicles was to see if differences in the effectiveness of drag straps could be detected on sleds having different weights and drags. The selection of the vehicles was dependent on two factors: (1) the drag of the vehicles had to be small, so that the drag of the strap would be significant combined with the drag of the vehicle itself, (2) the vehicle and propulsion cost had to be minimized. The selected vehicles are sled IMS 6303 (Figure 1) and sled IMS 6414 (Figure 2). Their essential characteristics are as follows:

Sled	Propulsion	Frontal area ft^2	Burnout weight lbs
IMS 6303	1 124-C	0.195	70
IMS 6303	1 HVAR	0.195	100
IMS 6414	1 Sparrow	0.42	100

Twelve runs were conducted in this series. Four of these runs (two with each vehicle) were control runs. The purpose of the control runs was to obtain accurate velocity versus distance profiles for the vehicles without straps. A pick up velocity of 500 feet per second was selected to stay within the structural limitations of the straps.

7. Straps. The type of drag strap used in the test series is shown in Figure 3. The strap is a 1-3/4 inch wide nylon strap with a tensile strength of 8700 pounds. As indicated in Figure 3 the strap was doubled. Each single strap is 50 feet long. A felt pad was sewn to the strap at the point where the strap engages the pick up hook (see Figures 1 and 2). The felt pad aided in the prevention of strap tearing at the pick up point. Also, as shown in Figure 3, a short connecting piece was sewn four inches aft of the strap midpoint to keep the strap from slipping off the pick up hook. One double strap weighs 7.25 pounds. The straps were suspended across the track in a support fixture (Figure 4) to be located above the rail at the proper height necessary to engage the sled pick up hook.

8. Data acquisition. The velocity data were acquired by permanently located ribbon frame cameras. The cameras are positioned 500 feet apart along the total length of the track and 1,040 feet east of the track. These cameras provide electro-optical position versus time data for preselected portions of the run. Sled velocities and accelerations are evaluated by numerical differentiation using digital computer routines, and tabulated versus time and distance.

9. Drag coefficient evaluation. A comparison of the aerodynamic drag force on the vehicle with and without straps is used to show the effectiveness of the straps. Since a suitable reference area could not be defined for the straps, the quantity to be compared is presented in the form of drag area ($c_D A$) rather than as drag coefficients. The following equation shows the comparison:

$$(5) \qquad c_D A_{strap} = c_D A_{sled + strap} - c_D A_{sled}$$

The drag coefficients of the sleds were determined during the free run phase, rewriting the equation of motion (4) in the form:

$$(6) \qquad c_D A = \frac{m \frac{dV}{dt}}{\frac{1}{2} \rho (V + V_w)^2} - \frac{c_F W}{\frac{1}{2} \rho (V + V_w)^2}$$

Since the wind velocity component (V_w) in the direction of sled motion was small during these tests, this term was neglected in the evaluation. It is further assumed that the friction force $F = c_F W$ is not affected by the drag straps in the velocity regime between pickup speed and approximately 100 ft/sec. In this case the friction terms will cancel out in evaluating the differences in drag area by equation (5). The tabulated acceleration data were severely scattered. This scatter is attributed to difficulties in defining exact sled positions on the ribbon frame films, and to the numerical differentiation methods used in the reduction process. Therefore, it was assumed that in the Mach number range of interest the drag coefficient is a slow varying function of Mach number, so that the term $\dot{V}/V^2$ can be replaced by constant average values within reasonable sized intervals ($V_1 > V > V_2$). This assumption allows expression of the equation (6) in the form:

$$(7) \quad c_D A = - \frac{m}{\frac{\rho}{2}} \frac{\dot{V}}{V^2} = \frac{m}{\frac{\rho}{2}} \frac{\frac{V_1 - V_2}{t_1 - t_2}}{V_1 V_2} = - \frac{m}{\frac{\rho}{2}} \frac{\ln \frac{V_1}{V_2}}{s_2 - s_1}$$

which is the equation used in the analysis. The foregoing drag coefficient evaluation is described more completely in reference 1.

10. An alternate method of evaluating the drag effectiveness of the straps is used to compare with the previous one. This method uses the equation of motion in the following form:

$$(8) \quad c_D A = \frac{W}{\frac{1}{2} \rho g} \frac{\frac{dV}{ds}}{V} - \frac{c_F g}{V^2}$$

For numerical evaluation the slope (dV/ds) is measured for selected velocities (V). The remaining terms in equation (8) are known with the exception of the friction coefficient, which is assumed as $c_F = 0.15$ in this velocity range in accordance with Figure 5-14 of reference 2.

SECTION IV

RESULTS AND DISCUSSION

11. Figure 5 presents sled velocity versus position for the sled IMS-6303 and shows the effect of the drag strap on the coast distance. The curves representing runs 104-2C, 104-2D and 104-2F before strap engagement have different slopes from those of run 104-2A and 104-2B. The variation in slope is due to the difference in burnout weight. The burnout weight for runs 104-2A and 104-2B was 70 pounds. The burnout weight of runs 104-2C, 104-2D and 104-2F was 100 pounds. A check of run 104-2F with runs 104-2C and 2D indicates that the engagement of two double straps does not greatly reduce the coast distance as compared to one double strap.

12. Figure 6 presents sled velocity versus position for sled IMS 6414 and shows the effect of drag straps on the coast distance. The data indicated in this figure are similar to those seen in Figure 5. The sled IMS 6414 which has a smaller ratio of weight to frontal area than the IMS 6303 has a shorter coast distance. This is indicated by the slight difference in the slopes.

13. Application of the alternate method of calculationg $c_D A$ previously described was made with values obtained from Figures 5 and 6. The values used and the resultant $c_D A$ are shown in Table 1, columns 6 through 10.

14. Figure 7 and 8 present the drag area $c_D A$ versus Mach number for the vehicles with and without drag straps. In the speed range in which the momentum exchange between sled and strap occurs, the data curve is interrupted, however, individual data points are indicated. In the speed range between approximately 500 ft/sec and 100 ft/sec the assumption is made that the drag area $c_D A$ and the friction coefficient c_F are both constant. With this assumption the drag area and the term F/q can be separated by an iteration process, which yields the drag areas indicated in columns 13, 14, and 15 in Table 1. The $c_D A$ values obtained on the IMS 6303 from Figures 5 and 6 compared to the $c_D A$ values obtained from figures 7 and 8 indicate that the actual $c_D A$ of one double nylon drag strap is in the order of one square foot. This value may be superimposed on monorail vehicles to approximate the effect of one double nylon drag strap as described on the vehicle under investigation. Both evaluation methods indicate that the $c_D A$ of the strap is higher on the IMS 6414 than

on the IMS 6303. An explanation for this apparent increase in drag strap $c_D A$ cannot be made from the available information.

15. Figure 9 shows the drag coefficient at higher Mach numbers for the vehicles tested. The general characteristics of these curves are typical of bodies of this type traveling in this Mach number range on the Holloman track.

SECTION V

CONCLUSIONS

16. The engagement of one double strap at 500 feet per second by a sled weighing 70 pounds and having a frontal area of .195 ft^2 reduces the coast distance by 75%. The engagement of one double strap at 500 feet per second by a sled weighing 100 pounds and having a frontal area of .41 ft^2 reduces the coast distance by 70%.

17. The engagement of two double straps does not significantly reduce the coast distance as compared to the engagement of one double strap.

18. The drag area $c_D A$ of a monorail sled is increased in the order of one square foot by the engagement of one double drag strap.

REFERENCES

1. Rasmussen, Hans J., Aerodynamic Measurements on Two Rocket Sleds on the Holloman Track Compared with Theory and Wind Tunnel Results, AFMDC-TR-60-22, unclassified

2. Rocket Sled Design Handbook, ISTRACON Technical Report 60-1, December 1961, unclassified

BIBLIOGRAPHY

Morgan, A.J.A. and Oliver, R.E., A Study of Various Braking Methods for Rocket Test Sleds, AER Inc Technical Report

Mullins, Peter L. and Schwinge, Heinz T., Development of Monorail Sleds on the Holloman Track from January through June 1958, AFMDC-TN-59-3, unclassified

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Run Number	Sled Number	Burnout Weight	Frontal Area	Number Straps	At 500 ft/sec No Straps	At 250 ft/sec With Straps	Sled	Sled and Strap	Strap	Strap Pick Up Speed	Coast Distance*	Sled	Sled and Strap	Strap
		W	A		$\frac{dV}{ds}$	$\frac{dV}{ds}$	c_DA	c_DA	c_DA		s	c_DA	c_DA	c_DA
		lbs	ft^2		sec^{-1}	sec^{-1}	ft^2	ft^2	ft^2	ft/sec	ft	ft^2	ft^2	ft^2
104-2A	6303	70	.195	0	.0360	---	.115	---	---	---	10,200	.080	---	---
104-2B	6303	70	.195	0	.0333	---	.102	---	---	---	10,200	.080	---	---
104-2C	6303	100	.195	1	.0233	.110	.085	1.206	1.121	450	2,900	.080	1.080	1.00
104-2D	6303	100	.195	1	.0233	.110	.085	1.206	1.121	440	3,080	.080	1.080	1.00
7X-B8	6303	70	.195	1	.0360	.145	.115	1.215	1.099	480	2,100	.080	1.080	1.00
7X-B9	6303	70	.195	1	.0360	.145	.115	1.215	1.099	510	2,500	.080	1.080	1.00
7X-C1	6414	100	.42	0	.045	---	.219	---	---	---	9,900	.20	---	---
7X-C2A	6414	100	.42	0	.045	---	.219	---	---	---	9,900	.20	---	---
7X-C3A	6414	100	.42	1	.045	.147	.219	1.67	1.45	515	2,800	.20	1.47	1.27
104-2F	6303	100	.195	2	.0233	.150	.085	1.85	1.765	445	2,100	---	---	---

*from 500 ft/sec or pick up of drag straps

TABLE 1 Data and numerical results

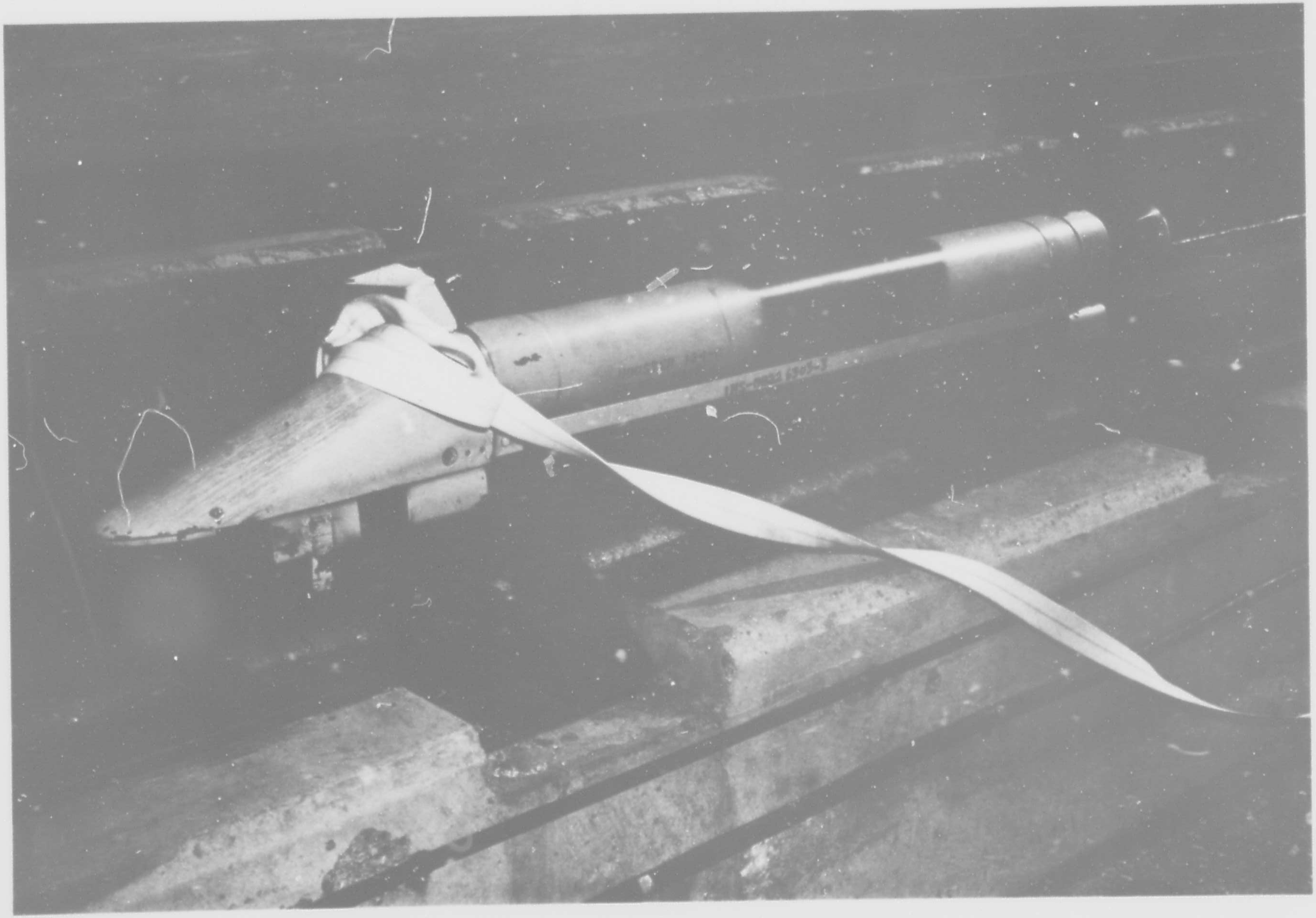


Figure 1   Monorail Sled TMS 6303

Figure 2 Monorail Sled IMS 6414

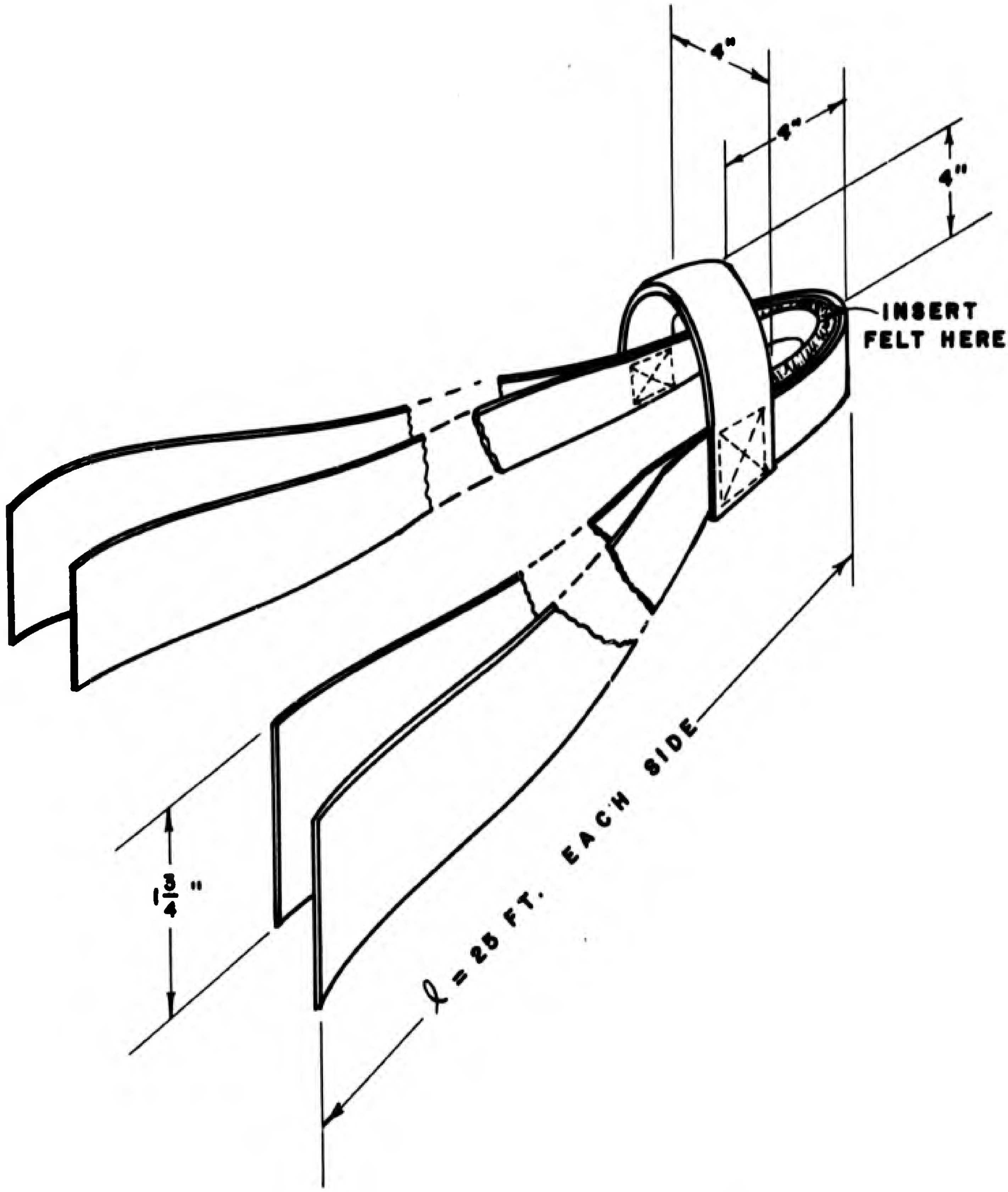


FIGURE 3 DOUBLE NYLON DRAG STRAP

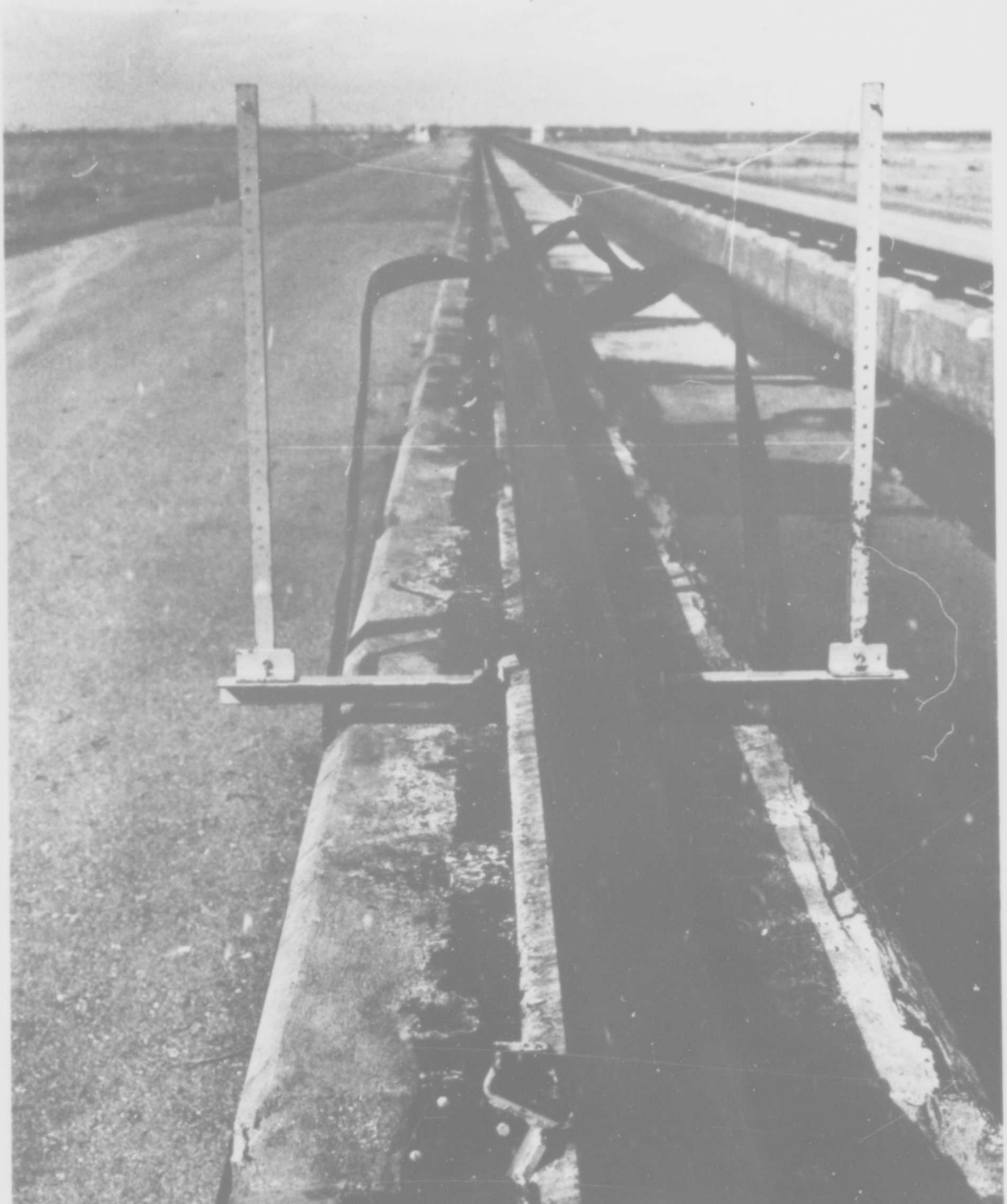


Figure 4   Drag Strap Support Fixture

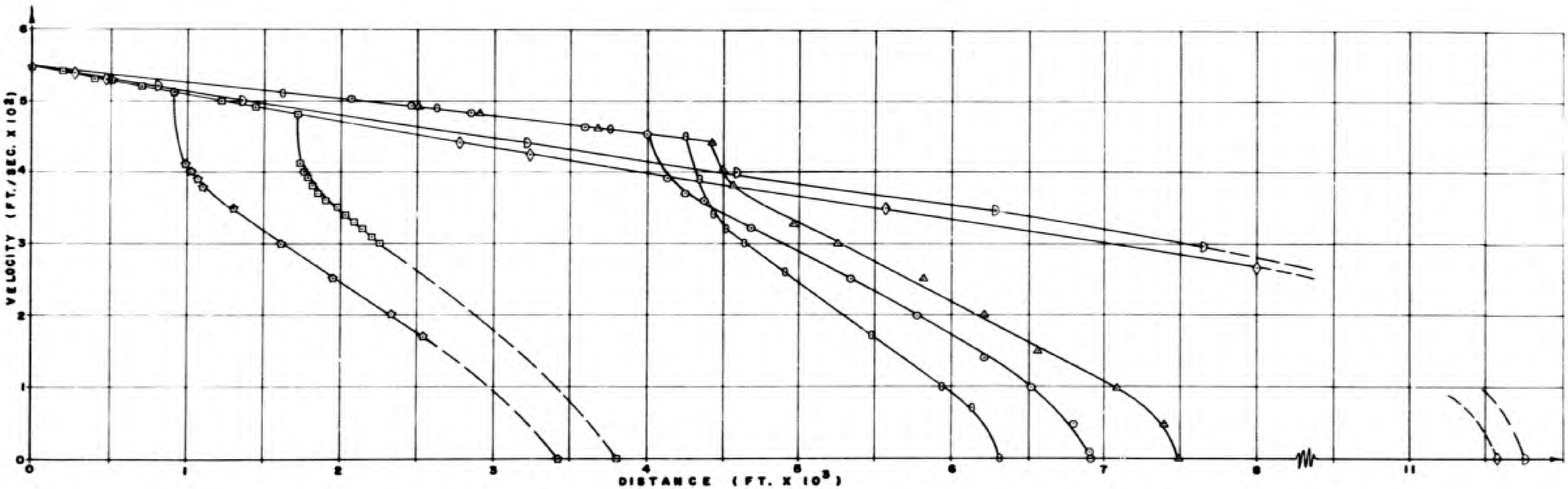


FIGURE 5 VELOCITY VERSUS DISTANCE FOR THE IMS 6303

◇ — 104-2A (CONTROL RUN, NO STRAP)
D — 104-2B (CONTROL RUN, NO STRAP)
⊙ — 104-2C (ONE DOUBLE STRAP)
△ — 104-2D (ONE DOUBLE STRAP)
θ — 104-2F (TWO DOUBLE STRAPS)
⊡ — 7XB8 (ONE DOUBLE STRAP)
☆ — 7XB9 (ONE DOUBLE STRAP)

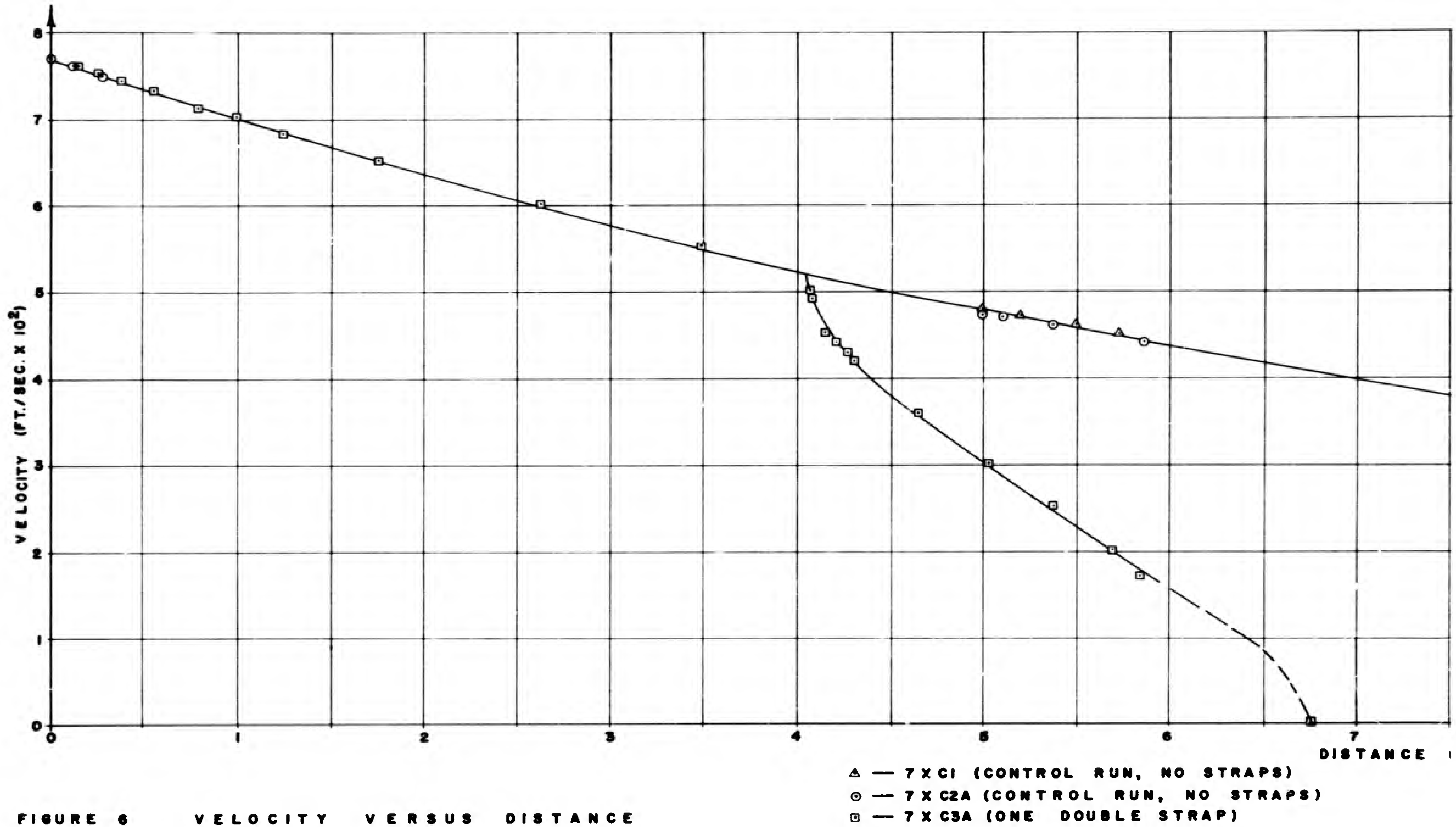
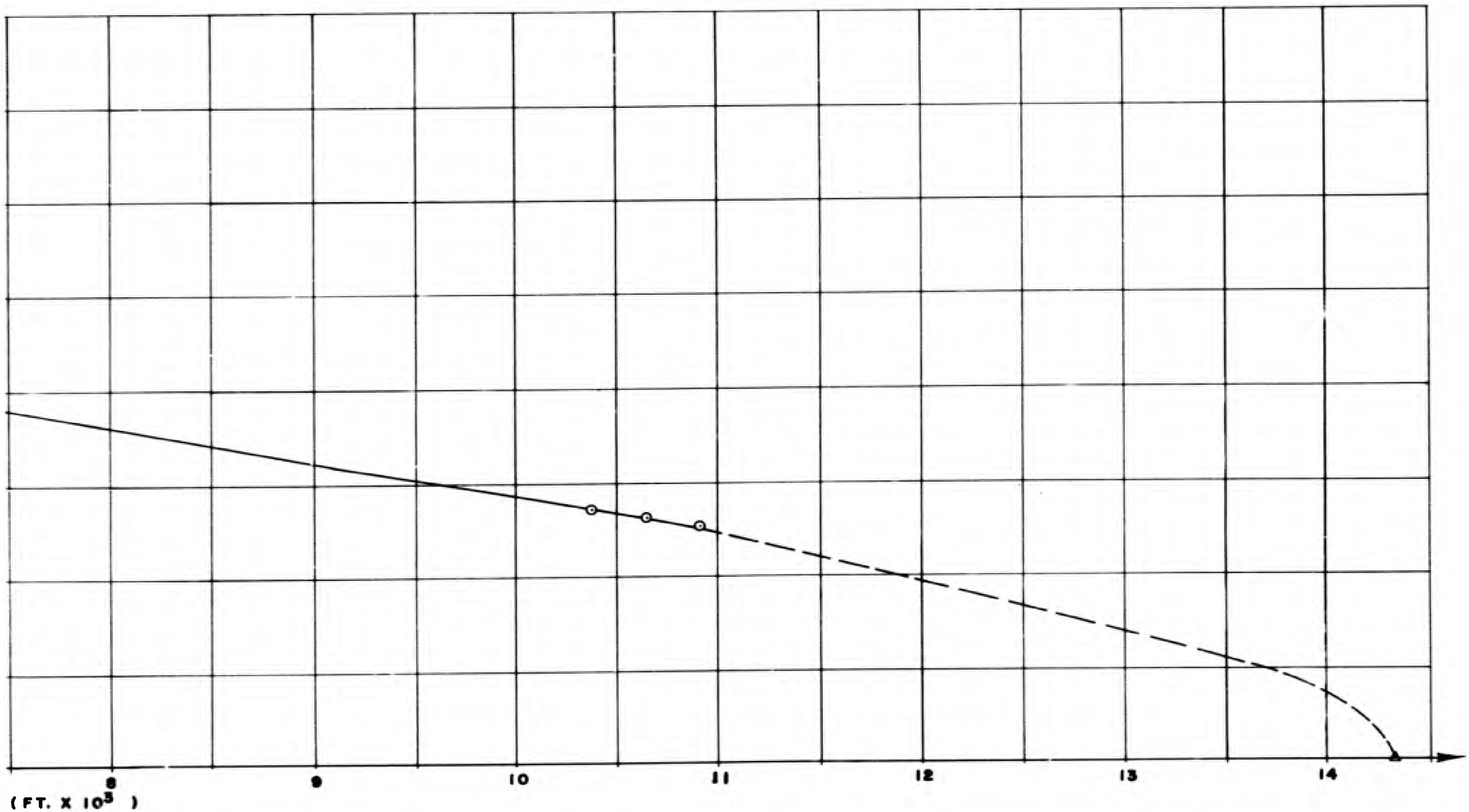


FIGURE 6 VELOCITY VERSUS DISTANCE FOR THE IMS 6414


8
9
10
11
12
13
14
(FT. X 10^3)

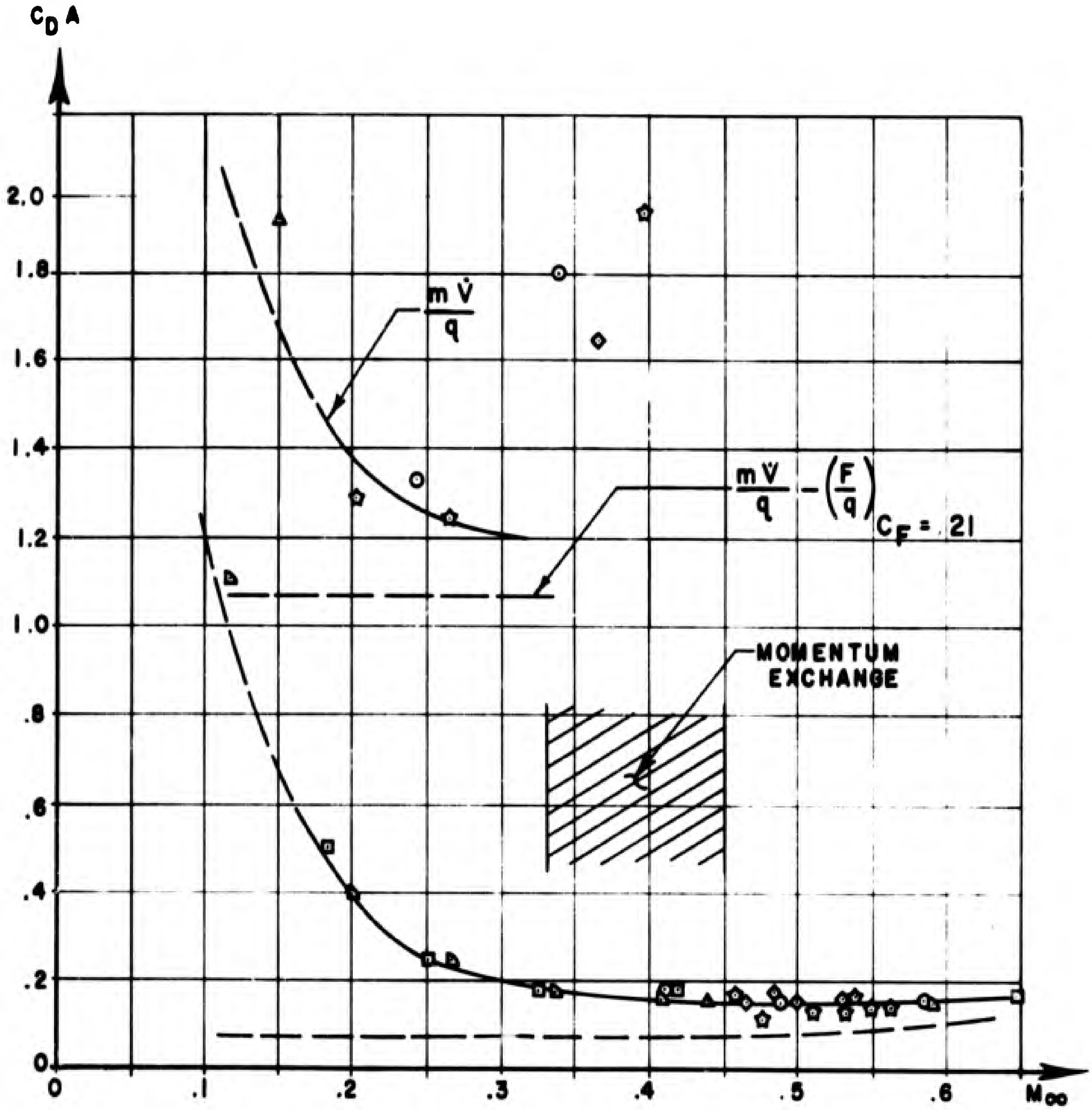


FIGURE 7 C_DA VERSUS MACH NUMBER FOR THE IMS 6303 WITH AND WITHOUT STRAP PICKUP

□ — 104-2A (CONTROL RUN, NO STRAP)
D — 104-2B (CONTROL RUN, NO STRAP)
○ — 104-2C (ONE DOUBLE STRAP)
△ — 104-2D (ONE DOUBLE STRAP)
◇ — 7XB8 (ONE DOUBLE STRAP)
✩ — 7XB9 (ONE DOUBLE STRAP)

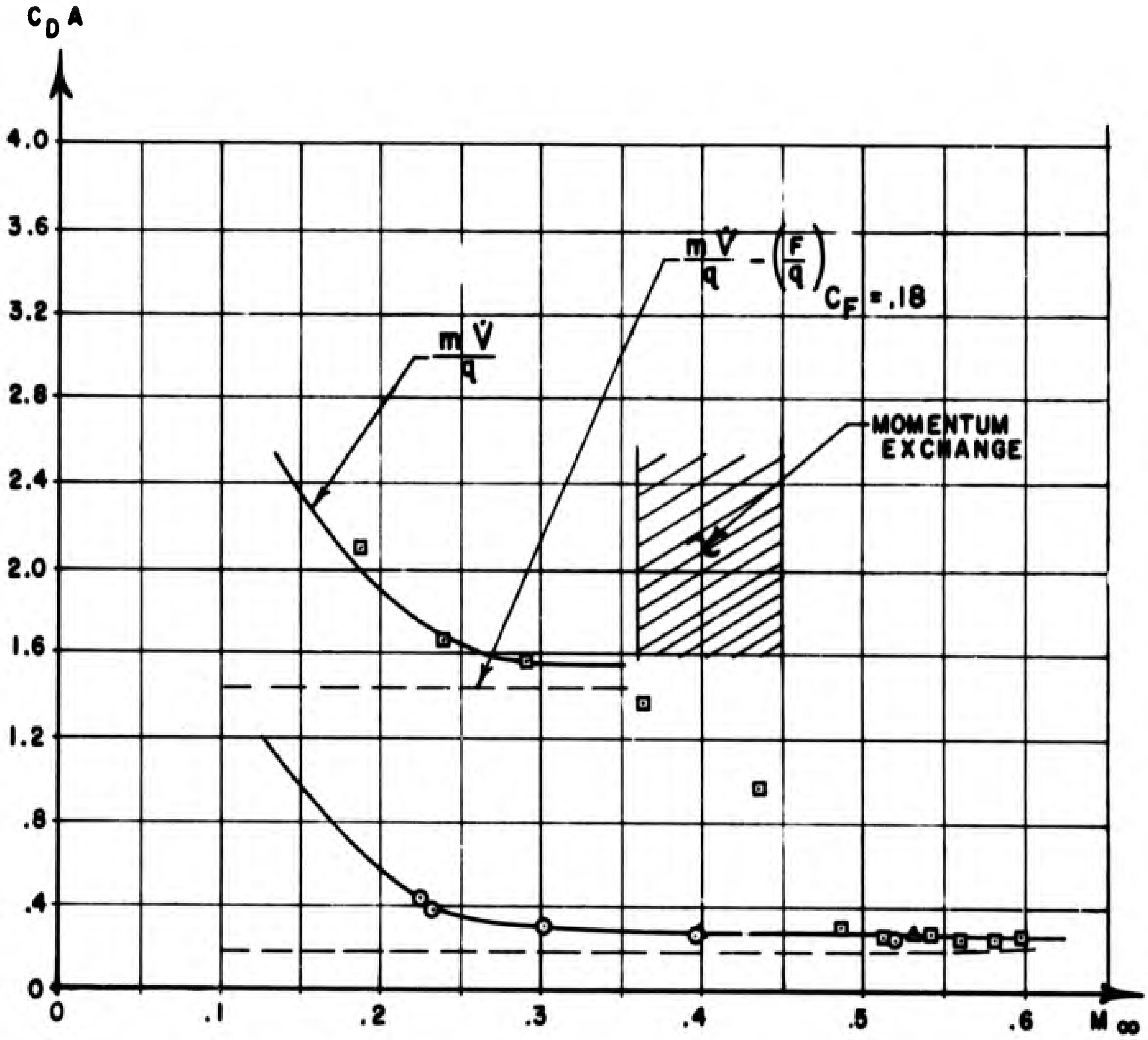


FIGURE 8 $C_D A$ VERSUS MACH NUMBER FOR THE IMS 6414 WITH AND WITHOUT STRAP PICKUP

▲ — 7XC1 (CONTROL RUN, NO STRAP)
○ — 7X C2A (CONTROL RUN, NO STRAP)
□ — 7X C3A (ONE DOUBLE STRAP)

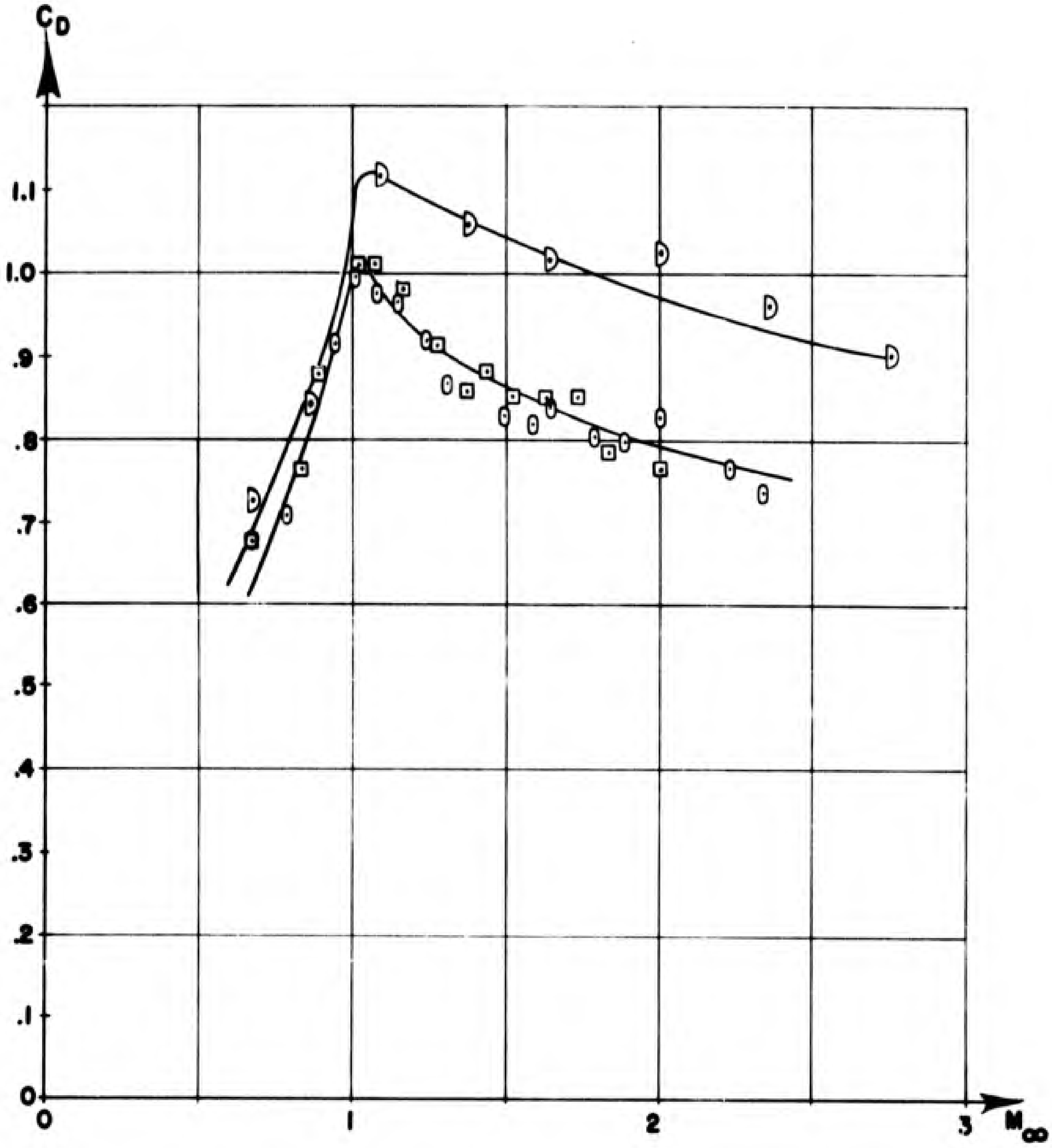


FIGURE 9 DRAG COEFFICIENT OF THE IMS 6303 AND IMS 6414 VERSUS MACH NUMBER

D — SLED IMS 6303 (REF. AREA - .195 FT^2)

□ & θ — SLED IMS 6414 (REF. AREA - .42 FT^2)

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) AFMDC (MDT) Holloman AFB, NMex 88330	2a REPORT SECURITY CLASSIFICATION Unclassified 2b GROUP

3 REPORT TITLE

Effectiveness of Nylon Drag Straps for Braking Monorail Sleds

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

N/A

5 AUTHOR(S) (Last name, first name, initial)

Krupovage, Daniel J.

6 REPORT DATE	7a TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1966	20	2

8a CONTRACT OR GRANT NO. b. PROJECT NO. c d.	9a ORIGINATOR'S REPORT NUMBER(S) MDC-TR-66-23 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) N/A

10 AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Directorate of Test Track (MDT) Holloman AFB, NMex 88330

13 ABSTRACT

Velocity versus coast distance measurements on two monorail rocket sleds were conducted on the Holloman track to obtain numerical information on the braking effectiveness of nylon drag straps. The data were obtained from ribbon frame camera readings and reduced to the form of drag area ($c_D A$) of the sleds and the drag straps. The straps as described are shown to increase the effective drag area of the monorail sleds used by approximately one square foot and to be an effective means for reducing recovery distance in the speed range velow approximately 700 ft/sec.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Nylon drag straps Monorail sleds Recovery Braking technique						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional

GPO 886-551

Unclassified

Security Classification