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DEVELOPMENT OF CURVES FOR ESTIMATING AIRCRAFT ARRESTING HOOK LOADS

BY

LYLE W. JONES

SYSTEMS ENGINEER

JULY 1982

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AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
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This Technical Information Memorandum was written to provide AFFTC engineers with a reliable, accurate method for predicting maximum aircraft arresting hook loads based on a knowledge of aircraft weight and groundspeed at the moment of cable engagement. Possible causes of excessive data dispersion are discussed and guidelines for minimizing dispersion are provided. Families

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) of curves relating hook load and groundspeed which fit BAK-12ER and BAK-13 arresting system test data are derived and confidence intervals are applied. The information provided in this TIM will be of interest to those involved with the design, fabrication, testing and/or operation of aircraft arresting systems.

PREFACE

This document investigates the apparently excessive deviation existing in arresting hook load data. Families of curves which fit hook load data from the BAK-12ER and BAK-13 aircraft arresting systems are derived and confidence intervals are applied. Procedures are established which should aid in reducing the magnitude of data deviations during future testing.

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-106 ... Engaging the BAK-13 Barrier During Compatibility
... Air Force Base, California

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INTRODUCTION

BACKGROUND

Most U.S. Air Force aircraft, in the fighter and attack categories, are equipped with arresting hooks. The hooks are for use in stopping the aircraft during takeoff or landing emergencies by engaging a pendant (cable) which is stretched across the runway. The cable is attached by nylon tapes to arresting engines (energy absorbers) on opposite sides of the runway. The combination of cable, tapes, and arresting engines is called a "runway arresting system." It is better known as a "barrier" and will be referred to as such in this document.

As new aircraft enter the Air Force inventory, their compatibility with commonly used barriers must be determined. Conversely, as new barriers are introduced they must be evaluated with all hook-equipped aircraft.

The process of evaluating aircraft/barrier compatibility requires aircraft to be arrested under controlled conditions. Arrestments are generally conducted both on and off the runway centerline at low, medium, and high aircraft weights[1] and at groundspeeds increasing from approximately 60 knots in 10 knot increments. Testing is terminated when a structural load limit is approached, such as tail hook tensile load or landing gear vertical or side load, or when the aircraft rotation speed is reached.

This Technical Information Memorandum presents in detail some solutions to the problems encountered during barrier compatibility testing.

OBJECTIVES

The objective of this TIM was to document the results of a study which was conducted to:

1) Develop a curve fitting routine which will, with reasonable conservatism, generate a family of curves relating maximum hook load (the dependent variable) to aircraft engagement groundspeeds for a range of aircraft weights.

[1]Henceforth in this document 'weight' infers gross weight unless otherwise specified.

2) Develop a method for barrier data analysis which will predict, with a predetermined level of confidence, the critical arrestment groundspeeds based on a knowledge of barrier type, aircraft weight, and arresting hook design load limit.

3) Identify types and sources of error which are responsible for the inordinate amount of deviation intrinsic in the barrier data which have been collected at the AFFTC.

BARRIER TESTING

BARRIER DESCRIPTIONS

The Aircraft Arresting System Test Facility at the AFFTC, shown in figure 1, is equipped with the Air Force's two most commonly used barriers; the BAK-12 and the BAK-13, shown schematically in figure 2. The BAK-12 is widely used on military airfields throughout the Continental U.S., whereas the BAK-13 is used mostly at United States air bases in Europe and the Far East. Most U.S. Air Force hook-equipped aircraft have been evaluated for compatibility with each of these barriers.

The two barrier systems each convert the kinetic energy of the arrested aircraft into heat energy; the BAK-12 through mechanical friction and the BAK-13 through a liquid turbine.

The standard BAK-12 can be configured for best performance with either 40,000 or 50,000 pound aircraft, through a combination of internal adjustments and changes in amount of tape stored on each arresting engine. The standard BAK-12 utilizes 950 feet of tape.

The unit currently in use at the AFFTC is known as an "extended runout" version of the BAK-12 and is designated the BAK-12ER. It has 1,200 feet of tape and is designed for best performance with aircraft weighing approximately 40,000 to 60,000 pounds. It has demonstrated the capability to arrest aircraft weighing from 18,000 to 90,000 pounds without damage to itself or the aircraft.

The BAK-13 is more efficient in dissipating heat than the BAK-12ER. Although it has only 950 feet of tape it performs best with aircraft weighing approximately 40,000 to 70,000 pounds. It has also successfully arrested aircraft weighing from 18,000 to 90,000 pounds. Because of the shorter runout, BAK-13 hook loads are greater than those generated by the BAK-12ER for a given aircraft kinetic energy.

Both the BAK-12ER and the BAK-13 have a maximum capacity of 85 million foot-pounds. Each can arrest a 53,000 pound airplane at 190 knots maximum groundspeed, or an 80,000 pound airplane at 150 knots maximum groundspeed.

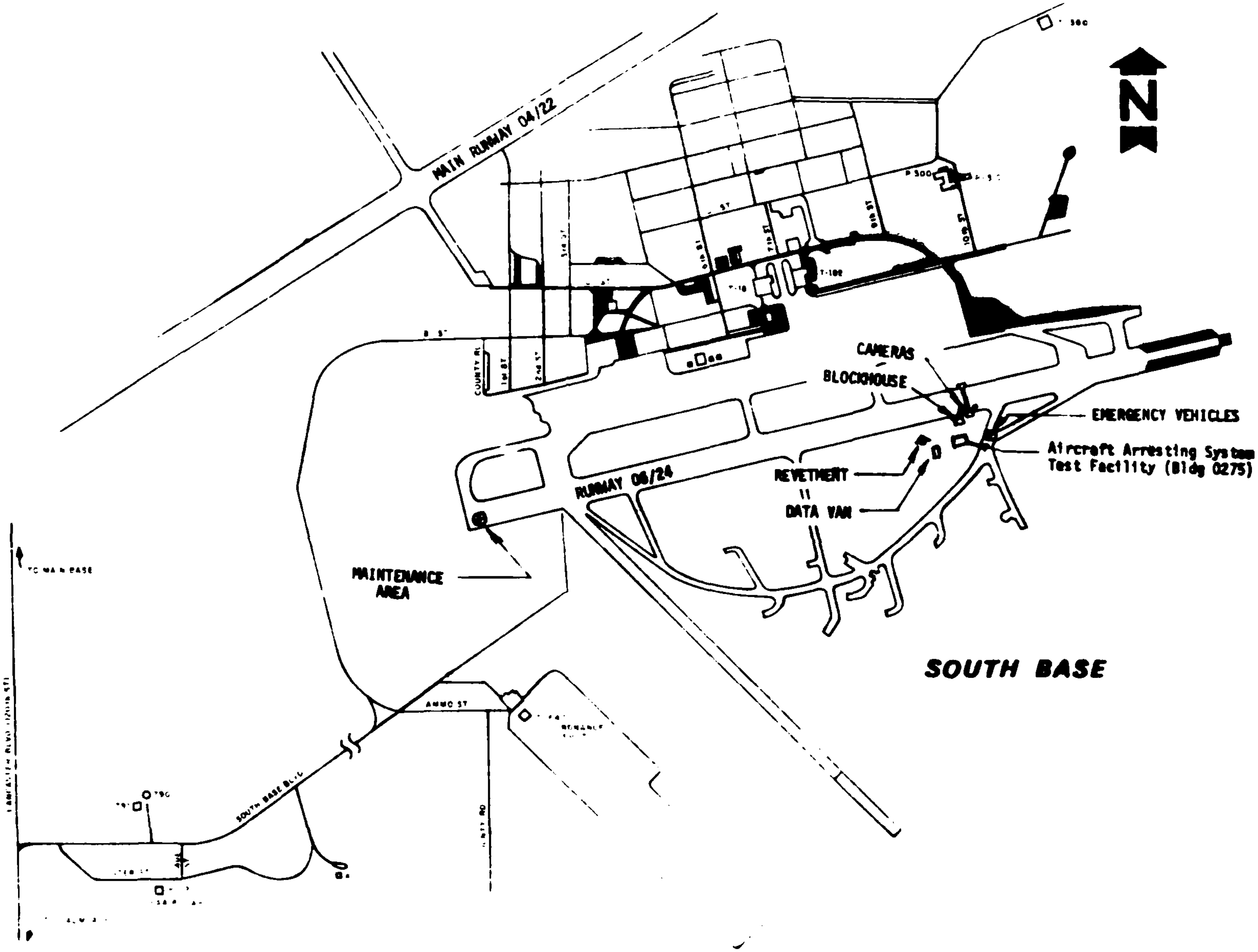
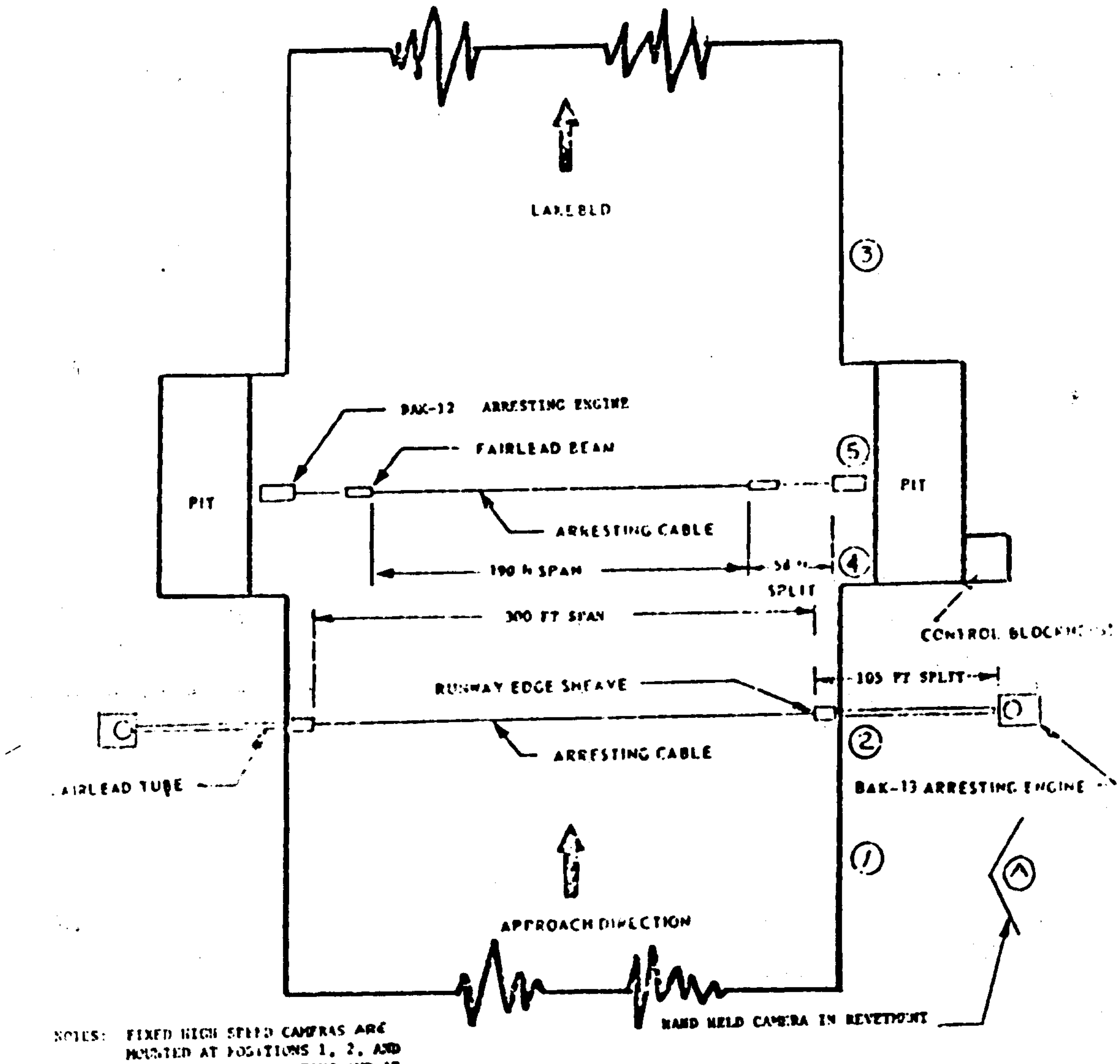


Figure 1 Map of the Arresting System Test Facility



NOTES: FIXED HIGH SPEED CAMERAS ARE MOUNTED AT POSITIONS 1, 2, AND 3 DURING BAK-13 TESTING AND AT POSITIONS 3, 4, AND 5 DURING BAK-12FK TESTING

THE BAK-12FK INSTALLATION IS REMOVED FOR BAK-13 TESTING

Figure 2 BAK-12 and BAK-13 Arresting System Installations

Best performance in these barriers is developed when the hook load is nearly constant during the steady braking part of the runout. Figure 3 shows typical histories of aircraft hook loads at low, medium, and high weights versus runout distances. The areas under the curves represent the energy absorbed by the barrier. The peak amplitude of the hook load is a function of the aircraft groundspeed and the point in the runout at which it is developed is a function of the aircraft weight. It is important to note that the groundspeeds referred to are engagement speeds. During the time period between cable engagement and the onset of maximum braking, some aircraft velocity is lost. This is accounted for in the energy required to accelerate the arresting engines, stretch the tapes, etc. An exception to this is the case of light aircraft such as the F-5, wherein the maximum hook load may occur at the instant of cable impact.

AIRCRAFT/BARRIER COMPATIBILITY

Compatibility between an aircraft and a barrier can be defined as the quality that allows them to interact harmoniously. The extent of this harmony can be expressed through the severity of the limitations that the barrier imposes on the aircraft arrestment conditions. Complete compatibility would require that the aircraft be capable of being arrested at any operational combination of weight and groundspeed within the kinetic energy limit of the barrier, within the load limit of the tail hook, and at any distance from the centerline of the runway up to 20 percent[2] of the barrier cable length. The most frequently encountered barrier-imposed limitations involve the arresting hook (tail hook) and nose landing gear structures.

Typical Test Approach:

The test aircraft is usually equipped with instrumentation for recording tail hook and nosegear loads and other critical parameters during arrestment tests. The data is also telemetered to a ground station where it is displayed in real time on strip chart recorders for comparison with tail hook and nosegear design load limits. The purpose of the tests is the determination of the arrestment conditions under which these limits are approached.

As testing proceeds the maximum hook loads obtained are plotted against the corresponding engagement groundspeeds. An approximating curve is drawn through the resulting

[2]From Military Specification MIL-A-83136, paragraph 4.3.3.1. (reference 11)

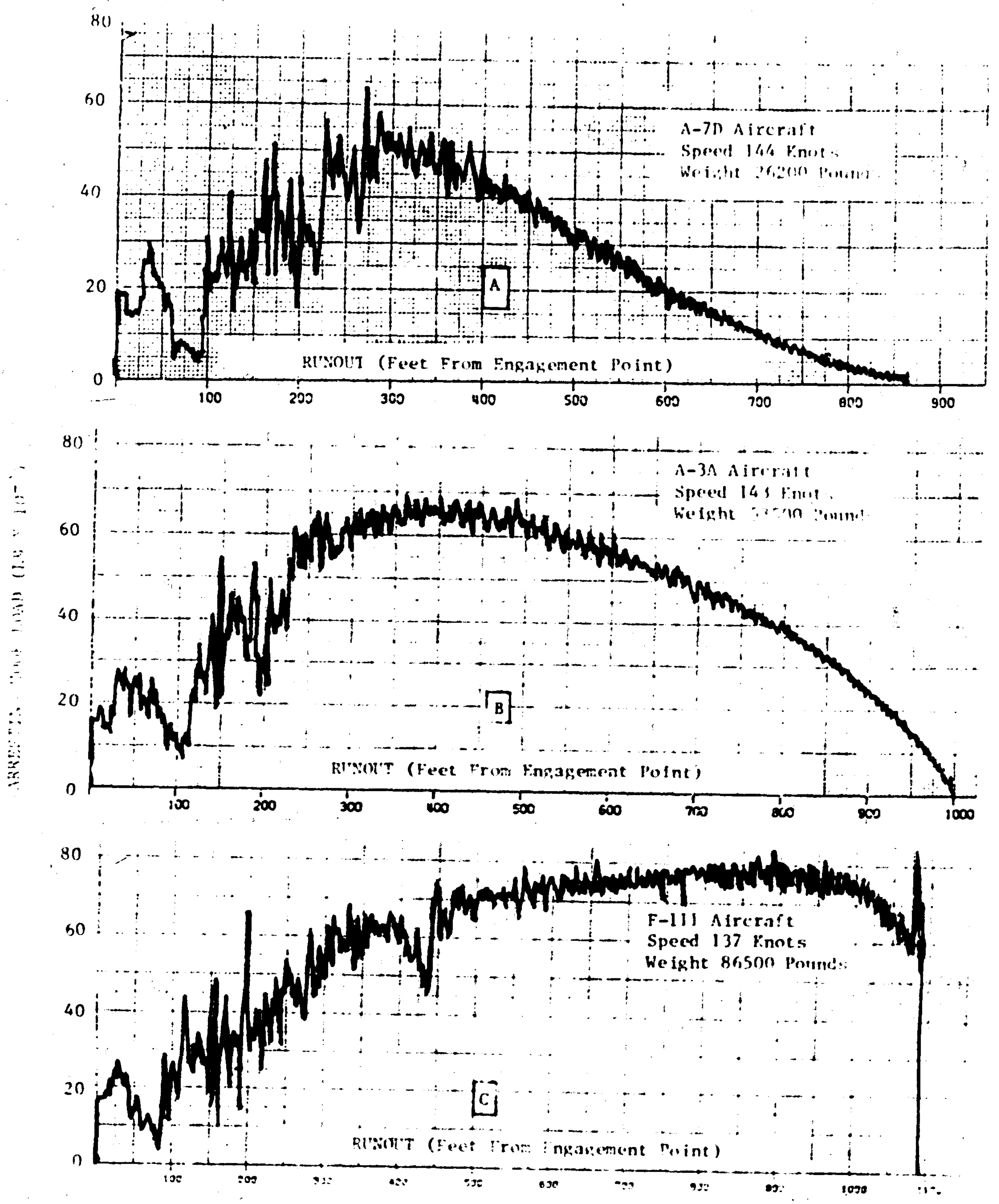


Figure 3 Typical Hook Load/Runout Histories of Aircraft Arrestments : A) Low Aircraft Weight B)Optimum Aircraft Weight C) High Aircraft Weight

scatter diagram and extrapolated through the hook design load limit. The groundspeed at which the curve crosses the hook design load limit is tentatively taken as the hook limit speed.

The above procedure is not always satisfactory because of uncertainty involved in constructing the approximating curve. There is a large amount of deviation in arresting hook load data, and the number of data points obtained at each test condition is seldom greater than approximately ten. This is the number of test runs generally required to cover the build-up in ground speed from approximately 60 knots to the hook limit speed.

After the testing is completed and all the hook load/velocity data have been reduced they are analyzed more thoroughly. To avoid individual judgement in curve fitting the method of least squares is used. Various equations for approximating curves are written, each of which is fitted to the data in the least square sense. The correlation coefficient, which indicates the degree of association between the dependent and independent variables, (estimated from the regression line) is then determined for each of the equations. The equation for the curve having the correlation coefficient with the highest absolute value is, by definition, the one best correlated with the data. A confidence interval estimate, which is a function of the standard deviation of the data about the regression line (curve), is then calculated. It has dimensions of hook load (pounds) and defines bounds above and below the regression line. If we assume the data distribution is normal, the upper and lower bounds of the 90-percent confidence interval are determined by multiplying the standard deviation by 1.645[3]. Then, for approximately normal distribution, we can expect to find a hook load/velocity data point lying within the confidence interval 90-percent of the time.

Shortcomings:

Curves relating hook load and groundspeed derived by the above method have some inherent shortcomings.

1) They are excessively conservative.

2) They do not "family" on an aircraft weight basis.

[3]The confidence coefficient for a confidence level of 90% is 1.645. (From Schaums Outline Series of Statistics, Chapter 9, page 157)

3) The confidence interval has a constant width which infers that the standard deviation is constant along the length of the curve.

Shortcoming number one results from too small a sample size. Normal data distributions usually have a sample size of at least 30.

Shortcoming number two exists because each of the curves in the weight family is generated by a different equation. As the constants in the equations are changed the slope of the line (or the shape of the curve) changes in such a way that it sometimes intersects adjacent members of the family.

Shortcoming number three comes about because the confidence interval estimate, although correctly determined, is incorrectly applied. The standard deviation used in determining the confidence interval estimate refers to the deviation of hook load samples with respect to the mean hook load, which is at the centroid of the scatter diagram. The part of the hook load curve of greatest interest is the region where it crosses the design limit hook load. This is generally in the high speed region of the curve, far removed from the data centroid.

BARRIER DYNAMICS

Aircraft arrestment by these barriers consists of three events; cable engagement, barrier acceleration, and aircraft deceleration. Cable engagement and barrier acceleration constitute the "dynamic" portion of the arrestment during which the barrier reels are accelerated and the cable and tapes are stretched. Following the dynamic period the barrier applies a steady (ideally constant) braking force on the airplane. However, the barrier is velocity sensitive and the aircraft's groundspeed at the beginning of the steady braking period determines the magnitude of the hook load. Heavier aircraft lose less velocity during the dynamic period than light aircraft and hence develop a greater maximum hook load for a given engagement speed. As tape is unwound from the barrier reels the moment-arm through which the arresting force is applied decreases. If the aircraft groundspeed is still high at this point, as would be the case with a heavy aircraft such as the F-111, the arresting force (and hook load) increases. The result is a hook load runout history similar to that shown in figure 3c.

Both aircraft weight and velocity are factors influencing arresting hook loads. However, without a complete analysis of the physics of the problem, the forms that they should take in a hook load equation are not obvious.

THE HOOK LOAD EQUATION

The most promising approach to the first two objectives was to develop individual equations that would best fit the hook load/groundspeed data from each of the three barriers, the standard BAK-12, the BAK-12ER, and the BAK-13. The first step in this process was to assemble all of the data.

ASSEMBLING THE DATA

At the time of this study there existed a large quantity of data from past AFFTC barrier compatibility programs. There were data from 545 test runs with the BAK-13; 121 test runs with the BAK-12ER, and 96 test runs with the standard BAK-12. The BAK-12ER and BAK-13 data are shown in figures 4 and 5 in the form of scatter diagrams. These data were published in AFFTC Technical Reports subsequent to the conclusion of each test program (see bibliography). Data pertinent to this study were taken from the reports and transferred to punched cards, one card for each data point (test run). Computer printouts of the data used in this study are shown in tables 1 and 2.

Identification of Errors:

During the process of assembling the data, it became obvious that there was an inordinate amount of dispersion in the hook load data. In order to obtain some insight into the possible causes for the dispersion, the appropriate AFFTC Technical Reports were researched. The research revealed some inconsistencies in data reduction methods and some apparent instrumentation anomalies. The data were carefully edited and only verifiable data were retained.

During this editing process, it became evident that much of the data dispersion was random in nature and therefore self-cancelling. For each test point that deviated on the low-side, there was one on the high-side. These compensating errors were unavoidable.

Systematic errors became evident too. In examining the test reports, it was discovered that the rules for interpreting data were not consistent. In some cases, the effective values of the hook load were read and in other cases the peak loads were read. In some barrier compatibility programs, the aircraft onboard data system introduced errors by having too low a data sampling rate

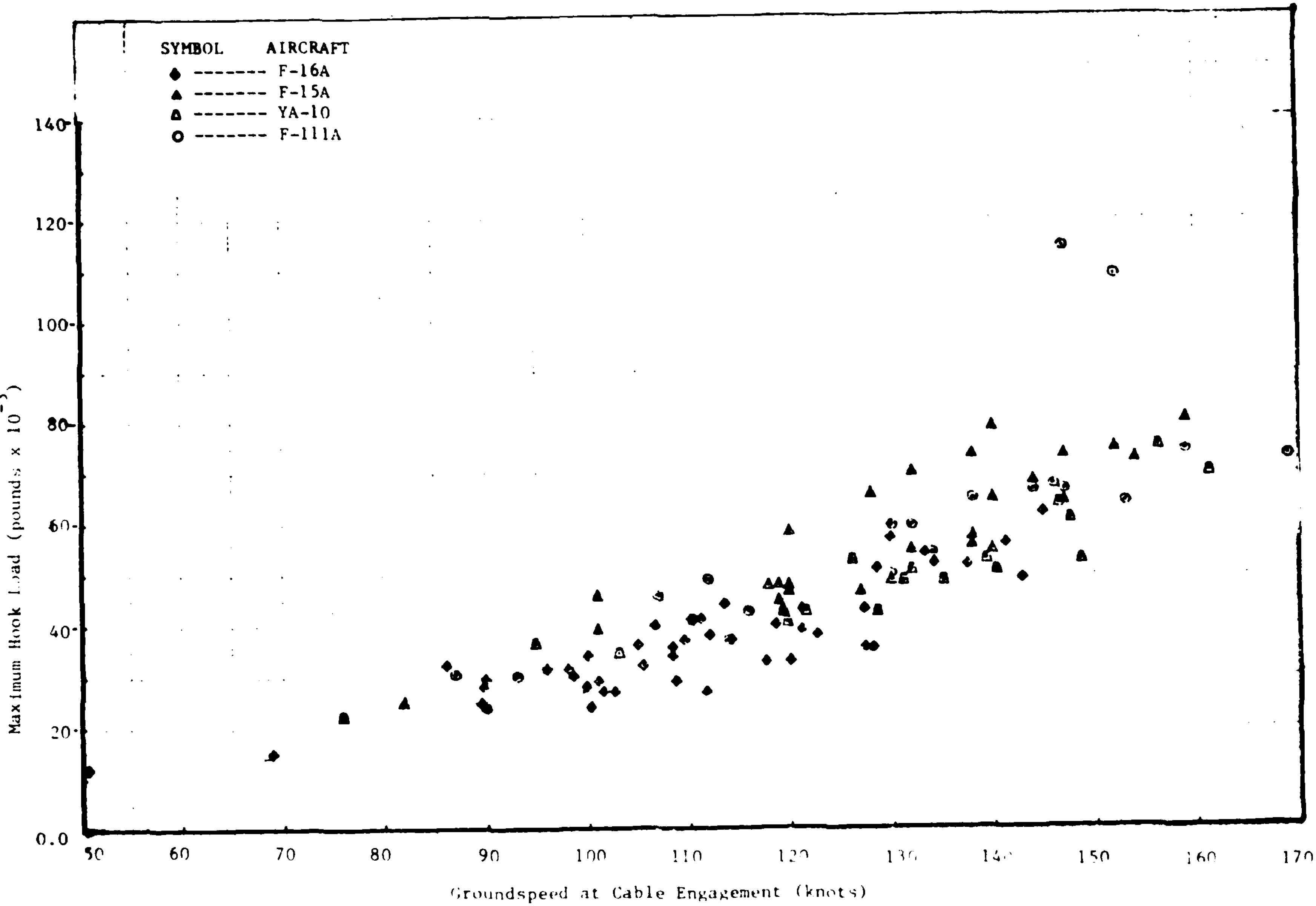


Figure 4 Scatter Diagram of BAK-12ER Barrier Data

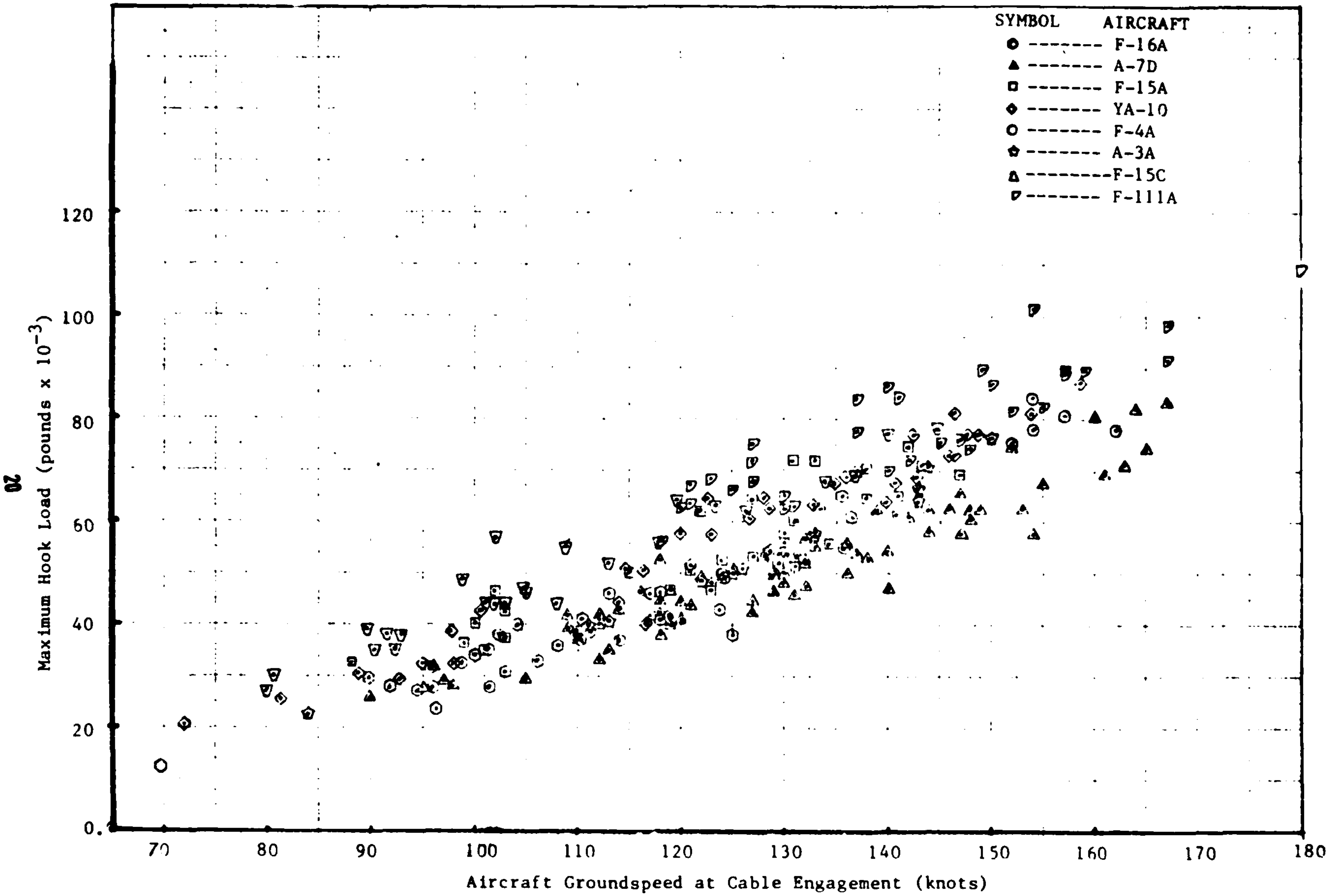


Figure 5 Scatter Diagram of BAK-13 Barrier Data

Table 1

SUMMARY OF BAK-12 (EXTENDED RUNOUT) ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
F-15A	34000	32600	54600	140.0	50	76-5	58
F-15A	34000	33000	48700	130.0	0	76-5	52
F-15A	34000	33300	54600	132.0	50	76-5	57
F-15A	34000	33700	47700	120.0	0	76-5	51
F-15A	40000	36700	80500	159.0	0	76-5	62
F-15A	40000	37400	68400	144.0	0	76-5	50
F-15A	40000	37700	74800	152.0	0	76-5	61
F-15A	40000	37900	69900	132.0	50	76-5	[illegible]
F-15A	40000	38400	57300	138.0	0	76-5	49
F-15A	40000	38700	47700	118.0	50	76-5	54
F-15A	40000	38800	46500	120.0	0	76-5	46
F-15A	54000	52000	72600	154.0	0	76-5	45
F-15A	54000	52200	46500	127.0	50	76-5	42
F-15A	54000	52500	47900	119.0	50	76-5	41
F-15A	54000	52600	44700	119.0	0	76-5	35
F-15A	54000	53500	25000	82.0	0	76-5	34
F-15A	54000	53500	64300	147.0	0	76-5	44
F-15A	54000	53600	76900	140.0	0	76-5	37
F-15A	54000	53700	39100	101.0	50	76-5	40
F-15A	54000	54300	65700	128.0	0	76-5	36
F-15A	54000	54300	64700	140.0	0	76-5	38
F-15A	54000	54500	55600	138.0	50	76-5	43
F-15A	54000	54700	45600	101.0	35	76-5	39
F-16A	18500	17400	49000	142.9	0	80-7	44
F-16A	18500	17900	33000	120.1	0	80-7	43
F-16A	18500	18200	35600	127.4	50	80-7	49
F-16A	18500	18300	27000	111.7	0	80-7	42
F-16A	18500	18400	35500	128.2	35	80-7	46
F-16A	18500	18400	32800	117.7	50	80-7	48
F-16A	18500	18700	24000	100.3	0	80-7	41
F-16A	18500	18800	27000	102.6	35	80-7	45
F-16A	18500	18900	27000	101.5	50	80-7	47
F-16A	26500	23600	43000	121.2	0	80-7	16
F-16A	26500	24400	44000	113.6	0	80-7	15
F-16A	26500	24900	32000	105.5	0	80-7	14
F-16A	26500	25500	30000	98.5	50	80-7	25
F-16A	26500	25500	28000	89.7	0	80-7	13
F-16A	26500	26000	56000	141.3	0	80-7	18
F-16A	26500	26200	62000	144.5	35	80-7	24
F-16A	26500	26300	54000	133.3	50	80-7	28
F-16A	26500	26400	52000	134.2	35	80-7	23
F-16A	26500	26400	39800	106.7	35	80-7	21
F-16A	26500	26500	37000	109.6	0	80-7	5
F-16A	26500	26600	36000	105.0	35	80-7	20
F-16A	26500	26900	41000	110.2	0	80-7	17

Table I

(Continued)

SUMMARY OF BAK-12 (EXTENDED RUNOUT) ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
F-16A	26500	26900	15000	68.9	0	80-7	2
F-16A	26500	27000	40000	118.7	0	80-7	82
F-16A	26500	27100	43000	127.3	50	80-7	27
F-16A	26500	27100	29000	101.0	0	80-7	4
F-16A	26500	27100	32200	86.2	0	80-7	11
F-16A	26500	27200	35600	108.4	25	80-7	19
F-16A	26500	27300	29000	108.7	50	80-7	26
F-16A	26500	27600	12000	50.7	0	80-7	1
F-16A	26500	27700	25000	89.5	0	80-7	3
F-16A	34000	32000	41000	110.5	0	80-7	9
F-16A	34000	32400	31500	95.9	0	80-7	6
F-16A	34000	32900	29500	89.9	0	80-7	7
F-16A	34000	33600	51000	128.6	35	80-7	37
F-16A	34000	34000	38000	122.7	50	80-7	40
F-16A	34000	34100	38000	112.1	35	80-7	36
F-16A	34000	34200	57000	129.9	0	80-7	34
F-16A	34000	34400	37000	114.3	0	80-7	31
F-16A	34000	34400	41200	111.2	50	80-7	39
F-16A	34000	34600	39000	121.2	0	80-7	33
F-16A	34000	35100	26000	99.8	50	80-7	38
F-16A	34000	35100	51700	137.5	0	80-7	35
F-16A	34000	35200	34000	108.4	0	80-7	32
F-16A	34000	35200	31400	98.0	0	80-7	30
F-16A	40000	39900	34000	100.0	0	80-7	10
F-111A	60000	60000	24000	90.0	0	69-9	35
F-111A	60000	60000	30100	93.0	0	69-9	44
F-111A	60000	60000	37000	114.0	25	69-9	37
F-111A	60000	60000	50000	130.0	0	69-9	43
F-111A	60000	60000	54100	134.0	0	69-9	41
F-111A	60000	60000	66500	144.0	0	69-9	45
F-111A	60000	60000	66500	147.0	0	69-9	46
F-111A	60000	60000	64000	153.0	0	69-9	42
F-111A	60000	60000	73100	169.0	0	69-9	47
F-111A	60000	60000	83400	172.0	25	69-9	48
F-111A	80000	80000	30400	87.0	0	69-9	40
F-111A	80000	80000	59400	132.0	0	69-9	51
F-111A	80000	80000	45700	107.0	0	69-9	50
F-111A	80000	80000	67500	146.0	0	69-9	52
F-111A	80000	80000	74400	159.0	0	69-9	53
F-111A	90000	90000	48900	112.0	0	69-9	58
F-111A	90000	90000	42600	116.0	0	69-9	54
F-111A	90000	90000	59400	130.0	0	69-9	55
F-111A	90000	90000	64800	138.0	0	69-9	56
YA-10	34000	34400	40500	114.6	0	78-3	47
YA-10	34000	34400	48600	131.2	50	78-3	51

Table 1

(concluded)

SUMMARY OF BAK-12 (EXTENDED RUNOUT) ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
YA-10	34000	34700	36500	94.8	0	78-3	46
YA-10	34000	34700	42600	121.6	50	78-3	50
YA-10	34000	35100	22300	76.0	0	78-3	45
YA-10	34000	35100	34500	103.1	35	78-3	49
YA-10	34000	35400	50700	132.0	0	78-3	48
YA-10	40000	41300	52700	148.7	0	78-3	54
YA-10	40000	41800	50700	140.4	0	78-3	53
YA-10	40000	42200	40500	119.8	0	78-3	52
YA-10	40000	42200	60800	147.6	50	78-3	56
YA-10	40000	42600	52700	126.2	50	78-3	55
YA-10	49500	48300	63800	146.5	0	78-3	59
YA-10	49500	48800	48600	135.1	0	78-3	58
YA-10	49500	49200	42600	119.4	0	78-3	57
YA-10	49500	49200	75100	156.3	50	78-3	63
YA-10	49500	49500	52700	139.4	50	78-3	61
YA-10	49500	49600	70000	161.3	0	78-3	62
YA-10	49500	49900	42600	128.6	50	78-3	60

Table 2

SUMMARY OF BAK-13 ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
F-16A	34000	32900	29500	89.9	0	80-7	7
F-16A	34000	33600	53500	129.5	0	80-7	67
F-16A	34000	33700	28000	91.8	75	80-7	70
F-16A	34000	34100	46000	118.0	0	80-7	66
F-16A	34000	34500	37000	110.2	50	80-7	69
F-16A	34000	34600	46000	112.0	0	80-7	65
F-16A	34000	35000	40000	104.2	0	80-7	64
F-16A	34000	35100	35000	101.3	50	80-7	68
F-16A	41000	39900	34000	100.0	0	80-7	10
F-100	26000	25000	34000	90.0	0	69-3	191
F-100	26000	25000	44000	120.0	35	69-3	25
F-100	26000	25000	60000	136.0	35	69-3	193
F-100	26000	25000	60000	148.0	35	69-3	194
F-101	34000	35000	62000	141.0	35	69-3	121
F-101	34000	35000	67000	141.0	35	69-3	121
F-111A	84000	80000	91000	149.0	0	69-3	206
F-111A	60000	60000	78000	144.0	0	69-9	8
F-111A	84000	80000	90000	149.0	0	69-9	31
F-111A	60000	60200	89900	157.0	0	73-36	65
F-111A	70000	68400	75800	145.0	75	73-36	78
F-111A	70000	71000	72000	140.0	0	73-36	75
F-111A	70000	71600	89000	157.0	75	73-36	84
F-111A	70000	72900	89900	159.0	0	73-36	79
F-111A	70000	73000	59000	118.0	0	73-36	71
F-111A	70000	73300	63500	121.0	75	73-36	73
F-111A	84000	80900	62800	120.0	0	73-36	88
F-111A	84000	81700	101500	154.0	0	73-36	87
F-111A	84000	84300	67400	121.0	70	73-36	97
F-111A	84000	84500	86500	140.0	0	73-36	86
F-111A	84000	86500	84000	137.0	70	73-36	100
YA-10	34000	32600	44300	114.0	50	78-3	11
YA-10	34000	32600	41400	118.7	75	78-3	14
YA-10	34000	32600	53200	130.3	75	78-3	17
YA-10	34000	33000	32500	98.3	25	78-3	10
YA-10	34000	33300	45300	116.6	50	78-3	13
YA-10	34000	33300	54000	130.3	50	78-3	16
YA-10	34000	33500	25300	81.3	0	78-3	2
YA-10	34000	33900	51200	121.2	50	78-3	8
YA-10	34000	34000	10100	49.3	0	78-3	1
YA-10	34000	34000	29500	92.8	75	78-3	12
YA-10	34000	34000	38400	111.4	0	78-3	9
YA-10	34000	34000	53000	128.6	25	78-3	15
YA-10	34000	34100	62900	133.5	0	78-3	5
YA-10	34000	34500	30500	89.0	0	78-3	7
YA-10	34000	34500	50700	114.6	0	78-3	4

Table 2

(Continued)

SUMMARY OF BAK-13 ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
F-15C	60000	59200	52000	113.9	60	80-33	31
F-15C	60000	59300	35000	92.3	60	80-33	25
F-15C	60000	59400	44000	101.2	40	80-33	32
F-15C	60000	59500	38000	91.5	40	80-33	21
F-15C	60000	59800	44000	101.9	0	80-33	10
F-15C	60000	59800	63000	123.5	0	80-33	5
F-15C	60000	59900	62000	126.3	15	80-33	12
F-15C	60000	59900	68000	134.2	0	80-33	6
F-15C	60000	60000	27000	80.0	60	80-33	24
F-15C	60000	60000	47000	104.9	60	80-33	30
F-15C	60000	61000	38000	92.9	40	80-33	20
F-15C	60000	61100	77000	140.0	0	80-33	4
F-15C	70000	66700	30000	80.7	60	80-33	27
F-15C	70000	67200	57000	102.0	60	80-33	35
F-15C	70000	67500	39000	89.7	60	80-33	33
F-15C	70000	67900	35000	90.4	40	80-33	26
F-15C	70000	68100	55000	108.6	40	80-33	36
F-15C	70000	68300	44000	101.2	40	80-33	34
F-16A	19000	17800	36000	108.1	0	80-7	72
F-16A	19000	17900	33000	106.1	50	80-7	77
F-16A	19000	18200	28000	96.2	0	80-7	71
F-16A	19000	18400	33000	106.1	50	80-7	76
F-16A	19000	18700	54000	130.3	50	80-7	80
F-16A	19000	19000	61000	136.5	0	80-7	75
F-16A	19000	19300	38000	125.0	50	80-7	79
F-16A	19000	19500	54000	128.2	0	80-7	74
F-16A	19000	19500	28000	101.5	75	80-7	81
F-16A	19000	19800	43000	123.8	0	80-7	73
F-16A	19000	20100	37000	114.0	50	80-7	78
F-16A	26000	24800	65000	135.6	0	80-7	61
F-16A	26000	25200	58000	130.0	0	80-7	60
F-16A	26000	26000	55000	135.6	50	80-7	59
F-16A	26000	26300	27000	94.4	75	80-7	63
F-16A	26000	26500	41000	116.0	50	80-7	58
F-16A	26000	26800	32700	98.8	50	80-7	56
F-16A	26000	27000	30700	103.0	0	80-7	52
F-16A	26000	27000	38000	109.9	50	80-7	57
F-16A	26000	27100	38000	102.3	75	80-7	62
F-16A	26000	27200	52000	129.5	0	80-7	55
F-16A	26000	27600	23700	96.4	0	80-7	51
F-16A	26000	27700	49000	124.2	0	80-7	54
F-16A	26000	28100	46100	117.0	0	80-7	53
F-16A	26000	28300	12500	69.8	0	80-7	50
F-16A	34000	32000	41000	110.5	0	80-7	9
F-16A	34000	32400	31500	95.9	0	80-7	6

Table 2

(Continued)

SUMMARY OF BAK-13 ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
A-3A	48000	47000	47000	115.0	0	69-3	126
A-3A	53000	55000	36000	92.0	0	69-3	140
A-3A	70000	60000	72000	121.0	35	69-3	153
A-3A	70000	60000	90000	164.0	0	69-3	173
A-3A	70000	70000	32000	86.0	0	69-3	208
A-3A	70000	70000	53000	113.0	0	69-3	209
A-3A	53000	53300	69000	143.0	0	73-36	44
A-3A	53000	53500	70000	143.0	75	73-36	50
A-3A	53000	54500	46000	118.0	75	73-36	48
A-3A	53000	54500	52000	122.0	0	73-36	37
A-7D	26000	25700	74000	163.0	75	73-36	94
A-7D	26000	26500	42000	119.0	0	73-36	18
A-7D	26000	26600	42000	120.0	0	73-36	3
A-7D	26000	26900	50000	129.0	0	73-36	21
A-7D	26000	27000	54000	138.0	0	73-36	8
A-7D	41000	40000	62000	140.0	50	73-36	34
A-7D	41000	40700	63000	142.0	0	73-36	25
A-7D	41000	41300	50000	122.0	75	73-36	31
A-7D	41000	41400	47000	118.0	0	73-36	23
F-4A	48000	44600	84000	157.0	0	73-36	59
F-4A	48000	44900	80000	162.0	75	73-36	61
RF-4C	34000	35000	44000	114.0	0	69-3	20
RF-4C	48000	47000	23500	88.0	0	69-3	67
RF-4C	48000	47000	86500	151.0	0	69-3	94
F-15A	34000	30900	42800	110.0	0	76-5	3
F-15A	34000	31300	65300	141.0	0	76-5	11
F-15A	34000	31600	38300	103.0	0	76-5	2
F-15A	34000	32000	52900	131.0	0	76-5	6
F-15A	41000	38500	48400	115.0	0	76-5	13
F-15A	41000	38600	47300	102.0	35	76-5	19
F-15A	41000	38900	55100	130.0	0	76-5	15
F-15A	41000	39800	75400	142.0	0	76-5	17
F-15A	53000	52600	72000	140.0	0	76-5	33
F-15A	53000	52600	58500	122.0	50	76-5	29
F-15A	53000	53100	70900	131.0	0	76-5	32
F-15A	53000	53500	40500	100.0	50	76-5	28
F-15C	53000	51300	69000	136.8	0	80-33	19
F-15C	53000	51500	44000	108.1	60	80-33	29
F-15C	53000	52500	64000	119.7	40	80-33	18
F-15C	53000	52600	49000	98.8	60	80-33	28
F-15C	53000	53600	44000	103.0	40	80-33	17
F-15C	60000	57500	52000	113.1	40	80-33	23
F-15C	60000	58600	46000	105.4	40	80-33	22
F-15C	60000	59000	56000	117.7	15	80-33	11
F-15C	60000	59000	78000	144.9	15	80-33	13

Table 2

(concluded)

SUMMARY OF BAK-13 ARRESTMENT DATA

A/C TYPE	A/C AVERAGE WEIGHT CATEGORY (LB)	A/C TEST GROSS WEIGHT (LB)	MAXIMUM HOOKLOAD (LB)	A/C GROUND SPEED AT ARRESTMENT (KT)	ENGAGEMENT DISTANCE FROM RUNWAY CENTER (FT)	AFFTC TECHNICAL REPORT NUMBER	TEST RUN NUMBER
YA-10	34000	35000	26700	72.6	0	78-3	5
YA-10	34000	35000	32400	98.0	0	78-3	3
YA-10	41000	41200	64900	122.7	0	78-3	23
YA-10	41000	41200	60800	126.6	0	78-3	23
YA-10	41000	41200	73000	146.5	50	78-3	26
YA-10	41000	41600	38500	97.8	75	78-3	17
YA-10	41000	41600	54700	128.6	75	78-3	22
YA-10	41000	41600	73000	146.0	0	78-3	25
YA-10	41000	41600	77000	147.6	75	78-3	28
YA-10	41000	42100	32400	95.0	0	78-3	18
YA-10	41000	42100	62800	128.7	50	78-3	21
YA-10	41000	42100	63800	140.9	75	78-3	27
YA-10	41000	42100	77000	142.4	0	78-3	24
YA-10	48000	47400	57800	123.1	75	78-3	34
YA-10	48000	47500	63800	133.3	50	78-3	33
YA-10	48000	47900	87200	158.7	0	78-3	37
YA-10	48000	48400	57800	120.1	50	78-3	32
YA-10	48000	48600	67900	135.1	75	78-3	38
YA-10	48000	48800	81100	153.9	0	78-3	36
YA-10	48000	48900	42600	100.5	75	78-3	31
YA-10	48000	48900	77000	148.7	50	78-3	40
YA-10	48000	49100	68900	142.9	75	78-3	43
YA-10	48000	49200	64900	128.2	0	78-3	30
YA-10	48000	49300	68900	136.1	50	78-3	39
YA-10	48000	49400	67200	158.7	50	78-3	42
YA-10	48000	49600	81100	146.5	0	78-3	35
YA-10	48000	49800	50700	116.3	0	78-3	29
YA-10	48000	49900	67900	140.9	50	78-3	41

and/or a filter which clipped the peaks. There was an instance where a strain gauge, intended to read pure tension, was installed at a point on the tail hook where bending was also present.

There were errors introduced into the test data because the aircraft's fuel quantity measurement system was inoperable and it was not possible to accurately estimate the aircraft test weight.

There are uncontrollable variables in the functioning of the barrier systems. The barrier preload cannot be maintained accurately from one arrestment to another; The tightness with which the barrier tapes are rewound onto the reels cannot be maintained constant between arrestments; The positioning of the cable supports varies with each cable retraction.

Exclusion of Standard BAK-12 Data:

Some of the AFFTC Technical Reports on arrestment test programs (Phase I Test and Evaluation of the BAK-13/F48A Aircraft Arresting System, reference 1; Category II F-111A Arresting Systems Compatibility Tests, reference 2; BAK-13 Aircraft Arresting System Phase II Test, reference 3) included a large number of reproductions of the original strip chart records of hook load time histories. These were invaluable in verifying the accuracy of the original data reduction. However, the reports on the Standard BAK-12 test programs (Category II A-7D Arresting System Compatibility Tests, reference 4; F-5E Standard BAK-12 Arresting System Compatibility Tests, reference 5; BAK-12/E32A Portable Aircraft Arresting Barrier, reference 6) did not include enough original data so that this procedure could be used. Those strip chart records that were included (references 5 and 6) revealed some problems with sampling rates and data reading methods. Therefore, the Standard BAK-12 data were excluded from the analysis. Data points from the F-5E and A-7D BAK-12 barrier compatibility test programs are plotted in figures A1 and A3. The curves shown in Figure A1 fit the Standard BAK-12 data poorly. Use of these curves for regression analysis of Standard BAK-12 data would result in extremely conservative results. The curves in figure A3 fit the Standard BAK-12 data much better but would also yield excessively conservative results. Therefore, it is not recommended that any of these curves be used for analyzing Standard BAK-12 data.

SELECTING THE BEST FITTING CURVE

The quest for a curve fitting equation was started with the BAK-12ER data. It represented the results of barrier tests with only four aircraft as opposed to 8 aircraft represented by the BAK-13 data. Consequently, if hook load deviation was a function of inherent differences in aircraft, the BAK-12ER data should be more compact and easier to curve fit than the BAK-13 data. The effect that aircraft differences have on data dispersion is discussed later.

When the BAK-12ER data were listed in ascending order of test weight it was noted that they fell into nine clearly defined categories. The median values, in pounds, for each of the categories, and the number of test points in each category (in parentheses) are shown in table 3.

Table 3

BAK-12ER TEST WEIGHTS

Median Gross Weight (Pounds)	Number of Tests Conducted
18,500	9
26,500	22
34,000	25
40,000	13
49,500	7
54,000	12
60,000	10
80,000	5
90,000	4

As was stated earlier, the forms in which aircraft weight (W) and engagement groundspeed (V) might appear in an equation for hook load were not known. Initially it was thought that weight and engagement groundspeed might be related to maximum hook load by kinetic energy only such that:

$$HL = f(KE) = f\left(\frac{WV^2}{2g}\right) \qquad (1)$$

where: HL = predicted maximum hook load (pounds)
W = aircraft weight (pounds)
V = aircraft groundspeed at engagement (ft/sec)
g = gravitational constant
f = arbitrary function

However, this relationship requires hook load to be directly proportional to weight for a given groundspeed. Review of the data in tables 1 and 2 revealed the relationship of weight, groundspeed and hook load to be nearly the reverse of this; hook load varied nearly directly with groundspeed for a given aircraft weight.

Many equations were written that complied with these obvious relationships between hook load and the variables W and V. Each one was fitted to the data in the least square sense using regression analysis. To select the best fitting curve a computer program was used that determined the "residual errors" for each curve fit. The residual errors were the differences between the actual (observed) hook loads and those predicted by regression analysis for the same groundspeeds. When the residuals from each curve fit (each representing a different hook load equation) were plotted versus groundspeed and compared, the best fitting curve could be selected. It was the one with the smallest, most evenly distributed residuals.

The equation for the curve that best fitted the entire mass of the BAK-12ER data was:

$$HL = B_1 TAN(V/B_2) \qquad (2)$$

where: HL = predicted hook load (pounds)
B_1 = 42,959.31 (say 43,000)
B_2 = 149.687 (say 150)
V = engagement groundspeed (knots)

Since weight did not appear in the equation the resultant curve expressed the relationship between hook load and groundspeed at the average of all the test weights; approximately 50,000 pounds.

ADDING THE WEIGHT TERM

In order to generate a family of curves of hook load versus groundspeed for a range of aircraft weights, it was necessary to modify the equation. Its final form was:

$$HL = B_1 TAN(V/B_2)(1 + TAN((W-50,000)/B_3)) \qquad (3)$$

where: B_1 = 43,000
B_2 = 150
B_3 = 450,452
V = engagement groundspeed (knots)
W = aircraft weight (pounds)
HL = predicted maximum hook load (pounds)

The family of mean curves shown in figure 6 was constructed by plotting the values of hook load obtained by solving this equation for various values of aircraft weight and engagement groundspeed. The weights were taken from table 3. The actual data points obtained during the test programs are represented by symbols which also identify the aircraft and the weights at which they were arrested.

CONFIDENCE INTERVAL ESTIMATES

The fact that the curves generated by the hook load equation fitted their data in the least square sense meant that there were approximately the same number of data points above and below the curves. Statistically we could be confident of finding a data point lying within one standard deviation of the curve 68.27 percent of the time. This was not an adequate confidence level, especially in the region where the curves crossed the arresting hook design limit load line. As stated earlier, ninety percent was selected as a satisfactory confidence level. Any higher confidence level would have resulted in excessive conservatism.

Hook load standard deviation varied with velocity along the entire length of the curve because of the difference in the number of tests conducted at each speed. In order to define the confidence limits in terms of hook load, it was necessary to first determine the nature of this variation. To do this, the data were assembled in ascending order of velocity and in groups centered on their median values. The residuals (observed hook loads minus predicted hook loads) for each group of velocities were then submitted to the computer for determination of standard deviations. The standard deviations thus obtained were multiplied by 1.645 to obtain the 90 percent confidence limits. These were then plotted versus groundspeed as the independent variable and an approximating curve was fitted as shown in figure 7. The 90 percent confidence curves of hook load versus groundspeed shown in figure 8 were constructed by adding the 90 percent confidence limits (pounds) (taken from figure 7) to corresponding hook load values predicted by equation 3.

Figures A1 through A9 in Appendix A show mean and upper 90-percent confidence curves for each of the weight categories tested with the BAK-12ER. The actual data points associated with the curves are also shown. The aircraft types represented by the data can be determined by reference to figure 6. Figures A1 and A3 also show some standard BAK-12 data points.

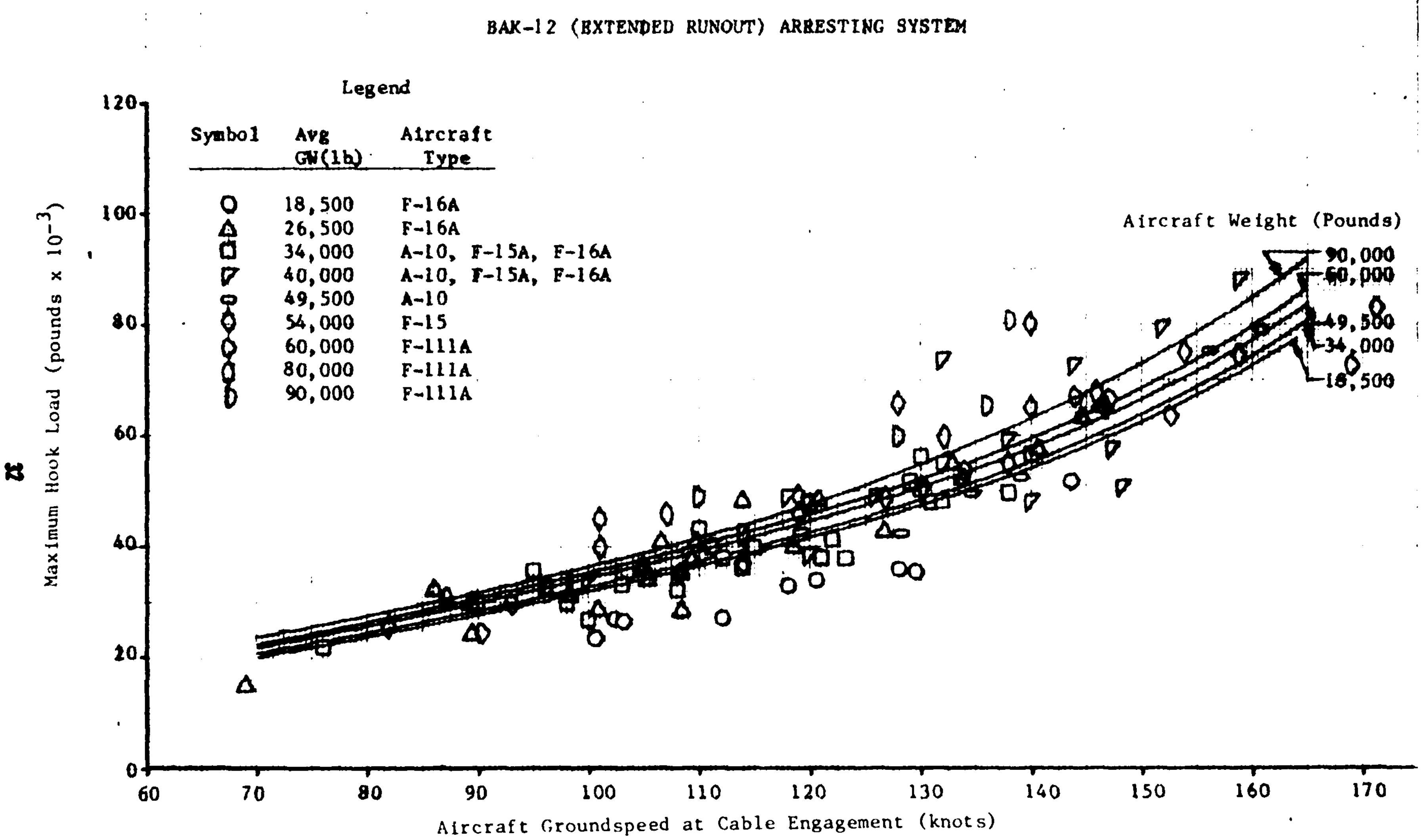


Figure 6 Mean Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barriers

BAK-12 (EXTENDED RUNOUT) ARRESTING SYSTEM

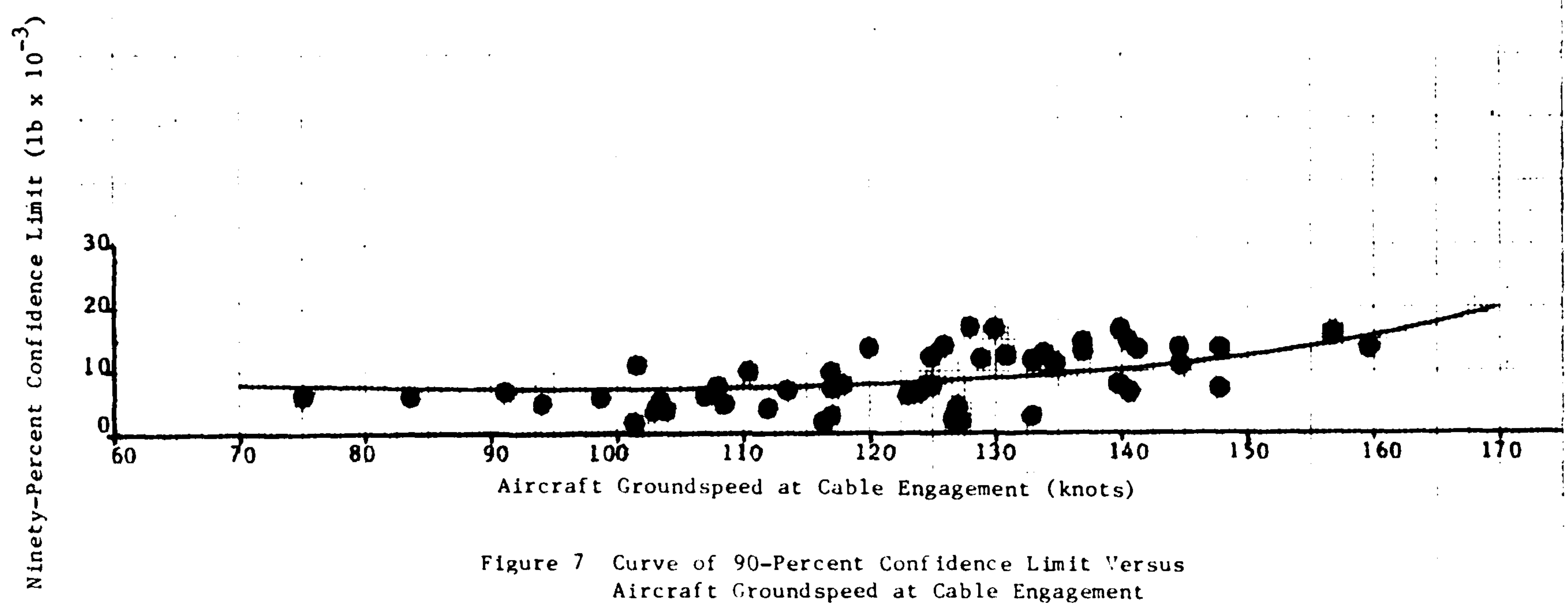


Figure 7 Curve of 90-Percent Confidence Limit Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barriers

NOTE: Ninety-Percent Confidence Limit = 1.645 X Standard Deviation of Hook Load Residuals

BAK-12 (EXTENDED RUNOUT) ARRESTING SYSTEM

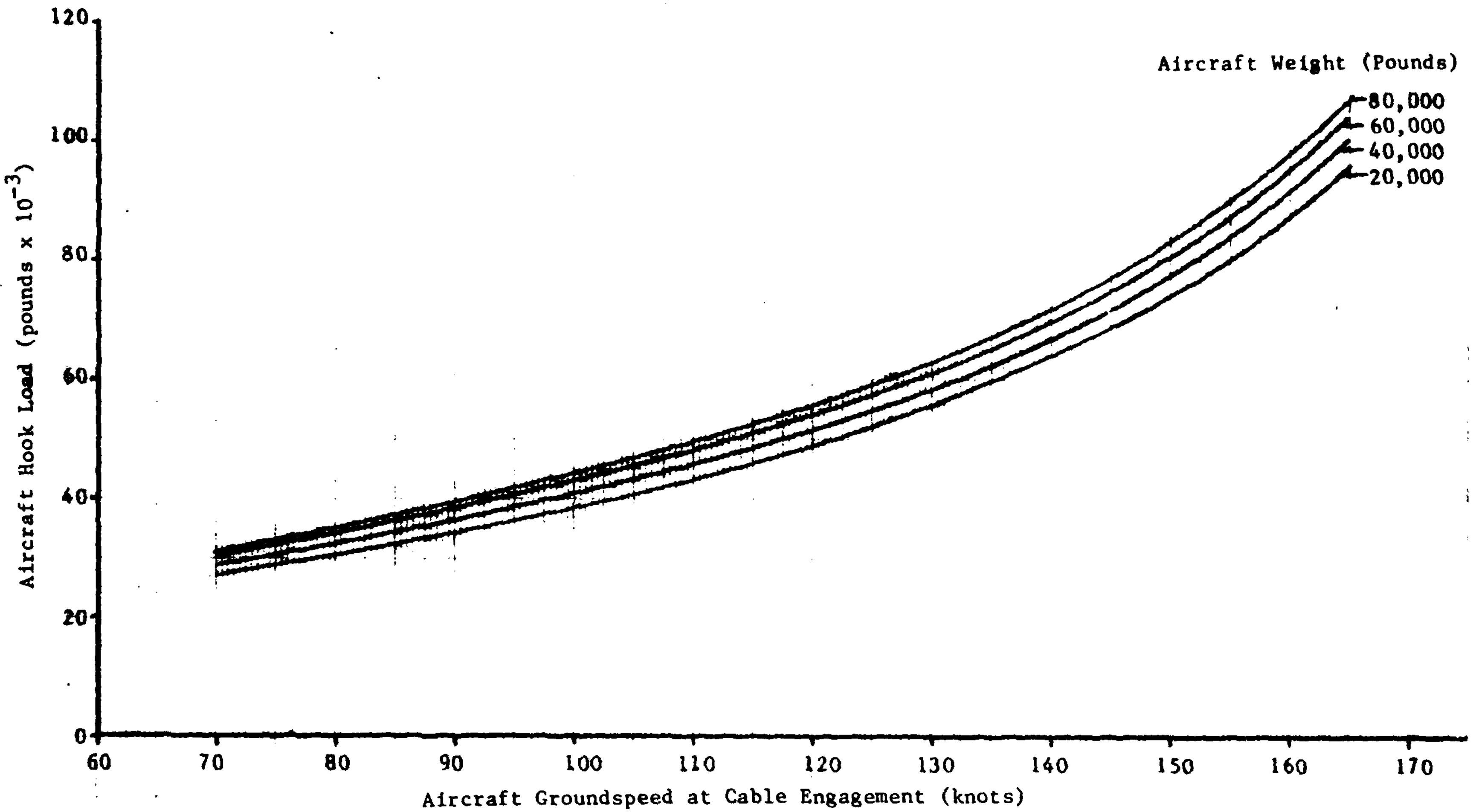


Figure 8 Ninety-Percent Confidence Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barriers

The family of curves shown in figure 8 are to be used for predicting the maximum aircraft arresting hook loads induced by the BAK-12ER barrier. Ninety percent of actual test data will fall on or below the appropriate upper confidence limit curve. Figure 8 can be used for aircraft weighing between 20,000 and 80,000 pounds. However, greatest accuracy is obtained for aircraft weighing approximately 40,000 through 60,000 pounds.

HOOK LOAD EQUATION FOR BAK-13 DATA

Each of the equations that were fitted to the BAK-12ER data were also tried on the BAK-13 data. In each case, the curve fit was unsatisfactory due to excessively large and/or poorly distributed residuals. Again, as was true with the BAK-12ER data, the shape of the hook load/groundspeed curve could not be predicted by inspection of the scatter diagram generated by plotting the data (figure 5).

The categories into which the BAK-13 test weights fell were determined by following the procedure previously used with the BAK-12ER data. Again there were nine weight categories. The median weights (in pounds) for each category and the number of test points in each category (in parentheses) is listed in table 4. The 34,000 pound category, having 34 points, was the largest in terms of number of data points. When plotted, the resulting scatter diagram revealed a linear relationship between hook load and groundspeed, at least for this particular aircraft weight and, assumably, for all the weights listed in table 4. This linear relationship indicated that the equation connecting the variables would be a first degree polynomial of the form $y = a_o + a_1x$. Several equations of this form were tried and the one which best fitted the data, having the lowest and most evenly distributed residuals, was:

$$HL = B_1 + B_2W + (B_3 + B_4W)V \qquad (4)$$

where: HL = predicted hook load (pounds)
B_1 = -34,056
B_2 = -0.012038
B_3 = 591.00
B_4 = 0.003[illegible]428
W = aircraft gross weight (pounds)
V = groundspeed at engagement (knots)

Table 4

BAK-13 TEST WEIGHTS

Median Gross Weight (Pounds)	Number of Tests Conducted
19,000	19
26,000	23
34,000	34
41,000	20
48,000	19
53,000	14
60,000	20
70,000	14
84,000	7

The family of mean curves shown in figure 9 was constructed using this equation and the weights listed in table 4. The actual test data are represented by symbols which also identify the test aircraft and the test weights.

BAK-13 CONFIDENCE INTERVALS

The 90 percent confidence intervals for the BAK-13 data were determined by following the same procedures used with the BAK-12ER data. The standard deviations of the hook load residuals were computed and were multiplied by the 90 percent confidence coefficient (1.645) to obtain the confidence limits. These were then plotted versus groundspeed as the independent variable and an approximating curve was fitted (figure 10). The approximating curve which best fitted the confidence limit data points in the least square sense was a straight line. Its equation was:

$$C = a_o + a_1 V \qquad (5)$$

where: C = 90 percent confidence limit
a_o = 5364.36 pounds (y intercept)
a_1 = 6.18 (slope of line)
V = groundspeed (knots)

The family of 90 percent confidence curves of hook load versus groundspeed shown in figure 11 was constructed by adding C, as determined by equation 5 for selected values of V, to the corresponding mean hook load predicted by equation 4. The mean and ninety percent confidence curves for the test weights listed in table 4 are shown in figures B1 through B9 in Appendix B. The actual test data points are also shown.

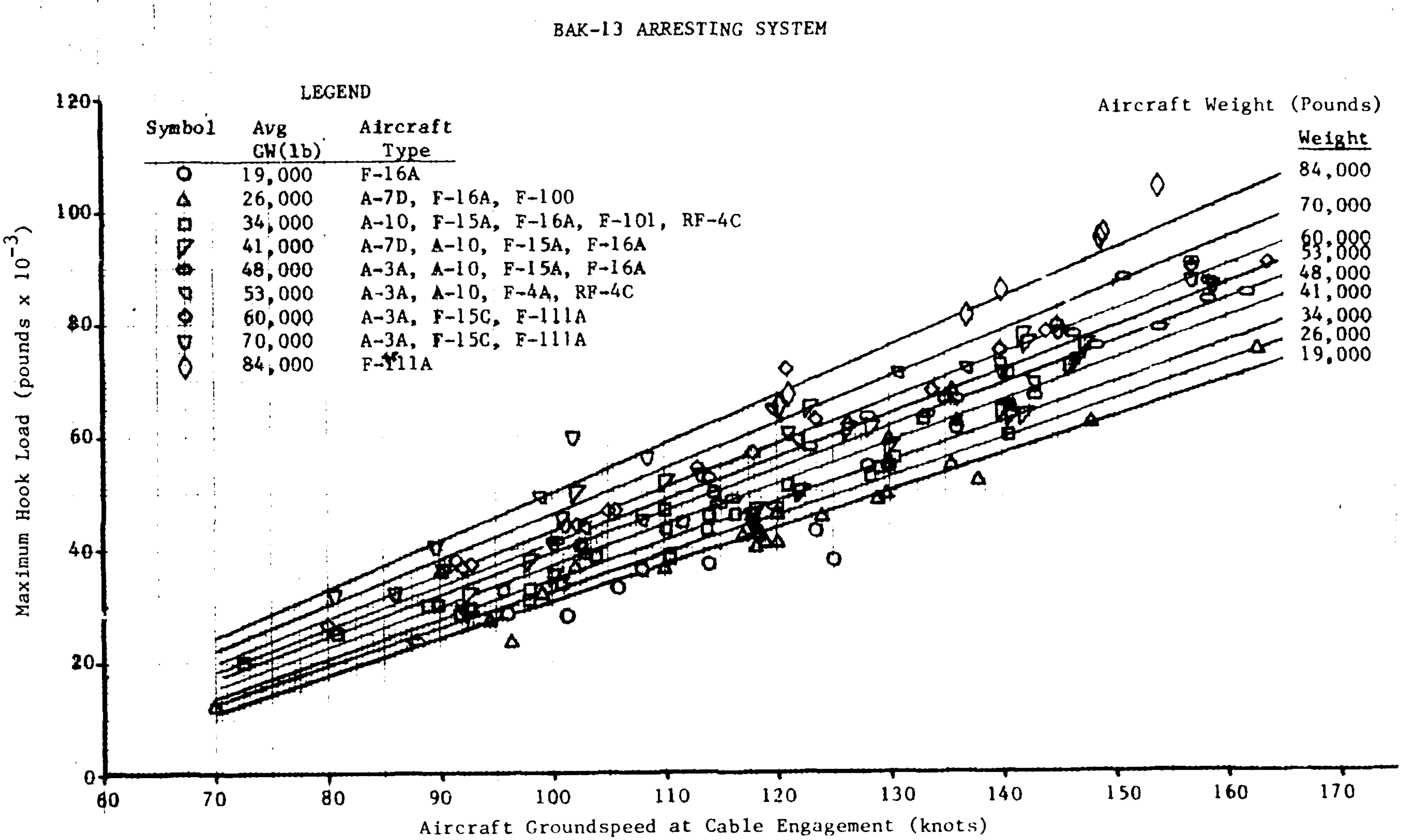


Figure 9 Mean Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

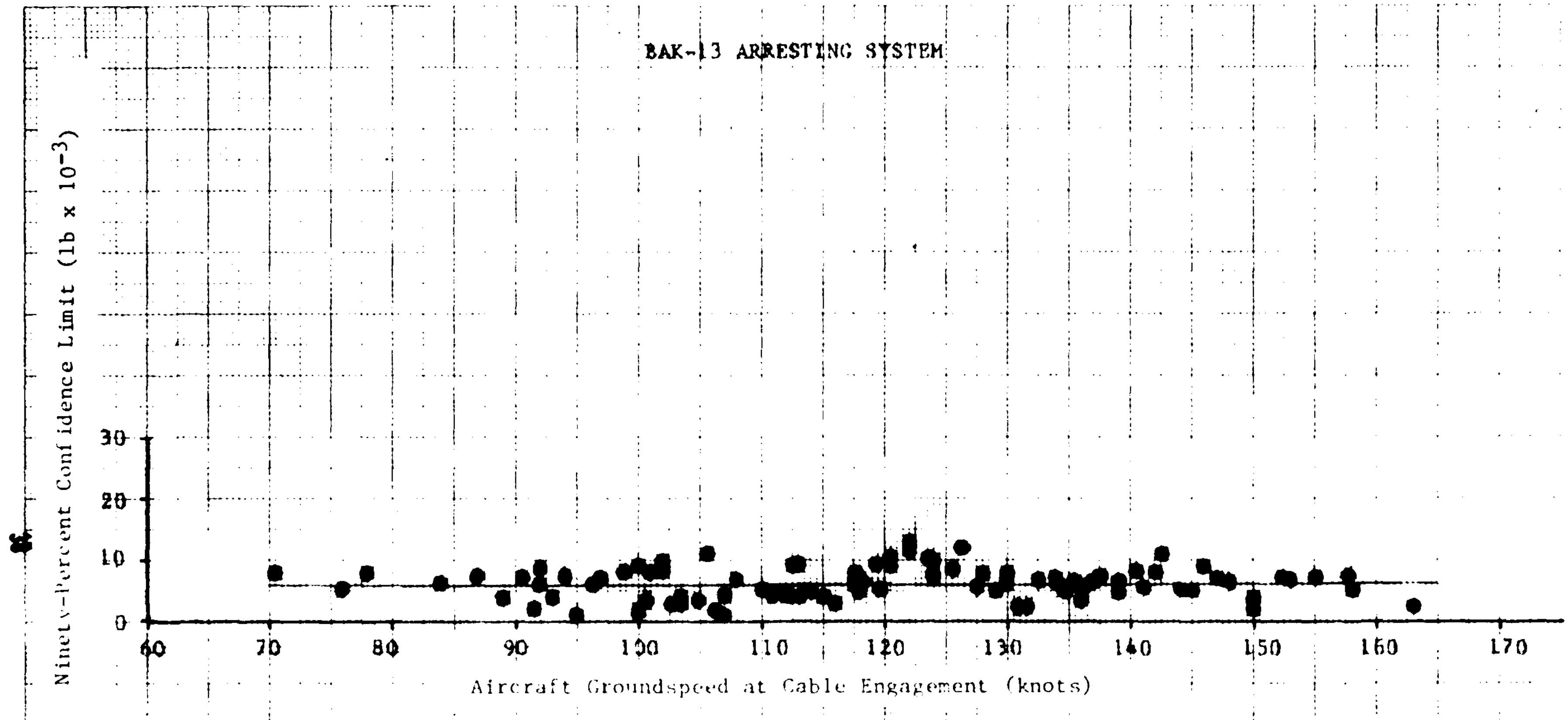


Figure 10 Curve of 90-Percent Confidence Limit Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

NOTE: Ninety-Percent Confidence Limit = 1.645 X Standard Deviation of Hook Load Residuals

BAK-13 ARRESTING SYSTEM

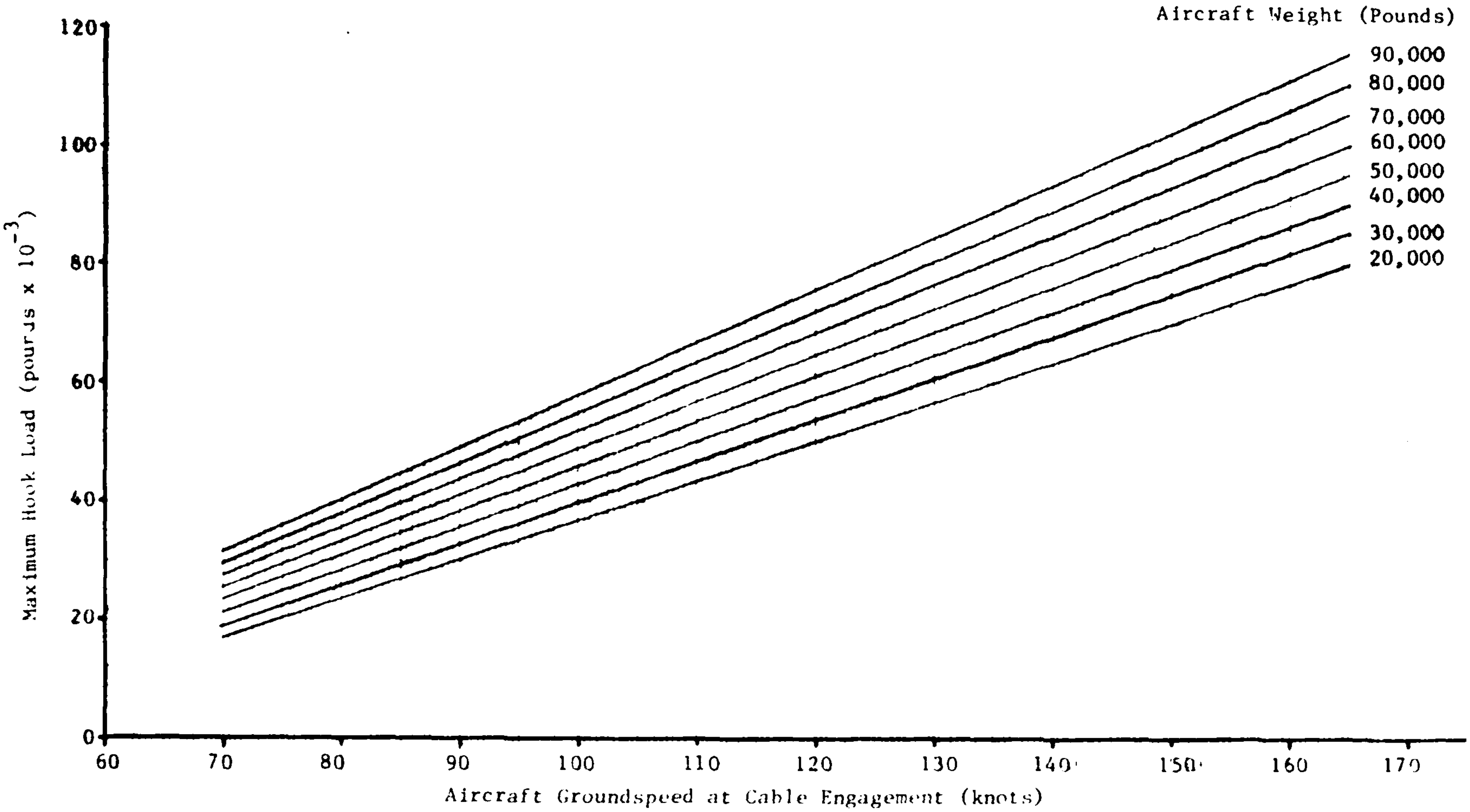


Figure 11 Ninety-Percent Confidence Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

The family of curves shown in figure 11 is to be used for predicting BAK-13 hook loads. It can be used for aircraft weighing between 20,000 and 90,000 pounds within the range of groundspeeds shown. Greatest accuracy is obtained for aircraft weighing approximately 40,000 through 70,000 pounds.

ARRESTING HOOK DESIGN SPECIFICATION

Military specification MIL-A-83136 (reference 11) covers the design and installation of emergency arresting hooks. It contains curves of hook load versus engaging speed from which approximate maximum BAK-13 hook loads are supposed to be obtained. These curves are reproduced in figure 12. They are shown again in figure 13 with the curves from figure 11 superimposed. There is little agreement between the two sets of curves. So that MIL-A-83136 can be corrected, copies of this document have been made available to the preparing activity (Naval Air Engineering Center, Lakehurst, NJ.).

OFFCENTER ARRESTMENT

All of the curves generated by the BAK-12ER and BAK-13 hook load equations apply to both oncenter and offcenter arrestments. Peak hook loads tend to be slightly less during offcenter engagement but not significantly so. The decrease in braking hook load results from an increase in energy loss during the early, dynamic phase of the arrestment when the airplane is sometimes yawing and skidding. The reduced hook load is accompanied by an increase in nose landing gear side loading. This factor may require reduced engagement speeds for offcenter arrestments.

AIRCRAFT DIFFERENCES AND THEIR EFFECT ON DATA DISPERSION

Some of the dispersion in arresting hook load data can be attributed to inherent differences in aircraft. Some aircraft have more aerodynamic drag than others; some have more rolling friction due to a large footprint or dragging brakes; some aircraft engines have more idle thrust than others.

Aerodynamic drag and rolling friction aid in slowing the aircraft and in so doing cause a slight reduction in arresting hook loading. Engine thrust adds directly to the tail hook loads. With some aircraft, especially those with two engines, idle thrust can amount to several thousand pounds. It takes more time for the thrust of some engines to decay in response to the throttle that others. Hence, the thrust can still be significantly above the idle value at the point in the runout where maximum hook load occurs.

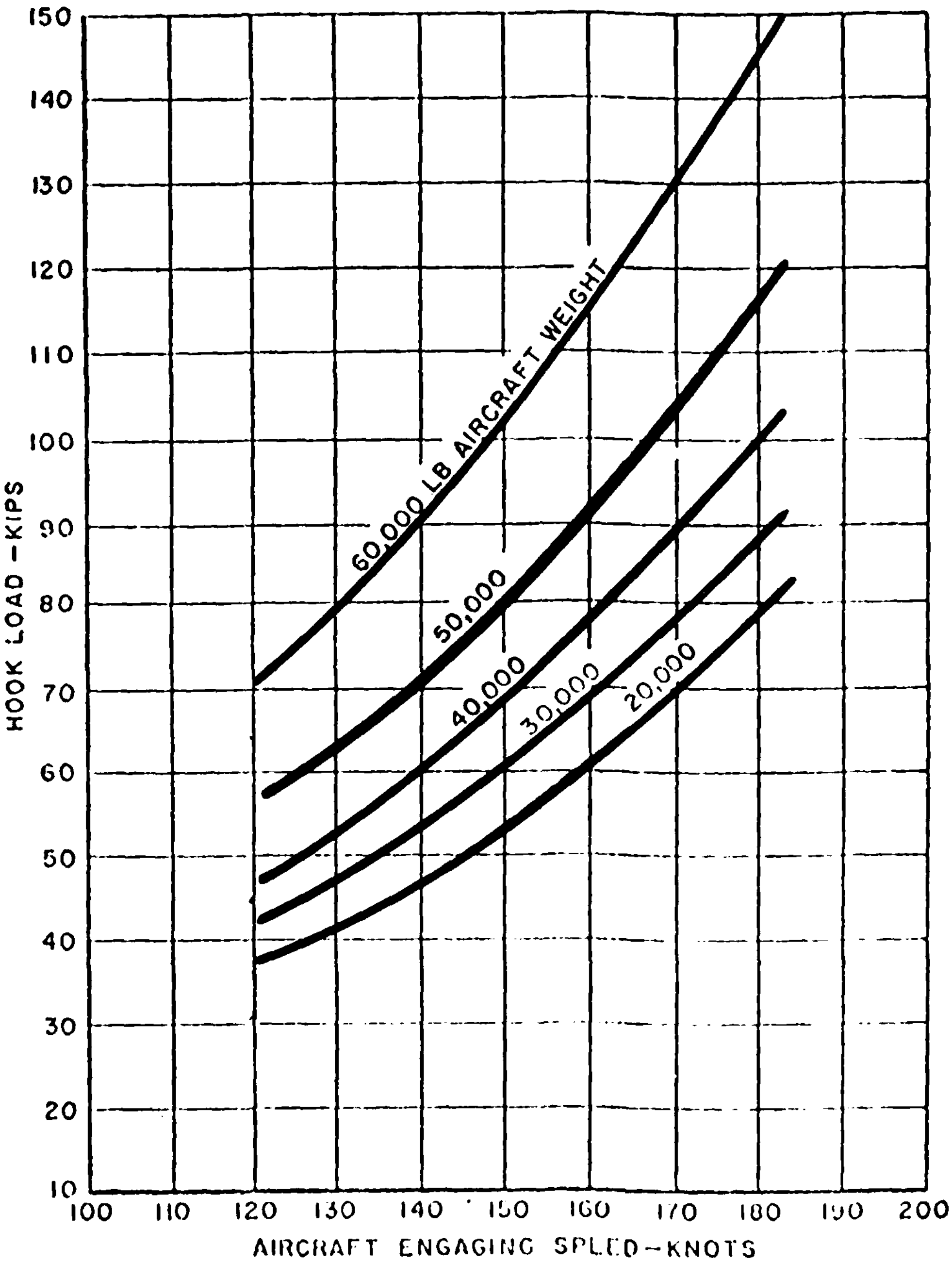


Figure 12 Curves of Aircraft Arresting Hook Loads Versus Cable Engaging Speed for the BAK-13 Arresting System (taken from MIL-A-83136)

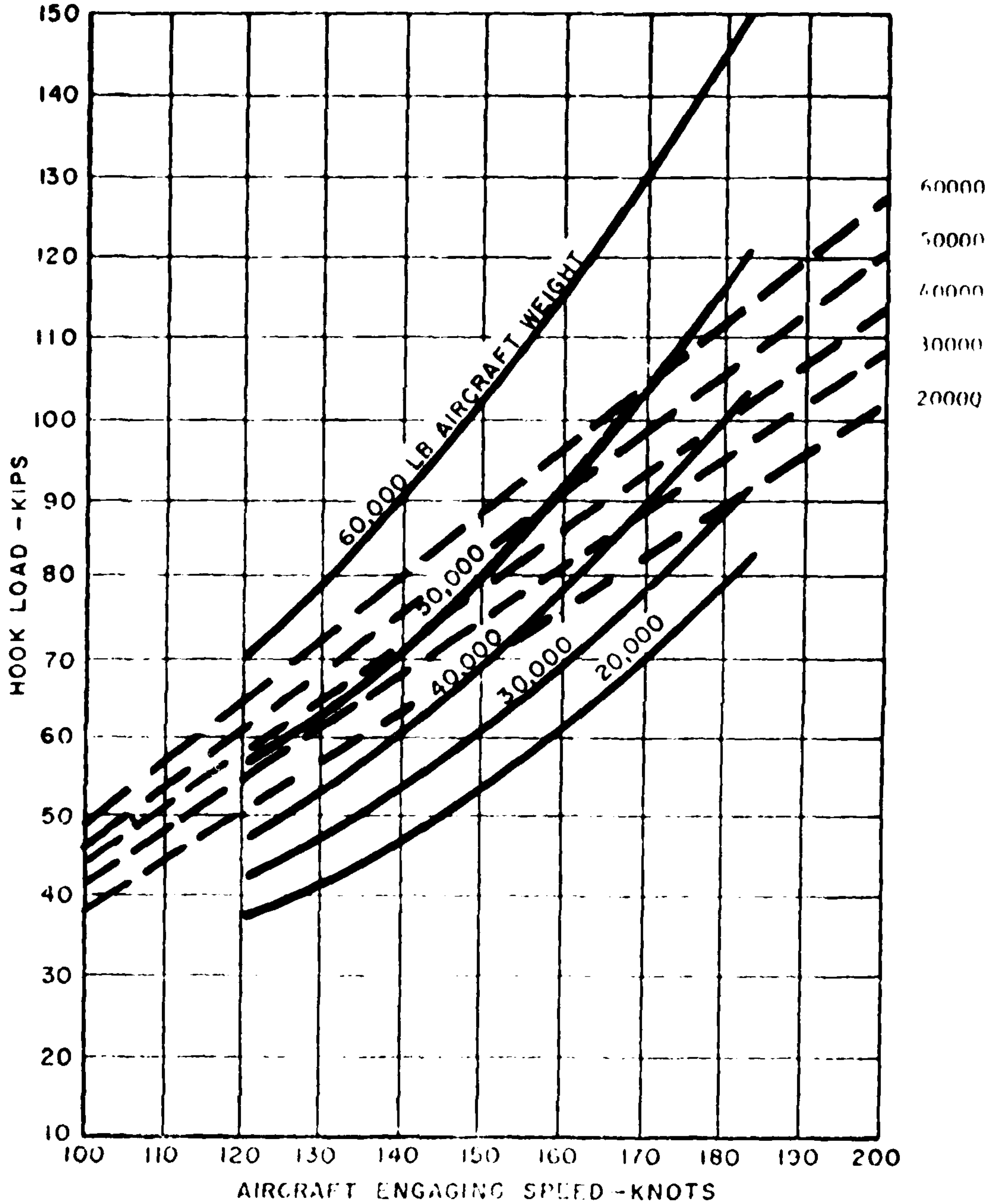


Figure 13 Curves from Figure 11 (dashed lines) Superimposed on Figure 12

These factors, combined with the inconsistencies committed during data acquisition and reduction, are responsible for some of the dispersion present in the tail hook load data.

Minimizing Data Dispersion Caused by Aircraft Differences:

The effect of engine residual thrust on hook load can be minimized by timely throttle reduction. This means that, during a test engagement, the pilot may have to overshoot his target-speed and retard the throttle before reaching the barrier, thus allowing more time for thrust reduction.

The effect of aerodynamic drag on hook loads can be controlled by consistent use of high-lift, high-drag devices such as flaps and speedbrakes. For instance, speedbrakes were extended during F-15 tail hook testing but were not used during F-16 testing. This inconsistency did not adversely effect the results of either test program but it did increase the overall dispersion when the data were combined.

Surface winds at the barrier test facility are almost always tail winds. This effect tends to increase hook loads slightly, especially for unclean airplanes, i.e., those with external stores, extended flaps/speedbrakes. Consistency is the keyword here.

Headwinds are to be avoided during barrier testing, especially at the higher speeds. This is because the target groundspeed plus the headwind component could exceed the takeoff speed for the aircraft. Also, if the wind should abate abruptly during a test run the aircraft groundspeed could exceed the critical limit.

SUMMARY

This document has traced the progress of a study which was conducted to develop curve fitting routines for BAK-12ER and BAK-13 aircraft arresting barrier data. The routines which resulted were used to create families of curves which expressed the relationship between aircraft barrier engagement speed and maximum aircraft hook loading for a range of aircraft weights.

The end products of the study are the curve families shown in figures 8 and 11. With these curves and a knowledge of the barrier type, the aircraft weight, and the design load limit of the aircraft arresting hook, the critical arrestment speeds can be predicted with 90 percent confidence. Figure 8 is for use with the BAK-12ER barrier. It can be used for predicting conservative hook load limit speeds for aircraft weighing between 20,000 and 80,000 pounds. Figure 11 is for the BAK-13 barrier. With it, conservative hook load limit speeds can be predicted for aircraft weighing between 20,000 and 90,000 pounds.

During the conduct of an aircraft/barrier compatibility test program the test data (hook load and groundspeed) should be plotted on the appropriate curve from figure 8 or 11. If the data points all fall below the curve the test conductor can feel confident in the accuracy of his data. However, he should review with caution any test data that fall above the curve. In the final analysis no more than ten-percent of the points should fall above the curve. In the case where this law is violated the test procedures should be suspect.

Be mindful of the fact that the curves in figure 8 and 11 apply only to the standard BAK-13 and the extended runout version of the BAK-12. They cannot be used to predict hook loading from other arresting systems.

REFERENCES

1. York, David A., First Lieutenant, USAF, Phase I Test and Evaluation of the BAK-13/F48A Aircraft Arresting System, FTC-TR-69-3, Air Force Flight Test Center, Edwards Air Force Base, California 93523, May 1969.

2. Fairchild, Frederic P., Category II F-111A Arresting Systems Compatibility Tests, FTC-TR-69-9, Air Force Flight Test Center, Edwards Air Force Base, California 93523, June 1969.

3. Day, Marius J., BAK-13 Aircraft Arresting System Phase II Test and Cable Bounce Limiter Test, FTC-TR-73-36, Air Force Flight Test Center, Edwards Air Force Base, California 93523, October 1973.

4. Rogers, James O. Jr., Category II A-7D Arresting System Compatibility Tests, FTC-TR-71-32, Air Force Flight Test Center, Edwards Air Force Base, California 93523, July 1971.

5. Rogers, James O. Jr., F-5E/Standard BAK-12 Arresting System Compatibility Tests, FTC-TR-73-30, Air Force Flight Test Center, Edwards Air Force Base, California 93523, October 1973.

6. Lucero, Frank N., BAK-12/E32A Portable Aircraft Arresting Barrier, FTC-TDR-63-34, Air Force Flight Test Center, Edwards Air Force Base, California 93523, November 1963.

7. Jones, Lyle W., F-16 FSD Arresting System Evaluation, AFFTC-TR-80-7, Air Force Flight Test Center, Edwards Air Force Base, California 93523, March 1980.

8. Darden, Douglas J., Air Force Development Test and Evaluation of the F-15A Airframe Subsystems, AFFTC-TR-76-15, Air Force Flight Test Center, Edwards Air Force Base, California 93523, January 1976.

9. Jones, Lyle W., Test and Evaluation of an Emergency Arresting Hook for the A-10A, AFFTC-TR-78-3, Air Force Flight Test Center, Edwards Air Force Base, California 93523, March 1978.

10. Jones, Lyle W., F-15C Arresting System Evaluation, AFFTC-TR-80-33, Air Force Flight Test Center, Edwards Air Force Base, California 93523, May 1981.

11. Military Specification: Arresting Hook Installation, Runway Arresting System, Aircraft, Emergency, MIL-A-83136, 6 August 1968.

BIBLIOGRAPHY

MA-1A Runway Overrun Barrier Tests of an F-104A Equipped With a Modified TX-28 Bomb Rack and Arresting Finger, AFFTC-TN-59-29, AFFTC Edwards AFB, CA, Aug 59.

Runway Barrier Evaluation of T-33 Arresting Hook, AFFTC-TN-59-31, AFFTC, Edwards AFB, CA, Sept 59.

Runway Barrier Evaluation of F-84F Arrestor Hook, AFFTC-TN-59-36, AFFTC, Edwards AFB, CA, Oct 59.

Runway Barrier Evaluation of F-106 Arrestor Hook, AFFTC-TN-59-43, AFFTC, Edwards AFB, CA, Dec 59.

Runway Barrier Evaluation of the F-105 Arrestor Hook, AFFTC-TN-60-11, AFFTC, Edwards AFB, CA, May 60.

Runway Barrier Evaluation of F-101 Arrestor Hook, AFFTC-TN-60-27, AFFTC, Edwards AFB, CA, July 60.

Runway Barrier Evaluation of the F-102 Arrestor Hook, AFFTC-TN-60-42, AFFTC, Edwards AFB, CA, Sept 60.

Tests of the T-33 Aircraft Engaging the MA-1A Runway Overrun Barrier, FTC-TDR-64-29, AFFTC, Edwards AFB, CA, Oct 64.

BAK-6/F22A Aircraft Arresting Barrier Absorber Evaluation, FTC-TDR-63-24, AFFTC, Edwards AFB, CA, Oct 62.

F-5A/Norway Category II/III Systems Evaluation, FTC-TR-66-4, AFFTC, Edwards AFB, CA, July 66.

BAK-9 Test Data, Unpublished, AFFTC, Edwards AFB, CA, 1962.

The Arresting Cable Popup Device, AFFTC-TR-61-17, AFFTC, Edwards AFB, CA, Apr 61.

BAK-12/E32A Portable Aircraft Arresting Barrier, FTC-TDR-63-34, AFFTC, Edwards AFB, CA, Nov 63.

T-38 Aircraft Engagement Capability with the BAD-12/MA-1A Barrier, FTC-TR-67-20, AFFTC, Edwards AFB, CA, Dec 67.

Category II F-IIIA/Arresting System Compatibility Tests, FTC-TR-69-9, AFFTC, Edwards AFB, CA, June 69.

Category II FB-III/Dual BAK-12A Arresting System Compatibility Tests, FTC-TR-71-13, AFFTC, Edwards AFB, CA, Apr 71.

Category II A-7D/Arresting Systems Compatibility Tests, FTC-TR-71-32, AFFTC, Edwards AFB, CA, July 71.

Testing of the BAK-14 Retractable Cable Support System, FTC-TR-72-41, AFFTC, Edwards AFB, CA, Mar 73.

F-4E/Standard BAK-12 Arresting System Compatibility Tests, FTC-TC-73-30, AFFTC, Edwards AFB, CA, Oct 73.

Air Force Development Test and Evaluation of the F-15A Airframe Subsystem, AFFTC-TR-76-5, AFFTC, Edwards AFB, CA, Jan 76.

Test and Evaluation of an Emergency Arresting Hook for the A-10A, AFFTC-TR-78-3, AFFTC, Edwards AFB, CA, May 78.

Phase I Test and Evaluation of the BAK-13/F48A Aircraft Arresting System, FTC-TR-69-3, AFFTC, Edwards AFB, CA, May 69.

BAK-13 Aircraft Arresting System Phase II Test and Cable Bounce Limiter Test, FTC-TR-73-36, AFFTC, Edwards AFB, CA, Oct 73.

AERAZUR Net/Model 64 Arresting System Test Program, Technical Letter Report, AFFTC, Edwards AFB, CA, Jan 71.

Emergency Aircraft; Runway Arresting System, Arresting Hook Installation, MIL-A-83136.

Airplane Strength and Rigidity, Landing and Ground Handling Loads, MIL-A-008862.

Catapult and Arresting Systems, Landing Systems, AFSC DH 2-1, DN 4B3, Apr 74.

Aircraft Arresting Hook Installations, MIL-A-18717.

Airplane Strength and Rigidity, Ground Loads for Navy Procured Airplanes, MIL-A-8863.

AFFTC Aircraft Arresting System Test Facility Operating Procedures, AFFTC Reg. 80-11, 21 Aug 74.

Alder, Henry L. and Roessler, Edwards B., Introduction to Probability and Statics, Fourth Edition, W.H. Freemand and Company, San Francisco, CA, 1968.

BIBLIOGRAPHY (Concluded)

USAF Type MA-1 and MA-1A Runway Overrun Barriers, T.O. 35E8-2-2-1.

Aircraft Arresting Gear, Model BAK-9/F48A, T.O. 35E-2-4-1.

Aircraft Arresting System, Model BAK-12/E32A, T.O. 35E8-2-5-1.

Aircraft Arresting System, Model BAK-13/F48A, T.O. 34E8-2-7-1

Deidhardt, Glen L., et al, An Analytical Approach to the Alleination of Dynamic Tensions in Aircraft Arresting Gear Cables, WADC Technical Report 58-217, Wright Air Development Center, Wright-Patterson AFB, Ohio, May 68.

Ayre, Robert S. and Abrans, Joel I., Dynamic Analysis and Response of Aircraft Arresting Systems, Journal of the Engineering Mechanics Division, Proceedings of the American Society of Civil Engineers, Paper 1580, Arp 58.

APPENDIX A

CURVES OF PREDICTED MAXIMUM AIRCRAFT ARRESTING HOOK LOADING VERSUS AIRCRAFT GROUNDSPEED AT CABLE ENGAGEMENT FOR BAK-12ER BARRIER

BAK-12 (EXTENDED RUNOUT) ARRESTING SYSTEM
Aircraft Gross Weight - 18,500 lb

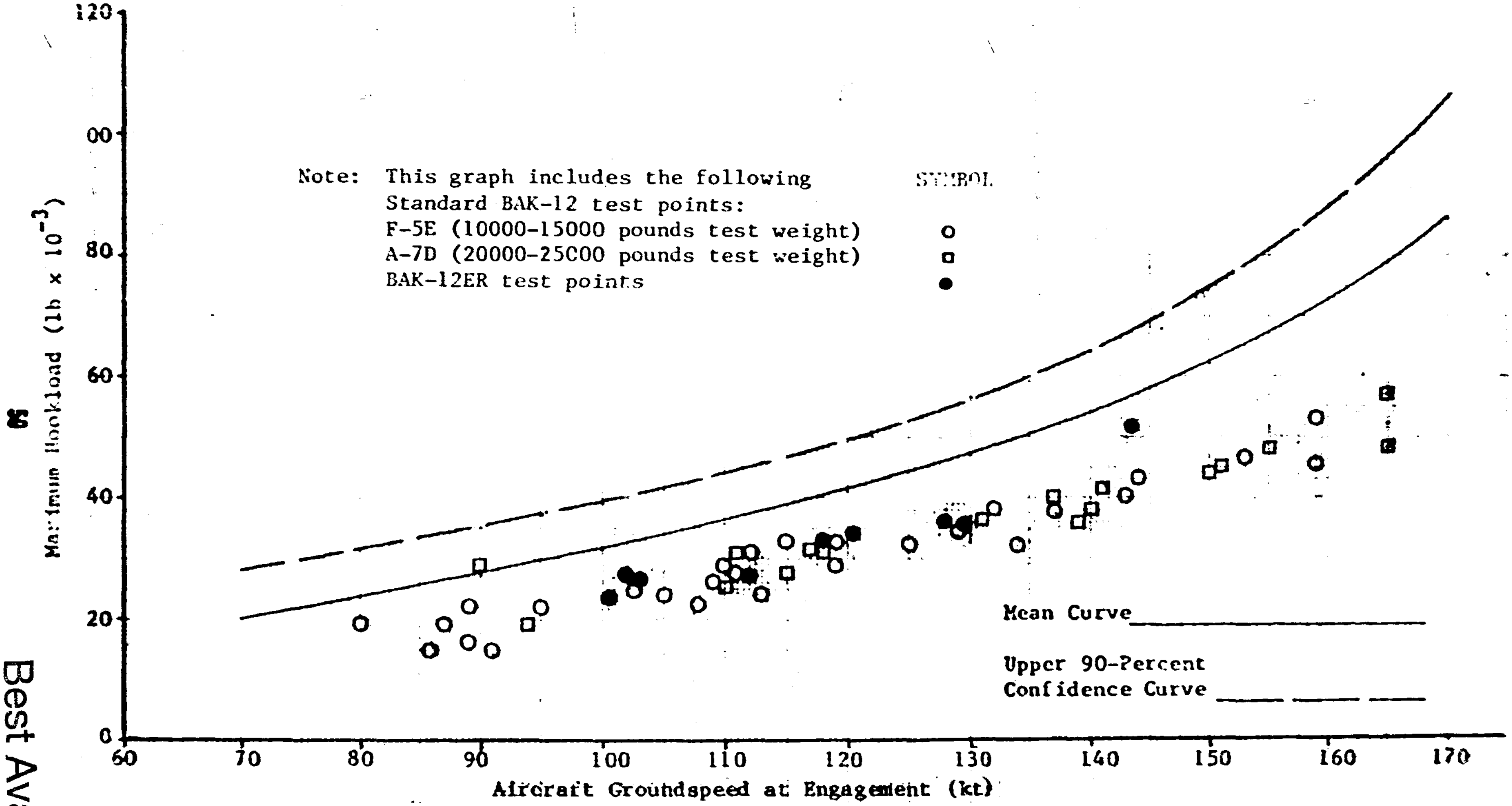


Figure A1 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

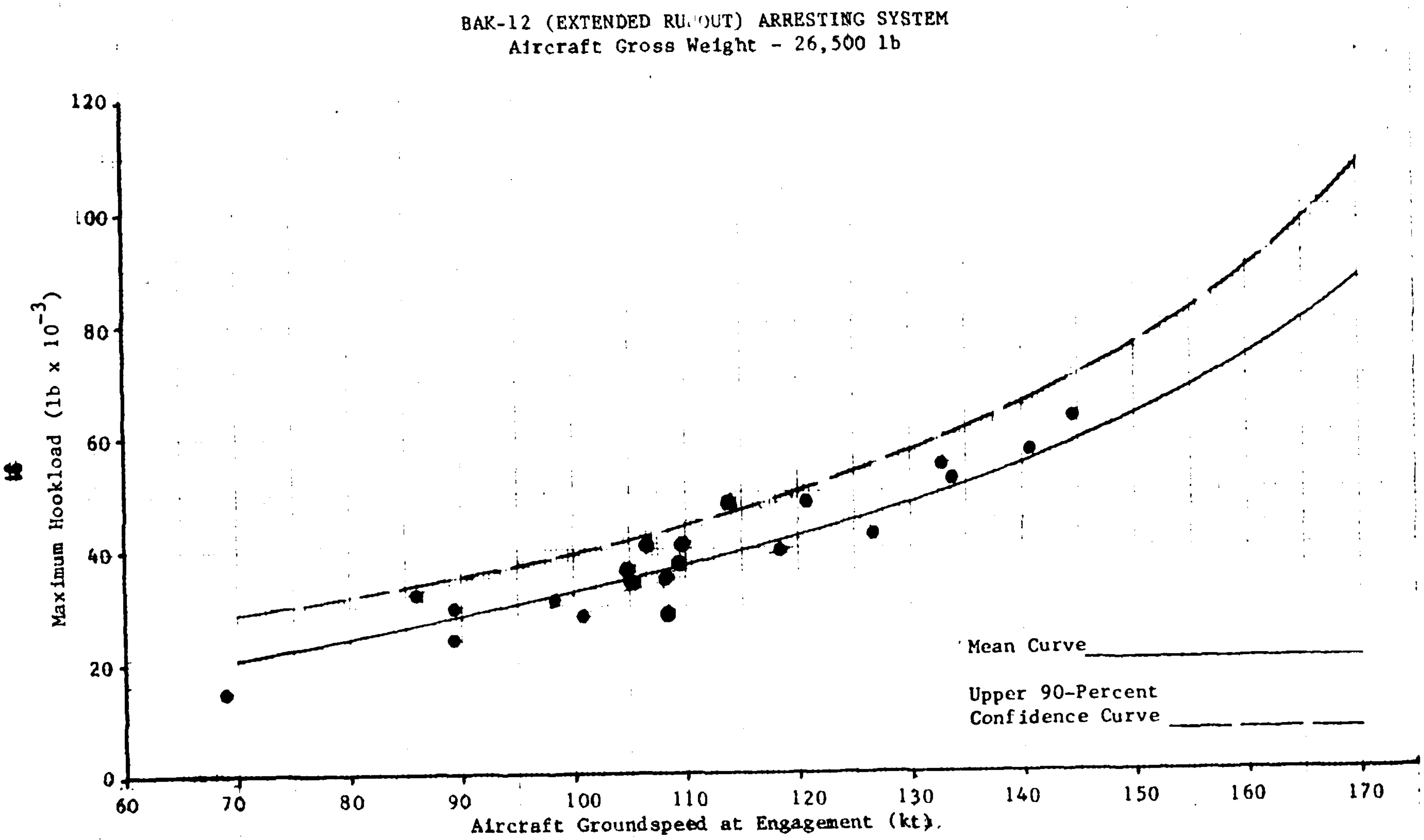


Figure A2 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

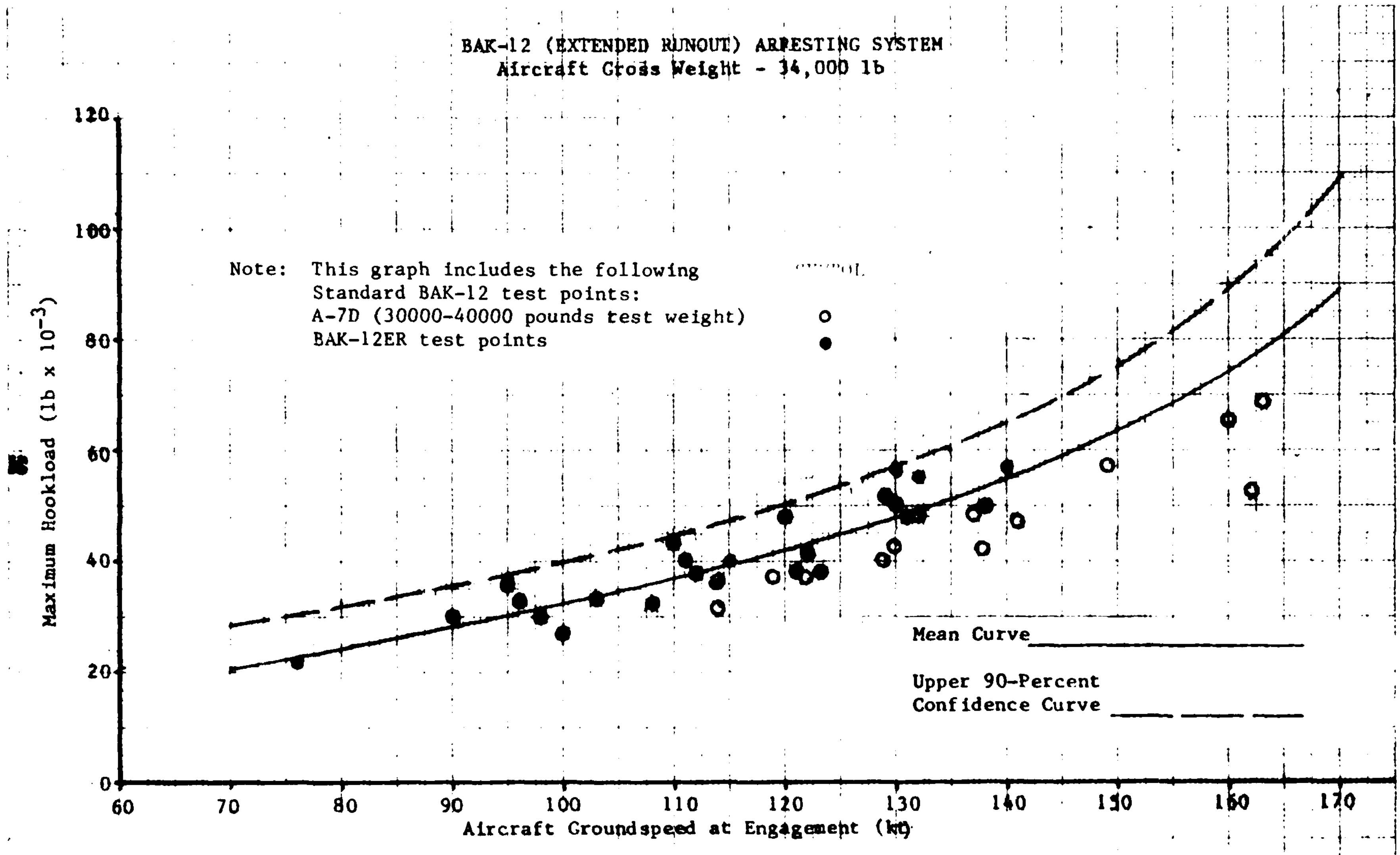


Figure A3 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

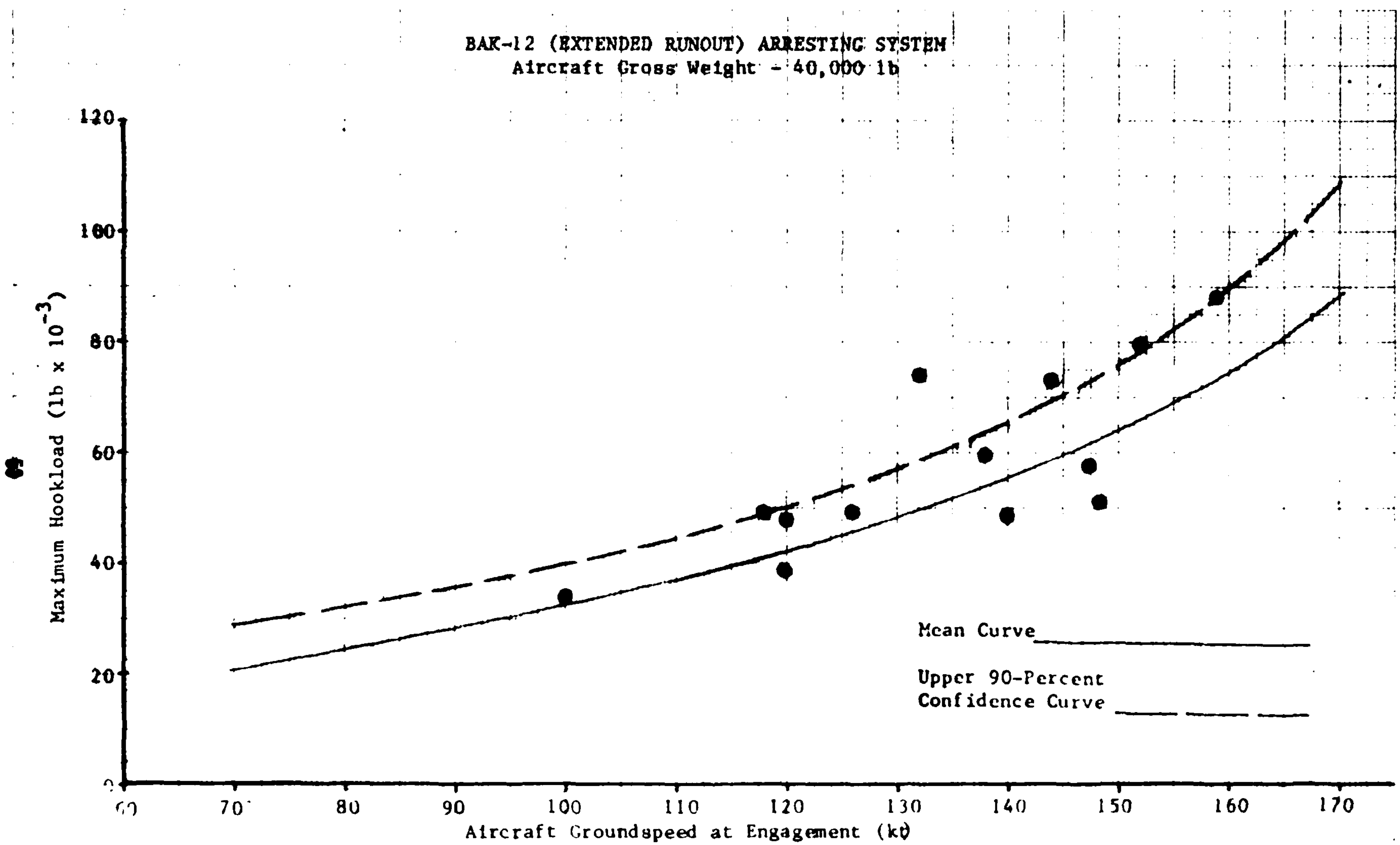


Figure A4 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

BAK-12 (EXTENDED RUNOUT) ARRESTING SYSTEM
Aircraft Gross Weight - 49,500 lb

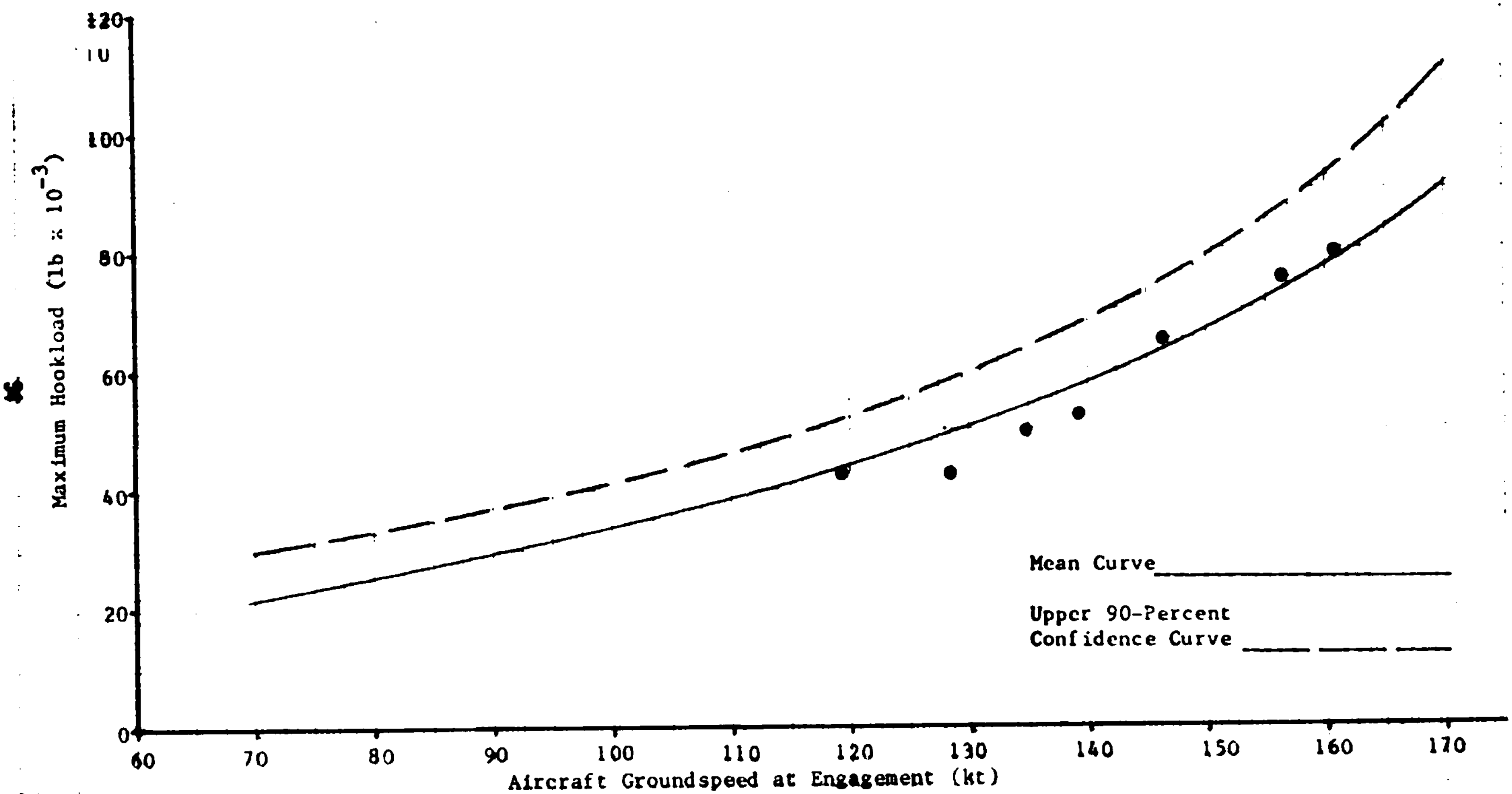


Figure A5 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

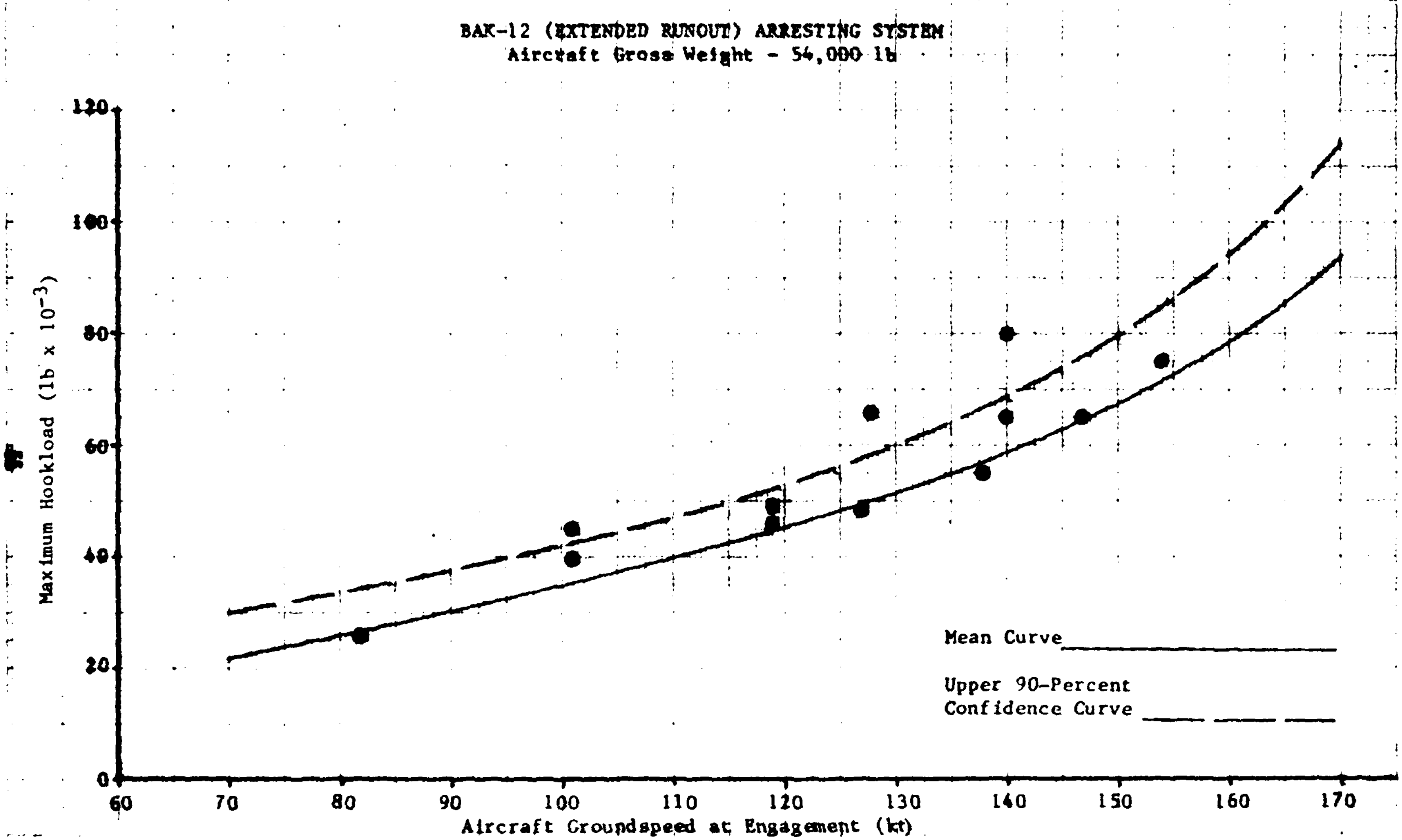


Figure A6 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

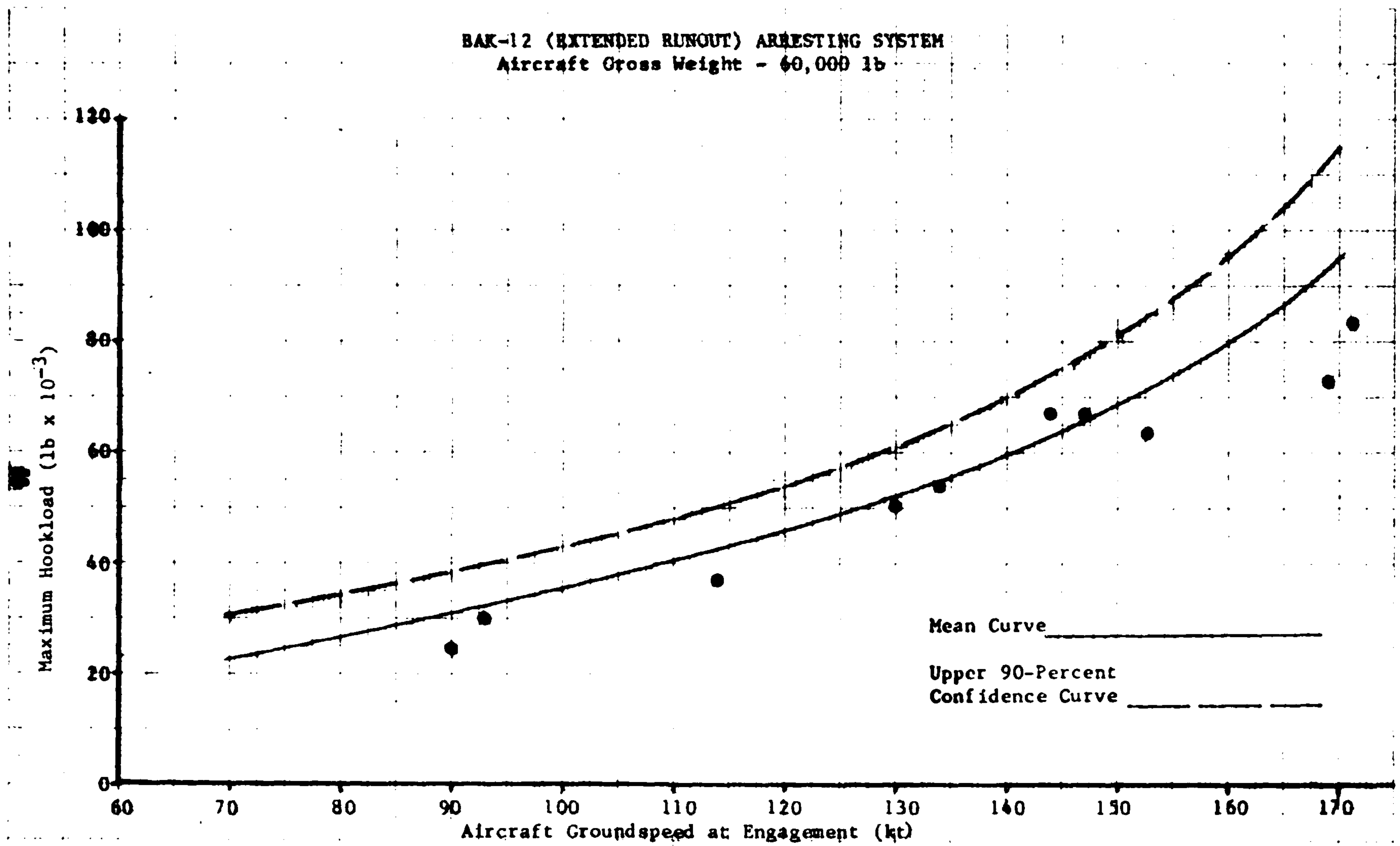


Figure A7 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

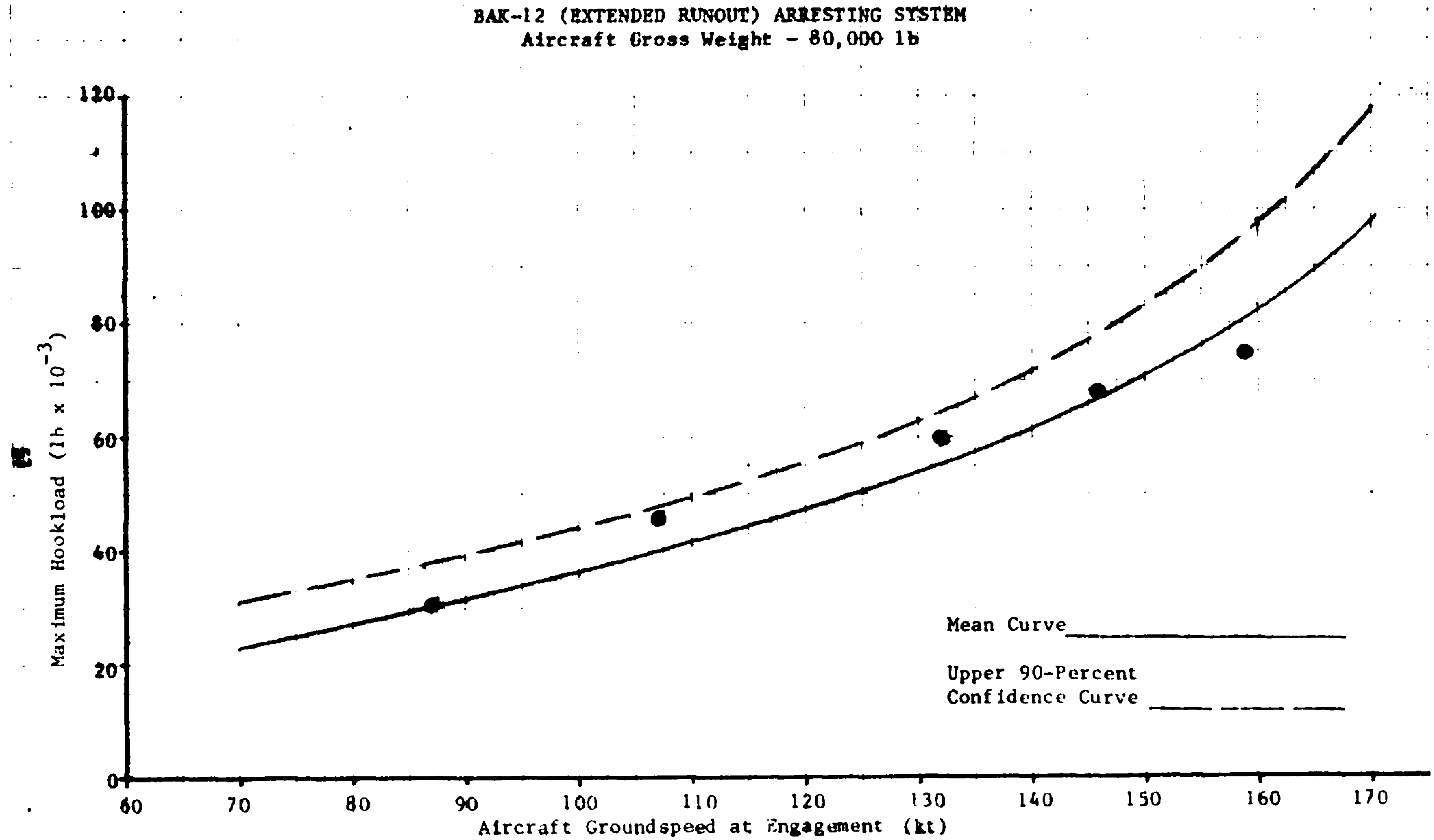


Figure A8 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

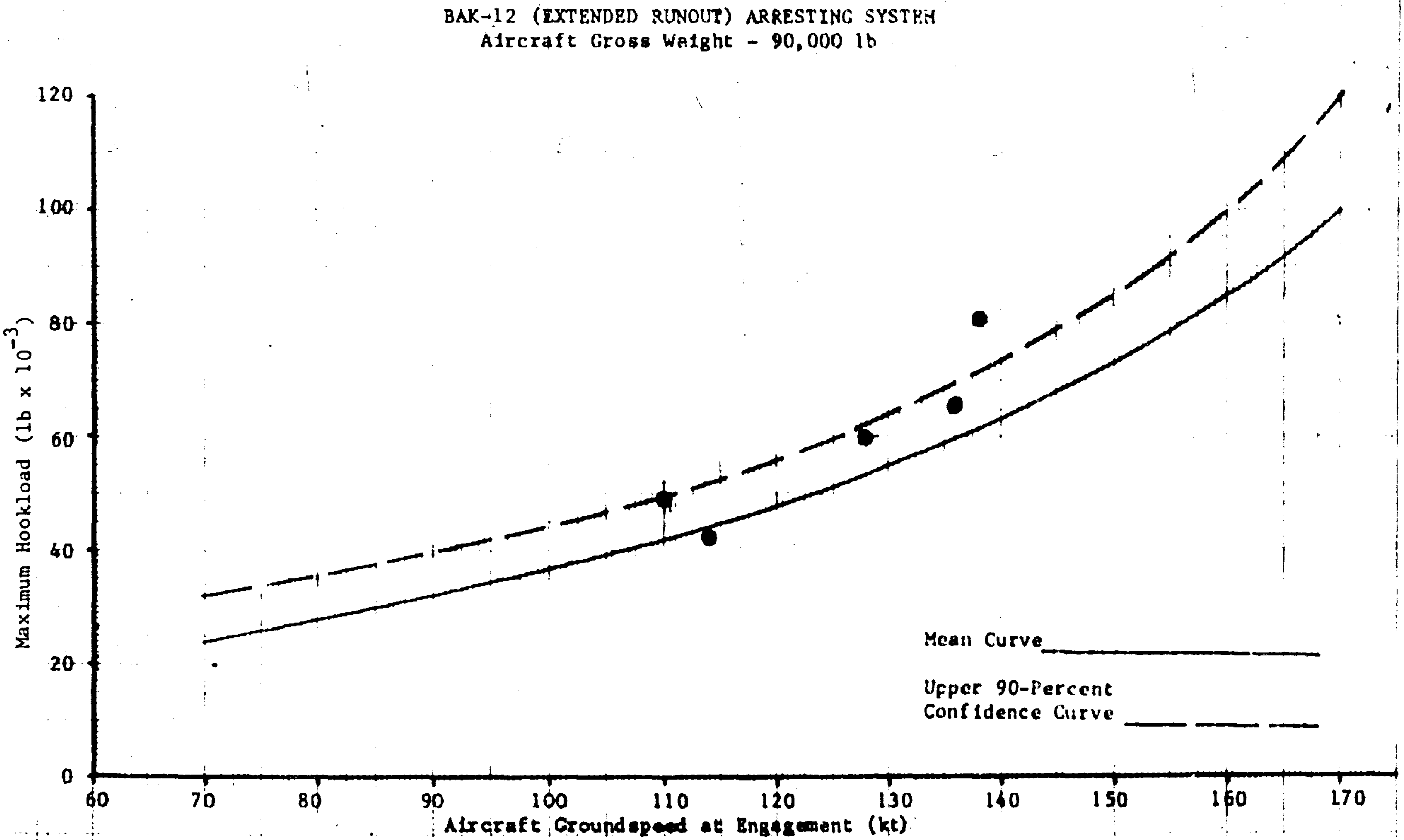


Figure A9 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-12ER Barrier

APPENDIX B

CURVES OF PREDICTED MAXIMUM AIRCRAFT ARRESTING HOOK LOADING VERSUS AIRCRAFT GROUNDSPEED AT CABLE ENGAGEMENT FOR BAK-13 BARRIERS

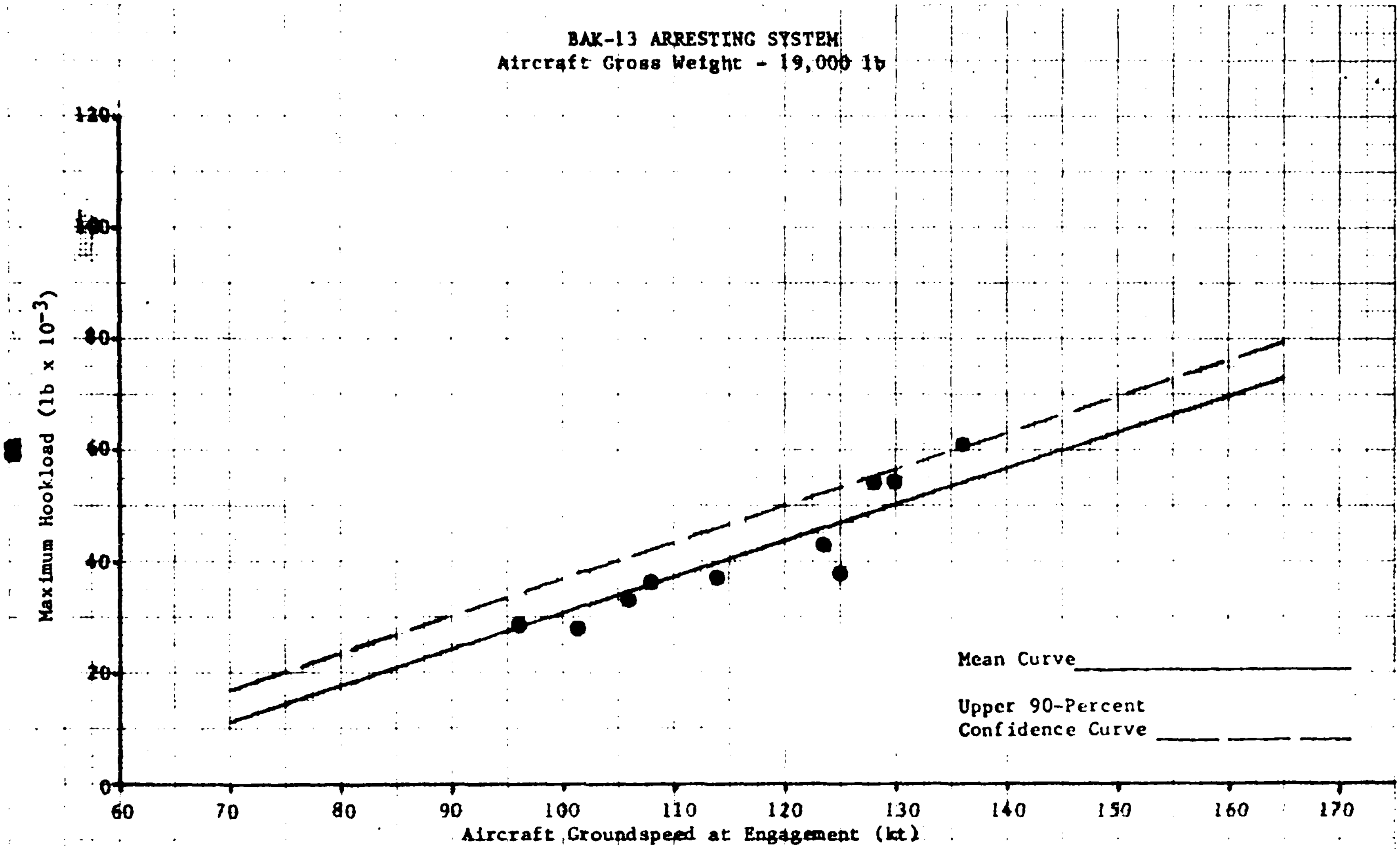


Figure B1 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

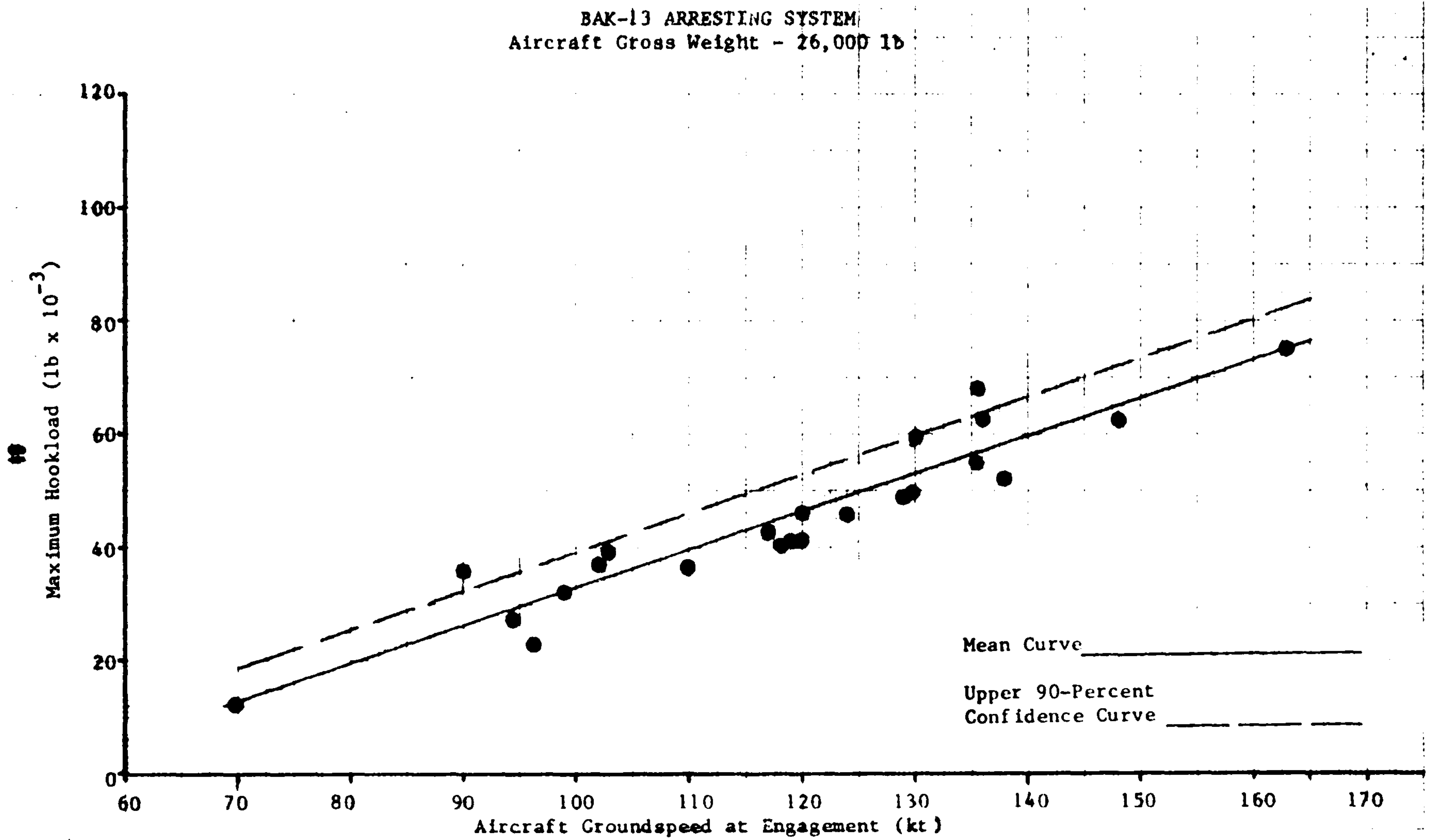


Figure B2 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

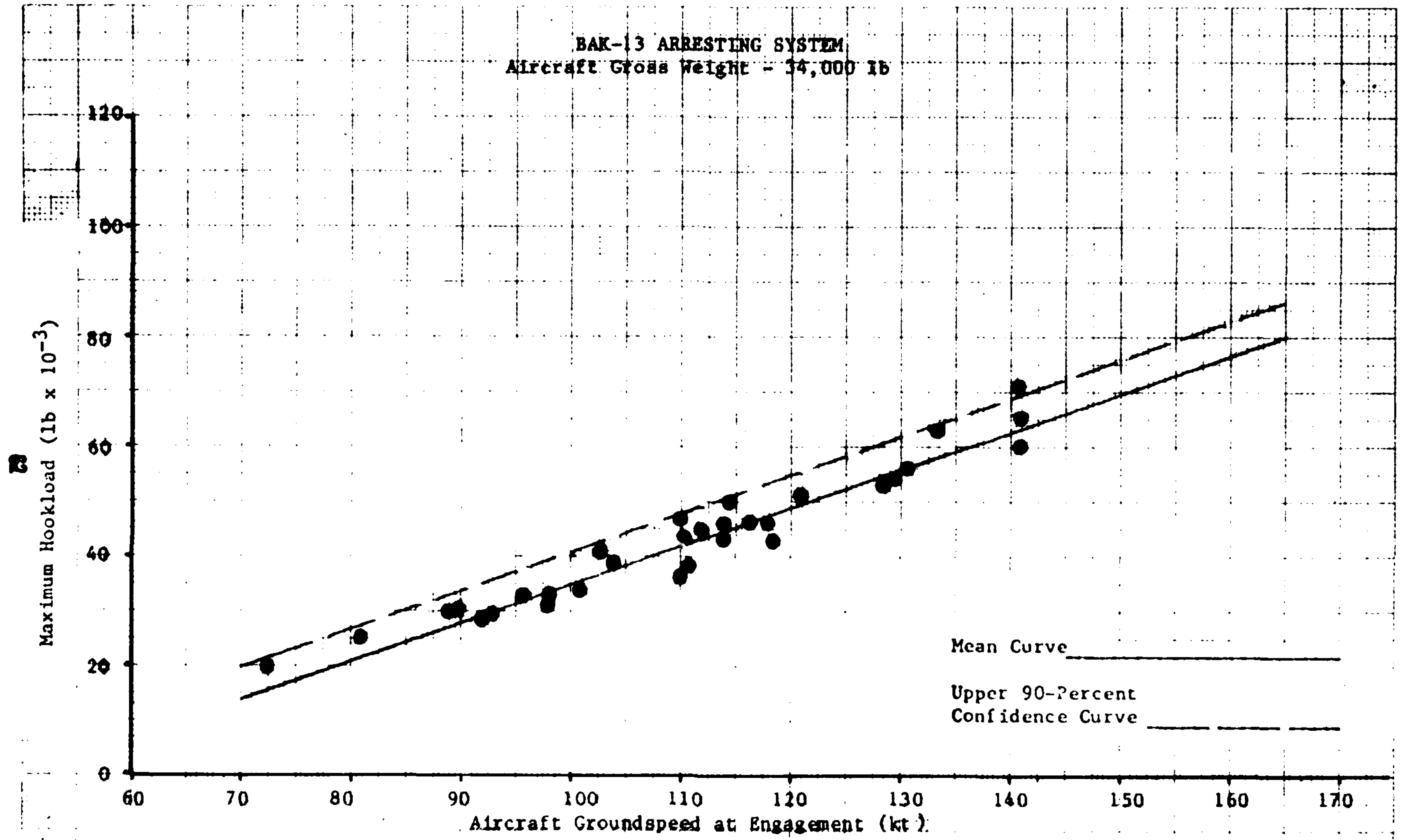


Figure B3 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

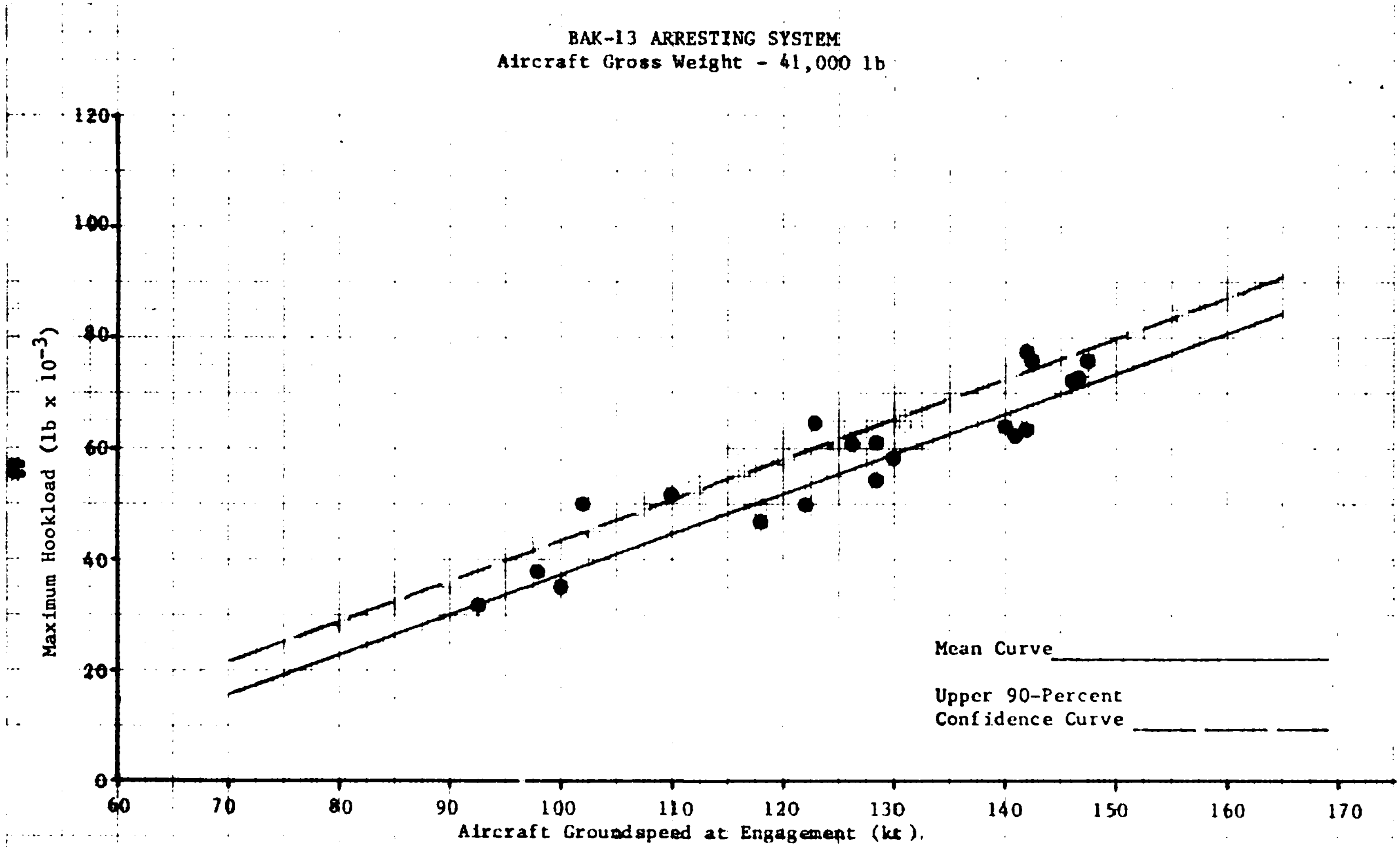


Figure B4 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

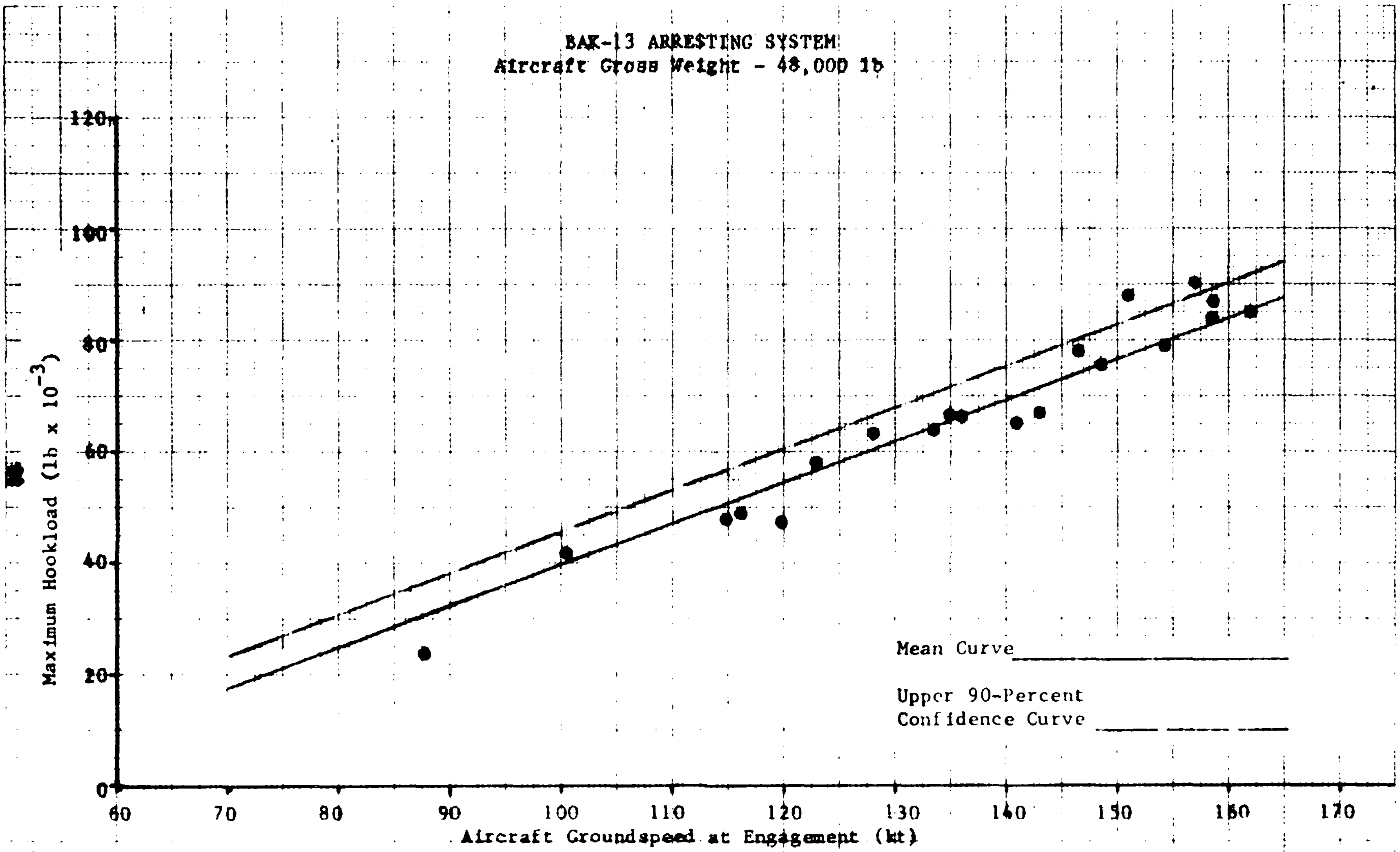


Figure B5 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

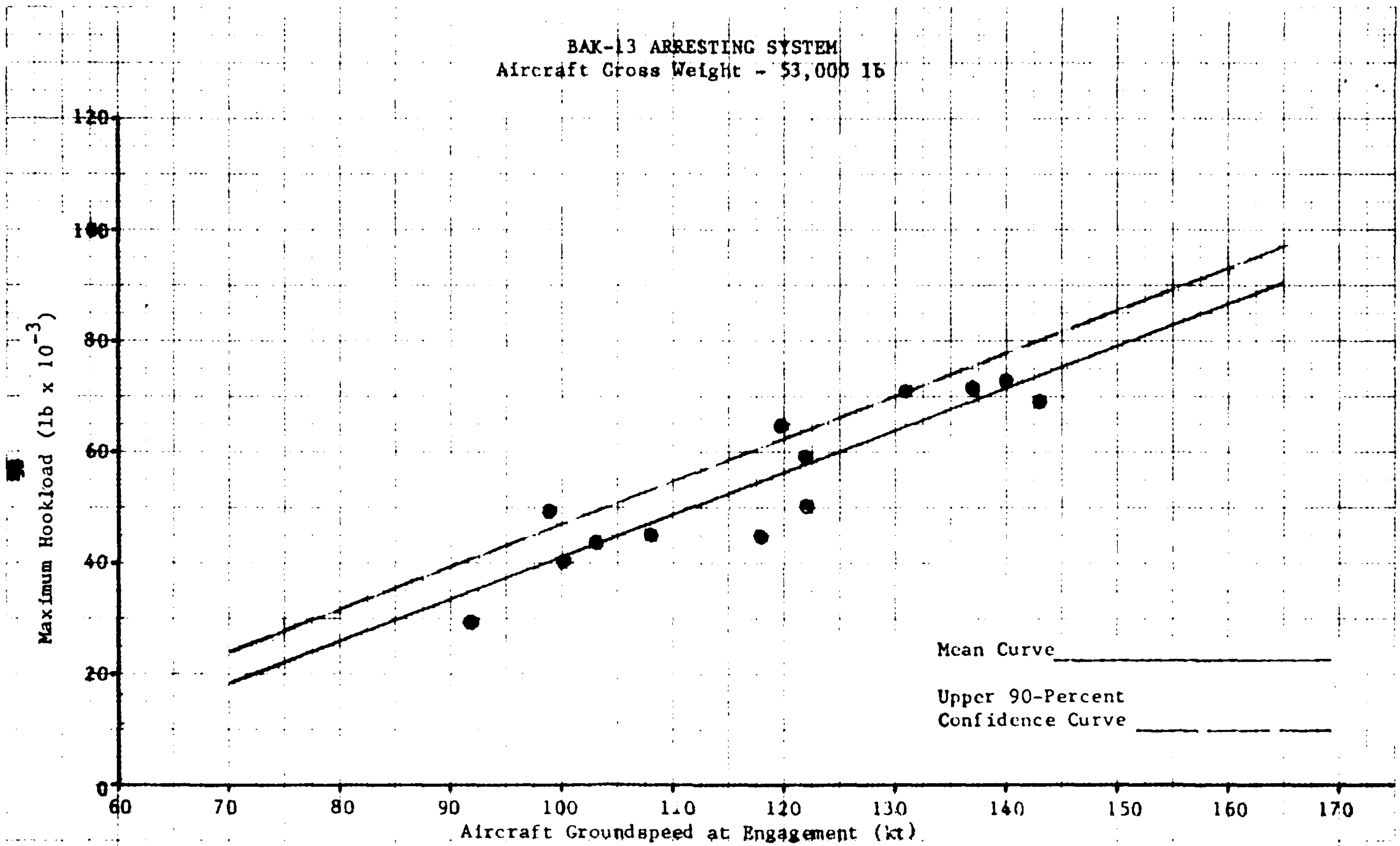


Figure B6 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

BAK-13 ARRESTING SYSTEM
Aircraft Gross Weight - 60,000 lb

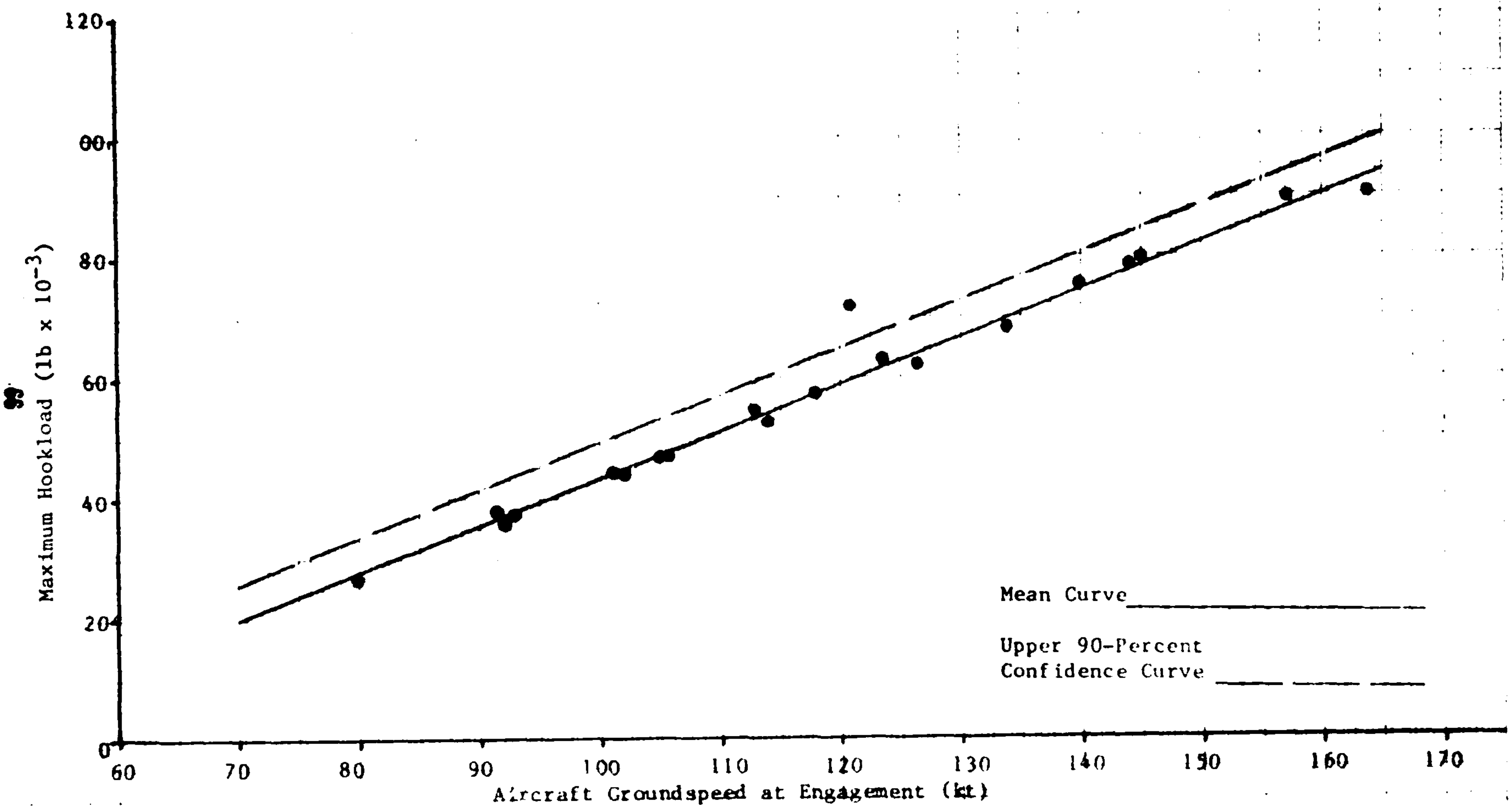


Figure B7 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

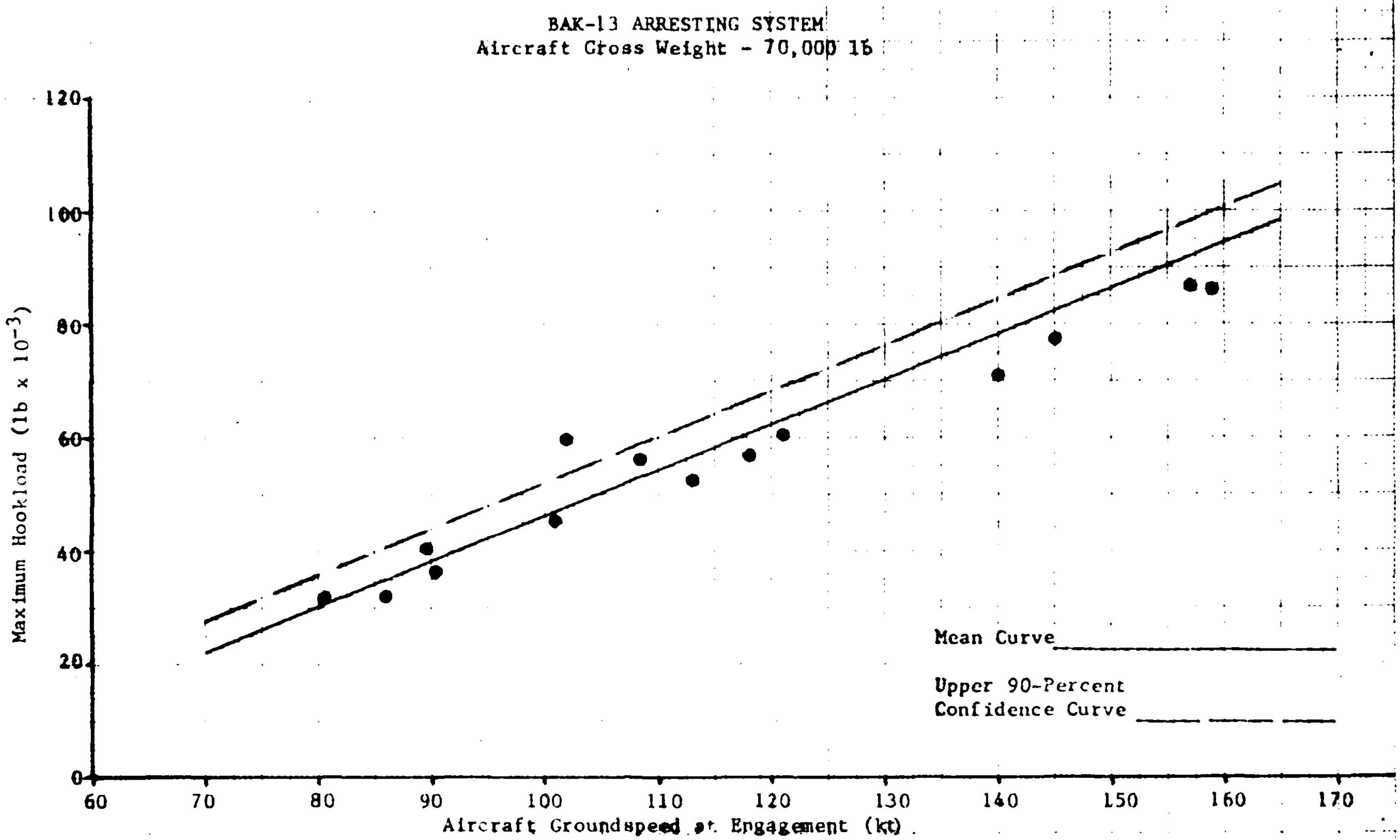


Figure B8 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers

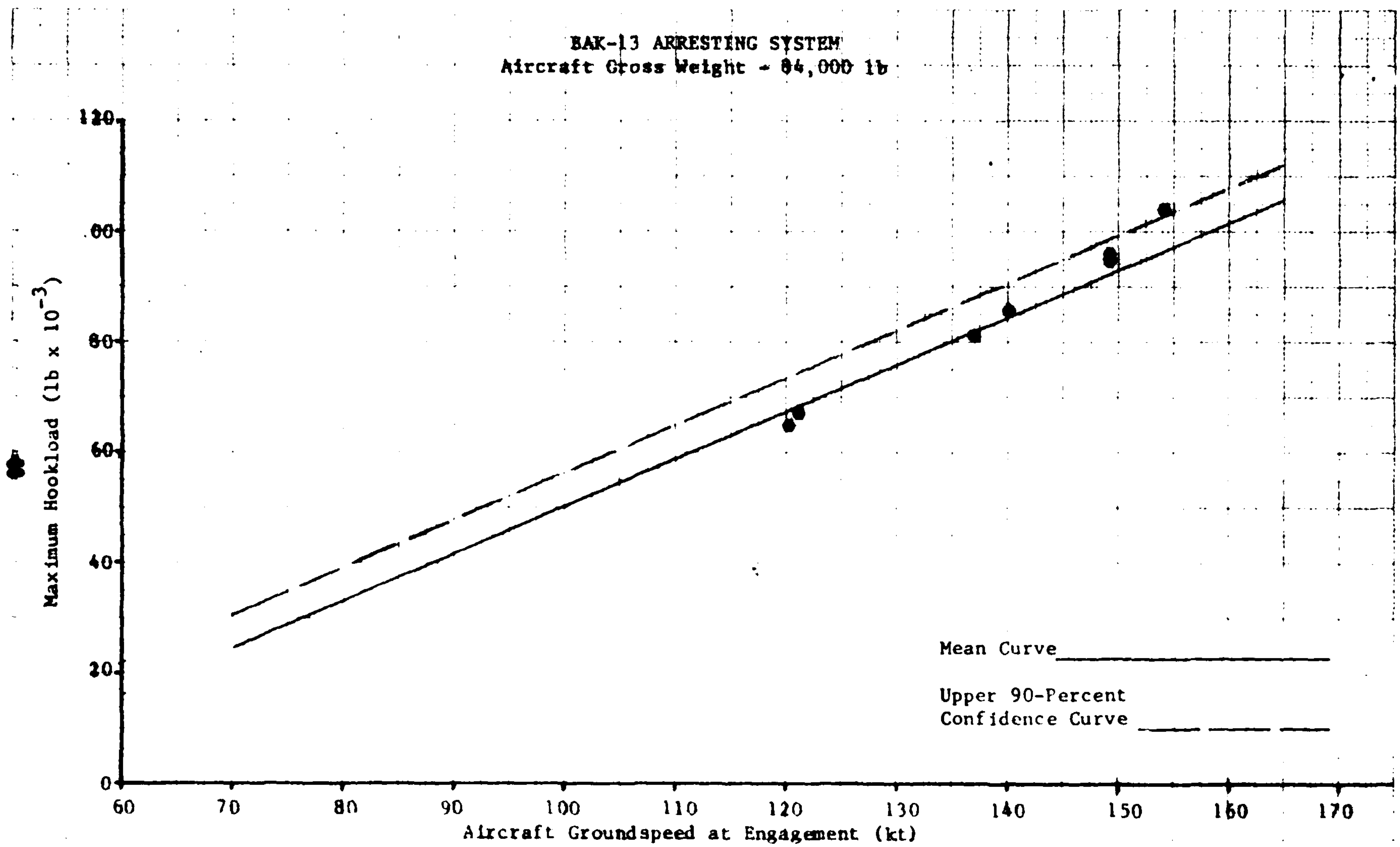


Figure B9 Curves of Predicted Maximum Aircraft Arresting Hook Loading Versus Aircraft Groundspeed at Cable Engagement for BAK-13 Barriers