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EFFECT OF WIND OVER DECK CONDITIONS ON AIRCRAFT APPROACH SPEEDS FOR CARRIER LANDINGS

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INTRODUCTION

The NAVAL AIR DEVELOPMENT CENTER performs photographic surveys of operational carrier landings to determine aircraft landing parameters and structural loads. Recent landing loads surveys have reported aircraft approach speeds in excess of those expected. This increase is a cause of concern, since higher approach speeds increase the loads on the aircraft's arresting hook, landing gear and associated support structure. These higher loads shorten the fatigue life and increase maintenance costs for the aircraft. Table (1) lists the mean values of principle landing parameters from recent carrier surveys. The column of table (1) labeled NATOPS Approach Speed is the recommended approach speed for an aircraft landing at the mean landing weight.

This report identifies the source of this approach speed increase, and shows that it is real and statistically significant. It identifies excess wind over deck, a wind over deck condition higher than the minimum recovery head wind, as the source of the increase in approach speed.

TABLE 1: F-14 DATA SURVEY COMPARISON

SURVEY		AVG SINK SPEED	ENGAGNG SPEED TD	WIND OVER DECK	APPRCH SPEED	GLIDE SLOPE BETA vv	GLIDE SLOPE BETA HW	A/C PITCH TD	LANDNG WEIGHT	NATOPS APPRCH SPEED
SURVEY 47	MEAN	12.5	117	31	148	3.4	3.6	8.1	50549	134.4
	STD DEV	2.24	6.16	3.95	4.88	0.66	0.51	1.31	1237	
	ALL LANDINGS NUMBER OF EVENTS	213	213	213	213	213	211	213	213	
SURVEY 47	MEAN	12.9	120	28	148	3.3	3.4	7.8	50807	134.7
	STD DEV	1.97	4.51	1.67	4.24	0.58	0.38	1.24	1246	
	3.5 DEGREE GLIDE SLOPE NUMBER OF EVENTS	103	103	103	103	103	103	103	103	
SURVEY 47	MEAN	12.2	113	34	147	3.4	3.8	8.3	50309	134.1
	STD DEV	2.43	5.17	2.98	5.36	0.72	0.54	1.32	1180	
	4.0 DEGREE GLIDE SLOPE NUMBER OF EVENTS	110	110	110	110	110	108	110	110	
SURVEY 45	MEAN	10.3	113	28	140	2.83	3.14	7.76	47788	130.7
	STD DEV	2.55	4.44	3.4	4.03	0.78	0.58	1.17	1629	
	3.5 DEGREE GLIDE SLOPE NUMBER OF EVENTS	157	158	158	158	157	156	158	156	
SURVEY 45	MEAN	11.9	109	31	140	3.36		7.53	47953	130.9
	STD DEV	2.76	6.56	5	5.88	0.89		1.34	1525	
	3.5 DEGREE GLIDE SLOPE NUMBER OF EVENTS	95	95	95	95	95		95	95	
SURVEY 42	MEAN	10.4	110	25	135	3.26	3.61	7.5	49415	132.9
	STD DEV	2.65	5.13	2.58	4.54	0.94	0.78	1.33	1666	
	3.5 DEGREE GLIDE SLOPE NUMBER OF EVENTS	83	83	83	83	83	82	83	82	

Approach Speed vs Wind Over Deck Analysis

The Angle of Attack Indexer, as well as the Angle of Attack (AOA) indicator on the heads up display, is the primary flight instrument used while flying an approach to a carrier landing. The AOA for an "on speed" approach is indicated on the instrument and is independent of aircraft weight. By holding the proper AOA, and maintaining the aircraft on the glideslope established by the carrier's Fresnel lens, a pilot will perform a successful carrier landing.

The NATOPS recommended approach speed curves are derived from flight test data for each individual aircraft model. For a fixed value of glideslope angle and fixed angle of attack, these curves result in a linear relationship between aircraft approach speed and landing weight.

The NAVAL AIR DEVELOPMENT CENTER (NADC) calculates approach speed for actual carrier landings from the sum of engaging speed (closing speed with the ship) derived from our film records and the "Wind over Deck" recorded on the aircraft carrier.

Attempts to verify the accuracy of NADC approach speeds with the recommended NATOPS curves have consistently shown that the measured approach speeds are higher than those recommended in the NATOPS manuals. Higher approach speeds have been measured during carrier surveys for all models of carrier aircraft. Figure (1) is a plot of measured approach speed versus landing weight for our entire F-14 data base. This data base includes F-14 landing data from Survey 33, performed aboard the USS ENTERPRISE in 1974, thru Survey 47, performed on the USS DWIGHT D EISENHOWER, in September of 1989. Figure (1) also shows the recommended NATOPS Approach Speed Curves for both the F-14A and F-14A PLUS aircraft.

For a carrier conducting flight operations, the aircraft recovery bulletins prescribe a minimum value of "wind over deck" required to land aircraft. The values are different for each aircraft type. "Wind over Deck" is the sum of two components, first the prevailing natural wind and second, the wind created by the forward motion of the ship. The carrier normally sails into the prevailing wind to maximize the value of "wind over deck". The actual "wind over deck" provided is determined by the requirements of the various types of aircraft in the landing pattern, the amount of natural wind, the sea state and other ship operating constraints (such as restrictions on operating areas, weather, other maritime traffic, speed capability or fuel state of escorting vessels). To reduce the carrier's fuel consumption, minimum ship speed is often used consistent with operational requirements.

The operating conditions during the tests to establish the NATOPS Recommended Approach Speed Curves may not be the same as those existing during an operational survey. The NATOPS tests are constrained by the low speed handling qualities of the particular

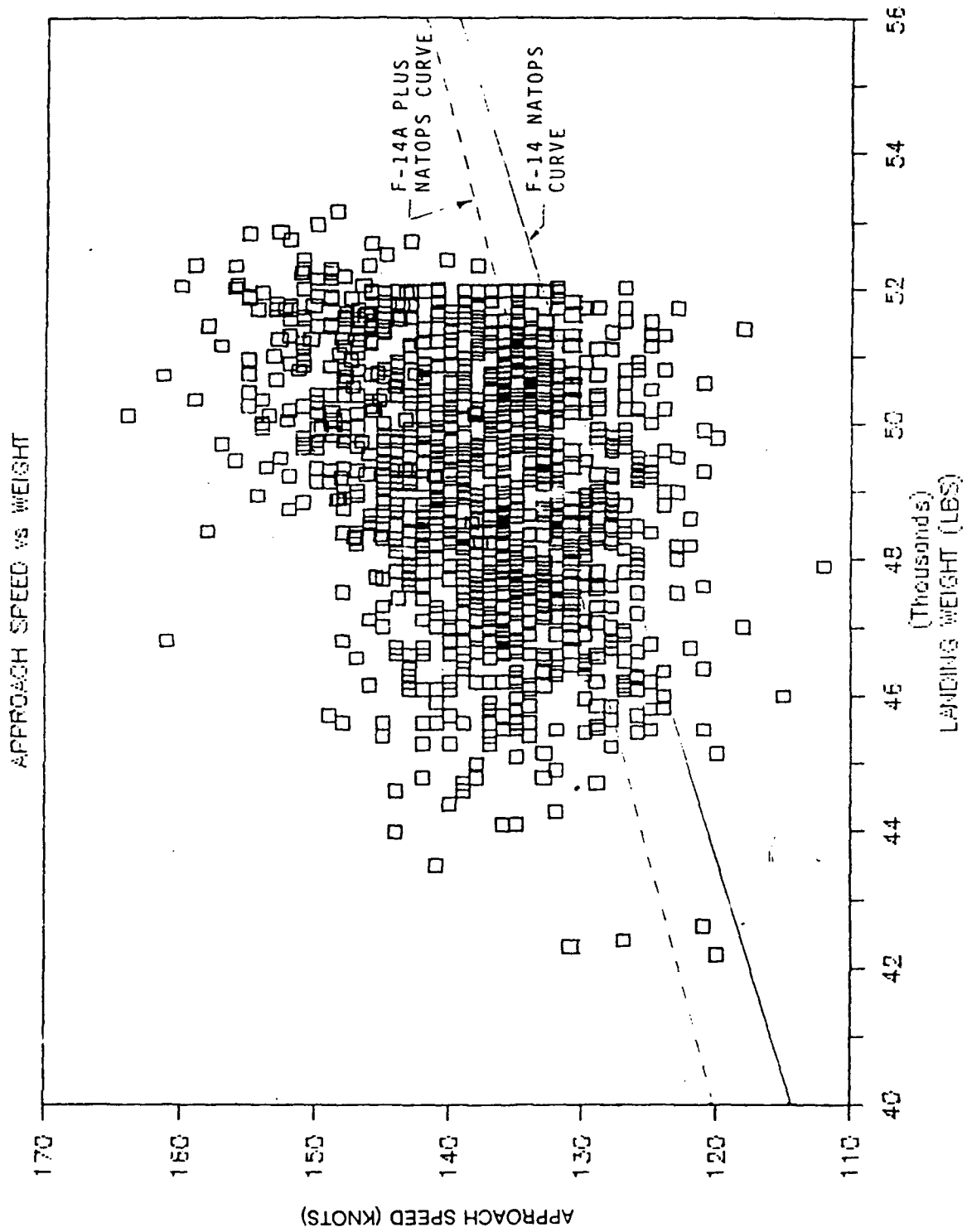


Figure 1. F-14A LANDINGS, ALL SURVEYS, APPROACH SPEED VERSUS LANDING WEIGHT (RAW DATA)

aircraft, which determines the minimum flying speeds for the aircraft. The glideslope followed during the test, which is defined by the fresnel lens, establishes the aircraft's sink rate. The minimum recovery head wind is determined by the difference between the minimum flying speed and the maximum engaging speed capability of the carrier's arresting gear.

If the "wind over deck conditions" or the combination of ship speed and natural wind is not identical to that existing during the NATOPS test program, the value of approach speed, glideslope angle or angle of attack maintained during an carrier landing will vary from the NATOPS test conditions.

During the final stages of a carrier landing, the pilot's principle guidance shifts from the AOA indexer to the glideslope indicator i.e. the "ball" seen on the Fresnel Lens. The pilot must maintain the ball centered in the mirror to land safely on the carrier deck. It is the corrections that the pilot makes to keep the ball centered that account for the approach speed variations we observe. This can be demonstrated by examining the following scenarios. Each of these cases start with an aircraft of identical landing weight flying the NATOPS recommended approach speed for that landing weight.

CASE 1

Assume the pilot is landing in still air onto a carrier which is not moving through the water. In this case, the aircraft's approach speed and engaging speed are identical. Further, assume that the pilot is maintaining the prescribed approach angle of attack, and flying down the prescribed glideslope, this establishes his sink rate. In this case, the aircraft's glideslope angle (BETA) as seen from the flight deck is defined by the equation

$TAN (BETA) = \text{sink rate} / \text{engaging speed}$
(engaging speed is equal to approach speed in this case)

CASE 2

Now, the pilot is performing the same carrier landing, at the same landing weight, but in this case a natural head wind of X knots exists. Again the carrier is not moving. The approach speed, AOA, and glideslope angle do not change. In this case, the engaging speed is the aircraft approach speed minus the head wind. The equation defining the aircraft's glideslope angle as seen from the flight deck is

$TAN (BETA) = \text{sink rate} / \text{engaging speed}$
 $= \text{sink rate} / (\text{approach speed} - X)$

CASE 3

Next, the pilot performs the same carrier landing under identical conditions of weight, natural head wind, approach speed, etc, except that the ship has a forward velocity of Y knots. In this case, the aircraft's engaging speed with the carrier deck is the aircraft's approach speed minus the sum of natural head wind and ships forward velocity, (this sum is the value of "wind over deck", W). $W = X + Y$. The equation defining glideslope angle as seen from the flight deck is

$$\begin{aligned} \text{TAN (BETA)} &= \text{sink rate} / \text{engaging speed} \\ &= \text{sink rate} / (\text{approach speed} - \text{wind over deck}) \\ &= \text{sink rate} / (\text{approach speed} - W) \end{aligned}$$

CASE 4

Finally , the pilot performs the same carrier landing under identical conditions of weight, approach speed, etc, except that natural head wind and the ship forward velocity have both changed. In this case, the aircraft's engaging speed with the carrier deck is the aircraft's approach speed minus the sum of new natural head wind and new ships forward velocity, resulting in a new value of "wind over deck", W'. The equation defining glideslope angle as seen from the flight deck is

$$\begin{aligned} \text{TAN (BETA)} &= \text{sink rate} / \text{engaging speed} \\ &= \text{sink rate} / (\text{approach speed} - \text{wind over deck}) \\ &= \text{sink rate} / (\text{approach speed} - W') \end{aligned}$$

Clearly, each of these four cases is different. If the approach speed is identical, then the sink rate or glideslope angle must change. The pilot must adjust the parameters within his control, e.g. AOA and engine thrust, to maintain his aircraft on glideslope, since this controls his touchdown point. This forces the pilot to change his approach speed and AOA to land.

To test this assumption on the effect of wind over deck with respect to aircraft approach speed, the NADC data base of carrier landing parameters was used. We currently have landing parameters from a total of over 1100 F-14 carrier landings from a variety of carrier surveys. This data was sorted by landing weight and wind over deck. Landings with weights within a range of one thousand pounds were analyzed. This was to determine if a relationship could be established between approach speed and wind over deck. The NATOPS Recommended Approach Speed versus Landing Weight curve indicates that a one thousand pound weight variation in landing weight results in a two knot variation in approach speed. The queue size of 1000 lbs was selected since the standard error of estimate for engaging speed for the 70mm film system is 2.077 knots for an individual landing, the same uncertainty associated with a one thousand pound weight variation.

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Linear regression curves were fitted to the "constant weight" landings. The equation fitted was

$$\text{Approach Speed} = A + B * (\text{Wind over Deck})$$

The results are as follows:

<u>WEIGHT</u>	<u>No. of Landings</u>	<u>"A"</u>	<u>"B"</u>	<u>Std Error</u>
44-45K	15	114.4	0.785	3.8
46-47K	99	114.9	0.720	6.4
48-49K	192	114.7	0.804	5.4
49-50K	196	112.0	0.965	6.4
50-51K	204	118.6	0.748	6.9
51-52K	175	119.0	0.777	7.2

Clearly, all the data for the F-14 shows an increase in measured approach speed with increasing wind over deck which is independent of increasing landing weight. These curves indicate that 80% of the increase in wind over deck is translated into an increase in approach speed. A series of approach speed versus landing weight curves, plotted for specific values of wind over deck, also shows higher approach speeds as a function of wind over deck. These curves are presented as figure (2) for the F-14, figure (3) for the F-18 and figure (4) for the A-6E.

The regression analysis performed on our F-14 data base was repeated using our EA-6B Aircraft data base. The relationship between approach speed and wind over deck for the EA-6B is similar to that for the F-14. The EA-6B was chosen since this data base does not include any landings from Survey 47, which experience unusually high gusts, wind over deck, and rough seas. The results for EA-6B Aircraft are as follows:

<u>WEIGHT</u>	<u>No. of Landings</u>	<u>"A"</u>	<u>"B"</u>	<u>Std Error</u>
37-38K	23	106.5	0.894	6.2
38-39K	36	118.0	0.522	6.0
40-41K	50	113.6	0.798	5.1

These data samples show the same variation of approach speed with wind over identified for the F-14.

To further pursue the effect of wind over deck and landing weight on approach speed, a multiple regression on our landing data base

Figure 2. F-14A LANDINGS, ALL SURVEYS, APPROACH SPEED VERSUS LANDING WEIGHT

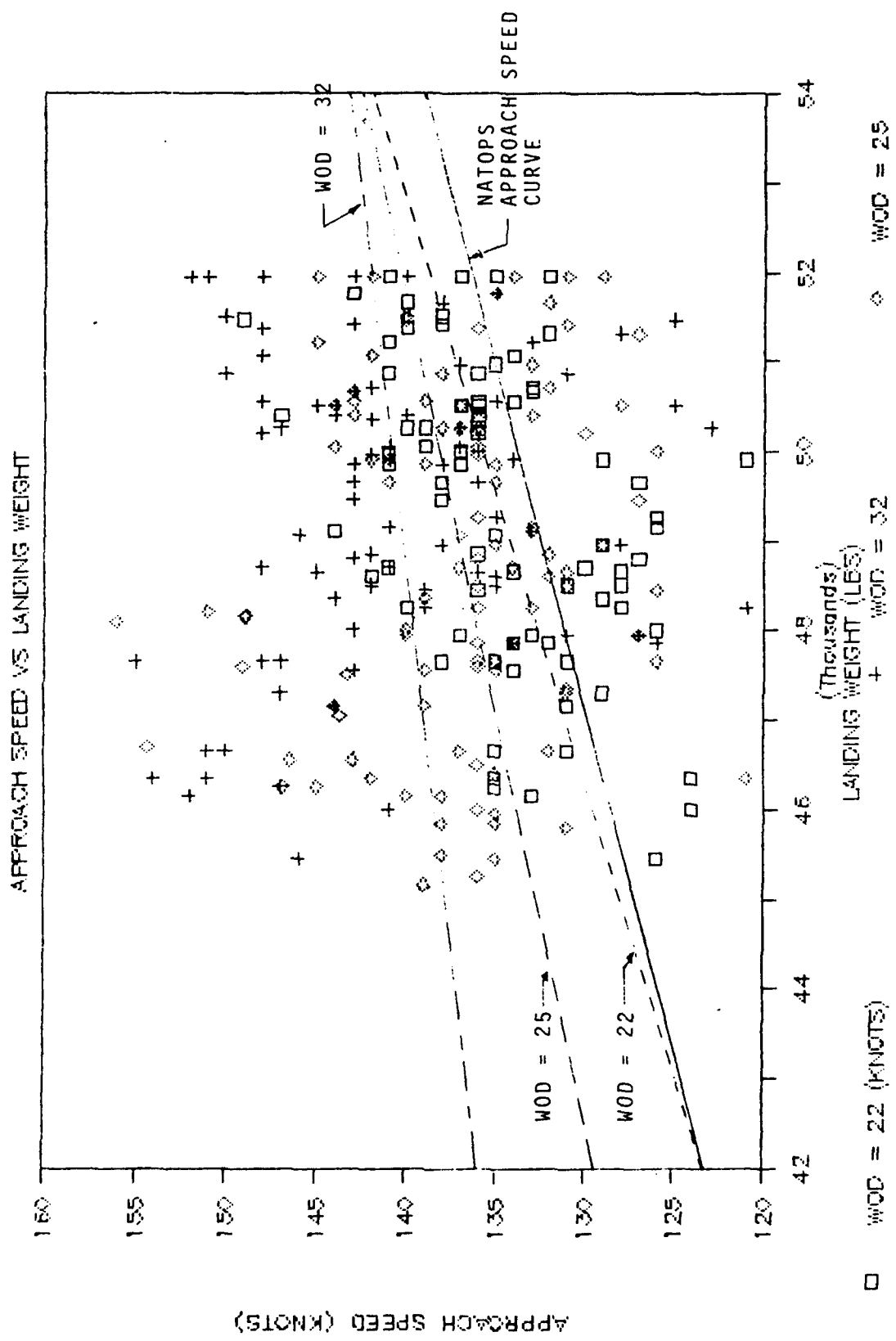


Figure 3. F-18 LANDINGS, ALL SURVEYS, APPROACH SPEED VERSUS LANDING WEIGHT

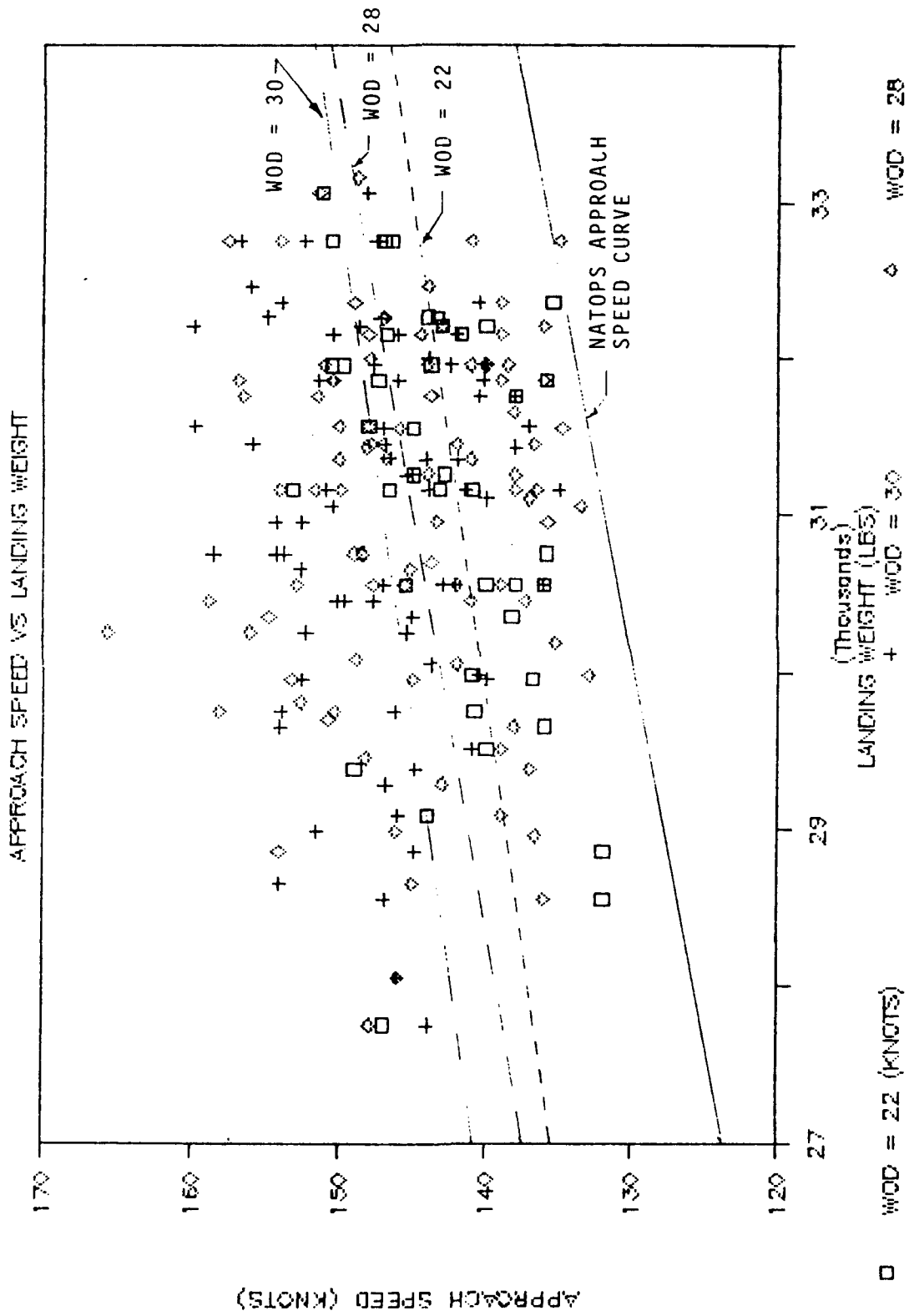
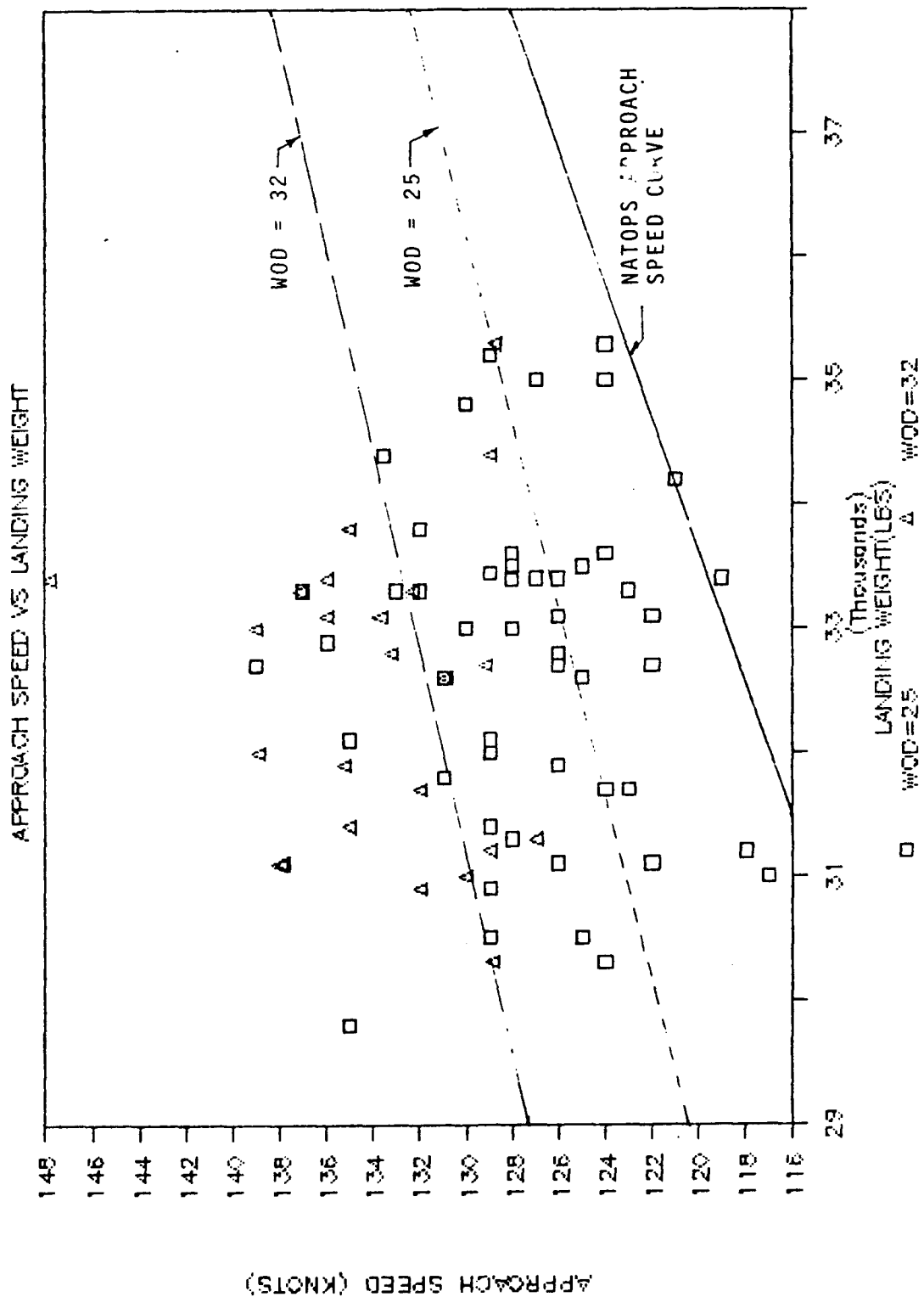


Figure 4. EA-6B LANDINGS, ALL SURVEYS, APPROACH SPEED VERSUS LANDING WEIGHT



was performed. This solves for the coefficients "A", "B" and "C" in the equation

$$\text{Approach Speed} = A + B * (\text{WIND OVER DECK}) + C * (\text{LANDING WEIGHT})$$

<u>MODEL</u>	<u>No. of Landings</u>	<u>"A"</u>	<u>"B"</u>	<u>"C"</u>
F-14	1130	112.0	0.780	0.000094
EA-6B	191	108.5	0.812	0.000081
A-6E	267	68.6	0.755	0.001175
F-18	608	90.7	0.270	0.001497

For these equations, the value of approach speed and wind over deck are in knots and landing weight is in pounds. The effect of a one knot increase in wind over deck causes a larger increase in approach speed than a 1000 lb increase in landing weight for all aircraft except the F-18. The typical increase in approach speed with landing weight on a NATOPS approach speed versus weight curve is two(2) knots per thousand pounds. Only the regression curve for the F-18 shows this typical NATOPS variation.

If the NATOPS tests to determine Minimum Recommended Approach Speed are all performed at the value of Minimum Recovery Head wind, essentially at constant "wind over deck", the effect of increasing "wind over deck" would not be apparent.

This analysis indicates that values of wind over deck in excess of that used while establishing the NATOPS approach speed curves forces the pilot to increase his approach speed to maintain his aircraft on the glideslope. Because changes in approach speed cause a change in lift for a fixed angle of attack, a corresponding change in sink rate will result. The excess wind over deck does not cause a one for one increase in approach speed. This is supported by the magnitude of the "B" coefficient of the regression analysis. The increase in approach speed coupled with the decrease in sink rate, reduces the glideslope angle. This variation in glideslope angle has also been observed in the surveys.

Table 1 of Military Specification MIL-A-8863A, Airplane Strength and Rigidity Ground Loads for NAVY Procured Airplanes, provides a design relationship between Aircraft Sinking Speed and Aircraft Engaging Speed.

This relationship is

$$\text{Average Sink Speed} = 0.128 * \text{Mean Engaging Speed}$$

where Sink Speed is in Feet per Second
and Engaging Speed in Knots

where the minimum value of sink speed is 11.5 Ft/Sec
and that the standard deviation of sink speed is given by

$$\text{STD DEV (sink speed)} = (0.015 * \text{Mean Engaging Speed}) + 1.667$$

with a minimum value of 3.0 using the same units.

These equations were plotted on curves of sink rate versus engaging speed. These curves are presented as figure (5) for the F-14, figure (6) for the F-18, figure (7) for the A-6E and figure (8) for the EA-6B. These curves show that the data from the landing loads surveys, with very few exceptions, does not exceed the structural design criteria of specification MIL-A-8863A. Curves of average sink speed plus one standard deviation of sink speed versus engaging speed are also provided. In addition, curves showing the expected values of sink speed as a function of engaging speed for a 3.5 degree glideslope and a regression curve of the measured values of sink speed versus engaging speed are also included. Figure (5) identifies a total of twenty three landings whose combination of sink speed and engaging speed exceeds the one sigma level of Mil-A-8863A. This is from a total of 1130 observations. Only two of these landings occurred during Survey 47 on the USS DWIGHT D. EISENHOWER (CVN-69). Thirteen of these landings were recorded aboard the USS ENTERPRISE (CVN-65) during Survey 33 which occurred in 1974. Four of the remaining landings occurred on the USS KITTY HAWK (CV-63) during Survey 38 in 1980. One night landing on the USS JOHN F KENNEDY (CV-67), during Survey 43 in 1984. Three landings, one day and two night, were recorded during Survey 45 aboard USS ENTERPRISE in 1985.

A significant portion of the increase in Aircraft Approach Speed observed during our carrier surveys can be accounted for by the increase in wind over deck above the required minimum recovery head wind. A calculated value of expected approach speed based on the NATOPS approach speed and excess wind over deck is listed in table 2 below for each F-14 Carrier Survey. The value of "B" used was 0.8. Excess wind over deck is the survey value minus 20 knots. The value of twenty knots was taken from table 1 of the structural design specification MIL-A-8863A. This is a representative value, since minimum recovery head wind varies with different aircraft carrier arresting gear type.

Figure 5. F-14A LANDINGS, BY SURVEY NUMBER, AVERAGE SINK SPEED VERSUS ENGAGING SPEED

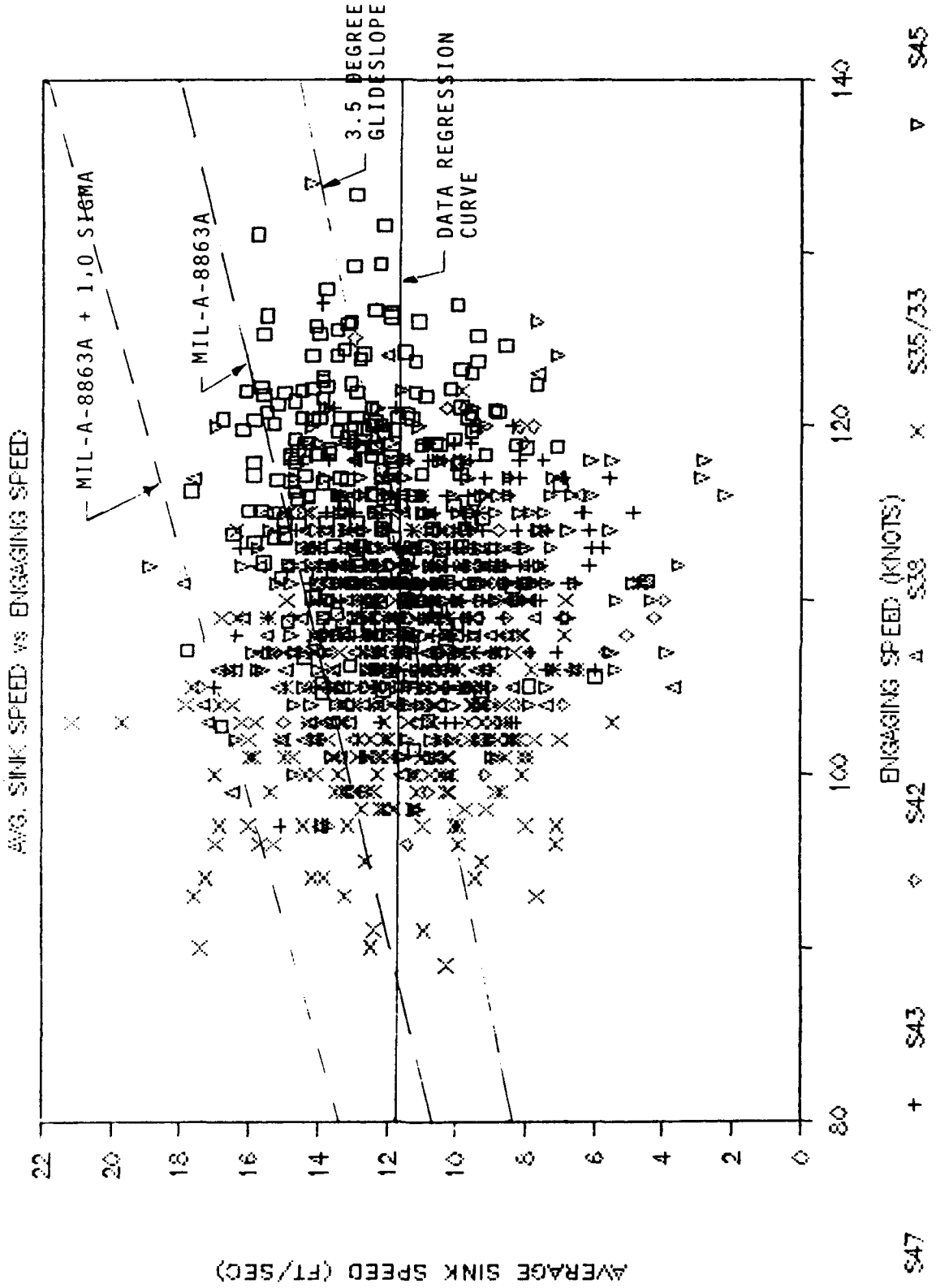


Figure 6. F-18 LANDINGS, BY SURVEY NUMBER, AVERAGE SINK SPEED VERSUS ENGAGING SPEED

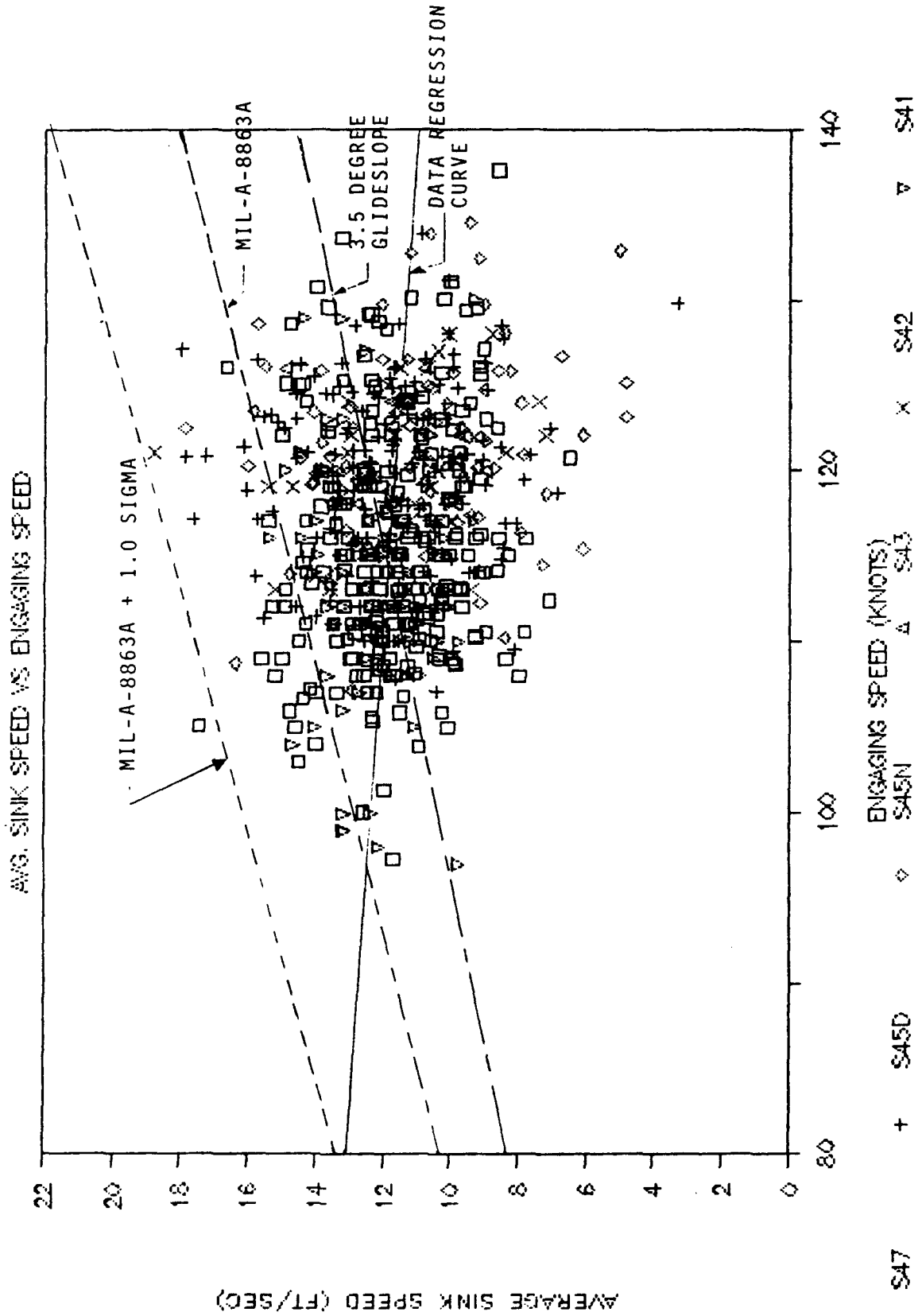


Figure 7. A-6E LANDINGS, BY SURVEY NUMBER, AVERAGE SINK SPEED VERSUS ENGAGING SPEED

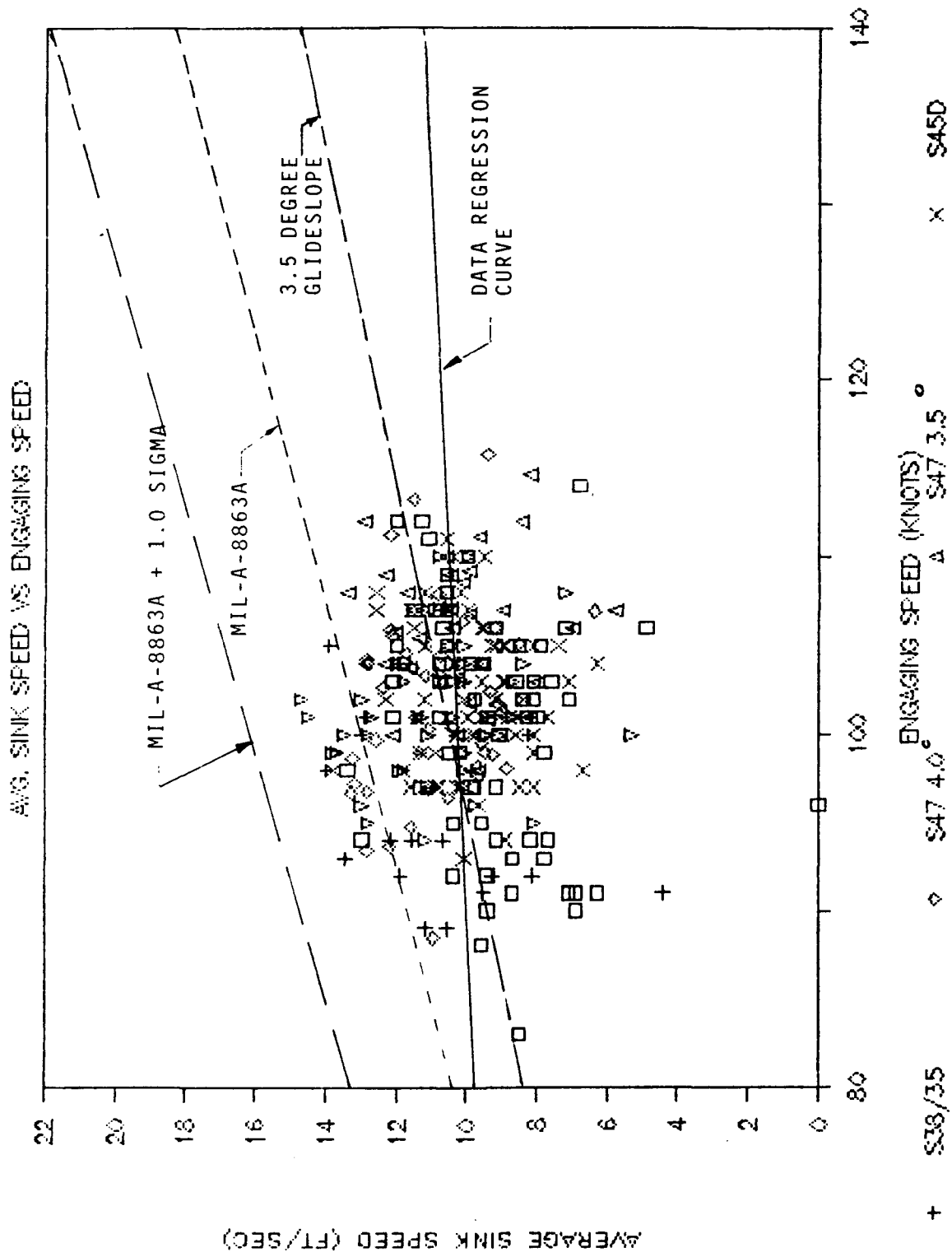


Figure 8. EA-6B LANDINGS, BY SURVEY NUMBER, AVERAGE SINK SPEED VERSUS ENGAGING SPEED

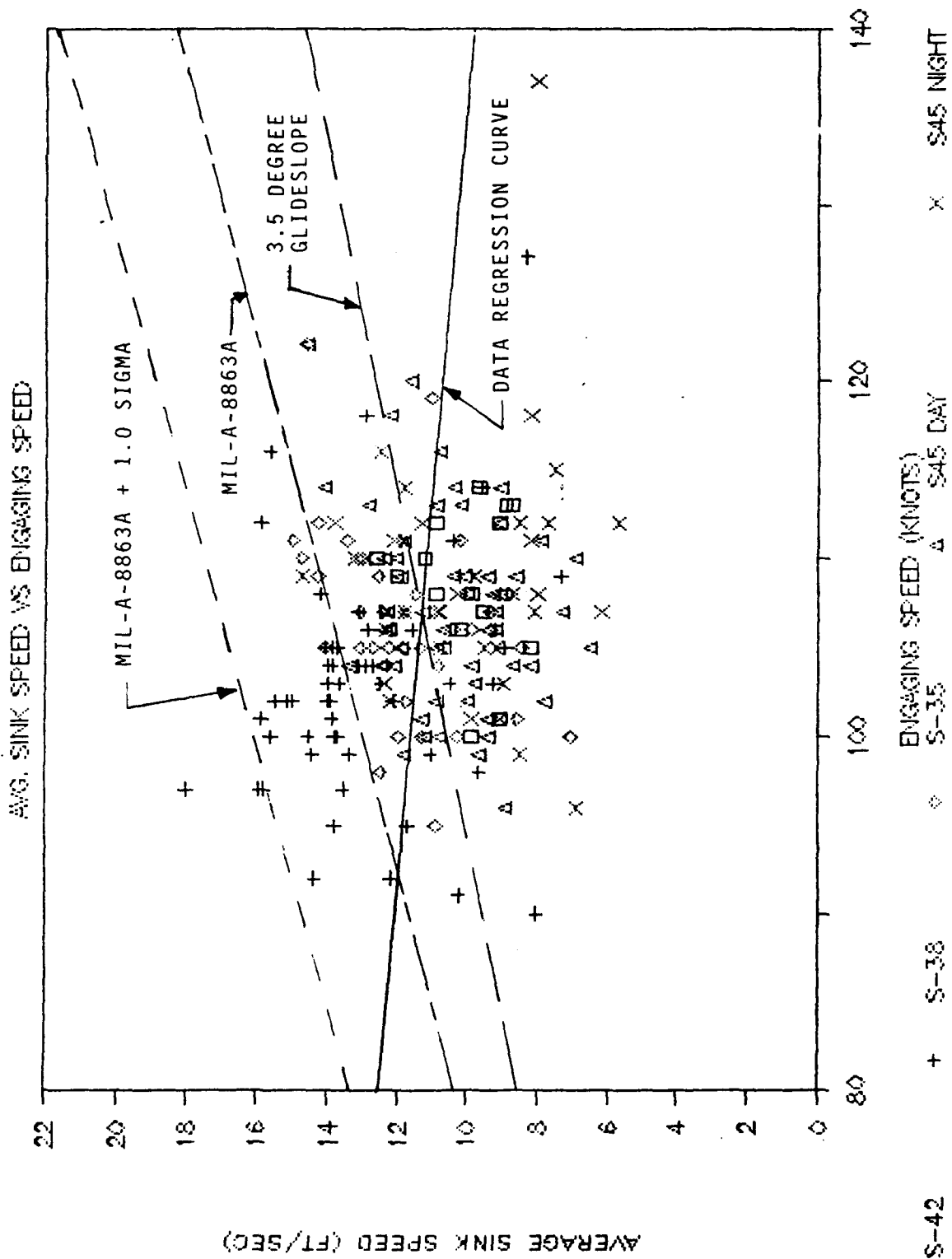


TABLE 2: MODIFIED F-14 APPROACH SPEEDS

SURVEY	NATOPS VPA	SURVEY VPA	EXCESS WOD	EXPECTED VPA
47 (3.5)	134	148	8	140
47 (4.0)	134	147	14	145
45 DAY	127	140	8	133
45 NIGHT	127	140	11	136
43 DAY	129	135	4	132
43 NIGHT	129	134	4	132
42	129	135	6	134
38	128	129	7	134
35	126	131	7	132

Comparison of the mean values of approach speed from our surveys with the calculated values of NATOPS Approach Speed plus the quantity "B * excess wind over deck" shows excellent agreement with our older survey data (prior to survey 45). Survey 45 night landings also match the prediction within 4 knots. The landings from Survey 47 using a 4.0 degree lens settings also agree with the prediction. The excess approach speeds for the day landings of Survey 45 and the 3.5 degree landings of Survey 47 are not completely accounted for. However the agreement with other F-14 data from the same surveys does indicate that the difference was not caused by an error in the survey procedures or data analysis.

Field Data Verification

In an attempt to verify the analysis of the effect of wind over deck on aircraft approach speed, the data from F-14 Field Carrier Practice Landings was reviewed. This data was collected during Survey 37 at NALF FENTRISS. These landings were performed with very little wind, typically two to four knots. The approach speed versus landing weight for a total of one hundred and eight F-14 landings were plotted on figure (9). When compared with the NATOPS approach speed curves the data shows approach speeds higher than recommended. However, to control sink rates for field landings, the glideslope is set at 3.25 degrees, not the 3.5 degree setting used for most carrier landings. When the measured values of approach speed are normalized to the 3.5 degree setting, the results change significantly, as shown on figure (10). This suggests that the increase in approach speed over the NATOPS recommendation seen in this data is caused by the lower lens angle.

This is another situation that supports the assertion that the corrections the pilot makes to hold in aircraft on glideslope result in the increase of observed approach speed.

Figure 9. F-14A FCLP LANDINGS, SURVEY 37, APPROACH SPEED VERSUS LANDING WEIGHT

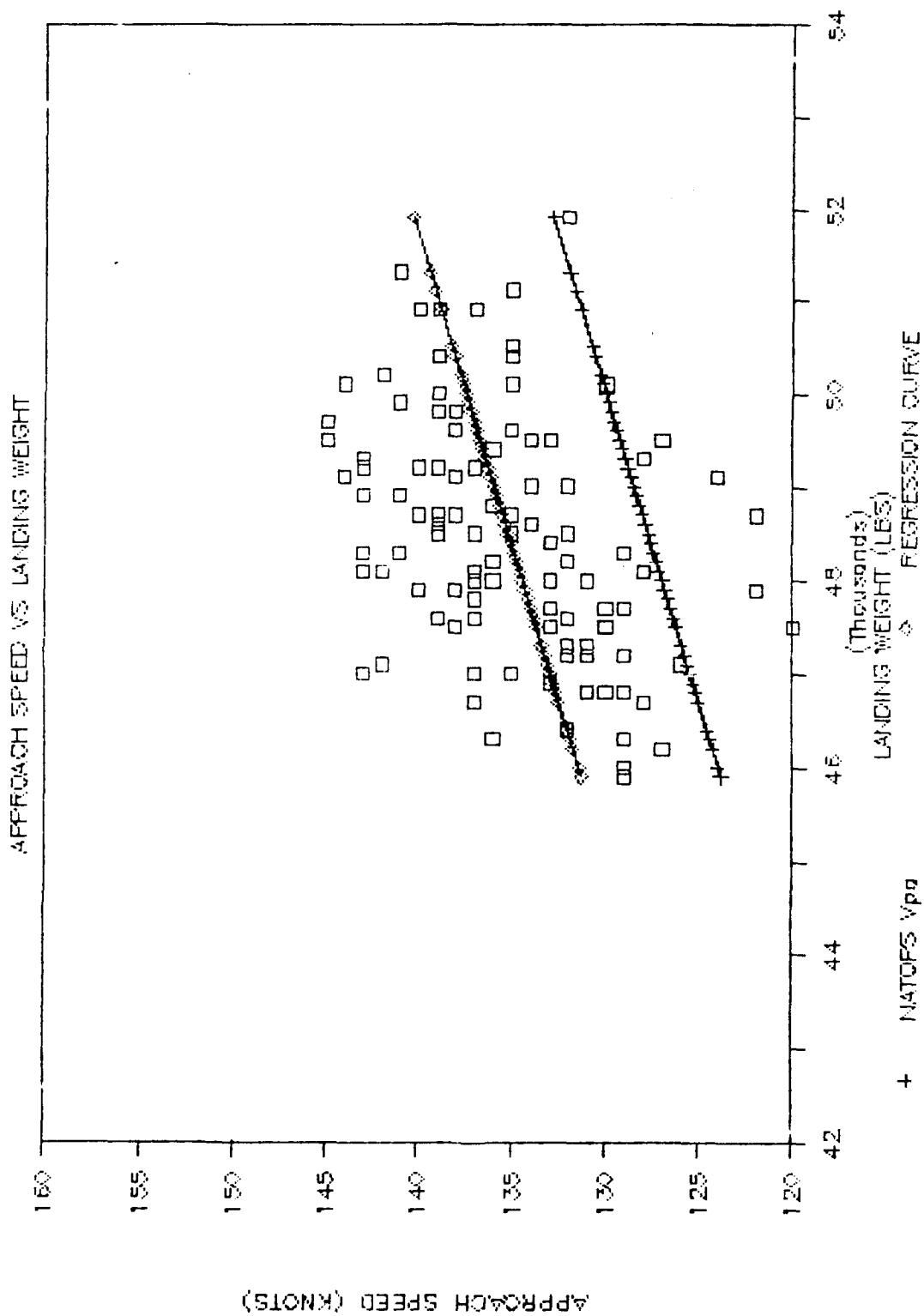
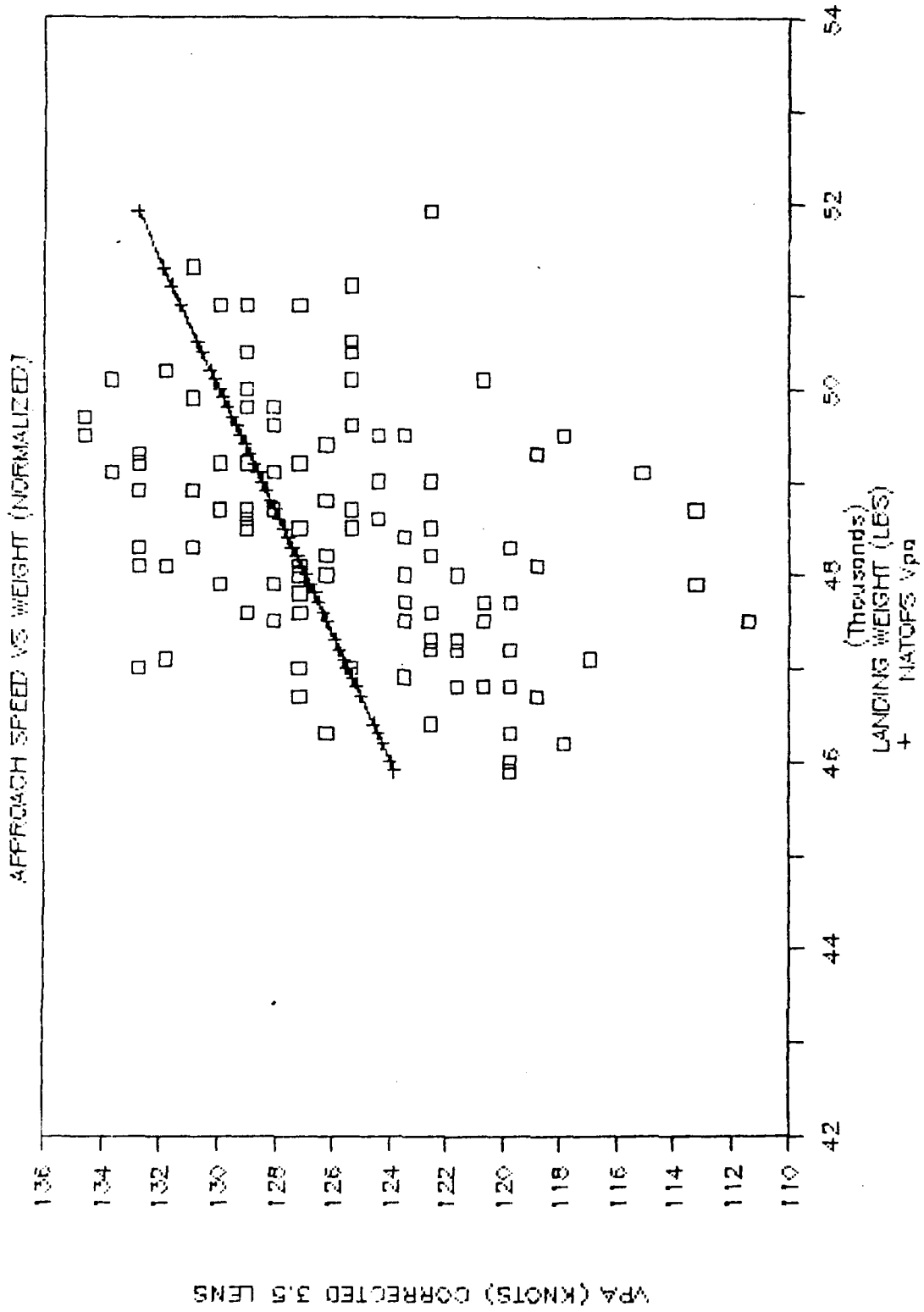


Figure 10. F-14A FCLP Landings, Survey 37, Approach Speed Versus Landing Weight (Normalized)



Engaging Speed Analysis

The F-14 data base was examined to determine the number of carrier landings which exceeded the hook load or arresting gear load limits. Figure (11) shows the engaging speed and landing weights for over 1130 F-14 landings as well as the hook load and arresting gear limit curves. This plot shows that very few of the aircraft landings exceeded the static structural design criteria.

From this data base, only twenty nine landings exceeded the limit curves. Twenty six of these landings are for F-14A (PLUS) landings from Survey 47 on the USS DWIGHT D. EISENHOWER. As for the other events, one occurred on Survey 43 on the USS JOHN F. KENNEDY, one occurred during Survey 42 on the USS CARL VINSON, and one was an F-14 night landing during Survey 45 on USS ENTERPRISE. Twelve landings were touch and go landings which do not involve hook or arresting gear loads. Four of the arrested landings exceeded the hook limit by less than 0.3 knots. We consider our camera system to be accurate to \pm two knots.

Two of the landings from Survey 47 exceeded the arresting gear limit for a MK7 MOD 3 arresting gear, the type of unit installed on three of these aircraft carriers. Landing 160 was a 52043 lb F-14A (PLUS) whose engaging speed was 0.9 knots faster than the arresting gear limit and caused a 182 " ram travel of the arresting gear. Landing 880 was a 50697 lb F-14A (PLUS) whose engaging speed exceeded the arresting gear limit by 4.4 knots and caused a 183 " ram travel. The MK 7 MOD 3 arresting gear should stop a 54000 lb F-14A at the arresting gear limit engaging speed in 183" of ram travel. These values of ram travel supports the argument that the approach speeds for these two aircraft were too high.

The one landing from Survey 43 which exceeded the hook load limit, landing 185, produced an arresting gear ram travel of 184". This was a 51450 lb F-14A whose engaging speed was 0.8 knots below the arresting gear limit.

The one landing recorded on the USS ENTERPRISE (landing 9342) was a 50100 lb F-14 which had an engaging speed of 134 knots. This ship is equipped with a MK 7, Mod 2 arresting gear, whose normal ram travel is 171". This landing was one of three night landings which produced 172" of ram travel.

The landing parameters for the twenty nine high engaging speed landings are included in table (3). All of these had adequate values of wind over deck. If the conventional assumption that engaging speed is reduced by increased wind over deck is applied, then these landings are difficult to explain. The reaction of the aircraft carriers arresting gear to these landings confirms the accuracy of the reported approach speeds.

Figure 11. F-14A LANDINGS, ALL SURVEYS, ENGAGING SPEED VERSUS LANDING WEIGHT

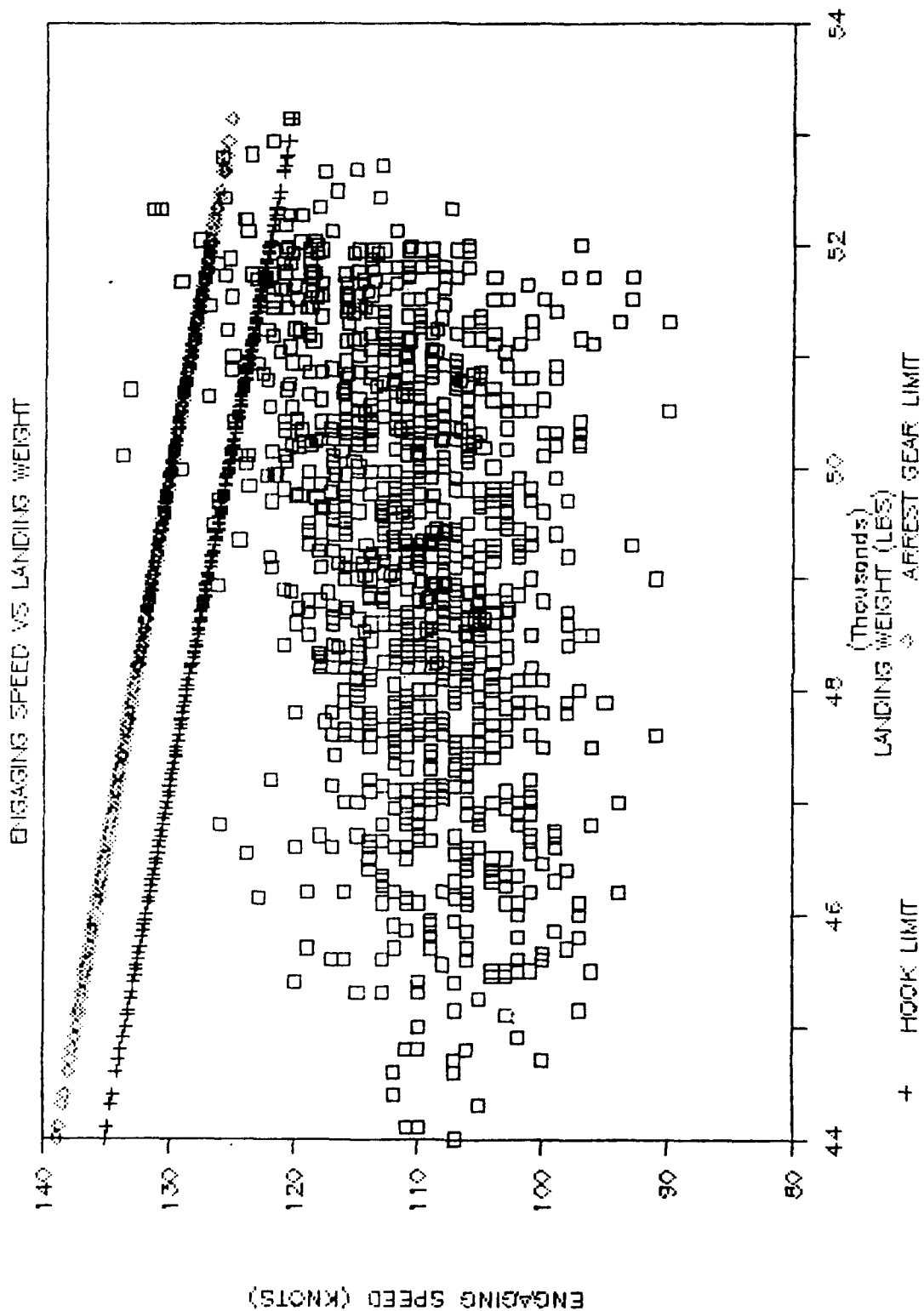


TABLE 3: F-14A+ HIGH VE DATA

EVENT NUMBER	SINK SPEED	APPROACH SPEED	ENGAGING SPEED	LANDING WEIGHT	WIND OVER DECK	HOOK LIMIT	ARRSTNG GEAR LIMIT	DELTA HOOK	DELTA LIMIT	LANDNG TYPE	ARG RAM
132	13.4	148	120	53143	28	120	125	0.1	-4.8	A	180
157	11.2	150	122	52943	28	121	126	1.2	-3.7	A	181
160	13.8	156	128	52043	28	122	127	5.7	0.9	A	182
589	13.5	155	126	51875	30	122	127	3.1	-1.7	T&G	
592	11.1	155	126	52797	29	121	126	5.1	0.2	T&G	
599	14.0	152	125	50874	27	124	129	1.3	-3.4	A	180
600	12.1	159	132	52332	28	122	127	9.8	5.0	T&G	
602	11.9	155	127	51832	29	122	127	4.0	-0.8	T&G	
RR 603	9.4	152	124	51732	28	123	127	1.1	-3.7	T&G	
605	15.6	152	125	51532	27	123	128	2.3	-2.4	A	180
609	13.0	154	129	49974	25	126	130	3.7	-0.8	A	180
618	13.2	151	126	52432	25	122	126	4.4	-0.5	T&G	
RR 636	11.9	157	126	49692	31	126	130	0.2	-4.2	A	
821	11.5	151	124	52232	27	122	127	2.4	-2.4	A	181
835	13.5	149	124	52132	25	122	127	2.0	-2.8	A	184
836	14.2	149	124	52232	25	122	127	2.2	-2.6	A	182
845	10.0	153	127	50632	26	124	129	2.5	-2.1	A	181
851	11.2	153	124	52828	29	121	126	2.9	-2.0	T&G	
853	15.8	156	131	52328	25	122	127	9.3	4.5	T&G	
855	13.1	152	126	51728	26	123	127	3.3	-1.4	T&G	
858	9.4	153	125	50992	28	124	129	1.4	-3.3	T&G	
859	12.2	154	129	51674	25	123	127	6.6	1.8	T&G	
870	12.4	153	127	49474	26	126	131	0.3	-4.2	A	182
874	9.9	152	123	51692	29	123	127	0.6	-4.2	T&G	
880	12.9	161	133	50697	28	124	129	9.0	4.4	A	183
883	14.1	153	126	51230	27	123	128	2.3	-2.4	A	181
185	13.9	149	127	51450	22	123	128	3.9	-0.8	A	184
645	13.0	147	125	50400	22	125	129	0.2	-4.4	A	182
9342	14.2	164	134	50100	30	125	130	8.7	4.2	A	172

MEAN	12.6	153.3	126.4	51552.5	26.9	122.9	127.7	3.4	-1.3		181.5
STD DEV	1.6	3.7	3.1	975.2	2.1	1.6	1.5	2.8	2.8		1.3

Statistical Analysis

To place these assumptions of the effect of Wind over deck on Approach Speed on a scientific footing, Rank Correlation Coefficients were calculated from survey data. These coefficients were selected since the distributions for Approach Speed, Engaging Speed and Wind over Deck were not normal. This lack of normality prevents the use of the correlation coefficients associated with the regression curves.

The values of the Rank Correlation Coefficient vary from +1.0 to -1.0. Each event to be compared consists of a variable pair (X,Y). The variables to be ranked are assigned a values 1 to N where N is the number of items in the list. The values of N are assigned to X in the sequence of increasing values of the variable. The values of N are then assigned to Y also in its sequential order. A value of 1.0 for the Rank Correlation Coefficient indicates a perfect correlation between the two variables involved ($\text{Rank}(y) = \text{Rank}(x)$). A value of -1.0 indicates a perfect inverse relationship between the the variables involved ($\text{Rank}(y) = \text{Rank}(-x)$). A value of 0.0 for the coefficient indicates that no correlation exists between the variables (X,Y).

Rank Correlation Coefficients were calculated for the F-14 aircraft for the combinations of Approach Speed and Wind over Deck as well as Engaging Speed and Wind over Deck. These coefficients were calculated for the entire 1130 landing data base as well as for the data base divide into 1000 lb weight classes. The results are summarized in table (4). The values of Rank Correlation Coefficients for Approach Speed vs Wind over deck are inconclusive. A degree of correlation appears to exist, but the correlation is not statistically significant.

The values of the Rank Correlation Coefficient between Engaging Speed and Wind over Deck for the F-14 show convincingly that there is no relationship between these variables. This is a significant observation, it indicates that the amount of wind over deck does not effect the engaging speed of the aircraft. This supports the theory from our regression analysis that increases in Wind over Deck result in an increase in approach speed not a decrease in Engaging Speed.

To extend this observation to other model aircraft, Ranked Correlation Coefficients were calculated for Engaging Speed and Wind over Deck for the A-6E, EA-6B and F-18 Aircraft. The Coefficients calculated for the 271 A-6E landings was -0.0645, and for the 194 EA-6B landings was -0.0327. These values indicate that no relationship exists between Engaging Speed and Wind over Deck for the observed landings of these aircraft. The value calculated for the F-18 was -0.3988, which is considered to be inconclusive. Further evaluation of 598 F-18 landings by

dividing the data base into 1000 lb weight groups was also inconclusive. These results are listed in table (5).

Analysis of F-18 aircraft landing was then extended to calculate the Rank Correlation Coefficient between Approach Speed and Wind over deck. These values, which also are included in table (5), are inconclusive. This indicates that the landing performance of the F-18 is different than that observed for the F-14.

TABLE 4: CARRIER LANDING LOADS SURVEY

F-14 RANK CORRELATION COEFFICIENT

WEIGHT GROUP	NUMBER OF LANDINGS	APPROACH SPEED vs WIND OVER DECK	ENGAGING SPEED vs WIND OVER DECK
ALL	1130	0.502	-0.125
44/45000	14	0.588	-0.122
45/46000	46	0.441	-0.104
46/47000	88	0.379	-0.181
47/48000	136	0.4197	-0.372
48/49000	183	0.6435	-0.153
49/50000	190	0.601	0.002
50/51000	202	0.478	-0.141
51/52000	173	0.495	-0.054
52/53000	27	0.237	-0.333

TABLE 5: CARRIER LANDING LOADS SURVEY

F-18 RANK CORRELATION COEFFICIENT

WEIGHT GROUP	NUMBER OF LANDINGS	APPROACH SPEED vs WIND OVER DECK	ENGAGING SPEED vs WIND OVER DECK
ALL	609	0.123	-0.369
28/28900	28	0.391	0.982
29/29900	100	0.096	-0.409
30/30900	176	0.127	-0.373
31/31900	198	0.145	-0.389
32/32900	97	0.206	-0.354
33/33900	10	0.87	0.96

Conclusions

The analysis of carrier landing loads data shows that increasing the amount of wind over deck causes a proportional increase in the aircraft's approach speed measured at touchdown. This argues against the traditional assumption that increased wind over deck does not increase approach speed but results in a decrease in aircraft engaging speed. The additional constraint of holding the aircraft on a prescribed glideslope causes this incremental increase in approach speed.

The higher than anticipated approach speeds reported by NADC carrier landing loads surveys are caused by the increment of approach speed resulting from higher wind over deck conditions.

The NATOPS Recommended Approach Speed Curves are correct for a minimum recovery head wind landings. An additional correction factor must be included in evaluating aircraft approach speeds to account for the variation in wind over deck conditions.

The structural loads on the aircraft during carrier landings are higher than those calculated when those calculations are based on the assumptions in MIL-A-8863A. Higher approach speeds, resulting in higher aircraft engaging speeds, increase the resulting hook and landing gear loads on the aircraft.

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