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CALIBRATION OF THE RECONFIGURED MARK 7 MOD 2 ARRESTING-GEAR SYSTEM AT THE RUNWAY ARRESTED LANDING SITE

Final Report
12 December 1967

by

Herbert A. Prince and George K. Rusk
Recovery Division

Prepared under Naval Air Systems Command
Work Unit Number AIR-5373-211-1

U. S. NAVAL AIR TEST FACILITY
(SHIP INSTALLATIONS)
U. S. NAVAL AIR STATION
LAKEHURST, NEW JERSEY
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Prepared by: George Rusk
for Herbert A. Prince
Recovery Division

George K. Rusk
George K. Rusk
Recovery Division

Reviewed by: C. T. Abrahamsen
C. T. Abrahamsen
Head, Recovery Division

Approved by: B. F. Kolacz
B. F. Kolacz
Superintendent of Engineering

ABSTRACT

This report presents the results of calibration tests of the reconfigured Mark 7 Mod 2 arresting-gear system and a comparison of these results with that obtained prior to the reconfiguration.

ON-CENTER, 20-foot-to-starboard, and 20-foot-to-port arrestments of various weight A-3, A-4, F-4, and F-8 aircraft were conducted at an initial engaging speed of 90 knots. The speeds were increased in 10-knot increments until each aircraft had been arrested at least four times at each engaging position. Both taxi-in and fly-in arrestments were conducted.

The reconfiguration of the Mark 7 Mod 2 arresting-gear system resulted in lower arresting-gear and aircraft loads for lightweight aircraft; however, these loads were increased for heavyweight aircraft.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

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I INTRODUCTION

A. The Mark 7 Mod 2 arresting-gear system, as originally installed in the pit at the Runway Arrested Landing Site (RALS), contained twice the number of fairlead sheaves considered to be optimum for a shipboard configuration. In addition, the purchase-cable lengths from the arresting engine to the deck-edge sheaves were considered to be excessive. This arrangement produced high A-4 aircraft loads and severe purchase-cable stresses due to bending.

B. Accordingly, the arresting system was reconfigured to effect an optimum system and then calibrated using various weight A-3, A-4, F-4, and F-8 aircraft. This report presents the results of the calibration tests and a comparison of these results with data obtained prior to the reconfiguration.

II ARRESTING-GEAR RECONFIGURATION

A. As originally installed in the RALS pit and later modified by the addition of sheave dampers, the arresting-gear system employed ten fairlead sheaves per side. Purchase-cable lengths from the deck-edge sheaves to the port and starboard crosshead assemblies were 173 and 208 feet, respectively, and the sheave dampers were displaced approximately 16 feet from the deck-edge sheaves. This arrangement did not simulate any shipboard configuration, caused higher A-4 aircraft loads, and produced more severe purchase-cable bending stresses than those produced by shipboard systems which have fewer fairlead sheaves.

B. In order to optimize the Mark 7 Mod 2 arresting-gear system, the total number of fairlead sheaves was reduced from ten to five per side; the sheave dampers were located four feet closer to the deck-edge sheaves; the arresting engine was relocated so as to more nearly equalize purchase-cable lengths between the arresting-engine crosshead and the deck-edge sheaves and the port and starboard purchase-cable lengths were reduced by 18 and 73 feet, respectively. (See Figure 1)

III TEST EQUIPMENT AND PROCEDURE

A. Arresting-Gear Configuration

1. Single reeved with 1-3/8 x 6 x 25 Lang-lay wire rope, PN A-92791-27.

2. Deck span - 120 feet.

3. K-15 cam, NAEL PN 502715-6P.

4. Weight-selector dial, PN 504094-1P.

5. Cam torque - 90 ±2 foot-pounds.

6. Cam-chain initial tension - 400 ±10 pounds.

7. Accumulator pressure - 400 psi.

8. Anchor dampers configured as follows:

a. 7/8-inch-diameter orifice ring for starboard purchase cable (outer reeving),

b. 1-5/8-inch-diameter orifice ring for port purchase cable (inner reeving),

c. 3/8-inch-diameter return-flow orifices in port and starboard flapper plugs, and

d. 5/8-inch-diameter port and starboard buffer orifice rings.

9. Sheave dampers configured as follows:

a. 2-inch-diameter port and starboard orifice rings,

b. 3/8-inch-diameter port and starboard return-flow orifices, damper end,

c. 1/2-inch-diameter port and starboard return-flow orifices, accelerator end,

d. Initial sheave-damper-accumulator pressure - 750 psi,

e. Initial accelerator-accumulator pressure - 300 psi, and

f. Damper and accelerator fluid levels 2 inches ±1 inch on the sight-level gauges.

B. Test Procedure

1. Test Outline: ON-CENTER, 20-foot-to-starboard, and 20-foot-to-port arrestments were conducted with the following aircraft:

Aircraft	
Type	Weight Range (Pounds)
A-3A	48,000 - 50,000
F-4A	32,000 - 34,000
F-8A	20,000 - 22,000
A-4B	13,500 - 14,500
A-4B	11,000 - 12,000

At each engaging position: All initial aircraft arrestments were conducted at an engaging speed of 90 knots; engaging speeds were increased in 10-knot increments until each aircraft had been arrested at least four times. It was attempted to obtain at least four arrestments with each aircraft to determine its performance. Repeat arrestments were conducted as required in order to complete data analysis.

2. Constant Runout Control Valve Settings: All weight settings on the CROV were at the aircraft gross weight ±250 pounds.

3. Aircraft Guidelines: Tests with aircraft were conducted under the following general guidelines:

a. Pilot Technique: The following pilot techniques, stated in Naval Air Engineering Laboratory (Ship Installations) (NAEL(SI)) letter NE-431:AD:kt 1932 of 12 April 1965, were used:

(1) Power was advanced to MRT as the aircraft touched down. For taxi-in arrestments, the technique was modified by advancing power to MRT at 75 feet prior to deck-pendant pickup.

(2) The throttle was held at MRT until forward motion of the aircraft stopped. At that time, power was reduced to idle to allow the aircraft to roll aft until the arresting-hook point was clear of the deck pendant. Brakes and/or power were used as necessary to control walk-back.

b. Type Arrestment: Tests covered both taxi-in and fly-in arrestments. Fly-in arrestments were scheduled whenever engaging speeds permitted, in order to simulate shipboard operations.

c. Mirror and Touchdown Point: The mirror was used for fly-in arrestments with main-gear touchdown programmed to be 75 feet before the deck pendant. Initial mirror setting was for a three-degree glide slope.

C. Data Obtained: The following parameters were recorded:

1. Engaging speed (Knots)
2. Deck-cable tension (Pounds)
3. Anchor-cable tension (Pounds)
4. Ram stroke (Inches)
5. Engine-cylinder pressure (PSI)
6. Cam-chain tension (Pounds)
7. Sheave-damper stroke (Inches)
8. Sheave-damper cylinder pressure (PSI)
9. Sheave-damper velocity (FPS)
10. Anchor-damper stroke (Inches)
11. Anchor-damper velocity (FPS)
12. Anchor-damper cylinder pressure (PSI)
13. Arresting-hook axial load (Pounds)
14. Longitudinal deceleration (G)

IV TEST RESULTS AND ANALYSIS

A. A total of 85 ON-CENTER and 20-foot OFF-CENTER to port and starboard arrestments were conducted with the reconfigured arresting gear, as outlined below:

				Range				
	Aircraft		OFF-CTR		Maximum Arresting-Hook	Maximum	Maximum	Maximum Engine-Cylinder
No. of Events	Type	Weight Range (1,000 Lb)	Dist (Ft)	Engag. Speed (Kn)	Axial Load (1,000 Lb)	Long. Decel (G)	Cable Tension (1,000 Lb)	Pressure (PSI)
5	A-4B	13.5-14.5	0	94-125	39.2-69.5	2.74-4.45	42.2-61.4	1,178-2,220
4	"	"	20 P	96-120	43.2-65.0	2.88-4.33	39.1-55.6	1,365-2,140
4	"	"	20 S	92-124	50.0-69.0	3.03-4.34	36.9-56.6	1,160-2,085
5	A-4B	11-12	0	90-121	37.9-59.1	2.75-4.08	44.6-60.6	*
6	"	"	20 P	90-121	35.5-60.7	2.62-4.37	34.6-66.5	1,005-1,650
8	"	"	20 S	89-123	42.8-69.8	3.38-5.17	32.2-51.7	890-1,702
7	A-3A	48-50	0	90-113	88.0-148.0	1.72-2.70	52.5-82.3	5,510-9,200
6	"	"	20 P	90-112	91.4-150.0	1.89-2.71	59.4-101.5	5,720-8,850
4	"	"	20 S	100-115	104.0-160.0	2.14-2.68	68.0-95.0	6,280-9,850
5	F-4A	32-33	0	90-115	62.9-84.8	1.41-2.36	44.8-59.4	4,340-5,740
3	"	"	20 P	87-107	52.2-75.5	1.36-2.09	39.5-56.1	3,530-5,000
4	"	"	20 S	90-116	61.0-88.0	1.48-2.29	40.8-65.5	4,400-6,025
11	F-8A	20-22	0	88-120	- -72.3	- -3.75	45.4-63.3	2,000-3,800
6	"	"	20 P	90-131	47.1-90.4	2.18-3.53	45.7- -	2,517- -
7	"	"	20 S	90-119	49.3-72.2	1.62-3.17	45.1- -	2,620- -

* Data questionable and not used.

1. The maximum deck-cable tension recorded was 101,500 pounds and occurred during a 109-knot, 20-foot OFF-CENTER-to-port arrestment of the A-3 aircraft.

2. The maximum engine-cylinder pressure recorded was 9,850 psi and occurred during a 115-knot, 20-foot OFF-CENTER-to-starboard arrestment of the A-3 aircraft.

B. The dynamic performance of the reconfigured Mark 7 Mod 2 arresting-gear system is presented in Figures 2 through 6. The curves drawn on Figures 2, 3, and 4 represent previous Mark 7 Mod 2 data (before the reconfiguration) obtained from reference (a). No previous F-4 or A-4 (13,500 to 14,500 pounds) aircraft arrestment data is available for comparison; however, it is assumed that the results of a comparison would be similar to those of the lighter-weight A-4 aircraft and the F-8 aircraft. The parameters in Figures 2 through 6 are discussed separately:

1. Maximum Deck-Cable Tension

a. A comparison of maximum deck-cable tensions produced by the A-3 aircraft is shown in Figure 2 and reveals that higher cable tensions occurred with the reconfigured system. There are two reasons for this to occur. First, the application of aircraft thrust during the arrestment is suspected to have been of longer duration during this test program. Second, there was less work done in bending and stretching purchase cable, and rotating sheaves in the reduced fairlead system. This, in turn, causes more energy to be transmitted to the arresting engine and produces higher hydraulic cable tensions. Because the heavyweight A-3 aircraft generally produces a maximum cable tension in the hydraulic region, it is inclined to be adversely affected by the reduction of sheaves and purchase cable in the system.

b. Figures 3 and 4 show that lower maximum cable tensions occurred with the reconfigured Mark 7 Mod 2 arresting-gear system during arrestments of the 11,000- to 12,000-pound A-4 aircraft and the F-8 aircraft. Because the sheave dampers are located closer to the deck-edge sheaves and less cable is in the system between the dampers and arresting engine, purchase-cable demand is more readily met and lower loads are obtained.

c. Figures 3 and 5 present the results of arrestments of the 13,500- to 14,500-pound A-4 aircraft and the F-4 aircraft into the reconfigured Mark 7 Mod 2.

2. Maximum Arresting-Hook Axial Load

a. Figure 2 indicates that a higher maximum arresting-hook load value occurs with the reconfigured Mark 7 Mod 2 during A-3 aircraft arrestments. Because the arresting-gear purchase-cable tension (resulting from hydraulic loading) for the reconfigured system exhibited higher load values, it is assumed that the corresponding aircraft arresting-hook load values will follow this pattern and exhibit higher load values. This is, of course, based on the supposition that cable configurations remain unchanged during that part of the arrestment influenced by arresting-engine hydraulic loads.

b. Because lower maximum cable tensions occurred with the reconfigured Mark 7 Mod 2 during A-4 (11,000 to 12,000 pounds) and F-8 aircraft arrestments, it was assumed that lower maximum arresting-hook loads would also occur. The curves on Figures 3 and 4 show that lower maximum arresting-hook loads occurred with these aircraft.

c. Figures 3 and 5 show the results of arrestments of the 13,500- to 14,500-pound A-4 aircraft and the F-4 aircraft into the reconfigured Mark 7 Mod 2.

3. Maximum Longitudinal Deceleration

a. Figure 2 shows no significant change in maximum longitudinal decelerations with the reconfigured Mark 7 Mod 2 for A-3 aircraft arrestments.

b. Figures 3 and 4 show that the maximum longitudinal decelerations were substantially decreased during arrestments of the 11,000- to 12,000-pound A-4 aircraft and the F-8 aircraft into the reconfigured gear.

c. Figures 3 and 5 present the results of arrestments of the 13,500- to 14,500-pound A-4 aircraft and the F-4 aircraft into the reconfigured gear.

4. Maximum Engine-Cylinder Pressure

a. Figures 2, 3, and 4 show that higher maximum engine-cylinder pressures occurred during tests of the reconfigured gear with A-3, 11,000- to 12,000-pound A-4, and F-8 aircraft. These higher cylinder pressures are attributed to:

(1) higher and longer application of aircraft engine power during the arrestment, and

(2) the reduction of purchase-cable lengths and number of sheaves in the fairlead system.

Both of these conditions resulted in additional energy absorption requirements by the arresting engine.

b. Figures 3 and 5 show the results of arrestments of the 13,500- to 14,500-pound A-4 aircraft and the F-4 aircraft into the reconfigured gear.

c. The maximum engine-cylinder pressure obtained during this program was 9,850 psi (limit 10,000 psi), which occurred during a 115-knot, 20-foot-to-starboard arrestment of the A-3 aircraft.

5. Maximum Arresting-Engine Ram Stroke

a. The data plotted on Figure 6 shows that a significant increase in arresting-engine ram stroke occurred during A-3 aircraft tests with the reconfigured arresting-gear system. The increase in stroke is attributed to:

(1) the increase in aircraft thrust experienced during this test program,

(2) the fact that less energy is dissipated in bending cable with the reconfigured system, and

(3) less energy is dissipated in turning sheaves in the reconfigured system. The increase in system kinetic energy must be dissipated by the arresting engine and subsequently influences the ram overtravel.

b. It can be seen in Figure 6 that the system approaches a two-blocking condition at approximately 115 knots. To preclude the system from two-blocking, a positive method of insuring control-valve closure is reeded.

6. Engaging Speed

a. Figures 3 and 4 indicate a significant increase in engaging-speed capabilities with lighter-weight aircraft. This was effected by the increased efficiency resulting from the arresting-gear reconfiguration.

b. The following table lists the test engaging-speed limits for the reconfigured Mark 7 Mod 2 arresting-gear system:

	Engaging-Speed Limit (Knots)		
Aircraft	ON-CENTER Arrestments	20-Foot OFF-CENTER Arrestments	Limiting Parameter
A-3	112	112	Ram stroke (175 inches)
11,000- to 12,000-Lb A-4	130*	127*	Arresting-hook axial load
13,500- to 14,500-Lb A-4	130*	127*	Arresting-hook axial load
F-8	148*	148*	Arresting-hook axial load
F-4A	130*	130*	Arresting-hook axial load

* Estimated - no limit reached; curve extrapolated.

V CONCLUSIONS

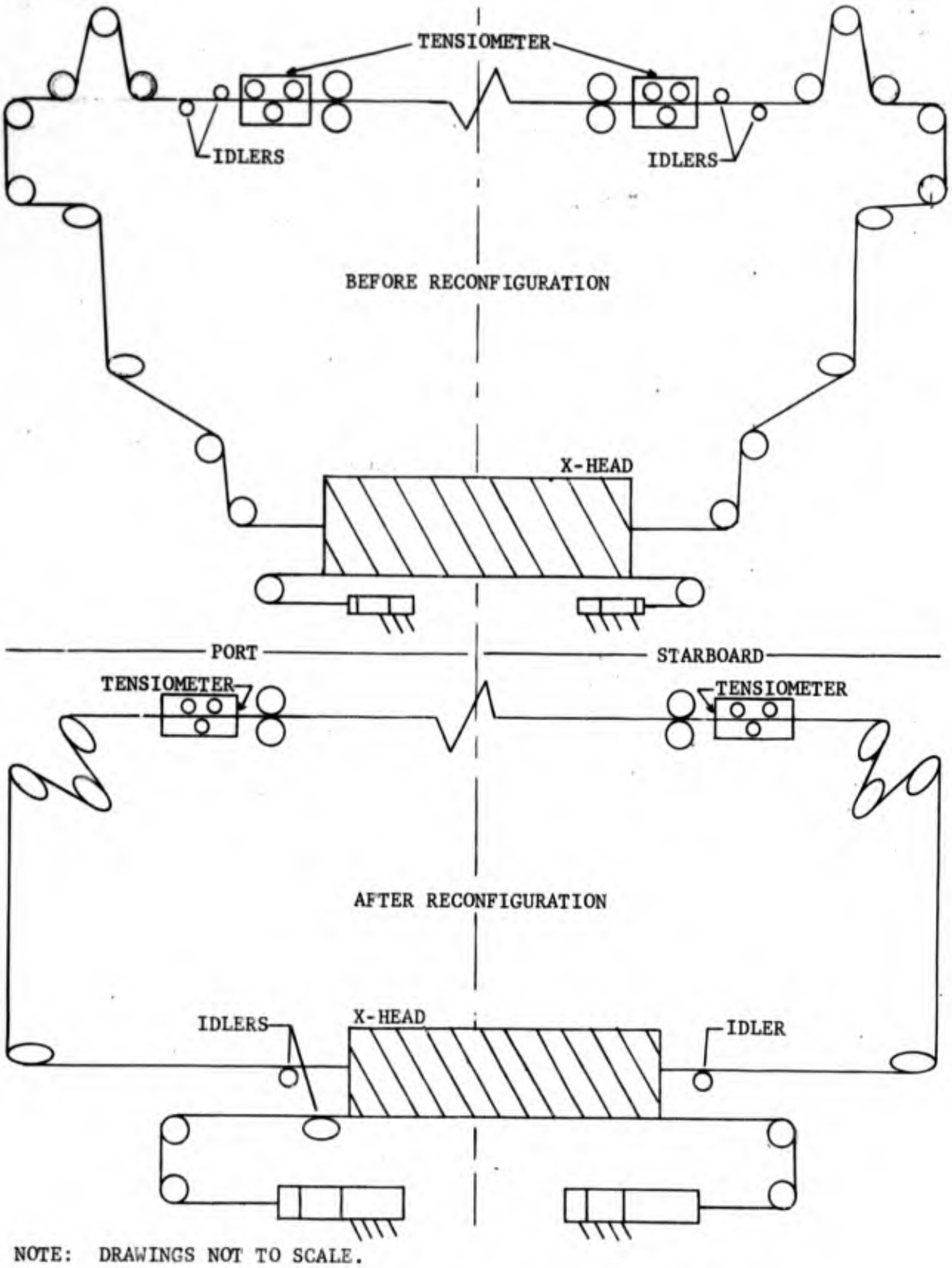
	Refer to Section IV, Paragraph
A. The arresting-gear reconfiguration resulted in:	
1. Lower maximum cable tensions, arresting-hook axial loads, and longitudinal decelerations for F-8 and 11,000- to 12,000-pound A-4 aircraft,	B1 B2 B3
2. Higher maximum engine-cylinder pressures for all aircraft tested,	B4
3. Significantly higher maximum arresting-engine ram strokes for heavyweight A-3 aircraft (this was also effected by increased thrust), and	B5
4. Increased engaging-speed capabilities of lighter-weight aircraft.	B6

VI RECOMMENDATIONS

A. Shipboard arresting-gear configurations should be rearranged to a five-sheave system to permit higher engaging-speed operations with lighter-weight aircraft.	B6
B. A positive method of insuring control-valve closure at the ram-stroke limit should be determined, to avoid chance of two-blocking the arresting engine during operations with heavyweight (50,000 pounds) aircraft.	B5

VII REFERENCE

(a) Report NATF(SI)-EI-45 of 19 September 1961: Preliminary Performance Report on the Mark 7 Mod 2-3 Arresting Gear System Incorporating Sheave and Anchor Dampers, Interim Report No. 1



NOTE: DRAWINGS NOT TO SCALE.

Figure 1 - Schematic Diagrams of the Mark 7 Mod 2 Arresting-Gear System Before and After Reconfiguration

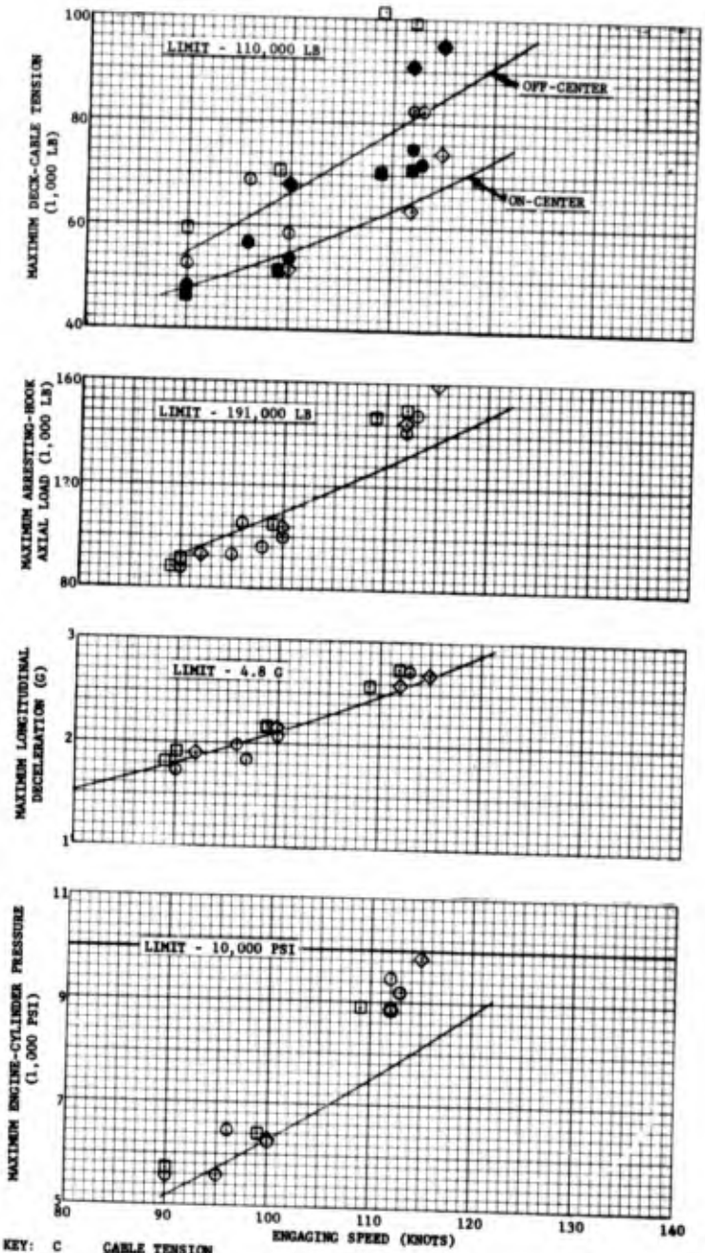


Figure 2 - Composite Graph of 48,000- to 50,000-Pound A-3 Aircraft Tests Showing Maximum Parameters versus Engaging Speed (Reconfigured Mark 7 Mod 2 Arresting-Gear System)

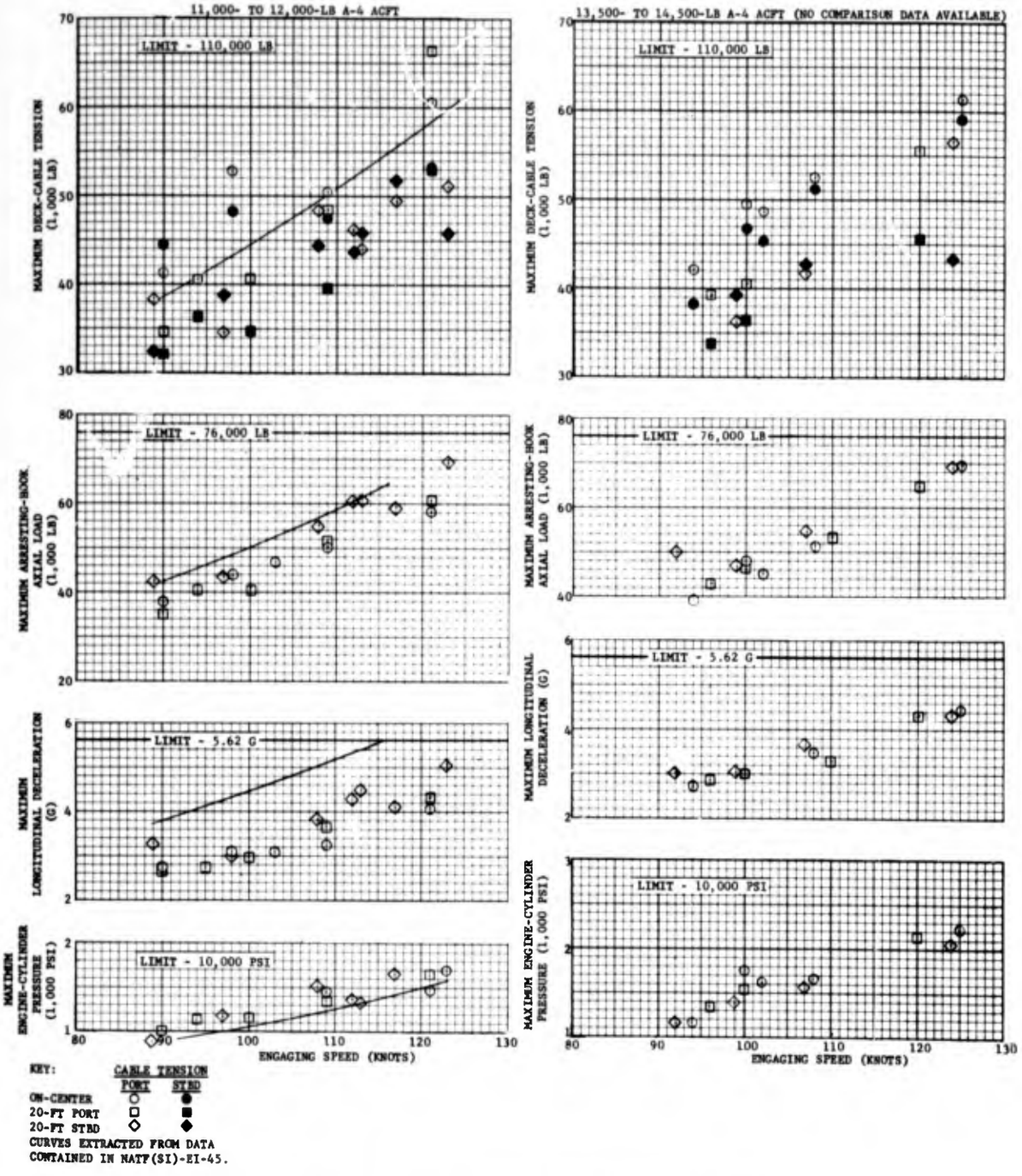
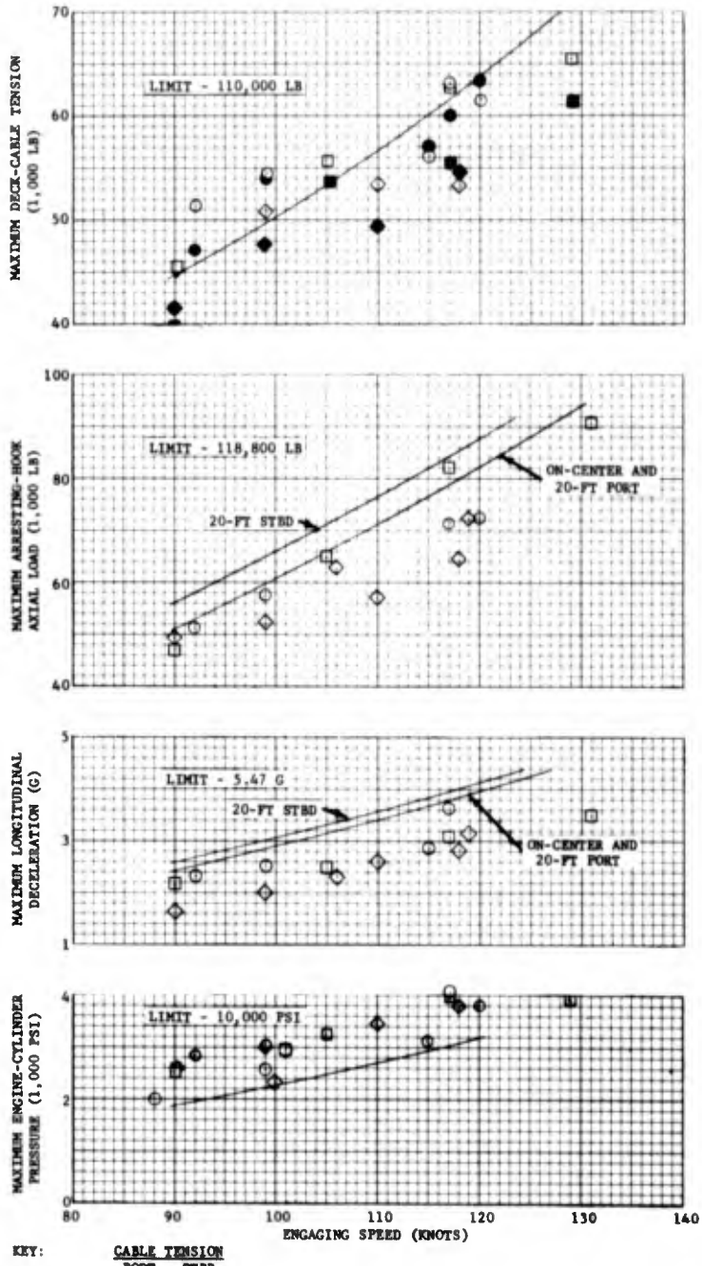


Figure 3 - Composite Graph of A-4 Aircraft Tests Showing Maximum Parameters versus Engaging Speed (Reconfigured Mark 7 Mod 2 Arresting-Gear System)

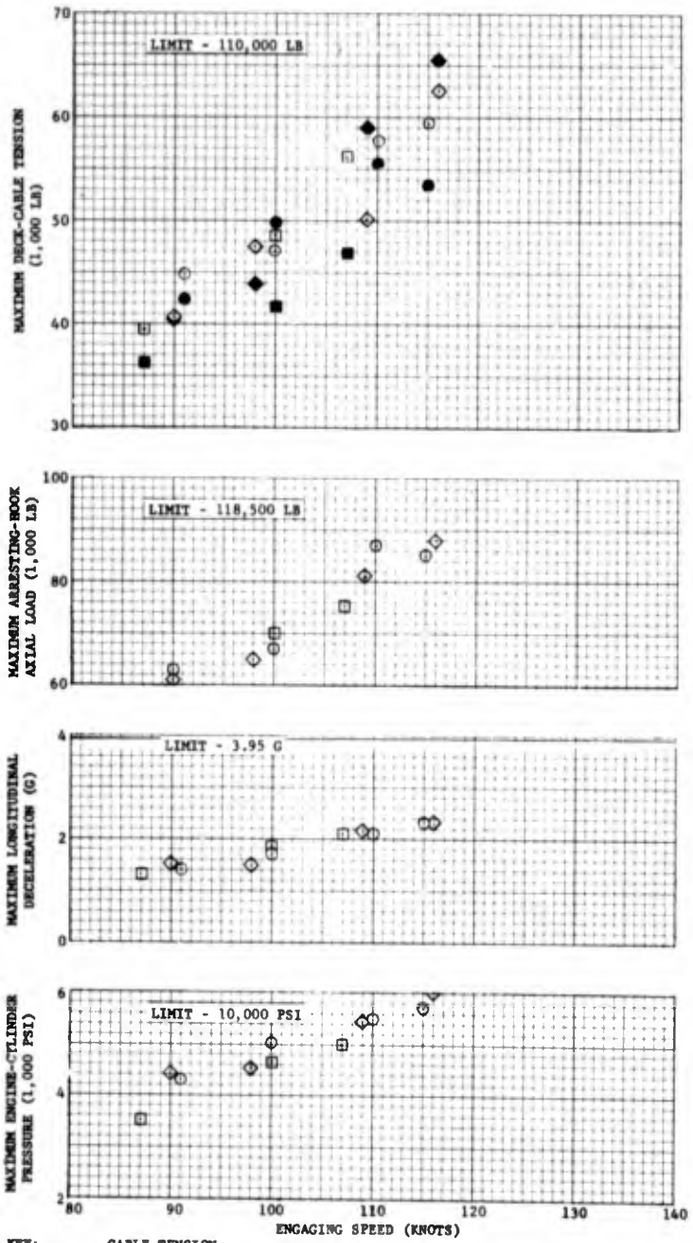


KEY:

	CABLE TENSION PORT	CABLE TENSION STBD
ON-CENTER	○	●
20-FT PORT	□	■
20-FT STBD	◇	◆

CURVES EXTRACTED FROM DATA CONTAINED IN NATF(SI)-EI-45.

Figure 4 - Composite Graph of 20,000- to 22,000-Pound F-8 Aircraft Tests Showing Maximum Parameters versus Engaging Speed (Reconfigured Mark 7 Mod 2 Arresting-Gear System)

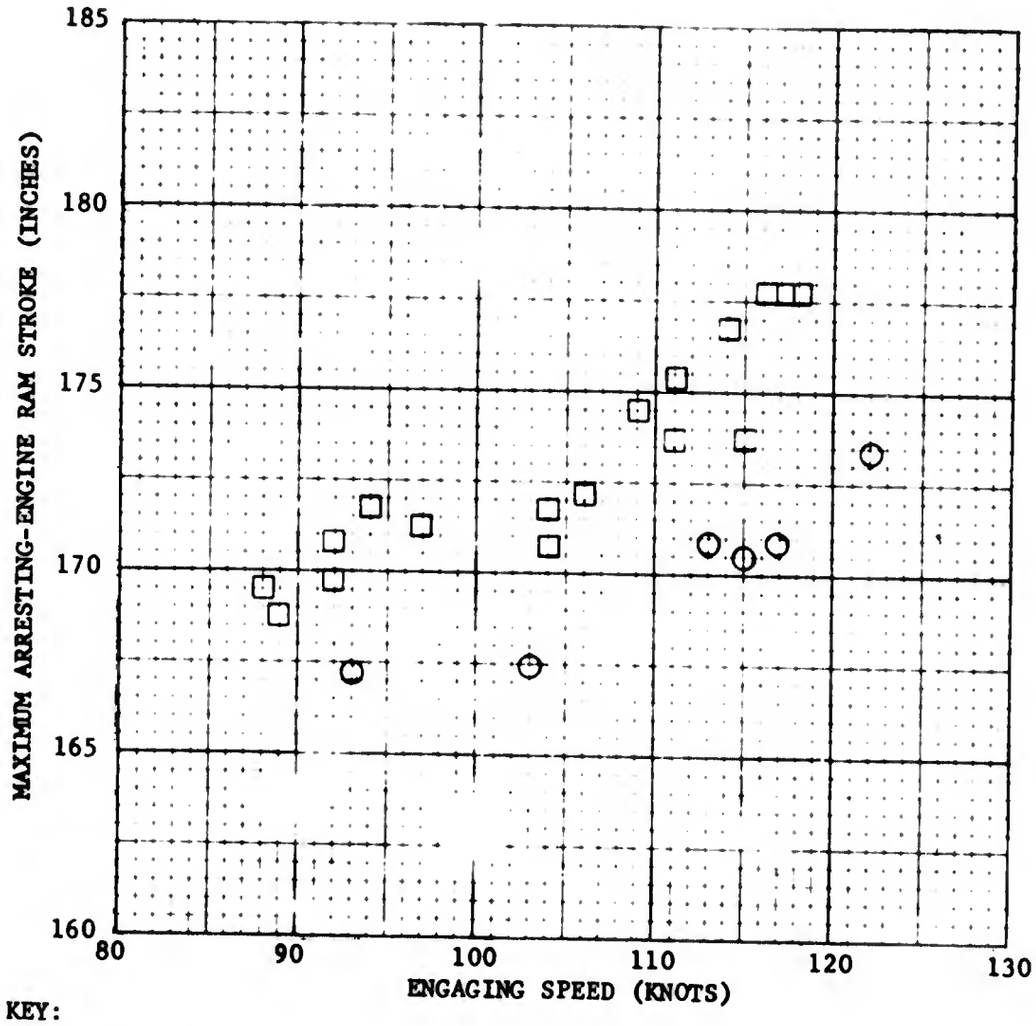


KEY:

	CABLE TENSION PORT	CABLE TENSION STBD
CV-CENTER	○	●
20-FT PORT	□	■
20-FT STBD	◇	◆

NO COMPARISON DATA AVAILABLE.

Figure 5 - Composite Graph of 32,000- to 33,000-Pound F-4 Aircraft Tests Showing Maximum Parameters versus Engaging Speed (Reconfigured Mark 7 Mod 2 Arresting-Gear System)



KEY:

ARRESTING-GEAR CONFIGURATION	SYMBOL	AIRCRAFT WEIGHT RANGE (POUNDS)
OLD	○	48,800 - 50,000
NEW	□	48,000 - 50,000

Figure 6 - Comparison of Maximum Arresting-Engine Ram Stroke versus Engaging Speed, A-3 Aircraft (Reconfigured Mark 7 Mod 2 Arresting-Gear System)

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Aircraft Arresting-Hook Loads						
Wire Rope						