FLIGHT DECK MACHINERY

BY

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This article is an edited version of a lecture presented by the Author on the work carried out in the Flight Deck Machinery Section from January, 1965, to November, 1967. The Author was Head of the Section during this period.

The Section is responsible in the Ship Department for all aspects of the design, development and installation of catapults, arresting gear and aviation fuel distribution systems in aircraft carriers, and for dealing with subsequent 'in service' problems. The Section is also responsible for specialist and guidance advice for aviation and motor transport fuel systems in ships other than aircraft carriers.

Introduction

For the first 14 months of the period covered by this review the Section was completely absorbed by the New Carrier. The remaining four fixed-wing carriers operating with either BS4 or BS5 catapults and Mk 13 arresting gear were receiving very little attention or effort. The new carrier requirements were:-

(*a*) A new catapult capable of launching aircraft of 60,000 lb weight at 150 kts, compared with 50,000 lb at 105 kts of the 200 ft BS5 catapult in H.M.S. *Eagle*.

(*b*) A new arresting gear capable of arresting aircraft of 40,000 lb weight at not less than 125 kts, compared with 30,000 lb at 112 kts and 37,000 lb at 100 kts of the Mk 13 arresting gear.

(*c*) The grouping of flight deck aircraft services to give a number of servicing points each capable of supplying stores, fuel, electric, pneumatic and hydraulic power, and coolants, for one or two aircraft.

The Government's Defence Review published in February, 1966, stopped all except the arresting gear and some catapult loading equipment aspects of this work by cancelling the new carrier. Although there had been rumours previous to the announcement the decision when it came made sudden and considerable impact on the Sections totally involved in the new carrier.

It is not proposed to dwell on the details of the work of the section that stopped with the cancellation of the new carrier, but to cover the work generated by the alternative carrier programme, highlighting in detail the more interesting aspects of that work.

The alternative carrier programme showed the four fixed-wing carriers operating until the phasing out period 1970–1975. Two of the carriers were to be refitted and equipped to operate the Phantom aircraft to be purchased from the United States. The first operational squadron to be formed in 1969. Modernization and conversion of the two carriers was to be limited to work essential for the operation of the Phantom. The two carriers subsequently proved to be *Ark Royal* and *Eagle*. The former commenced refitting in 1967.

From February, 1966, therefore the work of the Section has been directed at:

(*a*) The development of components to improve the life and reliability of existing catapult and arresting gear equipment.

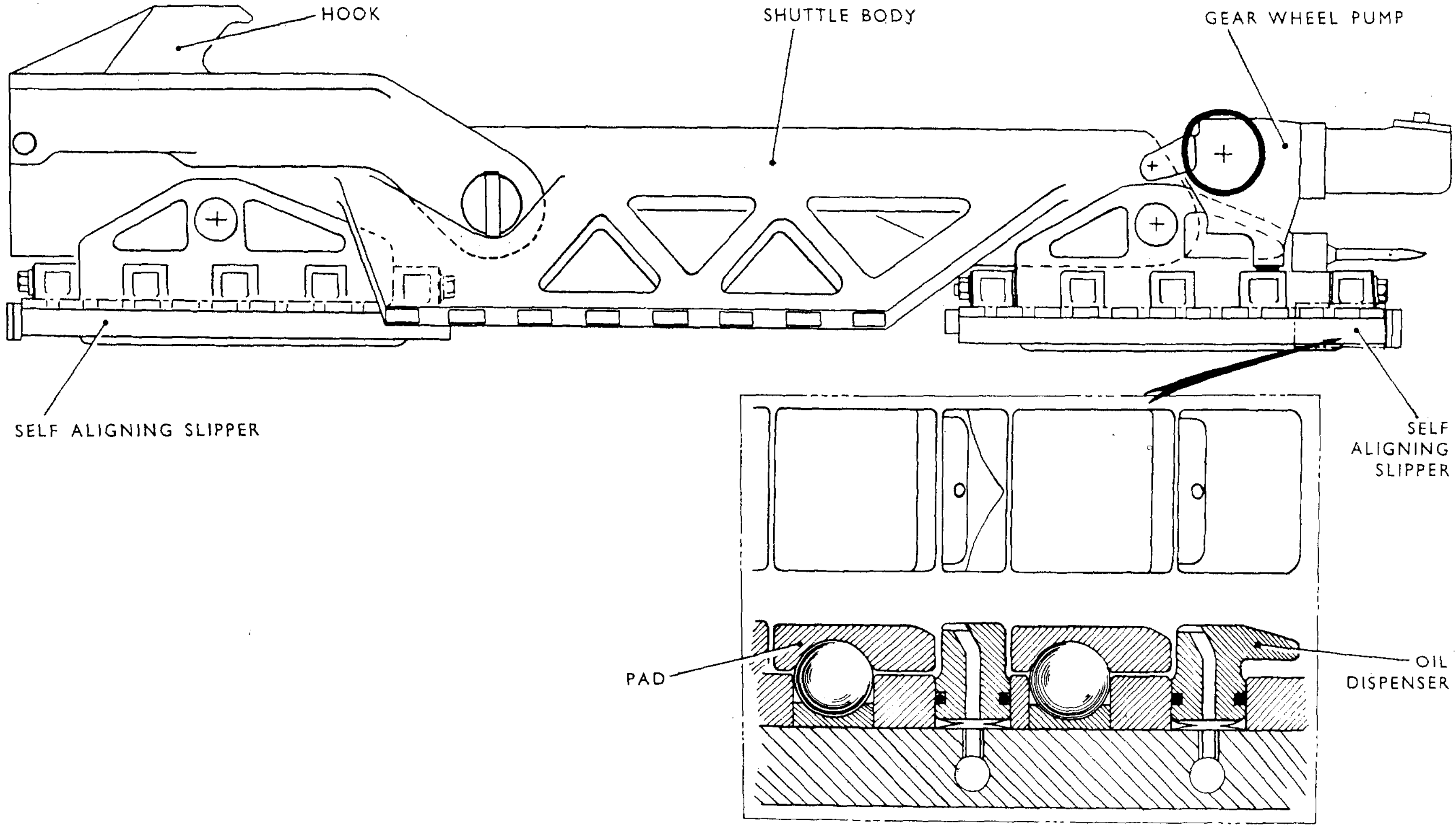

FIG. 1—C.R.T. SHUTTLE AND PADS

(*b*)] The design, development and installation of equipment essential for the launching and recovery of the Phantom aircraft.

CATAPULTS

The catapults now in service are the BS5 catapult, installed in H.M.S. *Eagle* and the BS4 catapult installed in all other fixed-wing aircraft carriers. The two catapults are similar and differ only in the method of transferring the towing loads from the aircraft bridle to the ship's structure. In the BS4 catapult this is done through the shuttle and shuttle rollers to the channel section of the track covers. In the BS5 catapults the load is not transmitted through the track covers, but taken directly from the shuttle and shuttle linear hydrodynamic bearing to a centre rail. All BS4 and BS5 catapults have wet accumulators and plug type launch valves.

Life and Reliability Improvements

The main problems being experienced with ship catapults are:

(*a*) Power cylinders—random slacking back or failure of flange bolts.

(*b*) Track covers—seizure of connecting dowels and supports.

(*c*) BS4 shuttle roller bearing failure.

(*d*) BS5 shuttle slipper pad wear.

(*e*) Jigger accumulator bore corrosion.

(*f*) Cylinder gap instability.

(*g*) Piston assembly wear.

All problems are being investigated either by ship or shore trials. The major R and D effort at NAD/RAE is being directed at the BS5 shuttle slipper wear and piston assembly wear problems.

BS5 Shuttle Slipper Development

The BS5 catapult shuttle has a self-aligning slipper assembly at each end. (FIG. 1.) Each slipper has eleven pads on each side pivoted on a steel ball to allow them to work on the Michell principle. Each pad has an area of approximately 2 sq. ins. Oil is supplied from a gear wheel pump driven by wheels running on the underside of the catapult track cover. Pad wear rates are high. Pad area has been increased as much as slipper and track dimensions will allow. Development is now aimed at:

(*a*) Better distribution of oil over pads.

(*b*) Increasing the quantity of oil to the pads.

(*c*) Providing more oil, sooner at the start of launch.

(*d*) Improving pad material. Material now used is a molydisulphide-treated SG iron against a phosphated mild steel bearing strip.

Pad materials under trial are:

(*i*) Sulphinuz treated steel

(*ii*) Graphite impregnated Orkot—a resin bonded fabric

(*iii*) Glacier DX

(*iv*) Phosphated mild steel.

Piston Assembly Development

The average life of piston assemblies is less than 1500 launches. At this life the limiting wear of the guide piston is reached and the whole assembly is

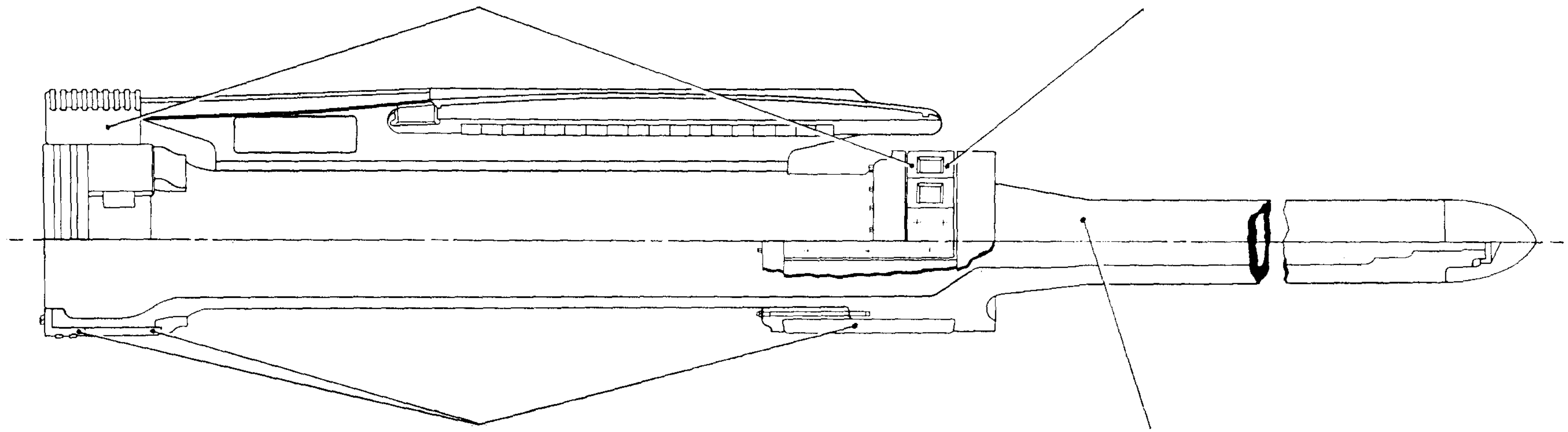

FIG. 2—IMPROVED BS4/5 PISTON ASSEMBLY

removed and replaced by a refitted on-board spare. Development is being directed at:

(*a*) Increasing the life of all wearing parts by improvements in design, material and lubrication.

(*b*) Enabling wearing parts to be renewed in place by redesign.

FIG. 2 illustrates the principles of the new Mk 17 piston assembly. This design incorporates:

(*a*) Segmented guide and power pistons.

(*b*) Steam pocketted guide pistons.

(*c*) Lightweight integral ram and distance piece construction.

(*d*) Wearing parts that can be renewed in place.

Materials for the wearing parts will be selected as the result of trials at NAD. Likely contenders are:

Piston segments—SG iron grade 37/2 or 27/12 SNG

Key/iron strips—sulphinuz heat treated mild steel or chrome plated mild steel.

In support of this development the cylinder lubrication system is being modified to spray oil to the lower half of the cylinder only, and the present 10 to 1 mix of OX275 and OX520 oils may be changed to either a 20 to 1 mix of OX275 and OX320 or a 5 per cent Oildag and 95 per cent OX275.

Phantom Modifications (FIG. 3)

The 200 ft catapults in *Ark Royal* and *Eagle* have performance sufficient to launch Phantoms up to the 50,000 lb take-off weight limit set by deck strength, in all but extreme ambient temperature conditions. At these extremes some natural wind is required, or a reduced launching weight is accepted. No modifications to increase catapult performance have been authorized.

The following modifications are essential and have been authorized:-

(*a*) *Loading Chocks*

The existing aircraft loading positioner fitted in all carriers is not very effective for aircraft above 45,000 lb weight and is being removed.

Flat-faced hydraulically operated loading chocks are being fitted. These chocks will have a vertical height of 7 ins. and are intended to stop aircraft in the correct fore and aft position relative to shuttle and hold-back loader. No alternative means of transverse positioning is being provided, reliance being placed on better pilot and direct techniques.

(*b*) *Flush Deck Resilient Holdback Loader and Track*

The Phantom breakout load is 75,000 lb and is above the design load of existing loaders and tracks. Advantage has been taken during the redesign to fit the loader in the track, and not above the track on deck as in present designs. This flush deck arrangement will simplify the aircraft's approach to the catapult and protect the loader from jet blast and temperature.

The object of the resilient loader is to hold and retain the hold-back 'T' anchor during loading and launching without over straining the hold-back breaking link.

The loader consists of a hook fitting, in which one end of the hold-back engages, connected to a liquid spring. The liquid spring has a stroke of 4¾ ins., a closing force of 39,000 lb, and is required to operate in temperatures up to 120 degrees C. The whole assembly is being designed for horizontal loads of 100,000 lb and vertical loads of 50,000 lb.

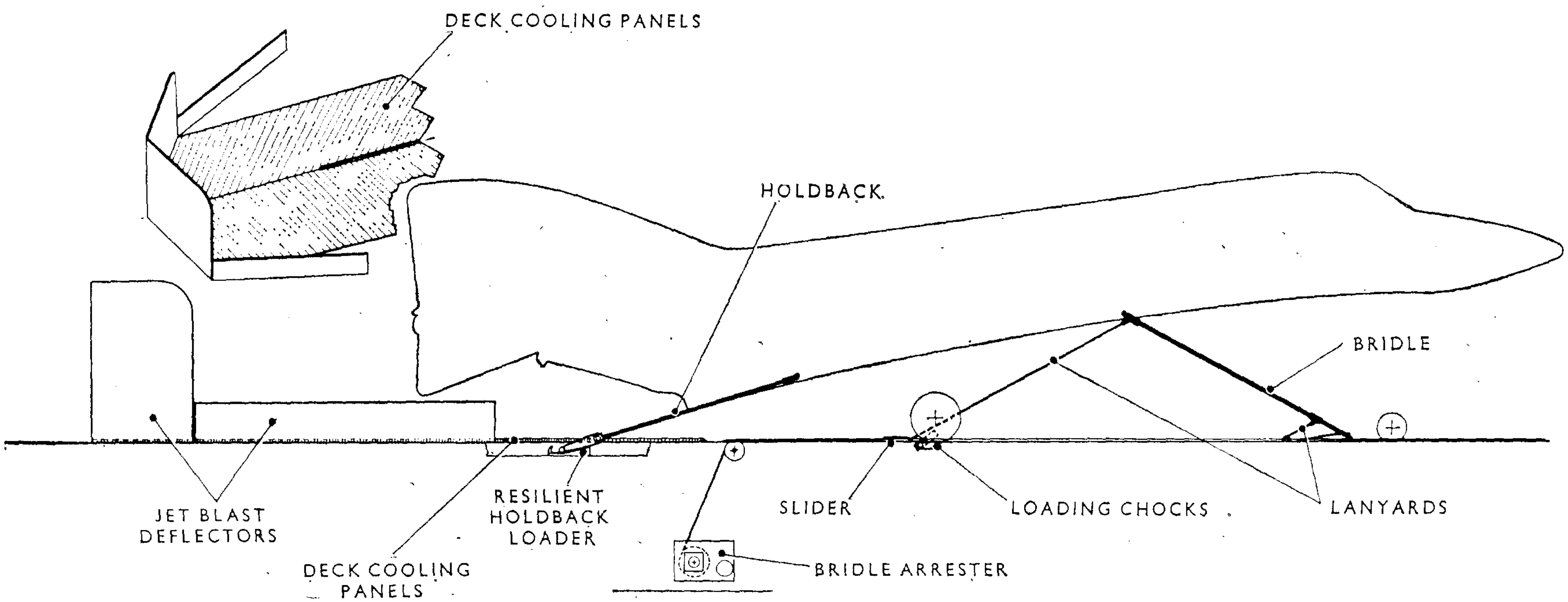

FIG. 3—PHANTOM MODIFICATIONS

(*c*) *Bridle Arrester*

Phantom aircraft and their under-wing stores may be damaged by bridle strike if launched without a bridle arrester. BS4 and BS5 catapults have never been fitted with a bridle arrester. The loss of the bridle after each launch has always been accepted. Various forms of arrester and catcher have been considered but none was developed. The Phantom aircraft creates a positive requirement for a bridle arrester. The time scale and cost were against a UK development venture and therefore the Van Zelm bridle arrester, in service in the USN as the USN Mk 2 Bridle Arrester, is being purchased from the US for fitting to each of *Ark Royal's* catapults.

The USN Mk 2 bridle arrester is a friction brake device designed to arrest the bridle after it has been separated from the aircraft without crippling the bridle or hitting the aircraft. The bridle weighs 175 lb and will be moving at speeds up to 115 kts. The bridle arrester then returns the bridle to the aircraft loading position.

The bridle is connected to the bridle arrester at all times by nylon lanyards to four sliders. The sliders run in two tracks, one each side of the catapult track. One slider is connected to a steel strap. The strap is led back to the bridle arrester engine in the catapult machinery compartment. Three cam-controlled sequentially-operated disc type brakes arrest the bridle over a run-out stroke of 40–50 ft after the launch completes. A motor driven hydraulic motor rewinds the strap and returns the bridle.

(*d*) *Jet Blast Deflector* (*JBD*) *and Deck Cooling Panel*

To meet the end-speed requirements of the Phantom aircraft at high take-off weights in conditions of no natural wind and high ambient temperature from the relatively short stroke catapults fitted in RN carriers, the Phantom will at times be launched with the engines at maximum reheat thrust. The engine characteristics at maximum reheat thrust are:

Thrust 13,000 lb—16,500 lb per engine (varying with ambient temperature)

Temperature	
approximately 12 ft from nozzle	1700 degrees C
,, 15 ft ,, ,,	1400 degrees C
,, 17 ft ,, ,,	1200 degrees C
Velocity	
approximately 16 ft from nozzle	2800 ft/sec
,, 18 ft ,, ,,	2600 ft/sec
,, 20 ft ,, ,,	2400 ft/sec
Noise	
up to 150 ft from nozzle	135 dB

These severe requirements exceed the capabilities of existing designs. The existing designs are also unsuitable aerodynamically. Other conditions to be satisfied are:-

(*i*) Crushing strength when lowered to withstand loading of 62·5 tons over an imprint of 24 ins. by 13 ins. from main wheel reaction of aircraft landing or bolting.

(*ii*) To be flush with the deck when lowered.

(*iii*) Panels to withstand full reheat for not less than 30 seconds.

(*iv*) Surface temperature of panel to be not greater than 170 degrees C 10 seconds after a launch.

(*v*) Raising and lowering times not to exceed 5 seconds.

(*vi*) Area behind JBD to be free of blast to enable aircraft and men free use of the flight deck.

(*vii*) Depth of recess in flight deck to accommodate JBD to be a minimum.

A completely new design of JBD has been developed to meet all these requirements. The deflector is made up of 4 panels. The 2 main panels are each 10 ft wide by 9 ft high and are arranged in a 'Vee' angled at 135 degrees. The apex of the 'Vee' is 57 ft 6 ins from the catapult datum. Each main panel is surfaced with an aluminium cooling panel, 1 inch thick with cooling passages of 1/2 in. × 1 in. section. The panels are hinged at the forward edge. Each main panel is raised by 2 hydraulic jacks, assisted for the first 15 degrees of up or down movement by a torsion bar, and locked up by locking struts. The 2 side panels are 12 ft 6 ins. wide (or as near this as can be tailored into the ship) by 2 ft high and are uncooled. The side panels are angled at 30 degrees to the catapult centre line (or as near this as can be arranged in the ship) and the after end butts against the outboard edge of each main panel. All plates are vertical when raised.

The side panels collect and sweep in the low temperature, low level jet gases that splay from the deck impact point. The 'Vee' main plates collect the main gas stream together with the side plate sweepings, and all flow inwards and upwards to the Vee apex from where it is expelled vertically upwards as a core of hot gas rising to a height of 50–60 ft before dispersing.

A major problem has been the design of the cooling panel and its securing to the main JBD structure. The design was hampered by a lack of information concerning the heat transfer rates of jet gases impinging on flat panels. Attempts were made to relate basic theory with practice using Lightning aircraft and small panel sections, but without success. In the end time pressed and the design is based on extrapolation from the Lightning results obtained at NAD/RAE.

The cooling panel is built from 12 ins. wide aluminium extrusion. These extrusions are welded to form each panel. The main cooling panels are 2-flow, cooling water entering at the bottom and apex side of each panel, and leaving at the bottom and outer side. The flow velocity is 10 ft/sec through the panel. Sea water is used for cooling.

The cooling panels are secured to the $\frac{1}{2}$ in. backing plate of the main panels by $\frac{3}{8}$ in. EN20 bolts.

Attachment points are provided through steel bushes inverted in the cooling panel of the welded joints.

The bolts and bushes are aluminium sprayed. The cooling panel and main panel are separated by a $\frac{1}{8}$ in. neoprene bonded cork joint (Nebar).

The main panel depth is 12 ins. excluding jack and strut fittings which penetrate the flight deck recesses.

Deck cooling panels are fitted over an area approximately 30 ft × 13 ft forward of the JBD. The same aluminium extrusion is used in the construction of the cooling panel as is used for the JBD.

Noise

The noise aspect of reheat launching has not received much attention and could be a problem. Trials action has been initiated with MDG to study the short and long term effects on catapult and flight deck crews working at close quarters with aircraft using reheat.

ARRESTING GEAR

Mk 13 Arresting Gear

The arresting gear installed in all fixed-wing carriers is the Mk 13. This gear came into service in 1955 in H.M.S. *Ark Royal* with a performance of:

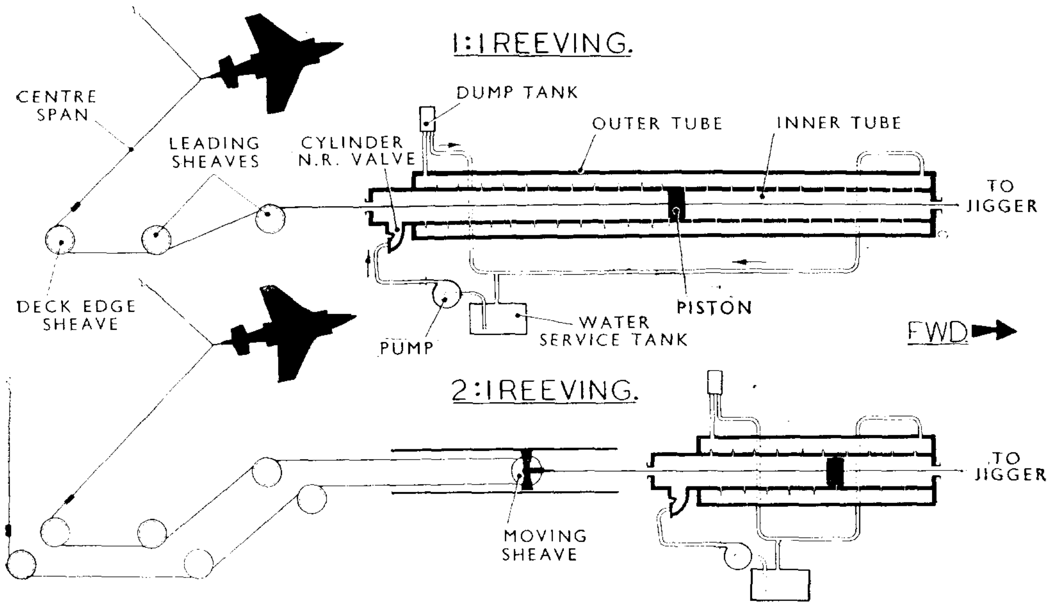

FIG. 4

up to 110 kts at 20,000 lb
up to 105 kts at 30,000 lb

The gear was uprated in 1960 to a performance of up to 112 kts at all weights up to 30,000 lb and at speeds equivalent to an energy of 16·7 $\times$ 10^6 ft lb at weights from 30,000–37,000 lb. A further uprating to a performance of 120 kts at all weights up to 30,000 lb and at speeds equivalent to an energy of 19·2 $\times$ 10^6 ft lb at weights from 30,000–40,000 lb has been agreed and is being released to the Fleet.

The latest increase in performance has been obtained without modification to the arresting gear and is based on accumulated in-service and trials experience, and a recently acquired ability to measure aircraft entry-speed.

No further development of or modifications to the Mk 13 arresting gear are planned.

Direct-Acting Arresting Gear (FIG. 4)

The direct-acting arresting gear was selected for development to meet the Staff Requirement for an arresting gear for the new aircraft carrier in 1962. At the beginning of the period covered by this review of the Section's work, three prototype direct-acting arresting gears were planned, two for shore development and trials at NAD/RAE and one for evaluation at sea in an operational carrier. The delivery of the first production gears was planned to commence in September 1969 for the new carrier.

This programme was upset by:

(*a*) The cancellation of the new carrier.

(*b*) The introduction of Phantom aircraft into RN squadron service in 1969.

(*c*) The phasing out of all fixed-wing carriers by the mid-1970's.

The Mk 13 arresting gear fitted in all carriers was incapable of arresting Phantom aircraft without excessive and unrealistic amounts of natural wind. It was obvious that the development of the direct-acting arresting gear must continue and be reorientated and retailored to meet the revised requirements.

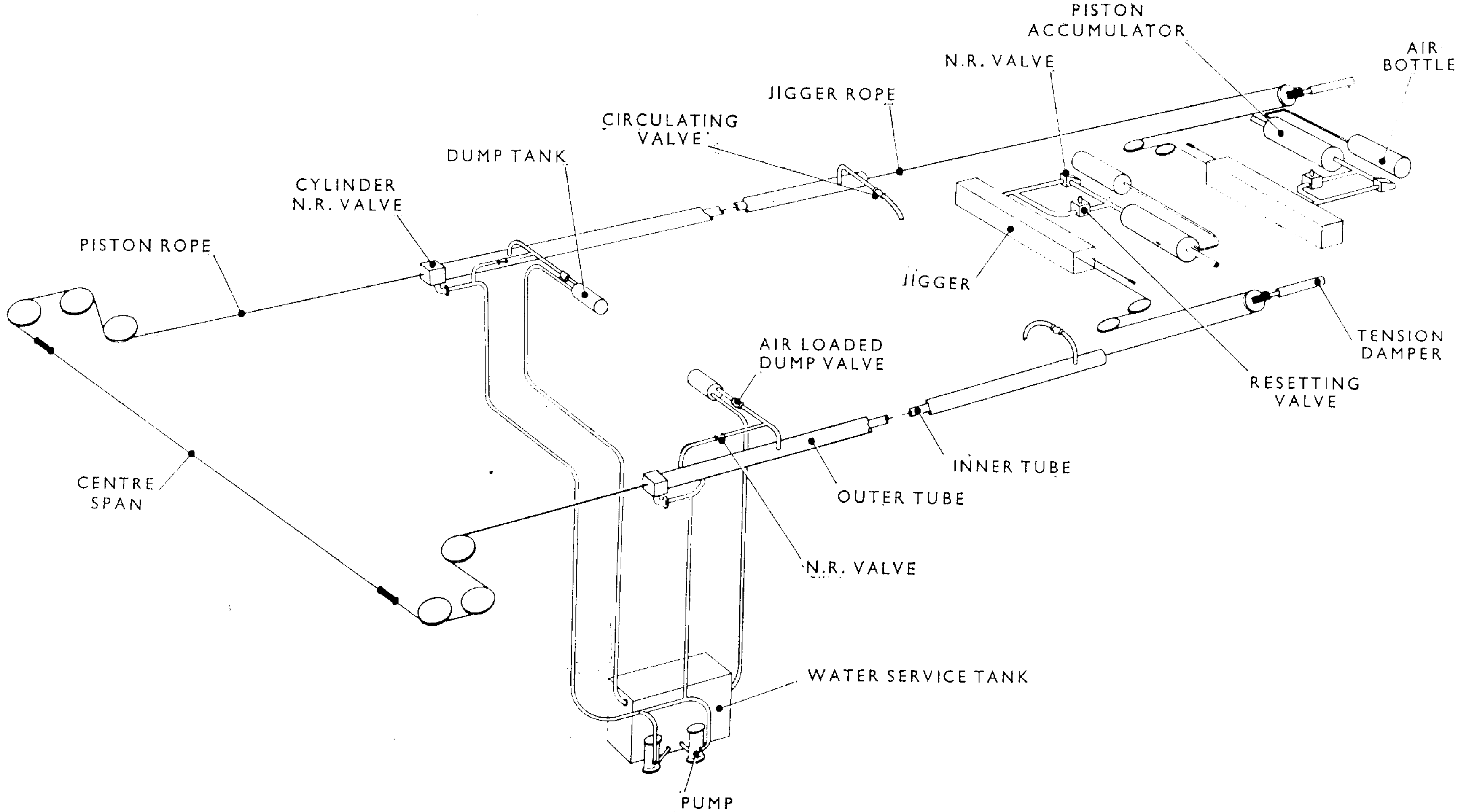
PISTON ACCUMULATOR
AIR BOTTLE
N.R. VALVE
JIGGER ROPE
CIRCULATING VALVE
DUMP TANK
CYLINDER N.R. VALVE
PISTON ROPE
JIGGER
TENSION DAMPER
AIR LOADED DUMP VALVE
RESETTING VALVE
INNER TUBE
CENTRE SPAN
OUTER TUBE
N.R. VALVE
WATER SERVICE TANK
PUMP

FIG. 5

By eliminating two major features of the direct-acting arresting gear development:

alternative resetting systems; and

energy absorber for emergency barriers;

the development programme was shortened to allow delivery of the first ships gears to commence in October, 1967, (23 months in advance of the new carrier deliveries) and the number of prototypes reduced to two, one on shore (DAX1) and one at sea (DAX2). This programme has led to the DA2 arresting gear now being installed in *Ark Royal.*

DA 2 Arresting Gear (FIG. 5)

The basic design for the new carrier arresting gear has been retained. The Staff Requirement for this design is to arrest aircraft in the weight range 15,000–40,000 lb from engaging speeds not less than 110 kts for the lower weight aircraft and not less than 125 kts for the upper weight, without exceeding a retardation of 4·2 g. From ship and equipment considerations the arrest must be completed within a run-out distance of 270 ft, with a deck-edge sheave spacing of 100 ft and with a limiting factor of safety (FOS) of not less than 2 on all arresting gear components. The arresting gear designed and being developed to meet these requirements is the DA2. The essential features of DA2 are:

(*a*) *The Energy Absorbing Unit* (FIG. 6)

This unit is an inner tube of $5\frac{3}{4}$ in. bore contained in a 10 in. bore outer tube and arranged in 2 lines approx. 230 ft long. Along each inner tube are approximately 200 orifices of $\frac{3}{4}$ in. diameter. A piston, 12 in. long, connected to the arresting gear rope system runs in each inner tube. Each tube length is anchored at one end only. The tube length is aligned and supported to within a limit of $\pm$ 0·1 in. over 220 ft and is free to move axially to allow for expansion of the unit or relative ship/unit movement from other causes. The inner and outer tubes are kept full of fresh water by pumps. When the rope system is engaged by the aircraft the pistons are pulled along the inner tubes expelling and circulating the water ahead of each piston through the orifices into the outer tubes and back into the inner tube behind the pistons. Pressures of up to 3,000 lb/sq in. are generated in the inner tubes. Pressures in the outer tubes are controlled to 600 lb/sq in. by air loaded relief valves. As the piston speed decreases during the arrest so does the orifice area ahead of the piston and a reasonably constant pressure and therefore aircraft retardation, is maintained throughout the arrest. By careful design of the orifice programme the gear is capable of arresting a wide range of aircraft weights and speeds and no adjustment of the gear for different aircraft weights and speeds in the specified range is necessary or fitted.

The inner and outer tubes are made up from 12 ft and 8 ft lengths as required to match the spacing of the ship's structure. Inner and outer tubes are solid drawn from EN26 and mild steel BS 806-B respectively.

(*b*) *Water System*

The energy absorbing units, 4 pairs in a 4-arresting-wire ship, are supplied and maintained full by fresh water supplied by any 2 of 4 arresting gear pumps from a drain and service tank. The water enters the tube units through a non-return valve at the main gland end of each outer tube. Pump capacity is sufficient to:

(*i*) make up water dumped from the outer tube relief valve of the engaged unit during an arrest, in the 20 second reset cycle, and

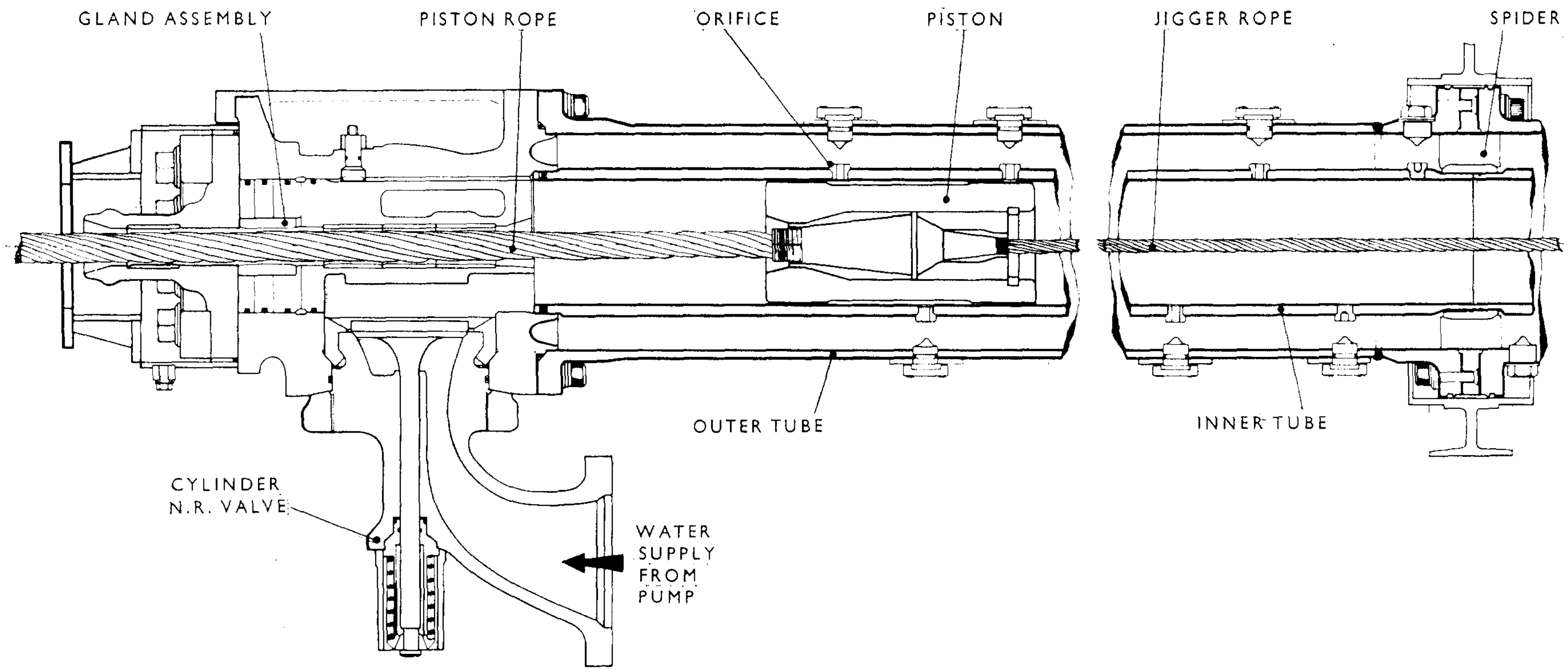

FIG. 6—DIRECT-ACTING ARRESTING GEAR—SECTION SHOWING GLAND, CYLINDER NON-RETURN VALVE AND PISTON

(*ii*) Make up gland leakage and maintain all units full in the stand-by condition.

A valve is fitted at the end of each unit opposite to the inlet non-return valve. This valve is opened on the engaged unit at the end of the arrest to promote circulation through the unit during the reset cycle and ensure full flushing and air freeing of the engaged unit.

A drainage system returns water leaking from rope glands, dumped from outer tube relief valves and circulated during reset to the drain and service tank.

(*c*) *Reset and Pre-Tension System*

The units are reset and pre-tensioned by recuperative system energized in part by the arrested aircraft. The system consists of a 14 ft stroke hydro-pnuematic jigger unit reeved 16 : 1 with a $\frac{5}{8}$ in. diameter steel wire rope (17·2 tons GBL) connected to the rear end of the main unit piston. The jigger is preloaded by an accumulator charged to 600 lb/sq in. The system working fluid is HS 271, a proprietory non-inflammable hydraulic fluid. Jigger units are double-reeved so that one jigger is connected to two main unit pistons.

When a unit is engaged the associated jigger crossheads are moved together and the jigger piston displaces fluid into the accumulator through a non-return valve. To reset the gear the jigger/accumulator non-return valve is by-passed by a remotely controlled reset valve.

The accumulator basic charge pressure is sufficient to pre-tension the rope system in the stand-by condition.

(*d*) *Rope System*

The engaged aircraft, energy absorbing units and reset/pre-tensioning gear are connected by the rope system. The rope system for each unit consists of:

(*i*) Centre span.

(*ii*) Two piston ropes.

(*iii*) Two jigger ropes.

Unlike the Mk 13 arresting gear, in which the ends of the main reeve connected to the main unit are prevented from rotating, the DA2 piston rope is free to rotate at both ends. To prevent rotation and unlaying of the piston rope when loaded, a special form of steel wire rope has to be used. These ropes are called non-rotating and are constructed of two layers of strands, the one layed in the opposite direction to the other. The rope at present selected for the DA 2 piston rope is constructed of 6 strands of 16 wires each layed over 6 strands of 10 wires each. This rope is $4\frac{1}{2}$ in. circumference and has a breaking load of not less than 100 tons when new. The target life for the piston rope was a 1,000 engagements. It is possible that this may be achieved in terms of fatigue life; the present life of about 500 engagements is set by wear from deck abrasion during reset.

To be fully compatible with the piston rope and ensure no detrimental interaction between the two ropes, a similar size and construction centre span was used during earlier shore trials and is in use in DAX2/*Eagle*. This construction is however proving unsatisfactory at high weight and high speed engagements at maximum off centre (15 ft) and is currently the limiting feature of the DA2 development.

A conventional single layer steel wire rope of 6 strands of 25 wires each is used for the jigger rope.

(*e*) *Signal and Control System*

The signal and control system is designed to give safe and automatic operation of the complete arresting gear system. During landing operations manual controls are limited to two:

(*i*) Reset, and
(*ii*) Safe to land.

The signal system is graded into two parts:

(*i*) That affecting the safety of operation of the arresting gear.
(*ii*) That required to monitor and diagnose system operation and faults.

The former are interlocked into the arresting gear state lights which indicate either unserviceable or serviceable but not ready, or ready and safe to land.

The signals and control system is consolised, with the main console sited in the arresting gear control room. The arresting gear state lights are repeated at Flyco and at the arresting gear deck edge control position, the latter also having the manual 'reset' and 'safe to land' controls.

Direct-Acting Arresting Gear Development Problems

One reason for the selection of the direct-acting arresting gear for development as the new generation arresting gear was its basic simplicity and the simple and straightforward engineering technique required for its manufacture. With only two exceptions this claim has been justified by the very small number of problems that have been met during the first two years of development. These two exceptions are:

(*a*) The more complicated water recirculation system found necessary to flush and vent the inner and outer tube lengths during reset to achieve a gear cycle time of 20 seconds from wire engaged to gear ready. To overcome venting problems and ensure an air-free tube length, each tube length is connected through a remotely controlled 6 in. plug valve to a common 6 in. bore recirculating and drain line. The plug valve is opened on the two tube lengths of the engaged unit only during reset.

(*b*) The unresolved problems of the steel wire rope system. The design target for this system was:

(*i*) FOS not less than 2 on breaking load of piston and jigger ropes at maximum performance.
(*ii*) A life of 1,000 engagements for piston and jigger ropes and 25 for centre spans.
(*iii*) A predictable failure of all three ropes in the system and an easily applied rejection criterion.

The achievements so far are:

(*a*) High impact tensions causing the limiting factor of safety of 2 in. piston and jigger ropes to be reached at much lower performances than expected and contributing to the unpredictable failure of centre spans.
(*b*) A possible life of 1,000 engagements for jigger ropes, and 500 for piston ropes, but uncertainty of centre span life and behaviour.
(*c*) Predictable failure of piston and jigger ropes, but unpredictable failure of centre spans for engagements at maximum off centre (15 ft).

Direct Acting Arresting Gear Development

Current development work can be grouped as follows:

Design Improvements

This group covers the refining and streamlining of the original design. This design was frozen at a very early stage to enable manufacture of the two prototypes to commence. Many 'insurance' and 'just in case' features were included in the design on the grounds that at a later date it would be easier to remove bits and pieces not required than it would be to add them. The extras include:

(*a*) An excess of signal and control facilities with the ability to operate in any one of three control modes.

(*b*) Additional and alternative tube filling arrangements.

(*c*) Generous instrumentation.

Operational experience from DAX 2/*Eagle* is enabling many improvements to be made. The value of this trial is very much increased by the resident trials team of one officer and three ratings, responsible to DG Ships through the MEO for the conduct of the trial, and their fortnightly reports.

Material Improvements

These are the changes to component design necessary either to improve life and reliability or downright unsuitability. The necessary information is coming from DAX 1/Bedford (2,000-plus engagements) and DAX 2/*Eagle* (600 engagements). The main items concerned are:

(*a*) Entry-speed camera—an automatic start/stop camera fitted with a 0·010 in. wide slit instead of a shutter which gives entry-speeds by night and day from measurement of image length.

(*b*) Jigger tension damper—a sheave attached to a piston accumulator to absorb rope tension energy and which is at present suffering from the high-speed impact type loading.

(*c*) Inner tube locking—the inner tubes are located and supported by spiders located in the outer tube flanges. Inner tubes are threaded and screwed into the spider support at one end and secured by Loctite. The inner tubes are unscrewing. The reason for this movement and the forces involved are not understood.

(*d*) Piston and jigger rope glands—segmented and sprung stellite-faced glands. Wear and leakage problems.

(*e*) Rope couplings—present rope socketting procedure using Babbit metal requires skill, cleanliness and careful temperature control. Resin socketting could make this process a lot easier.

(*f*) Sheave lubrication systems—a remotely controlled system for supplying lubricating oil to all sheave bearings.

(*g*) Centre span rope supports—metal bow springs.

Performance Improvements

These are changes to component and system design necessary to make good shortcomings in performance. These shortcomings are confined at present to the rope system which is proving to be the limiting feature of DA 2 in meeting current requirements and to meet foreseeable performance stretch requirements during the life of DA 2.

The present rope system problems are:

(*a*) Unpredictable centre span failure occurring above 35,000 lb and 120 kts entry weight and speed at maximum off centre.

(*b*) High rope tensions in piston, jigger and centre span ropes reaching the limiting FOS of 2 in. piston and jigger ropes at about 125 kts entry speed.

The centre span problem is thought to be due to a combination of factors:

(*i*) Rope tension.

(*ii*) Rope flexibility as it affects its ability to balance and evenly distribute loads during fleet through and bending round the aircraft hook.

(*iii*) Rope damage arising from interstrand and interwire nicking caused by the severe transverse and longitudinal loads applied at impact and during the arrest.

The latter two factors are a problem of rope design, while the first is a matter of gear design.

Performance problems are therefore being investigated by two separate lines of development: improvements in steel wire rope design, and reductions in rope tensions from improvements in gear design.

Steel Wire Rope Design

A project team made up of representatives of NAD/RAE, AML, DG Ships and Martin, Black (Wire Ropes) Ltd. has been formed. Its terms of reference are to establish the cause and mechanism of failure of the centre span construction at present fitted in the two prototype gears and to recommend variants of the original construction and new constructions for development and evaluation at NAD/RAE.

At present three different rope constructions are being evaluated for use as centre spans:

(*a*) 6 × 16/6 × 10 SWR with a steel wire rope core, and its variants:

  (*i*) 6 × 16/6 × 19 with filler wires.

  (*ii*) 6 × 16/6 × 18.

  (*iii*) 6 × 16/6 × 21.

(*b*) 6 × 25 flattened strand SWR layed to be compatible with a non-rotating 6 × 16/6 × 10 construction piston rope.

(*c*) 18 × 4/6 × 25 SWR.

and a fourth is under consideration:

(*d*) 7 × 15/6 × 19 SWR.

Rope Tension Reductions from Improvements in Gear Design

The type and pattern of tensions set up in an arresting gear rope system at impact and during the subsequent arresting cycle are involved and complex. Basically there are two phases:

(*a*) The impact phase during which transverse and longitudinal tension waves generated by aircraft hook impact dominate the system. This phase lasts for 0·2 seconds.

(*b*) The main body phase during which first the tensions set up by the inertia of the A/G moving parts and then the energy absorber dominate. This phase lasts between 2·5 and 3·0 seconds.

The problem is caused by short duration peak tensions occurring during the impact phase. These tensions are 60–70 per cent higher than the main body tensions and are generated when the transverse tension wave reaches the deck-edge sheaves and as the longitudinal tension wave reaches A/G moving parts along the rope system.

The peak tensions generated by the transverse tension wave could be reduced by deck-edge sheave dampers. Such a damper would require a 44 in. diameter sheave velocity programmed to move through a distance of about 6 ft in phase with the transverse tension waves and capable of taking the full engagement loads. Fitting a total of 8 such sheaves in *Ark Royal* and *Eagle* would be a costly solution.

The peak tensions generated by the longitudinal tension wave can be reduced by:

(*a*) Reducing the inertia of all moving parts. This includes:

(*i*) Deck edge and leading sheaves.

(*ii*) Piston ropes.

(*iii*) Resetting system.

(*b*) Reducing the equivalent weight of the column of water ahead of the pistons at the instant of first movement of the pistons.

(*c*) Absorbing the impact longitudinal tensions in damping or yielding devices at the pistons and between pistons and the reset system.

All these methods are being considered and some are being fitted to DAX 2/Bedford for evaluation. Limited trials indicate that the largest single reduction in impact peak tensions is likely from *a*(*iii*) above by the elimination of any form of tail rope resetting. The development of an alternative reset system, e.g., pump resetting, presents considerable problems and would be a drastic step to take at this stage and time in the development and installation of DA 2 arresting gears. It may however prove necessary to meet either the existing Staff Requirement or a revised Staff Requirement to meet Phantom performance shortcomings. It is at this stage that the development of the DA 2 arresting gear is poised.

DISCUSSION

The presentation ended with a brief discussion. Some of the questions and answers are given below.

Q. How does the DA 2 fixed orifice programme cater for varying aircraft weights and speeds?

A. The characteristics of the DA 2 A/G are such that one programme will cover the full range of the Staff Requirement. The gear performance is optimized at one particular performance to suit the aircraft to be operated from the carrier; for *Ark Royal* 36,000 lb at 125 kts. An entry-speed penalty is accepted for operating the low 'g' Gannet aircraft, which is outside the low energy end of the Staff Requirement for the DA 2 A/G.

Q. What is the water consumption of the DA 2 A/G?

A. DAX2 A/G trials in *Eagle* show the loss to be about 8 gallons per arrest. The gear is basically a 'no loss' system. Some water is carried onto the flight deck by the piston rope and lost. Other losses occur from system leaks.

Q. Was the use of sea water considered for DA 2 A/G?

A. Yes, but the corrosion problems, particularly in the piston rope, were considered unacceptable.

Q. Would dampers help reduce rope tensions?

A. Yes, and they are used in the DA2 jigger reset system between the piston and jigger with great effect, and further improvements from these dampers are expected following redesign. Deck-edge sheave dampers are also being fitted to DAX2/Bedford, but they are large and difficult to instal in existing carriers.

Q. How do the USN arresting gears cope with Phantoms?

A. This problem is peculiar to the non-rotating ropes used in DA2 gears and does not arise in the long pull out gears of the large USN carriers using the conventional steel wire ropes of rove arresting gears.

Q. What has happened to nose-wheel tow launching and automatic loading?

A. This was a Staff Requirement for the new carrier. Specifications for the replacements for existing aircraft required nose-wheel tow launching. This towing arm could also be used to guide the aircraft into the correct loading position. The RN flush deck system was well advanced but was cancelled with the new carrier and its aircraft.