

STATUS OF SUPER-4

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SUMMARY

The research and development effort leading to the modification of the British Rail 185 ton SR.N4 Mk.1 hovercraft to the 300 ton SR.N4 Mk.3 configuration is reviewed. The new craft — known as the Super-4 — has a payload capacity of 60 cars and 418 passengers, a 70% increase compared with the Mk.1 craft.

The design changes, including the development of a new, more efficient skirt in combination with a 50% increase in craft length and new, larger diameter, airscrews are illustrated and the expected improvements in speed performance and motion response are indicated.

An account of the construction and acceptance trials phase including confirmation of the expected improvements in seakeeping, is followed by a description of subsequent in-service achievements of the two Super-4's on the Dover-Boulogne-Calais cross Channel routes.

1. INTRODUCTION

In previous papers (references 1 and 2) presented to the American Institute of Aeronautics and Astronautics and (reference 3) to the Royal Institution of Naval Architects, the author has described the initial development phase of the Mountbatten Class SR.N4 Mk.1 hovercraft, its subsequent in-service development in Mk.1 and 2 forms and the anticipated improvements expected from the major modification to the Mk.3 (Super-4) configuration.

The present paper reports on the results of the construction and acceptance trials and the achievements of the first year of commercial operation of the Super-4. Both British Rail SR.N4 craft have now been converted from Mk.1 to Mk.3 form and are in regular cross Channel operation, in addition to the four Mk.2 craft operated by Hoverlloyd.

2. OPERATIONAL BACKGROUND OF THE SR.N4 SERIES CRAFT

The first SR.N4 commenced commercial operation with British Rail Hovercraft (Seaspeed) on the Dover to Boulogne and Calais routes in the Summer of 1968. This was quickly followed by two more craft operated by Hoverlloyd on the Ramsgate to Calais route in the Spring of 1969. These operations were steadily expanded until, in 1977, BR Seaspeed were operating two SR.N4 Mk.1 craft, each capable of carrying 32 cars and 254 passengers and the Hoverlloyd fleet comprised four SR.N4 Mk.2 craft with widened cabins which increased the payload by some 15%, to 37 cars and 284 passengers.

The general appearance and leading particulars of BR Seaspeed's Mk.1 craft are given in figure 1. Typical car deck layouts and the widened cabin conversion of the Mk.2 operated by Hoverlloyd are illustrated in figure 2.

Since 1976, the improving passenger appeal of hovercraft and the prospect of a larger share of the cross-Channel traffic have encouraged both Operators to consider further expanding their capacity. BR Seaspeed then decided to convert its two Mk.1 craft to SR.N4 Mk.3 (Super-4) standard, embodying the Mk.2 widened cabin and a radical increase of length (some 55 ft or 7 structural bays). As indicated in figure 2 the Super-4 configuration offered some 70% increase of capacity, from 32 to typically 57 cars and from 254 to 418 passengers. Against the increased capacity and the promise of improved craft motion and waterspeed, projected power increases were modest (the four 3400 HP Proteus engines

being updated to 3800 HP continuous) with an improved deeper skirt and larger 21 ft diameter propellers replacing the 19 ft propellers of the earlier versions.



LEADING PARTICULARS

Dimensions:	Overall length 130 ft.	Powerplant:	4 x Rolls-Royce Marine Proteus 15M/529
	Overall beam 82 ft.		13,600 Hp. max. cont. rating
	Cushion area 7600 ft. ²		4 x 19 ft. dia. Hawker Siddeley Dynamics Propellers
			4 x 11 ft. 6 in. dia. B.H.C. fans
Weights:		Performance:	Typical cruise waterspeeds:-
Max. Laden Weight	187 tons	Calm	(0-2 ft. sign. waves 5 knots wind) 60-65 knots
Max. Disposable Load	73 tons	Moderate	(3-5 ft. sign. waves 20 knots wind) 45-50 knots
Typical Fuel Load	12 tons	Rough	(6-8 ft. sign. waves 27 knots wind) 30-35 knots
Payload	32 cars 254 passengers	Endurance per ton of fuel	0.25 hours

FIG.1 SR.N4 Mk.1 HOVERCRAFT

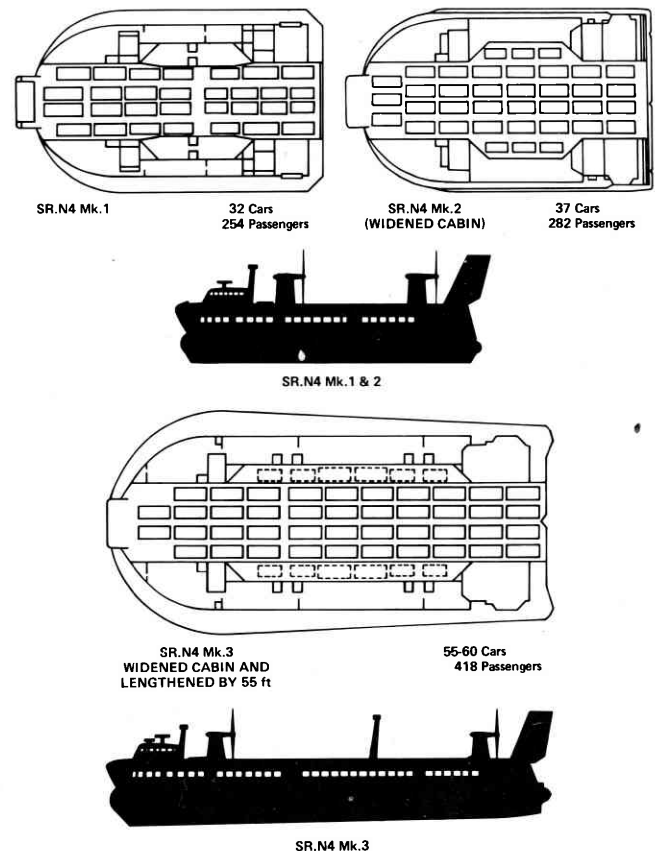


FIG. 2 COMPARISON OF GENERAL ARRANGEMENTS OF SR.N4 Mk.1, SR.N4 Mk.2 AND SR.N4 Mk.3

BR Seaspeed returned its first Mk.1 craft, GH 2007 (Princess Anne) to BHC for conversion at Cowes in February 1977. Following extensive and very successful acceptance trials, GH 2007 re-entered service as the first Super-4 in July 1978. The second Mk.1 craft, GH 2006 (Princess Margaret) which had continued in-service alone throughout the above period, was returned for similar treatment in September 1978 and re-entered service in May 1979. The appearance and leading particulars of GH 2007 after conversion are given in figure 3.



LEADING PARTICULARS

Dimensions:		Powerplant:	
Overall length	185 ft.	4 x Rolls-Royce Marine Proteus 15M/529	
Overall beam	82 ft.	15,200 Hp. max. cont. rating	
Cushion area	11500 ft. ²	4 x 21 ft. dia. Hawker Siddeley Dynamics	
		Propellers	
		4 x 11 ft. 6 in. dia. B.H.C. fans	
Weights:		Performance:	
Max. Laden Weight	300 tons	Typical cruise waterspeeds:-	
Max. Disposable Load	115 tons	Calm (0-2 ft. sign. waves 5 knots wind)	60-65 knots
Typical Fuel Load	15 tons	Moderate (3-5 ft. sign. waves 20 knots wind)	50-55 knots
Payload	55-60 cars 418 passengers	Rough (6-8 ft. sign. waves 27 knots wind)	40-45 knots
		Endurance per ton of fuel	0.23 hours

FIG.3 SR.N4 Mk.3 HOVERCRAFT



FIG.4 SR.N4 Mk.3 (GH.2007) ARRIVING AT DOVER HOVERPORT

At the same time as the first Super-4 was being converted, BR Seaspeed were completing construction of their new terminal – Dover International Hoverport – at Western Docks, Dover harbour. This facility, which can accommodate 3 or 4 Super-4 sized craft, is entirely self-contained and independent of ship ferry operations. A view of GH 2007 approaching the new terminal is shown in figure 4 and the layout of the Hoverport, its associated buildings and multi-lane arrival area for 178 cars, is given in figure 5.



FIG.5 DOVER INTERNATIONAL HOVERPORT

Immediately prior to entering service both Super-4 craft were employed for demonstration exercises. On the 25th May 1978 the first craft (GH 2007) demonstrated the feasibility of the Dover to Ostend (62 n.mile) route, indicated on the sketch map of the English Channel short sea routes (figure 6). The round trip was completed in approximately 3½ hours in fairly rough sea conditions, viz. Northerly force 7 wind, and 6 ft seas. The craft's good handling and manoeuvring qualities were demonstrated whilst proceeding through the confined river entrance to Ostend harbour (figure 7). On the 9th May 1979, the second craft (GH 2006) carried out a demonstration sortie from Dover, up the River Thames to the Pool of London (figure 6), again showing the good handling qualities of the craft.

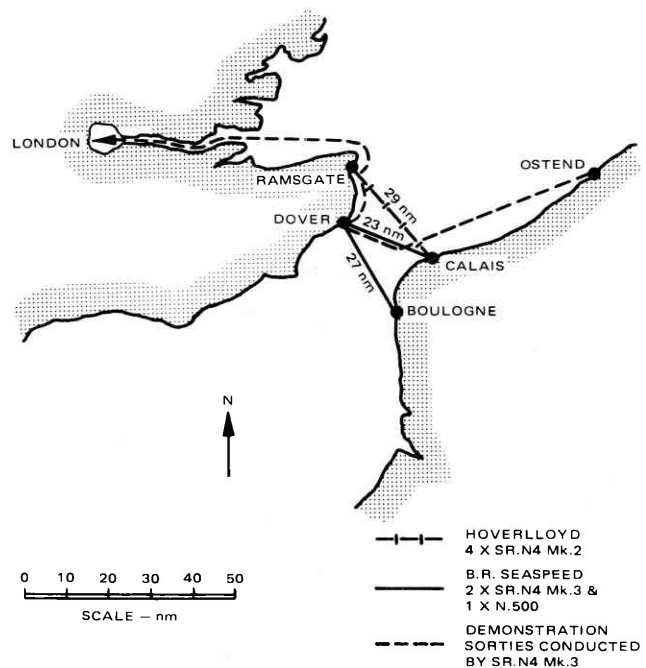


FIG.6 CROSS CHANNEL HOVERCRAFT ROUTES

The total number of passengers and vehicles carried by SR.N4 type hovercraft (both BR Seaspeed and Hoverlloyd) and the share of the total traffic that this represents are illustrated graphically in figure 8, for the period 1968 to 1978. Since 1971 the combined capacity of both Operators has remained almost static, largely due to the phased withdrawal of existing craft for modification or conversion. Despite this limitation annual traffic totals have grown almost without interruption and the percentage of total traffic (in the range 24-27%) has been maintained. With at least six large craft in



FIG.7 SR.N4 Mk.3 (GH.2007) ENTERING OSTEND

operation, the figures for 1979 are expected to show a significant increase. Accumulated totals at the end of 1978 are seen to be more than 13 million passengers and 2 million vehicles, the craft having operated a total of some 70,000 hours which approximates to 3½ million miles.

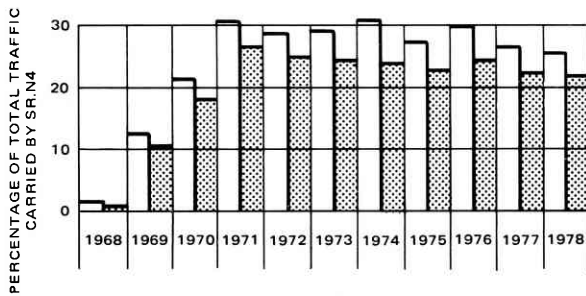
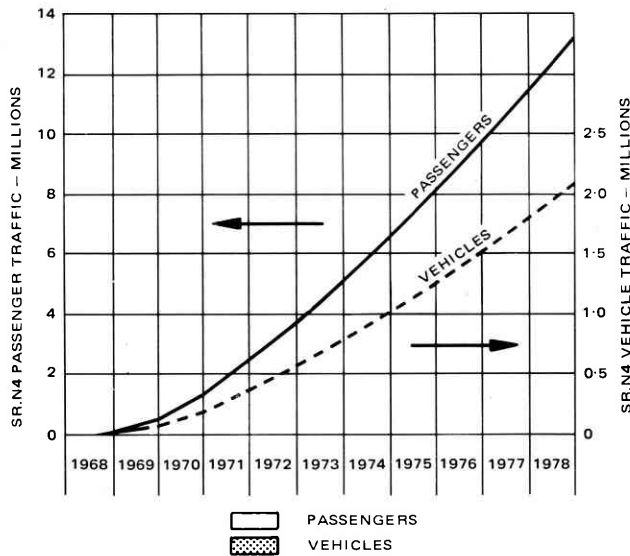


FIG.8 SR.N4 TRAFFIC VOLUMES IN THE FIRST DECADE OF OPERATION ON THE ENGLISH CHANNEL SHORT SEA ROUTES

3. SUPER-4 RESEARCH AND DEVELOPMENT ACTIVITY

Recent hovercraft research carried out by BHC and associated component specialists has been primarily directed towards power, and hence cost, saving through:-

- (1) Improving the efficiency of the lift system.
- (2) Reducing craft resistance.
- (3) Improving the efficiency of the propulsor system.
- (4) Reducing craft motion.
- (5) Improving engine air filtration.

Some encouraging results of this programme up to 1976 were described at length in reference 2 and the extent to which these ideas were applied to the Super-4 concept is also discussed. Reference 2 states the technical objectives of lengthening to be to:-

- (a) Substantially increase payload without reduction in performance and without changing engines.
- (b) Increase seakeeping ability and passenger comfort.
- (c) Increase craft hump speed and thus performance in extreme weather conditions.

Application of these objectives to SR.N4 Mk.1 suggested that total operating costs, including financing, could be reduced by 25% on a cost per passenger mile basis, if the craft were lengthened by 55 feet.

Research items (1) to (4) inclusive listed above are considered to have provided significant advances which have been incorporated into the Super-4 design. Apart from the improved propulsor aspect, where efficiency gains have been achieved using the larger (21 ft diameter) composite GRP/dural spar propellers developed by British Aerospace, the largest single source of power saving arises from the development of the new low pressure skirt system. This is responsible for the majority of the resistance reduction (through better skirt response in waves), the improved ride and the reduction of lift power requirement. Its development will now be briefly reviewed in the context of the continuous and extensive skirt development carried out on SR.N4 craft since the first Mk.1 entered service in 1968.

3.1 Skirt Development

3.1.1 SR.N4 Mk.1 and Mk.2

The form of the earliest SR.N4 skirt (designated Mk.1) is depicted in figure 9 which shows the BR Seaspeed Mk.1 prototype craft. The skirt is of standard BHC bag/finger construction, with a nominal 8 ft buoyancy tank clearance and 4 ft deep fingers. Fan air is distributed through the plenum to the bag and thence through cushion feed holes in the skirt. At the design A.U.W. of 185 tons, the cushion pressure was 55 lb/ft² and the bag to cushion pressure ratio was approximately 1.5.



FIG.9 SR.N4 Mk.1 PROTOTYPE – SHOWING Mk.1 SKIRT WITH SHALLOW BOW

As described in Reference 1, initial service quickly revealed a need for better skirt integrity and bow structure protection. The form of the first development designed to counter these problems, the Mk.2 or deep bow skirt, is illustrated by the Hoverlloyd Mk.1 craft shown in figure 10. In this configuration the finger design (in terms of attachment and pitch) was improved together with a modified bow bag construction. More noticeable was the raised outer hinge line around the bow – some 5 ft higher than previously.



FIG.10 SR.N4 Mk.1 LATER CRAFT FITTED WITH Mk.2 SKIRT – DEEP BOW

Although the Mk.2 skirt was satisfactory in-service, bow impact could still occur and the requirement to operate with slightly bow-up (about $1\frac{1}{2}^\circ$) hemline attitude remained. This resulted in heavy finger and cone wear at the stern and a short life for the rear sections of the bags.

Further research, including the development of a programme to compute inflated shapes and extensive model tests, led to the introduction in 1972 of a tapered skirt for the SR.N4. This increased the bow structure clearance by about 2 feet, provided improved rough sea capability and eliminated the $1\frac{1}{2}^\circ$ of hemline trim which had resulted in poor aft skirt component lives.

This tapered skirt form has subsequently been developed to improve its structural integrity and to improve craft performance. These developments have included the continuous anti-bounce web system, in which the side skirt anti-bounce web is continued around the bow and forms the anti-plough bag in the bow region. In previous skirts the anti-plough bag was formed by a web which crossed from the outer finger attachment point to the inner attachment point in the "tan point" region of the junction between the curved bow and straight sides. Although achieving a large anti-plough bag volume, this arrangement led to unfavourable overwave skirt loadings at the tan point and skirt weaknesses were also introduced due to the need to cut cushion feed holes in the inner skirt loop around the bow. In addition, it was also necessary to restrain bow skirt bounce tendencies with vertical straps from the outer finger attachment point.

The continuous anti-bounce web skirt removed all these difficulties. Although this gave a smaller anti-plough bag volume, the fact that it was now possible to feed the cushion directly at the fingers around the bow gave them a much better recovery re-inflation behaviour. This improved the overall craft behaviour in waves and essentially solved the plough-in problem. The other major development has been to improve the skirt design at the aft corners by a combination of fingers and "book end" cones arranged to reduce the rear corner gaps. (figure 29 of reference 3).

3.1.2 Super-4

To meet the objectives discussed earlier in this section, a considerable improvement in skirt efficiency was necessary for Super-4 and a completely new low pressure skirt with deeper fingers (6 ft instead of 4 ft) was designed. This process involved evaluating a large number of possible configurations and in each case the design was subjected to the following rigorous procedure:-

- (1) Computer design of skirt sections to establish the basic geometry, inflated shapes and material loads.
- (2) Two-dimensional modelling (1/6 scale) of various sections to check inflated geometry, pressure/flow characteristics, resistance to 'tuck-under' and dynamic stability and response.
- (3) Three-dimensional testing of the complete skirt on a fully representative dynamic model (1/12 scale), equipped for towing tank and remotely controlled free-flight operation.

Resistance and motion characteristics in calm water and irregular seas were established on the towing tank, using the free-to-surge sub-carriage. Particular attention was paid to craft safety aspects and simulated system failures at high speed and wake encounters in otherwise calm conditions. Computer studies of skirt capability to withstand tuck-under and plough-in were developed in association with data from special model tests involving beam-on towing in both calm water and steep waves. In the free-flight (radio-controlled) mode, tests were conducted in calm water and the highest possible wind speed and sea states to highlight any craft control, handling, performance or safety problems which may not have been apparent under the more controlled conditions of the towing tank.

An example of two-dimensional model testing of the Super-4 skirt sections at frames 6 and 14 (see figure 13) is shown in figure 11. In these particular tests the finger top and attachment flap profiles were being developed to determine a common finger geometry which would behave satisfactorily around the craft, when attached to the varying sections of the tapered bag. The example shown is representative of the 6 ft deep, 40 in pitch fingers employed in the final design. Other profiles had produced severe distortion of the skirt web (feed hole region of the bag) and/or finger creasing and buckling.

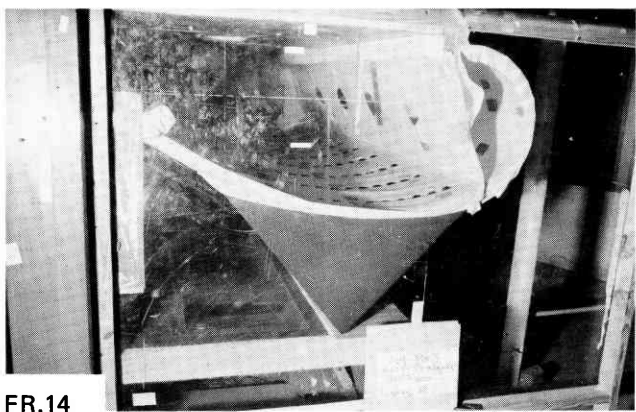
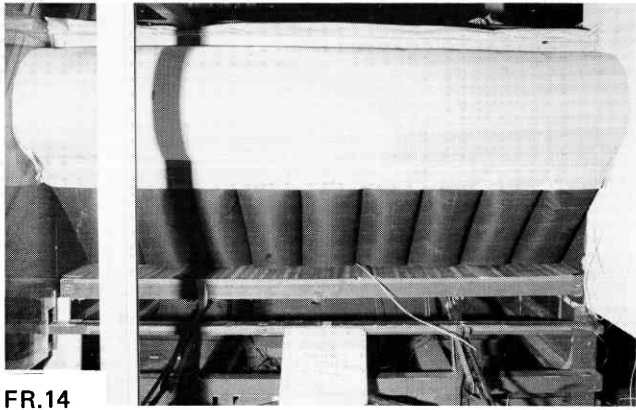
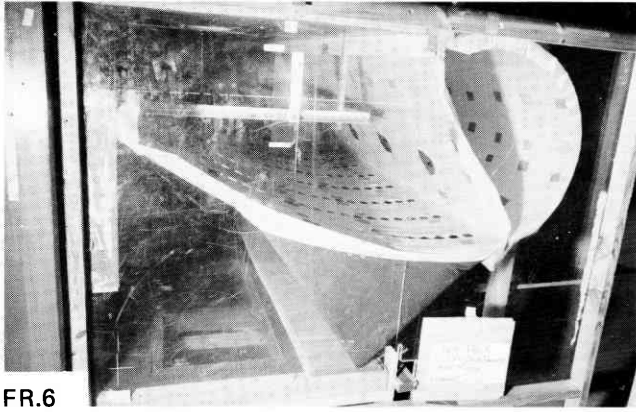
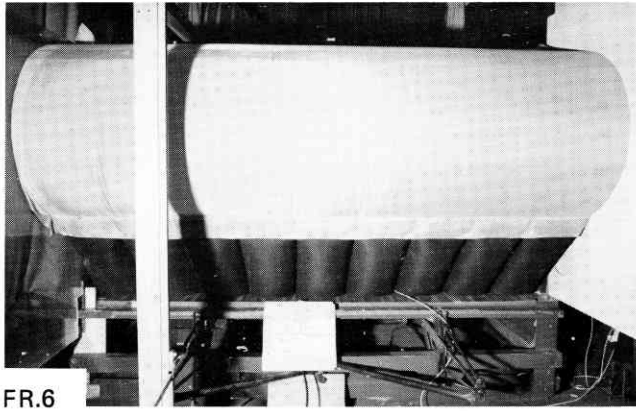


FIG.11 DEVELOPMENT OF 6 ft FINGER SHAPE AND PROFILE FOR SR.N4 Mk.3

Figure 12 shows the 1/12 scale Super-4 dynamic model (about 15 ft long) undergoing static hovering tests at a represented craft weight of 300 tons. The skirt form seen here is a low pressure, earlier configuration with 5.3 ft depth fingers.

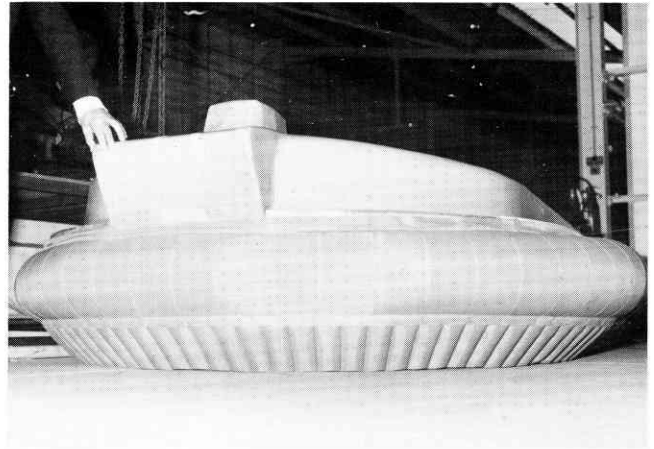


FIG.12 SR.N4 Mk.3 DYNAMIC MODEL FITTED WITH INTERMEDIATE (5.3 ft FINGERED) SKIRT

The final design was a tapered skirt incorporating a large, low pressure bag (bag to cushion pressure ratio 1.15 to 1.20) carried on wider spaced hinges, equipped with 6 ft deep, 40 in pitch fingers. This form appeared to provide favourable resistance and motion characteristics whilst simultaneously satisfying stringent safety requirements. The general arrangement of the bow and side segments, rear trunk, keel and stability dividers is shown in the skirt plan given in figure 13.

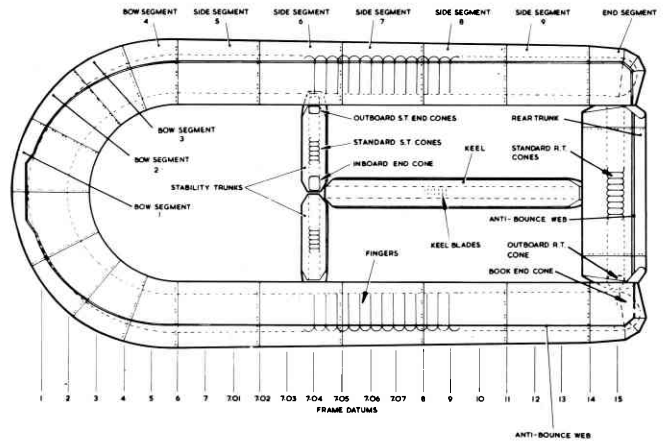


FIG.13 SR.N4 Mk.3 SKIRT PLAN

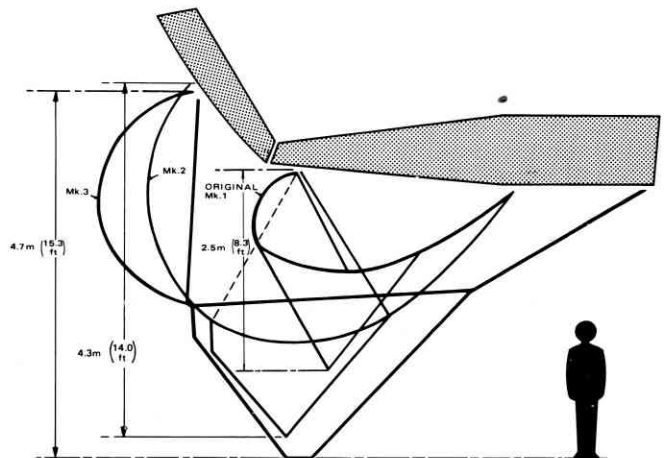


FIG.14 SR.N4 SECTIONS OF BOW SKIRT

An indication of the growth of the bow structure clearance and bag volume is given in figure 14 which compares the Super-4 section with earlier SR.N4 skirts. It can be seen that the outer hinge line around the bow has increased from about 8 ft on the first Mk.1 design to more than 15 ft on Super-4. The wider spaced hinges evident in the diagram contribute to the lateral stability for the low pressure section and in particular avoid skirt 'tuck-under'. The reduction of the pressure ratio from 1.5 to around 1.2 reduces the largest of the lift system power loss terms, i.e. that across the cushion feed holes -- see reference 2, by some 75% thereby enhancing the available propulsive power.



FIG. 15 FIRST SUPER-4 (GH.2007) DURING INITIAL TETHERED HOVER TESTS

A general view of the Super-4 skirt as first inflated on GH 2007 during initial tethered hovering tests is shown in figure 15. The cleanly inflated appearance of the fingers, bag web and attachment flaps, as viewed from inside the cushion looking aft, is given in figure 16. This view also shows the interesting cushion feed hole arrangement employed on GH 2007.

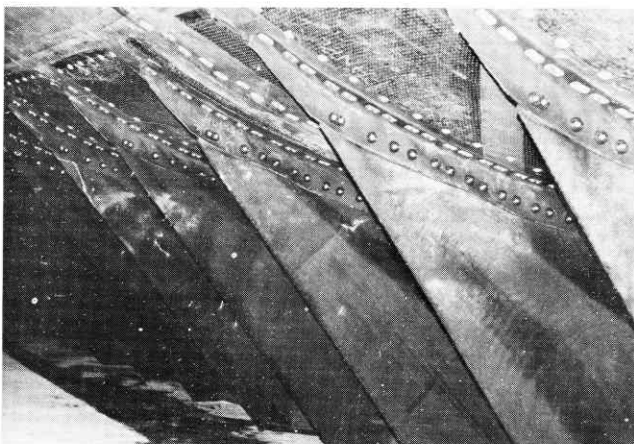


FIG. 16 VIEW INSIDE CUSHION LOOKING AFT ON SIDE FINGERS -- FIRST CRAFT SKIRT

Cushion feed on conventional SR.N4 skirts is achieved using a series of 6 in dia feed holes sited above each finger, which total about 150 ft² in area. For the low pressure skirt this feed area had to be more than doubled to approximately 350 ft², and to maintain the bag strength with the conventional techniques would have involved use of unacceptably heavy bag web fabrics. On GH 2007 the problem was overcome using panels of thousands of closely

pitched 5/16 in dia holes, which pierced the fabric between the fibres (see figure 16). Although as a feed arrangement this functioned satisfactorily, after a period in-service the joints between the bag web and inner/outer loops proved unreliable. On the second craft (GH 2006) similar but larger 3/4 in dia holes are employed in a revised fabric which enables a much improved joint to be formed at web/loop junctions.

A further problem area with early SR.N4 skirt designs was the cushion leakage gap between the after ends of the side skirts and the rear trunk (see reference 3). As already noted, this has been reduced by special finger/cone design on the SR.N4 Mk.2. On the Super-4 design this leakage was also greatly reduced using a modified terminal side skirt segment, fitted with specially developed 'book-end' cones. The first craft suffered some cone tearing and the design has been further developed on GH 2006. A view of the successful skirt form in this region is given in figure 17, which shows GH 2006 during its initial tethered trials.

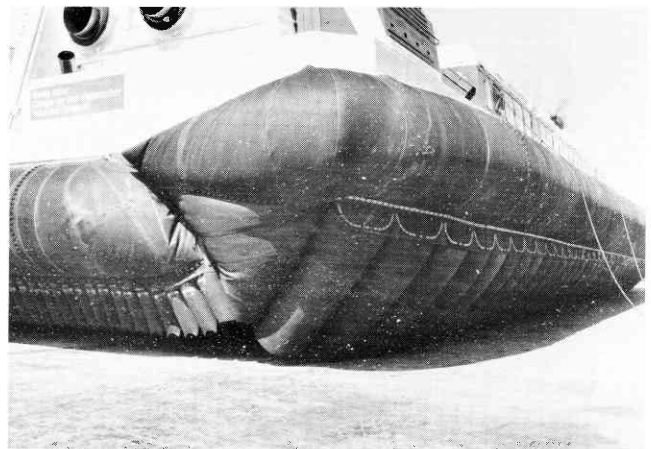


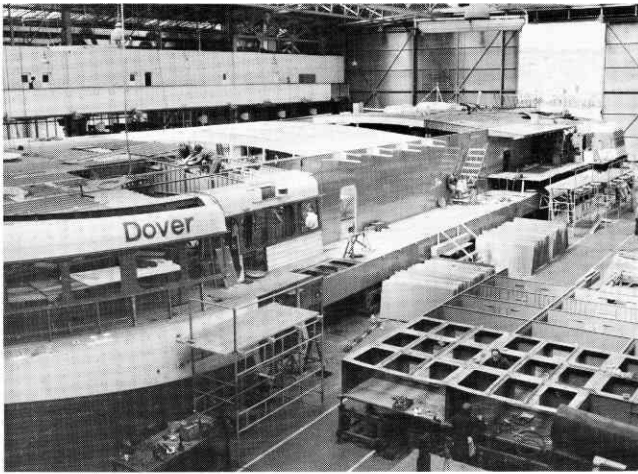
FIG. 17 SECOND SUPER-4 (GH.2006) DURING INITIAL TETHERED HOVER TESTS -- SHOWING DEVELOPED REAR CORNER DESIGN

4. SUPER-4 CONSTRUCTION

SR.N4 Mk.1 (GH 2007) was withdrawn from cross-Channel service and arrived back at BHC's Columbine Works at Cowes in February 1977. The craft was wheeled into the factory and its skirt system and rotating components including engines, gearboxes, transmission, fans, propellers, pylons, fins and rudders were removed. At this point the craft was literally cut-in-two between frames 7 and 8 (see figure 13), slid apart and cleaned back to the adjacent frames. One structural bay (just under 8 ft) was therefore lost in this operation and the new centre section was close to 63 ft (i.e. 8 structural bays) in length to provide the 55 ft (7 bay) overall length increase.

A view showing GH 2007 with the new centre section inserted is given in figure 18. The box-like structure seen in the foreground is the beginning of the buoyancy tank for the second craft, being prepared in advance.

Since, for the lengthened craft, the shear forces are substantially increased in the original fore and aft sections and the bending moment is similarly larger over the new centre section, considerable reinforcement of the structure was necessary. In the main this was achieved by reinforcement throughout the length of the two fore and aft bulkheads (just visible in figure 18), which are essentially the main shear walls. Over the new centre



**FIG.18 FIRST SUPER-4 DURING MODIFICATION.
NEW BUOYANCY TANK STRUCTURE
BEING ASSEMBLED FOR SECOND SUPER-4**

section the additional bending moment was catered for by doubling the sectional areas of the roof skin and stringers adjacent to the bulkheads. This lengthened 'strut' was stabilized by turning the transmission tunnel suspended beneath it into a structural member. Reinforcement of the transverse bulkheads, in both end sections, was also necessary and the area and load capability of each of the landing pads (now 7 instead of 5) was increased by about 50%.

With the structure complete and all but the propellers, fins and skirts fitted, the craft was wheeled out on to the apron. An indication of the construction and size of the skirt components is given by figure 19. This shows the rear trunk assembly, complete with cones suspended in the skirt shop during manufacture.



**FIG.19 VIEW OF REAR SKIRT BAG AND CONES,
SUSPENDED IN SKIRT SHOP
DURING MANUFACTURE**

Completed ahead of schedule, GH 2007 first main engine running took place on the 30th March 1978.

Conversion time for GH 2006, which returned to Cowes in September 1978, was several months shorter as the new centre section was almost complete when the craft arrived. Main engine running on GH 2006 was commenced on the 23rd April 1979, and the craft delivered two weeks later having completed its trials.

5. SUPER-4 PERFORMANCE

5.1 Acceptance Trials

5.1.1 GH 2007

Subsequent to a comprehensive programme of ground running trials, GH 2007 was launched from BHC's Columbine Slip on the 6th April 1978 and subjected to a series of sea trials and further tethered tests prior to acceptance by BR Seaspeed on the 26th May 1978.

These Acceptance trials (including some 70 hours at sea) demonstrated ample compliance with all the Specification requirements for water speed, stopping distance and endurance. Craft handling and safety aspects were also shown to be very satisfactory over the full weight range from light (210 tons) up to overload starting weight at 320 tons, in sea conditions ranging from calm up to 3 metre significant wave height. Some particular points noted were:

- (1) behaviour was very docile and easily controllable following simulated system failures. These covered propeller pitch, pylon and fin runaways, and engine cuts, over the water speed range up to 65 knots.
- (2) manoeuvring control was good in boating and semi-boating modes and skirt drainage times were acceptably brief (less than 2 minutes); base manoeuvring showed characteristics which were not significantly different from those of Mk.1 or Mk.2 craft — allowing for the extra craft length.
- (3) the skirt gave no plough-in tendencies in any of these conditions (with hemline attitudes down to negative values), or on ship's wake encounters; longitudinal decelerations were innocuous (i.e. less than 0.1g) and much less than noted on current Mk.1 or Mk.2 craft.
- (4) the combination of increased craft length and the deeper, low pressure ratio 6 ft fingered skirt, has resulted in a marked improvement in ride comfort; bow vertical accelerations are typically half to two-thirds those experienced on the Mk.1 craft in similar conditions. These results, predicted from model testing, have been confirmed qualitatively and by analysis of measured acceleration data.

For specification purposes, craft speed performance was related to the use of 3800 HP per engine and disposable loads up to 110 tons. Compliance was demonstrated at a nominal weight of 300 tons (113 tons disposable). The achieved beam wind waterspeeds, summarised in figure 20, are seen to be well in excess of the predictions, particularly in the higher waves.

Figure 21 shows limited data obtained on into and down wind headings (not specification requirements), for the nominal 300 ton/3800 HP per engine condition. When corrected to the 'standard' wind speed/wave height relationship, the worst into-wind speed results can be seen (figure 22) to be closely similar to the performance predicted using resistance derived from towing tank model data.

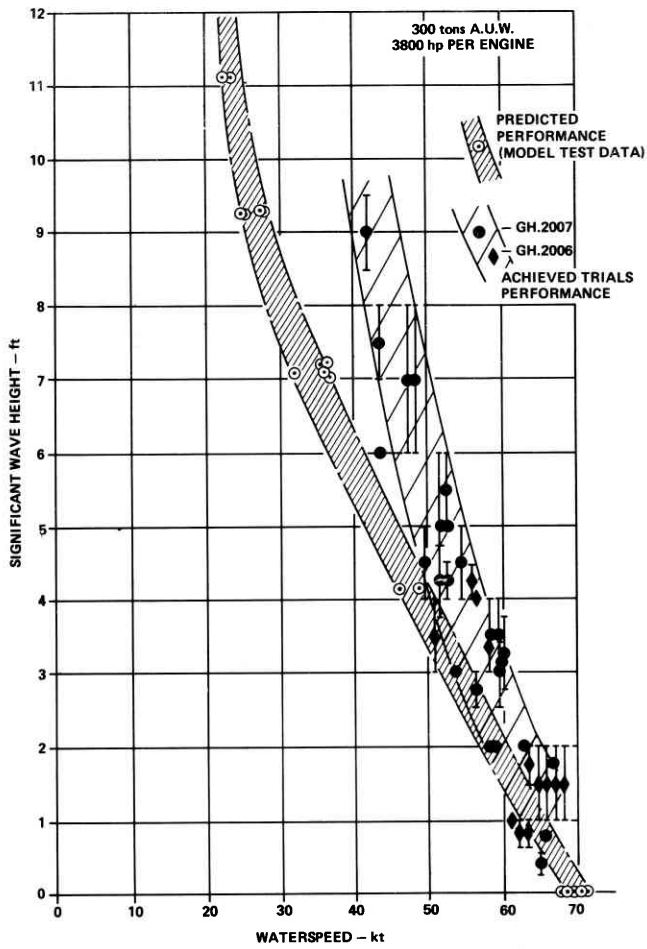


FIG. 20 SR.N4 Mk.3 BEAM-WIND WATERSPEED PERFORMANCE

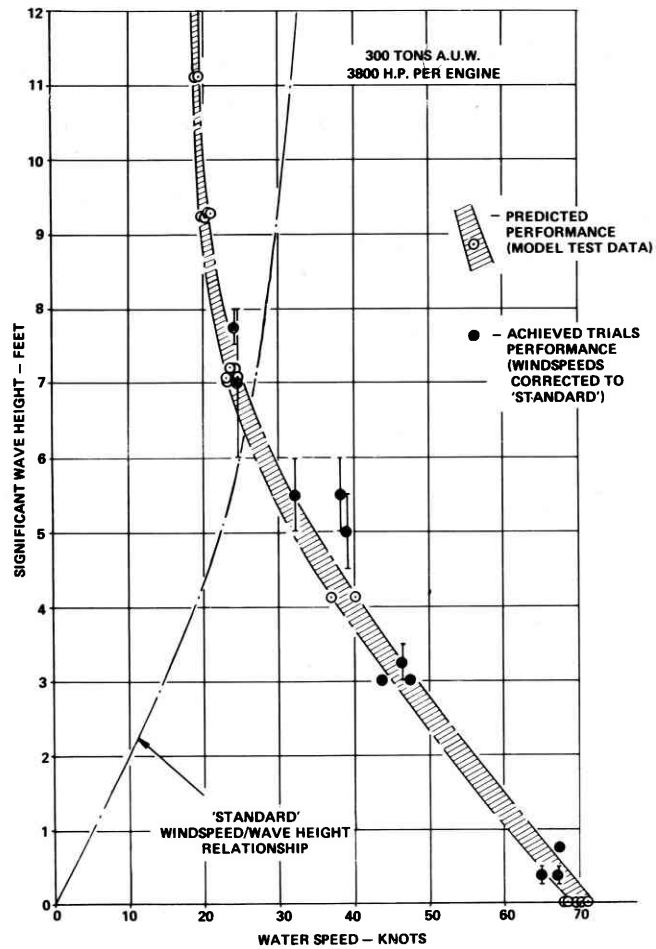


FIG. 22 SR.N4 Mk.3 INTO-WIND WATERSPEED PERFORMANCE

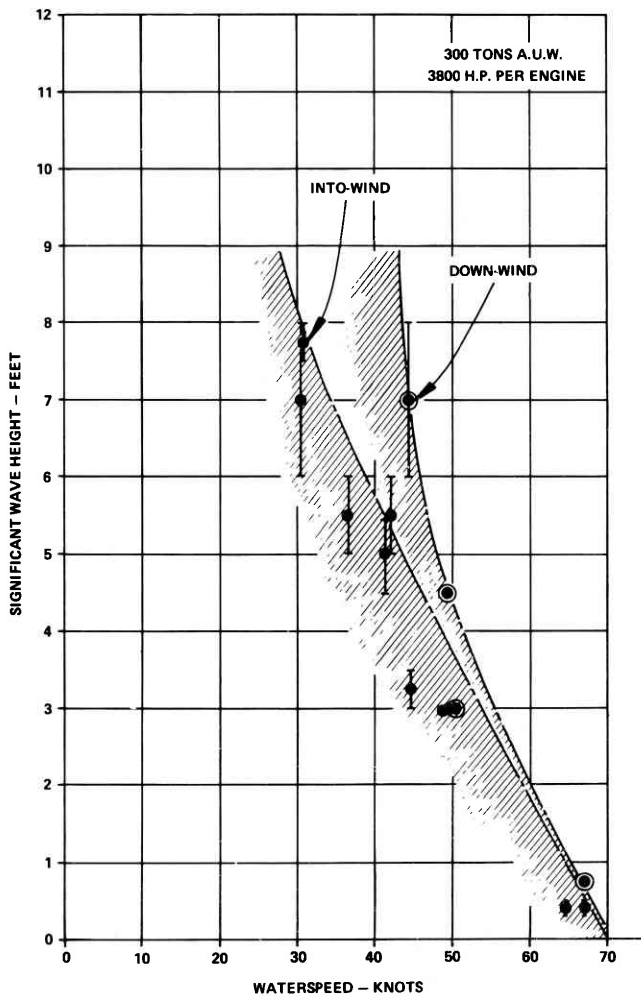


FIG. 21 SR.N4 Mk.3 WATERSPEED PERFORMANCE TRIALS ACHIEVEMENT

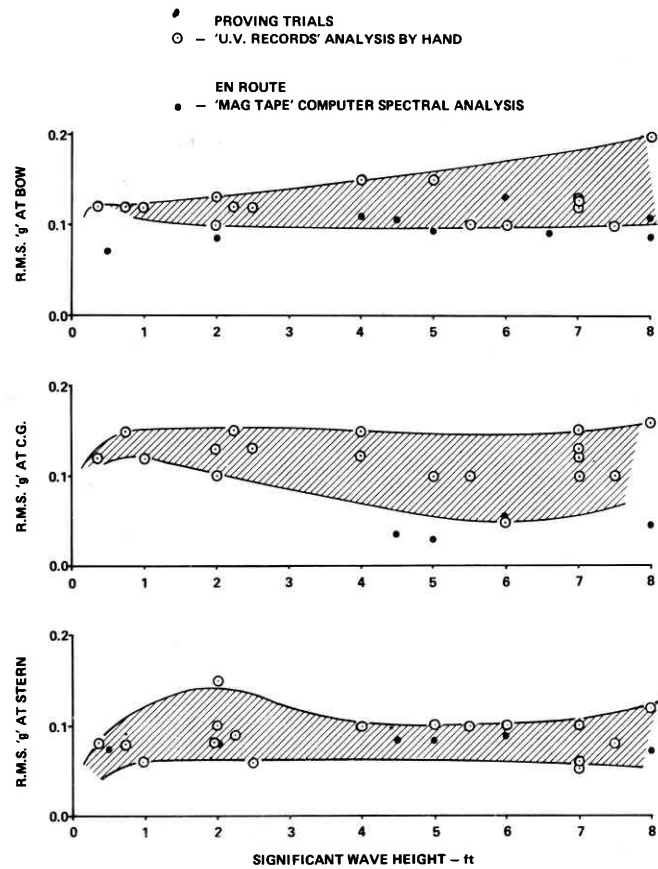


FIG. 23 SR.N4 Mk.3 SEA-STATE INDUCED CRAFT ACCELERATIONS (R.M.S.)

Vertical acceleration measurements (RMS 'g') obtained at bow, CG and stern stations on GH 2007 are summarised in figure 23, for a range of sea states. Levels assessed by hand analysis of U/V trials records are indicated by white spots – the black spots being computer spectral analysis of magnetic tape records obtained in-service. Acceleration levels are fairly constant (around 0.10 to 0.15 RMS 'g') with increasing sea state, due to decreasing craft speed (typically 60-65 knots in 0-1 ft seas and 35-40 knots in 7-8 ft seas). For a given wave height these accelerations are about 50 to 70% of levels experienced on SR.N4 Mk.1 and Mk.2 craft, whilst the craft speed is typically 10 knots faster.

An example of vertical acceleration spectra, derived from computer analysis of FM tape records, is given in figure 24. The condition illustrated corresponds to 34 knots waterspeed in 4 to 5 ft significant bow seas.

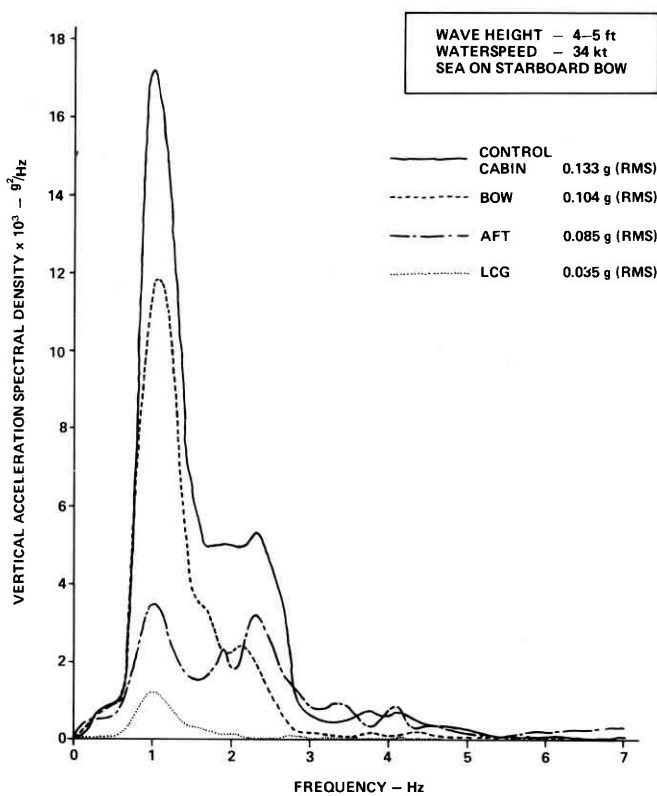


FIG. 24 SR.N4 Mk.3 VERTICAL ACCELERATION SPECTRA

Apart from tearing of the book-end cones (which have now been replaced by a modified design – see figure 17) the skirt behaviour throughout the trials period was entirely satisfactory.

5.1.2 GH 2006

The second craft was launched on the 23rd April 1979 and a compact version of the GH 2007 trials programme was carried out. As noted in section 3.1.2, some skirt developments including the modified aft corner geometry and the revised cushion feed web were incorporated in the skirt configuration – designated State 6. The behaviour of this skirt was faultless throughout the trials and has given no cause for concern in-service to date.

All Specification requirements were easily met in two sea sorties and a wide range of craft safety aspects was demonstrated, to the satisfaction of the CAA, at craft weights up to 310 tons. GH 2006 was accepted by BR Seaspeed on the 2nd May 1979.

Achieved beam wind water speed results for GH 2006, corrected to the standard weight and power condition, are the diamond shapes included on figure 20. These results are clearly typical of the achievement of GH 2007. Figure 25 shows the Super-4 beam wind performance compared with a wide band of results measured during SR.N4 Mk.1 and Mk.2 clearance trials for weights of 185 to 200 tons, at 3400 HP per engine. The expected effect of operating the Super-4 on 3400 HP per engine is indicated on the diagram, speeds being typically from mid to top edge of the Mk.1 and Mk.2 band.

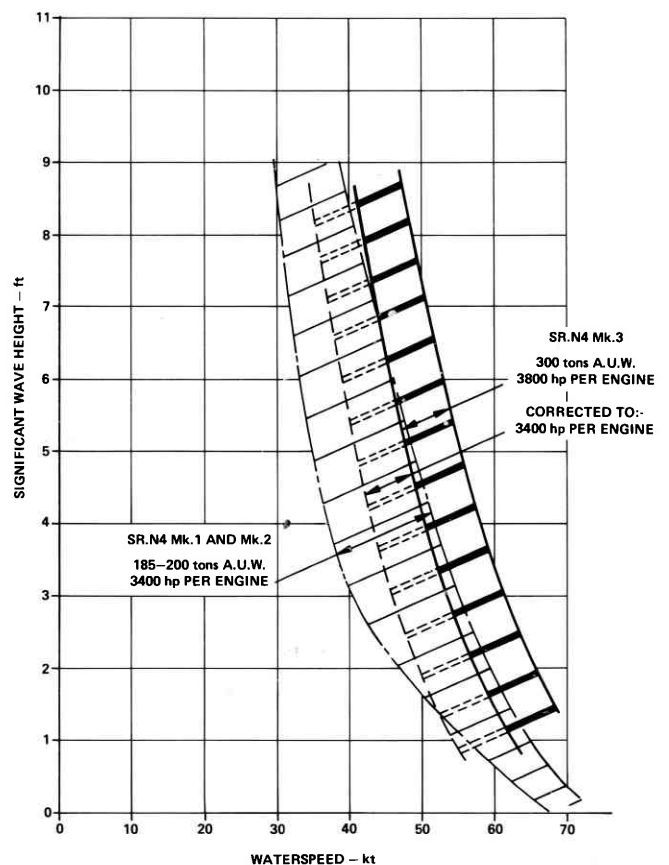


FIG. 25 SR.N4 Mk.1, Mk.2 AND Mk.3 BEAM-WIND WATERSPEED PERFORMANCE ACCEPTANCE TRIALS RESULTS

5.2 In-Service

GH 2007 entered service on the 8th July 1978. In view of the favourable performance demonstrated during trials, British Rail policy has been to conserve engine life by operating at powers of only 3400 HP per engine (as used on Mk.1) whenever possible, increasing toward 3800 HP per engine to maintain performance as required.

In the remaining six months of 1978 (i.e. from 8th July to 31st December), GH 2007 carried some 295,000 passengers and 46,500 vehicles on the Dover-Boulogne-Calais routes. Average block times were 37½ minutes (Dover-Boulogne) and 35½ minutes (Dover-Calais)

which are typically 1 to 1½ minutes less than the overall 1977 averages for the Mk.1 craft. In view of the crew familiarisation activity on Mk.3 and the use of engine powers well below the design value of 3800 HP per engine, the achieved times are considered to be very favourable.

In the same period craft turn round times have averaged 28 minutes. The target time is 25 minutes. Bearing in mind the 70% increase of payload relative to the Mk.1 craft, these times compare very reasonably with the average 20 minute Mk.1 turn round.

Route performance has been recorded and analysed for the period when GH 2007 was operating as a Mk.3 and GH 2006 as a Mk. 1. Beam wind speed results, corrected to 80% disposable load and normal continuous power conditions, are shown for the two craft in figure 26. Despite the data scatter, the speed advantage of the Mk.3 (up to 10 knots) is very evident, particularly in the larger wave heights.

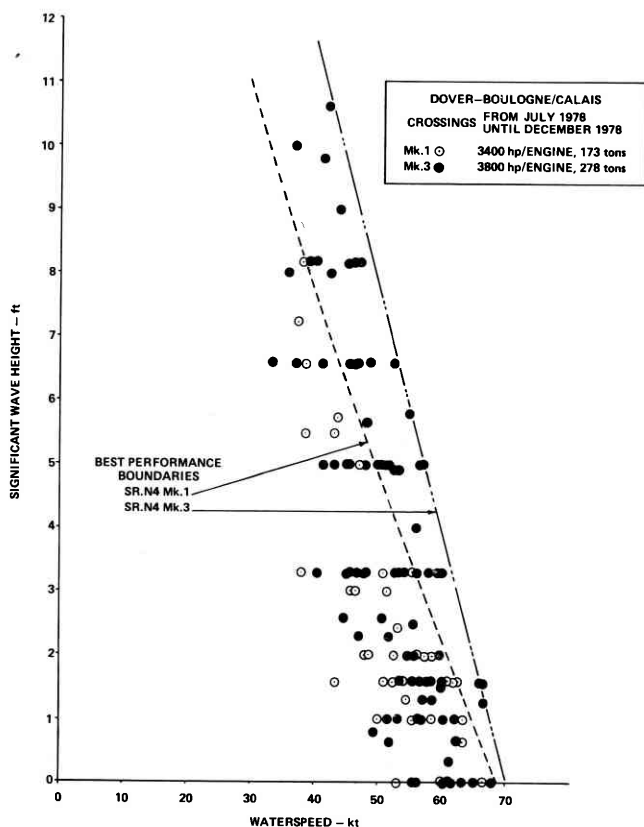


FIG.26 SR.N4 Mk.1 AND Mk.3 'IN SERVICE' BEAM-WIND WATERSPEED PERFORMANCE AT 80% DISPOSABLE LOAD

GH 2006 entered service on the 10th May 1979 and its in-service performance has, to-date, compared very favourably with that of the first craft. In the short operating period up to the 14th July 1979 (approximately 2 months), GH 2006 transported some 165,800 passengers and 24,500 vehicles across the Channel on 723 separate crossings. In the 5 weeks between the 14th July 1979 and the 18th August 1979, the peak of the Summer season, the combined traffic carried by the two Super-4 craft was 213,200 passengers and 34,000 vehicles.

Grand totals for 1979, up to the 18th August, were 670,000 passengers and 99,400 vehicles carried on 2940 crossings. Thus, the overall totals

carried by the Super-4 up to this date are just under 1 million passengers and 150,000 vehicles in a period of just over 1 year and with only 1 craft in commission for about half of the time. These figures are roughly twice those carried by BR Seaspeed in 1977 and about 60% higher than the previous annual rate with two Mk.1 craft.

Craft operating limitations established during the acceptance trials of GH 2007 correspond to a mean wind speed of 35 knots with gusts up to 45 knots and a maximum significant wave height of 2.7 metres in seas of critical length. Since entering service two further trials have been carried out in the severe weather conditions encountered during the period February-March 1979. These demonstrations have enabled the limiting weather conditions to be extended to a mean wind speed of 40 knots, with gusts up to 50 knots and 3.5 metre significant height critical waves.

These improved limitations are expected to reduce Super-4 Channel crossing cancellations due to rough weather to of order 1%-2%, based on mean annual occurrences. A further extension of the critical wave height limit to 4.0 metres significant is pending approval by the CAA.

In establishing these limitations trials have been carried out in Beaufort Force 10 winds and 7 metre seas with no handling difficulties and the craft general behaviour was reported as satisfactory by the Seaspeed crew who operated the craft.

6. FUTURE DEVELOPMENTS

The introduction of the Super-4 offers a significant improvement in SR.N4 operating economics, which is primarily derived from a substantial increase of payload, better waterspeed performance and much improved sea-keeping and passenger comfort.

Thus compared with SR.N4 Mk.1 the Super-4 has a 75 to 100% greater work capacity (payload x speed) together with a 40-50% saving in fuel per payload (ton) x n. mile.

As a measure of its immediate success, practically all the requirements of the craft Specification and Contract were amply demonstrated in the Acceptance Trials period. For many important aspects, such as speed performance, payload capability, relative motion and limiting wind speed/sea-state, the requirements, and the best expectations derived from model/computer studies, have been exceeded by a considerable margin.

Rapidly increasing fuel costs and supply difficulties have further underlined the Channel operators' need to improve fuel economy, both at present and in the future. To this end, BHC and the two operators are currently engaged in an assessment of in-service fuel consumption and its variation with craft operating techniques. In the immediate future, development of the SR.N4 craft series will, in the main, be directed toward further fuel and power savings.

Direct fuel saving can be achieved by the installation of alternative engines of more modern design, with notably better specific fuel consumptions. Recent studies have indicated the feasibility of installing power units such as the Detroit Diesel Allison 570-K, which offers 20% reduction of fuel consumption at SR.N4 power levels coupled with improved power availability at high ambient temperatures and lower maintenance/overhaul costs.

The lift and propulsion systems are both areas where further efficiency improvements are anticipated. Propulsive power reductions of order 30-35% are indicated from the propeller manufacturers' studies. The future choice will be between larger diameter, swivelling pylon, free propellers and smaller, fixed ducted units with lower noise levels. The use of the latter will, however, depend upon the successful development of thrust vectoring devices. Lift power savings arising from the use of such devices as inclined fan intakes with modified lip radii, arranged to take advantage of ram-recovery effects, are also being studied in conjunction with modified fan geometries.

The further development of skirt design and materials forms a major part of the continuous research and development programme at BHC. In addition to improving present designs, fully responsive skirt forms, with a bag to cushion pressure ratio of unity and fingers designed to deflect without buckling, are currently being model-tested.

In the longer term a replacement for the SR.N4 design will provide an opportunity to incorporate fully into a single craft, all the benefits suggested from current research. This will include better aerodynamic profiles, fans in volutes and other features which are incompatible with the structural layout of the present design. New methods of construction, such as welding and weld bonding and the wider use of stronger bonded honey-comb panels, are expected to result in simpler and more easily manufactured structures.

The combination of these developments will lead to craft with significantly lower initial, through-life and running costs together with further improvement in seakeeping ability.

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