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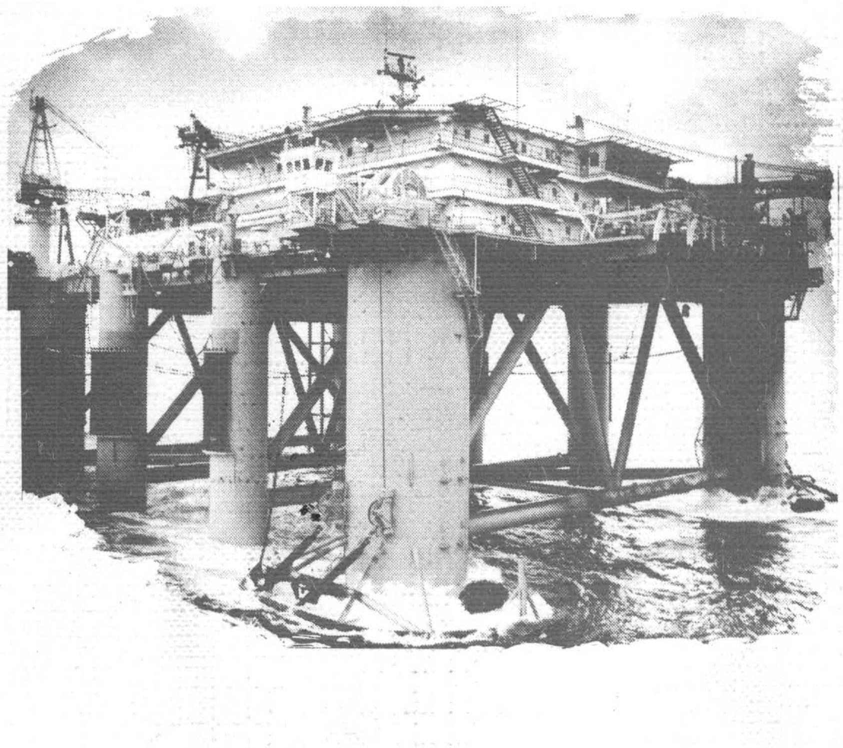
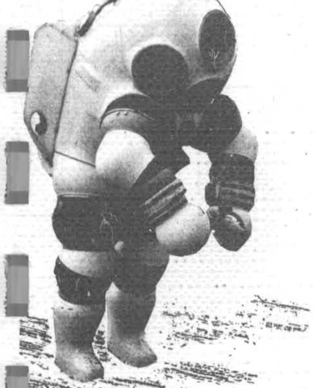
WAVE ENERGY OPERATION AND MAINTENANCE PARAMETRIC ANALYSIS





February 1982

EASAMS LIMITED

A Member of GEC-Marconi Electronics Limited

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WAVE ENERGY OPERATION AND MAINTENANCE PARAMETRIC ANALYSIS

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SUMMARY OF THE EASAMS WAVE ENERGY MAINTENANCE MODEL

The work presented in this report is based on the use of the EASAMS' Wave Energy Maintenance Model, which has been developed for the assessment of the operation and maintenance aspects of wave energy systems. For ease of understanding, a brief summary of the Model is included here. The model is presented in two volumes:

Volume 1 contains a systematic collation of maintenance information and fulfils the following objectives:

- it assembles the maintenance data available within the community into a compact, well-indexed volume.
- it indicates the confidence that can be attached to this data.
- it shows up areas of unreliable data and, where necessary, provides a set of assumptions that can be used as a consistent basis until better data becomes available.

Volume 2 provides a method of costing the maintenance of a wave energy system. Since the wave energy programme contains a variety of device concepts at different stages of development, the method of calculating costs was required to be parametric in nature yet sufficiently accurate to highlight sensitive areas. The data from Volume 1 can be used as the input to Volume 2 to produce an annual operating cost for a 2GW array based on a particular device. Alternatively, the user can work through the model using his or her own data.

The model is divided into sections by common maintenance practices and resources. These Cost Centres are:

- Servicing : On-board Systems
- Overhaul : On-board Systems
- Repair : On-board Systems
- Hull, moorings and foundations - inspection, maintenance and repair.

- Electrical cables (or collective hydraulic systems as appropriate)
- Shore Base

The total maintenance cost is the sum of results from the six costing areas. The sensitivity of the costs to various parameters can be investigated by varying input assumptions. The following sections show the results obtained from the Model in an investigation of sensitive areas.

1. AIMS OF THIS REPORT

The Wave Energy Maintenance Model, as described in the Summary, was produced to allow the effect of variations in WEC design or in maintenance strategy on the total Operation and Maintenance (O & M) costs of wave energy array to be easily and quickly calculated and assessed. Since the model is parametric, factors can be changed and the results of the changes can be seen in the costs of the various operations.

Having this facility available, an analysis of the sensitivity of the O & M costs to changes in certain parameters has been possible. The results presented in this report are not device specific. They are based on an array of devices which have the main plant items on-board the WECs. The devices may be bottom sitting or floating.

The aim of the results shown here is to indicate trends in O & M costs and to provide some basic rules of thumb that can be applied to O & M costs for any device. The actual costs given are of the right order of magnitude for current devices, but do not represent the actual O & M costs of a specific device.

Throughout the report, O & M costs are broken down into the same Cost Centres as used in the Model and described in the Model Summary.

This report also contains an Appendix which illustrates the inter-dependancies existing between cost items in different areas of the Model. This allows the full effect of a change in parameters to be seen. It also describes the fundamental assumptions implicit in these results presented in this report.

2. BACKGROUND

The results presented here all relate to a 2GW wave energy array situated off the Hebrides.

The device investigated is a wave energy convertor (WEC) with the main plant items situated on-board the WEC. A bottom sitting and a floating version have been considered. It has been assumed that on-board systems are exchanged offshore for Overhaul and Repair, where necessary. An example requiring WEC tow-in rather than offshore replacement of on-board systems has also been included.

The on-board systems of a device are referred to in terms of modules - that is, self-contained replaceable units such as the turbine, alternator, transformer/rectifier and louvre valve units. These are the main heavy, bulky items which define the size of vessel needed and the time taken. Smaller items of equipment which require Overhaul may be incorporated into the Servicing operation.

The Servicing interval is assumed to be one year throughout since any increase in the number of visits per year will cause costs to increase out of all proportion.

A six month offshore season has been used for Servicing and for Overhaul using offshore module replacement. In cases where WEC tow-in is used for Overhaul, a twelve month season is used.

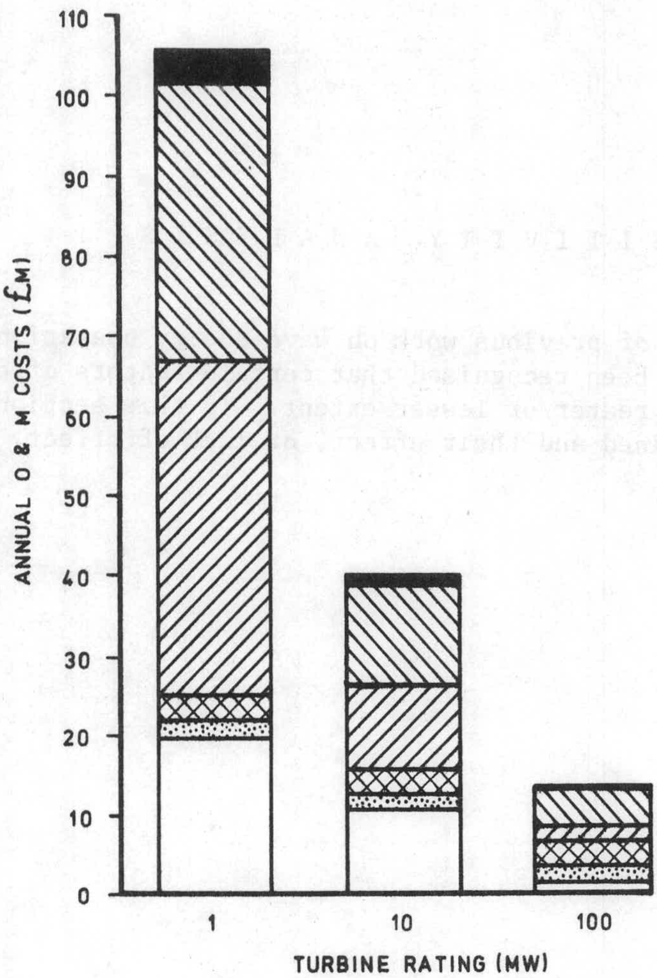
Volume 1 of the Maintenance Model has been used extensively to provide inputs to this exercise including:

- weight and size of all components of the WEC and associated systems such as hull structure, moorings, electrical cables, etc.
- maintenance requirements of all items.
- failure rates of all items.
- specification and costs of all maintenance resources (equipment, helicopters, vessels etc.) used in operations.
- environmental data such as wave, wind, visibility predicted.

Crew transport is assumed to be by helicopter for offshore vessel/ WEC transfer operations. For work aboard the WEC, an operational wave-height of 3 metres has been used in the case of floating arrays and 4 metres in the case of bottom sitting arrays due to the more stable platform and better lee. Section 3.5 shows the effect of reducing the operational waveheight.

3. SENSITIVITY ANALYSIS

During the course of previous work on wave energy operation and maintenance costs it has been recognised that certain factors affect the annual O & M costs to a greater or lesser extent. In this section these factors are further examined and their effect, or lack of effect, on total O & M costs assessed.



ARRAY CHARACTERISTICS

- BOTTOM SITTING IN 25 M OF WATER
- 3 YEAR OVERHAUL LIFE FOR ON BOARD SYSTEMS
- OFFSHORE MODULE REPLACEMENT

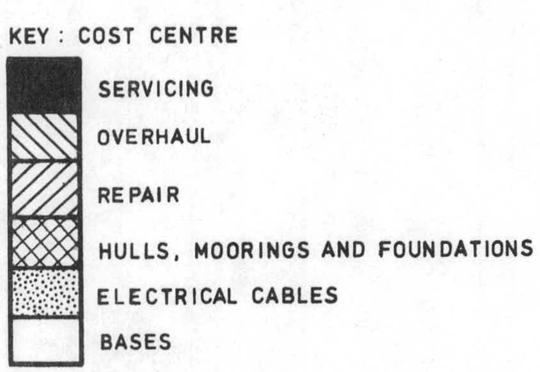


Fig.1 EFFECT OF TURBINE RATING AND THUS NUMBER OF ON-BOARD SYSTEMS, ON TOTAL O & M COSTS

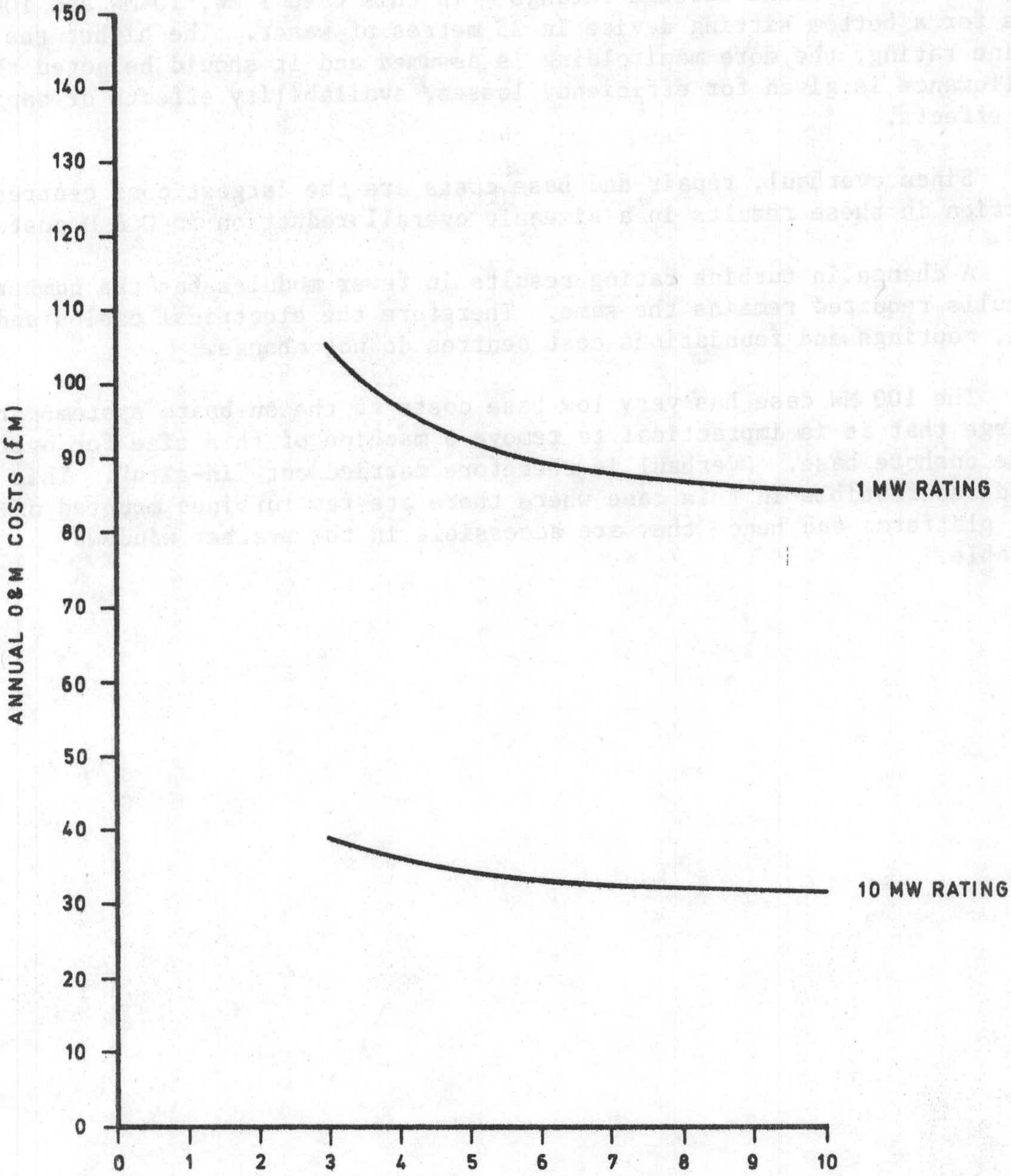
3.1 NUMBER OF MODULES IN THE ARRAY

A reduction in the number of on-board systems modules gives a reduction in servicing, overhaul, repair and base costs. The number of modules in the array can be changed by altering the rating of the modules or by combining several modules into one. Fig. 1 shows the change in O & M costs due to different turbine ratings - in this case 1 MW, 10 MW and 100 MW units for a bottom sitting device in 25 metres of water. The higher the turbine rating, the more manifolding is assumed and it should be noted that no allowance is given for efficiency losses, availability effects or capital cost effects.

Since overhaul, repair and base costs are the largest cost centres, a reduction in these results in a sizeable overall reduction in O & M costs.

A change in turbine rating results in fewer modules but the number of WEC hulls required remains the same. Therefore the electrical cables and hulls, moorings and foundations cost centres do not change.

The 100 MW case has very low base costs as the on-board systems are so large that it is impractical to remove a machine of this size for overhaul at the onshore base. Overhaul is therefore carried out "in-situ". This is considered feasible in this case where there are few turbines mounted on fixed platforms and hence they are accessible in the weather windows available.



ARRAY CHARACTERISTICS:

- BOTTOM SITTING – 25 m CONTOUR
- OFFSHORE MODULE REPLACEMENT

Fig. 2 EFFECT OF FREQUENCY OF OVERHAUL OF THE ON-BOARD SYSTEMS ON TOTAL O & M COSTS

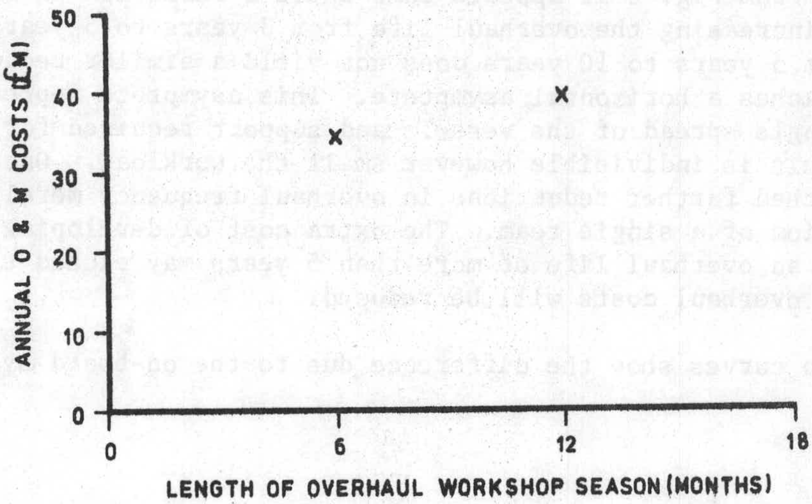
3.2 MODULE OVERHAUL FREQUENCY

To reduce overhaul costs the number of modules overhauled per year must be reduced. In 3.1 this was done by reducing the number of modules in the array. Another way of achieving this is to increase the overhaul life of the module.

Fig. 2 shows the effect of changing the overhaul frequency of the on-board systems modules from 3 years to 5 or 10 years. It has been assumed that all on-board systems on the WEC have the same overhaul life.

These changes to overhaul frequency result in changes to overhaul and base costs. From Fig. 2 it appears that while a reduction in costs is achieved by increasing the overhaul life from 3 years to 5 years, a further increase from 5 years to 10 years does not yield a similar reduction and the curve reaches a horizontal asymptote. This asymptote represents the cost of a single spread of the vessels and support required for offshore overhaul. This is indivisible however small the workload. Once this level is reached further reductions in overhaul frequency merely reduce the utilisation of a single team. The extra cost of developing on-board systems with an overhaul life of more than 5 years may exceed the amount by which the overhaul costs will be reduced.

The two curves show the difference due to the on-board systems rating.



ARRAY CHARACTERISTICS

- BOTTOM SITTING - 25 M CONTOUR
- 3 YEAR OVERHAUL LIFE
- 10 MW RATING

Fig. 3 EFFECT OF OVERHAUL WORKSHOP SEASON ON TOTAL O & M COSTS

3.3 NUMBER OF SPARE MODULES

Spare modules are required to compensate for the modules in transit to and from the base and those which are at the base in storage or undergoing overhaul. The capital costs of these modules must be included in the O & M costs of the system since the number required results directly from the maintenance policy adopted. The capital cost of the modules is discounted over their life of 25 years and appears as an annual cost as part of the Overhaul Cost Centre.

In the previous sections an offshore season for module replacement of six months and a base overhaul season of twelve months is assumed. Both of these operations are processing the same number of modules over different time periods. If they are to operate at constant rates a number of spare modules will be required to compensate for modules waiting to be overhauled or waiting to be replaced offshore at the end or the beginning of the offshore replacement season respectively. The annual cost of spare modules in the 10 MW example used in Fig. 1 and 2 is £7M.

Fig. 3 shows the cost of operating the overhaul workshop for the six month season corresponding to the offshore season.

Since both operations are processing the same number of modules over the same time period spare modules are only required to compensate for those actually in transit and to make up a contingency stock, typically of four weeks overhaul workshop throughput, to allow the workshop to function even when bad weather prevents offshore replacement. For the other six months of the year the facilities and staff are used where possible to complement the repair facilities. In this case the annual cost of spare modules is £2M for the 10 MW example.

The tow-in option shown in Fig. 4 has a twelve month offshore season and overhaul workshop season. It is therefore similar to the second case described above, in that it requires fewer spare modules. In this case a twelve-week throughput of the overhaul workshop is kept as contingency stock, as the tow-in option takes place all year round and longer periods of bad weather can be expected in winter.

The spare module costs are still high for this option at £17M as they include the cost of spare hulls, since in a tow-in case complete WEC's are removed from the array, thus incurring the cost of spare hulls as well as spare modules. In the model spare hulls can be treated in the same way as spare modules. Differences in the other cost centres between the two options can be explained as follows:

Repair - the tow-in cost is lower due to the 12 month offshore season. The repair section does not have to carry the cost of the overhaul resources during the winter.

Hulls, moorings and foundations - difference is due to different hull shape and mooring configuration.

Bases - the tow-in option cost is slightly higher due to the extra quays, jetties and ship lifts required to deal with the hulls.

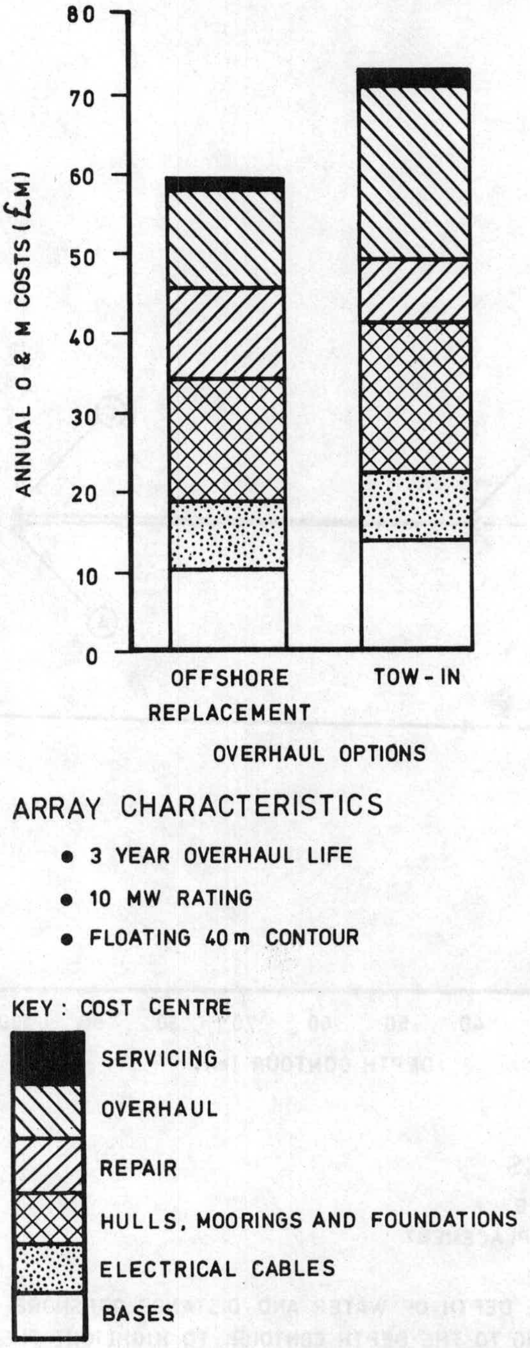
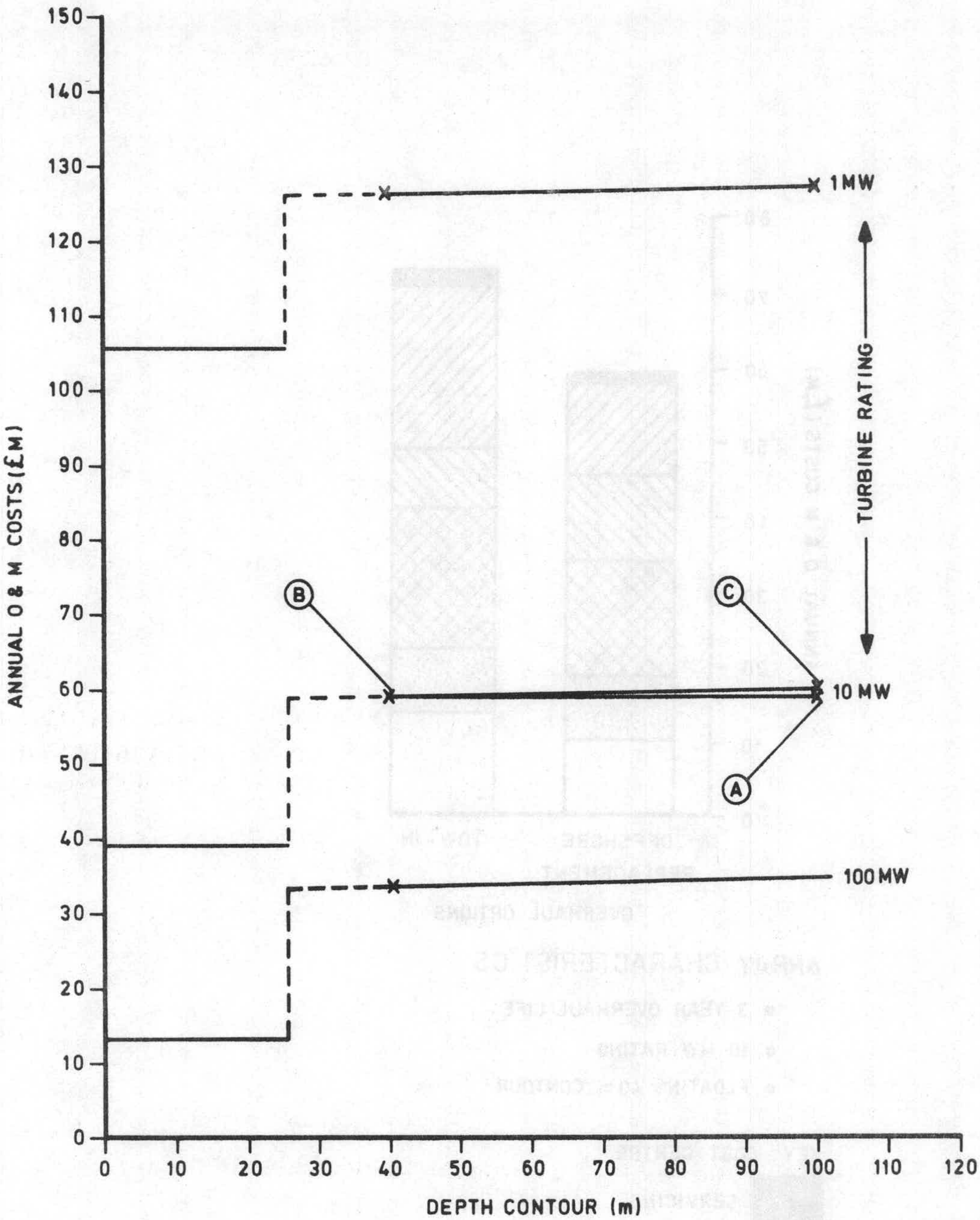


Fig.4 O & M COSTS FOR THE OFFSHORE MODULE REPLACEMENT OPTION AND THE TOW-IN OPTION



ARRAY CHARACTERISTICS

- 3 YEAR OVERHAUL LIFE
- OFFSHORE MODULE REPLACEMENT

IN ALL CASES EXCEPT (A) THE DEPTH OF WATER AND DISTANCE OFFSHORE ARE TAKEN AS THE VALUES CORRESPONDING TO THE DEPTH CONTOUR. TO HIGHLIGHT THE DIFFERENCE IN COSTS DUE TO DISTANCE OFFSHORE RATHER THAN DEPTH OF WATER THE POINT (A) REPRESENTS AN ARRAY AT THE DISTANCE OFFSHORE CORRESPONDING TO THE 100m CONTOUR BUT IN ONLY 40m OF WATER.

Fig.5 EFFECT OF LOCATION-DISTANCE OFFSHORE AND DEPTH OF WATER-ON TOTAL O & M COSTS

3.4 ARRAY LOCATION

The effect of the physical location of the wave energy array, in terms of its distance offshore and the depth of water it is in, on the O & M costs is shown in Fig. 5.

The following sections, 3.4.1, 3.4.2 and 3.4.3, isolate the effect of individual parameters.

3.4.1 Distance Offshore of Wave Energy Array

A number of device locations in terms of distance offshore and depth of water are shown in Fig. 5. In order to isolate the difference in costs due to distance offshore it is necessary to compare points A and B.

Point B represents a moored array at a distance offshore corresponding to the 40 m contour and in a water depth of 40 m. Point A represents the same array in a water depth of 40 m but at a distance offshore corresponding to the 100 m contour. By comparing these two points any effect due to water depth is eliminated.

The difference between the two options is £0.1M, which results solely from the increased flying hours of the helicopters transporting the servicing crews. The increased travelling distance is not sufficient to require any additional vessels or helicopters.

3.4.2 The Change from Bottom Sitting to Floating

The step in O & M costs between a bottom sitting array and a floating array is clearly shown in Fig. 5. The increase in cost is £20M. This increase occurs mainly in the hulls, moorings, and foundations and electrical cables cost centres, which account for £12.5M and £6.7M of the increase respectively.

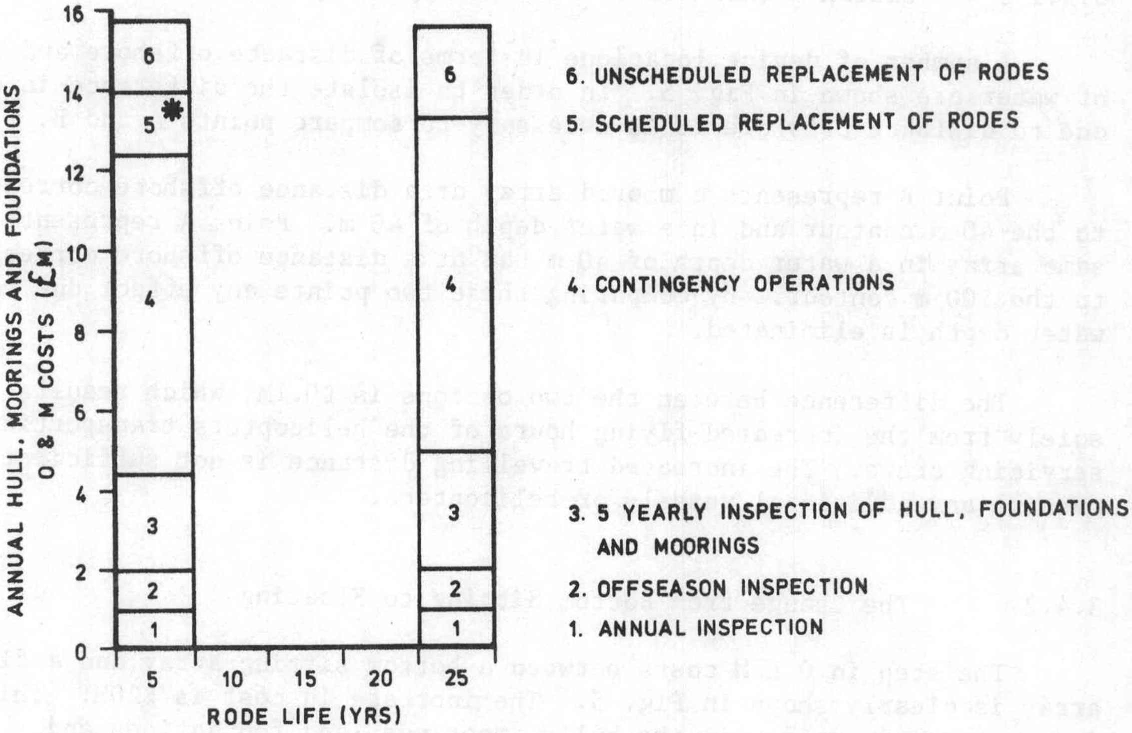
While the bottom sitting array only requires crews and support vessels for WEC hull inspection, the floating array requires resources to maintain and repair the hulls and the moorings and foundations. These cover crews, mooring vessels and replacement rodes for repair. The floating array also needs a contingency vessel capable of restraining a WEC whose moorings have broken.

The low maintenance cost of the electrical cables for the bottom sitting device is due to the lack of inter-WEC flexible cables.

The increase in costs of floating devices over bottom sitting devices is not affected by the rating of the on-board systems since the change in rating does not affect the number of hulls and therefore the number of moorings and electrical cables.

3.4.3 Moorings

The change from bottom sitting to moored devices results in a large step in mooring O & M costs as described in 3.4.2 - an increase of £12.5M in the case described here. However, once a device is moored, the depth of water in which the array is located does not greatly affect mooring O & M costs.



ARRAY CHARACTERISTICS

- FLOATING DEVICE IN 40 M WATER

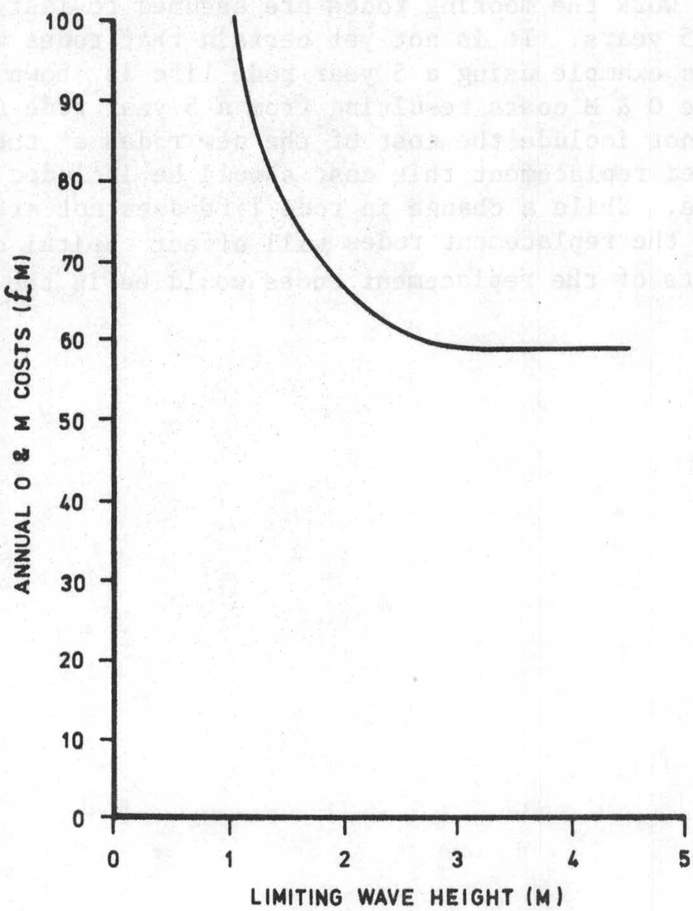
* N.B. THIS COST IS THE O & M COST INVOLVED IN REPLACING RODES EVERY FIVE YEARS. IT DOES NOT INCLUDE THE COST OF THE REPLACEMENT RODES THEMSELVES, SINCE AS ITEMS REPLACED ON A SCHEDULED BASIS THE COST SHOULD BE INCLUDED IN THE CAPITAL COSTS.

THE ANNUAL CAPITAL COSTS OF THE REPLACEMENT RODES WOULD BE IN THE REGION OF £15M.

Fig.6 EFFECT OF MOORING RODE LIFE ON O & M COSTS

From Fig. 5 a comparison of points A and C shows the difference in costs between an array moored in 40 m of water and an array in 100 m of water. The additional cost of £1.45 M is due only to the increased cost of replacement rodes due to their additional length. Moorings O & M costs do not therefore appear to be very sensitive to depth of water.

In the above work the mooring rodes are assumed to last the life of the device, i.e. 25 years. It is not yet certain that rodes will last as long as this and an example using a 5 year rode life is shown in Fig. 6. The graph shows the O & M costs resulting from a 5 year rode replacement strategy and does not include the cost of the new rodes at the end of five years. As a planned replacement this cost should be included in the capital costs of the device. While a change in rode life does not affect the O & M costs, the cost of the replacement rodes will affect capital costs. The annual capital costs of the replacement rodes would be in the region of £15M.



ARRAY CHARACTERISTICS

- FLOATING DEVICE IN 40 M OF WATER
- OFFSHORE REPLACEMENT
- 3 YEAR OVERHAUL LIFE
- 10 MW RATING

Fig.7 EFFECT OF LIMITING WAVE HEIGHT ON O & M COSTS

3.5 LIMITING WAVE HEIGHT

In previous examples the operational wave height has been assumed to be 3 metres for floating devices and 4 metres for bottom sitting devices. The operational wave height assumed governs the number of days available throughout the year on which the vessels can work. A reduction in the number of days available can lead to an increase in the number of vessels required. Fig. 7 shows the effect of varying the limiting wave height on O & M costs.

The limiting wave height for access to the WEC is affected by the design of the WEC hull and the method of attaching it to the seabed and also by vessel used.

From 3 metres upwards the O & M costs remain fairly stable - no improvement is gained by increasing the limiting wave height from 3 metres to 4 metres. The effect of reducing the limiting wave height from 3 metres to 2 metres, however, produces a 10% increase in O & M costs and a further reduction to 1 m would greatly increase costs.

4. MINIMUM MAINTENANCE COSTS

From the preceding sections a number of conclusions can be drawn about the characteristics of a low operation and maintenance cost device.

From 3.1 it can be seen that large reductions in cost can be achieved by increasing the rating of the on-board systems of the device, especially in the 1 MW to 10 MW region. Most devices have now reached the 10 MW stage. Further reductions can be achieved by increasing the rating to 100 MW but this would involve much manifolding and no assessment of the efficiency or capital costs has been made as part of this report.

Once the on-board systems rating has been defined a further cost reduction can be achieved if the overhaul life of plant items on the WEC can be increased to five years. From section 3.2, a further increase in overhaul life to ten years would not result in significant cost reductions.

The change from a bottom sitting device to a floating device results in a large increase in O and M costs, so from that point of view bottom sitting devices are preferable. However, if a device must float because of its method of operation, then its distance offshore and the depth of water in which it is located only affect O and M costs very slightly.

If access to the WEC is not possible at 3 metre wave height then the number of days available for maintenance drops considerably and O & M costs increase as shown in Fig. 7.

The factors discussed above are all related to device design. Another parameter which affects O & M costs is the cost of spare modules which is related to the maintenance strategy defined rather than the device itself. To reduce the number of spare modules it is necessary to balance the offshore module replacement season and the overhaul workshop season. This either leaves most of the overhaul workforce and equipment idle through the part of the year when no offshore work is carried out or means that the overhaul vessels and crews will be used less efficiently during the bad weather period. Fig. 3 shows an example of the first option, which reduces O & M costs even though the workforce and equipment are under-utilized during the winter.

From the previous sections the possible reduction in costs can be seen. Taking a bottom sitting device with 1 MW turbines and a three year overhaul life as a base case, by increasing the rating to 10 MW a 63% reduction in costs can be achieved (£67M). A further increase in rating to 100 MW gives an additional reduction of £25M.

These costs relate to bottom sitting devices. The additional O & M cost incurred by a floating device is £20M. This accounts for 16% of the annual O & M costs of a 1 MW device or 33% of the annual O & M costs for a 10 MW device.

Looking at the 10 MW rated system a 16% reduction in costs can be achieved by increasing the overhaul life of the on-board systems from three to five years. A 10% increase in O & M costs is the result of a limiting wave height of 2 metres rather than 3 metres.

From these figures, an array of bottom sitting devices with 100 MW rated turbines and a five year overhaul life would have the lowest O & M costs but no account has been taken of factors such as efficiency which could affect the final costs adversely.

APPENDIX A

A1 INTRODUCTION

This Appendix is written as a guide to illustrate how the general principles of wave energy maintenance operate and interrelate. These principles are based on the methodology of EASAMS Wave Energy Maintenance Model and are described here with three aims:

- to discuss the assumptions implicit in the results derived from this report and the Maintenance Model.
- to give an overall perspective, independant of the Maintenance Model, which will allow a full understanding of maintenance principles for wave energy.
- to describe the methodology of the model in terms of relationships between parameters.

Section 2 of this Appendix will therefore undertake the first of these three aims in the form of a brief discussion of the major areas of contention or uncertainty in translating these costs into a practical operation.

Section 3 illustrates maintenance parameters in the form of N^2 charts which will provide the following outputs:

- factors influencing any parameter.
- factors depending upon any parameter.
- nature of relationship between two parameters (e.g. step, linear, irregular, etc.).
- level of significance of the relationship between two parameters.

This section also includes a full description of the use of N^2 charts in this application.

A.2 MAINTENANCE MODEL ASSUMPTIONS

The following section is a listing of the important assumptions implicit in the operation and maintenance costings derived from the Maintenance Model and previous EASAMS studies. These assumptions have typically arisen due to aspects of wave energy maintenance which extend beyond current experience. A further measure of the confidence which may be applied to any specific item of information can be obtained from Volume 1 of the Maintenance Model. The basis of this rating system is described in Table 2 of the Maintenance Model (Volume 1).

Maintenance Load

Servicing (minor jobs of annual frequency) and Overhaul (major jobs of three or five year frequency) are specified as requirements of the equipment items. Although based upon current maintenance requirements, this load should be thought of as a specification, viz:

- servicing visits of not more than annual frequency
- overhaul of typically 3-5 year frequency

Abiding by these specifications should minimise the corrective maintenance requirements. Higher levels of servicing and overhaul will not significantly lower the corrective maintenance load; lower levels could significantly increase the corrective maintenance load.

Wave height and persistence

The assumed data for wave height and persistence levels for the Hebrides is specified in Volume 1 of the Maintenance Model. Collection of this data has been both intermittent and over a comparatively short period of time and only a low level of confidence can be associated with it.

Wave height data, persistence and depth effects are all of fundamental importance in sizing the maintenance resources required. In practice, maintenance periods will be defined by the operators, ship's captains, helicopter crew, etc. but reliable environmental data is essential to size a reasonable mean resource.

Access

It is assumed that access is taken fully into account in the final WEC reference design and that features such as boarding points for vessels are incorporated if necessary. The study assumes that helicopter access is possible for all devices with access points above sea level. Even if marine transport is preferred, it is likely that contingency helicopter operations must be possible in the event of emergency evacuation.

It is further assumed that helicopter travel is accepted as a safe, reliable transport method by the maintenance workforce. It is considered that with recent advances in helicopter applications and capabilities, this method of transport will become more acceptable, not less so.

Contingency requirement

It has been assumed that all moored wave energy devices require a high capability semi-submersible support vessel to assist in the event of major failure such as hull failure, fire or mooring failure. (Contingencies are defined fully in all EASAMS reports). This assumption results from the assumed maintenance philosophy derived from O & M studies and is not a definitive requirement.

Condition Monitoring

It has been assumed that not only is the condition monitoring system perfectly reliable but also that it is able to provide all information required to diagnose faults from the shore base facility.

Condition monitoring is essential for both the successful operation of the repair operation and, consequently, to keep availability high and hence the cost of generated electricity low.

In order to collect sufficient information for onshore diagnosis of faults a large number of transducers must be incorporated into the equipment design. These transducers will need to be both highly reliable and accurate and although such items are becoming available, they would represent a significant proportion of the equipment cost.

With the high level of system duplication in a large wave energy array it should be possible to cross match the performance of one unit with that of another unit experiencing similar conditions. In this way, irregularities should be discernible by absolute and comparative analysis of the data reaching the onshore base.

It should be possible therefore to not only diagnose failure but also to pre-empt it by referring to the large library of historical performance data built up during development and operation. The effect of predictive monitoring if achievable, would be to significantly increase the utilisation of the repair force.

There is a considerable benefit to be gained from being able to attend to repairs or predicted repairs in an order of priority rather than the alternative 'as it comes' approach. This is particularly important during the winter months when a delay due to the poor weather may represent a loss of up to a fortnight of what must be, by definition, high quality energy.

A3 WAVE ENERGY MAINTENANCE N^2 CHARTS

The parametric relationships involved in the maintenance model are presented in Figures A1 to A13 in the form of N^2 charts. The charts describe the relationships for the following wave energy system:

- floating WECs not utilising the oscillating water column principle.
- personnel transport by helicopters.
- offshore overhaul by module exchange.

The N^2 chart provides a simple method of illustrating inter-relationships between a number of parameters. The open and visually uncomplicated format allows a large amount of information to be communicated and readily assimilated.

A3.1 Method of using N^2 Chart

The N^2 chart consists of a list of parameters (or procedures, activities, tasks etc.) arranged diagonally across the chart from top left to bottom right. An interface or relationship between two parameters is represented by a symbol at the intersection of perpendiculars drawn from the parameters in question.

Vertical perpendiculars represent inputs to a parameter and horizontal perpendiculars represent outputs. Hence relationships from one parameter inputting to parameters further to the right will be represented above the diagonal and those to parameters further to the left will be represented below the diagonal.

External inputs (those resulting from sources outside the chart) are signified by downward vertical arrows and external outputs (those influencing parameters outside the chart) are signified by right-pointing horizontal arrows.

The points of intersection between perpendiculars from two parameters are represented by the symbol ○ if there is a relationship of low significance and the same symbol but in a bolder design if the relationship is of a high significance.

Within this symbol, a letter indicates the type of relationship between the two relevant parameters. The three relationships specified are linear (denoted L), step (denoted S) and irregular (denoted I).

External inputs are represented by three types of parameter:

R Reference Design. These inputs relate to parameters which are specified by the reference design of the wave energy system.

C Choice. These inputs relate to parameters which may be specified by the user and may be dependent upon such things are the maintenance philosophy.

D Data. These inputs relate to parameters which must be derived from external information such as cost data, component overhaul lives etc.

A3.2 Uses of the N^2 Charts

The N^2 charts can be used to provide the answers to a number of questions relating to wave energy O & M as follows:

- taking a specific parameter, which other parameters affect its value ? (section A.3.2.1).
- which of these factors are of major significance ? (section A.3.2.2.).
- what type of relationship do the dependent parameters have with the specified parameter? (section A.3.2.3).
- what other parameters are affected by the alteration of the value of the specified parameter?(section A.3.2.4).

A.3.2.1 Contributory parameters

The contributory parameters relating to any specified parameter are given in the vertical column which passes through this parameter. Every symbol within this column represents either the intersect of the horizontal line from a dependent parameter on the N^2 chart or an external input (these are listed at the top of the chart). An external input will be one of two parameter types:

- external inputs from other N^2 charts denoted by a circular symbol containing the relevant parameter number.
- external inputs not available from other N^2 charts denoted by a circular symbol containing the letters R, D or C as described in section A3.1.

A.3.2.2 Significance of contributory parameters

The significance of the contributory parameters listed in the vertical column is denoted by the symbol O. A bold symbol corresponds to a significant relationship and a lower intensity symbol corresponds to a relationship of lower significance.

A3.2.3 Contributory parameter relationships

Within the vertical column of contributory parameters the type of relationship is denoted by the letter contained within the symbol O. In accordance with the key on each chart, the following functions may be identified:

- indeterminate
- irregular
- linear
- step
- inverse

A3.2.4 Dependent parameters

For any specified parameter, there are a number of parameters which are dependent upon its value, and hence must change also if the initial parameter is varied.

These dependent variables may be found in the horizontal row corresponding to the specified parameter either within the chart for those relationships contained on the same figure or in the righthand column of the chart for those in other figures.

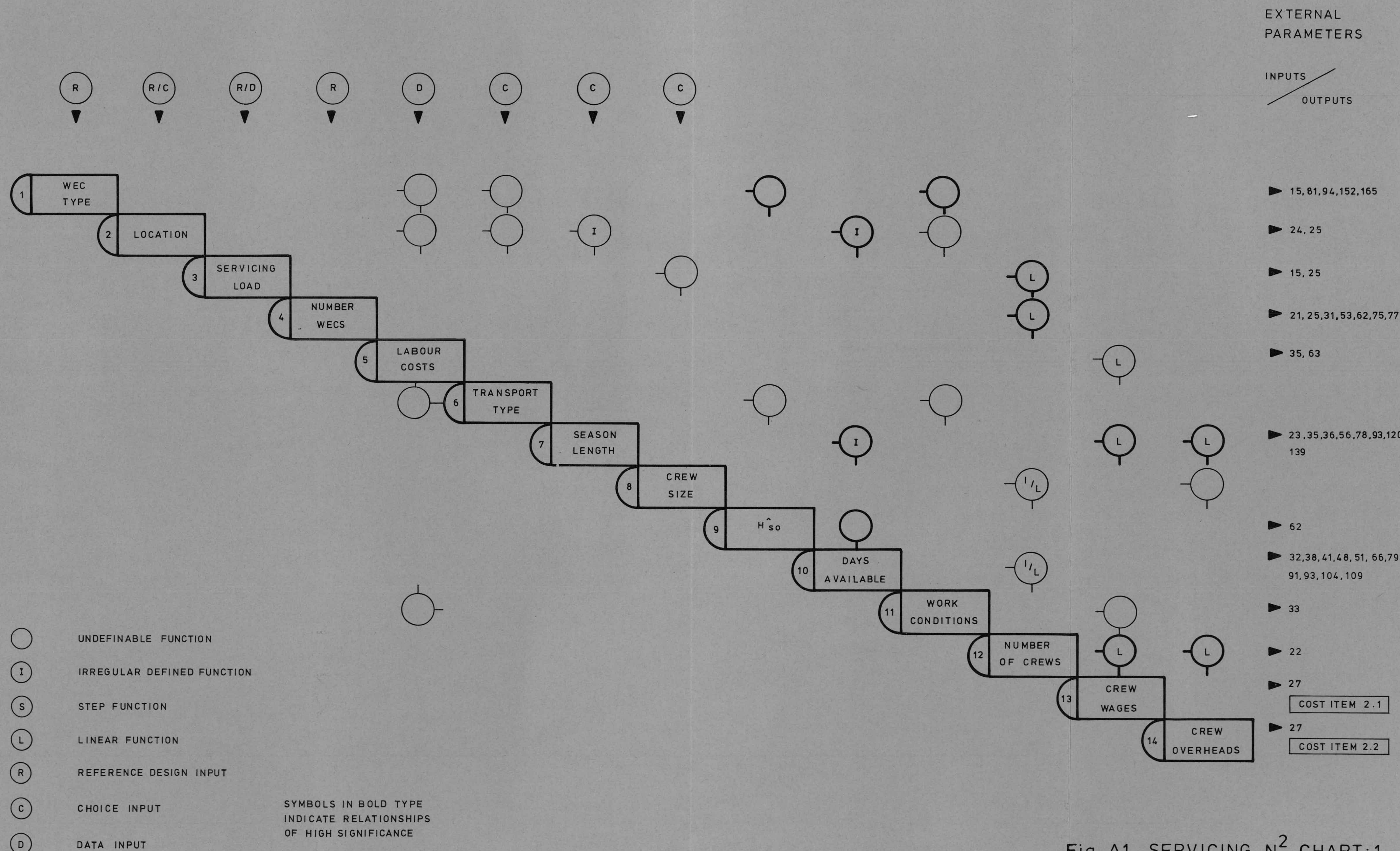


Fig. A1 SERVICING N^2 CHART: 1

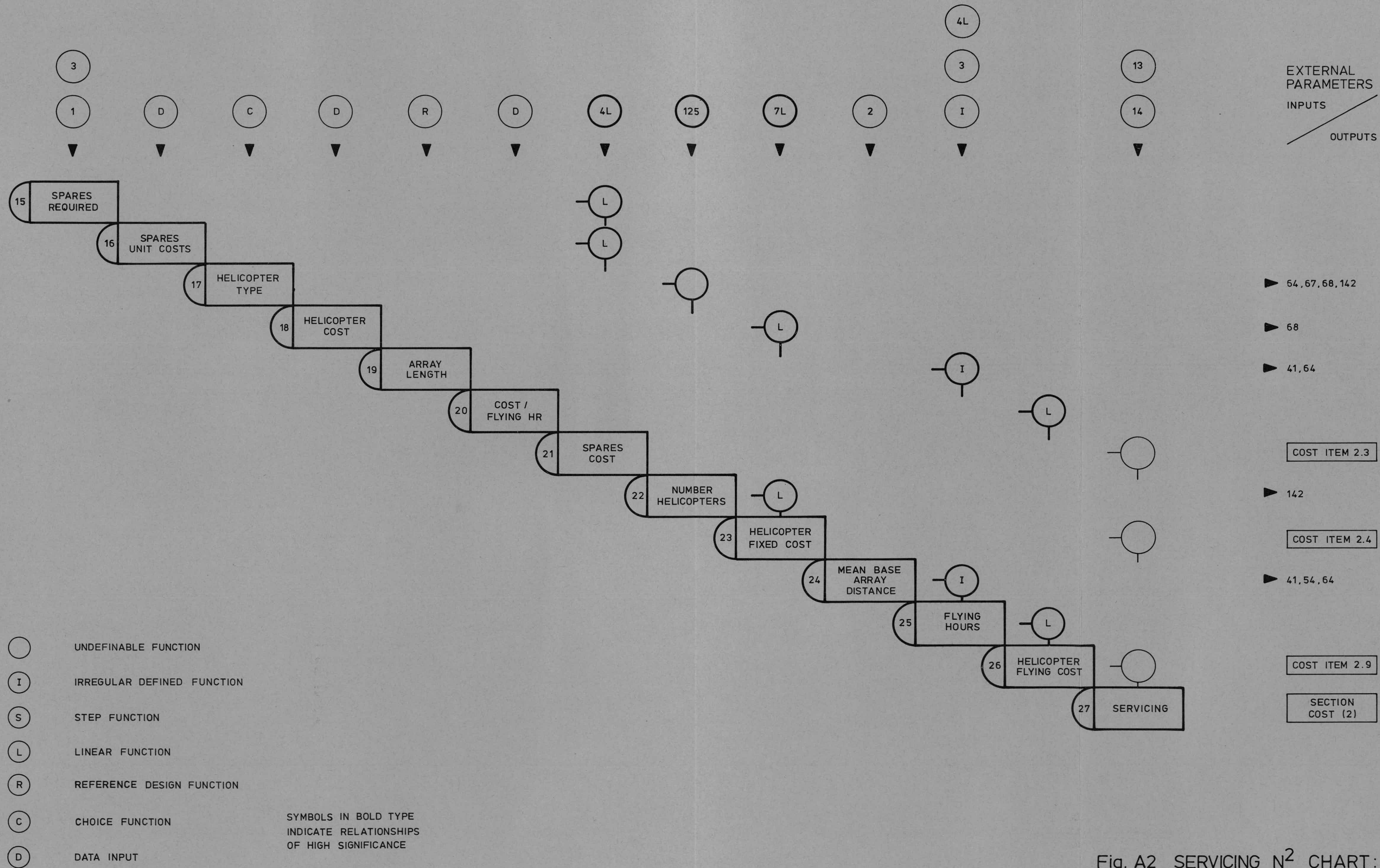


Fig. A2 SERVICING N^2 CHART : 2

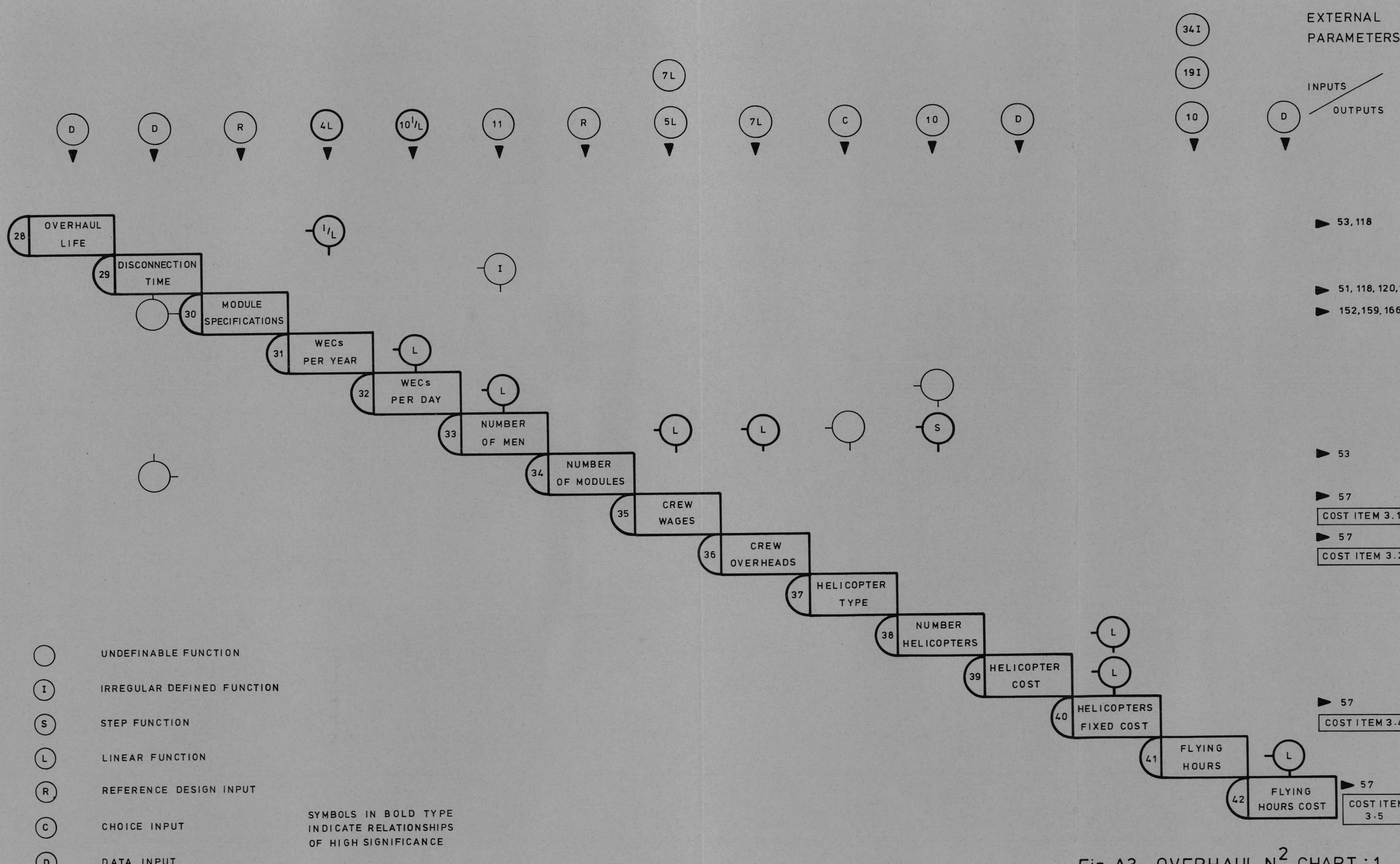


Fig. A3 OVERHAUL N^2 CHART : 1

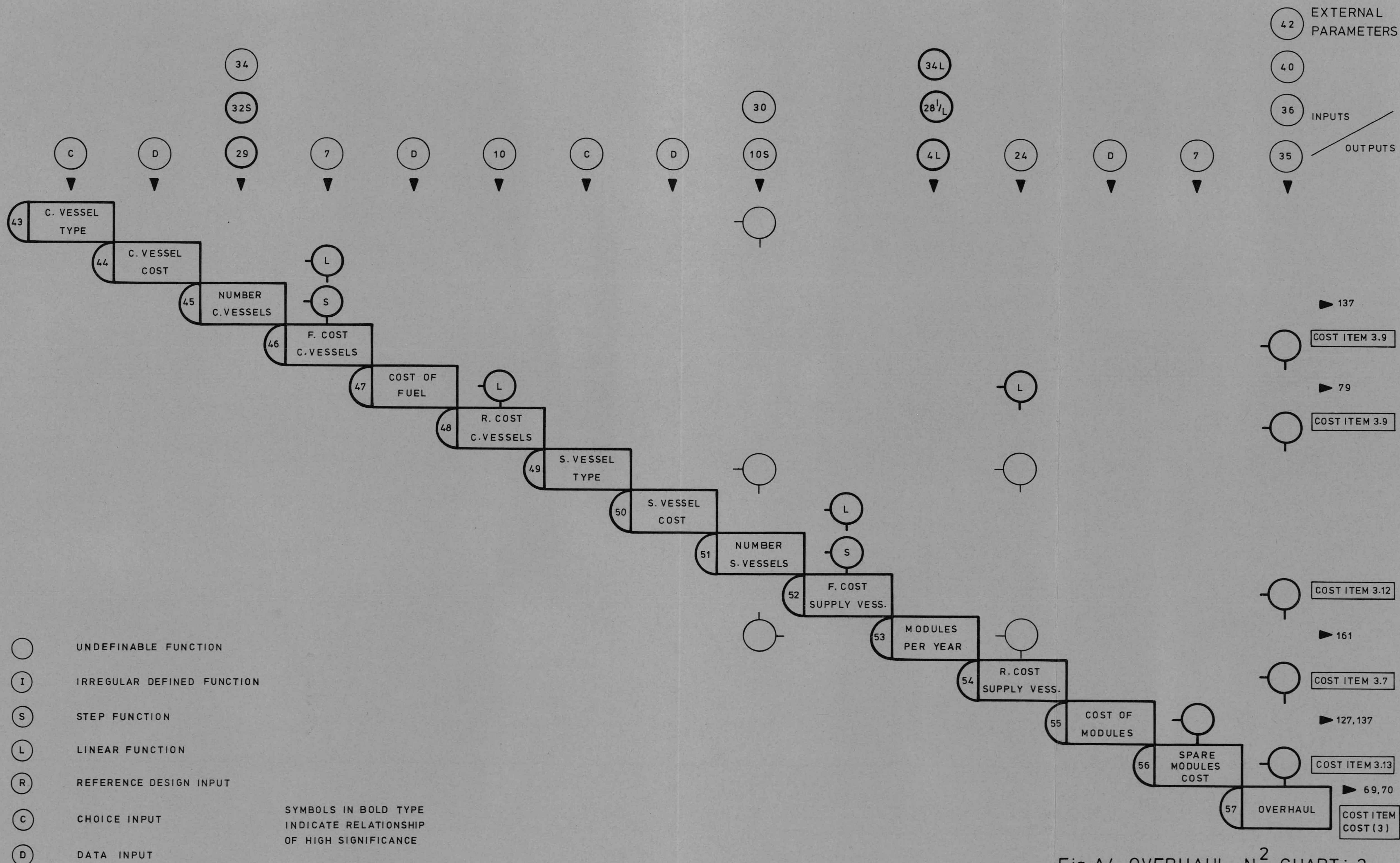


Fig. A4 OVERHAUL N^2 CHART: 2

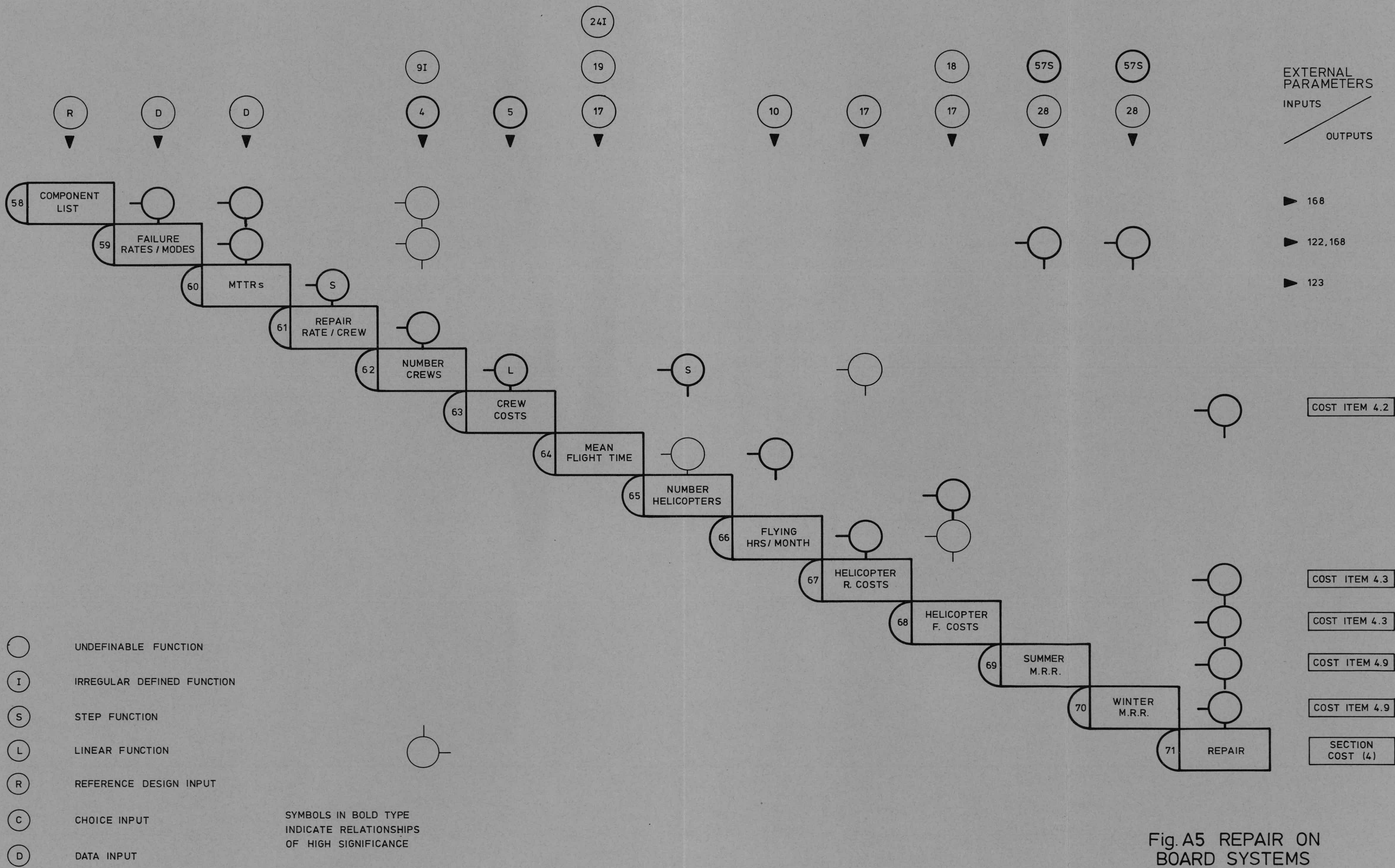


Fig. A5 REPAIR ON BOARD SYSTEMS

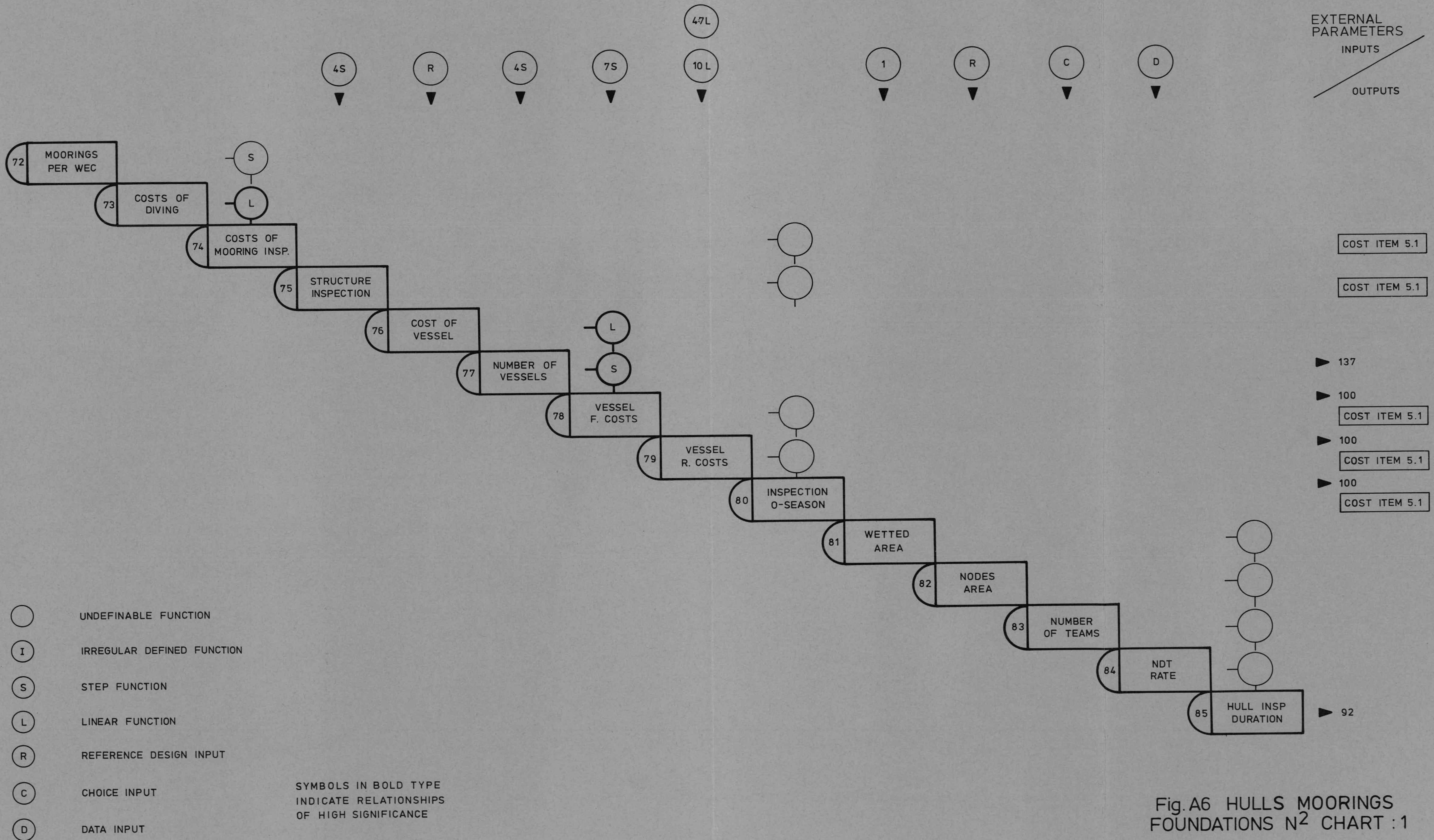


Fig. A6 HULLS MOORINGS FOUNDATIONS N^2 CHART : 1

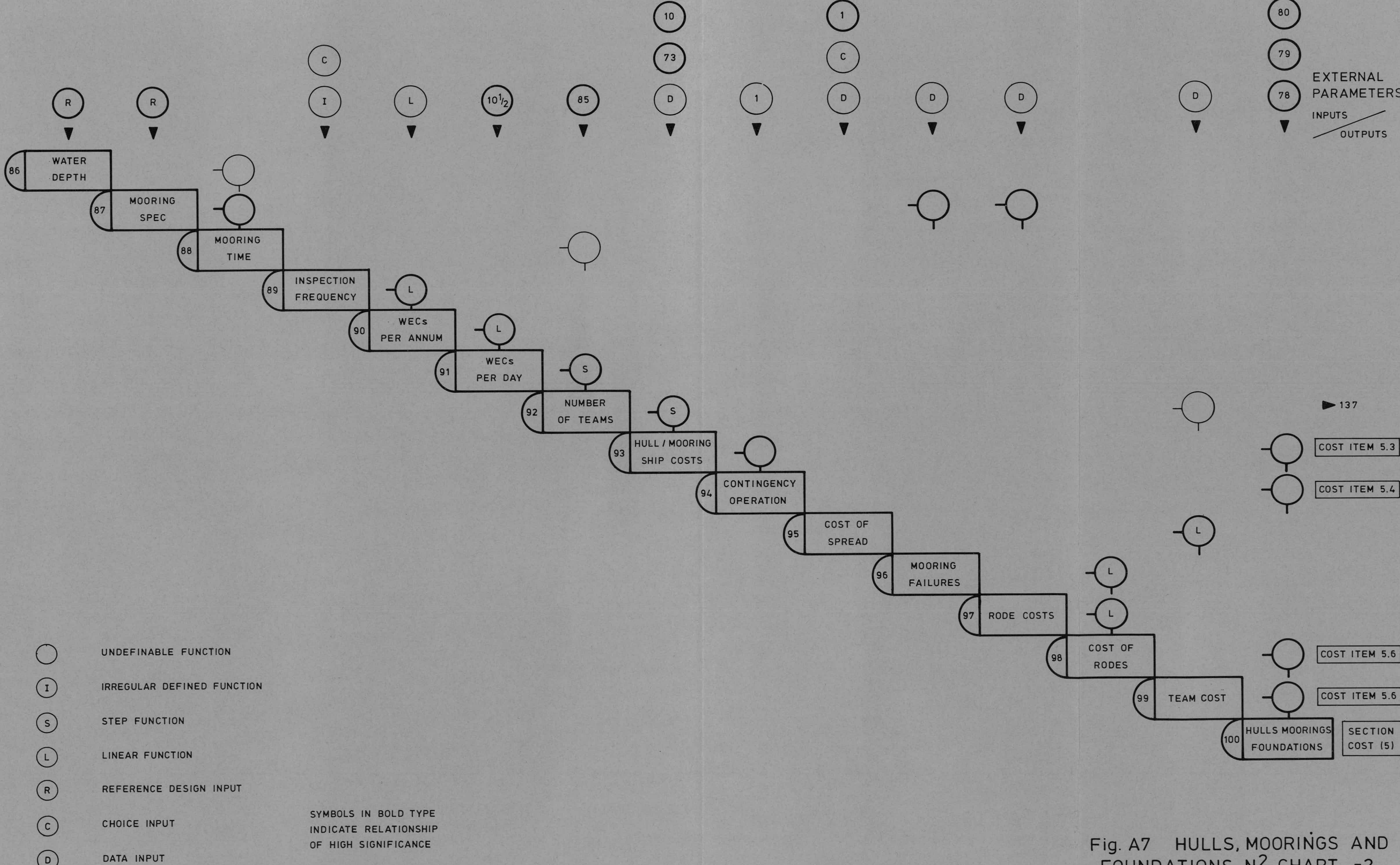


Fig. A7 HULLS, MOORINGS AND FOUNDATIONS N^2 CHART -2

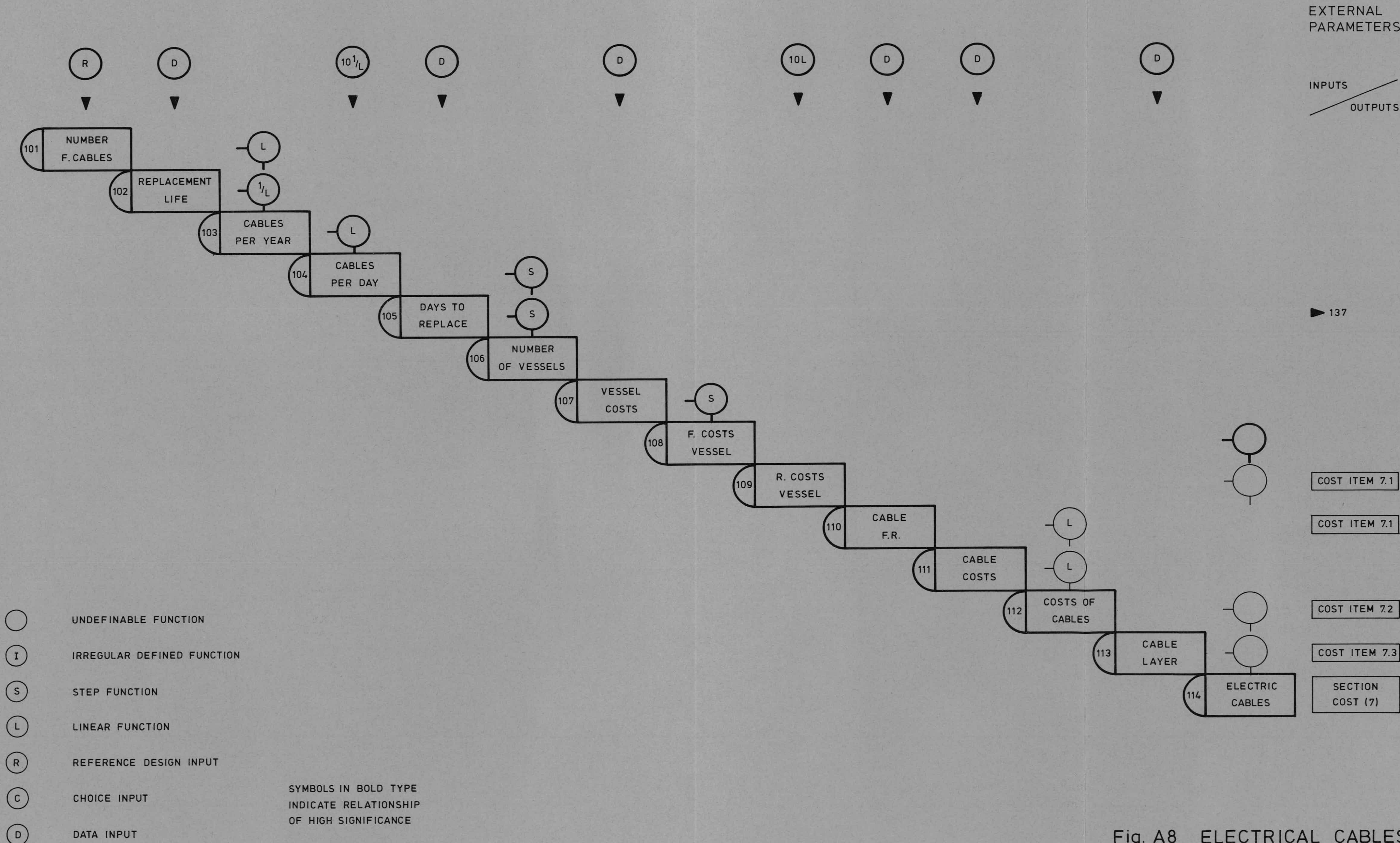


Fig. A8 ELECTRICAL CABLES

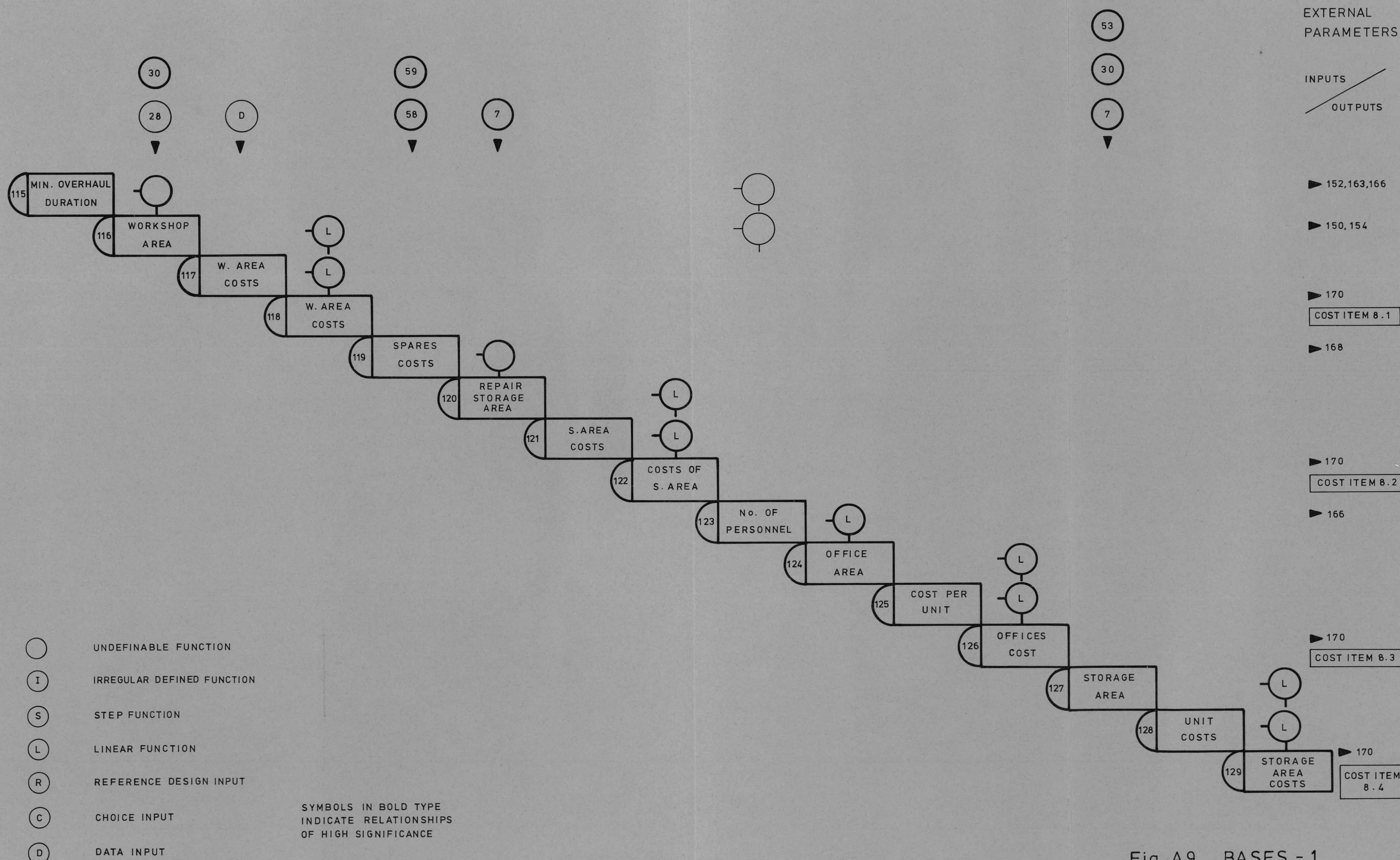


Fig. A9 BASES - 1

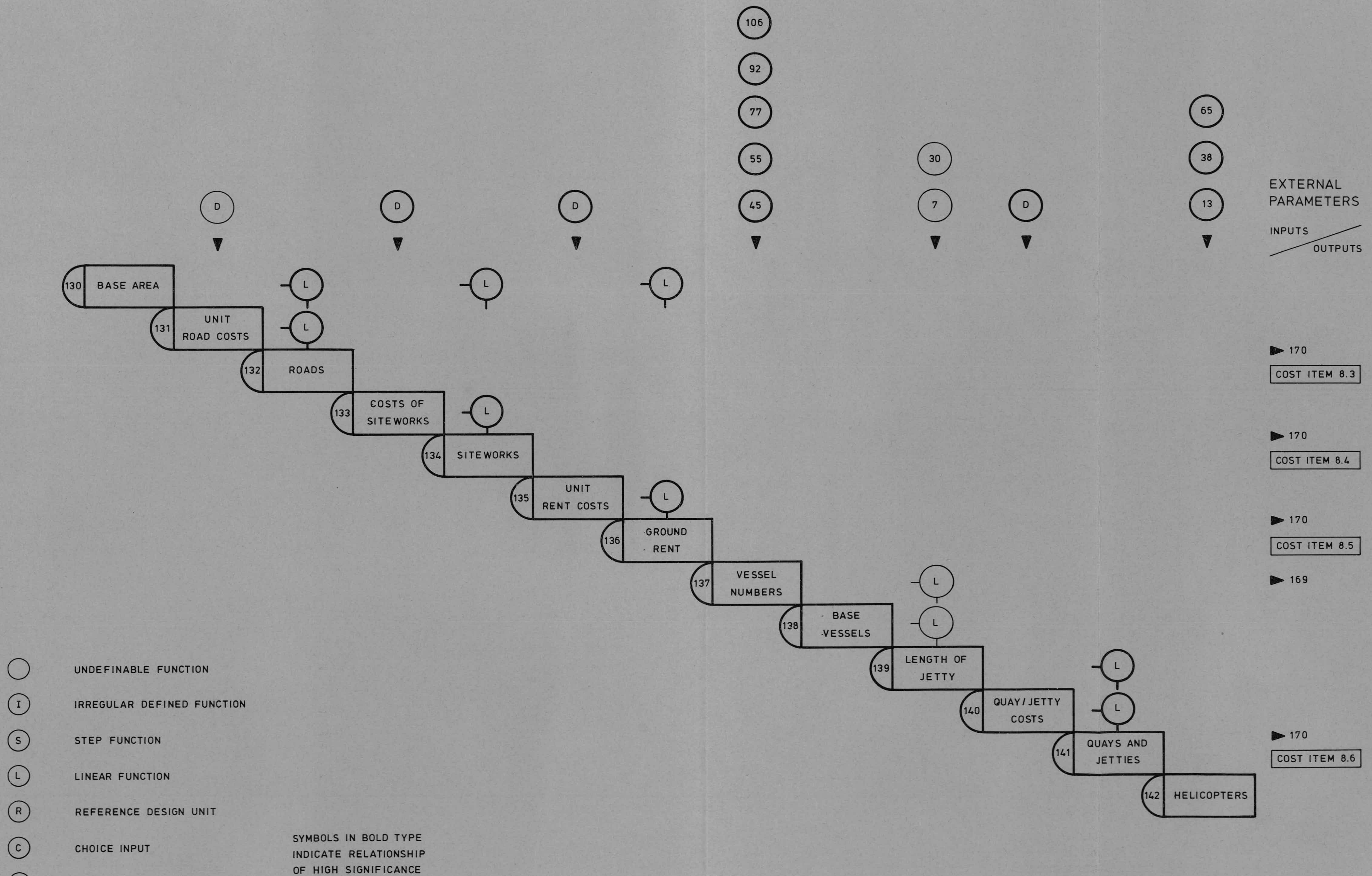


Fig. A10 BASES -2

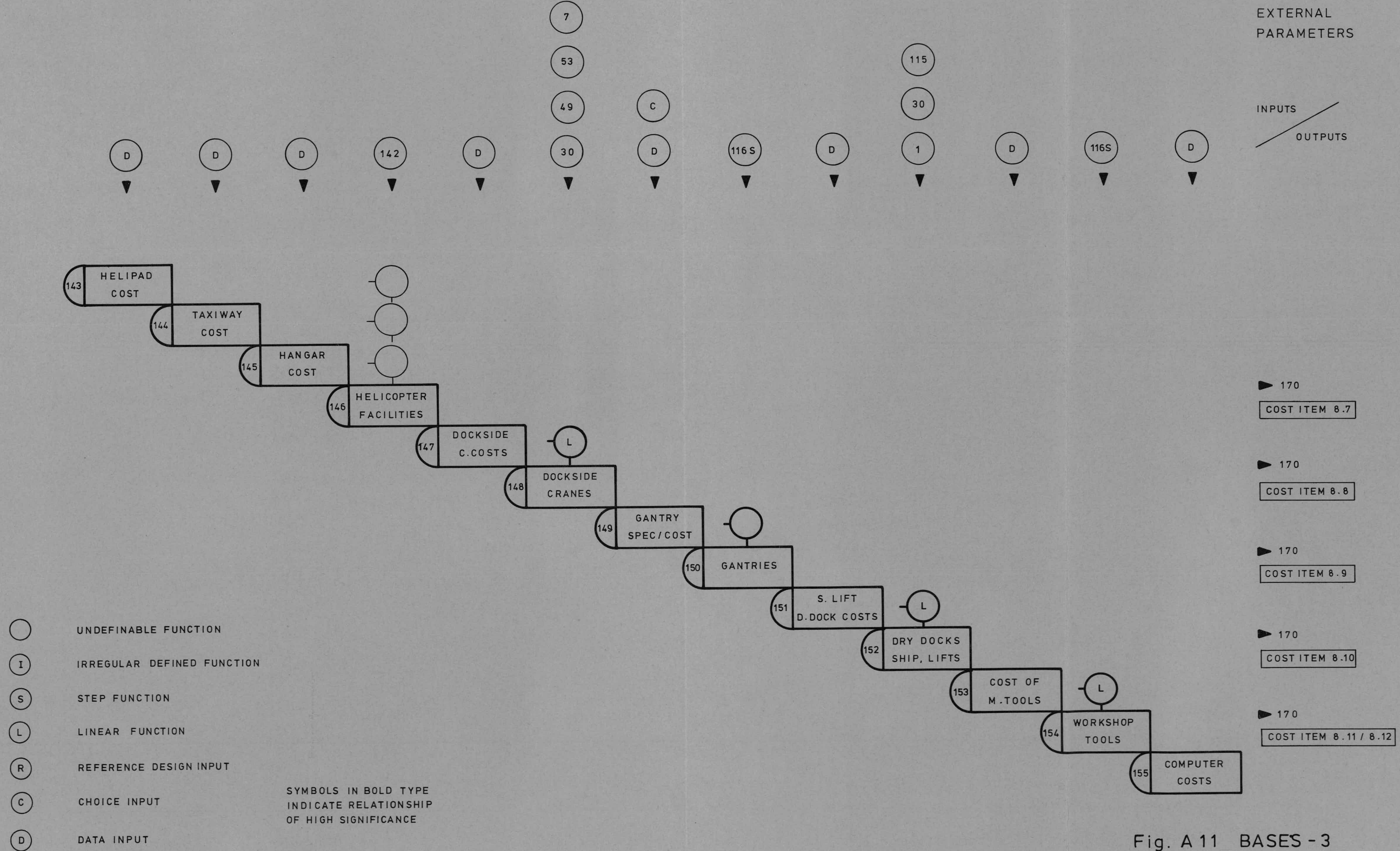


Fig. A11 BASES-3

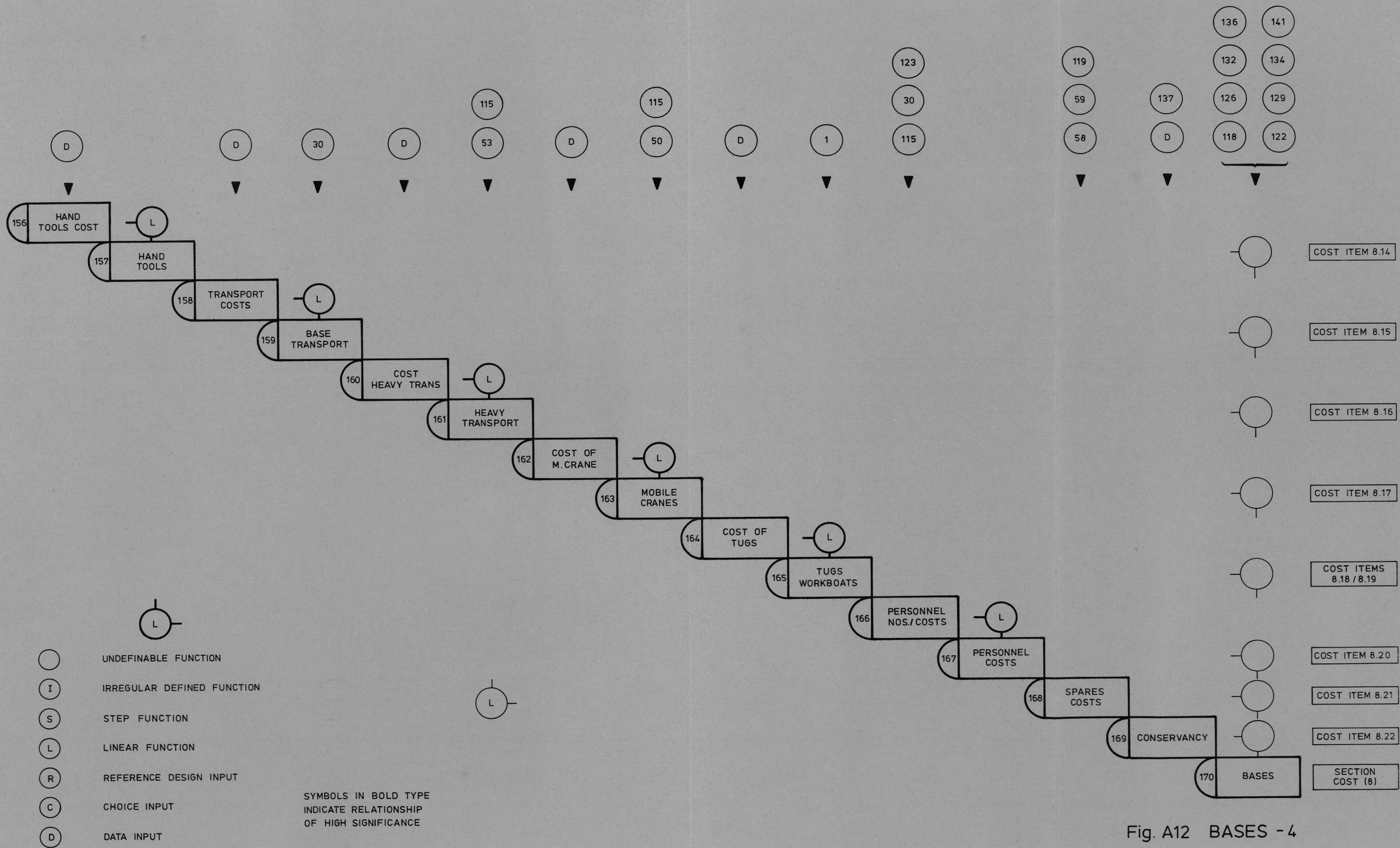
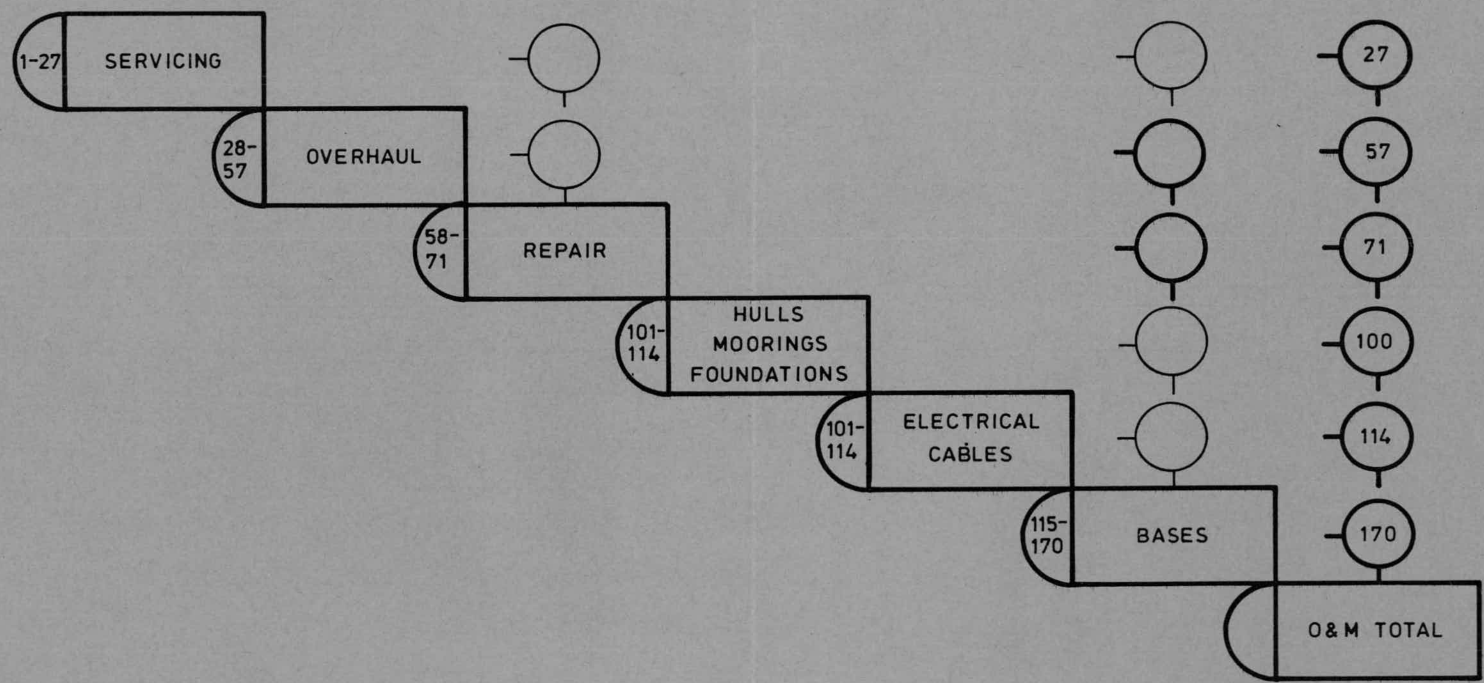


Fig. A12 BASES - 4



- ◯ UNDEFINABLE FUNCTION
- (I) IRREGULAR DEFINED FUNCTION
- (S) STEP FUNCTION
- (L) LINEAR FUNCTION
- (R) REFERENCE DESIGN INPUT
- (C) CHOICE INPUT
- (D) DATA INPUT

SYMBOLS IN BOLD TYPE INDICATE RELATIONSHIP OF HIGH SIGNIFICANCE

Fig. A13 SUMMARY