INSTRUCTION MANUAL

NA8-10

LARGE ANGLE SHIP STABILITY DYNAMOMETER

AND INCLINING MODEL

BY

R.L. TOWNSIN, B.Sc., Ph.D., Eng., F.R.I.N.A., F.I. Mar. E.

SCHOOL OF MARINE TECHNOLOGY

UNIVERSITY OF NEWCASTLE UPON TYNE

ENGLAND

NA8-10

ISSUE 10

MAY 2009

ARMFIELD LIMITED
OPERATING INSTRUCTIONS AND EXPERIMENTS

NA8-10 - LARGE ANGLE SHIP STABILITY DYNAMOMETER AND INCLINING MODEL

CONTENTS **PAGE NO.**

SAFETY IN THE USE OF EQUIPMENT SUPPLIED BY ARMFIELD

Before proceeding to install, commission or operate the equipment described in this instruction manual we wish to alert you to potential hazards so that they may be avoided.

Although designed for safe operation, any laboratory equipment may involve processes or procedures which are potentially hazardous. The major potential hazards associated with this particular equipment are listed below.

- *INJURY FROM INCORRECT HANDLING*
  The equipment is heavy and must be handled properly when unpacking, assembling or operating it. Care should be exercised at all times when lifting and positioning the model boat(s). Care should be taken when moving and fitting the various ballast weights as these are heavy will cause injury to hands or feet if dropped.

- *RISK OF INFECTION DUE TO LACK OF CLEANLINESS*
  Water will stagnate if left in the flotation tank. Water must be changed at regular intervals.

- *RISK OF DROWNING*
  The flotation tank will contain deep water after filling. Care should be taken to avoid the risk of drowning or other injury associated with a deep, open tank that is filled with water.

Accidents can be avoided provided that equipment is **regularly maintained** and **staff** and **students** are made aware of potential hazards.

Armfield Ltd. suggests that a comprehensive list of Laboratory Safety Precautions and Rules be made available to all laboratory users. Local laws or regulations related to laboratory practice or laboratory safety must be incorporated in these safety rules.

Please refer to the notes overleaf regarding the Control of Substances Hazardous to Health Regulations.

The COSHH Regulations

The Control of Substances Hazardous to Health Regulations (1988)

The COSHH regulations impose a duty on employers to protect employees and others from substances that may be hazardous to health. The regulations require the person responsible to make an assessment of all operations that are liable to expose any person to hazardous solids, liquids, dusts, vapours, gases or micro-organisms. That person is also required to introduce suitable procedures for handling these substances and keeping appropriate records.

Equipment supplied by Armfield Ltd may involve the use of substances that can be hazardous to health, for example cleaning fluids used for maintenance or chemicals used for particular demonstrations. It is therefore essential to implement the COSHH regulations.

The COSHH regulations require relevant Health and Safety Data Sheets to be available for all hazardous substances used in the laboratory. Any person using a hazardous substance must be informed of the following:

- Physical data about the substance
- Hazard from fire or explosion
- Hazard to health
- Appropriate First Aid treatment
- Hazard from reaction with other substances
- Cleaning/disposal procedures following spillage
- Appropriate protective measures
- Appropriate storage and handling techniques

Although the COSHH regulations may not be applicable outside the UK, it is strongly recommended that a similar approach is adopted for the protection of both persons operating the equipment and persons in the proximity. Local regulations must also be considered.

Water-Borne Infections

The equipment described in this instruction manual involves the use of water that under certain conditions may create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45 °C. Water containing this bacterium that is sprayed or splashed may create air-borne droplets that can produce a potentially fatal form of pneumonia called Legionnaires Disease.

Legionella is not the only harmful micro-organism that can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed: -

Water contained within the equipment must not be allowed to stagnate and rust, sludge, scale or algae, on which micro-organisms can feed, must be removed regularly. The water must therefore be changed at regular intervals to minimise any hazard to health. The interval between changes will depend on the ambient temperature and the biological / mineral content of the water. It may be necessary to change the water at intervals of one week under extreme conditions.

Where practicable the water should be maintained at a temperature below 20°C or above 45°C. When this is not practicable the water should be treated with a suitable disinfectant or bleach if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water. The use of bleach or disinfectant is not appropriate where skin contact with the water is involved. In this case the water must be changed more regularly at intervals dependant upon local conditions.

A scheme should be prepared for preventing or controlling the risks associated with the use of laboratory equipment.

Further details on preventing infection are contained in the publication "The Control of Legionellosis including Legionnaires Disease" - Health and Safety Series booklet HS (G) 70.

INTRODUCTION

This instruction manual describes the large angle stability system (NA8-10) which comprises a free standing dynamometer to measure righting moments and includes the following items:

- **NA8-11 Ships Flotation Tank**
- **NA8-12 Clinometer**
- **NA8-13 General Cargo Vessel with ballast weights**

The purpose of this Instruction Manual is to provide hydrostatic and other data relevant to the NA8-13 General Cargo Vessel model. It provides lecturers with information for a course of practical study in ship hydrostatics, flooding and stability and describes a number of experiments that are useful for students. The free standing dynamometer is mounted on castors for placing alongside the Ships Flotation Tank (NA8-11) to measure the righting moment, up to large angles of heel, on a floating ship model. The dynamometer exerts no vertical force on the model and will hold it at any angle of heel within the range, either free to trim or with the heeling axis kept horizontal as assumed in calculations. The righting moment is measured by counterbalancing to an equilibrium position. The dynamometer is supplied complete with counterbalance weights and a clamping device for attaching the righting moment arm to the model vessel.

The digital Clinometer (NA8-12) is calibrated from 0-10 degrees with a resolution of 0.01 degrees and above 10 degrees with a resolution of 0.1 degrees. This allows accurate determination of the angle of inclination of the model vessel with greater precision at small angles of heel.

The General Cargo Vessel model (NA8-13) supplied is a 1/70th scale representation of a vessel of 28,000 tonnes ship mass. The hull is constructed of glass reinforced plastic and is fitted with a number of transverse watertight bulkheads in their correct positions. The compartments are fitted with flooding valves.

The Instruction Manual does not pretend to be comprehensive because it is presumed that the reader has a good grasp of the basic principles of naval architecture. References to three recommended textbooks are given at the end of this Manual in ascending order of cost. Whilst the manual is not comprehensive, Armfield Limited will be pleased to supply any further information about the model or the dynamometer which may become important as a particular teaching or research programme is being developed.

Three alternative models are available (not supplied with NA8-10) which may be used in conjunction with the dynamometer, tank and Clinometer:

- **NA8-14 Trawler model**
- **NA8-15 Crane ship model**
- **NA8-16 Rectangular barge model**

These models are described in separate Instruction Manuals that are supplied with the appropriate model.

RECEIPT OF EQUIPMENT

1. *SALES IN THE UNITED KINGDOM*

The apparatus should be carefully unpacked and the components checked against the Advice Note. A copy of the Advice Note is supplied with the equipment for reference.

Any omissions or breakages should be notified to Armfield Ltd within three days of receipt.

2. *SALES OVERSEAS*

The apparatus should be carefully unpacked and the components checked against the Advice Note. A copy of the Advice Note is supplied with the equipment manual for reference.

Any omissions or breakages should be notified immediately to the Insurance Agent stated on the Insurance Certificate if the goods were insured by Armfield Ltd.

Your own insurers should be notified immediately if insurance was arranged by yourselves.

ASSEMBLY OF EQUIPMENT

All numerical references relate to Fig. 1 on page 8.

The dynamometer is supplied in the form of sub-assemblies and only a minimum of assembly work is required. Assembly may be completed using a basic tool kit.
The following assembly procedure should be used:

1. Assemble the pillar (1) to the base (2) using the M8 bolts provided.

2. Position the pivot housing assembly (3) complete with aims and struts to the pillar.

3. Screw the counterbalance weight stud (4) into end plate (5). Remove retaining knob (6), screw on counterbalance weight (7). Replace and tighten retaining knob.

4. Locate scale pans (8) onto balancing arms (19). Lock vertical strut (17) with locking plate (15).

5. Screw pointer (9) into bottom of pivot housing assembly using an open ended spanner on the flats provided.

6. Set pans (8) level using weights (18).

7. Fit clamping attachment (10) into swivel block (11).

8. Set horizontal arms (20) level with a spirit level using counterbalance weight (7).

RIGHTING MOMENT ARMS AND WEIGHT CARRIERS

The righting moment arms come completely assembled to the pivot housing assembly. The counter balance needs to be screwed on to the balance adjustment arm and retained with the ball-stop screwed in position.

The weight carriers are hooked through the holes at the ends of the adjustment arm and secured with lock nuts.

This completes the assembly of the dynamometer in readiness for positioning over the flotation tank and attachment of the model.

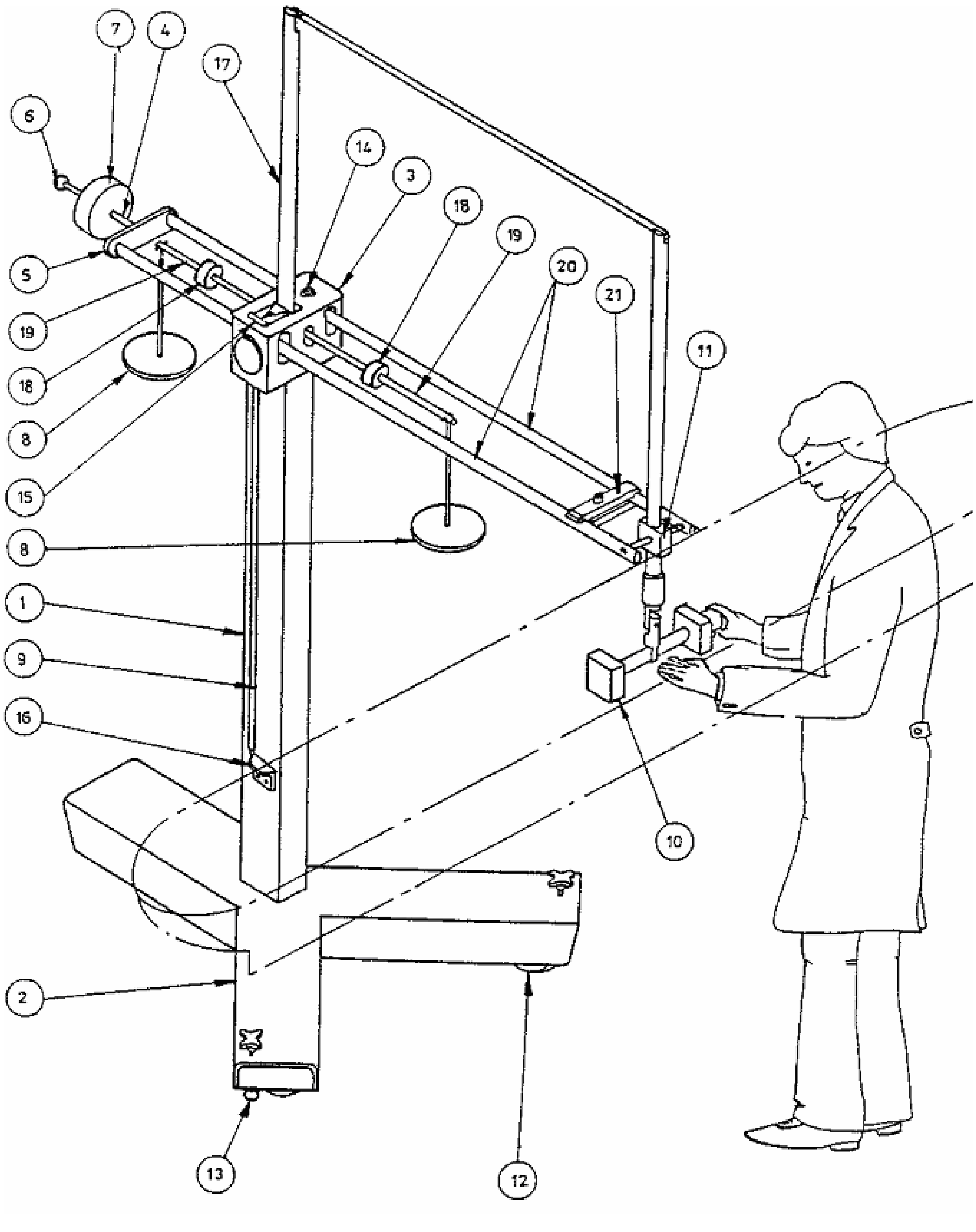


FIGURE 1 ARMFIELD LARGE ANGLE SHIP STABILITY DYNAMOMETER & MODEL.

COMMISSIONING

All numerical references relate to Fig. 1 on page 8.

SHIPS FLOTATION TANK (NA8-11)

Place the support frame for the flotation tank on a level floor in the desired position. Locate the GRP tank on the support frame. Ensure that the drain valve is closed and partially fill with water, checking for leaks.

LARGE ANGLE STABILITY DYNAMOMETER

Move the dynamometer on its castors (12) positioning the vertical clamping post over the centre of the flotation tank. When this position is established the dynamometer can be fixed and levelled by screwing down the three jacking pads (13) and using the spirit level (14) attached to the pivot housing.

Remove the sole plate from the model and attach it to the clamping attachment (10). This will eliminate any initial list caused by the sole plate. Adjust the counterbalance weight (7) until the horizontal aims adopt the horizontal position and are in equilibrium i.e. no movement.

Withdraw the locking plate (15) and check that the pointer (9) at the side of the stand aligns with the index on the plate (16). If these marks do not coincide adjust the counterbalance weights (18) on each of the lever arms (19). Replace the locking plate (15).

GENERAL CARGO VESSEL (NA8-13)

Attach the model hull to the dynamometer by the clamping attachment (10) and continue filling the flotation tank until the counterbalance arms are horizontal.

The equipment is now ready for stability experiments.

Detailed instructions for the Clinometer (NA8-12) are given on page 10.

THE CLINOMETER (NA8-12)

The Clinometer is a precision, battery operated, electronic digital gauge that allows the inclination of the model vessel to be measured. The angle of heel is indicated directly in units of degrees on a LCD display with a resolution of 0.01 degrees at angles less than 10 degrees and 0.1 degrees at angles greater than 10 degrees. The Clinometer incorporates an artificial horizon so that an independent reference is not required when taking measurements.

The Clinometer has additional features that are not utilised in conjunction with the NAB. These features include an Alternative Zero that allows measurements relative to a different datum and a serial port for connection to a PC. These features are not included in this instruction manual but may be utilised by the end user by referring to the manual supplied with the Clinometer.

A bracket is attached to the deck that allows the Clinometer to be securely attached to the model vessel. This bracket must be used to prevent the Clinometer from falling overboard when the vessel is heeled.

The Clinometer is a precision instrument and should be treated with respect. Any knocks may mean that recalibration is required and if severe may damage the instrument

The Clinometer is not waterproof and care should be taken not to drop the instrument into the flotation tank or capsize the model vessel while the Clinometer is attached.

CALIBRATING THE CLINOMETER

Before using the Clinometer for the first time it is suggested that the instrument be calibrated to minimise any errors induced during shipping. This exercise, referred to as the Self-calibration mode, is fully described in the manual that accompanies the Clinometer and only requires a stable horizontal and vertical surface to be available (the surfaces do not need to be perfectly horizontal or vertical).

These settings should be performed before fitting the Clinometer to the model vessel as the deck of the vessel will not provide a stable datum.

USING THE CLINOMETER

The Clinometer, supplied with a battery installed. It is switched on by pressing the On/Off button on the front of the instrument. The display will settle after approximately 10 seconds to indicate the inclination in units of degrees. At angles of heel up to 10 degrees the display will indicate with a resolution of 2 decimal places. At angles of heel greater than 10 degrees the resolution will drop to one decimal place.

The Clinometer will give approximately 250 hours of operation on a standard 9V Alkaline battery (type PP3). A low battery indicator is included on the display to shown when the battery must be changed but the accuracy of measurement will not be affected if the battery voltage is low. Details on how to change the battery are given in the manual that accompanies the Clinometer

The Clinometer will automatically switch off after a pre-set period (sleep mode) if the reading on the display does not change. Press the On/Off button to restore operation. The calibration of the Calibration is restored when the instrument is switched back on.

FITTING THE CLINOMETER TO THE MODEL VESSEL

Note: When fitting the Clinometer to the model vessel take care not to drop the instrument into the water.

If not fitted, attach the Clinometer mounting bracket to the holes in the transverse bulkhead (aft of amidships) of the model General Purpose Cargo Vessel using the countersunk screws, nuts and washers supplied. If fitting the bracket to any of the optional model vessels available then attach the bracket directly to the deck of the model using the fixings through the appropriate holes in the deck. Whichever model vessel is used, with the bracket correctly fitted, the display on the Clinometer should always be vertical and face towards the stern of the vessel.

Before installing the Clinometer in the mounting bracket, unscrew the two finger screws at the top of the bracket then slide the Clinometer into the bracket. Ensure that the bottom of the Clinometer is prevented from moving forwards by the flange at the bottom of the bracket, then secure the Clinometer by tightening the two finger screws. Ensure that the Clinometer is secure but do not over-tighten the finger screws.

The Clinometer is ready for use.

OPERATING THE CLINOMETER

Refer to the separate instruction manual supplied with the Clinometer for full details on using, storing and servicing the instrument. The following notes are intended to assist the user when using the Clinometer in conjunction with the NA8.

Press the On/Off button to switch the Clinometer on.

Ensure that the ALT ZERO indicator is not displayed. This indicates that readings are relative to an alternative zero i.e. not the horizontal datum. To cancel ALT ZERO simply press the ALT ZERO button.

Ensure that the low battery indicator is not displayed.

After a period of approximately 10 seconds the display will indicate the inclination (relative to the horizontal axis) in units of degrees in the form xx.xx° at angles less than 10 degrees and xx.x° at angles greater than 10 degrees. If the measurement is required in degrees and minutes simply multiply the decimal part by 60 to obtain the appropriate number of minutes.

Note that all readings on the display are positive. An indicator at the left- hand side of the display shows the direction of inclination. The convention is:

- Upward pointing arrow (▲) -ve / inclination to Port
- Downward pointing arrow (▼) +ve / inclination to Starboard

when the display on the Clinometer is viewed from Aft of the vessel.

After each adjustment of the model in the flotation tank, allow the model to settle then read the angle of heel directly from the Clinometer (the reading on the Clinometer will have a delay of approximately 10 seconds due to settling). When adjusting the heel of the model take care not to immerse the Clinometer in the water or cause the model to capsize.

The Clinometer will automatically switch off after a period of use to conserve the batteries. Simply press the On/Off button to continue operation. Calibration of the instrument is not affected by switching on or off.

For other features on the Clinometer refer to the instruction manual supplied with the Clinometer.

ROUTINE MAINTENANCE

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular servicing/maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

It is important to keep the whole apparatus under a dust cover when not in use. To obtain a satisfactory result, always level the dynamometer with extreme care and then check the freedom of movement.

Monthly - Add a few drops of fine oil to lubricate each roller bearing.

Yearly - Remove all the roller bearings, clean them carefully in paraffin, check for freedom and smooth running, oil lightly and refit. Renew any doubtful bearing.

When ordering spare parts please quote the Serial Number of the equipment and, where possible, part number and drawing number of the component required. All enquiries should be addressed to:-

Armfield Ltd
Bridge House
West Street
RINGWOOD
Hampshire
BH24 1DY
ENGLAND

THE GENERAL CARGO VESSEL MODEL (NA8-13)

DESCRIPTION

The model is of a general bulk cargo motor vessel with engines aft and a length between perpendiculars of 167.0m, a full load displacement of 28215 tonnes and a dead-weight of 21512 tonnes, at which the summer draught is 9.403m. The centre of gravity at this displacement varies between 7.53m and 7.86m above keel, depending upon the stowage conditions.

The model has a length between perpendiculars of 2.410m with a beam of 0.326m and is, therefore, approximately 1/70th of the ship in length. The model hydrostatic data are given in Table I. The bare model with the clinometer attached will have a mass in the neighbourhood of 15 kg which is slightly less than the lightship condition and must be augmented with ballast to bring it to a realistic ship service condition.

The ballast supplied is more than adequate to give the model a loaded displacement and in this condition the height of the model centre of gravity above keel, KG, will not represent the corresponding ship condition but will be smaller than the scaled ship KG. If it is necessary to achieve a realistic value for KG one piece of ballast may be placed athwartships at deck level (Across the vessel in a direction at right angles to the fore-and–aft line of the vessel). This may also be useful for rolling experiments.

Care should be exercised when ballasting the model to ensure that the weights do not damage the hull, bulkheads or deck when being inserted or withdrawn. Similarly, when handling the model it is best to lift it under the hull, perhaps with straps. The model should never be lifted by the deck. Loading or unloading of the model should be undertaken only with the model afloat, and the model and ballast should be weighed separately.

Some of the ballast may be fixed permanently by drilling the hull, tapping the ballast, and bolting through from the outside with the addition of fibre washers for water-tightness. For guidance, typical ballast and other conditions for the ship are given in Table II of Appendix 1.

Permanently fixed ballast, however, may prove a disadvantage if the effects of flooding individual compartments are to be studied. Also there are some advantages in conducting large angle stability experiments with the model in the lightest possible condition.

The model is fitted with simple flooding valves in the principal compartments to show the effects of bilging: the sinkage and change of trim may be measured from the draught marks which are set every 10mm from the flat of bottom. The change in initial stability due to bilging can be measured.

A closer examination of the free surface effect can be made using the free surface tray supplied. The gallows and hanging weight can be used to help explain the free surface effect as well as to show the effect on stability of hanging meat cargoes and other suspended masses. The effect of the hanging weight can best be observed in a light condition.

THE INCLINING EXPERIMENT

The purpose of this experiment is to find the vertical position of the centre of gravity of the model, KG, through first finding the transverse metacentric height, GM_T, and then using the hydrostatic data to find KM_T and hence:-

$$KG = KM_T - GM_T$$

First mark two parallel lines running fore and aft on the deck near amidships; the lines should be positioned so that the weights are clear of the deck edge. Measure the distance between the lines spaced d mm apart. All six inclining weights may be used, initially assembled three to port and three to starboard, with one long edge of each weight on a line as shown in Fig. 2 below.

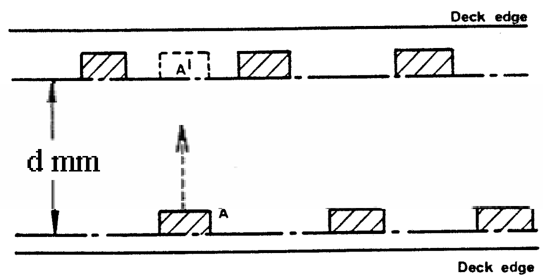


Fig. 2

When an inclining weight is moved from say A to A^1 the centre of gravity of the weight will move through a distance of d mm. Each weight may be moved from port to starboard or from starboard to port then back to their original positions giving three different angles of heel to port and three to starboard: for each of the movements the clinometer should be read. From these six angles of heel the mean heel for the shift of one weight can be determined.

When the clinometer reads exactly zero this does not necessarily mean that the model is exactly upright but since the mean change in heel for the shift of one weight is required, it is not necessary to start with the model exactly upright provided the maximum angle of heel does not exceed say, 2 or 3°. Larger angles than about 2° are liable to invalidate the linear relationship between moment and tan θ. The linearity may be checked during the experiment by plotting the moment against tan θ. It should be noted that the reading on the Clinometer will rise or fall depending upon the direction of heel.

This inclining experiment should be carried out each time the vessel is loaded to a different condition to determine the position of the centre of gravity KG. The position of KG can be calculated as follows:-

Total ship mass	Δ kg
Weight of one inclining weight	w kg
Distance moved by inclining weight	d mm
Moment for the shift of one inclining weight	= w.d

Mean change in heel for one weight shift θ degrees

GM_T can be calculated from the equation $GM_T = \dfrac{wd}{\Delta \tan\theta}$

From the hydrostatic data in Appendix 1-Table II values for the Draught T, KB and BM_T can be obtained (corresponding to the total ship mass Δ).

Therefore KM_T can be calculated from the equation $KM_T = KB + BM_T$

And KG can be calculated from the equation $KG = KM_T - GM_T$

NOTE: When testing a model boat with steel ballast weights it is likely that the centre of gravity will be unrealistically low compared with a full size vessel.

Because of this the ratio of KG / draught is typically 0.82 for the real vessel but only 0.39 for the model when the ballast weights are placed in the bottoms of the compartments. This can be improved by raising the position of the weights but care must be taken to ensure that the weights cannot move when the model is inclined. A weight can be mounted at deck level to raise the centre of gravity if required.

To complete the inclining calculations the effect of removing the inclining weights themselves must be estimated.

The inclining experiment can be repeated with water in the free surface tray on the deck. The mean change in heel for movement of one inclining weight would increase due to movement of the water inside the tray.

The hanging mass affects θ by only a few minutes when the vessel is fully loaded and hence its effect is better seen in a lighter condition. With water in the free surface tray or with the hanging mass in position, students may observe the augmented moment when an inclining weight is moved and hence concepts like "virtual loss in stability" or "virtual rise in the centre of gravity" can be avoided in teaching by demonstrating the phenomena.

LARGE ANGLE STABILITY

Values of the righting lever GZ for the model in fresh water are given in Appendix 1-Table III for an assumed positioned of the centre of gravity KG = 60.96mm. The correction to the actual position of the centre of gravity may be made in the usual way:-

$$GZ \text{ correction} = GG^1 \text{ Sin } \theta$$

where GG^1 is the distance between the actual and assumed position of the centre of gravity.

The cross curves of stability given in Appendix 1-Table III should be plotted and curves of stability taken from then as required. The appropriate curve of statical stability taken from the computer calculated cross curves may then be compared with the measured values using the "Armfield" Stability Dynamometer.

In preparing for the measurements the first step is to find the model KG value by going through an inclining experiment. It is recommended that a light displacement be used for large angle stability measurements; if any ballast is to be used it must be wedged in place to prevent it shifting at the large angles

Note: Values of the righting lever GZ may also be found for the General Cargo Vessel model by creating laminar sections of the underwater form of the hull from the table of offsets, using rigid material such as cardboard or thin plastic, then suspending these with a plumb-bob to find the centroid and hence the centre of buoyancy. The locations of the sections through the hull are chosen by applying Tchbycheff's rule. Sets of sections at different angles of heel can be created and measured to determine the changes in righting lever.

SETTING UP THE DYNAMOMETER

The dynamometer can be moved on its castors so that the model is either near the centreline of the tank or towards one side, depending upon which position is found most convenient. When the position is settled the base of the dynamometer can be fixed and levelled by screwing down the three feet. The counterbalance weight on the horizontal arms should now be adjusted until the arms freely adopt the horizontal position with the clamping attachment in position. Thus, when the clamp is subsequently attached to the model, the dynamometer will exert no vertical force on the model, which will, therefore, float at a constant displacement whatever the angle of the heel.

During an experiment the locking plate in the horizontal arm of the swinging frame should be clamped at all times and unclamped only when a final adjustment to the weights on the scale pans is to be made. Similarly, when setting up the dynamometer, the plate should be clamped to prevent the frame from swinging violently but it should be unclamped to check the zero balance before connecting the dynamometer to the model. With the horizontal arms correctly counter-balanced and the two scale pans in position, the marks on the plate and the pointer at the bottom of the frame should coincide. If the marks are not in agreement, the counter-balance may be moved to align the marks.

The model may now be connected to the dynamometer by the heeling clamp and the water level adjusted until the counter-balanced arms are horizontal. With the clamp free, the model should be upright.

TAKING THE MEASUREMENTS

In order to measure the righting moments the following procedure is recommended.

Check that the locking plate is operating.

Unclamp the model and give the model an angle of heel and re-clamp it.

When the water has settled down, balance the model restoring moment approximately by putting appropriate weights on the scale pans. Then, whilst holding the frame, release the locking plate and complete the balancing of the model restoring moment by making final adjustments to the scale pan weights until the pointer returns to its mark on the plate.

Read the angle of heel on the clinometer - an accuracy of $\pm 0.5°$ is adequate for this work.

The corresponding righting moment GZ = change in scale pan weight x 400mm.

Values of $\Delta.GZ$ may be plotted against heel θ at intervals of about $\theta = 5°$. It is recommended that if the model is being heeled to port say, measurements be also made for a few angles to starboard to obtain good definition of the statical stability curve as it passes through $\Delta.GZ = 0$. This may not occur exactly at $\theta = 0$ since zero on the clinometer may not refer exactly to the upright. Also a close definition of the slope of the curve at the origin allows comparison with the initial stability value of GM.

The maximum angle of heel will be determined by the angle at which the edges of the deck opening become immersed, which is one of the reasons for using a light displacement to give a large stability range. Whilst flooding through the opening may be a realistic limitation to an angle of heel, the user may be wish to take measurements at larger angles, in which case a temporary sealing of the deck openings will be necessary.

ADDITIONAL EXPERIMENTS

The purpose of this section is to indicate other possible experiments which may reinforce a course of lectures on ship stability. Some flooding and inclining experiments are described in the appendices.

1. A simple, box shaped vessel, e.g. "Armfield" Rectangular Barge Model (NA8-16), or a shaped but wall-sided vessel would be a useful alternative to the Ship Model supplied since students can calculate righting levers from the wall-sided formula and compare them with measurements:-

$$\mathrm{GZ} = \sin\theta\left[\mathrm{GM_T} + \frac{BM_t}{2}\tan^2\theta\right]$$

2. The Ship Model can be made initially unstable by adding deck ballast. The resulting loll to port or starboard indifferently, can then be demonstrated and the metacentric height in the lolled condition may be measured by inclining experiment.

3. The period of roll T_θ is given by:-

$$T_\theta = 2\pi\sqrt{\frac{k_{xx}^2}{gGM_T}}$$

where k_{xx} is the radius of gyration of the model about the longitudinal roll axis. More exactly k_{xx}^2 should be modified to $k_{xx}^2(1 + \sigma)$ to take account of the added virtual inertia of the surrounding fluid. If GM_T is known from the inclining experiment and T_θ is measured for small angles of roll using a stop watch, k_{xx}^2 may be estimated. GM_T may be altered by raising a piece of ballast from below the roll axis to an equal distance above the roll axis, thus raising G, reducing GM_T, but keeping k_{xx}^2 constant. A recalculation of the position of G and a measurement of the increased value of T_θ will allow a check of the relationship $T_\theta^2 \propto 1/GM_T$.

A more elaborate development of this study would first involve the measurement of k_{xx} by suspending the model on a torsion wire with its roll axis vertical. For nautical studies' students, however, the influence of a change in loading on roll periods is probably adequate as an exercise so that they may appreciate, for example, why bulk ore carriers have water ballast tanks high up in the vessel.

4. The behaviour of water in one component of the free surface tray whilst the model is rolling should prove interesting to students studying passive roll stabilisation methods. Trial and error methods can be used to restrict the flow across the tray in order to influence the decay of the rolling amplitude.

5. Values for the height of the longitudinal metacentre may be found from the Hydrostatic Data and hence simple trim experiments may be made with the model by measuring the trim change when a mass is moved longitudinally and comparing this with calculations.

6. The effect of flooding one or two compartments may be studied. The volume of the compartments may be measured with the aid of a graduated measuring cylinder and the permeability may be altered by inserting various blocks of 'cargo'. Changes in draught and initial stability can be the principal measurements to check after flooding. Exercises along these lines should help the student to differentiate between "lost buoyancy" and "added weight" approaches to flooding problems.

7. If sailing enthusiasts are among a group of student they will find it interesting to measure the large angle stability characteristics of a model yacht and compare the righting moment with calculated wind heeling moments at various angles.

BIBLIOGRAPHY

1. "Basic Naval Architecture"
   by K.C. Barnaby, Pub. Hutchinson.

2. "Basic Ship Theory"
   by K.J. Rawson and E.C. Tupper, Pub. Longmans.

3. "Principles of Naval Architecture"
   by The Society of Naval Architects and Marine Engineers, New York.

Supplementary Models

Three other ship models are available for use independently or together with the Large Angle Stability Dynamometer; they are as follows:

NA8-14 Trawler Model.
A 1/25th scale model of an ocean going trawler fabricated in GRP, fitted with transverse bulkheads and flooding valves. Watertight deck hatches allow the deck to be submerged.

***NA8-15 Crane Ship Model*:**
This 1/50th scale model allows stability and flooding problems connected with heavy lifts to be studied.

***NA8-12 Rectangular Barge Model*:**
A simple form allowing easy calculation of the stability characteristics.

Appropriate instruction manuals for use in conjunction with this manual are supplied with each of the above models.

A NOTE ON CORRECTIONS FOR HOG AND SAG

by Julian Wolfram, B.Sc., M.R.I.N.A. (Sunderland Polytechnic) (First published by "The Naval Architect", July 1980)

There are occasions when it is important for both a shipbuilder and a ship operator to estimate a vessel's displacement as accurately as possible. For the shipbuilder the displacement in the inclining condition must be estimated accurately as all the subsequent stability calculations are related to this figure. The ship operator often uses the ship as a weighing machine when loading bulk cargoes, in order to check shore-based figures of cargo weight. A discrepancy between ship and shore figures of more than 1% may cause a dispute. When loading oil at offshore terminals it is rarely possible to estimate exactly when the loadline is reached due to the motion of both vessel and sea. A measured quantity is, therefore, loaded which, according to the displacement table, would cause the vessel to float at the loadline amidships. If the vessel is likely to sag in the loaded condition then a correction must be made to the amount of cargo loaded.

Traditionally, draught corrected for hog or sag is obtained from the following expression:

$$\text{Corrected draught } = \frac{d_F + d_A}{2} + C_f\left[d_\Phi - \frac{d_F + d_A}{2}\right]$$

where d_F, d_A and d_Φ are draught forward, draught aft and mean draught amidships respectively. The correction factor C_f is usually used and sometimes three-quarters is adopted. In either case the correction for trim is also applied in the usual way.

Azad (1) has recently pointed out that the correction should vary with the fullness of the waterplane and produced factors which vary between 0.67 and 0.84 for waterplane area coefficients between 0.5 and 1.0. This analysis is based on the assumption that the hull deflects into a parabolic curve symmetrical about amidships. This is a somewhat sweeping approximation as it assumes that the bending moment would have to be more or less constant for a large part of the ship length.

Kaps (2) has performed a similar analysis but with a deflection curve which corresponds more closely to that likely to be found in practice for a homogeneously loaded ship. The values of the correction factor so found vary between 0.62 and 0.80 once again for waterplane area coefficients between 0.5 and 1.0. However, as will be shown later, these factors are inappropriate in non-homogeneous load-conditions. Another very neat expression which takes into account the exact shape of the waterplane is:-

$$\text{Correction Factor} = 1 - \frac{I_L}{25 * TPC * L^2}$$

where I_L, is longitudinal second moment of area about amidships.

However, this expression again assumes a parabolic deflection curve. It was developed at Swan Hunter Shipbuilders but has since been replaced by a generalised computer programme which can take account of the exact shape of the waterplane and the deflected profile of the vessel.

The Basic Problem

The basic problem is to find the volume of displacement beneath the hogged or sagged waterplane. As the volume beneath an undeflected waterplane can readily be found from the displacement table, after trim correction if necessary, the problem reduces to finding the difference in underwater volume for the two cases. This difference in volume denoted by v is shown for a hogging case in Fig. 1.

$$\text{Now } v = \int_0^1 bzdx$$

where b is the breadth at any section and z the corresponding amount of hog.

The usual correction can then be expressed as:

$$v = \int_0^1 bzdx = C_f * A_w * \left(d_\Phi - \frac{d_F + d_A}{2} \right)$$

where C_f is a correction factor (generally assumed to be two-thirds) and A_w is waterplane area at the mean draught. The sag correction can be expressed in the same manner.

The volume v will clearly depend upon the variation in beam along the length of the vessel and also upon the variation in z, the amount of hog or sag, along the length.

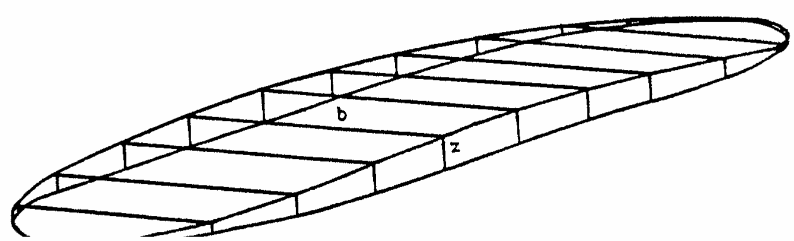


Fig. 1 Volume contained between the hogged and undeflected waterplane.

Variation in Beam with Length

Azad and Kaps assume that the beam at any point along the length can be expressed as:

$$b = B\left(1 - \left(\frac{2x}{L}\right)^n\right)$$

where B is the beam amidships and x is measured from amidships. The exponent n is obtained from the formula:

$$n = \frac{C_W}{1 - C_W}$$

where C_w is the waterplane area coefficient.

This approximate expression for waterplane shape has often been used by naval architects and is employed by Munro-Smith (3) for his approximate hydrostatics. Although it assumes that the waterplane is symmetrical about amidships, it is unlikely to give rise to any significant errors when used for hog and sag corrections provided C_w is greater than about 0.8, which is generally the case for ships which are carrying cargo in bulk. However, when the hog correction is made during an inclining test on a fine form such as a container ship or a ferry, where C_w may be less than 0.6, then this expression for beam variation may give rise to unacceptable errors. Fig. 2 shows the waterplane of a container ship in the inclining condition compared with that predicted by the equation above.

There is no reason why, when a shipyard performs an inclining experiment, the exact waterplane shape, as obtained from the lines plan, should not be used in the hog or sag correction.

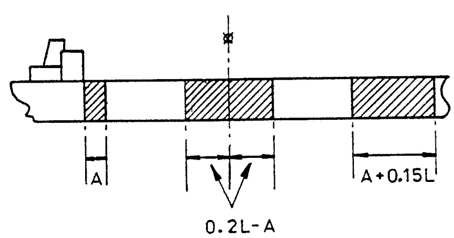
Fig. 2 Comparison between the actual waterplane shape of a ferry in the inclining condition and the shape given by Munro-Smith's approximate formula.

The Hog and Sag Deflection Curves

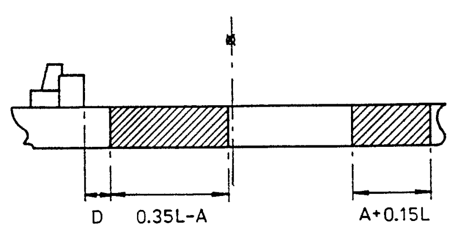
The principal source of hog or sag is bending deflection. However, shear deflection is important, and this can contribute up to 20% of the total deflection. In cases where the bending moment changes from hogging to sagging along the length of the ship, the shear lag effect (4) will be appreciable and the deflection may be up to 25% greater than calculated using simple bending and shear deflection theory. The effect of shear lag on deflection appears to be negligible for cases of homogeneous loading.

The range of deflection curves which may occur in practice has been investigated by systematically varying the cargo distribution in a typical 100,000 tonne dead-weight bulk carrier using a computer programme. The vessel which was designed to Det Norske Veritas rules has higher tensile steel in the deck. The variation in the structural second moment of area and the shear area along the length are assumed to follow the distributions suggested by Lloyd's [5]. The computer programme accounts for all the sources of the deflection mentioned above.

Two cases have been investigated. One in which the loading is essentially symmetrical about amidships and the other in which the loading is unsymmetrical. The loading arrangements in each case are shown in Fig. 3.



Symmetrical Loading



Unsymmetrical Loading

Fig. 3 Loading arrangements for the approximately symmetrical and unsymmetrical cases.

In the symmetrical case the parameter A has been varied between 0 and 20% of the length, and in the un-symmetrical case A varies between 0 and 11%L, and D simultaneously varies between 11%L and zero. The cargo stowage rate has been chosen such that the maximum bending for all values of A is equal to, but never exceeds, the maximum permitted by the Classification Society. The range of bending moment curves obtained and the corresponding deflection curves are shown in Figs. 4 and 5.

It is quite clear from these figures that the assumption of one type of deflection curve, be it a parabola or any similar shape, for all loading conditions is likely to lead to errors. The next question is how large are these errors?

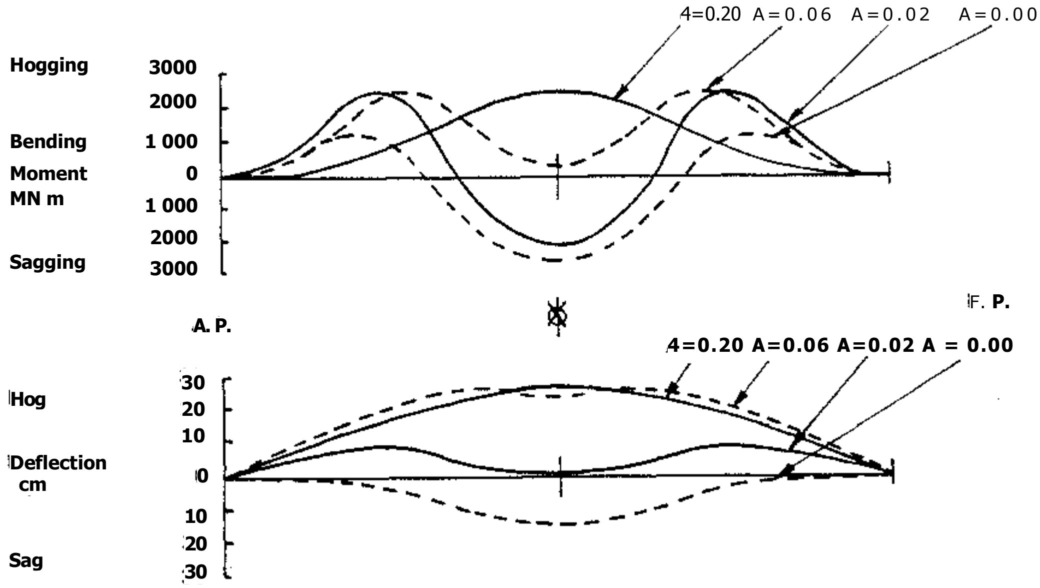


Fig. 4 Bending moment and deflection curves corresponding to the symmetrical loading cases.

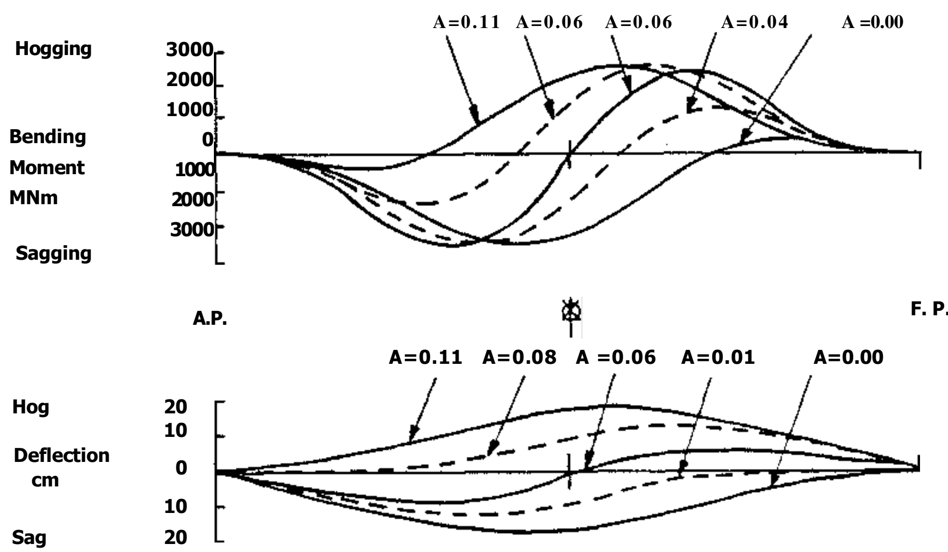


Fig. 5 Bending moment and deflection curves corresponding to the unsymmetrical loading cases.

The Magnitude of the Errors Caused by the Usual Hog and Sag Corrections

Figs. 6 and 7 show the errors involved for the bulk carrier considered previously herein when various hog and sag corrections are applied. Azad's procedure and the two-thirds rule have already been mentioned and the others are discussed later. Figs. 8 and 9 show the error using the "two-thirds" rule as a percentage of the ship's displacement. Similar percentage figures are likely to be found for most ships.

The percentage error in the displacement may not in itself be though considerable, however, when the cargo mass is estimated by subtracting two displacement figures the errors may be cumulative. Consider the bulk carrier entering a port in ballast, and taking on 2,400 tonnes bunkers and a part cargo of 20,000 tonnes of grain whilst simultaneously discharging the ballast. The arrival and departure conditions are shown in Fig. 10. In this case the ship based estimate of the cargo loaded will be about 240 tonnes out at 19.760 tonnes if the usual "two-thirds" rule is used to correct for hog and sag. This represents 1.2% of the cargo loaded and may well give rise to a dispute; being greater than the 1% which is often taken as the maximum acceptable difference between ship and shore based figures. The loading arrangement is quite practical, the shear force and bending moments are well within Classification Society requirements and the cargo distribution is not untypical for a ship which is to carry a mixture of part cargoes. It is possible to produce cases of slightly larger percentage discrepancies for both ships of this size and larger and smaller vessels.

Significant errors can also occur in the results of inclining experiments. When a large ship is inclined in a restricted depth of water the minimum of ballast must be added to achieve a reasonable trim without the vessel going aground. For a vessel with engines aft this means adding ballast right in the bow, giving rise to substantial hogging bending moments. For the 100,000 tonne bulk carrier above the hog may amount to 40 cm.

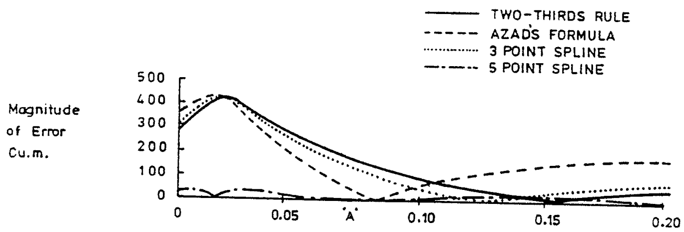


Fig 6. Errors in the hog and sag correction using various formulae – symmetrical cases.

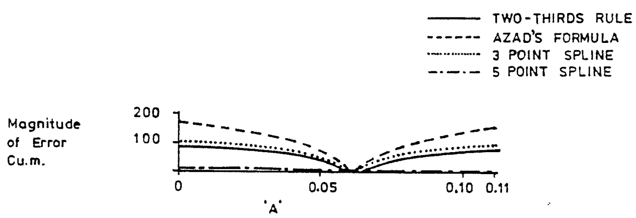


Fig 7. Errors in the hog and sag correction using various formula – unsymmetrical cases.

Now the usual expression used to obtain the vertical centre of gravity is:

$$\begin{aligned} KG &= KB + BM_T - GM_T \\ &= KB + \frac{I_T}{V} - \frac{wd}{\Delta \tan\theta} \end{aligned}$$

The manner in which KB is usually obtained makes no allowance for the curvature of the keel and is an over-estimation of the actual value. In addition, the volume of displacement may be under-estimated by about 0.5% when the usual "two-thirds correction" is applied. Consequently the vertical centre of gravity will be over-estimated by at least 4.5 cm.

For a 17,000 tonne containership which hogs 20 cm on inclining, the error in the estimated VCG is 5.1 cm if the two-thirds rule is applied. Once again, the calculated value is larger than the actual value.

Bearing in mind the stability requirements of the Load Line Rules, the 15 cm minimum initial GM for instance, these errors may be thought to be significant. If these errors are unacceptable, the question arises as to how a more accurate hog and sag correction can be made.

The Use of Splines

An increasingly common technique for fitting a curve to a number of points is to use a spline (6) (see Splines for Hog or Sag Deflection on page 34). The curve achieved, by mathematical means, is the same as that produced by a draughtsman's batten when lead ducks are used to hold it at some specified points which lie on the final curve. On a ship draughts are usually measured forward, aft and amidships: i.e. at three points along the length. Hence, a three point spline may be used. The error involved when the deflection curve of the ship is approximately by a three point spline is shown in Figs. 6 and 7.

The error is no smaller than that produced by the two-thirds rule, Azad's formula or Kap's formula. In fact, whatever method is used to approximate the deflection curve, the error produced will, on occasions, be considerable when the draught is measured at only three points along the length of the ship. In this respect the two-thirds rule is no worse than any other when applied to vessels that carry cargo in bulk and which have C_w values around 0.85, and in case of homogeneous loading, may often be of adequate accuracy.

Now if the draught was to be measured at five points along the length (AP, 0.25L, 0.5L, 0.75L, FP) a five-point spline could be used and the error very much reduced, as seen in Figs 6 and 7. The maximum error in the estimated displacement of 100,000 tonne bulk carrier is less than 40 tonnes.

In order to assess whether or not this is sufficiently accurate, the other sources of error in the estimation of displacement must be considered.

Other Errors in the Estimate of Displacement

Apart from hog and sag factors, the principal source of error in displacement calculations is the accuracy with which the draught can be measured. Kockums reckon that the draught can be estimated to the nearest 5 cm using automatic draught measuring devices, i.e. the draught has an error of ± 2.5 cm. The draught is equally likely to take any value in that tolerance range. However, when estimating displacement, the draught is measured at four points, as least, and it is unlikely that in all four cases the draught is under-estimated or over-estimated. It is unlikely, therefore, that the mean draught is 2.5 cm out. In fact, it can be shown statistically that on 83% of all occasions the error in the mean draught will be within ± 1 cm (see The Effect of Errors in Draught Measurement upon Displacement Estimates on page 36).

When a cargo weight is estimated, two displacements are subtracted involving at least eight measurements of draught. In 95% of cases the error in the estimate of the cargo weight due to the inaccuracy of the draught measurements is less than the average TPC value; in the case of the bulker considered above, less than 85 tonnes. When the draught at each point can be measured to the nearest centimetre, the error is 20% of these values.

There is another point which should not be overlooked and that is that the error in draught measurement is a random error. Therefore, for a ship on a regular run, the errors tend to cancel out on subsequent trips. The hog or sag error on the other hand, may be systematic or cumulative if the same loading conditions are used on each trip.

In the part loaded bulker example considered herein, the error would be about 10,000 tonnes after 40 trips.

There is another source of cumulative error which may be significant and that arises due to the difference between the size of the ship as built and the size assumed in the hydrostatic particulars. Nowadays, with computer controlled hull fairing and numerically controlled production facilities, discrepancies between the planned size of a ship and the actual size are likely to be small and to be due to the distortion produced by welding and poor lining-up. As an indication of the accuracy possible, the aluminium, hull mould of a mine-sweeper was 5mm out on length and 2mm out o n beam (7). For the 100,000 tonne bulker an error of 3cm in length and corresponding amounts in beam and depth would produce an error of around 50 tonnes at the full draught.

There is another interesting effect which arises out of the welding processes by which the majority of ships are built, and that is that ships grow with time in service. This is due to the phenomenon known as "shakedown"(8).

When a ship is welded together, residual stresses are set up. In areas close to welds these are tensile in nature and about equal to the yield stress of the material. Elsewhere the stresses are compressive and may be up to one quarter of the yield stress (8). During service when parts of the structure are subject to tensile loading, plastic stretching occurs in the region of the welds resulting in a reduction of the residual stresses. The stress relieving process is called "shakedown". The plastic stretching causes the vessel to grow in size, albeit only slightly. Complete shake-down of a 100,000 tonne bulker would increase its volume of displacement at load draught by about 70 to 80cm^3. However, complete shake-down is unlikely to occur before the ship has undergone a very rough weather passage and may be not even then. Hence, it is not possible to know to within about 0.1% the actual displacement of a ship; however accurately it is built, draught is measured and hog or sag accounted for.

There are other sources of error in the ship displacement calculation. (9) However, in most cases some correction can be made and in those cases where no correction is practical, the error is usually likely to be small.

From the foregoing it is clear that there is a limit to the accuracy with which the displacement of a ship in service may be calculated. It would seem that there is no point in trying to achieve greater accuracy for the hull deflection shape than that obtained using a five-point spline. In the inclining condition a seven- or nine-point spline might be considered; however, for most cases, a five-point spline should be adequate.

Before dealing with the measurement of draught at additional points along the ship length, it should be explained why the deflected shape cannot be reliably calculated by mathematical means for a ship in service. Apart from the complexity of the calculations, there are two main reasons why this would be very difficult to do. In hotter climates the temperature of the ship's deck may be considerably higher than the bottom giving rise to substantial hogging. For example, in the great lakes it is not uncommon to cool the decks with water to reduce hog so that the forward and aft draughts do not exceed the maximum limit permitted in the locks. To calculate the hog profile the temperature distribution throughout the hull must be found. This would be a very considerable task which is impractical on an ordinary operational basis.

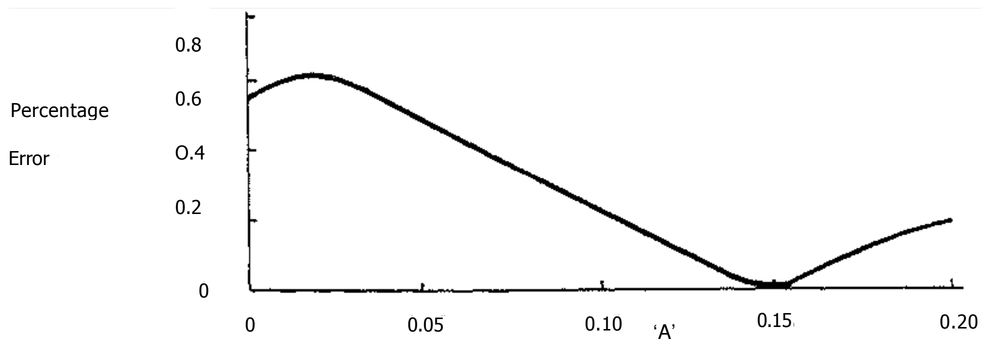


Fig. 8

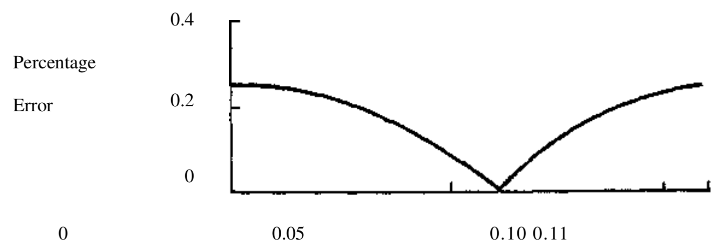


Fig. 9

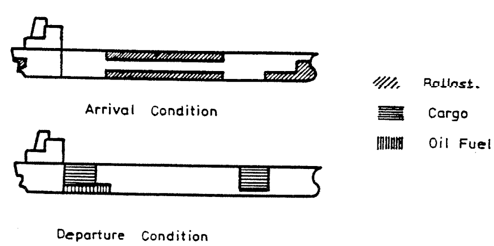


Fig. 10

It is quite possible for a ship during its life to suffer plastic distortion and for the hull to be slightly but permanently bent. This can occur through grounding, collision, very severe weather and sometimes even launching may leave the hull distorted. Unless the exact nature of the distortion is known, the hull deflection calculation cannot be made.

MAKING ADDITIONAL DRAUGHT MEASUREMENTS

Measuring the draught at additional points along the ship will necessarily involve a little extra expense. There are a number of possible ways of making these measurements. Draught marks could be painted on the vessel at the quarter and three-quarter length points on each side of the vessel. Alternatively, if automatic draught measuring devices were used aboard the ship, additional devices could be placed at these points. The latter, although possibly more expensive, would enable the displacement to be calculated directly using an on-line ship board micro-computer. Computer programmes in existence at Sunderland Polytechnic could be adapted for such purposes.

There are other, perhaps cheaper, alternatives possible. A portable draught measuring tube could be used which would measure freeboard allowing the draught to be obtained by subtracting this from the depth. A simple theodolite could be used to measure the deflection at deck level. A certain amount of experimentation would be necessary to determine the most cost effect procedure.

Conclusions

1. The current corrections made for hog or sag when calculating a ship's displacement may not be of sufficient accuracy in some cases.

2. To obtain a more accurate correction the draught must be measured at additional points along the length of the ship.

3. When a ship's draught is only measured at the forward and aft perpendicular and amidships, it is not possible to obtain a hog or sag correction that is always more accurate than the two-thirds rule.

Splines for Hog or Sag Deflection

This section describes simple splines for representing the deflection profile of a ship. A more complete explanation of the theory of splines may be found in reference 6.

Consider the usual situation in which the draught is measured at three points along the length: aft, amidships and forward. The hog or sag is measured relative to a straight line passing through the forward and aft draught marks. However, the curve is defined relative to this line by only one point: the draught amidships. A large number of plausible curves could be used to represent the deflection shape. The three point spline is that obtained when a draughtsman's batten is held by lead ducks at the three points on the curve: at each end and the point amidships. The bending moment applied to the batten is identical to that experienced by a beam with a concentrated central load. This is illustrated in Figs. A1(a) and (b).

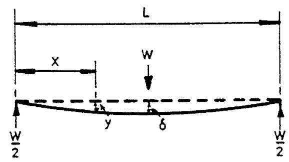
By applying classical beam theory the deflection curve may be found in terms of W:

$$y = \frac{W}{EI}\left[\frac{L^2 x}{16} - \frac{x^3}{12}\right]$$

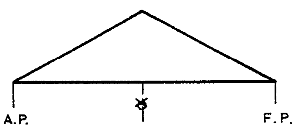
for θ < x < L/2 (Note: curve is symmetrical about L/2);

and the deflection at the middle point is

$$y_{\left(x=\frac{L}{2}\right)} = \frac{WL^3}{48EI}$$



(a) Deflection Curve



(b) Bending Moment Curve

(c)

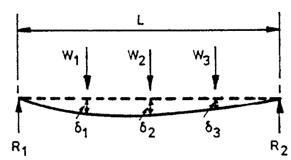


Fig. A1

But this central deflection is the amount of sag (or hog), call it δ.

$$\text{Hence, } \delta = \frac{WL^3}{48EI} \text{ or } W = \frac{48EI\delta}{L^3}$$

Substituting this expression for W in the deflection equation above yields:

$$y = \delta\left[3\left(\frac{X}{L}\right) - 4\left(\frac{X}{L}\right)^3\right]$$

This then is the equation of the spline representing the deflection shape from either end to amidships.

The procedure used to obtain a five point spline is similar. In this case, the deflection relative to a straight line through the end draughts is known at three points. The curve must be made to pass through these points and the corresponding loading on the batten is illustrated in Fig A1(c).

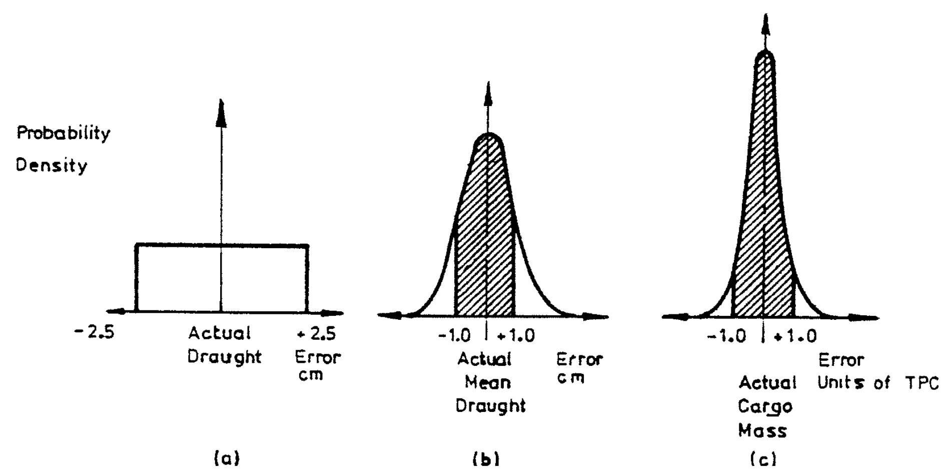
Once again, the deflection curve can be expressed in terms W_1, W_2 and W_3 (note R_1 and R_2 can also be expressed in these terms simply by taking moments). The expression for deflection can be equated to δ_1, δ_2 and δ_3 at corresponding positions along the length yielding three equations. These may be solved to find W_1, W_2 and W_3 in terms of δ1, δ2, and δ3. The deflection curve can then be expressed solely in terms of δ_1, δ_2, δ_3 and the fraction distance along the length (X/L).

The deflections, $\delta_{1\text{-}3}$ can hold any positive or negative value (ie. hog or sag at any given point).

The Effect of Errors in Draught Measurement upon Displacement Estimates

When the draught of a vessel is measured to the nearest 5 cm, then the measured value is equally likely to be anywhere in the range 2.5 cm either side of the actual draught. This is illustrated in Fig. A2(a) by the corresponding probability density distribution.

FIG. A2



However, to calculate displacement, the mean is taken of four draught measurements (forward, aft, port and starboard amidships). The probability density distribution of this mean value can be obtained using the convolution theorem (10) and is shown in Fig. A2(b). The central shaded portion covering the range actual mean draught ± 1 cm represents 83% of the total area under the curve. This means that on 83% of all occasions the mean value of the measured draughts is within one centimetre of the actual mean draught.

To calculate the mass of cargo in a vessel the difference in displacement, before and after loading, is used. This involves a total of eight draught readings. Given that an error of 1 cm in the mean draught means an error in the estimate of cargo mass equal to the TPC, the probability distribution of the error in the estimate of cargo mass can be presented as shown in Fig. A2(c). This, of course, is the error due to the inaccuracies of draught measurement alone and not the total error. The distribution is almost identical to a normal distribution. In 95% of all cases the error in the estimate of cargo mass is within the average value of the TPC: shown by the shaded portion in Fig. A2(c). This assumes that the draught is measured to the nearest 5 cm. If it is measured more (or less) accurately there will be a pro rata decrease (or increase) in the error.

Acknowledgement

The author would like to thank Swan Hunter Shipbuilders for providing details of some of the vessels which they have built and their general interest in this work. The author would also like to thank his colleagues Mr N Tate and Mr J Whatmore.

REFERENCES

1. Azad, S.A.
"Calculation of Correct Displacement of the Ship when Hogged or Sagged",
Tanker and Bulker International, May 1978.

2. Kaps, H.
HANSA, April 1977.

3. Munro-Smith, R.
"Merchant Ship Design",
Hutchinson.

4. Thein Wah.
"A Guide to the Analysis of Ship Structures",
U.S. Department of Commerce, 1960.

5. Aldwinkle, D.S.
"A Method for Estimating the Hull Girder Inertia and Shear Area Distributions for Ships with Particular Reference to Tankers",
Lloyd's Register of Shipping, Development Unit Report No. 94, 1975.

6. Ahlberg, Nilson and Walsh
"The Theory of Splines and Their Applications",
Academic Press, 1967.

7. Collis, M.E.R.
"Yarrow's New G.R.P. Facility Reviewed",
The Naval Architect, September 1979.

8. Harvey Evans, J. (Ed)
"Ship Structural Design Concepts",
Cornell Maritime Press, 1975.

9. Wolfram, J.
"A note of the practical problems of accurately determining a ship's displacement",
Seaways, No. 12, January 1978.

10. Freund, J.E.
"Mathematical Statistics"
Prentice Hall, 1962.

APPENDIX 1

TABLES FOR GENERAL CARGO VESSEL NA8-13

TABLE I - HYDROSTATIC INFORMATION
For 1/70th scale model supplied by Armfield (NA8-13)

Draft	Ship Mass in Fresh Water	KB	Ix	Iy	Volume	BMt	WaterPlane Area	BMl
mm	Kg	mm	m^4	m^4	m^3	m	m^2	m
5	2.139	2.39	0.003	0.119	0.002	1.500	0.494	59.500
10	4.742	5.14	0.004	0.137	0.005	0.800	0.541	27.400
15	7.528	7.95	0.004	0.15	0.008	0.500	0.563	18.750
20	10.376	10.5	0.004	0.16	0.01	0.400	0.577	16.000
25	13.28	13.2	0.005	0.167	0.013	0.385	0.588	12.846
30	16.203	15.8	0.005	0.174	0.016	0.313	0.597	10.875
35	19.223	18.4	0.005	0.18	0.019	0.263	0.605	9.474
40	22.267	21	0.005	0.185	0.022	0.227	0.611	8.409
45	25.406	23.7	0.005	0.188	0.025	0.200	0.615	7.520
50	28.419	26.2	0.005	0.195	0.028	0.179	0.623	6.964
55	31.551	28.8	0.005	0.201	0.032	0.156	0.638	6.281
60	34.634	31.4	0.005	0.203	0.035	0.143	0.631	5.800
65	37.886	34	0.005	0.21	0.038	0.132	0.638	5.526
70	41.067	36.6	0.005	0.215	0.041	0.122	0.644	5.244
75	44.423	39.2	0.005	0.221	0.045	0.111	0.65	4.911
80	47.417	41.8	0.005	0.225	0.048	0.104	0.654	4.688
85	50.718	44.5	0.005	0.233	0.051	0.098	0.663	4.569
90	54.018	47.1	0.005	0.239	0.054	0.093	0.667	4.426
95	57.436	49.8	0.005	0.246	0.058	0.086	0.675	4.241
100	60.68	52.4	0.005	0.253	0.061	0.082	0.681	4.148
105	64.136	55.1	0.005	0.26	0.064	0.078	0.687	4.063
110	67.522	57.7	0.006	0.266	0.068	0.088	0.693	3.912
115	71.017	60.4	0.006	0.273	0.071	0.085	0.7	3.845
120	74.528	63.1	0.006	0.279	0.075	0.080	0.705	3.720
125	78.041	65.8	0.006	0.284	0.078	0.077	0.71	3.641
130	81.562	68.5	0.006	0.289	0.082	0.073	0.714	3.524

LBP = 2410 mm

NOMINAL BULKHEAD POSITIONS
For 1/70th scale model supplied by Armfield (NA8-13)
Dimensions in mm

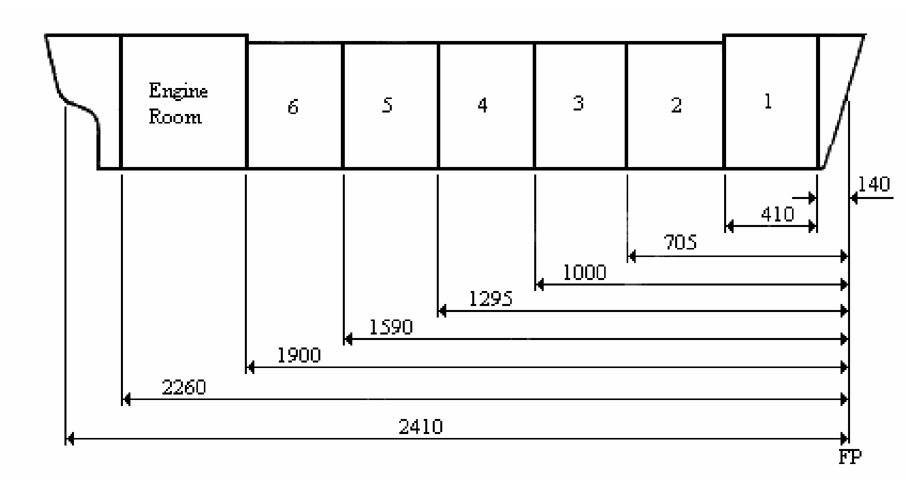


TABLE II - LOADING CONDITION
(For full size General Cargo Vessel)

SHIP CONDITION		SHIP MASS IN TONNES
Lightship	=	6703
Heavy ballast departure	=	16580
Heavy ballast arrival	=	14790
Light ballast departure	=	12850
Light ballast arrival	=	11060
Deep loaded departure	=	28215
Deep loaded arrival	=	27263

TABLE III – CROSS CURVES OF STABILITY
For 1/70th scale model supplied by Armfield (NA8-13)

Assumed KG is 60.96 mm **GZ in mm** **Δ in kg in fresh water**

GZ at 5°	66.82	18.49	9.85	7.34	6.47	6.34	6.80	6.91
Δ	3.258	16.660	31.796	47.541	63.667	80.349	97.619	115.118
GZ at 10°	77.23	36.11	19.84	14.64	12.96	12.80	13.67	12.69
Δ	4.672	16.738	31.893	47.776	64.108	80.980	98.507	114.651
GZ at 15°	79.06	49.70	29.95	22.15	19.63	19.54	19.96	18.02
Δ	6.190	17.173	32.080	48.189	64.884	82.105	99.514	114.336
GZ at 30°	74.96	62.97	53.62	46.13	41.25	37.61	34.51	31.39
Δ	10.970	21.272	34.774	51.080	69.104	86.299	101.570	114.069
GZ at 45°	69.68	67.92	66.10	61.85	56.15	49.84	44.42	40.65
Δ	16.709	28.185	42.305	57.575	73.423	88.979	102.894	114.238
GZ at 60°	70.65	70.48	67.58	63.97	59.82	55.33	50.73	46.79
Δ	24.994	37.241	50.537	64.366	78.121	91.391	103.921	115.084
GZ at 75°	63.93	63.08	61.00	58.88	56.77	54.62	52.43	50.25
Δ	33.212	45.055	57.809	70.670	83.167	95.112	106.381	116.755
GZ at 90°	50.92	50.89	50.52	50.12	50.51	50.66	50.50	50.33
Δ	40.226	51.965	64.319	76.755	88.990	100.288	110.590	120.068

TABLE IV – TABLE OF OFFSETS
For 1/70th scale model supplied by Armfield (NA8-13)
Dimensions in mm.

Length between perpendiculars	2410
Station interval	239.5
Breadth	326
Waterline spacing	14.3
Length of stern	85
Stern interval	29.8

Station Number	Deck Height	Deck Half Breadth	Station Number	Deck Height	Deck Half Breadth
	mm	mm		mm	mm
A.P.	243	99	5(⊠)	191	163
0.25	241	122	5.5	191	163
0.5	240	138	6	191	163
0.75	239	149	6.5	191	163
1	238	155	7	191	163
1.5	235	163	7.5	191	163
2	234	163	8	192	158
2.5	191	163	8.5	192	148
3	191	163	9	193	128
3.5	191	163	9.25	229	112
4	191	163	9.5	234	111
4.5	191	163	9.75	238	90
5(⊠)	191	163	F.P.	243	56

⊠ **Denotes amidships at Station number 5**

TABLE V – TABLE OF OFFSETS
For 1/70th scale model supplied by Armfield (NA8-13)

Waterline Half Breadths
1/70th Scale Model

Station Number	Draft (mm)														
	0	**5**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**
A.P.	0	0	0	0	0	0	0	0	0	0	17	34	50	63	74
0.25	0	6	3	2	1	1	2	2	6	20	40	58	74	89	99
0.5	0	10	13	18	22	26	30	35	43	53	65	80	95	107	118
0.75	0	16	23	34	42	49	56	63	71	80	90	101	113	123	132
1	0	25	36	52	60	72	80	88	96	104	112	120	128	135	142
1.5	0	50	68	88	102	111	120	126	131	136	141	145	148	152	155
2	0	86	104	123	135	141	146	150	153	155	156	158	159	160	160
2.5	0	119	133	146	158	161	163	163	163	163	163	163	163	163	163
3	0	143	152	159	163	163	163	163	163	163	163	163	163	163	163
3.5	0	155	160	163	163	163	163	163	163	163	163	163	163	163	163
4	0	155	163	163	163	163	163	163	163	163	163	163	163	163	163
4.5	0	155	163	163	163	163	163	163	163	163	163	163	163	163	163
5 (⊠)	0	155	163	163	163	163	163	163	163	163	163	163	163	163	163
5.5	0	155	163	163	163	163	163	163	163	163	163	163	163	163	163
6	0	155	163	163	163	163	163	163	163	163	163	163	163	163	163
6.5	0	155	163	163	163	163	163	163	163	163	163	163	163	163	163
7	0	152	158	163	163	163	163	163	163	163	163	163	163	163	163
7.5	0	143	151	158	163	163	163	163	163	163	163	163	163	163	163
8	0	122	133	144	150	153	155	156	156	157	157	157	163	163	158
8.5	0	84	99	116	125	131	135	138	140	142	144	144	146	147	148
9	0	41	55	72	83	92	98	103	107	111	114	114	120	123	126
9.25	0	24	35	49	59	67	73	78	82	86	91	95	99	104	109
9.5	0	10	17	27	35	41	46	50	54	58	63	67	73	79	86
9.75	0	0	1	7	11	15	18	22	25	28	32	36	42	49	57
F.P.	0	0	0	0	0	0	0	0	0	0	0	0	6	11	17

⊠ **Denotes amidships at Station number 5**

APPENDIX 2

TYPICAL RESULTS FOR GENERAL CARGO VESSEL NA8-13

The worked examples in this appendix are included to show how appropriate stability calculations are performed. Because of production tolerances each model vessel will differ in weight and each of the ballast weights is likely to differ slightly in weight and its mounted position.

When performing calculations based on the actual model supplied and specific loaded conditions, measured values should be substituted in the equations to obtain accurate results.

The worked examples use results that were obtained from a pre-production version of the NA8-10 Dynamometer and NA8-13 General Cargo Vessel with two notable differences from the current design.

The Dynamometer had a lever arm of 500 mm whereas the lever arm on the current production version is 400 mm.

The weight of the bare NA8-13 hull was lighter than the current moulding. The weight used in the calculations (the lightship mass) is 11.794 kg compared with a current hull weighing typically 16.1 kg.

DETAILED CALCULATIONS

In the following section a number of detailed equations and associated calculations associated with flooding and stability are presented for the assistance of lecturers in setting up problems with the Armfield general cargo vessel model. All dimensions referred to should always be checked against the particular model in use.

(Further information on this subject may be obtained from the section "A Note on Corrections for Hog and Sag" by Julian Wolfram, page 22.) In order to check the line of keel and the draught marks, a surface table may be used.

Note: The lever arm on the NA8 Dynamometer is 400mm.

Inclining experiment

Each time the vessel is loaded to a different condition an Inclining Experiment should be carried to determine the location of the Centre of Gravity of the vessel. The procedure is described on pages 16 and 17 of this instruction manual.

The Effects of Flooding

The first set of calculations provided is for a flooding experiment in which the whole of No. 6 compartment is free to flood.

Details of an experiment are also given in which asymmetric flooding is being studied and, in order to achieve asymmetry, No. 6 Hold has been subdivided by a longitudinal, watertight, centreline bulkhead. The centreline bulkhead is fitted with a hole, sealed with a rubber bung, near the bottom of the bulkhead. No working of results is included for this rather more ambitious experiment.

Influence of A Suspended Mass

A small mass is supplied with the model which may be hung from the suspension bracket in the model to demonstrate the loss of stability when a mass is free to swing, e.g. a hanging meat cargo. The demonstration is best made in the light condition as mentioned earlier in this manual.

Following the flooding calculations, instruction notes and equations are provided for an experiment to measure the effect of a suspended mass of about 2.4 kg. The experiment includes an inclining experiment and the measurement of stability at large angles.

The following worked examples apply a correction for hog in the model and require a different Hydrostatic table that has not been corrected:-

HYDROSTATIC INFORMATION
For 1/70th scale model used in worked examples
(Refer to Table 1 in Appendix 1 for current production model)

DRAFT mm	SHIP MASS IN FRESH WATER kg	KB mm	BM_T mm	WATERPLANE AREA mm^2	BM_L m
14.3	6.611	7.8	571.8	0.5352	21.056
28.6	14.516	15.3	286.6	0.5703	11.219
42.9	22.845	22.7	191.9	0.5905	7.776
57.2	31.375	30.2	144.8	0.6045	6.010
71.5	40.113	37.6	116.2	0.6152	4.923
85.8	48.957	45.0	97.2	0.6242	4.191
100.1	57.957	52.4	83.6	0.6327	3.676
114.4	67.054	59.9	73.5		3.329
128.7	76.344	67.4	65.7	0.6551	3.100
143.0	85.783	75.0	59.6	0.6682	2.927
157.2	95.458	82.5	54.7	0.6820	2.793
171.5	105.274	90.2	50.2	0.6942	2.661
185.8	115.289	97.9	47.4	0.7051	2.535

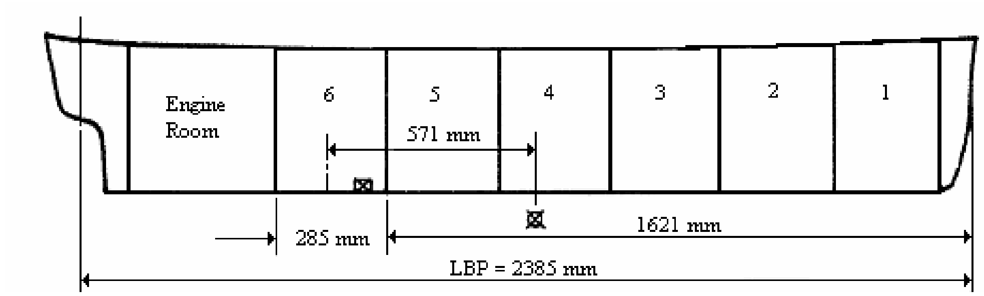
LBP = 2395 mm

THE EFFECTS OF FLOODING

The following calculations are based on flooding experiments using the a pre-production General Cargo Vessel model. When performing calculations based on a current NA8-13 model, loaded to a specific condition, measured values should be substituted in the equations to obtain accurate results.

ASSESSMENT OF RESULTANT LONGITUDINAL AND TRANSVERSE STABILITY BY MEASUREMENT AND BY CALCULATION WHEN NO. 6 HOLD BECOMES OPEN TO THE SEA.

1. Initial Condition



LBP is the Length Between Pependiculars
⊠ denotes the position amidships (half way between the perpendiculars)

1.1 The Initial Condition of the model is:-

Weigh and mark all of the individual components including each ballast weight and each inclining weight if fitted for the test. For this test it is usual to add ballast weights to the model to bring the total ship mass to approximately 35 kg.

Solid Ballast No 1 Hold	= 4.734 kg
Solid Ballast No 3 Hold	= 6.040 kg
Solid Ballast No 4 Hold	= 5.697 kg
Ballast on deck at Engine Room	= 5.697 kg
Two inclining weights	= 0.385 kg
Clinometer	= 0.864 kg
Bare hull mass	= 11.794 kg
DISPLACEMENT Δ	= 35.211 kg

Note: The current clinometer has a typical mass of 0.327 kg and the current bare hull has a typical mass of 15.3 kg.

1.2 The draughts measured fore and aft were:-

Float the model in the water and measure the draught at the stern T_{AFT} and the draught at the bow T_{FWD}.

T_{AFT}	=	70 mm
T_{FWD}	=	65 mm
Draft Length	=	2286 mm

1.3 Perform a simple inclining test:-
In a simple Inclining Test, two masses (0.385 kg) were transferred through 292 mm from one side of the vessel to the other and the angle of heel θ was measured using the clinometer to change from 1°10' Starboard to 1°01' Port, a difference of 2°11'

1.4 The particular model upon which the measurements were taken is known to have a hog of 6mm. Accordingly a parabolic (2/3) correction should be made to the apparent mean draught amidships.

Note: The current NA8-13 General Cargo Vessel model requires a correction for a hog of approximately 8mm.

1.5 The No. 6 Hold has dimensions:
285 mm length
323 mm breadth

Its mean sectional area coefficient C_m, obtained from the waterline offsets provided up to 63.5 mm above base, was calculated from the equation:-

$$C_m = \frac{A_x}{BWL * DRAFT}$$

Where A_x is the cross sectional area to the waterline calculated from the table of offsets using the trapezium rule and BWL is the Breadth at Water Line.

$$C_m = \frac{20091}{332 * 63.5} = 0.953$$

The permeability factor (μ) is assumed = 97% to allow for thickness of hull fibreglass and volume of the "sea inlet" box and plug.

1.6 The hydrostatic particulars are already provided for this model. Additionally, LCF is assumed to remain at amidships.

2. Calculations Based On Initial Conditions

2.1. Displacement

Mean draught amidships (T) $= \frac{T_A + T_F}{2} = \frac{70 + 65}{2}$ = 67.5 mm

Hog correction = -2/3 x 6 = -4.0 mm

Hence draught for Hydrostatics = 63.5 mm

By interpolation from hydrostatic table :-

$$\text{Displacement} = 31.375 + \left(\frac{63.5 - 57.2}{71.5 - 57.2}\right) \times (40.113 - 31.375)$$
$$= 35.225 \text{ Kg}$$

(Note the good comparison with section 1.1. The value to be used in subsequent calculations will be Δ = 35.211 kg as it is considered to be the more accurate figure.)

2.2. <u>Metacentric Height</u>

As initially inclined $\overline{G}\overline{M}_T = \dfrac{wh}{\Delta \tan\theta}$

$$\overline{G}\overline{M}_T = \frac{0.385kg \times 292mm}{35.211kg \times \tan 2°11'}$$

$$\overline{G}\overline{M}_T = 83.74 \text{ mm}$$

From hydrostatic particulars at draught T = 63.5 mm:-

$$\overline{KB} = 30.20 + \left(\frac{63.5 - 57.2}{71.5 - 57.2}\right) \times (37.6 - 30.2) = 33.46 \text{ mm}$$

$$\overline{B}\overline{M}_T = 144.8 - \frac{6.3}{14.3}(144.8 - 116.2) = 132.20 \text{ mm}$$

$\overline{K}\overline{M}_t = \overline{KB} + \overline{B}\overline{M}_t$ therefore $\overline{K}\overline{M}_T$ = 165.66 mm

$\overline{G}\overline{M}_t = \overline{K}\overline{M}_t - \overline{KG}$ so $KG = \overline{K}\overline{M}_t - \overline{G}\overline{M}_T$

Hence $\overline{KG}$ = 81.92 mm (say 81.9 mm)

2.3. Mean Draught at No. 6 Hold Mid-Length (T_C)

T_c can be calculated using the following formula.

$$T_C = T_F + \frac{Total\_Trim}{Draught\_Mark\_Length} * Dis\tan ce\_from\_F.P.$$

$$= 65 + \left(\frac{5}{2286} \times 1764\right) \qquad = 68.8 \text{ mm}$$

Deduct Hog correction = -4.0 mm

Therefore T_c = 64.8 mm

3. Lost Buoyancy Calculations

The plug is now removed from the sea inlet allowing water to freely enter No. 6 Hold. To calculate the resultant mean draught and trim, the lost buoyancy method is used.

(Subsequent calculations will then use ADDED MASS method).

3.1. Parallel Sinkage

Lost buoyancy	=	Volume of hold x Permeability (μ)
	=	(BWL x Hold Length x T_c x C_w) x μ (see Appendix 2-5)
	=	(0.332 x 0.285 x 0.0648 x 0.953) x 0.97
	=	0.00551 m^3
Lost Waterplane Area	=	0.323 x 0.285 x 0.97
	=	0.08929 m^2 (= a)

From hydrostatic particulars at T = 63.5 mm

Complete Waterplane Area $= 0.6045 + \left(\frac{63.5 - 57.2}{71.5 - 57.2}\right) \times (0.6152 - 0.6045)$

$= 0.6092$ m^2 (= A)

Therefore intact Waterplane Area

= Complete - Lost

= 0.6092 – 0.0893

= 0.5199 m^2

Parallel Sinkage $= \frac{Lost\_Buoyancy}{Intact\_Waterplace\_Area}$

$= \frac{0.005514}{0.5199} \times 1000$

= 10.6 mm

Hence, new draught for hydrostatics

= 63.5 + 10.6 = <u>74.1 mm</u>

(neglect second approximation allowing for increase in waterplane area over change of draught).

3.2. Trim

3.2.1. To calculate the longitudinal second moment of area of the complete waterplane at the new draught, from hydrostatics:-

$$\overline{BM_l} = 94.923 - \left(\frac{74.1-71.5}{85.8-71.5}\right)\times(4.923-4.191)$$
$$= 4.790 \text{ mm}$$

$$\Delta = 40.113 + \left(\frac{2.6}{14.3}\right)\times(48.957-18.50740.113)$$
$$= 41.721 \text{ kg}$$

Therefore $I_C = \overline{BM_L} * \frac{\Delta}{\rho} = \frac{4.790\times 41.721}{1000}$

$$= 0.200 \text{ m}^4$$

3.2.2. Centroid of lost waterplane area from ⊠

$$=1621-\frac{2385}{2}+\frac{285}{2}$$
$$= 571 \text{ mm } (= q)$$

New LCF from ⊠ $= \frac{Lost\_Area * Lever(q)}{Intact\_Waterplace\_Area}$

$$= \frac{0.0892\times 571}{0.5199}$$
$$= 98 \text{ mm } (= p) \text{ (FWD)}$$

Second Moment of Area of Lost Area

$$= \frac{0.285^3 * 0.323}{12}$$
$$= 0.623 \times 10^{-3} \text{ m}^4 \ (= i)$$

Hence, new I_L about F $= I_C + Ap^2 - \mu i - a(p+q)^2$

$$= 0.200 + \left(0.6092\times 0.098^2\right) - \left(0.97\times 0.623\times 10^{-3}\right) - 0.08929(0.571+0.098)^2$$
$$= 1.455 \text{ m}^4$$

3.2.3. Trimming Moment $= Lost\_Buoyancy \times (p+q)$

$$= 0.005514 \times 0.669$$
$$= 0.0036888 \text{ m}^4$$

Trimming Moment also

$$= I_L.\tan\theta = I_L.\frac{Trim\_Change}{Length}$$

Re-arranging this formula gives:

Trim Change due to flooding hold $= \dfrac{Trim\_Moment \times Draught\_Length}{I_L}$

$$= \frac{0.0036888 \times 2286}{1.455}$$

$= 58.0$ mm

3.3. Final Draughts

From Parallel Sinkage, T_{LCF} (apparent)

$= T_{LCF}$ (actual) + HOG Correction
$= 74.1 + 4.00$
$= 78.1$ mm

Change of Draught Aft due to change of trim (about LCF)

$$= \frac{58.0}{2286} \times 1171$$

$= +29.7$ mm

And change of draught Forward

$$= \frac{58.0 \times 1115}{2286}$$

$= -28.3$ mm

Therefore by calculation, Final T_{AFT}

= Original T_A + Parallel Sinkage + Draught Change
$= 70.0 + 10.6 + 29.7$
$= 110.3$ mm

Similarly, Final T_{FWD}
$= 65 + 10.6 – 28.3$
$= 47.3$ mm

4. Actual Draught Measurements

After flooding of No. 6 hold was complete, the draughts on the model were recorded as follows:-

	T_{AFT}	= 104 mm	(calculated = 110 mm)
	T_{FWD}	= 56 mm	(calculated = 47 mm)
and	Trim	= 48 mm by stern	(calculated = 63 mm)

5. Transverse Stability

The following calculations are based on the ADDED MASS method.

5.1. Hydrostatic Particulars

The final draught for hydrostatics particulars was obtained in Section 3.1 = 74.1 mm.

At this draught:-

$$\Delta \quad = 40.113 + \left(48.957 - 40.113 \times \frac{(74.1 - 71.5)}{85.8 - 71.5}\right)$$

= 41.721 kg

$$\overline{KB} \quad = 36.6 + \frac{2.6}{14.3}(45 - 37.6)$$

= 14.86mm

$$\overline{BM_t} \quad = 116.2 - \frac{2.3}{14.3}(116.2 - 97.2)$$

= 112.75 mm

5.2. Check On Added Mass

The difference between the initial (Section 2.1) and the final (Section 5.1) displacements

= 41.721 – 35.211 = 6.510 kg

From Section 3.1, new draught for old mid-length = 75.4mm and Added Mass in No. 6 Hold

= lost buoyancy + (lost w.p.a. x parallel sinkage)
= 0.005514 + (0.08929 x 0.0106)
= 0.006460 m^3
= 0.006460 x ρ
= 0.006460 * 1000
= 6.460 kg

Used Mean Value = 6.485 kg

5.3. **Change in $\overline{KG}$ Due to Added Mass**

Estimated vertical centroid of Added Mass
= 0.55 x depth of water at hold mid-length
= 0.55 x 75.4
= 41.5 mm

Original $\overline{KG}$ of model (section 2.2) = 81.9 mm

Final KG of the model can be found by calculating the moments about K

$$\text{Final } \overline{KG} = \frac{(\text{Mass}_{\text{Added}} \text{ x } \text{KG}_{\text{Added}}) + (\text{Mass}_{\text{Original}} \text{ x } \text{KG}_{\text{Original}})}{\text{Mass}_{\text{Final}}}$$

$$= \frac{(6.485 \times 41.5) + (35.211 \times 81.9)}{41.696}$$

= 75.617 mm

5.4. **Free Surface Correction**

$$\text{F.S.C.} = \frac{i}{V} = \frac{1}{12} \times \frac{0.285m \times (0.323m)^3}{41.721kg \times 0.001m^3/kg} \times \frac{1000mm}{1} = 19.18 \text{ mm}$$

5.5. **Metacentric Height**

$\overline{KB}$ = 38.95 mm
$\overline{BM}$ = 112.75 mm
$\overline{KM} = \overline{KB} + \overline{BM}$ therefore $\overline{KM}$ = 151.70 mm
$\overline{GM}_{SOLID} = \overline{KM} - \overline{KG}$ therefore $\overline{GM}_{SOLID}$ = 76.08 mm

less F.S.C of 19.18 mm

Final $\overline{GM}$ = 56.90 mm

5.6. **Second Inclining experiment**

(Added Mass Basis with sea-inlet plug replaced).

As section 1.3:

0.385 kg transferred through 292 mm when θ changed from 0°18' S to 2°17' P, a change of 2°35'.

$$\text{Therefore } \overline{GM} = \frac{0.385 \times 292}{41.721 \times \tan 2°35'}$$

= 59.61 mm (compared with 56.90 mm above)

AN ASYMMETRIC FLOODING EXPERIMENT

(No working or results given)

The AIM of this experiment with the General Cargo Vessel model, is to observe, measure and calculate the effect of flooding a side compartment and then the consequence of cross-flooding, a practice often adopted under these circumstances. Observe the progress of the flooding, remembering that it may be considered either as a loss of buoyancy or an addition of mass.

For this experiment a watertight, longitudinal, centre-line bulkhead must be fitted into No. 6 Hold. The bulkhead should have a hole at the bottom blocked with a rubber bung so that cross flooding is possible.

Procedure

1. Ensure that the model is upright by moving ballast Z, if necessary. Read the draughts forward and aft. Carry out a mini-inclining experiment by moving the pair of small weights (assumed to be ship's spare gear) across the width of the model and measuring the change of heel.

2. Measure the ship's angle of heel. Then carefully unscrew and remove the plug in the bottom of compartment No. 6 starboard. Observe how the trim and heel change. When ingress of water is complete (think how you may check this) measure and record the new angle of heel and the draughts at the perpendiculars. Measure the size of the compartment and estimate the volume of water admitted to the compartment.

3. Gently remove the rubber bung in the centre-line bulkhead. Note the progress of flooding. When it is complete, measure the draughts and the angle of heel and estimate the new volumes of water in both port and starboard compartments.

Report on the mini-inclining experiment.

Calculate

1. The initial displacement (from the draughts and assuming that LCF is at amidships) and the KG (from the inclining experiment). Check the displacement from a statement of the masses onboard.

2. The expected angle of heel by bilging compartment No. 6S. (Use the compartment dimensions measured).

3. The final displacement and $\overline{KG}$ (from the second inclining experiment).

4. The expected final draughts and $\overline{KG}$ by bilging No. 6 Hold (as a single compartment).

Draw up a table showing for the model comparisons between your measurements and calculations.

THE INFLUENCE OF A SUSPENDED MASS

INCLINING AND LARGE ANGLE STABILITY EXPERIMENTS SHOWING THE EFFECT OF A SUSPENDED MASS

Specification of Experiment

With the general cargo ship model a small mass is supplied which may be hung from the suspension bracket and will demonstrate the loss of stability when a mass is free to swing, e.g. a hanging meat cargo. This demonstration is best seen in the light condition as mentioned on page 15. The working given below shows how a detailed experiment may be conducted to measure the effect of a suspended mass of about 2.5kg. The experiment includes an initial inclining experiment and the measurement of stability at large angles.

The model of the general cargo vessel is attached to the dynamometer which allows it to be inclined to a chosen angle. The model is lightly ballasted.

The AIM is to draw two curves of statical stability and to determine whether the difference between them is equivalent to the introduction of a suspended mass. Tabulated values from Cross Curves of stability should be supplied for the model as a check.

DATA

Three pieces of information should be supplied: the ballast masses aboard, the initial KG of the model, the Cross Curves of Stability.

PRECAUTIONS

When heeling the model check that the ballast and suspendible mass (when resting on the bottom) do not move. Do not exceed about 20 degrees of heel. Clamp the locking plate on the balancing frame after each set of readings.

Take care when reading the clinometer. Take one reading with weights on the opposite side of the scale pan.

PROCEDURE

1. The suspendible mass is positioned on the bottom of the model beneath the gantry. The dynamometer locking plate is in its locked position. Set the clinometer to one of the pre-determined readings, (about 3°, 6°, 9° 12°, 15°). Release the clamp on the frame and incline the model until the clinometer angle is attained approximately.

   Release the locking plate and add weights on to the scale pan until equilibrium is achieved. Record the weight - the Righting Moment is when Weight x 400 mm. Adjust and read the clinometer to within about 5'. Clamp locking plate.

   Repeat the procedure for other angles to enable a curve of statical stability to be drawn. One inclination (about - 1°) should be attempted with weights on the other scale pan to find zero GZ position.

2. Suspend the mass from the gantry and repeat procedure. Measure the rise in mass centroid. (Suspended mass typically 2.5 kg).

CALCULATIONS

3. The two curves of statical stability can be drawn on the same graph. Because neither curve will necessarily go through the origin, the second curve should be raised vertically to intersect the first curve at zero righting moment of heel = θ". Measure righting lever values at θ ' + 5°, θ + 10°, θ + 15° for both curves. Show that the difference can be equated to the reduction in metacentric height due to the hanging mass. (G_1Z — $G_2Z = G_1G_2 \sin\theta$). Also compare the GM's using tangents to the statical curve.

4. Use the cross-curve values supplied and, by interpolation at the appropriate displacement, determine values of GZ for θ = 5°, 10°, 15°. Correct the values for the difference between assumed and actual KG (given). How does this corrected curve compare with the curve obtained in Procedure 1?

DETAILED WORKING OF RESULTS

The aims of these experiments are to measure and draw two curves of statical stability where the difference between them is caused by suspending an item of cargo already on board, from the gantry. The difference is compared with the virtual loss of $\overline{KG}$ due to a hanging load. Furthermore, one of the curves may be compared with tabulated values of $\overline{G}\overline{Z}$ which are supplied.

The model is ballasted with three block weights, one of which is bolted to the deck aft. The first objective must be to determine $\overline{KG}$ for the model in this condition from an Inclining Experiment.

INCLINING EXPERIMENT

The values in the following example were obtained using a similar a similar model boat to yours it may not correspond to your model boat exactly. When performing these calculations actual measurements from the model should be substituted.

Two small inclining masses, (0.385 kg) are moved through 295 mm.

Using the clinometer bolted to the deck, heeling angle changes from
0°14' S $\rightarrow$ 2°04' P = a change of 2° 18'

Model displacement is made up as follows:

Bare Hull	11.794 kg
Clinometer	0.864
Ballast V1	4.337
Ballast Z1	5.697
Ballast X1	5.697
Suspendible Mass (on bottom of model)	2.392
Inclining Masses	0.385
TOTAL MASS	31.166 kg

$\overline{G}\overline{M}$ (as inclined)

$$= \frac{wd}{\Delta \tan\theta}$$

$$= \frac{0.385 * 295}{31.116 * 0.0402}$$

= 90.65 mm (there is no Free Surface Correction)

Using Hydrostatic Data at Δ = 31.166 kg

By interpolation

$$\overline{KB} = 30.2 + \left(\frac{31.375 - 31.166}{31.375 - 22.845}\right) \times (30.2 - 22.7)$$

= 30.02 mm

$$\overline{B}\overline{M} = 144.8 + \left(\frac{31.375 - 31.166}{31.375 - 22.845}\right) \times (191.9 - 144.8)$$

= 145.95 mm

Hence $\overline{KM}$ = 175.97 mm

less $\overline{G}\overline{M}$ (as inclined) = 90.65 mm

$\overline{KG}$ = 82.32 mm

For the subsequent statical stability measurements, the inclining weights must be removed (discharged):

Inclining Weights Mass = 0.385 kg

and $\overline{KG}$ above base = 195 mm

Therefore reduction in $\overline{KG}$ (ie. $\overline{G_1}\overline{G_2}$) $= \dfrac{0.385 \times (195 - 85.32)}{31.166 - 0.385}$

= 1.37 mm

Hence final $\overline{KG}$ to be used = 85.32 - 1.37
= 83.95 mm

The corresponding displacement
= 31.166 - 0.385
= 30.781 kg

MEASUREMENTS FOR TWO STATICAL STABILITY CURVES

A. Suspendible Mass on Bottom of Model

Ø (degrees)	Mass on Scale Pan (gm)
2° 38' Starboard	250 left hand side
4° 28' Port	475 right hand side
9° 10' Port	1000 right hand side
13° 39'Port	1500 right hand side
18° 00'Port	1950 right hand side

B. Mass Suspended from Gallows

Distance between the original centroid of the mass and its suspension point = 460mm.

θ(degrees)	Mass on Scale Pan (gm)
2° 35' Starboard	200 left hand side
3° 13' Port	150 right hand side
8° 06' Port	500 right hand side
14° 09'Port	950 right hand side
18° 05'Port	1250 right hand side

These values are shown on the accompanying graphs.

The position of Graph B is adjusted (by a parallel rise) so that graphs A and B have a common origin at zero $\overline{G}\overline{Z}$ and θ' = (θ - 0°12' to Port) in this instance.

Comparison between the two curves

θ' (degrees)	Scalepan Weight from Graphs A (gm)	B (gm)	A-B (gm)	δ. $\overline{G}\overline{Z}$ * (mm)	Sinθ'	$\overline{G_A}\overline{G_B}$ § (mm)
5	535	360	175	2.84	0.0872	32.60
10	1075	720	355	5.77	0.1736	33.24
15	1620	1085	535	8.69	0.2588	33.58

$\sum = 99.42$

$$* \overline{G}\overline{Z} = \frac{\text{Scalepan Weight x 500mm}}{\text{model displacement}}$$

i.e. Change in $\overline{G}\overline{Z}$ (δ. $\overline{G}\overline{Z}$) between graphs A,B

$$= \frac{\text{Difference in Scalepan Wt (gm) x 500 (mm)}}{\text{30.781 x 1000 (gm)}}$$

§ The correction between statical stability curves (δ. $\overline{G}\overline{Z}$) = $\overline{G_A}\overline{G_B}$ Sin θ'

where G_A is the centroid of the model before the mass is suspended and G_B is the centroid of the model after the mass is suspended.

i.e. $$\overline{G_A}\overline{G_B} = \frac{\delta.\overline{G}\overline{Z}}{Sin\theta'}$$

The average value obtained from comparison of the curves at θ = 5°, 10 °, 15 °

$$= \frac{99.42}{3} = 33.14 \text{ mm}$$

By using the tangents of these curves at their origin, $\overline{G}\overline{M}$ for each could read at one radian (57.3°).

For the graphs: over 15°, δ.$\overline{G}\overline{M}$ = 8.69 mm

Therefore over 57.3°, δ.$\overline{G}\overline{M}$ = $8.69 \times \frac{57.3}{15.0}$ = 33.20 mm

(Note: since graphs and tangents are coincident here, these values should be the same).

These results should be equivalent to the virtual rise in G (from G_A to G_B) due to suspended weight.

$$= \frac{w \times h}{\Delta} = \frac{2.392 \times 450}{30.781} = 35.75mm \text{ (7.5\% error)}$$

COMPARISON OF MEASURED STATICAL STABILITY CURVE WITH VALUES FROM CROSS CURVES SUPPLIED

The Cross Curves supplied have an assumed $\overline{KG_o}$ = 60.96 mm

Actual KG for model during measurements ($\overline{KG_A}$) = 83.95

Therefore correction for GZ curves = $\overline{G_O}\overline{G_A} Sin\,\theta$
= ($\overline{KG_A}$ - $\overline{KG_o}$).Sin θ
= 22.99 Sin θ (a reduction)

Interpolating from the Cross Curves tabulation at Δ = 30.781 kg

$$@\ 5^\circ,\ \overline{G_o}\overline{Z} = 9.85 + \left(\frac{31.796-30.781}{31.796-16.660}\right)\times(18.49-9.85) \ = 10.43 \text{ mm}$$

@ 10°, similarly $\overline{G_o}\overline{Z}$ = 21.03 mm

@ 15°, similarly $\overline{G_o}\overline{Z}$ = 31.67mm

<u>To correct curves from assumed (G_0) to actual (G_A) centroid</u>:

$$\overline{G_O}\overline{G_A} = 22.99 \text{ mm}$$

θ (Degrees)	$\overline{G_o}\overline{Z}$ (mm)	Sin θ'	$\overline{G_O}\overline{G_A} Sin\,\theta$ (mm)	$\overline{G_A}\overline{Z}$ § (mm)	Scalepan Wt (A) (gm)	$\overline{G_A}\overline{Z}$ * (mm)
5	10.43	0.0872	-2.00	8.43	535	8.69
10	21.03	0.1736	-3.99	17.04	1075	17.46
15	31.67	0.2588	-5.95	25.72	1620	26.31

Where; $\overline{G_A}\overline{Z}$ § = $\overline{G_o}\overline{Z}$ - $\overline{G_O}\overline{G_A} Sin\,\theta$

$$* \ \overline{G_A}\overline{Z} = \frac{Scalepan\_Wt \times 500}{\Delta}$$ where Δ= 30.781

Columns $\overline{G_A}\overline{Z}$ § and $\overline{G_A}\overline{Z}$ * should have the same values (average error is 2.5%)

SOME GENERAL COMMENTS ON THE EXPERIMENT

Satisfactory agreement is obtained between the Cross Curves of Stability supplied and measurements taken from a heeling experiment (error about 2.5%). Comparison between the expected loss of due to a suspended mass and the difference between two measured statical stability curves was less good (7.5% error). During the calculations it becomes apparent how accuracy of some of the measurements affects the confirmation between theory and practice.

Care must be taken during heeling to ensure that ballast weights do not move, for example they must be wedged into the bottom of the holds, temporarily bolted to the transverse bulkheads or quite conveniently bolted on to the deck aft through a single drilled hole (which would not damage the integrity of a compartment to be used for a bilging experiment).

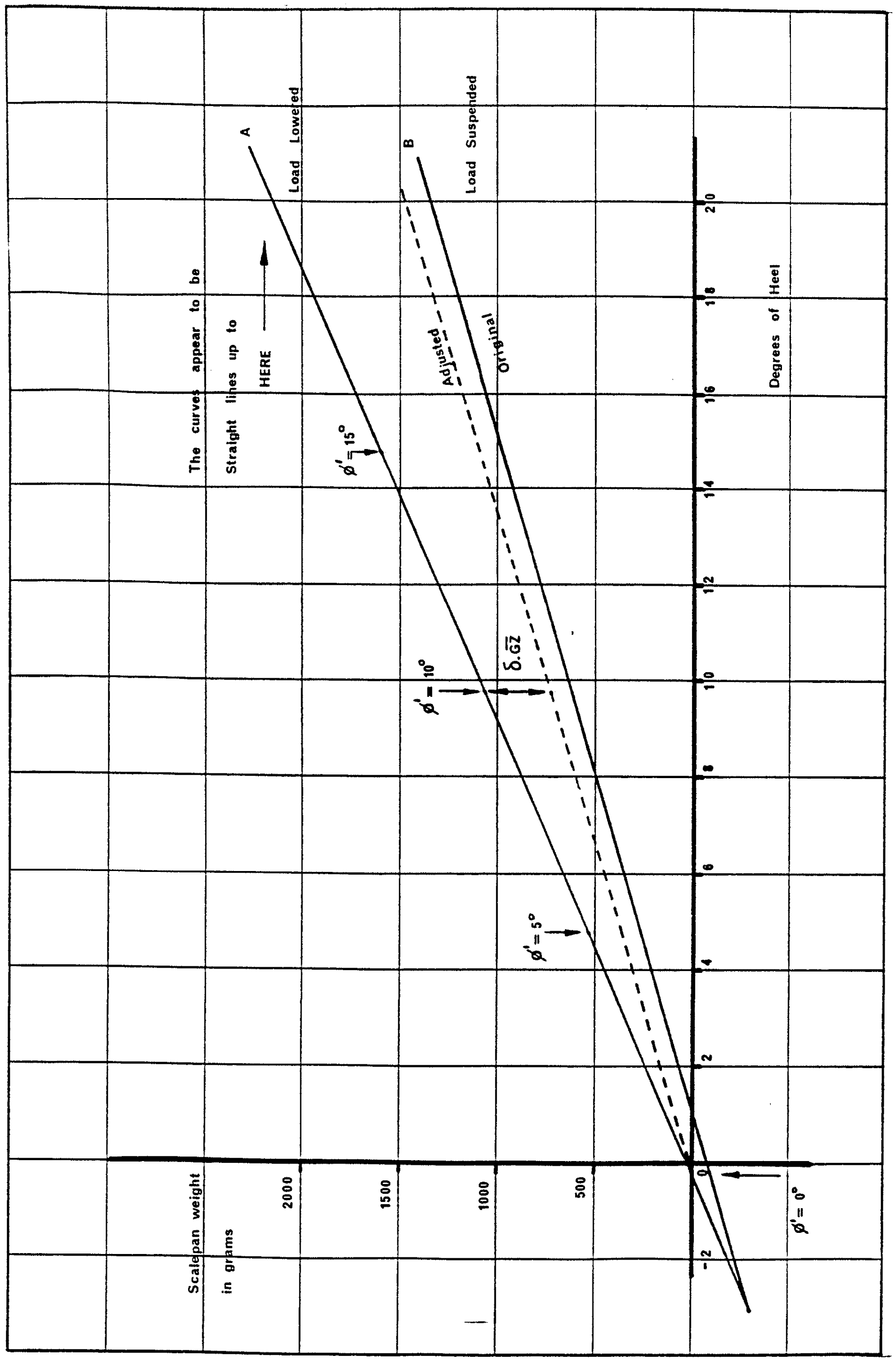
The statical stability curves must be drawn through the zero righting moment position. This requires that one angle of heel be chosen so that weights have to be loaded into the opposite side of the scale pans from the one used for large angles in the other direction of heel. For comparison purposes heel angles should not exceed about 20 degrees.

The weight to be suspended from the gantry should have a mass of about 2 kg so that the difference between the two statical curves is as large as possible: any error in taking readings from the graphs, or in the graphs themselves, then becomes small compared with that difference.

The experiment could be carried out using the free surface tank in place of the suspended load.

Note: The Dynamometer used in the above calculations had a lever arm of 500 mm. The current production version of the NA8-10 Dynamometer has a lever arm of 400 mm and this value should be used when performing calculations.

NA8-13 GENERAL CARGO VESSEL



BIBLIOGRAPHY

1. "Basic Naval Architecture" by K.C. Barnaby
   Pub. Hutchinson.

2. "Basic Ship Theory" by K.J. Rawson and
   E.C. Tupper
   Pub. Longmans.

3. "Principles of Naval Architecture" by The Society of Naval
   Architects and Marine Engineers,
   New York.

4. Supplementary Models See below

Supplementary Models

Three other ship models are available for use independently or together with the Large Angle Stability Dynamometer; they are as follows:

NA8-14 Trawler Model.

A 1/25th scale model of an ocean going trawler fabricated in GRP, fitted with transverse bulkheads and flooding valves. Watertight deck hatches allow the deck to be submerged.

***NA8-15 Crane Ship Model*:**

This 1/50th scale model allows stability and flooding problems connected with heavy lifts to be studied.

***NA8-12 Rectangular Barge Model*:**

A simple form allowing easy calculation of the stability characteristics.

Appropriate instruction manuals for use in conjunction with this manual are supplied with each of the above models.

GENERAL SAFETY RULES

1 Follow Relevant Instructions

a Before attempting to install, commission or operate equipment, all relevant suppliers/manufacturers instructions and local regulations should be understood and implemented.

b It is irresponsible and dangerous to misuse equipment or ignore instructions, regulations or warnings.

c Do not exceed specified maximum operating conditions (eg. temperature, pressure, speed etc.)

2 Installation

a Use lifting tackle where possible to install heavy equipment. Where manual lifting is necessary beware of strained backs and crushed toes. Get help from an assistant if necessary. Wear safety shoes where appropriate.

b Extreme care should be exercised to avoid damage to the equipment during handling and unpacking. When using slings to lift equipment, ensure that the slings are attached to structural framework and do not foul adjacent pipework, glassware etc. When using fork lift trucks, position the forks beneath structural framework ensuring that the forks do not foul adjacent pipework, glassware etc. Damage may go unseen during commissioning creating a potential hazard to subsequent operators.

c Where special foundations are required follow the instructions provided and do not improvise. Locate heavy equipment at low level.

d Equipment involving inflammable or corrosive liquids should be sited in a containment area or bund with a capacity 50% greater than the maximum equipment contents.

e Ensure that all services are compatible with the equipment and that independent isolators are always provided and labelled. Use reliable connections in all instances, do not improvise.

f Ensure that all equipment is reliably earthed and connected to an electrical supply at the correct voltage. The electrical supply must incorporate a Residual Current Device (RCD) (alternatively called an Earth Leakage Circuit Breaker - ELCB) to protect the operator from severe electric shock in the event of misuse or accident.

g Potential hazards should always be the first consideration when deciding on a suitable location for equipment. Leave sufficient space between equipment and between walls and equipment.

3 Commissioning

a Ensure that equipment is commissioned and checked by a competent member of staff before permitting students to operate it.

4 Operation

a Ensure that students are fully aware of the potential hazards when operating equipment.

b Students should be supervised by a competent member of staff at all times when in the laboratory. No one should operate equipment alone. Do not leave equipment running unattended.

c Do not allow students to derive their own experimental procedures unless they are competent to do so.

d Serious injury can result from touching apparently stationary equipment when using a stroboscope to 'freeze' rotary motion.

5 *Maintenance*

a Badly maintained equipment is a potential hazard. Ensure that a competent member of staff is responsible for organising maintenance and repairs on a planned basis.

b Do not permit faulty equipment to be operated. Ensure that repairs are carried out competently and checked before students are permitted to operate the equipment.

6 *Using Electricity*

a At least once each month, check that ELCB's (RCCB's) are operating correctly by pressing the TEST button. The circuit breaker must trip when the button is pressed (failure to trip means that the operator is not protected and a repair must be effected by a competent electrician before the equipment or electrical supply is used).

b Electricity is the commonest cause of accidents in the laboratory. Ensure that all members of staff and students respect it.

c Ensure that the electrical supply has been disconnected from the equipment before attempting repairs or adjustments.

d Water and electricity are not compatible and can cause serious injury if they come into contact. Never operate portable electric appliances adjacent to equipment involving water unless some form of constraint or barrier is incorporated to prevent accidental contact.

e Always disconnect equipment from the electrical supply when not in use.

7 *Avoiding fires or explosion*

a Ensure that the laboratory is provided with adequate fire extinguishers appropriate to the potential hazards.

b Where inflammable liquids are used, smoking must be forbidden. Notices should be displayed to enforce this.

c Beware since fine powders or dust can spontaneously ignite under certain conditions. Empty vessels having contained inflammable liquids can contain vapour and explode if ignited.

d Bulk quantities of inflammable liquids should be stored outside the laboratory in accordance with local regulations.

e Storage tanks on equipment should not be overfilled. All spillages should be immediately cleaned up, carefully disposing of any contaminated cloths etc. Beware of slippery floors.

f When liquids giving off inflammable vapours are handled in the laboratory, the area should be ventilated by an ex-proof extraction system. Vents on the equipment should be connected to the extraction system.

g Students should not be allowed to prepare mixtures for analysis or other purpose without competent supervision.

8 *Handling poisons, corrosive or toxic materials*

a Certain liquids essential to the operation of equipment, for example mercury, are poisonous or can give off poisonous vapours. Wear appropriate protective clothing when handling such substances. Clean up any spillage immediately and ventilate areas thoroughly using extraction equipment. Beware of slippery floors.

b Do not allow food to be brought into or consumed in the laboratory. Never use chemical beakers as drinking vessels.

c Where poisonous vapours are involved, smoking must be forbidden. Notices should be displayed to enforce this.

d Poisons and very toxic materials must be kept in a locked cupboard or store and checked regularly. Use of such substances should be supervised.

e When diluting concentrated acids and alkalis, the acid or alkali should be added slowly to water while stirring. The reverse should never be attempted.

9 Avoiding cuts and burns

a Take care when handling sharp edged components. Do not exert undue force on glass or fragile items.

b Hot surfaces cannot in most cases be totally shielded and can produce severe burns even when not 'visibly hot'. Use common sense and think which parts of the equipment are likely to be hot.

10 Eye protection

a Goggles must be worn whenever there is a risk to the eyes. Risk may arise from powders, liquid splashes, vapours or splinters. Beware of debris from fast moving air streams. Alkaline solutions are particularly dangerous to the eyes.

b Never look directly at a strong source of light such as a laser or Xenon arc lamp. Ensure that equipment using such a source is positioned so that passers-by cannot accidentally view the source or reflected ray.

c Facilities for eye irrigation should always be available.

11 Ear protection

a Ear protectors must be worn when operating noisy equipment.

12 Clothing

a Suitable clothing should be worn in the laboratory. Loose garments can cause serious injury if caught in rotating machinery. Ties, rings on fingers etc. should be removed in these situations.

b Additional protective clothing should be available for all members of staff and students as appropriate.

13 Guards and safety devices

a Guards and safety devices are installed on equipment to protect the operator. The equipment must not be operated with such devices removed.

b Safety valves, cut-outs or other safety devices will have been set to protect the equipment. Interference with these devices may create a potential hazard.

c It is not possible to guard the operator against all contingencies. Use common sense at all times when in the laboratory.

d Before starting a rotating machine, make sure staff are aware how to stop it in an emergency.

e Ensure that speed control devices are always set at zero before starting equipment.

14 First aid

a If an accident does occur in the laboratory it is essential that first aid equipment is available and that the supervisor knows how to use it.

b A notice giving details of a proficient first-aider should be prominently displayed.

c A 'short list' of the antidotes for the chemicals used in a particular laboratory should be prominently displayed.