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Problems in Ship Theory

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OUTLINE

Introductory Remarks;

I. Water Support; Classes of Ships.
II. Static Stability.
III. Resistance (Powering, Part I).
IV. Propulsion (Powering, Part II).
V. Maneuverability.
VI. Behavior in a Seaway.
VII. Vibration Problems.

INTRODUCTORY REMARKS.

We shall speak primarily about ships. However, most results or at least methods apply as well to other technical bodies moving in water or at its surface. Such bodies are submarines, torpedoes, paravanes, planing vessels, hydrofoils etc. One difficulty in promoting and applying scientific methods in our field stems from the fact that shipbuilding is one of the oldest trades. The most important theorem in ship theory - Archimedes' law - has been found more than two thousand years ago, but ten thousands of years before ships have been successfully built without any theoretical knowledge. From our present point of view this compares unfavourably with conditions in the fields of aircraft, electrical engineering, and chemistry which are essentially products of modern research, while ship theory represents the application of science to a classical field of technical work. We shall, however, try to show that the number of technical scientific problems in this field is large, that they are important from the point of view of practice, fruitful and many of them astonishingly difficult, even more difficult than in the sister science of aerodynamics, essentially due to the presence of the free water surface and to the complicated shape of the ship.

A surfey can be made from two principles (leaving aside the historical approach):

I. We may start in a general way from rational mechanics, espesially hydromechanics and theory of elasticity,and try to select problems pertaining to the ship.

II. We may state the general properties which constitute a ship from the point of view of rational mechanics, formulate the corresponding scientific problems and show what has been done and should be done to solce them.

Obvoiously the latter procedure appeals to the scientific engineer; it is more direct and evident and we shall follow it here.

Incidentally, it can, however, narrow the outlook and lead to repetitions. That is by no means detrimental from the present point of view since it indicated the need for integration of the field of research as aimed at by the project "Ship hydrodynamics" at this University.

The concept ship theory is used in two senses: 1) a broader one embracing the application of all parts of rational mechanics to technical ship problems. 2) More commonly, however, a narrower definition is accepted following which to ship theory belong those problems only in which the ship can be considered as a rigid body.

The second definition has its merits and weak spots. The simplified mechanical model of a rigid body is useful in several respects; in many cases extraneous forces acting on the ship can be calculated with reasonable accuracy following this scheme which means that matters of strength and elasticity are excluded from ship theory and are considered as an independent and equally important branch of ship science.

We shall use here this narrower concept because it allows us to concentrate primarily on hydrodynamics. It is obvious, however, that the separation made fails not only in principle, but also in practice; e. g. the theory of ship vibrations does not fit the artificial scheme at all.

A strong impetus towards developing ship theory results from the present trend to increase the ship speed, especially the sustained speed in a seaway; obviously the simple static and hydrostatic concepts on which a large part of ship theory rested earlier are crumbling under this impact.

Of the three methods of research, theory, model-testing, and fullscale investigations in the present brief review emphasis will be laid on the first one; but full credit will be given to model experimenting which almost for a century till today has represented a characteristic feature of our discipline.

It has been pointed out by von Karman that technical hydromechanics and other similar branches have developed roughly by the following pattern:

1. Approach by empiry and arbitrary ad hoc hypotheses. Therefrom results the use of formulas with "variable constants" of which the Admiralty formulas are famous examples.

2. The application of laws of similitude (model testing); in 3. The creation of consistent theories.

Problems of marine engineering expect those connected with propussion remain outside of the present talk; rather we shall suppose that marine engineers are able to supply us with anything we want from them. It must be acknowledged, however, that when technical progress in the ship business is discussed, generally, the lions share goes to marine engineering.

There are two branches of applied hydrodynamics from which ship theory has learned a lot: Aerodynamics and hydraulics. The importance of aerodynamics for our problems is well known, less well known is that hydraulic engineers have contributed valuable ideas and information in the fields of wave motions, shallow water effect, wave reflexion, etc.

The main properties which constitute a ship from the point of view of ship theory can be summerized approximatively as follows:

I. Buoyancy and lift or more generally water support. Problems referring to volume, space, deck space, etc. can be subsumed under this heading.

II. Transverse and longitudinal static stability.

III. Resistance, IV. Propulsion — as parts of the powering problems.

V. Maneuverability.

VI. Seaworthiness.

VII. Vibrations.

We leave out by definition the large field of strength.

I. Buoyancy:

Archimedes' law reduces the buoyancy problem to simple geometrical calculations. Certainly there is no need to dwell upon these matters. We may mention an interesting sideline of investigation- the representation of the hull form by algebraic expressions. There are some immediate practical reasons for studies in this direction, like a possible reduction of work on the mold loft; more important, however, is the desire to fix properly a ship shape and to perform variations of shape in a systematical way. D. W. Taylor was quite successful in starting this task; however, his work has been forgotten for a long t time.It present more advanced attempts in this direction are being made with the purpose to simplify and to systematize various important calculations like wave resistance, behavior in a seaway, etc.

Buoyancy does not, however, cover the whole story in this field. At present, we define a ship (or a boat) as a vehicle the weight of which is supported mainly by the action of water. This includes <u>hydrodynamic</u> forces beside the hydraulic buoyant forces.

From the character of the supporting force we derive immediately a fundamental classification of ships:

Class I- Displacement on Archimedean vessels (normal ships).

Group I -0/- Surface ship

I-2- Submerged bodies (e. g. submarines).

Class II- Hydrodynamic vessels.

Group II-1 planing vessels; the lift is created at the surface.

It is a craft sui generis.

Group II-2vessels with dynamic lift created simarily by immersed devices.

Vessels of Class II are obviously products of the rush for high speed. There are , of course, <u>transitions</u> and cross <u>breds</u> between the mentioned classes and groups which become increasingly more interesting.

Because of its overwhelming practical importance we shall speak almost only about displacement vessels, Class I, but to ap appraise properly the <u>sum of research</u> work needed one must consider the Class II on equal terms.

<u>II. Stability</u>:

The use of the concept stability in Naval Archotecture present a problem in itself. Fiest it it applied in the proper sense to describe an equilibrium condition, secondly one denotes by "stability" righting moments calculated for finite angles of heel and trim. Generally one restricts oneself to an approach based on hydrostatics, that is again to elementary geometricalcomputations. Even here appreciable errors are committed and quite a bit remains to be done to establish general dependencies of these "stability curves" upon the ship form. But the problem ceases immediately to be trivial when conditions underway or, what is still more troublesome, in a seaway must be considered. While the influence of the speed of advance on traverse "stability" has been checked experimentally and is of no great moment with normal ships, only rough estimates have been made of the shape of the stability curve in a seaway. Actually the correct pressure distribution around the ship must be known. We return to this problem later under the heading seaworthiness.

It is well known that an upper limit of "stability" is to be observed with respect to the ships behavior in a seaway, which to fix requires considerable skill pending further theoretical informations

III. Resistance (Powering, Part I):

Perhaps the greatest efforts are being invested today in solving two basic problems of powering. 1.) The determination of hulls and propellers which guarantee a required performance (prescribed displacement and speed) with the minimum power 2.) and the prediction of the amount of the power needed.

At present the pertinent investigations refer mainly to calm water conditions; however, an increasing amount of research is devoted to seaway performance which we shall mention later. The present work relies heavily upon model tests and full scale trials; the latter constitute an important prerequisite in power prediction especially because of the lack of sufficient knowledge of the actual ship roughness and its influence on the ship performance.

For simplicity we split the powering problem into that of resistance and propulsion although this approach is obviously artificial. In addition, experimental means (selfpropelled models) are used for a long time to attack the problem directly.

There are essentically four sources of energy dissipation for a body moving at the surface: waves, sprays, vortives, and viscosity; to them, clearly correspond four resistance effects which are called resistance 'components' R_w, R_s, R_i, R_v and for simplicity are listed as independent and therefore additive.

R_w - Wave resistance

R_s - Spray resistance

R_i - Induced resistance

R_v - Viscous resistance

$$R_t = R_w + R_s + R_i R_v R_v$$

The investigation of the interaction of these four effects is a serious scientific problem of practical importance which so far has evaded solution. For the time being we put $R_t = R_w + R_v$ neclecting the spray and induced resistance.

From the point of view of hydrodynamics the simplest problems are those connected with spray and wave generation since in principle they can be dealt with by the ideal fluid concept. However, the actual approach in Naval Architecture has developed on opposite lines. The famous Froude model method which relies upon Froude's law of similitude is based on the idea that the main part of the viscous drag R_v, the so-called frictional resistance of the 'equivalent' flat plate R_{fo}, can be easily determined.

We define $R_t - R_{fo} = R_r$ as rest or residual resistance and for the model state correspondingly: $R'_t - R'_{fo} = R'_r$

Although this method has worked rather nicely, in the long run it threatens to hamper progress seriously.

The residual resistance concept is a conglomerate of heterogenous physical effects. Neglecting interference we write:

$$R_r = R_w + R_{vp} \mp R_{f\ form}$$

R_{vp} being the viscous pressure resistance (eddy resistance following W. Froude's terminology) , $R_{f\ form}$ the excess of the bodies tangential resistance R_f over that of the equivalent plate.

$$R_{f\ form} = R_f - R_{fo}.$$

Froude's scaling applies, clearly, to the terms $R_w + R_s$=only.

Still more objectionable is the fact that the dependency of R_w and R_{vp} upon the ship form follow quite different laws.

Attempts are being made to replace Froude's method by something better, e. g. to use the relation $R_w = R_t - R_v$.

For determining R_v double models can be used or the Momentum method proposed by Tulin. A high accuracy is needed in predicting the magnitude of the frictional and more generally viscous resistance of the ship. It is well known that for most types of ships the frictional resistance is the largest resistance component because of the low dimensionless speed parameter F (Froude number) at which these vessels are operated. It is less known that the same applies to ships (boats) running at very high Froud numbers..Thus in first line frictional resistance increase represents a barrier for reaching extremely high speeds. Beside the orthodox ways of reducing friction (hydraulic smoothness, minimum wet surface) obviously limited in scope there are two ideas which may be promising although they sound desperate when applied to normal surface ships, i. e.:

1. To keep the boundary layer laminar.
2. To introduce air into the boundary layer or

or to to create an air cushioning at the bottom.

Both ideas are in the state of tentative exploration as far as ship model work is concerned; it is sufficient to state that both ideas present problems of considerable scientific interest.

Returning to orthodox matters, the determination of turbulent friction line for a smooth flat plate as a function of Reynolds number, it should be remembered that this problem is at best being treated on a semiempirical level. A tendency still exists that each well renowned tank should produce a frictional coefficient curve of its own . Much more experimental evidence is needed to settle the problem in a satisfactory way.

So far the problem of the viscous pressure resistance of ship forms has not received the proper considerations. RThe re reasons herefore are the extreme difficulties presented by theory and the tediousness of experimenting, i. e. , essentially performing pressute measurements. IT is therefore natural to shift to bodies of revolution as a first approximation to ship forms. For such forms useful calculations have been made by Young and successors. A promising if rather expensive method of experimental research consists in testing double (mirrored) models. Finally we expect progress from an application of the momentum method proposed by M. Tulin. Although the sum $R_{vp} + R_{f\ form}$ is not large with ressonable ship forms, there is a definite need to establish limits outside of which the increase in R_{vp} can be important.

Let us now make some short remarks on wave resistance around which model research in the resistance field centered for almost a century. With the larger number of ships it is not so much the absolute magnitude of this wave resistance R_w which make research in this field so decisive than rather the complicated variability of R_w with changes in the ship form and the speed (the Froude number). Because of the sensitivity of R_w to these changes it proves to be almost hopeless to establish functional relations by experimenting alone even if it were done in a more systematic way than at present; especially since R_w is generally identified with R_r and has to be derived as a difference of two numbers $R_t - R_{fo}$ which frequently are numerically not too distant from each other. In addition, it is well known that laminar flow conditions on models have seriously impaired the value of many experiments mainly with full slow cargo ship forms. For these reasons even practical people recognize now the importance of applying hydrodynamic theory in this field - a procedure which was earlier considered as a kind of hobby for minds with mathematical inclinations.

1) For surface ships we have to base our work still today essentially on Michell's formula published 1898. The limitations of assumptions underlying Michell's theory are rather severe (a) thin ship b) fixed position c) ideal fluid).

One of the basic hydrodynamic tools if by no means the only one in our field of research is the source and sink doublet concept which for us is as important as the vortex concept for aerodynamicists. Recently Inui has generalized the well known method of generating bodies of revolution to some simple three-dimensional cases.

Forces and moments experienced by shiplike bodies derived from sources and sinks are calculated by the so-called Lagally Theorem the counterpart of the famous Kutta-Joukovsky theorem $X= -\rho QU$ with Q the output of the source.

An important generalisation for non steady motion has recently been given by Cummins which may enable us to solve with resonable approximation manyyimportant problems in the field of resistance and seaworthiness of ships.

2) For the wave resistance of submerged boies the fundamenn tal solution have been given by Havelock using again the source and sink concept.

3) Further solutions are available for planing problems which originally were treated by two different methods: The th theory of pressure distributions applied to the free surface b) and an airfoil analogy. Recently combining Lamb's and H-H. Wagner's work Maruo has solved the pertinent boundary problem of planing.

4) We mention finally theoretical work on hydrofoils moving close to the surface. Still a lot remains to be done in this field.

Continuously attempts are being made to improve Michell's formula.

5) Similar solutions are available for the shallow water case and

6) for motions in a rectangular channel primarily due to Russian authors.

The latter enables us to work out tank corrections for model work similar to those used in wind tunnel research with the additional complication, however, that the results depend decisevely upon Froude's number.

Let us have one additional glance on the general character of a wave resistance curve for a surface ship, calculated under the assumption that the bodily sinkage and trim can be neglected.

Beside the oscillatory character of this curve R_w we state, that its absolute magnitude (not referred to v^2) reaches a very flat maximum at a high Froude number.in the vicinity of 1,5 or 2, say, and that $R_w \to 0$ when $F \to \infty$ though very slowly. The steep rise of the wave resistance curve which begins somewhat above a Froude number of 0.35 can be only slightly shifted by changes of the ship form. Thus for most commercial vessels a speed barrier is given by the wave resistance even before the frictional effects become prohibitive.

Propulsion and interaction between propeller and ship. Comparable to the treatment of the ship hull it is a standard procedure to investigate first the "free running" propeller.

By far the most effects are concentrated on problems presented by the screw propeller. Although the vortex line theory borrowed from aerodynamics has been rather thoroughly developed, its application meets difficulties when applied to propellers with broad blades.

Only recently solutions have been obtained which cover reasonably well all practical needs.

Obviously the appropriate model for a broad bladed propeller is a vortex sheet. Rather tedious computations have been made using this concept but for some time controverses were alive with respect to results obtained. Fortunately it appears at present that Weissinger's improved wing theory will overcome all essential difficulties and yield satisfactory values for the important effect of flow curvature without too much difficulties.

It were a thrilling task to show by reviewing the history of the matter as to how attempts to improve the theory led astray. This applies especially to the lattice effect.

In the experimental field the method of testing propeller model series based on geometrical form variation has been successfully applied. As in the case of ship form the systematical spirit of D.W. Taylor gave most valuable impulses in this direction. In the case of the propeller they were accepted and properly developed by his followers while for hull forms they were for a long time forgotten. Thus, fortunately, propeller model data published over this century do not present such a dreadful chaos as ship resistance data although neglecting flow conditions around model blades (e. g. the influence of the Reynold's number) led here also to considerable errors.

The problem of cavitation which was already known to Euler has been considered as one of the utmost importance since the end of the last century. Notwithstanding the fact that the main effect is clearly understood some phenomena connected with it require still a lot of investigation.

The screw propeller is a simple and in most cases efficient device. Therefore most attempts to improve its action by additional devices were doomed to failure except for the nozzle -which proves to be a very useful invention for heavily loaded propellers. A consistant theory of the Kort nozzle has recently been developed by <u>Dickmann and Weissinger</u>.

Obviously, the <u>interaction of the working propeller with the ship hull</u> is a most important problem. Recently, I had the opportunity to discuss working conditions of <u>fans</u> with competent people of the Voith plan in Germany which operates a beautiful research institute. These gentlemen were upset by the fact that the efficiency of nice fans may drop in a distu disturbing way when put into a bad casing - a fact with which our colleagues in hydraulic engineering are certainly much mo more familiar than myself. Although conditions with ships are less severe the analogy is to the point.

It is well known that one of the decisive steps in science consists in developing useful basic concepts. In this respect we are most indebted to the older naval architects like R. E. Froude for working out the concepts <u>wake and thrust deduction</u> (or resistance augmentation) commonly expressed as dimensionless ratios w and t.

$$w = \frac{u\ \text{wake}}{u\ \text{ship}} \qquad t = \frac{T - R}{T}$$

with u velocity and t thrust

While the physical facts behind the wake were under-

While the physical facts behind the wake were understood earlier (although the formulation of its 'components' $w = w_{pot} + w_{friction} + w_{waves}$ is not too old) the thrust deduction remained a kind of a myth.

Notwithstanding useful experimental research till the end of the thirties Dickmann made the problem available to theoretical treatment, - in a series of brilliant papers he explained the main effects by an interaction between sinks picturing a propeller and sinks representing the afterbody-using Lagally's theorem. Probably because of the war this work has not obtained the appropriate response. The whole problem has been clarified by him to a large extent although further work is needed to obtain quantitive data. The only continuation of Dickmann's investigations are due to Japanese writers and a recent project sponsored by TMB.

Studies of the combination propeller-ship and rudder are lacking.

MANEUVERABILITY

This property although certainly basic has been considered as less decisive than those of powering and seaworthiness as long as the development of surface ships alone was at stake. The aspect became different when the behavior of other bodies moving in water had to be investigated. In fact over the continuous struggle to reduce resistance the existence of other forces and movements exerted by the water in moving bodies has been neglected for a long time. The concept of maneuverability has to be subsumed to the wider problem of body mechanics. From this point of view, par example, the motions of ships in a seaway may be treated as a part of general ship mechanics also.

At the present state of knowledge, it pays to look for broad formulations. The latter are more than a kind of highbrow attitude. By applying in appropriate manner general theorems of mechanics and hydrodynamics one is able to close many gaps in the study of ship behavior which astonishingly so far have been left open.

We can, therefore, distinguish roughly two epochs in the development of ship maneuvering theory: the first one while we were primarily concerned with the action of the rudder and more groping than thinking about the resulting ship motion the second when the problem was put on a more solid ground by adopting concepts and methods of investigation developed in aerodynamics. The serious work invested into the study of airships performance proved to be of special value for work on ships and other floating bodies.

Thus we borrowed the concept directional stability which though known in naval architecture remained somewhat indefinite and methods of determining it.

When trying to calculate motions resulting from rudder action, we had to merge deeper into hydrodynamics. The first step in this direction resulted in a revival of the classic theory of a body moving in an ideal fluid developed by Kirchhoff and Kelvin. Earlier the presentation of this subject in Lamb's hydrodynamics was considered as a kind of mental exercise without any technical value. The newest step consists in the application of the circulation theory to low ~~aspects~~ aspect ratio foils which had been slightly neglected in aerodynamics. In determining hydrodynamic forces experienced by bodies oscillators and rotating arms proved to be valuable.

While earlier zig-zagging experiments on models and ships seemed to furnish an appropriate approach for determing maneuvering properties it appears at present that such tests based on rather arbitrary reasoning should be discarded in favour of more consistent procedures at least in the model range.

SEAWORTHINESS

The scientific treatment of this ample and important field has only recently been revived after a period of stagnation. The concept 'seaworthiness' embraces a lot of practical and scientific matters. We shall restrict ourselfs to the problem of thebbehavior of a ship as a rigid body in a seaway. However, some considerations will be given to the study of extraneous forces which determine the strength of ships and to the limits of applicability of the rigid body concept.The problem of spe speeddperformance in a seaway will be only shortly dealt with. Obviously the present subject is closely connected with oceanography. It is profiting from the recent progress made in the latter discipline.

It is a pleasant duty to acknowledge that valuable contributions to our subject are currently made at this University. They embrace the fundamental questions of irregular and regullar seaway, of motions of ships therein and of the influence of waves on civil engineering structures the study of which h hasan important bearing on Naval Architecture. It is further extremely fortunate that both theoretical and experimental work in this field is being done at Berkeley. The high level of knowledge reached here enables me to compress my exposition.

From a practical point there are two aspects of the subject-safety and seakindliness.Both present a lot of problems of the utmost importance: e. g. the development of appropriate ship forms with respect to motions, resistance and strength, the assignment of freeboard and the determination of suitable stability.

Although it must be admitted that present scientific tools are not yet strong enough to cope with some urgent practical questions it should be emphasized that much more could be done already in applying results so far obtained to practical needs.

Let us mention, for example, the problem of capsizing v because of resonance effects. Only later it was realized that it is not permissible to linearize the equation of roll when large angles occur. The formalism of non linear equations was adopted. However, to my knowledge no comprehensive studies were so far made in this field which lead to quantitive results with respect to maximum angles of roll reached for definite seaway conditions and for given forms of the stability curve mentioned before. The somewhat hypothetical value of the latter derived from statical consideration has been emphasized earlier.

The essential prerequisite for dealing with seaworthiness is the knowledge of seaway. For a long time ship theory used the regular seaway concept only. It is, obviously, a rather a artificial hypothesis; but in my opinion one should press it as hard as possible till all pertinent conclusions have been derived. The philosophy behind this postulate is that the state of synchronism in a regular seaway constitute probably the severest condition to be met. Certainly, the regular wave assumption fails when we are interested in the average performance of a ship in an actual seaway. Proposals have been m made to substitute in such investigations hypothetic regular seaways for the actual ones but they are void of any serious background.

Only more recently attempts are being made to cope in a rational way with the irregular waves, derive characteristic parameters and apply results to ship motions.

Essentially all informations about the forces experienced by a ship in a seaway can be obtained when the variation of the pressure distribution around the hull is known. The determination of these pressures is an awkward procedure, therefore one tries to avoid it by using more summary concepts. But the there is a definite trend nowadays to deal as far as possible with pressures.

The problem offmotions of a ship in a seaway can be formulated as a boundary problem. Although the solution of it is extremely difficult, it is not useless to state the task in such a general form; in fact a special case has b been splendidly treated by F. John. However, at present we sh shall consider a simplified approach, which consists in the d discussion of equations of motion; in the simplest case they are linear of the type for heaving and similar rolling and pitching.

$$M'_z z + Nz + cz = f(t) = f_o . \sin\Omega t$$

Here the apparent (virtual) mass M'_z,
(2) the damping N
(3) the restoring coefficient c
(4) and the exciting force f(t) must be determined from hydrodynamic considerations . We derive therefrom the natural period, dimensionless damping, and the whole motion.
(1) T

(1) The added mass concept (M'') has become rather important in ship theory. We assume as well known that for a body moving in an unbound liquid M' is a function of the body shape and the density of liquid only. Denoting the body volume by

$$K = \frac{M''}{\rho \forall}$$

is the so called added mass coefficient the magnitude of which varies with the direction of motion. Results for sphero roids can be found e. g. in Lamb's Hydrodynamics. For the two

For the twodimensional case added masses and moments of inertia for a wide class of contours (cylinders) have been determined; we mention expecially the work of F. Lewis, L. Taylor, K.Wendel.

For bodies moving at or close to a free surface the added mass becomes in addition a function of some flow parameters. In fact, the mere definition of the added mass causes difficulties. In our case we were primarily interested in oscillations; the appropriate parameter for forced oscillations e.g. of the type mentioned above is a dimensionless frequency parameter (kind of Froude number)

$$F_{\Omega} = \Omega \cdot \sqrt{\frac{a}{g}}$$

where a is a characteristic length (beam of the ship), draft, etc.). The dependency of the hydrodynamic inertia coefficients (added mass coefficients) $K_x K_y K_z$, $K_{xx} K_{yy} K_{zz}$ upon the frequency has only recently been solved for the two-dimensional case, but solutions for the three-dimensional case will be soon available. In a seaway further dependencies arise upon the wave characteristics.

2) The linearisation of the damping term is a rather crude procedure. It may lead to failure when large amplitudes of motions occurs e. g. in the case of roll; however, in the case of pitch and heave this simplification is not so objectionable since here the overwhelming part of the damping is due to <u>wave</u> generation, for which the linear theory is a good working hypothesis. The damping of heave and pitch is strong; defining a dimensionless coefficient

$\varkappa = \frac{N}{\sqrt{M_z' c}}$ $\varkappa$ is of the order of 0.4-0.5 $\quad \varkappa \approx \frac{\Delta}{\pi}$ where Δ is the logarithmic decrement referred to the total period.
In fact, depends upon the frequency parameter F_{Ω} speed of the ship, etc.

(3) So far the restoring force cz has been determined from purely hydrostatic condiderations. We mentioned already that the linearisation may become objectionable when dealing with roll. Neglecting this case for the moment we have to sta state that in general the "spring constant" c must depend up upon hydrodynamic effects due to the speed of advance, the seaway formation and the ship oscillations, i. e. the actual pressure distribution. Not too much is known about these effe fects except that moderate speeds do not seem to effect very seriously this "constant". But definitely serious attenpts mu must be made to determine the actual pressure conditions arou around the ship in the case of roll.

(4) Finally, the calculation of the exciting forces and moments so far rested on the Froude - Krylov hypotheis, following which the pressure distribution in a wave is not altered by t the presence of a ship. In a first approximation the pressures can be considered as hydrostatics when the influence of the w wave structure on the pressure is considered the deviations f from the hydrostatic assumptions and its effects are denoted by Smith effect. The obviously inconsistent Froude-Krylow hypothesis gives nonetheless a reasonable picture of forces e exerted on the ship in long waves when the speed of advance is moderate.

Dealing with regular waves the most important parameter is the range λ/L of wave length over ship length. Within the range of the linear theory motions are proportional to the wave hight or steepness.

Numerous attempts are being made at present to consider th e the influence of hydrodynamic effects on the generalized exciting forces, So far results have been obtained for wholly s submerged bodies moving on a straight horizontal path by Havelock for the spheroid and Cummins for a rather general class of bodies of revolution generated by a line-doublet distribution. It is to be expected that Cummins method will yiels many usef ful informations in the future. Amongst other things a periodic vertical force arises which for very high Froude numbers varies almost proportionally to the latter.

Further, the wave reflexion causee by

almost proportionally to the latter.

Further, the wave <u>reflexion</u> caused by the presence of a su surface ship has been studied; unfortunately the problem appe appears to be rather difficult whin the ship is advancing.

The determination of motions within the linear r0/a range is a matter of routine; in a regular seaway forced osci cillations are the most interesting subject. Pitching $\bar{\psi}$ and heaving amplitudes $\bar{Z}$ may be expressed in the form:

$$\frac{\bar{z}}{\bar{r}} = Z\left(\frac{\lambda}{L}\right)\mu_z \quad \text{and} \quad \frac{\bar{\psi}}{\bar{\vartheta}} = \Psi\left(\frac{\lambda}{L}\right)\mu_\psi$$

where the μ are the resonance factor ; $\bar{r}$ and $\bar{\vartheta}$ the wave hight and slope amplitude respectively, Z and Ψ functions dependent upon the ship form and the ratio λ/L.

From a scientific (method logical viewpoint, one of the mo most.important contributions in this field is a paper by Stok <u>Stoker</u> and Peters in shich the behavior of a wedge like ship (Michell ship) has been treated. The results of the first app approximation so far obtained cannot yet be applied to actual ships; the only slight objection against this fine piece of work consists in the fact that the authors did not state t this difficulty explicitly.

A thrilling subject is the <u>stabilization</u> of motions in a seaway. Following practical needs two principles can be dis distinguished: Reduction of absolute motions and adaptation o of the ship to the wave surface. So far only roll stabilisation has been actually developed because of the smallness of hull damping in this case which may lead to a large magnification factor and thus to large angles of roll close to synchronism, and relatively small exciting torques which are easier to handle. Fins and tanks are promising devices. Howev ever, in principle fins can be used for a reduction of pitching,too, though the forces involved become tremendous.

For the determination of resistance increase experienced by a ship moving in a seaway one relies so far on model experiments; especially self-propelled tests are appropriate. In the case of surface ships the calculation of the additional resistance due to waves encounters serious difficulties; as a first step one restricts oneself to the investigation of a ship performing forced oscillations in calm water. Even here different answers are found following different assumptions made. Reference is made to papers by Havelock, Brard and especially by Japanese writers.

Reviewing the ample field we may conclude that our attempts to deal with seaworthiness so far have a rather tentative character and that much important and fruitful work remains to be done. In fact, seaworthiness is at present the most thrilling subject for the hydrodynamicist, working in our field.

Accelerations and stresses due to impact forces may limit the performance of high speed ships more seriously even than power considerations. Possibly the use of active stabilizers will reduce accelerations due to heave and pitch. However, their feasibility has not yet been proved and, in addition, hereby one may run into serious troubles caused by hydrodynamic impacts. It has been already established that the irregularity of the the actual seaway plays an important part in this kind of research which complicates the whole problem tremendously.

Some remarks on the computation of extraneous forces causing stresses of ships may be appropriate. Starting from the weight and buoyancy distribution in calm water one obtains shearing forces and bending moments. Similarly, results are then obtained assuming static conditions in a seaway. This coarse approach proposed already by Euler represents the standard method on which the determination scantlings is based; it has fulfilled its putpose rather successfully. A more satisfactory solution requires the consideration of dynamic and and hydrodynamic effects - inertia forces and the actual pressure distribution of the ship. Because of lack of theoretical knowledge fullscale measurements have been made; the best known ate those on the San Francisco and the Ocean Vulcan. Only recently promisinf attempts have been made to apply to the solution of the problem involved.

As mentioned before beside seaway forces which vary comparatively slowly with the period of encounter of waves other forces of an impact character may arise. Although appropriate hydrodynamic concepts for dealing with them have been proposed already by Cauchy; it took a long time till actual use has been made of these means. I am indebted to Dr. Fuchs for information on pertinent work in the field of civil engineering which lags, however, behind investigations in the sea plane branch on which our present ideas are based.

An important group of these effects are summarized under the notation "slamming" where slamming roughly means the impact of the ship bottom or othera approximately horizontal parts of the hull on the free water surface. The theoretical treatment can be borrowed as far as the principal features are concerned from seaplane theory, the effect can be explained by abrupt changes in added mass values as shown in a truly classical paper by H. Wagner which represented the backbone of all later research in this field.

The application of Wagners theory to problems of naval architecture is not new. Because of confusing statement made in literature we started new investigations at the TMB 1951 the results of which can be found in current reports of this Institut by Dr. Szebehely and collaborators. As usual the problem in naval architecture turns out to be more complicated. than in the seaplane field and much remains to be done in determining quantitive results. This applies especially to the study of impact influence upon shea shearing forces and bending forces experienced by the ship as a girder. Full scale experiments (San Francisco and Ocean Vulcan) indicate that these girder stresses due to slamming d do not exceed about 30% of the measured "normal" saggings str stresses. These values may be of course incidental; rather crude results derived by Lewis from model experiments point at a somewhat higher maximum value.

We are indebted to Dr. Akita for a thorough model investigation on stresses experienced by a ship in a seaway including those due to slamming. The latter stresses following his research may reach in the worst case almost the triple amount of the sagging stress calculated by the standard method. If this result were applicable to normal oceangoing ship forms it were truly alarming. However, the occurrence of extremely high lslamming stresses can be explained by the form of the model, used by Dr, Akita; a high fullness c_p =0.83 wallside sections, a very hard turn of bilge and especially a completely flat bottom. It can therefore be concluded that in actull ship forms the slamming stress will be much more moderate. We are looking forward in the near future for results derived from finer ship models by Dr. Akita himself and the TMB.

It is well known that slamming has caused rather serious local damages in the forebody of full flat bottomed ships. To come closer to actual conditions the theory should consider elastic deformations as has already been done in the case of seaplanes. It seems possible, however, that in the case of good ships the elasticity of normal bottom constructions does not produce much changes in the impact force as compared with a completely rigid construction.

Because of certain restrictions imposed on the model it m may be premature to make far reaching conclusions from Dr. Akita's present investigation on the speed dependency of slamming effects; this statement has been kindly endorsed by Dr. Akita himself.

I wish to emphasize that similar to the vertical impact dangerous horizontal forces may arise when a ship is heading

I wish to emphasize that similar to the vertical impact dangerous horizontal forces may arise when a ship is heading with high speed into large steep waves. - Let me mention a story: during the war we designed a hydrofoil boat which on trial in a seaway was tested so severely that it occasionally was burried by waves. The bottom of the hull had been designed following Wagners theory and did not suffer; however, almost at deck level where the waterlines were rather blunt heavy buckling of the sideplates occurred.

Finally we should speak about the seaworthiness of the class of hydrodynamic vessels. The failure of gliding craft in a seaway is almost obviously explained by the permanent occurrence of hydrodynamic shocks (slamming of bad kind on every wave). In the same way the superiority (with respect to seaworthiness) of hydrofoil vessels over displacements ships for comparable size can be proved provided the air gap between the water surface and the bottom of the hull and the form of the latter are such that no heavy impact arise.

VIBRATIONS

In the precedent chapter on seaworthiness the artificial character of the separation between hydrodynamics and theory of structure already has appeared especially when we dealt with slamming. The theory of ship vibrations is essentially on the other side of our fence i. e. in the field of elasticity. We mention vibrations, however, here because of three contributions by hydrodynamics on which vibration theory has to rely: added masses, fluid damping, and hydrodynamic exiting forces.

There exist in this field two trends:

(1) The old classical approach tries to predict as accurately as possible the natural vibration frequencies of the hull,

especially those which refer to the ship as a single girder. By properly tuning (e.g. choosing an appropriate number of revolutions) the possible series of exciting forces, synchronism can be avoided. Only recently the problem of forced motions is more consistently approached,

(2) many modern researchers consider the determination of natural frequencies for higher models as superfluous for various reasons; difficulty of reaching the necessary accuracy of results, presence of a large number of natural frequencies etc. They suggest therefore to eliminate the <u>sources</u> of excitations as completely as possible, may these be due to the engine action or to hydrodynamic effects. A prominent promoter of this attitude is Dr. F. Lewis from MIT to whom we are indebted for valuable investigations in the field of ship vibrations.

In the present speakers opinion one should push this idea (2) without neglecting (1). In treating natural [2] forced vibrations [1] and one has to distinguish two matters:

(1) Feeding into the differential or integral equations the proper physical contents.

(2) Obtaining the formal solutions of the above mentioned equations.

Again in both respects much remains to be done. One could fill more than one lecture by this topic alone. However, I have the impression that it is time to finish my rather superficial exposition.