SPLASHLESS SHIP BOWS AND WAVELESS STERNS

by

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SUMMARY

In two-dimensional bow-like flows past a semi-infinite body, one must in general expect a free-surface discontinuity, in the form of a splash or spray jet. However, there is numerical evidence that special body shapes do exist for which this splash is absent.

In the first part of this thesis an attempt is made to demonstrate steady state flow for an arbitrary (non-special) bow shape. Such flows necessarily include a splash jet, i.e. a portion of the incident stream is deflected upward and backward in the form of a jet, which then (in the presence of gravity) falls freely forever. This problem is exactly solved here via hodograph techniques, but only for infinite Froude number, i.e. by letting $g = 0$.

In the middle part of the thesis, conditions are established on the bow geometry in order that it should be splash-free at zero gravity, by solving the mathematical problem exactly using complex variable techniques, assuming a continuous non-stagnant flow attachment at the extreme bow. Then solutions are obtained for finite non-zero gravity by solving a non-linear integral equation numerically. A class of splashless non-bulbous body geometries with a downward directed segment at the extreme of the bow, to which the free surface attaches tangentially, is discussed in detail.

In the final part of the thesis, the flows of interest possess a stagnation point at the attachment point and demand underwater bodies of bulbous type, in order to be splashless. The nature of the solutions is discussed, giving analytical evidence, and a numerical scheme is then presented. The variation in the bulb shape and

size with Froude number is discussed in detail. Figures and tables are given at the end of the each chapter.

TABLE OF CONTENTS

GENERAL INTRODUCTION

One of the most important problems in ship hydrodynamics concerns the wave resistance of the ship. In particular the resistance is strongly influenced by the flow pattern around the bow. The search for means to reduce or possibly to minimise this resistance has taken many directions. So far, one of the most significant solutions has been the development of a bulbous shape bow, that dates back to 700 or 800 B.C.

Due to the lack of adequate mathematical theories and related experimental results concerning the bulbous bow, as well as the added cost in their construction, until the nineteenth century many ships did not seem to have them and so were excluded from whatever advantages might have ensued.

The bulbous bow reappeared in the nineteenth century with the advent of mechanical propulsion. As a result of various developments in war-ship design, this bulbous bow became a distinctive feature at the beginning of the twentieth century. It was on hulls of this type that David W.Taylor[7](1911) did his experiments and observed a reduction of resistance and a hydrodynamic superiority in higher speed ranges. Taylor was convinced that a bulbous nose located deeply at the forefoot and of rounded shape would produce less wave drag, because of a newly created pressure pattern in the vicinity of the bow wave. Since then, bow wave phenomena have been studied experimentally and theoretically by many outstanding hydrodynamicists. From the modern hydrodynamicist's point of view, the wave resistance of the ship can be dissected into two parts: one associated with the non-breaking waves that are radiated far away from the bow, and the other associated with the wave energy that is dissipated by breaking close to the bow. This situation was first described by Froude(1955).

The non-breaking part is the one which was of main concern to Taylor, and the classical work on use of bulbous bows to reduce non-breaking wave resistance is that of Inui [13,14,15,16,17]. The breaking resistance received little attention until Baba[8,9] showed its importance. Since then, many researchers have studied the bow wave-breaking both experimentally and theoretically. Dagan and et al [11], Inui et al [12] and Baba[10] demonstrated the effect of reducing wave-breaking resistance by a bulbous bow. The so-called breaking waves are not so simple that they can be described in a few words. The term bow-wave breaking was used by Baba[8] for the white waves which looked like a necklace of pearls surrounding the ship. This term implied a plunging type of breaking, as defined in Peregrine[8], which breaks down vortically at the bow, and which was related to a spray jet by Dagan and Tulin[11]. In the latter theoretical study of the phenomenon for two-dimensional steady flow, breaking of the free surface was assumed to be related to a local Taylor instability, and application of the stability criterion determined the value of the critical Froude number which characterized breaking. Dagan and Tulin's high Froude number solution was based on a model of a jet detaching from the bow and not returning to the flow field.

This free streamline discontinuity in the form of a spray jet was later discussed by Tuck and Vanden-Broeck[2] for the flow around semi-infinite bodies. They called flows without such jets "splashless" and pointed out that in general if the flow direction is reversed, so solving a stern rather than bow flow problem, a train of waves can be expected at downstream infinity. On the other hand, if one has been able to construct a special stern flow without such waves, that flow can be reversed in direction to yield a splashless bow flow. Examples of such near-bow or near-stern flows were computed by Vanden-Broeck and Tuck[3] using series expansion in the Froude number, and also by Vanden-Broeck, Schwartz and Tuck[4]. These authors showed the existence of downstream waves for stern flows, but were not able to find continuous solutions without waves because of the restricted geometries they considered. However their work suggested that the wave-free and splash-free property may exist only for specially selected body geometries. Later, Vanden-Broeck and Tuck[5] studied linear and nonlinear free-surface flows under gravity in a two-dimensional framework, in which a disturbance was caused to an otherwise uniform stream by a distribution of pressure over the free surface. Even though such a disturbance, in general, creates a system of trailing waves, they observed the existence of special disturbances that do not have waves. Their work strongly suggested the existence of special splashless bow geometries. The investigation made by Schmidt[1] using linearized theory has also suggested such bow flows.

The flows of interest can possess a stagnation point at the attachment point, or alternatively can involve tangential (continuous) attachment. Tuck and Vanden-Broeck[2] demonstrated numerically one such bow shape with a stagnation point, and further suggested that those bow flows in which the splash drag component can be eliminated are of a bulbous character. These authors, using a numerical scheme, observed that a train of waves is present at infinity, downstream of a stern or upstream of a bow, and then they succeeded in a search for that particular body geometry which made the wave amplitude vanish.

Subsequent work by Tuck and the present author (1985)[6] is contained in chapter 2, which concentrates upon the tangential attachment case. The corresponding mathematical problem is exactly solved here for infinite Froude number by letting $g = 0$ and then, for finite Froude numbers, a special numerical scheme which always forces itself to converge to a waveless solution is presented. This is achieved by letting the scheme estimate one of the unknown parameters determining the bow geometry. The results obtained seem more suitable for a waveless stern rather than for a bow, since all the so-derived bodies (which are in general *not* bulbous) demand a downward slope at attachment.

Chapter 3 of the thesis concentrates on splashless and waveless bows which involve conventional-type bulbous bows with a stagnation point at attachment. It is proved that such a flow has a locally horizontal free surface at attachment, if the angle to the horizontal of the body at the stagnation point is greater than 60^0. A numerical scheme similar to the above mentioned is then employed to obtain only splashless solutions, by allowing the scheme to change the body geometry accordingly. Numerical evidence indicates that wave-free stern flows, or equivalently splash-free bow flows with a stagnation point at attachment, demand underwater bodies of unique bulbous shape for $F > 0.54$, where F is the Froude number based on the draught of the ship. For $0.50 < F < 0.54$, this unique shape is non-bulbous and essentially rectangular. For $0.45 < F < 0.50$ there seems to exist two or three distinct solutions and consequently two or three quite different bulb sizes that allow splash-free flows, and for $F < 0.45$, many solutions exist. The existence of many solutions for small Froude numbers ($F < 0.45$) supports the conclusion that body geometry is arbitrary in this range, in which gravity is effectively infinity and no stern creates waves.

A large collection of results is included, generalising the single case presented by Tuck and Vanden-Broeck[2]. In particular, variation in the bulb shape and size with Froude number is discussed in detail.