'dyalling', however, we find it there spelt 'plaines', and this characteristic indifference of the age to consistent spelling has helped to confuse the issue. But it is John Robertson who first unambiguously defines Plane Sailing and speaks of 'principles' from which it was 'deduced'. To those hard-bitten mariners who still continued to prefer the old-fashioned chart, it was because it was simple, plain, and straightforward: 'all plain sailing' in fact.

Early Pole Star Tables

from Lieutenant-Commander D. W. Waters, R.N.

I THINK Professor Taylor and I are at cross-purposes in our discussion of the influence of scientists upon the art of navigation before the nineteenth century.* Dr. Freiesleben expressed the view that until 1800, 'when our technical age began', there was a big gap between what interested scientists and what the seaman could understand and apply, that men of science were too remote from practical requirements.[1] The implication was that scientists were not concerned with seamen's problems nor seamen with obtaining scientific help. I pointed out that whatever the situation in the eighteenth century might have been, in the sixteenth and early seventeenth centuries improvements of a radical nature were made by scientists, working with and for seamen, in the means of practising the art of navigation, in particular by English scientists working in the latter part of the period under the aegis of Gresham College and the East India Company.[2] This is historical fact, little known perhaps, but none the less fact. I certainly never intended it to be understood that the seaman–scientist relationship peculiar to this period and resulting in such important developments typified, to use Professor Taylor's expression, 'the degree of cooperation between sailor and scientist prior to the nineteenth century'. I intended it to be understood as being descriptive of the situation or relationship peculiar to the period in which it occurred, roughly 1550–1640 and more particularly 1598–1637.

As the period during which this relationship existed closed over a century and a half before the French Revolution began I felt it desirable to draw attention to it for several reasons. First, because its occurrence invalidates Dr. Freiesleben's generalization about the scientific gap; secondly, because it suggests that 'the approach between seamen and scientists' in the nineteenth century was, in fact, a *rapprochement* and not an unprecedented *liaison*; thirdly, because the seaman–scientist relationship of the sixteenth and early seventeenth centuries had a very distinct effect upon navigation as practised up to that time. But this fruitful cooperation between scientists and seamen in the sixteenth and early seventeenth centuries is a subject quite distinct from that of 'complaints through the centuries . . . about the way that masters clung to outmoded and faulty practices' cited by Professor Taylor.[3] However I would like to pursue this latter subject a little further as it is of current interest.

In the last resort navigation is a personal accomplishment. No matter what knowledge and aids may be available to a particular navigator their practical

* Taylor, E. G. R. (1955). Early pole star tables (Forum). This *Journal* **8**, 288.

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value, so far as he is concerned, (and he is the only person who counts when it comes to determining the ship's position and movements) lies in his personal knowledge of navigational techniques and in his—and no one else's—skill in turning that knowledge to practical use. His knowledge will be derived from his instruction and personal study, his skill from his instructors, and his own natural aptitude developed by practice. Navigators are individual human beings, some are competent, some less competent. This is as true of navigators of the past as of today. Consequently in discussing the practice of a constantly developing yet individual accomplishment such as navigation it is not possible to do justice to its individual practitioners by generalizations. One has only to follow the current annual toll of wrecks, strandings and collisions at sea and in the air to be reminded that 'masters who cling to outmoded and faulty practices' in navigation are a constant feature in the history of the sea and air. Like the poor they are always with us. They represent, it is true, a poor standard of navigational practice—an inefficient type of navigator, if you will—but not the only standard or type. Their failure to use, or their misuse, of the latest navigational aids available to them individually is a reflection of their low or inadequate personal standard of education or skill, not of 'the degree of cooperation between sailor and scientist'. Rather is their failure to use, or their misuse of the aids, proof positive of antecedent cooperation between sailors and scientists to provide those aids. It was precisely this cooperation in the early decades of the seventeenth century that made revolutionary aids (including the means of calculation) available to navigators. Many promptly used them. Others did not, or used some, but not all of them. It was largely up to the individual but not entirely because the Trinity Houses only licensed pilots and masters when they were satisfied that they were proficient in navigation.

Thanks to the development of printing in the latter half of the fifteenth century the rapidity, ease and extent with which knowledge could be disseminated, and preserved, and transmitted from one generation to another was immeasurably increased. Amongst other things it meant that one man's invention could become the common knowledge and, if desired, the common property of many. In so far as progress in the art of navigation is concerned one result was that it was not the degree of cooperation between sailors and scientists in general that counted but the intellectual ability of particular scientists bent upon solving particular navigational problems, the financial means and time at their disposal, and their willingness or obligation to publish their results. From about 1600 to 1640 in England these conditions were satisfied to an unprecedented degree. Consequently a small number of scientists worked a revolution in the art of navigation as it *could* be—could be, but not necessarily was—practised by *all* navigators of sufficient intelligence and skill. The question of which ones practised the latest methods was fundamentally a question of education—the classic contrast between the 'scientific' and the 'empirical' navigator of the 1630's is provided by the journals of Captains James and Foxe in their voyages to the north-west, both made independently in 1631.

In a number of brilliant articles in this *Journal*, Professor Taylor has shewn how two Elizabethan scientists, Dr. Dee and Thomas Hariot, worked successfully on the solution of what at the time were outstandingly difficult navigational problems. Their works, however, were never published; they remained in manuscript. As a result the fruits of their labours were confined to a select *coterie* of sea captains whose confidential knowledge died with them. But this

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does not mean that these men did not practise a form of navigation much in advance of that generally known and practised in their lifetime, and even later, nor that it was not the result of scientists solving nautical problems. As Dr. Dee and Hariot both worked largely in secret (the one mostly for the Muscovy Company, the other for Sir Walter Raleigh) it is scarcely surprising that William Borough should complain of scientists criticising navigational techniques without producing improvements. He wrote in 1578. Dr. Dee, as Professor Taylor has herself shown, had by then already formulated the solution of the nautical triangle by trigonometrical methods and, within a dozen years, both Hariot and Wright (the latter working for the Earl of Cumberland) had in fact solved (in secret) the outstanding hydrographical and navigational problem of the time—how to produce a 'Mercator chart'.[4] Within ten years of Borough's death Gunter's Sector was to bring Dee's mathematical and Wright's hydrographical discoveries into a practical working relationship. The 1576 complaint of Digges, the scientist, which called forth William Borough's riposte was an echo of the navigator Stephen Borough's petition of the early 1560's to the Crown that English navigators should be trained in and be made to use the latest navigational techniques. When Hakluyt pressed, as he did in the 1580's and '90's, for a navigational lectureship, even if he knew of Gresham's will, he could not foresee when Gresham College would be established nor that its early professors would in great measure fulfil the tasks he envisaged for a navigational lecturer.

Invention depends both upon individual fertility of ideas, and upon individual energy to bring them into being, and frequently upon institutional vitality also. In the sixteenth and early seventeenth centuries the Trinity Houses played a key role in England in establishing and maintaining a minimum standard of navigational knowledge and skill. But even in the sixteenth century the Trinity House standards and influence fluctuated widely—according as the energy and accomplishment of the officials varied. It seems from the evidence available that from the middle of the seventeenth century the authority of the Trinity Houses over navigators dwindled. The disruption caused by the Civil War seems to have had much to do with this. Similarly the vitality of Gresham College fluctuated, and after the middle of the seventeenth century its authority and influence in the scientific field gave place to that of the Royal Society, the Savilian Professorships at Oxford, and the Royal Observatory. Again the Civil War seems to have been an important factor in this process. Further, the post-Civil War Gresham professors do not seem to have been as personally interested in navigational problems as their predecessors.

I do not wish to venture beyond the pre-Civil War period but where Professor Taylor has led I must follow. When, in 1599, Wright published in full his epoch-making discovery of the means of making charts on Mercator's principle he pointed out that the outstanding problems then remaining were the means of determining longitude accurately and the determination thereby of the correct longitude of every charted position. They were problems, he said, on whose solution he had neither the means nor the time to spend. Even then the true means of finding longitude, it was well known, would have to take some form of accurate time-measuring device. I do not know what Captain Harrison's proposal, of the 1690's, for finding longitude was, but I suspect it was not a practical solution of the time-measurement problem. If this was so the Royal Society was surely right in not wasting time on it. The fact that Captain Harrison saw no azimuth compass in the royal ships in which he served—presumably in

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the 1680's to 1690's—gives us indeed an interesting glimpse of the deficiencies of the navigational equipment of the ships in which he served, but it tells us nothing about the up-to-dateness of the navigational equipment of royal ships of the period I was discussing—some fifty to one hundred years before; still less does it illustrate the degree of cooperation between seamen and scientists in that period.

Both Mr. Postlethwaite and the ingenious Mr. Harrison writing about 1758 were doubtless quite correct when they said that 'seamen had very little concern about the perfecting of the discovery of the longitude'. Seamen knew that technically the task was quite beyond them, just as today the perfecting of Decca or some other navigational system is quite beyond the ordinary navigator. Furthermore the bulk of seamen practising navigation do so as a means to an end —to get a ship from A to B. They want to know the 'how' far more than the 'why'. Navigation is just one of a great many, often more pressing, preoccupations of their life at sea. Thus John Robertson in saying that 'most of our mariners belong to the class of readers who merely wish to learn the rules by rote' described a situation that was as true of his time as it was of earlier ages and is of the present age. Furthermore Captain Topley, Principal Examiner of Masters and Mates, commented in the same Forum, but on 'Navigating on the Spheroid', in 1955, 'Sailings are taught . . . to students of about the age of fourteen or fifteen. . . . It is not until much later in life that the student's mathematical knowledge is sufficient for him to understand and appreciate the finer points of navigation'.[5] These, as he implied, are frequently, as in the past, of no practical importance to 'most of our mariners' and, it may be added of insufficient interest to occupy them, *vide* the comparatively small response to the recent investigation into the accuracy of sights at sea. But this in no way reflects a gap between scientists and seamen, either today or in the sixteenth and early seventeenth centuries. No more does the fact that it would be indeed an 'exceptional sailor' who questioned what he read in his manual in the sixteenth and early seventeenth centuries. It would be today. He would be even more remarkable if he had the time and facilities to start querying the products of the Nautical Almanac Office, particularly over differences of stellar correction of little practical significance. As Professor Taylor points out the polar distance of 3½° in current use in the sixteenth century was the figure given by Portuguese astronomers around the 1480's, although by the middle of the sixteenth century it had been diminished by precession. However the very fact that it was provided in the first place by astronomers is proof of close liaison between the scientists and seamen who compiled the original 'rules of navigation' upon which later manuals were based. Again it was this particular and indeed limited both personal and temporal relationship that counted, not the general relationship, for the number of navigators involved was small until the sixteenth century; then the increased demand for navigational rules was satisfied largely by printing. But to revert to the Pole Star tables.

Navigators' observations were subject in the sixteenth century to a variety of observational errors which in practice limited their accuracy at sea to the order of $\pm 30'$ even for the most proficient. For a number of practical reasons they can as seldom have taken Pole Star sights as did navigators of the seventeenth century. Even in the early seventeenth century, when much superior instruments, though still open-sight, were available, navigators, to judge from the surviving English journals, rarely made a Pole Star observation and never any other stellar one.

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It is surely, therefore, not remarkable that seamen of the period I was discussing accepted the scientists' published polar distances of the Pole Star, natural that it should be a scientist, an astronomer, who should correct them, and that seamen should accept his corrections. Surely the fact that in 1599 a scientist should correct and publish stellar corrections for the benefit of all navigators supports my view that in England at the close of the sixteenth and opening of the seventeenth centuries, there was considerable scientific cooperation on the solution of nautical problems. I recognize that, as in the eighteenth century, the interest of the scientists who prepared the stellar tables was greater in the use of stellar observations for position finding at sea than was that of the seamen for whom they prepared the tables, and that this was because the practical difficulties in the way of taking reliable stellar sights at sea were usually greater than the scientists supposed. But when my generation was taught its navigation considerable space in the navigational manual used was still devoted to lunars, although in practice lunars were virtually never used at sea by practical navigators. This will suggest that the gap between scientists and seamen in the twentieth century is comparable to that between scientists and seamen in the sixteenth and early seventeenth centuries. This view would not appear to be an exaggeration when it can be related on unimpeachable evidence that in this year of grace the navigator of a large passenger ship of a world famous line takes his daily sights by a single celestial observation timed by a fifteen-second sand-glass!

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Dr. H. C. Freiesleben writes:

It would appear that certain misunderstandings exist between Lt.-Cdr. Waters on the one hand and Professor Taylor and myself on the other. On the question of the use of the Pole Star for navigation I find confirmation of Professor Taylor's view that prior to 1800 a wide knowledge of scientific principles among sailors was lacking—in Europe by and large since the Age of Discovery—whereas Lt.-Cdr. Waters shows, from his special knowledge and from data not generally available, that, as regards England, such principles were fairly well understood in the decades before the Civil War.

There is, of course, no doubt that special circumstances have always existed everywhere. Without a certain relevance to its practical application the work of the Junta de los Mathematicos in Portugal before 1500 would have been unthinkable; Galileo's negotiations with Spain and Holland about the use of the eclipses of the moons of Jupiter to determine longitude at sea would also have been impossible had there not been practical men in both countries who understood these scientific possibilities. So far Lt.-Cdr. Waters must be acknowledged to be right, and not only in regard to English conditions; but, in my opinion, one cannot speak of a widespread application of these conditions since the data to which Lt.-Cdr. Waters refers were never published.

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Since about 1800, however, a general interest in scientific questions has existed in nautical circles. Not only a small circle of practical men, as for instance those who belong to the Institute of Navigation, but many others who do not express their views are interested in scientific developments and follow them up. This general picture is not affected by an isolated instance of the use of an hour-glass in 1955. Professor Taylor must be understood in this sense, and I share her view.

A Note on the Relative Wind

from Captain Brett Hilder

In taking observations of the wind at sea, and in the study of the theory of air-navigation, it is often found difficult to give students a thorough conception of the relative (or apparent) wind. These notes are put forward to help instructors and others interested.

It is recorded that one of England's early Astronomers Royal went sailing on the Thames about 200 years ago, and what he learned that day made an advance in the science of astronomy. The Astronomer Royal was with some professional sailors, who must now be spiritual members of the Institute of Navigation. The learned gentleman was the Reverend Dr. James Bradley, who gave up his vicarage to become a professor of astronomy. The day in question had a wind of force four or five, but it was a steady wind, and the boat was tacking frequently.

At the masthead she wore a pennant, referred to by the doctor as a 'vane', and he noticed that it tailed away steadily enough down wind. But every time they went on to the other tack the direction of the pennant altered. The doctor was surprised that the wind should happen to alter every time they put about, but on mentioning this to the sailors he was told that the pennant only showed the direction of the relative wind, depending upon the direction and force of the true wind and the direction and speed of the boat, and their resultant changed every time they went about. How the sailors explained this without the aid of diagrams or algebra I don't know, but the doctor went back to his study of the aberration of the stars with just the clue he needed to solve the puzzle.

Perhaps I should mention that this annual aberration of the stars is quite a small amount of angular displacement, and it is remarkable that the astronomers of those days could detect it with their comparatively crude instruments. The aberration is caused by the speed of the Earth in its orbit compared with the speed of light, giving a proportion of one part in about 10,000. This gives a minute angle of displacement, in the same way as 'angle of drift' in an aircraft, or 'leeway' for a ship at sea. While an average angle of drift might be 4° for an aircraft, the angle is less than one minute of arc for aberration of a star.

Dr. Bradley's lesson in seamanship occurred about September 1728. During the next 200 years the pennants of ships continued to indicate the relative wind, except when they were at anchor, when the pennants would show the true wind. To be precise, the 'headwind' caused by the course and speed of the ship must be corrected to course made good and speed over the ground by