seldom agreeing, and when they repeat their observations they will find a new difference' (Zaragoza 1876: II; 363–364).) Furthermore, not only would these factors, even without being coupled to human errors, have tended to make an observation difficult, but they would have rendered an accurate observation virtually impossible, except by sheer chance or luck. They would not, however, have caused a consistent error; and even though a consistent error might have resulted from one or other of the factors which have been suggested in the preceding paragraph, their consistency would have been destroyed by the inconsistencies caused by the instruments or techniques of observation.

The extent of any error can only be gauged in relation to an identified landfall, and whilst some writers write blithely about consistency of error, they seem to fail to appreciate that in a transpacific voyage on which few landfalls were made the instances in which a recorded latitude can be checked represent but a small percentage of the total number of latitudes logged. To suggest, for instance, that a particular navigator showed a tendency to a southerly error in his latitudes on the strength of a few checks against identifiable landfalls (identifications which may in any case be disputed), when those latitudes may represent a very small proportion of the latitudes recorded, seems to be rather a rash assumption. There may well be support for this view in the latitude which Gallego observed at Estrella Bay, Santa Ysabel (Solomon Islands), which, if the normally accepted identification of the bay is correct, was only in error by $-5'$. If any of the observations which Gallego recorded were made on land and with great care, this was certainly one of them. This being so, its relative accuracy and its minus error would seem to indicate that in this case at least no cause existed for a consistent error, and that the errors of the other observations were the result of a variety of factors all tending to inconsistency.

BIBLIOGRAPHY

Engelbrecht, W. A., and Herwerden, P. J. Van (1945). *De ontdekkingsreis van Jacob Le Maire en Willem Cornelisz Schouten in de Jaren 1615–1617 Journalen, Documenten en Andere Bescheiden*. . . . The Hague.

Gallego, Hernan. *Relación*. MSS in the Alexander Turnbull Library, Wellington, N.Z.; Archivo General de Indias, Sevilla; British Museum, and Museo Naval, Madrid.

Guppy, H. B. (1887). *The Solomon Islands and their Natives*, London.

Sharp, A. (1960). *The Discovery of the Pacific Islands*, Oxford.

Wallis, H. (1954). *The Exploration of the South Sea, 1519–1644*. (Unpublished D. Phil. dissertation, University of Oxford).

Zaragoza, Don J. (1876). *Historia del Descubrimiento de las regiones Australes hecho por el General Pedro Fernandez de Quiros*, 3 vols., Madrid.

Long-range Navigation Aids

from J. E. D. Williams

FOR a quarter of a century now we have struggled in a curiously impotent way with the problem of long-range navigation of civil aircraft and the associated

problem of control of traffic in oceanic control areas. The deliberations of technical conferences of the International Air Transport Association alone during the past 15 years on the subject of Long-range Navigation of Civil Aircraft would fill a library.

The development of navigation has always been retarded by difficulties with the analysis of the operational requirement. It is, for example, inconceivable that if the operational requirement for astronomical navigation had been properly explained to eighteenth-century astronomers, they would have waited for practising seamen to invent the position line almost by accident. As neither the authors of Long-range Navigation of Civil Aircraft (D. E. Hampton and J. R. Mills. This *Journal* **17**, 183) nor any of the speakers recorded in the subsequent discussion are directly involved with the operation of aircraft some remarks on the assumed requirements may be helpful.

I am perplexed at the suggestion that requirements for improvements arise 'as the economic aspects of air operations increase in importance'. The objectives of civil aircraft operations can only be expressed in economic terms. There are no economic aspects of variable importance.

Hampton and Mills are unquestionably right in stating that it is separation standards (and hence the utilizable capacity of the airspace) which determine the requirement for the L. R. navigation system, but it is by no means evident that the requirement is for a permissible failure rate as low as $1 : 10^7$. The point is that, if the system fails, the risk of collision is still extremely remote. Some years ago it was pointed out that without any control the mean free path between collisions in oceanic control areas would be of the order of millions of miles or higher. Although effective control has broken down innumerable times on the North Atlantic due to communication failures, large navigation errors and a variety of other causes, there is not one case of collision on the North Atlantic. The figure 10^{-7} has sometimes been suggested as a maximum acceptable risk of a flight ending in catastrophe. If this is so it may be that a permissible failure rate could be as high as $1 : 10^4$. On a point of detail, this confusion between system failure and its possible consequences appears to extend to Fig. 2 which is entitled 'Chance of *Collision* . . .' whereas the curves are labelled 'Probability of *wing overlap*'. With present altimeter errors, the chance of collision is perhaps 2 orders more remote than the probability of wing overlap when aircraft are nominally at the same altitude. Nevertheless, the derivation of a non-gaussian experimental probability-distribution is most valuable. Although it has sometimes been pointed out on theoretical grounds that gross navigation errors should not show a gaussian distribution and some airlines have observed 3, 4 and even 5 sigma errors at a most unlikely frequency, there have been far too many attempts at requirement analysis on gaussian assumptions.

In expressing the view that the time is past when airlines can afford (on economic considerations) to carry a specialist navigator, Hampton and Mills have been misled. The facts are precisely opposite. The cost of a specialist navigator per unit of production (per passenger mile or per ton mile) has decreased from the Yorks of the post-war era to the VC.10's of 1964 by a whole order. Similarly, the cost of the specialist navigator compared with the cost of other components of the navigation loop has been sharply reduced to the point where he may cost less than the doppler installation alone after provision for adequate return on capital investment. The error is an interesting one. Operators stating their long-term operational requirements to scientists and engineers unconsciously tend to

couch their requirements in terms which make assumptions as to how the requirements are going to be met. Although, in historical fact, trades union pressures have probably played a greater part in determining crew composition policies than some managements would care to admit, there are two excellent reasons why most of us expect that a sound solution to the long-range navigation problem will exclude the specialist navigator. The first is that we cannot see how the traditional skills of the specialist navigator can have much application in a system of the speed, accuracy and reliability we want. The second is that the arbitrary limits of responsibility associated with the terms pilot, navigator, flight engineer, radio operator are becoming obsolete and appear to impede the design of operation for most efficient utilization of the human crew. Hence, the removal of the specialist navigator is not part of the operational requirement —it is an implied assumption on how the requirement will be met.

Hampton and Mills state that 'the number of aircraft accidents which occur through flying into mountains is an indication of the need for the aids to operate down to ground level'. I do not recall any airliner in recent years flying into a mountain as a result of the deficiency of *long-range* navigation. The problem is one which can be covered by short-range navigation systems so that coverage to ground level is surely a desirable rather than an essential feature of an L.R. system.

Reduction to the Prime Vertical Circle

from Charles H. Cotter

'Surprise has sometimes been expressed by mathematicians who have been led by circumstances to look into the subject of nautical astronomy that no method is practised by sailors for reducing a longitude observation to the prime vertical in the same way that an observation for latitude is reduced to the meridian.'

This quotation forms the opening paragraph of the first of three papers[1,2,3] by Mr. H. B. Goodwin, R.N., written in 1904–6 relating to the problem of reduction to the prime vertical. The following description of Goodwin's work in this connection may not be without interest in view of the recent interesting paper by D. H. Sadler[4] in which the author describes the investigations into the same problem made by G. F. Cunningham.

The vast difference, to which Mr. Sadler refers, between proposing and translating into practice, a new navigational table, is exemplified in the case of Goodwin's P.V. Tables. All the intermediate steps between proposing and producing are described with utmost clarity in Goodwin's three papers.

The important difference between the problems of 'Reduction to the Meridian' and 'Reduction to the P.V.' is that in the former, after the body has been reduced to the meridian, the problem of finding latitude is merely one of addition or