27.	Northerly turning error	The errors in a magnetic compass which are a maximum when the craft is headed true north or true south, caused by accelerations in turns.
28.	Plot	To draw courses or tracks on a map or chart.
29.	Pin point	A geographical position established from visual information.
30.	Point of no return	The point on a journey beyond which a craft has insufficient fuel to return to its starting point.
31.	Positioning error	An index error in a pressure instrument depending on the position on the outside of the craft where the pressure is detected.
32.	Position error	See Positioning error.
33.	Position line	A line along which the position of a craft has been established.
34.	Proportional navigation	The altering of course in proportion to the rate of change of bearing of an object in order to achieve interception.
35.	Quickening	The provision of early indications of action from rate information.
36.	Pelorus	See Bearing plate.
37.	Range	A limiting distance or a distance which has been measured directly.
38.	Run	The distance travelled in a certain time.
39.	Running fix	A fix obtained from successive position lines.
40.	Track guide	A navigation system that defines an intended track. (See Section C, Item 16.)
41.	Transit position line	A position line produced when two external objects are in line as viewed from the craft.

'The Schuler Pendulum and Inertial Navigation'

J. A. Lee

Mr. Bell and Professor Stratton have in the October *Journal* shed interesting light on the nature of inertial navigation as applied to navigation around a planet. It is a pity that Mr. Bell has repeated that in such inertial systems vehicle position and velocity are deduced from measurement of acceleration. This idea is certainly misleading so far as understanding error propagation in these systems is concerned, if not actually wrong.

It is a fact that in a typical aircraft inertial navigator the output signal from a nominally horizontally stabilized accelerometer is fed to two successive integrators, but this is neither the whole nor the most essential part of the story except in systems used for comparatively short periods of time, viz. short compared with 84 minutes for systems used on our planet.

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In a system in which this idea of double integration of acceleration is the basic principle, any error in acceleration measurement such as a bias error δf in the accelerometer will lead to a velocity error increasing with time (δft) and a position error increasing with the square of time ($\frac{1}{2}\,\delta ft^2$). This would be the case if navigating on Professor Stratton's hypothetical sphere with no gravitational field. A bias error of 0·003 ft/sec.^{2}, typical of current equipment, would lead directly to a position error of about 80 miles after five hours, not much use for trans-Atlantic flying. In this respect, as Professor Stratton points out, we are fortunate on Earth in having our radial gravitational field, the existence of which enables us to achieve useful long-term accuracy in practical present-day systems.

Signal flow in the over-simplified system depending on integration of acceleration is illustrated in Fig. 1.

FIG. 1.

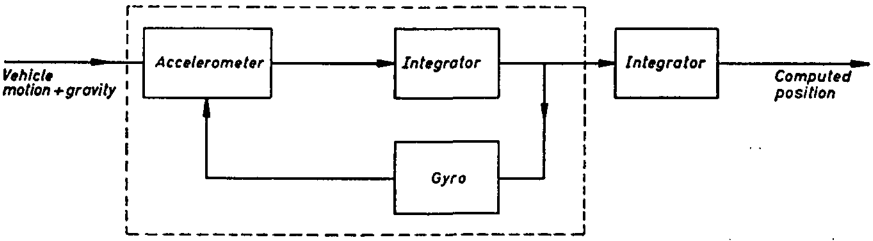

FIG. 2.

For a typical practical system the signal flow diagram is as shown in Fig. 2, which corresponds to Professor Stratton's Fig. 3.

It is clear that there is now a feedback around the first integrator. Happily it is negative feedback, giving a stable, closed loop. Elementary servo theory tells us that the relationship between the input and output of this closed loop is not now that of the integrator in the forward arm, but, for high-loop gain, is the inverse of the gyro characteristic in the feedback arm. In this case the output, the computed velocity signal, is not fundamentally the integrated acceleration input, but rather the gyro angular precession rate. Since the long-term action of the accelerometer is to keep the inertial platform aligned to local vertical, this gyro rate is on average the rate of travel of the vehicle around the Earth. This is true whatever the natural period of this servo loop. The particular virtue of Schuler, or 84-minute, tuning is simply that it eliminates transient or oscillatory errors which otherwise arise from vehicle acceleration. The natural period does not directly affect the average long-term accuracy of the system. The basic principle involved is not integration of acceleration, it is measurement of the changing direction of the gravity vector.

Viewed in this way it is easier to see that an accelerometer bias does not in the long term lead to an acceleration error, but since it causes a platform tilt it leads to a bounded angular distance error. For 0·003 ft/sec.^{2} bias the mean distance error is just over 3 miles ($\delta f/g \times$ Earth radius).

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For an 84-minute system the servo loop gain for 'high' frequency signals is low because of the filtering action of the integrator in the loop. The feedback action is then not very marked and system behaviour is approximately that of simple double integration of acceleration. This is true for missile inertial systems with flight times of only a few minutes, not for aircraft flying for several hours.

This is all well known to the specialists in the inertial field, but not to the increasing number of people who will be coming into contact with such systems as users, maintenance technicians, &c. For their sakes I plead for use of a more accurate description of the basic principle. For most aircraft inertial navigators this is the principle of measuring the change in direction of the local vertical.

Calvert's Manœuvres and the Collision Regulations

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1. Introduction. The aim of this paper, which was presented to the last meeting of Icotas (London, 14 January), is to show how the manœuvres proposed by Calvert (*Journal* **13**, 127) and by Hollingdale (*Journal* **14**, 243) could be incorporated in the International Regulations for Preventing Collisions at Sea. Calvert's objective was, as Hollingdale points out, to establish a set of manœuvres whereby a collision situation may be converted into a 'miss' of specified magnitude. In particular:

(i) the rules of procedure are the same for both craft;
(ii) the manœuvres depend *only* on the direction of the relative bearing of the threat;
(iii) each craft makes an instantaneous turn (assumed sharp) *without* change of speed . . . but a 'measure of speed change when the threat is nearly abeam would provide an added safety margin.'

The manœuvres are set down in Section 2 in full as they might appear if included as one of the 'Rules of the Road'. Brief notes (which would not be included in the Rules) amplify or clarify certain details. The complete set of manœuvres need not necessarily be adopted in its entirety; for instance, the proposal to permit 'reverse manœuvres' might be omitted without prejudice to the rest. The new Rule would replace the present Rules 18, 19, 21, 22, 24 and paragraph 6 of the Annex. Since it is essential that Rules should be readily comprehended, Section 3 is an attempt to put the same concepts into more ordinary and seamanlike language. Because much change to the wording of the Regulations may be deemed inadvisable, an attempt is made in Section 4 to incorporate the maximum amount of Calvert's manœuvres with the minimum of change to the Rules. Section 5 discusses the application of Calvert's manœuvres to all, not only power-driven vessels.

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