DEVELOPMENT OF A FLIGHT LEVEL INDICATOR

By

Robert W Knight and George L Pigman

Technical Development Division

Technical Development Report No 46

January 1945

U S DEPARTMENT OF COMMERCE

CIVIL AERONAUTICS ADMINISTRATION

WASHINGTON, D. C.

TABLE OF CONTENTS

TABLE INDEX

FIGURE INDEX

DEVELOPMENT OF A FLIGHT LEVEL INDICATOR

SUMMARY

This report covers the development of an instrument designed to provide vertical separation between aircraft in flight by relating flight altitude levels to compass directions The instrument consists essentially of an aneroid barometer mechanism providing a uniform measurement of pressure altitude from a fixed standard reference pressure The dial of the instrument is graduated like a compass rose, so that a definite pressure altitude of operation corresponds to each compass heading of the airplane The use of this instrument is suggested as a possible solution to the problem of assigning safe cruising altitudes for aircraft flying along, across, or off the civil airways

Flight testing and use of the instrument over a considerable period of time have indicated the practicability and reliability of the proposed method of flight control

INTRODUCTION

As traffic continues to increase, the necessity for maintaining vertical separations in flight becomes more critical Collisions in the air are not an uncommon occurrence even during favorable weather The possibility of such collisions will become increasingly great with the enormous growth of private and commercial flying anticipated in the next few years As density of traffic along and across civil airways increases, simplified methods of traffic control become more important and desirable Reports from air carriers, personnel of the military services, and the aircraft industry generally, have indicated the desirability of some positive method for controlling cruising levels at definite pressure altitudes which can be readily and accurately determined in all aircraft

The instrument suggested in this report as a possible solution to the problem was developed and tested in 1939 and 1940 A report of its principles and application is being presented at this time because of renewed interest in collision prevention and traffic control procedures

PRESENT TRAFFIC RULES

The present system of airway traffic control is described in detail in the Civil Air Regulations, Part 60 - Air Traffic Rules These specify generally that during instrument flight conditions, eastbound and northbound aircraft shall fly at odd thousand-foot levels and that westbound and southbound aircraft shall fly at even thousand-foot levels. The regulations also specify levels for airway intersections and for off-airway flights when crossing a civil airway No specific cruising altitudes are required during weather conditions permitting contact flight, although aircraft are required to keep to the right-hand side of radio range courses, and conformance to instrument rules when above 1,000 feet is recommended A pilot must have an instrument rating as well as suitable instruments and radio equipment in order to obtain flight clearance under weather conditions requiring instrument flight

The regulations are designed to avoid collisions between aircraft in contact flight by the lateral separation of opposing traffic along the airways, and in instrument flight by altitude separation as well as lateral separation Further, altitude and time separations are provided by airway traffic control centers for aircraft flying routes in the same direction along an airway The regulations governing separation of aircraft apply only to aircraft flying along or actually crossing a federal airway

The present regulations specify flight altitudes along the airways in terms of indicated altitude in feet above sea level, as determined by a standard sensitive altimeter The pressure values used in calibrating an altimeter are obtained by assuming that the sea level pressure is 29 921 inches of mercury, that the temperature at sea level is 15° C , and that the temperature decreases with increase of altitude at the rate of 1 9812° C per thousand feet It is only when these conditions exist that the altimeter will read true altitudes throughout its range, neglecting scale errors inherently present in the instrument

All sensitive altimeters, required by CAR - 60, have scale adjustments with which the instrument may be set for any reference sea level pressure from approximately 28 to 31 inches of mercury Since the barometric pressure may vary along the route of a flight, it is necessary for the pilot to reset his altimeter continuously if the instrument is to give readings of altitude based on the sea level pressure existing in the immediate vicinity of the airplane The procedure outlined in the regulations requires that altimeters be adjusted to the current setting of the nearest reporting control station along the route of flight However, there is on record at least one accident in which two aircraft have collided when each was flying indicated altitudes apparently affording vertical separation, but in which no actual clearance existed because the altimeters of the two aircraft were not set to the same base pressure

SUGGESTED UNIFORM CONTROL OF FLIGHT LEVELS

A uniform method of controlling cruising and holding altitudes has been suggested as a means for simplifying operations and maintaining safety in presently controlled zones, as well as in areas outside such zones This system of control is based upon uniform pressure altitude measurement from a fixed standard base by a type of instrument common to all aircraft One type of instrument which is suitable for such purpose, and which relates flight levels to compass directions, is described in this report The actual application of the system involving the use of the instrument would be determined by those who are concerned primarily with the regulation of air traffic

DESCRIPTION OF THE FLIGHT LEVEL INDICATOR

The instrument designed for such an altitude control system has been designated the flight level indicator The experimental unit, illustrated in figure 1, was developed by the Civil Aeronautics Administration in cooperation with the Kollsman Instrument Company

Basically, the flight level indicator is an aneroid barometer compensated for temperature variation No barometric pressure setting is provided as in sensitive altimeters, but an adjustment is available for resetting the hand if the instrument should develop a zero error The calibration of the instrument is identical with that of the sensitive altimeter and is based on the standard atmosphere formula and a sea level pressure of 29 92 inches of mercury The instrument is provided with a static connection for atmospheric pressure and with an electrical connection for illumination It weighs 1 17 pounds and is designed for mounting on the instrument panel Rim lighting is provided in the conventional manner with a 3-volt electric lamp

The face of the flight level indicator is of standard size It is graduated in degrees like a compass rose, as shown in figure 1, rather than in feet The dial is marked with the cardinal directions N, E, S, and W, and is further subdivided in intervals of 10° A pointer attached to the aneroid mechanism thus shows the direction in which the flight should be proceeding at the existent altitude The pointer makes one complete revolution (360°) for every nominal change of 2,000 feet in altitude to a maximum altitude of 16,000 feet

When the instrument is subjected to the standard atmospheric sea level pressure of 29 92 inches of mercury, the pointer is at W As the altitude is increased, the pointer moves clockwise through a 90° arc on the compass rose dial for each increase of 500 feet in pressure altitude Thus, clockwise movements of 90° , 180°, and 270° indicate increases of 500 feet, 1,000 feet and 1,500 feet, respectively Counter clockwise movements indicate corresponding decreases in altitude

For convenient reference to the compass bearing being flown, a direction marker on the outer edge of the dial can be set manually by a knob at the bottom of the instrument to the desired magnetic heading.

A subdial, which is visible through an aperture below the center of the main dial, indicates flight levels by numbers Each cardinal heading or 500-foot altitude step is designated as a flight level and given a number For example, sea level, W, under standard atmospheric conditions is flight level 0; 500 feet, N, is flight level No 1, 1,000 feet, E, is flight level No 2, 1,500 feet, S, is flight level No 3, 2,000 feet, W, is flight level No 4, and so forth

As altitude is increased or decreased, the subdial rotates slowly and indicates, against a reference index on the fixed dial, the number of the level, or the nearest level, on which the airplane is being flown There are 32 flight levels of 500 feet each, totalling 16,000 feet of nominal altitude, in the range of the instrument

Flight levels 1, 5, 9, etc , are automatically indicated for flights on northerly bearings, flight levels 3, 7, 11, etc , on southerly bearings, flight levels 2, 6, 10, etc , on easterly bearings, and flight levels 0, 4, 8, etc , on westerly bearings On intermediate headings, intermediate levels would be indicated For example, for flights on a magnetic bearing of 60°, and with the rotating pointer of the indicator on that course, a flight level two-thirds of the way between levels 1 and 2, or between 5 and 6, etc , would be indicated The purpose of dividing the progressive steps of nominal altitude into numbered flight levels, as described, is to provide a convenient method of reference between airway traffic control centers, communications stations, and pilots in flight, and also to assist in the preparation of flight plans

Several alternative and possibly simpler systems of flight level numbering might be used For example, a numbered flight level might be taken for each complete revolution of the instrument pointer, or for each 2,000 feet of standard pressure altitude Thus, with such a system, eight flight levels would be used to the maximum indicated altitude of 16,000 feet

APPLICATION

In using the instrument, a pilot would climb to his desired or assigned cruising flight level and then maintain the pointer in agreement with the magnetic bearing being flown. If he subsequently desired to fly at a higher or a lower altitude on the same compass course, he would climb or descend until the pointer of the instrument made one or more complete revolutions and again agreed with the magnetic bearing Thus, in this system of traffic, the pilot has a choice of flight altitudes which are in steps of 2,000 feet

The usefulness of the flight level indicator is limited to cruising and holding-level flight conditions Upon letting down for an approach or a landing, the instrument would be disregarded and attention given to the altimeter and other flight instruments

It can readily be seen, as illustrated in figure 2, that two aircraft arriving at the same point over the ground but flying in opposite directions nominally will be separated by at least 1,000 feet of altitude Similarly, if the two aircraft have paths intersecting at right angles, their nominal vertical separation will be at least 500 feet Two aircraft flying on the same magnetic heading might be at the same altitude unless supplemental control is applied to insure that the two airplanes are flying in differently numbered flight levels It is assumed that for flights along established airways such control would be applied by traffic control centers, the flight level indicator serving to supplement and simplify such centralized direction

For uncontrolled cruising flights other than along airways, the flight level indicator will not provide positive vertical separation for aircraft flying along identical paths However, it may be assumed that for this type of flight, the possibility of two aircraft flying closely identical magnetic headings over the same point on the ground, at the same time, under conditions of poor visibility, and of simultaneously having the pilots choose the same numbered flight level, is extremely remote unless density of such traffic becomes infinitely greater than it is at the present time It further will be noted that with one airplane overtaking another, maximum time is available to avoid collision

In order to be applicable, flight level indicators in all airplanes must have a common reference pressure Therefore, as mentioned previously, no means are provided for making barometric pressure settings in flight The common reference pressure is obtained by setting the pointers of all instruments at West (W) for a static pressure of 29 92 inches of mercury Thus, the flight levels of different airplanes will be positively related even though the barometric pressure for a given absolute altitude may vary with time Although the entire series of flight levels may vary with respect to their actual altitude above sea level, they remain spaced in proper relation to one another For this reason, the flight level indicator eliminates the ambiguities arising in flight level separation as a result of variation between altimeter settings in different airplanes

The flight level indicator cannot replace the altimeter entirely For ground clearance values and airport elevation readings, it still would be necessary to adjust the altimeter to the existent pressure conditions of the zone in which the aircraft is flying For purposes of vertical separation control, however, no reference to an altimeter would be required

The presence of the flight level indicator in an airplane can be of valuable assistance in checking the altimeter Such checking may be performed simply in the following manner The barometric scale of the altimeter first is set to 29 92 The indicated altitude then is compared with the product of the flight level number times the constant 500 The comparison in instrument readings should be made when the pointer of the flight level indicator is at a cardinal point so that no interpolation of the scale is required This method of checking will permit detection of hysteresis, drift, and other errors in the altimeter reading

The flight level indicator can be adapted also to the automatic pilot as a means of controlling cruising altitude In the installation of the instrument as a part of the automatic pilot system, the manually controlled course indicator marker and the indicating pointer would be interconnected to the automatic pilot in such a way that when the marker is set at the desired course, corresponding to a desired altitude or flight level, the automatic pilot will bring the airplane to this level and the pointer will remain on the selected bearing

PERFORMANCE CHARACTERISTICS

The ability of the flight level indicator to provide positive vertical separation of aircraft which are flying different magnetic bearings at the same point over the ground is limited by various factors These factors may be classified in two groups, (1) those which are variable in a random manner and which may cause unpredictable loss of altitude separation, and (2) those which are systematic in nature and which in effect tend principally to change the general pattern of the nominal separation system Included under group (1) are scale and miscellaneous instrumental errors, and inaccuracies in measuring the true existent atmospheric pressure Under group (2) are included the effect of variation of actual atmospheric temperatures from the assumed standard temperature distribution, and the effect of wind in causing difference in bearing between the magnetic heading and the true flight path of the airplane

The standard atmosphere formula, which is the basis for calibration of the sensitive altimeter mechanism, assigns a given altitude to each value of static pressure The difference in altitude registered by the mechanism and that assigned by the formula at a given static pressure is, by definition, the scale error of the instrument Specifications for altimeters usually indicate the allowable limit of such error over the entire scale range The cost of the instrument increases measurably with a decrease in the allowable scale error

In Tables I, II, and III are given tabluations of the original tolerances specified for the four experimental flight level indicators which have been fabricated and which are covered by this report While the total scale error tolerances indicated in the tables are as great as 305 feet, actual instrument calibrations, as shown in Tables IV and V, have much lower scale error values

TABLE I

PERMISSIBLE SCALE ERROR AT TEMPERATURE OF 20° C

Flight Level	Standard Altitude Feet	Pressure Inches of Mercury	Tolerance Degrees	Tolerance Feet (approx)
0	0	29 92	5	25
2	1,000	28 86	10	55
4	2,000	27 82	10	55
6	3,000	26 81	10	55
8	4,000	25 84	15	85
10	5,000	24 89	15	85
12	6,000	23 98	15	85
14	7,000	23 09	20	110
16	8,000	22 22	20	110
18	9,000	21 38	20	110
20	10,000	20 58	25	140
22	11,000	19 79	25	140
24	12,000	19 03	25	140
26	13,000	18 29	30	165
28	14,000	17 57	30	165
30	15,000	16 88	30	165
32	16,000	16 21	35	195

TABLE II

PERMISSIBLE INCREASE IN SCALE ERROR TOLERANCE AT-35° C

Flight Level	Allowable Change Degrees	Allowable Change Feet (approx)
0	8	45
10	12	65
20	16	90
30	20	110

TABLE III

PERMISSIBLE INSTRUMENT ERRORS

Instrument Errors	Test Point Flight Level	Tolerance	
		Degrees	Feet (Approx)
Hysteresis	15	12	65
Hysteresis After-Effect	0	8	45
Case Position	0	5	25
Case Leak	1	8	45
Pointer Movement (Vibration)	0	5	25
Change of Scale (Vibration)	0	8	45

TABLE IV

MEASURED SCALE ERRORS OF FLIGHT LEVEL INDICATOR
(Instrument No 1)

Test Point		Scale Errors in Feet					
		Flight Level Dial			Direction Pointer		
Altitude Feet	Flight Level	+20° C	−35° C	Change	+20° C	−35° C	Change
0	0	−50	0	+50	−11	+27 5	+38 5
1,000	2	0	0	0	0	+11	+11
1,500	3	0	0	0	0	+11	+11
2,000	4	−50	0	+50	0	+27 5	+27 5
2,500	5	−100	0	+100	−22	+22	+44
3,000	6	−50			−11		
3,500	7	0			0		
4,000	8	−50	−50	0	0	+ 5 5	+ 5 5
4,500	9	−150			−27 5		
5,000	10	−100			−16 5		
5,500	11	0			+11		
6,000	12	−50	0	+50	0	+ 5 5	+ 5 5
6,500	13	−50			+27 5		
7,000	14	−100			−22		
8,000	16	−100	−50	+50	−22	−5 5	+16 5
9,000	18	−100			−33		
10,000	20	−100			−27 5		
12,000	24	−100	−100	0	−44	−49 5	− 5 5
14,000	28	−100			−44		
16,000	32	−50	−50	0	−16 5	−38 5	−22 0

TABLE V

MEASURED SCALE ERRORS OF FLIGHT LEVEL INDICATOR
(Instrument No 2)

Test Point		Scale Errors in Feet					
		Flight Level Dial			Direction Pointer		
Altitude Feet	Flight Level	20° C	−35° C	Change	20° C	−35° C	Change
0	0	−300	−300		−16 5	−11	+5 5
1,000	2	−300	−300		−38 5	−16 5	+22
1,500	3	−250	−300	−50	−44	−38 5	+5 5
2,000	4	−350	−350		−22	−27 5	−5 5
2,500	5	−400	−400		−33	−49 5	−16 5
3,000	6	−350	−350		−16 5	−27 5	−11
3,500	7	−300			−27 5		
4,000	8	−350	−400	−50	−22	−38 5	−16 5
4,500	9	−400			−27 5		
5,000	10	−350	−400	−50	−16 5	−38 5	−22
5,500	11	−350			−33		
6,000	12	−400	−400		−11	−44	−33
6,500	13	−350			−33		
7,000	14	−350			−22		
8,000	16	−400	−400		−16 5	−55	−38 5
9,000	18	−400			−44		
10,000	20	−400	−400		−44	−66	−22
12,000	24	−400	−400		−66	−60 5	+5 5
14,000	28	−450	−400	+50	−66	−93 5	−27 5
16,000	32	−400	−400		−55	−88 0	−33 0

A sensitive altimeter usually is supplied with a card which lists corrections to be made to the instrument readings because of scale errors A similar card might be supplied with the flight level indicator which would list the correction in degrees for various flight levels Such correction is not considered practicable, however, as it is desirable that use of the instrument be made as simple as possible

A further possible error in flight level indication is the use of an inaccurate system of static pressure measurements on the airplane It is a practice in some instrument systems to use cabin pressure as the basis for static pressure measurements It has been demonstrated, however, that the cabin pressure may vary in an amount corresponding to several hundred feet of altitude throughout the speed range of an aircraft, independently of the static pressure of the free air Further, it has been shown by test that improperly located air speed tubes will result in static pressure errors corresponding to altitude variations of approximately 200 to 300 feet In using the flight level indicator, therefore, the static pressure errors of any airplanes involved must be allowed as an operational tolerance However, the altitude error from this source in a single instrument can be limited to a value of approximately 25 feet throughout the speed range of the airplane through the use of an airspeed tube of satisfactory design and installation

It should be noted, also, that as in the standard altimeter, the actual vertical separation for a given indicated altitude separation will vary with temperature A 1,000-foot indicated altitude separation will correspond to more than 1,000 feet of actual vertical separation when air temperatures are higher than the standard temperatures, and to less than 1,000 feet of actual spacing when the air temperatures are lower than standard The actual clearance can be reduced to 80 percent of the indicated value under conditions of extremely low temperature

Another limitation is placed on the ability of the flight level indicator to provide positive and precise vertical separation of aircraft because of differences which may exist between the direction of airplane track and the indicated magnetic bearing Two airplanes with an appreciable difference in air speed do not follow the same track when flying on equal magnetic headings in a cross wind and, hence, may have no altitude separation although their actual courses may differ Further, two airplanes following ground tracks of 180° difference in bearing in a cross wind will have magnetic compass readings differing by more or less than 180°, with a resultant variation in their altitude separation The principal effect of wind, as well of temperature variation, is to cause a general systematic modification of the separation pattern and to effect some increase in possibility of collision between aircraft converging along tracks of small angular separation Thus the already existent hazard of collision by overtaking aircraft, as previously discussed, might be slightly increased

In summary, the greatest error affecting the efficiency and safety of the suggested traffic system lies in the magnitude of scale and instrument errors found in the common sensitive altimeter This assumes that flight level indicators are accurately installed and carefully maintained in all aircraft With the present types of instruments available, the probable practical error to be expected for the flight level indicator, including scale, instrument, and static pressure errors, is approximately 150 feet and 175 feet at indicated altitudes of 10,000 and 16,000 feet, respectively

LABORATORY AND SERVICE TESTS

Four experimental flight level indicators have been given laboratory tests and numerous flight tests to determine (1) Accuracy of indication, (2) serviceability and endurance, (3) capacity for remaining in proper calibration under normal usage, and (4) pilot opinion Results of laboratory tests upon two of the indicators, which are typical of the four instruments fabricated, are shown in Tables IV and V It is seen that the maximum pointer scale error present corresponds to an error of less than 100 feet in altitude

Several hundred hours of flight testing in aircraft of the Army, the Navy, air carriers, private owners, and the Civil Aeronautics Administration, have indicated that the instruments function as intended and retain accurate calibration over a period of more than 18 months service

The majority of pilots using the instrument have commented favorably concerning its functioning and favor the employment of non-adjustable indicators for measurement of atmospheric pressures from a common reference base for purposes of flight altitude separation

CONCLUSIONS

1 The use of the flight level indicator, in relating flight levels to compass directions, offers a simple and uniform system for assigning cruising altitudes to all types of aircraft, whether on or off civil airways, and a system in which the possibilities of collision are minimized

2 The flight level indicator, within its limits of error, provides positive vertical separation between aircraft when they are following appreciably different compass courses, and possible but not positive separation when flying nearly identical compass courses Along established airways the instrument would serve to simplify and supplement present methods of traffic control

3 The use of the flight level indicator, which indicates altitudes from a common reference base, is independent of ground reference pressures which might be inaccurately set on the altimeter of an airplane, and eliminates the need for continuous resetting of the altimeter during the course of a flight for the purpose of maintaining proper vertical separations

4 The flight level indicator can serve as a simple and valuable check upon the functioning of the altimeter The altimeter, however, still will be necessary for the maintenance of terrain clearance and for height indications during the landing procedure

5 The flight level indicator may be used in connection with an automatic pilot as a means for automatically controlling cruising altitudes

6 The ability of the flight level indicator to provide positive vertical separation between aircraft is limited by the precision with which the various instruments are calibrated, installed and maintained It is estimated that the maximum probable variable error in flight altitude for an airplane on a given compass course is approximately 175 feet

7 Laboratory and flight testing have demonstrated that the flight level indicator will provide an accurate and simple system of vertical aircraft separation control, and that the instrument will maintain precise calibration over long periods of time.

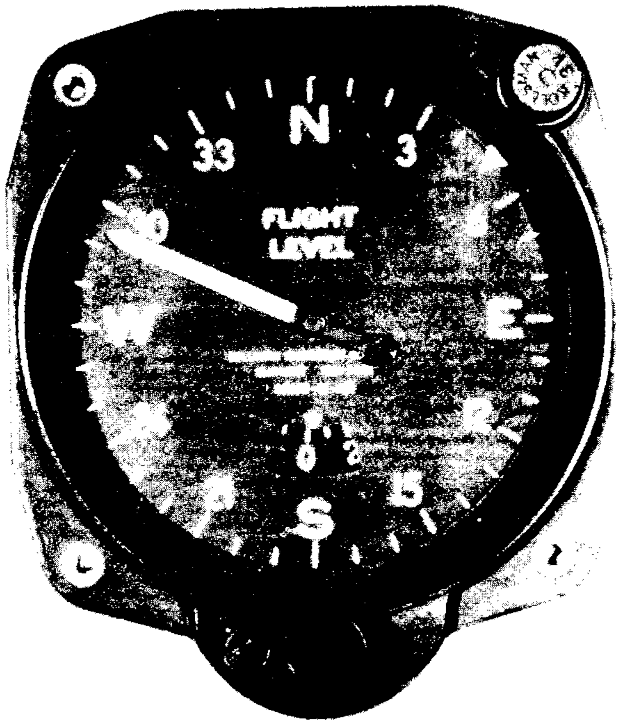

Figure 1. Flight Level Indicator Dial Face .

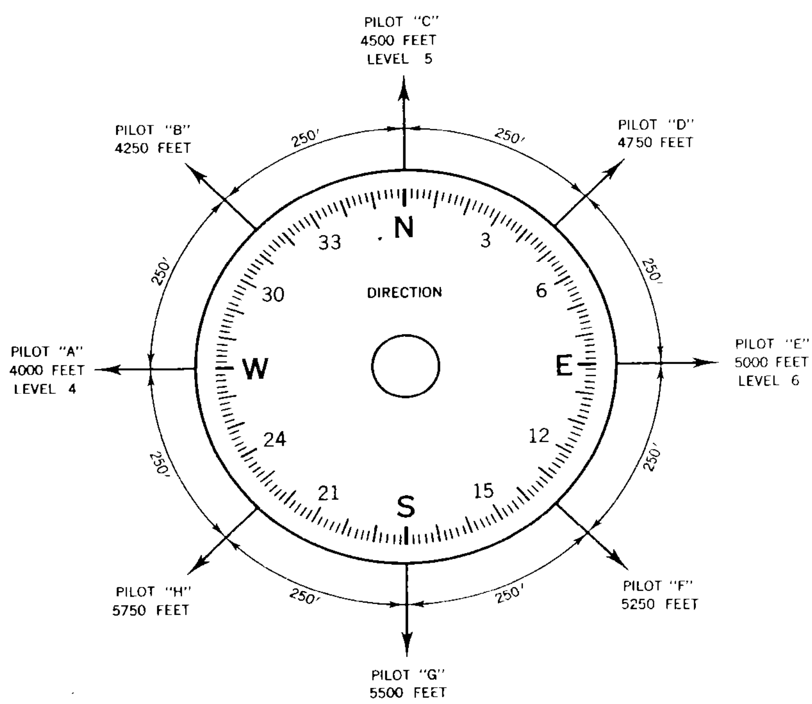

Figure 2. Compass Rose