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Determination of the indicated air speed without data from pitot tubes

A method of emergency IAS determination using data from satellite navigation system, magnetic compass and meteorological forecast is considered. An experiment is conducted as well.

Introduction

During the flight of the aircraft three kinds of horizontal speed are usually being measured: ground speed (GS), true air speed (TAS) and indicated air speed (IAS). While GS (rate of relative moving of the ground and aircraft center of gravity) is used by flight crew mostly for navigation purposes, TAS and IAS are very important for aircraft control. If IAS becomes too low, it leads to uncontrolled movement of the aircraft called stall. On the other hand, IAS increasing beyond limit can cause aircraft construction demolition. Nowadays an Air Data System (ADS) is used for IAS measurement. Its sensors are called pitot tubes and they are long sealed tubes, open at the forward end. They are located in the fore part of the aircraft so they can measure full (pitot) pressure which is the sum of static and dynamic pressure. It allows measuring IAS [1]. ADS is very accurate and reliable system, but it has one disadvantage: pitot tubes are inclinable to icing. Several air disasters have already been caused by ice or other pollutions in the pitot tube [2, 3, 4]. It is obvious that reserve emergency system is needed to provide safe landing in case of ADS fault.

Literature analysis

Investigation results in this area were embodied in directive documents issued by airlines. Generally, in case of unreliable speed detection pilots have to be directed by the Pitch-thrust table. This procedure allows keeping safe IAS by choosing proper rate of engines thrust and pitch angle for particular weight and configuration of the aircraft [5]. Desirable values are previously detected during flight investigation for each particular type of aircraft.

The Boeing company in 2013 reported [6] invention of new method of independent IAS measurement. For this purpose flight management and guidance system (FMGS) must know aircraft configuration, weight, angle of attack and its 3D position defined by GPS. Authors don’t divulge detailed formula.

Investigation purposes

The goal of this investigation is development of IAS calculation method which will not tap data from ADS.

Method description

GS, TAS and IAS are interrelated, so we can easily find any of these speeds knowing another one. In our case we use GS measured with GNSS gauge as a basis for further calculations. We can find TAS from GS using Navigation triangle of velocities [7], which includes GS, TAS and the wind speed (Fig. 1).

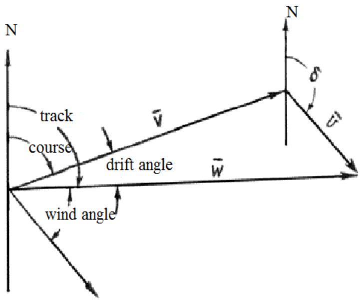

Fig.1 – Navigation triangle of velocities

On the above figure $\bar{W}$ is the GS vector, which direction is defined by the angle called track; $\bar{V}$ is the TAS vector, which heading is defined by the aircraft course. And finally, $\bar{U}$ is the wind speed vector. Its rate and direction can be defined respectively as speed of air moving along the ground and wind angle (δ). In [7] we can find formula for TAS:

$$V = \frac{W - U\cos\delta}{\cos(drift\_angle)} \tag{1}$$

The next stage is calculation of IAS from TAS. These two speeds are approximately equal at the sea level, but as the flight altitude grows IAS becomes smaller while TAS remains the same. The formula for IAS is:

$$IAS = \frac{TAS}{\sqrt{\frac{\rho_0}{\rho_H}}} \tag{2}$$

In formula (2) ρ_0 is the air density on the sea level, ρ_H is the air density on the flight level. Density can be calculated as follows:

$$\rho = 0{,}0473\frac{B}{T} \tag{3}$$

In formula (3) B is the atmospheric pressure (mm hg), T is the temperature in Kelvin.

Hence, the final formula for IAS calculation will be as follows:

$$IAS = \frac{\frac{W - U\cos\delta}{\cos(drift\_angle)}}{\sqrt{\frac{\rho_0}{\rho_H}}} \tag{4}$$

How can we obtain necessary components from the right part of equation (4) without using data from ADS? GS (W) and track, as was mentioned above, we can get from GNSS receiver, U and δ are known from SITA forecast [8], drift angle is the difference between track and course, and course gauge is magnetic compass. Pressure and temperature on the sea level we can obtain from METAR forecast, and temperature on the flight level is, once again, known from SITA. The most difficult task is to get value of the pressure on the flight level. We can't know precise value without ADS, but approximate value can be calculated using height-pressure table. Each 100 meters of climb cause 10 mm hg pressure decreasing.

Calculation example

For this particular example data obtained during A-320 flight in September 2013 were used. Before the beginning of flight SITA forecast on route was obtained. Its fragment is submitted on Fig. 2:

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SENAR                   ETP1                    METAT
FL350  352/37  M54      FL350  357/36  M52      FL350  357/36  M52
FL370  354/30  M52      FL370  358/28  M51      FL370  358/28  M51
FL390  356/23  M50      FL390  000/22  M49      FL390  000/22  M49

SANUL                   KTL                     ODOMI
FL350  005/29  M50      FL350  028/18  M48      FL350  033/16  M48
FL370  006/24  M49      FL370  022/16  M48      FL370  025/15  M47
FL390  008/19  M48      FL390  015/15  M47      FL390  017/14  M47

ADISA                   SONIB                   BUKET
FL350  041/15  M48      FL350  069/11  M49      FL350  143/15  M49
FL370  032/13  M48      FL370  061/9   M48      FL370  147/12  M48
FL390  023/11  M47      FL390  051/7   M47      FL390  152/10  M47
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Fig. 2 – SITA fragment

As we can see from Fig.2, meteorological forecast for SANUL point was: on the flight level 350 (35000 ft height) meteorological direction of wind is 5 degrees (which means that navigation direction is 185 degrees), wind speed is 29 knots, and the temperature is -50 degrees Celsius. Due to METAR forecast the temperature at the sea level was +3 degrees Celsius and the pressure at the sea level was 760 mm hg.

At the moment of SANUL crossing actual aircraft gauges data were as follows (Fig.3):

Fig.3 – Gauges data during SANUL crossing

In the upper left corner of navigation display we can see actual GS (434 knots). Next line contains actual values of wind direction and speed – 10 degrees and 26 knots. As we can see, discrepancies with the forecast data are insignificant. We'll believe that we don't have this data (obtained from ADS) and use the forecast data in further calculations. Under the wind parameters line there is course scale. It shows the actual course: short vertical line is placed on 59 degrees. On the same scale we can see track angle: 62 degrees. Hence, drift angle will be: 62-59=3 degrees. Wind angle value will be: 185-62=123 degrees. We can now calculate TAS using formula (2):

$$TAS = \frac{434 - 29\cos(123^0)}{\cos(3^0)} = 450,05$$

Comparing the calculated TAS value (450 kt) with measured TAS value (446 kt – it can be seen on the display near GS value), we can conclude that discrepancy is quite small. Now we have to define all input values we need for IAS calculation. Temperature on the ground level in Kelvin will be 274,15 deg; on the flight level – 223,15 deg, air pressure on the flight level, according to height-pressure table, will be 185,47 mm hg. Hence, the calculated IAS will be:

$$IAS = \frac{450}{\sqrt{\frac{0,13065}{0,03925}}} = \frac{450}{1,82} = 247,25$$

At the same time IAS measured by ADS, was approximately 259 kt, as we can see on the right gauge on Fig.3. It means that discrepancy between measured and calculated value amounted 12 kt. In the same way several other experiments were conducted. All of them showed similar results: error didn't max 16 kt.

Are this error and described method in general acceptable? The crucial criteria is ability to keep safe IAS. Stall IAS of Airbus A-320, one of the most popular civil aircrafts worldwide, is 185 kt, and its maximum acceptable IAS is 350 kt [5]. Hence, safety gap is 350-185=165 kt. If flight crew or FMGS will aim to keep the mean speed – 276 kt, safety speed stock on each side will be 82 kt. This value is much larger that the largest error obtained during experiments.

The conclusions

Experiment and analysis of its results showed that described method of IAS measurements based on data from GNSS, magnetic compass and weather forecast is valid enough to provide safe flight in case of ADS incapacity. This method may be used for UAV operations as well – generally these aircrafts have smaller safe velocity gap, but they are being operated at low flight level, so influence of pressure difference will be insignificant.

References

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