Route Calculation Study in advance for 4D Trajectory modeling in ATM

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Summary
Air Traffic Control System enables to air traffic flow management. Accuracy of route calculation is requiring because air traffic is increasing. Concept of existing route calculation is just simple departure/arrival time calculation. But latest systems real-time route calculation by using meteorological information. In this paper, we research about algorithm of basic real-time route calculation.

Key words:
Route Calculation, CNS, ATM, 4D Trajectory, Air Traffic Control

1. Introduction

The Route calculation is very essential function for Air Traffic Management(ATM) System that enables air traffic flow management of aircrafts. And faster and more accurate route calculation is required. Because air traffic flow is grow every year. Existing ATM system performs departure and arrival time, using planned route information for route calculation. With the increase in processing capacity and IT technology, gradually ATM systems currently being developed has been developed to be able to perform 4D route calculation using time information of the aircraft in real time. In this paper, we studied route calculation algorithm, using weather and aircraft performance information for previous research in 4D route calculation.

2. Route Calculation related Study

Existing ATM system performs route calculation, using flight plan(it includes fix information) for route calculation. NAVIDS(navigation aids) development trends change into CNS/ATM(Communication, Navigation, Surveillance/Air Traffic Management), so ATM systems consider flight plan as well as time information.

4D route calculation includes real time information of geographical and time, so it can accurate departure and arrival time of fix to fix point. Also it considered aircraft performance information and weather information, so it can reduce error.

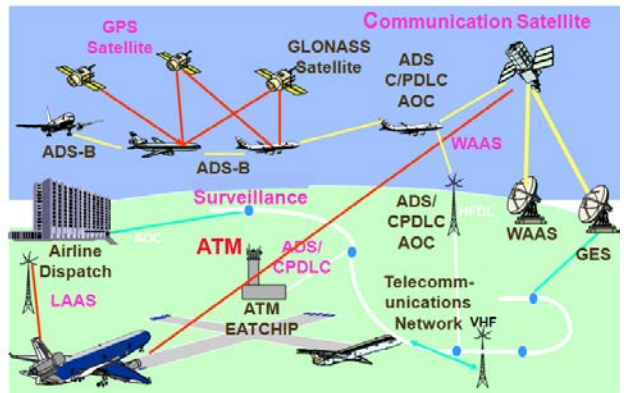

Fig. 1 CNS/ATM Concept (ICAO)

In this chapter, we explained about variety information for route calculation and how it can apply to route calculation. Following information are required when processes for 4D route calculation.[3]

- Route information
- aircraft performance data(speed, weight, aerodynamics, climb rate, descent rate, etc.)
- NAVAID(navigation aids)
- Runway information
- Approach/Departure procedure
- geographical data(GPS, ADS-B, radar, etc.)
- Weather information(wind speed, wind direction, temperature, humidity, altitude, etc.)

2.1 Vincenty's Formular

Vincenty's formular is distance calculation method that assume the earth is ellipse. So its calculation result is very exact, because its distance, azimuth and position error is below 1m on ellipse. Azimuth and distance at two points can be calculated when latitude and longitude are given at each point.[1,2]
Following table 1 is used variables in Vincenty's formular.

Table 1: Vincenty's formular variables

variable	meaning
Φ_1, Φ_2	latitude at points
λ_1, λ_2	longitude at points

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L	longitude difference(λ_2-λ_1)
U_1	$\tan^{-1}[(1-f)\tan\Phi_1]$
U_2	$\tan^{-1}[(1-f)\tan\Phi_2]$
a_1, a_2	shortest distance and azimuth
S	distance between two points on ellipse

2.2 Type of aircraft speed

Typically, aircraft speed represents relative speed that adjusted by the air, and it is different from car speed on the ground. This chapter represents variety type of aircraft speed and what is ground speed that used to route calculation.[4]

2.2.1 Indicated Airspeed (IAS)

IAS is the airspeed read directly from the airspeed indicator on an aircraft. It uses the difference between total pressure and static pressure, provided by that system, to either mechanically or electronically measure dynamic pressure. The dynamic pressure includes terms for both density and airspeed. Since the airspeed indicator cannot know density, it is by design calibrated to assume the sea level standard atmospheric density when calculating airspeed.

2.2.2 Calibrated Airspeed (CAS)

CAS is the speed shown by a conventional airspeed indicator after correction for instrument error and position error. When flying at sea level under International Standard Atmosphere conditions (15° C, 1013 hPa, 0% humidity) calibrated airspeed is the same as equivalent airspeed (EAS) and true airspeed (TAS). If there is no wind it is also the same as ground speed (GS). Under any other conditions, CAS may differ from the aircraft's TAS and GS.

For subsonic speeds, CAS is calculated as:

$$\mathrm{CAS} = a_0\sqrt{5\left[\left(\frac{q_c}{P_0}+1\right)^{\frac{2}{7}}-1\right]} \quad (1)$$

q_c : impact pressure
P_0 : standard pressure at sea level
a_0 : the standard speed of sound at 15℃
For supersonic speeds, CAS is calculated as:

$$\mathrm{CAS} = a_0\left[\left(\frac{q_c}{P_0}+1\right)\times\left(7\left(\frac{\mathrm{CAS}}{a_0}\right)^2-1\right)^2/(6^{2.5}\times 1.2^{3.5})\right]^{\left(\frac{1}{7}\right)} \quad (2)$$

2.2.3 TAS, True Airspeed (TAS)

TAS is the true measure of aircraft performance in cruise, thus listed in aircraft specs, manuals, performance comparisons, pilot reports, and every situation when actual performance needs to be measured. It is the speed normally listed on the flight plan, also used in flight planning, before considering the effects of wind. To maintain a desired ground track whilst flying in the moving airmass, the pilot of an aircraft must use knowledge of wind speed, wind direction, and true air speed to determine the required heading.
At low speeds and altitudes, IAS and CAS are close to equivalent airspeed (EAS). TAS can be calculated as a function of EAS and air density:

$$\mathrm{TAS} = \mathrm{EAS}\sqrt{\frac{\rho_0}{\rho}} \quad (3)$$

ρ_0 : the air density at sea level

ρ : the density of the air in which the aircraft is flying.

2.2.4 Ground Speed (GS)

Ground speed is the horizontal speed of an aircraft relative to the ground. An aircraft heading vertically would have a ground speed of zero. Information displayed to passengers through the entertainment system often gives the aircraft ground speed rather than airspeed.
Ground speed can be determined by the vector sum of the aircraft's true airspeed and the current wind speed and direction; a headwind subtracts from the ground speed, while a tailwind adds to it. Winds at other angles to the heading will have components of either headwind or tailwind as well as a crosswind component.
An airspeed indicator indicates the aircraft's speed relative to the air mass. The air mass may be moving over the ground due to wind, and therefore some additional means to provide position over the ground is required.
Ground speed is quite different from airspeed. When an aircraft is airborne the ground speed does not determine when the aircraft will stall, and it doesn't influence the aircraft performance such as rate of climb.
Ground speed is calculated as :

$$\mathrm{GS} = \mathrm{TAS} + \mathrm{Wind} \quad (4)$$

In this paper, we use TAS and GS for prediction of aircraft position.

2.3 Base of Aircraft DAta (BADA)

BADA is an aircraft performance model with corresponding database. BADA is being maintained and developed by the EUROCONTROL. BADA containing performance and operating procedure data for 294 different aircraft types.[6]

The aircraft model behind BADA that is used is a so-called TEM(Total Energy Model). It can be considered as being a reduced point-mass model. The operations performance model of BADA defines, besides TEM: the aircraft type, mass, flight envelope, aerodynamics, engine thrust and fuel consumption.
Following four different files are supported in BADA.

- Synonym Files : the list of aircraft types
- Operation Performance Files(OPF) : the thrust, drag and fuel coefficients to be used in TEM together with information on weights, speeds, maximum altitude, etc.
- Airline Procedures Files(APF) : the operational climb, cruise and descent speed.
- Performance Table Files(PTF) : the nominal performance of the aircraft model in the form of a look-up table.

In this paper we used OPF, APF, Synonym and PTF.

2.4 Weather information Message (METAR)

For more accuracy, we adopted aviation weather data supported by MOLIT(Ministry of Land Infrastructure and Transport).[7]
Following is weather message example.

Original Message
120330Z 25006KT 180V340 9999 FEW025 14/02 Q1018 NOSIG=

120330Z : weather message report time in UTC
25006KT : wind direction, wind speed(250° , 6 [Kt])
180V340 : variation of wind direction
9999 : visibility(10Km, 9999 means very clear)
FEW025 : presence of a few clouds over 2500ft
14/02 : temperature(℃)/humidity(%)
Q1018 : atmosphere
NOSIG : no significant change is expected

In this paper, we use wind direction and wind speed data.

3. Simulation Results

For verification of this paper, first we calculated ground speed. And then calculate during time for point to point and ground speed of that time.
Following flow chart is calculating algorithm for route calculation.

3.1 Ground speed calculation with aircraft speed, wind speed and wind direction

The wind blowing from any direction, the aircraft is affected by the wind, then aircraft speed is change. So, wind speed and direction to be considered when calculate for the aircraft speed. Calculating procedure is shown in Fig.3.

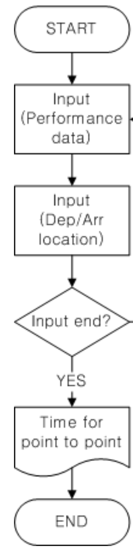

Fig. 2 calculating algorithm flow chart

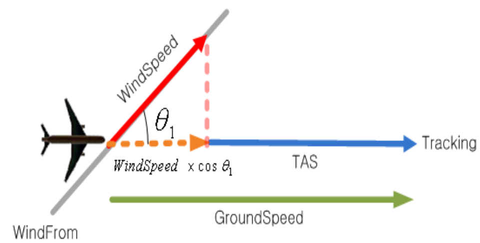

Fig. 3 Calculating procedure (using TAS, wind speed, wind direction)

For simulation, set the parameters to TAS(100 Knot), aircraft heading(180°), wind speed(17Knot) and wind direction(135°). As shown in Fig.4 ground speed calculation result is 148.492135 ft/sec. Fig.5 is changed wind speed to 50Knot and result is 99.652341 ft/sec. In the results, according to the wind can be seen that the ground speed is different.

```
D:\Route\Route>Route1


Calculation Ground Speed....
Using Tas, Tracking Angle, WindSpeed, WindFrom..

Input Data...
Tas(Knot) : 100
Tracking Angle(Degree) : 180
WindSpeed(Knot) : 17
WindFrom(Degree) : 135

Result....

Ground Speed is 148.492135 (ft/sec)
```

Fig. 4 Calculation result (using TAS, wind speed, wind direction)

```
D:\Route\Route>Route1


Calculation Ground Speed....
Using Tas, Tracking Angle, WindSpeed, WindFrom..

Input Data...
Tas(Knot) : 100
Tracking Angle(Degree) : 100
WindSpeed(Knot) : 50
WindFrom(Degree) : 135

Result....

Ground Speed is 99.652341 (ft/sec)
```

Fig. 5 Calculation result (changed wind speed)

3.2 Ground speed calculation with aircraft speed, climb rate, wind speed and wind direction

When the aircraft is climbing, wind effects should be considered. So in this section, used the aircraft speed, climbing rate of aircraft, wind speed and wind direction for ground speed calculation. Calculation concept is as shown in Fig.6.

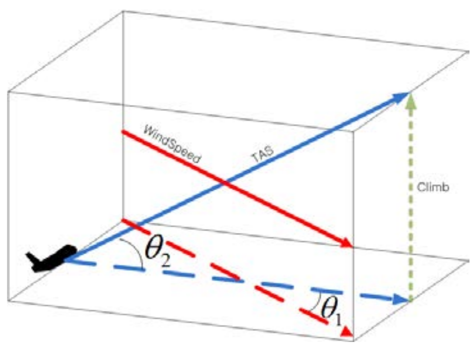

Fig.6 Calculating procedure (using TAS, climb rate, wind speed, wind direction)

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D:\Route\Route>Route3


Calculation Ground Speed....
Using Tas, Tracking Angle, WindSpeed, Wind Direction, Climb Rate..

Input Data...
Tas(Knot) : 100
Tracking Angle(Degree) : 1500
WindSpeed(Knot) : 15
WindFrom(Degree) : 290
Climb Rate(ft/min) : 2500

Result....

Ground Speed is 147.283506 (ft/sec)
```

Fig.7 Calculation result (using TAS, climb rate, wind speed, wind direction)

For simulation, set the parameters to TAS(100Knot), wind speed(15Knot) and climb rate is 2500 ft/min. As shown in Fig.7 ground speed calculation result is 147.283506 ft/sec.

3.3 Flight time calculation for from one point to another point

In this section, input the parameters(aircraft performance data, wind speed, wind direction, etc.) to the program then calculation for the flight time from SEL to BELMI. SEL and BELMI is practical using waypoint name in Korea. SEL and BELMI location is as shown in Fig.8 and calculation result in Fig.9.

Fig.8 Calculation location (SEL→BELMI)

(maps.google.co.kr)

```
D:\Route\Route>Route7


Calculation Estimate Time
Using Tas, WindSpeed, Wind Direction and Two Point..

Input Data...
Tas(Knot) : 100
WindSpeed(Knot) : 15
WindFrom(Degree) : 320

First Location...
Input Fix Name : SEL

Second Location...
Input Fix Name : BELMI

Result....

Distance between Two Point is 22.886761 (km)
Ground Speed is 187.328365 (ft/sec)
Estimate Time is 400.835184 (sec)
```

Fig.9 Calculation result

4. Conclusion

In this paper, researched about the aircraft route calculation contained time parameter. And it will be study in advance for 4D trajectory modeling that essential for next generation Air Traffic Management(ATM) System. First, calculate the ground speed using performance data of the aircraft and weather data. Then using the route information of the actual, due to the influence of the wind, it was possible to see the changes of time and changes in ground speed. So this study could be adapted for ATM system, it is possible to predict the arrival time more accurate under the real time environment condition.

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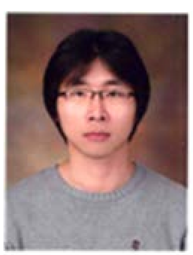

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