EN-029 Basic Analysis of Winds Aloft Forecast used for En-Route Trajectory Prediction

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- Background and objectives
- Methods
 - Aircraft ground speed calculation,
 - Target waypoints
 - Meteorological model
- Results
 - Wind aspect at high altitude
 - Seasonal tendency of aircraft ground speed
 - Ground speed prediction errors



BACKGROUND

- A global Air Traffic Management (ATM) concept is being developed by ICAO to accommodate a demand for safe, efficient and environmentally-friendly flights through technical advancement in the air transport industry with increasing traffic volumes.
- Trajectory-Based Operation (TBO) is the main axis of a global ATM concept.
- The impact factors for the prediction of aircraft trajectory are
 - Aircraft kinetics,
 - Intentions of the pilot or air traffic controller,
 - Atmospheric conditions, and so on.

To clarify the impact of the meteorological forecast, aircraft ground speed during cruse flights were calculated.







AIRCRAFT GROUND SPEED CALCULATION

- True airspeed (TAS) is the speed of the aircraft relative to the atmosphere.
- Aircraft Ground speed (GS) is assumed as a vector sum of TAS and Wind Vector.



GS was calculated under constant Mach number **0.84** in this study.

TAS is calculated by using a function of Mach number as

$$V_{TAS} = M \times \sqrt{\gamma \cdot R \cdot T}$$

 V_{TAS} is TAS

- $_M$ is Mach number
- γ is Adiabatic index of air
- R is Real gas constant of air
- T is temperature

TARGET WAYPOINTS

- Air traffic flow concentrates on Tokyo International Airport.
- Three waypoints, 200 -300 NM from the departure airport, were chosen.
- At those waypoints, aircraft has already reached cruising altitude.

Waypoint;Traffic FlowHPE(Hanamaki);from Sapporo to TokyoIGOSO;from Fukuoka to TokyoSHIBK;from Naha to Tokyo



METEOROLOGICAL MODEL

Numerical Weather Prediction (NWP)

- High-altitude atmospheric condition data
- Mathematical models
- Predict the weather

Meso-Scale Model (MSM)

- One of the NWP
- Grid Point Value (GPV)



The scope of MSM(GPV) of the JMA

- East-west and north-south direction of wind elements
- Temperature

Three pressure altitudesSelected Pressure altitudefeet in ISA300hPa30,065ft250hPa33,999ft200hPa38,662ft

APPLICABLE PERIOD

Four seasons characterized by atmospheric temperature difference and position of several air mass.

- The lowest temperature, January/February, Winter
- The highest temperature, July/August, Summer
- Between winter and summer, April/May, Spring
- Between summer and winter, October/November, Autumn
- In addition to the four seasons,
 September, defined as Typhoon season

4 weeks from each of the five seasons, total 140 days of MSM(GPV) data in 2011 were used.



and weak in the summer.

SEASONAL TENDENCY OF WIND VECTOR (250hpa)



- The main stream of upper wind at each waypoint is westerly wind.
- Strong westerly winds are showed in the winter at *IGOSO* and *SHIBK* meanwhile wind at *HPE* is weak and broadens wide range throughout the season.

SEASONALLY-VARYING AIRCRAFT GROUND SPEED (GS)





- IGOSO/SHIBK
- **HPE**

450

350

In the winter which is strong wind speed season, the difference between IGOSO/SHIBK and HPE is wide.



DISTRIBUTIONS OF AIRCRAFT GROUND SPEED (GS)



• *SHIBK/IGOSO* The peak varies among seasons.

• HPE

The peak are almost same in each season.



WEATHER PREDICTION ERRORS

- Meteorological forecast data at *zero* hour is assumed as a true value.
- Differences between data of forecast (*FT*=15, 12, 9, 6 and 3) and zero are regarded as prediction errors.



GROUND SPEED PREDICTION ERRORS

 Differences between GS calculated using meteorological forecast (*FT*=15, 12, 9, 6 and 3) data and that of zero hour data were defined as ground speed prediction errors.



GS prediction error distributions

Prediction accuracy of GS prediction improves when using weather data predicted in more recent hours.

SEASONAL TENDENCIES OF ERRORS

The percentage of prediction errors inside $\pm 7kt$

Wind Speed Prediction Error within ±7kt	winter	spring	summer	typhoon season	autumn
HPE	96%	91%	91%	84%	93%
IGOSO	90%	92%	96%	94%	95%
SHIBK	95%	92%	96%	94%	96%
Ground Speed Prediction Error within ±7kt	winter	spring	summer	typhoon season	autumn
HPE	98%	94%	93%	96%	97%
IGOSO	88%	93%	96%	96%	94%
SHIBK	96%	92%	94%	94%	96%

• Seasonal tendency of wind speed prediction errors are similar to that of GS prediction errors.

GS LARGE ERROR SITUATIONS

The largest GS prediction error was **53kt** at *IGOSO* on September 3.

High ground speed prediction error occurs in air turbulence potential areas-

- Typhoons (tropical cyclones) with a high cumulonimbus cloud,
- near the trough with horizontal/vertical wind shear along a strong jet stream,
- convective cloud area caused by unstable air.



ABJP chart valid 03UTC of September 3, 2011

COMPARISON OF ACCURACY BETWEEN GS PREDICTION ERRORS AND WEATHER PREDICTION ERRORS



Correlation of the between ground speed prediction errors and each weather prediction error at IGOSO

WIND VECTOR SUBTRACTION W_{forecast} W_{zero}

Wind vector subtraction $|W_{forecast} - W_{zero}|$ increase, prediction accuracy lowers.

Coefficient of determination (R^2)

	HPE	IGOSO	SHIBK			
GS/WS within \pm 7kt	0.91	0.99	0.96			
GS within \pm 7kt WVS within \pm 9kt	0.97	0.91	0.96			

High correlation between GS prediction and both wind speed error prediction and wind vector subtraction.



2011/09/03 03UTC 300hPa 15FT GS prediction error *HPE*: 0kt *IGOSO*: 53kt *SHIBK*: 6kt



- When the wind speed is high, the wind vector subtraction tends to be large.
- Even when the wind speed is weak, wind vector subtraction tends to be large when whirling wind (i.e. cyclones) moves.



 Aircraft Ground Speed(GS) was calculated under the influences of seasonal wind conditions and meteorological forecast accuracy during cruise flight.

- ♦ GS affected by a jet stream.
- Aspects of wind conditions at cruising altitude varied in each season depending on the position of waypoint, and whether a jet stream existed or not.
- The tendency of GS varied by direction of aircraft in addition to the wind conditions.
- Prediction accuracy of GS improved by using weather data predicted in more recent hours.
- High correlation between GS prediction and both wind speed error prediction and wind vector subtraction.
- Even when the wind speed is weak, wind vector subtraction tends to be large when whirling wind (i.e. cyclone) moves.