Did Weather play a key role for the crash of Air Asia Flight QZ 8501? A Review !

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Outline

- ***Brief overview of the history of Air Asia Flight QZ 8501***

  Background information on the Journey of the flight
  Final conclusions from the Ministry of Transportation, Indonesia
  Similarities in Air Asia & Air France Crash ! Key findings from Air France 447 Crash

- ***Severe Weather Hazards for Aircrafts***

  Inference drawn from the preliminary analysis based on Satellite Images & Radiosonde data
  Introduction to Thunderstorm induced Icing & In Flight Icing Conditions & Severity

- ***Experimental Design & Methodology using Numerical Modelling Approach***

  Meteorological Analysis *along the flight path of Air Asia QZ 8501*
  Aerodynamic Response *of the Aircraft based on Meteorological analysis along the Flight Path*

- ***Conclusions***

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1. Brief overview of the history of Air Asia Flight QZ 8501

Journey of Air Asia Flight scheduled on 28th Dec 2014

- **Information related to departure of Air Asia Flight QZ 8501 (Airbus A320-216)**

  - ***Take off*** *at Juanda International Airport, Surabaya* at 0535 LT (2235 UTC, 27 Dec 2014)
  - ***Arrival*** *at Changi International Airport, Singapore* at 0830 LT (00:30 UTC, 28th Dec 2014)
  - ***Total Persons*** *on board, 162 persons* (156 passengers, 2 pilots, 4 flight attendants)

- **Sudden disappearance of the Aircraft in route:**

  - ***At 2318 UTC***, the aircraft disappeared from the Jakarta Radar controller screen.

  - The aircraft last position according to the Automatic Dependent Surveillance-Broadcasting (ADS-B) radar was on coordinate ***3° 36"48.36"S - 109° 41"50.47"E*** and the aircraft altitude was approximately ***24,000 feet***.

Air Asia QZ 8501 Flight Track

Source: Ministry of Transportation, Indonesia

2231 UTC : Taxi; **2235 UTC**: Take Off

2249 UTC: FL 320

2257 UTC: anti Ice ON

2301 UTC: 1st MC

2304 UTC: Request for 15 miles left of track to avoid weather

2309 UTC: 2nd MC

2311 UTC: Flight turned to left to avoid weather (acknowledged)

2312 UTC: Requested for FL 380 and was asked to standby ATC

2313:41 UTC: 3rdMC

2315:36 UTC: 4th MC

2316 UTC: Clearance to fly FL 340

(No response from Pilot)

2316:27 UTC: 5th MC

2316:44 UTC:6th MC (A/P disengaged)

2317:18 UTC: Stall Warning

2317:41 UTC: A/C started descending at 20,000 ft/min

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Key findings from Ministry of Transportation, Indonesia on 1st Dec 2015

- *The cracking of a solder joint resulted in loss of electrical continuity and led to RTLU (Rudder Travel Limiter Unit) failure causing it to send four warning signals to the pilots.*

- *The crew resolved the issue the first three times, but on the fourth, the pilots tried to reset the system, which resulted in electrical interruption to the FAC (Flight Augmentation Computer)*

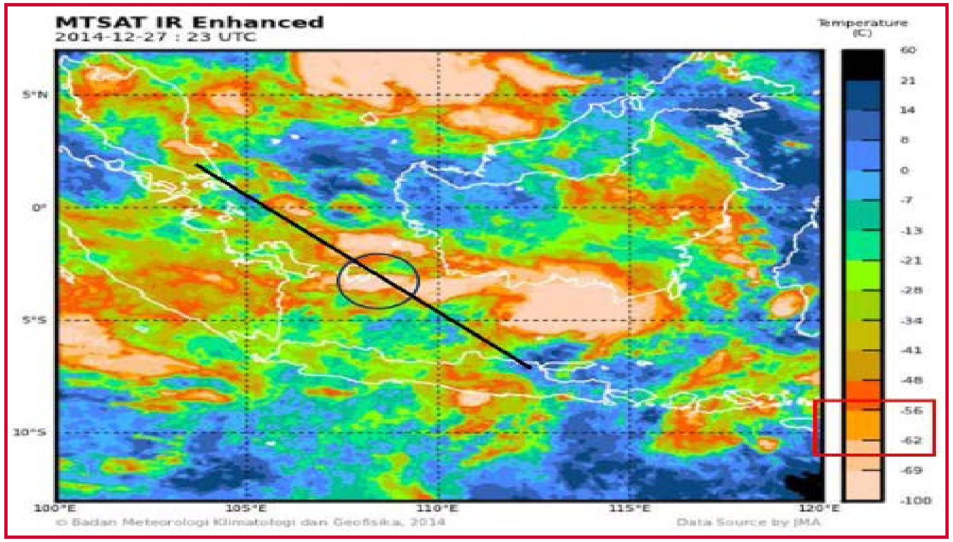
- *The electrical interruption to the Flight Augmentation Computer (FAC) caused the autopilot to disengage and the flight control logic to change from Normal Law to Alternate Law, the rudder deflecting 2° to the left resulting the aircraft rolling up to 54° angle of bank.*

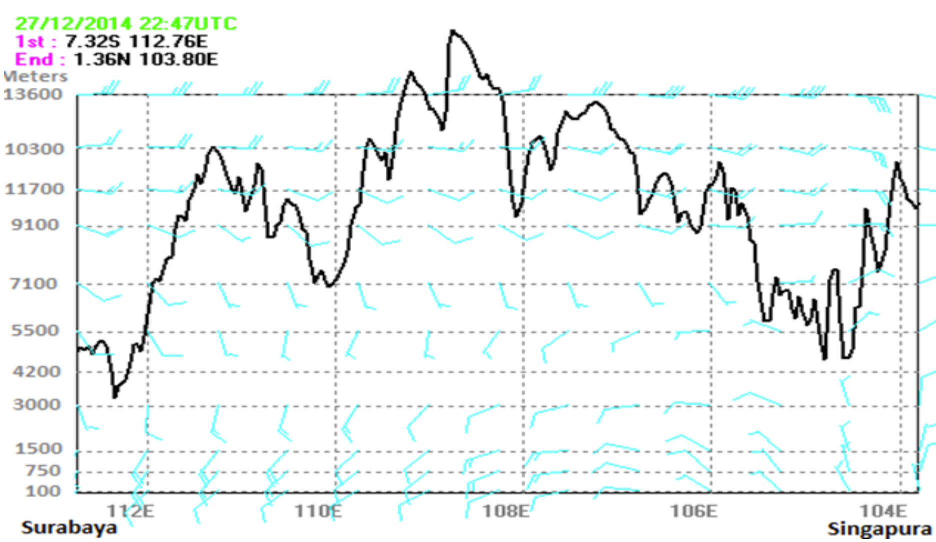
- *Subsequent flight crew action leading to inability to control the aircraft in the Alternate Law resulted in the aircraft departing from the normal flight envelope and entering prolonged stall condition that was beyond the capability of the flight crew to recover.*

- *Air Asia flight was not affected by the weather condition and investigation concludes that the weather was not factor to the accident.*

Note: (The RTLU controls the rudder, a part of the aircraft's tail. **There were 23 RTLU problems starting Jan 2014 to 27th Dec 2014- Almost one year !**).

Meteorological Information 27th Dec 2014 at 23 UTC





- *Shows partial area of towering cumulonimbus clouds formation. Top of clouds approx.* ***24,000 feet up to 44,000 feet*** *on the vicinity where the aircraft was flying.*

- *The wind direction when the aircraft was flying mostly westerly* ***with 15 to 20 kts.*** *The outside air temperature ranging from* ***-56° C to - 62° C***

Source: Ministry of Transportation, Indonesia

Have we come to a logical conclusion?

- The pilots were certified to fly the Aircraft. The Aircraft had its certified annual maintenance in Nov 2014 (Just *a month before its crash* !).

  "What made one of the worlds safest aircraft (Airbus A320) to fall down suddenly like a freely falling object from the sky ?"

- The pilot made his last contact to ATC at FL 320 at location S 3.3708 and E109.6911. *"at 2304 UTC Pilot requested to avoid weather and at 2312 UTC, pilot requested to fly at higher level F380"*. This leads to couple of important questions:

- *Why did the pilot request to fly at a higher level than FL 320? Was it due to the severe thunderstorm clouds?*

- *ATC gave clearance to climb and fly the aircraft at FL 340 but it was not replied by the pilot. What then suddenly made the pilot to perform such a rare steep climb of 38,000 feet with a rate of up to 11,000 feet per minute?*

- Was the weather condition so severe that while climbing for higher altitude the aircraft encountered multiple challenges that reduced drastically aircraft's performance?

- *The aircraft stall warning system informed of the approaching stall. Even if the aircraft reached such a speed and Angle of Attack (AOA), why couldn't the pilot avoid such approaching stall?*

Similarities in Air Asia & Air France Crash

The Deadliest Crash in Air France History !

- **Information related to Air France 447 Crash (Airbus A330-203)**

- **Date of Accident:** 1st June 2009
- **Journey:** Between Rio de Janeiro Galeão and Paris Charles de Gaulle.
- **Total Persons died:** 228 persons (216 passengers, 3 pilots, 12 crew members).

- **Key findings from the report Air France 447 Crash:**

- The obstruction of the Pitot probes by ice crystals during cruise caused the autopilot disconnection and the reconfiguration to alternate law.

- There were *powerful cumulonimbus clusters on the route of AF 447*. An additional meteorological analysis showed the *presence of strong condensation towards AF 447's flight level*, probably associated with convection phenomena.

…Similarities in Air Asia & Air France Crash

The Deadliest Crash in Air France History !

- **Key findings from the report Air France 447 Crash:**

- The *precise composition of the cloud masses above 30,000 feet is little known*, in particular with regard to the super-cooled water/ice crystal divide, especially with regard to the size of the latter.

- *No failure message on the ECAM clearly indicates the detection by the system of an inconsistency in measured airspeeds*.

- Although having identified and called out the loss of the airspeed indications, *neither of the two co-pilots called the "Unreliable IAS" procedure.*

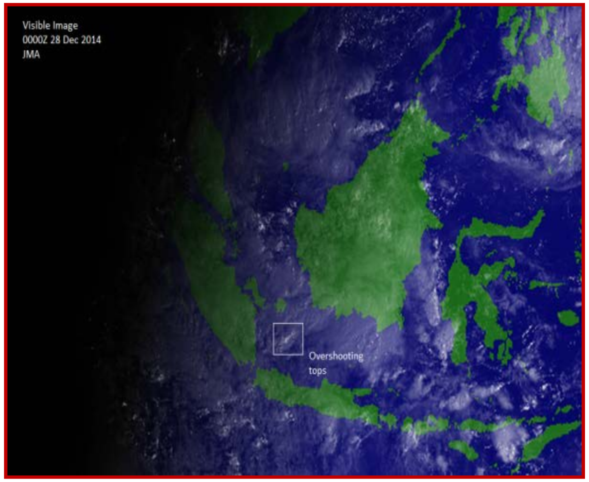
- The last recorded values were a *pitch attitude of 16.2 degrees nose-up, roll of 5.3 degrees to the left and a vertical speed of -10,912 ft/min*.

- The *crew's failure to diagnose the stall situation* and consequently a lack of inputs that would have made it possible to recover from it .

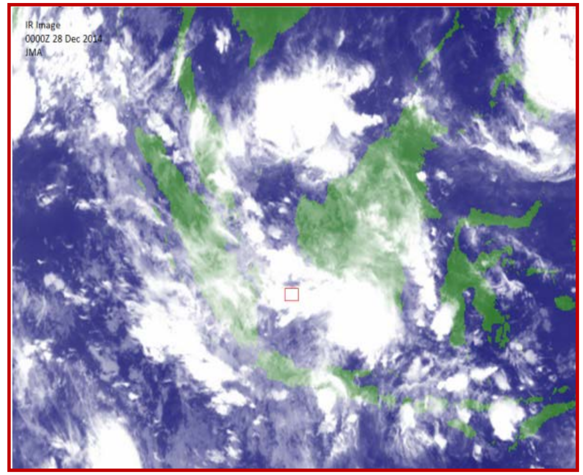
2. Severe Weather Hazards for Aircrafts

Satellite Images at 00:00 GMT on 28th Dec 2014

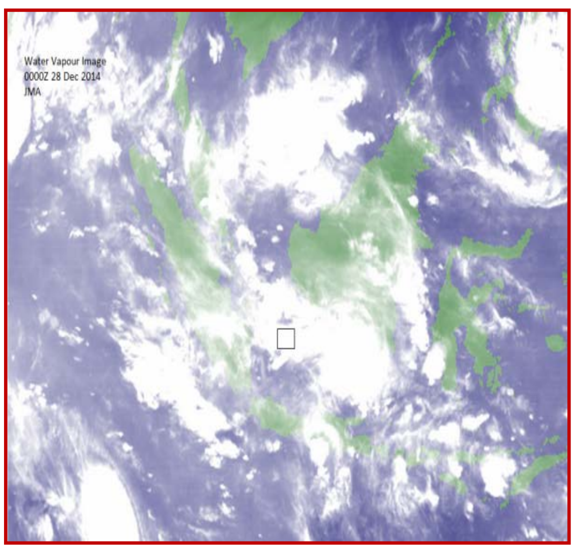
A. Visible image at 0000Z, 28 December, 2014.



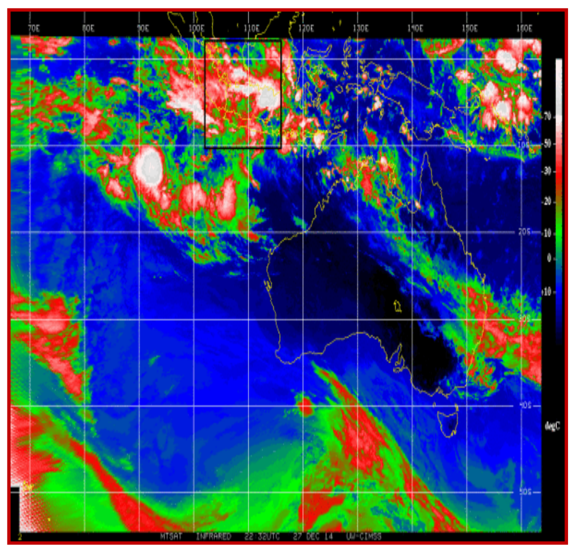
B. IR image at 0000Z, 28 December, 2014



C. Water vapor image 0000Z, 28 December, 2014



D. MTSAT enhanced IR image from 22:32 GMT,



- Vigorous Convection in Southeast Asia including Java Sea.
- Overshooting tops. These are updrafts indicating very unstable & turbulent atmosphere.
- The MTSAT enhanced IR images show the development of convection with extremely cold (high) cloud tops of well below -70 ° C.

(showing strong convection just to the east of the flight path)

Source: Japan Meteorological Agency & CIMSS, Irish Weather Online

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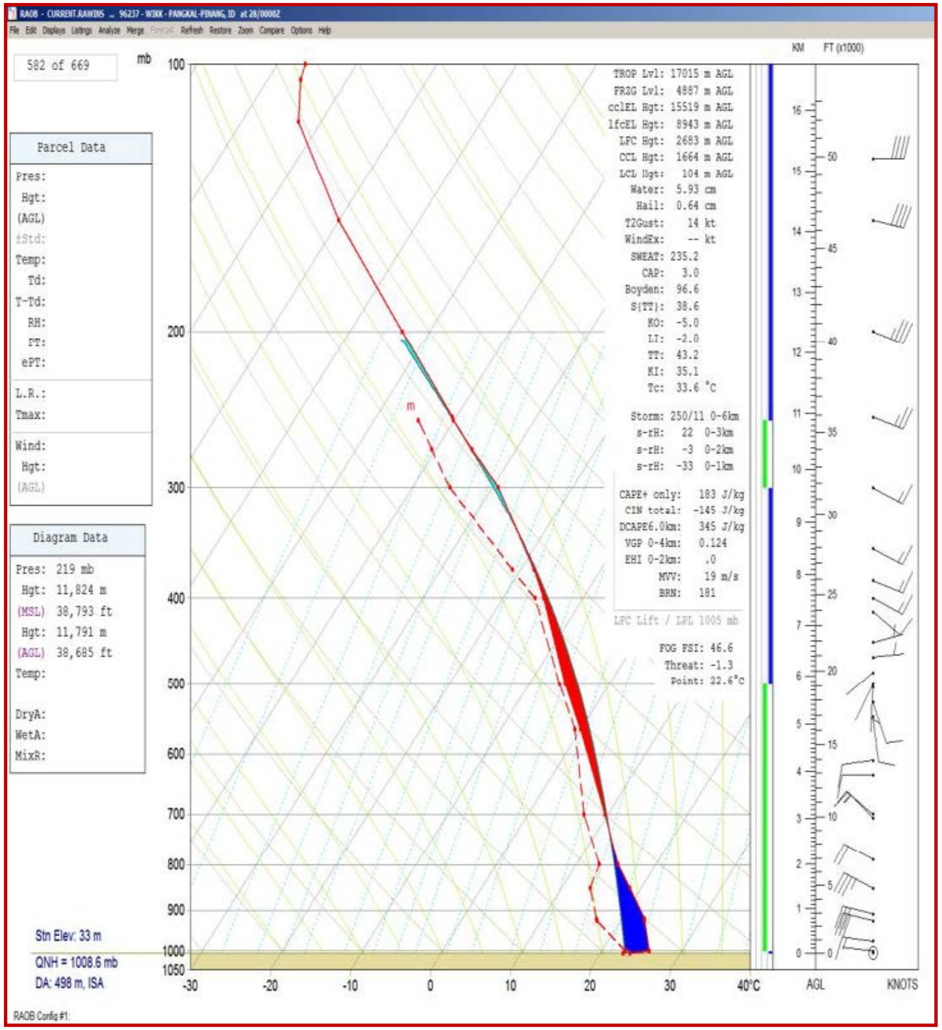
Sounding at 00 UTC on 28th Dec 2014



- *Location:* Pangkal-Pinang, about 80 nm west of the aircraft's approximated location.
- *Best guess of conditions*: Due to the extremely high tropopause (56,000 ft.), cloud tops almost certainly extended to above 50,000 ft.
- The critical icing layer extends from 17,000 to 23,000 ft., with the -20C layer at 27,000 ft. Flight level temperature was -29C.
- However as evidenced by Air France 447 incident (temperature at flight level -33C), clear icing can occur in much colder temperature regimes given high levels of water loading in the cloud.

"This raises important questions if tropical convection is particularly efficient at bringing super cooled water to higher levels ?"

Source: http://cimss.ssec.wisc.edu/ ; http://www.weathergraphics.com/

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Inference drawn from the preliminary analysis based on Satellite Images & Radiosonde

Based on the available results at the time and site of aircraft last location following meteorological conclusions are drawn:

- **MTSAT-2 10.8 µm** IR image at 23:00 UTC reveals that *there were clusters of deep convection* (thunderstorms with very high, very cold cloud tops) over the middle portion of the flight path.

- **COMS-1 10.8 µm** IR channel image at 23:00 UTC indicates that *the coldest cloud-top IR brightness temperatures were in the -80 to -85 ^{0}C range* with these thunderstorms. The corresponding COMS-1 0.675 µm visible channel images shows evidence that *there were some overshooting tops associated with these thunderstorms*.

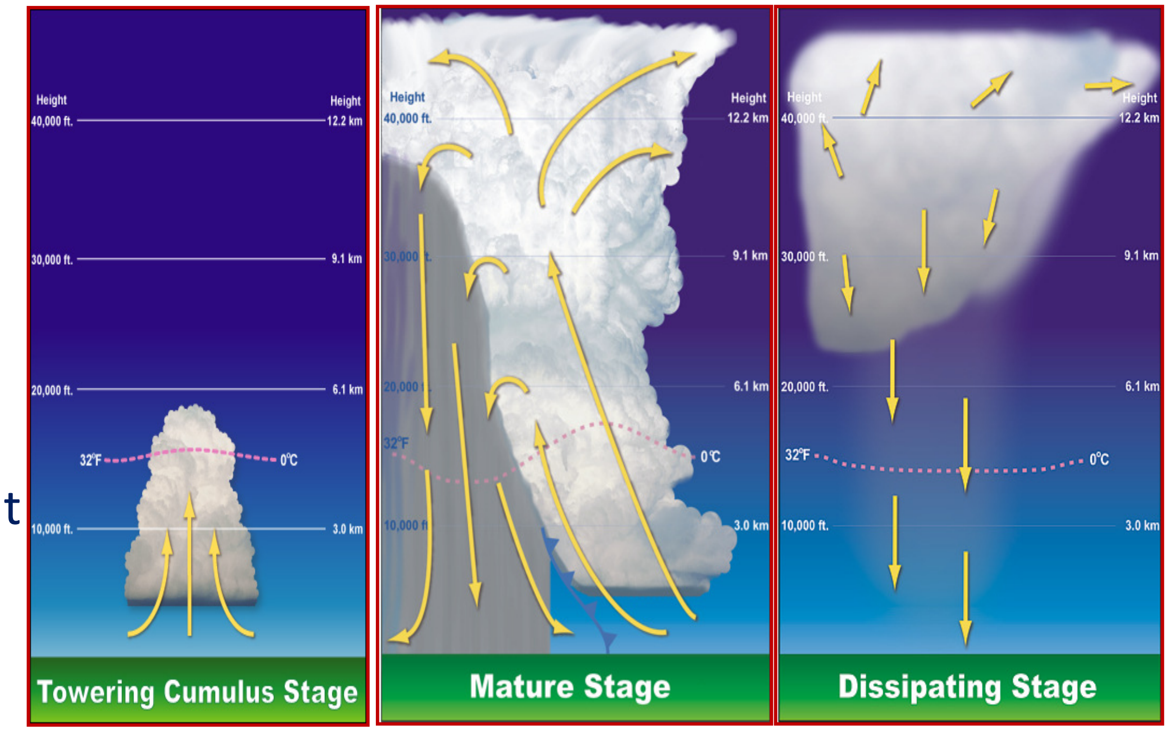
- **Radiosonde report** from Pangkalpinang at 00 UTC on 28th Dec shows that *Moisture was abundant throughout the atmospheric column, with a Total Precipitable Water value of 52.4 mm or 2.1 inches*. However, the sounding suggests weak, stratified instability, so the likelihood of turbulence or storm-scale circulations is doubtful. Due to the extremely high tropopause (56,000 ft.), cloud tops almost certainly extended to above 50,000 ft. *The critical icing layer extends from 17,000 to 23,000 ft, with the -20C layer at 27,000.*

Based on above meteorological information, the most likely hazard, if weather was to be a factor, appears to be Thunderstorm induced Icing !

Effects of Thunderstorm on Aircraft

- Aviation Weather Hazard associated with convection/thunder storms:

- Turbulence
- Wind shear
- *Icing*
- Reduced Visibility
- Lightning
- Damaging hail
- Tornado/ Water Spout
- Heavy Precipitation
- Water Ingestion
- Altimeter Inference



Source: http://www.nws.noaa.gov/

Source: Bureau of Meteorology

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Icing Schemes

Air Force Icing Scheme:

Parameters	Temperature in the moist layer								
	$-8 < T \le 0$ °C				$-16 < T \le -8$ °C				$-20 < T \le -16$ °C
	ddp ≤ 1 °C		$1 <$ ddp ≤ 3 °C		ddp ≤ 1 °C		$1 <$ ddp ≤ 3 °C		ddp ≤ 4 °C
Lapse rate	≤ 2	> 2	≤ 2	> 2	≤ 2	> 2	≤ 2	> 2	
(°C 1000 ft^{-1})	Stable	Unstable	Stable	Unstable	Stable	Unstable	Stable	Unstable	
Icing	Light Rim	Moder-ate Trans-parent	Traces Rim	Light Trans-parent	Moder-ate Rim	Moder-ate Mixed	Light Rim	Light Mixed	Light Rim

Note: T- Temperature; Td- Dew Point Temperature ddp-Dew point depression (T-Td)

NAWAU icing scheme (Today known as Aviation Weather Centre):

- High probability :

  -14 ≤ T ≤ -1 ^{0}C and RH ≥ 75% for altitudes higher than 900 m,

  -20 ≤ T ≤ 0 ^{0}C and RH ≥ 86% otherwise,

- Low probability : Conditions

  19 ≤ T ≤ 0 ^{0}C and RH ≥ 60% otherwise,

SCEM icing scheme:

Icing will occur whenever will occur whenever -15 ≤ T ≤ 0 ^{0}C and RH ≥ 80%.

Source: Royal Meteorological Society, doi: 10.1017/S1350482797000443

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Thunderstorm induced Icing

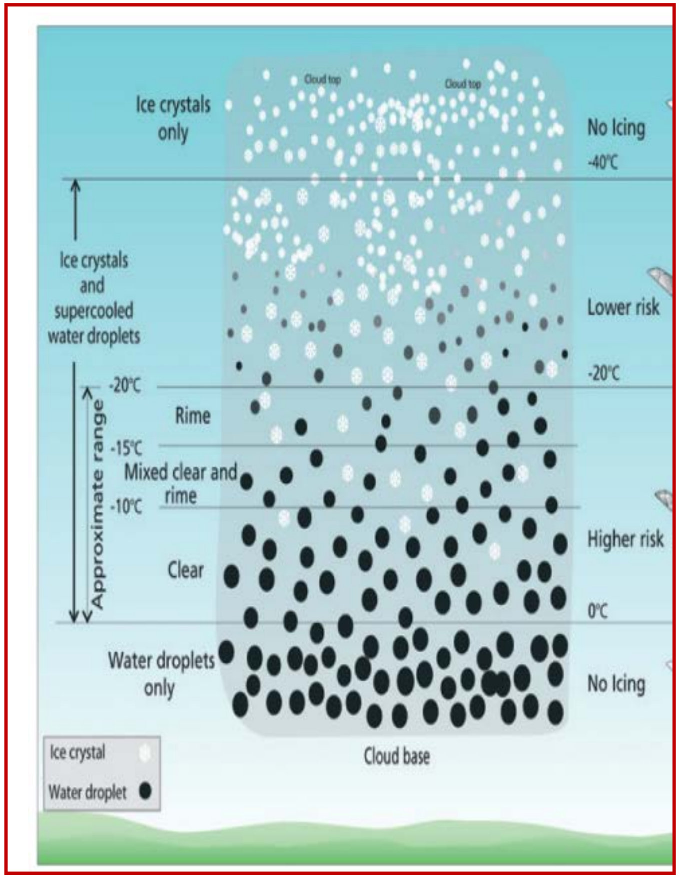
- **Mechanism:**
- Thunderstorm Updrafts support large drops of Super Cooled Liquid Water.
- The Super Cooled Water (*Liquid drops surrounded by air that is below freezing)* may freeze on large impact with Aircraft.

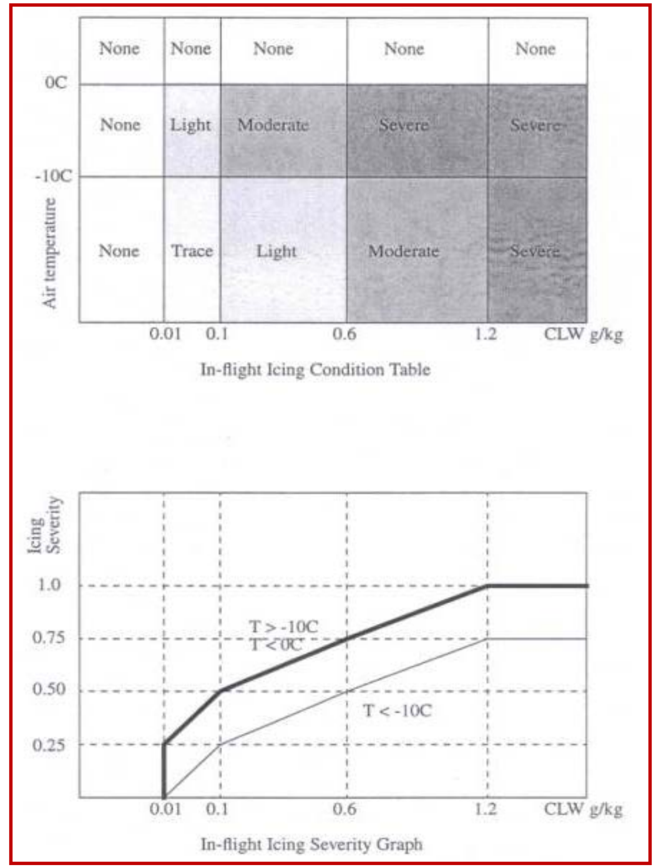
- **Meteorological Quantities : Most closely related to icing severity and type in order of importance are**:
- ***Liquid water content (LWC):*** Abundance of Super Cooled Water droplets
- ***Temperature :*** Icing can occur in temp as low as **-40^{0}C in convective clouds**
- Droplet size : Super Cooled Large droplets (diameter greater than 50 μm)
- Altitude : Type of Cloud (vertical motion)

(Icing pattern changes with droplet size but in Icing Hazard, droplet size is NOT as important as Temp. & LWC - http://www.crh.noaa.gov/)

- **Cause of Icing:**
- ***Not caused*** by the Ice in the Cloud
- Caused by Super Cooled Liquid Water

In Flight Icing Conditions & Severity





Air temperature					
above 0C	None	None	None	None	None
0C to -10C	None	Light	Moderate	Severe	Severe
below -10C	None	Trace	Light	Moderate	Severe
CLW g/kg	0.01	0.1	0.6	1.2	

In-flight Icing Condition Table

In-flight Icing Severity Graph

Source: http://aoaws.caa.gov.tw/

The severity number is interpreted as follows:

<= 0.25 None

>0.25 and <= 0.5 Light

>0.5 and <= 0.75 Moderate

> 0.75 Severe

Note: 1. In-flight icing only occurs when the air temperature is below 0 Deg. C

2. Icing severity increases with increasing cloud liquid water content

3. Clear icing has a more severe impact on aerodynamic performance than rime icing

Source: Bureau of Meteorology

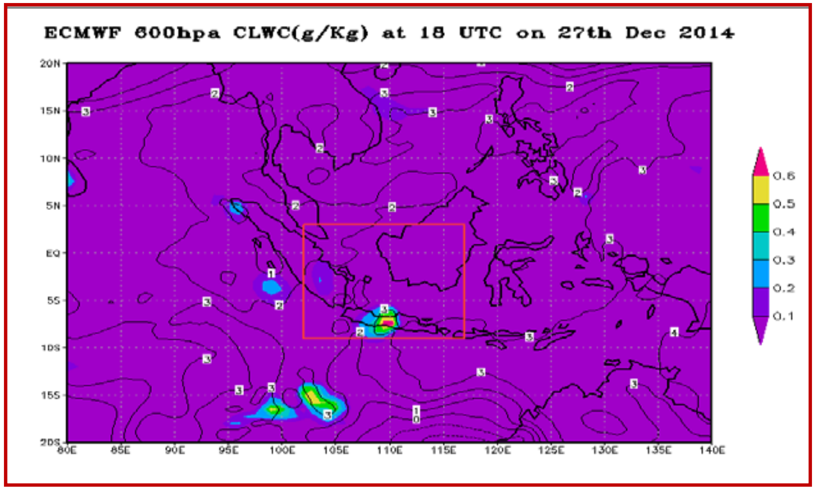
3. Experimental Design & Methodology using Numerical Modelling Approach.

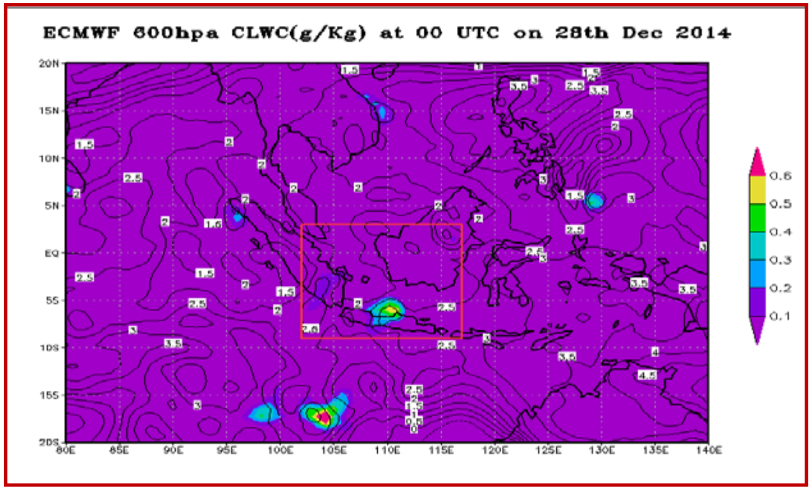
Cloud Liquid Water from ECMWF data on 27th & 28th Dec 2014

27th Dec 2014 at 18 UTC December, 2014.

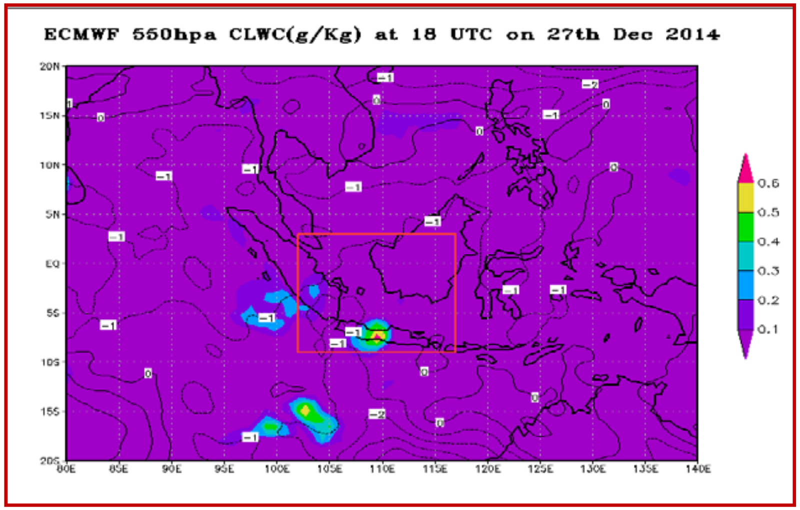
Below Freezing Altitude

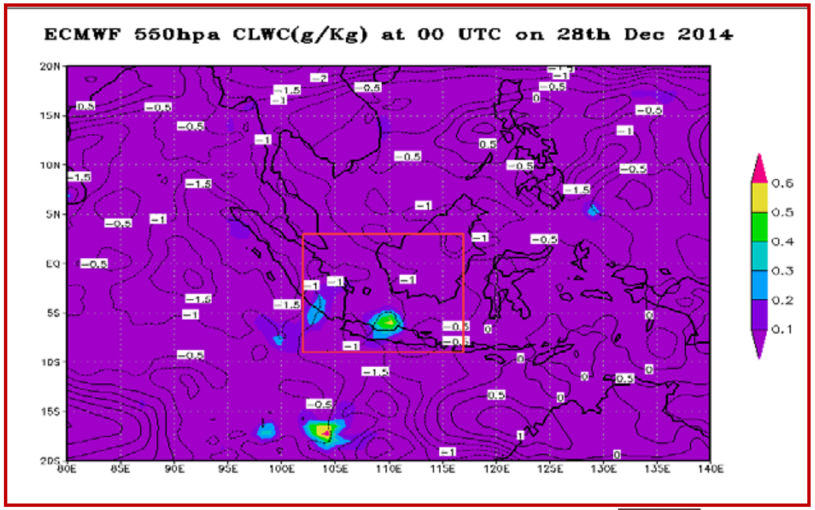
28th Dec 2014 at 00 UTC December, 2014.





Above Freezing Altitude





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Weather Research & Forecast Model (WRF)

- **Model:** Three dimensional regional *Numerical Weather Prediction*

- **Dynamical cores:** *Advanced Research WRF (ARW)* and *Non-Hydrostatic Mesoscale Model (NMM).*

- **Purpose:**

  -Research in Atmospheric science & Real time forecast.

- **Developers:** *National Centre for Atmospheric Research, National Centre for Environmental Prediction, National Oceanic & Atmospheric Administration, University of Oklahoma, Forecast System Lab, Air Force Weather Agency*, and *Federal Aviation Administration.*

Important applications of WRF Model

- WRF Model is considered to be suitable for a broad range of applications ranging from tens of meters to the global and includes the following:

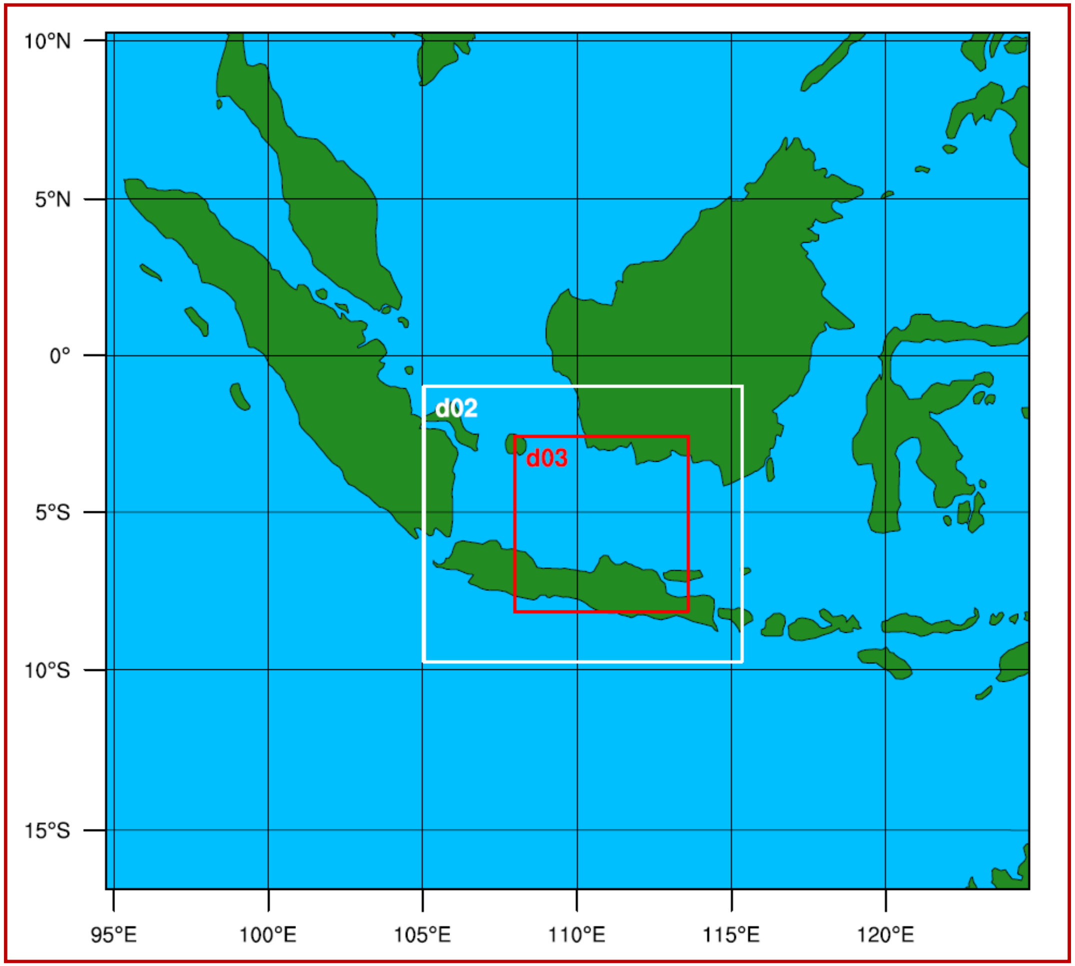
  - Meteorological research & Real-time NWP
  - Regional Climate Modeling
  - Data assimilation studies and development
  - Coupling with other earth system models

- WRF Model has been efficient in capturing the following Natural Hazards:

  - Modelling extreme rainfall, strong winds and surges from Tropical Cyclones (hurricanes/ typhoons/cyclones)
  - Monsoonal Winds, Flood (Rainfall), Droughts,
  - Tornadoes, Hailstorms, Blizzards, Ice storms
  - Thunderstorms, Thermal extremes
  - Extra Tropical Cyclone (windstorm)
  - Climate Change studies

- WRF has been used for analysis of aircraft icing episodes (e.g. Nygaard et al.,2011)

Model set up & Experimental design based on sensitivity experiments



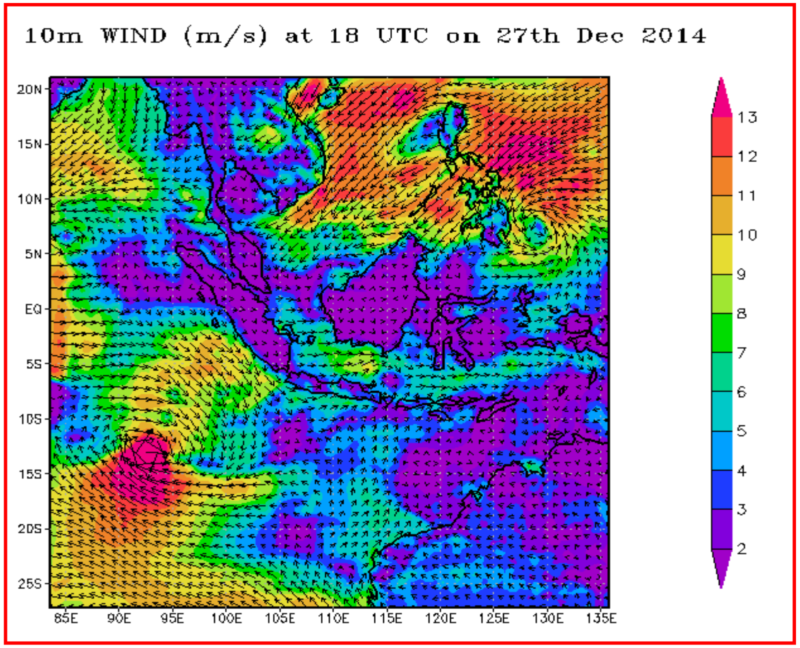
- **Domain: d01**-27km; **d02**-9Km & **d03**-3Km
- **27** vertical levels; Top pressure level: **50hPa**
- **31 days** simulations from:
  - -Dec 1st 00:00 UTC to
  - -Dec 31st 00:00 UTC
- Model predictive skill tested

WRF Model domain centered at location of Java Sea at the last location of Aircraft (3◦ 36' 48.36'' S; 109◦ 41' 50.47'' E)

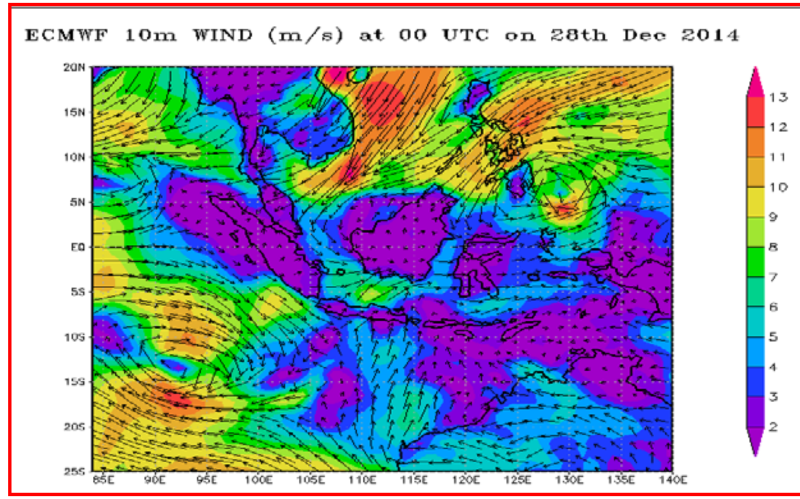
4.a Meteorological Analysis using WRF Model along the flight path

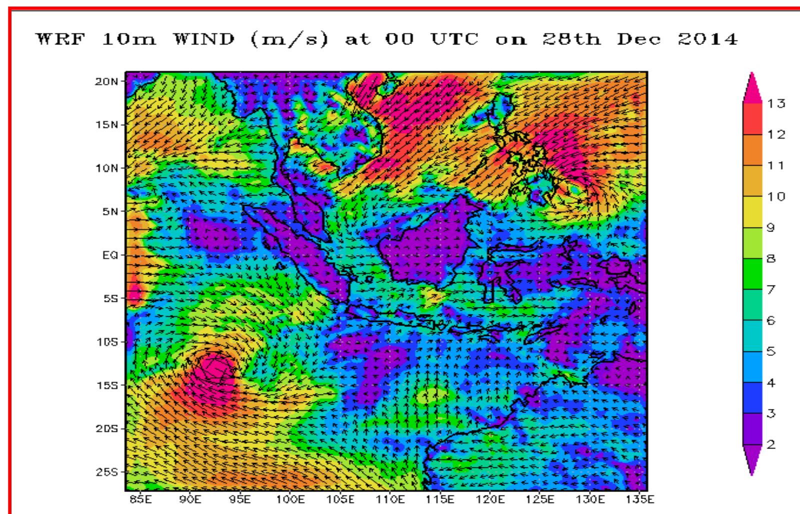
Comparison of WRF Model Prediction with ECMWF data

27th Dec 2014 at 18 UTC December, 2014.



28th Dec 2014 at 00 UTC December, 2014.





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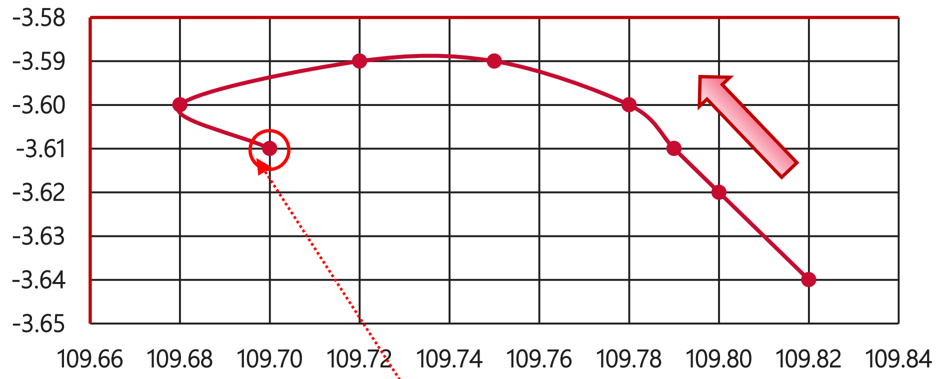
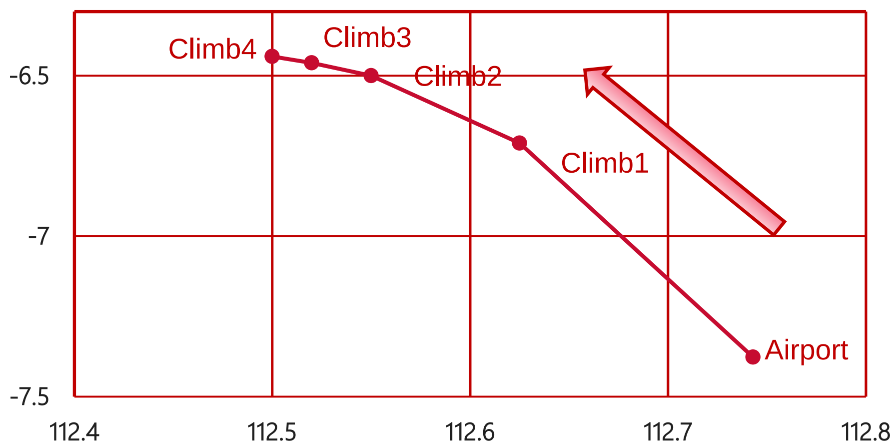
Co-ordinates of the Flight Path

Aircraft Started to climb from FL320



The aircraft last position according to the Automatic Dependent Surveillance- Broadcasting (ADS-B) radar Last Radar Contact -3.613° 109.697°at 2318 UTC. A/C was at an altitude of approx. 24,000 feet

From Take off to FL320



Georeferenced Climb locations with approximation

Locations	Positions
1	Climb-1
2	Climb-2
3	Climb-3
4	Climb-4

Source: FlightRadar24

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Meteorological Analysis along the flight path

A/C Location	Time (UTC) 27th Dec-2014	Pressure (hPa)	CLWC (g/Kg)	Temp (^{0}C)	Riming Intensity (Fraction)	Dew Point Spread	Relative Humidity (%)
Climb-1	22:40	700	0.556	9.932	0.698	-0.00703	100
Climb-2	22:45	500	1.3909	-3.663	0.81	-0.0006942	100
Climb-3	22:50	375	1.38256	-20.2211	0.749	-0.000823	100
Climb-4	22:55	275	1.13342	-33.1121	0.686	-0.004703	100

Source: FlightRadar24

Note: *1. The value of Ri is only computed when liquid water content is larger than a threshold of 0.01 g m-3*

2. Riming efficiency is near zero for small droplet size (<30 microns)

Source: Lin and Colle, 2011

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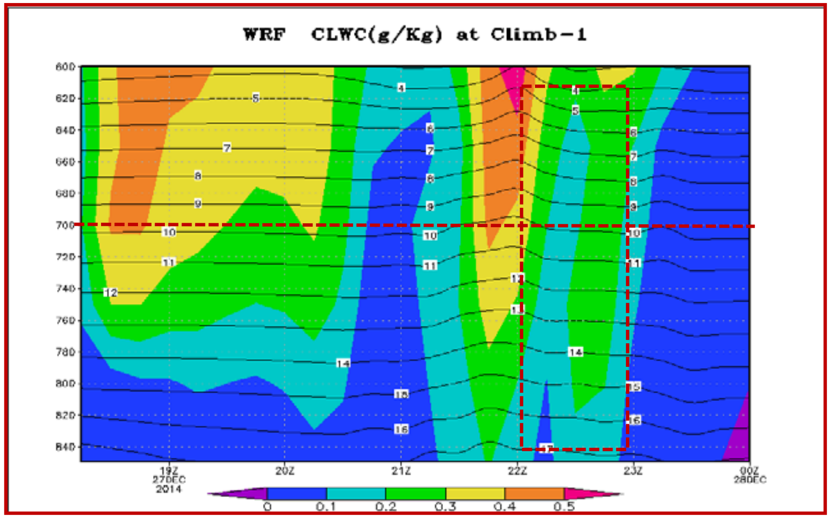
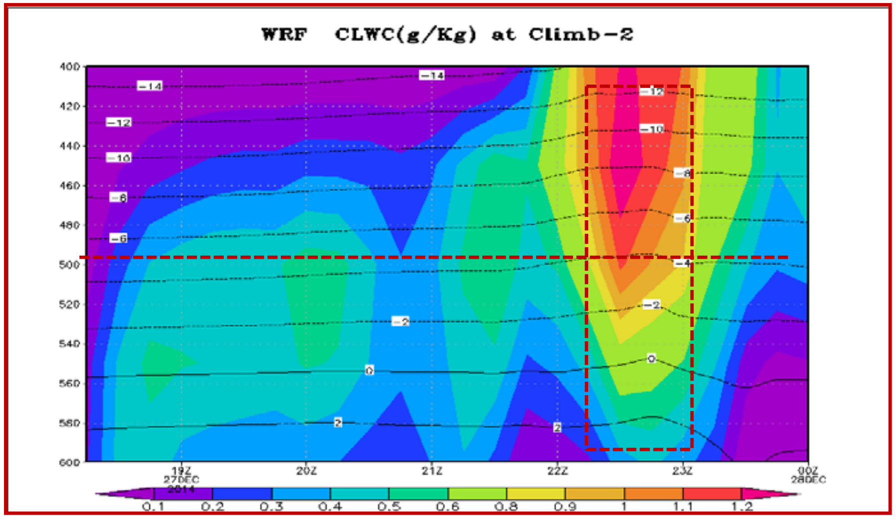
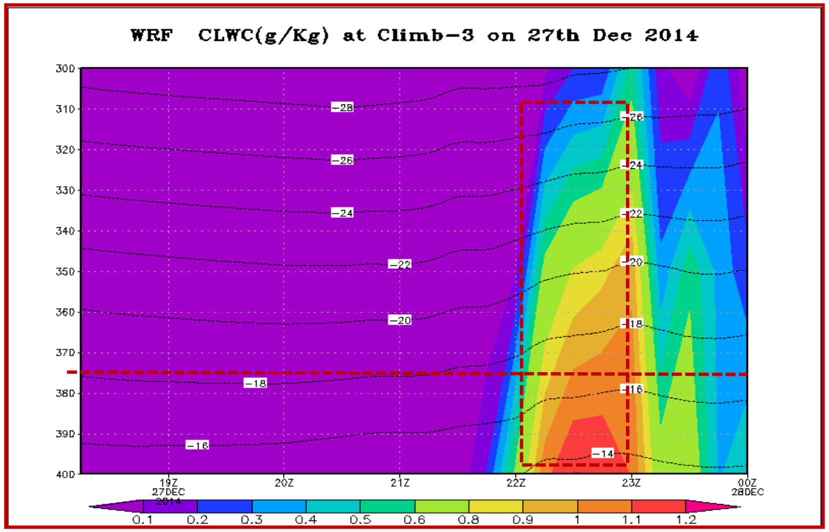
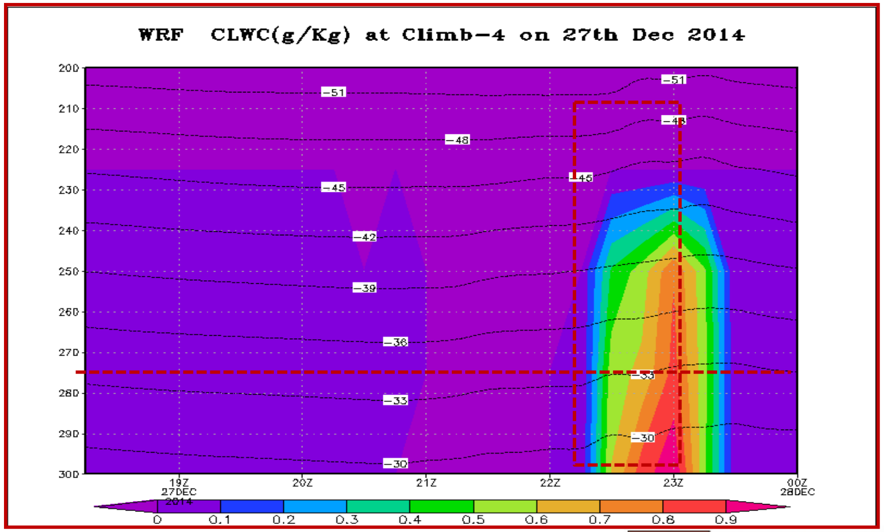
CLWC at Climb Locations between 2200 & 2300 UTC









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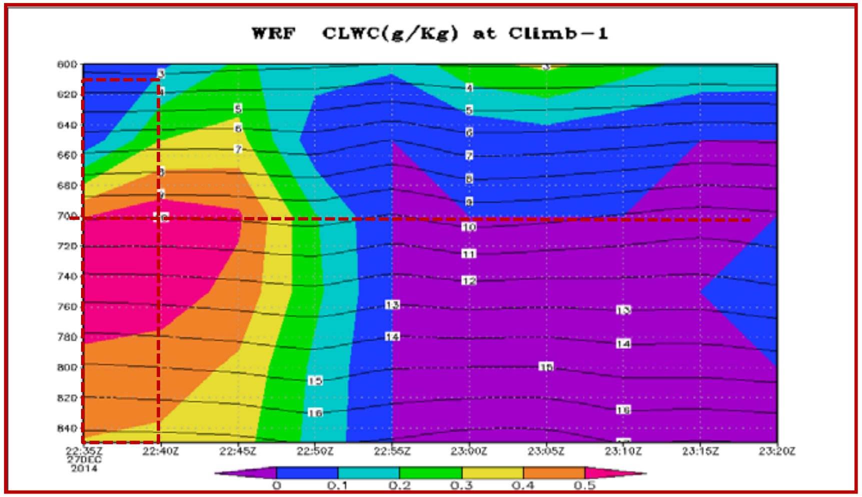
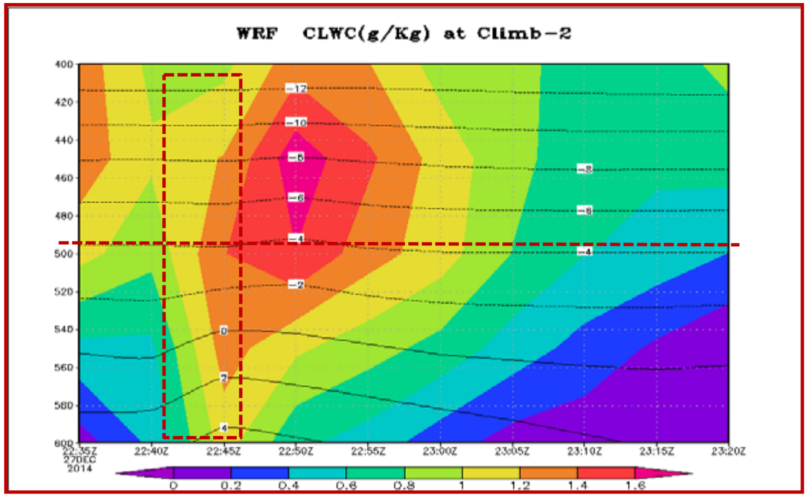
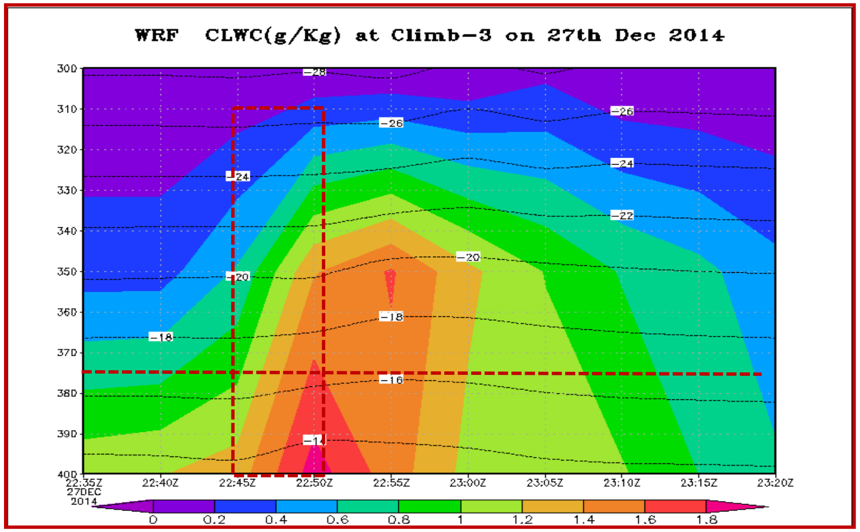
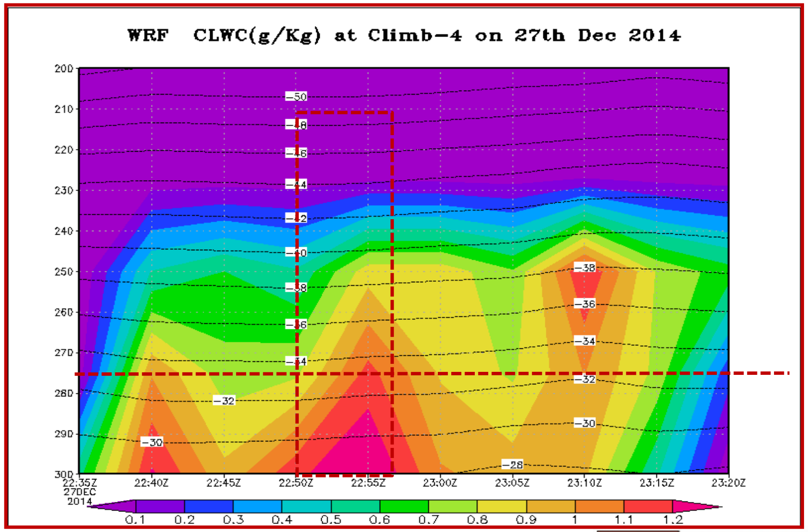
CLWC at Climb Locations between 2240 to 2255 UTC









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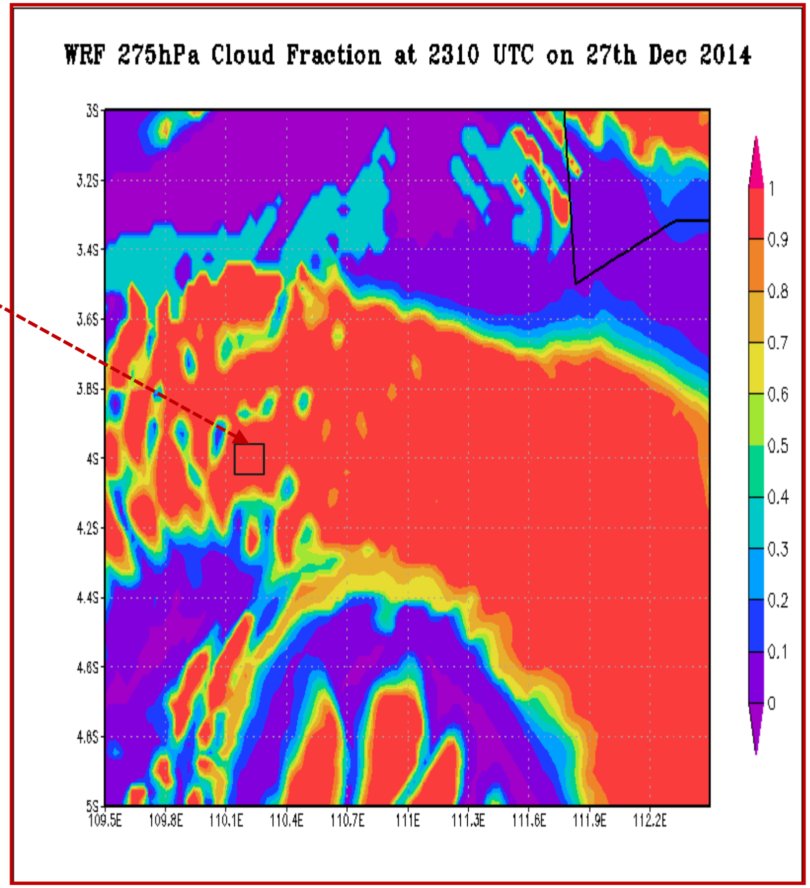
Can we still answer these Questions!

- *Why did the pilot request to fly at a higher level than FL 320? Was it due to the severe thunderstorm clouds?*
- ✓ *The model shows the cloud fraction with low reflectivity value of 10 BbZ (fig not shown) , indicating light mist.*



- *ATC gave clearance to climb and fly the aircraft at FL 340 but it was not replied by the pilot, what then suddenly made the pilot to perform such a rare steep climb of 38,000 feet with a rate of up to 11,000 feet per minute?*

X

- Was the weather condition so severe that while climbing for higher altitude the aircraft encountered multiple challenges that reduced drastically aircraft's performance?

X

- *The aircraft stall warning system informed of the approaching stall. Even if the aircraft reached such a speed and Angle of Attack (AOA), why couldn't the pilot avoid such approaching stall?*

X

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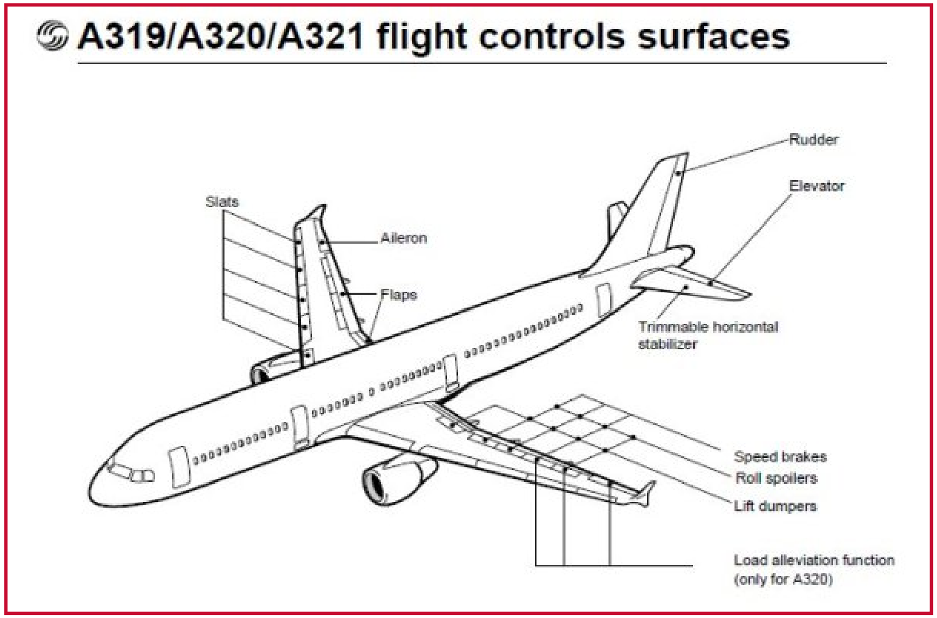
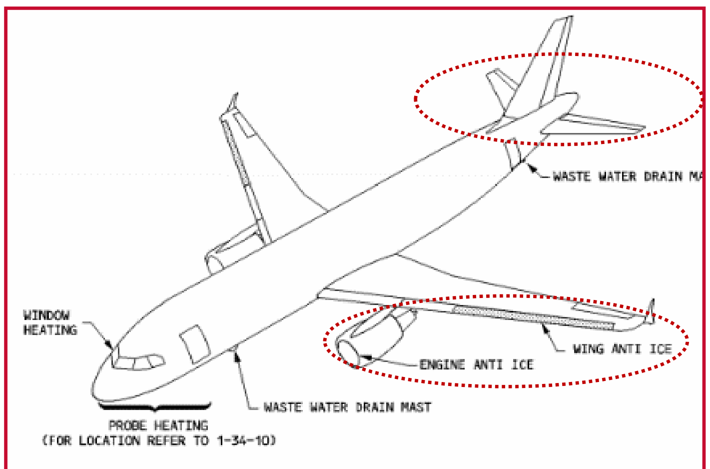
4. b Aerodynamic response of the Aircraft based on Meteorological analysis along the Flight Path

Potential Aircraft surfaces for collecting ice





- *Collection efficiency is dependent on three factors :*

  - ***<u>Airfoil:</u>*** *The radius of curvature of the aircraft component*
  - ***<u>Speed:</u>*** *The faster the aircraft the less chance the droplets have to be diverted around the airfoil by the air stream*
  - ***<u>Droplet size:</u>*** *The larger the droplet the more difficult it is for the air stream to displace it*

Source: http://modernairliners.com; A320 Flight Crew Operating Manual

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Effect of Auto Pilot operation during Icing

- **What if auto pilot is engaged during icing ?**

- Autopilots and auto-throttles **masks the aerodynamic effects of the ice** and may bring the aircraft into a stall or cause control problems.

- Situation can degrade to the point that where autopilot servo control power is exceeded, **disconnecting the autopilot**.

- Once autopilot is disengaged, Pilot is then faced with an **immediate control deflection** (Roll, Pitch, Yaw) for which there was no warning or preparation.

- There have been several accidents in which the autopilot trimmed the aircraft to stall upset by masking heavy control forces. Then **pilots have been surprised when the autopilot automatically disconnected with the aircraft on the brink of stall.**

"Aircraft stall warning system provide warnings based on an uncontaminated main plane stall. "

Source: Federal Aviation Administration

Aerodynamic behaviour of Air Asia QZ 8501 just before its upset !

- At 2316:44 UTC **The Auto Pilot (A/P) and the Auto-thrust (A/THR) disengaged**. Flight control law reverted from Normal Law to Alternate Law. The aircraft started to roll to the left up to 54° angle of bank.

- **Nine seconds after the autopilot disengaged**, the right side-stick activated. The aircraft **roll angle reduced** to 9 deg. left and **then rolled back** to 53 deg. left.

- The input on the right side-stick was mostly pitch up and the **aircraft climbed up to approximately 38,000 feet with a climb rate of up to 11,000 feet per minute.**

- At 2317:18 UTC, the stall warning activated and at 2317:22 UTC stopped for 1 second then continued until the end of recording. The right side stick input was mostly at maximum pitch up until the end of recording. **The lowest ISIS speed recorded was 55 knots**.

- At 2317:41 UTC the **aircraft reached the highest ISIS altitude of 38,500 feet and the largest roll angle of 104° to the left**. The aircraft then lost altitude with a descent rate of up to 20,000 feet per minute.

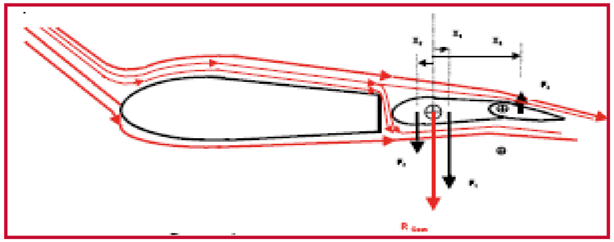
- At approximately 29,000 feet the aircraft attitude was wings level with pitch and roll angles of approximately zero with the airspeed varied between 100 and 160 knots**. The Angle of Attack (AOA) was almost constant at approximately 40 deg. up and the stall warning continued until the end of recording.** The aircraft then lost altitude with an average rate of 12,000 feet per minute until the end of the recording.

Air Asia QZ 8501 steep R/C Explanation !

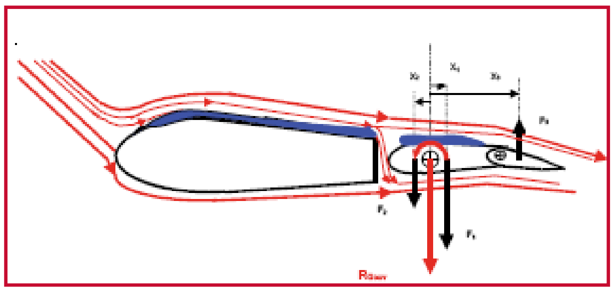
Step-1

- Aerodynamic Explanation of the Phenomenon:

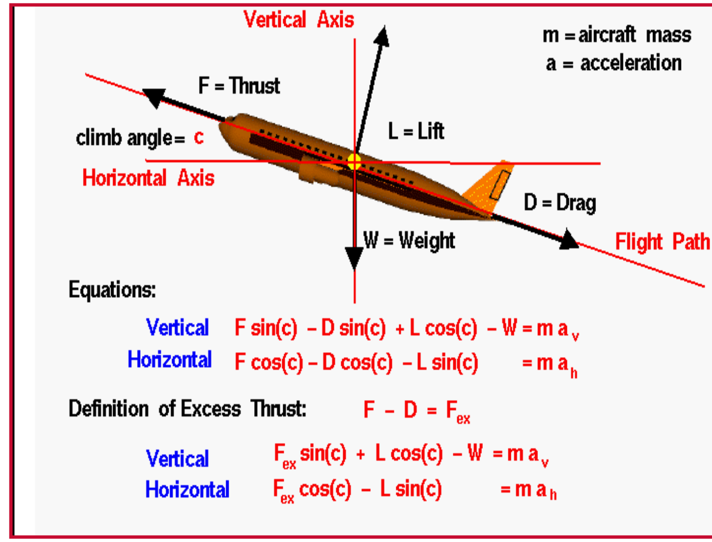
A. Without Ice



B. With Ice

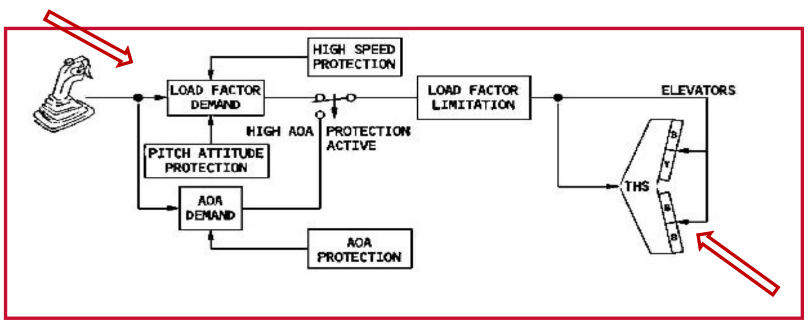


Step-2 +



Source: NASA Glenn Research Centre

Step-2



Pilot pulls the yoke and elevator is deflected upward

Step-3

$(R/C)_{\text{Extreme}} = (R/C) + (R/C)_{\text{Sudden change in aerodynamic profile}}$

"Extreme Rate of Climb during flight can only be achieved when there is sudden change in the boundary layer flow over the horizontal surface, which immediately influences the airflow over the wing"

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We can now answer these Questions!

- *Why did the pilot request to fly at a higher level than FL 320? Was it due to the severe thunderstorm clouds?*

- *ATC gave clearance to climb and fly the aircraft at FL 340 but it was not replied by the pilot. what then suddenly made the pilot to perform such a rare steep climb of 38,000 feet with a rate of up to 11,000 feet per minute?*

- *Was the weather condition so severe that while climbing for higher altitude the aircraft encountered multiple challenges that reduced drastically aircraft's performance?*

- *The aircraft stall warning system informed of the approaching stall. Even if the aircraft reached such a speed and Angle of Attack (AOA), why couldn't the pilot avoid such approaching stall?*

5. Conclusion

Can this be a Conclusion?

- The aircraft **encountered continuous subfreezing cloud liquid water** between 550 hPa to 275hPa during its take-off journey of 15 min.

- These liquid droplets **may have started freezing in the aft of the horizontal stabilizer and vertical stabilizer of the aircraft**.

- The first ECAM failure and the remaining failures for RLTU may be due to the contamination caused by the freezing of super cooled liquid droplets as clear ice. **The Autopilot could not detect it**. (Air France disaster :*No failure message on the ECAM clearly indicates the detection by the system of an inconsistency in measured airspeeds.* The similar ECAM message may also have been noted during the previous RLTU failures of the Air Asia Flight when not effected by ice)

- Pilots thus trained may **not recognize an ice induced stall that occurs before stick shaker activation**, and they might not be aggressive enough in recovery action even if they do recognize the situation (*neither of the two Pilots either in Air France or Air Asia Disaster called for emergency. No emergency message was transmitted by the crew*)

- **The formation of ice on the elevator changed the aft boundary layer profile of the elevator**. (In Autopilot mode With such formation of clear ice, elevator will tend to move up. To restore the equilibrium nose down trim has to be increased.) *Since autopilot suddenly disengaged pilot could not diagonize this situation***.** Instead of maintaining level flight they pulled the elevator up (also they already requested for a climb). This lead to the sudden breaking of the accumulated ice which caused the aircraft to climb at a very high rate of climb aerodynamically.

Note : The above analysis is purely my personal opinion and it is intended only to be shared as an additional information.

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Thank You !