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A "Short Course" on Ice and the TBM.

Icing is topical at the present time as a result of a recent accident in a TBM. I have had a number of conversations with pilots who I would consider knowledgeable and it is apparent that there is a lot of confusion surrounding this subject. Also noting on line posts this confusion is not limited to owner pilots. I have had occasion to be a victim of my own stupidity in a serious icing condition years ago and I can vouch that icing is a deadly serious situation in more ways than one.

Before going on with the subject we want to stipulate that the data we are about to provide is a summary of information that is to be found on line, along with narrative and data provided from knowledgeable instructors, if any of the data provided conflicts with anything you have been taught we urge you to satisfy yourself as to which data is correct.

TBM operators fly in the same airspace where we find Part 25 aircraft (Commercial Category) aircraft. There is a big difference in how these two categories of aircraft are affected by icing conditions. A 767 will often be climbing at over 300 kts and 4000+ ft/min at typical icing altitudes. This creates two very distinct advantages for the 767: first, their icing exposure time may be less than 1/3 of ours. Second, icing conditions are a function of TAT (Total Air Temperature), not SAT (static air temp). TAT is warmer than SAT because of the effects of compressibility as the airplane operates at faster and faster speeds. In a TBM at cruise speed, there is a 10-12C increase in temperature brought about by the compression of the air in front of the pitot tube cause by the speed at which we fly. A jet may see a 30+C increase. So that same 767 that reported no icing may have had a TAT of +5C, while our TBM at the exact same location and altitude is showing –5C and is picking up lots of ice as a result. If you receive a report that an airliner is experiencing moderate to severe icing in your area this should be treated as an immediate elevated warning and actions must immediately be taken to avoid the area.

What we as TBM pilots should realize is that the 'Known Icing' specification on the plane is not an all encompassing term, there are times that the icing protection on the aircraft cannot cope with the conditions. In addition AD 98-04-22 prohibits operations into Severe Icing Conditions.

It is one thing having this restriction on our operations but it appears to be entirely another item to understand how TBM pilots recognize that they are in Severe Icing Conditions. One thing that I hope to impart before the end of this narrative is if you find yourself in Severe Icing conditions you have a full blown emergency on your hands and you owe it to yourself and those around you to act with the kind of urgency that the condition calls for. Do not be complacent or slow to react, more on this later.

Over 500 PEOPLE HAVE DIED IN ICING ACCIDENTS IN THE LAST 16 YEARS!

NTSB and other accident database records from 1990 to the present for fatal turbine airplane accidents in which icing was blamed or was a factor or possible factor show the following ;.3 fatal accidents involving in-flight airframe icing in Part 25 jets (13 fatalities). One was a Falcon 20 and the other two Citation 560s. (One of the Citation accidents involved a Circuit City Citation at Pueblo, Colo., in February 2005, but the NTSB has not yet classified this as an icing accident; icing is suspected because it was reported by a sister airplane's flight crew that arrived at the same time.)

Six Part 25 jets suffered ground-icing-related fatal accidents (122 fatalities), although a Citation 560 crash in Zurich, Switzerland, is questionable; NTSB records report the possibility of ground icing before takeoff but there is no conclusive report from the Swiss authorities. Total fatalities in Part 25 jet ground and in-flight icing accidents during this period were 135, which includes 27 in a Flushing, N.Y. Fokker F-28 takeoff accident and 83 in a Fokker F-100 takeoff accident in Macedonia. AIN could find no Part 23 jets that suffered icing-related fatal accidents during this period.

Turboprops suffered the worst of the group killing 349 people in in-flight and takeoff icing-related accidents since 1990. Six of these accidents (32 fatalities) involved ground icing before takeoff, and five of these occurred to Cessna 208 Caravans. Three airline turboprop accidents accounted for 119 fatalities, an ATR-72 in Roselawn, Ind.; EMB-120 in Monroe, Mich.; and Shorts 360 in Libya. Of the remainder, Cessna's 208 had 12 in-flight icing-related fatal accidents. (One of these accidents also involved ground icing and one was not conclusive but raised the possibility of in-flight icing.) The Mitsubishi MU-2 suffered four fatal in-flight icing accidents, although a fifth accident in Pittsfield, Mass., on March 25, 2004, could have been icing-related.

The majority of Part 25 jet icing accidents occurred during takeoff with contaminated wings. Records show that turboprops continue to suffer the greatest number of turbine-airplane icing-related accidents. There are many more piston-airplane icing accidents in the NTSB records than turboprops but there are other variables at play here such as flight into known icing conditions in aircraft that have no de-ice or anti ice capability.

One can safely assume that some of the contributing factors to the accident losses in icing in the Turbo Prop group come from complacency and a high likelihood that pilots don't recognize the conditions that contribute to the definition of flight in severe icing.

Before describing the conditions that should lead to a pilot recognizing Severe Icing here is some Icing Trivia;

The FAA and UIUC wind tunnel test revealed that even a thin, sparse (5 percent to 10 percent density ice coverage) rough ice accumulation on the leading edge deicing boot results in *significant* aerodynamic degradation. The BF Goodrich estimation of an effective deicing boot shed leaves about 20 per cent of the accumulated ice on the boots brings into perspective the amount of actual performance degradation there could be in icing conditions. In the icing wind tunnel tests performed above the ice accumulation of 10 per cent happened in the first 30 to 60 seconds! Important to note here, when assessing the amount of ice accumulation the pilot has to take into account that there could be accumulation in areas that he cannot check, for example, aft of the deicing boot under the wing.

Operating Decisions.

One cannot make wise operating decisions, go or no go without a thorough understanding of the environmental conditions that you will be flying in. Ice typically forms on a wing when the surface collides with water droplets that have remained liquid although they are below the freezing point, (i.e. super-cooled water). In order to make an assessment a pilot needs to know the Temperature, Moisture level and Droplet size.

TEMP- Icing is most frequent when the SAT is between +2c and -20c. The closer to freezing the more hazardous are the ice shapes. Horns are formed where supercooled water droplets strike the leading edge and then flow aft before freezing, this usually forms horns which can substantially disrupt the airflow of over the wing. In colder temperatures the ice particles freeze on impact and stick to the front of the wing and form wedges also known as rime ice.

MOISTURE: In order for ice to accumulate there must be sufficient liquid in the air. Water in the form of snow, vapor or ice will generally not stick, and will not contribute to the overall buildup. Sufficient liquid in the air in the form of visible cloud or liquid precipitation will be conducive to ice build up. The more water the greater the accumulation rate. Measured in water per volume of air g/m3.

DROPLET SIZE. When an aircraft is moving through the supercooled cloud droplets will impact the wing and tail along a narrow band near the leading edges. However when there are larger droplet sizes, they are able to strike the wing further aft and these droplets are likely to form into shapes that will disrupt airflow causing acute handling problems. Most icing encounters are with droplets between 10 and 50 microns, however supercooled droplet sizes can be 400 microns and larger. These droplets accumulate aft of the boots and on areas where they can only be removed by melting or sublimation. With the ice being blown off the leading edge by the boots a ridge will develop aft of the boot rapidly that will disrupt airflow.

One of the biggest ice hazards for pilots are SLD’s or supercooled large droplets. Normally occurring at the surface, but also can occur below 12000 feet. The bands of where SLD’s are found are seldom thicker than 3000 feet. There are normally 2 conditions that result in SLD, a) temperature inversion or b) collision-coalescence process.

a.) Temperature inversion – Normally temperature decreases with altitude, when there is a temperature inversion this is not the case. In a temperature inversion a cold layer of air lies under a warmer layer. Freezing rain occurs when snow falls into air that is above freezing. The snow melts and forms liquid precipitation, these water droplets continue falling into a layer of air that is below freezing, and these will develop into ice pellets. The potential for SLD is therefore at the bottom of the freezing layer, hence the propensity for being found at lower altitudes.

b.) Collision-coalescence occurs when droplets collide within the cloud and coalesce into larger droplets, and these can be found throughout the cloud and are not formed as a result of any temperature differential. This happens in relatively warm, low altitude clouds below 12000 feet warmer than -12c.

When encountering these conditions of SLD exit immediately. Usually a change in altitude of greater than 3000 feet is sufficient. The cues to SLD on the plane are ice formation on side windows and aft of deice surfaces. You need to exit because your TBM is not certified for flight in these conditions simply because the de-ice system cannot adequately protect the aircraft in these conditions. More on this later…

Checking the Weather.

In order to accurately forecast the likelihood of icing along your route of flight you need to know the following; the temperature range and moisture content of the air, the stability of the air – are there fronts or mountain ranges than can lift this air? You must know the cloud tops and bases along the route of flight in case you need to exit icing conditions and of course you must know what he underlying terrain elevations are.

Knowing the reasons for cloud formation along your route; icing can be most intense at the tops of clouds because this is where the air has the most moisture, most cooling and the highest condensation levels. The best signal as to what kind of stability there is in the air mass is given by the kind of cloud formation, Stratiform or Cumulus Clouds.

Stratiform clouds develop in uniform horizontal layers usually because they are formed by lifting layers of stable air. They generally contain lower amounts of liquid water. They generally cover larger areas, and generally the icing layer in Stratiform clouds is less than 3000 feet and icing is found below 15000 feet. In Stratiform clouds if encountering icing, activate the deicing system and climb or descend 3000 feet.

Cumulus Clouds are formed when there is ample moisture and the air mass is unstable. The vertical growth of these clouds depends on how unstable the air is. They are usually limited in horizontal area. The icing in these clouds can cover many thousands of feet. In cumulus clouds the icing encounters are generally short but severe, and the formation of SLD is more likely. The horizontal extent of these clouds is generally 2-6 miles. Icing is generally found from 27000 feet and below at temperatures from -2c to -20c. Pilots around Cumulus clouds at temperatures between -2 and -20c should remain clear of cloud, navigate laterally around the cloud. Icing in these clouds is normally severe and a substantial risk to flight.

Geographic Effect: Knowing the terrain is important because although icing can occur anywhere, it is greater near large bodies of water. These bodies of water add heat and moisture to the system and induce instability which increases the risk of ice. Topography is also important from the aspect of terrain, this generally limits the pilot decision of climbing or descending out of ice to climbing only. Knowing the direction of the system in mountainous areas is also useful because as air traverses over a range and rises icing encounters are more likely on the windward side. When being routed along a mountain range always consider re planning the route to be along the leeward side to reduce the possibility of encountering ice.

Frontal Effect: Need to know the kinds of fronts that you will be flying through. What is a front? It is where 2 air masses of different temperatures and or pressures collide. There are 3 kinds of fronts; warm, cold and occluded fronts.

> Warm fronts are where warmer air slides over colder air, they are discernible by stratus cloud formations over wide areas. During the winter these can be very dangerous as the warm air rising above the sub-freezing air may result in the formation of freezing rain or drizzle. Signs of approaching the front are where cloud layers build quickly and the clear air between the layers disappears rapidly. So what should you consider when flight planning? If you route will take you along a front, consider crossing the front perpendicular to the direction of movement and flying behind the front. Look at the low altitude and prognosis charts for forecasts of freezing rain.
>
> A cold front is where the colder air under cuts the warmer air. There are 2 types of cold front, a classic cold front and a shallow cold front. A classic cold front is is one that is characterized by extensive cumulus cloud development which straddles the front. The classic cold front is also characterized by narrow bands of cumulus clouds, and thunderstorms, with heavy precipitation, turbulence, hail and high levels of supercooled water. If flying in these areas consider flying behind the front, be careful when penetrating these areas because of turbulence and the possibility of substantial icing. Classic cold fronts normally occur in warmer weather.
> A shallow cold front is characterized by widespread stratus clouds behind the front and one where the temperature inversion is not very deep. Where possible routing should be attempted ahead of the front, and although significant icing can be encountered, a climb or descent of 3000 feet will generally get you clear.

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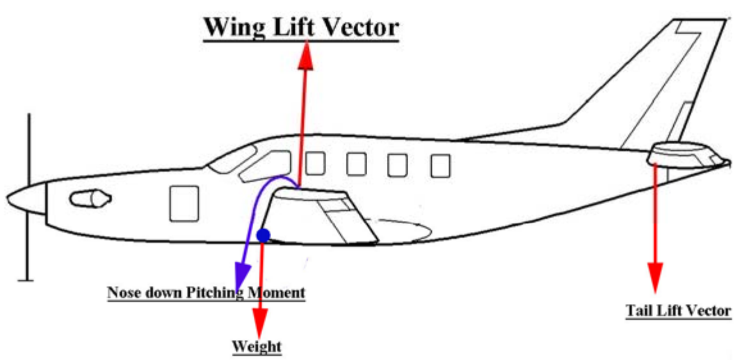
Occluded fronts occur when warm air is trapped between 2 cold air masses and is forced to a higher altitude. One could experience conditions of both hot and cold fronts. The risk of severe icing is higher in the vicinity of a warm or occluded front.

Before flying in icing conditions know your capabilities and those of the aircraft. Bear in mind that small amounts of ice can result in huge degradations in the performance and handling characteristics of your plane. Climb rate decays, cruise speed decreases, stall speed increases, the plane will have lower service ceilings, and increased fuel consumption resulting in reduced range. Experiments have shown that within 30-60 seconds lift can be reduced by 20-30%, critical angle of attack reduced by 8 degrees which brings about a substantially higher stall speed.

Small amounts of ice change the aerodynamic effects of the wings and control surfaces considerably. Of more significance however, there are no early warnings of the change in handling effects. Small amounts of ice will raise the stall speed of the wing by as much as 15 knots, this may also cause disruptive airflow over the ailerons causing the aircraft to behave in unusual ways, for example ailerons may deflect without pilot input causing uncommanded rolls. Wing stalls normally occur at slower speeds or following premature flap retraction.

TBM Specific Information.

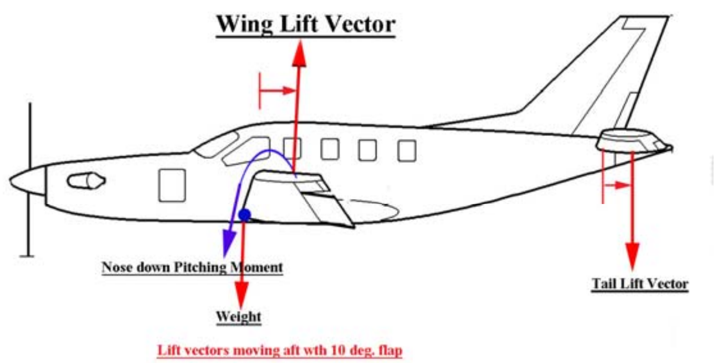
What is the relationship between Wing and Tail forces?



In the above diagram note that the Weight vector or Center of Gravity is forward of the Center of lift on the wing. Notice also that the center of Lift Vector on both the wing and the tail are towards the front of each of the respective surfaces.

As in most aircraft the C of G on the TBM is forward of the wing center of lift which generates a tendency for a nose down pitch. The stabilator counteracts this by generating downward lift. The airflow must stay attached to the lower surface of the stabilator to generate this effect, in just the same way as the air must stay attached to the upper surface of the wing to prevent a stall. Where this is most dangerous is on landing, because flaps increase the wing downwash and greatly increase the horizontal stab angle of attack. Increasing the angle of attack on the stabilator can cause the airflow to break on the stabilator and may bring about an un-commanded pitch change, in extreme cases causing the nose to pitch down. Tail stalls normally occur with flap extension at the high speed limit for the flap extension

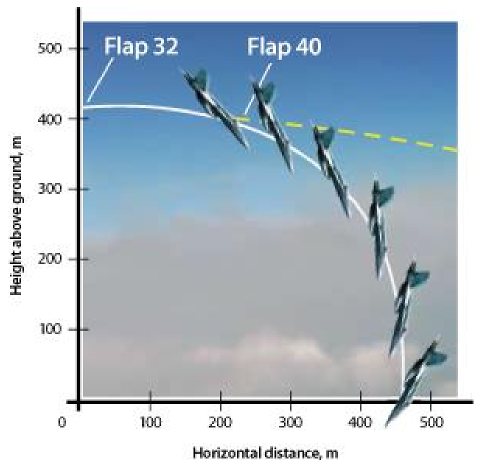
In icing conditions the rate of accretion of ice on the tail is 3-6 times quicker than ice on the wing. On turbo props, the prop wash cooling effect may further encourage the rate of ice formation on the tail.



As the wind flow over the tail is disrupted by ice accumulation either on the boots or aft of the boots, the laminar flow of air responsible for lift will detach itself from the forward part of the horizontal stabilator and reattach further back, causing the Tail Lift Vector to move further aft. This detaching and reattaching of the airflow in extreme cases will cause the pitch oscillations in the yoke to be felt, this is why we are encouraged to hand fly the plane when encountering icing conditions. If the aircraft does not exit Severe Icing conditions timeously, the laminar flow will likely continue to reattach further aft, ultimately reattaching on the elevator, this will result in an immediate pitch over with full control wheel deflection forward and a tail stall will develop because the critical angle of attack on the elevator will have been exceeded, A VERY DANGEROUS CONDITION.

See below from the Royal Canadian Air Force site a picture diagram of a tail stall on a fighter. Notice from an altitude of 1300 feet, the ground travel in meters is a little over 1550 feet along the ground, this is very abrupt and a pilot experiencing a tail stall close to the ground will have minimal chance of recovery, approximately one foot of lateral travel for every foot of altitude.

This is a dramatic descent rate and the chances of recovering from a tail stall close to the ground are almost zero.



In the TBM AFM in Chapter 3 it says if severe icing is encountered the following actions should be taken; (this verbiage is almost verbatim from AD 98-04-22):

1. Inform ATC to exit severe icing conditions by changing the route or the altitude.
2. Avoid any sudden maneuver on flight controls
3. Do not engage the autopilot
4. If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.
5. If an unusual roll response or un commanded roll control movement is observed, reduce the angle-of-attack.
6. Do not extend flaps when holding in icing conditions. Operation with flaps extended can result in a reduced wing angle-of-attack, with the possibility office forming on the upper surface further aft on the wing than normal, possibly aft of the protected area.
7. If the flaps are extended, do not retract them until the airframe is clear of ice.
8. Report these weather conditions to Air Traffic Control.

There are a couple of other items that should be added to this list as items to consider as precursors or indications of Severe Icing;

a. A pulsing of the control yoke. A lightening or buffeting of the elevator and/or ailerons is indicative of a possible airflow separation caused by ice forming aft of a boot. This is particularly ominous, as the next cue may be a full deflection of the affected control surface. This could be an ‘aileron snatch’ as possibly occurred in an ATR-72 over Roselawn, IN, or a full nose-down elevator movement as demonstrated by NASA during their very comprehensive tail plane icing studies. In an aircraft like the TBM with manually operated controls, the forces involved may be more than we can overcome with the yoke. NASA measured over 400 lbs of force required to overcome the nose-down elevator movement.
b. This occurs as the boundary layer detaches and reattaches to the tail plane lower surface aft of the leading edge causing the oscillation because the center of lift is

moving aft. When this is felt or observed, don't hesitate to get out of the area of icing immediately.

c. Loss of IAS.
d. Loss of climb rate and increased pitch attitude.
e. Visual cues include ice forming on the upper half of the windshield. It is not uncommon for ice to form on the lower half, but if the windshield is completely coated, it's time to look for a way out. Ice forming aft of the boots may or may not be obvious. Clear ice is difficult to see until the boots are activated, at which point the ice fractures and turns white.
f. If the entire upper surface of the boot is iced up, we must assume that it may extend onto the wing as well.
g. The propeller going out of balance is another cue that it's time to change our plans. The feeling is unmistakable – it will feel like someone turned on a switch that causes the airplane to vibrate. It is caused when ice is shed from one blade, but sticks to the opposite one. Normally, it will remedy itself when the system cycles back to those blades.

Icing is normally a manageable threat. It is a very dynamic phenomenon that generally occurs in limited altitude ranges and changes in severity quite rapidly. In other words, the icing present right now may change significantly in both location and severity over a relatively short time period. Because of the localized nature of icing events, we often have the ability to mitigate or avoid them either through changing our route, or more commonly, changing altitudes or modifying our climb/descent profile accordingly.

There are many factors at play when determining whether or not we can proceed though reported icing conditions.

How bad is the icing? If it is reported as severe, it is a non-starter. No aircraft is certified for flight into severe icing conditions. To do so willingly is a blatant disregard for your personal safety and those of your passengers. There are documented cases of ice accumulation rates of over an inch per minute! Needless to say, that is a virtual death sentence for anyone who encounters it. Accidental encounters with severe icing require an IMMEDIATE response. ATC must be notified (declare an emergency if necessary), and get out. If you were climbing and know that lower is better, then descend immediately. Whatever you do, do it NOW. *Severe icing encounters WILL be short lived, either because the aircraft exits them in a controlled fashion by the pilot, or in an uncontrolled fashion once Mother Nature takes over. Choose wisely.*

Reports of moderate icing mandate some careful threat analysis and prudent decision-making. Remember that in a turboprop, we are at highest exposure to icing events during the climb (ground operations excepted). We are limited in both speed and climb rate, and the inertial separator will prematurely impact our climb performance and will lengthen our exposure time as a result. In addition, the boots depend on the slipstream to remove the ice as they inflate. Boots are not as effective at 135 kts as they are at 235 kts like we might have in a descent.

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A report of moderate icing between 15-16,000 ft is probably a manageable threat for most TBM pilots. Our threat exposure at typical climb rates would be less than a minute. Furthermore, we can utilize techniques that further reduce that exposure time as we climb. For example, a commonly utilized profile in most turboprop airline cockpits is to reduce the climb rate considerably as you approach the bottom of the reported icing. This allows the aircraft to accelerate to the highest possible speed before entering the icing. As soon as the icing is encountered, raise the nose to increase the climb rate until your normal climb speed is reached. This simply trades excess kinetic energy (speed) into additional potential energy (altitude). This can more than double your climb rate for 1-2,000', and reduces your icing exposure time accordingly.

A report of moderate icing in the climb of more than ~2-3,000' is one that should cause us to seriously explore other options. Remember that even though we may have a perfectly functioning de-icing system, there will be accumulations on parts of the airplane that are not protected. The tips of the wings, horizontal and vertical stabilizers, antennae, most of the windshields, spinner, dorsal fin, etc. are all unprotected. These parts will become contaminated to various degrees and will add both weight and drag, further reducing our climb performance. As our climb rate is reduced, our exposure time is increased, further reducing our climb rate, and the cycle continues until we exit the conditions. *The climb rate you have when you enter the icing will be the highest you're going to get.* It will only get worse from there.

During a descent, we have several advantages that give us a bit more flexibility. First, our performance is not limited by the available engine power. We have a virtually unlimited descent rate available should we need it, and we can really limit our exposure time *as long as we don't allow ATC to stop us in the middle of the ice!* Second, airspeeds will be considerably higher and therefore the boots will function better. More airflow means better ice removal.

If you find that you have encountered severe ice and you have taken the plane out of this environment and you are going to land, but you still have ice on the top of the wings (and we can assume on the horizontal stabilator) flaps should be added only with extreme caution, and if you decide to add flaps, do so at a higher altitude than normal to give yourself the opportunity to recover the plane if you inadvertently induce a tail stall.

From the diagram below, you will see when you add flaps in any configuration the center of lift moves aft on both the wing and the horizontal stabilator. The danger is that the airflow detaches itself and reattaches onto the elevator, this will cause an immediate full nose pitch over that will most likely be unrecoverable close to the ground.

In addition, it is recommended that you try to avoid a cross wind landing, if you have ice accumulation on the horizontal stabilator you more than likely have it on the vertical stabilator as well, this will reduce your directional control effectiveness. The same applies to a downwind landing, the chances of more abrupt nose down control inputs are increased.

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Be cognitive of PIREPS when airborne these are *by far*, the best source of icing information we can get. Furthermore, ATC will be the best source of PIREPS, as anyone who enters moderate or worse icing is probably going to report it to ATC, and is more than likely not going to take the time to get in touch with Flight Service to submit an official PIREP.

NASA and the FAA have put an interactive course together that can be found at the following link, this is an excellent refresher.

http://aircrafticing.grc.nasa.gov/courses.html.

Reference Sources used in this article:
TBM-700 Aircraft Flight Manual, Chapters 2/3.
NTSB Data Base.
Royal Canadian Air Force (www.forces.gc.ca)
NASA tail plane icing studies