With S211, APS covers high-altitude jet upsets

by Matt Thurber

After spending time ingraining a disciplined and strategic application of upset prevention and recovery training (UPRT) techniques in an Aviation Performance Solutions (APS) Extra 300L single-engine piston aerobatic airplane, pilots might want to consider sticking around for a jet enhancement program to learn how to handle upsets at high altitudes.

APS currently offers high-altitude jet UPRT in its Siai Marchetti S211 single-engine jet trainers, one of which was on the static display at last month's NBAA Convention. I was recently invited to sample the half-day S211 UPRT session at APS's headquarters in Mesa, Arizona. APS also has facilities in Arlington, Texas, and Breda International Airport in the Netherlands, and the in-aircraft high-altitude UPRT is available in Texas and at customer request.

APS trainees can add the S211 high-altitude UPRT enhancement program to the end of their full Extra 300L-based UPRT or as part of a recurrent training event at APS, according to Paul "BJ" Ransbury, APS president and CEO. The enhancement takes half a day, either on the last half of the third day, or the morning of the fourth day. For recurrent students, the S211 high-altitude course can be added as a second-day training event. "We need to make sure the fundamentals are in place before we take them to high altitude," he said. "There's just so much going on there."

APS also offers low-altitude programs integrating the S211 with the Extra 300L program, with many customers taking the entire three-day course in the S211 exclusively. However, for human factors reasons and repetition to proficiency, Ransbury recommends that initial UPRT is best accomplished by using both training airplanes, with at least two flights in the Extra 300L.

The high-altitude training course begins with a ground session on high-altitude jet operations, then for pilots who haven't flown the S211 yet in the program, a differences briefing and a preflight discussion are provided to cover the training plan and profiles to be flown.

HIGH-ALTITUDE JET OPS

Karl "Schlimmer" Schlimm is APS's director of flight operations; he flew F-16s and OV-10s in the Air Force and also owned a charter operation. During the ground session on high-altitude jet operations, Schlimm covered the basics of transonic flight, highlighting the difficulties that pilots can experience when flying swept-wing business jets, especially jets that can fly at speeds where shock waves can develop on various areas of the airplane.

Shock waves, which occur at the critical Mach speed when the airflow at that area reaches Mach 1, can cause a number of effects that pilots need to be aware of. One of these is wave drag, which is a result of shock waves initially forming on areas of maximum camber such as wings, engine inlets and even areas on the fuselage.

More concerning is that flying at Mach numbers beyond maximum operating Mach (Mmo) can potentially develop further into Mach tuck because of a few factors, although modern transport-category airplanes integrate design features and technology to mitigate this hazard. At extreme speeds beyond Mmo, shock-induced airflow separation can cause a loss of downwash force on the tail, he explained, "potentially decreasing pitch control at a time when you need it most."

On the other end of the speed spectrum in slow flight operations near the aerodynamic stall, for example, in a T-tail jet the pilot may have the control authority in some circumstances to pull the airplane into a dangerously high angle of attack because, he added, "in a T-tail airplane the downwash of the main wing flows below the plane of the tail, because the stabilizer or elevator are not washed out like they would be in a conventional-tail airplane. If you do that right at a point where the turbulent stall-induced airflow separation comes to the inboard area of the main wing, the resulting low-energy turbulent airflow over the tail can cause the elevator to lose sufficient authority to reduce angle of attack to recover from the stall, thus causing a rare and dangerous deep stall."

During a sustained, aggressive stall in a swept-wing jet, the stall can progress from the wingtips to the root. This moves the center of pressure forward, which can induce a large pitch-up moment. "If you get the center of pressure too forward toward the center of gravity," he said, "you can lose the natural pitch-forward moment certification feature, and you get an airplane that gets pretty squirrelly in pitch. In the worst case it can be uncontrollable, and that's one of the reasons why some swept-wing airplanes have stick shakers and pushers." Some jets, Learjets in particular, have ventral fins on the aft fuselage, to provide a measure of pitch stability at high angles of attack. Flying too close to the aft center of gravity limit can exacerbate this situation.

While modern jets are designed to reduce the risk of Mach tuck, if it did happen, the tools available to get out of this situation are to add drag to slow somehow, reduce speed by lowering thrust and possibly adding speed brakes—or even by lowering the landing gear in extreme situations if approved by the manufacturer—and by using elevator trim to assist in alleviating control pressures to help the crew to bring the nose up.

STALL PREVENTION AND RECOVERY

A key area of focus in the high-altitude training

program is stall prevention and recovery at high altitudes, which are defined for UPRT purposes as stall occurring above 25,000 feet.

Because swept-wing jets can ultimately stall at the wingtips first in a sustained stall, the ailerons can lose effectiveness. This is one of the reasons most jets have roll spoilers: because they are placed farther from the tip and thus remain effective at high angles of attack. At high altitudes, however, available engine thrust is far lower, and power will not be as effective in generating acceleration. As at low altitude, angle of attack management in stall prevention and recovery is king. As a result of these factors, high-altitude stalls require the pilot to reduce angle of attack and be patient in allowing the airplane to accelerate away from the stall, typically requiring a descent of several thousand feet, and out of the slow flight regime. General guidance in high-altitude stall recovery is to accelerate to the appropriate cruise or climb before stabilizing the aircraft in altitude.

The APS All-Attitude Upset Recovery Strategy baseline process—push, roll, power, stabilize—can't be completed until the wing is fully unstalled, the lift vector carefully re-oriented, the energy state managed, and the aircraft stabilized in pitch, thrust, speed and altitude, while ensuring the aircraft is configured and trimmed appropriately. This can take a surprising amount of time, much longer than pilots experience in a similar situation but at low altitude.

"Pilots of large transport-category airplanes should not be surprised that it takes a long time to recover fully from a high-altitude stall and to a properly stabilized flight condition," said Schlimm. "You can get slow in a jet, start sinking and you get into trouble if you're not careful, and the pitch attitude looks normal outside. At high altitude, you can arrest that sink rate only by initiating a positive reduction in angle of attack, and accelerating with excess thrust when you have it, understanding that excess thrust reduces substantially with increasing altitude." If the pilot isn't patient, he added, "You can push out of the stall and pull right back into it."

Schlimm explained how easy it is to get into a buffet-limited condition at altitude, by turning too steeply, loading up the wing and losing airspeed with potentially no excess thrust available to regain the lost speed, especially if the situation is allowed to deteriorate below L/Dmax airspeed. This is one of the reasons why low bank angles are recommended at high altitudes. It is possible to get into this condition when flying into a warmer airmass, and it could be exacerbated further by turbulence, thus generating drag in a limited-thrust condition resulting in the speed decaying unnoticed while on autopilot, or as simple as the pilot accepting too slow an airspeed assigned by ATC at or near maximum altitude.

"In a swept-wing airplane near maximum altitude, when your speed is approaching an approach-to-stall condition," he said, "the rate of airspeed decrease will tend to increase and you may have only a few seconds to make a decision and descend because you didn't notice it before, and now it's time-critical."

"If you're caught in that speed-unstable region below L/Dmax speed [the slow flight region] with no excess thrust, you have to descend, and pilots should expect to lose 3,000, 4,000, 5,000 feet or more at high altitude, especially in a swept-wing airplane. It's important to take action as the pilot flying while getting assistance from the pilot monitoring such as requesting or announcing an immediate descent. If ATC does not respond, declare an emergency and squawk 7700. The airplane is coming down one way or another. It's up to the crew to take actions to ensure that the descent is in control."

Then Schlimm said he would seek an altitude that the jet can maintain where there is enough power for optimum cruise with sufficient excess thrust remaining. "You don't want to have to level off and then have to descend again either because you didn't accelerate sufficiently or descend to a sustainable altitude."

There is much more to the high-altitude jet operations ground training, but the primary focus is to help the student understand the differences when flying at high altitude and why the training focuses so much on not just handling the upset properly but recognizing when the airplane is in a stable recovery.

S211 AT HIGH ALTITUDE

The S211 is a relatively easy to fly, swept-wing, single-engine jet trainer, powered by a 2,500-pound-thrust Pratt & Whitney Canada JT15D-4C. Maximum speed is 400 knots (Mach 0.80) and clean stall speed 90 knots. To make the S211 more closely match the airplanes business jet pilots fly, APS installed a Garmin G3X display (both seats) driven by a GTN 650 navigator (front seat only but displays GTN routing in the back). APS recently added a second S211.

The high-altitude training has three objectives, Ransbury explained during our pre-flight briefing: to enhance awareness and reinforce upset prevention, knowledge and skills; understand, experience and practically apply key high-altitude learning concepts and control inputs; and successfully and consistently recover from a diversity of high-altitude stall and upset conditions.

"Upset prevention and recovery training programs often focus almost exclusively on recovery," he said, "and in reality it should be focused on prevention. We're going to be seeing a lot of both today."

The flight illustrated, sometimes in dramatic fashion, how a swept-wing jet can get a pilot into trouble at high altitudes, and differences in performance and handling at low versus high altitude.

"There is reduced maneuvering margin between the high- and low-speed buffet," Ransbury explained. "You're surprisingly close to the stall and don't realize it for a number of reasons. Yes, it's a smaller operating region, but also as we get into higher Mach conditions the stall angle of attack actually decreases. We're seeing the stall onset at a lower angle of attack than we normally would."

Couple that with the reduction in thrust at altitude, down to 20 to 25 percent of maximum thrust at the S211's 40,000-foot maximum altitude, and the challenge facing pilots gets more complicated.

If a pilot inadvertently allows the airplane to slow below the speed for max L/D (maximum lift over drag ratio) at high altitude in a thrust-limited condition (that is, the pilot can't accelerate out of it), then the only choice is to reduce angle of attack, accelerate to an appropriate Mach and stabilize the aircraft at a sustainable altitude to complete the recovery. But again, it will take a while to recover and the airplane will likely have to descend, because there might not be enough excess thrust to accelerate beyond L/Dmax while staying level.

"It's likely going to take more altitude loss to recover than expected," he said. In the S211, this can be 2,000 feet, more if the temperature is high or at altitudes close to maximum. To recover in this situation the pilot must reduce angle of attack until reaching climb or cruise Mach. "We want to get into a speed-stable region of the operating envelope," he said.

"Another factor at high altitude is reduced aerodynamic damping. We illustrate this by practicing calibration exercises at lower altitudes, feeling the amount of thrust available, how the controls feel, noting the duration of the full recovery process, then doing the same at high altitude and comparing. The lower aerodynamic damping means that at high altitude it's easier to overcontrol because there is a bigger response to control movement. "We need to remember [these factors] when recovering," Ransbury said, "and we need to be patient with whatever technique or strategy we're applying."

Ransbury went over the APS All-Attitude Upset Recovery Strategy baseline technique—push, roll, power, stabilize—and emphasized the steps I would take to recover from an upset.

Before needing to recover, however, it is first important to recognize the upset situation or that the aircraft is headed into an upset if nothing is done to fix the problem. "For example, inadvertent slow flight is an upset," he said. "That's where we want to fix it." If the crew doesn't fix it then, he added, it will get worse. "It's going to go from inadvertent slow flight, to approach to stall, to stall, to incipient spin, to spin. Unchecked, it's a stall-spin escalation."

Business jets aren't designed to recover from developed spins. "The further you get down the line in the escalation the more robust your skills need to be," he said. "But from an aerodynamic standpoint, the longer a pilot of a multi-engine jet allows a stall to exist, especially when combined with uncorrected yaw, the less likely you're going to survive the encounter. The earlier we can take effective action, the better."

Once the upset is under way, if the airplane is stalled it is imperative to reduce angle of attack. If the autopilot is on, it must be switched off in most airplanes before taking any further steps.

After unloading the wing (reducing angle of attack) so it can more effectively generate lift and be positively controllable in roll, the pilot reorients the lift vector. The lift vector is generally perpendicular to the upper surface of the wing, so this means getting that lift vector to point straight up by rolling the wings back to level. Pilots should not use rudder during the stall recovery, especially in swept-wing airplanes. If rudder must be used, pilots must be extremely cautious and measured in its application.

Managing energy is next, and this means adjusting power to suit the circumstances. Speed brakes might also be helpful. If recovering from an upright stall, full power will help accelerate to improve controllability and will ultimately help reduce the altitude loss. A mistaken split-S recovery from a roll upset that turns the airplane upside down would result in a dangerous steep dive, in which case power would need to be pulled back to idle.

The upset recovery isn't over until the airplane

is stabilized. Close to the ground, this likely means returning to a climb. At high altitude this could be leveling off or even descending if power isn't sufficient. "We're setting pitch and power for the airplane to perform in whatever condition is appropriate for this scenario," Ransbury explained. "When you say you're stabilized, think about that as a separate phase of recovery. You want to go to a pitch attitude and power setting to accomplish a performance." He suggested checking that pitch is as desired, power is set, speed is stable, then checking the configuration of landing gear, flaps, speed brakes and trim before declaring "recovery complete." He emphasized, "You don't want to take your mind out of recovery mode until you know the airplane is doing what we want it to do."

"Our mental state at high altitude should be that there is nothing that we have to rush. It doesn't mean we can't be expeditious in our decision-making because we need to be ahead of the airplane, but we can't rush control inputs and expect there to be a rapid response on what we're trying to accomplish. The good news is, at altitude ground impact is not the imminent threat."

This training helps pilots learn to focus on the recovery and not be distracted by an ATC call or other seemingly urgent issues such as going over inappropriate checklist items. "Crew Resource Management processes are up to the flight department. In an airplane upset, the standard procedure for operators is often for the pilot flying to stay the pilot flying while the pilot monitoring helps manage the flight deck and ATC, although some operators will automatically have the pilot monitoring take over. It varies," he said.

"In any case, I'd rather the pilot flying take two minutes in the final stabilization step to get it right. There's no upside to rushing through the stabilization process and missing a critical item that could propel the aircraft into another upset condition seconds, or even minutes, down the road."

MISSION ACCOMPLISHED

After briefing the mission profile, I put on my parachute and climbed into the S211's rear seat. I had flown with Ransbury in the S211 last December, so I was somewhat familiar with the cockpit layout, but we went over the switches and controls again, as well as the bail-out procedure. A most important piece of information is not to confuse the canopy handle with the throttle.

After taking off from Phoenix Mesa-Gateway Airport's Runway 12R, Ransbury handed me the controls for the climb-out, and I maintained 190 kias as we climbed toward the Globe military operations area east of the airport.

After I tried the calibration exercises at 16,000 feet to get used to the handling and throttle response, Ransbury had me slow the S211 to 100 knots and deploy the speedbrakes, then accelerate out of the slow down. Then I brought it into a stall and applied the push-roll-power-stabilize strategy, noticing that the angle-of-attack gauge showed two yellow chevrons, almost to the red, and we heard the stall warning horn beeping almost continuously. In the stall, the nose banked left about 30 degrees before I started the recovery.

"Would you agree it's pretty responsive in the recovery?" Ransbury asked. I did.

He took the controls and simulated a wake turbulence encounter with autopilot on by imparting a rolling moment with the rudder. "You may not get an upset," he said, "but I want you to apply the strategy." Later I would see that this upset is far different at high altitude.

The nose banked slightly to the right then to the left. I switched off the autopilot and applied the strategy. It was a fairly benign upset, and the autopilot could have handled it. "The point is we had a certain amount of rolling moment and we saw that the airplane was pretty responsive and dampening was pretty controlled," he said.

We then practiced recovering from a nose-high upset using roll to lower the nose. With the nose pitched up 46 degrees, he demonstrated the push to unload the wing, adding power, then banking to lower the nose to the horizon. It is important to watch the angle-of-attack gauge, he said, to avoid pulling the nose up too hard during the recovery to avoid a secondary stall. I then flew the same maneuver.

Next was intentionally exceeding the climb profile, and this simulated a situation where the pilot got distracted and didn't notice the excessive climb. We were at 24,000 feet by then, and Ransbury pointed out how the controls felt more sluggish and the rudder was less effective. I continued climbing and slowing down, and the angle of attack started showing one yellow chevron as we started to feel a slight stall buffet. I leveled off and noted that the S211 was barely accelerating even though we had full power set. "Maintaining control in this situation is more important than talking to ATC, at least initially," he explained.

A runaway trim exercise was next, using the strategy of banking to lower the nose because we were simulating not having pitch control available to drop the nose. I still had to push forward to unload the wing, but the only way to get the nose to the horizon was with roll.

Above 25,000 feet we flew some unusual attitudes and noted the reduced aerodynamic damping and how much longer it takes to get back to the Mach 0.35 climb profile. Stall angle of attack was now much lower, too, and we were high enough that it would be necessary to let the S211 descend to accelerate back to the Mach 0.35 climb speed.

We continued to climb to 33,000 feet for the meat of the program, the high-altitude UPRT maneuvers.

First was the thrust-limited slowdown and trying to use power to maintain altitude after getting too slow, an excellent upset awareness and prevention exercise. This took much longer at the higher altitude.

Next was simulating an aggressive deviation for weather with a 30-degree bank to the right at cruise thrust. I tried to thrust out of the resulting slowdown, and the power was barely enough to recover without losing altitude, and the recovery took a long time.

Going right into a stall, we felt the buffet much sooner with the angle of attack indicator nowhere near the red chevron, and no tone from the stall warning. The S211 lost 1,500 feet during this maneuver.

Ransbury did the exact same footwork with the rudder pedals for the wake turbulence encounter with the autopilot on. This time, the result was stunning. The nose banked slightly to the right, then abruptly swung around the horizon to about 160 degrees to the left and down 24 degrees, so when I started the recovery, we were basically upside down and pointing well below the horizon.

First I pushed on the stick, despite the temptation to pull back to avoid the ground, then I rolled, but I mistakenly had turned the autopilot off then back on because I was pushing the wrong button on the stick. Switching the autopilot off, I rolled upright and resumed the climb profile during the recovery. This time we lost 3,500 feet. "It gets your attention, doesn't it?" Ransbury asked. "The same little inputs turned us upside down. Not only does the input put you in a bad situation, but it's easy to overcontrol to try to get out of it. It's much more dramatic here at altitude."

We did another wake turbulence encounter, this time to the right, and the nose rolled 150 degrees and dropped 18 degrees, and this time allowed the S211 to descend after the recovery. At high altitude, he pointed out, thrust available is so low that it might make sense just to leave the throttles alone, even in a nose-down upset as it might add more controllability and help with the recovery; however, due consideration must be given to your margin of safety from Mmo at any point during the recovery. "Consider that the decision on power might be different at altitude."

It took much longer to recover from the next maneuver, a nose-high upset with roll to bring the nose back down. "Did you feel the airplane was very sluggish?" he asked.

When faced with rolling nearly upside down and with the nose down, the classic incorrect upset recovery is the urgent reaction to pull the yoke or stick back and end up in a high-speed, high-g split-S maneuver—instead of rolling back upright—where the nose is pulled back up through the horizon. During this recovery, I flew the procedure correctly by pushing on the stick (while upside down), rolling back upright, reducing power, adding speedbrakes then returning to a climb attitude.

Ransbury flipped us upside down again and this time, as instructed, I didn't recover but flew the incorrect reaction by pulling back on the stick and completing the split-S. We lost nearly 10,000 feet, and I could feel the airframe nibbling at the stall buffet as I carefully pulled the nose back up; the g level peaked at 3.7. Ransbury debriefed me that we were simulating a 2.5-g airplane, but he clarified that in a crisis where exceeding Mmo was imminent or ground impact likely, cautiously applying control inputs to generate an over-g condition may be the best alternative.

Clearly the split-S isn't the correct way to handle this upset, and it would be easy in a business jet to pull way too many gs trying to pull the nose up while avoiding the stall instead of simply rolling upright to recover.

ATC called and warned us that the MOA was about to become hot, so Ransbury took the controls and did another split-S to facilitate our rapid descent into APS's low-altitude training area a dozen miles from Phoenix-Mesa Gateway Airport. We performed a number of configured low-altitude stalls, uncoordinated stalls and airplane upsets with the selectable control feel engaged, giving the S211 the handling qualities of a large transport-category aircraft. The aircraft responded promptly, with high stability and plenty of excess thrust. These final exercises once again reminded me of the stark difference in performance and handling qualities of jet airplanes at high altitude.

The S211 is an excellent tool for teaching business jet pilots how to handle upsets in an airplane that more closely replicates the flying characteristics of the airplanes they fly, while allowing pilots to make mistakes and pull heavy g loads as part of the learning process. ❑