

USING A 1949 PISTON POWERED AIRPLANE TO TRAIN 21ST CENTURY FLIGHT TESTERS

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ABSTRACT

To evaluate “highly-adaptive, critical thinking flight test professionals”, the USAF Test Pilot School sought out an affordable aircraft with a large flight deck to replace the unavailable C-130. The Grumman HU-16 Albatross was found to be suitable for the task. Being unfamiliar to all students allows direct evaluation of the student’s adaptability. Because “Nothing (good) happens fast in an Albatross”, its limited performance forces the students to use more finesse to accomplish the test mission. The very lack of modern technology allows the school to evaluate the student’s grasp of the fundamentals of flight test without the augmentation of modern technology. As a flying boat, the Albatross allows the additional benefit of teaching completely new skills (water operations) during qualitative evaluations. Other organizations have also adopted the HU-16 into their curricula, including the US Naval TPS and International TPS, with the resulting invigoration of the Albatross owner community.

INTENT OF THE USAF TPS PERFORMANCE PRACTICAL EXAM

The mission statement of the USAF Test Pilot School (TPS) is to “Produce highly-adaptive, critical thinking flight test professionals to lead and conduct full-spectrum test and evaluation of aerospace weapon systems.” To accomplish this mission, the TPS curriculum is divided into four series. These series were previously called “phases” but that name has been deprecated since the series are taught more in parallel and less serially than in the past. Flight Sciences is broken into two series, Performance and Flying Qualities. The remainder of the curriculum falls under the Mission Systems series and the Test Foundations series (formerly known as Test Management).

Besides academic exams, each of these series culminates in a Practical Exam, where the students demonstrate that they can put into practice the skills they have been taught during that series. For the Performance series, the student Test Pilots demonstrate their ability to plan and fly a cross-section of performance Flight Test Techniques (FTTs) and to work with a Test Conductor. The student Flight Test Engineers (FTEs) demonstrate their ability to plan and conduct a test mission as an airborne test conductor, directing a test pilot and making real time adjustments to the plan as required by actual conditions.

HOW WE USED TO DO IT

From well before 1982 until 2001, the Performance Practical Exam was flown in a C-130. The C-130 was used because it was available and small enough to be reasonably economical. The primary benefit of the C-130 was its large cockpit. This cockpit provided room for the Instructor Pilot in the right seat, the student Test Pilot in the left seat, the student FTE, an evaluator Test Pilot, an evaluator FTE, and the Flight Engineer. The evaluators could be on intercom and could observe the students directly.

Because our mission is to create “highly-adaptive, critical thinking flight test professionals”, we need to put them in situations where they need to adapt and think critically. One excellent way to do this is to give them an evaluation in an aircraft they have never flown before while doing new things. While most student Test Pilots had never flown the C-130, the few who had flown it operationally had little advantage since they were now flying the C-130 in a very different way.

Through the 1980s a C-130 was generally readily available. Generally an Air Force Materiel Command C-130 assigned to Edwards or Eglin was used. Eventually the C-130 assigned to Edwards was deemed to be no longer needed for test missions and was returned to operational duty. A C-130A assigned to Eglin for systems tests was used for a few classes in the late 1990s, but eventually it was retired because of its advanced age and lack of test programs. At this point, attempts were made to “borrow” a C-130 from operational units. Operational units were running at full capacity supporting operations in the Middle East. One Air National Guard unit in Colorado supported for one semester, but was otherwise busy with their primary mission of fighting forest fires. After April 2001 all efforts to borrow a C-130 for the Performance Practical Exam were unsuccessful.

Out of desperation Practical Exams were flown in the C-12, which all of the pilots had flown several times during the TPS curriculum, and had even flown a mission that was essentially practice for the Practical Exam in the exact same aircraft. This negated the benefit of testing the students’ ability to adapt and think critically in a new situation. A different and better solution was needed.

THE SEARCH FOR ALTERNATIVES

The ideal aircraft for this mission needed to have a large cockpit, be reliably available on our schedule, be reasonably economical to operate, and be unfamiliar to most, if not all, TPS students.

Air Force aircraft that satisfied the requirement for a large cockpit included the C-130, KC-135, and C-17. The C-130 was already known to be unavailable. While a KC-135 was part of the TPS curriculum, it was known to be unreliable. When it was available to fly, it would be flying higher priority missions in support of Air Force Flight Test Center projects. TPS frequently could not complete the Heavy Aircraft Flying Qualities missions or the Engine Out missions that were already assigned to the KC-135, so it would not be smart to assign an important mission like a Practical Exam to it. No C-17s were permanently assigned to Edwards, and those that existed were busy supporting operational missions. Additionally, the C-17 was too

big and therefore expected to be too expensive. All of these aircraft also had the problem that some of our students would have flown them operationally.

Bombers, such as the B-52, B-1, and B-2 are large aircraft, but they have small cockpits and a lot of classified equipment that would cause a major problem with our international students. Other airliner-derived aircraft in the Air Force would have large cockpits, but are few in number and probably would not be reliably available on a regular basis.

THINKING OUTSIDE THE AIR FORCE BOX

In 2003, the TPS Director of Operations (DO) was looking across the ramp and saw the Grumman HU-16 Albatross that was parked there. The Albatross was there supporting the TPS Qualitative Evaluation (“Qual Eval”) Program that brings in a variety of different aircraft which the students fly to expand their experience base.

The Albatross had a large cockpit, or “flight deck” as the Navy would call it. Because it was on contract, it could be reliably brought in on our schedule. Because it was not an active duty aircraft, it wouldn’t get pulled away to support some higher priority mission. We knew what the operating costs would be since it was already on contract. Best of all, it was a good bet that none of the students had experience flying a large twin engine piston powered radial engine amphibious flying boat. Since the Air Force stopped flying the HU-16 in 1973, the Navy in 1976, and the Coast Guard in 1983, any student who had flown one before would have done it outside of the military and probably not extensively.

Based on this, the DO hatched a plan to assemble a test team and send them to evaluate the Albatross as a platform for the Performance Practical Exam. While they were at it, they would also evaluate the Albatross as a platform for two other problematic events, the Heavy Aircraft Flying Qualities event and the Engine Out event.

HU-16 ALBATROSS EVALUATION

Thus in June 2003 a test team of three test pilots and two FTEs traveled to Carson City NV to the home airfield of TPS’ then-current Albatross contractor. The evaluation lasted three days with nine sorties totaling eleven flight hours.

The flight deck was indeed large. As originally built, it had seats for the pilot and copilot. Behind the copilot was a seat for the radio operator. The original radios filled a large rack located behind the pilot. This radio rack had been removed and replaced with another seat. Down the center of the flight deck between the seats on either side was an access passageway that we dubbed “the trench”. This allowed room for one person to stand between the rear seats. Later this position would be upgraded by providing a bar stool (which was not used during takeoff or landing). The Albatross in use as this paper is written sports a jump seat from a Lockheed C-140 in this position, which is a great improvement.

The Albatross was found to be unsuitable for the role of Heavy Aircraft Flying Qualities. Even though it was bigger, the Albatross is in the same weight category as an F-16. Our highly experienced KC-135 Instructor Pilot determined that the Albatross did not have the large

moments of inertia seen in heavy aircraft. It was actually too responsive to satisfy the objectives of that event.

The Albatross was also found unsuitable for Engine Out demonstrations, which are centered around showing lateral motions that happen with an engine failure below minimum controllable airspeed (V_{mca}). The V_{mca} published for the Albatross is indeed a few knots above the stall speed, but that V_{mca} is for maximum gross weight and aft cg (the worst case). At the weights that we were testing at, the actual V_{mca} was less than the stall speed. While this is excellent for flight safety, it made the aircraft unsuitable for demonstrating the intended behaviour.

However, the Albatross did appear suitable for the original mission, the Performance Practical Exam. In fact, in some ways it seemed to actually be better than the C-130. In the C-130, to reduce performance sufficiently to fly reasonable sawtooth climbs, one engine had to be shut down. Since the level acceleration was flown with four engines, these two data sets could not be compared. With the Albatross, the available climb rate on two engines was low enough to do a reasonable sawtooth climb, and then these could be compared to the level acceleration results as we were teaching in the curriculum.

Lower performance actually turned out to be a major benefit. After the first day it was said “Nothing happens fast in an Albatross.” That is, it doesn’t climb fast, it doesn’t accelerate fast. However, it also doesn’t decelerate fast or descend fast. This would make an excellent test of the students’ planning and patience. The statement was later edited to “Nothing (good) happens fast in an Albatross” in recognition that there were some emergencies that could happen faster than desired, such as pulling the nose up way too high and watching the airspeed rapidly go away.

While we were there, we also had an extensive introduction to water landings and takeoffs. This was an experience very different than the background of most TPS students, and was significantly different enough to allow for many new learning opportunities. This was why the Albatross had been brought into the qualitative evaluation program.

The key realization that made the decision clear that we should use the Albatross for the Performance Practical Exam was the opportunity for a “2-fer”. On any given day, members of the junior class could do a Performance Practical Exam in the morning, followed by members of the senior class doing water landings and takeoffs at Lake Isabella in the afternoon. This increased the utilization of the aircraft, and it addressed one of the key limitations of the way the C-130 was implemented. The only time the students flew the C-130 was for the Practical Exam, and since they were stressing to do well on the exam, they learned very little about the C-130 and had no time to enjoy it. With two planned events in the Albatross, the students would get a second chance to learn about and enjoy the Albatross without the stress of an exam.

IMPLEMENTATION

Flight profiles and a new test plan were rapidly assembled for the Performance Practical Exam based on the old C-130 event. These were ready in time for TPS Class 03B to fly in September-October 2003. In the C-130 days, the FTE would compare the flight test results

with predictions from the flight manual. While an HU-16 flight manual with performance data was available, all of the charts were for MIL-F-5572 115/145 fuel and two drop tanks installed. The HU-16B (long wing) as flown used 100LL fuel and had no drop tanks, so the performance data were not applicable. Additionally, the published charts called for different engine settings than we use now, mostly because of the different fuel. Therefore, Class 03B simply collected data and faired curves through the flight test results.

An engine model was created based on information from the flight manual. Propeller blade measurements were used to create a propeller model. All of the flight test data from Class 03B were combined together to derive a drag polar based on the engine and propeller model. With this drag polar, flight manual type charts were created for cruise, climb, descent, and sustained turns. All subsequent classes would use these charts and the Matlab routines that created them to **Predict** their expected flight test values. After the flight (**Test**), these routines were used to standardize the flight test data, which were then used to **Validate** the provided model.

In 2007 the contract changed to another provider who used an HU-16A (short wing) Albatross. Class 07A simply compared their results to the HU-16B model. Class 07A flight test data were collected together and used to create a new HU-16A drag polar, which was used to create a new set of charts.

TESTING ADAPTABILITY

To test adaptability of Test Pilots, we want to have them do tasks that are familiar, but do them in an unfamiliar environment. While many student Test Pilots (and even some student FTEs) may have General Aviation experience with piston engines, it would be extremely rare to find any student Test Pilot with any experience with large radial engines on large multi-engine amphibians (in 16 years we've had exactly zero). Therefore, the Albatross is expected to be equally unfamiliar to all students.

While the Albatross is still an airplane, there are plenty of subtle differences to challenge the student Test Pilots. To wit:

- The Albatross is very much a two-pilot airplane. One pilot cannot fly and manage the engines at the same time. This requires working with a crew. While not that unusual for bomber or transport pilots, this can be very new for single-seat fighter pilots.
- Engine management is far more complex than in jets. For most jet engines, the pilot places the thrust control lever ("throttle") in the desired location and the engine controller takes care of everything and ensures the engine doesn't exceed any limits. For a large radial piston engine, the pilots have to manage Manifold Air Pressure (MAP), RPM, mixture, cowl flaps, and oil cooler doors. Other than specific climb power settings, the MAP and RPM are interrelated, and must be kept to $RPM/100 < MAP < RPM/100 + 10$ (MAP in inches of mercury). Thus an increase or decrease in power may require changing MAP and RPM. Mixture is NORMAL for $MAP \leq 30$ in Hg, RICH if greater.

- The throttles are not next to the pilot's left knee. The throttles hang from the ceiling on the pilot's right side.
- The student Test Pilot is only allowed to touch the throttles. All other engine controls are actuated by voice command to the copilot.
- Roll control is by a wheel. While not necessarily unusual to non-fighter pilots, it can be different for the fighter pilots.
- Trim controls are not on the control wheel, but are individual switches located on the center console.
- There is no nose wheel steering. Directional control on the ground is by rudder, differential power, and differential brakes (which can only be used sparingly)
- Takeoff is far more complicated than jets.
 - o Jets: Generally select MIL or MAX power, accelerate to takeoff speed, pull nose up to a specified attitude, retract gear
 - o Albatross: Line up on left side of runway 15 to 30 degrees right of runway heading. Set takeoff MAP. Release brakes. Nose turns left but rudder becomes effective by time runway heading is reached. Accelerate to 85 KIAS (V_{mca}). Rotate just enough to lift off. Hold pitch attitude, tap brakes, and retract landing gear. Accelerate to 105 KIAS (V_{yse}). Reduce power to "Climb 1" setting. Accelerate to 115 KIAS. Reduce power to "Climb 2" setting. Pitch to maintain 115 KIAS. This procedure takes nominally one minute and two miles to complete. This type of procedure is actually very common to other large radial engine airplanes, with power reductions from Takeoff Power to Maximum Except Takeoff (METO) Power, and then to Climb Power, but this sort of procedure is not well known to today's jet and turboprop pilots.
- Climbs and descents require big power changes (MAP and RPM). Partial power changes are not really effective.
- ~~Round dial instruments~~ Not really. The current Albatross we use has been retrofitted with glass PFDs. This was primarily because the round dial navigation instruments had become unsupportable. This is becoming more and more common in old airplanes.
- No speed brakes per se, but the flaps have significant drag and can be used as drag devices. However, the flap limit speeds must be honored.

PRACTICAL EXAM STRUCTURE

The Performance Practical Exam is set up to be relatively easy to do, as in it consists of techniques that the students have learned and practiced, or small extensions to techniques they have seen before. However, the exam is complex enough to be tough to do well.

To stratify the student performance, a time limit of 1 hour 35 minutes (1+35) is imposed. Sufficient fuel is carried that running out of fuel is not a significant concern, but running out of time is a very real possibility. This constraint is pitched as a "range time" after which the range must be vacated. It is intended to drive efficient transitions between test points and decisions made based on stated priorities. There is sufficient time to complete the required test points, but very limited time available for repeats. There is no penalty for finishing early, other than points are not awarded for maneuvers not flown. There is a stiff penalty for being late, which strongly favors finishing on time.

Success requires timeline planning and monitoring for effective execution. Most FTTs can't be done faster. A three minute cruise point takes three minutes. The only way to make up time is through efficient transitions and set ups. As shown in approximately 300 practical exams, the best student groups have completed the exam in 1+20 with no repeated maneuvers. No maneuvers were repeated because they were all done with good data quality the first time. Most student groups finish between 1+30 and 1+35, with at least half of them skipping some maneuvers to make that time. Repeated maneuvers are rare, and only seem to work if flown immediately after the first attempt while on conditions. There is usually insufficient time remaining to go back to a maneuver from earlier in the profile, because it was at a different altitude and airspeed than the current state and getting there would take too long. Very few student groups ever run over, because the penalty for being late is much greater than dropping a maneuver.

The test plan does not include a list of what data need to be collected for each maneuver. This is "left as an exercise to the student", but should be easy to determine from previous experience. No Data Acquisition System (DAS) is installed, so all data collection is "hand-held". The students get to decide what is an appropriate data collection rate, which like all hand-held data will be well below the Nyquist rate. The provided model can give insight into how fast the maneuver will progress.

All students fly the same maneuvers, but to ensure individual effort, each student team (test pilot and test conductor) are assigned an individual set of parameters (including airspeed and altitude) for flying each maneuver. Because of the variation in parameters, the optimal energy order for each group of maneuvers changes from team to team. Thus, while each flight profile is different, they are all similar. FTEs select their profile from a group of 15 profiles, so there is no room to complain that they were given "the hard profile".

Configuration control is an important part of the exam, for a test point perfectly flown in the wrong configuration is still bad data. Configuration elements include landing gear position, flap position, MAP, RPM, and mixture position. The strivers will also watch cowl flap and oil cooler door positions, but these are considered minor effects and are not covered in the grading.

Limits must be watched, and the Albatross comes complete with a large set of limits to haunt the students. Engine limits include keeping the MAP and RPM appropriately matched. Airspeed limits include a minimum speed of 1.1 stall speed ($1.1 V_{S1}$), minimum control speed (V_{mca}), flap limit airspeed (varies with deflection), landing gear limit airspeed, and a minimum safe maneuvering airspeed. They have to stay within the airspace boundaries. The maneuvers are designed to force the students close to these limits, requiring them to be aware of operating near limits. Oddly enough, the one limit the students really don't have to worry about is the maximum speed (V_{ne}). The never exceed speed for the Albatross is so high that it cannot be reached in a full power dive at maximum power. During the initial evaluation we tried and didn't even come close.

The "low" performance of the Albatross (compared to jet fighters) tends to require better technique and finesse for getting good data. Pilots cannot just use "more power" to cover up

lesser technique. Most of all, “Nothing (good) happens fast in an Albatross” means that patience is required. Those without patience will be frustrated.

Sustained level turns (thrust limited turns) will surprise pilots used to 9, 6, or even 3g available. At high cruise power settings, the maximum sustainable load factor is 1.2g to 1.3g. This translates to about 30 degrees of bank can be sustained, but 45 degrees of bank in a level turn will lead to a runaway loss of airspeed. g-meters good to 0.1 g are much too coarse to measure useable data, and a g-meter reading to 0.01 g varies too much to be readable. The only effective FTT at these low bank angles is the timed turn to measure turn rate. Because the heading gyro is expected to precess, turn rate must be measured by doing complete 360 degree turns measured off of a distant object. Twenty degree bank turns take a long time to go all of the way around (patience), and 30 degree bank turns are near the limit of what can be sustained. To get turn data near minimum speed, a constant airspeed method must be used. Fighter pilots can get frustrated when they try to “g it up” to reduce airspeed, because the high aspect ratio wing doesn’t create that much induced drag. The only methods that have been shown to work are either to pull power or use an aggressive climb to get slow.

Cruise points seem simple on the surface, but the difficulty is in the details. Our curriculum does not include a lot of practice flying cruise points since we dropped the cruise data flight. One cruise point is at the long range cruise speed. This one is straightforward, but teams can waste a lot of time getting there if they set the expected power too soon. The best technique is to get to the expected airspeed using throttle and altitude as required, then set the expected power setting. After that, just maintain altitude. The airplane should settle at the appropriate airspeed.

However, this technique will lead to ruin when attempting a cruise point at the best endurance airspeed. This airspeed was intentionally chosen because it is the minimum power airspeed. Slightly high on power will stabilize at a significantly different airspeed. Slightly low on power will never stabilize. The best technique is to aggressively get to the right airspeed and altitude and set the expected power setting. After that, aggressively maintain **airspeed**. If power is too high, the airplane will climb. If power is too low, the airplane will descend. The change in altitude will tell you how to adjust the power.

Sawtooth climbs require precise airspeed control and the need to fly teardrop reversal descents between consecutive climbs on reciprocal headings over the same geographical area. Efficient descents require reducing MAP and RPM as well as using flaps to create significant drag.

Initially the profile included a level deceleration, left over from the C-130 days. Pushing an engine to maximum power and then suddenly snapping it to idle is something that turbine engines take in stride, but reciprocating engines really do protest. Piston engines really don’t like any rapid throttle movement. In this case, the engine starts out very hot from running at high power. The snap to idle takes away the source of the heat, and the cylinders start to cool rapidly in the high speed airflow. However, the pistons, which can only reject heat to the oil or into the cylinder walls, don’t cool down as fast. The cylinder contracts faster than the piston can contract due to the difference in cooling rate, so the small clearances between the cylinder

and piston become even smaller. This “shock cooling” can lead to real damage, and the Albatross operators were not happy about doing level decelerations.

In an unrelated discussion, an Albatross pilot made the assertion that the drag of the airplane increases by 50 per cent when the landing gear is lowered. How could you measure that to test the assertion? Thus, the “Incremental Drag Descent” FTT was created to take the spot in the profile of the level deceleration. Our performance curriculum covers FTTs for validating aerodynamic models, and this was a technique that addressed the aerodynamic model of the Albatross, so it was a good fit in the profile.

The Incremental Drag Descent FTT starts with a trim shot in the clean configuration at the desired speed. Without touching the power setting, the desired configuration change (gear down, flaps 30°, flaps 40°) is made. The pilot pitches down as required to maintain the original airspeed. The assumption is that the engine thrust perfectly matches the drag of the aircraft in the clean configuration. Thus, the descent angle is determined solely by the additional drag of the configuration change. After a stabilized descent of one minute or 1000 feet, a teardrop reversal climb is made and the maneuver is repeated on the reciprocal heading, for all the same reasons as in the Sawtooth Climb FTT. The students are allowed to choose the altitude and airspeed for this maneuver to best fit in their energy profile. The students are expected to determine for themselves that the altitude doesn't really matter. The airspeed should be near the upper limit allowable. This creates the most additional drag, which leads to a largest descent rate. Larger descent rates are more easily measured with less uncertainty. In keeping with the desire to evaluate adaptability, this FTT is not practiced prior to the Practical Exam. Thus we see how well the students can implement a new FTT on the first try.

Other maneuvers in the profile are not that different in the Albatross as in other aircraft. The Level Acceleration is over a smaller airspeed range, but still takes as much time because of the lower excess power. Students can choose their own 3000 foot data bands for a check climb and a check descent. The useable altitudes only range from about 4000 feet pressure altitude (PA) to 10,000 feet PA, limited by terrain elevation and physiological limits (unpressurized cabin). The flight ends with a tower fly-by, which usually surprises the students with the high power setting required to get the desired airspeed.

EFFECT ON THE ALBATROSS COMMUNITY

While not our original intent, the USAF TPS adoption of the HU-16 Albatross in our curriculum seems to have reinvigorated Albatross owners beyond simply the one who holds the TPS contract. Compared to most personal general aviation aircraft, the Albatross is a very large aircraft and very expensive to operate. A pilot using an Albatross to fly for the traditional “\$100 Hamburger” would need to just put a grill under the wing and cook it himself. Actually flying anywhere in the aircraft would cost far more. A typical TPS Practical Exam flies for 1.8 hours and burns over 200 gallons of fuel. At a nominal cost of \$5 a gallon, that would be \$1000 for fuel cost alone. This says nothing of oil consumed or recurring maintenance. The aircraft is built for two pilots and cannot be flown single pilot. Thus, there is the possible expense of retaining a second pilot.

As such, the Albatross is an expensive aircraft for an individual to operate. To be practical, the Albatross needs to be “worked”, that is, it needs to be fulfilling a service for a paying customer. The USAF TPS plan created a customer, but not just one customer. Through normal discussions, the US Naval Test Pilot School (USN TPS) found out about what USAF TPS was doing and decided that the water landing qual evals would be a good thing for their curriculum too. USN TPS let their own contract with another Albatross provider to provide water qual evals on Lake Mead in Nevada/Arizona. These events are flown during the curriculum “field trip” either immediately before or after visiting USAF TPS in California.

The International Test Pilot School in London Ontario has gone so far as to purchase an Albatross for use in their curriculum. This fully instrumented aircraft is used not only to teach Performance and Flying Qualities, but also specifically to teach seaplane test pilots.

In any case, more customers for the Albatross implies more Albatrosses available and better logistical support. Thus, when an Albatross is needed, one should be reliably available. Which leads right back to where this project started—the search for an aircraft that could do the desired mission and was reliably available.

CONCLUSION

On one level, it might seem that the way to teach new flight testers to test the latest and greatest stuff would be to teach them on the most advanced aircraft and systems available. However, that would be like teaching basic Driver’s Education to a future race car driver in an Indy Car or NASCAR race car. As in most endeavors, it is necessary to learn the “basics” first to have a foundation on which to understand the latest technologies. While front line aircraft have amazing performance and flying qualities, much of this is due to heavy augmentation and other systems that obscure the underlying concepts from the budding flight tester. Many of today’s up and coming flight testers have never seen anything but highly refined aircraft, and they need to be taught just what that refinement is and where it came from. To see, understand, and experience those underlying concepts, it is frequently beneficial to go back to older, less refined designs. Thus, older, “obsolete” aircraft still have a beneficial role in teaching tomorrow’s flight testers. As such, the HU-16 Albatross has become an integral part of the USAF TPS curriculum.

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Mr. Erb is a long time member of SFTE, having joined in 1983 as a charter member of the Texas A&M University student chapter, the very first student chapter ever. He has held positions in the Antelope Valley Chapter and is currently a Senior Member. He has previously presented four Symposium papers (2017 Best of Symposium) and three Symposium training classes.