The Trailing Edge

February 2023

USAF Thunderbirds Smoke Oil

This year the USAF Thunderbirds spent a couple of weeks at Edwards AFB as part of their training season. For two weeks they flew two practice shows a day. Why at Edwards AFB instead of Nellis AFB where they are based? Presumably to be able to practice over terrain that is different from home but is still at an Air Force base where they can easily get maintenance and support, unlike most of the civilian fields that they do airshows at.

Since they were shutting down the airfield for an hour and a half twice a day, the Thunderbirds invited small groups of test aircrew and control room personnel to observe their flight briefings and debriefings. The intent was to give us a chance to observe how a tightly knit team briefed effectively and efficiently, exercising elements of crew resource management (CRM), with the hope that we might get ideas that we could apply to our test mission execution. In the debrief, we saw an environment where each member was expected to admit their mistakes without fear of retribution, with the aim of making the show and the overall team better. In between, we got to walk out on the ramp to show center, where the air boss, the announcer, and all of the ground personnel were that make the show happen. We were each provided with a wireless radio that allowed us to hear the usual show music and narration plus the inter-aircraft radio traffic as the commander talks the team through all of the maneuvers. It felt like a private airshow at great expense for just about 10 of us.

All of that was great, and I have a new respect for the men and women who represent our Air Force to the voting public. Yes, they put the public face on to convince people to serve their country in the Air Force, but they also have a very complex piloting job to do. I had a cool personal tie to this group because the commander (Thunderbird 1) was a TPS graduate, having been my student in Class 14B.

Of course, I have a tendency to notice oddball things at airshows. As I was walking into the hangar to attend the preflight briefing, I noticed pallets of 24 55-gallon drums labeled “Airshow Smoke Oil”. I thought that was an awful lot of smoke oil, and wondered if that was their supply for the whole season, or at least the two weeks that they would be here.

Without going through the order of how I learned all of this, here is the result. Just like our flight test F-16s have the gun removed and a Data Acquisition System installed where the ammunition barrel was, the Thunderbird F-16s have the gun removed and the smoke oil tank is installed where the ammunition barrel was. This tank holds about 55 gallons of smoke oil. The smoke oil runs from the tank through a pump, controlled from the cockpit. From the pump it runs through a tube that passes through the spine of the fuselage, over the engine, and then exits the fuselage on the left side of the engine nozzle. At the end of the nozzle, this tube turns to point into the exhaust plume. The heat of the exhaust plume ignites the oil, creating smoke. Watching the Thunderbirds in flight, it can be seen that the smoke is coming from the left side of the nozzle, not from the center of the exhaust plume. I wasn’t able to get close enough to the nozzle to measure the size of the tube, but from what I could see I’m guessing that it was about 1/2 inch in diameter.

I was told that the oil in the tank will create about 18 minutes of smoke, just enough for one flight demonstration. Doing some recreational maths, 55 gallons in 18 minutes gives a flow rate of 183 gallons/hour. For reference, my Bearhawk in cruise burns around 10 gallons/hour. An R-1820 radial engine in a Grumman HU-16 Albatross at takeoff power (approximately 1400 HP) has a fuel flow around 110 gallons/hour. Comparing it to fuel flows, the flow rate of the smoke oil sounds really high, but that’s mostly because we don’t understand how fast fuel really flows into engines.

For the purpose of trying to get a feel for the flow rate of this system, let’s assume all of the numbers I have quoted are correct and do some more recreational maths. Thus we have

Smoke oil tube radius r = 0.25 inch

Smoke oil volume rate $\dot{v} = 183 \frac{\text{gallons}}{\text{hour}}$

The tube cross sectional area is given by

$$A = \pi r^2$$

$$A = \pi(0.25)^2 = 0.1963\,\text{in}^2 * \frac{1\,\text{ft}^2}{144\,\text{in}^2}$$

$$A = 0.0013635\ \text{ft}^2$$

Changing the units on smoke oil volume rate

$$\dot{v} = \frac{183\,\text{gallon}}{\text{hour}} * \frac{0.13368\,\text{ft}^3}{\text{gallon}}$$

$$\dot{v} = 24.463 \frac{\text{ft}^3}{\text{hour}}$$

Volume flow rate is given by

$$\dot{v} = AV$$

Flow velocity is therefore

$$V = \frac{\dot{v}}{A}$$

$$V = \frac{24.463 \frac{\text{ft}^3}{\text{hour}}}{0.0013635\,\text{ft}^2} = 17941 \frac{\text{ft}}{\text{hour}} * \frac{\text{hour}}{3600\,\text{sec}}$$

$$V = 4.983 \frac{\text{ft}}{\text{sec}}$$

This is the velocity of the smoke oil as it comes out of the delivery tube into the exhaust plume. This really isn't that unreasonable. To get a feel for what that would look like, imagine you have a garden hose with a 1/2 inch inside diameter (which is actually a slightly smaller hose than what you actually have) with water flowing at this rate. If you pointed that hose straight up, how high would the water shoot up?

Coming out of the hose, we will say that the water has zero potential energy. When the water stops going up, it will have zero kinetic energy, having converted all of it into potential energy.

$$\frac{1}{2} m V^2 = mgh$$

Solving for height

$$h = \frac{1}{2g} V^2$$

$$h = \frac{1}{2\left(32.2\frac{ft}{sec^2}\right)}\left(4.983\frac{ft}{sec}\right)^2 = 0.385\ ft * \frac{12\ in}{1\ ft}$$

$$h = 4.62\ inch$$

So getting a flow rate that will shoot water about 5 inches straight up from a hose is quite reasonable.

Even so, why would they need such a high flow rate? When you are tooling along in you RV-7 at 100 knots, it doesn't take a lot of smoke oil to create a continuous stream of smoke. However, screaming along in your F-16 at close to 600 knots, you need a lot of smoke oil so that the smoke trail is thick enough to be seen by the crowd.

So those pallets I saw with 24 barrels of smoke oil? At the rate of one barrel per airplane per show, with six airplanes in the show, doing two shows a day, the "huge" amount of smoke oil I saw was only enough for TWO days!

- Russ Erb