Douglas Devries (right) and Tom Smillie flying in the outback in front of Uluru (Ayers Rock).

RISKY BUSINESS

Managing mechanical risk on extended cross-countries

DOUGLAS DEVRIES, EAA 526210

AS I ADVANCED THE THROTTLE to 35 inches of manifold pressure, the big Pratt & Whitney 985 supercharged radial engine roared to life and the de Havilland Beaver accelerated to liftoff speed. Upon establishing a positive rate of climb, I throttled back to 30 inches and 2000 rpm, decreased flaps to climb, and settled in for the ascent to cruising altitude.

Pow! Suddenly the engine was running rough and losing power, and the alarming essence of exhaust gas permeated the cockpit. At 400 feet above the surface, there was no time for engine checks. Twenty seconds later, I was once again on the surface of the planet. That day, September 28, 2002, I was lucky—the Beaver was on floats over a 20-mile water runway on Lake Washington near Seattle.

Moving forward to another time and place, in the fall of 2005 I flew through 4,000 miles of the remote Australian outback with nine other vintage aircraft. My venerable Stearman performed flawlessly; others weren't so lucky. As a group, we experienced a dead battery, one collapsed nose strut, a faulty fuel gauge, one broken manifold pressure gauge, and two magneto failures. In spite of months of planning, we were prepared for just one of the failures. (The Tiger Moth pilot had a spare magneto.) Unfortunately, this experience was not at odds with previous ventures—no matter how much I tried to anticipate the spares and tools we would need, often we came up wanting. »

Erica Harrison

According to the *2006 Nall Report*, 16.2 percent of all general aviation (GA) accidents are traced to mechanical or maintenance causes. Not bad, really, when you consider that a whopping 74.9 percent are caused by us pilots. Still, since we average pilots consider ourselves better than those 74.9 percent who contribute to the statistics, the mechanical failures are really quite disconcerting. The failures can appear to be random events over which we have little control…or do we?

Once the adventure-flying bug has infected you, it's hard to shake. My good friend, Mark Schoening, and I are planning to circumnavigate Canada in two de Havilland Beaver seaplanes in the summer of 2008. A good part of the trip will be above the Arctic Circle as we traverse through the Northwest Passage, a route first navigated by the explorer Roald Amundsen in 1905. The passage is choked with ice much of the year and has few aviation support services. As we looked back on experiences and forward to this challenging journey, the need for improved risk planning became imperative. How dangerous is a trip like this, and what can be done to mitigate the risk? After doing some research and talking to fellow pilots, we found little in terms of definitive methods to evaluate the risk of a mechanical failure. Turning to our engineering roots, we decided to apply the principals of risk analysis used by many companies that develop critical products, such as life support ventilators and critical flight systems.

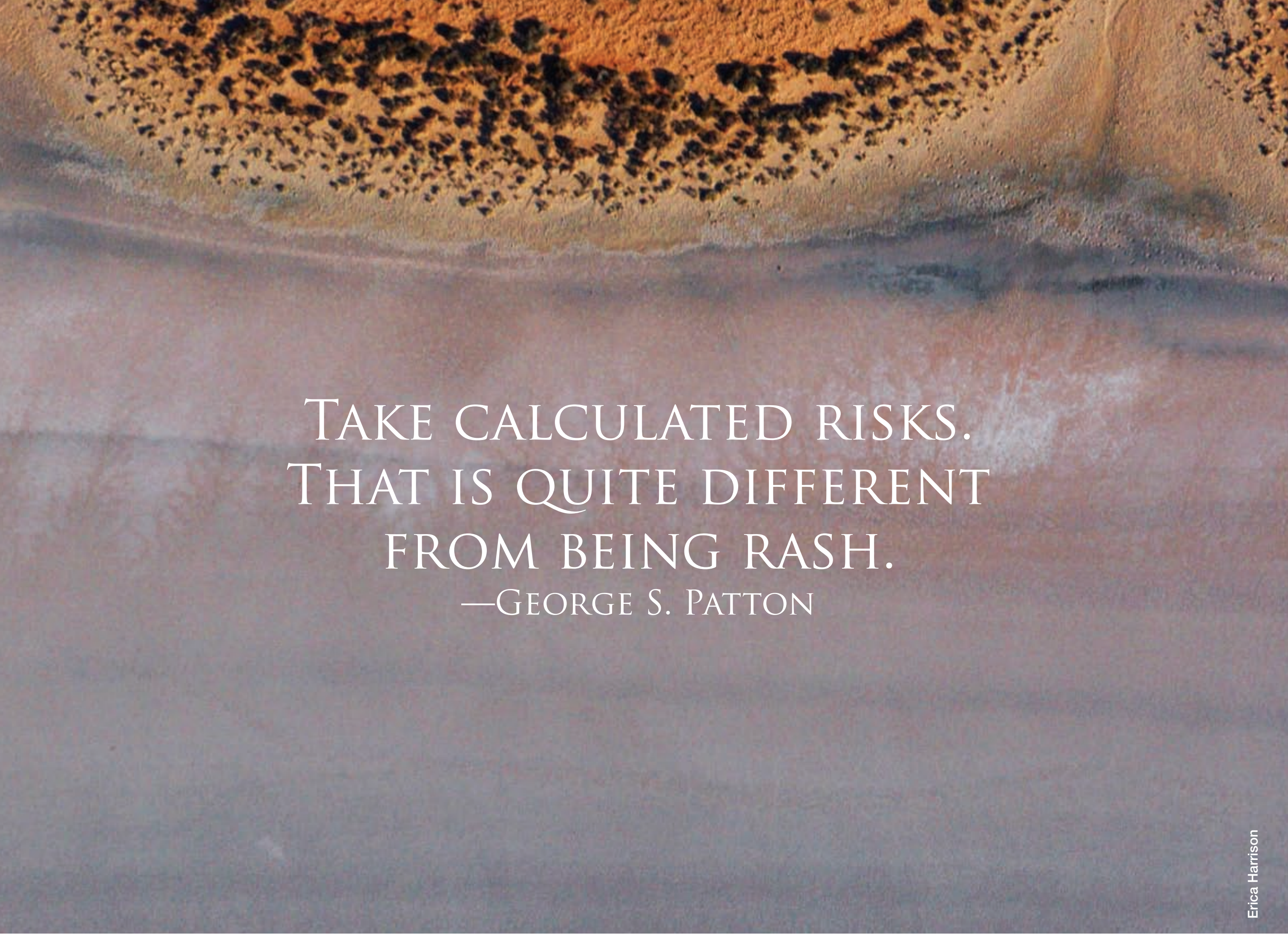
RISK ANALYSIS

The risk associated with an endeavor can be thought of as the product of the severity and the probability that a given adverse event will occur.

Risk = Severity x Probability

The severity of the risk can be categorized in many ways, but our friends at the FAA have provided guidance in these matters in the form of Advisory Circular 23.1309-1C, *Equipment, Systems, and Installations in Part 23 Airplanes*. The FAA developed this advisory "to facilitate the introduction of safety enhancing technologies for GA airplanes." Although this document was not specifically developed to analyze risk, as we are here, the definitions for severity and probability are a useful starting point. The following list, derived from the advisory, shows a simplified way of categorizing severity:

- No Safety Effect: No effect on operational capabilities or safety.
- Minor: Slight reduction in functional capabilities or safety margin.
- Major: Significant reduction in functional capabilities or safety margins; possible injuries.



Erica Harrison

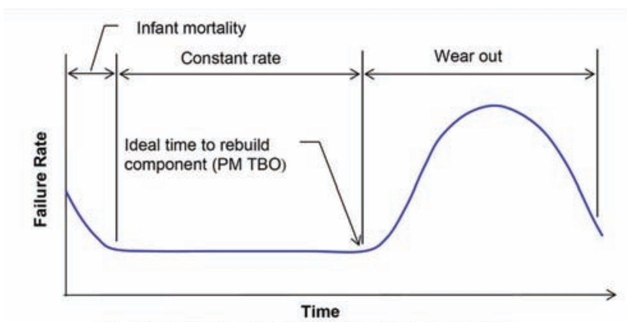
- Hazardous: Significant reduction in functional capabilities or safety margins; serious or fatal injuries.
- Catastrophic: Complete loss of airworthiness; multiple fatalities.

RISK PROBABILITY

The other part of the risk equation is probability, which is simply the number of times an adverse event will happen over a given time interval.

A model of how mechanical components fail over time is given by the Lusser mortality curve as shown at right.

Referring to the mortality curve, when the device or component is first put in service, the initial failure rate is relatively high, a phenomenon termed *infant mortality*. These initial failures are generally caused by errors in the manufacturing or installation process. For this reason, most manufacturers producing new components include a *burn-in* period at the factory to weed out these failures before the product is delivered to the customer. Failures during the next *constant rate* phase are random and usually occur due to unexpected environmental factors such as physical damage, high temperature exposure, or moisture exposure. After a long and useful life, the *wear-out* phase begins and the failure rate begins to rise. In this phase, "wear parts" such as bearings and sliding seals are literally wearing out.



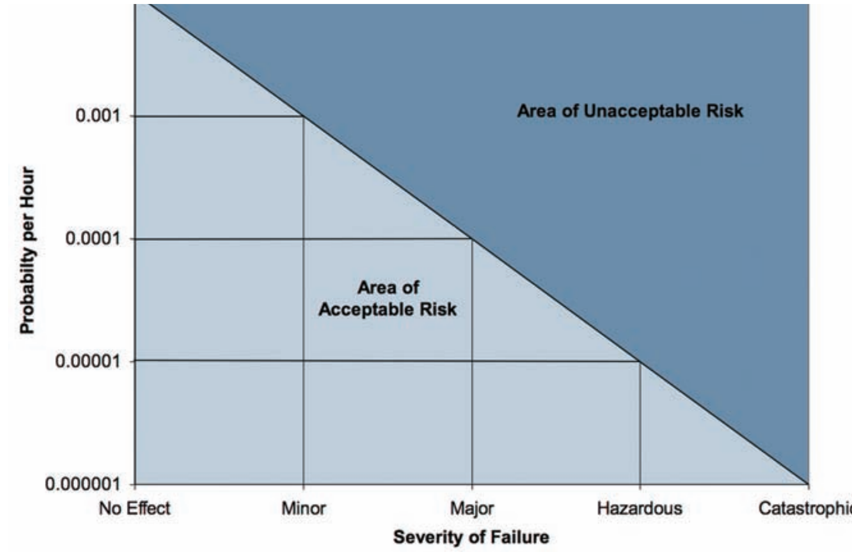
Typical Mortality Curve for Mechanical Components

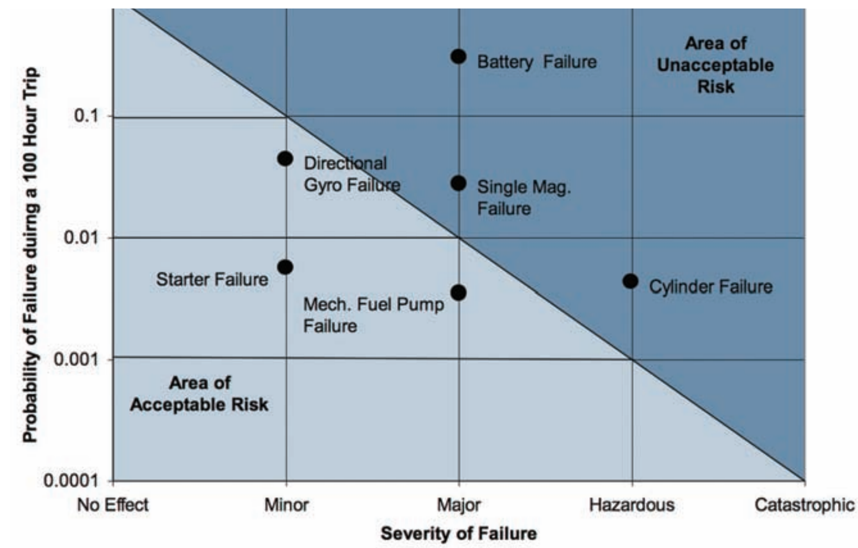
Douglas DeVries

The simplified probability calculations discussed in this article assume that all of the failures taken from the maintenance logbooks are in the constant-rate phase. There are a number of ways to determine the probability of failure. One method is to simply review the logbooks for a given aircraft type and tally up the number of failures over a known time interval for a given component. For example, if we reviewed 5,000 hours of airframe logbooks and counted 10 directional gyro failures, we could say the probability is equal to (10 failures)/(5,000 hours), or 0.002 failures/hour. So:

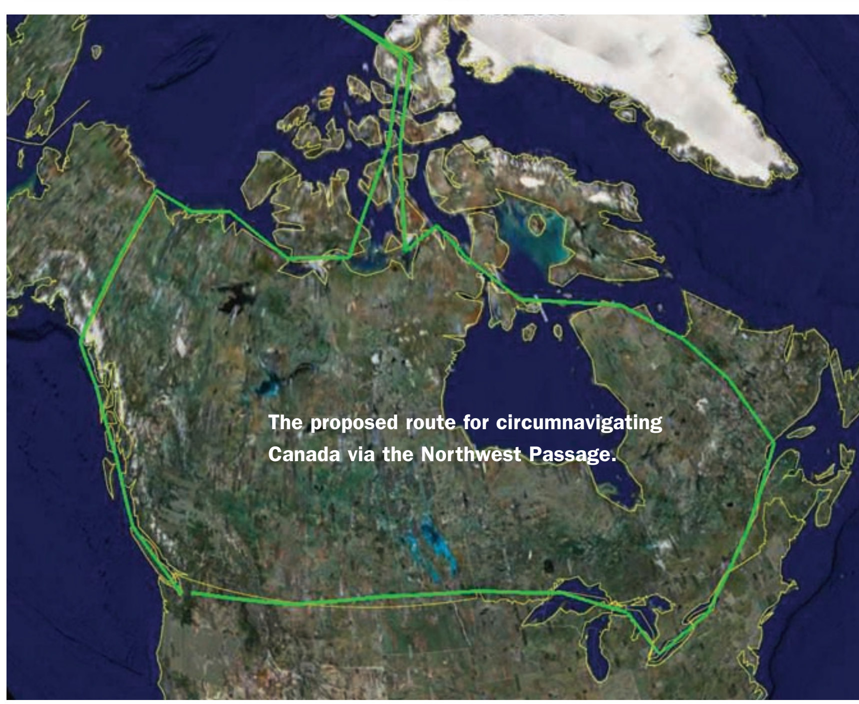
Probability = (Number of Failures)/(Time Interval)

If data is taken from aircraft logbooks, most of the





Graphs and charts courtesy of Douglas DeVries


The proposed route for circumnavigating Canada via the Northwest Passage.

failures are pre-empted through preventive maintenance (PM) measures, including rebuilding components at specified intervals. This, in fact, is the purpose of a PM program: to prevent most failures from occurring while the aircraft is in flight. Accordingly, any of the failure rates calculated for components that are replaced at predefined intervals are not true probabilities, but rather the resulting probability with a given PM program in place.

PUTTING IT ALL TOGETHER

Risk, an inherent facet of life, is a combination of the probability and severity of an undesirable event. On a daily basis, most of us are willing to drive to work because we believe that the probability of dying in an automobile accident is highly unlikely. (A valid assumption, since the risk of dying in an automobile accident is less than 1 in 10 million per hour). Fewer of us enjoy parachute jumping, with an estimated fatality rate of 1 per 80,000 jumps. Both activities could end up with the same severity (death), but most folks believe the odds favor driving over jumping. (Sky divers, your sport is still relatively safe, and we love you guys, so please don't write.)

Everyone has a different tolerance to risk, but in an effort to inject some logic into the analysis, the FAA through AC 23.1309-1C suggests that for single-engine GA aircraft under 6,000 pounds the relationship as shown in the graph above (left) is a good starting point.

The chart graphically illustrates the decision process we consciously or unconsciously use on a daily basis when we decide to participate in a potentially risky activity. The higher the severity of the risk, the lower the tolerated probability of occurrence.

If we follow through the risk-analysis process and find that the failure of a given component is within the acceptable range, life is good and let's go flying. If, however, we find that a given failure rate is in the unacceptable range, something must be done. There are several ways to mitigate risk; here are a few:

- Inspect if applicable; have the component checked by a mechanic before leaving on a long flight. For example, some of the newer vacuum pumps have an inspection port allowing the vanes to be checked for wear. Cylinders can be checked for burn marks indicating leaking combustion gases.
- Replace the component with a new or rebuilt one. This will ensure you are not in the wear-out phase. A word of caution: It is good practice to fly a few hours on the component before leaving on a long trip to ensure that the component is out of the infant mortality phase.
- Backup: Install a backup system such as a backup electric fuel pump or standby vacuum system.
- Spare: Carry a spare component with you on the trip. This may not stop the failure from happening, but it will keep you from being stranded for several days in Timbuktu, eating beetles while you wait for a spare to arrive.

A REAL-WORLD EXAMPLE

I'm a junkie for adventure tales of all types, and one thing I have concluded is that surviving intact is better than the alternative. With this in mind, we proceeded to apply this risk management technique to our upcoming Arctic trip.

First, we established the probabilities of failure for various critical components of the Beaver. There are many Beavers in the Seattle area, and we found the owners very willing to let us review the logbooks in return for a copy of the results. We looked at the maintenance records for several Beavers, covering 17,113 hours of airframe logs and 11,580 hours of engine logs. Failures were recorded for 49 different components. For simplicity, we will include only six of the components in this study. Failure probability for each component was calculated using the previously described equation. Since we were interested in failure rates over the entire trip, we multiplied the hourly probability by the trip time (100 hours) to determine the failure probability for each component over the entire trip.

Lastly, we categorized each failure into one of the aforementioned severity categories. The results are shown graphically on the chart on page 56.

As can be seen in the upper right section of the graph, there were three conditions where the probability of

Douglas Devries

FAR LEFT: Sporting an adventurer's grin, Douglas Devries, sits in the open cockpit of his Stearman. LEFT: His Beaver in Southeastern Alaska, moored in an inlet east of Sitka.

failure was higher than our acceptable limit. For these conditions, the risk will be mitigated as shown below:

- Battery Failure: Install a new battery prior to flight. Take along one fully charged spare battery and electrical cables for connecting the batteries of the two aircraft.
- Single Magneto Failure: Install freshly rebuilt magnetos and run for at least 50 hours, but no more than 300 hours. Carry one spare magneto on the trip.
- Cylinder Failure: Install a rebuilt engine including cylinders and run it for at least 50 hours, but no more than 300 hours. Inspect the cylinders for leaks and cracks, right before leaving on the trip, and run a compression check. Cache a cylinder assembly at Cambridge Bay, located midway through the most remote part of the flight.

FINAL THOUGHTS

The method discussed in this article is one way of evaluating risk for long trips over remote terrain or oceans; for a reliability engineer it will seem overly simplistic—for others it may be complex. The process is more important than the actual values shown in this report. You may choose to set your own definitions for severity and probability.

Obtaining the failure data for a specific aircraft may seem daunting, but it is really easier than you might expect. Type clubs, your local flight school or fixed base operator, or your own logbooks are all sources of reliability data. I found most pilots and operators willing to cooperate in a study like this.

The process may seem to require a lot of effort, but if you're planning an extended flight over remote terrain or the oceans, a risk analysis could ensure that you are around to brag about the trip afterward.

Oh, one last thing. If you are wondering what caused the Beaver engine problem described in the first paragraph—the number one cylinder head cracked into two pieces.

Douglas DeVries is an engineer, pilot, and restorer residing in Kenmore, Washington. He spends his leisure time flying and filming in a 1942 Stearman and a 1955 de Havilland Beaver seaplane. Contact him at douglasd@vectoredflight.com *or visit* www.VectoredFlight.com.