Name ______________________________________ Period ________ Date ___________

EXTRA CREDIT: Dimensional Analysis and The Crash of Flight 143

This assignment is worth 5 bonus points on your *Measurement Test*.

Read the accompanying article "The Crash of Flight 143," *ChemMatters*, October, 1996, pp. 12-15. Answer the following questions completely.

1. What are the three possible causes of the 767's fuel pump alarm?

   1)

   2)

   3)

2. The second fuel pump alarm made which possible cause most likely?

3. The faulty calculation occurred when converting from liters to kilograms. Why isn't jet fuel measured by volume like gasoline is in cars?

4. What units were needed on the number 1.77 to express the density of jet fuel? _________________

5. What units *should they have used* in order to make the correct conversion? ___________________

6. How did their calculation error affect the amount of fuel that was pumped into the plane?

7. Explain how using dimensional analysis could have prevented this crash.

8. Calculate the volume of fuel needed for a flight if jet fuel has a density of 0.803 kg/L. First, use dimensional analysis to convert liters to kilograms. Then, subtract to find how many kilograms need to be added. Then, use dimensional analysis to convert this mass into liters. For full credit, you must show your work, include units, and round off each answer to the correct number of sig figs.

Volume on board	8,550. L
Mass on board	
Mass required for flight	23,800. kg
Mass to be added	
Volume to be added	

The Crash of Flight 143

by Peter Banks

It was a smooth flight as Air Canada 143 made its way from Montreal to Edmonton on the afternoon of July 23, 1983. Below were cottony clouds, ahead only blue sky and clear air. The Boeing 767 cruised at 469 knots, nearing a route checkpoint at Red Lake, Ontario.

In the cockpit, Captain Robert Pearson chatted amiably with his first officer, Maurice Quintal. The two men were among only a handful of pilots trained to fly the twin-engine 767, then the most advanced jetliner in the world. "Everything's straightforward once you learn it," Pearson told Quintal, nodding toward the plane's sophisticated instrument panel. The 767 had indeed simplified a pilot's life. Computer screens replaced dozens of instruments. The easy-to-read displays reduced pilot fatigue on long flights. On this four-hour trip to Edmonton, Pearson expected to relax a bit as he carried his 61 passengers to western Canada.

The confusion of the preflight calculations seemed to slip away as the huge aircraft raced toward Red Lake.

But his calm was broken suddenly as the plane passed over Red Lake. A warning buzzer gave four quick beeps, and an amber light flashed.

Quintal glanced at the indicators in front of him. "Something's wrong with the fuel pump."

"Left forward fuel pump," Pearson added. "I hope it's just the fuel pump failing, I'll tell you that."

The 767 has three fuel tanks, one in each wing and one in the plane's belly. For each tank, two pumps deliver a steady stream of fuel to the engines. The warning told Pearson and Quintal that the forward pump in the left wing was not working. This could mean that the pump had failed, a fuel line was clogged, or that the left tank was running dry—although the fuel load had been checked and rechecked before takeoff.

Pearson consulted the plane's reference handbook, which said that normal flight was possible with one defective fuel pump. A few seconds of wary calm passed. Then more alarms sounded. The second pump in the left wing tank was also failing. It was too much of a coincidence for two pumps to fail at the same time—it was more likely that the left tank was running out of fuel.

"We've got to go to Winnipeg," Pearson said quickly, setting a course for the nearest large airport. Quintal radioed air traffic control, and they received immediate clearance to descend to 6,000 feet.

Pearson throttled back the engines and switched a computer monitor to display the descent into Winnipeg. But he began to doubt that the plane could even make it there.

The cockpit crew grew tense as the 767 nosed down toward the clouds below. More beeps blared the worst possible news: *all four* remaining fuel pumps were now failing. Pearson maneuvered the aircraft gently, trying to preserve every trace of fuel. Then the left engine stopped running.

Quintal radioed Winnipeg. "We've lost our number one engine." Preparing for a possible crash landing, he added, "We'll require all the trucks out."

The pilots set the flaps for the single-engine landing, hoping in spite of what they were witnessing that enough fuel remained. But as they passed 26,000 feet, the remaining engine stopped. The cockpit became quiet. The computer screens flickered off. Without power, the high-tech displays were dark and useless.

One hundred miles from Winnipeg, the massive jetliner was left with no electronic instruments and with fewer controls than a small single-engine plane. The world's most advanced aircraft was now a glider.

The unthinkable had happened: Flight 143 had run out of fuel.

* * * *

How? How does a modern jetliner—equipped with the latest technology and piloted by skilled people—run out of fuel at 26,000 feet? As with most air disasters, there was no single cause. Flight 143 was brought down by a string of errors in technology, communication, and training, but at the heart of the crisis was a simple mistake in calculating the amount of fuel needed for the flight.

PHOTO BY AP/WIDE WORLD PHOTOS

After both engines ran out of fuel, Flight 143 glided powerless for 29 minutes before the pilots brought it down on the end of runway 32. With a collapsed nose gear and two blown tires, the plane skidded to a stop just before hitting a telephone pole and a fence. The giant aircraft miraculously avoided skidding into people who were watching a sports car race on the abandoned runway.

The plane's instruments should have quickly detected the error. The 767 boasts an advanced fuel quantity processor that accurately gauges fuel on board. But, on this particular plane, the fuel computer had never worked properly, and maintenance workers lacked a spare computer.

> ***The pilots and air traffic controllers made some hasty calculations and reached a grim conclusion—without engines the craft would land 10 miles short of the airport.***

Because the 767 was a new addition to Air Canada's fleet, the written maintenance standards were still being revised. When the ground crew was preparing the plane for departure from Montreal, they found that the fuel gauge did not work. A maintenance worker assured Pearson—incorrectly—that the plane was certified to fly without a functioning fuel gauge if the crew manually checked the quantity of fuel in the tanks.

The manual procedure, known as a "drip," is as old as flying itself. Each fuel tank contains a drip stick, which is similar to the dip stick used to check the oil in a car, except that it is mounted upside down. When a mechanic under the wing loosens the drip stick, it falls within the tank until a float at its tip bobs on the surface of the fuel. The mechanic reads the depth of the fuel from markings on the drip stick, then consults a handbook that gives the corresponding volume of fuel in the tank.

Two Air Canada mechanics, Jean Ouellet and Rodrigue Bourbeau, had performed exactly this procedure on Flight 143 while it was on the ground in Montreal. They measured a fuel depth of 62 centimeters (cm) in one wing tank and 64 cm in the other. The manual showed that this corresponded to 3,758 and 3,924 liters (L) of fuel in the tanks, for a total load of 7,682 L.

It would seem simple to subtract this amount from the amount needed for the trip to get the amount that must be added to the tanks before take off. It would have been simple, but for three small complications.

For years, Air Canada pilots had computed the amount of fuel they would need in *pounds*, whereas the new 767's fuel consumption was expressed in *kilograms*. The metric specifications were in accord with the Canadian government's plan to introduce metric units nationwide. Secondly, the drip procedure told the pilots the amount of fuel on board not in pounds or kilograms, but in *liters*.

What's more, on the earlier airplanes, the fuel had been calculated not by the pilot or copilot, but by the third person in the cockpit, the flight engineer. The 767 did not carry a flight engineer because the computers had reduced the cockpit workload. Now, it was unclear whether the ground crew or the pilots were primarily responsible for the fuel calculations.

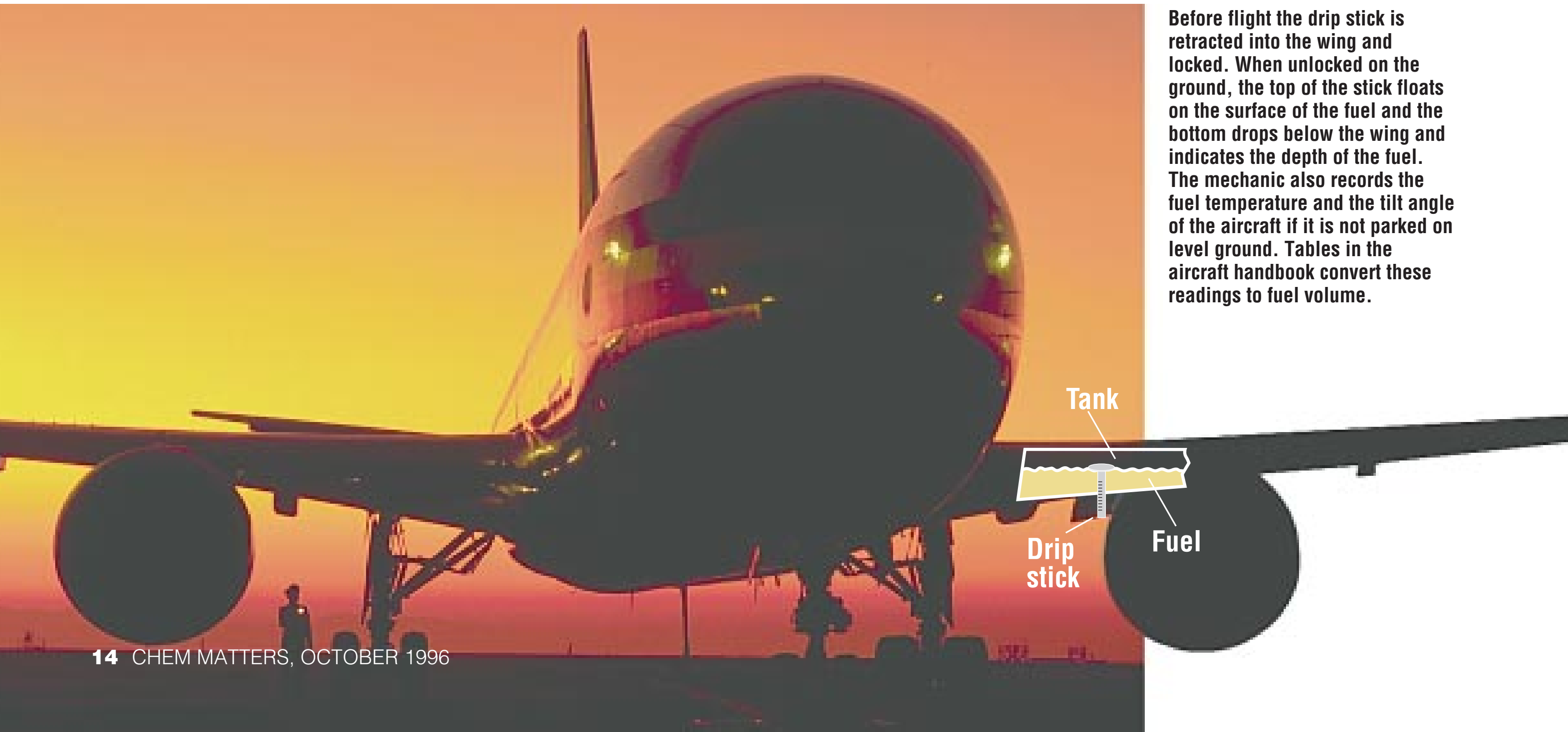
Ouellet and Bourbeau knew that the flight to Edmonton, which called for a brief stop in Ottawa without refueling, required 22,300 kilograms (kg) of fuel. Thus they faced this problem: If 7,682 L of fuel remained in the plane, how many liters had to be added to make a total of 22,300 kg? First Officer Quintal offered to help the mechanics solve the problem. "The number of liters times the weight of a liter will give you kilograms, right?" Quintal turned to a mechanic in charge of refueling and asked for the factor for converting liters into kilograms.

"1.77," the refueller answered.

Using that factor, Quintal and the mechanics figured that the plane now contained 13,597 kg and would need 8,703 kg more to reach the required 22,300 kg. This meant that the flight required an additional 4,917 L. The refueller added fuel, and the mechanics repeated the drips until Pearson was satisfied that the plane was properly fueled.

Unfortunately no one had asked the crucial question: What units go with the conversion factor of 1.77? (See box *Crash course in density*.)

PHOTO BY SAM SARGENT, CHECK SIX



Before flight the drip stick is retracted into the wing and locked. When unlocked on the ground, the top of the stick floats on the surface of the fuel and the bottom drops below the wing and indicates the depth of the fuel. The mechanic also records the fuel temperature and the tilt angle of the aircraft if it is not parked on level ground. Tables in the aircraft handbook convert these readings to fuel volume.

After takeoff, Flight 143 made a short trip to Ottawa, where it stopped for 45 minutes without refueling. Then, with Quintal at the controls, the plane took off full throttle, rocketing toward Edmonton. The confusion of the preflight calculations seemed to slip away as the huge aircraft raced toward Red Lake.

* * * *

As the plane glided powerless toward Winnipeg, the pilots and air traffic controllers made some hasty calculations and reached a grim conclusion. Without engines, the craft's rapid descent would bring it in at least 10 miles short of the airport.

Pearson was directed to Gimli, an airport once used by the Royal Canadian Air Force. Long abandoned by the Air Force, the airport had no control tower or fire trucks. It was unsuitable for landing a 767, but no other airport was in gliding range.

Swooping quietly over Lake Winnipeg toward Gimli, Pearson realized that the plane was coming in too high. The big plane would land too far down the runway and skid off the end. In a desperate move to lose altitude, Pearson tried a side slip—a maneuver used in small planes but unheard of in a jetliner. Turning the wheel for a left turn and pushing the rudder for a right turn, the plane fought with itself and descended faster.

When the plane tipped sharply onto its side, the passengers gasped in horror, as they watched the ground grow closer in the windows. Then at the last moment, Pearson righted the plane at the proper height. But the strip of concrete was no longer a runway. It had been converted to a auto race track complete with fences, race cars and spectators. People on the ground dove to get out of the path of the rapidly descending plane.

The speeding 767 touched down at the right point, just 800 feet from the start of the runway but blew out two tires and threatened to skid off the runway. Ahead was a steel barricade that had been erected across the runway. Suddenly, the front landing gear collapsed. The nose of the plane scraped along the runway throwing dangerous sparks but dragging the plane slower. Miraculously the plane stopped just in front of the barrier.

Fearing fire, the flight attendants rushed the passengers down the emergency ramps. There were many scrapes and bruises but only a few real injuries. The passengers and crew of Flight 143 had made it.

After the Boeing 767 was thoroughly repaired, Air Canada put it back into service. Flight crews gave it an ignoble nickname but vowed that it will never earn that name again. They call it the Gimli Glider.

CRASH COURSE IN DENSITY

When you refuel a car, the gasoline is measured by volume in units of gallons or liters. Because an airplane can lift only a certain amount of weight, its fuel must be measured in pounds or kilograms.

When the ground crew conducted the drip procedure they determined that the tanks contained 7,682 L. The crew knew that the flight required 22,300 kg, and they knew that volume should be multiplied by density to obtain weight. But the density of jet fuel can be expressed in various units such as pounds per gallon, pounds per liter, or kilograms per liter. The ground crew used the value 1.77 without being certain of its units.

They calculated:

7,682 L x 1.77 = 13,597 kg of fuel remaining on board

22,300 kg needed – 13,597 kg on board = 8,703 kg to be added

8,703 kg ÷ 1.77 = 4,916 L of fuel to be added

If they had kept track of the units and verified that the units canceled properly, they could have calculated:

$$7{,}682\ \cancel{L} \times \frac{0.803\ kg}{\cancel{L}} = 6{,}169\ kg\ \text{remaining on board}$$

22,300 kg needed – 6,169 kg on board = 16,131 kg to be added

$$16{,}131\ \cancel{kg} \times \frac{L}{0.803\ \cancel{kg}} = 20{,}163\ L\ \text{of fuel to be added}$$

The result was that they added about 5,000 L when they should have added about 20,000 L. At the time of takeoff Flight 143 had about 10,000 kg of fuel—less than half the amount needed to reach Edmonton.

Why did the pilots and ground crew so readily accept the value 1.77? Because, when accompanied by the proper units, it is a valid conversion factor that they had all used in the past. The density of jet fuel is 1.77 *pounds* per liter.

–Gail Marsella

Peter Banks is a freelance writer living in Fairfax, Virginia. His article "Ice That Burns" appeared in the October 1995 issue of *Chem Matters*.

FOR FURTHER INFORMATION

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