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Common Misconceptions in Airline Fuel Planning and Consumption - And the Mistakes They Lead To …

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Airline Group of the International Federation of Operational Research Societies

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A Little History of the Jet Age …

- The first jet aircraft were the Germen HE 178 & the British Gloster E28, both in 1939. They were first used in war in 1944 – first the German ME 262 and then the Gloster Meteor
  - Of course, the V-1 rocket (1939) was both a jet (pulsejet) and the first cruise missile!
- In 1949, the first big jets came into use
  - Commercial: the British Comet

  - Military: 6 pusher prop and 4 jets: the biggest bomber ever made: the American Convair B-36

The Evolution of Jet Aircraft

- It has all been about saving fuel – flying farther and longer
  - In 1952, the British Comet could carry 44 passengers for 1,300 miles
  - In 1958, the first American jet was the Boeing 707, carrying 174 passengers for 3,000 miles
  - Since 2015, today's longest range jet is the Airbus A-350, with 440 passengers for 8,300 miles
  - Since 2011, Boeing's 787-8 carries 359 passengers for 7,350 miles
- So how was it done? What gave us the ability to carry 10 X the passenger load for 6 X the distance over a period of 75 years?

The Industry Would Have You Believe It's Weight…

- Boeing says: "The use of composite materials in the 787's fuselage and wings makes the aircraft lighter, reducing fuel consumption and increasing range"
- The 787-8 replaced the 767, and burns 20% less fuel than the 767
- But is it really weight? Is it really the composites?

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What Really Made the Fuel Burn Difference?

- It is ***not*** weight!
- The 787-8 is only 6 feet (~2 m.) longer than the 767-300 ER, and some airlines fly the same seating configuration, but the Operating Empty Weight (OEW) of the aircraft is actually 30 tonnes (metric tons) more than the 767!
- A cubic meter of composite weighs a lot less than a cubic meter of aluminum, but it takes a lot more composite to have the same strength in the fuselage
- Where composite really helps in cutting fuel burn is that composites allow much more aerodynamic wing design than can be implemented with aluminum

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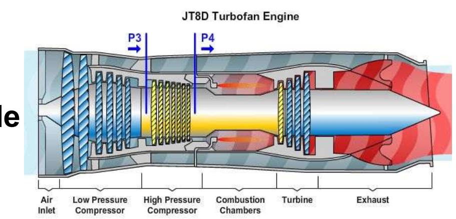
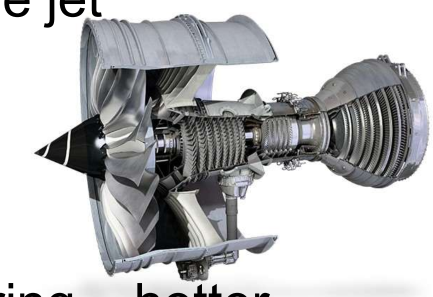
So What Was It?

- It's mainly in the engines
  - Bypass: In the old days, an engine got its thrust from the jet flame. Today it is mostly a big "propellor" pushing air and powered by a little jet

The workhorse of the 1960's:
707, 727, 737, DC9, MD80, Caravelle



The 787 Engine



  - Temperature: better alloys and complex turbine engineering – hotter temperatures produce more power from the same fuel

MD80: 390°C

787: 773°C

And Let's Not Forget Winglets …

- Winglets and other modifications at the wingtips save 4-15% of fuel
- It's all about the wingtip vortex – the plane is actually falling all the time, even as the wings generate lift. It creates a little "tornado"

- Understanding this started with the Spitfire – a clipped wing made it fly 5 kts faster
- Interfering with the vortex reduces drag

Modified Wingtips

So Now Let's Look At How You Define the Fuel

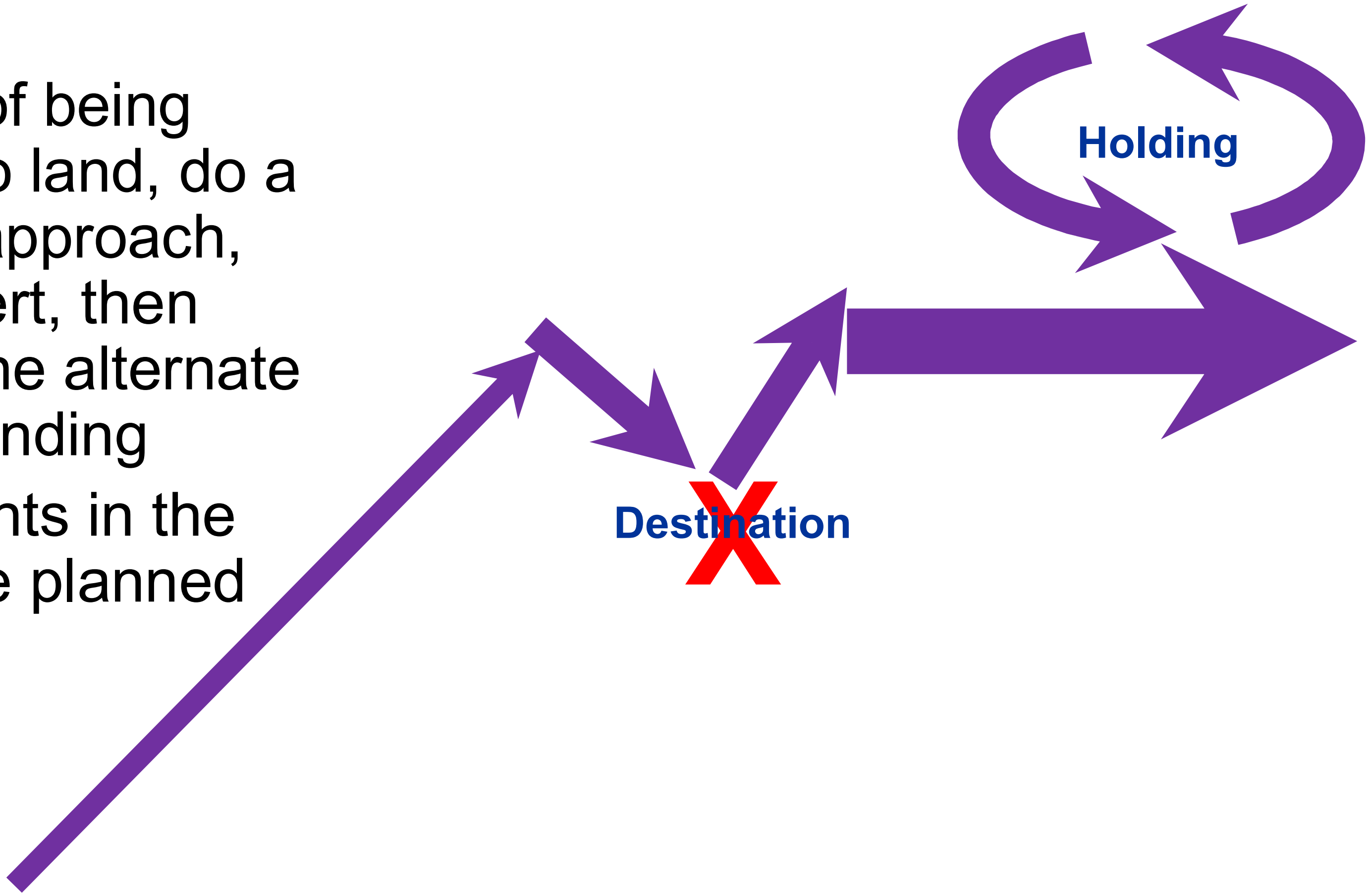
- **We build a flight plan**
  - Flight plan: iterative calculation, adjusting competing factors. It provides:
    - Route of flight
    - Series of altitudes, air speeds, times to fly, fuel to fly
  - Takes into account the weight of the airplane, and everything that is carried on the airplane
  - Uses comprehensive & complex 4-dimensional wind databases
    - Different winds going different directions at different altitudes, for each point's arrival time
- **Of course, the heavier the aircraft is, the more fuel it burns**
- **The higher the aircraft is, the slower it flies**
- **Many different contingency fuel calculations**
  - Rule-based
  - Human input (weather and congestion issues)
  - Maintenance-based (the plane may have a minor flaw which requires more fuel to overcome)
- **Flight planning systems have become more efficient over the years**. For instance, flying longer distances to save fuel via better tailwinds came into vogue in the mid-1980's

There Are Some Major Problems With the Flight Plan

- **Current rules cause too much contingency fuel for weather or congestion to be carried on most flights. The "arrival fuel problem"**
  - Contingencies are planned to ensure that pilots have a safe and comfortable amount of fuel when they land in bad weather
  - But current rules are based on the way flights normally operated in 1944, and codified in 1948! Things have changed over the past 80 years!
  - It's possible to plan flights with much lower contingencies, that will ***still*** land with more fuel. These can save as much as 2-3% of fuel
- **Airlines build in a lot of errors into their flight plans over time …**
  - These can hide major errors
  - And all planes of the same model are not identical in their fuel burn. Manuals, charts and systems are based on an "average" plane. Some airlines manage this well, others don't
- **And the biggest issue is weight**
  - Do we know what a flight weighs? Not really …

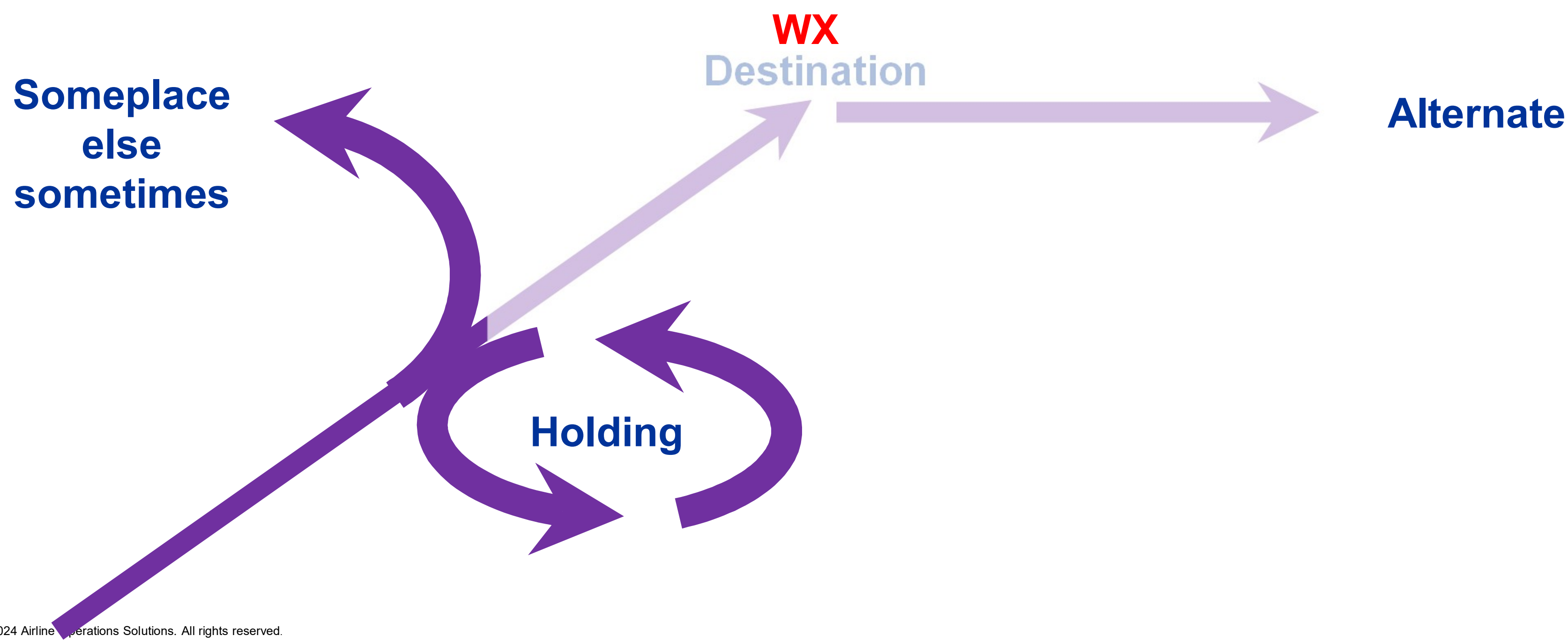
The 1940’s Approach to a Flight With Destination Weather

- In case of being unable to land, do a missed approach, then divert, then hold at the alternate before landing
- Most flights in the world are planned this way



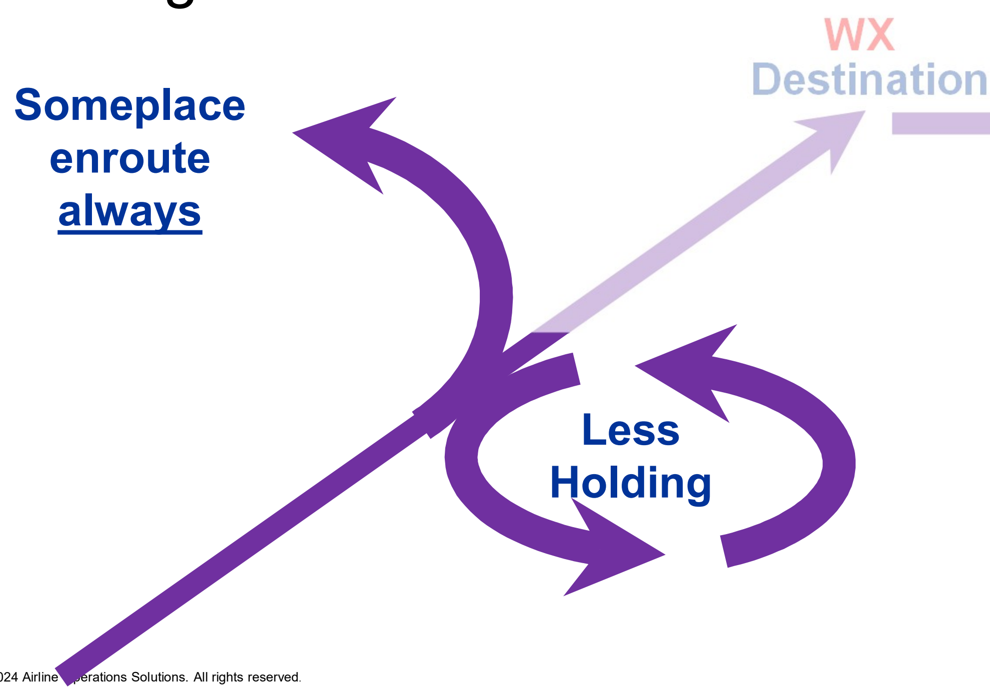
What Is Much More Common In Today's World

- Holding well before the destination, burning a lot of fuel for a long time
- Diverting when getting low on fuel



A Much Better Solution is Operational Enroute Alternates

- Use a very close alternate, only for real emergencies
- Holding for a short time, until it's clear that weather might persist
- Diverting while still have more fuel



This approach has been successfully implemented at 4 airlines. Most recently, in 2019 it cut arrival fuel by 1 tonne, with complete pilot and union buy-in

So Is the Flight Plan Correct Or Not?

- We have shown how the industry has made planes that fly a lot more efficiently
- But we have shown that flight planning standards make them carry too much fuel unnecessarily, without compromising air safety – we have shown how to reduce contingency fuels
- We have talked about how planes really are never identical
- So how about the flight plan itself?
- And do we really know what weight we should plan for, what the flight really weighs?

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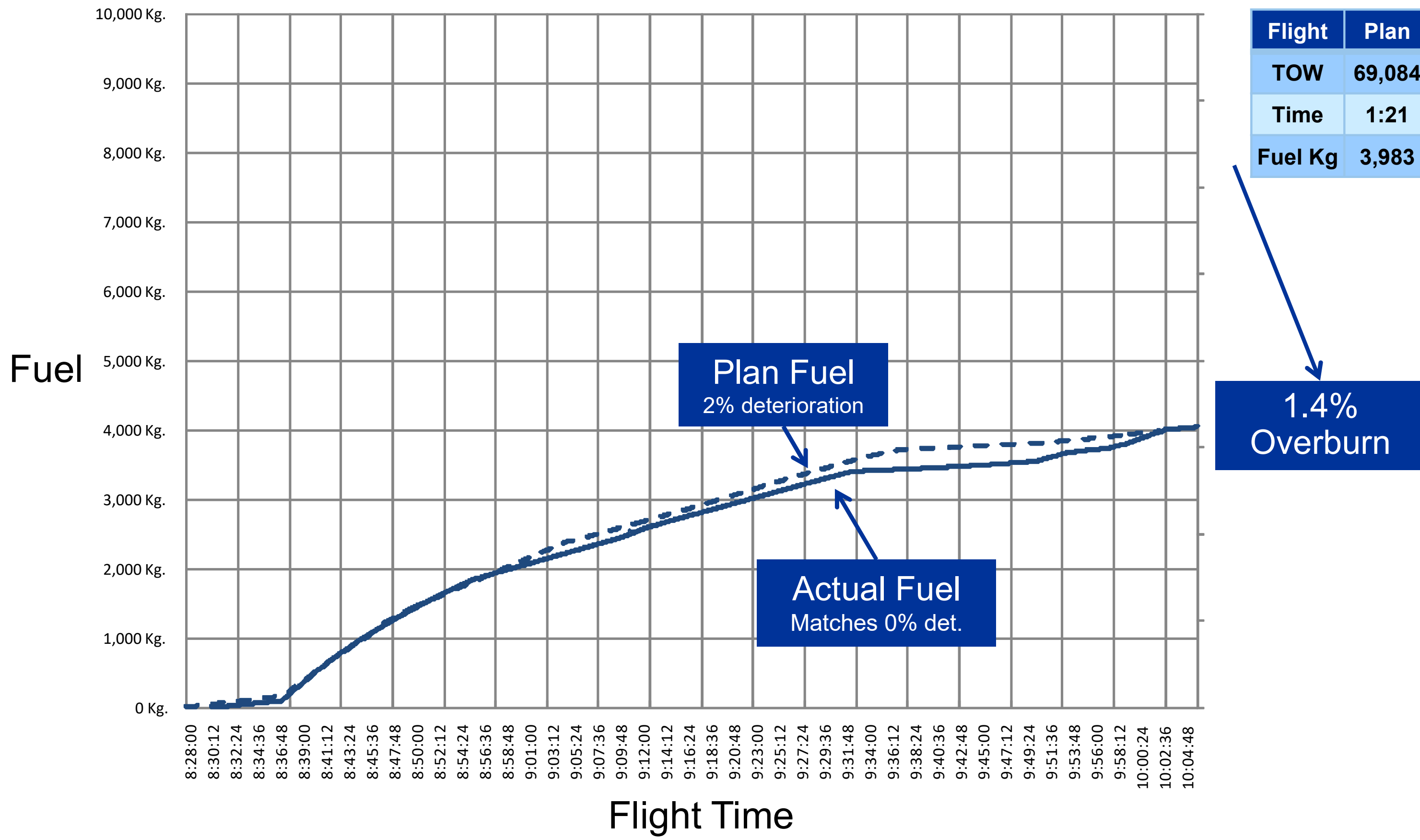
Example: An Almost Perfect Flight – Or Is it?

Airline: XXX Flight: XXX Route: XXX-XXX Date: 8-Jan-13 Type: 737-900ER



Flight	Plan	Actual
TOW	69,084	68,687
Time	1:21	1:25
Fuel Kg	3,983	4,040

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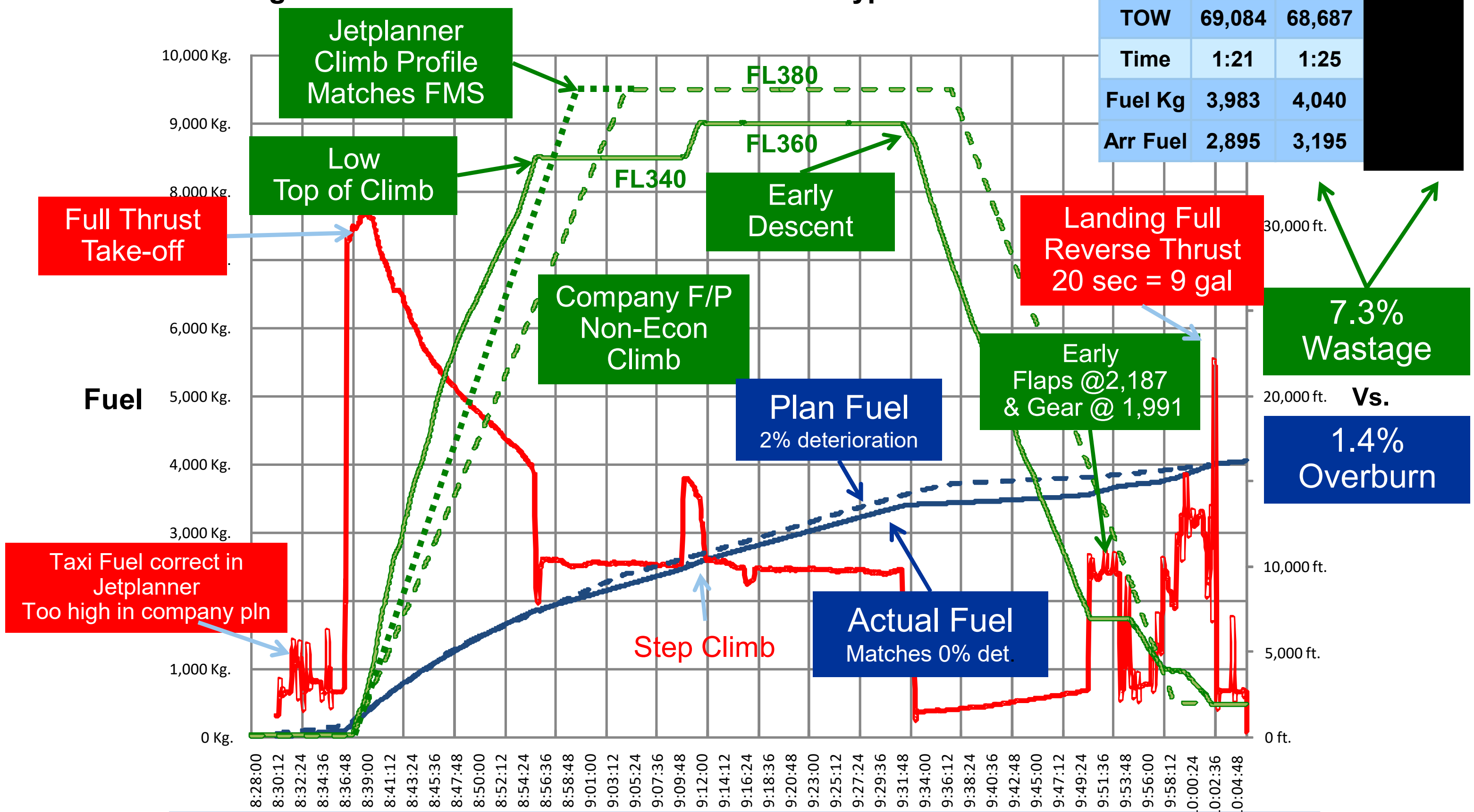
Example: Only LOOKED Perfect!

Airline: XXX Flight: XXX Route: XXX-XXX Date: 8-Jan-13 Type: 737-900ER

Flight	Plan	Actual
TOW	69,084	68,687
Time	1:21	1:25
Fuel Kg	3,983	4,040
Arr Fuel	2,895	3,195

[redacted]



Flight Plan Buffers can mask fuel efficiency opportunities

Buffers & Inefficiency Exposed: Examples

- **Hidden buffers in flight planning – adjustments over time that are never reviewed**
  - –Fuel degradation factors
  - –Inefficient standard company routes
  - –Excess taxi fuel
  - –Inefficient selection of alternate airports, and how to fly to them
  - –Excess holding fuel, and Extra Fuel, as requested by Dispatch, Mx, Pilot
  - –Excess fuel for descent procedures
- **Some potential inefficiencies in flying the flight**
  - –Flying inefficient altitudes
  - –Early Gear and Flaps configuration (too distant/high) in favorable weather and traffic conditions: Ideal energy management for better landing fuel efficiency
  - –Reverse Thrust, if runway length long, dry, and if aircraft is narrowbody
  - –Payload weight errors affecting fuel consumption

Now to the Big One: Weight Error

- Everything on the plane and the plane itself is weighed very carefully and exactly: the plane, fuel, cargo, bags (except in the U.S.),galley carts, fuel. Everything – except **YOU!**
- Passenger, Carry-On & Checked Bag Weights
  - Weight standards include carry-on bag weight, estimated at 7.5 kg./16 lb. **(mine weighs 16 kg.)**
    - –EASA: Male 84 kg./185 lb.
    - –FAA: Male 86 kg./190 lb. **(I might have weighed that when I was 15?)**
    - –ICAO: Male 100 kg./220 lb.
    - –But carry-on bag limits are typically 16 kg./35 lb.
  - Checked bags are estimated based on averages in the U.S., weighed in other countries
  - Many studies show that passenger weights can be ~ 10 kg./~20lb. over the standards
    - –On a widebody flight this could be 10 x 300 = 6,000 kg./13,000 lb.

So What Is the Effect of This Extra Weight?

- **The autopilot on the plane tries to fly too high**
  - This raises the angle of attack, which produces extra drag
  - The weight alone causes a calculation error. The sum of the drag and the extra weight on a narrowbody causes about an extra 3% of fuel burn
- Variance between flight plans and actual burn leads to distrust by the pilots. **When they don't trust the flight plan, they add more fuel, which wastes even more fuel to carry it**
- **Strangely, the best cure for the weight error is to violate one of the most "common sense" rules of flying**
  - Every aircraft type is designed for a particular most efficient airspeed, but flying slower should save you fuel and increase your range accordingly
  - But the solution to the aircraft being heavier than the flight plan, due to excess passenger weight, is to ***speed up!*** This lowers the angle of attack and **saves 1-2% of fuel**

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Weight Error vs. Real and Likely Deterioration

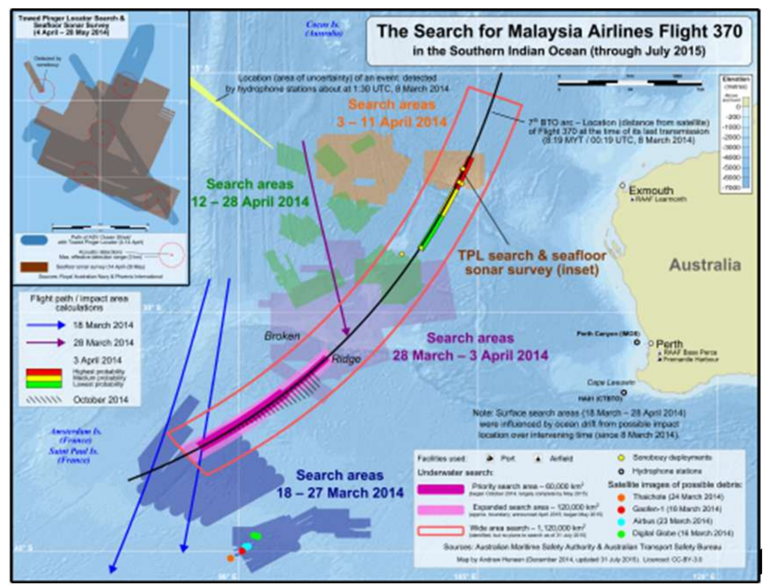
- Aircraft deteriorate over time, but not at the rates often measured by performance software
- Very little deterioration in first two years
- Typical deterioration at 6+ years
  - ~0.5-1% possible typical drag effects from age, patches
  - ~0.5% likely weight issues from condensation (insulation blankets) and dirt
    - An important reason to do periodic empty aircraft weighings
  - ~0.5% possible rigging
  - Deterioration possibly due to engine wear & tear
    - Cyclical, corrected by scheduled engine maintenance
- At 6+ years, true deterioration likely ~2.5%

What Do Airlines Do About Weight Error?

- Comply with their Civil Aviation Authorities weight standards
- There is a fear that thoroughly studying the passenger weight issue will result in more weight-restricted flights
  - A risk on hot & high departures or very long legs
- But airlines need to be aware that incorrect weights cost money on all departures

MH 370 KUL-BJS 8 Mar. 2014 – a B777-200ER – Missing!

- Instead of a 5 ½ hour flight north, it turned around, went up the Straits of Malacca, around the north end of Sumatra, turned south over the Indian Ocean, and disappeared
- Fortunately, we have periodic satellite transmissions where we know its path, and its position along that path over a range error of 5 degrees latitude (345 miles). But from the last position it could have crashed anywhere along a 460 mile path, based on a 56 minute gap between transmissions, and based on fuel burn and air speed
- Over $150 million was spent on searches
- It is likely that where on the 460 mile path it crashed was not accurately calculated
- The unsuccessful search lasted almost 3 years
- In 2025 a new search has started …



How To Do These Calculations

- How did the people in charge do these calculations? We don't know – that level of detail was not published
- How would I do it?
  - The flight papers are a matter of record – required by law. Flight plan, weight & balance, etc. The flight carried 2 pilots, 10 cabin crew, 227 passengers &14,296 kg (31,517 lb) cargo. Planned flight time 5:34, estimating 37,200 kg (82,000 lb) fuel burn. With reserves, total fuel on board 49,100 kg (108,200 lb), estimating 7:31 endurance
  - Calculate a flight plan for the actual route, using the load sheet data, and using historical wind data for that date, where available, and average data for that month where not available
    - **They clearly did this**
  - Research average fuel consumption (and burn error) in past flight data for that aircraft. Adjust expected burn accordingly. Did they do this? Maybe…
  - Use national data based on passenger mix to estimate passenger weight error. Adjust expected burn accordingly. **Did they do this? Maybe…**

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What Do We Know That They Did Not Do

- Any type of analysis that needs to produce exact results relating to fuel burn should be done with test flights. I always did, starting at AA!
- **We know they did not do test flights**, because it would have been part of the very comprehensive writings in the general and aviation press
- Test flights? These could have been done for several million dollars, a drop-in-the-bucket of the $150+ millions, prior to the sea searches
  - Lease a sister ship of the missing plane, with the same kind of engine. Even better, lease two!
  - Conduct a series of flights with exactly the same weight, using fuel as ballast to make up for the ~35 tonnes of passengers, bags and cargo. With a >94 tonnes maximum fuel capacity, the aircraft can handle the ~85 tonne fuel required
  - "Run out" of fuel on each flight – i.e. burn the 49,100 kg. of fuel completey. ~35 tonnes of "fuel ballast" gives you sufficient fuel & reserves to fly the ~1,500 miles from the later search areas to Perth. See where you "ran out" of fuel

In Summary …

- More than 75 years ago, at the time of the first commercial jets, ICAO set the rules for planning and flying flights
- After those 75 years
  - The capabilities of the jets and the technologies to support flying them have advanced so far and can do so much more
  - The way that commercial flights operate today is so very different
  - Yet we still operate under 75-year-old rules with their built-in inefficiencies
- Also, the way flights are planned is not as exact as it seems
- The combination of these issues creates much wasted fuel, and sometimes hides errors and influences poor decisions
- But this can be addressed with proper analysis and changes to operations, even while enhancing operational safety


Q&A

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Thank You!